# RCA Engineer

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## manufacturing

# RCA Engineer

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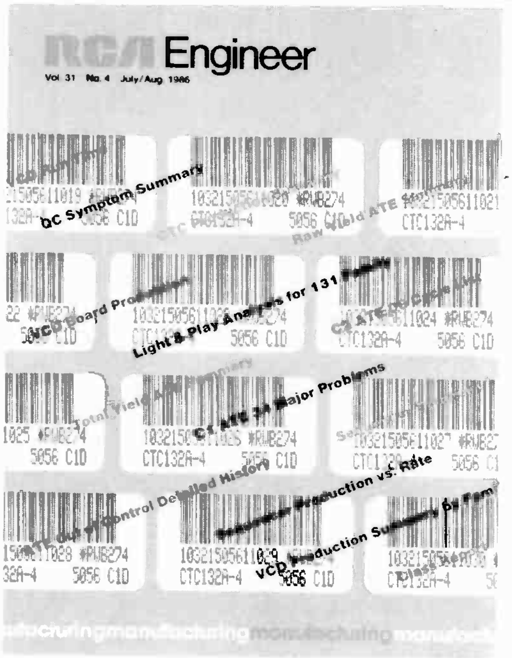

The cover was designed by the *RCA Engineer* staff. The bar-code labels were provided by **Nancy Gates**, Consumer Electronics Operations.

□ 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.

# The changing face of robotics

In 1979, the Robotic Institute of America expanded on earlier definitions of an industrial robot as follows: An industrial robot is a reprogrammable multifunction manipulator, designed to move materials, parts, tools, or specialized devices through variable programmed motions for the performance of a variety of tasks.

Reprogrammable is an important added word, because early robots were simple teach-and-repeat devices. High-performance microprocessors now allow robots with sophisticated languages to interact with their environments and make decisions.

The addition of computers to robotic systems increases their capability in three ways: motions can be described mathematically, communications are possible with other systems, and there is added decision-making capability. These things make it possible for robots to perform tasks that were previously impossible.

RCA Consumer Electronics is moving away from the "islands of automation" approach, and toward integrated systems that provide the necessary feedback of information into the process. System integration makes it possible to achieve additional levels of productivity and quality through real-time monitoring of processes. Adjustments can be made "on the fly" if tolerances are exceeded or products change, and communication between "intelligent" machines allows product information to be passed along the line.

The advanced instrument line (AIL) in the Bloomington, Indiana assembly plant is an example of the direction Consumer Electronics is taking in the integration of robotic workcells on a manufacturing line. GMF robot-based workcells perform assembly functions on the line, with status information being passed back to a host data collection system. The robotic workcells have resident programs for assembling several models, and when a model change occurs, the host broadcasts the model to be produced over a data highway to the workcells. Each workcell then executes the resident program for that model.

Future workcell developments will see a significant emphasis on the use of off-line graphics processors that allow the full simulation of all the workcell elements. Motion sequences will be developed, simulated, and tested to optimize the entire process. With off-line development, none of the robot's productive time is wasted.

Control system architecture will have to meet the requirements of new robotic applications, which will place a heavy demand on system processors and memory in an attempt to achieve greater throughput. Taking it all one step further, artificial intelligence will allow real-time decisions to be made by the robot.

Sensor technology has placed a greater emphasis on the integration of robots. Some say that by 1990, if a robot does not have vision, it will not be considered a robot. Vision will be as important to robots as programmable controllers are now..

The most important aspect of all future robotic applications will still be safety. With new sensor technologies, artificial intelligence, and faster processors, the robots will be able to "think" and react" in emergencies when an employee cannot. Continued training and education will be a priority to keep employees current with the new technologies.

Research and development in robotics within RCA today are being accelerated, and university laboratories are addressing some of the fundamental areas such as vision systems, artificial intelligence, and tactile sensing.

There is no doubt that robots, when properly applied to a task, can work longer for less, improve quality, and reduce overall cost.

B L Borman

*B. L. Borman*
Division Vice President
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# RCA Engineer

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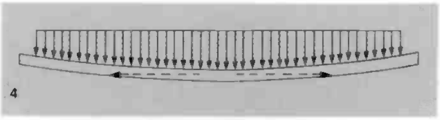
## manufacturing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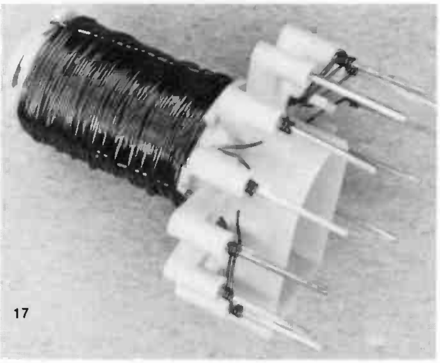
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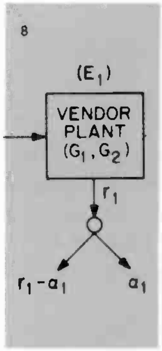
- **Miller:** *"Plotting a board of this size and complexity on mylar represented a new (and controversial) frontier for photolithographic technologists."*

- **Haslau/Hart:** *"We wrote vector equations to describe various tool positions relative to the contour surface and to satisfy tool-to-surface tangency requirements."*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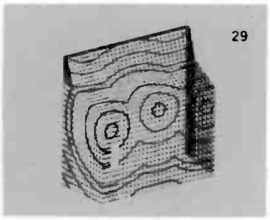
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35 FACTS System Overview

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42
                    MAT'L    BUY     NUM     NUM
MODEL   VOL.          $        $     MAKE    BUY
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- **Miller/Economou/Sharp:** *"The act of measurement is always accompanied by measurement uncertainty, whether large or small."*

- **Whipple/Huang:** *"Plastics injection molding is widely modeled in spite of known problems with the accuracy of the simulations."*

- **Jordan/Gates/Grayson:** *"FACTS is implemented as a group of independent processes communicating in real-time through a number of globally accessable, main-memory-resident common areas and a semaphore-based packet queuing system."*

- **Maleyeff/Miller:** *" . . . the user can enter proposed make-buy amounts and the system will calculate the results of these guesses."*

48 people

- **Su/Teh/Reiss:** *"In 1974, simultaneously with the expansion in Taiwan, SSD was preparing a new site in Malaysia for the assembly and test of power and IC products."*

## in the next issue . . .
the quality process

R.F. Miller

# A longer backplane PC board design increases testability and reduces assembly

*New production techniques allow mechanical designers to develop larger, more efficient PC board backplanes for the unique geometry and microcircuit module components associated with tactical phased-array radar antennas.*

The advent of leadless chip carrier printed circuit modules and the economies of scale realized in wiring and testing large backplanes have generated a need for larger, more complex printed-circuit board backplanes.

The concentration and miniaturization of electronics, coupled with geometric requirements imposed by a new phased-array radar antenna design, presented our backplane designers with a unique problem. Structural considerations dictated a maximum allowable backplane width of six inches and a possible length of over six feet. The additional requirement for five voltages used in the logic made a multilayer printed circuit approach attractive. From a manufacturing viewpoint, automated testing and wire-wrap parameters make a large backplane preferable to a small one.

**Abstract:** *The design of a reliable, producible, large-backplane product requires careful consideration by both the engineer and the manufacturer. Feature size and the trace and space widths are particularly critical in maintaining annular ring requirements (i.e., a minimum of 0.005 inch between the perimeter of through-holes and the edge of the plated through-hole pad). This paper presents the design methodology used to develop a long, complex printed-circuit (PC) board backplane using standard press-fit connector technology. Included in the discussion are the methods of circuit design artwork master creation, artwork processing techniques, special tooling-hole registration and drilling considerations, and backplane product testing. The solutions to the production-related problems encountered—backplane bowing and connector anomalies from tolerance build-up—are also presented.*

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A design advantage of a long backplane is that it allows the use of a large common groundplane that eliminates the need for balanced signal lines, reducing assembly weight and cost. Additionally, busbar hookups do not have to traverse the distance to a second board, and a set of board-to-board connectors and connections are eliminated.

Initially, long backplanes were produced in three lengths: 19.4, 25.7, and 32 inches. However, certain wiring and testing procedures were hindered when two 19.4-inch backplanes were stacked together in one assembly. Therefore, we decided to produce a 38.3-inch version to replace two stacked 19.4-inch backplanes (see Fig. 1). The situations we encountered in developing a backplane of this size and entering it into production are the subject of this article.

## Design methods

The first step in building the backplane was to find a suitable vendor—not many were receptive to the idea of manufacturing a 38.3-inch, nine-layer backplane with a 0.008-inch line width, 0.010-inch spacing, and 0.065-inch pads. The next priority was the generation of artwork and tooling.

### Master artwork development

The magnetic tapes that drive the artwork machinery are produced form logic netlists generated on the Applicon CAD system at Moorestown. The first problem encountered was that the backplane was too large to be input to the Applicon data files.

The CRT display of the Applicon represents a width of 32.766 "DA units." Normally each DA unit is assigned a value of 0.001 inch. Since all measurement readings performed by the Applicon are given in DA units, no conversion to thousandths of an inch is necessary. But the maximum-size board design that can be displayed on-screen is, consequently, 32.766 inches.

To create the 38.3-inch backplane file, the DA unit was reassigned a value of 0.002 inch, permitting the entire length of the board design to be displayed on the CRT screen. We then had to write a program to reconvert the DA unit data to the thousandths-of-an-inch scale for output to the standard Gerber plotter that generates the master artwork for the backplane board design. This program takes about six hours of computer time to convert the 0.002-inch DA unit data file.

After generating the magnetic artwork tapes, the process of plotting the actual artwork masters can begin. All plotting

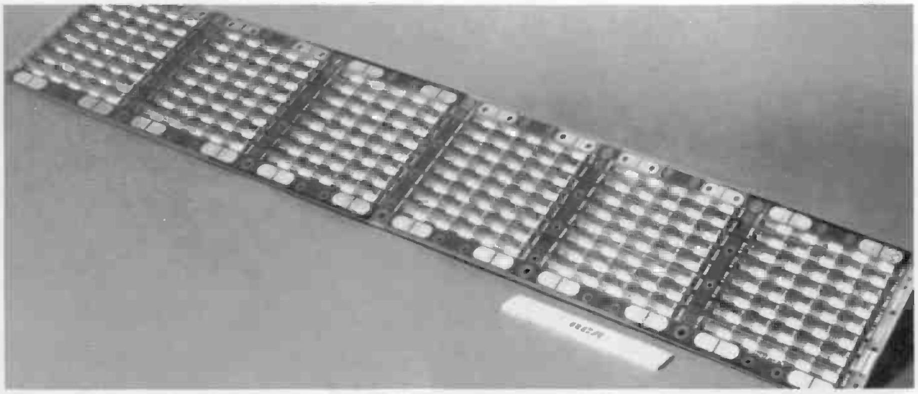


**Fig. 1a.** *The 38.3 inch, press fit compliant pin backplane developed at Moorestown.*

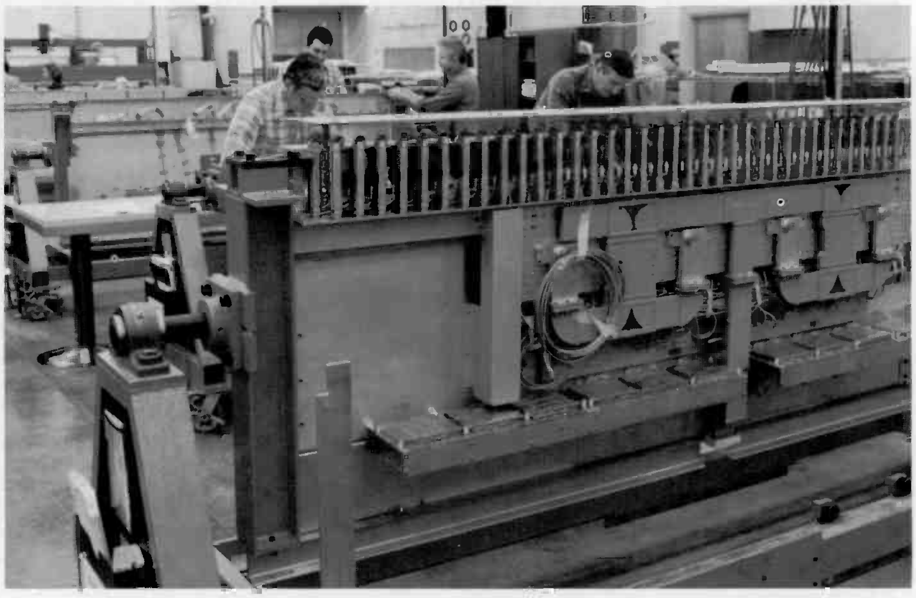


**Fig. 1b.** *Antenna column assembly showing position of two adjacent backplanes (bottom center of photo).*

## Soldering vs. press-fit compliant pins

An alternative method of obtaining a reliable electrical connection between two conductors has developed with advances in printed circuit board technology. Press-fit compliant pin (PFCP) connections, where contacts are made using spring tension with gold-plated contacts in plated through-holes (see Fig. 3), offer a number of general, as well as application-specific, advantages over solder connections.

In backplane production, wire-wrapped pins on one side of the board and plug-in receptacles for module cards on the other side make a wave-soldering process impractical. Individually soldering the hundreds of connections is slow and costly; resoldering a broken contact introduces heat that could damage wire on the backplane. PFCP connections offer an ideal solution to this problem.

Flowers-of-sulfur tests (see sidebar, page 6) show PFCP connections to be gas tight, and therefore highly resistant to corrosion. Cost savings can be realized in reducing the need for the relatively expensive soldering equipment.

was done on a Gerber-32 plotter at Camden. The size of the board created no problems in the plotting operation.

Originally, the artwork masters were to be plotted on 0.25-inch-thick glass, but we later decided to plot them on 7-mil mylar. Glass has better stability characteristics than mylar, but presents penalties in the form of high cost, availability, weight, and handling problems.

Plotting a board of this size and complexity on mylar represented a new (and controversial) frontier for photolithographic technologists. Variations in temperature and humidity cause mylar artwork masters to grow and shrink at a rate expressed in inches/design inch. Logically, one would reason that a larger/longer, more complex board with small, individually shaped features such as strip lines would hold a greater potential for tolerance-defying variations in size.

We have discovered, however, that mylar can be used for boards like our long backplane. The magnitude of the inch/design inch artwork variation obtained over the short feature size distances is too small to affect the finished product. However, an environmentally controlled lithographic process is needed in order to achieve overall backplane board design length and feature location.

The temperature and humidity are controlled at the point of mylar master artwork generation to ±2° F and ±5 percent relative humidity. The exact temperature and humidity are recorded on the documents accompanying the processed mylar art. To ready the artwork for use in board production, it must be restabilized—returned to the temperature and humidity levels at which it was generated.

During the artwork restabilization process, a closely controlled mylar wetting and drying procedure is required to prevent dimensional hysteresis. As the humidity is adjusted up or down to meet the specified

**Fig. 2.** *Compliant pins are inserted into PC boards using presses of this type. A vibrating conveyor shakes pins into the connector shell holes, and the press attaches the pins housed in the connector shell to the board as a unit.*

## Is it gas tight?

MIL-STD-1130B requires that 75 percent of the wire-wrapped assembly corners in contact with uninsulated wire (except for the first and last turns on the post) be gas-tight. The contacts in the wire-wrapped and compliant sections are checked by exposing them to the fumes of two chemical solutions that react and darken the metal surfaces they contact.

The posts are first suspended in a test tube above approximately 2 mL of a 1:1, concentrated hydrochloric and nitric acid solution for 10 minutes. They are then transferred to a second test tube and suspended above 1 mL of ammonium sulfide solution.

Once the chemical reaction has darkened the exterior surfaces, the posts are removed from the test tube and either unwrapped or pulled from the test substrate. The gas-tight portions of the post brightly contrast with the copper or gold sulfite colors that develop where the vapors penetrate.

generation level, this phenomenon can produce restabilized artwork that is larger or smaller (respectively) than its generation size.

Care is also taken to avoid and counteract the effects of temperature and humidity variation during transport of the mylar artwork masters.

## Tooling, modeling, and processing

The nine layers of artwork masters are sent to the vendor, checked, and measured for accuracy within ±0.003 inch throughout their 38.3-inch lengths. At this point they are ready to be used in the production of the backplane.

The grain structure quality of the board laminate material controls shrinkage and misregistration from material float. Grain structure is tested by the backplane vendor on a lot-by-lot basis. An 18×21-inch through-hole pattern is drilled in a sample board pulled from the laminated lot, and the distances between the through holes are precisely measured. The drilled board sample is subjected to a hot oil reflow procedure, and the distances between the holes are remeasured. If the change in distance between any of the through-holes is greater than ±0.0028 inch, the entire lot of PCB laminates is considered to be unsuitable for production.

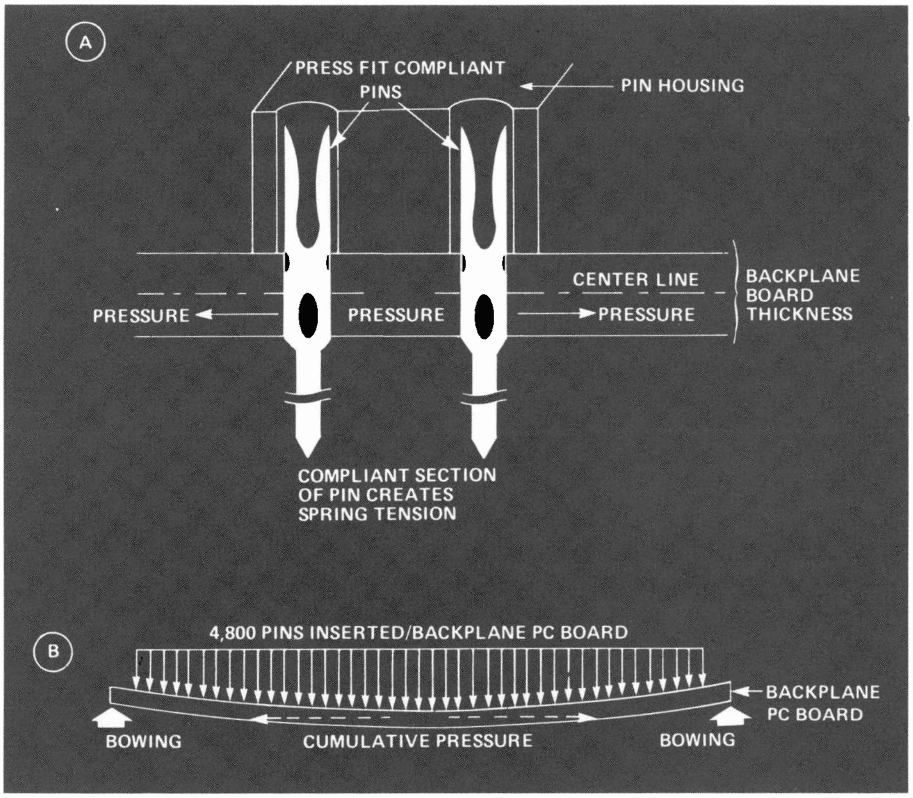


**Fig. 3.** *Spring tension from the insertion of the press fit compliant pin creates pressure below the center line of the board thickness (A), causing the board to bow upwards (B).*

Lamination techniques are critical; the processing parameters of press time and cool-down time are held to close tolerances. Careful control of these parameters has sharply reduced board shrinkage below the normal 0.005 inch/inch ratio. Also, tight control during the press cycle has helped to control warp and twist in the board.

Most circuit board drill machines are designed for drilling modular PC boards, which are generally less than 24 inches long. By restricting the drill span to 24 inches, equipment manufacturers can produce multiple-spindle drill machines that occupy less floor space than larger single-spindle machines. Consequently, our 38.3-inch boards were drilled using the multi-spindle technique, whereby adjacent spindles on a multi-spindle machine each drill one portion of the board. This technique eliminated the need to step the board to a different location for drilling by the same spindle, and also eliminated the errors that could occur in repositioning the board.

One effective production technique used was to run the boards two-up to utilize laminate material efficiently. This was possible because of the relatively narrow (6-inch) width of the backplane.

PC board pin and connector shell installation was not hindered by the size of the board. However, substantial bowing occurred over the length of the backplane from the press-fit pin insertion process (Figs. 2, 3). We solved this problem by securely fastening the backplane to a rigid logic-nest assembly.

Other potential problem areas are the size of the processing tanks and the photographic equipment as, once again, most board manufacturers have selected their equipment for the processing of 24-inch long (or smaller) PC board products. Fortunately, some manufacturers do have equipment that can handle longer boards.

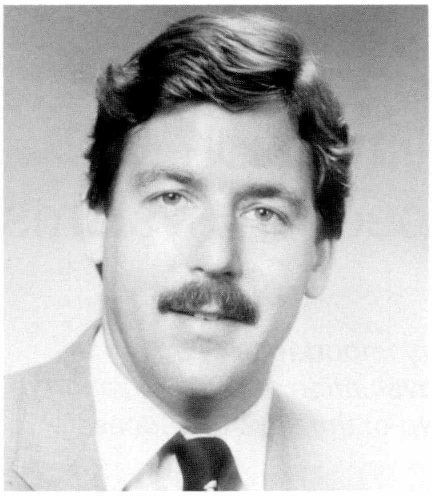
### *Testing*

The size of the backplane posed no problem to semi-automatic and automatic wire-wrap machines, nor to a bed-of-nails tester designed and built specifically for this family of backplanes. MIL-A-28870 requires that testing for circuit opens and shorts be performed at twice the maximum board voltage. We routinely test metal plate backplanes to 500 volts at 1 ampere to catch possible wire-wrap insulation breaks. It was determined that 500 volts could possibly cause degradation of the multilayer backplanes, so the testing voltage was lowered to 125. No problems were encountered while testing at 125 volts.

## Conclusions

A long, complex, multilayer backplane design can be produced efficiently and economically, offering substantial benefits in wire-wrapping and testing. This sets new standards for maximum backplane size, and allows more options in forthcoming electronic packaging and interconnect designs.

Given the size and complexity of the backplane, locating a procurement source may be difficult. But the opportunity exists for additional advances in this area. The ability to add more layers to the backplane would reduce or eliminate wire-wrapping and redundant testing. This process will be investigated to determine if favorable trade-offs are possible.



**Roger F. Miller** is a Member, Engineering Staff at Missile and Surface Radar Division. He received his Bachelor of Science Degree in Aerospace Engineering from the University of Arizona. Roger designs and oversees production of backplanes and logic nest assemblies that are cabinet frame mounted or integrated into phased-array radar antennas. He has also done extensive work in the area of wire-wrap and automated testing of wire-wrapped assemblies. He is presently involved with the design of pluggable circuit module connectors and electronics packaging on a system level.
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S.R. Miller | J.E. Economou | M.C. Sharp

# Evaluation and optimization of manufacturing inspection systems

*The reduction of costs is of primary importance in a manufacturing environment. The evaluation and optimization of product inspection systems are two of the keys to successful cost reduction.*

The manufacturing environment is highly competitive. It is an environment characterized by incessant change and the struggle for product survival. To assure product survival, manufacturing constantly faces the challenge of simultaneously attaining the goals of product quality and reliability, manufacturing efficiency, and enhanced productivity. Survival in such an environment also requires efficacious judgments and decisions. Necessity often demands, however, that these decisions be based on information that is incomplete, or "clouded" with uncertainty. Consequently, it is entirely possible that incorrect decisions will be reached. Manufacturing must then be alert to the frequency and types of errors being made, and the costs associated with such errors, in order to minimize the subsequent effects of erroneous and costly decisions. Our paper addresses this concern in the specific area of inspection systems, but a similar analysis could be applied to many other decision-making areas. Because of its importance, we shall preface our presentation with a brief discussion of uncertainty and its relationship to scientific belief.

**Abstract:** *Within any manufacturing environment, one is constantly faced with inspecting a product and evaluating its performance. However, the inspection and evaluation are often complicated by the variabilities that are inherent both in the inspection system and in the product itself. Consequently, erroneous and costly decisions can be reached. This article introduces a methodology for analyzing single and multiple inspection systems and their classification errors. In particular, we present a numerical algorithm that minimizes the misclassification costs through optimization of performance specification limit tolerances (i.e., guardbands). The methodology is highly flexible and can be adapted to a wide variety of manufacturing inspection systems.*

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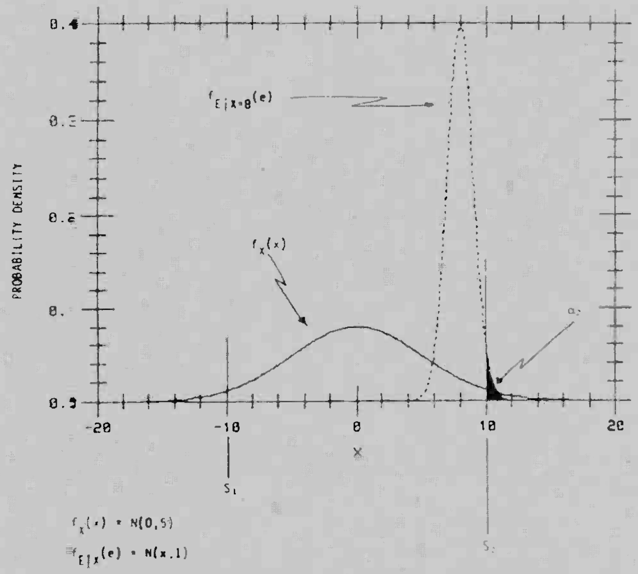
## Uncertainty—Nature's "ubiquitous creature"

A scientist is presented with three primary tasks: (1) experimentation, or the measurement of phenomena; (2) the generalization to rules or laws governing these phenomena; and (3) the creation of a theoretical framework that explains the derived rules or laws and provides predictive capability. The first task is analytic (reductionistic) in spirit, while the latter two tasks are synthetic (constructionistic). The phenomenon of interest may involve the interaction of elementary particles, the synthesis of messenger-RNA, the onset of agression in the human animal, or the etching of printed-circuit board patterns. Regardless, scientists attempt to measure, generalize, and predict. Their efforts at coordinating phenomena are complicated, however, by the presence of uncertainty. In fact, we may more strongly assert that uncertainty is a fundamental issue in any scientific undertaking, because it directly impacts our underlying belief structure. It is worthwhile, therefore, to consider this "ubiquitous creature" of nature in greater detail.

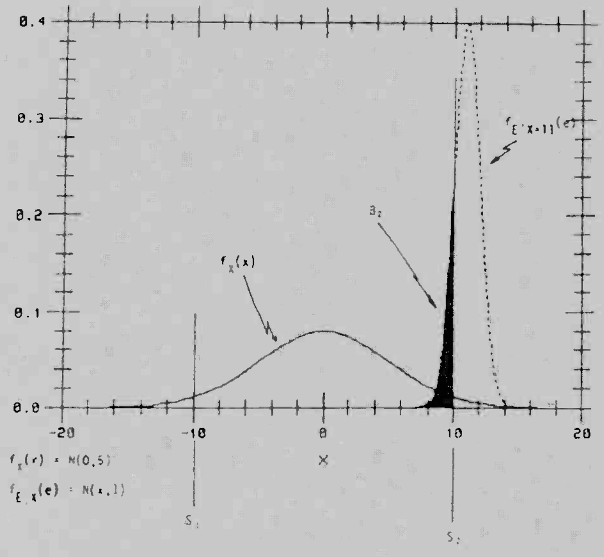
The act of measurement is always accompanied by measurement uncertainty, whether large or small. The sources of uncertainty are various. The uncertainty may be attributable to variability (random error) and/or bias (systematic error) in the measurement apparatus. White noise (thermal fluctuations) and mechanical vibrations are examples of random errors, while device calibration is a possible source of systematic or constant error. Uncertainty may also arise from the variability inherent in the phenomenon itself, as, for example, the variability associated with etching PC board patterns, or that associated with metal forming. Finally, the uncertainty may arise from some more fundamental limitation, as that imposed by nature upon the simultaneous measurement of canonically conjugate variables at the atomic and subatomic levels (e.g., the Heisenberg uncertainty principle). Regardless of the source, the existence of uncertainty complicates the task of generalization.

The synthetic role of the scientist is also complicated by the fact that the gen-



FOR ILLUSTRATIVE PURPOSES THE GUARD-BANDS G1 & G2 ARE ASSUMED TO BE ZERO. $\alpha_2$ IS THE PROBABILITY OF REJECTING A GOOD PRODUCT WITH VALUE $X = 8$ BECAUSE THE MEASUREMENT ERROR E IS SUCH THAT THE OBSERVED VALUE $8 + e > 10$.

**Fig. 1a.** *Type I error.*

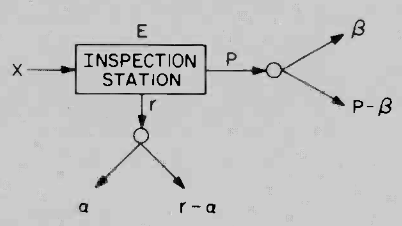


FOR ILLUSTRATIVE PURPOSES THE GUARD-BANDS G1 & G2 ARE ASSUMED TO BE ZERO. $\beta_2$ IS THE PROBABILITY OF ACCEPTING A BAD PRODUCT WITH VALUE $x = 11$ BECAUSE THE MEASUREMENT ERROR IS SUCH THAT THE OBSERVED VALUE $11 + e < 10$.

**Fig. 1b.** *Type II error.*

*DEFINE*

$S_1$ = LOWER SPEC LIMIT
$S_2$ = UPPER SPEC LIMIT
X = PRODUCT CHARACTERISTIC RANDOM VARIABLE
E = MEASUREMENT ERROR RANDOM VARIABLE
"BAD" PRODUCT = $(X < S_1)$ or $(X > S_2)$
"GOOD" PRODUCT = $(S_1 < X < S_2)$



*WHERE,*

P = PROB {PASSING A PRODUCT}
r = PROB {REJECTING A PRODUCT}
$\alpha$ = PROB {FALSELY REJECTING A GOOD PRODUCT}
$\beta$ = PROB {FALSELY ACCEPTING A BAD PRODUCT}

**Fig. 1c.** *Single-inspection station system and parameters.*

eralization to rules or laws often proceeds in an inductive manner from observations, and is thus, of necessity, probabilistic in nature. (This is not true, of course, of the deductive reasoning employed by mathematicians, logicians and scientists.) Conclusions that are reached from finite numbers of observations, and generalizations made from sample sizes of limited extent, are extrapolative in nature, and hence never completely certain, although the degree of certainty varies; that is, certain statements are more probable than others.

The degree of certainty associated with our acts of analysis and synthesis can be placed on a quantitative level by means of the calculus of probabilities. Statistics is that branch of probability concerned with samples drawn from populations, and statistical inference is the process of drawing conclusions about the populations from these samples. Thus, statistics is of fundamental importance to the scientist who is formulating and testing hypotheses. Within statistics, one considers a particular observation to be a value that arises with a certain frequency of occurrence from some probability density function (which may or may not be known). A set of such values constitutes the range of a function known as a random variable, and a statistical hypothesis is any assumption concerning the probability density function (pdf) or frequency function of this observed random variable. The hypothesis could be, for example, an assumption about the value of the mean of the pdf, or its variance. Sampling from the random variable gives rise to two fundamental issues: (1) a consideration of what constitutes an appropriate sample, and (2) the question of how one can make reliable statements about the population once this sample has been drawn. Statistical inference is concerned with the second issue, and it is this issue that is implicit in the work we shall describe below.

## Consequences of product inspection

Although at the present time the trend in manufacturing is away from excessive product inspection and overriding specification concerns and toward more process-oriented approaches, product testing is still of paramount importance in the assessment of product quality. However, because of product variability, and the variability and/or bias inherent in the test equipment itself, misclassification is possible. In particular, inspection can give rise to two types of decisional error: (1) a Type I error, which involves the rejection of acceptable product, and (2) a Type II error, which involves the acceptance of unacceptable product. More specifically, let us assume that we are testing a particular product attribute. Given the probability distributions for product attribute performance and for measurement system error, there is a probability $\alpha$ of rejecting product that conforms to the performance specifications for the product attribute being tested (Type I error), and a probability $\beta$ of accepting product that does not conform to these performance specifications (Type II error). Figures 1a-1f show this situation graphically. A Type I error results in a direct loss to the producer, while a Type II error results, in effect, in a loss to the consumer, and ultimately also adversely affects the producer. By knowing the two probabilities $\alpha$ and $\beta$, and also the costs associated with making these errors, the cost incurred by inspecting the product can be computed. Thus, $\alpha$ and $\beta$ are very reasonable performance measures of an inspection system. As will be shown below, for 100-percent inspection, $\alpha$ and $\beta$ are functions of the fixed lower and upper performance specification limits $S_1$ and $S_2$ and the guardbands $G_1$ and $G_2$ about these limits. The guardbands are tolerance bands that are introduced to account for measurement errors in the test equipment and represent the differences between the performance specification limits and the pass/reject classification limits (i.e., the test specification limits). The cost of testing (i.e., the risk function) can be minimized by choosing appropriate values of $G_1$ and $G_2$. This paper will describe a specific numerical algorithm that we have developed at RCA Laboratories for performing this risk function optimization. Furthermore, as we shall show, this algorithm can be utilized to predict the benefits to be expected from improvements in the measurement system; that is, from reductions in the random measurement errors (measurement variability) and/or the systematic measurement errors (measurement bias). Finally, we shall describe a few important generalizations of the basic problem that we have considered.

For the single station case, the equations for $\alpha_1$, $\alpha_2$, $\beta_1$, and $\beta_2$ are as follows:

$$\alpha_1 = Pr\,(S_1<X<S_2,\ X+E<S_1+G_1)$$
$$= \int_{S_1}^{S_2} F_E\,(S_1+G_1-x) f_X(x)dx$$

$$\alpha_2 = Pr\,(S_1<X<S_2,\ S_2+G_2<X+E)$$
$$= \int_{S_1}^{S_2} \left[\,1-F_E\,(S_2+G_2-x)\,\right] f_X(x)dx$$

$$\beta_1 = Pr\,(X<S_1,\ S_1+G_1<X+E<S_2+G_2)$$
$$= \int_{-\infty}^{S_1} \left[\,F_E\,(S_2+G_2-x)-F_E\,(S_1+G_1-x)\,\right] f_X(x)dx$$

$$\beta_2 = Pr\,(S_2<X,\ S_1+G_1<X+E<S_2+G_2)$$
$$= \int_{S_2}^{\infty} \left[\,F_E\,(S_2+G_2-x)-F_E\,(S_1+G_1-x)\,\right] f_X(x)dx$$

where:

$E$ = measurement error random variable with pdf $f_E(e)$

$X$ = product value random variable with pdf $f_X(x)$

$S_1$, $S_2$ = lower and upper spec limits

$G_1$, $G_2$ = guardbands for lower and upper spec limits

and

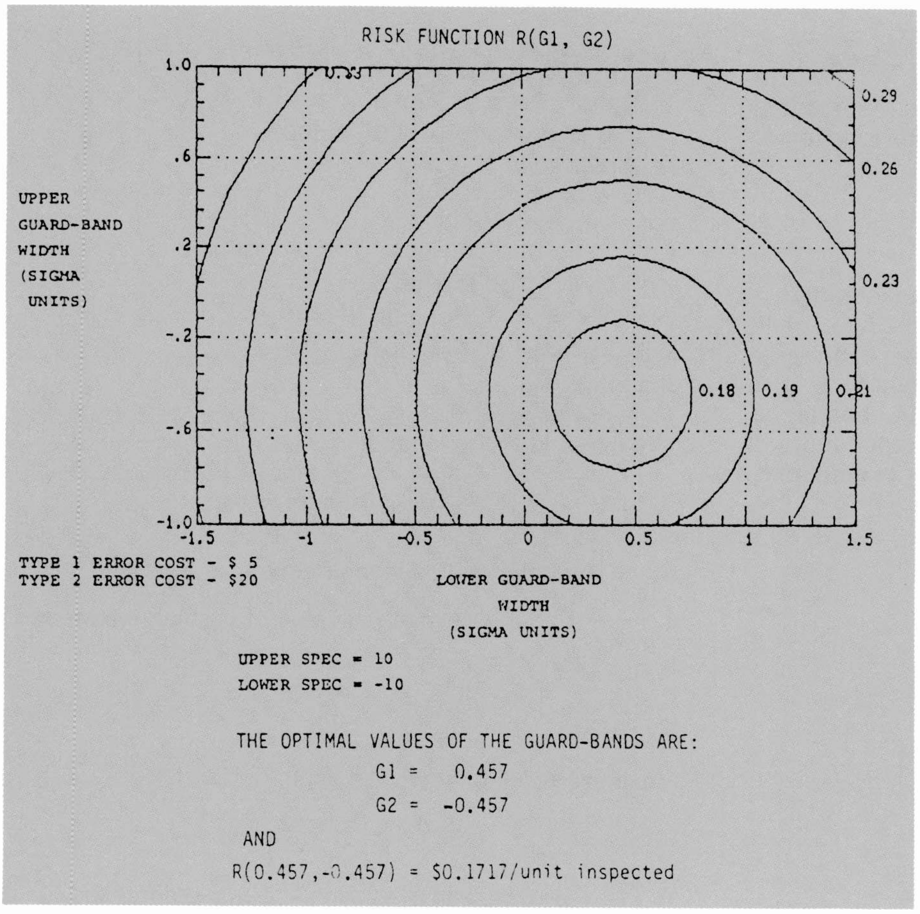
$$F_E(x) = \int_{-\infty}^{x} f_E(e)de \qquad \text{(distribution of } E\text{)}$$

### *Mathematical formulation*

To develop probability expressions for Type I and Type II errors, we must define the random variables of interest. We let the random variable $X$ denote the product's "true" value, with $x$ being a particular value of $X$. The random variable $E$ will denote the measurement error, with $e$ being a particular value of $E$. Finally, we let $Y$ denote the product's "measured" value, with $y$ being a particular value of $Y$; that is, $Y$ represents the product's value as read from the inspection (measurement) device. With these definitions, we can write the value observed from a particular measurement as $y=x+e$. We note that $E$ represents the convolution of all non-product random variables contributing to $Y$, as, for example, setup variability, measurement repeatability, calibration, etc., and that the pdf of $E$ is conditional on the value of the random variable $X$.

Consider now the situation where testing involves both lower ($S_1$) and upper ($S_2$) specification limits, and guardbands $G_1$ and $G_2$ about $S_1$ and $S_2$, respectively. $S_1$ and $S_2$ define what is and what is not a good theoretical product (regardless of the measurement system) and, therefore, are given constants. $G_1$ and $G_2$, on the other hand, are controllable and are set with respect to the measurement system. As we mentioned above, our criterion for choosing appropriate values for $G_1$ and $G_2$ is based on minimizing the average inspection cost per product.

There are four probabilities of interest: (1) $\alpha_1$ is the probability of falsely rejecting a good product (one with $x$ inside the specification interval ($S_1$, $S_2$), because its observed value $y$ is below the guardband adjusted lower specification limit ($S_1+G_1$); (2) $\alpha_2$ is the probability of falsely rejecting a good product because its observed value $y$ is above the guardband adjusted upper specification limit ($S_2+G_2$); (3) $\beta_1$ is the probability of falsely accepting a bad product because its product value $x$ is less than the lower specification limit $S_1$, but the measurement error $e$ is such that the observed value $y$ lies within the guardband adjusted specification interval ($S_1+G_1$, $S_2+G_2$); and (4) $\beta_2$ is the probability of falsely accepting a bad product because its product value $x$ is greater than the upper specification limit $S_2$, but the mea-



```
THE OPTIMAL VALUES OF THE GUARD-BANDS ARE:
               G1 =   0.457
               G2 =  -0.457
AND
R(0.457,-0.457) = $0.1717/unit inspected
```

**Fig. 2.** *Risk function $R(G_1, G_2)$.*

surement error $e$ is such that the observed value $y$ lies within the guardband adjusted specification interval $(S_1+G_1, S_2+G_2)$. Now, since the events associated with $\alpha_1$ and $\alpha_2$ are mutually exclusive, and the union of these events is the event associated with $\alpha$ (i.e., the total probability of falsely rejecting good product), $\alpha$ can be expressed as $\alpha=\alpha_1+\alpha_2$. Similarly for $\beta$ (i.e., the total probability of falsely accepting bad product), we have $\beta=\beta_1+\beta_2$. The mathematical expressions for the probabilities $\alpha_1$, $\alpha_2$, $\beta_1$, and $\beta_2$ are given in the sidebar.

### *The risk function model*

The expected cost of inspecting a product, which we refer to as the cost or risk function, has two components: (1) the expected cost of falsely rejecting a good product, and (2) the expected cost of falsely accepting a bad product. (We are assuming that the cost of making a correct decision is zero and so does not enter into the risk function.) Assuming a simple linear model for the costs, we can write the inspection cost per product as: $R(G_1, G_2)=k_1\alpha+k_2\beta$, where $\alpha$ and $\beta$ are the Type I and Type II probabilities defined above, $k_1$ is the cost associated with rejecting a good product, and $k_2$ is the cost associated with accepting a bad product. The idea now is to choose $G_1$ and $G_2$ in order to minimize the inspection cost per product, $R(G_1, G_2)$. The risk function can be evaluated for a given $G_1$ and $G_2$, provided that the probability integrals are solvable. This is not possible in general, however. (For example, we have been able to derive explicit analytic results for only two special cases: the Laplace pdf and the logistic pdf.) Moreover, even if the integrals can be evaluated, the matter of optimizing $R(G_1, G_2)$ is by no means a trivial task. Therefore, a numerical procedure was developed to evaluate the integrals and to minimize the risk function $R(G_1, G_2)$.

### *Numerical algorithm*

The numerical algorithm consists of two essential parts. The first is the evaluation of the risk function for some $G_1$ and $G_2$. This step requires a numerical integration routine. The second part is the optimization of the risk function with respect to $G_1$ and $G_2$. Since the risk function in general is a function of more than one variable, a line search alone could not be utilized to perform the optimization. Instead, a multidimensional search that employs single-variable line searches was used. The multidimensional search method chosen was the method of Hooke and Jeeves, while the line search method used was the Fibonacci search. These search routines are not derivative-or gradient-based. Consequently, we were able to develop the software for generic probability density functions, and thus provide for greater flexibility. The sidebar describes the Fibonacci line-search algorithm. We should also note that the numerical algorithm was validated through comparison with an explicit analytical solution derived for the Laplace, i.e., the double exponential pdf. Complete agreement with the analytical solution was found for the specific example that we considered.

### A specific example—Symmetric product performance value pdf

Let us assume the following:

1. The pdf of the product value ($X$) is normally distributed with a mean of 0 and a standard deviation of 5; i.e., $f_X(x)=N_{(0,5)}$;
2. The pdf of the measurement error $E$ is $f_{E|X}(e)=N_{(x,1)}$; (Note: this pdf is conditional on the value of the random variable $X$);
3. The cost $k_1$ of falsely rejecting a good product is $5.00;
4. The cost $k_2$ of falsely accepting a bad product is $20.00;
5. The upper specification limit of $X$ is 10, and the lower specification limit is $-10$;

where the situation is depicted graphically

> ***". . . chance left free to act falls into an order as well as purpose."***
>
> *—G.M. Hopkins*
> *Journal, 1873*

## Fibonacci Search Algorithm

The following is the Fibonacci Search Method for maximizing (minimizing) a quasiconvex function over $[a_1, b_1]$.

### Initialization Step

Choose an allowable final length of uncertainty $l>0$. (The point at which the maximum of the function lies will be after completion of the algorithm in an interval of length at most $l$.) Also choose a distinguishable constant $\epsilon>0$. Let $[a_1, b_1]$ be the initial interval of uncertainty of the independent variable, say $x$. Determine the number of iterations $n$ to be taken such that

$$F(n)>(b_1-a_1)/l$$

where

$$F(n) = F(n-1) + F(n-2),\ F(0) = F(1) = 1$$

or

$$F(n) = \frac{1}{2}\left(1+\frac{1}{\sqrt{5}}\right)\left(\frac{1+\sqrt{5}}{2}\right)^n - \frac{1}{2}\left(1+\frac{1}{\sqrt{5}}\right)\left(\frac{1-\sqrt{5}}{2}\right)^n$$

Let

$$\lambda_1 = a_1 + \left[\frac{F(n-2)}{F(n)}\right](b_1-a_1)$$

$$\mu_1 = a_1 + \left[\frac{F(n-1)}{F(n)}\right](b_1-a_1)$$

Evaluate $f(\lambda_1), f(\mu_1)$ where $f$ is the function to be maximized. Let $k=1$, go to main step.

### Main Step

```
1. If $[f(\lambda_k)>(f(\mu_k)]$ then go to Step 3 (2), else if
   $[f(\lambda_k)\leq(f(\mu_k)]$ then go to Step 2 (3).
2. Let $a_{k+1}=\lambda_k$
       $b_{k+1}=b_k$
       $\lambda_{k+1}=\mu_k$
       $\mu_{k+1}=a_{k+1}+[F(n-k-1)/F(n-k)]\,(b_{k+1}-a_{k+1})$
   If $(k=n-2)$ go to Step 5.
   Else evaluate $f(\mu_{k+1})$ go to Step 4.
3. Let $a_{k+1}=a_k$
       $b_{k+1}=\mu_k$
       $\mu_{k+1}=\lambda_k$
       $\lambda_{k+1}=a_{k+1}+[F(n-k-2)/F(n-k)]\,(b_{k+1}-a_{k+1})$
   If $(k=n-2)$ go to Step 5.
   Else evaluate $f(\lambda_{k+1})$ go to Step 4.
4. Let $k=k+1$ go to Step 1.
5. Let $\lambda_n=\lambda_{n-1}$
       $\mu_n=\lambda_{n-1}+\epsilon$
   If $(f(\lambda_n)<(>)f(\mu_n)$ then let $a_n=\lambda_n$
                                     $b_n=b_{n-1}$
   Else if $(f(\lambda_n)\geq(\leq)f(\mu_n)$ then let $a_n=a_{n-1}$
                                           $b_n=\lambda_n$
```

Stop. The solution lies in the interval $(a_n, b_n)$. Use $\left(\frac{b_n-a_n}{2}\right)$ as the estimate of value of $x$ which maximizes (minimizes) $f$.

### Example

Maximize $f(x)$ subject to: $0\leq x\leq 3$

$$f(x)=x,\ 0\leq x\leq 2$$
$$=6-2x,\ 2<x\leq 3$$

let $l=0.1$, $\epsilon=0.05$, and $a_1=0$, $b_1=3$, thus the condition

$$F(n)>\frac{(3-0)}{0.1}=30$$

gives $n=8$.

| # (n) | F(n) |
|---|---|
| 0 | 1 |
| 1 | 1 |
| 2 | 2 |
| 3 | 3 |
| 4 | 5 |
| 5 | 8 |
| 6 | 13 |
| 7 | 21 |
| 8 | 34 |

| Iteration | $a_k$ | $b_k$ | $\lambda_k$ | $\mu_k$ | $f(\lambda_k)$ | $f(\mu_k)$ |
|---|---|---|---|---|---|---|
| 1 | 0 | 3 | 1.147 | 1.853 | 1.147 | 1.853 |
| 2 | 1.147 | 3 | 1.853 | 2.294 | 1.853 | 1.412 |
| 3 | 1.147 | 2.294 | 1.588 | 1.853 | 1.588 | 1.853 |
| 4 | 1.588 | 2.294 | 1.853 | 2.029 | 1.853 | 1.942 |
| 5 | 1.853 | 2.294 | 2.029 | 2.118 | 1.942 | 1.765 |
| 6 | 1.853 | 2.118 | 1.941 | 2.029 | 1.941 | 1.942 |
| 7 | 1.941 | 2.118 | 2.029 | 2.0295 | 1.941 | 1.941 |
| 8 | 1.941 | 2.029 | 2.029 | 2.079 | 1.941 | 1.842 |

$$x^*=\left(\frac{2.029+1.941}{2}\right)=1.985 \text{ (actual is 2.0).}$$

Table I.

| Year | Units to be inspected | Inspection cost per unit | Fixed cost | Total cost |
|---|---|---|---|---|
| *Present system* | | | | |
| 1 | 2000 | $0.17 | $0.00 | $ 340.00 |
| 2 | 3500 | 0.17 | 0.00 | 595.00 |
| 3 | 5000 | 0.17 | 0.00 | 850.00 |
| 4 | 2500 | 0.17 | 0.00 | 425.00 |
| Total | 13000 | $ -- | $0.00 | $2210.00 |
| *Proposed system* | | | | |
| 1 | 2000 | $0.08 | $1000.00 | $1160.00 |
| 2 | 3500 | 0.08 | 0.00 | 280.00 |
| 3 | 5000 | 0.08 | 0.00 | 400.00 |
| 4 | 2500 | 0.08 | 0.00 | 200.00 |
| Total | 13000 | $ -- | $1000.00 | $2040.00 |

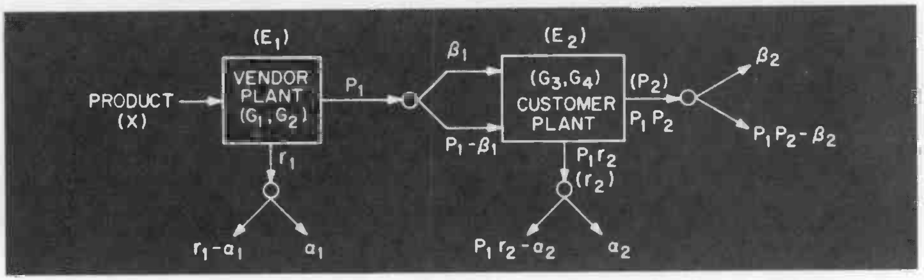


**Fig. 3.** *Two inspection stations in series (e.g., vendor-customer plants).*

in Figs. 1a and 1b. Because $f_X(x)$ and $f_{E|X}(e)$ are symmetric, the guardbands $G_1$ and $G_2$ will also be symmetric and $G_1=-G_2$. Therefore, the two-dimensional optimization reduces to a one-dimensional optimization. An algorithm was developed for the special case of symmetric probability density functions which only requires a line search as given in the sidebar. As a result of applying this algorithm, it is found that the minimum occurs at $G_1=0.457$, and so, $G_2=-0.457$, and the value of $R$ at that point is $0.1717 per product inspected. A contour plot of $R(G_1, G_2)$ versus $G_1$ and $G_2$ is shown in Fig. 2. We note that if guardbands were not utilized, the risk function would have a value of $0.1915 per product inspected. Thus, as a result of minimizing the risk function $R$, we can expect a savings of $0.0198 per product inspected. If one were to produce a million units, for example, this would result in an overall savings of $19,800. If we multiply this by many inspection stations we have a very sizeable cost reduction.

Let us now suppose that a new inspection (measurement) system is being considered and that its measurement error distribution is $N_{(x,\ 0.5)}$; that is, the new measurement system is more precise. The cost of purchasing this new system is $1000. (For simplicity assume that no extra labor or overhead is required for the new system over the old.) The natural question that arises in this situation is, "Is the new system worth purchasing?" With the algorithm that we have developed, we can supply the quantitative information that is required to provide intelligent answers to this question. Let us assume that the costs of the Type I and Type II errors are as given above, $5 and $20 respectively. The present system's optimal inspection cost by using the guardband optimization algorithm is $0.1717 per unit inspected ($G_1=-G_2=0.457$). For the proposed system, the optimal cost per unit inspected is $0.0814 ($G_1=-G_2=0.322$). The inspection cost per year was calculated and is given in Table I. The payback period is 3.24 years, which corresponds to a breakeven number of 11,111 units. (For simplicity, the present value of money, taxes, etc. have been ignored.)

## Extensions and future work

There are many variations on the basic inspection station problem that we have considered thus far. We have solved some of these, and are currently working on others. We wish to describe here some of these extensions.

### *Vendor-customer problem*

The most important extension that we have considered and solved is that of two inspection stations in series. This situation arises, for example, with finished product inspection at a vendor plant and incoming inspection at a customer plant. It can also arise with inspection of the same product characteristic at two different locations within a single plant's manufacturing operations (e.g., manufacturing and QC). We shall consider the vendor-customer situation depicted in Fig. 3. For such a situation, each of the plants has its own concerns. The vendor plant, for example, may ask the following questions:

- ☐ What is the customer plant's perceived quality of our product?
- ☐ How effective is our product screening process?
- ☐ How often do we misclassify good product as bad and bad product as good?
- ☐ How can we add guardbands so that we minimize our misclassification costs?
- ☐ Is it worthwhile to improve our measurement system?

The customer plant may ask:

- ☐ Do we actually need an incoming product inspection?
- ☐ How often do we pass bad product through our system?
- ☐ What percent of incoming product can we expect to have to return?

We have developed the mathematical theory and the software necessary to evaluate and optimize the guardbands (all four of them) in this case. The solution to this problem allows us to provide the quantitative information that is required to help answer in an intelligent manner the questions that are of interest to either the vendor or the customer.

### *Product reinspection*

Manufacturing is often under pressure to get as much product through the door as possible. Thus, there is a tendency to reinspect product until it passes. This could be done by simply remeasuring a failed product a number of times until it passes, or by sending a product that failed at one inspection station to another station for reinspection. It is important to understand the implications of such measurement policies (whether deliberate or inadvertent) on the ultimate product cost. In actuality, there are an untold number of measurement policies that could be considered, and we have investigated several. As an example, consider a policy that specifies that a product is acceptable if it passes at least *k* times in *n* tries. That is, we continue to inspect the product until one of two events occur: (1) we observe the product to pass *k* times, or (2) we have inspected the product *n* times without it passing *k* times. If event (1) occurs, the product is passed; if event (2) occurs, the product is rejected. The optimization software for this situation is currently under development. We note that in terms of optimizing the risk function, $R(G_1, G_2, k, n)$, the problem is now a four-dimensional optimization, where two of the variables, *k* and *n*, are constrained to be integers. We also note that when $k=1$, this policy reduces to a simple reinspection where the product is acceptable if it passes at least once. This situation is depicted in Fig. 4.

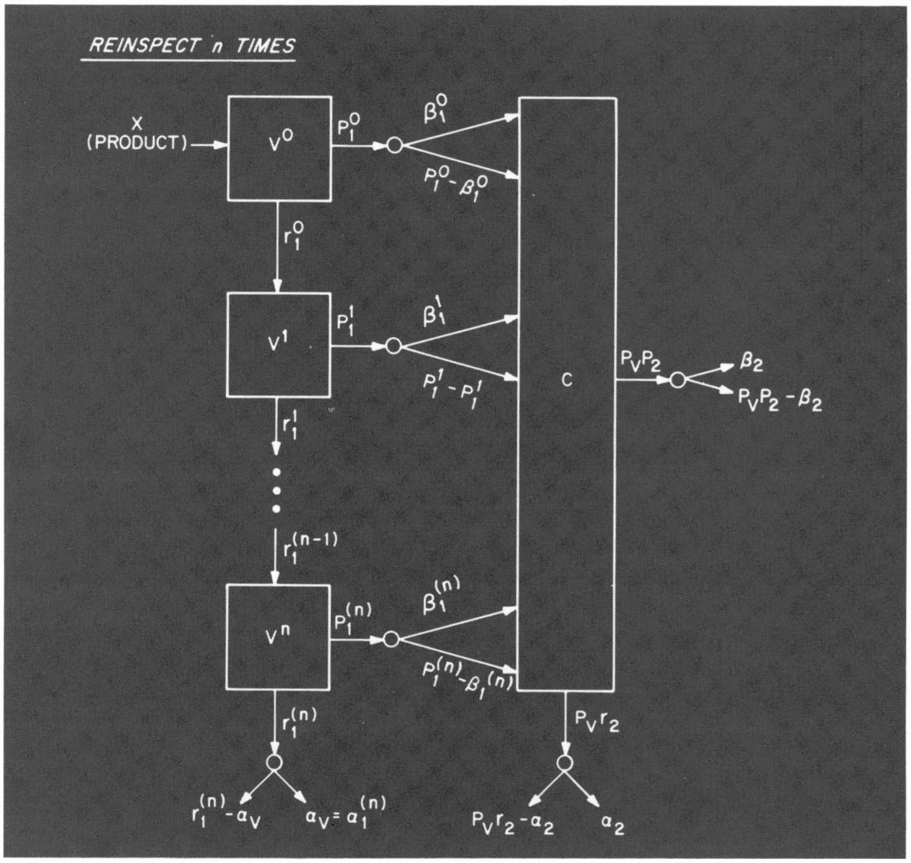


**Fig. 4.** *Reinspection system.*

### *Multivariate product and error distributions*

In many circumstances, more than one product characteristic or attribute is inspected on each product. For example, on a resistor, not only is the resistance important, but also the length and width of each lead is critical for proper assembly. Let us suppose that we are to measure *c* product characteristics. If each of the *c* product characteristics were independent of each other, we would just solve the guardband problem *c* times. However, if some of the characteristics were correlated, we would have to consider the multivariate problem. That is, where *X* has been a random scalar variable, it is now a random vector. Similarly, *E* and *Y* would also be random vectors. The mathematical expressions for the inspection station characteristics in the multivariate case turn out to be no more complex than the scalar case; however, they do involve *c*-fold integrals. This presents a numerical problem because of the computation time required. We estimate, however, that the computation is viable for small *c* (say less than 5). We also note that the optimization of the risk function is now over 2*c* variables, which also makes it extremely computation intensive.

## Conclusions and future work

We have tried to show how the uncertainties that are inherent in product inspection can be placed on a quantitative basis through the use of probabilistic methods. We have outlined the mathematical development and described the numerical algorithms that provide for evaluation of the Type I and Type II errors. The numerical algorithms are flexible and can be adapted to a wide variety of manufacturing inspection systems and to arbitrary product and error probability density functions. We feel that the intelligent use of these algorithms can prove invaluable to those individuals who are intimately involved with inspection.

Although we have treated many variations of the basic inspection problem, there are many avenues that remain to be explored. The first is that of sampling. Until now we have assumed 100-percent inspection of the product. We would like to extend our results to encompass the evaluation of sampling inspection systems, of both the batch and continuous-sampling types. The second area of importance concerns the decomposition of the error distribution into its component parts; that is, into known and unknown sources of error.

Finally, the third major area of interest is the development of an efficient procedure for determining the probability density functions of *X* and *E* from data. In our discussion thus far, we have implicitly assumed that these were known. Yet, only the pdf of *Y* is actually known, because this is the quantity that is directly measurable. Although some reasonable assumptions can be made concerning the pdf of *E* (e.g., normality), this is not in general true of the pdf of *X*. To determine this latter pdf, we are investigating a generic experimental design procedure that could possibly be applied to most of the cases of interest.

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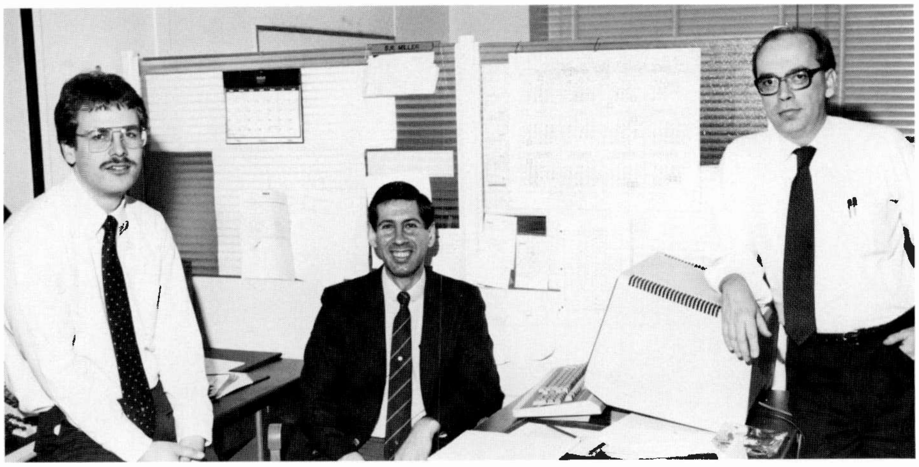

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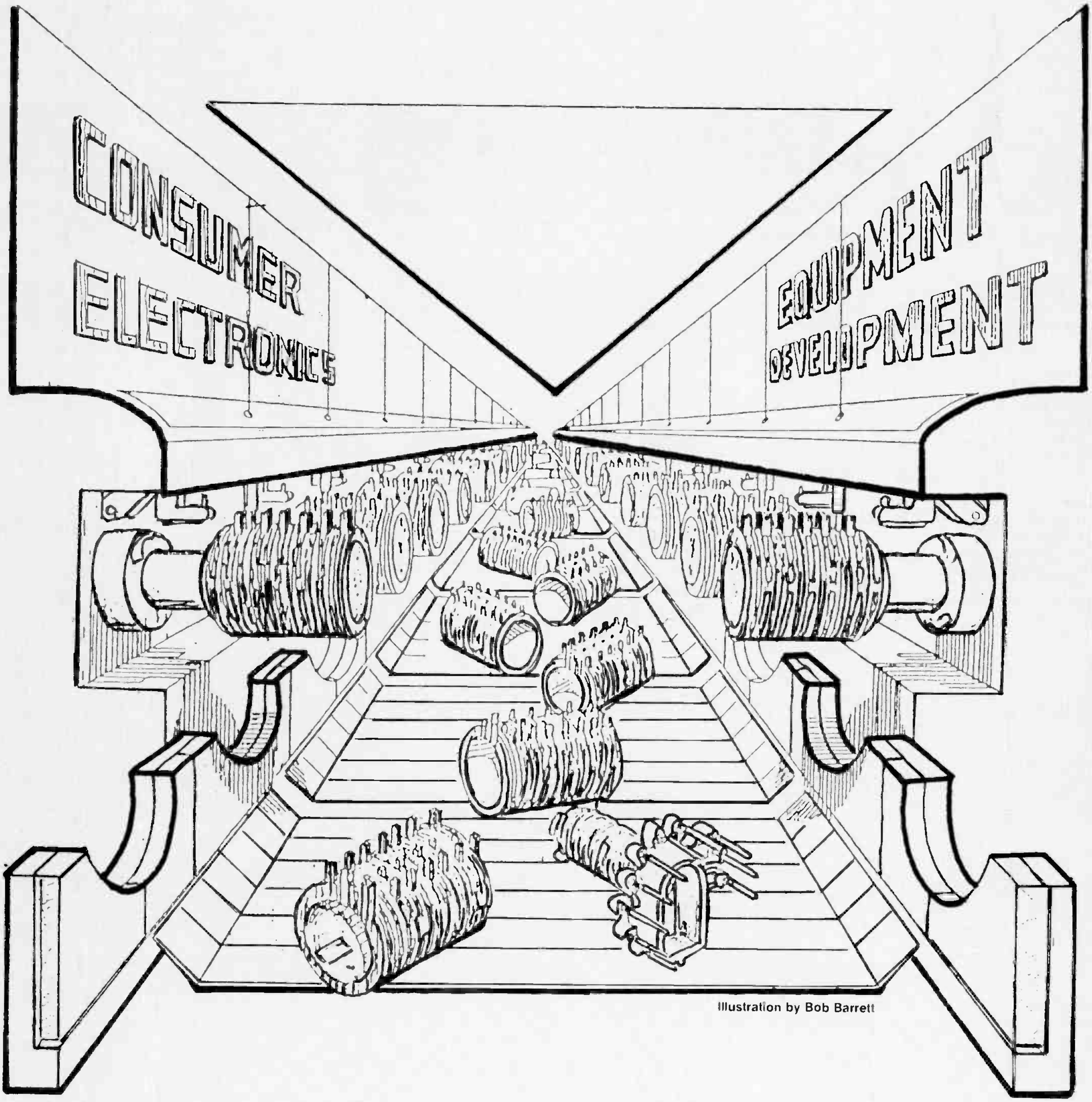

Illustration by Bob Barrett

H. Haslau | J. Hart

# In-house design of manufacturing equipment

*A design group provides expertise for developing and building equipment for the manufacture of competitive products.*

For many years, Consumer Electronics Equipment Development has been actively developing manufacturing and assembly equipment for deflection yoke and high-voltage transformer components and other associated manufacturing equipment. This article will describe several machine and tooling concepts for winding the saddle and toroidal coils that are traditionally used in deflection yoke assemblies and the stick- and bobbin-wound coils that are used in high-voltage transformers.

## Saddle coil winding tool

The deflection circuit engineer provides the winding tool designer with contour data for the coil that deflects the electron beam in the horizontal plane.

**Abstract:** *In-house development of manufacturing and assembly equipment for television deflection yokes and high-voltage transformers has been and remains active. Various yoke and transformer manufacturing methods are illustrated, and the development of specific manufacturing equipment for RCA Consumer Electronics is described. How overall process development, product design constraints, and technological advancements in machine controls affect the evolution of equipment design is discussed. Finally, the authors conclude that continued and increased levels of cooperation between product-process-test and manufacturing equipment groups will be needed to ensure highly efficient and competitive manufacture of yoke and high-voltage transformer products.*

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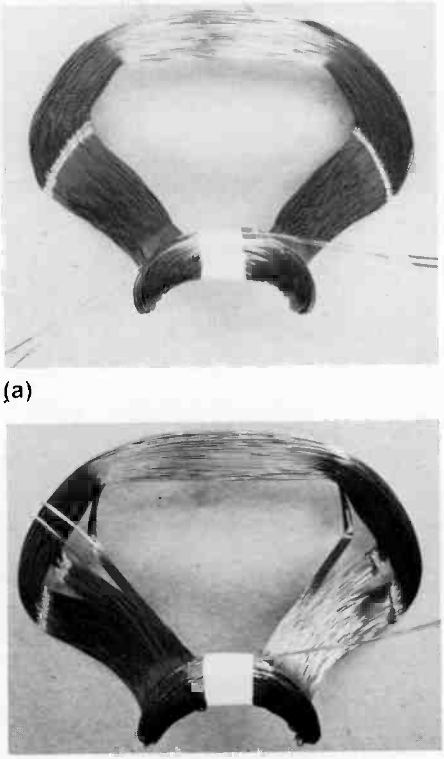
Figure 1a shows a traditional saddle coil. Two of these coils are matched; the small flare end surrounds the picture tube's neck, and the large flare end fits on the tube's funnel. To alter the magnetic coil characteristics the yoke designer changes the coil cross section in the plane perpendicular to the tube's central axis or the funnel contour of the large flare. Figure 1b displays a "peg" type saddle coil. This coil gives the yoke designer flexibility for distributing the wire between the pegs during winding. Pegs are short pins that block the cavity; they may be inserted in various locations at different times during the winding cycle.

Obviously, if one were to wind either coil configuration in Fig. 1, one would need some way to hold the shape and fix the coil during winding. Figure 2a shows such a device, which is called a rotary saddle coil winding arbor, or simply the arbor. The male arbor portion (Fig. 2b) conforms closely to the exterior contour of the picture tube on which the deflection yoke will be mounted. End flanges that control coil length constrain the male part of the coil. A female arbor surface (Fig. 2c) conforms to the coil's desired outside surface.

These two contours must be aligned to each other, and the coil's center portion must be blocked out to retain the desired inner coil shape—the so-called "window." Additional arbor features are required to guide the wire into the cavity.

The following method was developed to bond the coil in a permanent shape after winding. For a short time, a high current of up to 40 amps is passed through the coil while the preformed wire is retained in the arbor cavity. Resistance heating occurs and melts a thermal adhesive coating on the coil wire. After the coil heat has been conducted to the arbor, the adhesive sets and fixes the coil into a rigid permanent shape. Cooling air, blasted through channels in the arbor, may be used to cool the coil after the bonding current is removed.



(a)

(b)

**Fig. 1.** *Typical electron beam deflection coils. (a) is the traditional saddle coil produced for many years by RCA Consumer Electronics, and (b) is a typical peg-type saddle coil, developed and produced by RCA.*

The arbor configuration will depend largely on two things—tube size and yoke

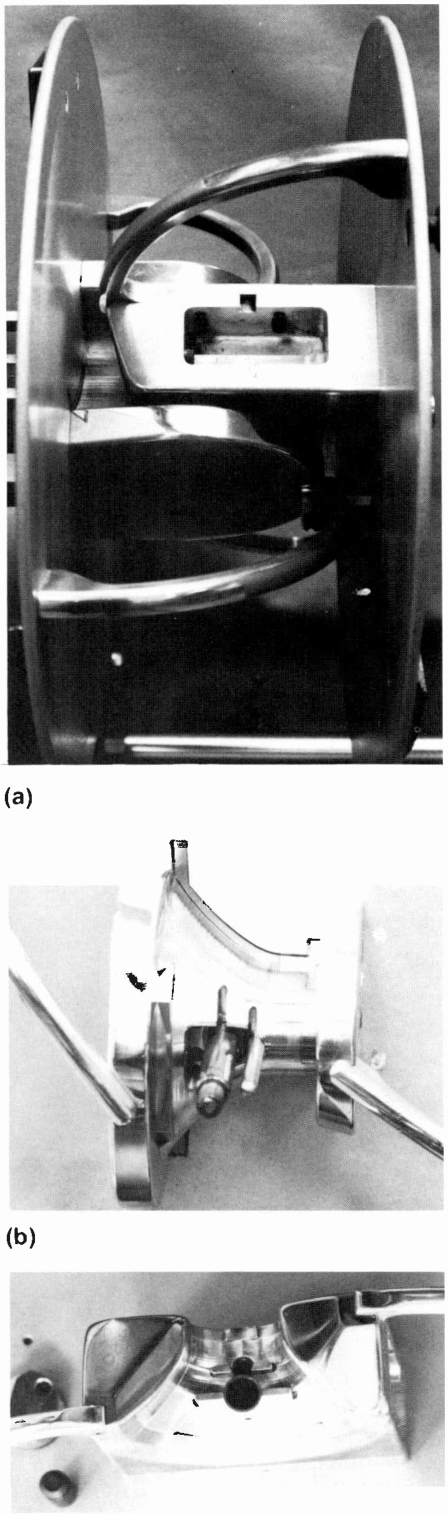


**Fig. 2.** *(a) Typical rotary saddle-coil winding arbor. (b) Male portion of rotary winding arbor. (c) Female portion of rotary winding arbor.*

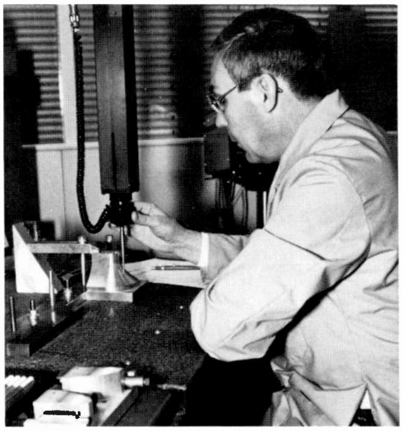
## Complex contour machining

Arbors are manufactured with NC machine tools. Programming a coil's contours is very time consuming. The outside coil surfaces are described by a series of arcs whose radii do not lie on a common axis. Complex calculations must be made to determine the cutter configuration that will optimize the contour surface.

To reduce the tedium of NC programming and the calculation error rate, a small Hewlett-Packard HP 85 computer was used. A data communication link was established with the HP 1000 computer in Magnetics Engineering, which generates and stores the coil contour data.

Vector equations were written to describe various tool positions relative to the contour surface and to satisfy tool-to-surface tangency requirements. Agreement was reached on standardized milling machine fixtures and blank part sizes for each arbor part that was to be contour-machined.

Computer programs were written that enabled coil data to be downloaded to the HP 85 computer, where the data is processed through the proper set of vector equations to determine tool cutting positions, and into an NC program for the milling machine. Later, all programs were converted from HP Basic to Fortran 77.



*Contour measurements on male arbor taken on Cordax machine.*

These programs are menu-driven and protected so that noncomputer personnel who are familiar with arbor fabrication can effectively run the programs and produce quality NC software. All computer programs were generated in-house because, when the project started, no commercial software was available to machine three-dimensional, convoluted, curved surfaces with ball end mills.

Processing the coil data and generating NC milling machine software on a computer saves about 80 manhours per arbor manufactured. In addition, all female and male arbor contours are verified on a Cordax Machine.

performance requirements. Throughout the industry, either rotary or stationary winding arbors that may or may not contain pegs are used to wind these coils. Deflection yokes with more demanding performance specifications will usually require the use of pegs.

To begin arbor development, all contour data is transformed into computer-generated programs for the milling machine (see sidebar). For common parts, standard programs are used. But as many as 13 numerically controlled programs are newly generated or reused to contour-machine various arbor parts. At this point, the tool design is essentially completed and fabrication of parts can begin.

Completed parts are assembled in the Equipment Development Lab, (Fig. 3), and the finished arbor is installed on a winding machine for initial tests and subsequent prove-in. Coils are wound and processed into fully assembled deflection yokes, and their performance is tested.

Using the test information obtained, the arbor may be adjusted to obtain desired coil performance changes. When performance is acceptable, the arbor is approved for production use, and the tool is released for shipment to CE production facilities. All arbor approval tests are done on production compatible equipment located in the Equipment Development Laboratory to ensure that the arbor will produce an acceptable product when it reaches the production plant.

## Saddle yoke coil winding machines

In the late 1940s, RCA was instrumental in developing rotary yoke saddle coil winding equipment for black-and-white television. From these early machines, today's winding equipment (Fig. 4) has evolved into very reliable, high-output machines.

This rotating arbor design is very efficient because it does not have periods of inactivity during the winding cycle, as does the oscillating type of machine. The high rotary inertia of this system eliminates the need for complex tension control devices to take care of wire loops or pullback. Wire dynamic loading in the tension device is greatly reduced because the only moving part is the wire.

The high-speed rotary winding machine typically winds a non-peg saddle coil in less than 10 seconds. Usually, the total machine-cycle time will be less than 20 seconds. Figure 5 shows the winding concept for this machine. As the arbor rotates, a fixed-position wire guide and tension device feeds wire via highly polished wire guidance vanes into the arbor cavity. To remove the coil, the arbor halves are separated along the axis of rotation much the same as a plastic part comes out of an injection press mold.

One machine feature that should be mentioned is the arbor protection system that prevents arbor damage from shorts between the coil and arbor surface during the bonding cycle. During bonding, the machine provides up to 40 amps to the coil and occasional breakdown of the wire insulation cannot be avoided. Notable circuit design improvements have been made for arbor protection so that arbor damage from shorting or burning is an extremely rare occurrence—in the early days, production tools were removed frequently for repair. This single improvement in arbor protection contributes much to the overall productivity and reliability of arbor and machine.

Another machine concept that CE has used for yoke development is the oscillating flyer winder (Fig. 6) that feeds wire through the rotary axis and out to the tip of the flyer. The flyer may revolve up to 270 degrees before reversing rotational direction. When one compares it to the earlier machine, the arbor axis is perpendicular to the flyer rotary axis.

To guide the wire into the cavity, the outside contour of the female arbor half is formed into a vane that is canted. Just before the flyer reverses direction, the wire

**Fig. 3.** *Arbors in final assembly stage handled by skilled and experienced technologists in the Equipment Development machine lab.*

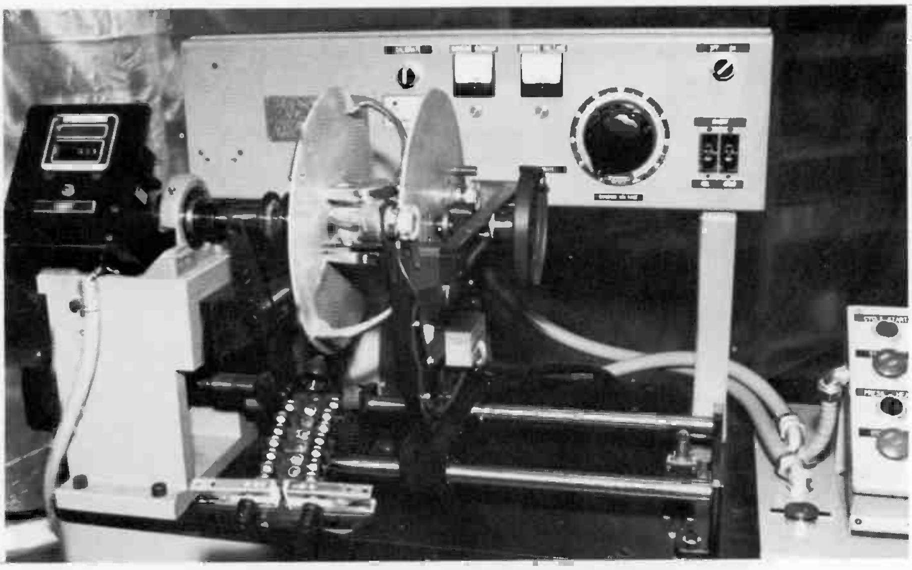


**Fig. 4.** *Rotary arbor mounted on production winding machine.*

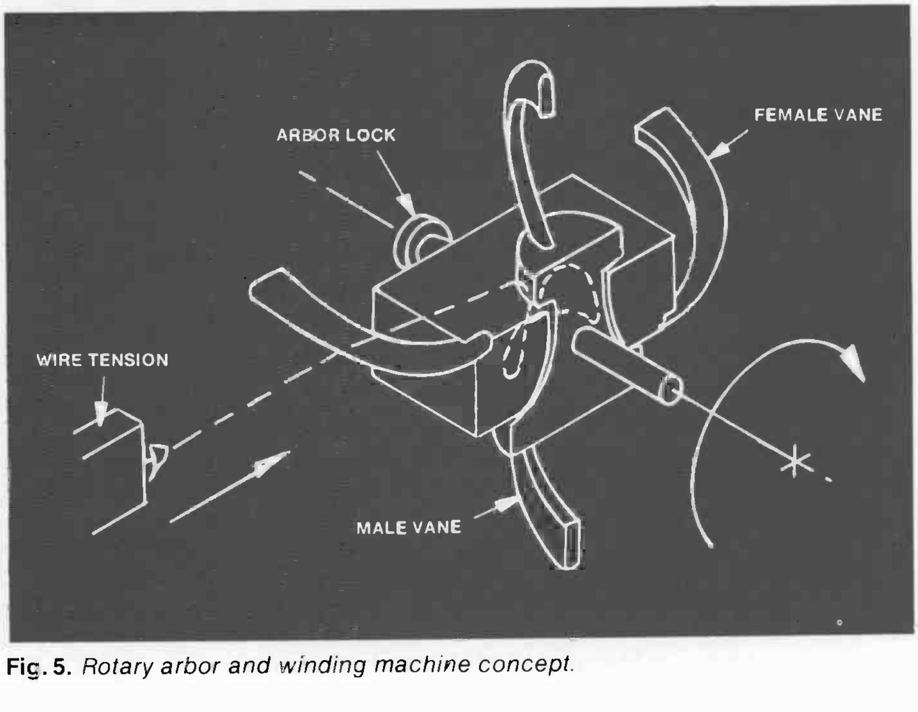


**Fig. 5.** *Rotary arbor and winding machine concept.*

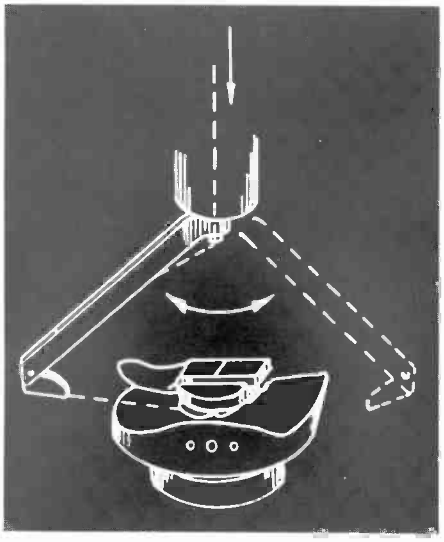


Fig. 6. *Stationary arbor and oscillating flyer machine concept.*

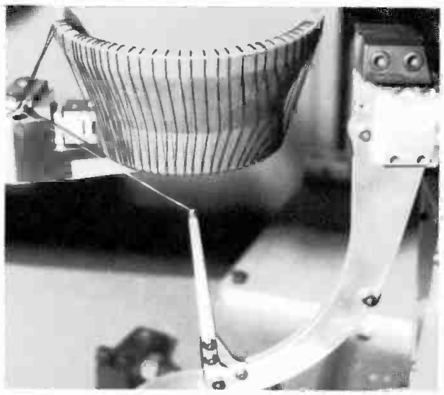


Fig. 8. *Typical placement of first layer turns on a ferrite core half. Wire distribution patterns are numerically controlled.*

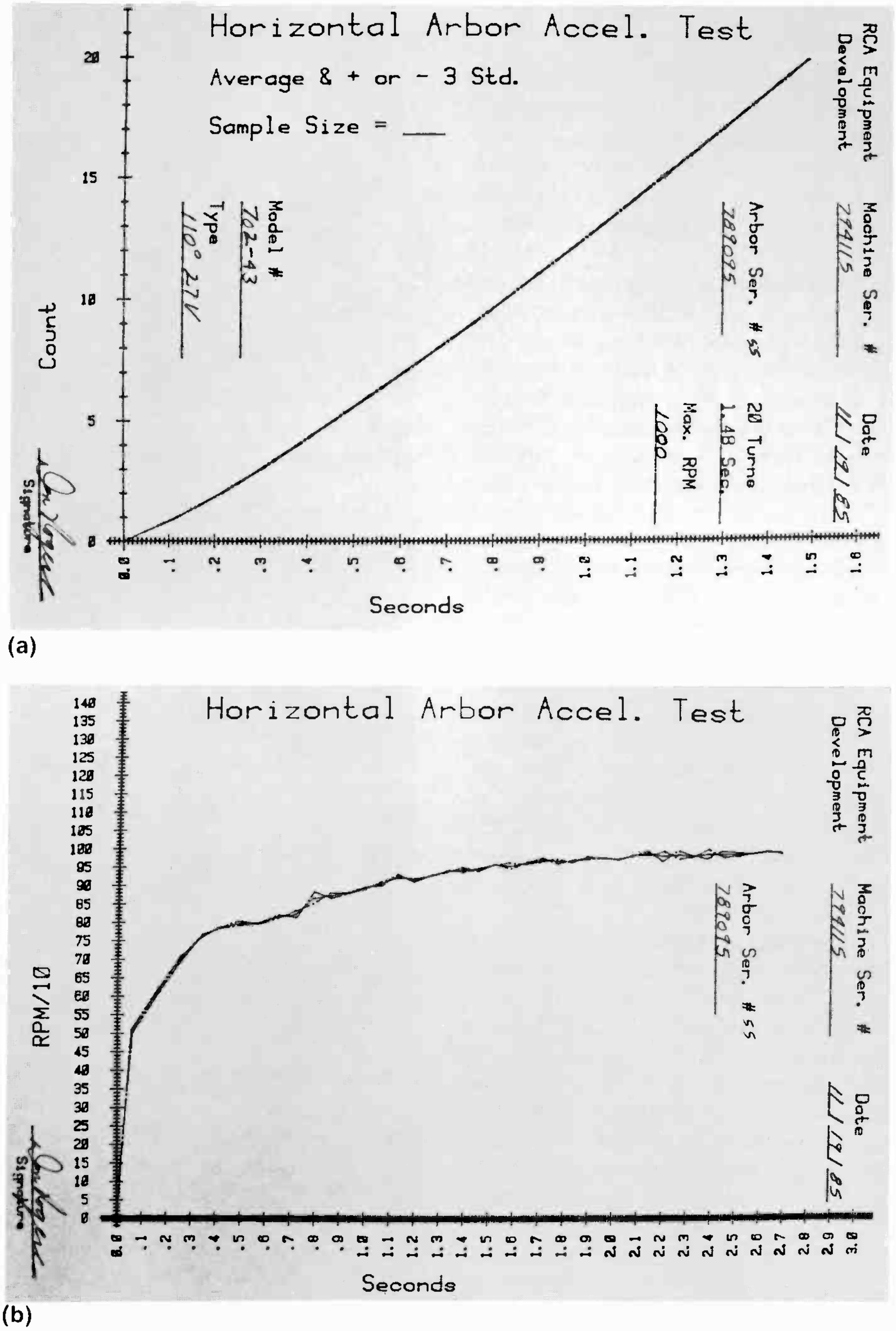


Fig. 7. *Test curves for arbor acceleration: (a) rotary displacement and (b) velocity, with bounds for average and standard deviations. Machine and arbor acceleration must be within a certified tolerance window before arbor approval run can begin.*

clears the vane tip. The wire tension device provides pull-back to retain wire tension at all times. Thus, the wire is forced to slide up on the top or bottom of the vane surface, depending on the direction of the flyer reversal, and guides the wire into the arbor cavity. To open the cavity, the flyer must be revolved clear so that the female arbor part may be removed from the male portion.

## Machine and arbor system performance test

Equipment Development has developed a machine performance test procedure to ensure that all production winding machines can be quickly tested. This test is done with the arbor mounted on the machine. Signals from the winder control board are processed by an HP 85 computer. Prompting software guides the tester through the test procedure, and ten data sets are recorded as the arbor accelerates from zero to steady-state speed. Time averages and standard deviations are computed for each full revolution up through the fortieth. This data is incrementally differentiated to obtain the arbor velocity as a function of time. The rotary displacement (Fig. 7a) and velocity data (Fig. 7b) plus bounds for plus or minus three standard deviations are plotted. This documentation is used to coordinate arbor and machine setup in the Torreon facility for the newly approved arbor.

## Toroidal yoke coil winding machines

Equipment Development has designed and fabricated manufacturing equipment to wind toroidal coils on ferrite cores for vertical yoke deflection. The windings on

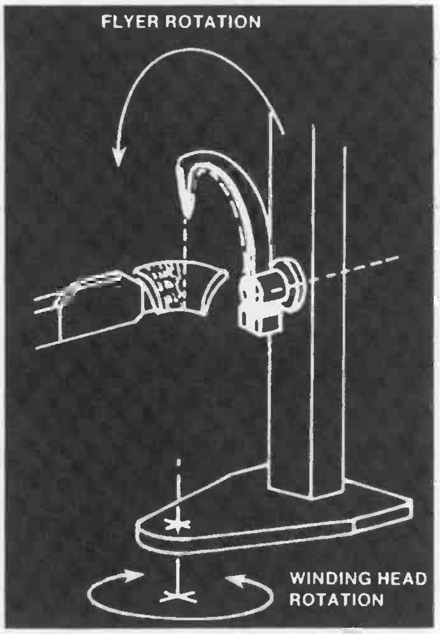


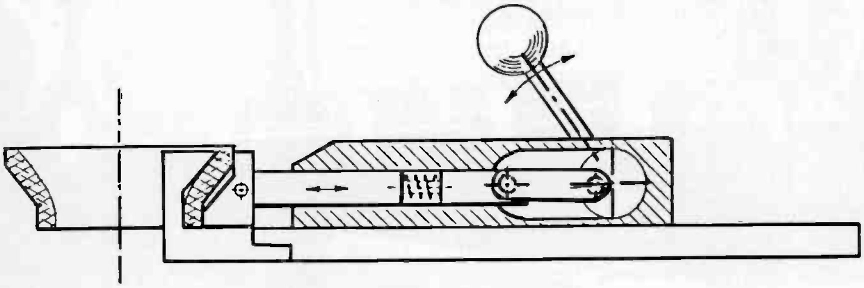
**Fig. 9.** *Cradle-mounted flyer for winding toroidal coils.*

the core, which may be multilayered, are characterized by the type of wire distribution, such as radial, slightly biased, and severely biased. Figure 8 shows a partially wound toroidal coil. For the machine designer, this product presents interesting challenges: How to hold the cores, how to wind and hold the windings in place, and how to wind cores with high machine output?

Equipment Development has developed the two-axis machine concept (Fig. 9) where the core is fixed in space. Mounted on a mechanical yoke assembly, the flyer rotates radially to the core, while the yoke pivots on an axis to keep the flyer tip rotating in a plane that includes the central core axis. With the two axes set this way, radial coil turns will be wound onto the ferrite core. If one designs the core holder so that the core and flyer axes are not perpendicular to each other, one can wind slightly biased coil turns onto the core. The degree of bias is a function of the frictional coefficients between the wire and ferrite core and between the wire and the previous wire layer.

This concept evolved into a machine (Fig. 10) that simultaneously winds four cores in the vertical plane. Core clamps are mounted on a four-level tree with several branches. While one set of cores is being wound, another core set that has been wound can be removed and replaced with unwound cores. This design has enabled high machine productivity rates because loading and unloading do not inhibit the winding process. In addition, the floor

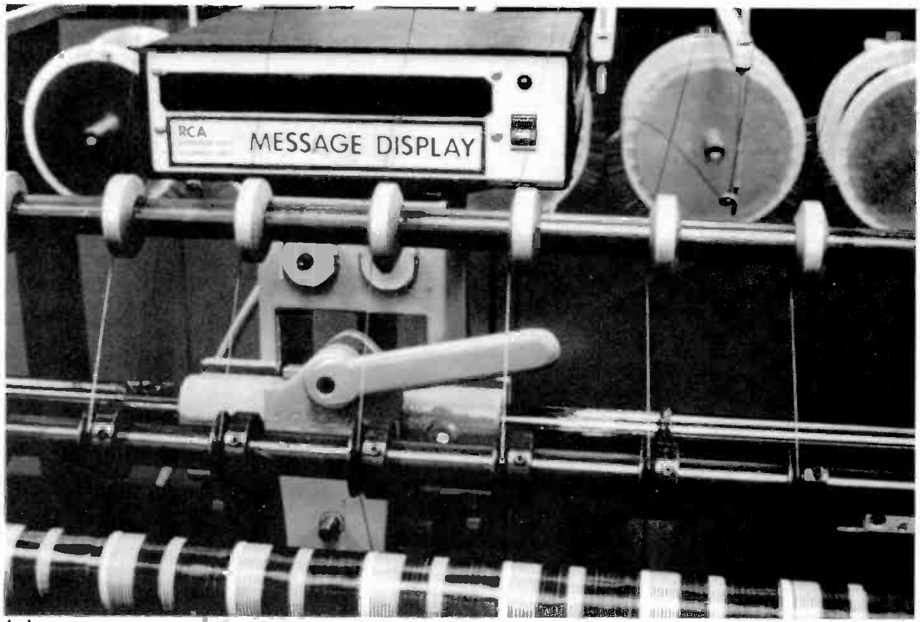
## Toroidal coil winding process



*Core clamp concept for toroidal coil winding machine.*

Another aspect of putting toroidal windings onto ferrite cores is the method used to hold the cores during the winding process. The fired ferrite material is like glass in strength and impact resistance. The accompanying figure depicts the basic method used to clamp the core on the end for a two-axis winder, or in the middle for a three-axis winder. Compliance must be built into the clamp mechanism to accommodate core thickness variations—the clamp must not crush the thicker core, yet it must grip the thinner core with enough pressure so that the core can withstand winding forces without moving in the clamp.

**Fig. 10.** *Four-level production winder for toroidal-type vertical deflection coils under construction in the Equipment Development machine assembly lab.*



(a)

**Fig. 11.** *Numerically controlled "stick winder" with message display for machine operator: (a) coil stick; (b) stick-wound coil cut from stick with taps pulled from the cut ends.*

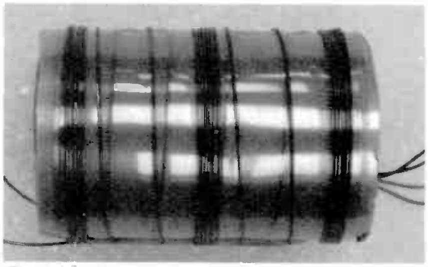


**Fig. 11. (b)**

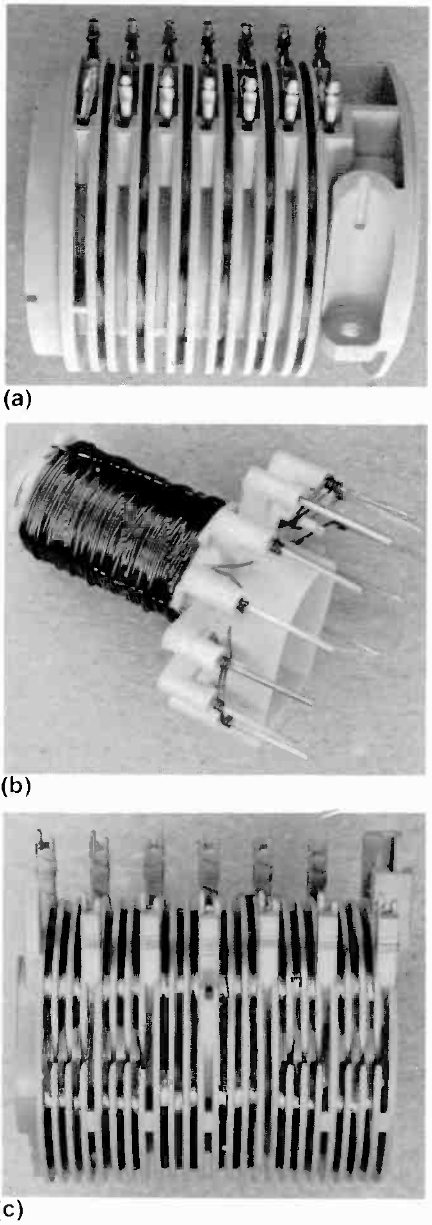


**Fig. 12.** *Three types of bobbins for high-voltage transformer (HTV) coils: (a) HVT tertiary coil bobbin wound and terminated on in-house designed and built winding machines; (b) ROSE primary bobbin as it comes off the winding machine prior to the dip-solder operation; and (c) ROSE transformer tertiary coil as it comes off the 12-spindle automatic winder.*

**Fig. 13.** *High-volume HVT tertiary coil winder.*

space required for the machine is greatly reduced, and minimal operator movement is required for servicing the machine.

## High-voltage transformer winding and assembly equipment

As with deflection yokes, RCA-CE has a long tradition of producing its high-voltage transformer windings on in-house-designed equipment. Two fundamentally different winding methods are currently in use to mass-produce high-voltage transformers at CE. One is the "stick winding" method, and the other is the "bobbin winding" method. Equipment Development has designed and fabricated both types of winders.

The "stick" winder (Fig. 11) simultaneously winds a series of identical multiple-layer coils. It coordinates two axes so that the traverse placement of wire for each layer can be numerically controlled. The first coil layer is initially wound on a paper tube that the operator slides over a long winding spindle. After each wire layer is wound, the machine stops or slows down

## ROSE winding equipment

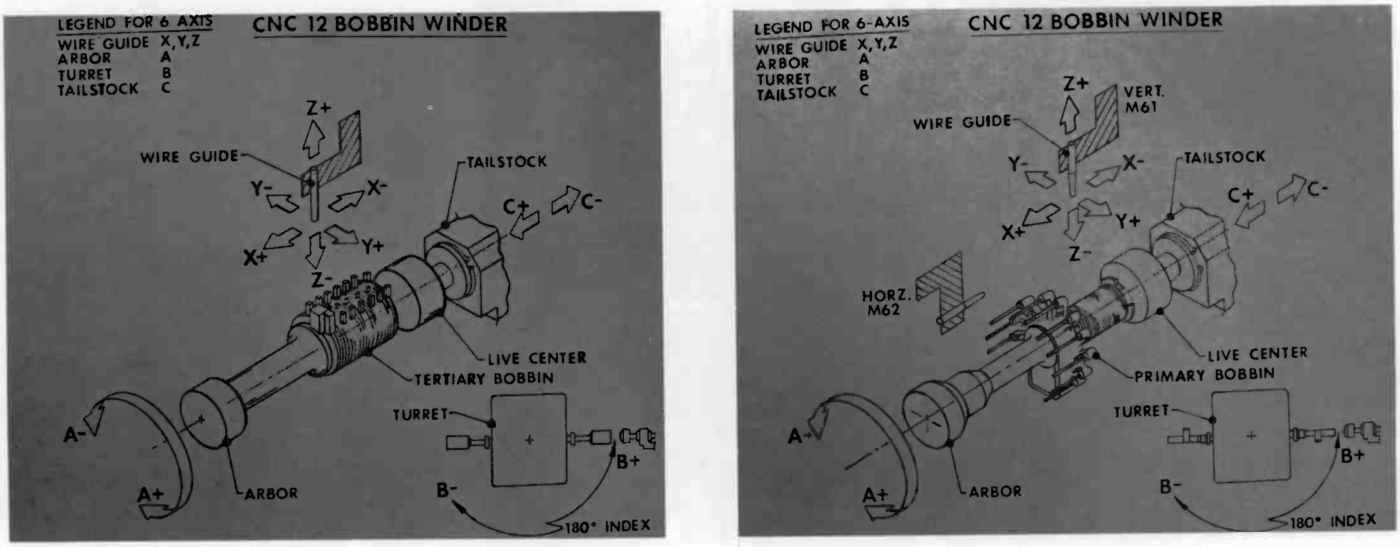
Production winders for ROSE transformer primary coils in operation at CE's component plant in Indianapolis.

ROSE production winder for tertiary coils. Winding on the right, load and unload on the left.

The ROSE winding machine shown here mounts two sets of twelve spindles. One spindle set is located on each side of a turret that rotates in the horizontal plane. A wire guide nozzle bar, which holds twelve nozzles, locates and guides the wire to the bobbin-mounted spindles.

This machine has a programmable six-axis numerical control. Four of the axes are coordinated by linear, circular, and helical interpolation so that bobbin rotation and movement of the wire guide nozzle are interdependent. Control resolution is one ten-thousandth of an inch at the wire guide nozzles. Resolution for the bobbin in rotation is 0.001 revolution for the primary winder and 0.002 revolution for the tertiary winder. Bobbins can be rotated at more than 3000 revolutions per minute. All drives are powered by dc servomotors.

Standard controls are used that were modified for the application. Winding machine programs can be entered from an on-console keyboard, read from a magnetic tape, or downloaded to the control through the RS-232 interface. Winding machine control memory can be viewed on the console screen. Also, memory can be dumped to magnetic tape, or uploaded through the RS-232 port to an HP 1000 computer for program editing and storage.



(a)

(b)

**Fig. 14.** *Movements of numerically controlled axis on CE's 12-spindle bobbin winder: (a) setup for ROSE-type tertiary bobbins; (b) setup for ROSE-type primary bobbins.*

so the operator can insert a sheet of mylar film that is wound onto the coil stick to insulate each winding level. Much operator and machine interaction is needed to ensure a high-quality product.

After the coil stick has been wound and removed from the spindle, an operator cuts the stick to separate the identical coils (Fig. 11b), pulls taps from the cut ends, and mounts the coil with the other components that make up the transformer. The method's advantages are: the winding machine requirements are straightforward, and a large number of coils can be wound simultaneously on one machine. However, this method of coil winding is somewhat labor intensive, and requires that machine operators have good coordination skills to obtain high machine productivity.

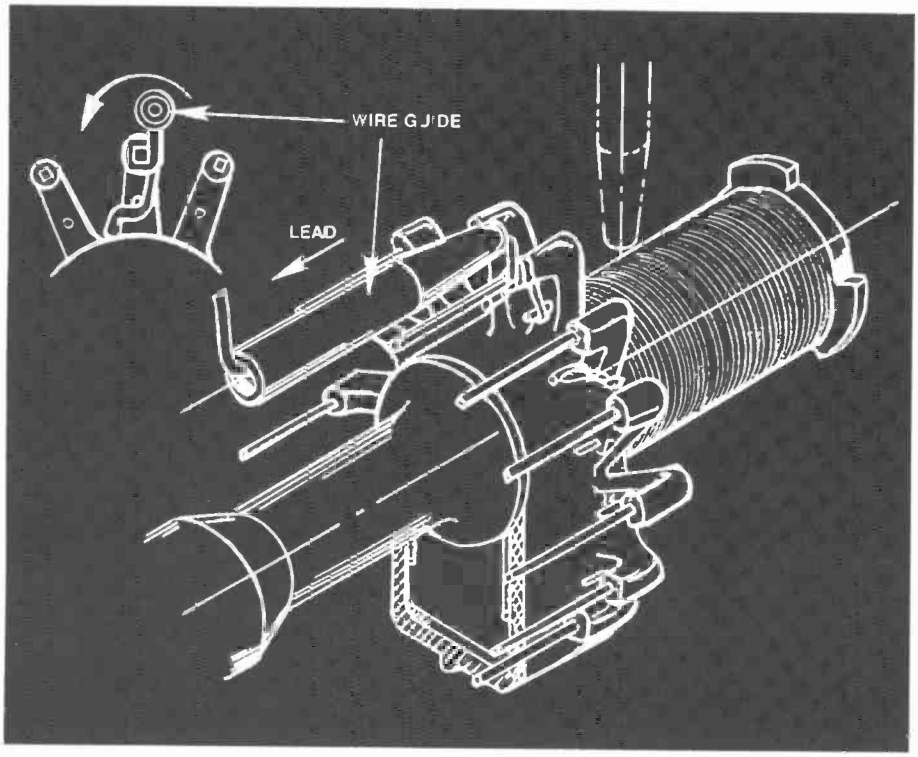


**Fig. 15.** *Horizontal wire guide in process of wrapping square stake lead on primary bobbin.*

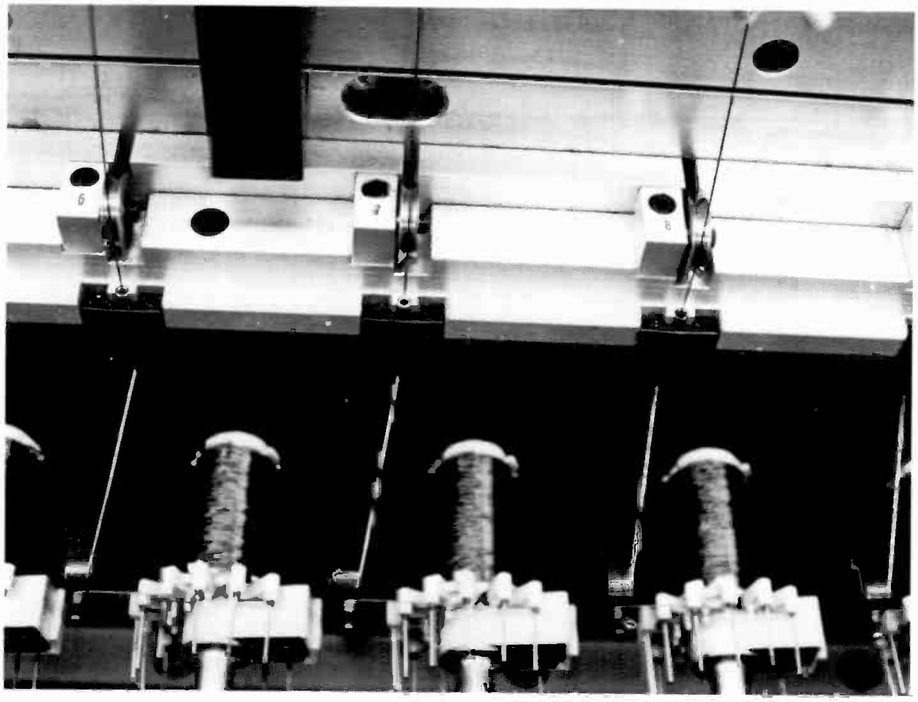


**Fig. 16.** *A completed winding cycle on the 12-spindle ROSE primary bobbin winder. All wires are terminated on bobbin terminals. All wires from the supply spools are secured and wrapped around the tie-off post. The turret is ready to rotate 180 degrees and start the next winding cycle.*

To counter these disadvantages, the various coils that make up the high-voltage transformer (HVT) can also be wound on plastic bobbins (Fig. 12).

Tertiary coils (Fig. 12a) for the stick-wound primary flyback transformer are bobbin-type coils. These coils are wound on a four-axis winding machine (Fig. 13) that simultaneously winds 30 wires onto five bobbins with automatic wire termination. The horizontal-axis turret allows bobbins to be on- and off-loaded while the machine is winding. The numerical control and the machine were built in-house. Winding machine programs are loaded into erasable, programmable memory, and installed in the control.

Until the new ROSE (reliability optimized and stress engineered) high-voltage transformer was introduced, four tertiary coil machines produced all high-voltage tertiary coils for CE.

The ROSE primary coils (Fig. 12b) are usually wound with a larger diameter wire than the tertiary coils (Fig. 12c). In addition, the primary bobbin contains square wire stakes for most internal and external electrical connections to the transformer.

The winding machine for the tertiary coil (Fig. 14a) must coordinate axes to rotate the bobbin, and move a wire guide in a plane that is perpendicular to the wire guide axis. It also moves the wire guide along its own axis. Two additional control axes are required for auxiliary functions that permit loading and unloading the bobbins while the machine is winding.

The primary bobbin winding machine (Fig. 14b) requires one more control axis for pivoting the wire guide nozzle to wrap finish and start square stake leads that lie on axes parallel to the bobbin's rotary axis.

## Wire termination

A major reason for winding transformer coils on preformed plastic bobbins is that the wire can be automatically terminated and controlled during and between winding cycles. Several methods have been developed for doing this.

For primary coil bobbins, a square wire

stake driven into the plastic bobbin acts as a position for wire termination and a way for mounting the completed transformer to the printed circuit board. Figure 15 shows the wrapping of the square wire stake.

But how does one move from a finish lead to a start lead without having to remove wire manually between the two leads? This is done with a machine wire tie-off post, Fig. 16. Here, the nozzle wire wraps the finish stake and then moves to the left to wire-wrap a machine-mounted tie-off post. As the arbor rotates clockwise, the wire breaks on the sharp edge of the square wire stake.

The bobbin is then rotated to the next start-lead stake, the nozzle moves to wrap this square wire stake (Fig. 17), and the wire nozzle stops above the start stake. Again, the bobbin is rotated clockwise to break the wire between the tie-off post and square stake, and at the square stake. To remove the wire from the machine tie-off post, the post retracts, which strips the wire from it. The wire falls into a collection tray.

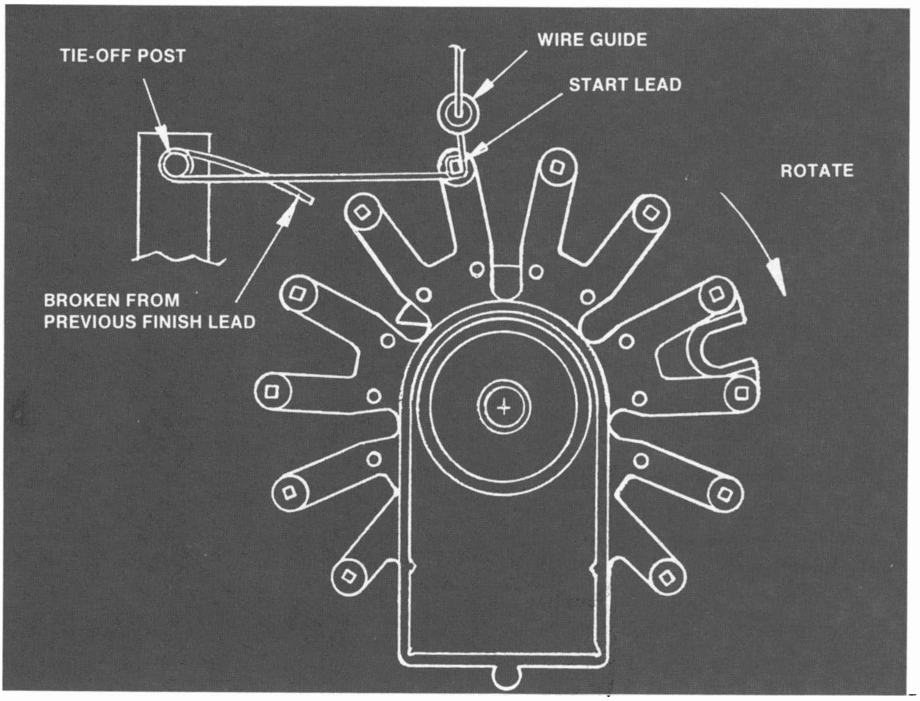


**Fig. 17.** *Wrapping start lead and breaking of wire by rotating bobbin.*

On tertiary bobbins, special bobbin features control wire termination during winding. Figure 18 illustrates a simple bobbin with square wire stakes and auxiliary tie-off posts for automatically cutting the wires. Suppose one comes from the machine tie-off post and wraps start-stake one, winds wire into the slot, wraps finish-stake two, and then wants to wrap start-stake three. Without the auxiliary post, you would have to hold the wire while cutting both ends next to stakes two and three. But, if you wrap the auxiliary post before wrapping stake three, the wire is secured. A simple, square breaker bar then passes just inside the stakes to break the wires on each side from the stakes. Another pass through the middle removes the auxiliary tie-off posts, and the bobbin is ready for dip-soldering. However, the reflow soldering termination technique requires that additional features be added.

Figure 18b shows the method used to break coil-start leads. To stabilize the wire, the nozzle approaches the top of the start post and wraps two turns about the taller of the two prongs that rise from it. Then, as the nozzle dives down to wrap the bundle on the main post, it breaks the wire near the start lead post, where the wire

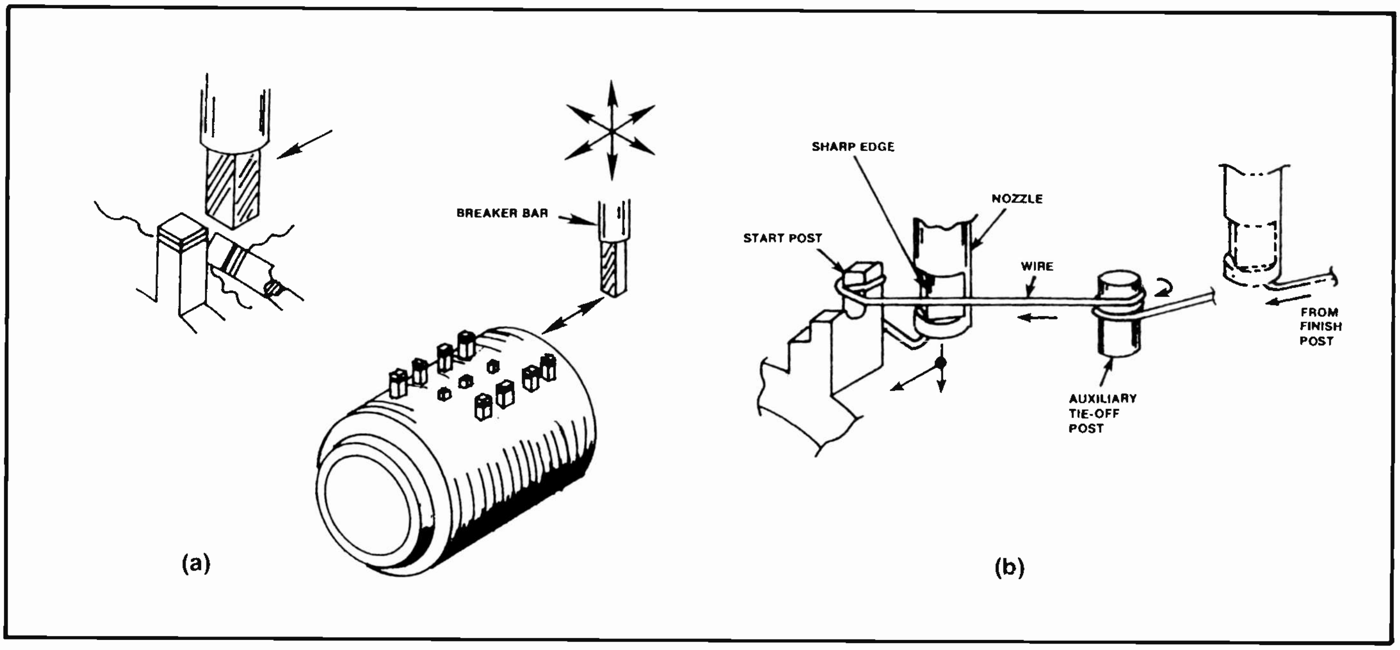


**Fig. 18.** *Controlling wire terminations for tertiary bobbins: (a) removal of temporary wire termination posts by breaker bar; (b) wire control while wrapping tertiary bobbin start post.*

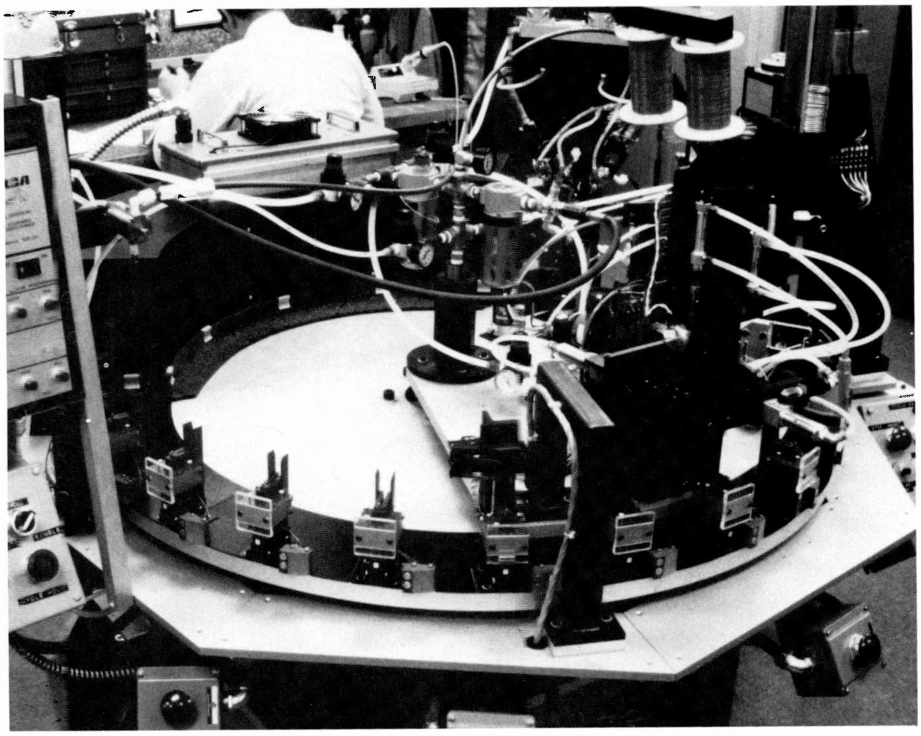


**Fig. 19.** *Inductance set and assembly machine for ROSE transformers.*

breaks is controlled by the programmed nozzle position and the sharp surface ground onto part of the nozzle. All coil finish leads and auxiliary bobbin tie-off posts are broken or removed by the square breaker bar method described previously.

## Assembly

Assembly of the ROSE high-voltage transformer begins by inserting the primary-wound bobbin inside the tertiary-wound bobbin. Then, both bobbins are placed in a thin-wall plastic cup. Epoxy material is poured into the cup to fill all intervening space. After the epoxy has cured, the transformer is ready for final assembly.

Using a machine developed in-house (Fig. 19), the operator places one half of the C-core onto a fixture, and puts the encapsulated coil over the C-core half with the stake leads down. The fixture moves under a station that automatically cuts and places a small length of twisted copper wire on each upper surface of the C-core half. It moves again, and the operator puts the second C-core half in place. The mating surface is coated with a fast setting adhesive. Next, the fixture moves to where a spring-clip is inserted to hold the two C-core halves firmly together against the twisted copper wire.

After the fixture moves to the next station, a ram moves down to press the upper C-core half against the copper wire and the lower C-core half. Through electrical connections made to the transformer mounting fixture, transformer inductance is tested, and the ram crushes the twisted copper wire until the proper transformer inductance is found. After the inductance has been set, the ram retracts, and the fixture proceeds to another station. Here, adhesive is applied to the spring clip, the upper C-core surface, and on each side of the upper C-core where it passes into the top of the cup. The transformer moves through an adhesive curing station to a final inductance test station. After final test, an ink spray marks the good transformers, and the operator removes them from the machine. The machine can process one transformer every 10 seconds.

The ROSE assembly and inductance set machine is an example of a cooperative effort between the Machine Development and Test Equipment Development Design groups. The basic machine is numerically controlled, and the test and inductance set equipment are computer controlled. The machine was designed for manual and automatic operation.

**Jack Hart** joined RCA at Indianapolis in 1981 as a Senior Member of the Engineering Staff. Dr. Hart's chief responsibility has been to initiate and support advanced yoke development projects within the Equipment Development group. Much of his effort has centered on higher language software development to produce NC programs for product development and on sigma reduction projects. Jack received his PhD in Mechanical Engineering from the University of Missouri. Prior to joining RCA, Jack was an Associate Professor of Mechanical Engineering with the Purdue University School of Engineering and Technology located in Indianapolis.
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**Consumer Electronics Operations**
**Indianapolis, Ind.**
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**Horst Haslau** joined RCA in 1960 as an Equipment Development Engineer in Camden, New Jersey. In 1968 he transferred to Indianapolis, Indiana to become Manager of Mechanical Design in CE's Equipment Development group. Currently, he manages this group. Prior to his service with RCA, Horst spent many years in Europe designing and building manufacturing equipment for the TV and radio industry. He is a recipient of the David Sarnoff Award for Outstanding Technical Achievement. Horst received his Engineering Degree in 1952 from the School of Engineering in Kiel, West Germany.
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**Fig. 20.** *Machines designed for the Torreon production facility: (a) high-voltage transformer primary coil stick winders; (b) saddle coil winding machines; (c) toroidal coil winding machines.*

## Summary

Equipment Development has been fortunate because we normally develop both the engineering prototype and the manufacturing production equipment. Therefore, we can advise product development engineers of the risks associated with product designs that require new and unproven manufacturing techniques. Also, because we develop the prototypes, we can use the knowledge we gain to design production machines. This helps to smooth the transition of the product from design development into production.

The proximity of product design and production helps Equipment Development maintain the continuity of projects and shorten project schedules rather than work with outside vendors. The in-house design group's expertise ensures that RCA-CE interests are paramount when we deal with outside vendors for those pieces of manufacturing process equipment that are not priority.

Without such a pool of expertise, much stronger constraints would have to be placed on product design groups to accommodate the availability of vendor equipment. Also, Manufacturing would have to increase its pool of expertise or use more consultants from vendors in order to maintain and repair sophisticated manufacturing process equipment.

Equipment Development is committed to production machine designs that are cost effective. It designs machines that have high ratios of product to labor, to capital, and to downtime. To achieve these gains, most designs use state-of-the-art electrical control systems. We follow conservative mechanical design to ensure that machines will outlast the product line produced and require a minimum maintenance. All these machines were designed with the idea that they will be serviced by automatic materials handling equipment.

At this point some observations may be in order about the future of Equipment Development and its role. RCA-CE is facing strong competition, and needs a well-designed and manufactured product that must be produced at a competitive price. The level of sophistication of the product and the manufacturing process is increasing. The integration of automation into the manufacturing process will become necessary to keep the product competitive, to improve product consistency, and to enhance product quality and performance.

To provide this automation, all functional groups involved must cooperate with one another. Product design, manufacturing, test equipment, and manufacturing equipment will have to work in parallel to collapse product development times and ensure low-risk startup of new product manufacturing lines. Support groups, such as Equipment Development, must coordinate their efforts to help identify possible risks involved when their equipment is merged into a manufacturing process line.

To achieve the needed level of integration, in-house expertise must be maintained and upgraded to keep the manufacturing equipment facilities at the state-of-the-art. Equipment Development must aggressively study changing technologies, anticipate what skills will be needed in the future, and then actively encourage upgrading personnel to meet those needs. If we can do this, Equipment Development will become stronger, and RCA-CE will become less dependent on outside vendors for new manufacturing technology. Such a pool of expertise produced the machines shown in Fig. 20 for the Torreon facility.

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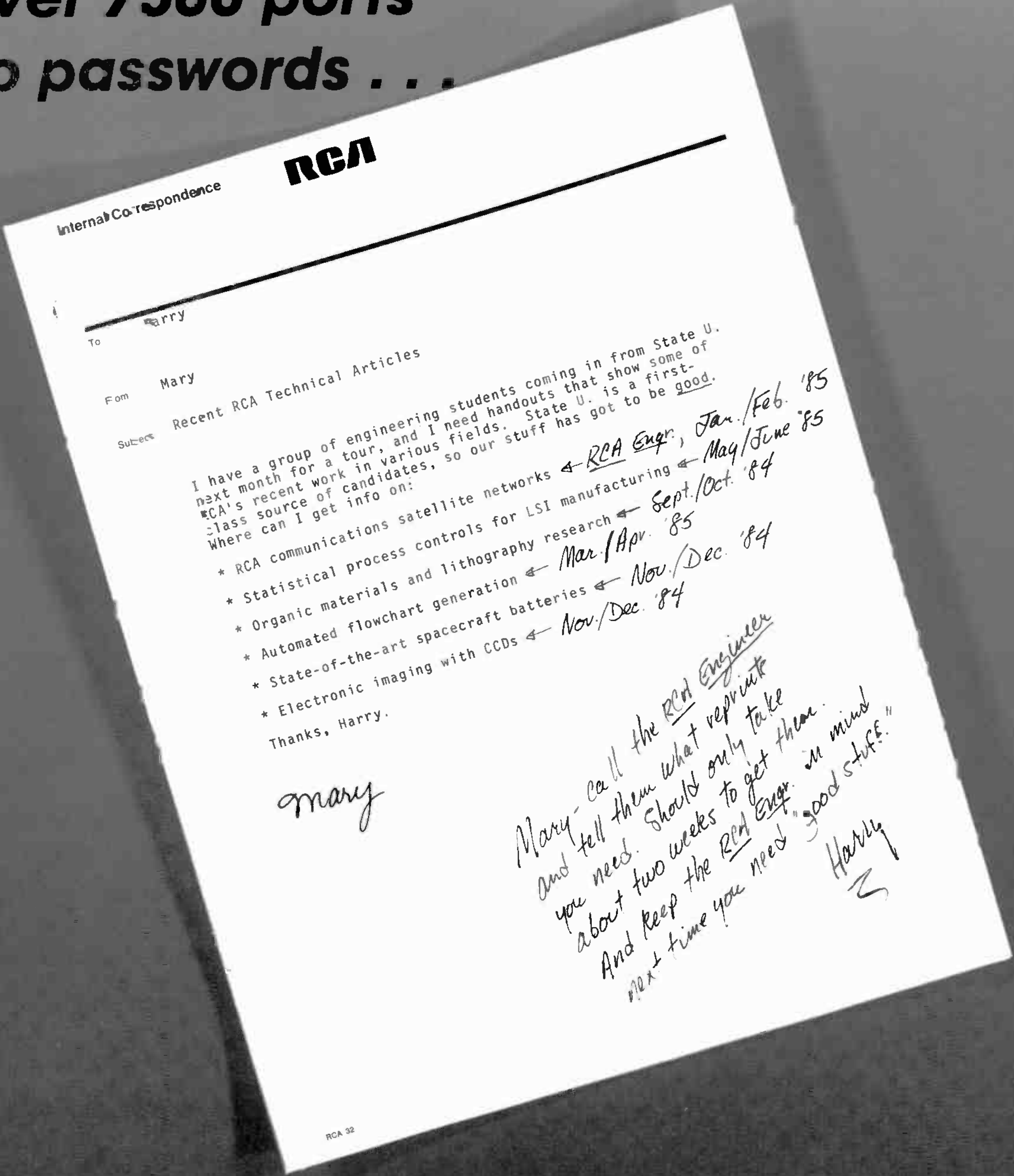

Internal Correspondence

RCA

To Harry

From Mary

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Thanks, Harry.

Mary

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RCA 32

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# Imperfect computer simulations provide valuable results

*Nearly everyone agrees that the absolute values of plastics processing computer simulations are unreliable, so why and how do we use them to make decisions that may have serious consequences?*

Imperfect computer simulation results, when used carefully, can provide valuable insights. Plastics injection molding is widely modeled in spite of known problems with the accuracy of the simulations. But even with their shortcomings, these programs may be used with confidence to predict actual conditions and get real answers.

## The molding process

Before we move on to the discussion of simulations, a brief description of the molding process is called for. The injection molding process can conveniently be thought of as two relatively separate operations. The injection phase is the filling of the mold with hot molten plastic; the packing phase is the cooling and shrinking of the part until removal from the mold. Generally, the injection phase determines many of the critical physical properties, and the packing phase determines the appearance and final dimensions.

As the plastic flows to fill the mold cavity, the injection pressure depends on the geometry, filling speed, and viscosity of the plastic. The viscosity depends on shear rate and temperature. During injection, heat is generated by viscous dissipation and removed by conduction through the mold walls.

After the mold cavity is filled and cooling begins, the plastic shrinks 10-25 percent. As the material shrinks, additional plastic is packed into the mold to keep the cavity full and to reproduce the details of the mold.

During the injection-molding process the hot plastic is injected under pressure into a cold mold. Injection pressure is maintained as the plastic cools and shrinks so that additional plastic is forced into the mold cavity to replace the loss due to shrinkage. The plastic continues to flow as long as the pressure is greater than the resistance of the solidifying material. As the plastic cools in the mold, the slow transfer of heat in the plastic controls the process. The thicker the part, the longer the time to cool. This means that areas of concentrated mass, as where two walls intersect or where bosses are attached to the main part, will be the last to cool. As the part cools and solidifies, material continues to flow and pack in areas with lesser flow resistance. Since the areas of concentrated mass are last to cool compared with surrounding areas, they are soon isolated within a frozen mass. The material in these areas continues to cool and shrink, creating localized areas of reduced volume called "sinks." These sinks are noticeable blemishes on the outer surface of the part. Sink marks dictate many of the limitations of the part, mold, and process in the injection molding of quality plastic parts.

### *The impact of sink marks*

A recent case in point was the structural mask that forms the front of a TV cabinet and supports the TV tube and many other smaller components. To support the TV tube in this structural plastic part, large bosses are used as fastening points. These bosses are located directly behind areas that are decorated with reflective metallic paint. Any surface imperfection in this area is highly visible and constitutes a major limitation in the manufacture of this part.

There were several reasons for these critical sinks—the generous radii at the intersection of the ribs of the boss, the u-shaped section just upstream of the sink in the flow path, the part thickness in the sink area, and the dimensions of the runner system gates. Examining each of these potential problem points showed that the radii and the part thickness could be changed with little effort by properly anticipating the problem. The u-shaped channel could be altered to enhance flow without

**Abstract:** *How can computer simulations best be used in plastics injection molding for mold and runner design? How well can the structural requirements of the final part be determined before it is produced? We describe the general method of analysis, and we show where the simulation does not agree with actual results, and how these limitations of simulation can be minimized. Examples of actual analyses and results are shown.*

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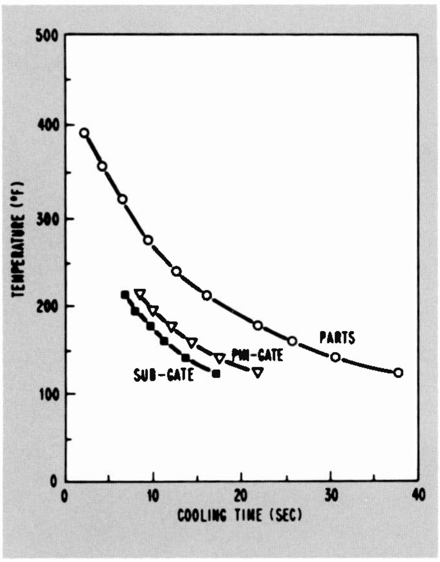

**Fig. 1.** *This chart shows the cooling temperature differences of the part and runner system. The runner system cooled first and prevented additional plastic from packing into the cavity. As a result, severe sink marks were formed. The redimensioning of the runner to cool at the same rate as the part reduced this tendency.*

detracting from the intended appearance of the part. The runner system, however, required the most analysis to determine its effect. It is considerably more than a distribution system to deliver melted plastic from the injection unit to the mold. The system requirements for the injection phase can differ considerably from those of the packing phase. The flow resistance must be low so that excessive pressure is not needed to fill the mold. Runner dimensions yield an important parameter for determining the temperature of the plastic as it enters the part cavity. The sizes of the gates and runners determine the flow distribution into the mold. The cooling and solidifying behavior of the runner system can control sink marks (see Fig. 1).

Various processing temperatures and packing pressure profiles were evaluated prior to any mold changes, but the sink marks were still objectionable. All of the considered mold changes were made. The radii were reduced, the part depth was reduced, the u-channel was altered, and the runner dimensions were altered. The sink marks were reduced to an acceptable level but not eliminated.

## Simulation

Plastic parts are normally designed as a "folded two-dimensional" construction similar to folded sheet metal parts but with additional features, such as ribs and bosses. Normally the part is designed first and then the mold is constructed with little or no alteration to the original part. The simulation analysis proceeds as follows.

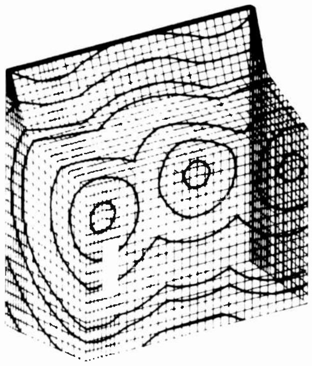

**Fig. 2.** *The filling pattern of a TV back cover.*

The part dimensions are entered and gate locations are tentatively assigned. A finite-element model is constructed and a filling pattern is calculated and shown graphically (see Fig. 2). The gate locations are altered until the best possible filling balance is achieved.

Next, a "layflat" of the part is constructed. The two-dimensional layflat is similar to the starting part in sheet-metal fabrication prior to bending. Three-dimensional features such as corners, ribs and bosses are indicated by common boundaries, just as if the entire part were to be constructed out of sheet material.

The selected gate locations are indicated on the layflat, and the filling pattern is constructed. The filling pattern is based on the concept that the flow-front distance traveled at any time increment is proportional to the inverse of the thickness. The filling occurs in a manner similar to the waves that are formed when you drop a pebble in a pubble. Starting at the injection point, the filling pattern is a constantly increasing circle. Using relatively simple geometric rules, a filling pattern for any complex shape can be constructed. The completed filling pattern clearly indicates potential problem areas of weld lines and trapped air. Further modifications of the gate locations are made at this time.

The completed filling pattern of the layflat geometry is further divided into flow elements (cylinders, plates, and sections of a circle). The dimensions of these flow elements are then used as the input to the computer simulation for the filling phase. This phase utilizes some specific CAD programs to simplify repetitious tasks.

### Glossary

**Cadmould.** A computer simulation program that calculates the pressure and temperature gradients in the plastic mold-filling process.

**Mefisto.** A simulation of the mold filling phase, indicating the flow front at injection times.

**Patran.** A finite-element preprocessing program used to create the mesh for Mefisto.

**Air pocket.** An area of trapped air created during the mold-filling process.

**Gate.** Section of the runner system that connects with the part.

**Hot drop.** Heated portion of a hot runner system that connects the part and the distribution manifold.

**Mask.** The front portion of a TV cabinet resembling a picture frame.

**Runner.** Portion of the runner system that connects the gate to the sprue.

**Runner system.** The distribution section of a mold that connects the injection unit to the part cavity.

**Sprue.** Part of the runner system that connects the injection unit to the runners.

**Weld lines.** Places in the plastic part where two flow fronts meet.

Material properties and process conditions added to the flow element geometry are the inputs needed for the calculation of pressures, temperatures, wear rates, and shear stresses in the injection phase. The examination of these initial values determines the next step in the analysis. If the calculated values are close to the desired ranges, then it's time to explore various possible processing conditions. If the values are not within those desirable ranges then part, gate, and even material changes are considered. Some iteration is usually performed to examine the process window at this stage.

Next, the runner system is detailed. Prior to this stage the general type of runner system has been determined. The tentative runner system is added to the part, and the

## Mask mold configuration

Hot runner molds consist of heated runner channels and valves at the entrance of the mold cavity. These systems reduce or eliminate the need to recycle runners and provide more control during processing. The question of how many "hot drops" are optimum and the tradeoffs involved were the subject of the following investigation.

A part design was established, but the location and number of gates had yet to be established. The thickness of the part was set tentatively. First, the gates were tentatively located at points that would fill the part as uniformly as possible. The simulation program was used to calculate the pressures, temperatures, filling times, shear rates, and shear stresses for various combinations of numbers of gates and part thicknesses. The major results are shown in Fig. 3. Note that a two-gate configuration requires injection pressures that are above the operating limits of the machine. The figures indicate that the parts can still be molded when their overall thickness is reduced substantially. The final results of this analysis allowed the part thickness to be safely molded to limits imposed by physical strength required, rather than by the process.

In addition to the material savings, the cost and maintenance savings of using three instead of four "hot drops" in the mold are realized.

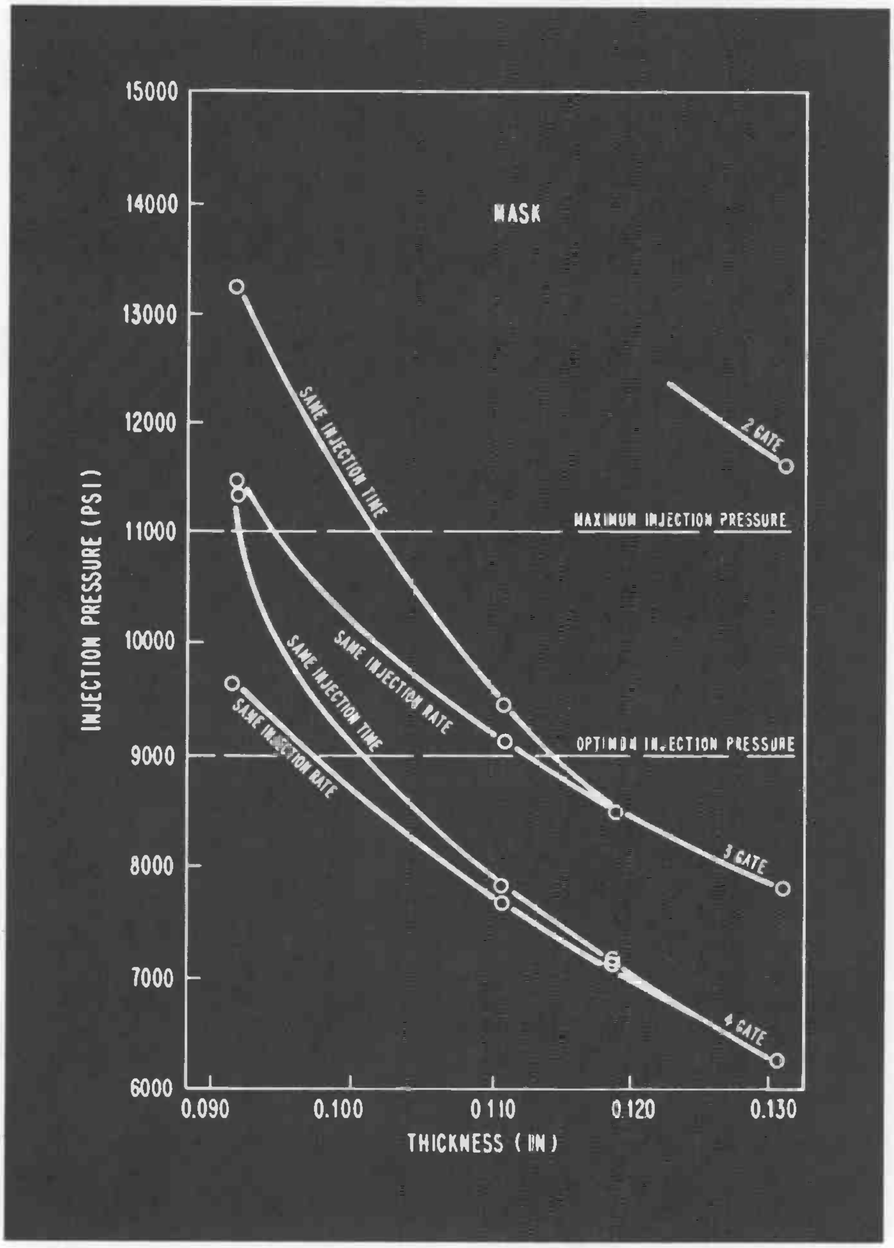

**Fig. 3.** *Most injection machines for this type of part operate up to a maximum of 11,000 psi, but 9000 psi is a much more desirable aim point. The 3- and 4-gate arrangements need less than 9000 psi, so the effects of reducing the part thickness was investigated.*

total system is simulated. Various combinations of geometries, configurations, materials, and process conditions are evaluated for the best compromise between a particular part and runner system.

The simulation specifically addresses the filling phase, but information from the filling phase can be directly applied to the packing phase.

The temperature distribution is known at the end of the filling phase, which corresponds to the beginning of the packing phase. One of the key questions to be answered in the packing phase is the time it takes for the various parts to cool until additional flow into the mold is no longer possible at the available injection pressure. Cooling rates for the various geometries in the flow elements are calculated, starting with the ending temperatures after filling. Runner (or perhaps even part) dimensions are changed to match cooling rates. The entire simulation, or portions of it, may have to be repeated at this stage.

### Structural analysis

Another computer simulation that can be applied to plastic parts is the finite-element method (FEM). FEM is an established engineering method that has broad applications in different areas. However, if the finite-element method is applied indiscriminately to the design of plastic structures, or if it is assumed that a design analysis run on a computer must be correct, the results can be disastrous.

The finite-element method is an approx-

## Drop test simulation of the structural frame

A structural frame was recently designed in Consumer Electronics, and a finite-element analysis was set up for the study to help the design engineers understand the mechanical responses of the structural frame subjected to the maximum acceleration during the drop test.

Figure 4 shows the back view of the structural frame. The kinescope and speakers are represented by the rigid steel bars connected to each mounting screw. For the bottom drop simulation, a maximum acceleration is applied at the centers of gravity of the picture tube and speakers in the Y direction. For the back drop analysis, the load is applied in the Z-direction.

The injection-molded frame is made of PS/PPO blend, which behaves linearly up to the yield point. The ANSYS finite-element package was used for this analysis. For the model, 752 node points and 1356 elements were used (triangle plastic shell element). Each kine mounting corner was represented by 150 elements. Because the maximum deflection during impact loading is much greater than the structure thickness, a large deflection key was used in the FEM analysis to update the stiffness matrix in each iteration. This resulted in a much more accurate calculation.

Figure 5 shows the stress distribution during the bottom drop. All the high stress occurred on the interface between the boss and plate and on the ribs connected to the boss. The numerical results are consistent with those observed in experiments. The maximum stresses are very close to the yield stress of the material.

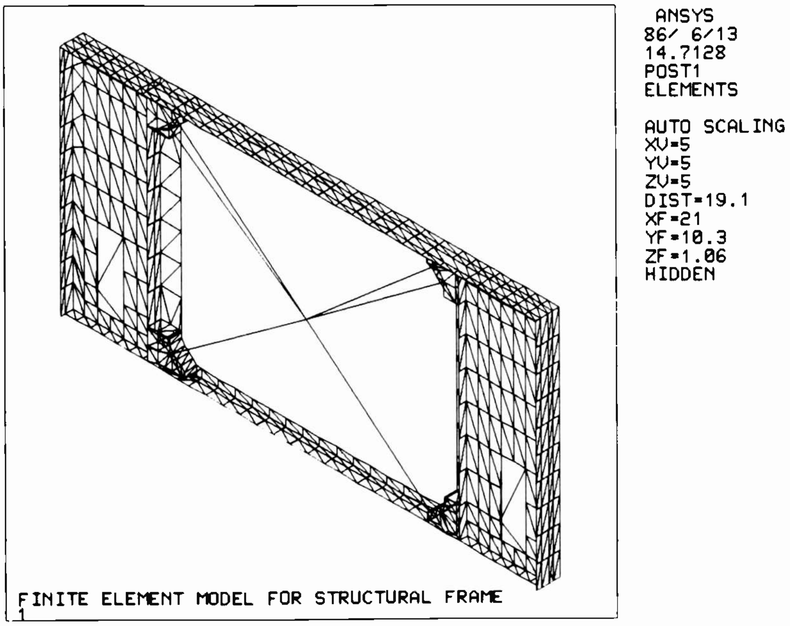

**Fig. 4.** *Finite-element model of the structural frame.*

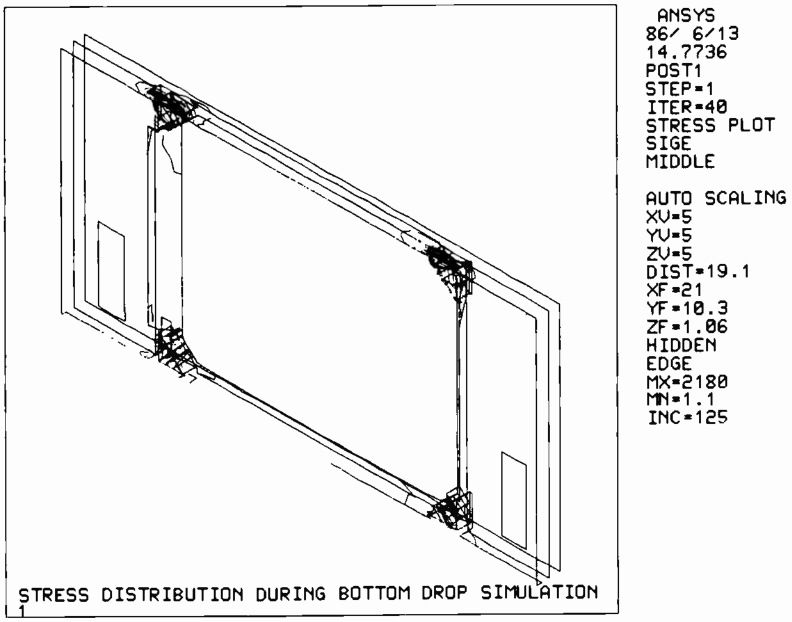

**Fig. 5.** *Stress distribution of the structural frame during the bottom drop simulation.*

Based on the FEM results, the design engineer has modified the kine-mounting corners. After the model was modified, another computer run was performed to confirm the design. According to the FEM solutions, the stress levels are about 1000 psi less than the previous design. Also, by changing the staple locations, we can distribute the reaction forces on the fixed points more evenly. Although correlation to calculated results with part performance is difficult in this case, doing the FEM analysis lets us identify the trouble spots in the early design stage.

imate method for solving differential equations in engineering and mathematical physics. With this approach, a structure is broken into a network of simple elements, each of which has stress and deflection characteristics easily defined by classical theory. The network of simple elements is called a "mesh," or "grid," with elements connected at "nodes." The total pattern of elements is called a "model." The simultaneous equations describing the model usually number in the hundreds or thousands, so that a computer and specialized data handling programs are needed to implement the method.

Due to the process-related properties and the nonlinearity of the plastic material, the strategies for the structural analysis of plastic are more difficult than those for metals. Good design of plastic structures requires a sound understanding of basic engineering design principles and their limitations, as well as an appreciation of the differences between metals and plastics. For example, the structural integrity at weld regions of injection-molded parts is a major concern for FEM applications.

**Table I.** *Experimental data gathered for specimens with and without center weld lines.*

*(a) With center weld lines*

| Case no. | Gate no. | Melt temp. (°C) | Mold temp. (°C) | Injection speed (%) | Weld line* temp. (°C) | Young's modulus (psi) | Yield stress (psi) |
|---|---|---|---|---|---|---|---|
| B-1 | 2 | 238 | 40 | 30 | 218 | 319000 | 3800 |
| B-2 | 2 | 238 | 40 | 60 | 235 | 320000 | 4150 |
| B-3 | 2 | 240 | 40 | 90 | 251 | 325000 | 4600 |
| B-4 | 2 | 252 | 40 | 60 | 240 | 328000 | 4550 |
| B-5 | 2 | 270 | 40 | 60 | 247 | 320500 | 5000 |
| B-6 | 2 | 240 | 60 | 60 | 239 | 330000 | 3900 |
| B-7 | 2 | 253 | 60 | 60 | 243 | 325000 | 4500 |
| B-8 | 2 | 270 | 60 | 60 | 250 | 315000 | 5100 |

*Weld line temperatures are based on CADMOULD predictions.

*(b) Without center weld lines*

| Case no. | Gate no. | Melt temp. (°C) | Mold temp. (°C) | Injection speed (%) | Young's modulus (psi) | Yield stress (psi) |
|---|---|---|---|---|---|---|
| A-1 | 1 | 238 | 40 | 30 | 320000 | 5900 |
| A-2 | 1 | 238 | 40 | 60 | 322000 | 6100 |
| A-3 | 1 | 238 | 40 | 90 | 320000 | 6100 |
| A-4 | 1 | 252 | 40 | 60 | 318000 | 6000 |
| A-5 | 1 | 270 | 40 | 60 | 317000 | 5900 |
| A-6 | 1 | 240 | 60 | 60 | 317000 | 5950 |
| A-7 | 1 | 253 | 60 | 60 | 322000 | 5900 |
| A-8 | 1 | 570 | 60 | 60 | 323000 | 5900 |

### *Tensile properties at weld lines*

Whenever separate flow fronts of a polymer melt meet, an area of different morphology and properties from the bulk is formed. these regions are called "weld" or "knit" lines. In general, the weld regions constitute weak spots that diminish the structural integrity of the molded parts.

As mentioned earlier, in the application of FEM analysis to injection-molded parts, the structural integrity problem at weld regions is a major concern. A basic understanding of weld line strength is important for developing FEM analysis strategy in molded plastic parts.

Recently, we conducted a study to quantify the tensile strength at weld lines. A systematic analysis that included injection-molding experiments, CADMOULD analysis, and tensile tests were conducted to address this issue. The standard yield stress of PS/PPO blend without welding lines was determined to be 6000 psi. By changing the molding conditions, the yield stress at weld regions varied dramatically. Table I contains the experimental data with and without weld lines in the center of specimens. The weld line temperatures in column 6 are based on the CADMOULD prediction. The values of the yield stress can be correlated to the weld line temperature. A yield stress as low as 3800 psi at weld lines was observed in the experiment with low weld-line temperature.

Although the yield stresses change with molding conditions, the Young's modulus at weld regions is almost constant throughout the experiments. Thus, in the FEM analysis of plastic parts, one can treat the whole structure (including weld lines) with the same material data. However, in the interpretation of FEM results, lower criteria (lower yield stress) have to be used in the weld regions.

For example, when the structural frame is used during the bottom drop simulation (see sidebar), the stresses are as high as 5000 psi inside the corner boxes. Outside of the mounting area, the stress drops to less than 2000 psi. Given the FEM results and a knowledge of plastic weld line strength, the designer can skillfully select the gate locations and prevent the weld lines going through the kine-mounting boxes.

## Summary

How well do the predicted results agree with the actual results? The filling pattern is remarkably accurate in predicting just how a part will fill during molding. Weld lines and trapped-air pockets are usually just where predicted if the layflat and flow fronts are made with sufficient detail. Pressure predictions generally fall in the ±30 percent range. Accurate temperatures of flowing plastic are extremely hard to measure. Our experience with several instrumented test molds and actual production molds indicates, however, that measurements of temperature and pressure shifts from one operating condition to the next are reliable.

Computer simulations of processes all have limitations in predicting outcomes, but they can be extremely useful when used by knowledgeable specialists who can relate the results to the actual process situation. When this is done, the results become predictable and usable, resulting in higher quality parts produced faster and at lower cost.

Why, when nearly everyone agrees that the absolute values of computer simulations are unreliable, do we use them? Why do we trust the results sufficiently to base important decisions on them, decisions that have serious consequences? Most will agree that shifts in calculated values from one condition to another are reasonably trustworthy, and that the ability of simulations to indicate critical or potential trouble spots is good. What appears to be needed most is a successful combination of numerical analysis with expert analysis and comparison of known results.

The authors would like to acknowledge the assistance of R. Lai in the FEM analysis and I. Chen in the weld line studies.

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In 1984 he transferred to RCA Laboratories as a Member of the Technical Staff. There he did basic exploration of the processing limitations of injection molding and, more recently, wrote computer programs that are being used at the RCA Consumer Electronics. He left RCA in mid-June 1986.

**Sheng M. Huang** received a BS degree in Marine Engineering from National Cheng-Kung University, Taiwan, in 1975. In 1979 and 1982 he received the MS and PhD degrees in Mechanical Engineering from the University of Pittsburgh. In 1986 he became a licensed Professional Engineer in the State of New Jersey.

From 1982 to 1983 he worked as a mechanical engineer for Schneider Consulting Engineers. There he was responsible for water hammer analysis for a nuclear power plant in Pittsburgh, and also for initiating CAD techniques for piping system design.

Dr. Huang joined RCA Laboratories in 1983 as a Member of the Technical Staff in the Manufacturing Systems Research Laboratory. He has been using computer programs to check the design and analysis of molds and, more recently, has been applying the finite-element method to plastic parts design. In 1985 he shared an RCA Laboratories Outstanding Achievement Award.

Dr. Huang holds one U.S. patent and has authored or coauthored five technical papers. He is a member of the American Society of Mechanical Engineers and the Society for Plastics Engineers.

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# FACTS: Real-time information in the manufacturing environment

*The concept of using computer-based systems to provide real-time manufacturing information has replaced traditional methods of data collection and analysis.*

FACTS (Factory Analysis, Control and Tracking System) is a computer-based, real-time manufacturing information system that collects data from all phases of the high-volume chassis manufacturing process and makes information available to interactive terminal users throughout the plant. The objective of FACTS is to utilize the power and speed of computers as a primary tool for providing manufacturing and engineering personnel with timely and accurate information on the current status of factory operations, allowing for real-time factory management.

## Background

Information is the key to effective control of any manufacturing process. Increased manufacturing volumes, greater product complexity, and automation of test equipment have outrun the capabilities of manual information systems. Traditional methods of data collection and analysis are slow, incomplete, and often subject to error.

The concept of using computer-based systems to provide real-time manufacturing information is not new to the Consumer Electronics (CE). The first such system, DARTS (Defect Analysis for Real-time Supervision), was developed in 1978 at RCA Laboratories for the chassis test portion of two television instrument lines in the Bloomington plant. The second generation of Factory Information Systems (FIS) was the Manufacturing Analysis and Control System (MACS). It was developed in 1980 by a joint team from CE's Manufacturing Technology Center (MTC) and RCA Laboratories with assistance from Indianapolis VideoDisc Operations and the Bloomington VideoDisc Player Manufacturing facility. MACS supported the test portions of three VideoDisc Player lines. The most recent system, FACTS, was designed and implemented by MTC with specification assistance from RCA Laboratories and Juarez. The initial installation was in 1982 on two color television chassis lines and about 15 ACI (Automatic Component Insertion) machines. Since then, FACTS has undergone continuous expansion and enhancement, so that now all ten chassis lines and about 70 ACI machines are supported. Additional FACTS systems have been installed in Torreon (February 1986, for ROSE transformer production) and Bloomington (July 1986, for instrument assembly).

## System overview

Each of the 100 chassis area data collection devices and 70 ACI machines in the Juarez plant is connected to one of four DEC 11/23 minicomputers (Fig. 1), which act as communications controllers. All device-level communications protocol functions are implemented on these controllers. Data packets are forwarded to a single DEC 11/44 communications concentrator, where they are then passed to the main computer system, a Prime 750, for final storage and analysis. Over 50 user terminals spread throughout the plant's production and office areas are connected to the Prime via a system of short-haul modems. An X.25 packet-switching interface to other Prime systems in Indianapolis, RCA Laboratories, Bloomington, and Torreon permits external access to real-time information.

FACTS is implemented as a group of independent processes communicating in real-time through a number of globally accessable, main-memory-resident common areas and a semaphore-based packet queuing system. In order to achieve the speed necessary for real-time response, most data storage and interactive report generation is done through the specially structured common areas. All data is eventually written to disk files where it can be

**Abstract:** *Consumer Electronics has had to make significant improvements in manufacturing process yields across the entire business to realize substantial cost reductions through better product quality and process efficiencies. The Factory Analysis, Control and Tracking System (FACTS) is an important element in a comprehensive program of yield improvements at the Color Television Chassis (CTC) plant in Juarez, Mexico.*

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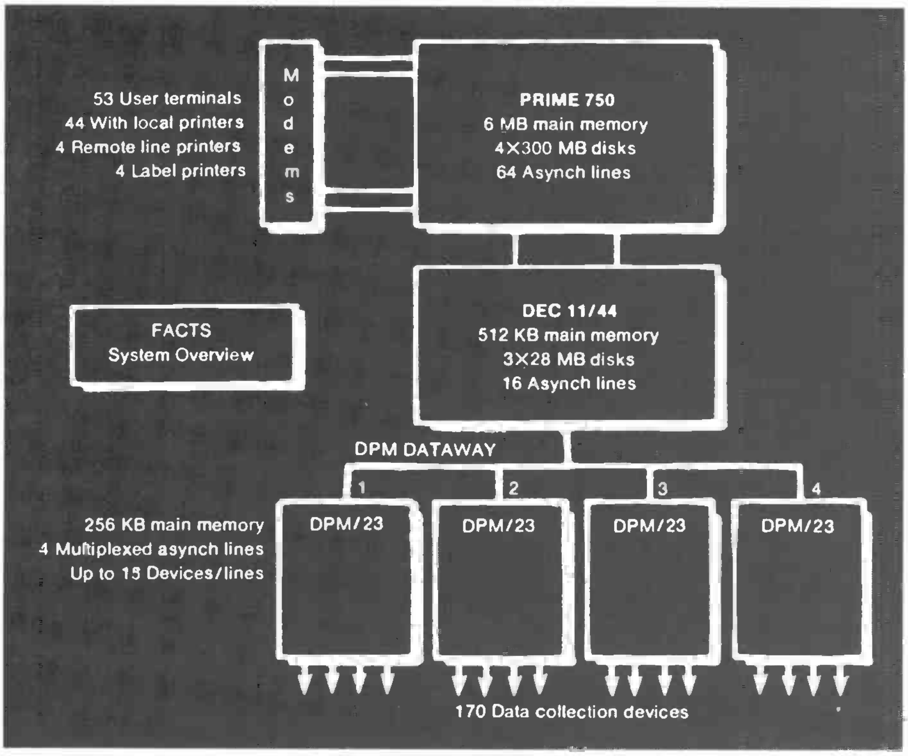


**Fig. 1.** *Juarez FACTS hardware configuration.*

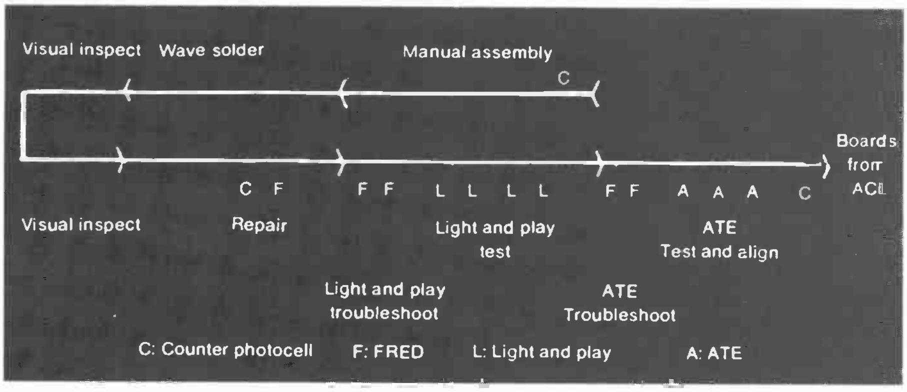


**Fig. 3.** *Chassis flow and data collection points on a typical Juarez chassis line.*

**Fig. 2.** *The VCD machine inserts parts from sequenced reels into each circuit board.*

accessed using more traditional data retrieval methods. Disk files are also used to save snapshot dumps of the common areas for automatic recovery in case of a catastrophic system failure. Most data storage work consists of structuring the collected data for fast, simple access by the many interactive terminal users.

Data collection is automatic, whenever possible. For those locations requiring manual input, special data entry devices were designed for high speed and accuracy so that normal production operations would not be adversely affected. Each TV chassis is uniquely identified by a bar-coded serial number. This label is read by a hand-held scanner at each data collection point, and serves as the basis for discrete chassis tracking.

## ACI area data collection

The automatic insertion of bare PC boards is a four-part process. First, the bare PC boards, produced in Indianapolis, pass through the staking department where stakes, terminal beads, and eyelets are pressed onto the board. No FACTS data is presently collected from this area due to its lack of automation. In the next step, sequencer machines produce tapes of axially-leaded components to match a programmed insertion sequence. Using both the sequenced tapes and the staked PC boards they are then axially inserted using a variable center distance (VCD) machine (Fig. 2). Finally, these partially populated boards are sent to radial inserters for the last phase of automatic component insertion.

Each ACI machine has a minicomputer that controls the machine and records performance statistics. FACTS accesses these controllers every hour for each of the three working shifts to collect machine-level information that includes run time, downtime, number of boards/sequence produced, and component-level information. Included as part of the component-level information are data indicating the total number of components (hits) inserted and all machine-related errors (misses, tolerance, opens, non-taped). These statistics not only provide total machine performance, but also head-level information. Sequencer machines have up to 100 heads, radial machines have 40 heads, and VCDs have two heads.

## Chassis area data collection

Once the boards are ACI-inserted, they enter the head of a chassis line (Fig. 3). Brackets, wire harnesses, and other parts are manually assembled to the chassis board prior to wave soldering. After soldering, the bar-coded serial label is attached to the chassis (Fig. 4). Solder inspection/touchup, additional assembly, and several visual inspections are performed prior to entry into the test portion of the line. Each chassis proceeds through a preliminary light-and-play test, and then to automatic test equipment (ATE) for final test and alignment. Failure at either location results in analysis by a troubleshooter and re-entry at the head of the test sequence. Good units are sent to a packing area for eventual shipment to Bloomington.

FACTS collects five major data types from every chassis line: on/off line counts, assembly (visually detected) rejects, light-and-play results, ATE results, and all troubleshooter repairs. Counters are the simplest and most automatic data input devices in use. Photocells are mounted at three locations on each line and sense the passage of each chassis. The counter locations used by FACTS measure the number of chassis coming onto the line, the number leaving the assembly portion of the line, and the number leaving the end of the line. Each controller is linked to FACTS, and accumulated counts are transmitted in response to scheduled FACTS requests, normally every six minutes.

As a chassis proceeds through the first part of the line, inspectors visually check for proper assembly. Any defects detected are written as part name/defect type pairs on a travel tag connected to the chassis. Just prior to the test area of the line, an operator scans each passing chassis for defects noted on the travel tag. The operator enters these defects into FACTS using an on-line data entry device called a FRED (Factory Reject Entry Device), shown in Fig. 5. A digitizer pad within the FRED converts touched points on a template into part and defect type names. All defects for the chassis are accumulated and automatically transmitted to FACTS.

The first power-on test of a chassis occurs at light-and-play. There are three or four parallel semi-automatic test stations on each line. Each operator removes a chassis from the line, mounts it on a test fixture, and the microprocessor-controlled light-and-play tester performs a test sequence. Each operator has a hand-held bar-code reader connected to the tester's microprocessor. Sometime during the test sequence, the operator wands the chassis serial number. On completion of the test, the microprocessor transmits the serial number as well as the results of the test sequence.

After a chassis passes at light-and-play, it proceeds to one of two or three parallel automated testers for final test and alignment. As with light-and-play, the operator places the chassis on the ATE's test fixture (Fig 6) and the actual testing and alignment is performed automatically. During the test cycle, the operator wands the chassis serial number using a hand-held bar-code reader connected directly into the ATE. On completion of the test cycle, the results are automatically transmitted from the ATE into FACTS. The information includes the chassis serial number and details of the test result. Any chassis rejected at either light-and-play or ATE is given to a troubleshooter for problem analysis and repair. Each troubleshooter has a FRED station identical to the one used to enter assembly-detected defects.

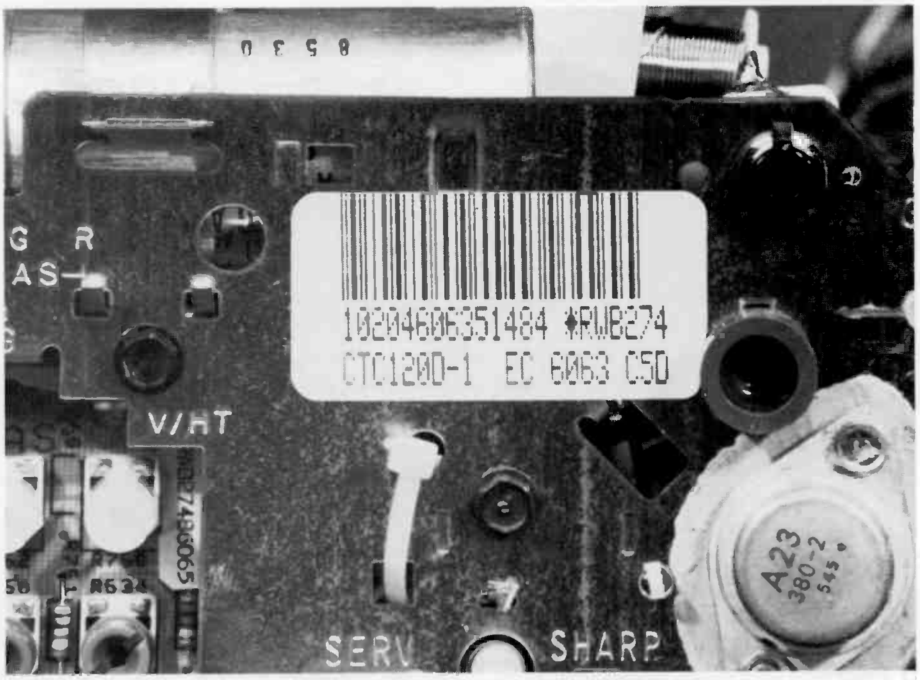


**Fig. 4.** *Each chassis has a unique bar-coded label identifying the chassis model, assembly line, and production date and shift.*

**Fig. 5.** *All defects detected at troubleshoot and visual assembly inspection are entered using the FRED terminal.*

### System products

FACTS report generation is heavily oriented toward fast interactive references to the current day's production information. There is no schedule for automatic report generation. Information is available in reports as soon as it is received from the factory floor—normally within a few seconds of its collection. Although the em-

## Major FACTS reporting packages

***ATEMON*** is used by Test Maintenance to monitor the performance of the chassis ATEs. Subject matter includes counts, yields, equipment status, rejects, test measurement distribution, statistical process control, and detailed cycle-by-cycle tester histories.

***CTCMON*** is designed for line superintendents, supervisors, and group leaders. It concentrates on subjects similar to ATEMON, but covers the assembly, light-and-play, and troubleshoot sections of the line.

***SN_LIST*** retrieves the history of any requested chassis.

***ANALYZE_CTC_RUNS*** is an interactive, investigative tool for study of the relationships between the individual events of any line/shift production run.

***EMS_GUIDE*** rates the effectiveness of all attempted repair actions to any test reject.

***SEQMON***, ***VCDMON***, and ***TDKMON*** provide count, yield, reject, difference to rate, machine speed, and total downtime information for each of the three major ACI areas for a single production day.

***SEQ_DT***, ***VCD_DT***, and ***TDK_DT*** are used for detailed analysis of the causes of machine down time in each of the major ACI areas.

***PRODEFF*** produces information similar to that available with the *MON* packages, but covers any span of production days.

***QC_REPORT*** and ***QC_DEFECT_REPORT*** support analysis of all QC-detected defects for the ACI area as well as the chassis and module lines.

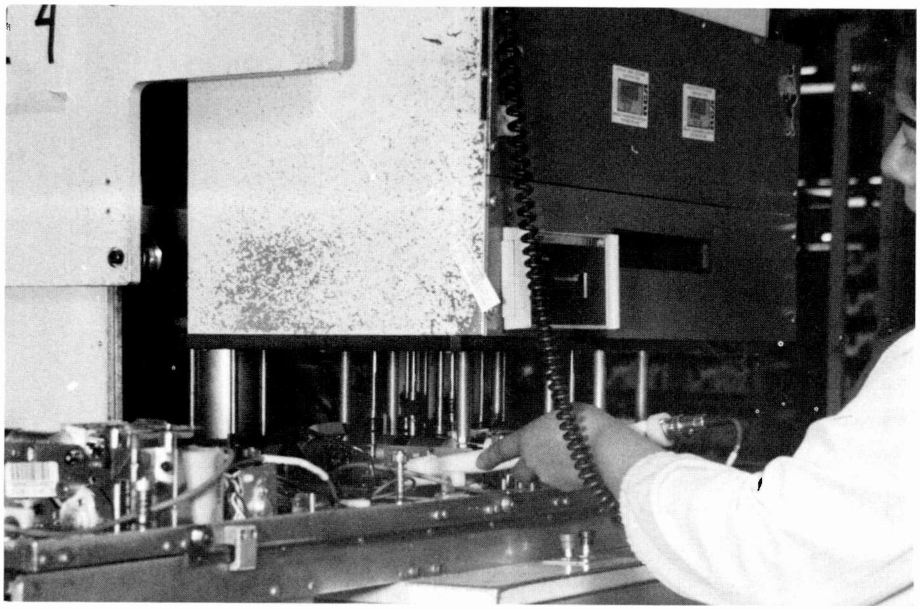


**Fig. 6.** *As each chassis is tested and aligned at an ATE, the operator wands across the bar-code. The serial number is read by the ATE and passed back, along with the test results, to the main computer.*

phasis is on screen display of reports, most terminals have small printers attached that can produce a local hard copy of any information presented on the screen. Most reporting packages extract data directly from the memory-resident common-area data structures. Snapshot common-area dumps and other file-based data structures are available for longer term or other specialty reporting packages.

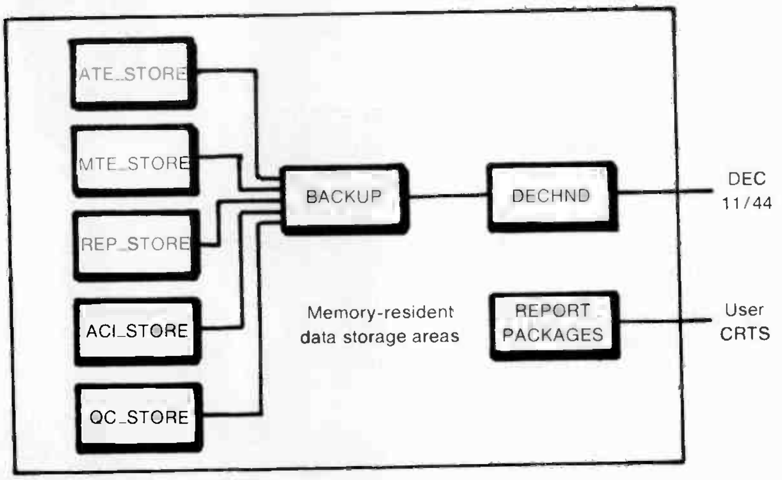
Each real-time reporting package is customized for its intended users. A hierarchical structure is common to all. An upper level of relatively general reporting screens is continuously displayed and updated. More detailed screens are accessed by single function keystrokes. The continually updating automatic screens show the presence (or absence) of problems, while the detailed lower level screens are used to determine the cause of problems. A set of selection options is assumed for each lower level screen, but the user can easily specify his own options using English/Spanish key-worded statements. This permits a "guided tour" for the casual or unsophisticated user, while still allowing the more skilled user to do investigative analysis. On-line help screens are provided for all options.

There are five major reporting packages for the chassis lines, five more for the ACI area, and two for plant quality control, providing a total of over 70 different screen presentations. Utilization of these packages is rather heavy, with between 2000-2500 individual report references (automatically measured) each working day. Information presented covers the relatively simple, traditional manufacturing subjects (counts, yields, failures, repairs, down time) as well as analysis of the relationships between them (effectiveness of repairs for various failure symptoms, effect of assembly defects on ATE performance, etc.). A few of the available reports are detailed in Figs. 7-10.

Recent enhancements to the system allow FACTS to automatically apply continuous statistical process control algorithms to identify production abnormalities as they occur. For example, one algorithm monitors the ordered sequence of pass/fail results from an ATE to detect abnormal failure frequency. Once a problem has been detected, it is flagged as 'out of control' on all CRT screens monitoring ATE operation. The flag remains raised until continued automatic examination indicates that the process has returned to normal. Multiple test cycle windows, each with its own triggering failure and recovery parameters, can be externally defined for each machine. The multiple windows allow identification of both long and short term problems. External specification of triggering parameters makes it easy to adjust the sensitivity of the alarm system in response to real improvements or reductions in process capability.

Although FACTS was specifically designed to collect, store and process data for factory applications, the use of the PRIME computer has not been limited to just those applications. Juarez personnel also have available many stand-alone software packages to do things as simple as electronic mail, text editing and file manipulation as well as more complex

## Internal data flow

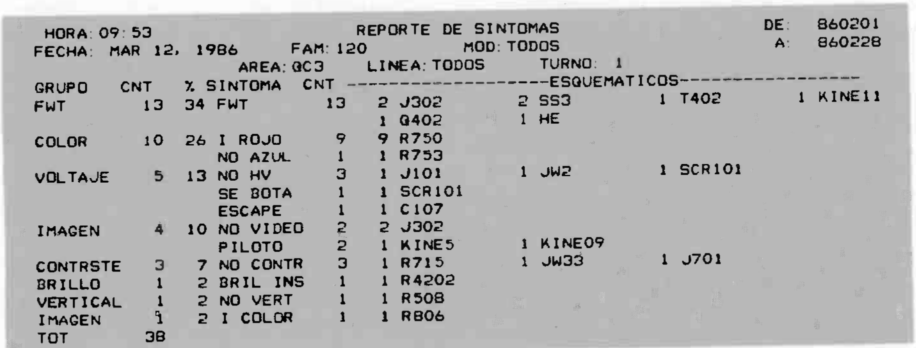


All raw data transmitted by any of the on-line devices (ATE, FRED, ACI machine, etc.) is initially received by that device's servicing DEC 11/23. These raw packets are then sent to the DEC 11/44, where they are passed to the Prime 750. The process *DECHND* implements the communications protocol between the Prime and the 11/44. Received data packets are placed into a memory block (coreblock) obtained from a system pool, and then placed in a queue to the central clearing house process *BACKUP*. Here the coreblock is routed to one of several data storage processes. If the destination process has fallen behind its incoming data load and has more than some configurable amount of waiting packets, the raw data passes through a circular disk file. As the consuming process catches up, the data is recovered from disk and passed on for processing in its original order. This insures that no data is lost during those peak periods when data collection exceeds data storage capacity. Five major storage processes handle message packets from different machine types. The coreblocks are analyzed and stored in memory-based data structures and, in some cases, disk files. After data extraction, the coreblocks are returned to the pool. Most report packages reference the memory-based data for on-line screen generation. This reliance on memory data storage permits efficient handling of the relatively high transaction rate (over 3000 events per hour) at a cost of only 25-30 percent of the Prime's CPU power.

tasks such as exploratory data analysis, p-charting, plotting, and spreadsheets. These software packages, either developed or purchased by RCA, have given the users added flexibility and convenience for engineering support of manufacturing and daily administrative functions.

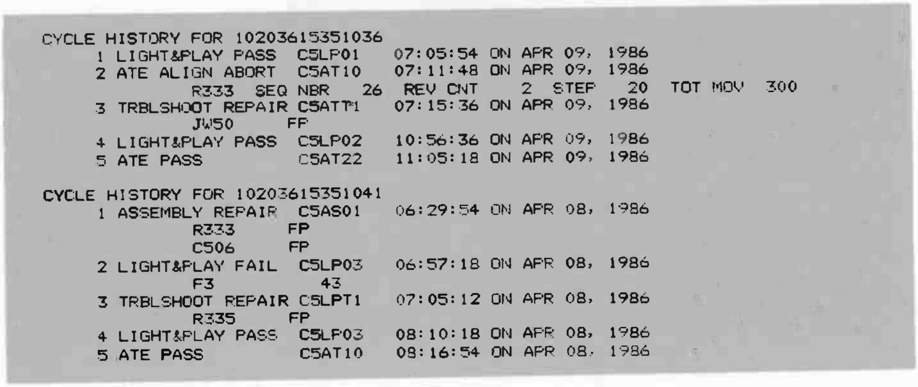
### Future directions

Although FACTS was initially installed in 1982, it has undergone almost constant enhancement and expansion. The same is expected for at least the next two years. Expansion is planned to cover the module assembly lines, chassis rework lines, automatic integrated circuit testers, in-production material inspection (PMI), and new chip machines in ACI. Additional functionality will include heavier reliance on statistical process control for automatic problem identification, increased utilization of graphical data presentation methods, automatic recommendation of troubleshooter repairs based on recent failure experience, and extended tracking of modules and chassis from bare circuit board to completed instrument. New developments and



```
 HORA: 09: 53                     REPORTE DE SINTOMAS                    DE:   860201
FECHA:  MAR 12, 1986     FAM: 120          MOD: TODOS                     A:   860228
                    AREA: QC3    LINEA: TODOS        TURNO:  1
GRUPO     CNT    % SINTOMA   CNT ---------------------ESQUEMATICOS--------------------
FWT         13   34 FWT         13    2 J302         2 SS3          1 T402          1 KINE11
                                      1 Q402         1 HE
COLOR       10   26 I ROJO       9    9 R750
                    NO AZUL      1    1 R753
VOLTAJE      5   13 NO HV        3    1 J101         1 JW2          1 SCR101
                    SE BOTA      1    1 SCR101
                    ESCAPE       1    1 C107
IMAGEN       4   10 NO VIDEO     2    2 J302
                    PILOTO       2    1 KINE5        1 KINE09
CONTRSTE     3    7 NO CONTR     3    1 R715         1 JW33         1 J701
BRILLO       1    2 BRIL INS     1    1 R4202
VERTICAL     1    2 NO VERT      1    1 R508
IMAGEN       1    2 I COLOR      1    1 R806
TOT         38
```

**Fig. 7.** *Rejects detected at QC inspection stations are categorized by group and symptom in this screen from the QC_DEFECT_REPORT package.*



```
CYCLE HISTORY FOR 10203615351036
      1 LIGHT&PLAY PASS   C5LP01    07:05:54 ON APR 09, 1986
      2 ATE ALIGN ABORT   C5AT10    07:11:48 ON APR 09, 1986
             R333  SEQ NBR   26  REV CNT    2  STEF   20  TOT MOV  300
      3 TRBLSHOOT REPAIR C5ATT1     07:15:36 ON APR 09, 1986
             JW50     FP
      4 LIGHT&PLAY PASS   C5LP02    10:56:36 ON APR 09, 1986
      5 ATE PASS          C5AT22    11:05:18 ON APR 09, 1986

CYCLE HISTORY FOR 10203615351041
      1 ASSEMBLY REPAIR   C5AS01    06:29:54 ON APR 08, 1986
             R333     FP
             C506     FP
      2 LIGHT&PLAY FAIL   C5LP03    06:57:18 ON APR 08, 1986
             F3          43
      3 TRBLSHOOT REPAIR C5LPT1     07:05:12 ON APR 08, 1986
             R335     FP
      4 LIGHT&PLAY PASS   C5LP03    08:10:18 ON APR 08, 1986
      5 ATE PASS          C5AT10    08:16:54 ON APR 08, 1986
```

**Fig. 8.** *The history of any chassis can be retrieved using SN_LIST.*

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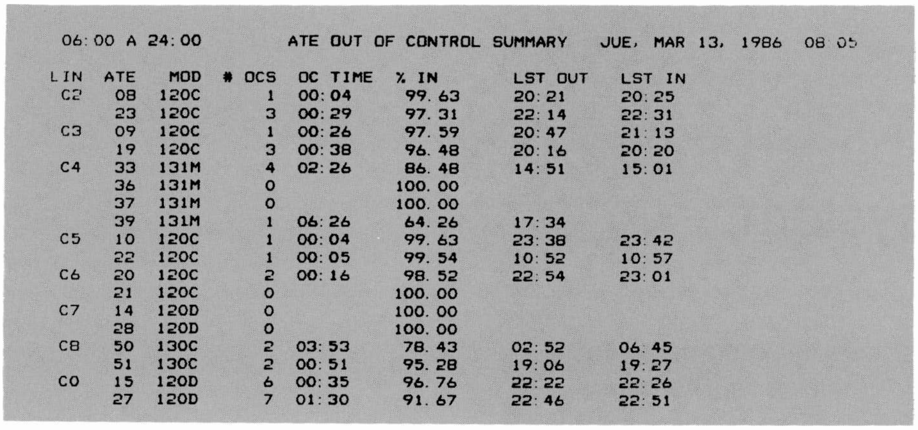
*Authors Gates (seated), Grayson (left), and Jordan.*

lessons learned on other FACTS systems (Torreon and Bloomington) will be incorporated into the Juarez system.

## Summary

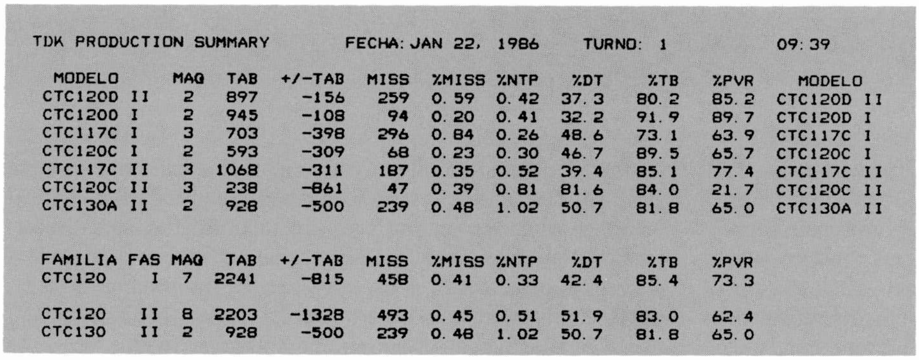
The objective of FACTS is to collect and distribute real-time factory data, thereby providing a source of information to be used for improved control and monitoring of the manufacturing process. FACTS has become the primary information source in the manufacturing process control loop. Information itself is not an end product. It is not listed as an asset on any financial report. In fact, the information gathering process costs time and money. There is no value in simply reporting that a certain yield is low, that a line is experiencing a sudden rash of a certain kind of problem, or that failure to follow defined process steps adversely affects productivity. It is the involvement of factory staff, interpreting and analyzing the information, that leads to the eventual resolution of process problems. The enhanced capabilities of FACTS greatly increase the potential of production, engineering, and quality users to control and improve the manufacturing process.



```
 06:00 A 24:00          ATE OUT OF CONTROL SUMMARY   JUE, MAR 13, 1986  08:05

LIN  ATE   MOD  # OCS  OC TIME  % IN      LST OUT   LST IN
 C2   08  120C      1  00:04     99.63    20:21     20:25
      23  120C      3  00:29     97.31    22:14     22:31
 C3   09  120C      1  00:26     97.59    20:47     21:13
      19  120C      3  00:38     96.48    20:16     20:20
 C4   33  131M      4  02:26     86.48    14:51     15:01
      36  131M      0           100.00
      37  131M      0           100.00
      39  131M      1  06:26     64.26    17:34
 C5   10  120C      1  00:04     99.63    23:38     23:42
      22  120C      1  00:05     99.54    10:52     10:57
 C6   20  120C      2  00:16     98.52    22:54     23:01
      21  120C      0           100.00
 C7   14  120D      0           100.00
      28  120D      0           100.00
 C8   50  130C      2  03:53     78.43    02:52     06:45
      51  130C      2  00:51     95.28    19:06     19:27
 CO   15  120D      6  00:35     96.76    22:22     22:26
      27  120D      7  01:30     91.67    22:46     22:51
```

**Fig. 9.** *A summary of ATE performance based on statistical comparison of current behavior with a historical standard is shown in this screen from ATEMON.*



```
TDK PRODUCTION SUMMARY        FECHA: JAN 22, 1986     TURNO: 1            09:39

  MODELO       MAQ  TAB  +/-TAB  MISS  %MISS %NTP   %DT    %TB    %PVR   MODELO
 CTC120D II     2   897    -156   259  0.59  0.42  37.3   80.2   85.2  CTC120D II
 CTC1200 I      2   945    -108    94  0.20  0.41  32.2   91.9   89.7  CTC120D I
 CTC117C I      3   703    -398   296  0.84  0.26  48.6   73.1   63.9  CTC117C I
 CTC120C I      2   593    -309    68  0.23  0.30  46.7   89.5   65.7  CTC120C I
 CTC117C II     3  1068    -311   187  0.35  0.52  39.4   85.1   77.4  CTC117C II
 CTC120C II     3   238    -861    47  0.39  0.81  81.6   84.0   21.7  CTC120C II
 CTC130A II     2   928    -500   239  0.48  1.02  50.7   81.8   65.0  CTC130A II


 FAMILIA FAS MAQ  TAB  +/-TAB  MISS  %MISS %NTP   %DT    %TB    %PVR
 CTC120     I  7  2241    -815   458  0.41  0.33  42.4   85.4   73.3

 CTC120    II  8  2203   -1328   493  0.45  0.51  51.9   83.0   62.4
 CTC130    II  2   928    -500   239  0.48  1.02  50.7   81.8   65.0
```

**Fig. 10.** *This TDKMON screen shows overall area performance with respect to each chassis model.*

J. Maleyeff | S.R. Miller

# An interactive PC-based make-buy decision support system

*This make-buy decision support software combines a user-friendly spreadsheet for input/output with a mathematical programming algorithm, making "what if" analyses possible.*

Planning production in an environment that includes make or buy options adds difficulty to an already complex problem. This situation is often encountered at RCA's Consumer Electronics Operations, where several satellite plants produce subassemblies for final assembly operations. Each satellite plant must provide the central facility with on-time deliveries, or notify the central facility in time for outside vendor purchase. With a market as volatile as that of the consumer electronics industry, it is not unusual for models and styles to change frequently. Hence, decisions regarding which of the products to produce at the satellite plant and which to purchase from vendors are made frequently.

These make-buy decisions should simultaneously consider costs as well as the plant capacity. The costs include manufacturing costs (e.g., material, labor, setup, tooling), and each product's outside purchase price. The plant capacity is usually somewhat flexible, especially when overtime or additional shifts can be added. Effective planning reconciles all of these factors and results in both cost savings and increased production efficiency.

This paper describes a personal computer-based decision support system for make-buy analysis. The system combines spreadsheet input and output with a mathematical programming algorithm. Hence, the system includes the required mathematical integrity while promoting user interaction. The spreadsheets facilitate quick and easy sensitivity analysis, including the relaxation of some cost and/or capacity linearity assumptions. Finally, the system is modular, with the spreadsheet software independent of the mathematical programming software. In this way, the user can enter proposed make-buy amounts and the system will calculate the results of these guesses.

**Abstract:** *A personal computer-based system for make-buy decision support is described. The system combines user-friendly* Lotus 1-2-3 *or* Symphony *spreadsheets (for input/output) with a mixed-integer linear programming (MILP) optimization algorithm. The MILP formulation minimizes all relevant costs, including labor (regular and overtime), materials, and purchase while satisfying all demand requirements and workcenter capacity limits. The user performs "what if" analysis to experiment with various capacity change options and to determine the sensitivity of key parameters. The system is structured to enable the incorporation of step functions for both cost (e.g., quantity discounts) and capacity limits (e.g., additional shifts).*

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## Problem description

A satellite plant manufactures or purchases a multitude of products for a central facility. The facility may be considered a job shop, since each product can follow a unique route through the facility with varying utilization rates. In addition, setup times are significant and vary by product.

Periodically, the facility plans production based on the sales forecast for each product in its portfolio. The option of purchasing some or all of each product exists. The time frame for these plans depends on lead time factors such as manufacturing cycle time, raw material acquisition, and external vendor lead times. The time horizon is usually medium-term (one to several months).

The facility may or may not have the capacity required to produce all of the units forecast. Within this medium-term planning period, capacity change options are generally limited to overtime, additional tooling, and some temporary hiring. Also, it may be cost effective to purchase products, even when capacity is available for in-house production (e.g., small batches with long operation setup times). A thorough discussion of production planning and scheduling is provided in references (1) and (2).

## Mathematical programming formulation

The system is designed to evaluate product requirements against key workcenter capacities, and determine the optimal make-buy quantities. It does this by minimizing a cost function containing all relevant costs, while considering any potential combination of workcenter production loads. It is assumed that during the planning period (usually one month or one quarter), at most one production run is made for each product. The model "loads" workcenters, since "scheduling" is not required for planning and the resultant number of variables for a scheduling model would preclude a mathematical programming approach.

The formulation consists of three sets of constraints:

1. Satisfy the product sales requirements, by either in-house production or outside vendor purchase. Let:

   $X1(i)$ be the in-house production quantity for product $i$,

   $X2(i)$ be the purchase quantity for product $i$,

   $D(i)$ be the demand for product $i$, and

   $N$ be the number of different products.

   The first set of constraints are:

   $X(i)+X2(i)=D(i)$ for $i=1,2,\ldots,N$

2. Satisfy the workcenter capacity limitations. A workcenter cay have some minimum number of hours that will be worked, regardless of its load. Additionally, there exists a maximum amount of regular and overtime hours. Let:

   $R(\mathrm{i,k})$ be the production rate (hours/unit) for product $i$ on workcenter $k$,

   $S(\mathrm{i,k})$ be the setup time (hours) for product $i$ on workcenter $k$,

   $$Y(\mathrm{i})=\begin{cases}1 & \text{if } X1(i)>0\\ 0 & \text{if } X1(i)=0,\end{cases}$$

   $H1(k)$ be the minimum hours for workcenter $k$,

   $H2(k)$ be the maximum hours with regular labor for workcenter $k$,

   $H3(k)$ be the maximum hours with overtime for workcenter $k$,

   $W1(k)$ be the regular hours worked for workcenter $k$,

   $W2(k)$ be the overtime hours worked for workcenter $k$, and

   $M$ be the number of workcenters.

   ($R$, $S$, $H1$, $H2$, $H3$ and $M$ are input variables, $Y$, $W1$ and $W2$ are model outputs)

   The second set of constraints are:

   $$\sum_{i=1}^{N} X1(i)\times R(i,k)+\sum_{i=1}^{N} Y1(i)S(i,k) \leq H1(k)+W1(k)+W2(k)$$

   for $k=1,2,\ldots,M$,

   $W1(k)\leq H2(k)$ for $k=1,2,\ldots,M$,

   $W2(k)\leq H3(k)$ for $k=1,2,\ldots,M$,

   $Y(\mathrm{i})\geq X1(i)/D(i)$ for $i=1,2,\ldots,N$.

3. Satisfy minimum production or purchase levels. These constraints are optional and are used for two situations: (a) some level of production or purchase is required to satisfy contractual arrangements, testing, or other miscellaneous reasons, and (b) step functions exist for cost elements or workcenter capacity limits. Case (b) is discussed in detail later. Let:

   $B1(i)$ be the minimum production quantity for product $i$, and $B2(i)$ be the minimum purchase quantity for product $i$.

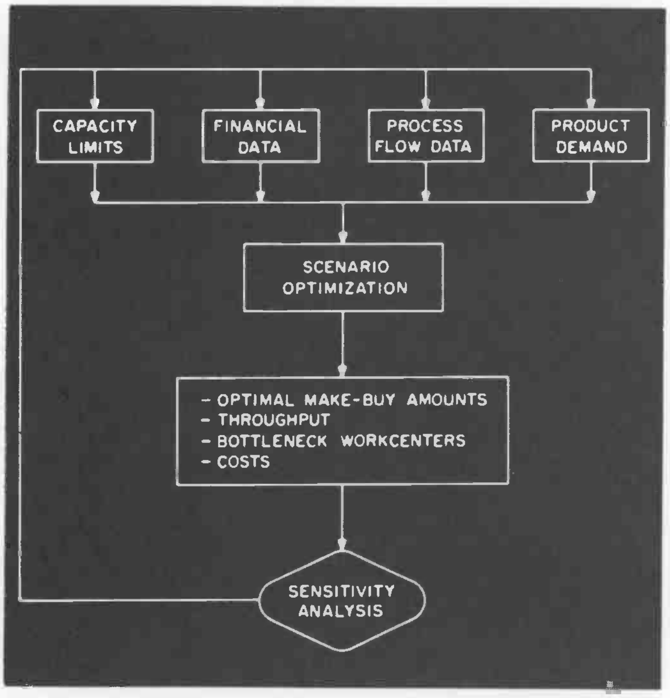

**Fig. 1.** *Flow diagram of the make-buy system.*

   The third set of constraints are:

   $X1(i)\geq B1(i)$ for $i=1,2,\ldots,N$,

   $X2(i)\geq B2(i)$ for $i=1,2,\ldots,N$,

   Note that setting a minimum make amount is equivalent to setting a maximum buy amount, and vice versa. For example, if $X1(i)\geq B1(i)$ then $X2(i)\leq D(i)-B1(i)$).

The following equations are needed to assure non-negativity of real variables and 0/1 values for integer variables:

$X1(i), X2(i)\geq 0$ for $i=1,2,\ldots,N$,

$W1(k), W2(k)\geq 0$ for $k=1,2,\ldots,M$,

$Y(i)=0$ or 1 for $\mathrm{i}=1,2,\ldots,N$.

The objective function (to be minimized) consists of all relevant costs. Let:

$C1(i)$ be the unit material cost for product $i$,

$C2(i)$ be the unit purchase price for product $i$,

$C3(k)$ be the regular hourly labor cost for workcenter $k$, and

$C4(k)$ be the overtime hourly labor cost for workcenter $k$.

The objective function is:

$$\sum_{i=1}^{N} C1(i)\times X1(i)+\sum_{i=1}^{N} C2(i)\times X2(i) + \sum_{k=1}^{M} C3(k)\times W1(k)+\sum_{k=1}^{M} C4(k)\times W2(k)$$

The formulation is a mixed-integer linear program (MILP); a thorough treatment of this subject is provided in Bradley et al.[3] Several computer packages are commercially available for solving MILPs (see Sharda[4] for a survey of microcomputer-based packages). The formulation is usually small enough for microcomputer software and the computations manageable enough for interactive decision support.

**Table I.** *Definition of I/O spreadsheet terms.*

| | |
|---|---|
| **Product data:** | |
| MODEL | Product identification (input) |
| VOLUME | Units required during the planning period (input) |
| MAT'L $ | Unit cost for materials (input) |
| BUY $ | Unit purchase price (input) |
| NUM MAKE | Units to be produced in-house (output) |
| NUM BUY | Units to be purchased (output) |
| SETUP | Setup time, in hours (input) |
| RATE | Production rate, in units per hour (input) |
| MIN MAKE | Minimum units to produce in-house (input) |
| MIN BUY | Minimum units to purchase (input) |
| **Workcenter data:** | |
| THROUGHPUT | Total units to be produced in-house (output) |
| NAME | Workcenter identification |
| MIN HRS | Minimum workcenter utilization, in hours (input) |
| MAX STD | Capacity limit, using regular labor (input) |
| MAX OT | Capacity limit, including overtime labor (input) |
| STD $/HR | Cost per workcenter, regular labor (input) |
| OT $/HR | Cost per workcenter-hour, overtime labor<br>(input) |
| TOT HRS | Total workcenter utilization, in hours (output) |
| +/− STD | Over/under maximum regular labor hours (output) |
| +/− OT | Over/under overtime capacity limit (output) |
| **Financial data:** | |
| MAT'L | Total material cost (output) |
| LABOR | Total labor cost (output) |
| TOTAL MANUF | Manufacturing cost, materials and labor (output) |
| PURCHASE | Total cost of purchases (output) |
| TOTAL COST | Overall cost for the scenario (output) |

## System description

The system is PC-based with all input and output being carried out using *Lotus 1-2-3* or *Symphony* spreadsheets; the MILP is solved using *LP83/MIP83* software (Sunset Software, Inc.). *LP83/MIP83* runs on PCs with MS-DOS and at least 384k RAM. *LP83/MIP83's* spreadsheet option enables the mathematical programming software to interact directly with *Lotus* spreadsheets.

Figure 1 is a flow diagram of the system. The inputs consist of costs, capacity limits, process flow data, and the product sales forecast. "What if" analyses can include any or all of these input groups. The same spreadsheet serves both input and output functions (referred to as the I/O spreadsheet). Table I defines the terms used in the spreadsheets. For input, the I/O spreadsheet that appears as in Table II contains the data needed to run the system. After running the "scenario optimization" (the MILP), the make-buy quantities are printed directly into the I/O spreadsheet (see Table III). Other reports can be included, such as Table IV, which shows specific setup and run times for each product produced by each workcenter.

Key outputs are the plant throughput, the bottleneck workcenter(s), purchase costs, and manufacturing costs. The user performs "what if" analysis by changing input values directly. Spreadsheet input/output precludes the tedious development work of prompting the user for all possible what if options. Cells that should not be altered are "protected", ensuring that no changes are made to the system's logic. In addition, no separate database is needed. Both the input and output data are contained on the I/O spreadsheet.

## "What if" analyses

Spreadsheet input/output facilitates the performance of "what if" analyses. This interactive capability enables the planner to thoroughly analyze each plan. For example:

1. When new products are introduced, the planner can run scenarios with various setup times, production rates, or costs to determine the sensitivity of these parameters before production begins.
2. The effect of proposed changes to the production process can be analyzed. Examples are setup time reductions and the installation of faster machines.
3. The cost of proposed contractual arrangements for product purchase can be determined. In this case, the minimum buy quantities are changed in the spreadsheet.
4. The allocation of labor to workcenters can be changed. This includes both increasing the capacity of bottleneck workcenters or decreasing the capacity of other workcenters. The cost for these changes may be linear (the plant only "pays" for the labor used) or a step function (e.g., an additional shift).
5. The cost effectiveness of purchase price quantity discounts can be determined. This is done as follows: First, the higher cost (no discount) scenario is run. Second, a scenario with the minimum purchase quantity, along with the discounted cost, is run. This forces the plan to use the discount. The best solution is the scenario having the lowest total cost.
6. Major plant expansions can be evaluated by preparing longer-range forecasts and running the system with and without the proposed expansion.

## Extensions

The same basic methodology described previously can be used for several related problems. This section explores two of these possibilities, discussing both the mathematical programming formulation and implementation concerns.

### *Multi-period problem*

The formulation can be extended for longer-range planning. Here, multiple time periods and inventory holding are included, and the assumption of one setup is abandoned. This leads to a

**Table II.**

```
MAKE VS BUY ----

PRODUCT DATA:

              MAT'L    BUY    NUM    NUM WORKCENTER 1 WORKCENTER 2 WORKCENTER 3 WORKCENTER 4  MIN    MIN
MODEL  VOL.      $      $   MAKE    BUY SETUP  RATE  SETUP  RATE  SETUP  RATE  SETUP  RATE  MAKE    BUY
---------------------------------------------------------------------------------------------------------
X01    2000    $25    $80      0      0   2.0    50    5.0    75    1.0   180    5.5    45
X02    7100    $15    $55      0      0   0.5    55    0.0     0    1.0   200    6.0    40
X03    5900    $35    $89      0      0   2.5    55    3.0    50    0.0     0    4.5    75
X04    7400    $45    $77      0      0   2.0    75    4.0   100    0.0   220    3.0    45
X05    2000    $10    $37      0      0   0.5    45    0.0     0    0.5    90    0.0     0
X06    4500    $40    $85      0      0   2.0    80    2.0    95    2.0   210    3.5    55
X07    2900    $23    $47      0      0   3.0    55    6.0    75    0.0     0    6.0    45
X08    4600    $44    $67      0      0   1.5    45    4.0    70    0.0   195    2.0    50
X09    3800    $27    $62      0      0   0.0    45    2.0    45    2.0    30    1.0    85
X10    3500    $12    $39      0      0   1.5    50    0.0     0    0.5   210    3.0    45
X11    4500    $11    $32      0      0   2.0    50    6.0    55    3.0    90    4.5    80
X12    4700    $44    $85      0      0   1.5    80    4.0   110    1.0   200    3.0    50
X13    2000    $61    $96      0      0   3.0    80    2.5    50    0.0     0    5.5    45
X14    1500    $22    $46      0      0   0.5    70    5.0    75    2.0    30    0.0     0
X15    2200    $29    $51      0      0   2.0    50    8.0   110    1.0    60    4.0    30

WORKCENTER DATA:        THROUGHPUT-      0 UNITS

         MIN    MAX    MAX    STD     OT    TOT   +/-    +/-
NAME     HRS    STD     OT   $/HR   $/HR    HRS   STD     OT
-------------------------------------------------------------
W/C 1    600    900    900   $300   $450      0     0      0
W/C 2      0   1500   1500   $200   $300      0     0      0
W/C 3    300    300    300   $440   $660      0     0      0
W/C 4    300    600    720   $350   $525      0     0      0

FINANCIAL DATA - COSTS ($000):

             TOTAL   PUR-  TOTAL
MAT'L LABOR  MANUF  CHASE   COST
--------------------------------
    0     0      0      0      0
```

more complete, but larger model. The previously defined variables remain the same except for an additional index, *t* (corresponding to the time period). The revised formulation includes an additional factor: producing a product in the time period prior to its being required. Now, the options for satisfying the sales forecast are: (1) produce in the period needed, (2) purchase in the period needed, or (3) produce in a period prior to the period needed. However, the problem becomes extremely large, probably requiring a mini or mainframe computer to solve. It can be a slower, yet effective, decision support tool.

With some loss of realism, the integer variables can be excluded from the model (assume that batch sizes are relatively consistent and the setup time is a fixed percentage of the run time). The problem then becomes somewhat smaller. The factory environment will dictate whether this simplification is warranted.

### *Subcontract operations*

Some companies subcontract one or more component operations (not the entire product). Both the one-period and the multiperiod model described in the previous section can be expanded to address this problem. This is accomplished by changing the variables $X1$ and $X2$ so that another index $k$ (corresponding to the workcenter) is added. In addition, capacity limitation constraints are required for each operation. If all individual operations are considered, the problem size increases appreciably. A recommended strategy is to focus on those operations that are most likely to be subcontracted. Again, the factory environment will dictate whether simplification is warranted.

## Conclusions

This make-buy system combines the best features of "trial-and-error" manual approaches and "black box" analytical algorithms. While the planner has full decision making control, the scenario optimization ensures that the best solution is found for each scenario presented. An important feature to note is that no *a priori* estimate of standard manufacturing cost is used. Standard manufacturing cost is used for accounting purposes; it is based on average production runs. However, the actual cost to manufacture is dynamic, depending on several operational factors such as throughput, product mix, batch sizes, and overtime. This is especially true when capacity is limited and the market is volatile.

The spreadsheet input/output has several advantages: (1) it precludes the development of prompting routines that address all possible "what if" questions, (2) the planner's input data, along with the system output, appear on the same spreadsheet, and (3) the system is modular, so the optimization routine and the I/O spreadsheet can operate independently. For example, the planner can enter make-buy amounts directly and the spreadsheet logic will determine the cost of the contrived plan.

The system is also structured for potential use in evaluating plant expansion decisions, determining the effect of production

### Table III

```
MAKE VS BUY ---- CASE I

PRODUCT DATA:

             MAT'L    BUY    NUM     NUM WORKCENTER 1 WORKCENTER 2 WORKCENTER 3 WORKCENTER 4   MIN    MIN
MODEL VOL.       $      $   MAKE     BUY  SETUP  RATE  SETUP  RATE  SETUP  RATE  SETUP  RATE  MAKE    BUY
-----------------------------------------------------------------------------------------------------------
X01   2000     $25    $80   2000       0    2.0    50    5.0    75    1.0   180    5.5    45
X02   7100     $15    $55   7100       0    0.5    55    0.0     0    1.0   200    6.0    40
X03   5900     $35    $89   5900       0    2.5    55    3.0    50    0.0     0    4.5    75
X04   7400     $45    $77   5936    1464    2.0    75    4.0   100    0.0   220    3.0    45
X05   2000     $10    $37   2000       0    0.5    45    0.0     0    0.5    90    0.0     0
X06   4500     $40    $85   4500       0    2.0    80    2.0    95    2.0   210    3.5    55
X07   2900     $23    $47      0    2900    3.0    55    6.0    75    0.0     0    6.0    45
X08   4600     $44    $67      0    4600    1.5    45    4.0    70    0.0   195    2.0    50
X09   3800     $27    $62   2993     807    0.0    45    2.0    45    2.0    30    1.0    85
X10   3500     $12    $39      0    3500    1.5    50    0.0     0    0.5   210    3.0    45
X11   4500     $11    $32      0    4500    2.0    50    6.0    55    3.0    90    4.5    80
X12   4700     $44    $85   4700       0    1.5    80    4.0   110    1.0   200    3.0    50
X13   2000     $61    $96   2000       0    3.0    80    2.5    50    0.0     0    5.5    45
X14   1500     $22    $46   1500       0    0.5    70    5.0    75    2.0    30    0.0     0
X15   2200     $29    $51      0    2200    2.0    50    8.0   110    1.0    60    4.0    30

WORKCENTER DATA:       THROUGHPUT- 38629 UNITS

          MIN    MAX    MAX    STD     OT    TOT   +/-     +/-
NAME      HRS    STD     OT   $/HR   $/HR    HRS   STD      OT
--------------------------------------------------------------
W/C 1     600    900    900   $300   $450    642  -258    -258
W/C 2       0   1500   1500   $200   $300    448 -1052   -1052
W/C 3     300    300    300   $440   $660    300     0       0
W/C 4     300    600    720   $350   $525    720   120       0

FINANCIAL DATA - COSTS ($000):

             TOTAL   PUR-   TOTAL
MAT'L LABOR  MANUF  CHASE    COST
---------------------------------
1273    687   1960   1000    2960
```

### Table IV

```
              WORKCENTER PROFILES - HOURS UTILIZED

         WORKCENTER 1 WORKCENTER 2 WORKCENTER 3 WORKCENTER 4
MODEL    SETUP    RUN SETUP    RUN SETUP    RUN SETUP    RUN
-------------------------------------------------------------
X01        2.0   40.0   5.0   26.7   1.0   11.1   5.5   44.4
X02        0.5  129.1   0.0    0.0   1.0   35.5   6.0  177.5
X03        2.5  107.3   3.0  118.0   0.0    0.0   4.5   78.7
X04        2.0   79.2   4.0   59.4   0.0   27.0   3.0  131.9
X05        0.5   44.4   0.0    0.0   0.5   22.2   0.0    0.0
X06        2.0   56.3   2.0   47.4   2.0   21.4   3.5   81.8
X07        0.0    0.0   0.0    0.0   0.0    0.0   0.0    0.0
X08        0.0    0.0   0.0    0.0   0.0    0.0   0.0    0.0
X09        0.0   66.5   2.0   66.5   2.0   99.8   1.0   35.2
X10        0.0    0.0   0.0    0.0   0.0    0.0   0.0    0.0
X11        0.0    0.0   0.0    0.0   0.0    0.0   0.0    0.0
X12        1.5   58.8   4.0   42.7   1.0   23.5   3.0   94.0
X13        3.0   25.0   2.5   40.0   0.0    0.0   5.5   44.4
X14        0.5   21.4   5.0   20.0   2.0   50.0   0.0    0.0
X15        0.0    0.0   0.0    0.0   0.0    0.0   0.0    0.0
-------------------------------------------------------------
TOTAL     14.5  627.9  27.5  420.6   9.5  290.5  32.0  688.0

UTIL             642           448           300          720
-------------------------------------------------------------
MIN HRS          600             0           300          300
MAX STD          900          1500           300          600
MAX OT           900          1500           300          720
-------------------------------------------------------------
OT USED            0             0             0          120
+/- MAX         -258         -1052             0            0
-------------------------------------------------------------
COST (000)    $192.7         $89.6        $132.0       $273.0
=============================================================
```

process changes, and as a guide in determining the true cost of new products. The methodology can be expanded to consider multi-period plans and the subcontracting of individual operations.

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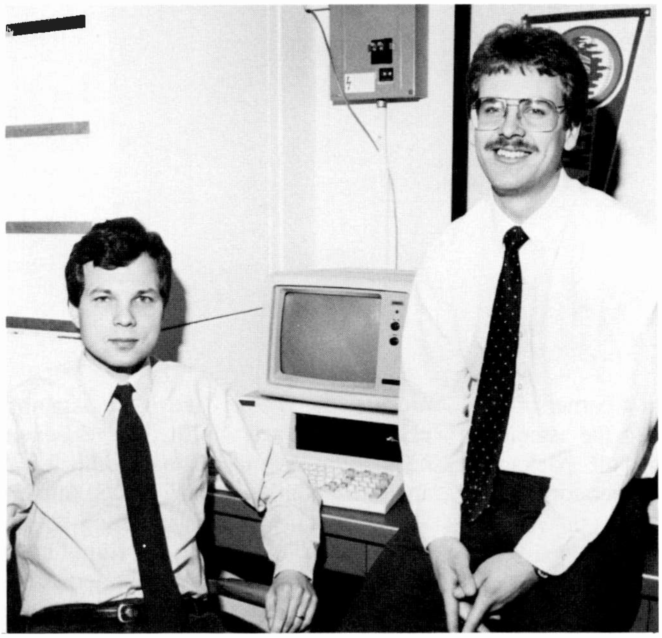

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# Solid State Division, Far East Manufacturing—plants, products, people—progress

*The plants, the products, the people, the progress—SSD has them all, of quality, in its Far East manufacturing operations.*

The Solid State Division (SSD) began the assembly and testing of ICs in late 1968 at a Consumer Electronics (CE) plant near Taoyuan, Taiwan, a then developing city 16 miles south of Taipei. The original facility, literally tucked in a corner of the CE plant, was dedicated to the assembly of ICs in plastic dual-in-line packages (DIPs), and employed 30 operators and a handful of managers.

**Abstract:** *The Solid State Division established its Far East assembly and test operations nearly 20 years ago in a corner of a Consumer Electronics facility in the city of Taoyuan, Taiwan. By any standard, the operation, dedicated solely to the assembly of ICs, was small, comprising only a few managers and a few tens of operators. Today, Far East operations include facilities in two countries, Taiwan and Malaysia, occupy more than 370,000 square feet, employ 5,500 people, assemble and test both IC and Power products, and ship more than 4,000 different products (50 million devices) per month to RCA customers throughout the world.*

*The fact that this dramatic growth in a high-technology business, which requires good communications, transfers of technology, and coordination of purchasing, production, and distribution, was accomplished at locations half a world apart by people of very different cultures and speaking different languages, is a tribute to the dedication of the RCA people involved.*

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The rapid growth of the IC business and the need to reduce unit costs resulted in a rapid expansion of SSD space and manpower requirements at the Taoyuan facility. But, at the same time, CE was also growing fast, and so the space available for SSD expansion was limited. For that reason, in the early 1970s, SSD contracted out some work to two Taiwanese integrated-circuit assemblers. This move gave SSD additional facilities in Taipei and Ilan. In 1976 and 1977, SSD bought out these independent assemblers and established a fourth location in San-Chung, Taiwan, for a Taiwan Design and Construction Shop (TDCS). The shop, now located in Taoyuan, still functions as the Far East design and construction facility for finishing tools, molds, jigs, fixtures, and burn-in/life-test boards, and provides shop support to all of our Far East assembly and test operations. By the late 1970s, assembly operations had expanded to include both plastic and ceramic packages, and included a sophisticated test operation. A distribution center provided direct shipments to customers worldwide.

It soon became evident that the logistics of moving product between locations in Taiwan were adding complexity to the assembly process. A decision was made to expand the Taoyuan facility to accommodate the Taipei and Ilan assembly plants, which were located in residential neighborhoods and originally designed as apartment houses, and the TDCS. Another 75,600 square feet were added to the Taoyuan facility during 1984 and 1985. This expansion included a modern Class 10,000 cleanroom for die attach and wire bonding. The consolidation was completed in the spring of 1985.

In 1974, simultaneously with the expansion in Taiwan, SSD was preparing a new site in Malaysia for the assembly and test of power and IC products. This plant is situated on the outskirts of Kuala Lumpur, the capital of Malaysia, and is the most distant satellite facility from SSD headquarters in Somerville.

Malaysia, once a British colony, is now a well-developed country and a major exporter of ICs. The Malaysia facility, usually referred to at SSD as "KL" (Kuala Lumpur), has grown in leaps and bounds since 1974. The original staff of about six Somerville and Findlay expatriates and 511 employees has grown to more than 3,200 employees.

The expansion took place in two phases. First, the original building was extended by 60,000 square feet in the late 1970s. Then, in 1979, a separate building comprising 64,000 square feet and located approximately one kilometer from the plant was leased. With some smaller expansions, what started out as a relatively modest manual assembly plant has now grown into a 208,000-square-foot automated assembly and test facility with a cleanroom environment. The production capacity in Malaysia for power devices and ICs is greater than 40 million devices per month.

## Products

SSD's Taoyuan, Taiwan, plant assembles the higher-lead-count, lower-volume IC products of all RCA IC technologies in a broad array of packages. Chips in wafer form are produced in the Division's U.S. wafer-fabrication plants: ICs in Findlay, Ohio, and power devices in Mountaintop, Pennsylvania. This full spectrum of products includes many highly diverse types intended for a wide range of circuit functions in commercial, military, consumer, and industrial applications.

The matrix shown in Fig. 1a represents approximately 8,000 types of products being shipped from Taiwan. Diversity in assembly and test is characteristic of Taiwan's production style: small-lot multitype manufacturing.

The Malaysian facility services the same general markets as the Taiwan facility, except that Malaysia's focus is on high-volume, low-cost plastic ICs and power devices (Fig. 1b).

The Taoyuan, Taiwan, plant has a capacity of 8 million ICs per month, which, together with Malaysia's 40 million IC and power devices per month, adds up to a Far East capacity of close to 50 million devices per month. It is interesting to note that the dollar value of each location's output is very similar, in spite of their differences in output. This phenomenon reflects the significant range of market values of the products produced.

### *Product management*

Prior to the end of 1978, product flow in the Far East was almost totally manually controlled with pencil and paper. But at approximately year's end 1978, Somerville's IBM mainframe facilities were extended to the Far East through the installation there of remote terminals and printer controllers: Data-100 computers operating through a leased 4,800-bps satellite line. Since then, many more (in quantity and sophistication) control systems have been designed by the Manufacturing Systems Group in Somerville, with input from the Far East locations. The most important of these systems were the Production Reporting System, an internal plant system using batch-processed data to track work-in-progress (WIP) inventory, and CICS/TOPS (Customer Information Control System/Total Order Processing System), a worldwide system used to track finished goods and inventory and to distribute products to customers based on the computer-generated packing slip.

The rapid growth in business and the evolution of more powerful computers has been followed by a continuing upgrade of all of the systems used in the Far East, both in hardware and software. For example, the Data 100s have been replaced by HP 3000-48 computers, and the satellite line has been upgraded to 9600 bps. In software, the production reporting system has been replaced by a more advanced

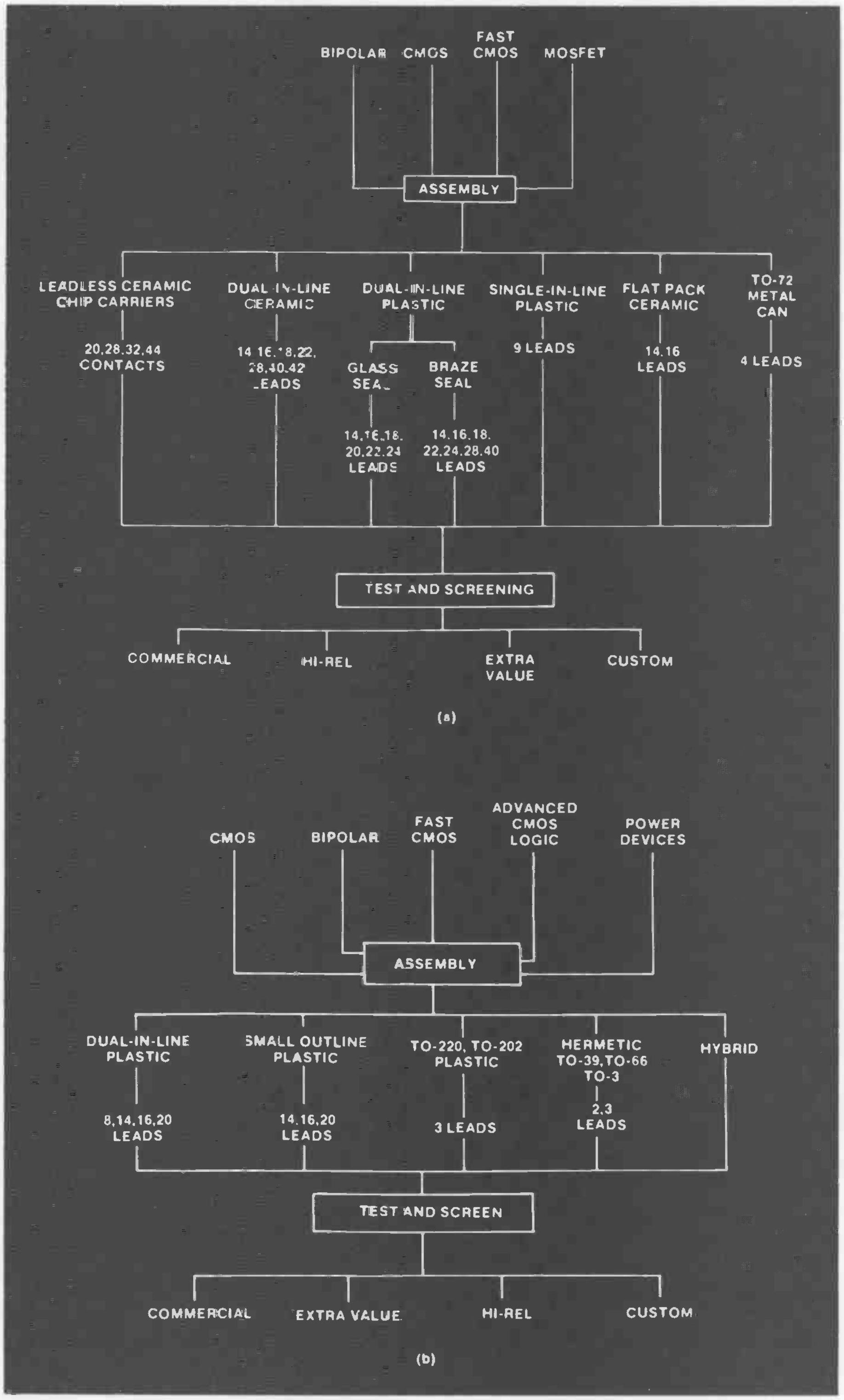

**Fig. 1.** *Products assembled and tested in (a) Taiwan and (b) Malaysia.*

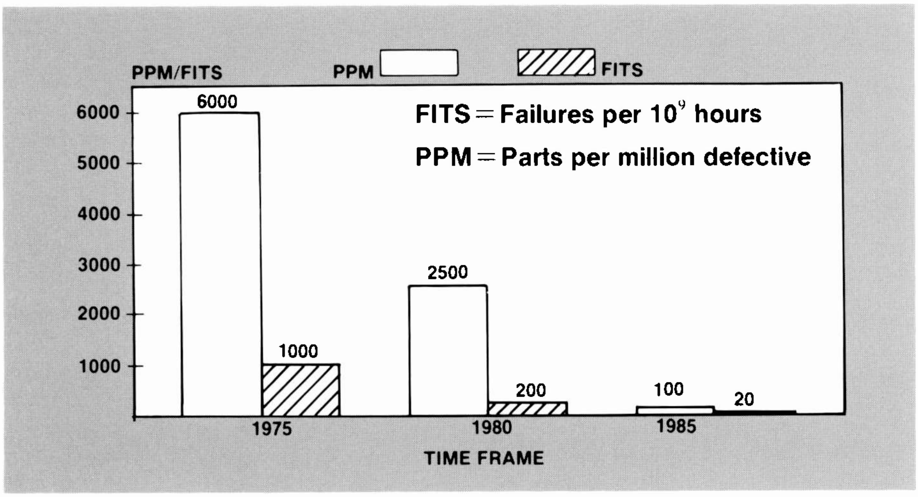

**Fig. 2.** *Advances in quality and reliability in Taiwan and Malaysia.*

on-line, by-lot WIP inventory tracking system (IC-10) running on local HP 3000 computers. TOPS has been replaced by another worldwide, more powerful Sales, Orders, and Accounts Receivable (SOAR) system. SOAR is an on-line interactive system running on the Somerville IBM mainframe. It not only provides local-management finished-goods inventory status but order, customer, and packing-slip information as well.

IC-10 and SOAR make available real-time, accurate data, and provide input data for several planning systems required for the on-time delivery of product. Both of these systems are essential to the management of the more than 16,000 line items shipped monthly from the Far East.

### *Communications*

In any business, communication is vital, but when you're situated about as far away as you can be, halfway around the world in fact, from your Division headquarters, communications and personnel interaction can be very challenging. Add to distance the fact that you're working with people of different cultures and races, speaking different languages, and living and working in different time zones, and you have a situation that even a company like RCA, a leader in communications, is hard pressed to accept. Imagine the discussion of an engineering problem at 9 a.m. in Somerville with engineers in Malaysia or Taiwan where it is already 9 p.m. or vice versa. The resolution of this aspect of communications and its continued smooth running are really a tribute to the people at both sides of the world; a great many sacrifices have been made by people at each of the locations in overcoming the communications barrier caused by a 12-hour time difference.

Although there is still a fair amount of direct communication by telephone, most intra-Division communications are now in the form of computer-transmitted messages, computergrams, and, to a lesser degree, facsimile. The computergram first became available in 1978 with the installation of the Data 100 computer. The computergram system was very limited, but was continually upgraded. Today it is a very sophisticated, powerful communications tool. And whereas the twelve-hour time difference is undesirable in communications by telephone, it is actually advantageous when using computergrams. A message is sent from Somerville during the day, which is night in the Far East. The information required for the response is gathered and transmitted back to Somerville during the day in the Far East, which is night in Somerville. Upon arriving at work the next day, the Somerville engineer finds the answer to his query waiting.

In 1982, an HP 3000 system was installed in the Far East plants to give them computing power. A Wang OIS system was also installed to decentralize the Somerville Documentation Center (maintainers of engineering standards and specifications) and involve the plants in the writing and maintenance of their own operating instructions. When these new systems came on line, the leased satellite line was multiplexed in parallel among the HP 3000, Data 100, and Wang OIS.

At the end of 1985, the HP 3000 took over the entire Data 100 load, and evolved into a separate network of HP 3000s. The DS/3000 network of manufacturing plants is centered in Somerville's HP 3000/68 system A, and has successfully relieved the Far East of bottlenecks in printout transmission from the Somerville IBM to local printers at peak times. The DS/3000-HP 3000 network in SSD's plants led to the idea of implementing electronic mail, which promises to upgrade communications and information storage and retrieval in all manufacturing locations.

In the foreseeable future, various electronic mail systems may be "popping up" in the varied networks used by RCA: HP Mail, DECMAIL, PROFOS. The challenge will be to overcome the computer language barrier, which at times seems even more difficult than the human-language barriers.

1985 was also the year that 26 personal computers were installed in Taiwan and Malaysia. It is expected that this computing power at the departmental level will play a major role in increasing both office and plant productivity.

### *Quality and productivity*

Product quality is the primary focus in both Far East assembly plants. The total quality program includes statistical process controls, regularly scheduled preventive maintenance, in-plant training and, in Malaysia, operator participation through Quality Circles.

The Quality Circle, or "4M" as it is called in Malaysia—menjaga kebersihan (clean environment), mencegah campuran (prevent mixing), menjamin mutu (ensure product quality), and membaiki cara kerja (improve work methods))—is a most successful "people-related" program. The 4M program was initiated in 1982 and has grown steadily to encompass 80 active circles, making it one of the largest Quality Circle programs in Malaysia.

The program has two major objectives. The first is to assure a good work attitude among the factory workers, to get them involved, interested, and participating in company business. Over the years, this attention to attitude has had very noticeable and rewarding results. The second objective of the program is to encourage the circles to work on problem solving, cost reduction, and quality improvement. The contributions made by the operators in improving the products and/or the plant's performance have been truly amazing, and are a resource that had not been tapped in the past. One of the major rewards for both participants and management is the biannual QC convention, where the QC circles present their projects to top management. The progress in quality made by both plants is impressive, and is shown quantitatively in Fig. 2.

The progress in productivity is just as impressive as that in quality, mainly because of automation. The first program in automated operations, a joint effort of Assembly Technology engineers in Somerville and Malaysia, involved a capital investment of over 13 million dollars and took three years to accomplish. The project acronym was RAMP (RCA Assembly Mechanization Program). The productivity gains shown in Fig. 3a for Taiwan resulted in very significant cost reductions and improved product quality; both of these factors keep RCA very competitive in the production of dual-in-line plastic (DIP) products. Productivity gains in Malaysia are shown in Fig. 3b.

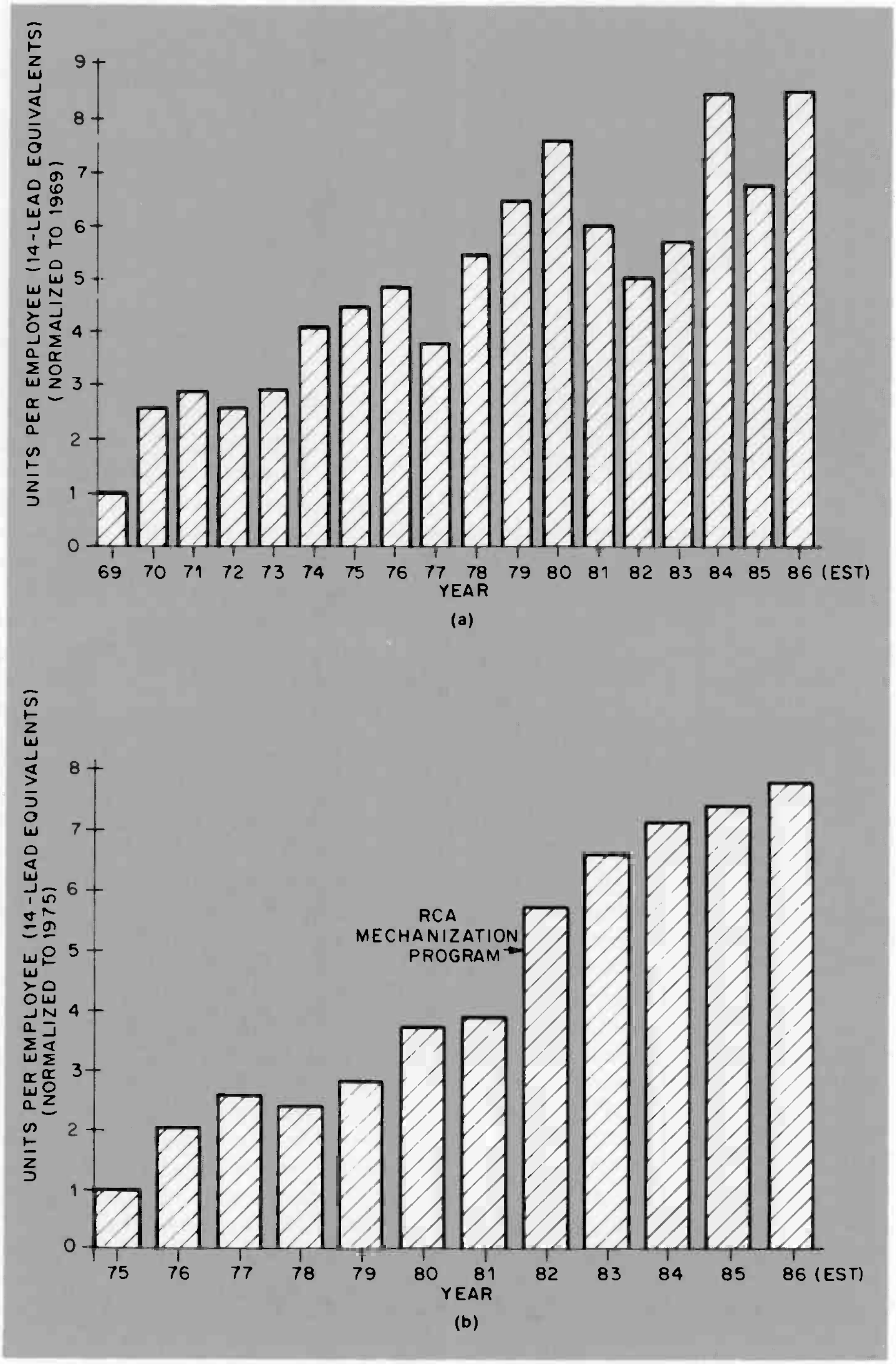

**Fig. 3.** *Productivity improvement in (a) Taiwan and (b) Malaysia.*

## People

### *Culture*

The Taiwan facility has a sole ethnic background—Chinese. All in-plant communications, both written and verbal, are in Chinese, with English used for communicating with facilities outside of Taiwan. Generally, the direct laborers have a high-school education, and salaried employees are college graduates.

The Malaysian plant population is made up of three major races, each having a very different culture. The Malays, or Bumiputras ("children of the soil"), are native to Malaysia, while the Chinese and Indians are mainly third-generation citizens whose ancestors came to work in the tin mines or on the rubber plantations. English is the primary language used within the plant. The national language is Bahasa Malaysia.

Figure 4 is an interesting example of how far RCA has gone to minimize the culture shock on the various ethnic groups working in the Far East. In this photograph of a cleanroom, the woman at the left is wearing a cleanroom head covering specially designed to match her customary native dress.

A unique aspect of Malaysian culture is the many festivals and holidays. The multi-ethnic makeup of Malaysia—this country has often been described as a mini-U.N.—makes for an almost constant round of festivals and holidays, from Deepavali, Feast of the Hungry Ghosts, to Christmas. One festival seems to follow another, and each by itself is significant and important to the lives of those who celebrate it.

In January, there is Thaipusam, a religious festival celebrated by thousands of Indians who come to pay homage to Lord Muruga, also known as Subramaniam, Sivaguru, Arumugam, etc. The highlight of this festival is the Kavadi, or sacrifice procession, in which participants carry objects ranging from simple pots of milk to elaborate decorated structures bearing spikes that are hooked onto the devotees bare bodies. Some pierce their cheeks with skewers several feet long. These are removed at the shrine of the diety, surprisingly leaving hardly a trace of scar.

The Chinese New Year falls in February. It is a time of "good wishes" cards and homes decorated with slips of red paper and scrolls bearing inscriptions signifying happiness and long life. This is the time for the once-a-year family-reunion dinner. On the eve of the new year, all members of the family gather for the last meal of the old year. On Chinese New Year morning, parents present their offspring

**Fig. 4.** *An example of the steps taken by RCA to assure minimum disruption of culture: cleanroom head coverings designed to match native dress.*

with "angpows" (red packets containing money—one dollar and ten cents being standard in the old days). The day follows with visiting, dining, drinking to the choruses of "yam seng" (cheers), and nibbling specialties like "love-letters" and melon seeds. The spectacular lion dance is the order of the day.

With March comes the festival of the Goddess of Mercy and Easter. April has its Tomb Sweeping days. Buddha's birth and enlightenment day falls in May.

After a month of fasting from sunrise to sunset, the Muslims celebrate Hari Raya Puasa (New Year) in June, paying respect to their elders by praying in the mosques. On the eve of this festival, selected religious leaders make their journeys to specific hilltops to sight the moon. Only when the moon is sighted will the following day be declared Hari Raya Puasa. On New Year's Day, hosts will serve generous portions of mouth-watering beef and chicken to go along with traditionally cooked dishes.

The Dragon Boat Race, St. Anne's festival, the Moon Cake festival and others follow until Christmas and the New Year most of us know.

### Big Sisters

The vast majority of the workforce in Malaysia is female, with an average age of about 20. These women come from rural areas within a 50- to 100-mile radius of the plant. For them, just coming to the city would be a major event, but staying away from home and family is indeed a major social and cultural change. The Big Sister program was set up to help them through these changes. A Big Sister is a senior woman from the workforce, a volunteer who is trained as a social consultant. Consultations are normally held during meal breaks or after work. The subjects most commonly discussed are boyfriends, housing accommodations, and loneliness. The Big Sister is a very comforting person to the young women who have come to the city for the first time and to work and live by themselves. With the guidance of their Big Sisters, these young women do make the transition from rural to city life and achieve a sense of belonging.

### Dormitories and transportation

Single female workers and employees who live far from home live in dormitories in Taiwan. About 500 SSD operators and 600 CE workers live together in the dormitory area just adjacent to the main plant. The eight housing buildings and the Family Social Center offer an enriching and colorful life for the residents.

The Family Social Center, under the auspices of the Employee Relations Department, offers a variety of organizations, training programs, and social activities for the young women. The counterparts of the Malaysian Big Sister in Taiwan are the fourteen advisors who live in the dormitories themselves, and who are available for general consulting. Folkdance, flower arrangement, choral, social service, and charity clubs are all open to interested women. Many women also attend the language training courses.

A wide-ranging transportation network is another feature of the Taiwan plant. With a three-shift turnaround, 51 commuter buses must run daily to pick up employees living within a 10- to 20-mile radius.

## Progress

Remarkable progress has been made in the past two decades by the people in our Far East plants, but they know as we do that in a high-technology business like SSD's, upgrading of facilities and new products are indeed the name of the game; both of these factors are now being addressed by projects underway or in planning in both Taiwan and Malaysia.

### New products/programs

***Malaysia.*** *Small-outline package*—Malaysia is in the final stages of installing a line for small-outline plastic package (SOP) production. The spacing between leads of these packages is only half that of the DIP, which has 50-mil centers. Small-outline packages are soldered to the surface of a printed circuit board rather than having their leads soldered into holes in the printed circuit board, as is true for the DIP. As a result of their small size, their use amounts to a considerable savings (over the use of DIPs) in the board area required to fabricate a given circuit function. This type of packaging will be used primarily for automotive, telecommunications, and computer applications. By 1990, small-outline packages could represent 50 percent of Malaysia's assembly capacity.

The tasks for developing this package design were shared between Somerville Assembly Technologies and Malaysia Assembly Engineering. Tooling and equipment made in the U.S. was specified and tracked by Somerville with inputs from Malaysia. The tin-plating system was specified and tracked by Malaysia with inputs from Somerville. The production line for the first three lead counts, 14, 16, and 20, should be operational in Malaysia by August 1986.

*Surgectors*—Surgectors represent a new type of surge-suppression technology. This product is designed to protect sophisticated electronic circuits from rapid, high-voltage power surges that conventional suppressors cannot handle. An automated assembly and test line is being installed in Malaysia and is scheduled for mid-year start-up. This program is a joint effort of the Mountaintop Equipment and Package Engineering staff and Malaysia Engineering.

***Taiwan.*** *Mechanization program*—The Somerville and Taiwan Assembly Technologies groups have initiated an aggressive program to upgrade and modernize the Taiwan facility. The program will be completed in the second quarter of 1987.

**Willy Su** is Staff Manager of Manufacturing and Manufacturing Engineering for the Solid State Division in Taiwan. His responsibilities cover manufacturing and assembly and related engineering support. Willy began his career with RCA Taiwan in 1974 as an Industrial Engineer. He was subsequently promoted to Staff Manager, Industrial Engineering, MIS and Plant Engineering in 1982, and then into his present position. Willy received the BSIE degree from the Chung Yuan Christian University, Taiwan, and he is a Senior Member of IIE.
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**Taoyuan, Taiwan**
**(033) 32-2181, Ext. 249**

**C.B. Teh** is Manager, Manufacturing Operations, Kuala Lumpur, Malaysia, with responsibilities for production, production control, and equipment maintenance for both IC and power product lines. He joined RCA Kuala Lumpur as a pioneer staffer in the Quality and Reliability Assurance Department in 1974, and prior to his present assignment, had various responsibilities in Engineering and power product line operations. He graduated from the University of Malaya with a major in Physics.
**Contact him at:**
**RCA Solid State Division**
**Kuala Lumpur, Malaysia**

**Gene Reiss** is the Director of Assembly Technologies and Manufacturing Support for the Solid State Division. The Assembly and Technologies Groups are responsible for development of new IC packages, evaluation of assembly materials, development of packing containers, and facilitation of Far East assembly operations. Recently the Assembly Technologies Groups have introduced surface-mounted packages, mechanized various assembly operations, improved brand adherence, and introduced bar-coded labels for shipping containers. Gene has a BS in Chemistry and an MBA in Management from Fairleigh Dickinson University.
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**RCA Solid State Division**
**Somerville, N.J.**
**Tacnet: 325-6654**

Like Malaysia's RAMP program, the Taiwan effort will focus on the mechanization of the dual-in-line plastic package line for all lead counts, 18 through 42. An automated wire bonding facility was installed in the early 1980s, so the Taiwan RAMP program will now focus on pellet management (the sawing of wafers into individual chips, which are then held in place on a plastic film), die attach, molding, lead form and trim, lead finish and branding, and the installation of state-of-the-art automated equipment, such as that used in wafer mapping and computer-aided manufacturing. Since the chips assembled in the higher-lead-count packages are more costly, the expected improvements in assembly yield will generate a reasonable return on investment. The mechanization of Taiwan's DIP line will enhance productivity, quality, and cycle time, and reduce cost, which are all moves in the direction of Just In Time (JIT) manufacturing methods. JIT methods assure on-time delivery of goods to a customer to allow him to maintain only minimum inventory. These methods require careful planning and execution on the part of the supplier.

*Plastic leaded chip carrier*—The plastic leaded chip carrier (PLCC) is a surface-mounted package intended for high-lead-count products. Lead spacing is on 50-mil centers, similar to the SOP, with leads on all four sides of the package. The PLCC has lead counts ranging from 18 to 84. This family of packages will be installed in Taiwan in keeping with its charter for high-lead-count, lower-volume packaging.

The PLCC program will be jointly planned by the Somerville Assembly Technologies Groups and Taiwan Assembly Engineering. Tooling orders for the long-lead items (mold and lead forming equipment), have been placed. The plan is to introduce one lead count first to gain experience. Other counts will then be added rapidly. The first lead count chosen was 68; it will be operational in the third quarter of 1987. In the meantime, PLCC packaging of RCA chips will be provided by subcontract assemblers.

***Combined Malaysia/Taiwan programs.*** Surface mounting has become the prime technique for reducing circuit board size by improving packaging density. This technology offers the additional advantages of better performance, easier handling, and low-cost PC boards through automation. Both Taiwan and Malaysia will continue to expand their production capability for packaging chips in surface-mount packages. This expansion will require continual process development and upgrades in addition to the procurement of state-of-the-art equipment for assembly, test, and preparation for shipment to customers. As lead counts increase to over 200 per package, lead spacing will probably decrease from the surface-mount-device (SMD) 50-mil centers to 30-mil or even 20-mil centers. As this change occurs, new packaging techniques such as tape automated bonding (TAB) will be required.

Anticipating that these new directions would require engineering resources beyond those available in Somerville's Assembly Technologies Groups, SSD's management, in the fall of 1985, formed two new Far East Assembly Technology Groups, one in Taiwan and the other in Malaysia. The prime objective is to apply the international assembly engineering talents of SSD to the development of packages for new products. In April 1986, the first International Assembly Technologies Meeting was held in Taiwan, with representation from Malaysia and Somerville. Technical approaches to the resolution of assembly issues were the number one topic.

## Acknowledgements

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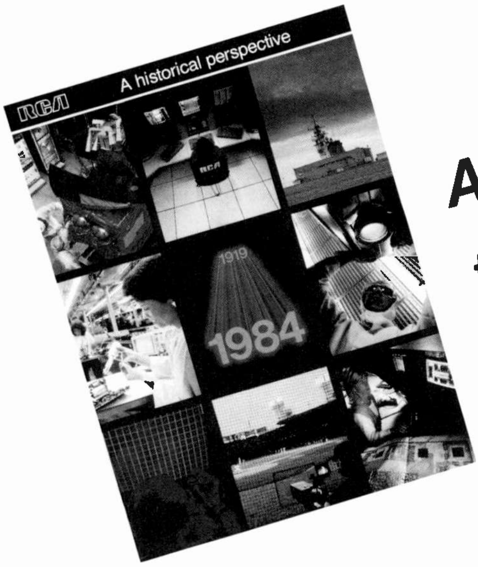

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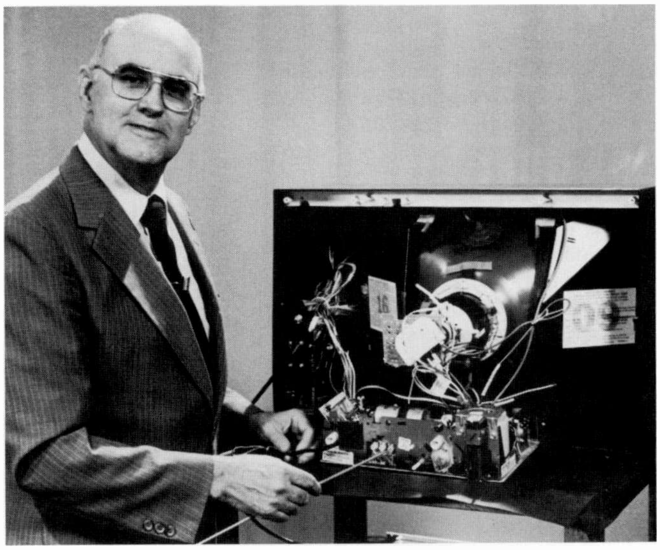

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K. Malakian | G. Adomian
**Existence of the Inverse of a Linear Stochastic Operator**—*Journal of Mathematical Analysis and Applications*, Vol. 114, No. 1, February 15, 1986

J.V. Melody | M.E. Perie | A. Wong
**Use of Software Standards in the FAA's Advanced Automation Program**—presented at the Computer Standards Conference 1986, IEEE Computer Society, San Francisco, Cal., May 13-15, 1986

F.E. Oliveto
**Tutorial on Reliability**—presented at the 17th annual Reliability Symposium, Horsham, Pa., April 30, 1986

F. Reifler | R.D. Morris
**A Guage Symmetric Approach to Fierz Identities**—presented at the International Conference on Physics of Phase Space, College Park, Maryland, May 21, 1986

D.P. Schnorr
**Packaging and Interconnecting Structures for Chip Carrier/Surface Mounting Technology**—presented at the 17th Annual Reliability Symposium, Horsham, Pa., April 30, 1986

R.L. Stegall
**Multiple Object Tracking Radar**—presented at the Military Microwave '86 Symposium, Brighton, England, June 24-26, 1986 and published in the *Proceedings*

J.D. Steben | L.J. Streletz | R.G. Fariello
**Multiprocessing Computer System for Sensory Evoked Potentials and EEG Spectral Analysis for Clinical Neurophysiology Laboratory**—*Journal of Medical Systems*, Vol. 9, 1985

L.H. Yorinks | F.I. Sheftman
**A Printed-Circuit Log-Periodic Radiating Element for Wideband Phased Arrays**—presented at the 1986 International IEEE AP-S Symposium, Philadelphia, Pa., June 1986 and published in the *Digest*

# Engineering News and Highlights

## Howe is head of CISD

**Charles A. Schmidt,** Group Vice President, RCA Government Communications Systems, has announced the appointment of **Joseph B. Howe** as Division Vice President and General Manager of RCA Communication and Information Systems Division. Mr. Howe returns to the division—which he served in a similar position previously—from the Aerospace and Defense organization, where he had been Staff Vice President, Systems and Manufacturing. Before that, he had held the position of Staff Vice President and Chief Engineer for the Aerospace and Defense organization.

From 1981 to 1984, Mr. Howe served as the Division Vice President and General Manager of the Broadcast Systems Division, which was then called Commercial Communications Systems.

Mr. Howe joined RCA in 1951 as a co-op student while attending St. Joseph's University. He held a variety of management positions until 1979, when he was appointed Division Vice President and General Manager of Government Communications Systems.

## Miller elected GE officer

**Richard W. Miller,** Executive Vice President, RCA Consumer Products and Entertainment, has been elected Senior Vice President, Consumer Electronics Business, reporting to **John F. Welch, Jr.,** GE Chairman of the Board and Chief Executive Officer. Mr. Miller has overall responsibility for both the General Electric and RCA consumer electronics businesses. Reporting to Mr. Miller is **Jacques A. Robinson,** Vice President of General Electrics's Consumer Electronics Business, and **Jack K. Sauter,** RCA Group Vice President, Consumer Electronics and Video Components.

## Solid State Division announces organizational changes

On June 30, several changes were announced in the organization of the GE/RCA semiconductor activity. **James E. Dykes** was appointed Vice President and General Manager of the General Electric Semiconductor Business. **Carl R. Turner** has been elected a General Electric Vice President, and was appointed General Manager of the Solid State Division, reporting to Dykes. In addition, Turner continues to head RCA Solid State Division and manage its components.

Four General Electric components report to Turner: GE Intersil, **R. Paul Gupta,** President; Custom Integrated Circuit Department, **Stephen W. Michael,** General Manager; Power Electronics Semiconductor Department, **J. Larry Smart,** General Manager; and Semiconductor Sales Department, **Stephen L. Pletcher,** General Manager. Also reporting to Turner at RCA Solid State Division are **Gordon W. Bricker,** Division Vice President, Business Development and Planning; **Herbert V. Criscito,** Division Vice President, Marketing; **Larry J. Gallace,** Division Vice President, Product Assurance, MIS and Materials; **Walter J. Glowczynski,** Division Vice President, Finance; **Robert P. Jones,** Division Vice President, Power Products and International Manufacturing; **Heshmat Khajezadeh,** Division Vice President, IC Products; **William R. Shebey,** Senior Counsel; and **Dominick A. Zurlo,** Division Vice President, Employee Relations.

## Staff announcements

### Aerospace and Defense

**John D. Rittenhouse,** Executive Vice President, Aerospace and Defense, announces the appointment of **Joseph C. Volpe** as Staff Vice president, Quality and Manufacturing Operations.

### Astro-Electronics Division

**Louis Gomberg,** Division Vice President, Remote Sensing Satellite Programs, announces the appointment of **Ronald C. Maehl** as Manager, Mars Observer Program.

### Communication and Information Systems Division

**Joseph B. Howe,** Division Vice President and General Manager, Communication and Information Systems Division, announces his organization as follows: **John R. Allen,** Principal Scientist; **Joseph B. Christopher,** Director, Plant Operations; **Bernard S. Jacks,** Director, Product Assurance; **Donald D. Miller,** Division Vice President, Engineering; **Bill Moore,** Director, Information Processing Systems; **Donald J. Parker,** Division Vice President, Digital Communications and Recording Systems; **John F. Serafin,** Division Vice President, Integrated Communications Systems; **John C. Shannon,** Director, Transmission Systems; **Alfred C. Thompson,** Division Vice President, Business Development; and **Edward W. Williams,** Director, Finance.

**John B. Christopher,** Director, Plant Operations, announces that the COMSEC Manufacturing activity in the Digital Communications and Recording Systems organization is transferred to his staff.

**Donald J. Parker,** Division Vice President, Digital Communications and Recording Systems, announces the appointment of **Edy J. Mozzi** as Director, Future Secure Voice Systems.

**Donald J. Parker,** Division Vice President, Digital Communications and Recording Systems, announces the appointment of **Joseph Pane** as Director, Special Programs.

**John F. Serafin,** Division Vice President, Integrated Communications Systems, announces the appointment of **Guy H. Shaffer** as Director, Advanced Systems Development.

**Bernard S. Jacks,** Director, Product Assurance, announces his organization as follows: **Richard Barone,** Manager, Integrated Logistics Support; **Meyer R. Greenberg,** Manager, Quality Control; **Berard S. Jacks,** Acting Manager, Systems Effectiveness; **Jerry L. Lenk,** Manager, Program Product Assurance; **James D. Logan,** Manager, Purchased Materials Quality Assurance; and **Robert K. Swenson,** Manager, Quality Assurance Engineering and Administration.

**Joseph B. Christopher,** Director, Plant Operations, announces his organization as follows: **J. Neal Dexter,** Manager, Government Manufacturing; **George H. Lines,** Manager, Fabricated Products; **Marvin Livingston,** Manager, GWEN Manufacturing; **Carlene Marchese,** Manager, Manufacturing Administration; **Vincent J. Mazzaglia,** Manager, Plant Engineering; **Richard H. Moyer,** Manager, COMSEC Manufacturing; **Charles F. O'Donnell,** Manager, Material Acquisition; **Fred Pfifferling,** Manager, Test Engineering; **David C. Sparks,** Manager, Manufacturing Industrial Engineering; and **Vincent V. Valente,** Manager, Material Administration.

## Consumer Electronics Operations

**Harry Anderson,** Division Vice President, Program Management, announces the appointment of **Perry C. Olsen** as Program Manager-CTC146/149.

**G. Bruce Dilling,** Plant Manager, Bloomington Plant, announces the appointment of **Roger D. Peterman** as Manager, Display Systems Operations—Bloomington.

**Perry C. Olsen,** Program Manager—CTC146/149 announces his organization as follows: **Leroy Boone,** Administrator, New Product Manufacturability: **Edward M. Hague,** Quality Assurance/Reliability Engineer; **Dudley W. Jaggar,** Administrator, Development Projects; and **Paul C. Wilmarth,** Manager, Project Engineering.

**Willard M. Workman,** Division Vice President, Product Assurance, announces the appointment of **Randall R. Mitchell** as Manager, Quality Systems Engineering.

**J.B. Thomas,** Plant Manager, Indianapolis Plant, announces the appointment of **Keith A. Searcy** as Manager, Plant Quality Control.

## Display Systems Division

**Larry A. Cochran,** Division Vice President, Engineering, announces his organization as follows: **Larry A. Cochran,** Acting Manager, Display Systems Resident Engineering—Bloomington; **Gary W. Hubbard,** Administrator, Monitor Projects; **John J. Nigborowicz,** Manager, Monitor Engineering Systems; **Ronald R. Norley,** Manager, Monitor Development; **Roger L. Lineberry,** Manager, Monitor Design Engineering; **Jereld R. Reeder,** Manager, Monitor Design Engineering; **G.K. Sendelweck,** Manager, Monitor Design Engineering; and **Lawrence E. Smith,** Manager, Monitor Design Engineering.

## Government Communications Systems

**Charles A. Schmidt,** Group Vice President, Government Communications Systems, announces his organization as follows: **Joseph B. Howe,** Division Vice President and General Manager, Communication and Information Systems Division; **Joseph L. Mackin,** Division Vice President, Government Volume Production; and **Allan E. Matt,** Director, Employee Relations.

## Microelectronics Center

**Robert A. Geshner,** Manager, Photomask Technology Operation, announces his organization as follows: **Ronald M. Melewski,** Manager, Process Engineering and Production Services; **Robert Nestel,** Manager, Product Assurance, Equipment, Engineering and Planning; and **Mary E. Evancho,** Manager, Applications, Order Entry and Tooling.

## Missile and Surface Radar Division

**William V. Goodwin,** Division Vice President and General Manager, Missile and Surface Radar Division, announces the appointment of **Robert T. Markes** as Program Manager, Submarine Combat Systems.

## NBC

**Michael Sherlock,** Executive Vice President, Operations & Technical Services, announces his organization as follows: **Joseph McCourt,** Director, Network Distribution Operations; **Arthur Waardenburg,** Manager, Skypath Operations; **James Keane,** Manager, Computer Imaging; **Steven Berkoff,** Director, Database Resources; **John Leland,** Technical Manager; **Dennis A. Mann,** On-Air Technical Manager; **Ross D. Triplett,** Manager, Telecommunications; **Cragi Zeller,** Manager, Graphics Imaging; **Michael L. LoCollo,** Director, Broadcast Systems Engineering; **Stewart E. Forman,** Manager, Network/Local Graphics Projects; **Eugene Hammerle,** Senior Engineering Planner, Relocation Project; **Jeffrey Birch,** Project Manager, Broadcast Systems Engineering; and **Raymond Lowe,** Project Manager, Broadcast Systems Engineering.

## RCA Laboratories

**Frank J. Marlowe,** Director, CAD Taskforce, announces the appointment of **James S. Crabbe** as Head, CAD Systems Services.

**James S. Crabbe,** Head, CAD System Services, announces his organization as follows: **Rodney L. Angle,** Manager, VLSI Design System and **William M. Cowhig III,** Manager, VLSI Design Services.

**Arthur H. Firester,** Director, Advanced Displays Technology, Research Laboratory, announces the appointment of **Roger G. Stewart** as Head, Advanced Displays Device Research.

**David Richman,** Director, Materials and Processing, Research Laboratory, announces the appointment of **Aaron W. Levine** as Head, Thin Film Technology, Lithography and Organics Research.

## Solid State Division

**Heshmat Khajezadeh,** Division Vice President, Integrated Circuit Products, announces the appointment of **James E. Gillberg** as Director, Application Specific Integrated Circuit Products.

**Dale M. Baugher,** Manager, Application and Product Engineering, Standard Products, announces his organization as follows: **Dale M. Baugher,** Acting Section Manager, Packaging; **Dale M. Baugher,** Acting Section Manager, RAM & ROM Products; **Robert W. Nearhoof,** Section Manager, QPL Programs and Government Liaison, **Joseph W. Rauback,** Section Manager, LSI Products; and **Marlan N. Vincoff,** Section Manager, 4000 Series, QMOS and Linear Products.

**Michael Zanakos,** Manager, Program Management and Test Operations, announces his organization as follows: **Robert F. DeMair,** Section Manager, Test Engineering; **Michael Zanakos,** Acting Program Manager, In-house Programs; **Eugene P. Wehr,** Program Manager, TRW Programs; **Michael Zanakos,** Acting Program Manager, E-Systems; and **Michael Zanakos,** Acting Manager, Test Operations.

**Edward C. Crossley,** Manager, Applications and Product Engineering—ASIC Products, announces is organization as follows: **Edward C. Crossley,** Acting Section Manager—Small ICBM; **Donald G. Kock,** Section Manager, Class S; and **Boris Maximow,** Section Manager, Class B.

**John R. Steiner,** Director, Environmental and Plant Engineering, announces his organization as follows: **F. Douglas Rue,** Manager, Plant Engineering and **Selwyn P. Smith,** Manager, Calibration and Standards Laboratory.

**James E. Gillberg,** Director, Application Specific Integrated Circuit Products, announces his organization as follows: **R. Adrian Bishop,** Manager, Product Marketing; **Al A. Key,** Manager, Product Engineering and Test; **Henry S. Miller,** Manager, Design Centers; and **Joel R. Oberman,** Manager, Design and Development Engineering.

## Professional activities

### Brill named Fellow of AIAA

**Yvonne C. Brill,** RCA Astro-Electronics, has been elected a Fellow of the American Institute of Aeronautics and Astronautics (AIAA). Ms. Brill, a staff engineer, has more than 30 years of experience in propulsion engineering. Since joining RCA in 1966, she has been responsible for the analysis and design of a number of spacecraft propulsion systems for use in communications, navigation, scientific, and meteorological applications. In 1974, she was granted a U.S. patent for her design of a dual thrust level monopropellant spacecraft propulsion systems, which enables a spacecraft to change its orbit.

Ms. Brill is a recipient of an RCA Engineering Excellence Award. She received a Bachelor of Science degree in Mathematics from the University of Manitoba, and a Master of Science degree in Chemistry from the University of Southern California.

### Paluck earns CPE

**David Paluck,** Facilities Engineering Supervisor, Solid State Division, has attained the status of Certified Plant Engineer (CPE). The distinction was granted by the Certification Board of the American Institute of Plant Engineers (AIPE).

AIPE certification was established in 1975, and is now a standard of excellence for the plant engineering profession. The certification process requires either a combination of engineering education and experience or a passing grade on a comprehensive seven-hour examination.

### van Raalte is president

**John A. van Raalte,** Director, Display Systems Research Laboratory, RCA Laboratories, has been elected President of the Society for Information Display (SID) for 1986-1987. Dr. van Raalte was installed at the recent SID Symposium in San Diego.

### Cullen is VP of FMS

**Glenn W. Cullen,** Head, Materials Synthesis Research, has been elected Vice President of the Federation of Materials Societies (FMS). Dr. Cullen previously served as an FMS trustee for both the Electrochemical Society and the American Association for Crystal Growth.

### Keith receives Honorable Mention

**Michael Keith,** Member of the Technical Staff, Digital Products Research Laboratory, RCA Laboratories, has received Honorable Mention in the 1985 Eta Kappa Nu Recognition of Outstanding Young Electrical Engineers. He was cited for contributions in computer graphics and music, and for his involvement in church and cultural activities.

Eta Kappa Nu is the national Electrical Engineering honor society.

### Gross is session chairman

**D. Gross,** Manager, Robotics and Space Servicing, Astro-Electronics, was Session Chairman, Theoretical and Practical Applications of Finite Elements to Structural Response, at the AIAA 27th Structures, Structural Dynamics, and Materials Conference. He also participated in the Technical Program Committee on Structures for the 28th Structural Dynamics and Materials Conference.

### Degrees awarded

Two engineers at Astro-Electronics, **Christian M. Harris** and **George Piper,** received the MSME from Drexel University.

### Nine receive patent awards at VCDD

Video Component and Display Division has named the award recipients in its inventor recognition program. The 5th patent recipients are **Frank T. D'Augustine, Craig E. Deyer, Bruce G. Marks, Stephen T. Opresko, Joseph J. Piascinski,** and **Edgar M. Smith.** The 10th patent recipients are **Ralph J. D'Amato, Hsing-Yao Chen,** and **Robert P. Stone.**

# Technical excellence

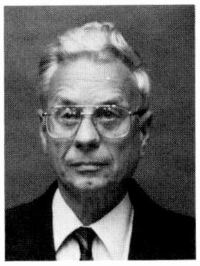
## SSD 1985 Annual Awards

The winners of the Solid State Division's 1985 Annual Technical Excellence Awards are:

**Michael Low, Ray Giordano,** and **Mel Hagge**—for the design and implementation into silicon of a large custom chip in a record time of five months, thereby supporting a very aggressive customer development schedule, and achieving success on the first cut.

**James O'Keefe**—for the development of the AUTOGATE program, which helps designers of standard cells eliminate errors in preparing their RCAP files for cell simulation.

**Tom Pampaline** and **Frank Kuyan**—for the development of a photoresist system that minimizes dimensional variation over steps for the 1.25-micron design rule circuits.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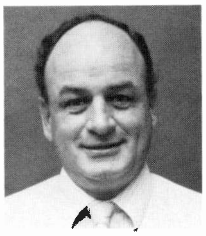
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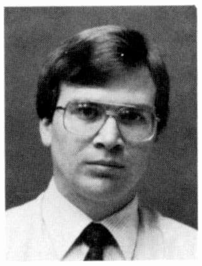
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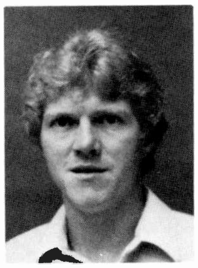
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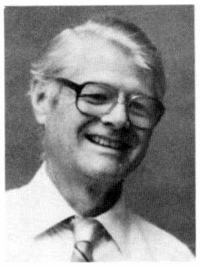
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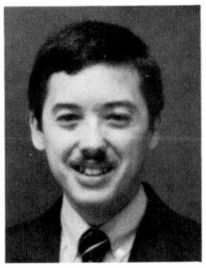

Williams


Pirani

## Eight at CE receive TEC Awards

Eight Consumer Electronics engineers have received first-quarter 1986 Technical Excellence Awards. They are:

**John Allen**—for innovation in the design and modification of electrical and mechanical systems in generic OEM display monitors to suit specific customer's needs.

**Ken McGlashen**—for the identification of the origin of purity problems with the CTC133/27V system and the development of a suitable "in-line" purity test to detect problems and eliminate customer complaints of incorrect color patches in the picture. This test revealed the need for redesign of the tube.

**Bob Barrett**—for the mechanical design of the CNC-12 bobbin winder. The machine currently runs at a very high yield while supporting production rates with few mechanical problems. This same machine is used to wind both primary and tertiary coils, and has been designed to accept future transformer designs with a minimum of modification.

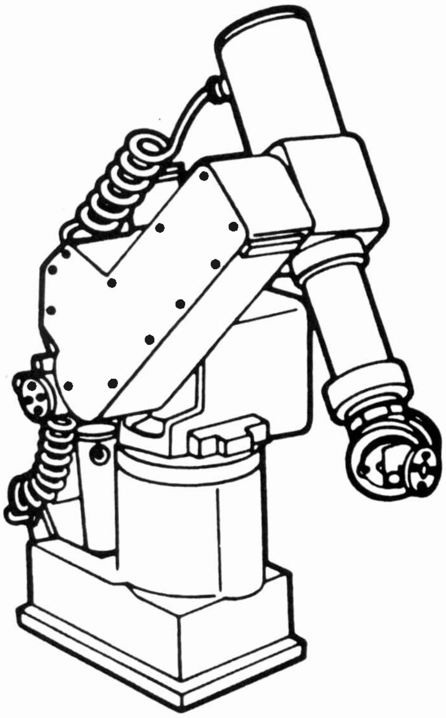
**Peter Osman** and **Hugh Sutherland**—for the development of an RGB monitor that operates on any line voltage from 85 to 265 VAC without external switching. This new internal switching concept reduces the number of parts to a minimum, thereby keeping costs down.

**Glen Coxhead** and **Doug Williams**—for the development, design, and implementation of four robotic index table and spray booth systems. The project required significant innovation in the design and interface of the robot, paint booth, and tooling components.

**Aziz Pirani**—for initiating and coordinating the most comprehensive and effective quality planning effort at CE to date. This effort involved the formation of quality planning committees at the home office, Bloomington, Juarez, Taiwan, and Indianapolis. The quality committees now have many controls in place, improving current production, with the ultimate goal being that CTC136 start-up will meet aggressive projected yield and quality goals.

*Announcing a new video course produced by Corporate Engineering Education*

# Applied Robotics



Applied Robotics (Course No. MF22) begins with an introduction to applied robotics and proceeds all the way through how to organize a robot project. A generous amount of videotape footage from various robotic applications within RCA makes this course especially well suited to RCA technical personnel. The course covers such topics as:

- Coordinate systems
- Performance characteristics
- End effectors
- Power and servo systems
- Robot control
- Robot programming languages
- Vision
- Flexible manufacturing systems
- Applications
- Future trends

The course has no prerequisites and comprises thirteen 2-hour sessions. Upon successful completion, 2.6 CEUs (Continuing Education Units) are awarded.

The references supplied are:

1. *The MF22 Study Guide*—An RCA-produced guide that includes all visuals used in the video course tapes, and comments.
2. *Robotics and Automated Manufacturing,* By R.C. Dorf, Reston Publishing Company, Inc, (1983).

At the completion of this course, the participant should be able to make informed decisions leading to successful robotic applications. This is a course on applying robots in manufacturing, not on how to design robots.

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## Interested?

For further details on course content, contact **Frank Burris, Tacnet 226-2971.** To schedule or order this course, call **Lorena Katulka, Tacnet 226-2972**.

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June 3, 1986

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