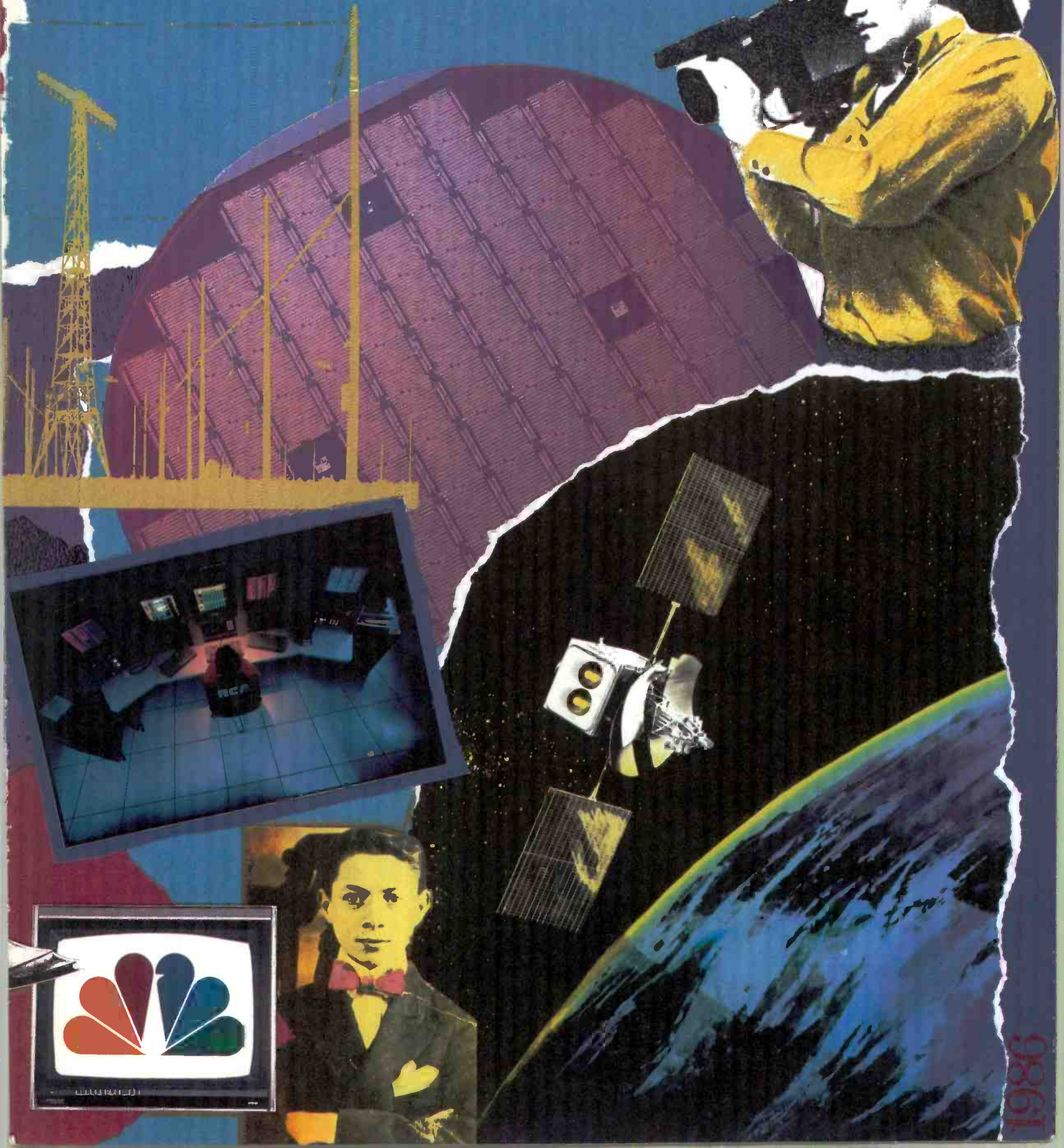
RCA Engineer

Vol. 31 No. 5 Sept./Oct./Nov. 1986



RCA Engineer

A technical journal published by the
RCA Technical Excellence Center ☐ 13 Roszel Road ☐ P. O. Box 432 ☐ Princeton, NJ 08543-0432

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OBJECTIVES OF THE MAGAZINE

☐ To serve as a medium of interchange of technical information among various groups at RCA

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

☐ 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 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 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.

For information about the cover, see third cover panel.

Cover design by Terry Foreman, Design In Mind, Middletown, NY

A community of engineering interest

With this issue, the *RCA Engineer* will cease publication. Since the first issue in 1955, the magazine has encouraged the free exchange of knowledge within the company about RCA technical activities, developments and techniques. It fostered a community of engineering interest and stressed the interdisciplinary aspects of technical projects. In some instances, certainly, it kept engineers from re-inventing the wheel. Equally important, *RCA Engineer* gave many readers their first opportunity to write a professional paper — to become participants in the ongoing dialogue that was the magazine.

The members of four groups who made invaluable contributions over 31 years deserve our thanks at this time:

1. The Editorial Staffs

   Their dedicated efforts, imagination and skill have ensured that the magazine stayed close to its original objectives (which have always been printed on the inside front cover).

2. The Editorial Representatives and their co-workers who supported the authors' efforts

   Their guidance in planning issues and following up during the editorial process amplified the effect of the staff. Though they were appointed to represent the interests of their respective business units, they were not reluctant to contribute ideas and hard work on behalf of other organizations.

   The current group of Ed Reps is listed on the inside back cover. Recognize that they, along with your technical librarians, will be valuable sources of technical information in the months ahead.

3. The Advisory Board

   Engineering management has consistently supported the magazine. In such a technically diverse company, they recognized that good communications were essential to remaining competitive.

4. The Authors and Readers

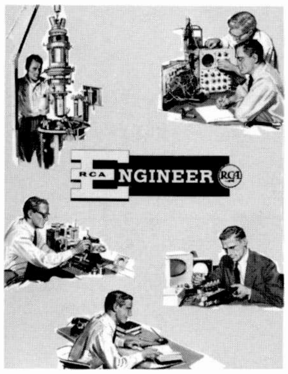
   Your support — by writing articles and using the magazine as a conduit of RCA information — has made it live up to its slogan, "by and for the RCA engineer."

It is particularly appropriate that the theme for this last issue is the Quality Process. It was selected in 1985 after the Ed Reps reported on the quality improvement initiatives in their businesses. General Electric's emphasis on Total Quality is stressed both in a guest editorial by Fred Garry and in the paper by Len Morgan about GE's quality training program. The RCA quality-related papers in this issue reflect the competence with which you are responding to the challenges of today's business environment.

Taken as a body of work, the 31 volumes of *RCA Engineer* articles should make you feel proud of what you bring to the merged company.

Thomas E. King

Thomas E. King
Editor



Issue No. 1
June/July 1955

RCA Engineer

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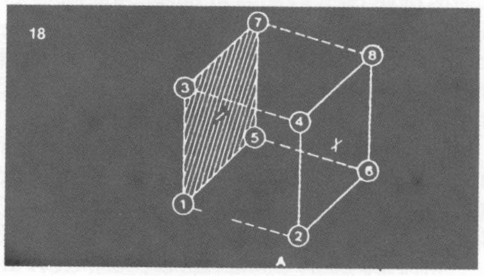
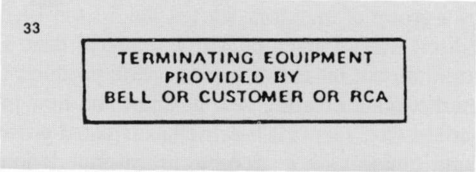
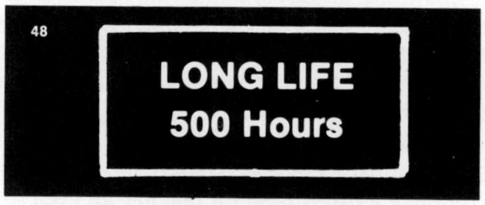
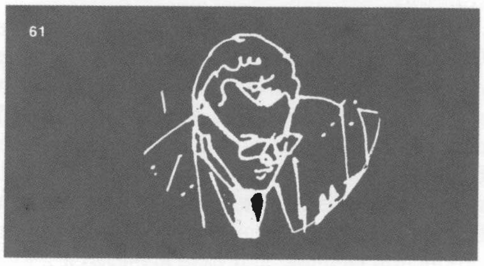
in this issue . . .
The quality process

- **Killion:** *“Throughout RCA and the industry in general, various organizational concepts exist to implement design review functions.”*
- **Barra:** *“When we establish incoming inspection criteria and procedures, we should not use Acceptable Quality Levels (AQLs), which mean an expectable level of poor quality.”*
- **Gallace:** *“As statistical methods continue to grow in use in complicated engineering studies of processes and materials, they are becoming more sophisticated and yet simpler.”*
- **Thoelke:** *“To be successful, the SQA effort must be integrated with engineering, program management, and configuration management efforts.”*
- **Schmidt/Constantini:** *“The requirement to improve quality presented an opportunity to demonstrate the effectiveness of statistical process control techniques applied to a service industry.”*
- **Van Hoorde/Sukey:** *”The American consumer can select from European, American, and Far Eastern product with little or no government restrictions or tariffs.”*
- **Kratz/Gray:** *“When we identify a design, manufacturing, device, or supplier weakness, we address it through corrective action, testing, and screening.”*
- **Floridis:** *“Since 1980, many American companies have begun to respond to the overseas challenge of price and quality by taking a new look at management style and methods for reducing costs and improving quality.”*
- **Thierfelder/Hinnenkamp:** *“A product’s reliability with operating time usually has three distinct failure patterns.”*
- **Trapani:** *“With quality circles (QC), employees can discuss ideas to improve the operations and act on these ideas with minimal red tape or bureaucratic interference.”*
- **Morgan:** *“World-class quality in all products and services would be a prerequisite to making General Electric the natural choice of our customers in each market we serve.”*

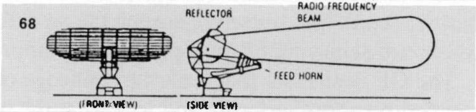




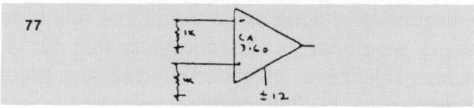




- **Mulle:** *“We have observed that foreign customers usually do not gain sufficient understanding of complex subjects from viewgraph presentations.”*



- **Bowker/Stein/Stein:** *“I spent all but a few hours of my entire college career in a chicken coop and in a 10-foot square basement room of the college’s student activities building.”*



EDITORIAL

A note to RCA's engineers

Fred W. Garry
Vice President—Corporate Engineering and Manufacturing General Electric Company

With the completion of the merger of General Electric and RCA in June, integration of businesses in the merged companies got underway and has continued in recent months under the auspices of joint teams established in several key business areas—semiconductor, aerospace and defense, consumer electronics, communications and services. Other teams have been looking at integration issues involving international operations, licensing and patent activities, and research and development. These various activities have shown the potential for turning opportunity into growth by melding the strengths of the two companies into one.

The engineers and scientists of RCA have built an impressive record of technical accomplishments ranging from the pioneering work in wireless communication in 1919 to the forefronts of electronics and communications of today.

There are many similarities between RCA and GE. General Electric's beginning was in 1878 when Thomas Edison, backed by a group of investors, started the Edison Electric Company. Edison was an inventor with a practical bent. He valued research, but his thrust was to create products that won in the market place creating new business and new jobs. From these earliest days General Electric has equated growth and contribution with a strong technical foundation.

GE was a major corporate entity involved in the formation of the Radio Corporation of America in 1919. GE and RCA arranged for cross-licensing of radio patents, and GE became the major RCA stockholder—a relationship terminated by U.S. Government decree in 1932.

A half century later, the combined technical and engineering strengths that RCA and GE have developed separately constitute a major basis for building an even stronger combined company.

Core manufacturing businesses today provide about 20% of GE earnings compared to about half of earnings in 1980. This reflects the high growth rates and additions of high technology and service businesses. We have not abandoned, and must not abandon manufacturing. Many of our high technology businesses such as Aircraft Engine are also b;uilt on our manufacturing expertise. Over the past five years we've invested billions in plant and equipment in GE to provide state of the art production facilities, and have achieved a 2 to 3% average annual productivity gain. But unless we do much better than this, we won't find ourselves among the world's best—some of whom are achieving 6% plus productivity improvement levels.

The GE businesses that took the challenge of our offshore competitors more seriously and looked at the root cause design questions have done better than those that didn't. But across the board, we engineers must recognize that our design work (which I define as integrated product and process engineering) dictates some 60-75% of direct costs and impacts every other element of cost. Our response must be to achieve more producible designs that meet market quality performance requirements at affordable prices.

A key to competitiveness is research. The U.S. carries on about half the Western World's basic research and the number of Nobel prizes in science won by U.S. researchers suggests that this work is outstanding. In total, the U.S. bill for R&D this year will be well over $200 billion. Our company conducts about 3-4% of the country's R&D not related to health and agriculture. Even though the General Electric balance of payments in world markets is positive by $2.6 billion, the growing imbalance of U.S. trade in manufactured goods will grow from $113 billion in 1985 to a projected $146 billion in 1986. This dramatically points out that we're becoming less competitive. For us as engineers, it emphasizes the need to use our creativity and technology to turn out designs that are compatible with both shop floor requirements and market demands.

We are in a head to head battle for markets with the world's best engineers. In this competitive struggle, U.S. engineers cannot hope for victory through world-shattering breakthroughs. We must address ourselves to a continuum of improvement. Year after year refinement. Better reliability, durability and performance for our customers. Greater harmony between product and process to achieve world class competitive stature through *lowest total cost in manufacture.*

The competitive designs we need to strive for will:

- ☐ Have fewer parts
- ☐ Use materials more effectively
- ☐ Minimize direct labor costs
- ☐ Have predictable processing requiring less manufacturing machinery and equipment, lower inventory, less plant space—in short lower investment
- ☐ Have fewer pieces to handle, which lowers indirect costs by reducing the number of transactions a business makes
- ☐ Need smaller warehouses because of both reduced parts count and the higher reliability inherent in simple, rugged design

In conclusion, good design means customer satisfaction. This means market share growth opportunity which permits spreading our base costs over greater volume. To achieve the levels of productivity improvement demanded by today's environment, it is necessary to have in place continuing product and process design programs that give consideration to all aspects of total cost.

We need to keep reminding ourselves that good design is one of the most highly leverageable investments a business can make to achieve competitive total cost productivity improvements.

We welcome RCA engineers to General Electric and look forward to your contributions in our new greater, stronger Company. Together, we can make it the world's most competitive enterprise

J.Fogleboch and B. Turowski receiving Sarnoff team award.

Sarnoff team award presented to (back row) D.C. Polson, R.R. Russo, J.R. Young, (seated) P.R. Knight, D.P. McCorkle, L.W. Nero, L.S. Onyshkerych.

A.H. Ashkinazy, G.A. Gendel, Y.I. Shor receiving Sarnoff team award.

Thirteen RCA Scientists and Engineers honored with 1986 David Sarnoff Outstanding Achievement Awards

The 1986 David Sarnoff Awards for Outstanding Technical Achievement, RCA's top technical honors, were conferred upon 13 scientists and engineers for major achievements in optical recording media, integrated circuits, signal processing, and an automated television high voltage transformer.

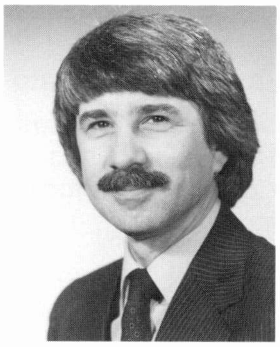
The David Sarnoff Awards were established by RCA in 1956 to commemorate the fiftieth anniversary in electronics of the late David Sarnoff. Since then, awards have been made annually to scientists and engineers within RCA. Each recipient is given two medals — a gold one and its replica in bronze — a citation and a cash award.

GE Vice Chairman Edward E. Hood and RCA Executive Vice President Roy H. Pollack made the presentations on September 26 in New York City.

Sarnoff Award is presented to R.A. Bartolini by E.E. Hood (at left) and R.H. Pollack (right).

1986 David Sarnoff Awards for Outstanding Technical Achievement

For the conception, understanding, and development of optical recording media.

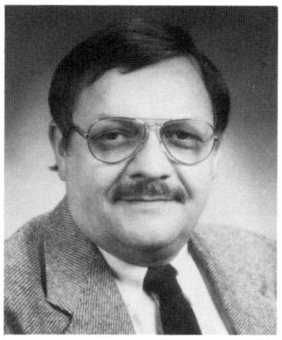


Robert A. Bartolini

Group Head,
Optoelectronic System
Research Group
RCA Laboratories,
Princeton

1986 David Sarnoff Awards for Outstanding Technical Achievement

For major advances in the signal processing state of the art through successful implementation of VLSI programmable processing elements.



John Fogleboch

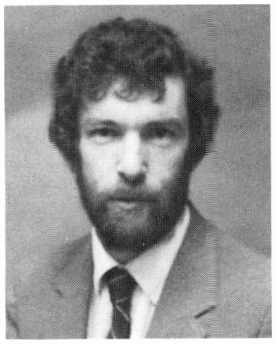
Manager, Advanced
Signal Processing Systems
Missile and Surface
Radar Division,
Moorestown

Bernard Turowski

Unit Manager, Array
Processors
Missile and Surface
Radar Division,
Moorestown

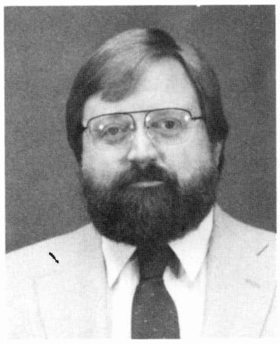
1986 David Sarnoff Awards for Outstanding Technical Achievement

For outstanding accomplishment in the development of a cost reduced and automated television high voltage transformer.



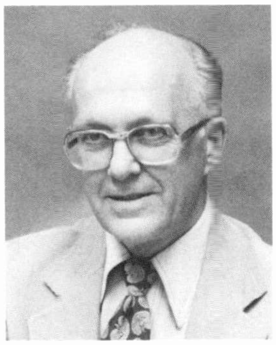
Peter R. Knight

Manager, Deflection and
Power Supply
Consumer Electronics,
Indianapolis



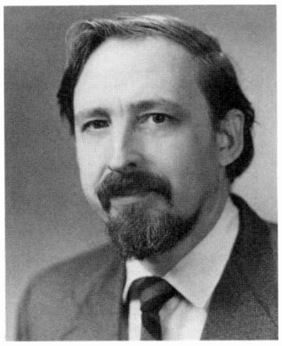
David P. McCorkle

Manager, Advanced
Electronic Systems
Consumer Electronics,
Indianapolis



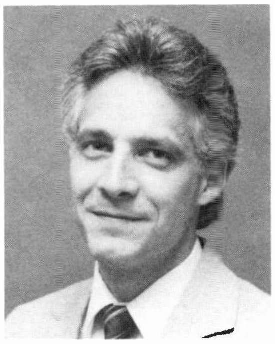
Leroy W. Nero

Principal Member,
Engineering Staff
Consumer Electronics,
Indianapolis



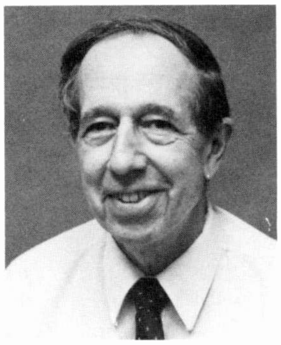
Lubomyr S. Onyshkevych

Head, Electronic
Packaging Research
RCA Laboratories,
Princeton



Daniel C. Polson

Manager, Process
Engineering
Consumer Electronics,
Indianapolis



Robert R. Russo

Manager, Process
Development
Engineering
Consumer Electronics,
Indianapolis

James R. Young

Senior Member,
Engineering Staff
Consumer Electronics,
Indianapolis

1986 David Sarnoff Awards for Outstanding Technical Achievement

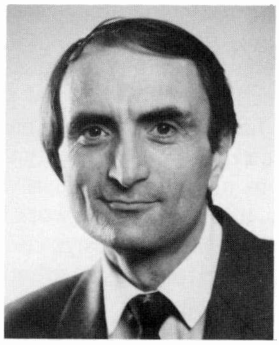
For innovative contributions in the design and implementation of a multi-level simulation system for integrated circuits.

Aaron H. Ashkinazy

Principal Member,
Technical Staff
Microelectronics Center,
Somerville

Gary A. Gendel

Member, Technical Staff
Microelectronics Center,
Somerville



Yefim I. Shor

Member Technical Staff
Microelectronics Center,
Somerville

R.E. Killion

The design review function

Design reviews continue to be an important phase of the development process.

A tradition of design review goes back as far as formal engineering design groups have existed. The design review function at MSRD dates from the opening of this division in Moorestown over 30 years ago. In 1957, what is now called Technical Assurance was called the Design Methods Group. This activity conducted about 50 design reviews for the TALOS program. Shortly after this, when the BMEWS program was in the early design phase, the design review activity consisted of an electrical and a mechanical group and may have had as many as eight to ten design review engineers supporting this effort. At that time, there was no software design review activity. Software design review was made part of Technical Assurance in 1978. Today the Technical Assurance design review activity is staffed with six engineers. This group addresses the full scope of hardware design (electrical, mechanical, logic), software, and systems. The personnel are all senior people with many years of design and design review experience. From 1982 through 1985, they have averaged about 144 design reviews per year. Immediate goals are to make better utilization of the experience of the overall MSRD design activity when conducting reviews; place greater emphasis on cost; and structure reviews to assure that areas of risk, technical uncertainty, and critical function are given appropriate priority. Over the past two years Technical Assurance lost a number of key personnel through retirements. The difficulties we encountered in finding suitable replacements caused us to reexamine our organizational concept, our operating effectiveness, and our future needs. The more significant findings resulting from that introspective study are outlined in the following paragraphs.

Abstract: *To continue achieving the MSRD goals of project success and cost control through realistic and affordable designs, the Technical Assurance activity recently took stock of its operation. This action was triggered by the fact that the activity was losing a pool of experience as key engineers reached retirement. This article analyzes the alternative organizational concepts that were considered to implement design reviews and the role of Technical Assurance in the project design process.*

Final manuscript received Sept. 8, 1986

Reprint RE-31-5-1

Organizational concepts

Throughout RCA and the industry in general, various organizational concepts exist to implement design review functions. The most common are:

1. Full-time technical chairpersons
2. Peer reviews
3. Full-time administrator
4. Part-time administrator.

RCA MSRD generally utilizes Concept 1 and supplements it with Concept 2, particularly in the software area. Concept 1 is based on the maintenance of a full-time activity devoted exclusively to the design review function and the staffing of that activity with technical personnel who have strong design backgrounds. It is a direct-labor activity that participates in all proposals involving design effort. Its total scope of work is a combination of scheduled design review tasks and level of effort for consultation support.

Other organizations chair their design reviews with administrative personnel who have the responsibility for scheduling and planning the review rather than taking the lead technical role as an independent reviewer. This type of an organization generally comprises a very small staff, and design review is frequently a part-time assignment. This approach is represented by organizational Concepts 3 and 4. From our historical vantage point, the weakness of this approach is the inability to retain the cumulative design review experience in a centralized location. It is true that case histories and bad practices can be accumulated for future reference, but technical specialists who can interpret a specific problem and bring to bear their applicable experience are not available in this organizational structure. Organizational Concept 2 suffers from the same weakness. Design review, at best, can be only a secondary consideration if the conduct of the review is the responsibility of the design activity. Human nature being what it is, this peer-review approach also incurs a risk of compromised objectivity when recommended design changes impact cost and schedule.

During the two-year period when we were losing experienced design reviewers through retirement, we experienced considerable difficulty finding qualified replacements. We considered all of the aforementioned organizational concepts as possible solutions to our problem. Because we utilized the full-time technical chair concept for many years at MSRD, we were not totally unbiased in our preference for that organizational concept. As a result, we have restaffed our design review activity and retained our original method of operation. The advantages of this approach, as we perceive them, are the following:

- The activity's full time responsibility is design review.
- Technical experience is retained by reviewers and applied at subsequent reviews.
- The permanent staff members serve as independent consultants between scheduled reviews.
- As a permanent organization, its visibility enhances the effectiveness of design review within the Engineering Department.

Design review activity critique

After our staffing problem was resolved, and since we retained our existing organizational structure, we decided to critique our performance as a design review activity. A ground rule established at the outset was to examine our own role in the design review process rather than the role of the design engineer or his organization. We utilized the Nominal Group Technique (see Fig. 1) to identify and prioritize problems. Some of the resulting concerns expressed by the design review chairpersons were:

- How effective or ineffective have their efforts been?
- How can they become more informed about the big picture of a specific program (operational considerations, cost, management concerns, customer's priorities, etc.)?
- How do they cope with the pressure placed on design engineering, relative to schedule and cost, that tends to weaken the chairperson's ability to initiate effective action items?

The first concern has to do with feedback on a specific program. The design review activity personnel would like to know the kinds of problems that were experienced throughout the integration and test phase leading up to sell-off to the customer. With this information, they would know what problems they helped to avoid and what problems were missed. The latter category would aid them in refining their future reviews. Various sources of feedback already exist such as word of mouth, problem sheets, ECNs, and the normal management attention given to any major problem. A need exists for an overall summarization and critique of each integration and test program so that all can benefit from lessons learned. The new quality measurement system of determining the Cost of Quality will be an aid, but in its present form it is neither inclusive enough nor does it highlight specific programs.

The second concern listed expresses the desire of the design review chairpersons to have the necessary background to prioritize their plans and actions. This condition can be solved by selective distribution of project information to chairpersons on a routine basis and by encouraging them to participate in periodic program reviews. In addition, better dialogue with the responsible Project Management personnel can provide some of the information they need.

The last item on the list is a recurring concern, and its impact on a design review can be minimized but never totally eliminated. Possibly the best way to minimize the impact of the consequences of proposed action items and program schedule limitations is the timely scheduling of design reviews. This approach will provide the maximum time to take any necessary corrective action. Design reviews must be included on the program schedules reviewed by management (see Fig. 2). When a schedule slips, its impact on design review effectiveness can then be considered.

Action items that incur additional cost on a program that already has a cost problem are usually not received without a lot of concern. Several steps can be taken to minimize this problem. Cost reduction and producibility should be inherent considerations in every review. If this is a routine discipline, the impact of an action item that incurs cost may be offset by cost savings that have been previously achieved. Another possible way of minimizing this problem is to have an effective set of design guidelines and disciplines tailored to MSRD product lines based on our past experience. This will tend to minimize design errors that dictate the need for costly corrective action in response to design review action items. Documented design guidelines and disciplines will not only aid the inexperienced engineer but will also serve as a guide to the experienced designer new to RCA and as a refresher to long-term RCA designers. Several design activities have been directed to initiate this action, and it is underway.

Nominal Group Technique

Trial 1

Eight people were in the group including a moderator.

Each individual was asked to identify three major concerns about the design review system; write one each on three idex cards and rank them from 1 to 3 with 3 most important.

All cards were collected and anonymous answers were listed on a chalk board.

Answers were grouped by common answers and their point ranking.

Top three answers based on point score sum of common answers were then identified.

Trial 2

A second trial was run to identify the most consistently recommended corrective action for the three highest ranked concerns. These results formed the basis for our follow-up corrective action.

Fig. 1. *The nominal group technique identifies and prioritizes design review problems.*

Typical design review results

The contributions made by Design Review committees extend throughout the design review process. Reviews scheduled during the *specification* phase of a program frequently result in recommended changes where omissions have occurred or additions are required. During a recent radar system specification review, the Design Review committee noted the lack of requirement for a television camera and telescope. These essential items had to be included in the pedestal equipment where their per-

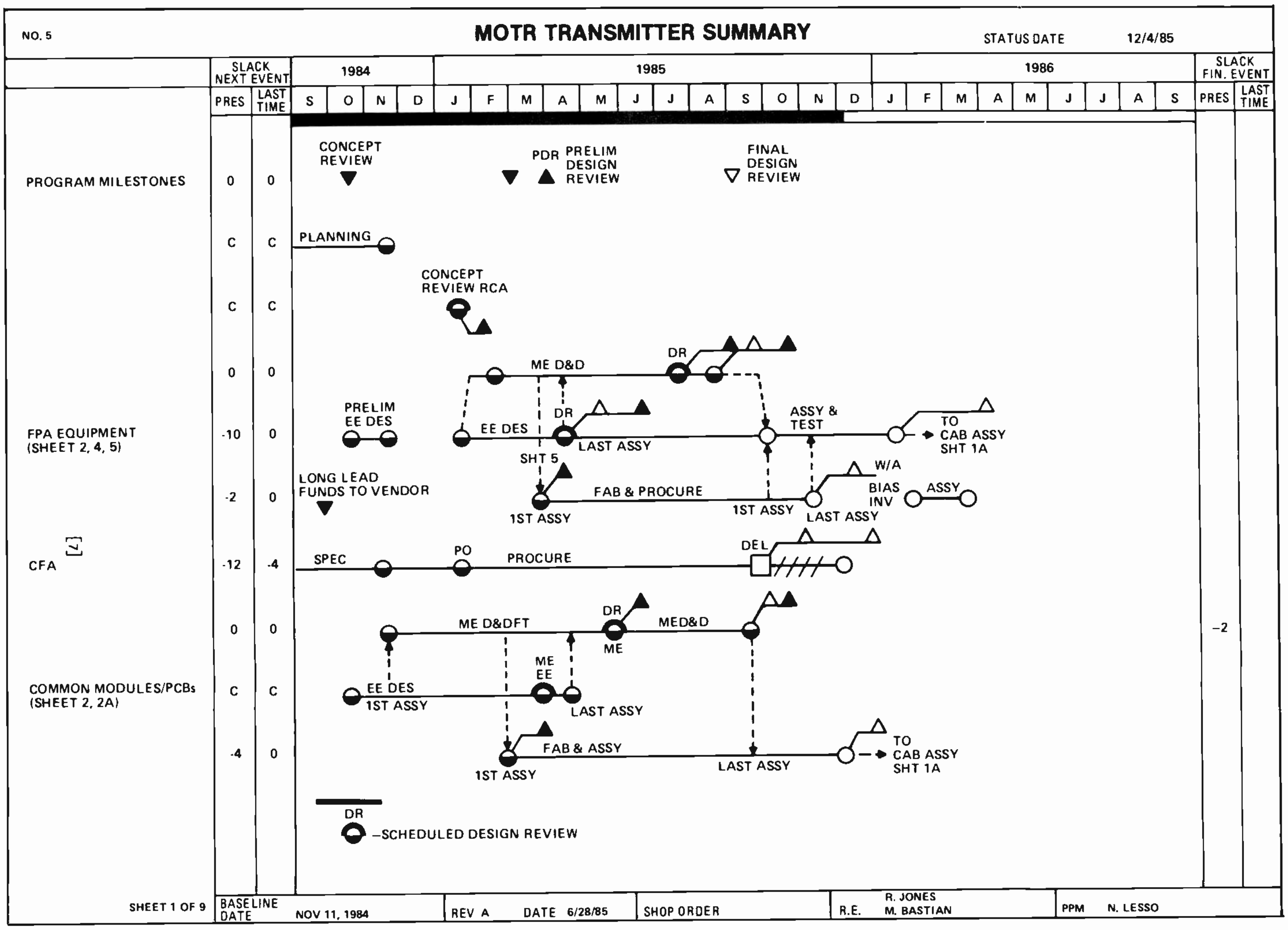


Fig. 2. *Design reviews as part of a program schedule.*

formance, environmental, and interface requirements need to be delineated.

Reviews held during the *conceptual* phase frequently result in design changes that ensure or improve performance and reduce cost.

A conceptual review of a high-power amplifier revealed that the proposed design could produce a high-power tube failure if an arc occurred within the tube. A configuration was recommended for the output stage that prevented the arc current from exceeding the specified power tube limit.

Occasionally, conceptual design deficiencies can only be reported and design change recommendations are not made by the review committee. Where a design requires performance that is beyond the state-of-the-art development, the only recourse may be a change in specification.

Many improvements are made as a result of design reviews during the *detailed design and component selection* phase of a program. Typical of these improvements are the following:

1. Change made to component specification to prevent system performance failures. Premature failures of a tri-state bus transceiver during breadboard testing of a computer led to discovery that the device's direction control transition time can be longer than the enable time of the other tri-state bus in a two-way communication between two data buses. This caused a bus contention problem leading to the premature failure. A Technical Assurance bulletin described the problem, recommending proper wiring and logic setup. This then became a consideration by Design Review committees for this type of application.

2. Change made to drawing to improve information transfer. On the schematic of a BITE monitor module, a resistor network was shown as a box. For adequate understanding of the operation of the voltage comparator circuits, the Design Review committee recommended including a schematic for the resistor network on the module schematic.

3. Delineation of responsibilities of design engineering in controlling and documenting microprocessor devices. The Design Review committee recognized the need for control of Programmable Read Only Memories, Programmable Logic Arrays, and the codes (truth tables) contained within them. Therefore, a policy was issued by Technical Assurance to cover the proper sequence of procedures to put all of the following items under MSRD configuration control: the deliverable hardware (PROMs, EPROMs and PLAs), specification control drawings used to purchase the devices, Altered Item drawings to document the truth tables used as the criteria for profiling the firmware devices, and the disks used to profile PROMs.

Experience Retention Listing

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                                    "RCA ANALYSIS OF RCA-DESIGNED AEGIS P/S COMPLIANCE WITH NAVY P/S
                                    DESIGN CRITERIA"
                                    "A COMPARISON OF AEGIS P/S CHARACTERISTICS WITH PROPOSED &
                                    EXISTING MIL P/S SPECIFICATIONS" FILE 010186
                                    This file contains Power Supply papers, RCA vs. MIL power supplies, a summary of
                                    RCA AEGIS P/S compliance with Navy P/S design guidelines, a booklet entitled
                                    "Navy Power Supply Reliability: Design and Manufacturing Guidelines," A
                                    Supplement and Background for the Standard Power Supply Program — Power
                                    Supply Specification, an AEGIS Ship Combat System booklet (5/13/77), an AEGIS
                                    Shipbuilding Program booklet (3/1/79), and a letter on Power Supply Reliability
                                    dealing with topics such as power density, junct. temp. of semiconductor devices,
                                    case/hot spot temps., & P/S maintainability w/ drawings.
ET   821125  AF     JR            BUS CONTENTION      TRI-STATE/LPS    ELECTROMIGRATION
                                    "BUS CONTENTION LOW POWER SCHOTTKY" 54LS374 FILE 010106
                                    Bus contention among low power Schottky is of little concern since most devices
                                    are designed to carry extra current without damage or degradation, because the
                                    driving device will try to supply current I(OS) when it is in the high state and
                                    receiving devices in their low state will try to pull out of saturation. Electromigration
                                    would occur when the cross-sectional area of the metal film conductor is
                                    inadequate.
ET   811222  DBW    JVF           WIRE-WRAP WIRE      KYNAR WIRE       TEFZEL WIRE
                                    "INVESTIGATION OF 30 GAUGE WIRE-WRAP WIRE, KYNAR VS. TEFZEL" FILE
                                    010135
                                    In an investigation of 30 gauge wire-wrap wire, Kynar wire was less expensive and
                                    slightly better than Tefzel in mechanical properties. A table lists the salient features
                                    of each wire (Ex. cut-through, cold flow, & dielectirc constant). For RCA's
                                    experiences with these wires on AEGIS & IVCS, see comments made by mr. L.
                                    Hageman, Camden wire-wrap foreman, and Mr. D. P. Schnorr of MSRD.
T    840215  CTS    MSRD          TRANSMITTER         HVPS             TWT                      CWI
                                    "TRANSMITTER PROBLEMS" FILE 010227
                                    In a letter to this file, various problems occurring with transmitters used in AEGIS
                                    programs have been listed and discussed. Most of the problems deal with parts
                                    and materials. This list will aid in procurement and avoidance of problem parts.
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Fig. 3. *Experience retention file sample abstracts.*

4. Change made to prevent device failure. The Design Review committee reviews system parts lists for devices that are electrostatic discharge sensitive (ESDS). A Technical Assurance bulletin lists all microcircuit devices classified ESDS and describes proper marking and packaging for MSRD manufacturing.

5. Elimination of unnecessary components to reduce cost. In an alphanumeric display system design, the Design Review committee recommended circuit changes for the display driver module to obtain sufficient gate-to source "on" voltage to produce a low "on" resistance for the driver FETs. The complementary emitter follower circuits were replaced with "5406" inverting buffers. The display was then maintained in an

Experience Retention Data Submission

Title:

Author or Originating
Activity:

Date Originated:

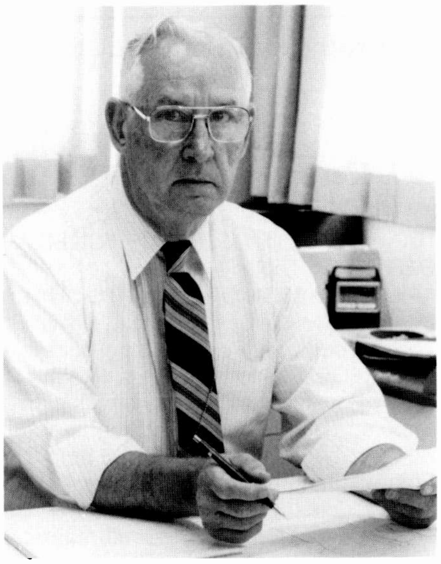
Key Words:
#1 #3
#2 #4

(At least two and no more than four should be provided)

ABSTRACT: (six lines maximum)

Fig. 4. *Experience retention abstract submission form.*

"off" state with drive removal by using resistor divider pull-ups on the module inputs. These changes simplified the design and produced additional display failure protection when the drive was removed. In a solid-state-switch multiplexer design for microcomputer data lines, relatively elaborate electronics were required in the input/output portion of the circuit. The Design Review committee recommended relays be used as a less expensive and more reliable switching approach. Also, the "power off" state of the multiplexer could not always be known and for the relays it could be determined by the design engineer. This is an example where a state-of-the-art switching technique may not always be superior to an older technology.



Bob Killion is the manager of the Technical Assurance Activity within MSRD's Engineering Department. His career at MSRD began in November of 1958 with various design support activities, including reliability, maintainability, parts and materials, maintenance engineering, and design review. More recently, his responsibilities expanded to include Design-to-Cost and Life-Cycle Cost, and he is personally involved with these timely cost considerations. Mr. Killion received a BSEE and an MS in Statistical Analysis from Villanova University.
Contact him at:
RCA Missile and Surface Radar Division
Moorestown, NJ
Tacnet: 224-2628

Future needs

What changes are taking place that should influence the operation of a design review program? The following are worth noting:

- ☐ The change of personnel mix from experienced to less experienced designers.
- ☐ The loss of design reviewers with many years of RCA experience through retirement.
- ☐ Greater emphasis on cost because of competition and more fixed-price contracts.

The first two changes will result in a loss of know-how based on years of experience. To offset this effect, an "experience retention" system will be needed so that the less experienced designers and design chairperson can utilize and build on it. This can take the form of design guidelines tailored to our products because they have been based on past successful practice. This system can include a database of product-oriented experience (problems encountered and effective practices). The design guidelines effort is currently underway. Various design activities have been tasked to produce specific design guidelines. An experience retention file has been initiated, and it will be available to anyone with access to the MSRD VAX™ system. Our current tasks involve expanding the database. Fig. 3 illustrates samples of several abstracts now in the system. These abstracts are backed up by the hard copy source documents that are maintained in the Technical Assurance area. Fig. 4 illustrates the abstract submission form that will be made available to all MSRD engineering personnel for submitting candidate abstracts into the system.

The greater emphasis on cost resulting from increased competition, as well as an increase in the number of fixed price contracts, dictates a greater sensitivity to cost in our designs. More Design-to-Cost requirements are being included in our contracts. They provide additional motivation to produce less expensive designs. Design review functions must take a lead role in creating a greater sensitivity to the need for less costly designs. This sensitivity to cost cannot be limited to acquisition cost. It must also include a sensitivity to the operation, maintenance, and support cost resulting from the characteristics of the system acquired.

R. Barra

Working with vendors, a "new approach"

*Relationships with vendors must change . . .
to improve quality, productivity, profitability and customer satisfaction*

Vendors, as you know, have a major influence on any business. For many companies, including RCA, over 40 percent of manufacturing costs are in purchased materials, parts and services.

During the past five years, as a result of their overall quality improvement efforts, many companies have come to appreciate the "40-30-30 Rule" even more. This simple formula suggests the typical distribution of the causes of product quality problems. According to this rule, 40 percent of the problems can be attributed to poor product design; another 30 percent to poor manufacturing process control; and the final 30 percent to defective materials, parts and components purchased from vendors.

This final 30 percent should be the target of vendor-related quality improvement policies and procedures that are aimed at preventing defects and reducing them to zero percent.

Abstract: *If we are to provide the high-quality, low-cost products that consumers want, we need to look at our relationships with vendors. We've already changed our perceptions on procurement quality. Now we must change the way we view vendors. Some American and Japanese manufacturers who have cooperative, long-term relationships with fewer, more reliable vendors are already reaping the benefits. This paper looks at ways to achieve this new relationship.*

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Changing perceptions

As a prelude to examining how vendor relationships need to change, let's review some basic changing perceptions of Procurement Quality (see Table I). *The dollar impact of buying on price is dramatically demonstrated if we study the "life cycle costs" of purchasing a specific item.* These costs are the acquisition cost plus the cost of owning the item, from the time we receive it through the end of the warranty period in which we use it. Many of these costs occur whenever material is rejected.

When we establish incoming inspection criteria and procedures, we should not use Acceptable Quality Levels (AQLs), which mean an expectable level of poor quality. AQLs foster a self-fulfilling prophecy that defects will occur—and sure enough, they do.

If we reject a product at point of receipt, a succession of white- and blue-collar tasks must occur to process its rejection and replacement.

While we may recapture some blue-collar costs (such as sorting or rework) from the vendor, few, if any, white-collar costs (such as adjusting the account, entering rejection data, or

Table I. *Changing perceptions of procurement quality*

View	Old Perception	New Perception
Buying decision based on:	Price and delivery	Quality and total cost of ownership
Vendor relationship is:	Adversarial and short-term	Cooperative and long-term
Purchasing should use:	As many vendors as possible	Fewer, more reliable vendors
Defective material is usually:	The vendor's responsibility	Joint responsibility
A certain level of defects is:	Acceptable and is to be expected	Unacceptable and can be improved
Incoming inspection always:	Improves quality and is necessary	Costs money and should not be necessary
Defect-free material costs:	More	Less
Inventory should be bought:	Just-in-case	Just-in-time

reordering replacement material) are recovered. These uncaptured, white-collar rework costs typically exceed blue-collar rework costs by two to one.

If we discover the defective material at successive levels of use later, ownership costs can increase by orders of magnitude at each level, especially with high-technology parts. (See Table I).

If new products are being evaluated, it may be possible to get a rough estimate of life cycle costs based on vendor advertising, claims, statements, and Mean Time Between Failure (MTBF) projections. This is admittedly difficult. However, the time spent developing such information can be very rewarding. Full life cycle costs can easily range from 1.5 to 100 times the original purchase cost.

Vendor relations

To capitalize on these new perceptions, bring vendors up to the quality levels that are required, and keep them there, a company must make *four basic changes* in its relationships with its vendors.

The first basic change

A company must see its vendors as an extension of its own organization.

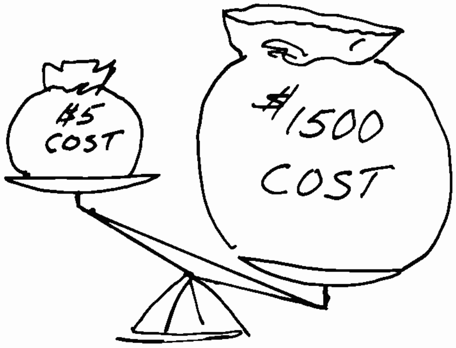
No longer can a company deal with a vendor at arm's length. The old adversarial relationships must give way to close, cooperative ones.

A striking example of the new relationship is found in the Ford Motor Co. Four years ago, Ford was rejecting and returning nearly 9 percent of the steel it purchased because of surface defects or faulty chemistry. Working together, Ford and its suppliers brought the rejection rate down to 2 percent. Also, as a result of the improved Ford-supplier relationships, the steel makers have improved their delinquent deliveries to the company to less than 3 percent, from 20 percent just two years ago.

However, building such new relationships is not easy. For example, when one company asked to examine one of its key vendor's proprietary processes, they balked. So the company opened its own shop first, and exposed *its* expertise to the vendor. That was the beginning of a cultural turn-around that lead to full and open communications and cooperation.

Table II. *Cost of detecting defects increases at each level of the cycle*

Detecting the defective device at:	Costs:
Vendor facility (by vendor personnel)	$ 0
Incoming test	5
Printed circuit test	50
Major assembly level	500
System level	1500



The second basic change

Also required is a selective reduction in the number of vendors.

Many companies deal with large numbers of vendors, all scrambling competitively for an order. Often price is predominant; quality and on-time delivery considerations get lost in the scramble. A new approach must be taken.

Every prospective vendor should be evaluated by specialists who can analyze the vendor's process capabilities, examine his facilities and procedures, and evaluate his output to establish whether he has the expertise and experience to do the job. Historical data on the vendor's quality track record, along with his schedule and cost performance, should also be considered.

The third basic change

We must actively help vendors improve their ability to deliver high-quality materials, parts, and components.

At some companies, commodity enhancement teams—made up of engineering, manufacturing, quality assurance, and procurement people—work directly with their key vendors.

For example, one company had six vendors that supply unpackaged integrated circuits, or bare chips, with a 61 percent first-time yield at incoming inspection. By changing specifications, restructuring buying documents, and communicating more effectively with vendors, the company was able to reduce the number to three vendors. The first-time yield rose from 61 to 90 percent, resulting in a multimillion dollar savings.

At another company, groups of vendors participate in symposiums to learn more about the company's requirements, and exchange quality data with each other. The vital ingredient is two-way *communications.* It makes the vendor-customer relationship a cooperative dialogue that can be used to better match vendor capability with the company's needs.

Vendors should also be included in selected Design Reviews to give them a better insight into the role their material or part will play in the final product or service. In general, involving vendors in the initial Design Review stage facilitates early, low-cost design enhancement, while optimizing downstream productivity.

The fourth basic change

We must monitor more closely the ongoing performance of key vendors.

Regularly scheduled quality review meetings should be held, alternating between the vendor's and customer's plants. Problems should be Pareto-analyzed so that the top problems can be targeted for resolution.

At Burroughs Corp., an electronics-based information systems company, suppliers are called "partners in excellence" and each year the best receive "Supplier Excellence Awards."

"Suppliers recognized for their outstanding contributions are considered for increased and long-term business opportunities," says Joseph J. Zeccardi, Burroughs' vice president of quality and service. "We also involve key suppliers during the design phase of new product programs. We're looking for up-front supplier involvement to ensure quality designs, quality processes, and quality parts. And our plans include long-term contracts with key suppliers to support the level of capital investment essential in meeting our product standards and introducing innovative technology."

The new relationship

All four changes in relationships with vendors benefit both the purchasing and vendor companies who are involved.

Vendors benefit in several important ways. As they go through a process of selection, upgrading and monitoring, they develop and refine the skills that will make them more valuable suppliers. For example, they learn about sophisticated test techniques, statistical process control methods, and formal Design Review procedures.

For a company, the benefits of such vendor quality improvement are substantial. Quality improvement drives productivity improvement, reduces costs, and leads to additional business with attractive profit margins.

Japanese automobile companies have gained a competitive advantage by using vendor policies and procedures that are very similar to those just described.

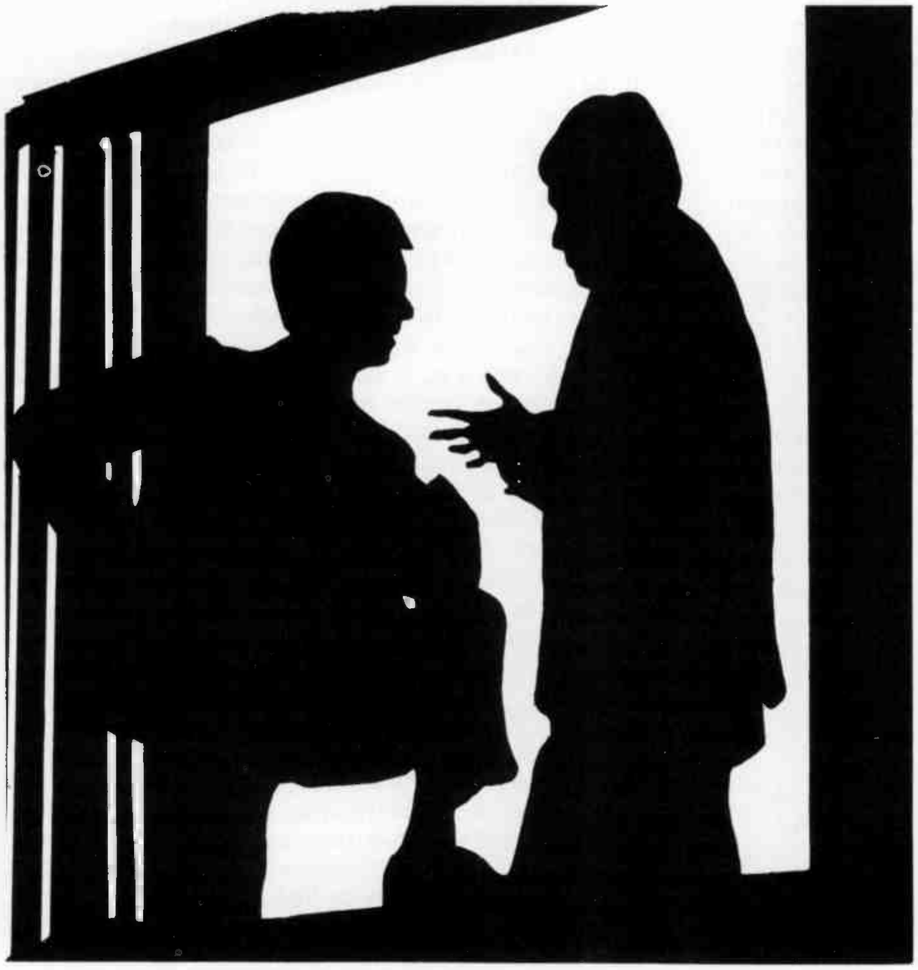
Nissan asserts that, as a result of involving their vendors in the early stages of a new design, about 70 percent of all their cost reductions are made while a new model is still "erasable"; that is, while it is still on the drawing board.

The Japanese go quite far in reducing the number of vendors they use. A typical Japanese automobile company uses about 200 vendors, or only about 7 percent of the 3000 vendors that a typical American automobile company uses.

An obvious question concerning the reduced number of vendors is "How to maintain cost competitiveness?" The Japanese automobile producers do this by making cooperative "Should Cost" studies and setting specific, annual cost-reduction targets. Nissan, for example, expects a 3-percent price reduction each year from its vendors and, apparently, has been able to negotiate such arrangements over many years.

If we apply the same approaches to vendor relationships as the Japanese have been practicing, the American automobile industry can reduce the costs of their components and materials by about 15 percent. Of this, 6 percent is from the efficiencies that result from having fewer vendors, 4 percent from improved quality, 2 percent from improved producibility, 2 percent from reduced material handling costs, and 1 percent from reduced overhead costs. Significantly, this 15 percent represents about half the current difference in manufacturing costs between American-made and Japanese-made automobiles.

Vendor quality improvement should be a top-priority objective at any company. In this context, forging a bond of long-term, stable relationships with its vendors will enable a company to achieve ambitious quality goals . . . and will lead to substantial gains for its key customers.



Ralph J. Barra, president of Barra International, is a "boardroom to boiler room" quality breakthrough consultant, specializing in coaching executives how to form and lead a top-to-bottom network of quality improvement teams and circles.

During the last seven years of his thirty-year career on the quality and productivity front for Westinghouse, he was Director of Corporate Quality. In that capacity, he directed a corporate-wide enhancement activity which included administering a quality college, managing Westinghouse's 2000 worldwide quality circles, and providing consulting and teaching services to all of Westinghouse's operating units and over 200 of its customers and suppliers.

Since forming his own firm, Mr. Barra has worked with such clients as Houston Lighting & Power, the Pennsylvania Department of Transportation, Thompson-McCully Construction, Standex International, Magma Copper, Dentsply, and Det Norske Veritas.

RCA retained Mr. Barra to lead the development of the quality-management-improvement-process courses and training materials. Since the inception of the program in 1985, he has presented this material to over 300 of RCA's top executives.

L.J. Gallace

The application of factorial experimental designs to develop and improve solid-state manufacturing processes

Factorial designs consider how variables relate to each other, helping to produce better manufacturing processes.

The factorial experimental design is a natural extension of good engineering practices because it allows engineers to view the dynamics of a process rather than the static "snapshot" (which is often the basis of data interpretation) and to determine process variability and boundary conditions. In addition, the factorial experimental design identifies the components of a process and their interactions in the process; traditional, nonstatistical approaches often do neither. The Appendix gives an overview of factorial experimentation.

In this paper, we present examples that verify the simplicity of factorial designs, their power, and efficiency. We emphasize the experiment's original design. The simplified approach to data analysis enables engineers to develop a feel for the data before applying sophisticated statistical-analysis procedures, such as analysis of variance and analysis of means. Graphical methods to which engineers can easily relate are used to show the relationships of an experiment's significant factors.

Why experiments?

Experiments are conducted to measure the effect of one variable on another. There is a rational methodology for optimizing an experiment that minimizes time and cost while maximizing the amount and quality of data and information. Optimization is the essence of any engineering investigation, and statistically designed experiments enhance the optimization procedure by eliminating the educated guess and conjecture in the absence of data.

As statistical methods continue to grow in use in complicated engineering studies of processes and materials, they are becoming more sophisticated and yet simpler. The procedures cut the time formerly used in trial and error searches, and the adaptability to computer analysis reduces the time required to calculate results.

In any engineering or scientific investigation that employs statistical methods, we need to keep the key variables under study clearly in focus while we experiment and collect data. The factorial experimental design does this, and encourages the experimenter not to let preconceived information prevent an unbiased look at the data. With traditional methods, we give more emphasis to the mathematical treatment than the variables, and lose the experimental objective.

A simple cube (Fig. 1) geometrically illustrates an experiment with three factors at two levels each. This three-dimensional representation, which is valid for both traditional and factorial-experimental-design approaches, gives a picture of the behavior of the independent variables; the edges of this cube represent their operating ranges. Although there are more detailed methods that use factorial designs, this paper concentrates on the 2^3 factorial design approach, yet mentions the higher-level variations. The concepts described are valid for all 2^n factorial designs.

Two-level factorial

As the first step in the experimental design procedure, most engineers who use the traditional approach try to simplify the problem under study and then plan the collection of data. In the experimental approach they most often adopt, two or three variables are held constant while one is varied over a range of values, from low to high. Such an experimental procedure is plagued by several pitfalls, such as a possible loss of randomness during measurement and data collection.

Abstract: *Engineers in high-technology industries, such as the solid-state semiconductor industry, often do not realize the value of statistical methods in investigating the complex processes that are characteristic of their businesses. Their view, chiefly the result of lack of information and experience, is that statistics are only useful in summarizing large amounts of demographic data, survey sampling, etc. This paper will correct that view for semiconductor engineers by demonstrating an approach to using factorial experimental designs to develop new processes and solve problems in existing processes.*

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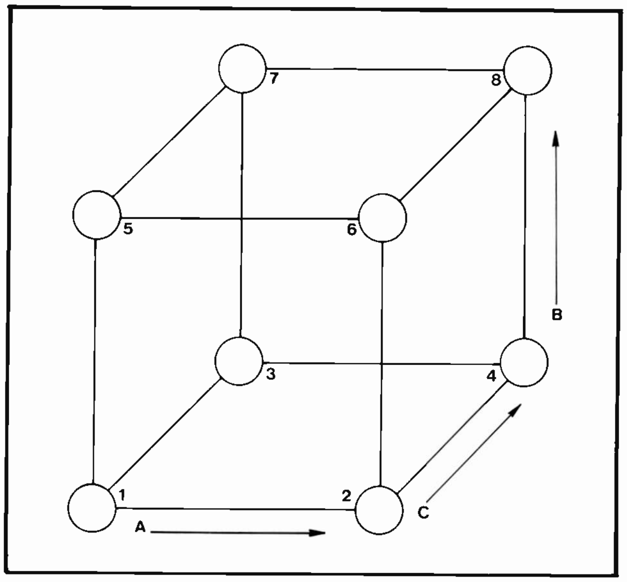


Fig. 1. *Geometric representation of 2^3 factorial experimental design.*

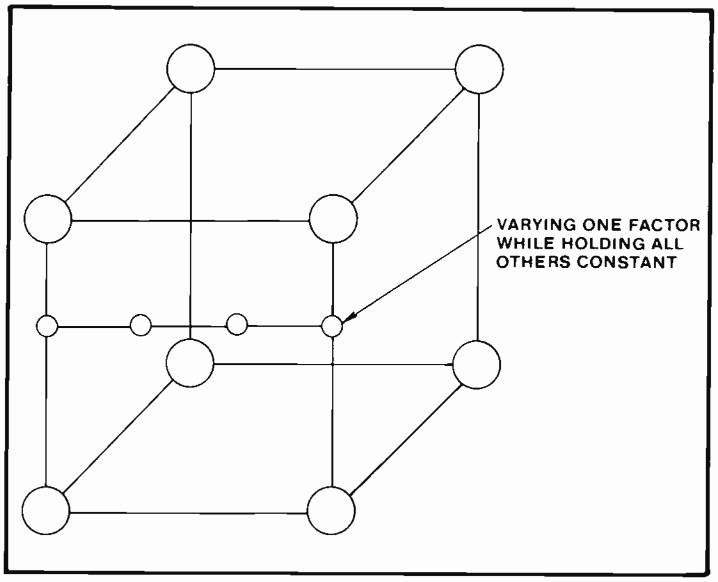


Fig. 2. *Representation of experiment where one of three factors is varied while the others are held constant.*

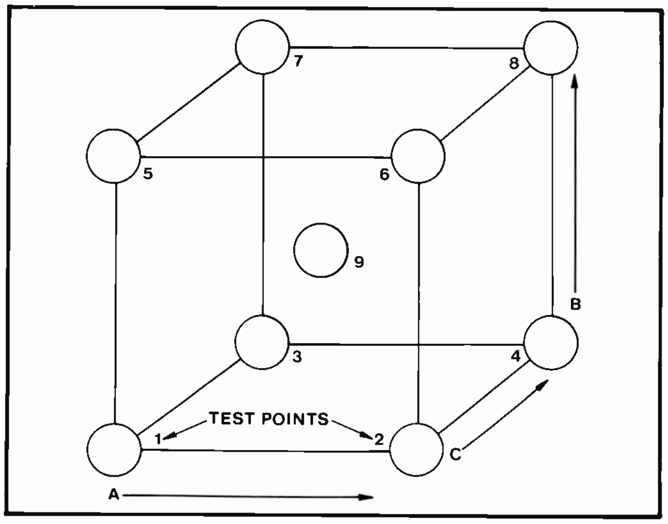


Fig. 3. *2^3 factorial experimental design with center-point added.*

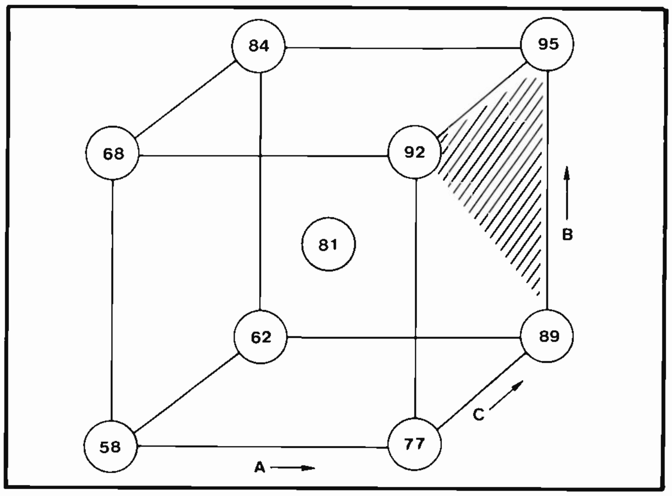


Fig. 4. *Representation of yield of various test points showing when response is maximized.*

Most important, this approach does not study the interaction between the independent variables.

If we vary one component at a time on a three-factor experiment, we essentially change Fig. 1 to the representation in Fig. 2, where the cube that once held all the information is narrowed to a one-dimensional line. The particular face of the cube on which this line appears depends on the factor varied. Obviously, this traditional type of approach is very inefficient in time and cost because each variable studied requires a separate set of experiments.

To eliminate this inefficiency, the factorial experimental design obtains optimum information and minimizes or reduces uncertainty about the data. Once we select the key factors, we study their effect on some response, such as yield or reliability. Then, we select a test plan that locates a pattern of points on or in the cube space, usually in the eight corners of the cube. This pattern minimizes experimentation, but gives information about the space in the cube. A center-point is often added as the cube's "ninth" point (Fig. 3).

Each point in the experimental pattern is a point in a design matrix. We use the average value of the dependent variable to analyze the data. By placing the values in the design matrix array as depicted by the cube, we get a clear picture of the response of dependent variables. If we need more experimental points, they can be selected on any surface of the cube to optimize the dependent variable. Fig. 4 shows how we can use the analysis of average values of the response variable to determine quickly optimum operation of the independent variables under study.

Box-Behnken

To define the operating region of a variable in more detail, we can use the Box-Behnken plan in place of or to supplement the two-level factorial plan. Fig. 5 shows the test pattern for Box-Behnken. The plan calls for twelve experimental points at the edges of the cube plus one at the center, which is tested three times to estimate experimental error. This amount of

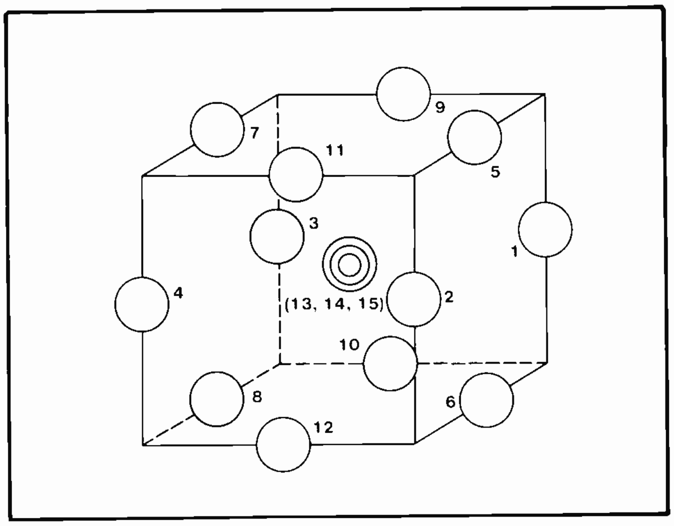
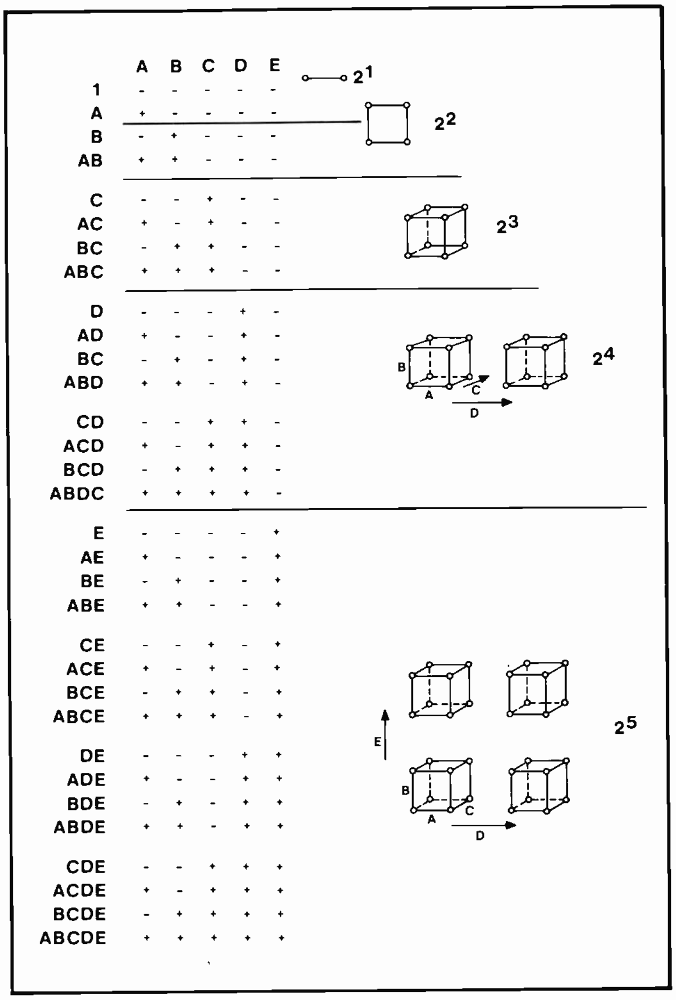


Fig. 5. *Box-Behnken representation where twelve experimental points with a center point are replicated three times to quantify experimental error.*



	A	B	C	D	E
1	-	-	-	-	-
A	+	-	-	-	-
B	-	+	-	-	-
AB	+	+	-	-	-
C	-	-	+	-	-
AC	+	-	+	-	-
BC	-	+	+	-	-
ABC	+	+	+	-	-
D	-	-	-	+	-
AD	+	-	-	+	-
BC	-	+	-	+	-
ABD	+	+	-	+	-
CD	-	-	+	+	-
ACD	+	-	+	+	-
BCD	-	+	+	+	-
ABDC	+	+	+	+	-
E	-	-	-	-	+
AE	+	-	-	-	+
BE	-	+	-	-	+
ABE	+	+	-	-	+
CE	-	-	+	-	+
ACE	+	-	+	-	+
BCE	-	+	+	-	+
ABCE	+	+	+	-	+
DE	-	-	-	+	+
ADE	+	-	-	+	+
BDE	-	+	-	+	+
ABDE	+	+	-	+	+
CDE	-	-	+	+	+
ACDE	+	-	+	+	+
BCDE	-	+	+	+	+
ABCDE	+	+	+	+	+

Fig. 6. *View of various levels of factorial design.*

data can be fitted to a second-order equation that will describe the response variable.

Fig. 6 shows the levels of factorial design for an experiment that requires 2^5 or 32 runs. The low levels of a factor are indicated by a minus sign and the high levels by a plus sign. The figure shows all the interactions among variables as well as the main effects for any design. For example, the 2^3 or 8-cell design has three second-order interactions and one third-order interaction.

At times, it may not be desirable or cost-effective to run a complete factorial. In these cases, we can develop a screening design or fractional factorial design from the type of matrix shown in Fig. 6. In a typical case, a screening design may be used to examine main effects while interactions are temporarily ignored.

Fig. 6 shows that the 2^3 factorial design requires eight runs, 1 through ABC. If we designate the third factor in the experiment as the product of the levels of the first two, then we only need four runs for the fractional factorial. Fig. 6 shows that a three-factor design repeats the two-factor design with the third factor at both the low and high levels. The four runs are said to have variables "confounded" with the second-order interaction AB. This design is known as a 2^{3-1} or half-replicate design, because it has half the runs of the original design. Other variations of the fractional factorial design are possible, such as quarter-replicate designs, 2^{n-2}.

Analysis

There are many rigorous statistical methods for analyzing experimental data, such as the analysis of variance, the analysis of means, and regression analysis. However, a simple comparison of the averages usually can provide 75 percent of the information required. The key to analysis lies in the original design of the experiment and the proper execution of the experimental cell. We can easily analyze properly designed experiments and, in particular, factorial experimental designs by calculating the averages for each experimental cell and then displaying them graphically.

Fig. 4 is an example of this type of analysis and display. The averages for the nine individual experimental cells are calculated and inserted in their respective geometric locations. Conditions that would yield a maximum or minimum become readily apparent. To determine the effect of any of the main factors (A, B, or C), we take averages at the opposite faces of the cube. For example,

Low level of factor A average
$= (58+62+68+84)/4 = 66.5$
High level of factor A average
$= (77+89+92+95)/4 = 89.0$

Similar simple calculations can be used to quantify the other main factors.

Interactions, two-factor effects, can be handled in a similar way. If we were to evaluate factor A and factor B, the calculations would produce four averages, and the interaction would be the differences in those averages. For the data in Fig. 4, averages for:

A low level and B low level $= (58+62)/2 = 60$
A low level and B high level $= (68+84)/2 = 76$
A high level and B low level $= (77+89)/2 = 83$
A high level and B high level $= (92+95)/2 = 93.5$

The averages are represented in Fig. 7.

The differences between averages for low levels of factor A are 76 minus 60 or 16, and for factor B, 93.5 minus 83 or 10.5.

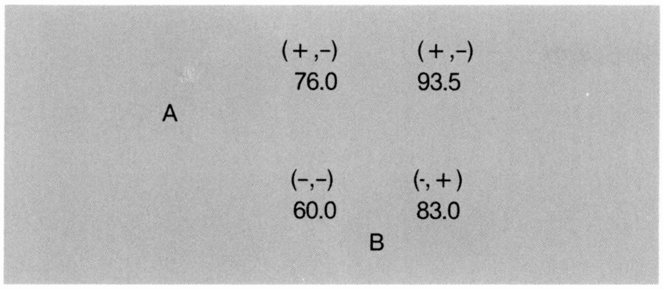


Fig. 7. *Averages of interactions.*

We can define interactions as the failure of the differences to be the same. Here, 16 is greater than 10.5 — i.e., the differences are not the same — therefore, we suspect an interaction. Combinations of these two factors do not yield a linear response.

These examples do not imply that you should not use the more rigorous statistical-analysis methods but do demonstrate how easily you can get information by simply comparing averages from properly designed experiments. Most statistical analysis methods are available on computers. The data used should be analyzed with the appropriate method because you need to quantify the variability and accurately evaluate all factors and their interactions, shown schematically in Fig. 8. If the differences between two numbers is small, you need the estimate of this variability to determine what probability risks exist in stating that there are differences.

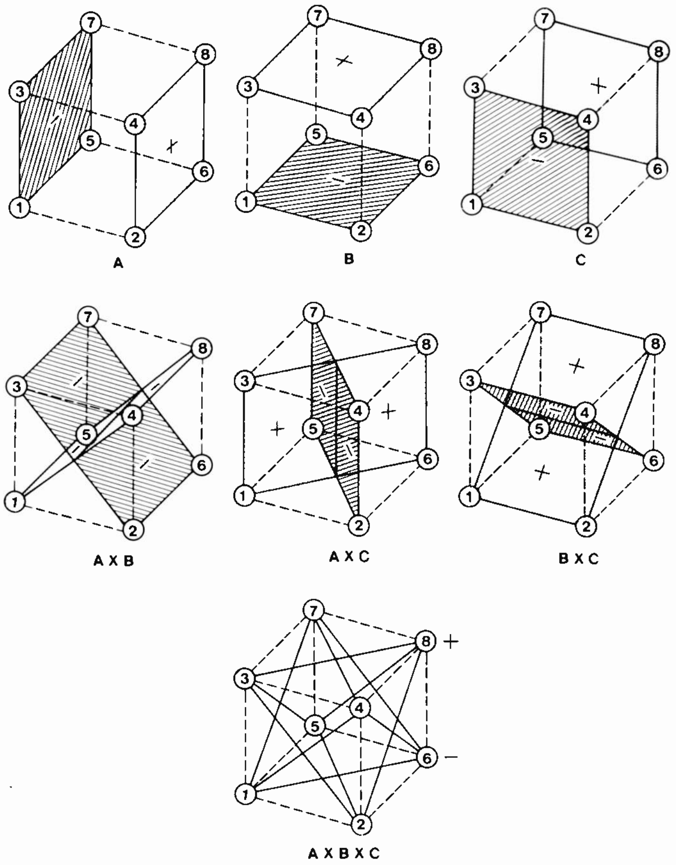


Fig. 8. *Factorial design at two levels. (From G.E.P. Box, W.G. Hunter, and J.S. Hunter, Statistics for Experimenters, John Wiley & Sons, 1978, p. 312.)*

Some case studies

In a study of the key variables that affect how the plastic encapsulation of integrated circuits responds to moisture, we conducted a 2^4 (16) cell experiment. It consisted of both quantitative and qualitative factors. Table I and Fig. 9 show the response of pressure-cooker testing on the 16 cells. Fig. 10 clearly shows that there is a significant interaction between post-mold cure time and mold transfer pressure. That is, to get the best results on the pressure-cooker test and the most efficient encapsulation, we need both the 1000-psi (high) mold transfer pressure and the 16-hour (high) post-mold cure time. Previous experiments conducted with one variable at a time had missed this interaction, but repeated factorial experiments produced statistically the same results.

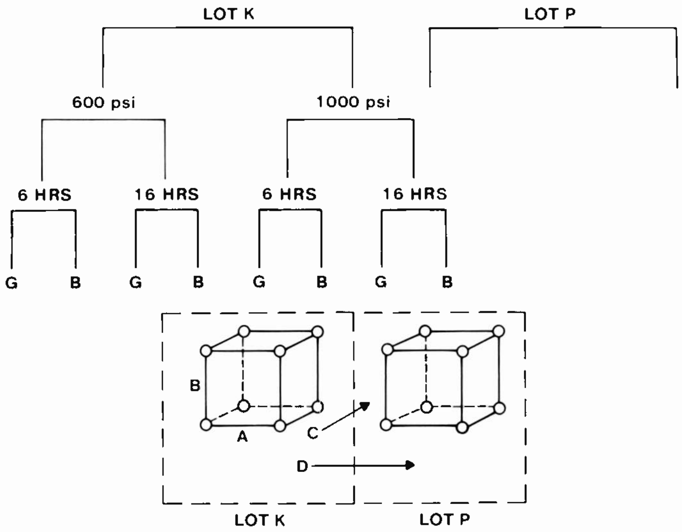


Fig. 9. *Results of molding pressure, post-mold bake experiment. A = solder process control, B = post-mold bake time, C = transfer pressure.*

A 2^3 or eight-run experiment was designed to investigate the reliability of integrated circuits in plastic encapsulated packages. The response variable was percent defective after high-temperature life tests. Figures 11 and 12 describe the experiment and the results. The epoxy material was significant at the 1-percent level based on an analysis of means. Because of these findings, we also investigated the die overcoat, epoxy encapsulant, and lead-lock frame. Results from these experiments showed that the lead-lock frame was another important variable.

A third example of the application of factorial design experiments involved a study to optimize the soldering process of an integrated-circuit package. Figures 13 and 14 show the 2^4 factorial design experiment and results. Again, analysis of means was used to analyze the data.

The interesting point here is that the engineers involved insisted that they had to have a precleaning step before soldering. However, their experience was based on a manual solder system, and not the automatic solder-dip operation included in the process under investigation. The observed data showed that the results were the same whether or not the

Table I. ***Molding Pressure/Post-Mold Bake Matrix***

Cell	Wafer Lot	Mold Trans. Pressure (PSI)	Post-Mold Bake (Hrs)	Solder-Dip Process Control	Pressure Sample	Cooker (48 Hrs) Falls (EMA)
1	K080	600	6	Good	200	7
2	K080	600	6	Bad	200	10
3	K080	600	16	Good	200	30
4	K080	600	16	Bad	200	15
5	K080	1000	6	Good	200	10
6	K080	1000	6	Bad	200	10
7	K080	1000	16	Good	200	0
8	K080	1000	16	Bad	200	0
9	P046	600	6	Good	200	1
10	P046	600	6	Bad	200	14
11	P046	600	16	Good	200	12
12	P046	600	16	Bad	200	15
13	P046	1000	6	Good	200	16
14	P046	1000	6	Bad	200	12
15	P046	1000	16	Good	200	0
16	P046	1000	16	Bad	200	0

Summary — Molding Pressure vs. Bake Time:

	Modling Pressure (PSI)	
Bake (Hrs)	600	1000
6	32/800	48/800
16	72/800	0/800

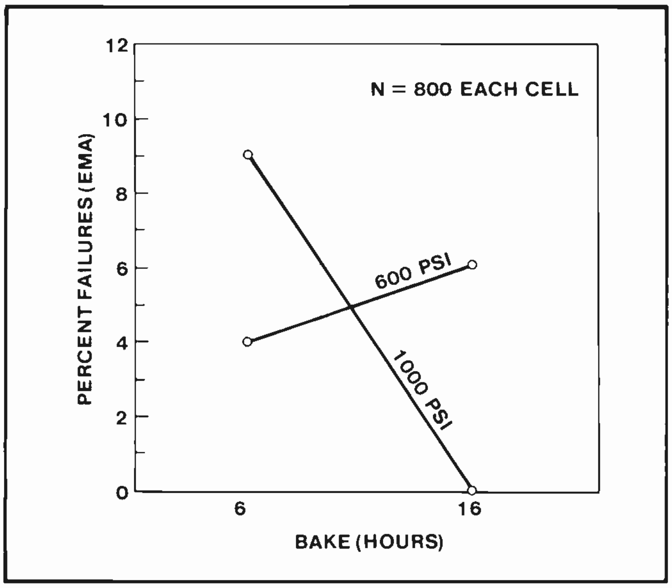


Fig. 10. *Molding pressure versus post-mold bake (48-hour pressure-cooker test).*

preclean step was used. The significant factors were flux concentration and the preheat temperature before soldering.

Why wasn't preclean effective with automatic soldering equipment? Unlike manual soldering, there is a time lag between preclean and soldering that allows the leads to reoxidize.

This experiment produced information that was not evident after 17 previous nonstatistical-design experiments. No doubt, the earlier experiments contributed to the final factorial experimental design, but they did not produce a process.

If we alter the two-level factorial (axial points outside the cube space), we can optimize response points and show this in a surface response plot. Figure 15 shows the modified two-level factorial called the Central Composite Design. Figure 16 is a three-dimension, surface response plot of the key parameters in an oxide-protect layer applied over the surface of a semiconductor die.

This type of analysis of contour plots is important to understand what happens when process variables are normally changed in manufacturing. In simple experimentation procedures, it would be difficult to determine the interactions between factors that this surface response clearly demonstrates.

Surface response methodology requires detailed knowledge of experimental design and the mathematics of regression analysis. Today, there is substantial interest in this technique because computers are available to analyze the data.

Summary

We have discussed two-level factorial experimental design, emphasizing technique and application rather than arithmetic calculation. Engineers, as experimenters, should be able to apply these methods to develop experimental plans that are statistically valid and demonstrate the interactions among variables. Unlike the static experiment, which depends on the luck of the draw of the sample to determine significant variation in a process, material, etc., the dynamic factorial experimental design studies the change in the variables involved and how they interact with each other.

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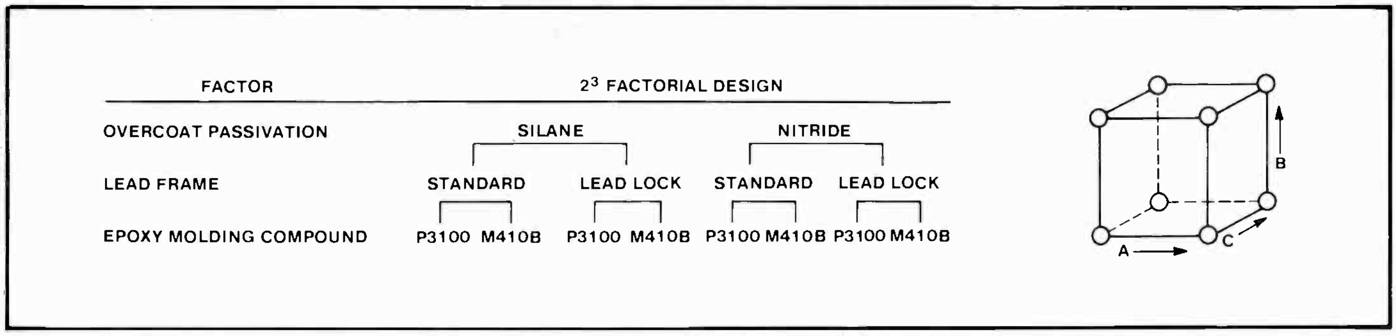

Fig. 11. *Design of complementary metal-oxide semiconductor (CMOS), 14-lead, dual in-line package (DIP), plastic-package experiment. Users analysis of means of attributes data to examine the effect of variants on electrical test yield. A = overcoat passivation (silane), B = lead frame, C = molding compound.*

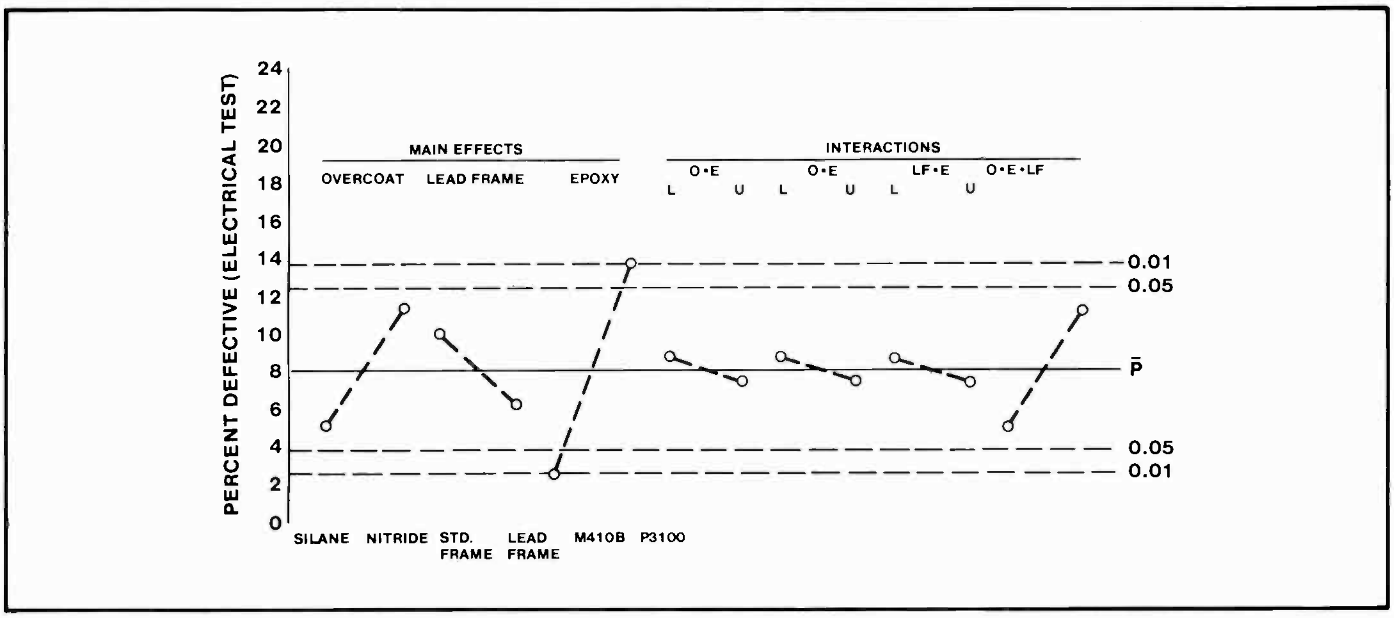

Fig. 12. *Analysis of means chart for CMOS, 14-lead DIP, plastic-package experiment.*

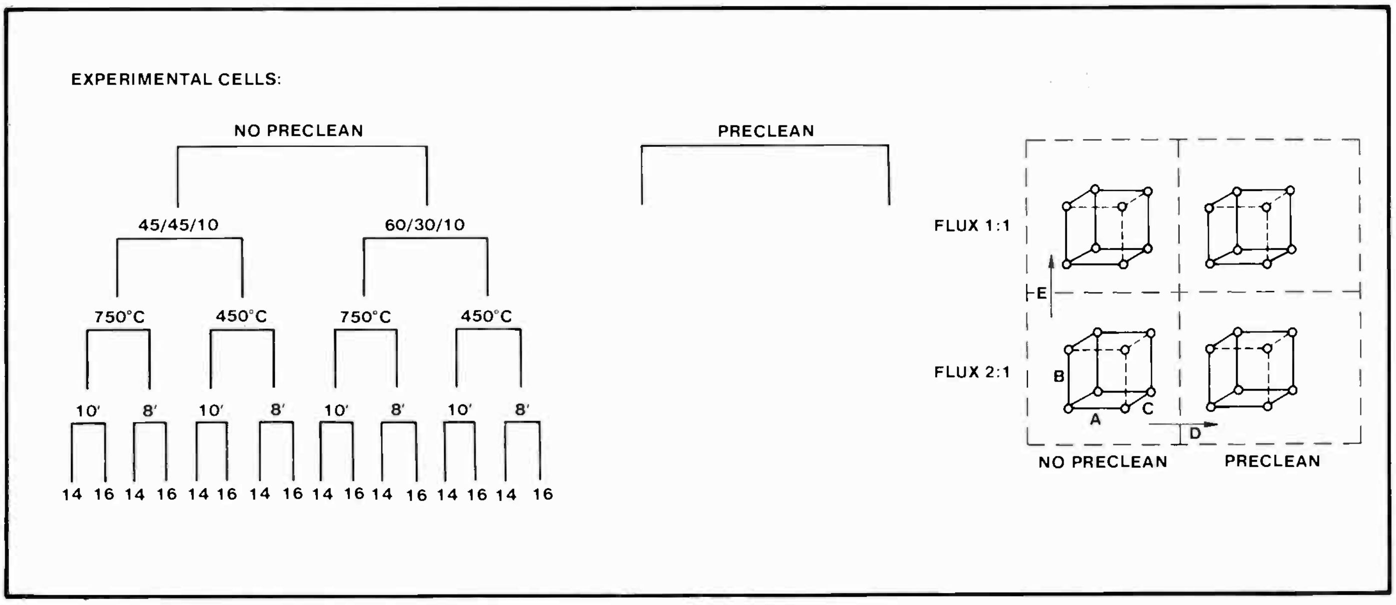

Fig. 13. *Design of soldering-process oxidation experiment. A = lead configuration, B = belt speed, C = preheat temperature.*

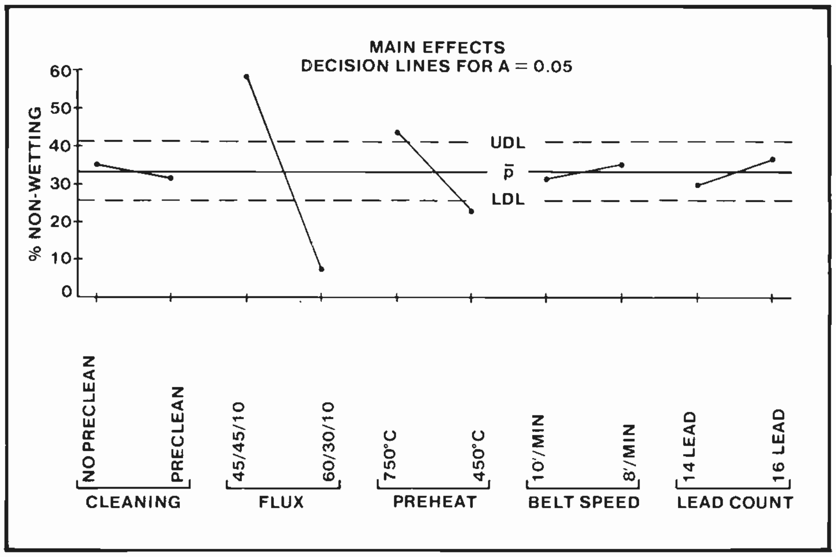

Fig. 14. *Results of soldering-process oxidation experiment.*

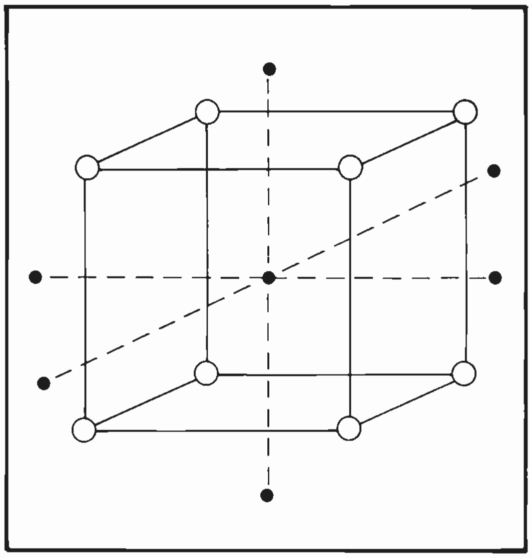

Fig. 15. *Central composite design.*

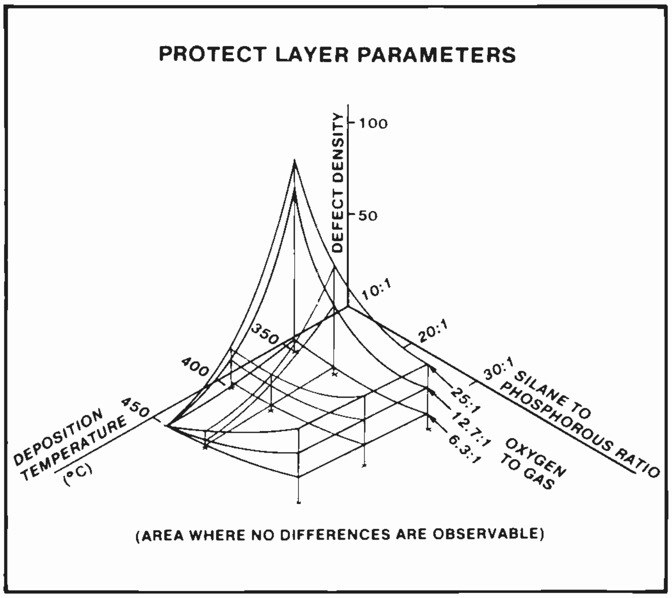

Fig. 16. *Three-dimensional response surface.*

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Factorial experimentation

The early recognition of factorial experimentation, or the design of factorial experiments, is largely associated with Sir Ronald Fisher and Frank Yates. Whether Fisher "invented" the factorial experiment is not clear. It seems entirely plausible that the factorial experiments began when the Lord took the rib from Adam and created Eve.

Since that time, man has pondered and sought answers to the question: "Do females respond differently to experimental treatments than males?" — i.e. when sex became a factor, we needed to consider it even in the simplest experiment that involved some other experimental comparison. When we needed to ascertain the effects of that experimental treatment separately for males and females, a factorial (two-factor) experiment was involved, with sex and the experimental treatment as the two factors.

The original question about differences in male and female responses was one of asking if there was any interaction between the experimental treatments and sex. Failure of the sexes to respond in the same way to the treatment would constitute a real interaction, whereas similar responses would indicate the absence of interaction. This might be visualized graphically as shown in Fig. 1.

In investigations of almost any sort, we need to examine, experimentally or empirically, the effects of various factors on the phenomena or criteria of interest — to examine the way these criteria respond to changes in levels of the factors in question. Such investigations are what we now refer to as factorial experimentation, and are aimed at ascertaining, not only the effects of the various factors, but also their interrelationships. Are there any interactions among them? We might describe interaction negatively as the failure of the effects of one factor to be the same at the different versions of the other factor. We can examine interaction efficiently only in factorial type experiments, where the different versions of the factors under study appear in combination with one another. If interaction is absent, we say that the effects of the factors are independent of one another, and the effects are additive. If we find that two factors interact with one another, the effects of those factors are not independent — the effect of each factor depends on the version of the other, and their effects are not additive.

ANOME — analysis of means

This method of analysis is an extension of Shewhart control-chart techniques. It tends to encourage the design of experiments, and is an effective method of presenting the findings. The analysis involves dealing directly with means, in contrast to the analysis of variance where means are compared by taking ratios of mean squares.

Beginning with k means of n measurements each, the analysis compares the individual means with the grand average of the k means directly analogous to a control chart. We make the decision about a significant difference by comparing points that represent the k means with lines drawn parallel to the line of the grand mean.

However, instead of control limits drawn at:

$$\bar{\bar{X}} = \pm 3\sigma_{\bar{X}} = \bar{\bar{X}} \pm A_2\bar{R}$$

as with the Shewhart control chart where one mean is taken at a time, we draw decision lines at:

$$\bar{\bar{X}} \pm H\alpha\,\hat{\sigma}_{\bar{X}}$$

where H, the Halpern factor, is an adjustment for the risk associated with observing k means at a time.

We construct a chart using these decision lines. If all the plotted points fall between the upper and lower decision lines, we interpret it as representing only random variability, i.e., no significant differences. If a point falls outside either decision line, it is considered evidence of nonrandomness with risks.

Estimating σ from R

When we have k samples of n each (and n is small, i.e., less than six or seven, usually), the procedure for estimating σ begins with finding the average R for the k samples. Then:

$$\hat{\sigma} = \bar{R}/d_2^*$$

where d_2^* is a constant for a given value of n and k.

Computations for both the analysis of means and analysis of variance require reference to the number of degrees of freedom. There is a loss of about 10 percent in the number of degrees of freedom from that associ-

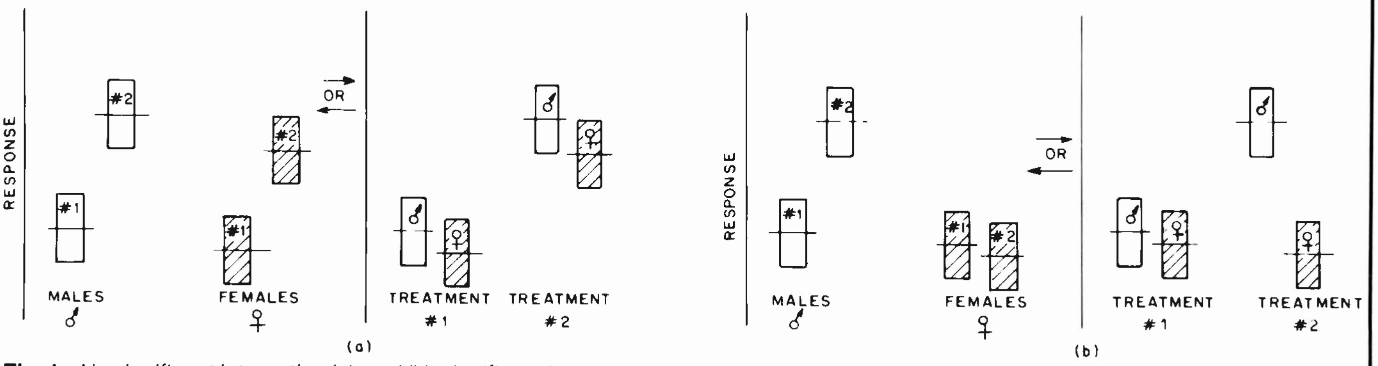

Fig. 1. *No significant interaction (a), and (b), significant interaction.*

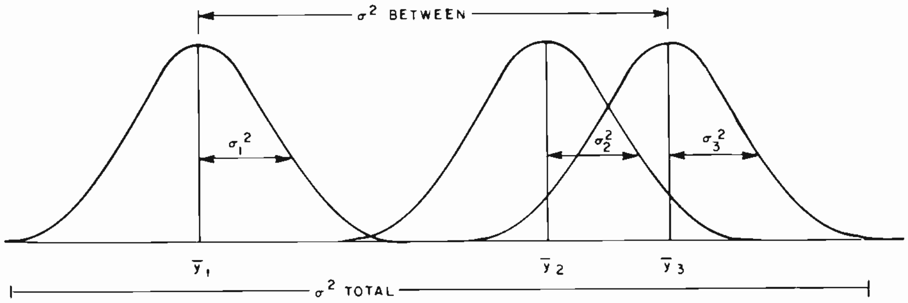

Fig. 2. *Comparison of three means.*

ated with the pooled variance procedure. Thus, the degrees of freedom to be used with equation (1) is:

$$\text{Degrees of freedom} = 0.90k\,(n-1)$$

The advantages of the analysis of means are:

1. It provides a direct study of possible effects of the factors by dealing with means instead of variances.
2. It provides a graphical comparison of effects.
3. It enables us to pin-point the sources of nonrandomness.
4. It is more sensitive in detecting the nonrandomness of a single means than the analysis of variance.
5. It frequently provides a bonus by suggesting the presence of certain types of nonrandom variability.

ANOVA — analysis of variance

The analysis of variance procedure is a way to test hypotheses about the homogeneity of several means or the effects of several levels of one or more factors. It involves the use of double or multiple summation operations and the associated symbols.

$$\begin{array}{cccc} X_{11} & X_{12} & — & X_{1k} \\ X_{21} & X_{22} & — & X_{2k} \\ X_{n1} & X_{n2} & — & X_{nk} \end{array}$$

We break down each observation into components to explain the algebraic identity:

$$\sum_{i=1}^{kn} (\underset{\vee}{y_i} - \bar{\bar{y}})^2 = \sum_{i=1}^{kn} (\underset{\vee}{\bar{y}_i} - \bar{\bar{y}})^2 + \sum_{i=1}^{kn} (\underset{\vee}{y_i} - \bar{y})$$

The *sum of squares (SS)* $\sum_{i=1}^{kn} (\underset{\vee}{y_i} - \bar{\bar{y}})^2$ is called the *total SS*, the SS of the composite sample of the *kn* observations.

The *sum of squares* $\sum_{i=1}^{kn} (\underset{\vee}{\bar{y}_i} - \bar{\bar{y}})^2$ is called the *among sample SS*.

Finally, the *sum of squares* $\sum_{i=1}^{kn} (yi - \bar{y})^2$ is called the *within sample SS*.

The three sums of squares measure the variation of the *kn* observations in different ways. The total SS, which measures the overall variation of the *kn* observations is the same. The *among sample SS* measures the variation among the *k* sample means. It is equal to zero if all the *k* sample means are equal, but the observations within the sample do not have to be the same. The *within sample SS* measures the variation of the observations within the samples. It is equal to zero if all the observations within each *k* sample are the same, but the *k* sample means do not have to be the same.

Figure 2 presents a graphic comparison of three means.

If we combine the data from all three distributions and compute the variance, we will get a variance that is far greater than if we pooled the variances within each distribution into one variance.

Equation follows — see what you can do with it

$$\sigma_\rho^2 = \frac{\sigma_1^2 + \sigma_2^2 + \sigma_3^2}{3} + (\text{variance within})$$

$$\sigma^2_{\text{between}} = \sigma^2_{\text{total}} - \sigma^2_{\text{within}}$$

$$F = \frac{\sigma^2_{\text{between}}}{\sigma^2_{\text{within}}}$$

If the *F* is greater than the tabulated *F* value, then we do not have a chance happening, but a difference in the means. The mathematical model for this matrix can also be written as:

$$X_{ij} = \mu + \beta_j + C_{i(j)}$$

where μ = overall mean
β_j = the effect due to j^{th} population
$C_{i(j)}$ = experimental error (unexplained chance variation)

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His early work was in reliabiltiy engineering and product assurance. He was the recipient of a 1968 RCA Engineer Achievement Team Award for silicon plastic power transistor engineering. In 1972, he was appointed Manager of the Reliability Engineering Laboratory for all solid-state devices, which included integrated circuits and power devices. Since that time, he has been heavily involved in developing test methods for characterizing the reliability of CMOS devices. In 1974, he was one of the recipients of the David Sarnoff Team Award for his contribution to the development of high-voltage power transistors for automotive ignition and other applications.

Mr. Gallace was named Director of Quality and Reliability Assurance for the Solid State Division in 1981, and in 1984, shared the David Sarnoff Team Award for improvements in the reliability of plastic encapsulated integrated circuits.

Mr. Gallace has published a number of articles on the reliability of silicon devices in addition to teaching courses on reliability engineering and statistical methods.

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RCA engineers garner top Eta Kappa Nu awards

The Eta Kappa Nu (Honorary Electrical Engineering Society) Jury of Award has named **Michael J. Keith,** Member, Technical Staff, RCA Laboratories, Princeton, as the 1986 Winner of the Award Program recognizing outstanding young electrical engineers. Mr. Keith is being recognized for "his outstanding contributions to the fields of Computers in the Arts, Teletext Systems, and in church and cultural activities."

Lauren A. Christopher, Group Head, Consumer Electronics Integrated Circuits Research, RCA Laboratories, Princeton, has been selected for Honorable Mention. She is being recognized for "her contributions and leadership in Digital Integrated Circuit Design and participation in civic and cultural activities." Three others recognized as finalists are: **Russell T. Fling,** RCA Consumer Electronics, Indianapolis, IN; **Gary Gendel,** RCA Microelectronics Center, Somerville, NJ; and **Steven D. Krueger,** Texas Instruments, Inc., Dallas, TX.

Mr. Keith, Ms. Christopher and the three finalists will be honored at the Annual Award Banquet on Monday Evening, April 6, 1987, at the New York Marriott Marquis, 1535 Broadway, New York City.

Since 1936, Eta Kappa Nu has annually recognized outstanding young electrical engineers. The purpose of this recognition is to "emphasize among electrical engineers that their service to mankind is manifested not only by achievement in purely technical affairs, but in a variety of other ways. It holds that an education based upon the acquisition of technical knowledge and the development of logical methods of thinking should fit the engineer to achieve substantial success in many lines of endeavor."

In the past 51 years, fifty-one young engineers (including the 1986 winner) who are less than 35 years of age, and who had received their Baccalaureate degree less than 10 years before, have received the award, and 109 others of similar characteristics have received Honorable Mention. Prior to Mr. Keith, the most recent RCA employee to be named the winner is John G.N. Henderson (RCA Laboratories), who was selected in 1977. In the past, other winners have been employees of some of the largest corporations in the United States, notably AT&T Bell Laboratories, IBM Corporation, Westinghouse Electric Co., and General Electric Co.

If you would like further information concerning this award program, please refer to page 20 of the July/August 1984 issue of the *RCA Engineer*, or contact **Jim D'Arcy** RCA Astro-Space Division (Tacnet 776-2359).

H.C. Thoelke

Software quality assurance: current thoughts

Does the software we deliver work the way it should?

Software quality assurance (SQA) is on its way to becoming a new driving force in the arsenal of the military software vendor. As with hardware quality assurance before it, the past decade has seen the SQA role expand on two fronts.

First, vendors are relying more on their SQA organizations. Second, the government is actively exercising its own QA muscle and hiring outside QA consultants to scrutinize all vendor contracts for quality and completeness. For example, government representatives now arrive for an acceptance test with consultants in tow. The Army relies on such a structure to ensure the purchase of quality software for its Automatic Test Equipment (ATE) in the same way that all Services rely on the structure for most major software acquisitions.

The Software Quality Assurance program outlined here has been in active use for military programs at installations across the country for some time. These SQA precepts apply broadly and experience shows that such programs—designed for any type of business, military, or commercial project—can expect a high rate of success.

Abstract: *The software quality assurance program described here has been ensuring that software we deliver satisfies our customer. It includes a detailed plan that covers roles and responsibility, documentation, training, and tests. Most important, the program starts before the first line of code is written. Through a series of reviews and audits conducted at various stages of design development and delivery, it ensures that software always meets requirements.*

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In the past, SQA plans were tolerated only because the contract required them. Now, because of changing priorities, we are coming closer to true software excellence. Outlined here are the guidelines and philosophy that illustrate and justify such faith.

An SQA program

The central purpose of any SQA program is to assure that delivered software satisfies all contract requirements, thus creating a positive atmosphere for new contracts. Such an SQA program defines and implements specific measures, such as safe operation of Automatic Test Equipment, which assure the high quality of delivered software. Further, it provides for testability, maintainability, and reliability.

Traditionally, these responsibilities have been given to an SQA group that works alone, using a small fraction of the project funding. As a result, such efforts have yielded only superficial results.

To be successful, the SQA effort must be integrated with engineering, program management, and configuration management efforts. Truly independent SQA status may require a larger portion of project resources, but the resulting product will have far greater integrity.

The traditional SQA group can appear as an external force to the design staff. But by working with the design staff from the project's inception, SQA becomes an influential partner in project direction. This more Utopian approach to practical, visible SQA gives everyone part of the responsibility. Throughout the software-development life cycle, members of the development team must identify and act on QA concerns to assure a quality product.

Quality can't be added on or tested in afterward; it must be a part of every step along the way. For example, a faulty design that works for some test cases or menus that only the sophisticated user can follow are the result of poor SQA throughout software development. A system should be simple enough to be used by someone at the entry level, but not so cumbersome as to defeat its purpose.

Thus, the SQA group's primary function is to develop and manage the SQA plan that defines standards and advises on their application. This does not require high-level software development expertise and becomes less difficult and costly to staff as the plan is perfected. SQA, as part of a process, is shown in Table I, which displays organizational roles over the project duration for all development life-cycle phases.

Requirements definition phase

The first SQA task is to draft the Software Quality Assurance Plan (SQAP) that defines project requirements. Example:

The SQAP covers several areas:

- ☐ Organization—Defines the roles of each project group and assigns tasks to them.
- ☐ Requirements traceability—Assures that top-level specifications are satisfied by the lower-level specifications.

Thus, it provides an audit trail to illustrate each branch.

- ☐ Documentation—Defines standards for preparing documents, and metrics to assure that documents comply with all requirements and practices for both customer and contractor.
- ☐ Software engineering methodology—Specifies the use of the structured walkthrough (as outlined by Yorden), software development folder (SDF) that acts as a repository for all project-related documentation, and compliance monitoring of all project phases.
- ☐ Training—Defines the required level of QA expertise for each aspect of a project and proposes a method for accomplishing any needed training or tasks.
- ☐ Formal reviews—Elaborates on the reviews to be conducted or participated in by SQA. These reviews are of the design, configuration, and readiness type, and are performed with and in anticipation of the customer's arrival.
- ☐ Test plan—Defines SQA's conduct of tests, criteria for customer acceptance, certification of test results, and discrepancy reporting. This test plan leads to the Test Procedure, the vehicle of final customer acceptance.
- ☐ Configuration management—Assures unambiguous identification of hardware, software, and documentation. This task is absolutely necessary to maintain the integrity of any software product throughout its development cycle.

If the scope of many of the projects encountered is similar enough, a generic plan may be evolved. From this template,we can tailor SQAPs to suit most projects. Combining all QA aspects of the development process into a single plan assures a compatible, integrated program.

Software quality must begin with the development process. The first priority is to define the functional software system requirements and related performance parameters (e.g., timing and sizing). There must be no uncertainty or ambiguity about the deliverables—the customer must get what he expects because he will judge quality after delivery. The key to producing quality software is a strong system engineering group. It handles the more abstract requirements, such as portability and reliability, that can affect specific design standards, and makes decisions that will affect the program later.

Common plans and specifications

The Computer Program Development Plan (CPDP) that Software Engineering creates, provides a specific, detailed, life-cycle plan for managing, developing, and maintaining a project's computer programs and associated documentation. The SQA engineer reviews the CPDP to become familiar with the software development process that software engineering will use, and ensure that the CPDP is written to the requirements of the Software Development Plan, DI-MCCR-80030.[2]

The Software Requirements Specification (SRS) for each computer software configuration item (CSCI) (type B5 specification) documents the programming, size and timing, interface, adaptation, and detailed functional requirements of the software to be developed. The SQA engineer reviews the SRS to ensure that it meets the requirements of DI-MCCR-80025 and MIL-STD-490A.

The Software Top-Level Design Specification (STLDS) is the first part of the type C5 specification for each CSCI. The STLDS establishes the software's functional design at the program level, and is the basis for the program's detailed design. The SQA engineer reviews each STLDS to ensure that the STLDD (Software Top-Level Design Document) is written in accordance with DI-MCCR-80012 and MIL-STD-490A.

In addition the SQA engineer reviews the Software Configuration Management Plan (SCMP) to verify that the software configuration management program's objectives are being met, and ensure that the SCMP is written in accordance with DI-MCCR-80009.

Preliminary design phase

In the design phase, SQA must occupy the foreground. When the detailed design of a software program module starts, a precise and detailed definition of its purpose, performance, operating environment, and external interfaces must already be available. Then, during preliminary design, the SQA program assures that these requirements are met.

List of Acronyms

CCB—Change Control Board
CDR—Critical Design Review
CPDP—Computer Program Development Plan
CSC—Computer Software Component
CSCI—Computer Software Configuration Item
DR—Discrepancy Report
FCA—Functional Configuration Audit
ICD—Interface Control Document
IRS—Interface Requirements Specification
PCA—Physical Configuration Audit
PDR—Preliminary Design Review
SCM—Software Configuration Management
SCMP—Software Configuration Management Plan
SDF—Software Development Folder
SDR—System Design Review
SQA—Software Quality Assurance
SQAP—Software Quality Assurance Plan
SRR—Software Requirements Review
SRS—Software Requirements Specification
SSR—Software Specification Review
SSS—System Segment Specification
STLDD—Software Top-Level Design Document
STLDS—Software Top-Level Design Specification
TRR—Test Readiness Review

Detailed requirements, system environment, as well as machine and man-machine interfaces are identified in software development. To evaluate this hardware-intensive area, we used considerable specific knowledge at the system level. The only practical approach is to give this responsibility to system engineering. They have defined the top-level requirements, resolving difficulties that arose from interpretation or intent, and are therefore uniquely qualified. This approach is not an abdication of QA responsibility, but a compromise in an area that is treated as a black box and whose functionality will be demonstrated repeatedly during development.

There is a direct relationship between the quality of a software product and the ease of testing it. This testability must have the highest priority. The test group traces the module's requirements to the preliminary test plan that it is preparing and feeds back any special design requirements needed to implement the plan. This method involves QA in the design phase earlier than was customary before.

Indispensable to intrateam communication is the software development folder that documents life-cycle events for both module and project from requirements definition to test. The SDF—which includes requirements, environment, and interfaces—helps SQA oversee the product life cycle.

As the preliminary design stabilizes, top-level specification changes begin to require formal control. This is the function of the Change Control Board (CCB) that provides a forum and stamp of approval for change acceptance. The CCB works best if program management seats a working group of top-level managers and members who are empowered to make immediate decisions.

Common reviews and audits

Eight reviews and audits are conducted during the life cycle to check for compliance with MIL-STD-1521B.

We conduct the Software Requirements Review (SRR) after we complete functional analysis and preliminary requirements allocations. The analysis and allocations determine the initial direction and progress of the system engineering effort and converge on an optimum and complete configuration. The SRR is self-stimulating and self-motivating because everyone wants to appear favorably. An audit ensures that the SRR is conducted in accordance with MIL-STD-1521B.

The System Design Review (SDR) for each CSCI evaluates the optimization, traceability, correlation, completion and risks of the allocated requirements in fulfilling the system and segment requirements. We reach technical understanding on the validity and degree of completeness of the System Segment Specification (SSS) and the SRS.

The Software Specification Review (SSR) is a formal review of each CSCI's functional, performance, interface, database, and special qualification or delivery requirements. Normally it is held after the SDR but before the start of CSCI preliminary design. The SSR authenticates the CSCI's SRS and any related Interface Requirements Specification (IRS) that is used to direct a preliminary CSCI design. The SSR determines that the SRS and IRS provide a satisfactory basis for proceeding with CSCI design.

The Preliminary Design Review (PDR), a counterpart of the SSR, follows the preliminary design phase. It is a formal technical review of the basic design approach for a CSCI or functionally related group of CSCIs. We hold the PDR after the Software Top-Level Design Document is available, but before the start of detailed design.

The statement, "Quality cannot be tested in; it must be built in," is often quoted and always true. Software interface development work is complex and requires special attention. For the most part it is done by the software development group that produces Interface Control Documents (ICDs), with the help of system engineering. This, therefore, brings two heads together to deal with the frequent redefinition of approach that occurs during early development.

The Critical Design Review (CDR) is a buffer between design and code-and-test. It is conducted for each CSCI to ensure that the detailed design solutions, which are reflected in the draft software detailed design document, satisfy requirements established by the Software Top-Level Design Document. The CDR assures that a well-defined, efficient design is in place, and guards against the need for redesign. It provides a top-level review of quality, e.g., completeness of documentation, adherence to easily audited standards, and traceability of functional requirements to design implementation.

However, CDR is not suitable for reviewing the lowest level detail of the design for which the structured walkthrough is more effective. SQA should prepare and approve the walkthrough plan, which includes, as a minimum, module name, participants, date, and a report on the proceedings. In this informal walkthrough setting, the programmer or engineer can lead several reviewers through the complete design, making it possible to evaluate the software's ability to be tested, operated, maintained, and transported. Documenting these tests is critical for repeatability and regression testing.

The Test Readiness Review (TRR) is a formal project review to verify formal CSCI-level test readiness. We conduct it after the software test procedures are available and Computer Software Component (CSC) integration testing is complete. The TRR determines that the software test procedures provide a satisfactory basis for conducting formal software tests and the project is ready for CSCI-level testing.

The Functional Configuration Audit (FCA) verifies that the performance of each CSCI complies with its software requirements.

The Physical Configuration Audit (PCA) formally examines the as-built version of a configuration item against its technical documentation to establish the product baseline.

Detail design and code

The code-and-debug phase has few places that allow scrutiny. During this phase, management visibility is reduced and care must be taken to maintain software quality.

After a successful compilation, the programmer or engineer does a line-by-line review using the structured walkthrough technique. This is the only way to check adherence to coding and documentation standards. Only experienced panel members should maintain the software development folder. This is a demanding discipline to impose on the programmer or engineer. But the SDF is the best offset against the "trust me" syndrome and is the foundation for preparing formal test procedures and user's manuals.

The time and effort are well spent because of the SDF's visibility. As a "public" document, it is open to the world. When each module is released to the test group, the software development supervisor and the SQA completely review the SDF. Documented evidence of debugging is required before module release and the test program is firmed up.

Test and operations

Software quality assurance is not a test group, but directs the test group, a separate entity.

As we describe the SQA plan used during the test phase, notice that SQA's role in testing is minor. We can trace this to the basic differences between hardware and software and how we test them. Software testing does not monitor gauges or analyze scopes and is quiet and repeatable. Hardware testing, on the other hand, can be destructive, uses a variety of tools and gauges, and is sometimes impossible or prohibitively expensive to repeat.

We do all significant SQA tasks before and after testing, which is fundamental to establishing a proper SQA program. Thus such a program focuses on methods and techniques that reinforce software quality, while hardware QA focuses more on the actual test.

The first two milestones for software testing are: identify what is being tested, and define the test environment. For both, we use a controlled software library from which we obtain all test software (code and database) and totally control version and identification. Without such controls, there can be no formal testing. Next, we define the test in concrete terms, especially the pass/fail criteria, and obtain prior test procedure approval from all parties, especially the customer. A pretest readiness review allows us to modify test procedures until we all agree on them.

While testing, SQA assures that we follow the procedure, control changes, and correct documentation. The test director should conduct a post-test meeting where SQA certifies that the test report is correct, including Discrepancy Reports (DRs) generated during the test. Each DR should be assigned appropriately for resolution and reported to the CCB.

The discrepancy reports provide a good measure of software quality when SQA interprets the DR statistics and reports on them. Some measurements that help identify weakness in the software process are: number of DRs, frequency distribution of DRs by type, mean time of closure, and DR rate as a fraction of product life. DR analysis continues while software is placed in the field; later, product improvements and future designs will draw on this informational database.

Quality is directly proportional to the degree that the software has been exercised, generating expected results without errors. Tools that help measure and quantify are becoming available commercially but have existed in homemade versions for some time. Some tools can count and tabulate how often paths are executed. Others include code analysis tools that support the metrics of software quality and existing tools such as editors and compilers for software design and test.

A significant challenge for SQA in a finished product is to uncover code that is not executed or is redundant. Then we must determine if there is a hole in the test program, a flaw in the design, or superfluous code to be removed.

When following the test plan, the test group applies all requirements and reports deficiencies of the programming or engineering effort. Independent testing brings objectivity and can be cost effective. By separating the test group from the design group and developing test plans in parallel, we can now test software that had been tested as a unit, but not yet integrated.

Another major SQA milestone is the configuration audit that we conduct before delivery. This audit gives the customer and contractor management the high degree of confidence needed to put software in the field.

The configuration audit requires the following:

- ☐ The product to be shipped is compared with the configuration items of the applicable statement of work, specifications, and manuals.
- ☐ Test results and DRs are reviewed to verify that the software meets specified requirements.
- ☐ The software to be delivered is compared with the configuration managed version.
- ☐ Any requirement that was not verified by testing is verified by inspection.
- ☐ All open items that are to be resolved after placement in the field are identified on a problem list.

Summary

The SQA plan must emphasize the management and control of changes. It is vital for management to agree that productivity is closely related to demonstrated software quality. Software quality assurance is the keystone of this philosophy.

A successful program has:

- ☐ A highly visible, clearly defined SQA plan.
- ☐ A program organization that assigns SQA tasks directly.
- ☐ Access to software tools.
- ☐ Metrics for measuring the SQA program and establishing software quality.
- ☐ SQA personnel who are integral to the project team.

Whatever else, SQA must be assigned a realistic role in a program, and each person involved must do his or her part. Quality assurance can only measure quality—it cannot create it.

Henry Thoelke joined RCA in August 1983 as a Software Quality Assurance Engineer. Henry earned a BSCS from Northeastern University in 1982, having returned to academia after twenty years in the insurance industry. At RCA, Mr. Thoelke served on the Software Assurance Practices Committee and has been responsible for ensuring quality in all areas of Equate system software, from the run-time system to test program sets. Prior to joining RCA, Henry held the position of Software Engineer with Signal Processing Systems in Waltham, Mass. He is active in IEEE, ACM, and the NSIA Quality and Reliability Assurance Committee and SQA Committee. He is currently pursuing a Master's degree in Electrical Engineering at Northeastern University.
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Life Cycle Phase	System Engineering	Software Development	Integration & Test	Project Management	Quality Assurance
Requirements					Prepare software Quality Assurance Plan (SQAP)
Definition	Develop requirements traceability				Audit requirements traceability
	Conduct technical specifications				Audit technical specifications review
					Define documentation and standards
	Elaborate on formal reviews				Audit review plans
		Develop training plan			Review plan scope
		Prepare test plan procedure			Review procedure
				Prepare software configuration management plan (SCMP)	Review CMP for completeness
Preliminary Design	Prepare software requirements review (SRR)			Conduct SRR	Assure SRR Conduct
		Initiate software development folder (SDF)			Audit SDF
	Prepare system design review (SDR)			Conduct SDR	Assure SDR conduct
	Prepare software specification review (SRR)			Conduct SSR	Assure SSR conduct
	Technical review PDR material	Prepare preliminary design review (PDR)		Conduct PDR	Assure PDR action item closure
	Technical review CDR material	Prepare critical design review (CDR)		Conduct CDR	Assure CDR action item closure
			Prepare test readiness review (TRR)	Conduct TRR	Assure TRR Conduct
	Requirements traceability analysis				Audit traceability analysis
	Revise technical specifications				Review standard compliance
		Complete engineering procedure		Establish change control board (CCB)	Procedure completion
					Audit CCB implementation
			Trace test requirements to test plan		Audit traceability
Digital Design and Code		Trace requirements to design			Audit traceability
		Initiate (SDF)			Audit SDF
					Review documentation and standards for compliance
	Conduct structured walkthrough				Audit walkthrough
					Audit SDF maintenance
Test & Operations			Trace test plans to test procedure		Audit traceability
			Conduct test readiness meeting		Review test readiness meeting
	Technical review test procedure	Technical review test procedure			Audit review
					Review documentation and standards for compliance
			Conduct post test meeting		Certify results
	Prepare discrepancy reports (DRs)		Prepare DRs	CCB DR description	Monitor DR closure

A.E. Schmidt | C. Constantini

Quality improvement in communication services

The application of process measurement and control provides a substantial improvement in channel availability for RCA American Communications customers.

What prompted RCA American Communications, Inc. (Americom) to pursue a service-quality improvement program for the Private Leased Channel (PLC) product line at this time? Was there a surge in customer complaints? Did performance measurements show a decrease in PLC service quality? Neither of these events occurred. Rather, management realized that increasing competitive pressures resulting from the AT&T divestiture required response in terms of lower costs and improved service quality.

Abstract: *RCA American Communications undertook a quality improvement program in the Private Leased Channel product line to provide better service to customers, thereby improving their perception of service quality. The program identified key performance factors that affect the customers' use of the service—channel availability, mean time to restore service after an outage, and frequency of repeat/chronic circuit troubles. The program concentrated on specific aspects of performance improvement, and established improvement goals. The Reliability and Quality Assurance Department coordinated the participation of Technical Operations' headquarters and field staff and the regional Bell operating companies. The joint effort to improve circuit installation and maintenance processes resulted in fewer outages and shorter repair times. This paper illustrates some techniques, the corrective actions taken, and improvements achieved.*

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The requirement to improve quality presented an opportunity to demonstrate the effectiveness of statistical process control techniques applied to a service industry. The communications industry does not supply integrated circuits, televisions, cars, stereos, or other fabricated products. But it does supply a product—the successful operation of communication channels. This product comprises many distinct processes that can be measured and controlled using traditional process control techniques.

Fortunately, the data required to support the development of a process measurement and control program was available through the computerized Trouble Call Management (TCM) system placed in service in October 1981.

For the initial process control effort, we selected the Americom Central Telecommunications Office (CTO) in New York City and New York Telephone Company (NYT), because they typically experienced many circuit outages of long duration. The New York City location has the most circuits in the RCA Americom system and thus has the largest impact on overall PLC performance. The San Francisco CTO and Pacific Bell-San Francisco (PTT-SF) were selected as controls because of their better than average performance.

The quality improvement program used a three-pronged approach. One, we held a series of quality improvement meetings with the telephone companies (Telcos), where we adopted a team approach to solving customer-oriented problems. Two, we used statistical analysis of the data in the TCM system to identify areas in the communications process that have the greatest influence on quality of performance. Three, we did a series of observational studies at the two RCA Americom CTOs to identify physical and procedural factors that affect performance.

Substantial improvements in key performance measures were obtained through the use of statistical process measurement and control techniques. We attribute this to the combined efforts of management; communications, quality, and industrial engineers; and statisticians. As a result, RCA Americom has more efficient operations that provide customers with better service and thereby stays competitive in the communications marketplace.

PLC system overview

The ground segment of RCA Americom's Private Leased Channel system consists of microwave links between commercial earth stations and the CTOs in the nearby urban areas. At the CTO, RCA Americom interfaces with a local telephone company that provides land lines directly to the customer's office. This configuration exists at each end of the communication path. The middle of the circuit path, the space segment, consists of an uplink from one earth station to an RCA Americom-owned satellite and a downlink to another earth station. Figure 1 shows the complete path.

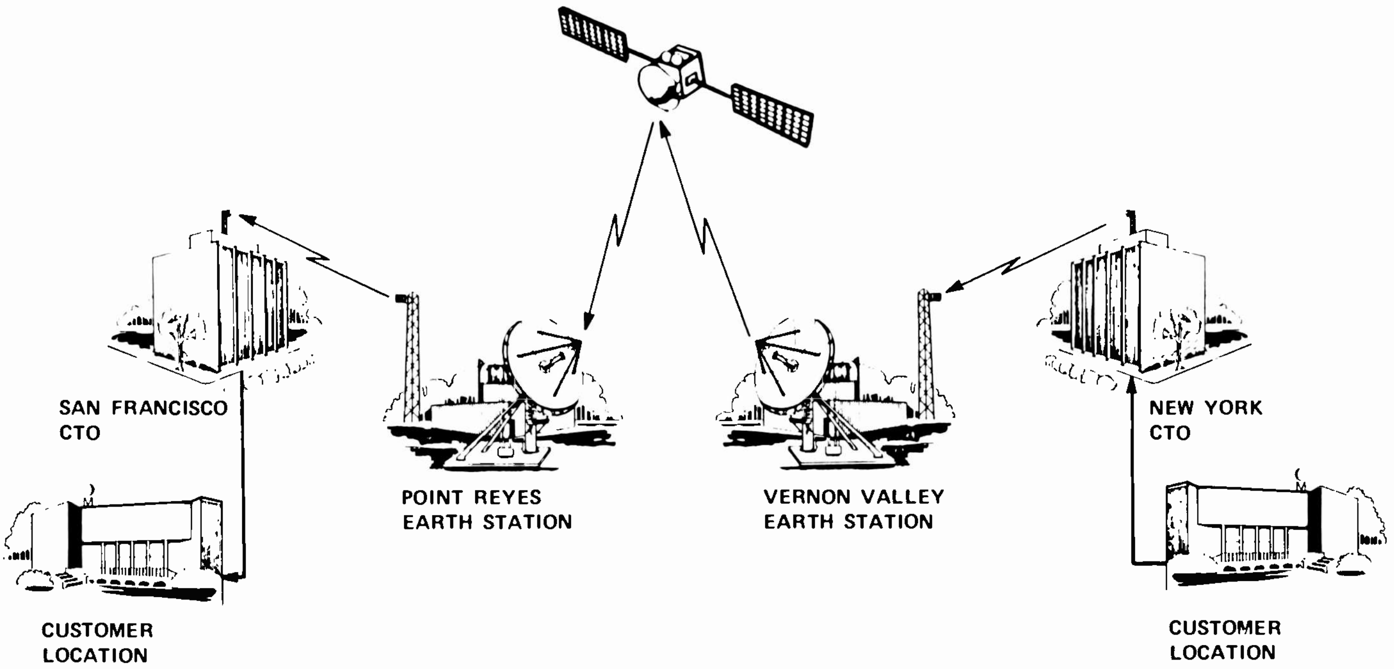

Fig. 1. *RCA Americom's typical private-leased channel configuration provides voice-grade service.*

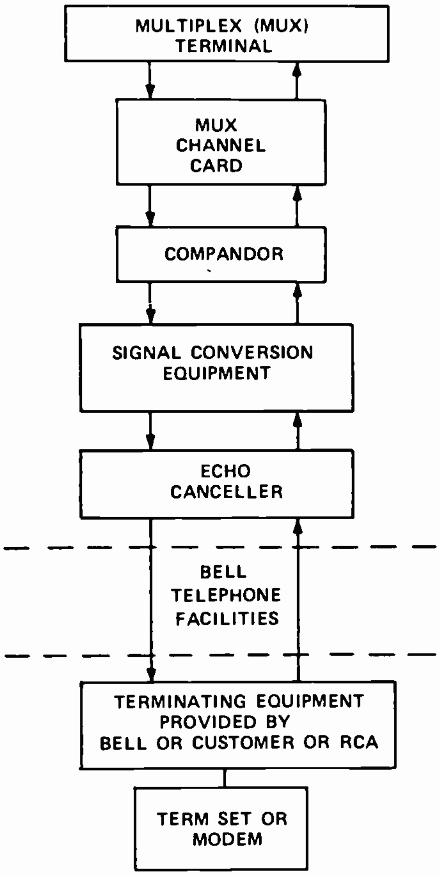

Fig. 2. *Typical circuit configuration for a private-leased channel as seen by the CTO maintenance organization. A high degree of fragmented responsibilities causes many difficulties when we try to resolve a troubled circuit problem.*

Earth station and microwave design features use extensive redundancy (duplicate circuits), with automatic switching and highly reliable equipment. These features ensure that these terrestrial segments have negligible effect on PLC performance. Unfortunately, the circuit path through the CTO and local telephone company is primarily single-thread; there is no provision to switch the circuit to a backup parallel path if the primary path fails. Figure 2 shows a typical circuit configuration in the CTO/telephone company segment.

Today, 99 percent of all corrective circuit maintenance is initiated through a customer call to the RCA Americom Customer Service Center (CSC) located at headquarters in Princeton, N.J. The CSC refers the trouble to the appropriate CTO, coordinates and tracks the resolution of the trouble, and informs the customer of status and actions to be taken. The information that the CSC collects includes the troubled circuit number, customer, CTOs and Telcos involved, times and dates the trouble started, and intermediate actions.

The computerized TCM database saves this data, as well as computed fields such as the duration of the trouble. This data provides most of the input for the Reliability and Quality Assurance (R&QA) analyses and performance measures used in the PLC quality improvement program.

First steps

As we tried to define and quantify the scope of the program, we saw the need for a set of factors that influenced customers' perception of quality. Numerous brain-storming sessions were held by Paul DeBaylo (former R&QA Manager) with Martin Rayl (formerly of David Sarnoff Research Center), Robert Nelson and Al Schmidt (both R&QA staff). As a result, they developed key quality measures of the installation and maintenance processes that would be meaningful to field and headquarters personnel and the Telcos. Some of these factors and the algorithm used to calculate them are shown in Table I.

The historical data of circuit troubles in the TCM system was used to develop 1984 performance baselines of the key quality measures adopted. We produced these baselines separately for the CTOs and Telcos but, for some measures, considered their joint effect. We also examined plots of weekly or monthly averages of the measures. Figure 3 shows the chart of PTT-SF's 1984 weekly mean time to repair (MTR). Additional measures, such as the percent of troubles that lasted more than 24 hours and the percent with undetermined causes, narrowed the focus of some of the broader measures.

The R&QA department coordinated numerous meetings with RCA Americom operations managers. We

Table I. *Key quality measures*

Availability = 1 − unavailability
= 1 − [circuit-minutes interrupted ÷ active circuit-minutes]

Mean Time to Repair = [total circuit-minutes interrupted ÷ total number of circuit interruptions]

Trouble Rate = troubles per 100 circuits
= [total circuit troubles ÷ (number of circuits ÷ 100)]

Repeat/Chronic Trouble Rate = 100*[number of chronic troubles ÷ total number of troubles]

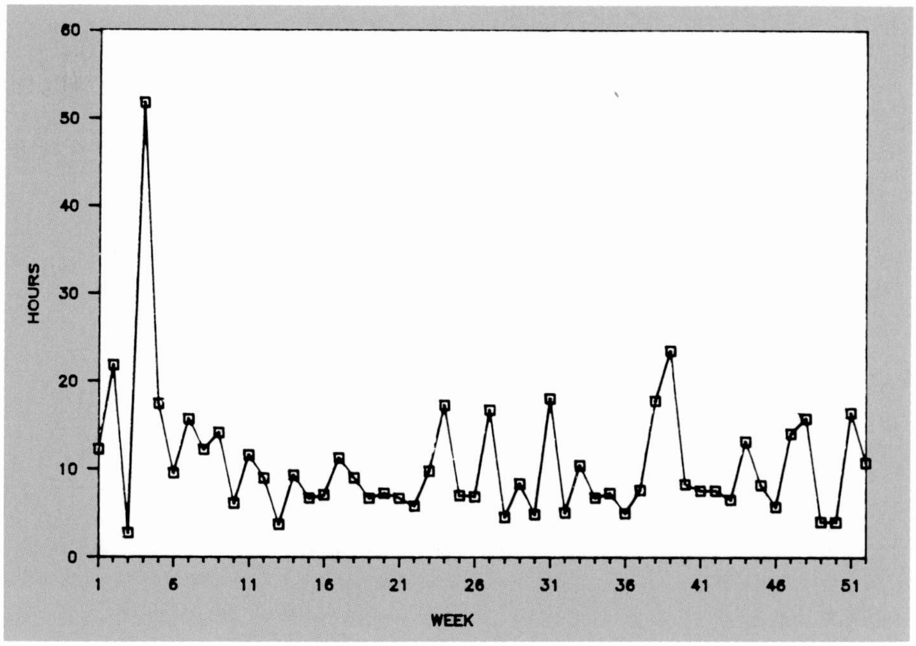

Fig. 3. *The plotted weekly averages of PTT-SF's mean time to repair helped determine the baseline performance during 1984. When calculating the baseline MTR, we eliminated an extreme value during the early part of 1984.*

explained the purpose and methods of the quality improvement program and introduced statistical process control techniques. We also obtained the support and services of selected staff members as team participants.

At this point the following improvement goals were established:

1. Unavailability at NY and SF: 50-percent reduction
2. Repeat/chronic trouble rate: 25-percent reduction
3. Troubles over 24 hours duration: 25-percent reduction
4. Mean time to repair: 25-percent reduction.

To solicit a cooperative approach to this program, John Christopher, RCA Americom's Vice President of Technical Operations, held bimonthly meetings with the New York and San Francisco telephone companies' upper management. These meetings stressed the need to improve our customers' perception of service quality, and introduced the concepts of process measurement and control. The New York Telephone Company then invited Mr. Christopher to speak at an off-campus symposium for 150 top-level NYT operations managers. The goal was to improve the understanding of what interexchange carriers, such as RCA Americom, were expecting as maintenance service. Because these meetings displayed upper management's commitment to improving PLC service quality, they substantially improved the program's credibility.

Concurrently, Thomas Kenyon, RCA Americom Carrier Relations Manager, scheduled working-level meetings with the New York Telephone Company and Pacific Bell-San Francisco. The R&QA staff introduced the concept of the quality improvement program to their marketing and operations managers. They conducted briefings on statistical process control, and presented the theory of control charts. Graphs that depict the telephone companies' baseline performance for 1984 were discussed.

RCA Americom and the telephone companies agreed to hold monthly problem-solving meetings to improve customers' perception of service quality. The initial thrust of these efforts was to reduce the frequency of occurrence of long-duration telephone company troubles.

Observational studies were conducted at the New York and San Francisco CTOs and the headquarters CSC. The aim of these studies was to observe and suggest improvements in troubleshooting, ticket handling, dispatch procedures, and interactions of the CTO, telephone company, customer, and CSC. The physical environment was observed to identify if changes or improvements would increase repair or installation efficiency.

Analysis of performance data

Graphs of the weekly 1984 performance measures of the CTOs and Telcos displayed the changes in the installation and maintenance processes that occur over time. However, to identify significant changes or study the effect of factors on the indices, we needed a standard of evaluation and used control charting techniques. Such charts indicate expected dispersions in the data and, through limits, define normal and abnormal values.

The points on control charts represent arbitrary divisions in a process. For example, in the repair process, one week's repair times are averaged to give the weekly service level for a particular CTO, Telco, or the system. Then, we evaluate these averages to determine if the process is in a "controlled" state. Once we see such a state, we can determine the process's limits that provide the standards of evaluation.

However, such a breakdown of the repair process does not reflect the influence of a single factor, as control charts traditionally do for manufacturing processes. The repair process depends on many uncontrollable variables, such as the location of the trouble, available manpower, and workload. However, control charts could provide a general level of process analysis that reflects the effect of new procedures and equipment.

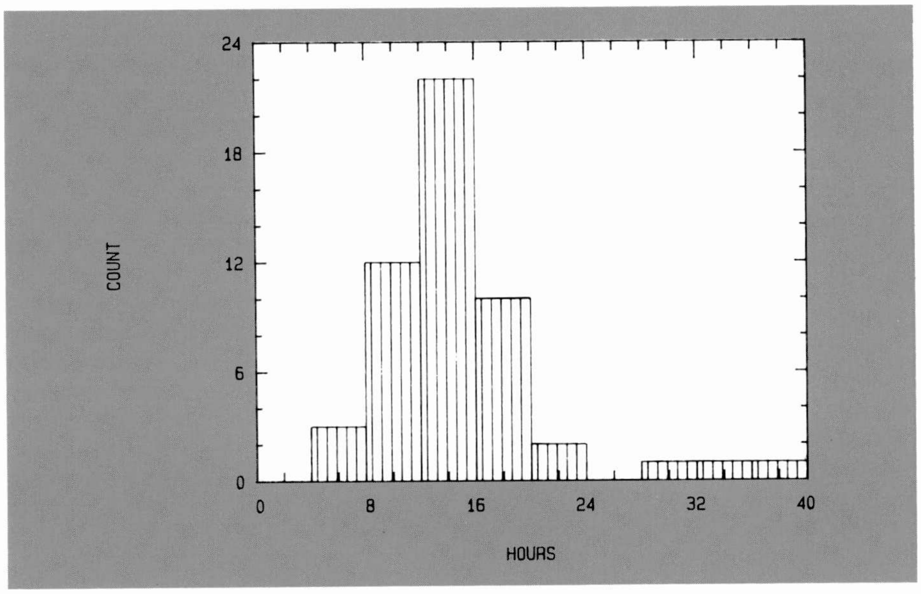

Fig. 4. *Except for three large values, this plot of the weekly mean repair times reveals a repair process that can be modeled by a normal distribution.*

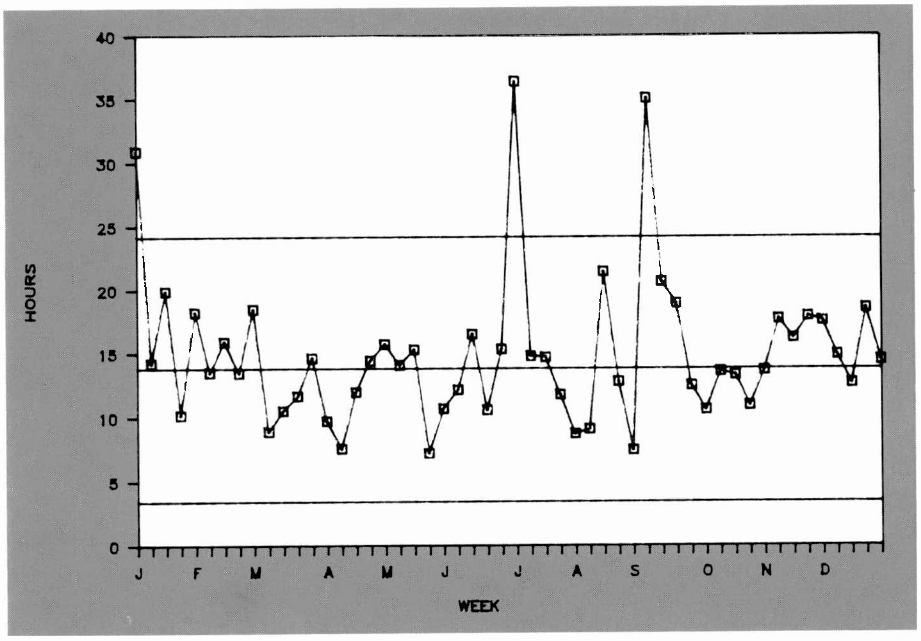

Fig. 5. *The control limits define the range where 99 percent of the output of the controlled repair process should fall. Significant changes in the process can be detected by the future movement of values on the chart.*

To use the process control capabilities of control charts, we need to determine the controlled state. For example, we developed an X-bar control chart for the weekly mean time to repair (MTR) for the CTOs and Telcos. For every week in 1984, we computed a weekly MTR, and then examined and tested the MTRs for normality; that is, do they constitute a normal distribution. Such a distribution can be modeled by specific statistical parameters that would define the control limits.

Figure 4 displays the distribution of NYT's 52 weekly MTRs for 1984. Except for three outlying values in the 32 to 40-hour range, the distribution appears normal. Removal of these points is justified, because they do not reflect the typical repair process. The result is a normal distribution—as determined by a chi-square, goodness-of-fit test—with a mean of 13.8 hours and a standard deviation of 3.54 hours. This mean reflects the expected output of the "controlled" repair process.

We based the control limits on the moving-range technique. The absolute value of the difference between consecutive weekly MTRs (outliers removed) is computed. The upper and lower control limits are calculated as the mean of the controlled process plus or minus 2.66 times the average absolute difference between weekly MTRs. The resulting control chart is displayed in Fig. 5. Theoretically, the control limits should encompass 99 percent of the weekly MTRs (excluding the outliers).

The traditional rules established for judging the future movement of points on the chart, determining abnormal values, and detecting process change cannot be strictly applied to RCA Americom's situation. In many manufacturing processes, one can react to abnormalities by changing some controllable, influencing factor. Such factors are not readily apparent in RCA Americom's repair process. We use the charts to monitor general trends; abnormalities serve as an impetus for discussion and investigations with the parties involved.

In addition to monitoring general performance measures, exploratory analysis of the TCM data revealed many underlying factors that affect the quality of service. Various statistical techniques—such as analysis of means, graphical data displays, and hypothesis testing—are used to identify the behavior of certain variables as well as their relationships to other variables.

For example, the distribution of PTT-SF's repair times showed a significant number in the 18 to 30-hour range (Fig. 6). Such a bimodal distribution of times may have accounted for the erratic weekly MTRs.

We developed and tested hypotheses about factors that influence repair times. Analysis determined that the average duration of troubles referred to PTT-SF after 12 noon is significantly larger than those referred before noon (Table II). However, when we did a two-way analysis of variance on the effects of time-of-day and day-of-week of the referral, the results showed that this is true only for Tuesday and Wednesday referrals, with an opposite pattern for Friday (Fig. 7). PTT-SF's studies indicated that many of the long-duration troubles resulted from referrals made during nonbusiness hours when a PTT-SF technician was unavailable for dispatch to the customer's location.

RCA Americom's trouble referral

Table II. *Hypothesis test comparing PTT-SF's repair times of morning and afternoon referrals*

Step 1. Nine months of repair times

Repair duration

	Count	**Average (hrs)**	**Variance**
Afternoon	140	10.51 hrs	96.96
Morning	358	7.28	103.33

Step 2. After log transformation to normalize distributions

Afternoon	140 (N1)	.825 (X1)	.456 (V1)
Morning	358 (N2)	.601 (X2)	.475 (V2)

Step 3. Form the null hypothesis that there is no difference in the average repair times for morning and afternoon referrals

$$HO: X1-X2 = 0 \qquad HA: X1-X2 > 0$$

Step 4. Under HO

$$Z = \frac{X1-X2}{((V1/N1)+(V2/N2))^{**}1/2} = 4.68$$

Step 5. Reject HO if Z > 1.645 (95 percent confidence level)

Step 6. Therefore reject HO. evidence indicates PTT-SF's afternoon-referral average repair times and significantly larger than morning-referral.

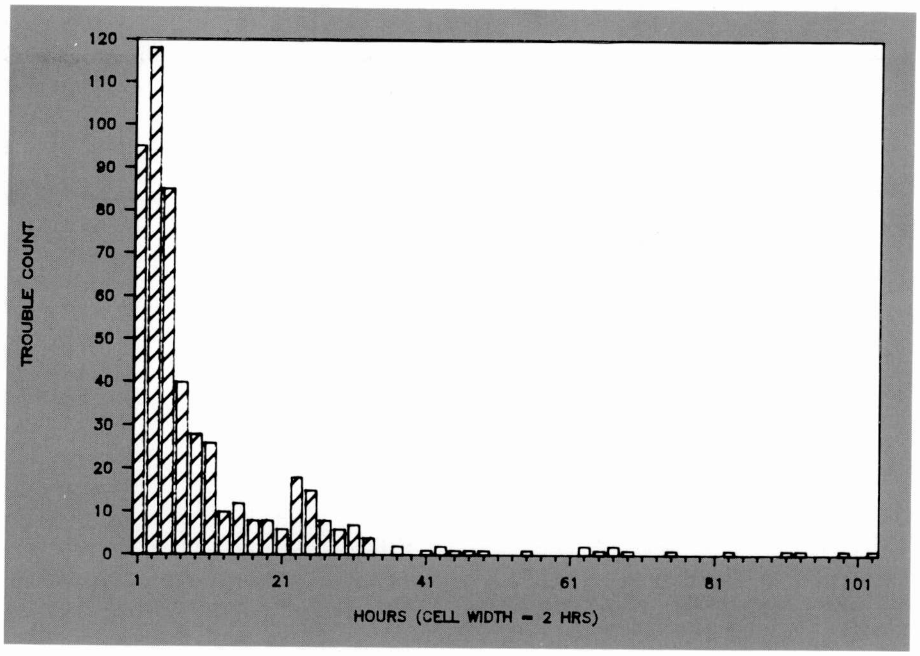

Fig. 6. *The bimodal shape of this distribution of repair times indicates two processes may be involved. We compared the types of troubles centered in the 3 to 4 hour range to those centered in the 23 to 24 hour range.*

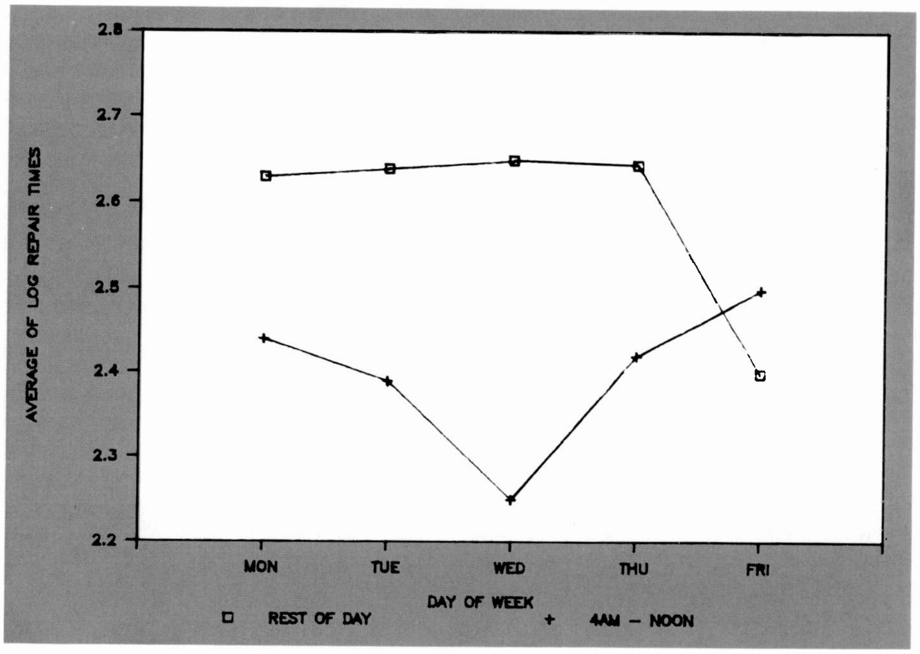

Fig. 7. *Analysis of variance results displays relationships between repair times and time-of-day/day-of-week of referral. Differences in morning/rest-of-day averages are significant only for Tuesdays and Wednesdays, with an opposite pattern on Fridays.*

policy, which was adopted to reduce NY CTO workload, was to refer all troubles received at the CSC between 7 a.m. and noon to the NY CTO and those from noon to 6 p.m. to the distant CTO. Analysis indicated that this policy resulted in a 5- to 13-percent increase in repair duration for troubles that were initially referred to the wrong location. The negative effects of the policy were identified as sources of improvement to the repair process.

Analysis of NYT and NY CTO data revealed many opportunities for improvement. We found that the repair-times distribution of NYT was bimodal. Twenty percent of all troubles were in the 24- to 40-hour range and accounted for 40 percent of NYT's total outage time. A chi-square analysis (Table III) tested the hypothesis that troubles referred to NYT have an equal probability of lasting longer than 24 hours regardless of the day the trouble is referred to them. Fridays had a higher probability than other days of the week. Other findings included:

- □ High-probability NYT troubles occur on circuits less than 60 days old—the infant mortality problem (Fig. 8).
- □ 8 percent of the troubled circuits (the chronic circuits) accounted for 29 percent of all troubles in New York.
- □ 50 percent of each repair duration was spent in queue waiting for a technician at the NY CTO.

To further identify and understand the underlying causes of the process that result in such negative effects, headquarters and field staff jointly developed Ishikawa diagrams. Figure 9 shows such a diagram for long-duration troubles. This technique forces attention on the mechanics of the entire process. Similar diagrams were made for

Table III. *Chi-square analysis of NYT's longduration randomness.*

Step 1. Six months of repair times

Observed number of durations

Day Referral	**>24 hrs**	**<24 hrs**	**total**
Monday	24	251	275
Tuesday	24	241	265
Wednesday	23	266	289
Thursday	21	218	239
Friday	41	200	241
	133	1176	1309

Step 2. HO: probability of long duration (>24 hrs) equal
for all days of referral

Step 3. Compute expected values

Expected number of durations*

Day Referral	**>24 hrs**	**<24 hrs**
Monday	28	247
Tuesday	27	238
Wednesday	29	260
Thursday	24	215
Friday	25	217

*Expected number = total x (P1 or P2) where

P1 = total number of >24 hrs duration troubles = 133 = .102;
total number of referrals 1309

P2 = total number of <24 hrs duration troubles = 1176 = .898;
total number of referrals 1309

Step 4. Compute cell chi-square values and sum cell chi-square values = (observed — expected)²

expected

	>24 hrs	**<24 hrs**	
Monday	.56	.06	
Tuesday	.32	.04	
Wednesday	1.38	.16	
Thursday	.44	.05	
Friday	11.14	1.26	Sum of values = 15.4

Step 5. Reject HO if sum > chi-square book value with 4 d.f., 95 percent confidence level = 9.5

Step 6. Reject HO — caused mainly by high Friday >24 hrs chi-square value where the observed number is greater than expected

Conclusion — probability of long duration trouble higher for Friday referrals than other days

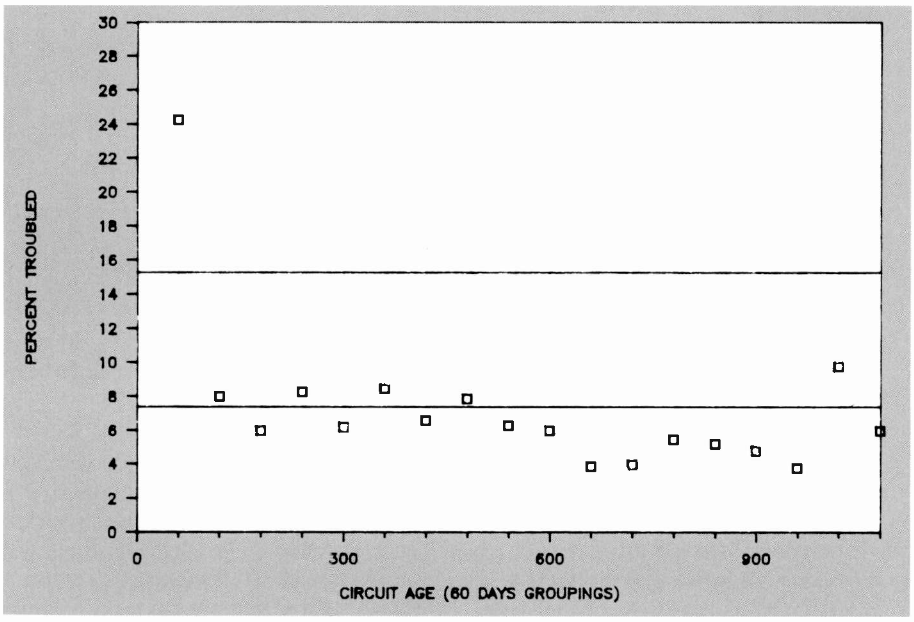

Fig. 8. *Ott's analysis of means procedure uses each age class's average percent, overall average percent (7.5) and number compared to determine confidence limits (0,15) for significance. The 24 percent of the circuits in the 0 to 60 day class with troubles is significantly higher than all other classes.*

repeat and chronic circuit troubles, infant mortality circuits, and no-trouble-found testing results.

Observational studies

Initial observations at the New York CTO revealed many areas where changes in methods, procedures, or facilities could improve efficiency and reduce irritations that maintenance technicians experience. Some examples included: lack of troubleshooting documentation for some equipment, an inadequate telephone system to handle the volume of calls, not enough computer terminals and printers, and a facility layout that contributed to poor work flow.

The San Francisco CTO suffered similar problems, but to a lesser degree. Considerable irritation was caused by a lack of telephones in certain areas, constant interruptions to answer the door buzzer, and a need for training on and documentation for some newer equipment.

We conducted a formal work measurement study at the headquarters CSC to determine an appropriate match of total workload to staffing, identify unnecessary tasks being performed, and determine if additional facilities were required.

Resulting actions

As a result of the data analyses and observational visits, headquarters, CTO, and Telco team members met and developed new policies and procedures. Some were initiated to resolve identified problem areas, whereas others were for general system improvement. Changes that affect the Telcos, CTOs, and headquarters individually as well as the interfaces among them were adopted. For example, because of the CSC work measurement study's findings, additional WATS (wide area telephone service) lines were installed and the hours of coverage were increased to provide improved response to the customer.

To address the infant mortality problem at the New York location, the telephone company set up a test board in the installation area to improve the initial testing of circuits. They also established a Maintenance Analyzer position to investigate young circuit troubles. Reversed wiring and incorrect option setting of telephone terminating equip-

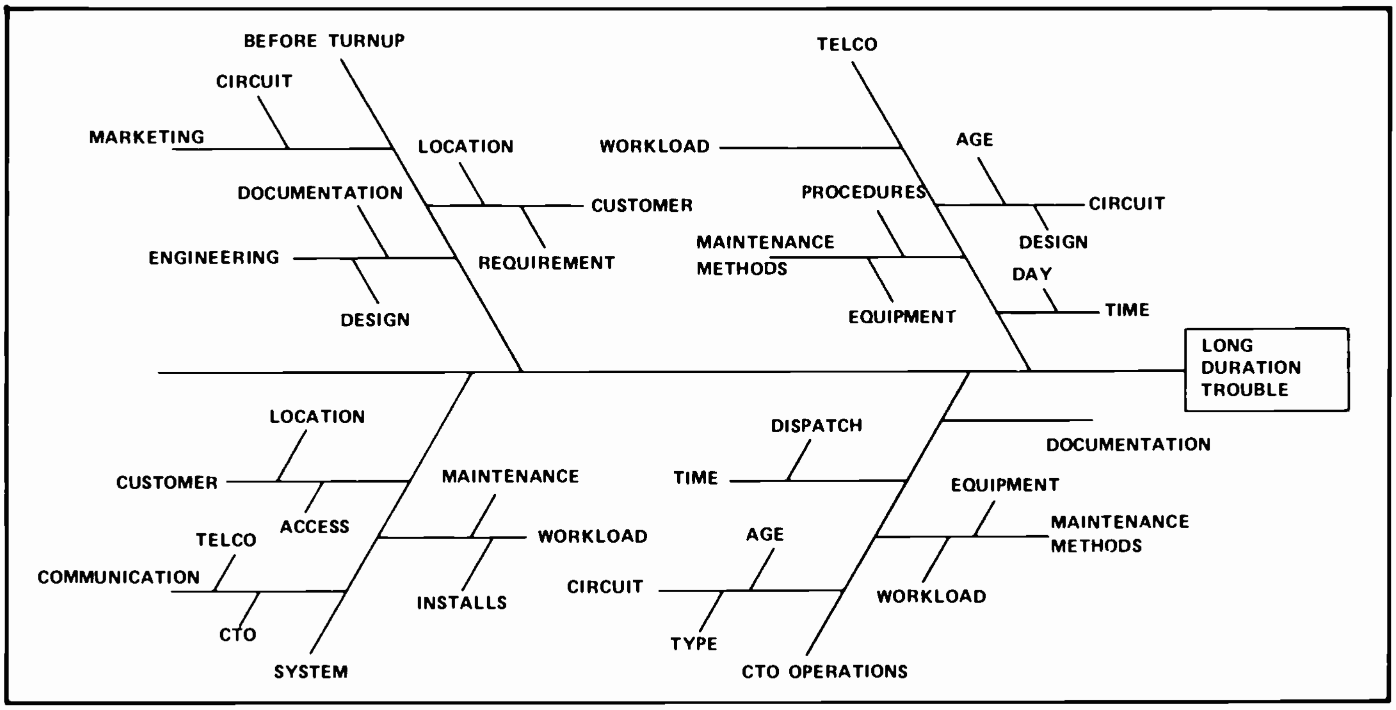

Fig. 9. *The aspects of the system that may influence the occurrence of long-duration troubles include Marketing, Telcos, and headquarters and field operations.*

ment were quickly identified as two causes. The NY CTO also set up an installation test board and a procedure that would refer all suspected telephone troubles on new circuits to NYT's installation department instead of their maintenance department.

For long-duration troubles, NYT devised a new tag system for quicker identification of circuits at the customer's location. The Maintenance Analyzer was also assigned to investigate all such troubles. Meetings between NYT and CTO technicians improved communications and understanding of each other's work.

Many changes occurred at the NY CTO to improve repair times and increase efficiency, including:

- Computer-printed trouble tickets provide additional information, such as the age of the circuit and number of troubles in the last 30 days.
- TCM terminals, technician headsets, and patchcords were added.
- The maintenance work area was rearranged.
- The site engineer was relocated from headquarters to the CTO.
- A new phone system was installed.
- A new maintenance console workstation provided quick test capabilities.
- More documentation was provided, as was advanced training for field technicians.

To reduce their occurrence, the R&QA department at headquarters generates a monthly list of chronic circuits that the Field Services department, CTO, and NYT use for investigating causes. Recurring troubles on chronic circuits are flagged at the CTO with a special trouble ticket for quick identification and, if necessary, directed to the NYT's Maintenance Analyzer.

In San Francisco, PTT-SF adopted changes in its operations similar to those at NYT.

- A quick test facility was installed to reduce the time to the first test.
- Specific technicians were assigned to RCA Americom's account. Their work hours were adjusted to increase coverage during evening hours for dispatches.
- A chronic-circuit analyst position was established.

In addition, PTT-SF adopted a unique change; it issues a clearance time commitment to the customer. When it receives a trouble, PTT-SF will give a time when the trouble will be cleared. Because of its confidence in its maintenance staff and procedures, PTT-SF measures its performance by how often the commitment times are met. Typically, it now meets 85 to 90 percent.

To improve repair times and increase efficiency at the SF CTO, headquarters changed the internal trouble-referral policy to route troubles there earlier in the day. Headsets were provided to technicians for freedom of motion while troubleshooting. A new phone, night bell, cipher lock, and door buzzer were added.

Many changes to the work environment, procedures, and policies at New York and San Francisco were implemented at various times during 1985. Therefore, we did not expect immediate, drastic improvements in specific problem areas or overall performance. Rather, we hoped to achieve progress after an adjustment period.

Independent of the quality improvement program, RCA Americom management had forseen the need for a preventive maintenance program for PLC services. Robert Blount of Plant Engineering was assigned the task of developing the specifications for a computer-controlled automatic test system. Besides detecting impairments, the system was required to isolate faults to a specific section of the circuit.

The processor unit and peripheral equipment are located at RCA Americom's headquarters in Princeton, N.J. Dial-up modems provide the communications link to each CTO, where the circuits are wired into a switch matrix that

Table IV. *Improvements 1984 vs. 1985*

	1984	1985	Percent improvement
Mean time to repair (hours)			
SF CTO	3.6	1.8	50
PTT-SF	10.7	6.3	41
NY CTO	4.3	2.8	35
NYT	15.2	13.0	15
Troubled service %			
SF CTO	.22	.07	68
PTT-SF	.11	.05	55
NY CTO	.19	.11	42
NYT	.21	.16	24
Troubles Per 100 circuits			
SF CTO	9.41	6.87	27
NY CTO	15.21	11.92	22
PTT-SF	1.45	1.24	14
NYT	2.34	2.03	13

provides access for testing. Hekimian Laboratories, Incorporated (HLI), which provided the hardware and software, worked closely with Robert Blount to develop the required functions.

Originally, the HLI system was for routinely tested circuits to locate and repair transmission impairments before customers noticed them. However, plans are underway to use the HLI system as a quick test facility to further improve our response to customer-reported troubles. Troubles that are called into the CSC will be referred to the technicians assigned to this facility. With the HLI system, they will isolate the trouble to a segment of the circuit and refer the trouble to the appropriate CTO for resolution.

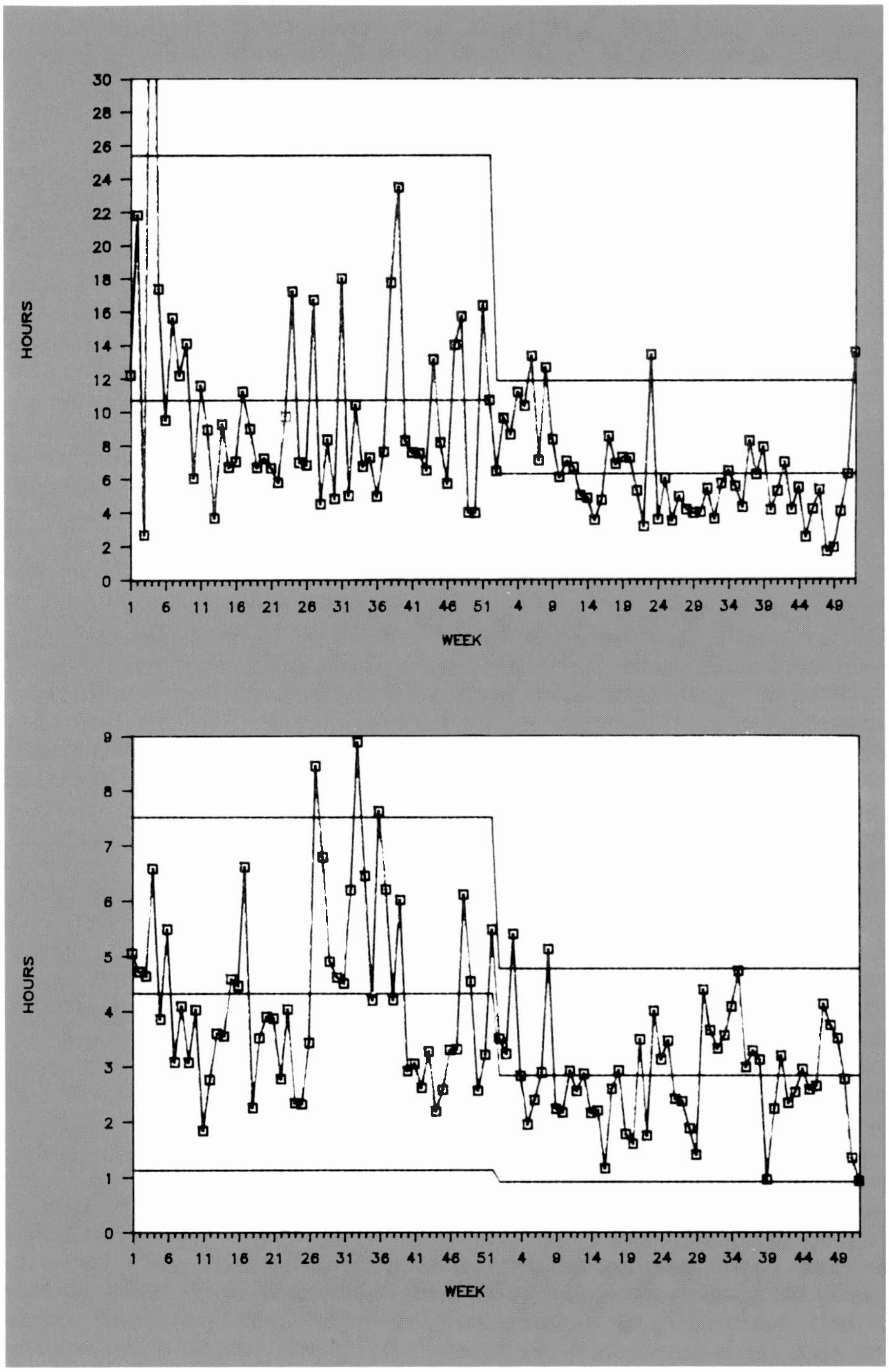

Fig. 10. *Mean time to repair for (A) PPT-SF and (B) NY CTO. Because of actions of the quality improvement program as reflected in 1985 data, the new control limits show a decrease in the repair process average and weekly variability.*

Performance monitoring

Each month, the R&QA department computes and adds weekly key performance measures to the control charts. At the request of management and the Telcos, additional indices are charted, including percent of troubled circuits across the system, system availability percent, and mean reaction (queue) time to a trouble. All control charts, as well as the listing of chronic circuits, are developed for each CTO and Telco in the system. Also distributed is a monthly CTO Manager's report that lists various activities such as the number of troubles handled, referrals to other CTOs and Telcos, the causes of troubles at that location, and so on.

Accomplishments

Based on the policy and procedure changes that resulted from the observational studies, data analyses and joint meetings, 1985 performance improved significantly over 1984. We computed new control limits and averages for the key quality measures based on 1985 data. Table IV and Fig. 10 compare the measures for 1984 and 1985.

In New York, NYT's infant-mortality trouble rate decreased 34 percent from 41 to 27 troubles per 100 circuits (Fig. 11). NYT's percent of troubles with greater than 24-hours duration decreased 27 percent from 15 to 11 percent. The percent of chronic circuits decreased 71 percent from 4.2 to 1.2 percent (Fig. 12).

In San Francisco, PTT-SF's percent of troubles of greater than 24-hours duration decreased 58 percent from 8 to 3.4 percent. The percent of chronic circuits decreased 67 percent from 1.8 to 0.6 percent.

Not only did the level of many measures improve but their week-to-week or month-to-month variation decreased. This indicates that the respective CTOs and companies began to stabilize their operations.

As mentioned previously, the New York location is the largest in terms of the number of circuits. Because availability is a function of the trouble rate and outage restoral time, the quality improvement efforts in New York, as well as San Francisco, meant the percent of troubled service for the entire RCA Americom system decreased 33 percent from 0.40 to 0.27 percent. Figure 13 displays the corresponding improvement in circuit availability for the PLC system from 1984 to 1985. RCA Americom's customers are receiving higher quality communications channels with fewer outages and shorter repair times.

Conclusions

If we compare the accomplishments to the improvement goals, it is apparent that statistical process-control techniques, combined with a multidisciplined team approach to problem solving, can achieve significant quality improvements in a service organization. However, efforts must continue to maintain the accomplishments and strive for further improvements.

Many other quality improvement areas remain to be addressed. With a systematic method of determining the cost of nonconformance for certain operations and processes, we can identify the ones with the greatest pay-back potential and measure the results achieved. Finally, the concept that quality is everyone's job must become second nature to all in the organization.

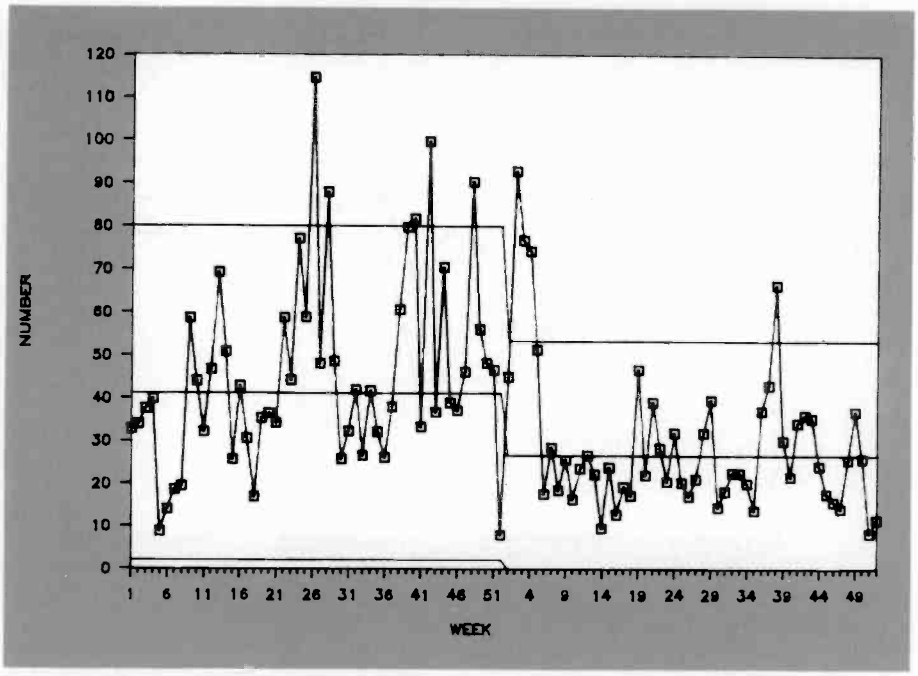

Fig. 11. *Significant improvement in the trouble rate for young circuits (0 to 60 days) resulted from the changes in the installation process at the NY CTO and telephone company.*

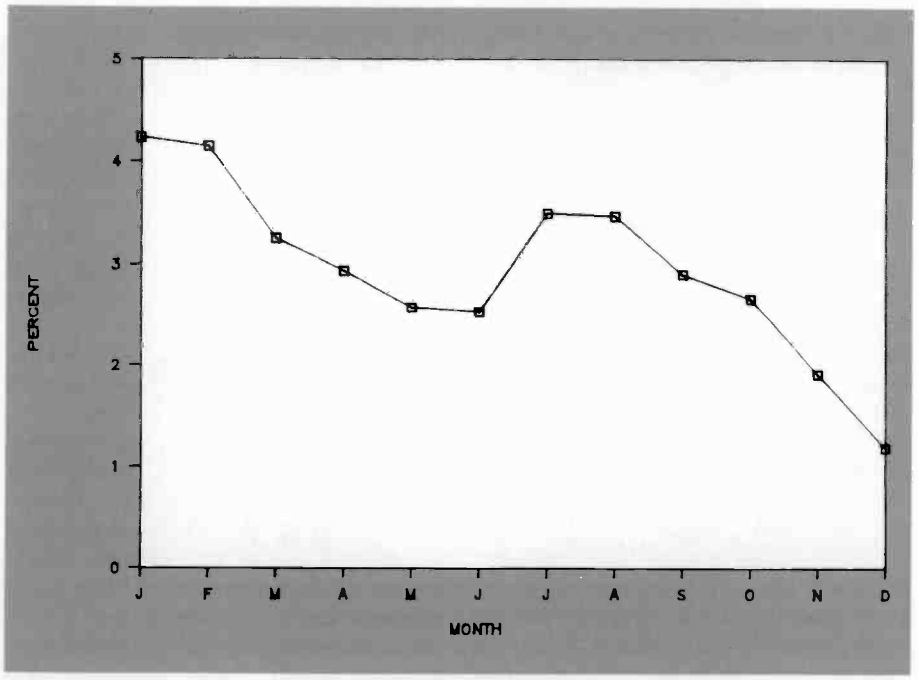

Fig. 12. *Through improved trouble-shooting procedures, work flow and communications with NYT, the percent of circuits experiencing many outages in short periods of time decreased.*

Acknowledgments

The authors especially want to thank Robert Nelson, our coworker, for his programming expertise that provided access to much of the data used during this project. Our thanks also go to Murray Fruchter and his staff who participated as team members. Special thanks also go to Mike Sollazzo, New York CTO manager, and Wade Nielsen, San Francisco CTO manager, whose efforts were crucial in achieving the improvements noted in this paper.

Valuable editorial input was provided by A. Labib, R. Moats, and S. Schreier, and J. Connelly advised and helped prepare artwork.

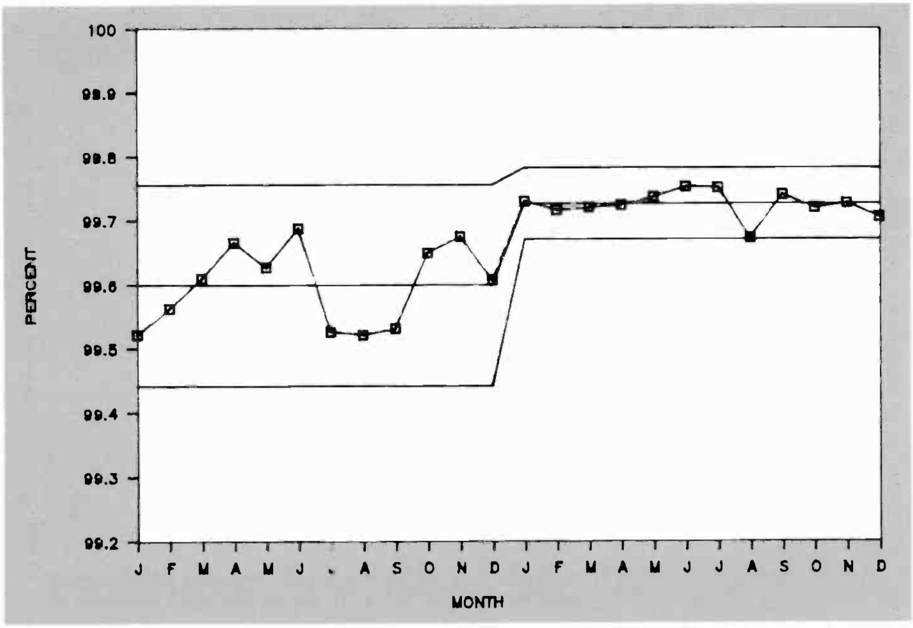

Fig. 13. *This general index of PLC system performance summarizes the effect of the quality improvement program at RCA Americom. Fewer circuit troubles with decreased duration are the causes.*

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M.F. LeVarn | J.C. Lofton

Automated incident reporting

From a distant terminal, RCA field representatives can report problems for quick solution.

RCA Automated Systems Division (ASD) provides the organizational maintenance test set for the M1 Abrams tank and the M2/M3 Bradley Fighting Vehicle. Over 700 of these STE-M1/FVS test sets are in use at Army facilities in the United States and Europe.

The effectiveness of STE-M1/FVS in detecting and isolating vehicle failures is primarily a function of its application programs or firmware. To maintain and improve the quality of this firmware, RCA field representatives must give ASD immediate feedback on any problems that they discover. Then, we at ASD send corrected application programs to the field as part of periodically scheduled field updates. An automated incident reporting system simplifies describing these problems, and also reports hardware failures and documentation errors or omissions.

Automated Incident Reporting

In the past, problem descriptions were handled manually. Paper forms, called incident analysis reports (IARs), were completed by hand and sent through the U.S. Mail. Today, automated incident reporting replaces this slow and laborious process with an electronic system that allows immediate transmission of product problems via electronic mail. This system helps ASD track failures and make rapid adjustments to its products.

Abstract: *Electronic communications are helping field representatives report and solve maintenance problems in the field. A new electronic reporting system eliminates the old slow, tedious way of filling out and mailing incident reports.*

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Although we initially created the Automated Incident Reporting system for the STE-M1/FVS program, it can be used to facilitate field communications on virtually any product. For STE-M1/FVS, the new reporting system is built around the existing electronic mail system that the U.S. Army Tank Automotive Command (TACOM) operates in Warren, Michigan, to which RCA subscribes. Figure 1 depicts the full system, as it was designed and currently operates.

Hardware

At the field location, the RCA field representative uses a personal computer to create an electronic version of the IAR. In the course of setting up the electronic reporting system, we investigated several computers and selected the Actrix terminal because of its combination of features.

The Actrix terminal contains a 12-inch screen display, keyboard, printer, dual floppy-disk memory, and a 600-baud modem (modulator-demodulator) and acoustic coupler for communications. Its chief disadvantage is a weight of 40 lbs. But this disadvantage is minimal, because most units are seldom moved once they are set up at a field location.

With the Actrix terminal, the field representative can call up a blank IAR form on the screen, fill it out and edit it off line (off line means the terminal is not communicating with a main computer). The terminal's memory can store up to 14 completed forms. At this point, the generation of the IARs is complete.

Then, through the Actrix modem and coupler, the field representative can dial the electronic mail system using a special 800 number, access the control sequence, and transmit the completed forms to the Prime computer at TACOM. The Actrix screen displays the text that is being sent and indicates when the file has been transmitted.

Software

The software that the reporting system uses is a combination of standard utilities provided with the Actrix terminal, and unique software that we developed to generate the IAR forms and perform the control sequences required to access TACOM's Prime computer. We wrote the new software in the BASIC language to permit ready adaptation to newer types of terminals that may be deployed at future field sites.

The BASIC software also allowed the data entry field for the problem description to expand from four lines on the original IAR form to a maximum of 200 lines on the electronic system. To counter the potential problem of wasted disk space, we designed a separate indexed file that corresponds to the particular IAR, but grows only as needed.

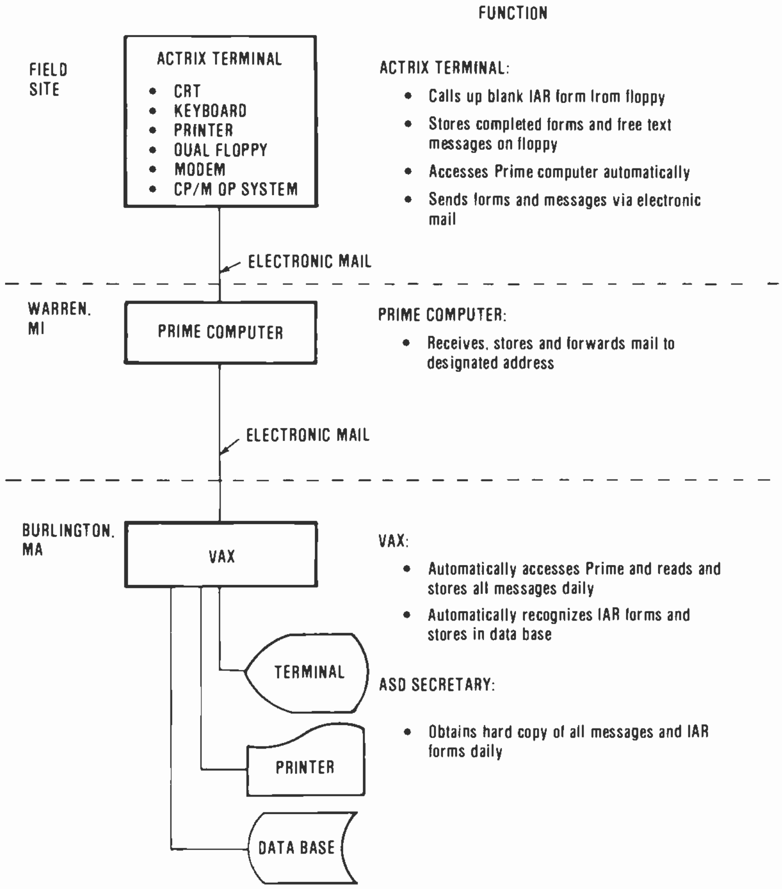

Fig. 1. *Each field representative uses his terminal to compose and transmit IARs and other messages. The Prime computer, with its 800-number access, provides a central message storage. Field reps can read each other's reports as well as bulletins originating from ASD.*

A new field, called *EXTRA PAGE*, contains a *Y* or *N* to indicate if extra text is in the indexed file.

In addition to handling IARs, the electronic reporting system can also process free text messages. Because all field locations and ASD share a single subscriber identification, all RCA field representatives can read mail that originated at any location. This allows rapid two-way communication. Newly discovered problems are disseminated immediately via IARs, and field representatives who have experience dealing with the problems can relay their solutions or clarifications via a free text message. Field bulletins that originatated at ASD are broadcast to all field representatives in the same way.

ASD obtains the IAR and free text messages from TACOM through a Racal-Vadic modem and PASCAL language software. The PASCAL programs cause the Digital Equipment Corporation VAX™ computer at ASD to call TACOM's Prime computer automatically each day to read and store all messages. To distinguish between IARs and free text messages, the VAX computer looks for the phrase *Incident Analysis Report*. It then assigns a number to each IAR and stores them in a local database. The IAR files correspond to the database entry fields on the IAR form.

To retrieve files, the VAX computer uses the *DATATRIEVE* database language that can be accessed through the PASCAL program. The *DATATRIEVE* language permits selective retrievals of IAR data from any of the fields of the form. These include: date, location, failed hardware component or assembly, software routine in use, and similar pertinent information.

An ASD secretary prints a copy of the mail from the VAX computer and checks to see if any Incident Analysis Reports or free text messages were received. Engineers and managers can then begin the process of solving product problems.

Future enhancements

Currently, the RCA field representatives do not see the IARs once they are sent and do not know the IAR number assigned by the VAX program.

Possibilities for the future might include allowing the representatives to dial directly into the VAX computer at ASD in Burlington. In this way, a representative could access the database of IARs and perform any number of inquiries.

For more information about Automated Incident Reporting, call **Marc LeVarn** at **Tacnet 326-3596** or **Jeffrey Lofton** at **Tacnet 326-5264.**

G.R. Van Hoorde / L.M. Sukey

Predicting the reliability of color television

The television receiver is a major contributor in RCA's effort to provide reliable sets.

Abstract: *A simple tool computes the reliability of a television receiver. Modeling the reliability of color television receivers in today's competitive environment is a complex project. This paper focuses on the identification and description of the parameters that model the color televisions system reliability in its design phase. It will also discuss the impact of these parameters on the TV receiver's reliability. The model is comprised of five major components that contribute to the system's total effectiveness: Inherent-Design Active/Dormant, Vendor, Manufacturing, Storage and Transportation.*

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Reprint RE-31-5-7

The modern television receiver is designed to meet the requirements of a very sophisticated market. It may not be obvious at first, but the market is exceptionally knowledgeable for several reasons.

First, consumers are able to compare all major characteristics of the product in dozens of retail outlets competing for their business. By evaluating competitive sales presentations, consumers can detail any possible advantage of a particular receiver such as appearance, performance, features, warranties, and price.

Second, independent testing laboratories, at little or no charge, inform the consumer of subtle parameters that may be more difficult to ascertain personally such as safety, reliability, ease of repair, and perceived value. The consumer, too, spends over eight hours a day, every day becoming familiar with the product. Probably no other manufactured items in today's marketplace has as much interface with the consumer for such a prolonged time as the television receiver. When today's consumers go out to buy a TV receiver, they will be very aware of the best values and where to obtain them.

Besides well-informed consumers, a third factor in the marketplace has caused the television to achieve its highest value to the consumer in history. This is the wide selection of product manufactured by the best and most efficient corporations in the world.

The American consumer can select from European, American, and Far Eastern product with little or no government restrictions or tariffs.

Today's manufacturers, the survivors of two decades of upheaval in the television industry, have added a color picture and dramatically improved performance. They have increased screen size and improved reliability to more than ten times that of earlier sets. They have added remote control that allows the consumer to access the entire system from an easy chair or bed. And, they did all this while reducing the price of the product in spite of inflation.

The survivors of this upheaval are the giants of industry. All the less sophisticated, less efficient, less committed manufacturers have long since left the field.

This is the environment in which RCA currently finds itself and where it must struggle to maintain its position as the foremost supplier of televisions in the United States. This paper describes the method of computing the reliability of the television receiver, which is a major element of reliability's contribution to RCA's effort.

Color television reliability and failure rates

The probability of survival of a television receiver in the field is defined by the classical reliability formula

$$R = e^{-\lambda t}$$

where

R is the probability of survival,

e is the constant 2.7183,

λ is the failure rate in failures per unit of time and,

t is the operating time.

However, in the television industry, a failed circuit is repaired and the TV receiver is returned to service. Therefore, the emphasis does not lie in the probability of survival, but rather on the number of failures that have occurred over a certain time, usually the warranty period.

As a result, we have chosen to present the color-television reliability model in the form

$$\begin{gathered}\lambda_T = (\lambda_1 t_a) + (\lambda_2 t_d) + (\lambda_3 t_1) \\ + (\lambda_4) + \\ (\lambda_5 t_s) + (\lambda_6)\, 100\end{gathered}$$

λ_T = Total number of service calls per 100 instruments in 90 days

t_a = Active operating time = 662 hours

t_d = Dormant time = 1,498 hours

t_s = Storage time = 4,320 hours

λ_1 = Contribution of inherent, active failure rate to system reliability

λ_2 = Contribution of inherent, dormant failure rate

λ_3 = Contribution of vendor failure rate

λ_4 = Contribution of manufacturing-process failure rate

λ_5 = Contribution of storage degradation

λ_6 = Contribution of transportation effects.

Now that the system reliability model has been defined, we can analyze each component of this model.

Inherent active component

The design-inherent active component describes the inherent reliability of the design. The reliability estimate is based on part specifications, parts lists, and application stress measurements applied to the most-current engineering prototypes. It represents an intrinsic reliability that cannot be modified significantly except by further basic design change.

For practical purposes, this component is described during the TV receiver life in the field by the constant failure rate, and is measured in terms of random failure rates. Design-inherent failures are caused by external thermal, electrical, or environmental stresses on the parts and materials.

To calculate device active failure of individual parts, in contrast to dormant failure rates explained below, we use historical or theoretical data from outside sources such as MIL-HDBK-217. Our own television receivers and reliability development models demonstrate field failure rates.

Specific models are developed for each type of part and integrated into a general model. As an example, one reliability model we developed is an integrated circuit model. It allows us to evaluate an integrated circuit based on its own technology and the special characteristics found to influence reliability of those devices.

To illustrate consider a CD4013B integrated circuit manufactured by complementary metal-oxide semiconductor (CMOS) technology. It has 3422 sq. mils of chip size, 1900 sq. mils of metalization area, 2700 sq. mils of active area, three diffusion steps, and 14 bonds. Table I presents the model that reflects these considerations. (See references 1 and 2.)

Table I. *Integrated circuit reliability mathematical model*

$$\lambda_T = (\lambda_a TT_T TT_Q) + (\lambda_b TT_T TT_Q) + (\lambda_c TT_T TT_Q) + (\lambda_d TT_Q) + (\lambda_e TT_Q) + (\lambda_f TT_T TT_Q) + (\lambda_g TT_Q) + (\lambda_h TT_Q)$$

Failure mode	Baseline failure rates in failures/10^9 hours
λ_a—Oxide layer	6.5/1000 sq. mils of metalization
λ_b—Faulty bonds	0.37/bond
λ_c—Metalization	2.25/1000 sq. mils. of metalization
λ_d—Faulty diffusion	0.42/diffusion step
λ_e—Foreign materials	0.42/1000 sq. mils of active and metalization areas
λ_f—Die header bonding	6 per device
λ_g—Surface defect	0.043/1000 sq. mils of chip area
λ_h—Crystal imperfections	0.33/1000 sq. mils of chip area

TT_Q = quality factor
TT_T = thermal degradation

The quality factor for the model is developed from the performance of similar integrated circuits currently used in television receivers. The data is identified by technology and, within each technology, by individual supplier. The thermal degradation factor represents degradation mechanisms that are accelerated by temperature and electrical bias. It is largely composed of phenomena that follow the ARRHENIUS model.

For the reliability model, the acceleration factors from changes in junction temperatures are listed in Table II.

Now, use the CD4013B integrated circuit example presented above and assume a junction temperature of 45°C and a quality factor of 4.1. The resulting failure rate of this device under the given conditions is 213 FITS (failures/10^9 hours).

Table III illustrates the procedure for performing the calculation.

Inherent dormant component

The inherent, dormant failure rate covers the time that the television receiver is off in the customer's home. This failure rate largely depends on temperature cycling stresses that result from power cycling when the customer turns the set on and off.

Our model incorporates the failure rate techniques described in reference 2.

Vendor component

To arrive at a vendor failure rate component, we apply a quality factor multiplier to the active failure rate. It is added to the model using the quality factor (TT_Q) described previously. When we use a poor supplier for a critical device, this practice allows us to add a larger factor than would be needed for a simple, low stressed device. This number is then extracted from the model to identify the vendor contribution to the system model.

To derive factors for integrated circuits, we use the most recent, demonstrated performance of each supplier in the corresponding technology, as measured in the final, instrument life test. Other active or passive device quality factors are taken from models described in MIL-HDBK-217D and then modified by our experience factors.

Manufacturing component

In the model, the manufacturing failure rate component represents the field failure mechanisms that the assembly process contributes as a result of inadequate assembly and test methods, improper handling, and shortcomings in the manufacturability of the design. Failures predicted for new television receivers are based on the instrument life test data of current similar product.

Then, we compare this data with the proposed yield goals for the new models and the associated programs to achieve these goals. This comparison generates the expected percent defective for the manufacturing component.

Table II. *Multiplication factors*

Junction temperature (°C)	Multiplying factor (TT_T)
25	1.0
55	2.0
75	3.3
100	6.1
125	11.1
150	21.0
175	37.8
200	70.0
250	237.0

Table III. *CD4013B failure rate calculation*

λ_a Oxide layer	$= 6.5 \times 1.9 \times 1.7 \times 4.1$	= 86 FITS
λ_b Faulty bonds	$= 0.37 \times 14 \times 1.7 \times 4.1$	= 36 FITS
λ_c Metalization	$= 2.25 \times 1.9 \times 1.7 \times 4.1$	= 30 FITS
λ_d Faulty diffusion	$= 0.42 \times 3 \times 4.1$	= 5 FITS
λ_e Foreign materials	$= 0.42 \times 4.6 \times 4.1$	= 8 FITS
λ_f Die header bonding	$= 6 \times 1.7 \times 4.1$	= 42 FITS
λ_g Surface defect	$= 0.043 \times 3.422 \times 4.1$	= 1 FITS
λ_h Crystal imperfections	$= 0.33 \times 3.422 \times 4.1$	= 5 FITS
		Total 213 FITS

Storage component

This component models the time period when the television receivers are stored in their cartons before sale without being operated or energized periodically. During this period, some of the major stresses the receiver will experience are extremes in temperature and humidity. This phase in the model is assumed to be an average of six months and includes storage at RCA and distributor warehouses.

Transportation component

The transportation component of the model describes the failure occurrences from mechanical stresses, vibration, and shock while the television receivers are transported by truck, rail or plane and during warehouse handling. All packaging factors form a matrix and the performance scores for each factor determine a rating. Then we combine the individual ratings to produce an overall rating.

Model evaluation

This model is evaluated by empirical testing conducted by our Product Protection Laboratory. The test sequence consists of the following segments:

Packing design—Packaging design refers to the shock and vibration protection that the packaging offers to the instrument.

Cabinet type—The basic cabinet type is considered as a factor that affects the instrument's reliability. For example, a large wood console may have long cables and speakers, possibly held in place with plastic push rivets. Both of these items tend to degrade the reliability of the instrument.

Shock fragility—Shock fragility is the basic shock sensitivity of the instrument.

G-level factor—This factor measures the G-level that is transmitted through the package during an impact; for example, when a packaged instrument is accidentally dropped. The G-level that the instrument, without packaging, is able to withstand is compared to the G-level transmitted through the packaging. This comparison generates a safety G-level or safety margin.

Vibration displacement—This factor measures the amplified displacement at resonance. A displacement that is too high tends to cause broken components or solder connections.

Random vibration performance—This factor measures how well the instrument performs in the standard truck, rail, and plane simulations.

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Van Hoorde

Sukey

G.R. Van Hoorde is currently a Senior Member, Engineering Staff, C.E. working with the reliability of color TV receivers and monitors. He has been associated with the Scientific Research Laboratory of Ford Motor Co., Bendix Aerospace Systems, Martin Marietta Corp., TRW Systems, Laboratory for Electronics, Raytheon MFG Co., and General Electric.

His experience covers the fields of test, design, reliability, and microelectronics technology and applications. He received his BS and MS in mathematics in Bogota, Colombia, and his BBA in Engineering and Management at Northeastern University, Boston. Among his awards are: Meritory Recognition for Outstanding Contributions to the Development of MOS/LSI Technology from the Data Systems Lab of TRW Systems; Technical Excellence Award from RCA Consumer Electronics. He has written two books in microelectronics—*Evaluation of Experience with Microelectronics Integrated Circuits* and *Appraisal of Microelectronic Integrated Circuit Performance*.

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Larry Sukey is currently Manager of Reliability Engineering for RCA's Consumer Electronics Division and is responsible for the quality of television designs in the field. He has been with RCA for three years. He has been concerned during this time with the development of new math models to forecast design performance, increasing the accuracy of reliability predictions and decreasing the failure rates of new television design.

Prior to his association with RCA, he managed the Purchased Material Quality group for the North American Philips Consumer Electronics Corp. in Knoxville, TN. There he was responsible for the quality of all devices, components and materials purchased from outside vendors. He developed test philosophies and implemented the Corporate Parts Per Million Quality Program. He also coordinated the specification correlation program between Engineering, Manufacturing and the vendors, and headed the Corporate Component Failure Analysis and Corrective Action Program.

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I.J. Kratz / D.J. Gray

Semiconductor quality assurance and reliability programs

Constant testing and analysis ensure that consumers get reliable televisions

The televisions that RCA Consumer Electronics produces are manufactured with components of the highest quality and reliability practical within the constraints of the competitive marketplace. Taken as a family, the semiconductor is the most dominant component in the evolution of television's technology, quality, and reliability in recent years. A semiconductor component may be incorporated in a tuner, a remote transmitter, a color television built by the Taiwan facility, or in a television assembled at the Bloomington facility. It must, however, conform to CE specifications and standards designed to ensure semiconductor quality and reliability.

The CE semiconductor quality system starts with the selection and qualification of components from suppliers with proven quality and reliability performance. Before, during, and after the television manufacturing process, we extensively test and monitor the component performance. When we identify a design, manufacturing, device, or supplier weakness, we address it through corrective action, testing, and screening.

Abstract: *A component quality system helps us obtain high-quality, reliable components from our semiconductor suppliers. Continuous monitoring, testing, and analysis enable us to identify problems quickly and take corrective action.*

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The device's improved quality and reliability performance then becomes a new standard for gauging future device and supplier performance, thus providing an ever-improving target for device quality and reliability.

Supplier selection and device qualification

The supplier selection process is a forum of Design Engineering, Component Engineering, Reliability Engineering, Strategic Sourcing, and Components Quality Assurance (QA). All groups want the best part at the best price, but each has its own priorities and areas of responsibility.

Strategic Sourcing supplies the piece price and development costs for each supplier, Design and Component Engineering provide the technology and electrical performance requirements, and Reliability Engineering and Components QA provide the quality and reliability history.

Standard quality and reliability data, expressed in parts per million (PPM) or failures per 10^9 hours (FITS), can seem somewhat nebulous when compared to electrical performance or part cost. Consequently, we often translate the reliability data into an actual "cost of quality" that is expressed as the cost per part above and beyond the original purchase price.

This translation of the data provides a much more tangible expression of reliability that helps us make decisions. We also use this "cost of quality" in negotiating yearly contracts for piece price and determining contract allocation for multiple suppliers. For example, Table I lists the "cost of quality" calculations based on 1985 production data for a given supplier.

The true part cost to RCA to use these parts was 8.1 cents more per part than the initial part price. Each semiconductor device (or family of devices) must receive Engineering Approval ("E"-Approval) and Manufacturing Approval ("M"-Approval) before being used in production applications. The "E"-Approval process tests whether the device conforms to parametric specifications, functionality, and quality and reliability standards. Although several different groups do this testing and evaluation, Component Engineering is responsible for coordinating them and documenting results.

During part and application development, engineering performs extensive device characterization testing, process matrix sample evaluations, and supplier test correlation work to ensure that the actual "E"-Approval samples conform

Table I. *Cost of quality*

Commodity	Line (PPM)	Reliability (FITS)	Usage (10^6)	Cost impact per part ($)
Zener Diodes	16	839	7.6	0.0807

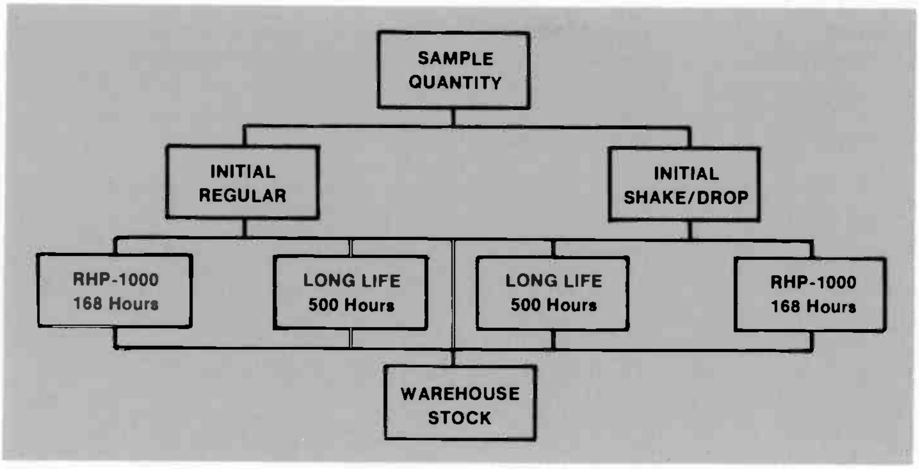

Fig. 1. CAL sample quantity test sequence.

to the specification. They test samples for functionality and conformance to specifications using a combination of automatic, bench, and application tests. For custom or semicustom parts, this process is repeated with each design cut of the integrated circuit. For all semiconductor devices the process is repeated with each design revision or sample build of the instrument or module (engineering go-rounds, factory pilot, pre-production, and production). Formal "E"-Approval testing repeats all previous tests using production-ready parts in a production-ready application.

Each device type must undergo both physical and reliability evaluation by the Component Reliability Lab (CRL), a section of Components Quality Assurance. For custom and semicustom integrated circuits, the evaluation starts at first-cut silicon with a destructive physical evaluation. The device's physical construction is evaluated to standards based on MIL-STD-883C, Condition B. At second cut we do the physical evaluation again as well as a reliability evaluation that includes humidity testing, thermal shock and burn-in. We repeat this process on subsequent cuts and formal "E"-Approval samples.

For discrete semiconductors and standard, commercial integrated circuits we may do a preliminary physical evaluation on a limited sample to help us select a supplier. A thorough physical and reliability evaluation is then performed once the supplier selection has been made. "M"-Approval is performed in the user plant by the Material Quality Department/Purchased Material Inspection group (MQD/PMI). The "M"-Approval process tests the same parametric and functional specifications as "E"-Approval to determine the form, fit, and function of a mass-produced device in a mass-production environment.

When any construction changes, a manufacturing location changes, or previous approvals have been rescinded because of poor incoming test, line or reliability performance, a supplier must resubmit qualification samples for "E" and "M"-Approval. This includes documentation that outlines the reason for the resubmission, a detailed description of the changes or corrective actions taken, and samples that show those changes or corrective actions. The appropriate CE groups then evaluate the description of the changes as well as the devices submitted to determine the effect or effectiveness of the proposed changes.

Supplier qualification

The minimum quality and reliability system requirements that a supplier must meet when supplying components to CE are outlined in RCA/CE Quality, Reliability and Safety Manual Specification 04-03-02, formerly QRSM-III. This specification covers items such as device qualification and approval, acceptance of production material, and supplier's requirements. We do initial surveys and periodic audits of the supplier's facilities to verify compliance with the document's requirements. Surveys and audits are performed at the supplier's wafer fabrication facility and assembly facility, even if it is the supplier's subcontractor.

Sometimes, additional testing or screening may be required to meet quality and reliability goals. If so, a QRSM-Q & R Supplement, added to the purchase contract, outlines any special testing requirements. Tests or screens that might be required include burn-in, preconditioning and lot acceptance testing.

Production process monitors

Once the semiconductor device has been qualified and reaches the production plant, the Quality Control (QC) Department monitors, documents, and reports its progress through incoming inspection, production and finished instrument or module testing. Incoming inspection is the responsibility of the Material Quality Department/Purchased Material Inspection group (MQD/PMI). Product QC monitors line performance and QC Engineering does tracking and follow-up. Sample testing of the finished module or instrument is the responsibility of the Consumer Acceptance Laboratory (CAL). The primary responsibility of MQD/PMI is to assure that purchased material and material from other CE plants complies with the drawings and specifications. Depending on a part's performance history, the incoming sampling schedule may be ship-to-stock (only occasional sampling), skip-lot sampling, sampling of each lot, or full inspection. The sampling plans that PMI uses are based on MIL-STD-105D. Usually rejected material is returned to the supplier. But if the material is needed to support production, then the Material Review Board (QC, Components QA, and Components Engineering) decides if it can be reworked or sorted.

MQD/PMI maintains the inspection results for each lot of material by part number and supplier and regularly sends the supplier an Appraisal Material Purchase Systems (AMPS) report that summarizes the inspection results. The AMPS report enables CE and the supplier to analyze the incoming test results and provides the basis for corrective action.

In addition, the AMPS information that is used to calculate a quality performance rating provides a comparative measure of a supplier's performance for all the device types it may supply.

The quality performance rating (Table II) is based upon a six-month summary and is calculated as:

$$\text{Performance} = \sqrt{\frac{N}{N + 1}} \times \frac{A}{N} \times 100$$

where:
N = Number of lots inspected
A = Number of lots accepted

Table II. *Performance Ratings*

P	*(Preferred)*	95.00 and above
A	*(Acceptable)*	85.00 to 94.99
U	*(Unacceptable)*	84.99 or below
I	*(Unrated)*	0 lots inspected; or N = 1, A = 1; or N = 2, A = 2

Table II lists the performance rating criteria.

Production QC monitors semiconductor performance on the assembly line. Troubleshooters save all semiconductor devices that are pulled during module or instrument repairs and routinely return these failures to PMI for confirmation. The data accumulated is reported in the Solid State Performance Report. This report details the monthly usage, number of line pulls, confirmation rate, and confirmed process average (the number of confirmed failures reported in parts per million) by part number and supplier.

QC Engineering or Resident Engineering (the design and factory liaison) selectively forward parts pulled from the semiconductor line to QA for return to the supplier or failure analysis. (Failure analysis is the in-depth, physics-of-failure analysis that CRL does, although both the Juarez and Taiwan plants have limited failure-analysis capability). CRL sends the failure analysis results to the supplier (when it is a supplier-related problem) and to the QC, Resident, Design and Component Engineering groups for corrective action.

The Bloomington, Juarez, and Taiwan plants each have a Consumer Acceptance Lab (CAL) that conducts sample inspections and reliability tests on ready to ship products. We will only discuss Bloomington CAL here.

The Consumer Acceptance Lab

The Bloomington Consumer Acceptance Lab (CAL) performs a daily sample inspection (Table II) on completely assembled TV sets from each of the fourteen production lines. The samples are taken from warehouse stock after the instruments have been packed for shipment.

Before inspection, they subject a subset of each sample to a simulated shipping test. The inspection (CAL-Initial Test) is a functional light and play test at room temperature.

Instruments from one model line are selected on a rotating basis from the CAL-Initial Test samples each day for the RHP-1000 Test. This is a 168-hour operating life test at 90 = F ± 5 = F ambient with the line voltage at 130 Vac. The power is cycled periodically, resulting in the equivalent of 134 hours of field operation.

When a failure is detected in initial, RHP or long-life testing, the CAL analyzes the instrument to determine the exact cause of failure. If a component caused it, the failed component is tagged and all pertinent information is logged into the computer. Semiconductor failures are routinely forwarded to CRL for confirmation, characterization, disposition, and tracking. The CAL log data system is revised and updated as the failures are analyzed.

From this information, Reliability Engineering calculates the predicted field-failure rates by part number and supplier:

$$\text{Failure Rate} = \frac{I(\%) + 1.61\,(RHP\,(\%)) \times 10^6\ \text{FITS}}{400}$$

where: $I(\%)$ is the percentage of failures in the CAL Initial Test, and $RHP(\%)$ is the percentage of failures in the RHP 1000 Test.

In addition, Reliability Engineering uses the CAL data and device-construction data (die size, active area, technology, etc.) to calculate a Quality Factor for each supplier by technology. This information provides a relative figure of merit for comparing or selecting suppliers. The Quality Factor also provides a historical reference that we can use to predict reliability for future part and application development.

Problem solving and follow-up

CRL—the testing, evaluation, and failure analysis section of Components QA—does the reliability and physical evaluation portion of the "E"-Approval process. Production line failures, CAL failures, field failures, etc. are routinely forwarded to CRL for confirmation, physics-of-failure analyses, or return to the supplier. CRL's analytical capabilities include microprobes; microscope; and scanning-electron-microscope examinations; analysis by energy dispersive X-ray, cross-sections, angle-laps; and accelerated, environmental and burn-in testing. These test capabilities enable Components QA to characterize failures, determine the physics-of-failure, and develop and perform screens or lot-acceptance testing. In addition, they can evaluate the effectiveness of screens or corrective action proposed by the supplier, other groups within CE, or QA.

CRL's reliability test, study, and failure analyses results are widely communicated through CE and to the supplier both verbally and in writing. This information provides the foundation for decisions that concern part, module, and instrument disposition, screens, and corrective action.

Components QA administers and coordinates the follow-up and corrective action process from data collection and analysis through corrective action development, prove-in, and implementation. The short-term goal of the corrective action process is to obtain a reliable product to support production. The long-term goal is to correct the manufacturing process (either the supplier's or CE's) to eliminate the possibility of a recurrence. If we cannot totally eliminate the problem, we devise a test gate or screen and incorporate it into the standard manufacturing process. If the problem is supplier related, the special tests are specified in the purchase contract by the QRSM-Q&R Supplement mentioned previously. While addressing a specific component problem may be one of the most-visible functions of Components QA, most of its effort is spent on improving general component quality and reliability. Addressing general component reliability may range from recommending a process change that encompasses an entire family of parts to individually isolating and correcting each problem.

The AMPS, Solid State Performance, and CAL Reports and CE failure analyses are routinely communicated to the suppliers by Components QA. The results of a supplier's quality and reliability testing and failure analyses are, in turn, routinely communicated to CE. A constant exchange of communication among Components QA, Component Engineering, Strategic Sourcing and the suppliers coordinates efforts to isolate, understand, and correct component problems.

Summary

The consumer's perception of the quality and reliability of RCA televisions is based in part on the quality and reliability of the components that are used in the manufacture of those products.

The CE quality system provides three key functions to obtain and maintain quality semiconductor suppliers:

- Numerous monitors provide CE with the data to measure device and supplier performance before, during, and after the television manufacturing process.
- Analytical capabilities to isolate and analyze device problems enable CE to react quickly and take an active role in the corrective action process.
- Constant communication with semiconductor suppliers provides an enlightened and cooperative effort toward product improvement.

The CE component quality system plays an active and effective role in providing a television with the quality and reliability that the American consumer demands.

Based on 1981 and 1985 field service data, the cooperative effort between CE and its semiconductor suppliers has resulted in a 46-percent reduction in the number of 90-day service calls for semiconductor related failures. This translates into a 50-percent reduction in service calls for diodes and transistors, and a 41-percent reduction in service calls for integrated circuits. With the increased use of integrated circuits, this represents a 71-percent improvement in their reliability despite a significant increase in device complexity.

Irwin J. Kratz is Manager of Components Quality Assurance for Consumer Electronics. The Components QA Group, which includes the Component Reliability Lab, CRL, is responsible for developing, maintaining and coordinating a cost-effective Quality and Reliability Assurance System that assures compliancewith established objectives and specifications for all purchased components and subassemblies. Mr. Kratz graduated from the Milwaukee School of Engineering and joined RCA in 1962, working in the Audio Products group. In 1974, he transferred into Components Engineering where he undertook various component assignments and later became supervisor of the Components Test Laboratory. He has been Manager of Components Quality Assurance since 1981.

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Gray

Dan Gray joined RCA consumer Electronics in his present position in 1981 as Manager of the Component Reliability Laboratory. The Lab's functions include semiconductor reliability analysis and component failure analysis.

Prior to joining RCA, Dan was a Failure Analysis Engineer on the Trident and SEM (Standard Electronic Module) Programs with the Naval Weapons Support Center. Dan received his BSEE in 1975 from Purdue University.

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G.F. Floridis

RCA Service Company—A quality beginning

Customers return if we have an image of quality service

For more than forty years, RCA Service Company has successfully supported the RCA tradition of quality by providing services to its customers. RCA Service Company has grown over this period into an international, diversified organization that provides a variety of services and products to government, business, and consumer markets. There is no comparable service organization anywhere in the world.

Why the additional investment in quality?

It may be helpful to portray the size, complexity, and breadth of RCA Service Company.

With over 17,000 employees and 13 businesses, RCA Service Company makes two million residential and one million business service calls per year. We sell almost a quarter of a million TV sets per year and have an installed base of over 1,300,000 telephone lines. We have 440 government contracts and operate in over 500 locations worldwide. And, we have over 1,200,000 consumer service contracts in force.

Abstract: *Customers come back to us, if they see we give quality service. As the part of the company whose sole product is service, what are we doing to preserve and enhance our image of quality? This paper describes some steps we have taken for the Service Company's quality improvement process.*

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Obviously, the Service Company has an enormous exposure to customers through millions of direct contacts. But we do not do image advertising. Our customers know us and come back to us strictly on how they perceive the quality of service we render.

The Service Company growth has resulted in a unique but complex organization structure. Our staff activities and top executives must lead many businesses, unlike most divisions or companies that are concerned with only one business. These diverse and geographically dispersed businesses continue to challenge our ability to communicate internally, respond quickly to worldwide market changes, and otherwise provide effective management.

Growth and change have defined a clear need for each employee to be aware and responsible for quality responses to customer requirements. Further growth and change have increased our need to manage systems and processes, as well as people.

But growth and change are affecting not only RCA and the Service Company; many progressive American companies are now responding to the changing requirements of competition. The American Society for Quality Control began a recent advertisement entitled, "The Renaissance of American Quality," with the following paragraph:

"America is in the midst of a renaissance. Like a slumbering giant belatedly stirred to action, hundreds of industrial and service companies have launched ambitious new campaigns to produce better products and services, eliminate waste, unlock the creative potential of their employees and suppliers, and meet the challenge of international competition."

Since the early 1970s, the marketplace has changed from Main Street in *Hometown, USA* to the very competitive global market that confronts us today. In American markets, the customer has learned that there are new dimensions to price and quality for products available from overseas competitors. Since 1980, many American companies have begun to respond to the overseas challenge of price and quality by taking a new look at management style and methods for reducing costs and improving quality.

Competition

What all this says to RCA Service Company is that both overseas competitors and American competitors in the markets we serve have targeted improved quality and lower costs as primary objectives.

Don Cook, President of RCA Service Company, put it this way:

"Today quality is more important than ever before. Our tasks are more complex, our customers expect more from us, and our stronger competitors are concentrating on quality as a primary way to attract and retain customers. In such an environment, quality makes the difference between success and failure."

RCA Quality Initiative

An additional stimulus for RCA Service Company's rededication to quality is the RCA Quality Initiative that Robert R. Frederick, President and chief executive

Managers participate in RCA Service Company's first Quality Management Training Process Seminar held at Cherry Hill in March 1986. Thirteen hundred managers will be trained over a period of 21 months.

After the RCA/Fort Monmouth Quality Circle presentation at Cherry Hill, Don Cook, then Service Company President, presents a Quality Achievement Certificate to Ron Brown, Grounds Maintenance Specialist.

officer (CEO) of RCA Corporation, announced at the Quality Symposium in April 1985. Mr. Frederick assembled RCA's top 200 executives and charged each to initiate a quality improvement process. Each division would be free to design a process tailored to its own particular needs, but five basic tenets would drive all processes.

- ☐ Quality is *conformance to requirements.*
- ☐ Our performance standard is *perfection.*
- ☐ Our quality methodology is *prevention.*
- ☐ Our measurement of results is the *cost of nonconformance.*
- ☐ Quality is *everyone's job.*

Growth and change, competition, and the corporate quality initiative are compelling reasons for RCA Service Company's additional investment in Quality. But, other facts and concepts that are also emerging from this renaissance which make quality investment good business.

Today, the accepted definition of quality today is conformance to requirements. But there is a problem; making sure that we do things right and fixing things that we do wrong consumes from 15 to 30 cents of every sales dollar in most American industrial companies and about 35 cents of every dollar in the typical service organization.

If you do the right thing correctly the first time to meet customer requirements, you eliminate rework, waste, and the need for inspection, and cut costs accordingly.

Eighty-five percent of the cost of waste and rework results from problems in systems and processes. Management is responsible for systems and processes.

Quality Improvement Process

The Service Company's quality improvement process consists of three basic steps: determination, education, and implementation.

Determination. Says Sanford N. McDonnell, Chairman and CEO of McDonnell Douglas:

". . . When you get into the guts of what must be done, you find that top management leadership is essential to success in the Quality Improvement Process."

All quality gurus and CEOs of companies that successfully implement a quality improvement process agree that top management commitment is the first step. At the RCA Quality Symposium, Bob Frederick committed the corporation to the quality improvement process and asked each executive and manager to demonstrate his or her commitment.

Don Cook has also made this commitment for the Service Company. It was not lip service. This is what we have done to date.

The Service Company has subscribed to the following beliefs:

- ☐ Customers must be satisfied and products and service must meet requirements.
- ☐ Each employee is the customer of other employees in the process of satisfying requirements.
- ☐ Building people results in improved quality and competitive potential.
- ☐ Employees know their jobs best and are best able to develop the solution to problems in their work area.
- ☐ Management is responsible for allocating resources and providing time, training, and processes for effective involvement of employees.
- ☐ A *spirit of quality* must be present in every action of the company organization.

In addition we have published and communicated the following quality policy statement to employees:

The goal of RCA Service Company quality improvement process is total conformance to requirements *perfection.* The products and services delivered and the way we do our jobs must conform to this standard. Quality shall be as important as schedule and cost. Each individual and department shall be committed to this goal to perform *work right the first time.*

We have appointed an Executive Quality Council that consists of the members of the President's staff. It is responsible for:

- ☐ Providing leadership for quality improvement.
- ☐ Planning and guiding the process.
- ☐ Approving quality improvement projects.
- ☐ Providing recognition for quality achievement.
- ☐ Making provision for quality training.
- ☐ Quality measurement.
- ☐ Communications to all employees about the quality process.

The Service Company has committed resources and staffed a Quality and Management Improvement Department to develop and deliver quality training and provide consulting services for implementing the quality process. Quality circles and quality improvement teams are being started and nurtured.[1]

These actions speak to our long-term commitment to a process, not a finite program.

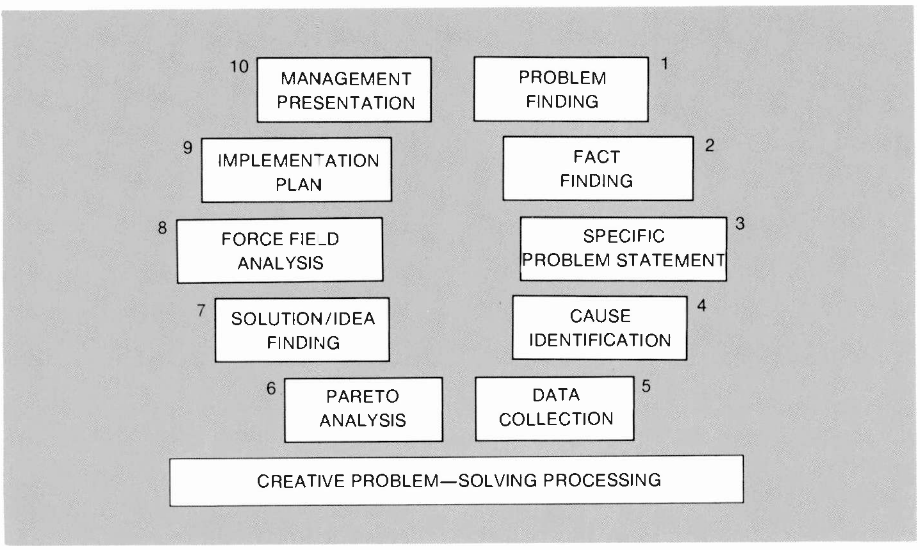


Fig. 1. *The creative problem-solving process. Steps 1 through 3 focus on developing the best statement of the problem. Steps 4 through 6 encompass analysis and documentation, while steps 7 through 10 plan strategy and implementation.*

Education. The Service Company had developed and started a quality education program for its employees. But now that RCA is part of the General Electric Company our plans may have to change in 1987. Still, some training has already been completed.

To date, 80 top executives have attended a two and a half day executive quality seminar. In April 1986, we began pilot seminars of a five-day quality management training process for our 1300 managers.

In addition, 100 managers and professionals have received leader and facilitator training for quality circles and over 300 quality circle members have been trained in creative problem-solving processes.

We have referred to quality circles and quality improvement teams. But what are they?

A quality circle consists of a small group of volunteers, usually six-to-ten people who work together in the same environment. They identify, investigate, analyze, and resolve work-related problems that are common to all members. Circle members usually meet for about one hour each week during regular working hours and determine what problems will be addressed.

A quality improvement team consists of members who are appointed by management, and the problem to be solved is assigned by management.

Both quality circles and quality improvement teams use a ten-step creative, problem-solving process (Fig. 1).

Implementation and participation. By the end of 1985, thirty quality circles had been established within RCA Service Company. They have been formed among field technicians, facility maintenance employees, clerical and administrative employees, professional employees (including Engineering), purchasing personnel, field region personnel, Employee Relations, Payroll, Material Control, Credit and Collection, Business Analysis, and Government Projects.

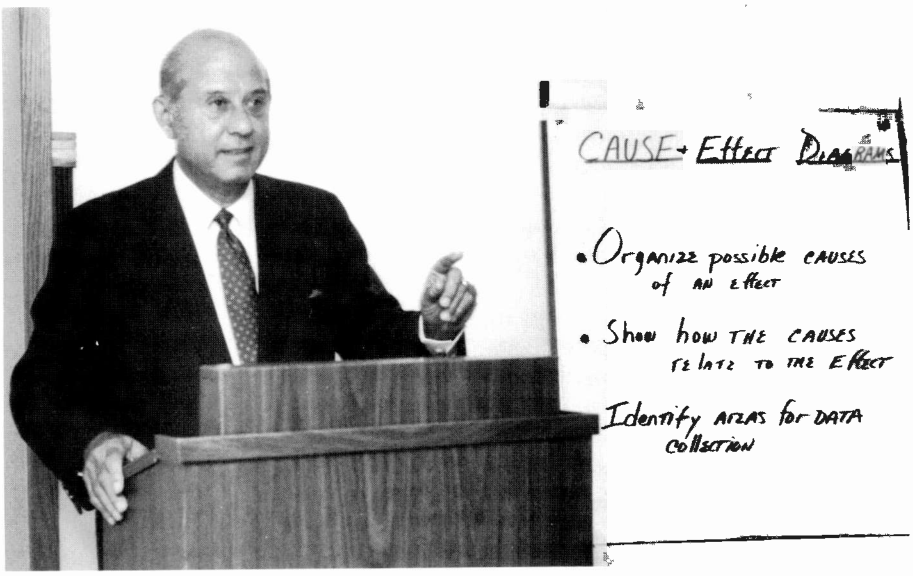
When we ask employees to volunteer for a quality circle, 80 to 95 percent have agreed to participate.

Initial results of quality circles include better employee understanding of the work performed by other employees in the department; a sharp increase in quality awareness and sensitivity to waste; and enthusiasm because they had the chance to participate in solving work-area problems.

Initial recommendations to management from only two quality circles already have projected annual savings of $50,000 and $70,000.

Thus far, we have established quality improvement teams among top management of Consumer, Business Systems and Services, Government Services, and the financial activity.

The Government Quality Improve-



George F. Floridis, Director, Quality and Management Improvement Process, Graduated from the University of Michigan with AB Degree; majors in Psychology/Employee Relations. Completed two years post-graduate work in Industrial Psychology and Employee Relations.

Subsequently, he worked and consulted on Systems and Procedures in the steel and automotive industries. He has over thirty-one years with RCA and, for over twenty years, he was Director, Employee Relations, for the Consumer & Commercial Business of RCA Service Company.

Recently, Mr. Floridis has completed Advanced Engineering Courses at George Washington University under Dr. W. Edwards Deming and has attended Crosby Quality College in Florida. Since 1984, Mr. Floridis has researched Quality Processes and Initiatives of major U.S. and Japanese companies.

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ment Team has given priority to five key quality issues in Government Services, and five additional quality improvement teams have been assigned to address these issues.

For Measurement Systems, the Executive Quality Council has asked each line and staff activity to identify two key areas of the activity's nonconformance to requirements. After the Executive Council reviews the project that these line and staff activities select, quality improvement teams will be assigned to develop improvement methods, select cost-reduction goals, and implement the methods that they developed.

In the Service Company, the quality and management improvement process is in its early stage. During 1986, determination and commitment to the process will mature. To develop as behavior models, our executives will make long-term quality-first decisions; use techniques and processes to release the creative potential of managers and employees; and stimulate training, recognition, and communication.

By the end of 1986, the educational process will be in full swing and by 1987 or early 1988 management quality training should be substantially complete. Pilot implementation projects should blossom in 1987, with clearly measurable results and significant evidence of improvement as we move into 1988.

In the meantime, every employee in the Service Company can and must participate in the quality improvement process. They must renew their dedication to meeting customer requirements and constantly focus on doing the right thing right the first time.

C.W. Thierfelder | F.J. Hinnenkamp

Strategic plan to improve reliability

Reliability had to improve and RCA had to upgrade its image with quality products.

Before 1981, RCA picture tube engineering and manufacturing monitored internal and customer life test results. After analyzing life test failure defects, we started defect prevention programs, and initiated reliability improvement programs based on circumstantial analysis of the data from a full test that nontechnical personnel made of all warranty tube failures. This approach reached a climax with an $14.8 million dollar quips (Quality Improvement Program) capital investment project. It was based on "sound" engineering opinions and principles that an engineering and manufacturing team formed after touring Japanese tube plants and observing their techniques for improved reliability and quality. Unfortunately, problems and environment at RCA were different, and the changes we made did not address the true root-failure causes. Consequently, the $14.8 million expenditure did not cause any significant reduction in field failure rates.

Finally, we recognized that the high field reliability defect and failure rates would continue until we realistically defined and prevented the causes of the defects.

Abstract: *In late 1981, RCA recognized the need to upgrade the reliability performance of its picture tubes to regain parity with the improved Japanese tubes. We formulated a detailed strategic plan whose objective was to regain leadership and recognition as the top world-wide supplier of the longest lived and most reliable picture tube. This plan was based on six reliability management principles: adequate sampling of failures; trained defect analysis personnel; true, root-cause defect analysis; prompt feedback to engineering and manufacturing; implementation of corrective actions; and monitoring of those actions. We achieved the strategic plan's goals. The two-year field reliability performance increased to 0.9985, and the failure rate improved by a factor of five. Warranty cost was reduced by more than nine million dollars during the first four years of the plan, and the reliability rating of RCA television receivers was greatly improved.*

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The reliability model

A product's reliability with operating time usually has three distinct failure patterns.

The first failure pattern that occurs is called infant mortality and is characterized by a decreasing failure rate throughout the product's life. These types of defects are usually caused by manufacturing problems that have escaped the factory detection system or require a short operating time to appear. These failures are really factory substandard units.

The second pattern is chance or accidental failures that are caused by sudden or extreme environmental changes. During the product's operating life, the failure rate is constant and the distribution of failures is exponential. The product has no inherent flaws to cause the failures but is the victim of circumstances beyond its control.

The third pattern is wearout. The product exhausts its capability to perform satisfactorily because one or more parts associated with operation have been depleted beyond the allowable limit. During operating life, the failure rate increases constantly, and the number of failures that occur with time is best represented by the normal distribution.

The only major contributor to wearout for a color picture tube is the emission from the cathode. When the emission falls to a value low enough to decrease the picture's brightness below acceptable viewing levels, the tube has "wornout."

Very few, if any, wearout failures appear in the normal, two-year warranty period because the cathodes have not operated long enough for the emitting material to be depleted significantly. Even after five years of normal operation, the number of tubes that fail because of wearout is quite small although by then this failure mechanism has started. Field data are usually not adequate to provide information about this phase of reliability and in-house life tests are necessary.

The strategic plan was concerned mainly with the first pattern of the reliability model, infant mortality, because these failures are the major portion of warranty returns. However, the extended life failure, wearout, is also important and was not neglected. RCA extended life had always been good but was further improved during this period, even though low-cost manufacturing processes were developed and introduced.

The six reliability tenents

Conceptually, the field reliability performance characteristics of a product design, material, or manufacturing process is a "process" that links picture tube manufacturing operations to the consumer (Fig. 1).

Consumers will continue to receive defective product until we define and prevent the true causes of design, material and process defects. Therefore, we needed to establish a statistically sound, sampling procedure to capture and analyze at least 50 percent of the field rejects.

To do this, we created a Defect Analysis Center (DAC) that consists of six well-trained engineers and technicians. Task force teams were organized to focus the effort of development, manufacturing, and reliability engineers on correcting the five top, field failure defects, which accounted for 80 percent or more of the total failures.

Adequate and regular sample

Before 1982, all field returns were given a cursory examination to determine the failure mode but only small, intermittent samples of field failures were analyzed in any depth for the true root cause of failure. This type of sampling was not consistent in time, quantity, type, or source and did not properly characterize the reliability problems.

Today, we collect and analyze most of the early failures from any one production period to determine the causes of the failures. After enough tubes have been examined, we reduce the sampling rate—but never to zero—until no more tubes fail within the two-year warranty period.

In this system, about 50 percent of the failures receive an extensive analysis, which is more than enough to represent the entire population. We monitor the manufacturing plant, tube type, period of production, length of field service, type of defect, etc. to ensure adequate representation from all categories.

Trained defect-analysis personnel

All persons involved in the effort are exposed to engineering and manufacturing experts in the different areas of interest and to the various tools and techniques of root-cause analysis. Continuing contact between such people is essential and always highly encouraged.

Root cause as the main objective

Determining the true root cause of failure is a major building block of the reliability program. For years, incomplete, incorrect failure analysis had haunted RCA and led to expensive, futile efforts to correct problems that did not exist. Many conclusions were based on opinions or superficial failure analysis that were later found to be erroneous and, therefore, expensive. A major goal of the reliability program is to eliminate these management pitfalls and inefficiencies by determining the root of the failures.

Consider a field reject for electrode shorting. We must know:

☐ the participating grids
☐ exact physical location of the short
☐ type of particle that caused the short (analysis)
☐ the source of the particle that caused the short
☐ reasons the particle existed at the source
☐ possible corrective actions to eliminate the particle.

But equally important are: manufacturing plant and date (tubes and mounts), serviceman comments, service life, and tube type.

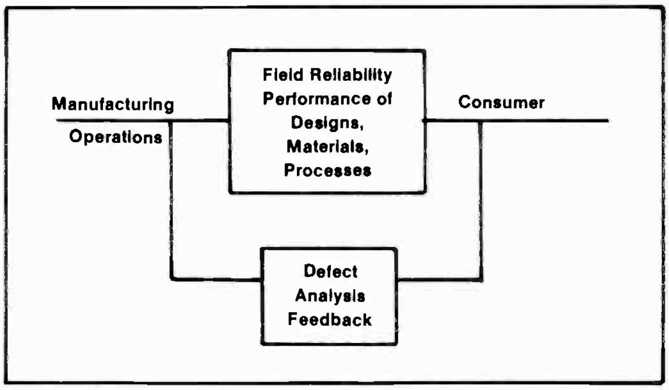

Fig. 1. *Field reliability performance of manufacturing consumer designs, operations materials, processes defect analysis feedback.*

Feedback to engineering and manufacturing

A second major building block in the reliability effort is to share the information obtained from the defect analysis with the managers, engineers, and technicians who will use the data to correct the problems.

We have used several techniques to communicate the data. First, for all major defect items, task teams have been organized with representatives from factory engineering (tube, mount, and parts plants), tube and mount design, process and material engineering, quality and reliability, and management.

Second, two or three times a year, we visit the tube manufacturing plants and review the field reliability and defect analysis results with key personnel including the top plant management, staff, and engineering leaders.

Third, the defect analysis and engineering and manufacturing staffs stay in contact, an essential element in achieving good reliability.

Corrective actions

A reliability program is incomplete and ineffective if we don't try to correct the problems that have been defined by the root cause information from the defect analysis center. This is the reliability building block toward which all the efforts have been directed.

An effective corrective-action program consists of representatives from engineering, manufacturing, and reliability who have the authority and responsibility to introduce those changes that defect analysis has shown are needed to correct the problems and improve the product reliability. Previously, this was often a stumbling block because opinions, not facts, were frequently used as the basis for corrective action.

Monitor corrective actions

Now that the true root cause has been analyzed and the proper corrective action proposed and implemented, we must confirm the effectiveness of the action.

Often, the factory scrap can indicate the value of the corrective action. Each tube manufacturing plant has a one-week life test called an "infant mortality test" (IMT) that can provide input concerning the action. And results from the Consumer Electronics Division's one-week life test, identified as RHP, are also available. But the final judge of the effectiveness of the corrective action will be the field returns.

Unfortunately a long time is needed before meaningful results are obtained with the field data. This is usually at least nine months after tube production for 90-day warranty data and twelve months for 24-month data. Nevertheless, the ultimate value assigned to field reliability will be from actual field data, and we need a procedure to collect it.

Field reliability for the two-year warranty period

Early estimates

Because many television sets are not sold for a year or more after the tube manufacturing date, we cannot determine final field reliability until two or more years have elapsed. Therefore, we need a method to make an early estimate of the final field reliability to minimize warranty costs.

The technique selected for this early estimate is simple, but requires an extensive computer database and program. The database consists of all field return tubes from 1980 production to the present from all television sets for which RCA is responsible for the warranty cost of failures. The tube production month, set sale month, tube fail month (claim month), and root cause of failure are included in the database.

The tubes are grouped by production quarter, months from production quarter to fail month, production plant, length of customer operating periods, and type of defect. We build a return rate historical profile that consists of at least 11 pieces of data for each estimate to be made. If we look at this profile and assume that the current product will follow the same return-rate profile, we can estimate the final field reliability for recently made tubes, based on the early failure returns. Using statistical techniques, we can include a confidence limit with this estimate.

As more data is obtained, the estimate for any production period will change somewhat and approach the actual final value. In the past, an estimate within plus or minus 10 percent of the final true value has been possible nine months after production for failures that occur within 90 days of use and 12 months after production for failures that occur within 24 months of use.

Forecasts of final field reliability

"Forecast" is defined as the value assigned to the final field reliability based on one-week life tests of regular product. These tests are conducted by Video Component and Display Division manufacturing plants at Marion and Scranton and by the CE set manufacturing plant at Bloomington.

All failures at these locations are analyzed. We study the root cause of failure and the conditions or facts that accompany it to determine if the same symptoms or facts in the customer environment would also cause failure. For those tubes that represent true field failures, we adjust the data to represent the number of failures that could occur in 90 days of field service, which is an average of 650 hours of viewing. The adjustment is necessary because life tests run only for a total elapsed time of 168 hours.

In the past, the forecasts have been reasonably close to the final value for Marion product, but greatly underestimated for the Scranton product. The main difference is the Scranton life tests have a very low failure rate, so the forecast is also very low. In spite of several investigations, we don't know why this happens.

Field reliability beyond the two-year warranty period

Most field failures within the two-year warranty program are from the infant mortality and early chance failure patterns; but we still need to test color picture tubes beyond these periods to determine the extended life of the product. This is best done under controlled conditions where we can monitor and evaluate the tubes at specific intervals or whenever desired. The extended-life failure is often referred to as wearout.

At Lancaster, 864 regular receiver positions are available for extended life operation. Many tubes are kept on life test for as long as five years, which is equivalent to 16 years of operation in the normal customer environment.

Some of these tubes are regular product samples (two per week per manufacturing plant), but most are engineering tests of new or modified materials, designs, and processes. Many of these engineering variables are prepared for life test in factorial format (statistical design of experiments) so we can study possible interactions and use the minimum number of life positions.

Throughout the life test, we also measure electrical and other types of responses at periodic intervals. After the five-year period (40,000 hours of operation), many of the tubes can still provide an acceptable viewing picture. Most of the tubes are examined thoroughly after completing the required time on life.

We use operating and test conditions that are different than those normally encountered to stress the product and induce early failures of the same type that occur in regular use. This shortens the time to failure and helps us quickly evaluate many engineering proposals as well as regular product. Although stress testing is used mainly in evaluating long term life, we also use it for other failure mechanisms where we know the correlation with field performance.

Factors that are appropriate for stressing include cathode temperature, anode voltage, beam current, ambient temperature and humidity, and tube processing conditions (such as exhaust speed and temperature).

Key component approval testing

Two of the most important components in the tube are the heater and the cathode. Because both have created numerous field problems in the past, we must control their impact on performance.

Cathode approval test

A sample from each cathode lot is put on life at a high cathode temperature for two and eight weeks. We read the initial and final emission, examine all cathodes for coating appearance and adherence, and check other items. Each lot must pass all tests before we approve them for production use.

This simple test has helped us maintain good cathode coating adherence and pointed to other types of problems with the cathodes and the coating. Because of the test results, we have improved weight and thickness levels and controls for the sprayed cathode coating, maintenance of the cathode firing furnace, and material and process control for the ingredients and manufacturing of the coating lots used at spraying.

Heater approval tests

All heater production lots are sampled and checked for voltage breakdown between the heater and cathode after operating 48 hours at elevated heater temperatures. The breakdown level must be high enough to ensure that the heater will perform well if it is exposed to the high voltages that can occur between the electron gun components during actual operation. All heaters that fail the standardized limits or pass but are seemingly below par are examined closely for failure cause.

Today, the average breakdown voltage is about 4000 volts, and the heater field performance is excellent with a two-year field reliability of 0.99995 or better. In 1979 and 1980 when the breakdown voltage was much lower, heater field reliability was as low as 0.995 for certain tube types and production periods.

This vast improvement resulted from the use of a dark coated heater that lowered the heater operating temperature by about 300°C. The new heater has also improved extended emission life, probably because the cathode's operating temperature, as hours of use accumulate, is less for the dark heater than the white.

Other corrective actions helped to improve heater performance. We have a new heater firing furnace and improved temperature and humidity controls at firing. We also have better control of the coating weight and reduced the tungsten in the dark coating from 33 percent to 8 percent.

Statistics in the reliability improvement program

Product reliability involves many variables that often are impossible to evaluate properly. Therefore, we designed statistical tests for most experiments to improve the reliability of the color picture tube. The designs include factorials of different types, paired comparisons, AB tests and stress/Weibull tests.

Statistical analysis procedures include analysis of variance, linear regression, student T, Chi Square, Fisher exact, F ratio and nonparametric.

We varied factors and levels of parts design, materials, processes and operating conditions, especially on life test, to collect the most information from each experiment or series of experiments. Often, interaction effects are important and the test design must allow these interactions to show. An example of such a project is described in the next section.

Authors Thierfelder (left) and Hinnenkamp.

Charles W. Thierfelder has now retired after holding the position of Division Vice President, Product Safety, Quality and Reliability of the Video Component and Display Division since January of 1978. Prior to this, he held the position of Division Vice President of Technical Programs during 1976 and 1977. Mr. Thierfelder had previously been Division Vice President, Manufacturing, from June of 1973 through December of 1975; Division Vice President, Engineering, and Chief Engineer from 1965 to May of 1973; and has held various picture tube engineering positions since 1943.

Mr. Thierfelder received a BS in Electrical Engineering from Oklahoma University, an MS in Physics from Franklin and Marshall College and attended a post-graduate course in management at Northwestern University.

Frank J. Hinnenkamp, who has now retired, held the position of Manager of Reliability, Warranty and Life Test for the Video Component and Display Division. His previous experience at RCA includes cathodes, heaters, life test and statistical work in areas of design of experiments and data analysis.

Mr. Hinnenkamp received a BS in Chemical Engineering from Villanova University and an MS in Physics from Franklin and Marshall College.

Exhaust speed increase

In the early 1970s, we needed to increase the production rate to meet improving sales. If all processing throughput rates stayed constant, we could only increase the manufacturing rate by building more exhaust lines or modifying the existing exhaust lines, both expensive options.

Another solution was to build more tubes per hour with the existing equipment. But what effect would increasing the exhaust speed have on the extended life of the tube? For a higher exhaust speed we needed to lower exhaust temperatures, because the heating and cooling rates at the higher speed and the previous high temperature would cause more glass to break. We had never processed tubes at these new, lower temperatures and needed to determine their effect on gas absorption and removal and extended life in general.

Before we could finally approve the drastic processing change, we did engineering studies followed by small, one-month production runs.

The initial tests began in 1974 and have continued. Exhaust speeds have gradually increased from about 45 to 60 per hour to the current 105 to 130 per hour, a truly remarkable step that saved RCA millions of dollars in expansion costs.

All phases of the test program:

1. Use statistical design and analysis for all engineering tests.

2. Include exhaust speed and temperature levels that are beyond the desired new processing values. This provides a safety margin for actual production.

3. Put enough tubes on extended life test so we can remove some at 10- to 20-week intervals to examine and check the amount of getter capacity that remains. At least one year of life operation is required for proper evaluation.

4. Make a one-month production run and wait one year for the field return results before beginning regular use of these new levels.

We followed these steps for each new phase of the test program when Manufacturing requested a further increase in the exhaust rate.

The results of this carefully planned, statistical approach have been very satisfying. Production rates have more than doubled, and exhaust temperatures have decreased by nearly 100 degrees with absolutely no effect on the extended life of the picture tube.

Acknowledgments

Current and past personnel of Lancaster's Defect Analysis Center have made many important contributions to the reliability improvement. They are John Coble, Jack Coffin, Donovan Graybill, Rick Griffith, Andrew Hartman, Vincent Heesen, Richard Roland, and Cheryl Zwally.

Others in management, engineering, manufacturing and reliability also helped greatly, too many to mention. We wish to thank everyone who contributed.

N.J. Trapani

Quality circles at MEC

Employees who do the work are usually the best place to look for solutions to problems.

This imaginary but probable conversation exemplifies the need for quality circles:

Walking past an open area, you overhear Jack speaking to Joe, his supervisor. "Joe, we have a problem with the work on the x-y-z job. We'll make delivery only if maintenance can come up here and adjust the tolerances on that machine!"

To which Joe, the supervisor replies, "How many times have I told you that the problem is not the machine. Now get back to work, the more time you waste, the later the delivery will be."

In this exchange, the supervisor has managed to do two things: alienate an employee who's trying to solve a problem, and overlook a possible solution to that problem. The supervisor's attitude is that, as the boss, he should have all the solutions. In his own mind, he has already determined the cause of the problem—the employee. Jack, on the other hand, knows that he understands the working details better than his supervisor; after all he does it all day, everyday. However, he decides if that is Joe's attitude, he will never offer another suggestion when there is a problem.

Sound familiar? It is this type of situation that quality circles try to prevent. The people doing the work, know the job best. They have the ability to find many solutions to problems that are more difficult than this one and that management often overlooks.

The management of RCA Microelectronics Center (MEC) has acted to eliminate this all too familiar situation. They have changed management style to a participative approach through the use of quality circles. With quality circles (QC), employees can discuss ideas to improve the operations and act on these ideas with minimal red tape or bureaucratic interference. The QC concept is designed to put some power into the hands of the people who know best the details of the operations. (For a more detailed description of quality circles, see inset.)

Abstract: *Excellence, dependability and quality for our customers and for ourselves is the RCA Microelectronics Center's (MEC) management credo. Quality circles have been introduced throughout the MEC organization, as part of an overall effort to meet this standard. They have been so successful that other groups are starting their own quality circles.*

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Early identity

During the early stages of the 1984 start-up effort, a slogan contest was held to develop an identity for quality circles at MEC. Establishing an early identity for quality circles is an integral step toward demonstrating visible management support for quality-circle activities.

The contest was designed to involve all employees in developing a slogan that best exemplified the objectives of quality circles. Focusing attention on this new area helped to demonstrate MEC/RCA's concern for its employees and its quality performance. The QC steering committee made the selection and presented prizes to the employees who submitted the top two slogans.

Selected as the MEC slogan was: *Action, Creativity and Teamwork, Put the ACT in action.* Engineering Publications developed the logo artwork that each quality circle now uses to identify its projects.

Since the startup, four new quality circles have been started, about one

What is a quality circle?

A quality circle is a group of between 4 to 12 employees from the same work area who meet voluntarily for an hour each week to identify, analyze, and solve work-related problems. At the Microelectronics Center, these meetings are held on company time. The ultimate goal of a quality circle is to develop proposed solutions to job-related problems, present them to management, and then have them successfully implemented.

A quality circle is based on simple concepts. First, the people most qualified to address problems are the ones who understand those problems best— the workers who experience the problems. Second, almost everyone will take more pride and interest in his or her work if he or she is part of the decision-making process.

All participants in a quality circle have an equal voice in making decisions or recommendations; thus, a main objective is to have all circle members participate. This responsibility falls on the circle leader who is usually the area supervisor. The leader has equal standing with other circle members, but also has the responsibility for ensuring adherence to procedures and smooth-flowing work sessions. To assist the circle leader, a facilitator is the catalyst who makes things happen, and is the link between management and the circles. The facilitator also is responsible for training the circle in problem-solving techniques and developing each circle into an effective problem-solving team.

The quality circles technique recognizes the individual worker as a human being with the ability and desire to help solve work-related problems. Participation in a quality circle is voluntary and all employees are free to participate or not to participate.

Quality circles is a people-building philosophy that directly involves employees, at the work level, in analyzing and solving product quality problems. It is not just asking employees for suggestions; it is a bold step forward in re-establishing the dignity of a person and the job that person does. It is providing training in the basic tools of problem solving so that employees have a means to analyze problems and synthesize solutions. It is enabling employees to contribute their brainpower, and develop, recommend, and implement solutions.

In short, quality circles is more than a program . . . it is a process.

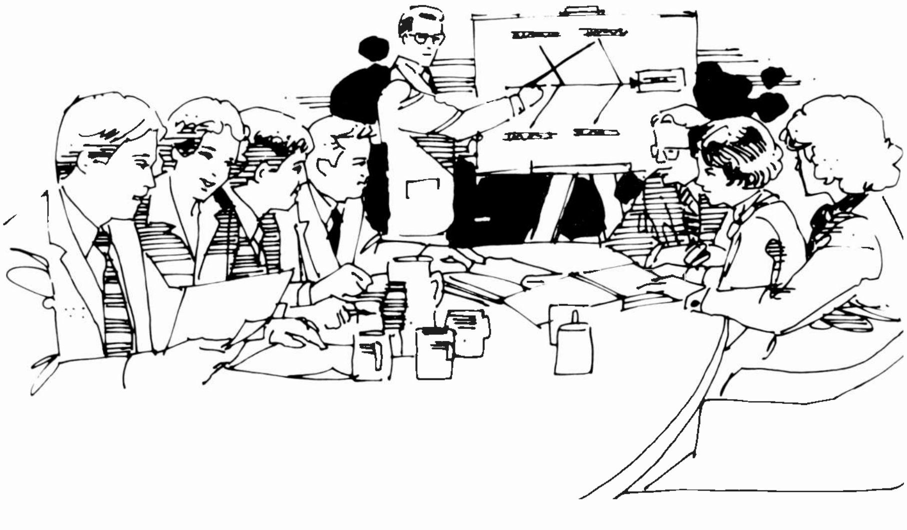
every eight months. Since 1984, active involvement in quality circles has grown from seven employees in one circle to over 85 employees in 13 circles, which is about 15 percent of MEC's population.

Initially, the areas targeted for quality circles were in manufacturing but recently, at the request of several secretaries, two secretarial circles were formed and trained.

It has been exciting for all, with momentum building to the point that other groups of employees are asking, through their managers, to start circles in their areas. The key to MEC's success with quality circles has been that we adhered to a carefully thought-out, start up plan while still remaining flexible.

People are the key

Every quality circle that is formed at MEC consists of volunteers who receive ten hours of training in consensus-decision making and problem-solving techniques. Each circle meets for one hour each week to identify, analyze, and solve its work-related problems. The significant event that culminates the problem-solving process is the management presentation. During these presentations, a circle communicates the results of its efforts to the management staff. It is a unique experience because the circle members, most of whom have never made a presentation before, have an opportunity to speak formally to the MEC management.



The people at MEC have made Quality Circles successful. Their participation, commitment, and accomplishments have advertised the concept and resulted in the constant expansion of circles. By solving real and important problems, making and holding management presentations, and successfully implementing the changes, the quality circles have created a level of visibility that helps sell the concept to other employees.

Positive results

The most significant contributions have come from the wafer manufacturing circle, which started over three years ago as a pilot program. This experience has taught us that the more mature circles tend to make the most significant changes. This group has deviated from the standard practice of making the area

supervisor the circle leader and has recruited a Member of the Technical Staff to lead the group. This group, known as *The Challengers,* has completed several projects.

One project dealt with reducing the breakage of Silicon-on-Sapphire (SOS) wafers during the diffusion process. Because of their problem-solving effort, this circle recommended a design change that incorporated the use of larger slots in the quartz boats that carry wafers into hot furnaces. New quartz boats were ordered and have been in use for over a year now. The large slots do not stress the wafers as did a snug fit and have resulted in a $10,000 cost savings during 1985.

This circle also recommended changing the deionized wafer temperature during the before- and after-etch rinse. As a result, fewer wafers crack or break when submerged in the deionized water, with an estimated cost savings of $9,600.

The Quality Control Inspection Circle in Photomask Operations dealt with the problem of foreign matter buildup on photomask plates while the plates were awaiting inspection. Their solution was to install nitrogen boxes that hold the product while it was waiting to be inspected. As a result, fewer photomask plates must be cleaned before inspection.

A less tangible idea that was implemented involved putting on the gown properly when entering the clean room. The circle developed a set of posters that describe the proper clean-room gowning procedures. They increased awareness that the human body is the most contaminating item in a clean room, and the product is ensured protection by proper gowning.

Also in Photomask Operations is a circle that is currently redesigning the layout of the MEBES process room. The circle is working closely with the facilities engineering group to develop a room layout that increases the efficient use of available floor space while reducing the congestion that a crisscrossed product flow causes.

In the package and assembly area, the circle has enlisted the aid of the technical training group to develop a videotape on pellet handling procedures for training new operators who enter the department.

Conclusion

These contributions, coupled with managements leadership, have given the Quality Circle process staying power within MEC.

It has been these contributions, coupled with management's leadership, that have given the quality circles process the staying power within MEC. Management's adoption of a system which includes those people who are most familiar with the daily operations and the subsequent problems that arise in the decision making process has kept this progressively oriented organization in the forefront of innovation.

Nicholas J. Trapani is the Quality Circles Administrator at the Microelectronics Center. Nick joined MEC in 1984 and is responsible for training circle leaders and members and for facilitating Quality Circle meetings. Nick has also been heavily involved in other projects for MEC, including coordinating the Opinion Survey, developing a Supervisors Handbook and facilitating Quality Improvement Teams. Nick received his BS degree from Rider College and an MBA for Augusta College.
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L. A. Morgan

Training for quality leadership

The General Electric Corporate effort to provide quality training on a Company-wide basis began in the early 80's when the need for fundamental changes in the way we do business was perceived in order to survive and thrive in the face of increasing global competition and escalating customer requirements. World-class quality in all products and services would be a prerequisite to making General Electric the natural choice of our customers in each market we serve. World-class quality would also be a prerequisite to achieving the highest levels of productivity — absolutely essential to profitable survival in the face of fierce world-wide price competition. Fred Garry, in his editorial in this issue, discusses these needs and the complementary relationship between quality and productivity.

Meeting these quality goals and objectives required creation of a Company environment that encourages achievement of individual excellence on the part of every employee and that assists employees in their pursuit of excellence by providing them with skills training. The importance given by senior management to the creation of such an environment was confirmed by the issuance in 1981 of a formal Company policy statement "Company-Wide Quality" (see Figure 1). A central element of this policy is the fact that it makes every business responsible for the quality of their products and services. One element of the GE strategy to achieve quality goals and objectives centered on development of the General Electric Quality Leadership Curriculum (QLC). A significant multi-year and multi-million dollar effort was involved since appropriate quality training was not available. A lot of motivational materials were available but very little in the skills training area was found. In addition, essentially all the available materials were consultant intensive and not suitable for mass distribution at multiple locations. Some 97 specific quality techniques were identified, evaluated, narrowed down and incorporated into ten courses (see Figure 2). This activity drew upon the many talents of 34 course development specialists, 45 subject-matter experts, four video production companies, three software development companies and hundreds of reviewers from GE businesses.

Heading the curriculum are QLC-1, a one-day business quality assessment and QLC-2, a three-day follow-on planning session. In QLC-1 the major quality improvement

Objective

It is the objective of the General Electric Company to perform all activities with dedication to quality; the quality of the Company's products; the quality of its services; the quality of its communications to various audiences; and the quality of its fulfillment of citizenship responsibilities. In support of this objective, the Company encourages the achievement of individual excellence on the part of every employee in every job.

- ☐ Company-wide Quality, as a corporate objective, means attaining a level of overall performance and attitude that makes General Electric the natural choice of customers and earns the respect of all those affected by the Company's activities.
- ☐ Company-wide Quality, as an individual objective, is achieved by employees whoo aspire to be better than the best. General Electric is committed to assisting employees in their pursuit of excellence by providing them with the leadership, cooperative climate, training, facilities, and materials consistent with the overall Company quest for quality.

Statement of Policy

It is the policy of General Electric, in offering products and services that fill a wide range of customers' needs, to pursue and deserve a reputation for quality leadership, and to merit customer trust because full value is being received.

It is the policy of General Electric, in fulfilling its social responsibilities and in every aspect of its relationships both outside and inside the Company, to demonstrate total dedication to the attainment of quality leadership.

Implementation and measurement

Responsibility for implementation and measurement under this Policy is assigned to direct reports to the Corporate Executive Office, who will conduct the affairs of their respective components in accordance with this and related policies.

The Officers noted above shall make regular reports to the Corporate Executive Office on fulfillment of Company-wide Quality objectives by their components.

In measuring and rewarding both individual and managerial effort at all echelons, the highest value will be placed on quality performance that reflects excellence, creativity, productivity, and pride in accomplishment.

Fig. 1. *Company-wide quality*

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Course	Title	Length (hours)
QLC-1	Quality leadership assessment	8
QLC-2	Roadmapping quality change	24
QLC-3	Design for assembly	8
QLC-4	Customer requirements	6
QLC-5	Design for reliability	10
QLC-6	Quality problem solving	6
QLC-7	Statistical quality control	14
QLC-8	Station control	6
QLC-9	Designing experiments	10
QLC-10	Individual excellence	12

Fig. 2. *QLC courses.*

opportunities are identified by the general manager of a business and his or her business team and a list made of the top quality issues and changes required to improve or maintain world-class competitiveness. QLC-2 is an intensive, interactive three-day planning session for a multi-functional team selected by the general manager. The team develops the initial phase of a multi-year plan to implement quality changes and to respond to the quality issues and challenges identified in QLC-1. Participants are taught a structured process for examining their business' key quality issues and for determining necessary quality culture and skill base changes.

QLC-3 through 9 cover specific quality skills — quality improvement techniques and procedures that are quantitative in nature — that can be used by engineers in design, manufacturing and other functions. These courses are also typically attended by relevant subsets of the professional and hourly populations of a business to obtain practical skills which can be implemented immediately in their jobs to improve product and process quality.

QLC-10 is the culture change course directed at individual excellence and the individual's impact on business excellence. It is literally intended for every employee in the business.

Each QLC course can be mapped into the three arenas of the General Electric quality change strategy (see Figure 3). Deficiencies in either systems or practices and gaps in either skills or attitudes are identified in QLC-1. The skill gaps are closed by QLC-3 through 9. The business practices and system deficiencies are closed via QLC-2 action plans aimed at improving the business infrastructure that supports quality as a way of life. Attitudes gaps are narrowed by QLC-10. Thus, QLC provides vehicles for well balanced improvements in all three circles and thereby creates a lasting quality culture change. An individual business may not require the entire curriculum to orchestrate its culture change.

To date QLC programs have been initiated at 28 General Electric businesses. This has involved over 28,000 course enrollments and over 42,000 student-days of training — at over 50 different sites including several foreign locations. In addition, GE businesses have involved over 600 supplier companies in their programs. Other GE businesses are assess-

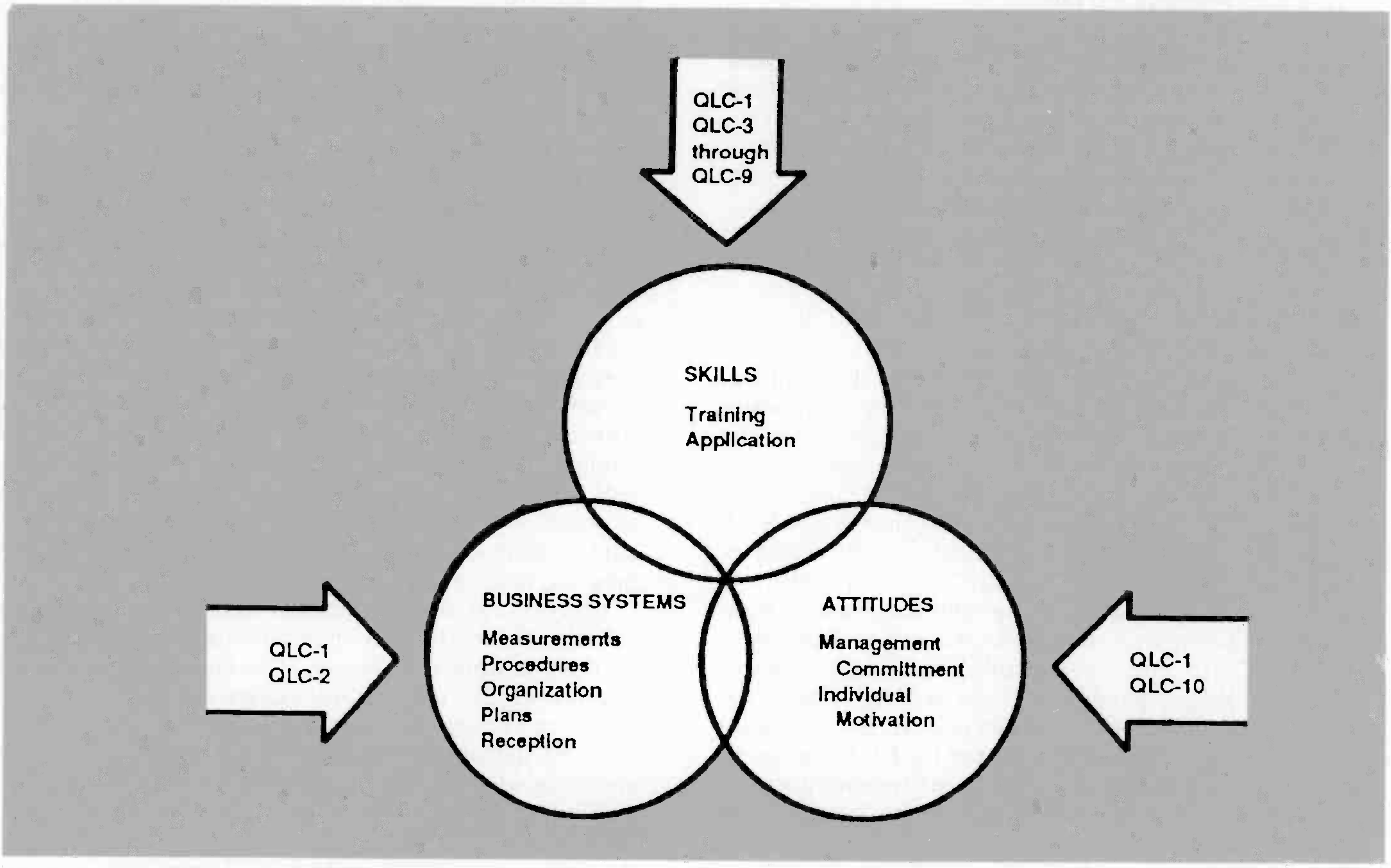

Fig. 3. *Strategy for quality culture change.*

RCA's QMTP graduates can build on strength

In quality improvement education, RCA got started about three years after General Electric and with a different initial direction.

As is described in the accompanying article, the GE approach was to develop an integrated and comprehensive ten-course quality leadership curriculum to help management increase business competitiveness and achieve business excellence by teaching and implementing proven quality techniques and practices. Two courses are focused on management aspects, seven cover specific technical skills areas and one addresses individual attitude.

While the long-term objective and plans were comparable, RCA's principal emphasis in its initial two years of developing and implementing quality improvement training courses was on management aspects, with plans to begin addressing technical training needs in 1987 or later.

The merger has made that future course development work unnecessary. Any of the GE QLC-3 through -10 courses can be very effectively utilized by an organization which has based its Quality & Management Improvement Process on the two RCA training courses: the Executive Quality Seminar (EQS) and the Quality Management Training Process (QTMP).

In the RCA EQS/QMTP courses (EQS is an abbreviated version of QMTP for senior executives), the managers develop an understanding of the need for, and a commitment to a process of, continual quality improvement in all staff and line functions, including how to structure an effective quality improvement process. They identify key quality issues, including sources of nonconformance to business requirements. They learn a ten-step creative problem solving process employing a dozen effective techniques, and gain experience in using that process in a team attack on a nonconformance existing in their organization. They identify potential obstacles to implementing quality improvement processes and, in a team workshop, develop a plan to overcome those obstacles.

A careful examination of Len Morgan's article shows the marked similarity of the RCA management-oriented courses to the GE management-oriented courses OLC-1 and -2.

When the currently scheduled EQS/QMTP courses have been completed about 4000 managers will have been trained, from RCA's Aerospace & Defense divisions, the Service Company's several operations, the Distributor and Special Products Division, and from Americom. In parallel, an increasing number of these managers will have gained experience in Quality Improvement Team activities in their organizations.

Considering the training and experience they have had, it is evident that the EQS/QMTP-trained management cadre will be well prepared to lead the implementation of selected General Electric QLC-3 through -10 courses in their organizations. They can build on the quality improvement management strength they've developed through EQS/QMTP, by bringing to their business units the technical depth of the GE Quality Leadership Curriculum.

G.D. Prestwich
Staff Vice President & Corporate Quality Executive
RCA Corporation

ing their quality requirements to determine the QLC program format best suited to their needs.

In some components of RCA an effective quality improvement training effort is underway via two Corporate-developed courses for operating component managers. The objective is similar to that of GE — to initiate mechanisms to create a fundamental change in how operating components manage quality. The principles underlying the GE and RCA approaches are also similar, resulting in the two RCA courses being compatible with QLC-1 and -2. Consequently, it is expected that RCA components that have completed or are in the process of completing the two RCA courses will be able to use the QLC 3-10 courses as a complementary, logical follow-on activity. Where components have not yet initiated the RCA courses, QLC-1 and -2 will be available, possibly modified to include appropriate elements of the RCA courses, to start the quality training process. George Prestwich discusses this aspect in more detail in his accompanying comments (see box).

The QLC courses can be implemented by a business in several ways. Utilizing QLC courses as continuing education courses is a start, but the participation usually is narrow, the application of the techniques is ad-hoc, and the resulting business benefits are rarely documented and known by management. By extending the courses with additional weekly structured application project sessions, technique implementation is facilitated and impact is more visible and measurable. Usually, five weeks are required for participating teams to select an application project and the techniques to be implemented, develop an action plan, review implementation progress, and achieve first results.

Experience at several major GE businesses has shown that radiation of the structured application approach throughout the business along with changes in the business measurements and systems can create a real culture change and a major impact can be expected. At some businesses QLC-6 Quality Problem Solving and -7 Statistical Quality Control are being applied in what we call the productive training format. This training involves both hourly and salaried personnel in learning and applying the skills, thus linking the classroom with the factory. At Major Appliance Group, the customer requirements and design courses (QLC 3-5) are also being applied effectively. With application of learned skills to specific quality improvement projects, learning is being focused on a massive scale to support a specific business goal. This approach fostered the creation of multi-job function, multi-job level teams which has resulted in breaking down traditional internal barriers. Thus QLC courses are the tools these businesses are using to drive a change from reacting to quality problems surfaced during inspection and service to putting a prevention system in place that permits doing things right the first time. Based on this experience, work is underway to increase the use of all QLC courses in the productive training format.

These businesses have also instituted activities aimed at changing their measurements and systems — to insure a permanent change in culture. The approaches involve such areas as work planning, compensation, organization structure and recognition of the enlarged body of people being asked to assume responsibility for quality — aimed at transferring ownership for quality to the lowest layers of the organization and redefining management's role as one of leadership for quality.

This total approach to the three arenas of the quality change strategy (Figure 3) has led to the targeting by one of the businesses of a fifty percent reduction of the direct and measurable quality costs — i.e. losses, scrap, rework and warranty complaints. For this business, using the 6:1 ratio of indirect to direct quality costs cited by quality experts, the targeted goal translates to a total cost saving comparable to net earnings.

Results reported by GE businesses confirm the effectiveness of QLC and the approach to quality leadership. With more than 100 projects based on QLC techniques completed or underway we are already beginning to see changes in the culture of our operations, and cost savings of over 70 million dollars have been documented. By focusing on techniques and cultural changes rather than just solving current problems, we believe we are on the fastest track to the prevention mode — with the highest probability of success of solving quality problems long term.

We anticipate the long term return for GE and RCA operations will be a dramatic improvement in quality and pull-through of productivity gains — which will improve our overall competitiveness in world markets, bring about increased customer satisfaction and market share, and enhance profitability. Perhaps even more significant is the satisfaction our employees will have from knowing that we are providing our customers the best possible quality goods and services.

Biography

Leonard Morgan is Manager, Technical Resources Consulting at General Electric Company's Corporate Engineering and Manufacturing activity in Bridgeport, Connecticut. He joined General Electric in 1954 and has worked in various Engineering, Manufacturing, and Marketing functions at a number of GE locations. In addition to membership in several technical societies, Len serves on NEMA's Professional Engineers' Licensing Committee and on the Stanford University School of Engineering Advisory Council.

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W.A. Mulle

A radar/phased array radar primer

Manufacturing and system integration processes have matured to the point where phased arrays are increasingly becoming the radar of choice in land, sea, and airborne military applications.

The marketeer attempting to sell any complex system or piece of machinery must always face the problem of "tutoring" his customer. Instructional methods combine presentations, advertisements, brochures, and proposals. If the customer is an office or agency of the United States Defense Department, the marketeer presumes a very high level of technical and operational expertise. In addition, that customer can enlist government research laboratories to help evaluate the merits of products being offered or proposed, and to assess the advantages and risks of new technology.

The situation can be vastly different in places like Indonesia or Thailand. Customer knowledge of specific technologies may be superficial at best, and the problem of educating the decision-makers is compounded by differences in language and social customs. For example, in some Oriental cultures, the social imperative to "save face" inhibits oral questions during a marketing presentation. Members of the customer's group affirm that they understand and appreciate all aspects of the presentation, but subsequent comments and questions submitted in writing will reveal that, in fact, they do not.

The problem is aggravated by the lack of language facility on the part of both salesperson and customer. A salesperson from the USA who travels to six different countries is not likely to be proficient in each language, and the customer usually has only a limited grasp of "everyday" English — much less scientific terminology. The result can be frustrating for an aggressive marketing manager.

Abstract: *The author recently compiled a primer on conventional and phased array radar systems for members of MSRD's International Programs and Marketing Groups to use in presenting the advantages of phased arrays in an easy-to-understand format. This article, derived from that primer, offers general fundamentals to the **RCA Engineer** reader unfamiliar with radar.*

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We have observed that foreign customers usually do not gain sufficient understanding of complex subjects from viewgraph presentations. This is because (a) the listener's mind is partially occupied by on-the-fly translation (assuming that he does not normally think in English) and (b) few visual clues indicate that the listener doesn't understand ("face saving" as mentioned earlier). The printed word (and picture) is a more effective means of communication with foreigners because it circumvents these problems.

Members of MSRD's International Programs and Marketing groups have recently faced this situation in attempting to explain the operation of phased array radars to non-U.S. staff officers. Their solution: a "primer" that explains not only how a phased array works, but, more importantly, what military advantages ensue from including it in one's arsenal. The primer is tailored to build on the customer's functional knowledge of conventional radar operation. This article, derived from the primer, provides the RCA engineer with fundamentals of the phased array radar, so important to MSRD.

The radar primer — conventional vs. phased array

Modern radars can be categorized by the method used to direct the RF beam at the target:

- Conventional, mechanically rotated antennas
- Electronically steered (phased array) antennas

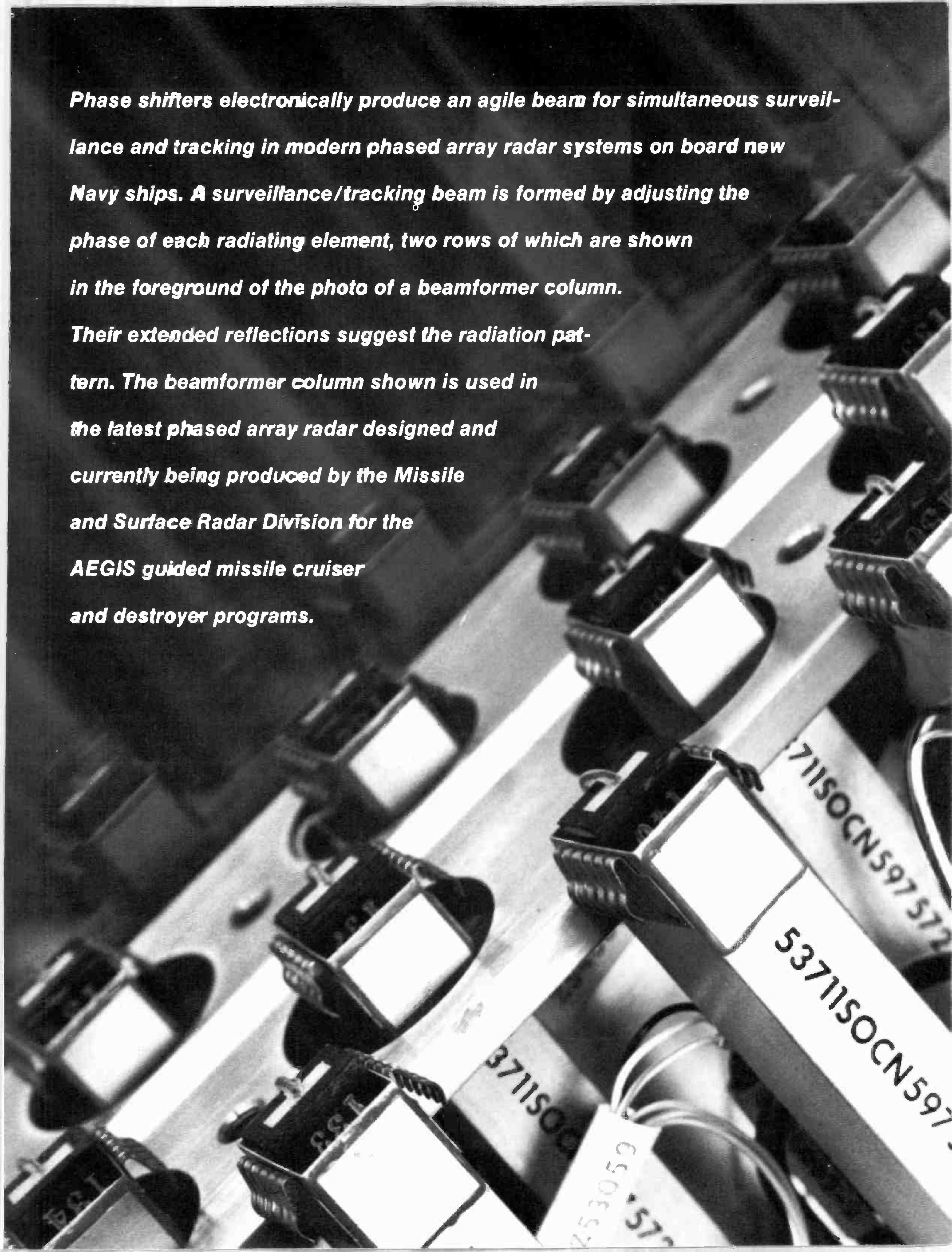
Considering first the mechanical antenna systems, these can also be functionally classified into two groups:

- Search radars, both 2-dimension (2D) and 3-dimension (3D)
- Tracking radars

Let us consider the mechanically positioned radar systems first.

The 2D search radar — major drawbacks

As its name implies, a 2D radar provides only two target coordinates, usually range and azimuth. A 3D search radar provides target data for range, azimuth, and elevation.



Phase shifters electronically produce an agile beam for simultaneous surveillance and tracking in modern phased array radar systems on board new Navy ships. A surveillance/tracking beam is formed by adjusting the phase of each radiating element, two rows of which are shown in the foreground of the photo of a beamformer column. Their extended reflections suggest the radiation pattern. The beamformer column shown is used in the latest phased array radar designed and currently being produced by the Missile and Surface Radar Division for the AEGIS guided missile cruiser and destroyer programs.

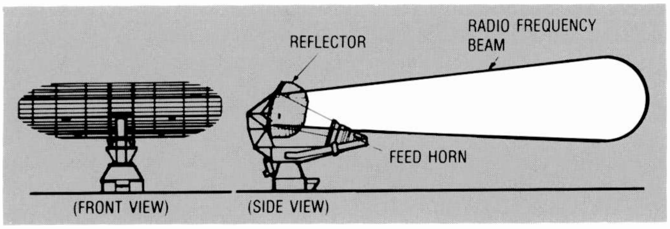


Fig. 1. *2D search radar.*

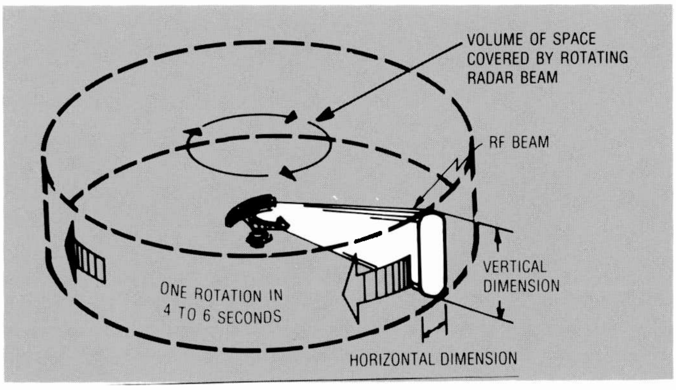


Fig. 2. *Rotating beam pattern of 2D radar.*

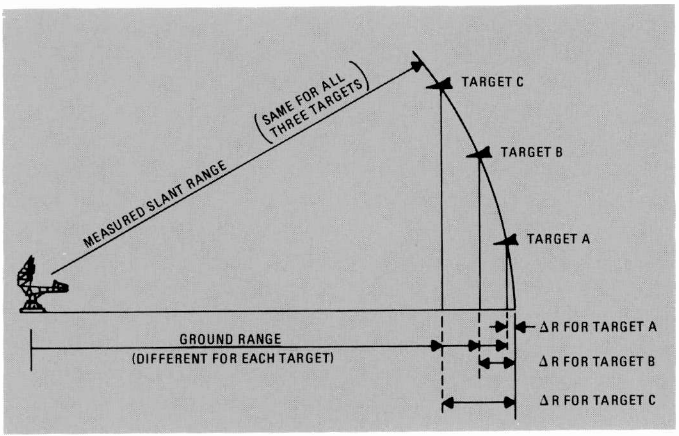


Fig. 3. *Range error with 2D radar.*

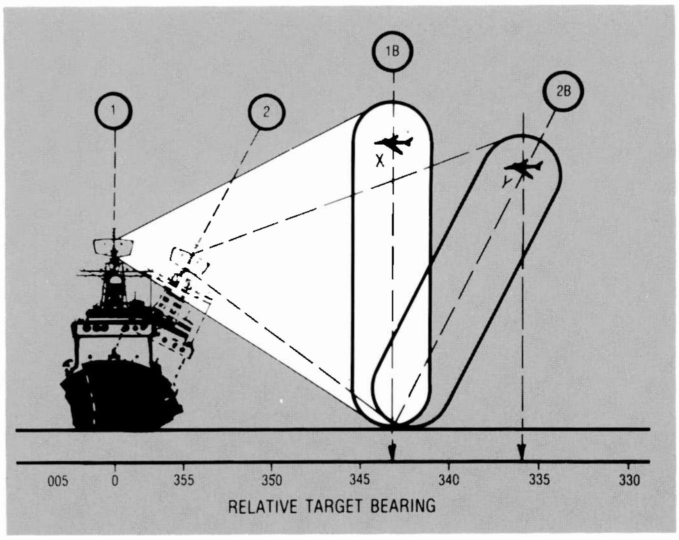


Fig. 4. *Coning error with 2D radar. The radar beam tilts with the ship's pitch and roll.*

The 2D and 3D systems, though both rotating search radars, are configured differently to perform their respective assignments. With the 2D system, RF energy is directed from a single feed horn against a parabolic reflector, from which it radiates into space. This reflector is wider in its horizontal dimension than in its vertical dimension (see Fig. 1), which causes the RF beam to be narrower in the horizontal axis.

The resultant beam cross section is an oval that moves with the rotation of the antenna, as shown in Fig. 2.

This vertical extension of the beam permits the 2D radar to detect targets at various altitudes with an acceptably accurate initial fix on target azimuth and a precise determination of slant range. However, the actual ground range of the target is not accurately determined for any target above the horizontal plane — see Fig. 3.

This ground range error is caused by lack of elevation data in a 2D search radar system. The ground range may differ from the slant range by the range error, ΔR in the figure, where ΔR increases as target height increases. This is one of two significant sources of error for the 2D search radar. The other is coning error, which is associated with shipboard search radars. Coning error is caused by ship pitch and roll, when the radar antenna is not stabilized, which is often the case for shipboard rotating search radars. In Fig. 4, when the ship is vertical, the search beam is also vertical, and detects a target, X, at relative bearing 343°. When the ship rolls to port (position 2), the top portion of the beam also tilts (position 2B), and now detects target Y, which is at relative bearing 336°. Even if the radar antenna rotation were stopped at 343° for target X, it will now detect target Y at 336° relative bearing. In this example, the coning error is 343 - 336, or 7°.

The 3D search radar adds elevation data

The physical configuration of a 3D search radar mitigates the shortcomings of the 2D system by providing approximate target elevation. As shown in Fig. 5, multiple feed horns direct RF energy to the reflector for the typical "stacked beam" 3D search radar. The mechanical positioning of the feed horns is such that the resultant reflected beams "stack" in space. Each feed horn produces a separate beam at a slightly different fixed elevation, shown as A, B, C, and D in the figure. By rotating this stack of beams in azimuth as shown in Fig. 6, the 3D search radar can determine approximate target elevation by indicating the beam in which the target is located.

As an alternative to the 3D search radar, a 2D system could be used in conjunction with a height-finding radar. A height-finding radar operates like a 2D radar turned on its side. Now, as shown in Fig. 7, the RF beam has a smaller vertical dimension. This permits more precise measurement of target elevation. The RF beam is raised or lowered by tilting the antenna. Thus paired with a 2D radar, the height-finding radar provides system performance better than most 3D radars. There is, of course, the disadvantage of requiring two pieces of equipment to do the job.

Trade-offs

Conventional rotating search radars require other trade-offs, depending upon their intended use. Most system parameters are

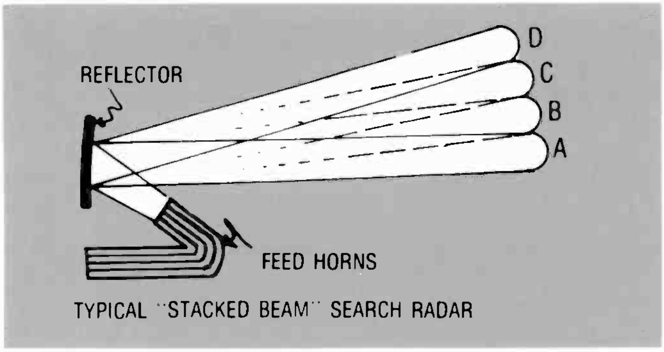


Fig. 5. *The 3D search radar provides another target coordinate — elevation.*

predicated upon performance desired or required. For example, desired operating range affects transmitter power, antenna gain, and antenna rotation speed. Obviously more transmitter power and/or antenna gain are required for a long-range search radar. The effect of antenna rotation speed is more subtle. For a long-range (greater than 100 km) search radar, the fastest antenna rotation speed practical is about one revolution every 6 seconds. Some radars use rates of 10 or 12 seconds. Aside from the purely mechanical considerations involved with rapidly rotating a large antenna structure, there is an important system limitation. If the antenna rotates too rapidly, not enough RF energy will hit the target for the radar to detect the return. This shortcoming can be offset by decreasing the speed of antenna rotation to permit more of the RF pulses to hit the target. Unfortunately, this approach introduces another problem — the increased time between target scans adversely affects reaction time of the system.

Conversely, a short-range search radar can rotate faster because the radar echo from the target doesn't have to travel as far. This allows the pulse rate to be increased. Also, because the RF beam energy is greater at short ranges, not as many pulses are needed to illuminate the target. A short-range, low-altitude search radar can be used to detect low-flying targets, such as cruise missiles, as shown in Fig. 8.

Here, a low-flying target will be detected when it appears above the horizon. However, this short-range radar will not detect approaching high-altitude aircraft because its beam is fixed to illuminate the surface up to about 10°.

The limitations of a conventional rotating search radar system are summarized below:

- Slow antenna rotation — causes delay in weapon engagement of a hostile target.

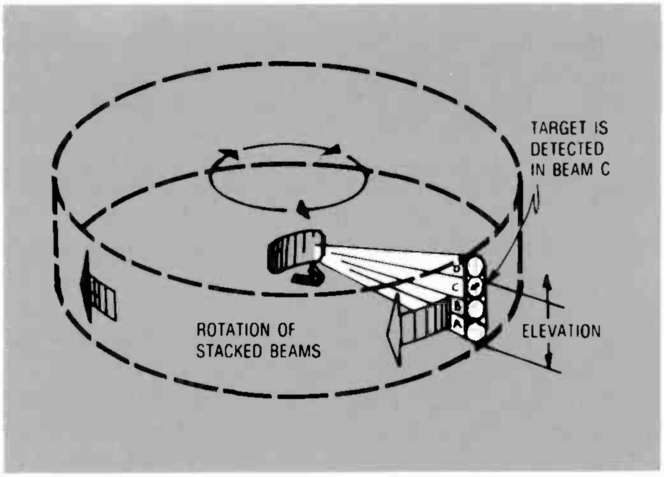


Fig. 6. *3D elevation determination. The particular "stacked beam" in which the target lies is indicated.*

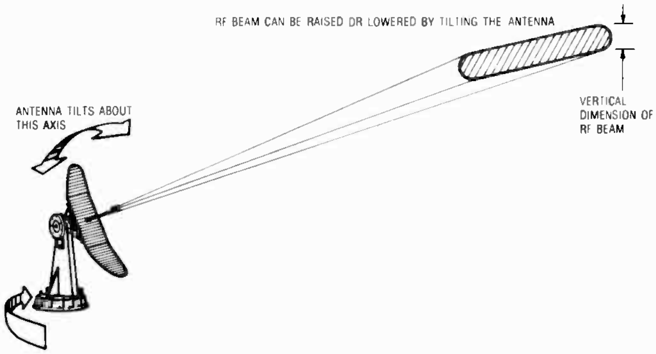


Fig. 7. *A height-finding radar. The antenna produces an RF beam with a smaller vertical dimension. This gives more precise measurement of target elevation.*

- Compromised performance on moving platforms — ship-mounted radars suffer degraded performance unless they are mechanically stabilized.
- Relatively imprecise — the wide RF beam prevents the radar from obtaining precise target position data.
- Cumbersome — large rotating antenna structures require extra power to move.
- Purpose-oriented restrictions — two separate search radars are needed to meet the different requirements imposed by long-range air surveillance versus low-altitude/surface surveillance.

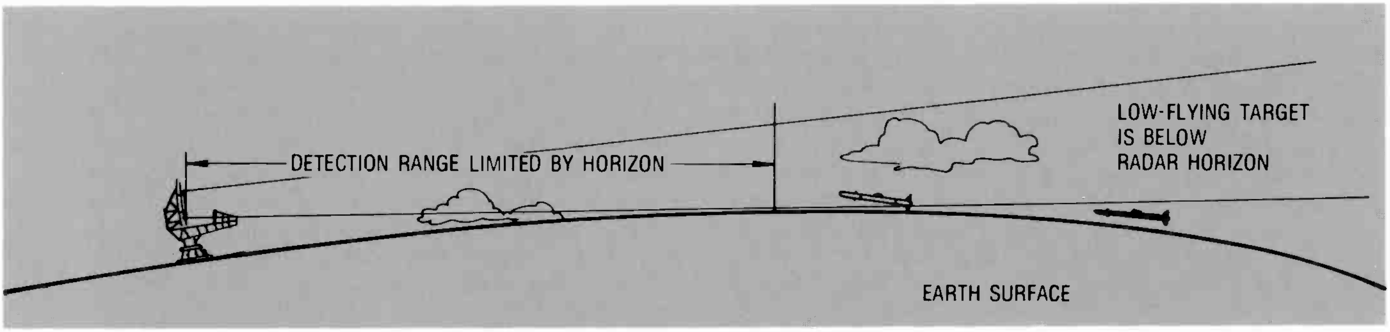


Fig. 8. *The short-range, low-altitude search radar is effective for cruise missiles.*

The tracking radar supplements the search radar

Assume we have the proper radar to perform a specific search function. Further assume that this radar successfully fulfills its assigned task and detects the target. Establishing the presence and position of a potential threatening target is only the first step in a radar-directed weapon system engagement. The next step is establishing an accurate track of the target — the target's position, speed, and heading. For fast moving air targets, we cannot wait 6 to 12 seconds between each measurement for the search radar to sweep past the target position. At this rate, a delay as long as 48 seconds is required to confirm the detection and obtain the first track information. A track is determined by obtaining several independent measurements of the target's position. These measurements are then combined into a smoothing algorithm to form an estimate of the target speed and heading. Because of the long time intervals between search radar measurements, and the lack of precision of these measurements, this preliminary track information is subject to large errors.

To obtain accurate target position, the rotating search radar is supplemented by a track radar. The search radar has done its job and now precise track data must be obtained as quickly as possible. Therefore, the search radar data are transferred to the track radar at this time. These data provide the track radar with a designated bearing and range for the detected target. The track radar turns to the designated bearing, then moves its beam through a preprogrammed search pattern around the designated bearing until the target is found. At this time automatic tracking begins. The track radar antenna is mounted on a two-axis or three-axis servo-controlled pedestal, so its beam can be positioned at any point in the hemisphere above the horizon (Fig. 9).

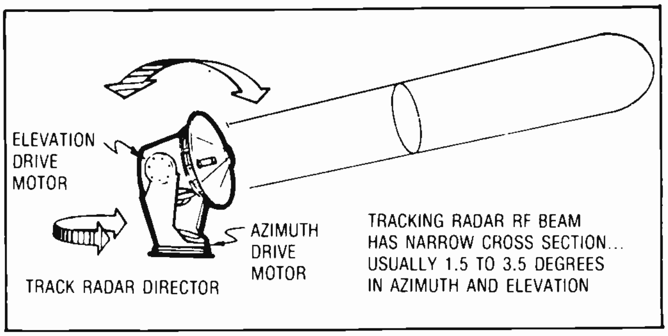


Fig. 9. *The track radar supplements the rotating search radar.*

Servo drives permit matching antenna motion to target angular rates so the RF beam can be held on target continuously, thus providing a very high data rate for target position data.

Modern mechanical tracking radars obtain their servo control signals by using monopulse tracking. In this approach, a single transmitter supplies the RF pulse, which radiates as the "sum" (or reference) beam from the center of a multiple horn feed system. On receive, these feed horns are used individually to feed the radar echo into separate azimuth and elevation "difference" channels. These channels use separate receivers to generate appropriate servo error signals to move the antenna as required to keep the target return centered in the middle of the sum beam at all times (Fig. 10). This permits the transmitted radar beam to follow the target continuously.

Fig. 11 shows the typical response time of a weapon system that uses a 2D search radar and mechanical track radar. As noted on the figure, this radar combination typically requires 15 to 45 seconds after initial detection before the target can be engaged. This reaction time may be too slow to cope with a rapidly approaching hostile target. In this case the mechanically steered search/track radar system is inadequate to defend against a single target of this type, let alone multiple hostile targets. A system with a faster reaction time is required — one that can handle more than one target. This is where the superiority of the phased array (electronically steered) radar system is highlighted.

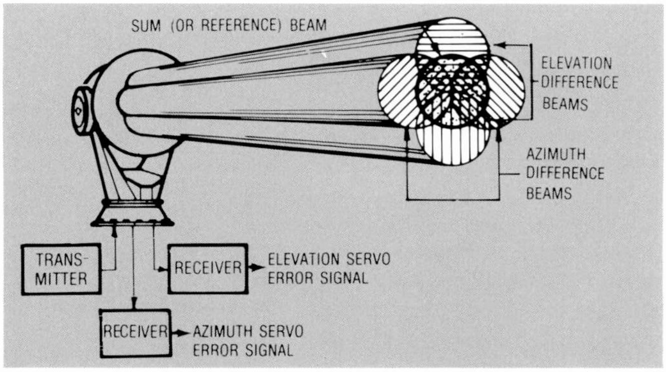


Fig. 10. *The monopulse tracking radar holds the target in its sum beam.*

The phased array radar system

Generically, the conventional radar system and the phased array system are similar. Both types require the same basic subsystems to perform — antenna, transmitter, receiver, antenna/beam positioning system, signal processing, and control — but the similarity stops here.

The most striking departure from the conventional, mechanically positioned radar system is evident in the antenna for a phased array system. Nothing physically moves. The radar beam is positioned and steered electronically by shifting the phase of the radiating (and receiving) elements.

A typical phased array radar consists of four fixed array faces to provide 360° coverage (Fig. 12). If less than complete hemispheric coverage is required, fewer faces can be used, reducing the size and cost of the radar. Each array face provides approximately 90° of azimuth coverage (with some overlap).

Where conventional mechanical radar systems use a feed horn assembly and reflector, each phased array consists of a large number (hundreds, or thousands) of radiating elements spaced throughout the plane face of the array. RF energy is usually distributed to and from each radiating element by means of waveguide and/or coaxial cables. The radiating elements are arranged in rows and columns on the plane of the array face, as shown in Fig. 13. Consider one column of radiating elements (refer to Fig. 13 for definition of rows and columns). When the transmitter radiates, and its output is distributed to each radiating element in the column via equal lengths of transmission line, then each element will radiate the pulse of RF energy with the same phase (Fig. 14). If more columns of elements are added to the original single column and fed equal output power through identical lengths of transmission lines as before (Fig. 15), the pattern would resemble that shown in Fig. 16. A monitoring device positioned several hundred feet in front of the array would confirm that the pulse of RF energy had been formed into a beam radiating perpendicular to the face of the array.

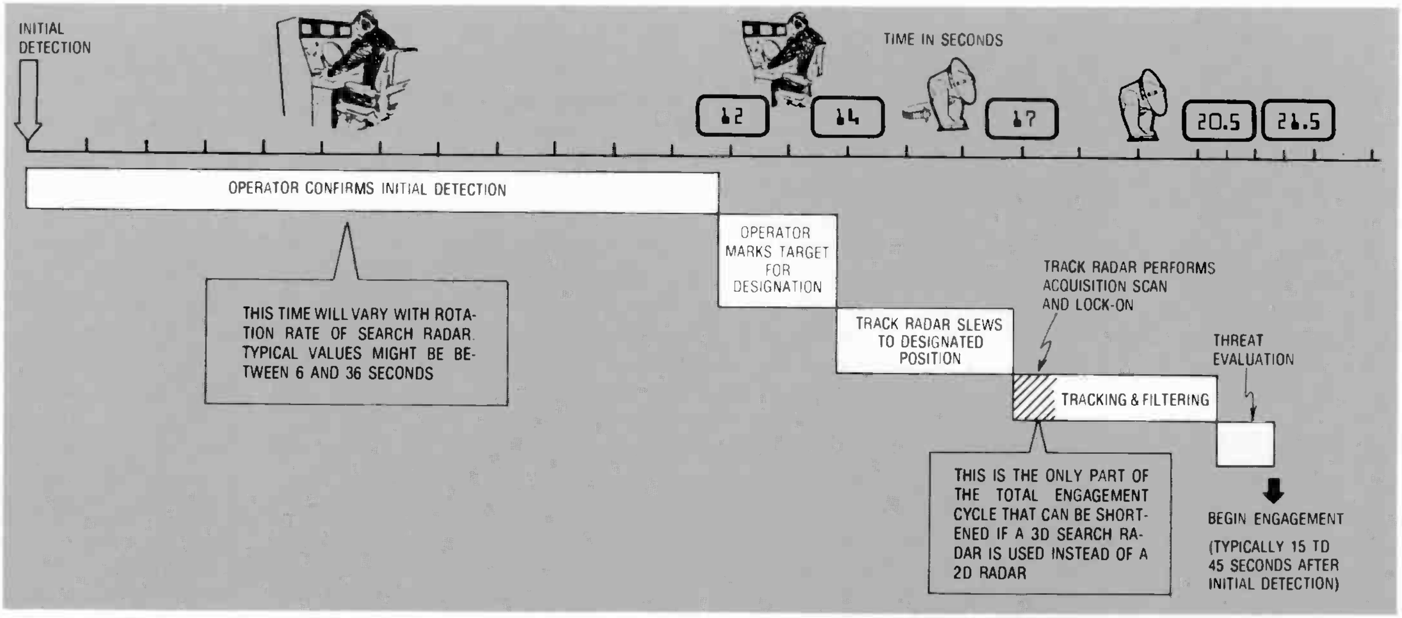


Fig. 11. *Typical response time of a weapon system using a rotating 2D search radar and a mechanical track radar.*

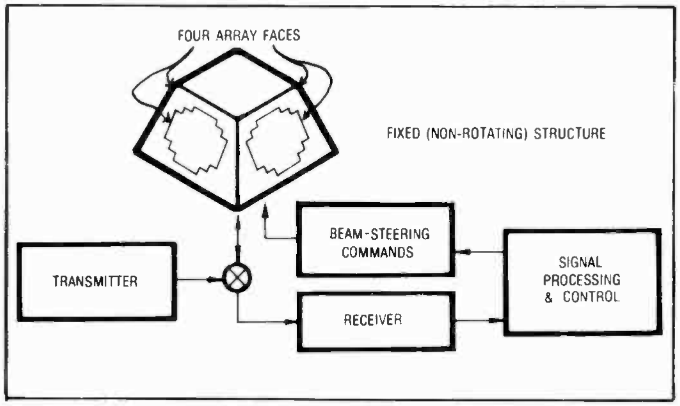


Fig. 12. *Typical phased array radar.*

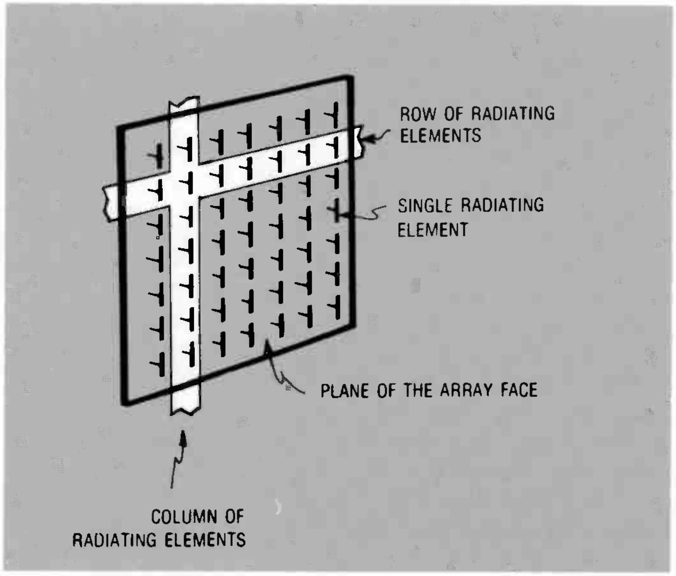


Fig. 13. *Rows and columns of elements on the array face.*

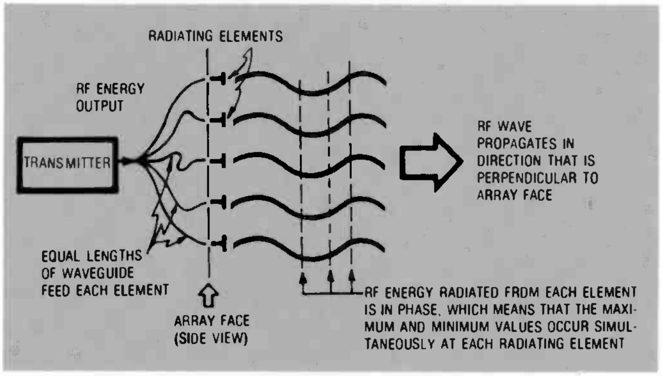


Fig. 14. *Basic radiating elements of a phased array radar (no phase shift).*

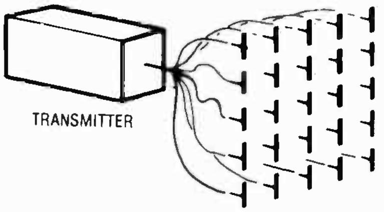


Fig. 15. *Phased array of multiple rows and columns (no phase shift).*

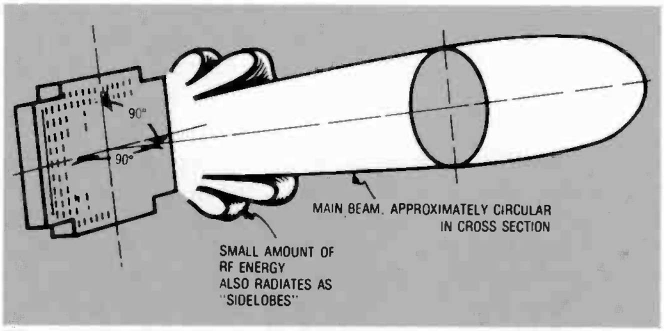


Fig. 16. *Beam pattern for phased array of multiple rows and columns (but no phase shift).*

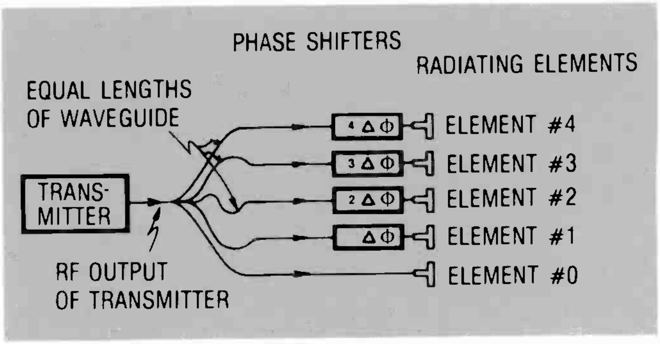


Fig. 17. *Phased array with phase shift added (Δφ).*

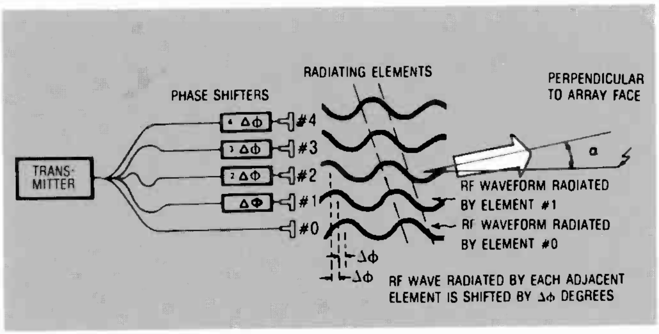


Fig. 18. *Transmitted beam radiated from phase-shifted elements.*

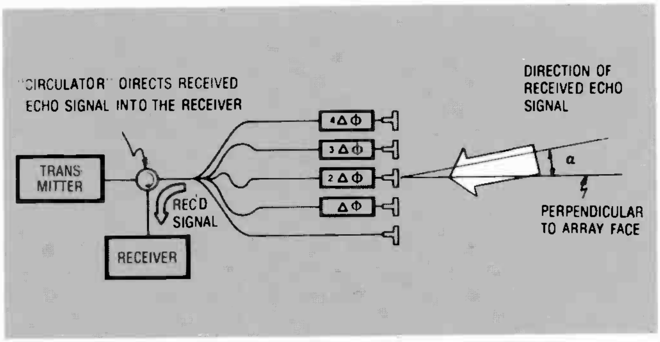


Fig. 19. *Received signal with phase-shifted elements.*

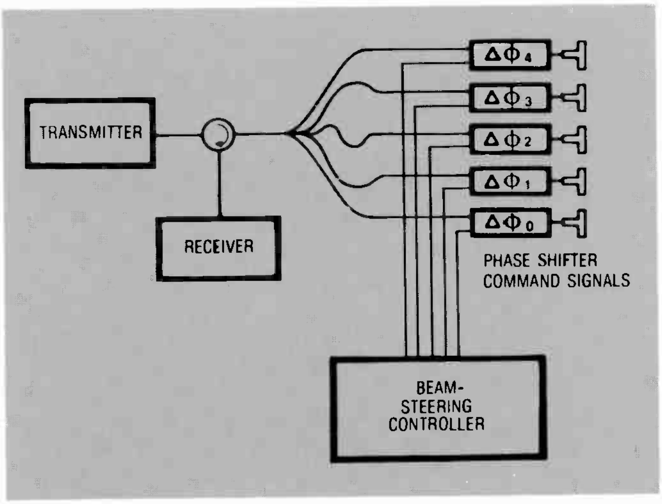


Fig. 20. *The beam-steering controller sets the phase shift for each element.*

Shifting phase shifts the beam

Now, again considering a single column of radiating elements, suppose a phase shifter is placed in the transmission line feeding each element. Further, we'll specify that the phase shifter feeding element number 1 causes a shift of phase equal to $\Delta\phi$, the phase shifter feeding element number 2 causes a phase shift of $2\Delta\phi$, and so on for each remaining element (see Fig. 17). Each phase shift ($\Delta\phi$) is equal to a fraction of one cycle of the radar transmitter frequency. If our monitoring device were again placed out in front of the array, we would now find that the RF pulse has been formed into a beam radiating at some angle, α, that deviates from the perpendicular to the array. The amount of deviation from the perpendicular is determined by the amount of phase shift, $n\Delta\phi$, introduced by each phase shifter. This is illustrated in Fig. 18. In most array designs, the phase shifters are reciprocal — they perform the same function for RF energy being transmitted or received. For this discussion, we will assume reciprocal phase shifters.

If the RF pulse is reflected from a target located in the path of the transmitted beam, then this reflected pulse will be received by each array element and passed through its associated phase shifter, as shown in Fig. 19. The received RF signal will be shifted in phase by the same amount as the transmitted signal was, so the energy from each individual antenna element will arrive at the receiver "in phase." This would not be true for RF energy (at the same frequency) entering the array from a different direction. Hence, one can consider that the phased array is "looking" in the direction established by the amount of phase shift inserted by each phase shifter — the same direction in which the RF pulse was transmitted. The RF waveguide structure can be configured to form sum and difference beams as described earlier for the monopulse tracking radar, so precise target position can be obtained with a single pulse.

After the last echo (from the maximum range of the radar) has been received, the direction of the beam can be changed by inserting different values of phase shift ($n\Delta\phi$) in each phase shifter. These devices are designed to be controlled by electrical signals.

Beam-steering controller

A computer, called the beam-steering controller, calculates the values of phase shift needed to be inserted at each element to cause the radar beam to be directed toward a specific point in space. This beam-steering system is depicted in Fig. 20.

The time required to change all phase shifter settings is very short — on the order of microseconds. Once the phased array radar has completed processing target echoes at a given beam position, a new set of phase shifter commands is established by the beam-steering controller. The next RF pulse is now radiated into space in a different direction. The time between two successive settings of the phase shifters is called a dwell (Fig. 21). More than one pulse may be transmitted during one dwell. The sequence of events is as follows. First, the beam-steering controller sets the phase shifters to establish the direction in which the radar beam will point. Then, the transmitter produces a series of several pulses. During the time between transmitter pulses, the radar receiver detects echoes from any target that may be in the radar beam. When the required number of pulses has been transmitted, the beam-steering controller sets the phase shifters for a new beam position. The number of RF pulses transmitted during one dwell depends upon which operating mode of the radar has been selected by the radar control computer. Each successive dwell can be different, if required by the specific operating situation.

Dwells are distributed

A typical sequence of dwells for a phased array radar in operation might follow the pattern shown in Table 1. In a typical system, approximately 240 dwells are completed in one second, or 960 in 4 seconds. If the RF beam is approximately 3.5° wide, this number of beams is sufficient to complete the horizon search, obtain several data samples on each of the targets being tracked, and complete more than half of the long-range, high-altitude search dwells needed to fill the total search coverage volume of space. Fig. 22 shows this type of operation and also depicts the dwell sequence described in Table 1. Since long-range search need not be completed more often than once every ten seconds, there is enough time to transmit approximately eight track dwells for each of 100 separate tracks within each ten-second period. The radar computer distributes these dwells so threatening air targets under engagement are illuminated by track beams more often than nonthreatening air targets. For example, the former may be illuminated four times each second, while a nonthreatening air target may be illuminated perhaps once every two seconds.

Advantages of phased array system

Just how good is a phased array radar system like the one we've just described? Let's compare the reaction time chart shown earlier for a weapon system using conventional radars with the reaction time for a system using a phased array (Fig. 23).

As shown in Fig. 23, an engagement can begin 3 to 5 seconds after initial target detection with the phased array radar. A weapon system using conventional radars typically requires 15 to 45 seconds after initial detection before beginning an engagement. And this is just one target. When the system is confronted with multiple threatening targets — 5, 10, 50, or more — the conventional radar is quickly overwhelmed, but the multiple threat situation is easily managed by a phased array system.

What makes the phased array radar so much more effective in practically any operating situation? The major advantages of phased array radars over conventional, mechanically positioned radars are summarized below:

- The radar RF beam can be switched in microseconds from one point in the coverage space to any other point in the coverage space.
- One phased array radar can perform multiple functions, such as horizon search, long-range search, and tracking. These functions can be switched in microseconds and can be changed randomly from dwell to dwell under computer control.
- When operating in the search mode, a phased array radar provides 3D information on detected targets (i.e., range, azimuth, and elevation).
- Once a target has been detected initially, a track beam can be scheduled within 0.1 second to "re-visit" the target. Precise track information can be obtained within a few seconds.

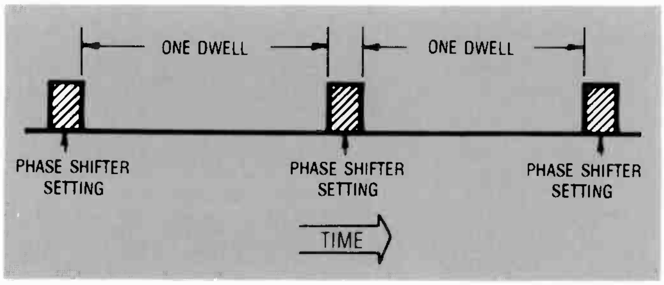


Fig. 21. *Dwell sequence for phased array.*

Table 1. *Typical dwell sequence for phased array radar.*

Dwell Number	Cumulative Elapsed Time (ms)	Radar Operating Mode
•	•	•
•	•	•
•	•	•
n	0	Long-range, medium-altitude search
n+1	5	Horizon search (pulse doppler)
n+2	12	Track target #1 (monopulse processing)
n+3	14	Track target #2 (monopulse processing)
n+4	16	Horizon search (pulse doppler)
n+5	23	Track target #3 (monopulse processing)
n+6	25	High-altitude search
•	•	•
•	•	•
•	•	•
•	•	•

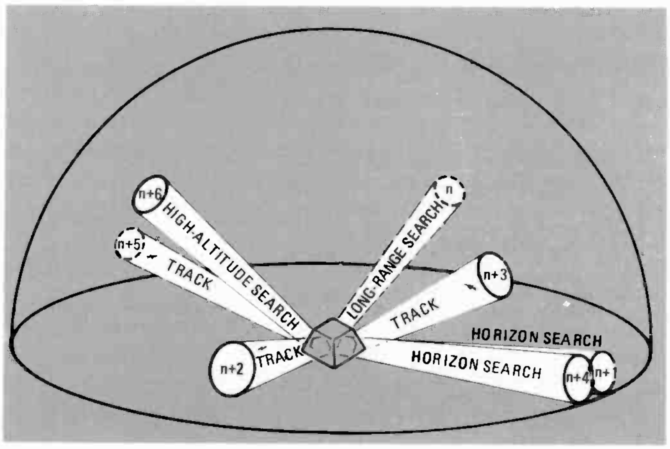


Fig. 22. *Typical beam sequence for phased array (using dwells shown in Table 1).*

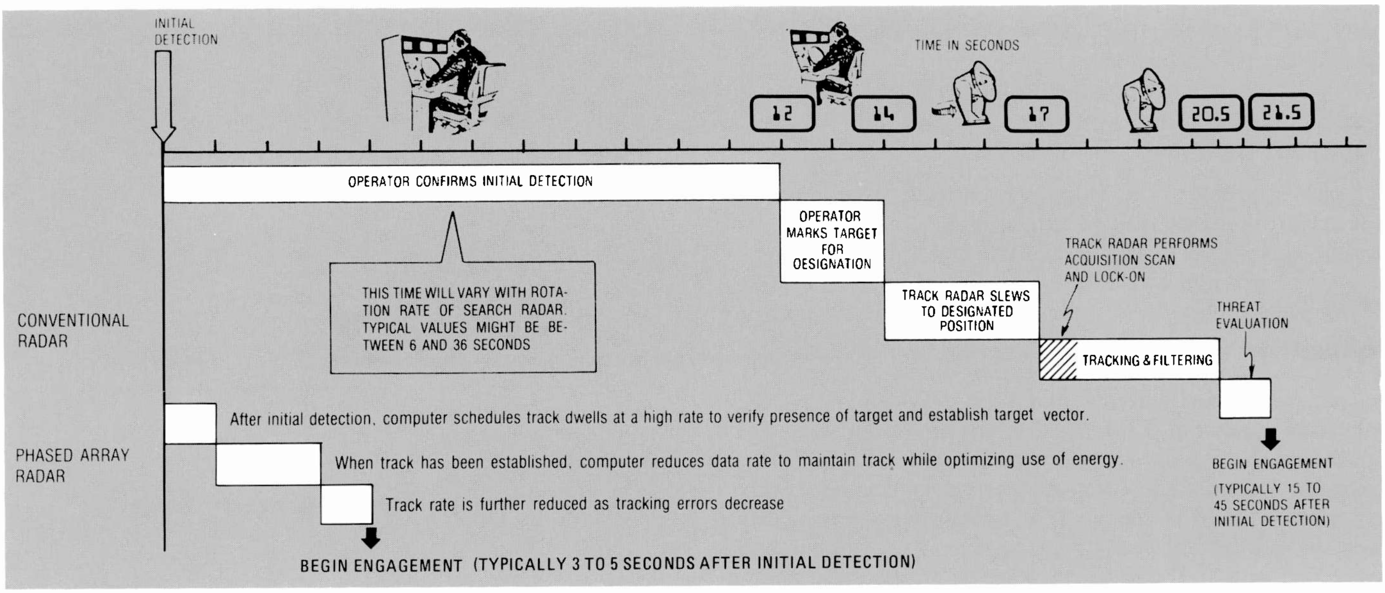


Fig. 23. *Reaction time comparison for phased array system versus conventional mechanical radar system.*

- Precision tracks can be maintained on many targets at the same time. Data rates for each target can be adjusted by the radar computer as needed.
- Surveillance can be maintained in different sectors at different rates (e.g., horizon search every four seconds, and long-range, medium-altitude search every 10 seconds).
- In shipboard applications, the radar beam-steering commands can be adjusted by the computer to provide full stabilization against ship roll and pitch.
- Because its beam position and RF pulse characteristics appear to be random to an outside observer, the phased array radar enjoys extra protection against several types of electronic jamming.

Past, present, and future

The phased array radar is not a new development. In 1965, Bendix installed the first phased array in the U.S., the AN/FPS-85, but it was destroyed by fire before achieving full operational capability. That radar was rebuilt in 1969 and is now operating as part of the USAF Spacetrack network. A prototype of the Safeguard Missile Site Radar built by Raytheon operated on Meck Island in the Pacific from 1968 to 1976. RCA's engineering development model AN/SPY-1 radar operated first at Moorestown before being installed in *USS Norton Sound* in 1973 for at-sea testing with live missile engagements. Today, the production version, AN/SPY-1A, operates as part of the AEGIS Weapon System Mark 7 on the latest U.S. guided missile cruisers. AN/SPY-1D will be installed in the new *Arleigh Burke*-class missile destroyers.

The operational advantages of phased arrays are well recognized by military planners, but few countries have the technology base needed to produce such systems. Although the U.S. has been the leader in this field, large land-based phased arrays are operating in Russia, and experimental systems have been or are being built in France, Germany, and England.

Interest is now centered on two areas:

- Reduction of cost, weight, and size of shipboard and land-based arrays.
- Development of very lightweight solid state arrays for use in aircraft and spacecraft.

And, of course, there is the continuing effort to improve performance by improving anti-jam capability and detection in adverse environments.

Acknowledgements

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John Bowker | Philip Stein | Daniel Stein

Radio broadcasting as a hobby

This article can be attributed to one of life's many coincidences. A few weeks ago, a chance discussion in the lunch line at RCA Laboratories between John Bowker and Philip Stein led to their realization that each had been deeply involved in the development of carrier-current (or wired-wireless as some prefer) radio broadcasting stations for their respective colleges.

Each realized how his participation had led to terrific father-son relationships, had improved on-campus communications and had even led to some interesting careers over the years. The editor of RCA Engineer asked if they would relate their stories for the magazine.

I spent all but a few hours of my entire college career in a chicken coop and in a 10-foot square basement room of the college's student activities building.

Study was difficult. The chickens had left one of my rooms a year earlier, and there was no air conditioning in the other. The power distribution system and boilers in the adjoining basement room were a constant reminder that the outside world was still there using electricity and hot water. But the oddest part was that the outside world turned to me to learn what was going on in the world and on the campus!

I was easy to find—right there with my microphone and records at 750 on every AM radio dial on campus.

It all started in high school . . .

Here I was, 15 years old with a summer vacation before me. My folks had recently purchased a cottage on the shores of a small mountain lake in Vermont, good fishing, great boating and swimming—quiet and peaceful. Night life? Not really.

I was one of only three teenagers at the lake so there wasn't much going on most of the time. So one adapts.

Watch TV? Not when I was 15. But radio! Yes, the complete answer to whiling away idle hours. But you have to remember that portable radios used expensive batteries in those days and so I was usually cut off from my swing music stations when out in a boat.

My dad, a radio buff who had once helped build a pioneer broadcasting station in Medford, Massachusetts, suggested I build a crystal radio like in the old days—no batteries and very good fidelity on earphones.

Shortly, with his help, I was hearing the local stations even when out on the lake!

But the crystal radio wasn't sensitive enough to pick up any station carrying the Red Sox ball games from Boston (another permanent addiction). That took a sensitive radio connected to a 100-foot antenna wire in the wilds of western Vermont.

However, synergy was already at work in my life. That same summer I had started reading some of the magazines that tell how to build boats, airplanes and radios—all in the same issue.

One article had caught my eye—the one about a "phono oscillator."

"Build your own broadcasting station"

According to this magazine article, with just one radio tube and a handful of parts, you could build a complete radio station—and that would mean I could rebroadcast the Red Sox games from an indoor radio out to the boat! A few chores to raise some capital and, shortly, I had the parts to assemble my phono oscillator. And it really worked...a nice long wire for a transmitting antenna, and my problem of hearing the games in the middle of the lake with a crystal receiver was solved!

Word spread very quickly that Lake Iroquois had its own radio station carrying music, local fishing news and the Red Sox games! It didn't take long for the "ham actor" in me to recognize that I had a potential audience of over 40 families around the lake for my broadcasting antics. The studio was a small "doll-house" cabin in the woods, and the programs consisted mostly of what other distant stations were broadcasting (even some shortwave broadcast stations that came in particularly well at night).

Whenever possible, there were reports on lake activities and, on several occasions, we broadcast the lake ping-pong tournament play by play from our porch. My initials became the call letters of the fledgling station.

The summer ends

That fall, everything was moved to our home on the edge of Middlebury College. The campus was easily within range of

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Building a college carrier-current station

I first conceived of starting a student station when someone showed me a very low power FM transmitter and demonstrated how good it sounded at a distance. Borrow a couple of turntables, a tape player, and a mixer, and I could set up a station in anybody's room, so I thought.

Other students here at Antioch College in Yellow Springs, Ohio, were also excited about the idea. We could have student DJs who would play all those records we never heard on commercial radio, and were only played at 3:00 a.m. on our local FM public radio station, WYSO.

Then, we had to see how our ideal fit into reality.

My father found out (from John Bowker) that small scale FM was impractical because 10-watt licenses were no longer being issued. He suggested we could use carrier-current AM, which uses the entire building wiring as an antenna, and which has a legal limit at 540 kHz of about 200 feet. So our project began.

There were four dorms we wanted to cover. Each had its own power transformer, so tapping a common power source was not worth the effort. For simplicity, we decided to have a transmitter in each dorm and to send a line-level audio signal via unused phone wires in the school's PBX. The phone lines worked well, but we put isolation transformers on the lines at the transmitters to minimize noise and ground loops.

Next, we worked on getting RF onto the power lines. The buildings are three-phase 208 volts ac, with each phase serving a different part of the building. We tried connecting the transmitter output through capacitors into a wall outlet. That worked well if we wanted to serve only one-third of the dorm. To fix this, we built bridging boxes that used more capacitors to bridge the RF between phases. Finally, we were broadcasting to the entire building.

The school gave us a room to use as a studio. For safety, it was across the hall from the security office. Now it was time to equip and build the studio.

I found a broadcast turntable in the basement of a dorm and used an old record changer for the other. I salvaged a cheap stereo that someone was discarding and hooked it up as a monitor.

All of this ran through a $70 stereo mixer from Radio Shack. I borrowed a microphone and relays (to mute the monitor speakers when the mike was on), and got wood from the school to build tables. Finally, it was finished.

Antioch Underground Radio was on the air.

—*Daniel Stein*

my phono oscillator, and the idea of swelling my potential audience to 1800 was overwhelming.

Of course, a new antenna wire had to be strung to get complete coverage of the campus (and most of the town, it turned out)—probably 500 feet of antenna wire on the little transmitter.

We put out quite a signal! It took the Federal Communications Commission field inspectors nearly two months to find me. In exchange for my entire radio station, they left me a copy of the FCC rules.

College radio in the early days

There was still no radio station at Middlebury College when I matriculated a couple of years later. But I had learned that the FCC rules do allow for campus stations, provided the power is controlled and radiation into free space is limited. So it was time to sample the interest among the student body in starting a campus radio station. The response was immediate.

Thirty students answered an ad in the daily college newsletter. The Science Department Chairman offered to provide the parts for a new transmitter and help design the facilities for broadcasting, if someone would do the actual construction. Studio space was a problem on campus so our family chicken house was refurbished and became "radio central."

By the Spring term, we were ready to go on the air. We had solved the problems of operating with moderate power, and we picked a vacant frequency on the AM band (FM was only an experimental plaything in those days; almost nobody had an FM radio).

Is it really legal?

The FCC rules accommodate AM campus stations rather nicely. Without any kind of license, a station can be operated on the AM broadcast band provided the signal does not radiate widely outdoors (see sidebar).

Technically, a suitable signal can be produced inside a building if the transmitter and its antenna are also inside the building. The signal must fade to virtual zero within about

200 feet outside the building to keep within the FCC rules. (This can be checked with a good car radio: If the signal can't be heard 200 or so feet away from the building or outdoor power lines, chances are the transmitter is operating legally.)

So the trick is to run the antenna as close to every desired radio as possible inside the building. It is for this reason that most college stations connect their radio signals to the regular electrical wiring circuits or water system inside a dormitory building. Thus the term "wired wireless"—or "carrier current"—is applied to this form of broadcasting. The signal can be quite strong inside the building while dropping to virtually nothing right outside.

No license or permit is needed for operation of the station provided it operates in accordance with FCC Rule Part 15. The people operating such a station need no license or permit either.

The equipment

The minimum equipment needed to put a broadcasting station on the air was easy to come by. By 1949 one could purchase ready-built phono oscillator transmitters from any of the radio catalog houses. Record players for 78 rpm records were a dime a dozen—the new 33 or 45 rpm versions were only available on loan from fellow students but, after all, there wasn't much music available on those new-fangled things.

And microphones found their way into the studios by any number of means. Equipment for the original station in the chicken house cost about $30 out of pocket. By the time we moved to the student activities building and started operating legally, we had well over $100 sunk into the venture!

The technical system was simple enough. The audio signal from the home-built studio console was fed through a home-built audio distribution amplifier to sixteen home-built transmitters located in each college-owned residence building.

Bell Telephone lines distributed the audio to each building from the studio. Eleven of the sixteen transmitters operated at 750 kHz and the remaining five operated at 760kHz.

Our problem was not with interference from regular commercial stations on those frequencies, but our own transmitters in the next building caused interference on some radios due to their proximity. To minimize this, the transmitters in alternate dormitories broadcast on alternate frequencies.

The transmitter RF output in each dorm was connected into the electrical service (from which we often experienced a distracting hum) or between a copper water pipe and the electrical system ground (no hum, but unpredictable signal strength inside the building). Several ohms of impedance are available between such tie points in most dormitories—enough to make connection from a transmitter output quite easy (see sidebar).

In fact, though, the connections from the transmitters in every building were unique. No two were the same. There was as much witchcraft as science in providing satisfactory signals from the transmitters to every room in a dormitory. But, with perseverance, it all came together and worked rather well.

The station matures

As the technical facilities came of age, the programming developed from simple disk jockey shows to daily interview programs with faculty and college visitors. Our program schedule was printed in the weekly newspaper.

Audiotape recording equipment became available to us during the early 1950s and this opened new vistas simply unimagined a year earlier.

The Intercollegiate Broadcasting System was riding a peak of popularity; programs were exchanged between college stations and the magazine, *College Radio*, carried monthly photo essays on campus stations and offered tips on programming and engineering matters.

More and more people were needed to make the station tick once we became wed to magnetic tape and to program exchanges with other schools. In all, with an 18-hour program day, we had over 80 students on the station roster during my senior year.

When LP records really became established, the whole concept of programming changed. An LP could take care of 20-30 minutes of air time without attention. The major change this brought about was a significant improvement in class grades!

We could bring homework to the studios and, with the station playing classical music during the afternoon, one's attention to the books was largely uninterrupted.

But interruptions would occur...

There was the day we learned we couldn't be heard in Gifford dormitory, so I went over to investigate. I arrived at the same time as the fire trucks. It took them less than a half hour to find the source of the fire. Without going into great detail, my assignment immediately became (1) design a new transmitter that wouldn't catch fire, and (2) build a transmitter of the new design for Gifford Hall since the old one was now a charred tangle of aluminum and wires.

We were off the air less than a week while I installed fuses in the B^3+ line of 15 transmitters and took care of Gifford with a standby unit suitably modified.

The age of FM

Unlike AM carrier current stations, there is no equivalent unlicensed nonradiating type of broadcast operation available on the FM bands. College FM stations must be licensed by the FCC. This involves a comprehensive legal, financial and technical application, and the acceptance of responsibility for the station by responsible college officials.

Then, there's a lengthy wait for FCC action that usually runs more than a year before any construction can begin.

A knowledge of application and operating procedures as described in Part 73 of the FCC's Rules and Regulations is required. Formidable, perhaps. But lots of campuses now have FM broadcasting stations.

Educational FM

There are 20 frequency slots in the FM band from 88.1 MHz to 91.9 MHz set aside for use by noncommercial broadcasters. Stations with as little as 100 watts of power can be licensed and, thereby, provide radio service to any small town or community where an open frequency can be found.

Colleges all over the country have jumped at the opportunity to go on the air with programs that could be heard

A low-power AM transmitter you can build.

When Dan Stein first suggested building a radio station for school, he was thinking of a low-power FM station in the 88 to 108-MHz band. As mentioned above, this band is very crowded and there are no more special rules for low-power stations. We agreed that it would be best to operate in the AM broadcast band using carrier-current techniques.

Carrier-current signals are superimposed on the ac power lines and can be received only a few feet outside of the building they serve.

When I attended Columbia College, in New York City, I had worked at their station, WKCR, and I had constructed two low power AM transmitters for carrier-current use in the dorms. They used vacuum tubes, of course, push-pull 6L6s for both output and modulator sections. With power supply and controls, each transmitter took up a waist-high 19-inch wide rack.

I decided that it would be possible to make a much smaller, simpler design with today's miniature electronics, and proceeded to design and build a solid-state 10 watt AM transmitter for the 550 to 1600-kHz AM broadcast band. It operates best at the low end of the band (550-650 kHz), which is appropriate for carrier-current AM broadcast service, and of course it's much smaller and lighter, about the size of a large telephone book.

We built five transmitters, four for dorms on the campus and one spare. The college's community council provided some money, and most of the parts were purchased at the country's largest electronics flea market, the National Ham Radio Convention in nearby Dayton, Ohio.

Circuit description

Overall, the transmitter owes much more to audio circuit design than to RF design. Refer to the schematic diagram (Fig. 1).

A crystal oscillator at 8 or 16 times the carrier frequency is divided digitally in 74HC76 T-type flip-flops to a square wave at the carrier frequency. An R-C low-pass circuit rounds this waveform somewhat and centers it around dc zero. Part of this low-pass circuit is a resistive divider that serves to limit the output power by reducing drive, and also keeps the modulator dissipation within limits. (Note that both phases of the exciter waveform are carried through here because the modulator is a differential, balanced configuration.)

Incoming audio is adjusted by the modulation control, which divides the signal directly from the input jack. It is then isolated from the source by a simple follower, and is bandpassed and dc offset in a simple biased inverter. Both of these circuits center around CA3140 operational amplifiers. A CA339 comparator senses whether the biased, bandpassed audio ever passes through zero, and if so, lights the OVERMOD light on the front panel.

Carrier and audio meet at the modulator, a two-

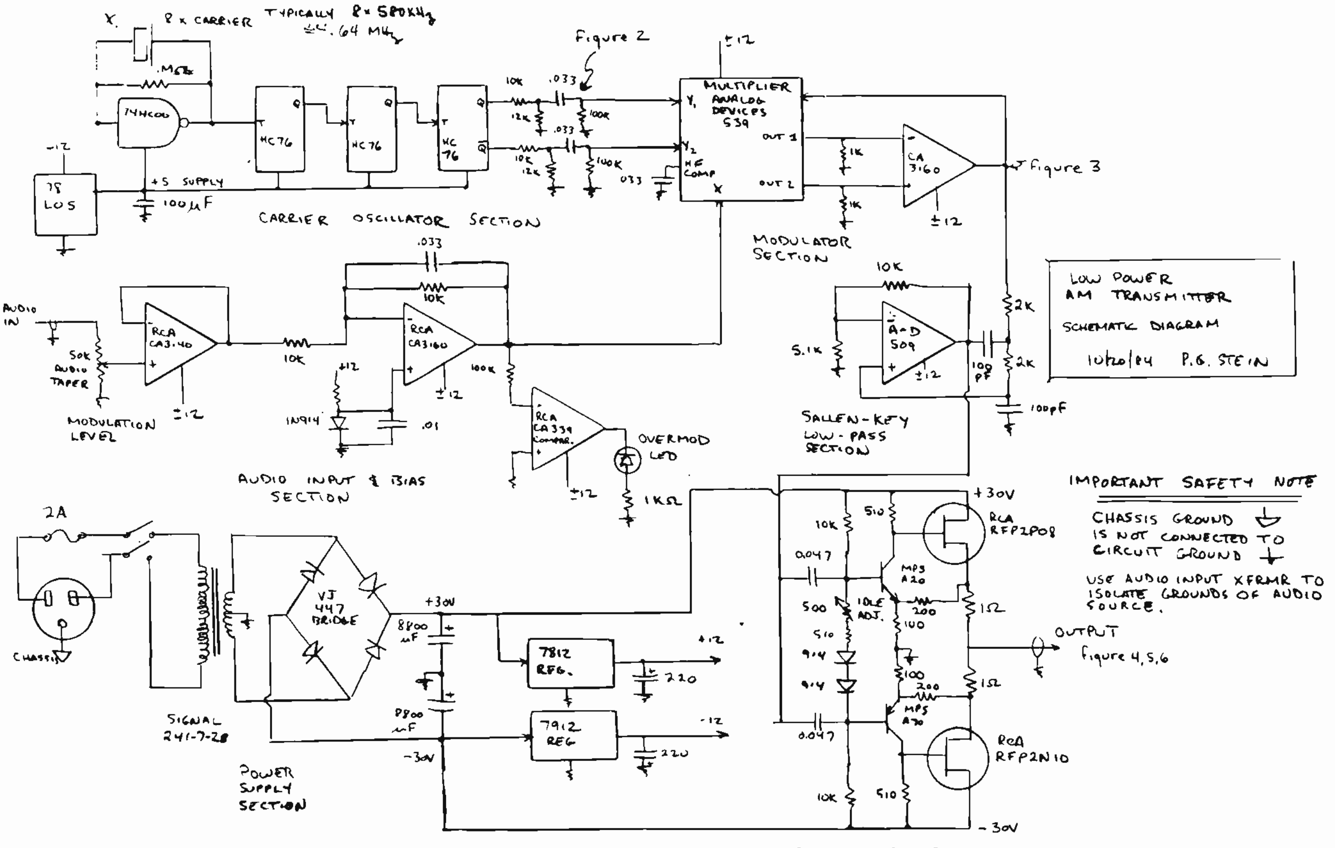

Fig. 1. Schematic diagram of transmitter.

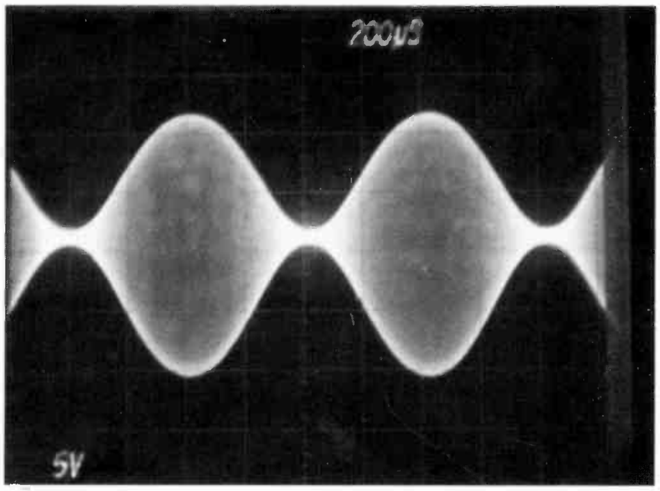

Fig. 2. Photo of output waveform.

quadrant multiplier. This is a two-channel device used in a differential configuration to reduce distortion while keeping signal level high. The multiplier outputs are summed in a differentially configured operational amplifier, a CA3160.

Natural rolloffs in the circuit to this point have reduced the modulated carrier to a rough triangle wave. This is now passed through a two-pole Butterworth filter of the Sallen-Key type, which removes most of the residual harmonics and leaves a pure modulated sine wave.

This signal now passes to a class AB1 linear amplifier of the "Universal Tiger" configuration, featuring RCA MOS power transistors in the output. This circuit has a gain of three (as configured by the ratio of the emitter resistors in the driver transistor bases). Output impedance is an ohm or two. Power output is controlled by another pot, which attenuates the input drive to the final amplifier. Maximum power is limited mostly by phase shifts in the output devices. Five-ten watts RMS output is easily obtained, and more can be had at low impedance loads by tweaking. The output waveform is shown in Fig. 2 at about 90% modulation.

Power comes from a conventional bridge rectifier/filter for plus-or-minus 25 volts for the output stage. This is reduced by integrated regulators to plus-or-minus 12 volts for the driver, modulator, and audio stages, and to plus 5 volts for the oscillator and dividers.

Incoming ac is surge-protected and filtered to help remove circulating signals coming back from the transmitter output, which is, after all, connected to the ac line.

Coupling to the power lines is accomplished with isolating capacitors, and is always a problem with carrier-current systems. The large voltage at 60 Hz often modulates the output stage of the transmitter, causing hum and buzz in the signal. Impedance is usually a problem, too. Even at RF, the ac line presents only a few ohms, far too low for most 50 ohms transmitters.

Fig. 3. Photo of transmitter.

This transmitter design, however, has a very low output impedance. This is a big help except that the isolating capacitors must be very large (about 1.0mF, at 1kV). These provide less than one ohm coupling impedance at the carrier frequency, but only about 5000 ohms isolation at the power line frequency.

The only solution, short of large, expensive notch filters, is to make the transmitter output stage very linear so that it will not be modulated much by the 60 Hz, and to put up with whatever remains of the buzz in the transmitted audio.

—*Philip Stein*

FCC rules for AM broadcasts

FCC RULE SECTION 15.111 reads in pertinent part: A low-power communication device may be operated on any frequency between 540-1600 kHz subject to the condition that the emission of rf energy on the fundamental frequency or any harmonic or other spurious frequency does not exceed: Field Strength (microvolts/m) = 2400/F(kHz) at a distance of 30 meters.

FCC RULE SECTION 15.113 reads in pertinent part: In lieu of meeting the requirements of Rule Section 15.111, a low-power communication device may operate on any frequency between 540-1600 kHz provided it meets all the following conditions:

(a) The power input to the final radio stage (exclusive of filament or heater power) does not exceed 100 milliwatts, and

(b) The emissions below 510 kHz and above 1600 kHz are suppressed 20 dB or more below the unmodulated carrier, and

(c) The total length of the transmission line plus antenna, plus a ground lead if used, does not exceed 3 meters, and

(d) Low power communication devices obtaining their power from the lines of public utility systems shall limit the radio frequency voltage appearing on each power line to 200 microvolts or less.

reliably for a distance of five or more miles from the campus.

Middlebury College is among those with a fortunate antenna site for its FM station. From the cupola of a college dormitory building on top of a hill in the Champlain Valley, WRMC, operating with 100 watts, receives regular listener reports from up to 15 miles away, and has letters from attentive listeners over 35 miles away.

History sure repeats itself

My wife and I moved to New Jersey in 1953 and, shortly, our oldest son was involved in Little League baseball—which meant that I was too.

The press box seemed a natural fit for my talents and it wasn't long before it occurred to me that the mothers and fathers in the stands would probably like to hear their son's name more often than could be announced on the public address system.

It took about a week to build a complete low-power AM radio station using junk parts at home and, within a few days of broadcasting the evening games over a range that reached to the right-field stands, it was apparent that the idea had clicked.

Parents brought portable radios to the games. I was the appointed sportscaster in the press box. Attendance at the games picked up nicely. Son John took over behind the microphone the year he graduated as a player, and I took over as official scorer. We loved it—except when John would question my scoring decisions on the air. For better or worse, John was hooked on broadcasting. (John is now pursuing a career in banking in Indiana, but is heard regularly on commercial station WLJE in Valparaiso as a sports reporter and commentator.)

and again...

By the early 1970s, it became apparent that my adopted New Jersey hometown had very little identity and, too often, township affairs were going unnoticed.

Armed with the success of WRMC in Vermont, I proposed a noncommercial, educational FM station for the local high school to use as a teaching station. The students would be able to augment their communications and social studies classes with actual hands-on experience in broadcasting. On evenings and weekends, the school could broadcast their sporting events at home and away and, on other evenings, the station could be used (under school supervision) for a variety of broadcasts by other school clubs, senior citizen or local adult groups.

The Board approved the idea and, with two weeks of my RCA vacation spent constructing the studios and erecting the antenna and a dozen more evenings used up testing and training, on November 18, 1975, WWPH signed on the air.

John, by now, was at school in the mid-West, but his younger brother Daniel had helped design the station and became Chief Engineer and morning disc jockey for several of his high-school years.

His morning show started each Monday through Friday at 6:00 a.m. and included a variety of news items, some from a news teletype machine and other items culled from his early morning calls to the local police. (Dan Bowker went on to attend college in Connecticut, spent four years in various roles on the campus radio station, and married a college-mate who was also involved with the campus station there. He is now pursuing a career with RCA in computer science.)

Local sports at home and away continue to be a major hit for the station and the public reaction to our broadcasts of local candidates prior to township elections has been very rewarding. In fact, the FBI granted press credentials to sons Dan and John on behalf of the station to cover President Ford's brief visit to Paterson, New Jersey to dedicate a water conservation project. All in all, I saw more of my sons in radio studios during their growing-up years than at home!
—John Bowker

Connecting the transmitter output

The trick usually is to find a convenient and safe connecting point in the electrical system where the impedance is more or less constant. For instance, the electrical service in a dormitory laundry room is subject to wild variations in electrical impedance whenever the appliances are turned on or off.

To minimize these effects on received signal strength, extremely low impedance output connections from the dormitory transmitter are required if reliable signals are to be produced in the building.

What this loses in efficiency is more than compensated by satisfied listeners. Typical transmitter output power levels in a large dorm are 20-25 watts.

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Authors Bowker (left) and Stein.

Patents

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Katz, A. | Sidarsanam. R. | Aubert, D.E.
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Solder composition—4588657

Martinetti, J.L. | Katz, A.
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Research and Engineering
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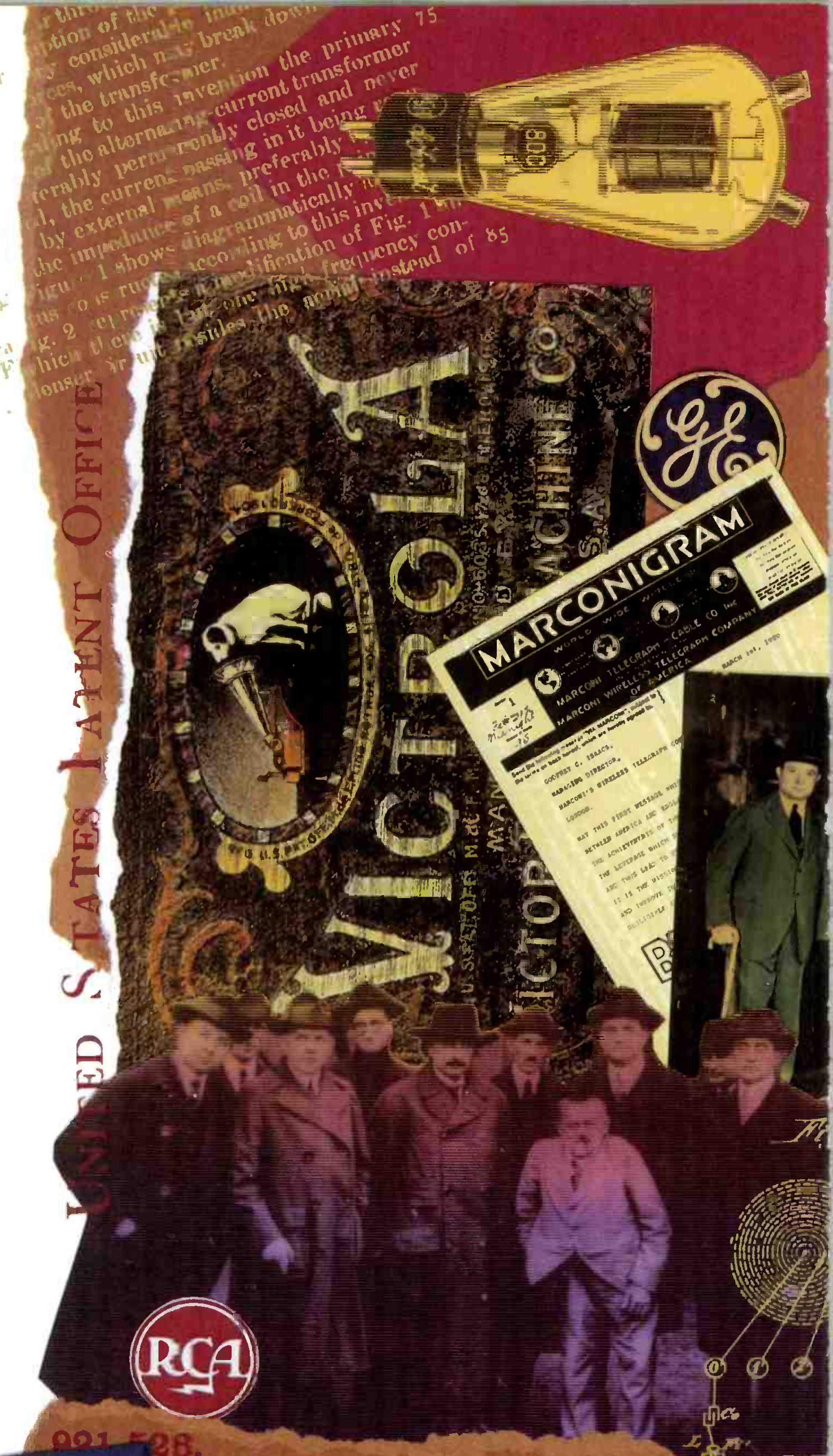
W.C. Morrison
Chief Engineer
Broadcast and Communications Products Division
1964

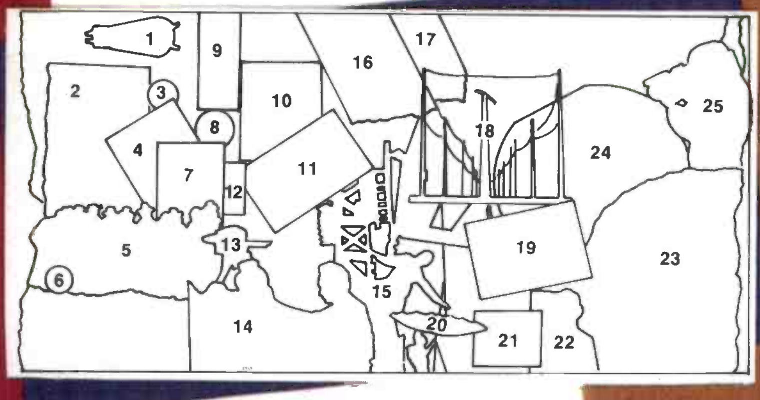
About the cover:

For this last issue of *RCA Engineer*, we decided not to follow our usual practice of designing a cover that is in keeping with the theme of the issue. We chose instead to assemble a historical montage of RCA people, products, and milestones. In this case even our intentional digression has failed to separate the cover from the content. The theme of this issue is the quality process, and we submit that RCA history is itself an embodiment of that process. Over the years, the quality of RCA people and products has provided us with a rich heritage.

The RCA tradition of quality has its roots in the General Electric Company, from which RCA came. In 1986 we are again part of GE, and the tradition will continue.

1 RCA-800 three-electrode rf transmitting tube, ca. 1933. **2** Victrola name plate used on phonographs, ca. 1925. **3** GE logotype. **4** First wireless service message between the U.S. and England, March 1, 1920. **5** Communications pioneers, 1921. David Sarnoff is in the front row, on the left, and Albert Einstein and Nikola Tesla are in the center. **6** RCA logotype, 1932. **7** David Sarnoff and Guglielmo Marconi, 1933, Riverhead, Long Island. **8** David Sarnoff Award for Outstanding Achievement, established in 1958. **9** RCA portable TV "station," 1956. **10** RCA argon laser holography, 1967. **11** Furnace used in the manufacture of solid-state laser diodes. **12** *RCA Engineer* begins publication, 1955. **13** TK-10, first commercial black and white orthicon tv camera, ca. 1945. **14** Early NBC broadcasting station. **15** Antenna of RCA Satcom communications satellite being aligned at RCA Astro-Electronics. **16** Systems designer, RCA Laboratories, Zurich. **17** Nipper. **18** RCA Radio Central towers at Rocky Point, Long Island, early 1920s. **19** RCA Americom's tracking, telemetry, and control console, Vernon Valley, New Jersey. **20** RCA "umbrella" antenna deployed on the moon, February 5, 1971. **21** New NBC logotype, 1986. **22** A very young David Sarnoff. **23** RCA Satcom I, 1975. **24** Integrated circuit wafer, RCA Solid State Division. **25** RCA Hawkeye M-format portable television camera.





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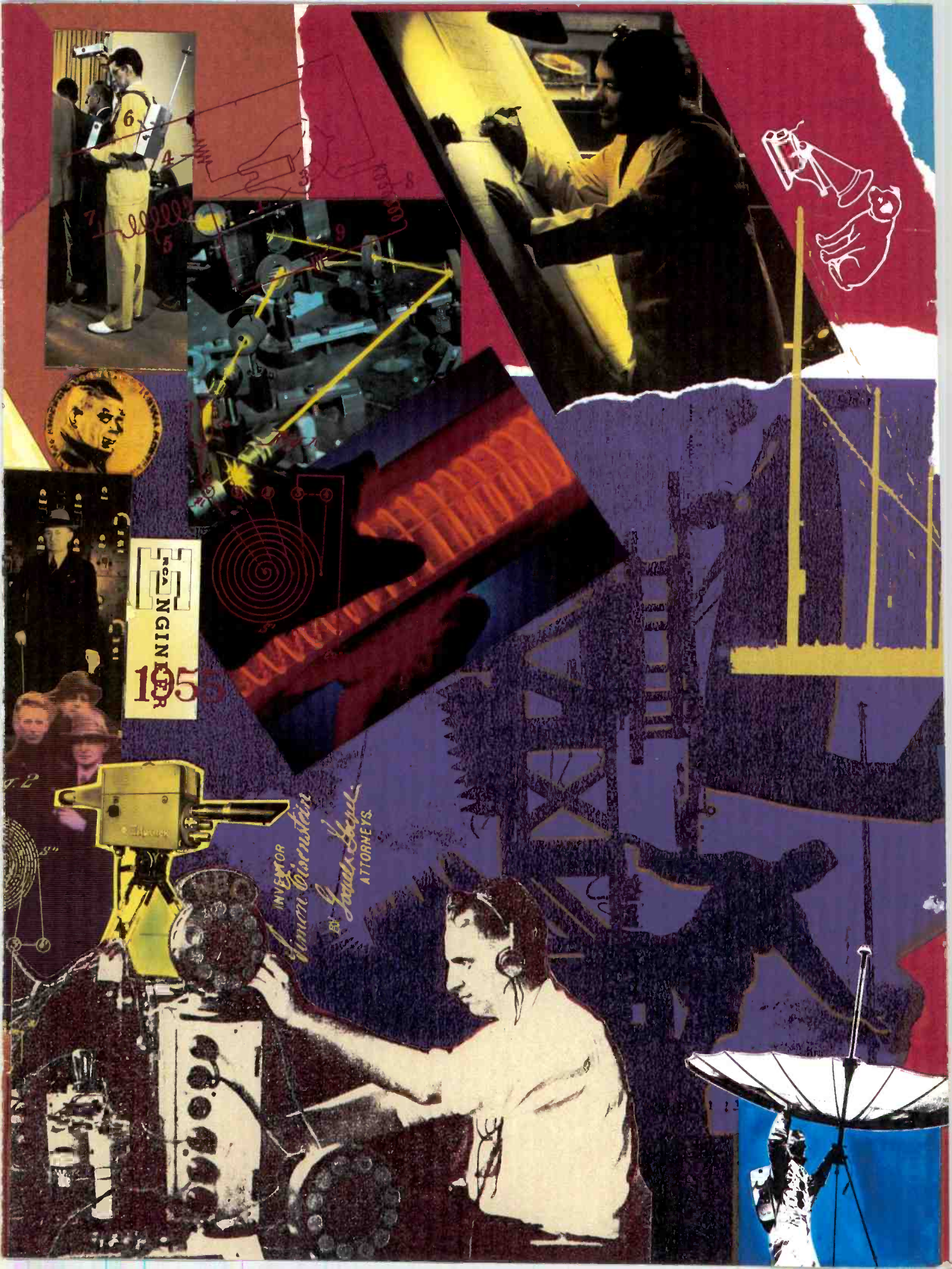
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