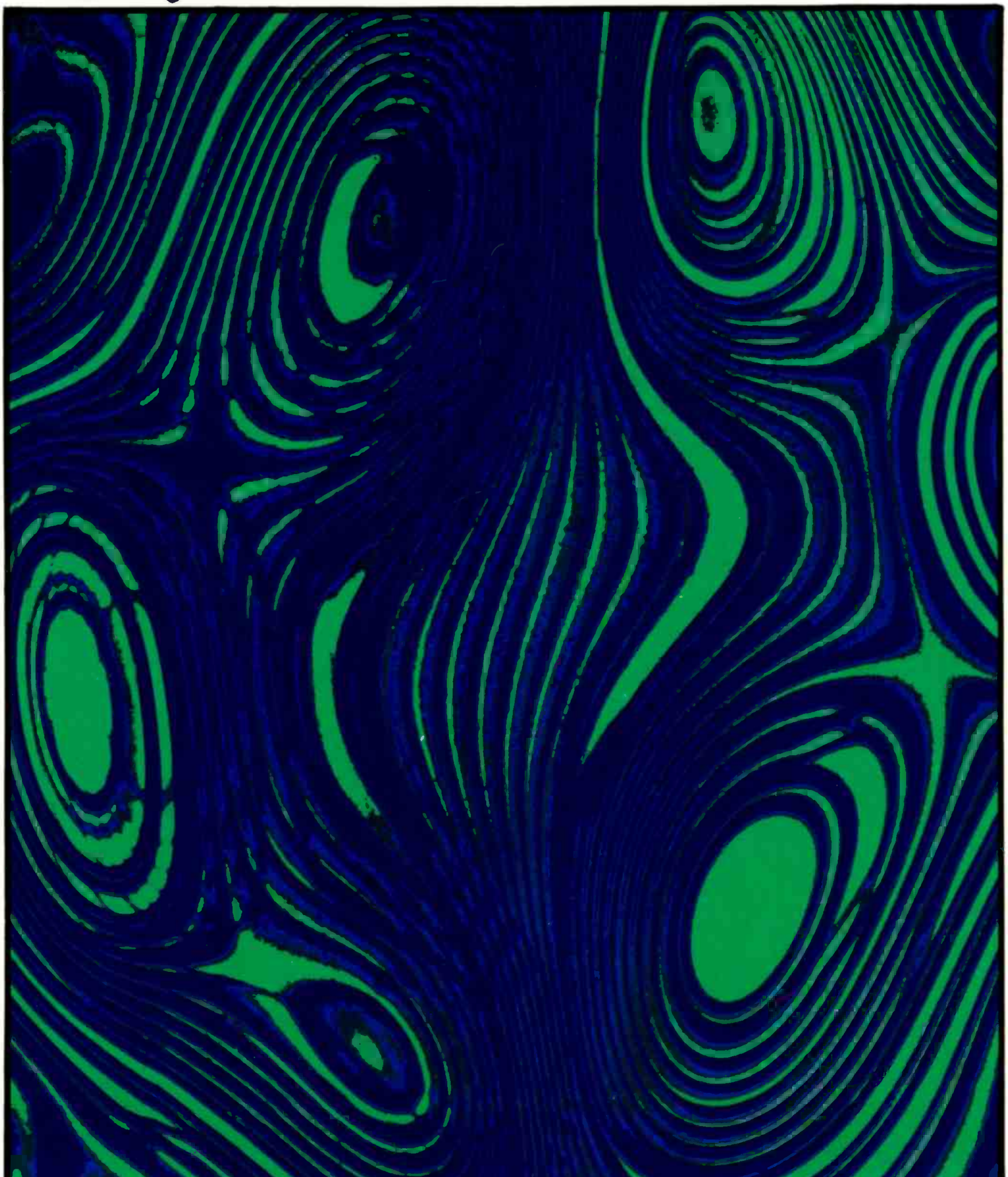
# RCA Engineer

Vol. 27 No. 4 July/August 1982

computer music - disk



**Cover design and illustrations** on pages 4, 5, 6, and 9 by Louise Carr

**An X-ray diffraction topograph of a warped silicon wafer**

We chose and developed the cover image from a black-and-white photograph (above) that S.H. McFarlane gave to Eva Dukes, our Editorial Representative at RCA Laboratories. Dr. McFarlane, who does materials characterization research for RCA Laboratories, offered the photo and a technical description for inclusion in the "Engineering Form and Function" section of this Anniversary Issue of the *RCA Engineer* (see page 33). Here's his description of the image:

> "X-ray diffraction topography is an analytical technique to reveal defects and strain in nearly perfect crystals. The crystal is oriented at the Bragg angle in a thin, vertical X-ray beam, and crystal and film are translated in the beam so that the entire sample is imaged. If the crystal is bent, the diffracting planes do not maintain the same orientation relative to the X-ray beam, and only part of the crystal produces an image on the film. The picture shown is a superposition of about 30 projection topographs of a badly warped silicon wafer. The crystal orientation has been changed 0.1° between topographs. A single topograph would show only one pair of the light and dark lines. The topograph was taken with Cu radiation; (220) diffraction planes are used."

We welcome further "short" contributions, be they illustrations accompanied by short technical notes, or simply the technical notes alone. These two forms of communication allow you to give a by-lined description on an aspect of technology that otherwise might not merit a full article in the *RCA Engineer*.


# RCA Engineer

A technical journal published by
RCA Research and Engineering
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Cherry Hill, NJ 08358
TACNET: 222-4254 (609-338-4254)




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

Thornton F. Bradshaw

# Strategic framework to strengthen RCA

This anniversary issue of the *RCA Engineer* marks a pivotal point in the corporation's history. The recent past has been difficult for RCA, and the present is full of challenge. But today, even more than when I became Chairman a year ago, I am convinced that the future holds great promise for RCA. And paradoxically, we will move ahead by going back to our roots.

One of my first priorities as Chairman was to evaluate RCA's current mix of businesses, to determine which of those businesses would be likely to dominate in the future, and to redeploy the company's assets within a new strategic framework. Those evaluations have been completed, and RCA is now ready to focus on electronics, communications, and entertainment as its core businesses.

The means by which RCA will enter these businesses, some of which are forecast to grow at more than 20 percent annually over the next decade, could involve acquisitions, joint ventures, and the strengthening of our core electronic and communications activities. As part of this strategy, we are considering selling Hertz and other of our nonelectronic subsidiaries. Hertz is a fine company with outstanding management. But it does not fit our new emphasis on electronics, communications, and entertainment.

I need not recount for the readers of this magazine the milestones that RCA established throughout the history of the electronics industry. Many of you have contributed to those innovations. You and your 5,600 fellow scientists and engineers constitute one of RCA's major resources. Shaping a corporate strategy that focuses on your talents, skills, and professionalism represents a significant aspect of the challenge facing RCA today.

Our new strategic concept is designed to give us greater leverage in the penetration of new growth businesses and, in the process, we will build on RCA's reputation as one of the world's leading technological companies.

*Thornton F. Bradshaw*
Chairman of the Board and
Chief Executive Officer

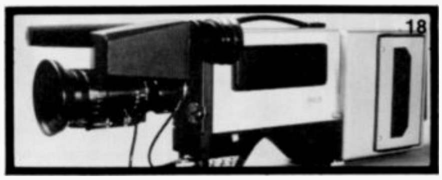
# RCA Engineer

Vol. 27 | No. 4 July | August 1982

**in this issue ...**
***RCA Engineer*'s 27th-anniversary articles**


■ **Awards:** *This year, RCA's most coveted award for engineers and scientists goes to two teams and two individuals.*

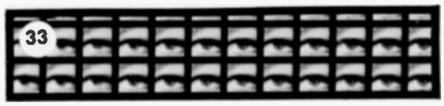




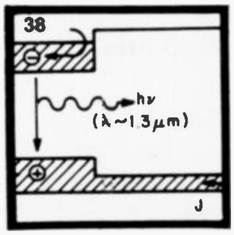

■ **Freeman/Mehrotra/Repka:** *"In addition to adding a second audio channel, the sound capacity has been enhanced to levels comparable to high-quality audio-cassette reproduction."*

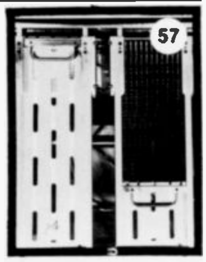
■ **Bendell/Bazin/Clarke:** *"In the Hawkeye, the third stage of the evolution has been achieved because the camera and recorder have been combined into a single package."*

■ **Barbin/Simpson/Marks:** *"RCA Picture Tube Division has decided to address the fastest-growing segment of the data-display-CRT market, the color sector."*

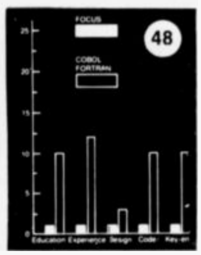


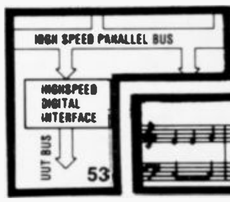

■ **Engineering Form and Function:** *Technology has put powerful visual tools at the engineer's disposal—some of the results, shown here and on the back cover, are explained.*









■ **Olsen/Ettenberg:** *"Most fiber-optical systems will probably operate at 1.3 μm, while long-distance systems might employ 1.55-μm single-mode lasers."*

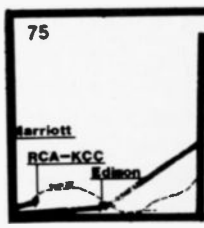
■ **Williams:** *"What can be done is to convert coal to simpler materials that can then be used in existing fuel cells."*

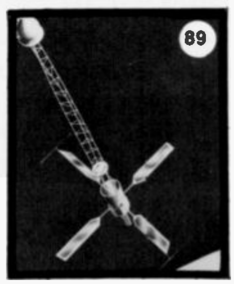
■ **Myers:** *"If FOCUS had not been available, the work could not have been done as effectively with FORTRAN or COBOL even if many more people had been hired."*

■ **Fay:** *"The modular generation could very well become a natural step in the evolution of ATE architecture rather than a radical departure from the conventional ways of constructing test systems."*

■ **Koskulitz/Rosenfield:** *"The mechanized RAMP process 'builds in' quality as opposed to 'screening' it in."*

■ **Mercuri:** *"Bound within this copy of the* RCA Engineer, *you will find a 33⅓ rpm stereo soundsheet containing examples of electronic music from 1956 to 1981."*



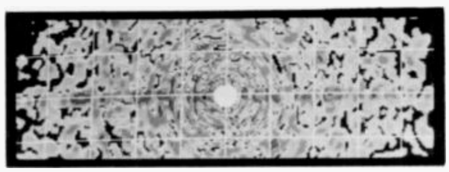


■ **Solomon:** *"The microwave system is expected to save RCA more than $2 million during the first five years at current Bell System rates."*

■ **Clark:** *"If it is to bring a bonanza to its operators rather than absorb their capital like a black hole with no return, DBS must bring its customers as good or better programs at the same or less cost than its competitors."*

■ **Staniszewski:** *"As NOVA passes its first anniversary of operation . . . it is time to reflect on achievements already confirmed by its on-orbit performance."*

**in future issues...**
microwave technology
modelling, simulation, and analysis
engineering productivity—tools and techniques



# 1982 David Sarnoff Awards for Outstanding Technical Achievement


***Karl G. Hernqvist***
Fellow of the Technical Staff
Display and Energy Systems Research
RCA Laboratories


*For understanding the cause and eliminating quality defects in color picture tubes.*

## ACHIEVEMENT

Two of the major quality defects in RCA color picture tubes of the past were arcing and blocked apertures. For both of these defects Dr. Hernqvist undertook a study of the mechanisms responsible for the observable defects and was able to identify the causal chain of events. Once the underlying processes were clear, he proposed a group of preventative procedures, and followed through with co-workers from both the Laboratories and the Picture Tube Division until the most cost-effective procedure was identified and implemented.

In the case of arcing, Dr. Hernqvist found that the vast majority of arcs were caused by an electron-avalanching effect in the channel between the glass neck and the glass beads holding the gun parts. He correctly reasoned that if a means of preventing voltage build-up were introduced in this channel, the arcing (trigger arcing) would be prevented. He suggested a variety of ways of preventing this build-up and arrived at the metallized bead concept, now a part of RCA commercial tubes.

In the case of blocked aperture-mask openings, Dr. Hernqvist made use of the fact that fully half of them are associated with insulating particles such as glass. He found that, in most cases, the apertures were not physically blocked but the insulating particles near the openings were charging and causing a deflection of the electron beam to the wrong phosphor area. With this knowledge he sought ways of dislodging the particles or discharging them. This technique is now in use at all Picture Tube Division plants.

The business implications of these quality improvements are highly significant in light of the competition our tubes face in the marketplace from both domestic and Japanese suppliers. In the area of arcing, on the order of 80 percent of RCA tubes now show no arcing and the remainder, only an occasional arc. As for tube returns from set maker's lines for blocked aperture defects, preliminary data would seem to indicate a reduction of about one-half.

Dr. Hernqvist has been the key individual in this quality effort, developing the insights and a variety of possible solutions. After possible solutions were identified, Dr. Hernqvist continued to work along with a considerable number of other people to find the best commercial approach. Even after an approach had been introduced into production, he has continued to follow the results and to improve them with further refinements. Presented and published papers by Dr. Hernqvist on arc suppression include "Studies of Flashovers and Preventive Measures for Kinescope Guns," presented at IEEE Consumer Electronics Conference in Chicago, Illinois, in November 1980 and published in *IEEE Transactions on Consumer Electronics*, May 1981, Vol. CE-27, No. 2, pp 117-128. There have been no outside publications or presentations on blocked-aperture technology.

# INDIVIDUAL

Karl Hernqvist received the PhD in Electrical Engineering from the Royal Institute of Technology, Stockholm, Sweden, in 1959 while working at RCA Laboratories. He worked on radar and microwave instrumentation in the Royal Swedish Air Force in 1945 and 1946. From 1946 to 1952, he was concerned with electron-tube research at the Research Institute of National Defense, Stockholm. He was an American-Scandinavian Trainee at RCA Laboratories in 1949.

In 1952, he joined RCA Laboratories where he worked on microwave tubes, electron guns, and gas-discharge devices. In 1956, he independently conceived and reduced to practice the thermionic energy converter.

In the 1960s, he became involved with gas laser technology, an area in which he made a number of pioneering contributions. Dr. Hernqvist has gained an international reputation for his work. He has received five RCA Laboratories Achievement Awards, and he received the 1974 David Sarnoff Award for Outstanding Technical Achievement for his gas laser work. In 1977, he turned his attention to color-picture-tube technology He holds a total of 34 issued patents.

***Frank J. Reifler***
Principal Member Engineering Staff
Naval Systems Department
Missile and Surface Radar

*For contributions to mid-course and terminal guidance technology.*

# ACHIEVEMENT

Modern air-defense systems face increasingly demanding requirements arising from higher threat velocities and greater attack coordination. These factors lead directly to a requirement for increased guidance performance and enhanced ability to attack more targets simultaneously.

In anti-air warfare (AAW) system applications, the missile is guided to the target by means of a midcourse-guidance phase followed by a shorter terminal-homing phase. The midcourse-guidance phase is supported by a single radar system with the inherent capability to control many missiles simultaneously using time-multiplex techniques. In contrast, the shorter terminal phase requires the dedicated support of a radar-like equipment for each missile-target pair.

Dr. Reifler's achievement involves two major, and independent, contributions to missile guidance technology. The first of these deals with midcourse guidance, the objective of which is to place the missile close to the target in the least amount of time so that the greatest possible residual velocity will be available for the terminal homing phase.

Of special significance is Dr. Reifler's development of algorithms that produce major enhancements in missile effectiveness. These algorithms, called KAPPA guidance, provide reduced time of flight to intercept, while simultaneously resulting in increased missile speed at the start of terminal engagement. These two effects provide, with existing missiles, faster reaction time and superior performance against maneuvering targets. A major contribution was his invention of elegantly simple, effective, and powerful algorithmic approximations for optimal solutions, well within computer resources allocated to an operational warship.

Dr. Reifler's second contribution, of even greater importance, was in the area of terminal homing—a breakthrough that cut down the period of precision terminal guidance, thereby permitting more missile engagements per unit of time.

The key to Dr. Reifler's accomplishment was his recognition that surface-based radar data, suitably processed, can be used to remove a certain class of missile-induced error, thereby significantly reducing the homing time required to achieve intercept and, consequently, the equipment usage required to support it. This solution has its basis in modern control theory and derives from the application of Pontryagin's maximum principle to a command-guidance system.

Dr. Reifler's work provided a dramatic increase in the terminal engagement capability without an attendant increase in shipboard equipment. This technique, called RAF guidance, reduces semi-active homing times by factors of 2 to 1, thereby providing a potential doubling of anti-air warfare ship firepower. This spectacular increase in firepower, moreover, is achieved simultaneously with reduced miss-distance and higher kill probability. The result is a system vastly more capable of operating against massive raids while maintaining its fighting posture.

# INDIVIDUAL

Frank Reifler has been a System Design Analyst in the Naval Systems Department Systems Engineering organization since he joined RCA in 1975. His analytical work on rocket-motor design optimization during 1977 was cited as outstanding, as were his contributions to advanced filter theory in 1978. Since 1979, he has been engaged primarily in analysis and algorithm development for missile guidance.

From the University of Washington, Dr. Reifler received his BS in Mathematics in 1966 and his PhD in Mathematics in 1971. He was a mathematics instructor at the University of Wisconsin from 1971 to 1972. He taught and served as a consultant at the Weizmann Institute of Science, Rehovot, Israel, from 1972 to 1974. He has received four technical excellence awards since joining RCA and he won the Annual Award in 1980 for work cited here.

Darrel L. Billings — Gerald E. Theriault — James M. Keeth — Larry M. Turpin — Larry J. Byers — Bennie L. Borman

*For team accomplishment in the design, development and implementation of automated alignment systems for consumer electronic instruments.*

**Darrel L. Billings**
Senior Member Engineering Staff
Test Technology
RCA Consumer Electronics Division

**Gerald E. Theriault**
Member Technical Staff
Consumer Electronics Research Group
RCA Laboratories

**James M. Keeth**
Member Engineering Staff
Test Technology
RCA Consumer Electronics Division

*Larry M. Turpin*
Manager, Systems Support
Test Technology
RCA Consumer Electronics Division

*Larry J. Byers*
Manager, Chassis Test Systems
Test Technology
RCA Consumer Electronics Division

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

# ACHIEVEMENT

This award is based upon the successful development and implementation of automatic alignment for all functions in a color-television chassis. These functions include the IF, chroma, sound, luminance and deflection circuitry. This accomplishment ranks significantly as an industry "first" in terms of both its technical merit and its business economics.

To compensate for circuit tolerance build-up in critical sections of a color-television receiver, adjustable elements (such as resistors, capacitors and inductors) are used for final adjustments after assembly to assure proper circuit performance. Historically, these adjustments have been made manually with the use of oscilloscopes, meters, various signal sources and numerous hook-up connections to the various modules under alignment.

A program was established to develop a planar (one board) chassis for improved field reliability, better manufacturability, increased line yields and substantial cost reduction. One of the major elements of this program was the requirement for automatic alignment to eliminate all operator interface for the adjustment of the variable circuit elements. System design mandated a servo-driven, automatically engaging unit capable of analyzing the complex waveforms in a television chassis and aligning the variable circuit elements for optimum performance.

One key element in the success of this system is the innovation of incorporating the computer within the servo loop. This novel approach provides the ability to compensate for response-time variations that plague classical hardware servo loops. In addition, the system uses a fast switching synthesizer to digitally sweep the device to be aligned. The system uses the stored response to predict the direction and angular position, thereby avoiding minor peaks and nulls while searching for a global peak or null. This prevents improper alignment that can occur due to responses that are present before obtaining the proper curve shape.

The computer can calculate a slope or rate of change of a parameter to optimize alignment speed. Alignment speed is further enhanced by the ability of a computer to remember the alignment history of previous chassis. Using this history, the system can dynamically preset the adjustable components during the warm-up phase of chassis alignment. During this phase, the alignment speed is still further enhanced by the ability to perform dynamic presets simultaneously.

Also key to the success of the automatic alignment system is the development of complementary sources and measurement instrumentation capable of operating at the required speed. One such noteworthy achievement is the development of a fully programmable spectrum analyzer, which must operate at a rate 100 times faster than any commercially available system.

Further key to the success of the automatic alignment system is the development of the mechanical interface. This includes the design of the alignment tools and the adjustable components. To provide for the positioning differences between the alignment tool and the adjustable component, the tool shaft is designed to allow for angular flexing while maintaining rotational rigidity Design efforts on the adjustable component further enhanced the ability to perform automatic alignment.

As a direct result of the success of this program for a color-television chassis, a system was developed and implemented for the complex signal board contained in the "SelectaVision" VideoDisc player, which requires automatic alignment of 24 adjustments. All color television chassis, and all VideoDisc player signal control and stereo boards are automatically aligned. The ColorTrak series requires 24 adjustments per chassis, the XL100 series requires 16 adjustments and the "SelectaVision" VideoDisc player boards require a total of 31 adjustments. Automatic alignment is a success due to the cooperative effort between RCA Laboratories and the Test Technology function of manufacturing.

Consumer Electronics chassis production must achieve maximum cost effectiveness commensurate with good performance, quality and reliability. Automatic alignment and evaluation techniques described herein are the central technology required to achieve this goal. Without automatic alignment, chassis used in the instrument plants of Bloomington, Indiana and Prescott, Ontario would show unacceptable variation in quality, reliability and performance.

Systems are now in place in Bloomington, Juarez and Taiwan to align all color-television chassis (except 9" which is scheduled for 1983) and all "SelectaVision" VideoDisc player signal boards. With moderate conversion cost, these systems are adaptable to future chassis designs, with the replacement of the locating plates for the servos and modified software.

Adjustments that required six minutes to set manually are now accomplished in fifteen seconds, together with improved quality, reduced operator training, better performance and reduced floor space. The cost savings of automatic alignment is conservatively estimated at $2 per television instrument. It is also important to point out that the "SelectaVision" VideoDisc player directly received the technological and manufacturing advantages of automatic alignment, which equates to a permanent cost savings of $3 per unit as well as consistent quality and performance.

# INDIVIDUALS

**Darrel Billings** contributed significantly and uniquely to the accomplishment of automated alignment by developing the mechanical concepts and hardware embodiment of the system. Significant mechanical systems considerations entered into the complex optimization process, including component design, tool-tip design, equipment reliability and maintainability, probe and probe-plate design, speed, torque, engagement tolerances and system backlash. He was solely responsible for the mechanical design of the alignment hardware, which, by virtue of its current performance, must be judged one of the key contributions to the success of automated alignment. One of his specific contributions related to an analysis of system backlash, which led to a hardware/software implementation capable of rotational alignment accuracies of $\pm$ 0.9 degrees rotation.

**Bennie Borman** was responsible for the development of the overall system concept and the management of its successful implementation. He recognized the fundamental requirements for desensitized tuning capability, single-slug coils, precise mechanical positioning of the variable circuit elements, and top-side accessibility, and he established these as product-design requirements at the outset of the program. His determination and dedication to the task led to the successful solutions to the innumerable problems encountered during the design, debug, and start-up phases. His leadership, both technically and managerially, was key to the successful accomplishment of this program.

**Larry Byers** was instrumental in structuring the electrical and mechanical interfaces between the TV chassis and the alignment system. His specific contributions related to the matching of a complex set of requirements with a wide variety of approaches, which directly led to: the open-loop hardware structure closed by software; the selection of the specific stepping motors required by the electro-mechanical interface; and the specific details of product design—both electrical and mechanical—related to tool engagement, coil and potentiometer configuration, and circuit tolerances compatible with the developing hardware and software systems configurations.

**James Keeth** designed and developed the initial system architecture, particularly the fundamental feedback algorithms by which circuit function is sensed, analyzed, and translated into interactive servo motions to accomplish the alignment process. He also contributed significantly to the minimization of alignment time, particularly in the chassis-alignment station. These contributions were all made possible by his unique understanding of test and measurement methods, servo-feedback systems, software systems, and TV-system performance. His design and development of the programmable high-speed spectrum analyzer was key to the successful alignment of the player signal board.

**Gerald Theriault's** thorough understanding of IF response characteristics under a wide variety of tolerance situations among the approximately 125 electrical components comprising the IF function, and the translation of these into the sophisticated algorithms required to deal with large-scale production, was a major element in the success of the system. One of his specific contributions was to substantially strengthen the specification, documentation, discipline, and feedback techniques associated with preset requirements of the adjustable components.

**Larry Turpin** contributed uniquely to the achievement of automated alignment through his expert structuring of the system software, making rapid real-time modifications to both hardware and software throughout the program. His unique understanding and discussions of the software system led substantially to this achievement.

Martin L. Levene · Gerald Spector · Manuel A. Robbins · Peter T. Patterson · Dennis J. Woywood

*For team performance in analysis of U.S. Postal Service Operations, conceptualization, and implementation of an electronic mail service.*


***Martin L. Levene***
Unit Manager, Engineering Staff
Advanced Technology Laboratories

***Manuel A. Robbins***
Program Manager
Special Systems
Government Communications Systems

***Dennis J. Woywood***
Division Vice-President
Broadcast Video Systems
Commercial Communications Systems Division

***Gerald Spector***
Unit Manager, Engineering Staff
Special Systems
Government Communications Systems

***Peter T. Patterson***
Manager, System Engineering
Special Systems
Government Communications Systems


# ACHIEVEMENT

Systems work is a recognized and vital engineering science. It is a creative science in its own right, used to evaluate many alternatives and technologies, and to merge these technologies to meet complex needs. The Electronic Mail Development Team used systems engineering as their tool to translate USPS requirements into hardware. Applying systems principles, the Team structured a system architecture, based on achievable technological capabilities, that would meet USPS requirements. They implemented this architecture by exploration of facsimile, character recognition, word processing, satellite communications switching, and laser printing technologies.

In common with many other innovative achievements, initial electronic message service (EMS) development was predated by a number of evolutionary developments in the information processing field. By 1971, Government Communications Systems (GCS) had decided that prospects for EMS were bright enough to warrant allocation of investment funds to support research and development.

In 1976, GCS won a competitive United States Postal Service (USPS) contract for an Electronic Message Service System (EMSS) Definition and Evaluation Study. In 1978, GCS received another competitive USPS contract, this time for an Electronic Mail System Validation Test Bed that would serve as the basis for a Postal Service System.

The next major milestone in EMS development was receipt of a USPS contract for design, assembly, integration, and test of an Evaluation Test System (ETS), which was to be a laboratory model containing most of the essential elements of a mature EMS. The heart of the ETS was a digital computer that simulated the volume and speed of message traffic that a representative EMS station could be expected to handle. Some of this traffic was "real" in the sense that it consisted of actual letter inputs and tape inputs to EMS, and actual reproduced letters delivered to the addressed stations.

The ETS design accommodated input received from tapes; floppy disks; OCR devices; high-resolution facsimile equipment; telephone lines connected to office facsimile machines and word processors; direct data satellites; and satellite links. Output copy was produced on high-speed printers and packaged by enveloping equipment.

A comprehensive survey of vendor equipment was undertaken, and hardware capable of meeting ETS performance objectives was selected for integration and testing. Because off-the-shelf software could not be obtained to perform all ETS functions, programming of validation, sorting, printed forms generation, and numerous other tasks was required. Functional software was implemented by use of modular techniques that allowed parallel development. This approach proved to be very effective in terms of time and money saved. In little more than 8 months, more than 15,000 lines of code were designed, written, integrated, and tested.

The operational ETS was capable of accepting input from standard computer peripherals, such as magnetic tape media and diskettes, as well as non-standard peripherals, such as digital and analog facsimile scanners, word processors, and OCR equipment. The software allowed merging of signatures, pre-stored forms, and company logos with message text. Messages were routed to any of three output stations via leased satellites or terrestrial communcations links to be reproduced on a universal printer/plotter that had been modified for ETS use. Printed messages were sorted according to final destination in order to expedite introduction of printed message traffic into the USPS mail stream. A full command language allowed ETS operators to monitor and control processing. The operational ETS provided system architectural verification, generation and analysis of fully modelled traffic statistics, and evaluation of alternative equipment designs. In a basic sense, the ETS provided validation and demonstration of system concept, architecture, system design, implementation, and operation.

After configuration, integration, and preliminary testing in RCA facilities, the ETS was shipped to the USPS research and development facility in Rockville, Maryland for further testing in a simulated real-world environment.

The final phase of EMS gestation, the culmination of more than a decade of research and development, was the award of a contract by the USPS in January 1981 for development of an Electronic Computer Originated Mail (E-COM) system with initial deployment scheduled for 25 major cities. A key element in the contract was the requirement for initiating operation on January 4, 1982, less than one year from start of contract.

By the end of 1981, more than 120 postal employees had been trained, and 37 engineers and managers had traveled more than 200 thousand miles testing equipment. In addition, the initial group of users had been technically validated by RCA and extensive on-the-job training had been conducted for USPS operators.

The first E-COM transmissions began at 2:00 AM on January 4, 1982, as scheduled; by 6:30 AM all 25 cities had received and successfully processed the initial messages. No compromises were necessary. The complete E-COM system was fully operational within the allotted time period.

Over the past six years, RCA has captured almost $40 million of USPS business. The 12-month program just completed was an outstanding team effort resulting in an operational system. There is a potential for much more. According to Ms. Karen Uemoto, USPS Director of E-COM Operations, first-year volume is estimated at 20 million pieces with an eventual flow of 500 million pieces. Even at that level, a mature E-COM system would be handling less than 1 percent of the 60 billion pieces of first-class mail processed in 1981.

## INDIVIDUALS

**Martin Levene** has been the responsible mechanical engineer for the series of EMS contracts. The fact that EMS input and output are physical objects made Mr. Levene's efforts critical to the entire development effort. He was responsible for the definition, analysis, specification, testing, and approval of the paper-handling equipment. Because the printed letter is the only output of the system, Mr. Levene's acknowledged expertise regarding printers, printing techniques, and paper handling was essential to success.

In the EMSS Definition and Evaluation Study and E-COM phases of development, he directed extensive investigation and experiments in such areas as facsimile conversion standards, optical character recognition performance capabilities, high quality electronic printing technology, and paper handling equipment selection.

**Peter Patterson** contributed significantly to all phases of EMS development. His contributions to the EMSS Definition and Evaluation Study included analysis of mail characteristics and statistics; the cost impact of centralization; sorting and directory requirements; privacy and accuracy requirements; economic factors; and risks.

In the EMS Validation Test Bed phase, Mr. Patterson prepared detailed plans for analyzing the market; evaluating hardware; evaluating work-force performance; and developing and installing the first operational system. He also prepared budget estimates and implementation schedules. During the ETS phase, he was responsible for input form specifications, format and media test deck requirements, the functional requirements document, the test and integration plan, and acceptance test procedures. In addition, he prepared media test material and performed acceptance testing.

As Systems Engineering Manager, Mr. Patterson made essential contributions to the E-COM program by furnishing technical direction for the system design and architecture tasks, allocating functions, and employing simulation techniques to evaluate and select hardware.

**Manuel Robbins** has been master strategist guiding the EMS effort since its inception late in 1971. In the early years of EMS development, he was Technical Director of the USPS EMSS System Definition and Evaluation Study. Even earlier, Mr. Robbins served as Director of EMS studies and directed the activities of engineers and scientists from five divisions and organizations. He was Program Manager of the E-COM contract.

He contributed to the USPS system design and evaluation contract by verifying system requirements, conceptualizing a system architecture, defining the system implementation, coordinating system engineering, subsystem alternative development, computer program development, and modeling. In addition, Mr. Robbins integrated study tasks, assuring compliance with Statement of Work requirements, and he directed task iteration. He was responsible for overall technical/cost/schedule performance, updating the program plan, and maintaining technical liaison with the USPS.

**Gerald Spector** applied his computer architecture design skills to solving EMS security and privacy problems. On the EMSS Study, Mr. Spector, as Lead Systems Engineer, was responsible for computer system architecture, node (conversion subsystem) architecture, system security, and data integrity. He also studied the nature of mail, particularly the user requirements and emerging business trends and standards for "return documents" (for example, bill stubs, transaction slips, and envelopes) as they relate to handling such mail in an electronic system.

On the ETS contract, Mr. Spector was responsible for the system studies that confirmed the design concept, and developed system design requirements. He also was responsible for developing and implementing the integration and test plan which monitored the hardware and software designs for compliance with requirements, unit test and integration of hardware and software modules, and predelivery system integration and test. He also was responsible for the acceptance tests of the system, training of USPS personnel, and development of demonstration test material.

**Dennis Woywood** was the Business Area Manager responsible for Electronic Message Service System programs. In this capacity for the past three years, he was organizationally responsible for EMSS definition, the System Validation Test Bed Plan, and the ETS contracts. During this period of intensive activity, Mr. Woywood developed a detailed understanding of Postal Service operations, objectives, and constraints. He brought to the E-COM program both understanding of the equipment and software required, and an executive management perspective of the needs and operating realities of the USPS. He is currently Division Vice-President, Broadcast Video Systems, Commercial Communications Systems Division.

E.J. Freeman | G.N. Mehrotra | C.P. Repka

# The CED stereo VideoDisc system

*The stereo VideoDisc will add a dimension to concerts and many feature films that is unavailable through your TV set alone.*

**Abstract:** *The constraints that had to be satisfied before stereo VideoDisc could become a reality are given. Next, the authors give the system design features that led to success, followed by a description of the noise-reduction system chosen, and the mastering method used.*

The addition of stereo sound represents a significant capability improvement in the CED VideoDisc system. In addition to adding a second audio channel, the sound capacity has been enhanced to levels comparable to high-quality audio-cassette reproduction. Because of the basic purpose of the system, the design must satisfy several constraints simultaneously. For example, the system must give good audio reproduction on typical home stereo component systems. The system must produce acceptable monophonic audio on a typical television system. Stereo discs and existing monophonic discs must be forward and reverse compatible. The system must be able to reproduce two independent audio channels for bilingual or special-purpose programs.

## System design

To ensure compatibility with mono players, the stereo signal is fed through an L + R, L − R matrix (L is the left channel, R is the right channel). A mono player recovers the compatible sum signal. A stereo player decodes the sum and difference signals back into their original left and right components. When playing a mono disc, a stereo player behaves the same as a standard mono player (it does not apply the decoding matrix). For bilingual applications, the encoding matrix and the decoding matrix are bypassed and the two channels are recorded independently.

For adequate reproduction of high-quality stereo programs through a home system, stereo system goals have included a minimum audio bandwidth of 15 kHz, distortion levels of less than 2 percent, and a dynamic range of at least 60 dB. Satisfying these demands requires optimization of the audio-noise performance of the CED system.

The audio channels on the VideoDisc are recorded on FM carriers. The first channel at about 716 kHz is used for the sum or monophonic signal; a second channel at about 905 kHz is used for the difference signal (Fig. 1). As in any FM system, the demodulated signal-to-noise ratio is a result of the composite effects of the deviation, the de-emphasis characteristics, the carrier levels, and the magnitude of phase-noise sources.

Choice of these parameters is severely restricted in the disc by the reverse compatibility requirements and the tight frequency division multiplexing with the video FM signal. Reverse compatibility defines the maximum deviation on the sum channel as the same ± 50 kHz defined for the monophonic signal. Consequently, changes in deviation large enough to affect

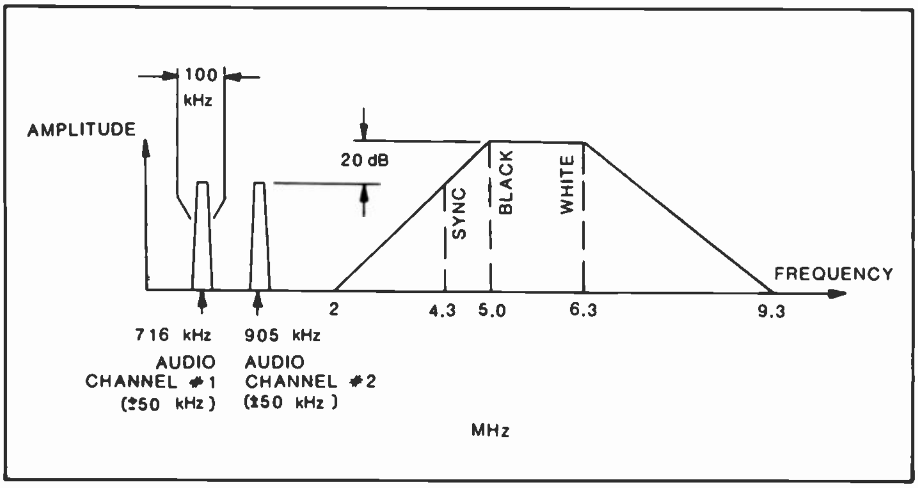



**Fig. 1. Spectrum assignments for the CED stereo VideoDisc system.** Channel 1 is the sum channel, and channel 2 is the difference channel.


Final manuscript received May 26, 1982.
Reprint RE-27-4-2

## VideoDisc system sales are up, and stereo is in

Despite the recession, American consumers spent more than $90 million for CED VideoDisc players and albums in the product's first year, Thomas G. Kuhn, Division Vice-President, RCA VideoDiscs, has announced.

"VideoDisc hardware and software sales in the first 12 months exceeded the combined first-year sales volumes of black-and-white television, color television, and videocassette recorders, an achievement that becomes even more dramatic when viewed against the economic environment of the past year," Mr. Kuhn told a press dinner prior to the opening of the Consumer Electronics Show in Chicago, Illinois. RCA exhibited their new stereo VideoDisc CED system, the SGT 200, at the show.

Mr. Kuhn said disc sales have far exceeded RCA's expectations. He said there are some 250 titles currently available on the CED system, a number which is expected to exceed 400 by year's end. Of the 30 top grossing movies of all time, 14 currently are available on CED format albums. In addition to the 11 new stereo VideoDisc albums, which were announced, RCA is releasing nine new monaural VideoDisc titles in June and 13 more in July. The June and July titles include a mix of recent and classic motion pictures, sports programming and RCA's first dual-track disc. Mr. Kuhn also noted that CED monaural and stereo discs are totally compatible and can be played on any CED player.


**VideoDiscs go stereo.** The first 11 stereo VideoDiscs, and the first dual-track disc ("Jane Fonda's Workout"), along with the new SGT 250 stereo player with remote control.

"Jane Fonda's Workout" will be the first RCA VideoDisc to use the unique dual-sound capability of the Capacitance Electronic Disc (CED) system. "Each groove on a CED VideoDisc has two completely separate sound tracks, which makes possible rich stereo sound, bilingual programs or a choice of audio channels," said Seth M. Willenson, Division Vice-President, Programs and Business Affairs, RCA VideoDiscs, in a news release from his New York office.

The exercise disc, available at retail outlets in July, gives owners of the CED stereo VideoDisc players the choice of listening to music and instruction while they exercise, or to music only, as part of a regular exercise routine, Mr. Willenson added. He said that owners of monaural VideoDisc players receive both music and instruction. "RCA is committed to developing programming which meets the needs of the consumer and which takes advantage of specific features of the CED VideoDisc system, such as dual sound tracks," he said.

Mr. Kuhn said that "the rate of disc sales is a strong indication of consumer satisfaction with the CED VideoDisc system." He said that VideoDisc player owners who have owned the player for 12 months or more have already accumulated an average of more than 32 discs. "Software is the locomotive behind this product, and we're picking up steam," Mr. Kuhn said.

signal-to-noise ratio (SNR) are impractical.

Another direct way to improve audio SNR is to increase the level of the audio carriers on the disc. However, too great an increase produces proportional "sound beats" in the luminance signal. A correction circuit in all CED players cancels these beats by adding an inverse beat.[1] Extensive measurements of the sound-beat signal and the practical performance of correction circuits showed that audio-carrier levels could be safely raised 4 dB at the outer disc radius and 1 dB at the inner disc radius. Stereo substrates are cut with a linear "amplitude taper" that decreases toward the inner radius, and reflects the available increases.

Additional margin has been gained by improving the performance of the basic disc compound, partly as a consequence of manufacturing gains made during the initial year of monophonic production, and partly from formulation changes. The gains made using the above techniques apply to the noise attributed to the carbon in the disc. This noise is conveniently approximated for the audio channel as white noise, band limited by the FM-demodulation systems. It is uncorrelated from channel to channel. The performance improvements with respect to this noise source were sufficient to unmask the importance of another type of noise in the disc, displacement noise. Displacement noise arises when variations in the position of the disc surface with respect to the stylus electrode displace the estimates of zero crossings on the FM carrier. Such displacements can arise from surface rough-

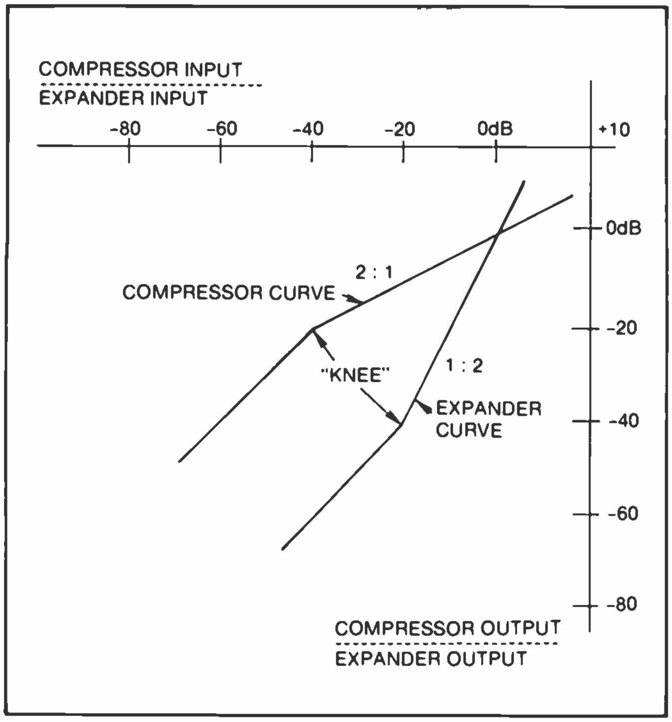



**Fig. 2. Compressor and expander input/output curve.**

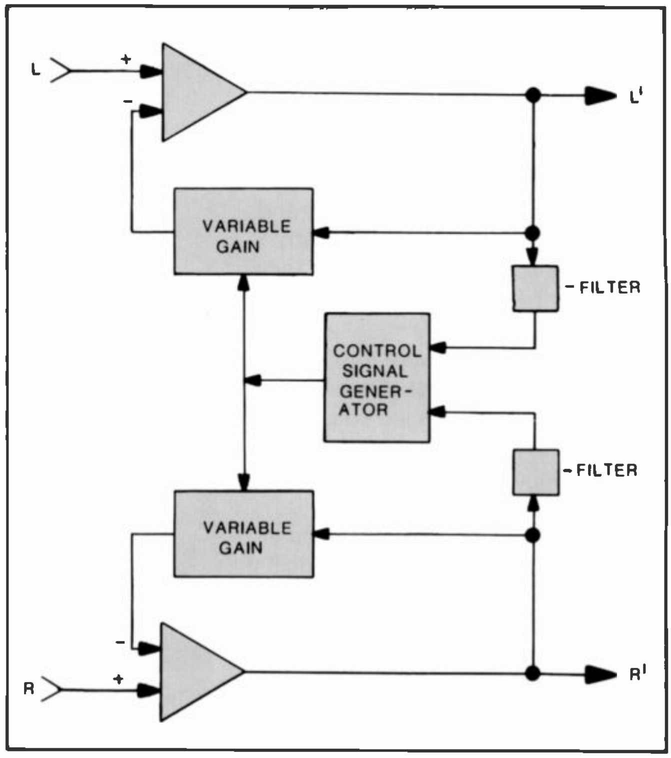



**Fig. 3. CX stereo compressor.** The CX noise-reduction system contributes to the VideoDisc stereo dynamic range.

ness of the disc or vibration of the stylus. The underlying mechanisms cause this noise to be correlated from one channel to the other. When matrixed by the stereo decoder, they reinforce one another in the left channel, and nearly cancel in the right channel.

Control of these noise sources proved extremely difficult. Cancellation of these noise components was potentially possible (the behavior of the right channel providing tangible evidence of this possibility), but fundamentally required adding random noise back into the system along with the cancelling information. Because of this trade-off, it was desirable to reduce the main contributors of such noise below detectable levels. A resonance in the cartridge was damped by a design change, reducing its contribution by about 10 dB at 10 kHz, and disc surfaces were improved by process changes. These improvements successfully lowered the "left-channel" noise back into balance with the "right-channel" noise.

To further improve stereo performance, noise-reduction systems were investigated. After evaluation of several systems, the newly developed CBS CX* system was selected over competing alternatives. Although some other systems promised more noise reduction, CX encoding was attractive for several reasons:

- It was possible to foresee that the masking of noise by high-level signals could be made adequate on the disc, thus assuring acceptable performance of the CX system.
- The CX system had been designed with a primary emphasis on compatible play of unexpanded material. This not only assured reverse compatibility of stereo discs on monaural players, but also solved the problem of presenting adequate dynamic range to stereo inputs, while restricting dynamic range on television rf inputs. The compressed material is fed out to the TV rf modulator, while the expanded material drives the stereo outputs.
- The CX system generally reduced the audibility of "ticks" and "pops"; some other systems exaggerated their effect.
- A variety of economical circuit executions with interchangeable component sources are possible with CX.
- Only inaudible waveform distortions arose from forcing the CX-encoded signal through an FM system with limiting.

A bonus arose from the decision to use the pre-emphasized signal in the CX control loop. Dynamic range in the basic FM system diminishes at a rate of 6 dB per octave beginning at the pre-emphasis break frequency. However, the action of the CX system reduced this to 3 dB per octave for steady-state signals. This characteristic suggested that additional pre-emphasis could be added in mastering, while still maintaining greater than benchmark dynamic range. Empirical work on a variety of program tapes confirmed this effect with complex audio waveforms, and a second breakpoint was added at 6.1 kHz (25 $\mu$s). Subsequent de-emphasis in the player contributes significant noise margin to the system (approximately 3-dB A-weighted SNR).

## CX noise-reduction system

The CX process provides up to 20 dB of noise reduction by means of a complementary compansion process. Audio signals are compressed by a 2 : 1 factor (on a dB scale) during the disc-mastering process. During playback, the demodulated audio signals are expanded by a 1 : 2 factor (Fig. 2).

A simplified block diagram of the CX compression system is shown in Fig. 3. Voltage-controlled amplifiers in the feedback loops of the left and right channels are adjusted by a control signal derived from the left- and right-channel outputs. Unlike other compansion systems (for example, Dolby or DBX) compression takes place with no spectral alteration. This characteristic permits playback of the compressed signal without an expander for compatible reproduction.

* CX is a trademark of CBS Laboratories.

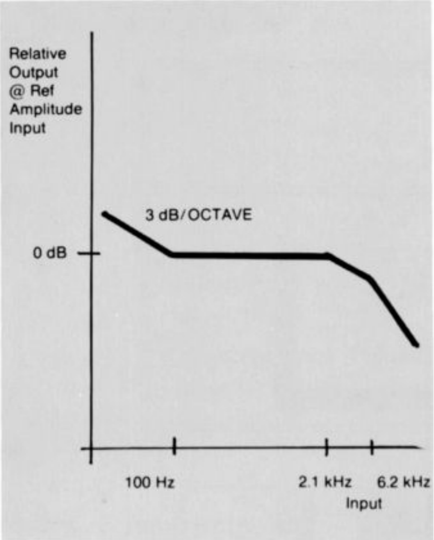



**Fig. 4. CX signal compression versus frequency characteristic (sinusoidal input only).**

Compression occurs at 2 : 1 characteristic only for signals greater than −40 dB with respect to a reference. All signals below −40 dB retain a 1 : 1 characteristic. For the CED system, the reference operating level is defined as ± 25 kHz deviation of the FM sum-channel sound carrier, with a 1 kHz sinusoidal modulating signal applied to both left and right inputs in phase.

Audio signals below 100 Hz are attenuated by 6 dB per octave before being applied to the control-signal generator. This prevents gain pumping that can be caused by strong subsonic signals. System pre-emphasis is added to the audio signal before it is applied to the control-signal generator. This improves system headroom (margin from standard signal level to maximum signal level before significant nonlinearity occurs), and noise-reduction characteristics, at high frequencies. The resultant compression-frequency response for single-channel steady-state sinusoidal-input signals is shown in Fig. 4.

The transient response of the control-signal generator is nonlinear and has been designed to minimize audible side effects. A block diagram of the control-signal generator is shown in Fig. 5.

Filtered left and right signals are fed to the input cell where they are passed through ideal full-wave rectifiers to produce absolute-value-level signals. In addition, a minimum signal-level reference is generated. The largest of the level signals or the minimum level reference is rectified and passed through a complex network that generates control responses for rapidly rising, rapidly falling, or slowly changing audio-signal levels. The compressor and expander are the inverse of one another.

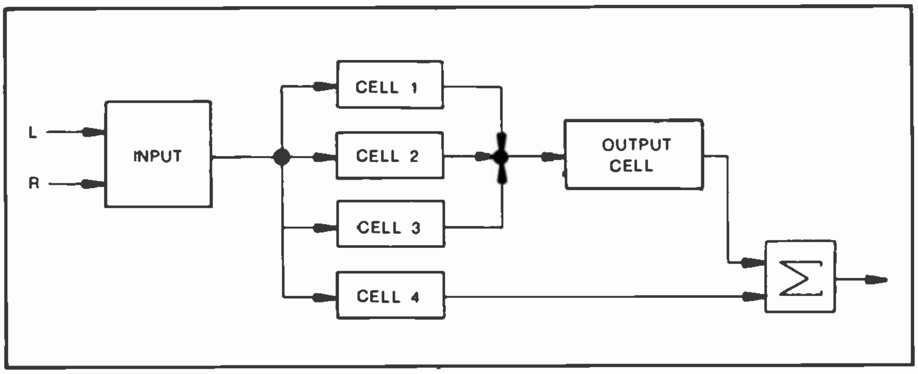



**Fig. 5. CX control-signal generator.**

## The stereo-mastering system

The audio portions of VideoDisc mastering systems have been redesigned to accommodate stereo quality levels. Figure 6 shows the audio block diagram of a VideoDisc mastering system. Stereo audio programs can be supplied either on tracks 1 and 2 of the 1-inch C-format tape or on a separate 1/2-inch audio tape. Because of the limited audio performance of C-format VTRs (wow and flutter, especially at half speed, stereo signal phase tracking, and distortion), 1/2-inch audio tape is the preferred format. Video and audio are synchronized by using the SMPTE time code, recorded on the videotape and on track 4 of the 1/2-inch audio tape.

The mastering process takes place at half speed. The appropriate scale-factor modifications have been made to all tape machines, equalization networks, and time constants within the audio-signal path. From the tape machine, the audio signal is fed through a Dolby A decoder. To ensure the highest possible quality, all stereo-program master tapes are Dolby A encoded.

Following the Dolby A is a filter set. The filter can be used to optimize the bandwidth of the audio chain to match the bandwidth of the program material. Many film sound tracks, for example, have a bandwidth of only 8 kHz. By optimizing the audio chain to fit the program, system SNR can be improved by 2 to 3 dB. For high-quality programs with low source noise and wide bandwidth, the filters are set for a 16-kHz bandwidth. The filter can also be used as a notch filter to remove single-frequency spurious tones from program sources.

After bandpass filtering, the signal is CX encoded. The CX encoder used in the signal chain incorporates equalization circuits within the control loop that cause the encoder to compress the audio signal as if it were pre-emphasized. Actual pre-

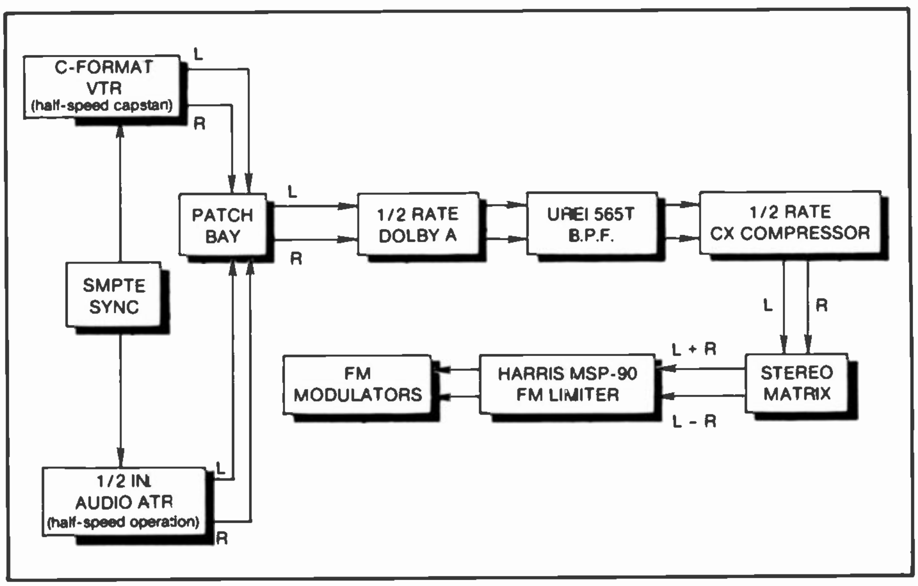



**Fig. 6. Audio signal path in the CED stereo mastering system.**

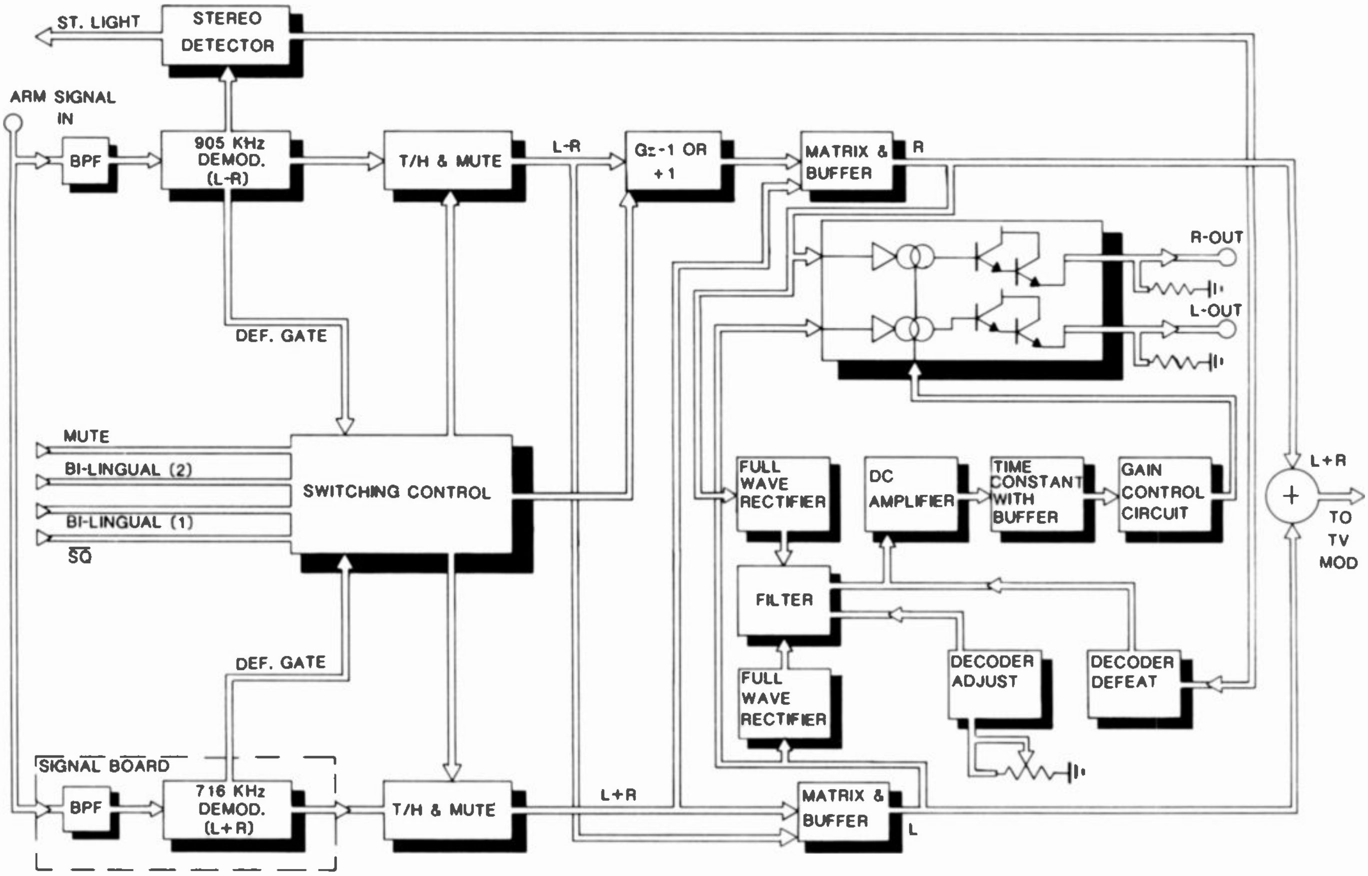



**Fig. 7. The stereo signal section of the SGT 200 stereo CED player.**

emphasis takes place later in the signal chain.

After CX encoding, the left and right stereo signals are added and subtracted in the stereo matrix to form sum and difference signals. The sum and difference signals are then pre-emphasized and limited to peaks equivalent to 100 percent (± 50 kHz) deviation. Audio-program material can have a peak-to-average ratio greater than 10 to 12 dB, which means that some form of signal limiting must be applied to prevent over-modulation. Limiting is applied to the sum and difference signals. This permits a higher average signal level before limiting as compared with conventional left/right limiting.

The limiter is a two-channel unit with the highest input to either channel controlling the limiting action on both channels. This prevents changes in stereo separation when the limit circuits are active. Limiting is by means of gain reduction as much as possible, thus avoiding obvious distortion of extreme peaks.

The output of the limiter drives the audio modulators whose output is then summed with the FM-modulated video signal. The composite signal is amplified and used to drive a PZT cutting head that scribes the signal onto a copper substrate.[2-4]

## RCA's introductory CED stereo player

The SGT 200 stereo player is similar to the SFT 100 and SGT 100 monaural players in many respects. The video circuitry, control circuitry and playback mechanism are identical on the three players. Addition of a stereo-indicator light in the front, and audio/video output jacks and a bilingual switch on the back, account for the differences in the outward look of the stereo player.

The main blocks of the complete stereo signal section consist of two demodulators, mute/track and hold circuits, and matrix and CX decoder circuits (Fig. 7). The 716-kHz carrier is demodulated by circuitry on the main circuit board. The 905-kHz demodulator and other circuits are located on a stereo-board subassembly. The stereo player uses the identical custom-designed phase-locked loop IC used in the SFT 100 player to demodulate the audio signals.[5] However, the voltage-controlled oscillator gain has been reduced and output amplifier gain reduced by a similar amount to improve the audio SNR. The loop filter has been modified to increase the audio bandwidth.

The 905-kHz demodulator functions the same way as the 716-kHz demodulator with the exception of squelching capability when the carrier is missing. With mono discs (no 905-kHz carrier) the 905-kHz demodulator IC puts a "low" on the squelch line and this function is used to turn off the stereo light and disable the decoder and CX expander. The above three functions are also disabled whenever the bilingual switch is moved from normal position to select either channel 1 or channel 2.

A track-and-hold circuit is used for (L + R) and (L − R) channels separately. This technique is very effective in reducing ticks and pops. However, if high frequencies are present in the software, a track-and-hold circuit can degrade the tick-and-pop performance. To avoid this, the track-and-hold circuit has a charging time constant of approximately 98 μs which limits the hold function to frequencies below 1.6 kHz while allowing tracking at frequencies above 1.6 kHz. A CMOS quad-switch (CD4016) is used for this function. These switches are also used for muting the player or selecting any language by muting one channel at a time.

The left and right signals are recovered by adding (L + R) to (L − R) and (L + R) to −(L − R) respectively. An inverter amplifier is used to invert the gain of the (L − R) signal. When independent audio-channel 2 is selected, the gain of this amplifier is changed to +1 to get in-phase signals at each output. Left and right signals from matrix output are also added back to get an (L + R) signal for the TV modulator.

The CX decoder is designed using low cost, commonly available ICs. Two CA324-type operational amplifiers and one LM13700-type transconductance amplifier are used. The function of the CX decoder is to provide complementary expansion of the compressed signal.

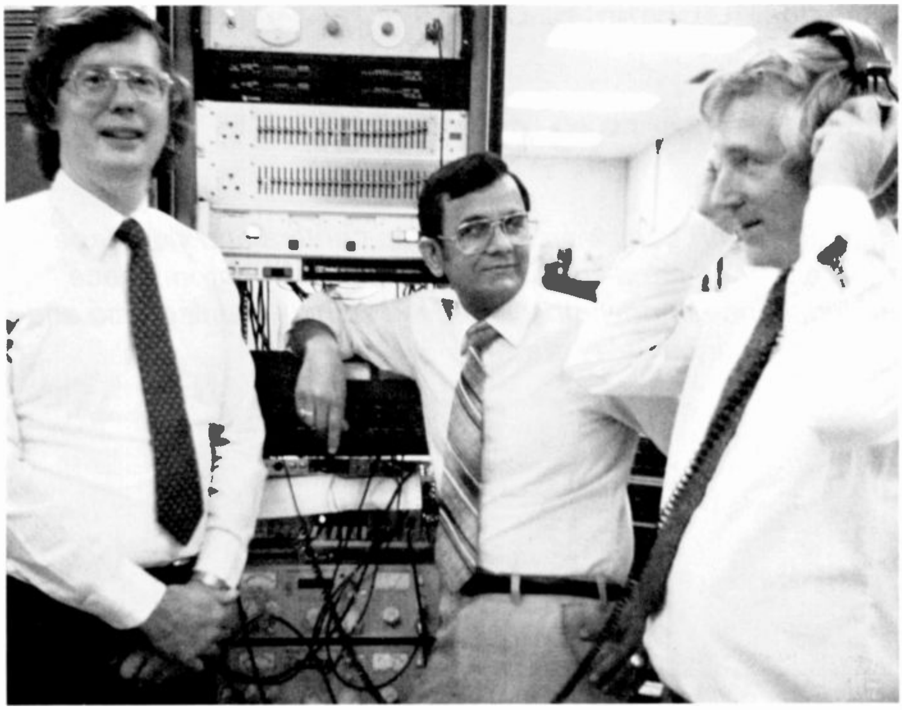
The decoder consists of a full-wave rectifier for each channel and a filter/peak-detector that gives a dc output corresponding to the peak signal from both channels. This dc is amplified to the right level for proper dead-band operation. This dc voltage goes to a time-constant circuit and finally controls the current of the transconductance amplifier, thereby changing its gain. A precision limiter is used to adjust the knee of the −40 dB break point. A single-pole *RC* network is used at the output of the transconductance amplifier to provide necessary de-emphasis at 25 $\mu$s. The L and R expanded signals are then connected to the output jacks through the buffer stage and given an additional de-emphasis of 75 $\mu$s.

## Conclusions

We have described the important elements of the CED VideoDisc stereo system. Experience with recording and testing early stereo programs for the catalog has confirmed (in the authors' opinion) that concerts and many feature films are significantly enhanced with this new CED VideoDisc stereo system.

## Acknowledgment

Others have contributed significantly to the work we are summarizing here. We thank our colleagues at the David Sarnoff Research Center in Princeton, and RCA "SelectaVision" VideoDisc Operations in Indianapolis for the opportunity to be their spokesmen.



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## References

1. J.J. Gibson, F.B. Lang, and G.D. Pyles, "Nonlinear Aperature Correction in the RCA VideoDisc Player," *RCA Engineer*, Vol. 26, No. 9 (November/December 1981).
2. H. Weisberg, "Manufacturing the VideoDiscs: An Overview," *RCA Engineer*, Vol. 27, No. 1 (January/February 1982).
3. F.D. Kell, G. John, and J. Stevens, "VideoDisc Mastering The Software to Hardware Conversion," *RCA Engineer*, Vol. 27, No. 1 (January/February 1982).
4. J.J. Brandinger, "The RCA CED VideoDisc System," *RCA Review*, Vol. 42, No. 3.
5. G.D. Pyles, B.J. Yorkanis, "VideoDisc's Video and Audio Demodulation, Defect Detection, and Squelch Control," *RCA Engineer*, Vol 26, No. 9 (November/December 1981).

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# The Hawkeye camera

*This unit, which combines a television camera and videotape recorder in one hand-held unit, features wider chrominance and luminance bandwidths, improved signal-to-noise ratio and less chrominance delay error.*

**Abstract:** *The authors present engineering design decisions that resulted in success for the Hawkeye camera, an innovative combination of television camera and videotape recorder. By using 1/2-inch pickup tubes and other innovations, the engineers designed a totally new camera system, with demonstrated improvements in all relevant performance parameters.*

RCA's camera/recorder system, aptly dubbed Hawkeye, represents the third stage in the evolution of portable cameras and videotape recorders (VTRs) designed for electronic news gathering (ENG).

In the early Seventies, ENG began and the equipment used at that time can be considered the first stage. This equipment usually consisted of three packages, the camera head, the camera electronics and the VTR. These early VTRs were fairly cumbersome quadruplex machines using 2-inch tape. With the introduction of the TK-76 in 1976, the second stage was reached when the camera (including the camera head and camera electronics) became a completely self-contained unit requiring only a connection to the VTR. About this time, videotape recorders using 3/4-inch tape were coming into prominence for ENG applications, even though the performance level was considerably lower than that of the newly developed cameras that use 2/3-inch pickup tubes.

Today, almost six years later, although great improvements have been made in both cameras and recorders, the VTR with 3/4-inch tape has still not attained the performance level of the camera.

In the Hawkeye, the third stage of the evolution has been achieved because the camera and recorder have been combined into a single package. This step makes the electronic camera system ergonomically compatible with its arch-rival, the 16-mm film camera. The three evolutionary steps in ENG cameras and VTRs are shown in Figs. 1a, 1b, and 1c.

The combining of the camera and VTR has not resulted in any performance compromises; on the contrary, it will be shown that the performance is substantially better than any previous system.

## A new look at old problems

Designing a camera to be integrated with a VTR required a new look at old problems; that is, size, power, and weight. With respect to size, this is determined to a first degree by the size of the optics, which is directly related to image format.

Our decision to press for development of the smaller 1/2-inch tube (8-mm scan) in Hawkeye was the result of observing 2/3-inch (11-mm scan) tubes underscanned to 8 mm, and of considering gun improvements and other upcoming developments.

The smaller pickup tube presented new mechanical and electrical requirements if the registration, stability, and linearity performance of 2/3-inch tubes was to be met or exceeded.

A key design decision, reached after review of traditional methods of yoke/tube fabrication, was that of considering the two elements as a single entity, thus taking a system approach from the start. It was fully appreciated that such a new concept would pose both marketing and technical problems. Nevertheless, in light of the ambitious performance goals set forth, the system approach was chosen, and this decision has proven successful beyond our expectations. Fig. 2 shows a cross section of the 1/2-inch tube and yoke in its final stage of assembly.

## Tolerance control is the key

The inside glass diameter is held to a tight tolerance using a mandrel technique. The tube-gun elements are then referred to this precise inside diameter (I.D.) such that concentricity of the I.D. relative to the tube central axis is within 0.001 inch. The outside of the glass envelope is quite different from any other pickup tube, in that a special elongated cylindrical surface is formed to provide a precision reference surface. This surface is mandrel ground such that the outside diameter (O.D.) is concentric to within 0.001 inch of the I.D., resulting in a maximum deviation between the O.D. and the tube central axis of 0.002 inch. The O.D. surface interfaces mechanically with the inside diameter of the yoke. In previous designs, tube location within a yoke used a target ring as a mounting surface. This method has never been completely satisfactory due to cumulative tolerance build-up of the relatively flimsy ring, and fabrication inac-


Final manuscript received May 11, 1982
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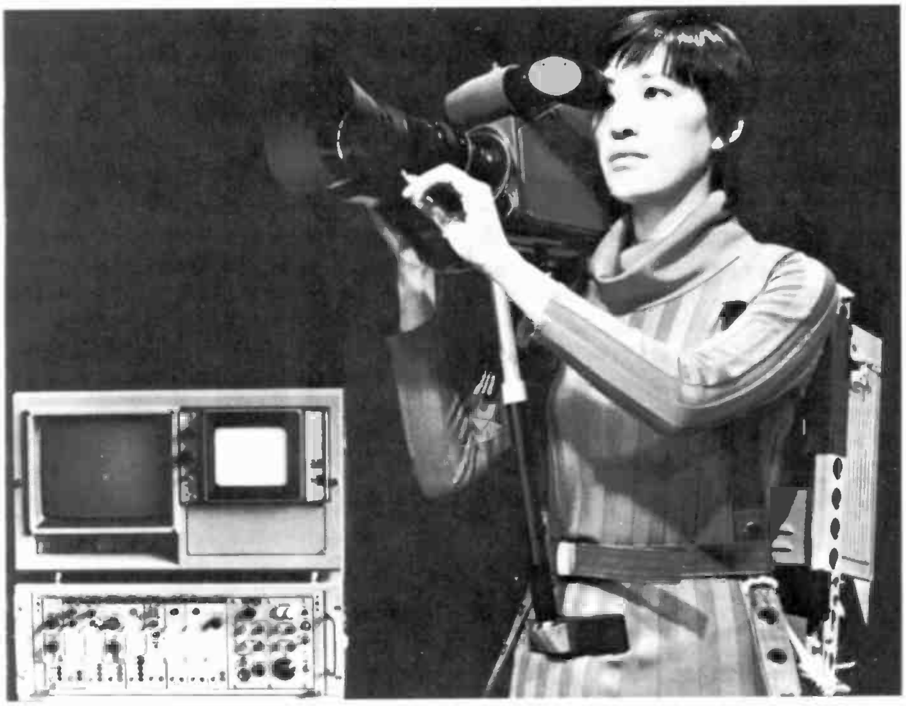
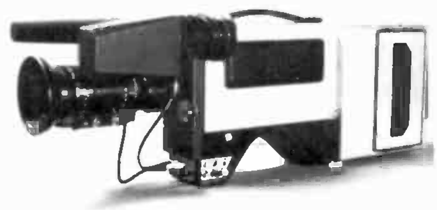


(a)



(b)



(c)

**Fig. 1. The three stages in the evolution of portable cameras and videotape recorders are shown: (a)** the early equipment wherein the camera, video head and electronics comprised three packages; **(b)** the next evolutionary step where the video electronics and camera head were combined in the TK-76 but the recorder was still separate; **(c)** the Hawkeye with the camera, video electronics and recorder all in one package.

curacies. In the Hawkeye design, the target ring is used merely to make the electrical connection.

Figure 2 also shows a cross section of the yoke focus coil and its inner Faraday shield. The main objective in the design of the Hawkeye yoke is to precisely control the dimensions and concentricity of each coil, so that the inside and outside diameters become the precision interface for adjacent coils. When the yoke is fully assembled, the net result is that the yoke and tube are essentially a "slip fit." Both pieces are then rigidly fastened with a bonding material placed at the front and rear of the yoke-tube interfaces. In the same way, the mumetal shield is bonded to the O.D. of the yoke through the use of precision tooling to assure concentricity.

Before the yoke and tube are bonded, each unit is measured for a number of parameters such as geometry, registration, centration, and so on, using computerized equipment. From the resulting data, tube/yoke matches are selected for registration by using an algorithm that combines the individual geometries of both tube and yoke.

The advantages of this method of grouping tube/yoke data together is that an enormous database is possible from a relatively small population of tubes and yokes. For example, from a population of 20 yokes and 20 tubes it is theoretically possible to derive 46-million combinations of yoke/tube RGB triplets. From this enormous database it becomes practical to set very tight registration limits. As a result, the Hawkeye camera can achieve a registration error of less than 0.3 percent in zone 3, without the need for complicated high-order electronic correction.

## Dealing with decentration error

A major cause of geometry and, hence, registration problems is the decentration error caused by the optical image falling on other than the axis of the pickup-tube faceplate. The integrated tube/yoke assembly allows a technique for eliminating this problem. Figure 3 shows how a flange assembly is mounted to a sleeve bonded to the mumetal shield. The flange assembly mounts and locates the tube/yoke to the optical housing. The two locating bush-

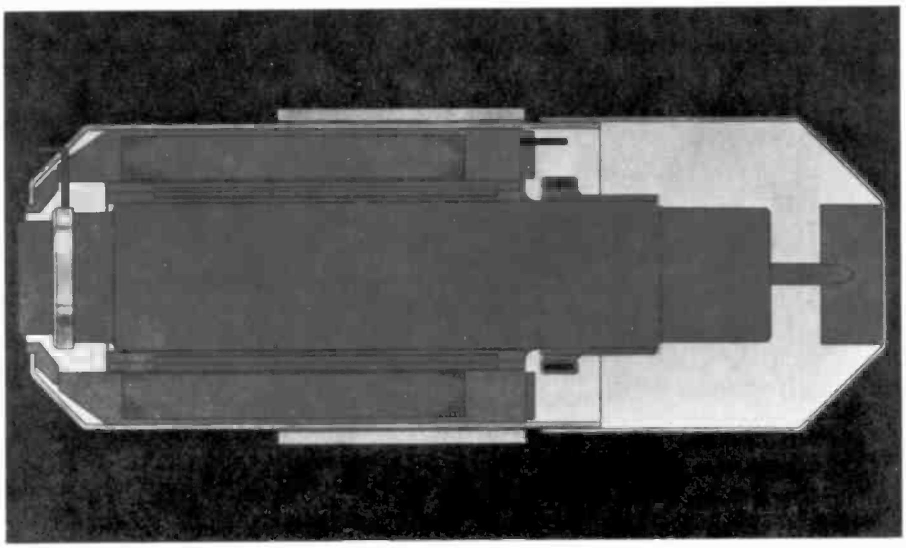


**Fig. 2. A cross section of the yoke/tube in its final stage of assembly.**

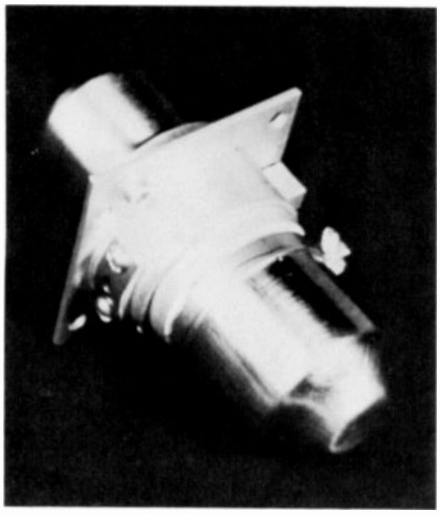


**Fig. 3. The integrated yoke/tube assembly for the Hawkeye camera, with the mounting-flange shown.**

ings on the flange are located and bonded to the flange such that the midpoint between the two bushing centers is exactly coincident with the tube axis. This technique ensures that the optical image will always fall on the axis of the tube faceplate for any integrated assembly and any port in the optics block. The Hawkeye registration specification of zone 3 is 0.3 percent whereas 0.5 percent is typical for 2/3-inch tubes. This is a remarkable improvement considering that on an 8-mm scan diagonal the displacement error for 0.3 percent misregistration is only 15 micrometers. The foregoing discussion refers to the RCA-designed Saticon® tube/yoke system. In addition, Philips in Eindhoven has been developing a Plumbicon® counterpart in the 1/2-inch size. The Hawkeye camera is designed to use either type of pickup-tube assembly.

## Effect on stability, lag and sensitivity

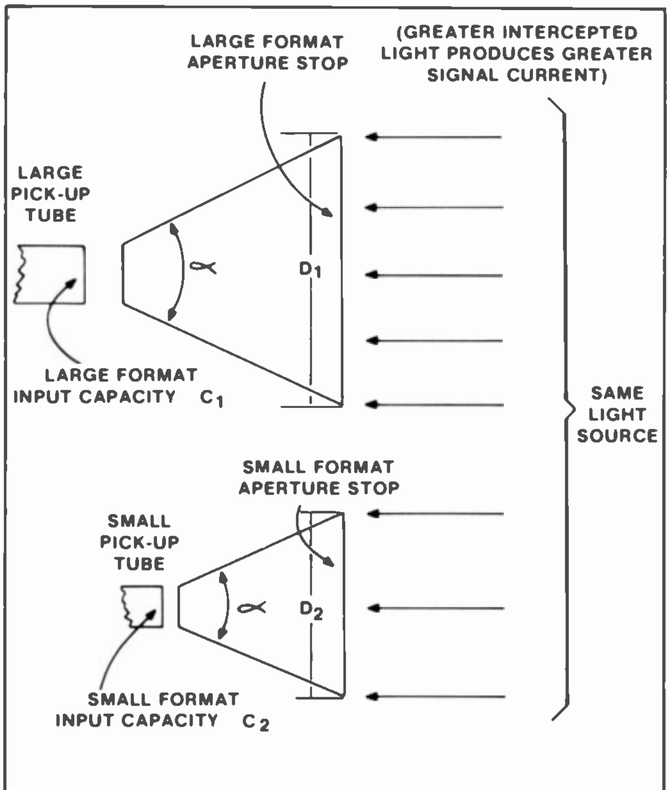
Improvements have also been achieved in the stability of the deflection- and focus-current circuits used to drive the integrated yokes. With the progress made in resistor and voltage-reference stability, it is now possible to obtain absolute stability of the deflection- and focus-current amplitudes by using feedback-control techniques.

The 8-mm format image size offers advantages not only of reduced camera weight and size, but most importantly, reduced lag. An improved electron gun and optical design provides a level of resolution performance such that this factor is no longer a key issue in format choice. In addition, camera sensitivity is essentially the same for all pickup tubes ranging from 30-mm down to the 1/2-inch tube. The equivalent performance is due to the pickup tube capacitance decreasing linearly with the decrease in area of the photoconductor.

## The result of small tubes on the optical system

Figure 4 shows a simplified comparison of two optical systems that would be typical of a large versus a small pickup-tube camera.

Note that the entrance pupil of the larger pickup-tube camera gathers more light than its smaller counterpart, and this produces more signal current. But, the smaller tube format also has reduced capacity, and, if the scaling conditions are correct, the signal-to-noise ratios can be equivalent. In this analysis, it has been assumed that the optical transmission factors of the lenses are equivalent, and the signal-to-noise ratio of the preamplifier varies as an inverse proportion of the total input capacity. This is essentially correct for a well-designed preamplifier, where the dominant noise source is that contributed by the input transistor. Another assumption that has been made is that the cone angle of light passing through the prism is the same in both systems,




$$\frac{(\text{SIGNAL TO NOISE RATIO})_{\text{LARGE FORMAT}}}{(\text{SIGNAL TO NOISE RATIO})_{\text{SMALL FORMAT}}} \approx \frac{D_1^2 C_2}{D_2^2 C_1} \approx 1$$

**Fig. 4. Simplified comparison of two optical systems** typical of large and small pickup tubes for cameras. Although the larger pickup-tube camera gathers more light than the smaller, the signal-to-noise ratios can be equivalent.

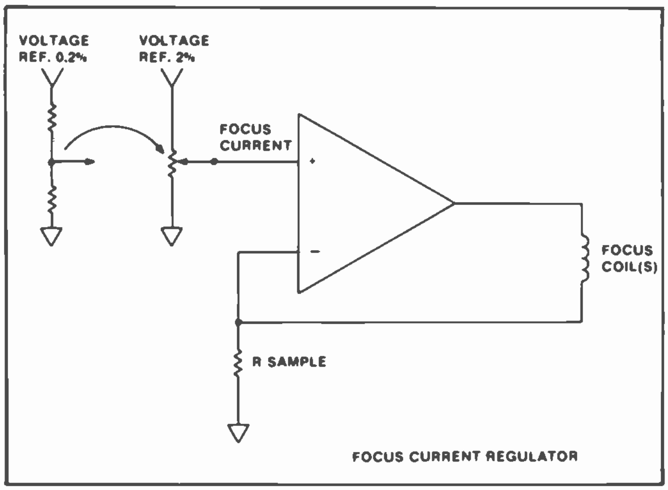



**Fig. 5. Focus current-regulator circuit.**

and the intrinsic layer sensitivity is independent of format size. This is a requirement for minimum color-shading errors and optical aberrations.

An asymptote is reached in the equivalent performance theory at close to the 1/2-inch image format, because of the practical limitation in making zoom lenses or prisms faster than f/1.4.

## Long-term stability improved

The development of the single-package ENG camera in 1976 demonstrated that high-quality pictures can be consistently produced with a minimum of remote controls. The design and development effort in the Hawkeye project has been to pursue this theme and improve on it. The design goal has been to eliminate the need for set-up controls, and, consequently, to improve the long-term stability.

If a camera can be designed so that the set-up can last as long as the time between failures, then set-up can be accomplished in the maintenance shop, where the equipment to make the necessary corrections is readily available.

The color encoder is a natural candidate for reducing the number of adjustments. The function of the encoder is precisely specified, and is not subject to change. A typical encoder has 13 adjustments that are required to optimize performance. Sample-and-hold techniques and feedback loops have been used to eliminate all but two of the 13 adjustments. In previous designs it was possible to achieve a subcarrier suppression of −46 dB. With the excellent IC operational amplifiers available today, subcarrier suppression can be made greater than −50 dB without manual adjustment.

Reference has been made above to improvements in focus-current stability. The circuit for regulating the current in the focus coils is shown in Fig. 5. A small change in focus current will significantly affect color registration and camera resolution. The focus control has been eliminated because of the availability of a precision laser-trimmed voltage reference. This simple modification removes a control, and the consequent possibility of incorrect set-up.

Another area where much has been done to eliminate set-up controls is in the automatic black-and-white balance circuits. Analog-to-digital converters are used to store the black-and-white correction signals. The converters are low-power CMOS devices; a small battery can keep such a memory alive for many days. The range and precision of both black and white balance circuits is such that channel-gain controls and black-balance controls can be eliminated. By comparison with older camera designs, the new design results in the elimination of seven more controls.

## Camera size reduced to minimum

Perhaps the most difficult problem engineers faced during the design of the Hawkeye was that of producing an ergonomically acceptable package. The decision to use a VHS cassette with 1/2-inch tape determined the dimensions for the VTR. Although field experience has shown that size and weight are very important, balance and/or comfort factor is even more important. It was obvious that the smaller the camera, the better chance there was of obtaining the best compromise in all three parameters. The decision to use smaller optics was the first step in the direction of minimizing the camera size. The next step was to increase module and component density. Printed circuit boards were reduced from a nominal thickness of 0.064 inch to 0.030 inch.

The synchronizing and pulse signals are generated digitally, which allowed two custom LSI circuits to be designed, resulting in a savings in board space. The printed wiring board containing the circuits are shown in Fig. 6. Both LSIs are low-power CMOS devices.

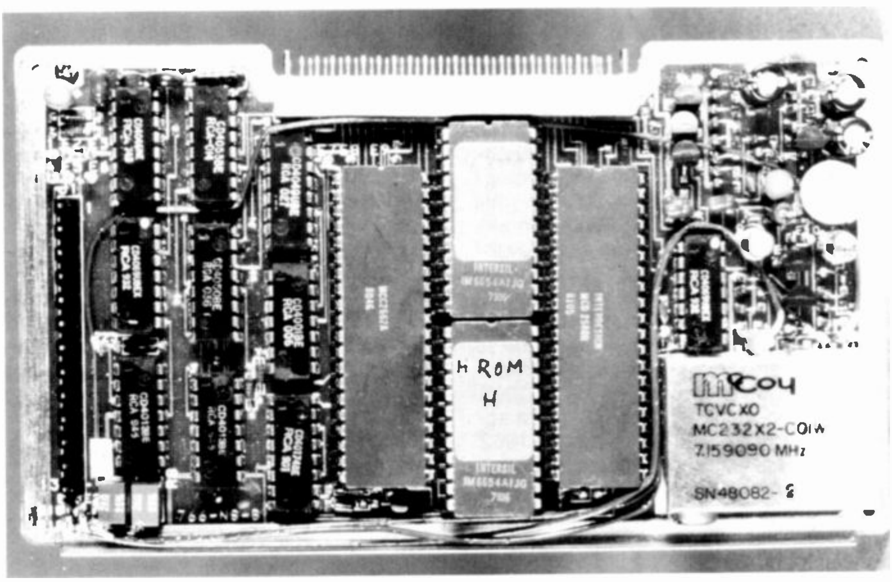



**Fig. 6. Printed wiring board containing the synchronizing and pulse signals that are generated digitally.** Note the two LSIs.

Another increase in circuit density was obtained by the use of hybrid circuits. A hybrid, single-in-line-package video amplifier that is used 13 times in the Hawkeye camera is shown in Fig. 7. It features wide bandwidth, large signal swing, and gain performance that is not easily obtainable with integrated circuits. The single-in-line-package also uses the space above the board and minimizes the area taken on the board.

Conventional wiring harnesses demand considerable space in electronic packages and, in addition, place restraints on the location of modules or other mechanical assemblies. In the Hawkeye design, wiring harnesses have been replaced by flexible printed circuits. Another advantage of the flexible printed circuit is the high degree of repeatability in performance and producibility attained. It would have been impractical to connect the 62-pin interface connector to the camera backplane with a wiring harness. The 62-pin connector is the only electrical interface between the camera and VTR. Implicit in the camera design is the ability not only to interface with a VTR, but also other electronic packages. The VTR can be replaced with an adapter that allows the camera to be operated with a separate portable recorder, much the same way as present-day ENG cameras. Another adapter can interface with a base station via a multicore or triax cable. In these latter two modes, a remote control panel (RCP) is used (see Fig. 8) which has all the normal video operator controls and some set-up functions. The RCP design is microprocessor-based, requiring only twisted-pair connections to the small base station. The analog

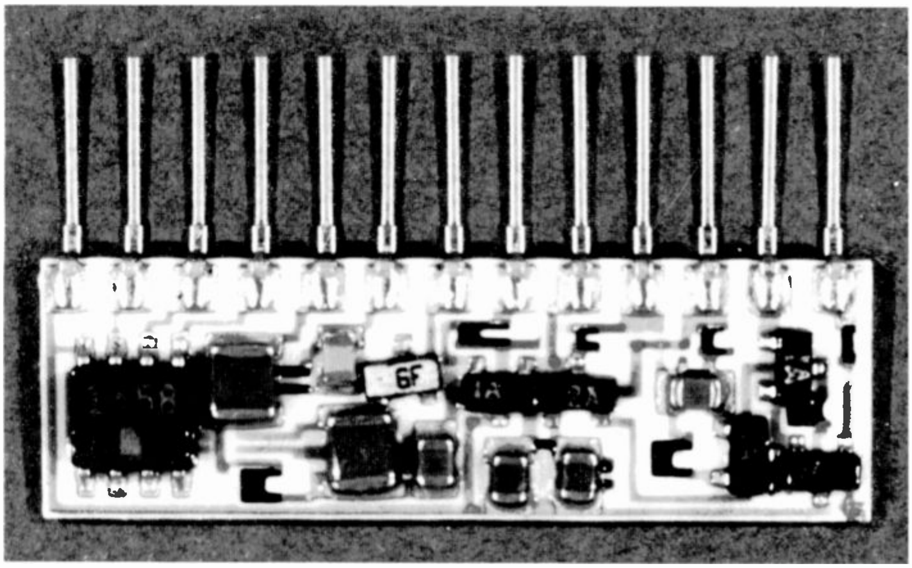


Fig. 7. The hybrid video amplifier that is used 13 times in a Hawkeye camera is shown.

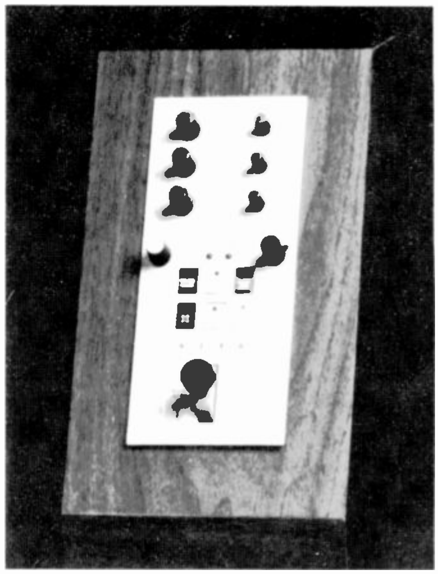
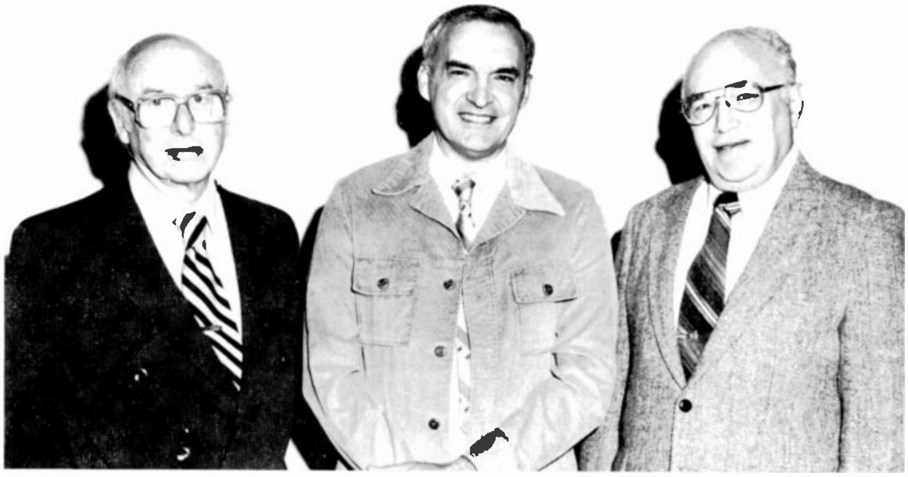


Fig. 8. Remote control panel for interfacing to either a base station or a separate video recorder.

control functions between the base station and camera are transmitted via a digital link.

## Conclusion

By using 1/2-inch pickup tubes, we reduced lag in the Hawkeye camera with no compromise in other performance parameters. This reduction is important because lag limits sensitivity in current ENG cameras. In addition, the higher-precision techniques applied to the pickup tubes, deflection yokes, and their location in the optical assembly results in better registration and stability. The net result is a totally new camera designed to fully complement the advancements in the Hawkeye VTR.



**Authors (left to right) Clarke, Bazin, and Bendell** were leading members of the design team responsible for the revolutionary TK-76 portable color camera.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**Lucas Bazin** majored in Physics at the Drexel Institute of Technology, where he received a B.S. in 1959. He also received a M.S. in Engineering from the University of Pennsylvania in 1970. He has been associated with the RCA Broadcast Camera Engineering activity since 1963 and has contributed to the development of systems and circuits relating to this activity. He is presently a Principal Member of the Engineering Staff assigned to the Hawkeye handheld camera-recorder design group. He has obtained 20 U.S. patents on systems and circuits relating to television cameras.
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R.L. Barbin | T.F. Simpson | B.G. Marks

# A color-data-display CRT: A product whose time has come

*By making and selling these high-resolution data-display color CRTs RCA is obtaining business for scientific and commercial applications now, and preparing itself for the consumer business of the future.*

**Abstract:** *Color-display devices are key components in the quest for more productive use of computer-generated data. In February of this year, RCA announced its entry into this fast-growing field with the introduction of a 13V high-resolution color-display tube. This tube is now in production at the Picture Tube Division facilities in Lancaster, Pennsylvania. This paper describes the color-data-display market and the technical requirements it places on the picture tube over and above that of the consumer TV market.*

The computer-generated data display is an idea whose time has come. The technical and business communities are demanding rapid, flexible, and understandable displays of the data with which they make decisions—whether that is equations, schematic diagrams, flowcharts, PERT charts, balance sheets, inventory lists, or market quotations. The ability to quickly display this data, reorganize it for best understanding, and incorporate up-to-the-minute inputs, is vital to the computer's contribution to today's scientific and business world.

The display device that serves this function best is the raster-scan CRT (Fig. 1). It is fast—it can erase and rewrite its entire contents in a sixtieth of a second. It supports a wide variety of display types: alphanumeric displays of varying formats; line, bar, or pie graphs; or diagrams, such as schematics, mechanical drawings, or photographic images. The computer translates numbers to x-y locations for graphics, and inexpensive semiconductor memory provides a display-refresh memory. Best of all, raster-scanned computer displays can build on a consumer-TV technology to keep the system cost low.

A unique capability of raster-scan CRTs is full-spectrum color. Color can differentiate or highlight data, and it can add a third dimension to graphics. In situations where life or large economic consequences are at stake, color highlighting of danger can be vital—for more mundane applications, color can make training easier and work less fatiguing. Teamed with semiconductor memory, a fast computer, the right software, and creative people, today's CRT displays make pen and paper seem almost counterproductive by comparison.


Final manuscript received April 23, 1982.
Reprint RE-27-4-4

## Economics: The driving force

The reason for the data-display CRT's increasing popularity is the combination of the right system price and a critical economic need. White-collar productivity—the ability of technical and office professionals to produce the right results—has remained basically unchanged for decades. While massive investment in factories has raised blue-collar productivity by quantum leaps over the years, investment in equipment to support white-collar decision-makers has been all but nonexistent.

In the United States today "information workers" make up more than 50 percent of the work force. These key people derive the information that determines the direction of business. Any improvement in the relevance of information they have, and their ability to develop understanding from it, will result in increased competitiveness, for both their business, and for the nation of which it is a part. The promise of better decisions from more accurate information is the driving economic force behind the proliferation of computer systems and their attendant data displays throughout the business and technical communities.

### The marketplace

The flexibility of their display capability, and the economic need for their use make the potential market for data-display CRTs a very broad one. These products are already pervasive in the newspaper industry for rapid writing and editing of news articles. They are presently invading the design and drafting fields, where computer lines-and-solids modeling capabilities are revolutionizing the design of automobiles, airplanes, and office buildings. Biological researchers model DNA and other complex molecules. These technical applications tend to need the most sophisticated displays, which have very high resolution (1000 × 1000 pixels or above) and usually incorporate complex graphics capabilities. Color displays are rapidly per-

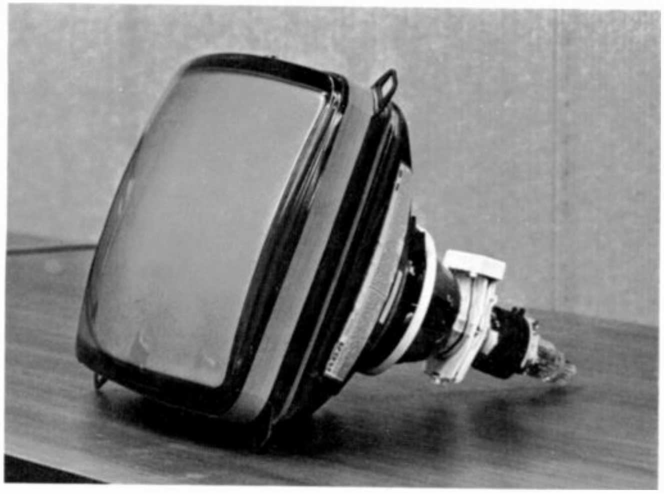


**Fig. 1. The RCA high-resolution color-data-display CRT** with the deflection yoke and neck component attached.

**Fig. 2. A data-display CRT in a typical application.** The CRT is used with keyboard, viewed from arm's-length distance.

vading technical applications and will dominate them in years to come.

A far larger potential market, however, exists in general business applications—the "electronic office." This general application covers a broad range of more specific uses, the simplest being the familiar word processor. More sophisticated interactive terminals are used to query large databases and plot graphic projections of "what if?" scenarios for potential business analysis. These systems must satisfy a variety of needs, from secretarial entry of business letters, through communications with large corporate computers, to generation of boardroom graphics describing operating business results.

The attractiveness of this market results from its immense potential size. By 1990, the number of white-collar workers in the United States can be expected to exceed 60-million people. At that time, 50 percent or more can be expected to have a data-display terminal on their desk. This potential market of 30-million units or more is exceeded only by the consumer market, and represents an excellent opportunity for firms possessing the required video technology.

RCA Picture Tube Division has decided to address the fastest-growing segment of the data-display-CRT market, the color sector. Color, with its ability to differentiate and highlight data, offers an added dimension of understanding and performance to users. Color is likely to dominate those applications where business or other graphics capabilities are required, and color may also acquire a substantial share of the alphanumeric-only applications, where rapid operator training or prevention of operator boredom are an issue.

### *Growth will be rapid*

IBM began the real growth of the color-display market in 1979 with the introduction of its model 3279 color terminal. Many color products will be introduced in 1982. Growth will accelerate in mid-decade as IBM introduces its second-generation terminal and other major manufacturers introduce their color products, bringing their substantial marketing forces to bear on expanding the color market. As more users become aware of the benefits of color, and adequate software becomes available to support the easy use of color in business applications, color-data displays will probably comprise one-third or more of the data-display market by the middle of the next decade.

### *The application defines the design*

As information workers become increasingly dependent upon the computer as their source of information, they spend an increasing amount of time using their data-display terminal. Information professionals tend to spend much of their day viewing their data, whether it be alphanumeric or graphic in nature. They typically do this seated at a desk, with a keyboard controlling the display, and with the display screen viewed from a distance of 1½ to 2 feet (Fig. 2).

Because of the desire to manipulate large amounts of data, professionals will also require that a large amount of material be presented on the screen at one time; each element of the presentation then, is fairly small. Alphanumerics, for example, tend to mimic typewriter-size lettering (Fig. 3). These characteristics—intensive use, close viewing, and dense presentations—define the display's design requirements.

## Technical characteristics

A color-data-display tube, similar to a consumer television tube in gross design, differs considerably in detail. For example, electron-beam-focus characteristics, screen structure, and the reduction of reflected glare are important for this application. In general, this matching of the machine's human-interface characteristics to the needs of the people using the device is referred to as "ergonomics."

### *Resolution*

The most obvious of these ergonomic considerations is the high-resolution requirement—the information must be legible. The resolution of a display system is often described in terms such as the number of characters, the number of scan lines, number of pixels, or the size of the screen structure. A lot of confusion can result from the intermixing of these criteria to describe various systems and, with any of them, the question normally left unanswered is "What will the performance level be?" A system may be said to be capable of resolving 2,000 characters—but how complex are the characters and what readability criteria are met?

For raster-scan data-display terminals, the picture information is generally stored bit by bit in memory and read out sequentially to modulate the electron-beam intensity of the CRT as it is scanned. Thus, the screen is divided into an array of addressable picture elements (pixels). In the vertical direction, each picture element is a

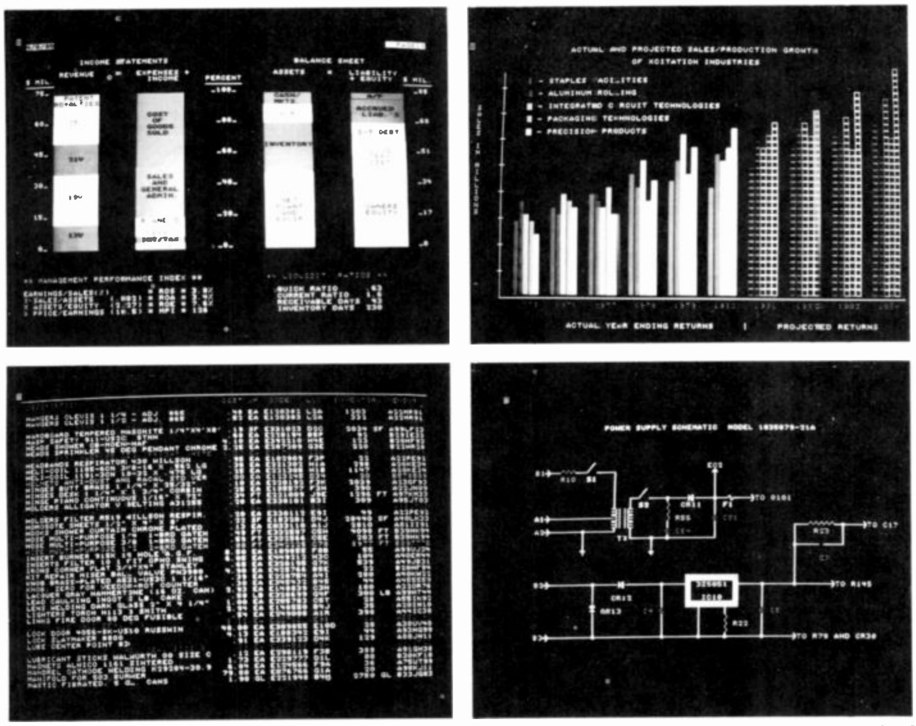
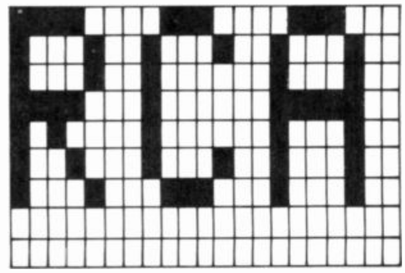


**Fig. 3. Photographs of actual data displays on a high-resolution CRT, showing typical applications.** On the actual display, different shadings are in bright colors.



**(a)**

**(b)**

**Fig. 4. Character representation in a 5 x 7 array. (a)** "RCA" shown diagrammatically; and **(b)** a photograph of the characters in (a) shown on the RCA high-resolution display tube. Dots are 0.31 mm apart, measured in a vertical line.

scan line. In the horizontal direction, the picture elements are turned on or off by the video waveform driving the electron gun. We prefer to describe the resolution of the display by the number of pixels that can be resolved to a definable criterion. The resolution capability of the system can be significantly affected by:

- The pixel characteristics—the number, size, and shape;
- Frequency response (bandwidth) of the display monitor;
- Electron-beam-size characteristics of the CRT;
- Screen structure of the CRT;
- Convergence of the three electron beams; and
- Antiglare treatment effects.

## *Pixel representation*

Alphanumeric characters are generated by activating the appropriate pixels inside a predetermined array size similar to the "light-bulb" displays commonly seen underneath the clock outside the local bank. The simplest format commonly used is a 5 × 7 (horizontal × vertical) with one or more blank pixels between characters to separate them. Figure 4 shows this representation for the characters "RCA" as well as an actual photograph of these characters in a 5 × 7 pixel representation on an RCA high-resolution color-display tube. For the normal 80-character computer-output display, the number of pixels required for this simple format representation is 560 per line—80 characters times 7 pixels per character (five active plus two "off" pixels for character spacing). More pixels per character such as 7 × 9 or 9 × 13 give better character definition, but require more pixels per line and, thus, a higher-resolution system to display the same number of characters.

In the horizontal direction, the electron beam will travel some finite distance across the screen during the time the electron gun is turned on for an "on" pixel. The length of this time is under the control of the monitor designer, up to the total time from one pixel to the next. Generally for an "on" pixel, the electron gun is turned on for the full length of time for that pixel and is not turned off until an "off" pixel is encountered. This gives the maximum brightness for the same drive voltage and peak beam current. The ideal driving waveform ("infinite bandwidth response") for alternating on/off pixels then becomes a squarewave. In the vertical direction, each pixel is a scan line and there is no significant travel of the electron beam in the vertical direction during the "on" time of the pixel; consequently, the size of the illuminated pixel area on the screen of the display tube is just the size of the electron spot. In the horizontal direction, it is the size of the spot plus horizontal scanning translation during the "on" time of the pixel.

## *Spot-contour profile*

The electron beam has a finite size and distribution of electron density, which gives a corresponding light-intensity distribution of the spot on the CRT screen. Figure 5 shows a typical spot-contour (electron-beam) profile for a display tube. At the low electron-beam currents of data display (approximately 200 microamps), the shape of these contours are Gaussian. The size of the spot that one observes with the unaided eye corresponds to the width of these contours at about the 2-percent to 5-percent intensity level. These profiles are determined by slowly moving a vertical (or horizontal) scanned line across a narrow slit with a photomultiplier behind the slit to sense the light intensity. They will

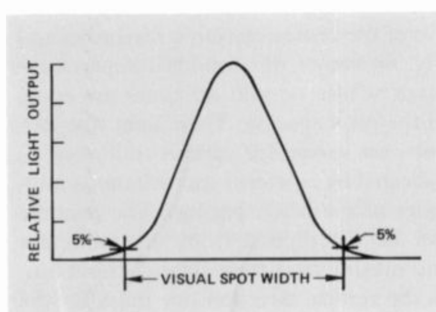



**Fig. 5. A spot-contour profile.**

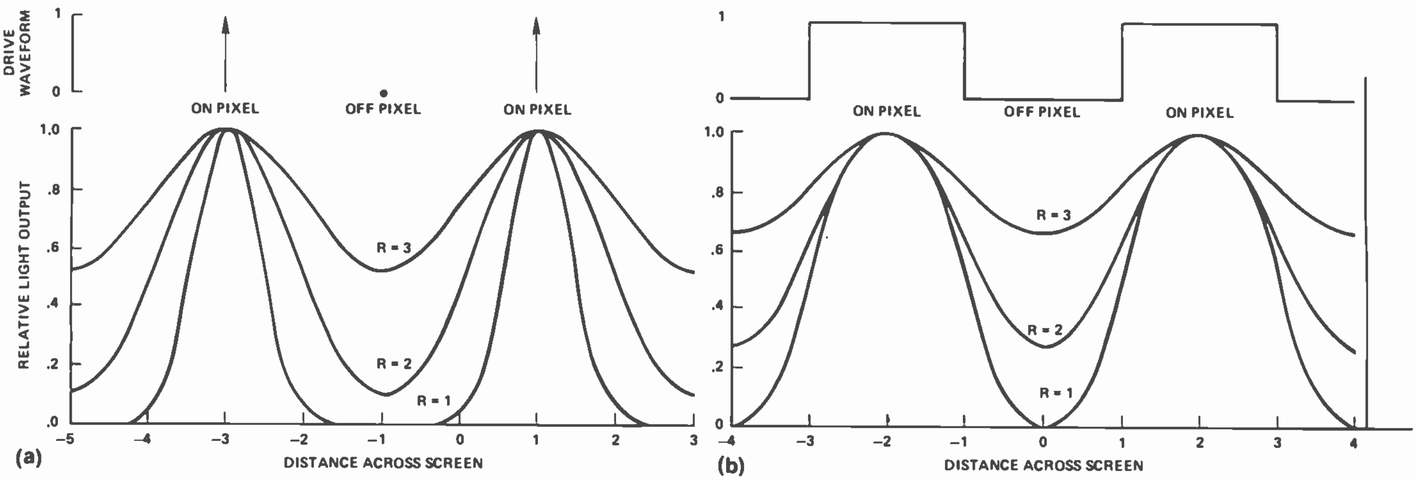



**Fig. 6. Light distribution on CRT for on/off pixels.** Various spot sizes are shown, where R equals the 5% amplitude spot size, divided by the pixel spacing. **(a)** Vertical direction, impulse pixels. **(b)** Horizontal direction, squarewave pixels.

in general be different in the horizontal and vertical directions due primarily to the asymmetrical effects of the yoke field and gun optics.

## Light distribution across the CRT face

If we ignore, for the time being, the mask and screen structure of a shadow-mask color picture tube, the light distribution for the pixel information on the CRT face can be calculated by convolving the spot-contour line profile with the driving pixel waveforms. Strictly speaking, the actual monitor response and the nonlinear drive (current versus voltage) of the CRT should be included in these calculations. However, substantial understanding can be obtained (with significant simplification) by looking at the infinite bandwidth response condition. In this case, the electron gun is either fully on or fully off and the spot-size changes as a function of drive can be ignored.

A useful resolution criterion is the contrast of alternating on/off pixels. Figure 6a shows the light distribution on the screen for impulse-type pixels, representative of the vertical-direction resolution and Fig. 6b shows this for ideal squarewave pixels whose on and off times are equal to the pixel spacing. These light distributions are shown for various spot sizes, as indicated by 5-percent spot widths as multiples of the pixel spacings. The contrast can be determined from the minimum and maximum of these light distributions. In the vertical direction one must also be concerned that sequential on/on pixels give a smooth light-output representation. The spot size can be too small so that individual scan lines are undesirably resolved. It has been stated[1] that there is an optimum spot-size compromise for minimum modulation with on/on pixels and maximum modulation for alternating on/off pixels. In this paper, the recommended 5-percent spot size is 2.2 times the pixel spacing, which gives a minimum-to-maximum intensity ratio of 0.96 for on/on pixels and 0.17 for on/off pixels. In the horizontal direction, because of the beam motion during the on time of the pixel, the spot size must be smaller to get a corresponding contrast for alternating on/off pixels. For the same 0.17 minimum-to-maximum ratio, the 5-percent spot size in the horizontal direction can only be 1.6 times the pixel spacing. Under these conditions, and assuming no ambient reflection, the contrast for on/off pixels is a respectable 6 to 1. A limited bandwidth monitor would further degrade resolution in the horizontal direction.

## Effects of self-convergence on spot shape

As has already happened in the consumer market, we expect in the future that the vast majority of the color display tubes will use in-line guns. The lower cost and the better stability of the convergence as a result of the elimination of the dynamic convergence circuits are the reasons in-line-gun tubes will dominate. The same deflection-yoke fields that are required to obtain the self-convergence of the three electron beams also distort the shape of the individual electron beams. The main part (or core) of the electron beam is underfocused at the screen due primarily to the effects of space charge. Spherical aberration of the main focusing lens causes overfocus of the outermost rays, which may then show up as a flare or haze around the main core of the spot. The self-converging yoke field inherently underfocuses the beams in a horizontal direction and overfocuses them in a vertical direction. The yoke field has no effect on the beams in the center of the screen since there is no deflection, but as the beams are deflected, it tends to increase the size of the underfocused core in the horizontal direction and decreases the size of the core in a vertical in the corners of the tube, as shown in Fig. 7. It also tends to accentuate the flare or overfocused beams in a vertical direction and eliminate them in the horizontal direction where they become buried inside the core. This increase in the spot size in the horizontal direction is opposite to what is desired, as was shown in the previous section.

To correct for these self-converging yoke effects, RCA display tubes use an asymmetrical beam-forming region similar to that described in reference 2. This region

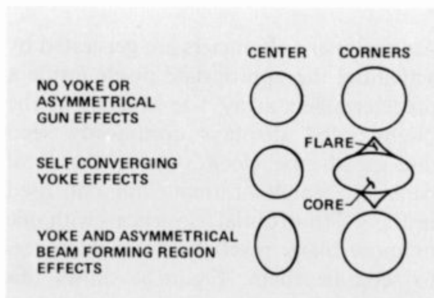



**Fig. 7. The effects of the self-converging yoke field and the asymmetrical beam-forming region on spot shape.**

uses a slot on the #2 grid to shift the horizontal and vertical crossovers such that the beams tend to be overconverged in a horizontal direction and underconverged in a vertical direction. These effects are opposite to those of the self-converging yoke field so that the net result is a round spot in the corners of the tube. While the yoke effects reduce to zero in the center of the tube, the effects of the asymmetrical beam-forming region still exist there. These effects make the spot smaller in the horizontal direction and larger in the vertical direction, which is the preferred direction because of the different pixel representations. The vertical to horizontal ratio of the spot size in the tube center for the RCA display tube is 1.4, which is very close to the desired 2.2/1.6 for equal contrast of on/off pixels in the horizontal and vertical directions.

## Screen structure

One of the most common (and erroneous) ways of expressing the resolution of shadow-mask color-display tubes is to describe the screen structure as if each phosphor dot was individually addressable. Just because there may be 720 dot trios across the screen does not mean that the tube can resolve 720 pixels. Resolution is primarily determined by the spot size and the contrast ratio of on/off pixels that one is willing to accept. To perceive the information on the screen, the eye must be able to determine the location of the center of the electron beam that conveys the information. Each beam must light enough dots that the eye can readily interpret this beam location. Practically, this means that the screen structure should be small enough that at least three columns (or rows) of dots should always be lit by one pixel of information. They will be lit with different intensities due to the electron-beam density profile, and the eye will interpret this as a center of brightness of the beam. To get this required density of screen elements in a practical manner, high-resolution display tubes use a dot screen with fine spacing. Figure 8 shows the structure of this screen compared to a consumer tube with a line screen. Figure 9 shows the single color-dot elements lit by one-pixel-wide horizontal and vertical lines on the high-resolution dot tube with the same electron-beam sizes. With only a single phosphor line being lit on the consumer tube, the actual electron beam can move a significant distance before the eye detects any shift in location—only a change in intensity of the phosphor line is observed. This makes the characters very difficult to determine as the photographs in Fig. 10 show.

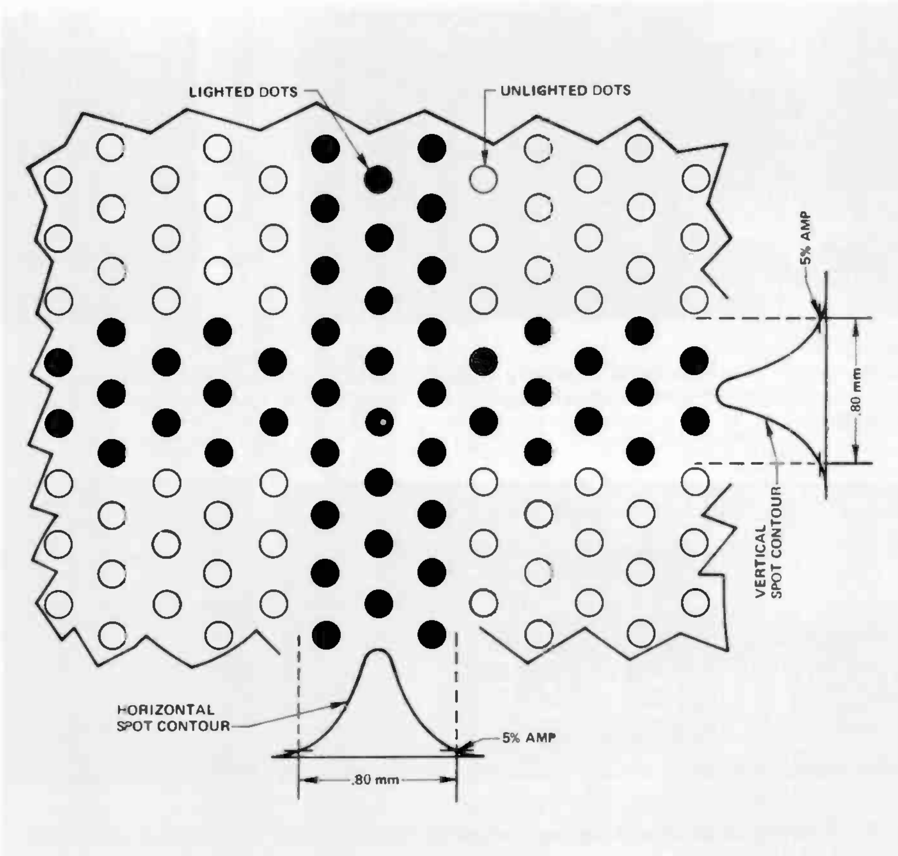



**Fig. 9. Illustration of dots lighted by single-pixel horizontal and vertical lines.** Only one color shown.

Almost coincidentally, in a properly designed system, the number of pixels that can be displayed is roughly equivalent to the number of dot trios across the screen. This is because the spot size is generally two to three times the pixel spacing and there should be three dot trios lit per spot size. An increase in the number of trios by making the dot spacings smaller will not increase the tube resolution without a corresponding reduction in the electron-gun spot size.

## Convergence

To make any color other than the three primaries—red, green, or blue—at least two electron guns must be on simultaneously. The resolution of this resultant composite spot is a function of the accuracy of the alignment between the energized guns. For white, all three guns must be superimposed on each other at the screen. Misconvergence of these beams creates a larger composite spot, thus degrading the resolution, and also creates an

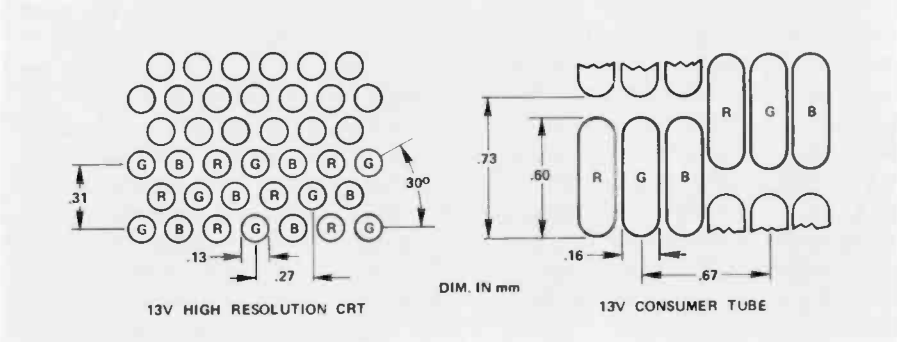



**Fig. 8. Illuminated screen structure.**

Fig. 10. **Actual photographs of displayed alphanumeric characters (one gun on). (a)** RCA 13V high-resolution display tube with dot screen; and **(b)** RCA 13V consumer tube with line screen.

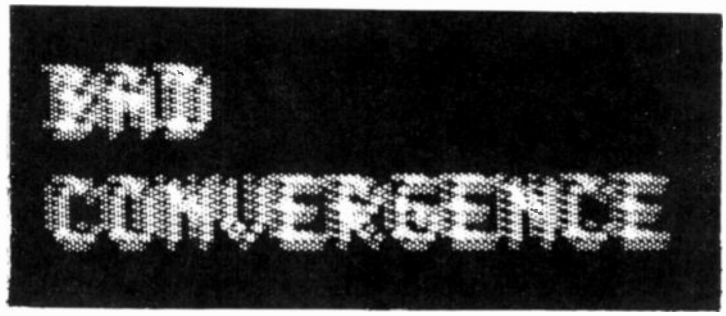


Fig. 11. **Example of good and bad convergence.** RCA 13V high-resolution display tube. All three guns on.

annoying color fringing if the beams are far enough apart that the eye resolves the individual primary colors. The allowable misconvergence for high-resolution data-display systems is much less than what is tolerable for consumer product. For data display, the convergence certainly must be less than the electron-beam diameter and probably should be less than half the beam diameter. Figure 11 shows the effects of good and poor convergence on resolution.

## *Contrast enhancement*

In addition to resolution, another important ergonomic factor is contrast. The ability to distinguish information is affected not only by the contrast of on/off pixels, but by the contrast between the computer-generated information and extraneous light. Since contrast affects the accuracy and fatigue level of the display-unit operator, it is treated with more importance than in ordinary television viewing.

Contrast may be described as the ratio between the desired information and unwanted light from outside sources reflecting from the screen. There are several ways to increase contrast—some the user can control and others the tube designer must correct. The most obvious solution is to reduce the intensity of the outside light source or move it so it does not reflect from the screen. Proper work-station design can help immensely with this problem. Another way to improve contrast is to simply increase the beam current of the cathode-ray tube; however, this has a penalty in increased spot size, which affects resolution.

The tube designer may use a number of contrast-improving techniques that may be combined in several ways depending on the application. The display tube can be designed so that the screen reflectance is kept to a minimum. This is typically done by the use of a black matrix screen and pigmented phosphors. The matrix screen reduces the reflectivity by surrounding each active phosphor dot with graphite. This eliminates the reflection from the unlit tolerance portion of the phosphor dot. The pigmented phosphor is a special phosphor that is tinted with its own color. This means that only the color of the phosphor dot is reflected while all other colors are absorbed. This principle of reducing the screen reflectance is very efficient because it does not reduce the lighted phosphor information as other methods do.[3]

A common way to increase contrast is with the use of a neutral-density filter placed in front of the cathode-ray tube. This can be done by tinting the front portion of the tube itself, or by bonding a separate tinted panel to the tube. It can also be done by merely placing a tinted panel in front of the tube, although this causes some light loss due to the second glass-to-air surface.

In Fig. 12, it can be seen that the filter increases the contrast ratio but also reduces the light output from the cathode-ray tube. Increases in the beam current of the cathode-ray tube to achieve the same light output will degrade the electron-beam spot size. A typical example using a 62-percent neutral-density filter will improve the contrast ratio by 2.6 times, while reducing the light output by 40 percent. In order to regain the same light output, the beam current would have to be increased 60 percent, and the spot size would be degraded by approximately 20 percent.

A better way to increase contrast is to reduce only the reflected light by interposing selective filters. These include polarizing filters, direction-sensitive filters, and the quarter-wavelength interference filter. This latter device is used extensively and can be bonded directly to the display-tube face. In principle, it simply combines the reflected light from one side of its special surface with the reflection from the other side so that the two reflections cancel. This filter can reduce the reflected light approximately ten times with a corresponding improvement in contrast.

### *Annoying reflections*

Just as the general amount of reflected light reduces contrast and interferes with the displayed information, so does the quality of the reflected light. If there is a reflection of a small, sharp image on the screen, it will distract the operator in the following manner:

1. If the reflection is bright, it may interfere with the operator's ability to read the desired information on the screen at that point.
2. If the reflected image is sharp and interesting, it could lead to errors caused by the operator trying to focus on the distant object rather than the desired information.

These annoying distracting reflections can lead to errors and eye fatigue. There are two general methods to reduce these reflections. The first is to reduce the amount of reflection by means of an interference filter. This method is costly but reduces the amount of reflected light so that the distractions, while still sharp, are much less noticeable. Figure 13 shows examples of treated and untreated tubes. One problem with the interference action is that it depends on matching the index of refraction from glass to air. The fingerprint oil destroys this match and produces visible smudges that must be cleaned.

A second method is to produce on the surface of the display tube a fine wavy finish that diffuses the reflection so that it is no longer distracting to the operator (Fig. 14). Although less costly than the interference filter, it has two problems. The total amount of reflected light is still the same as a polished tube face, so there still may be a bright diffuse reflection that can obscure some display data. The bigger problem is optimizing the amount of waviness to diffuse the reflection while maintaining sharp focus of the displayed information. The wavy surface acts like a lens in the operator's optical system that blurs faraway objects much more than close objects. Since most annoying reflections originate at large distances from the surface and the displayed information is very close to the surface (usually 12 mm), the waviness is chosen so that resolution is not degraded noticeably.

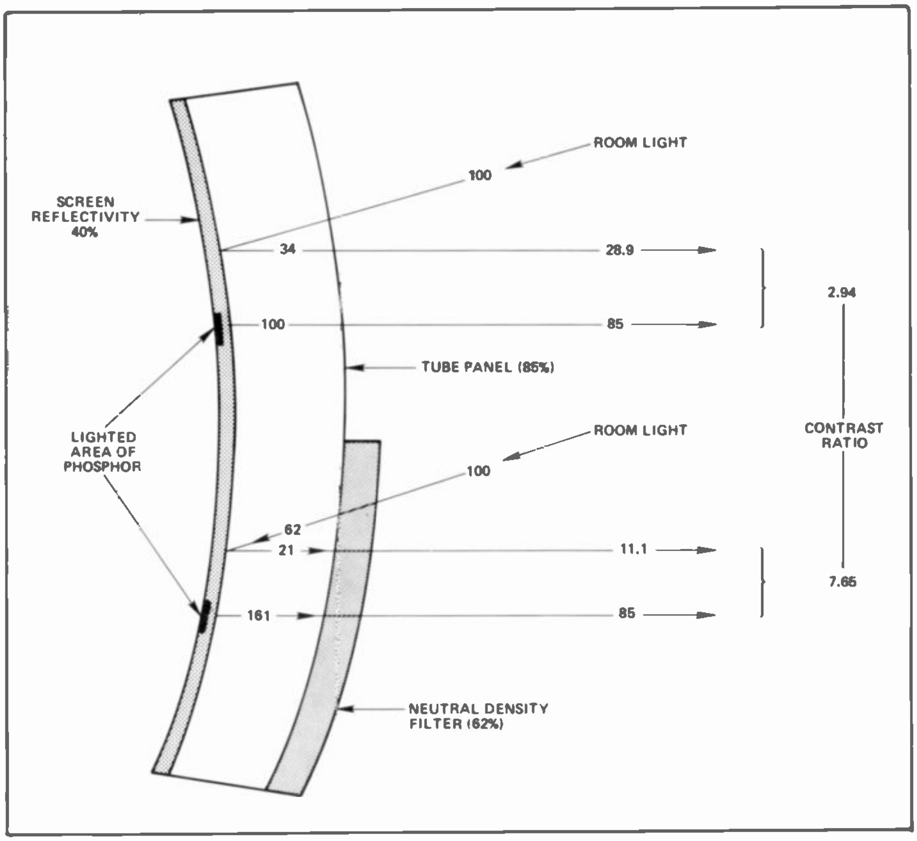



**Fig. 12. Filter effect on contrast ratio.**

### *Flicker prevention*

Another distraction that may occur in video-display units is the flicker caused by slow refresh rates of displayed information. It has been found that flicker becomes objectionable as the refresh rate goes below 60 Hz. Our motion picture and television experience has brought us to the point that we expect information change to occur at least 24 times per second for motion continuity. At the same time, our illumination and television sensitivity to flicker has dictated a 60-times-per-second refresh rate (using U.S. illumination standards). Television has solved this problem with a 30-times-per-second refresh rate in an interlaced system using medium short-persistence phosphors.

In a data-display system where the operator can resolve each horizontal scan line (vertical pixel), a television-interlaced system may be unacceptable because the pixel would be refreshed at a 30-Hz rate, which is annoying. Therefore, the flicker problem has to be solved.

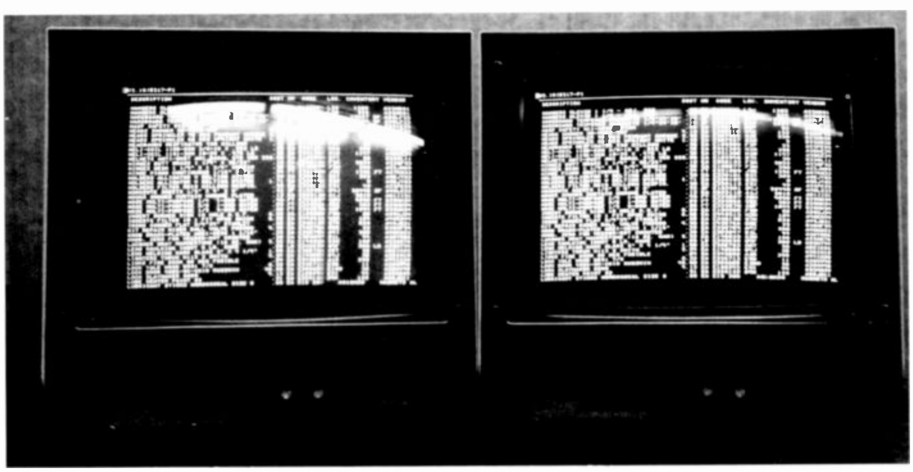


**Fig. 13. Comparison of tubes without treatment (left) and with anti-reflection treatment (right).**

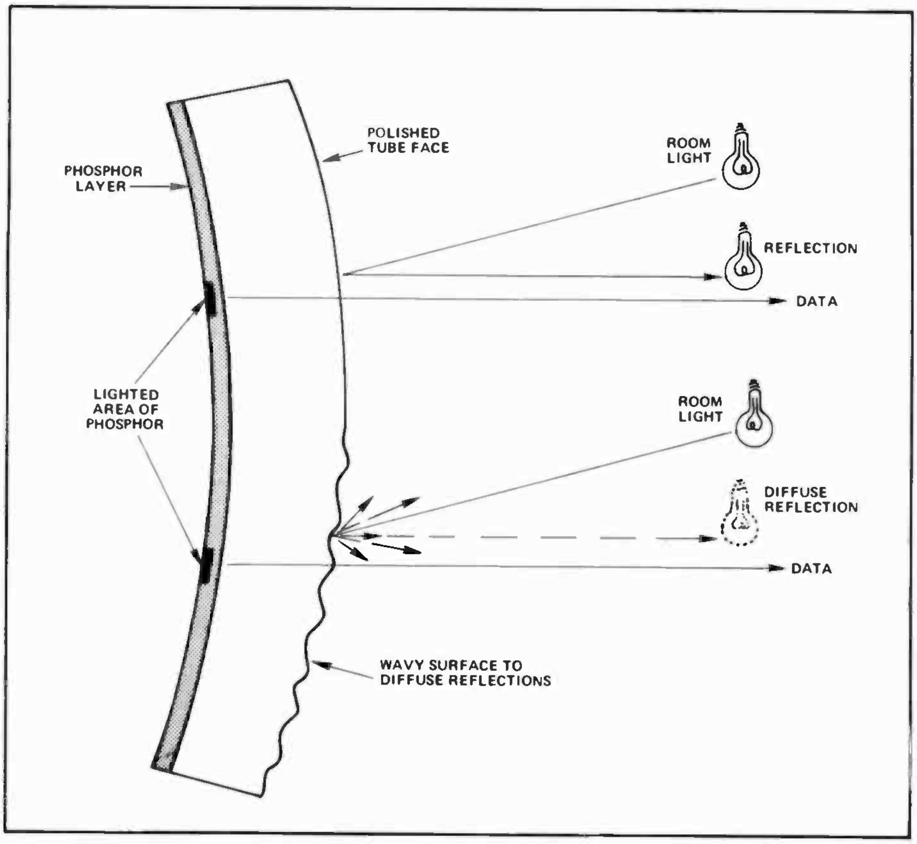



**Fig. 14. Wavy tube surface diffuses reflections.**

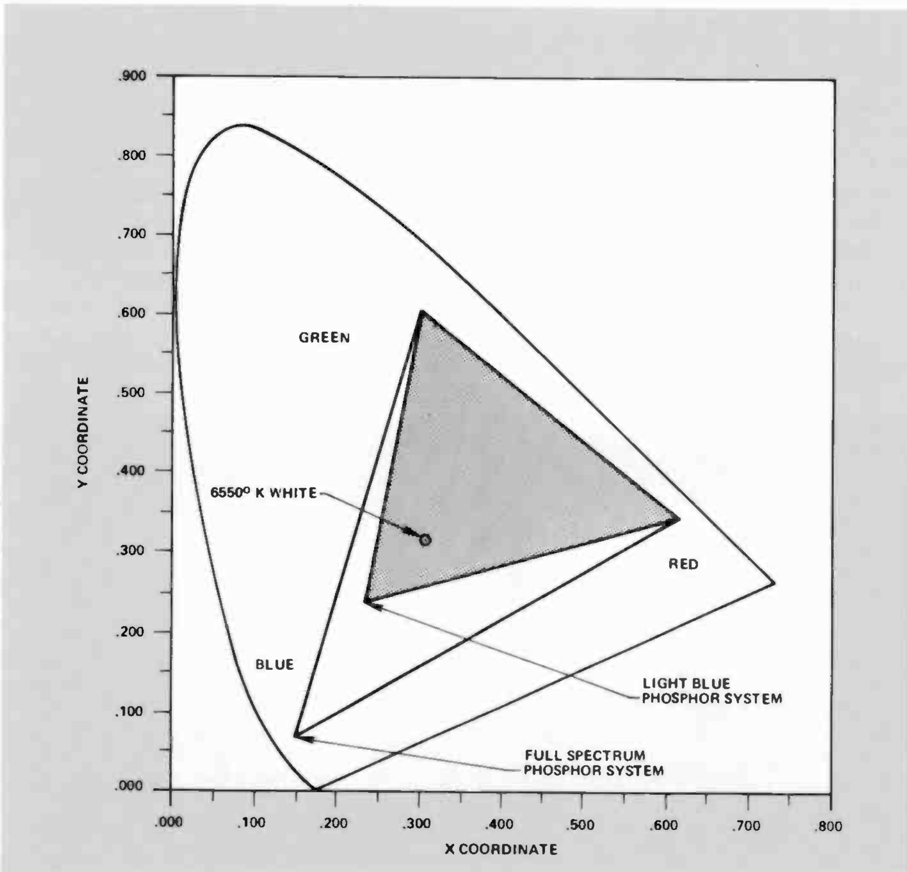



**Fig. 15. The chromaticity areas of two display phosphor systems.**

Two methods are used to eliminate flicker. One, of course, is to speed up the refresh rate of the display-tube driving circuitry so that the 60-Hz pixel-refresh rate is achieved. This is done in some cases using a 60-Hz noninterlaced mode that produces 80 characters of data in 24 rows. This mode uses TV scan frequencies but requires 10-MHz data bandwidth. Additional rows of data require higher scan rates with higher associated costs.

Another method is to use a lower pixel-refresh rate, which means lower horizontal and video circuit costs, in conjunction with long-persistence phosphors. The longer the persistence, the more time it takes for the lighted phosphor element to fade before it is energized again by the electron beam. Typical green persistence times are 150 $\mu s$ (short persistence) and 150 ms (long persistence). The long persistence reduces flicker but causes smearing problems when text is scrolled or images are moved on the screen. In addition, these phosphors have significantly reduced light output, which means a spot-size degradation for equivalent brightness.

## *Color perception*

The full-color display is somewhat like color television but information display has some special requirements. There are two general needs satisfied by color—separating concepts and highlighting specific instructions. Two phosphor systems have been developed with different chromaticities to meet these needs.

A full-spectrum color-phosphor system similar to television is used for graphics and general-display presentations. This phosphor system is useful where the widest possible variety of colors must be displayed. Figure 15 shows the difference between this system and a second, light-blue system developed for text readability.

The color used to highlight specific text data must be highly visible in order to reduce operator error. The standard blue chromaticity is so far at the end of visual sensitivity that it is very difficult to read alphanumeric information produced by this phosphor. Because of this, the standard blue phosphor system is often operated with both the blue and green guns turned on. This desaturated color is easier to see and still offers a different color from green. The light-blue chromaticity system avoids the convergence problem and provides very legible alphanumerics, while still giving a useable color area for graphic displays.

## RCA product description

Table I lists the features of the RCA 13V 90° data-display tube. This tube has been designed to fit the needs of the office data-display market and incorporates a high-resolution screen capable of resolving 80 characters per line. There are two phosphor systems: a low-reflectance pigmented phosphor system in standard chromaticity, and a desaturated blue system for improved readability. Both systems incorporate a matrix screen to improve contrast.

An in-line gun and self-converging yoke system is provided with the yoke preset and permanently attached to the tube. This provides a self-contained color tube with the installation simplicity of a monochrome tube. The high-resolution gun incorporates asymmetrical optics to provide optimum trade-off between center and edge spot size, in addition to providing the correct spot shape to maximize pixel resolution. The drive characteristics have been optimized to reduce the gain-bandwidth requirements.[4] At 100-volt cutoff, 40 volts of video drive provides adequate brightness.

An internal magnetic shield is incorporated in this tube to simplify the monitor and terminal design. This internal shield system, coupled with proper degaussing coils, provides for simplicity and portability needed in small desk-top display units.

The tube is provided with integral implosion protection and convenient mounting lugs so that the tube may be installed in the customer's monitor with minimal problems.

**Table I. Product characteristics of the RCA 13V-90 degree data display tube.**

| | |
|---|---|
| *Self-Converging In-Line System* | |
| Preset convergence, tube-yoke system | |
| No convergence circuits needed | |
| Stable convergence over tube life | |
| Several yoke impedances available | |
| *Fine Array Dot Matrix Screen* | |
| Trio spacing of 0.31 mm | |
| High-contrast black matrix | |
| Two phosphor systems: | |
| High-brightness, light-blue phosphor | |
| Low-reflectance, pigmented phosphor | |
| *Precision In-Line Gun* | |
| High-resolution, high-focus potential | |
| Electron-spot shape optimized for pixel oriented presentations | |
| Asymmetrical optics for best center-corner resolution | |
| Focus optimized for 40-volt drive | |
| *Internal Magnetic Shield* | |
| *Integral Mounting Lugs* | |
| *Typical Operating Voltages* | |
| Anode: | 25 KV |
| Focus: | 7 KV |
| Grid number 2: | 550 V |
| Cut-off: | 100 V |
| Video drive: | 40 V |
| Heater: | 6.3 V |
| *Physical Size* | |
| Screen dimensions | |
| Diagonal: | 13.2" (335 mm) |
| Horizontal: | 11.1" (282 mm) |
| Vertical: | 8.3" (212 mm) |
| Area: | 90 sq. in. (581 sq. cm.) |
| Length: | 13.9" (354 mm) |
| Weight: | 13 lb. (5.9 kg.) |

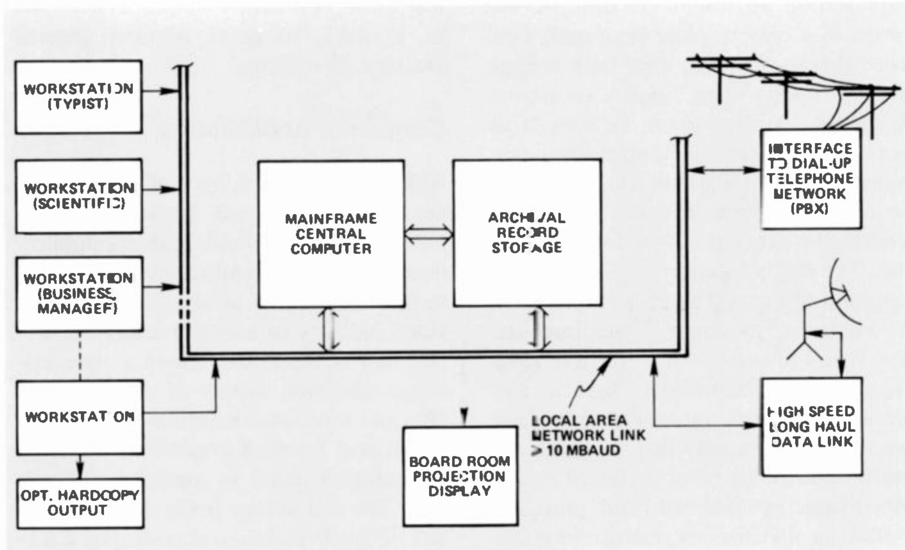



**Fig. 16. Conceptual diagram of electronic office of the future.**

## The future of data displays

As the "window into the computer," the data display will become the heart of the electronic office of the future. A conceptual diagram of such a system is shown in Fig. 16. Each information worker, from the clerk up to the executive, will have a

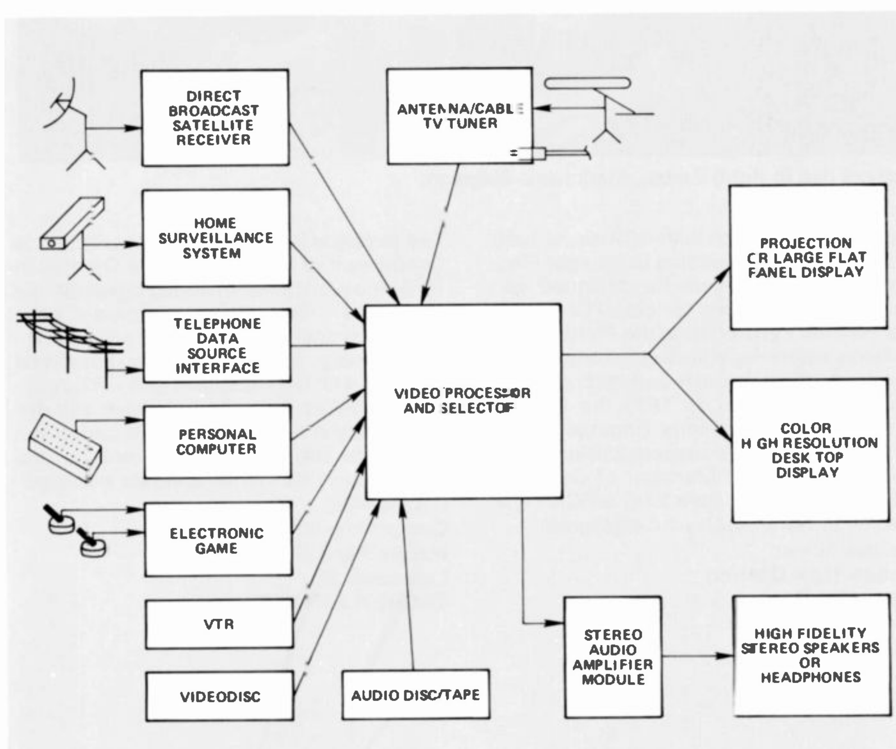



**Fig. 17. Conceptual block diagram of modular home-entertainment and information audio-visual system.**

work station on his or her desk. It will consist of a data display, keyboard, local processing capabilities, local bulk storage such as "floppy disks," and a communications link to other work stations of its kind and the business's central computer. Connections to long-haul data links and the dial-up telephone network will also be available for communications with remote sites. The display stations will be used for communications between workers, such as "electronic messaging" and mail service. It will also be used to retrieve long-term database information, such as current and past operating results for business reports. The data may then be processed locally, put in the form preferred by the information professional, and presented to others in alphanumeric, tabular, or graphical form. Hard-copy output devices will be available to make portable records available as required.

### Consumer applications

Although the technology of high-resolution data displays will be developed initially for scientific and business applications, the same technology may be applied to future consumer products. Many in the video industry foresee a trend in the second half of the 1980s toward a high-definition television system of perhaps 1050 lines and wide video bandwidth. The often-stated goal for such a system is a picture presentation equal in quality to 35-mm film. The technology being developed today for high-resolution data-display CRTs would be much the same as that required later for an HDTV system. The display portion of such a system would, in fact, be a general-purpose module that could be used in the home for entertainment, or as the display portion of an in-home work place, an information-access system, or an education and adult-training center. Signal sources could include network broadcasts, videotape recorders, video disc systems, cable TV, and perhaps direct broadcast satellites (Fig. 17). Consumers could buy the modules required for the uses they prefer and plug them in, to make their own custom-designed modular system. This modular concept may well represent the next major home-entertainment product trend.

## References


1. P.G.J. Barten, "Optical Performance of CRT Displays," *Proceedings of Euro Display*, pp. 160-165 (September 16-18, 1981).
2. H.Y. Chen and R.H. Hughes, "A High Performance Color CRT Gun With An Asymmetrical Beam Forming Region," IEEE Chicago Spring Conference on Consumer Electronics, Chicago, Ill. (1980).
3. S.S. Trond, "Filter Phosphors," *RCA Engineer*, Vol. No. 2 (August/September 1979).
4. H.Y. Chen, "An In-line Gun for High Resolution Color Display," *Proceedings of SID* (May, 1982).


**Authors (left to right) Barbin, Marks and Simpson.**


**Bob Barbin** has been with RCA since 1960. Until 1970, he was with the Consumer Electronics Division, where he designed various deflection yokes for color-TV receivers. He then transferred to the Picture Tube Division where he was instrumental in the development of the self-converging precision in-line system. In 1975, he became Manager of Applications Engineering for PTD with worldwide responsibilities. Since 1980, he has been Manager of Data Display Tubes, responsible for the RCA high-resolution color-display-tube program.
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**Ted Simpson** joined the Color Applications Department of the Picture Tube Division in 1965. His work there included development of circuits and systems to operate non-shadow mask displays. Later projects included design of microprocessor-based test systems with CRT displays and CRT operator interfaces. Based on his user and design experience with CRTs, he joined the PTD Data Display Group, where he has responsibility for market analysis and product planning.
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**Bruce Marks** joined RCA in 1973 and has been active in electron-gun development, especially in high-resolution optics design. In 1978, he assumed responsibility for electron-gun design where the wide-angle-deflection electron optics and the display optics were developed. Since 1981, he has been Manager, Product Development, Data Display Tubes.
Contact him at:
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**Lancaster, Pa.**
**TACNET: 227-3357**

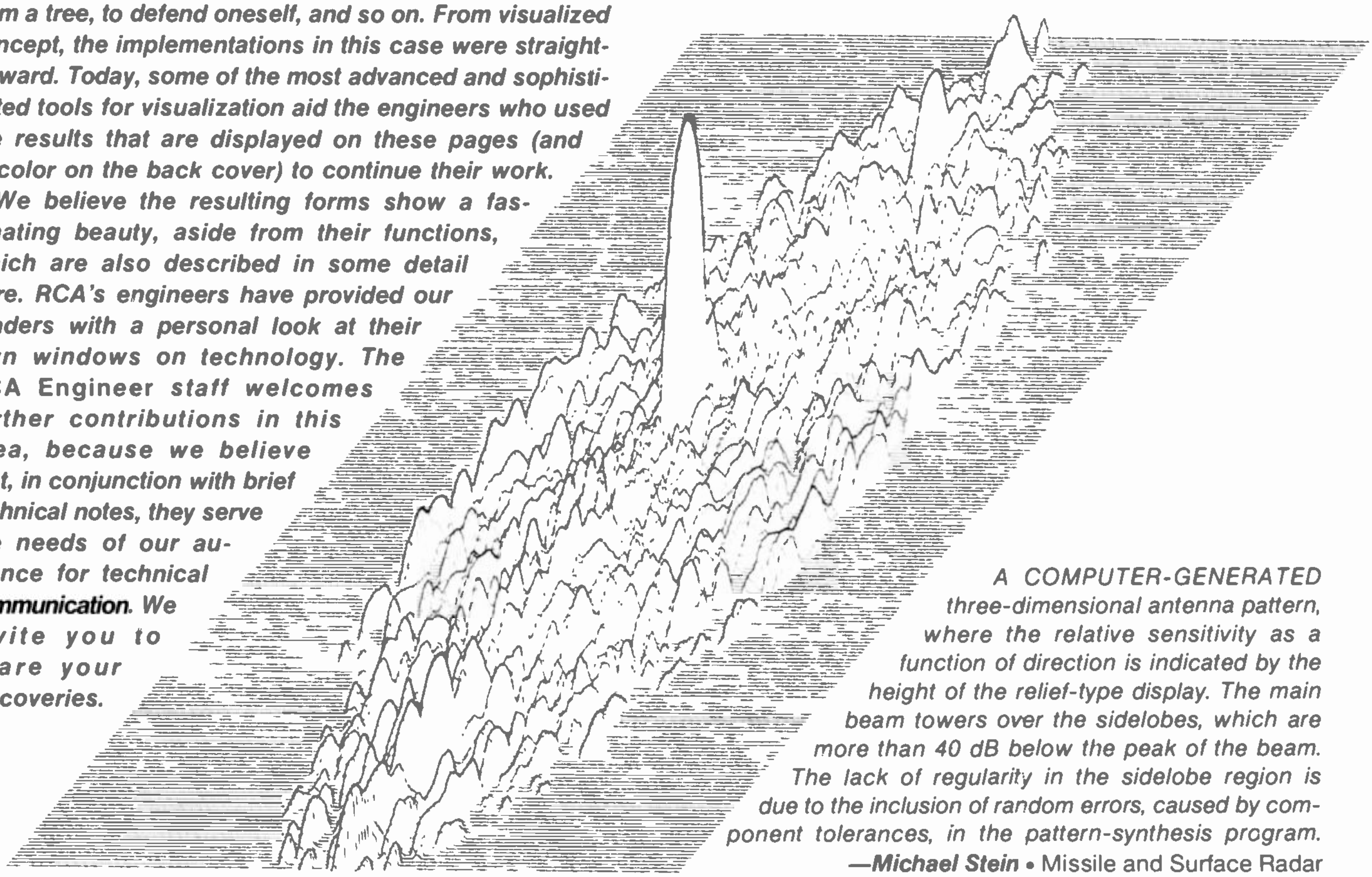
# Engineering Form and Function

## Windows on RCA Technology

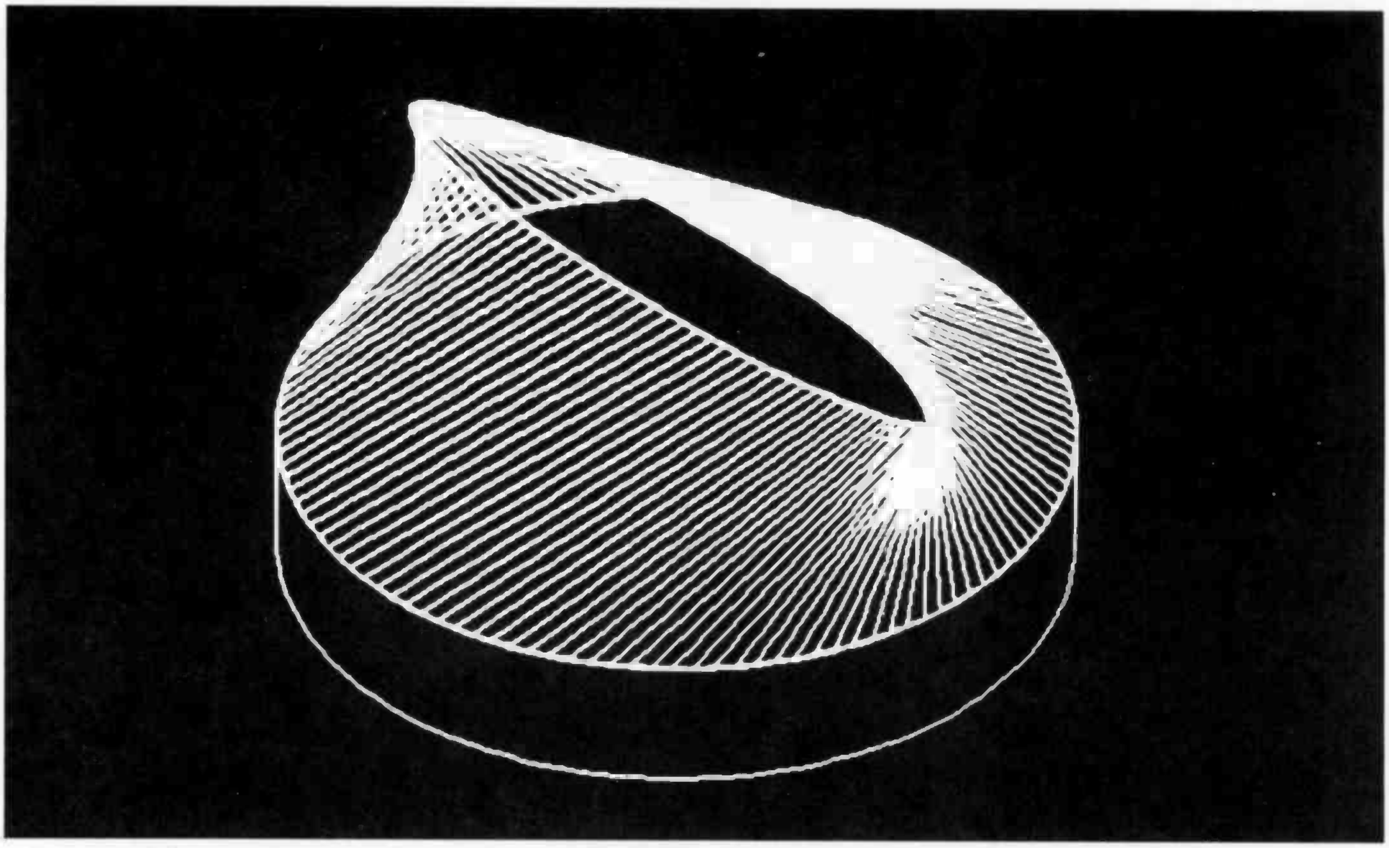
*Stop for a moment and consider how many procedures, methods, and tools allow you each day to see the unseen. Our impulses to explore the other side of the mountain, to discover, and to create—all relate critically to our ability to visualize. At the dawn of man, someone with "engineering talent" managed to visualize that a stick could be used as an extension of man's hand, to take fruit from a tree, to defend oneself, and so on. From visualized concept, the implementations in this case were straightforward. Today, some of the most advanced and sophisticated tools for visualization aid the engineers who used the results that are displayed on these pages (and in color on the back cover) to continue their work.*

*We believe the resulting forms show a fascinating beauty, aside from their functions, which are also described in some detail here. RCA's engineers have provided our readers with a personal look at their own windows on technology. The RCA Engineer staff welcomes further contributions in this area, because we believe that, in conjunction with brief technical notes, they serve the needs of our audience for technical communication. We invite you to share your discoveries.*

*Many of the images in this section are shown in color on the back cover of this issue.*

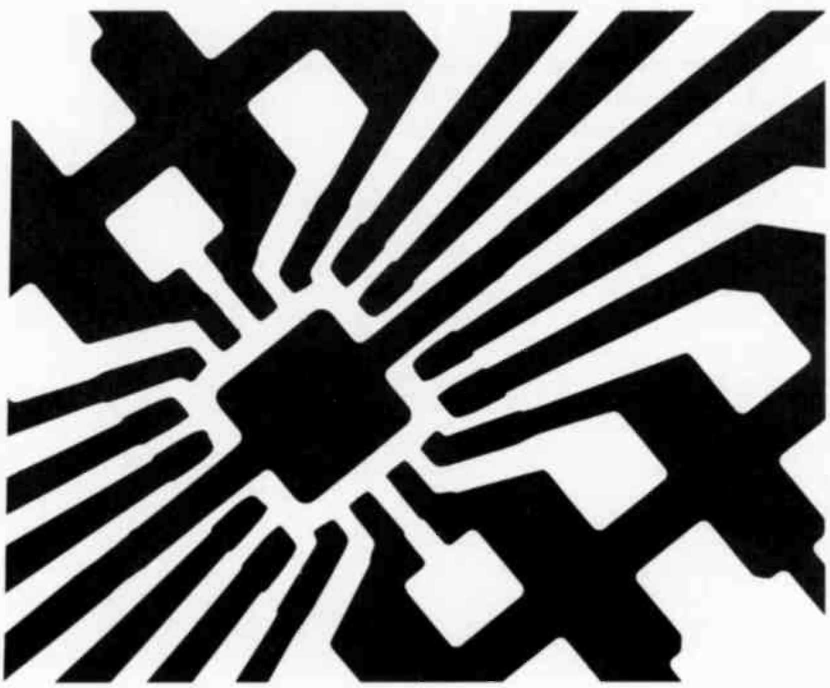


*A COMPUTER-GENERATED three-dimensional antenna pattern, where the relative sensitivity as a function of direction is indicated by the height of the relief-type display. The main beam towers over the sidelobes, which are more than 40 dB below the peak of the beam. The lack of regularity in the sidelobe region is due to the inclusion of random errors, caused by component tolerances, in the pattern-synthesis program.* **—Michael Stein** • Missile and Surface Radar



*THIS EXPERIMENTAL VIDEODISC spindle was designed for possible use in an advanced development effort, in an attempt to solve two problems. When a caddy is inserted into the player, the spindle must move out of the way—possibly the caddy could push the spindle down. Once the disc is free of the caddy, the spindle must center the disc. A cone is easier to make but it is not the best shape since the optimum contact angles for the two functions are not the same. The design was done on the Computervision computer-aided design system at the Labs. A tool path was then developed and transferred automatically to a numerically controlled milling machine, which cut the spindle from a plastic cylinder.*

***—Keith Reid-Green***
RCA Laboratories

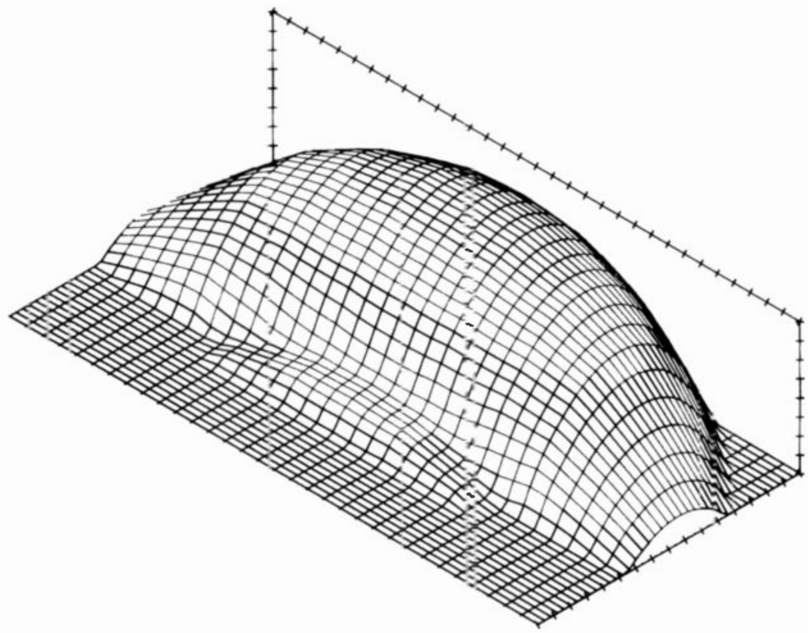


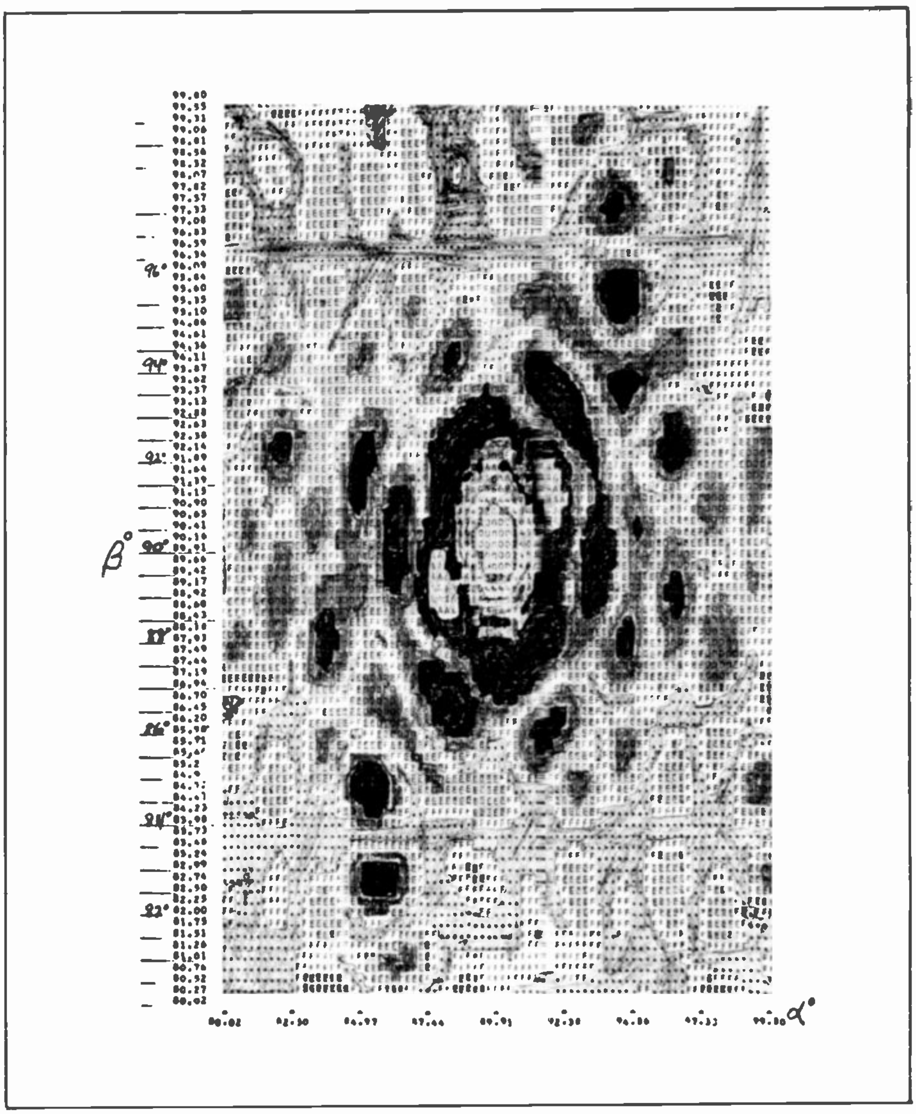
*PICTORIALLY, THIS REPRESENTS the center portion of a lead frame for a DIP (dual-in-line plastic package for IC device chips). The black square is the mounting pad for the device chip. Surrounding the mounting pad are black areas that are the bonding pads for wire connections, which lead from the chip to the outside leads of the package. This particular lead frame has sixteen lead connections to the "outside world."*

***—Al Stoeckert***
Solid State Division

*THIS IS A three-dimensional color display of an antenna pattern (see back cover of this issue). The desired task was to evaluate the antenna performance as installed in an air vehicle. This task was accomplished in the following manner. Two principal plane cuts of the system antenna were taken using an analog antenna-range measurement system. The data was then digitized using a computer and a plotter. This data was then rotated to represent the actual installation in the air vehicle; and the resultant antenna pattern in aircraft coordinates was computed, tabulated, and plotted in three dimensions.*

***—Gerard Des Autels***
Automated Systems



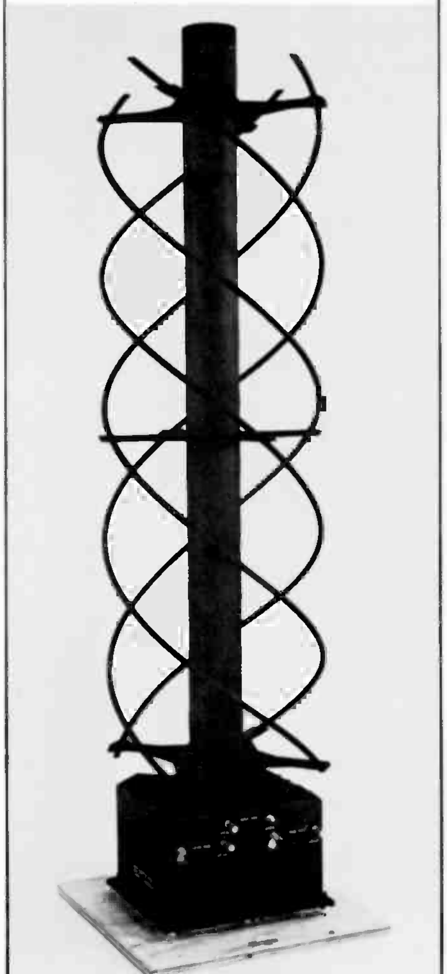


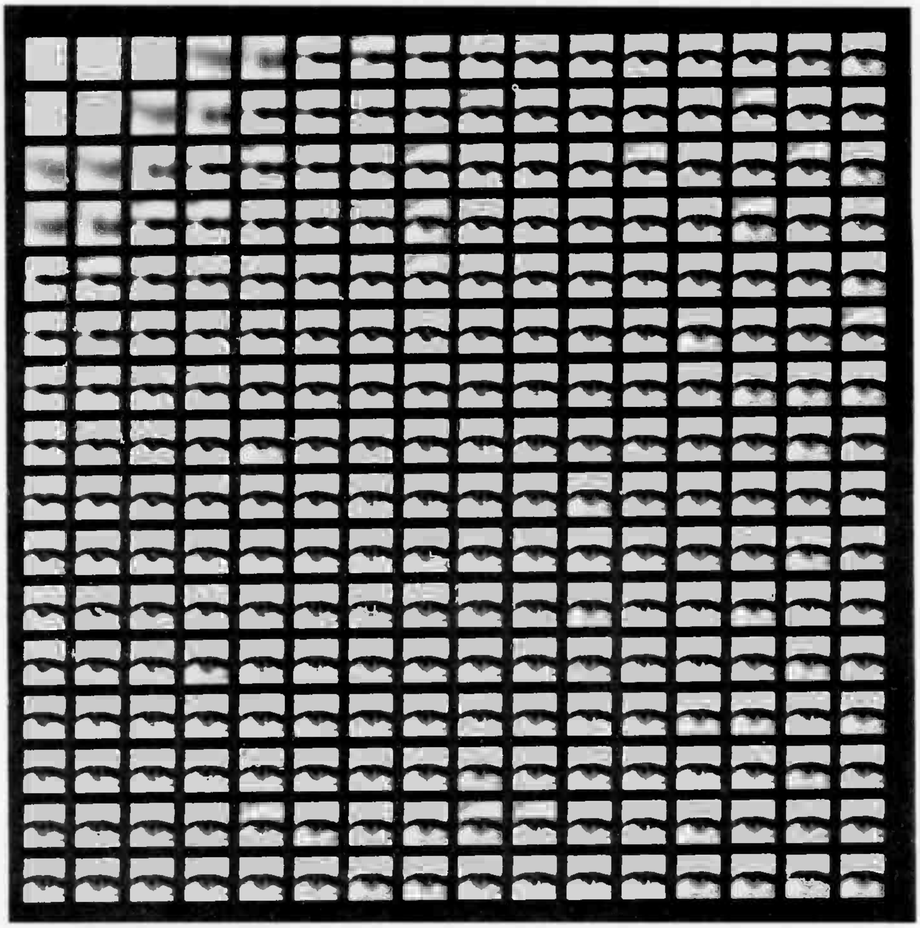

*THE PICTURE REPRESENTS a computerized plot of an antenna test pattern with the inked-in colors (see back cover) used for emphasis and recognition of the sidelobe power-level contours around the main beam. The original computer printout with numbers and letters makes it difficult to interpret and visualize the antenna pattern. Use of color for each relative power level makes it easier to "see" the pattern.*

***—Milt Kant***
Missile and Surface Radar

*THE SEARCH-AND-RESCUE receive antenna (SRA) on Tiros-N can operate at three widely separated emergency frequencies. Its unitized design negates the need for three separate antennas that are normally required. The SRA is a circularly polarized quadrifilar-type antenna. It uses a pair of large tubular helices as the outer structure and a pair of ribbon helices on the inner cylinder, which also serves as the main supporting member. The outer elements operate at the two lower frequencies and the inner elements operate at the higher frequency. Signal separation and feeding is performed by passive circuitry located in the base. The coverage of this antenna is horizon-to-horizon over the entire earth's surface as viewed from the low-orbiting Tiros-N satellite.*

***—George Rosol***
Astro-Electronics





*THESE TWO FIGURES (one above, and one on the right) illustrate graphically why the two-dimensional cosine-transform technique is effective for achieving bandwidth reduction in imagery.*

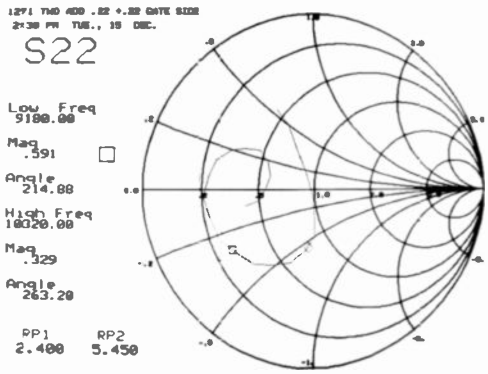
*The figure above shows the image buildup obtained by the addition of successive two-dimensional cosine-transform components in the sequence shown below. Each eye picture is 16 X 16 picture elements in size.*

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1 | 2 | 4 | . | . | . | . | 241 |
| 3 | 5 | . | . | . | . | . | . |
| 6 | . | . | . | . | . | . | . |
| . | . | . | . | . | . | . | . |
| . | . | . | . | . | . | . | . |
| . | . | . | . | . | . | . | . |
| 136 | . | . | . | . | . | . | 256 |

*The figure on the right shows the 256 individual two-dimensional cosine components that are successively added with the proper weighting factor to achieve the pictures in the figure above. Each cosine basis function is also sampled on a 16 X 16 grid. Picture 1 represents the dc term only, while picture 256 represents the summation of all 256 properly weighted frequency terms.*

*It is readily apparent that a rendition of the original image adequate for many applications is obtained using a fairly small subset of the 256 components. This then is the reason that transform encoding works. The image energy is compressed toward the low-frequency corner of the two-dimensional frequency space, which permits it to be represented by fewer frequency terms than there are picture elements in the original image.*

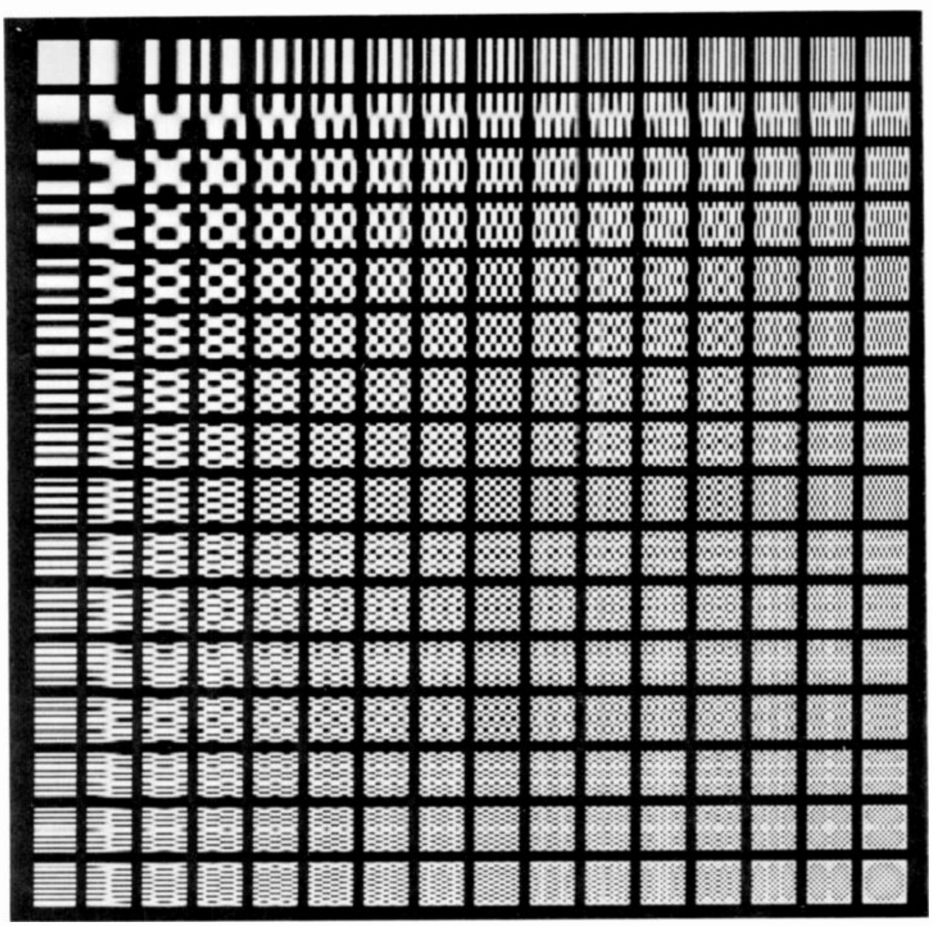
***—Bernie Schaming***
Advanced Technology Laboratories




*THIS SMITH CHART is a popular method of displaying the input or output immittance properties of a microwave network. In this case, it represents a single type of graphical data provided by an automated phase-locked network analyzer system. This particular system, is used for characterizing a variety of microwave components and devices, for development as well as acceptance testing purposes. It consists of a network analyzer under the control of a software package named PLANA/1000, which runs on a minicomputer system. It can measure the complex electrical properties of a network over the frequency band from 0.1 to 20.0 GHz with automatic error correction tc compensate for hardware deficiencies.*

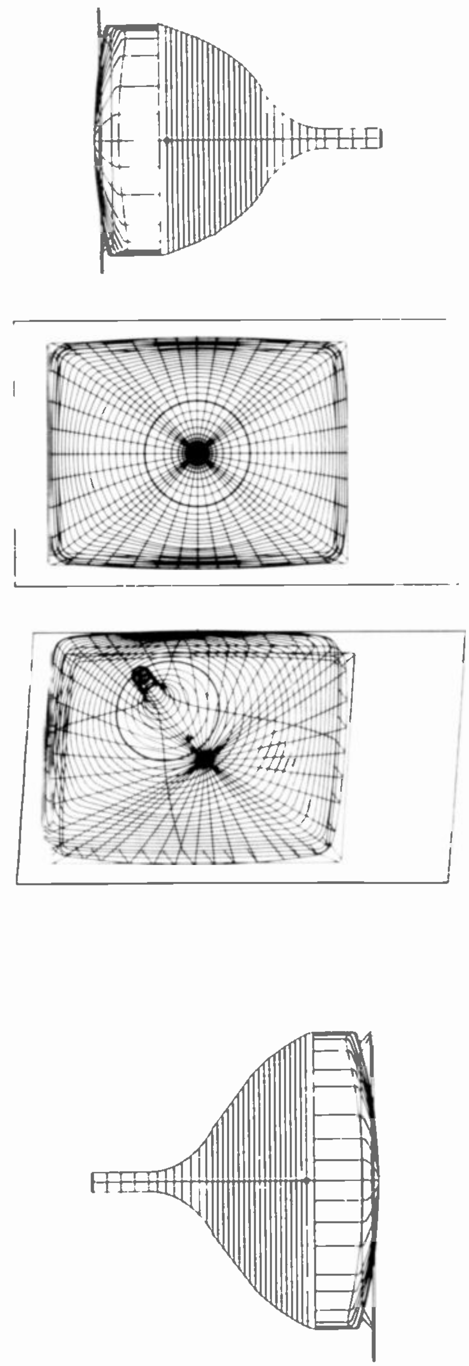
*The data shown (see back cover for color) was generated by a 512 × 768 × 4 color display system that includes an interactive digital tablet. This data represents the output circuit scattering or S22 from a microwave field effect transistor. The information displayed to the left of the graph shows the reference planes, which are indicative of the physical point from which the data is viewed, and three pieces of information relating to the markers. The two markers on the graph are drawn as a square and as a rhombus and are representative of two different frequency points.*

***—Barry Perlman, David Rhodes, Jonathon Schepps***
RCA Laboratories



*FOUR VIEWS OF a picture tube and mask modeled on a Computervision computer-aided design system at the David Sarnoff Research Center by Vincent Ruggeri and Walter Feick, as part of a project proposal for a television set that can be assembled automatically.*

***—Keith Reid-Green***
RCA Laboratories



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# Long-wavelength semiconductor diode lasers for optical communications

*What makes diode lasers that emit longer wavelengths so special? This tutorial tells how they're made and gives their operating principles and performance characteristics.*

**Abstract:** *Quaternary alloys of semiconducting III-V compounds, currently being researched at RCA Laboratories, are used to make diode laser devices that emit in the long-wavelength, 1.2- to 1.7-μm spectral region. The benefits that accrue from such lasers are given, together with materials considerations, principles of operation, characteristics, comparisons of LEDs and lasers, and future directions.*

The quest for improvements in communication capacity and speed has led to the use of lasers and optical communications. The purpose of this paper is to describe the principles of operation, the structures, and the operational characteristics of semiconductor laser diodes and optical communications in the 1.2- to 1.7-μm spectral region.[1] Diodes emitting at these longer wavelengths differ from more common diode lasers emitting at 0.820 to 0.880 μm for the following reasons:[2]

*Low fiber attenuation.* Losses as low as 0.5 dB/km at 1.3 μm and 0.2 dB/km at 1.55 μm have been reported with silica fibers.[3] Repeaterless data transmission for over 100 km is thus possible.

*Low fiber dispersion.* Pulse dispersion in silica fibers can be made vanishingly small in the 1.2- to 1.7-μm spectral range. Data rates in the gigahertz range have already been demonstrated with optical fibers. Distance-bandwidth products over 200 GHz-km have been predicted at 1.55 μm.[4]

*Eye safety.* The maximum permissible exposure of the eye to light of wavelength greater than 1.4 μm can be 10,000 times greater than for light of wavelength less than 1.4 μm. Eyesafe rangefinding and training systems are thus possible.[5]

*Atmospheric transparency.* Light near 1.6 μm penetrates smoke and haze better than does light near 0.85 or 1.3 μm.[5] This feature has obvious satellite and military applications.

## Materials considerations

Laser diodes are constructed from semiconductor materials that have direct-energy bandgaps. These materials allow current-carrier transitions from the conduction to the valence band to be made without momentum changes (that is, phonon transport), and therefore they have high radiative recombination efficiencies. The successful tailoring of these devices requires the following:

- A material with the desired emission wavelength (determined by the direct-energy bandgap) that can be the lasing medium;
- A higher-bandgap ($\Delta Eg \geq 0.2$ eV) material for electron-hole confinement, with atomic lattice spacing equal to that of the lasing medium, that can be synthesized together with the lasing medium. The high-bandgap material must also have a lower refractive index ($\Delta n \geq 0.2$) to properly confine the light; and
- A readily available substrate whose lattice spacing is the same as that of the devices which it supports. This avoids the formation of misfit dislocations, which reduce radiative recombination.

Alloys of III-V compounds will meet all of these requirements. In fact, they are the only known compounds from which practical semiconductor injection-laser diodes for the 1.2- to 1.7-μm spectral region have been made. Figure 1 contains a plot[4] of energy bandgap and lattice compounds for the major III-V compounds. This plot greatly aids the selection of materials. Binary alloys are indicated by points. These alloys have fixed lattice parameters and bandgaps. Ternary alloys are denoted by lines between the binaries. Quaternary alloys are denoted by areas bounded by four binary alloys. Quaternary alloys have two degrees of freedom since a range of lattice parameters is available for each bandgap. Conversely, a range of bandgaps is available for each lattice parameter—this is really the attractive feature of the alloy system. The epitaxial methods that are used to deposit the layers are liquid-phase epitaxy[6] (LPE) using liquid indium solution; vapor-phase epitaxy[7] (VPE) using vapors of InCl, GaCl, $AsH_3$, and


Final manuscript received April 8, 1982.
Reprint RE-27-4-5

A version of this article was printed in *Laser Focus* (Advanced Technology Publications), March 1982.

$PH_3$; organometallic chemical vapor deposition[8] (OM-CVD) from organic vapors of the Group III and V elements; and molecular-beam epitaxy (MBE), where the atoms are basically deposited one at a time in high-vacuum systems. To date, LPE has produced the vast majority of commercial devices with the best characteristics, while good progress has also been observed with the VPE technique. The other two methods have so far been confined to the research laboratory although rapid progress is taking place.

Table I shows an interesting comparison of the "best" laser results at 0.85, 1.3, and 1.55 $\mu$m achieved with each of these growth techniques. These numbers were current in mid-1981, but undoubtedly have already been improved upon. Although best results have generally been achieved with the LPE technique, the other three growth techniques are not necessarily inferior. LPE has received the most development. OM-CVD and MBE are the newest techniques; this accounts for the "empty space" in their columns. However, the AlGaAs device results achieved with these two techniques are comparable to those obtained with LPE.

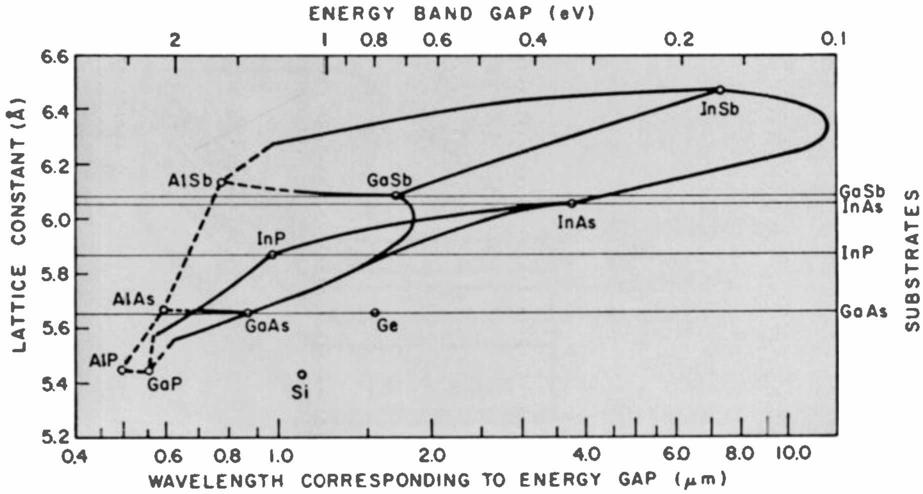



**Fig. 1. Lattice parameter versus energy bandgap (or bandgap wavelength) for III-V compound alloys.**

Similarly, excellent long-wavelength detectors and room-temperature continuous-wave (cw) lasers between 0.7 and 1.65 $\mu$m have been made[10] with the VPE technique. The bottom line here is that the best crystal-growth process may be a function of the exact details of the crystal-growing technique more than of the basic process itself.

## Principles of operation

Figure 2 is a sketch of an oxide-stripe gain-guided geometry laser. In this laser, the lateral light distribution is determined by the flow of current in the active region. Index-guided structures in which the lateral light distribution is limited by a refractive index profile will be described shortly.

**Table I. "Best" laser results (as of 7/81).**

| *1.3 µm* | *LPE* | *VPE* | *OM-CVD* | *MBE* |
|---|---|---|---|---|
| $J_{th}$ (A/cm$^2$) | 675 | 1,500 | 1,050 | |
| $I_{cw}$ (mA) | 8.5 | 85 | 250 | |
| LED reliability | 14,000 h @ 175°C | 20,000 h @ 70°C | | |
| CW laser reliability | 5,000 h @ 70°C | 20,000 h @ 20°C | | |
| $T_{cw}$ (max) | 115°C | 60°C | | |
| $P_{cw-sm}$ (max) | ~7 mW | 3 mW | | |
| *1.55 µm* | | | | |
| $J_{th}$ (A/cm$^2$) | 1,200 | 1,200 | 2,500 | |
| $I_{cw}$ (mA) | 13 | 200 | | |
| LED reliability | | 500 h @ 20°C | | |
| CW laser reliability | 5,000 h @ 50°C | | | |
| $T_{cw}$ (max) | 97°C | | | |
| $P_{cw-sm}$ (max) | 5 mW | | | |
| *0.87 µm* | | | | |
| $J_{th}$ (A/cm$^2$) | 475 | 1,140 | 560 | 700 |
| $I_{cw}$ (mA) | 4.5 | 135 | 120 | 80 |
| LED reliability | 3,000 h @ 180°C | | | |
| CW laser reliability | MTTF 11,000 h @ 70°C | | 6,000 h @ 20°C | MTTF : 8,600 h @ 70°C |
| $T_{cw}$ (max) | 170°C | | | 100°C |
| $P_{cw-sm}$ (max) | 40 mW | | | |

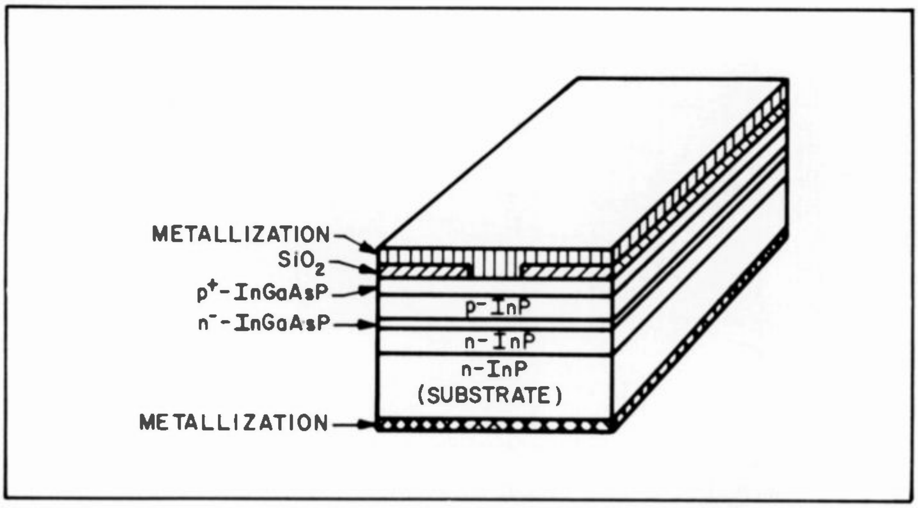



**Fig. 2. Conventional oxide-defined stripe-contact gain-guided InGaAsP/InP double-heterostructure laser.**

The gain-guided region may be defined by an insulator, by proton bombardment, or by a reverse-biased junction.

Figure 3 shows an idealized sketch of a typical double-heterojunction semiconductor-laser energy-band diagram and refractive index profiles. The laser cavity or active region (~1500-Å thick) consists of undoped low-bandgap material surrounded by higher-bandgap *n*- and *p*-type material. Under forward bias, electrons from the *n*-region and holes from the *p*-type material are injected into the laser cavity. These carriers are confined to the active region by the energy barrier at each heterojunction. This confinement, together with the high radiative recombination rates of direct-bandgap materials, promotes an efficient electron-hole recombination in the laser cavity that generates spontaneous light emission. At this stage, the device functions as an LED, and the radiation is emitted in a Lambertian fashion (uniformly in all directions). Although the internal quantum efficiency—the ratio of radiative recombination rate of carriers to total recombination rate in the cavity—can be greater than 50 percent, the LED external quantum efficiency—the ratio of emitted photons to input electrical power—is, at best, only a few percent. External quantum efficiency is low because the small critical angle for total internal reflection (17°), due to the high semiconductor refractive index (~3.5), causes most of the radiation to be trapped and absorbed in the device.

Any photon generated within the cavity can stimulate the recombination of additional electron-hole pairs to emit photons that are coherent with it (have the same wavelength and phase). As the injected carrier density increases, the gain due to stimulated emission can approach and exceed the absorption losses of the cavity. When this happens (at injection levels of approximately $10^{18}$ carriers/$cm^3$), the device becomes an amplifier and the intensities of all modes of the optical field increase. The waveguiding effect of the confining layers (caused by the refractive index step) and the gain profile of the device (defined by material parameters) allow certain modes of the optical field, those that are nearly perpendicular to the facets, to achieve much greater net amplification (incur much lower loss) than others. A narrowing of the emitted spectrum together with an abrupt increase in emitted power occurs. The device is now said to lase.

Whereas spontaneous emission has a spectral half-width of several hundred angstroms, coherent emission has a spectral half-width of only tens of angstroms. In turn, individual modes with half-widths of tenths of an angstrom or less form this spectral half-width. Since the stimulated lifetime is much shorter than the spontaneous lifetime of minority carriers (typically $10^{-11}$ versus $10^{-9}$ s), further increases in input current will result almost entirely in stimulated emission, and the internal differential quantum efficiency (stimulated photons created per injected electron-hole pair) of the lasing process can be as high as 50 to 100 percent. Due to small losses within the cavity, the external differential quantum efficiency is usually half to three quarters of the internal efficiency. The current density at which the device begins to lase is called the threshold current density. This relatively high external differential quantum efficiency, together with small size and low power requirements, is what distinguishes semiconductor injection lasers from all other types of lasers. The external efficiency of the overall process is usually below 15 percent but can be as high as 20 to 30 percent.

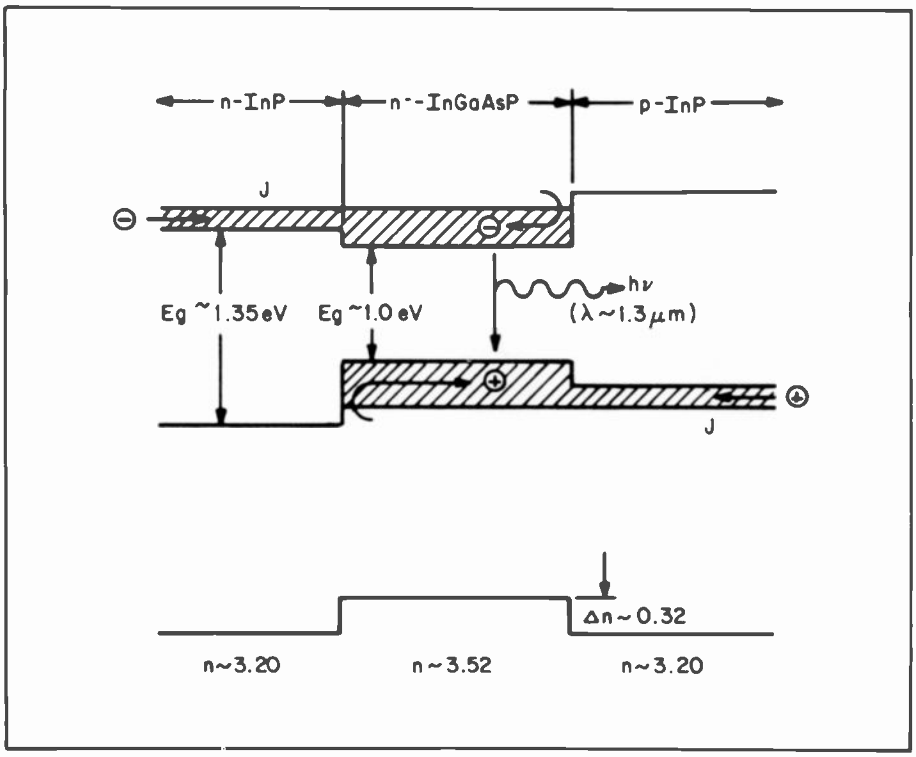



**Fig. 3. Energy band diagram and refractive index profile for an InP/InGaAsP/InP laser diode.**

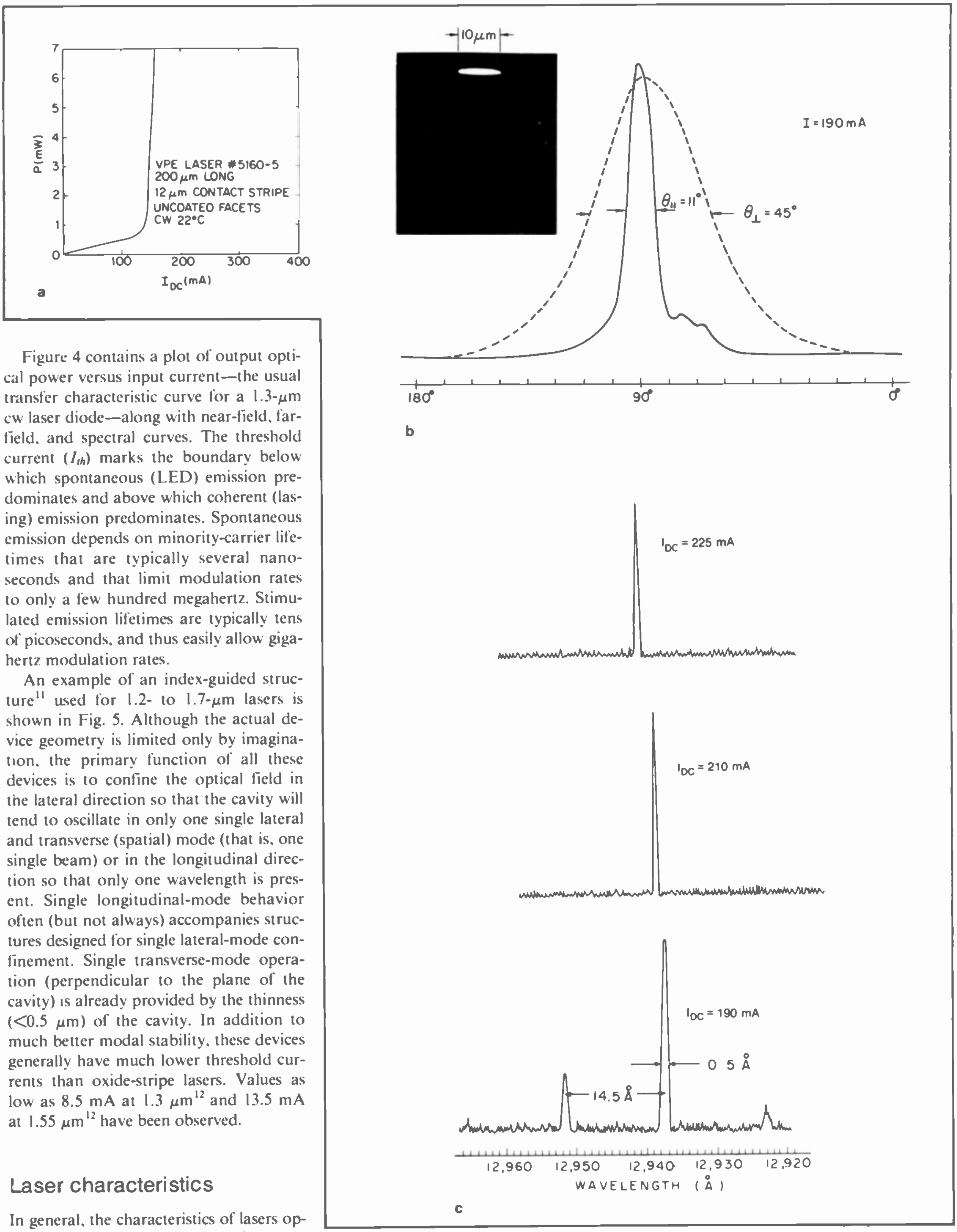



**Fig. 4. Output characteristics for an InGaAsP cw laser diode including (a) light power versus current; (b) near- and far-field patterns; and (c) spectrum.**

Figure 4 contains a plot of output optical power versus input current—the usual transfer characteristic curve for a 1.3-μm cw laser diode—along with near-field, far-field, and spectral curves. The threshold current ($I_{th}$) marks the boundary below which spontaneous (LED) emission predominates and above which coherent (lasing) emission predominates. Spontaneous emission depends on minority-carrier lifetimes that are typically several nanoseconds and that limit modulation rates to only a few hundred megahertz. Stimulated emission lifetimes are typically tens of picoseconds, and thus easily allow gigahertz modulation rates.

An example of an index-guided structure[11] used for 1.2- to 1.7-μm lasers is shown in Fig. 5. Although the actual device geometry is limited only by imagination, the primary function of all these devices is to confine the optical field in the lateral direction so that the cavity will tend to oscillate in only one single lateral and transverse (spatial) mode (that is, one single beam) or in the longitudinal direction so that only one wavelength is present. Single longitudinal-mode behavior often (but not always) accompanies structures designed for single lateral-mode confinement. Single transverse-mode operation (perpendicular to the plane of the cavity) is already provided by the thinness (<0.5 μm) of the cavity. In addition to much better modal stability, these devices generally have much lower threshold currents than oxide-stripe lasers. Values as low as 8.5 mA at 1.3 μm[12] and 13.5 mA at 1.55 μm[12] have been observed.

## Laser characteristics

In general, the characteristics of lasers operating at 1.2- to 1.7-μm are similar to those working at 0.85 μm, with the excep-

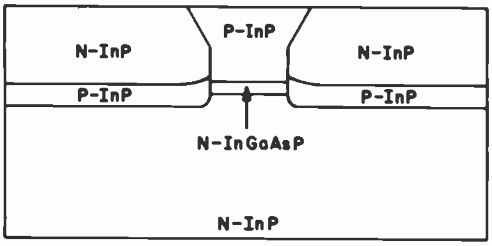



**Fig. 5. Buried-heterostructure InGaAsP/InP laser diode—an index-guided structure.**

tion of threshold-current temperature dependence and laser reliability. Figure 6 contains a plot[11] of cw power-output versus current-input characteristics for a typical oxide-defined stripe-geometry 1.3-$\mu$m InGaAsP/InP double-heterojunction laser at various ambient temperatures. The large threshold current increases with increasing temperature above room temperature, and the decrease in efficiency and saturation at high output powers is typical for lasers in the 1.2- to 1.7-$\mu$m regime. The threshold current ($I_{th}$) is related to the ambient temperature ($T$) by the expression

$$I_{th}(T) = I_{th}(20°C) \exp[(T - 20)/T_0].$$

This characteristic temperature ($T_0$) for the laser is measured at low duty cycle (<1%) with short pulses, so as to exclude the effects of joule heating (internal). The $T_0$ for (AlGa)As lasers is typically 120 to 180°C while that for InP/InGaAsP lasers is 40 to 80°C. The low $T_0$ for 1.2- to 1.7-$\mu$m lasers has a more serious effect on their cw characteristics than on their low-duty-cycle performance, as illustrated in Fig. 7, where we compare the calculated pulsed and cw threshold currents for a 1.3- and 0.8-$\mu$m laser. The laser characteristics chosen (threshold currents, thermal and electrical resistances, and $T_0$ values) are somewhat worse than those typically observed, but these values simply highlight the greater cw temperature sensitivity of the 1.3-$\mu$m lasers and account for nonuniformities in the device that would give them higher thresholds than the calculated values shown. The reason for the low $T_0$ values with InGaAsP lasers in the 1.2- to 1.7-$\mu$m region is not fully understood, but Auger recombination[13] and carrier leakage[14] have both been suggested as possible causes. However, room temperature $T_0$ values in the range from 40 to 80°C appear to be consistently observed by researchers worldwide, regardless of growth technique or wavelength within the range. Low $T_0$ may be a fundamental property of lasers at these longer wavelengths.

The spectral output of 1.2- to 1.7-$\mu$m lasers is similar to that of (AlGa)As lasers, with the so-called gain-guided devices emitting in a number of longitudinal modes, while the index-guided devices tend to emit in a single (line) spectral mode. The gain-guided or multimode lasers are like the oxide stripe devices, where the guide in the plane of the junction is simply the current distribution; on the other hand, in the index-guided or single-mode laser, lateral perturbations in active-layer geometry, induced by growth over channels or produced by regrowth, confine the light. The various structures and differences in device characteristics of the many index-guided lasers are beyond the scope of this paper (see reference 15). In addition to the spectral differences, index-guided lasers have smaller emitting areas (1 $\mu$m × 2 $\mu$m versus 1 $\mu$m × 8 $\mu$m) than have gain-guided lasers. This leads to lower threshold currents of 10- to 50-mA, and sharper "knees" at threshold in the power-output versus current-input characteristic as well as better-defined single-spatial-mode (single-lobed) far fields. The far-field patterns of gain-guided lasers may be multilobed in the plane of the junction. The far-field width perpendicular to the junction for both laser types is 35° to 45°, while the parallel beam is 6° to 10° for gain-guided lasers (for example, Fig. 4) and 10° to 25° for index-guided lasers because of their smaller emission width. The modulation characteristics of both types of lasers are similar, with speeds well in excess of 1 gigahertz possible. For multimode fiber optics, it is not clear which device (gain-guided or index-guided) is better since multispectral lines are necessary to reduce modal noise in the fiber unit. However, the lower thresholds and

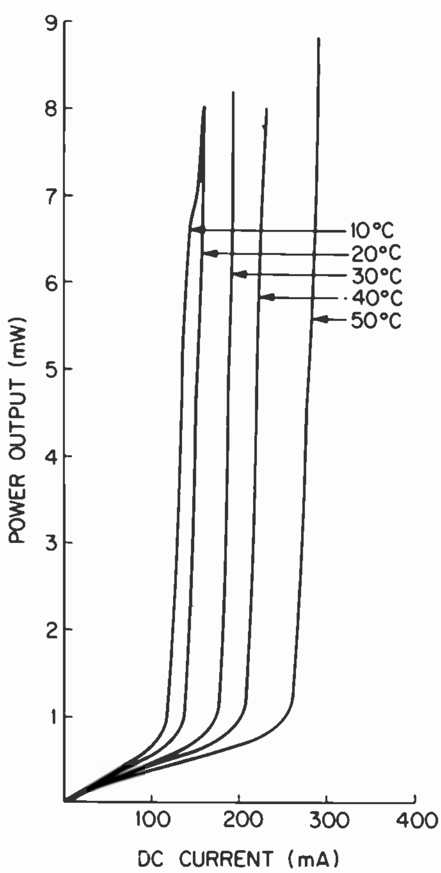



**Fig. 6. Output power versus current at various temperatures for a 1.3-$\mu$m InGaAsP/InP laser diode.**

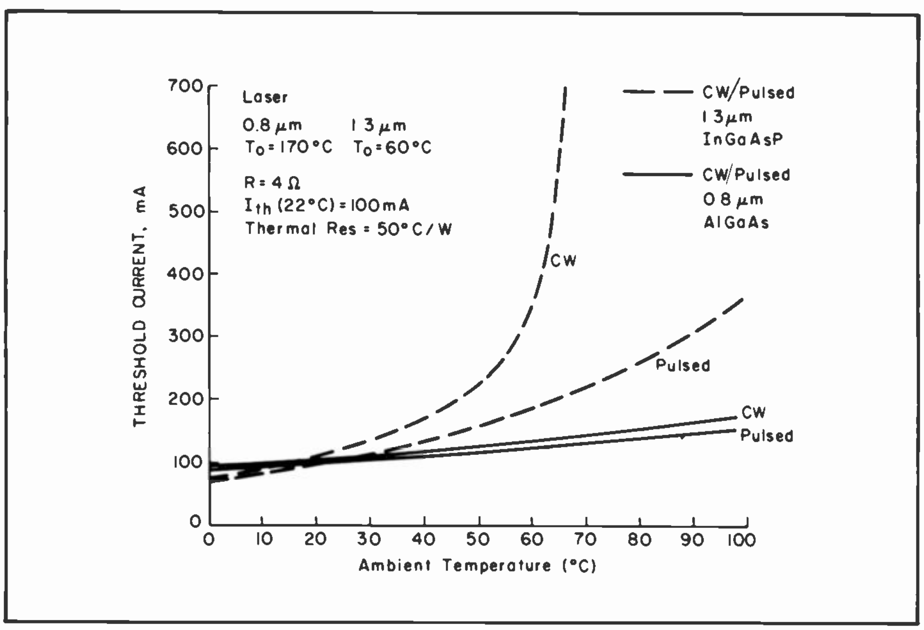



**Fig. 7. Calculated lasing threshold current versus temperature for an InGaAsP/InP laser diode in the pulsed and cw mode.**

sharper turn-on characteristics of the index-guided single-mode lasers are clearly preferred for the single-mode-fiber applications.

Diode lasers fail basically because of the following: (1) internal degradation, where nonradiative defects formed within the laser during forward-bias operation reduce the internal efficiency, and thus raise the laser threshold; (2) facet or mirror damage, where the mirror facet fails or erodes with time; and (3) contact failure, where the electrical or thermal resistance of the contact increases with operating time. Lasers in the 1.2- to 1.7-$\mu$m regime appear to be sensitive to contact degradation. The overall reliability to date appears to be comparable to that of (AlGa)As—$10^5$ to $10^6$ hour extrapolated operating lifetime at room temperature[16] —but possibly somewhat less reproducible. The exciting potential reliability feature of 1.2- to 1.7-$\mu$m lasers is that the movement or formation of defect centers for nonradiative recombination appears to have slowed significantly—as compared to (AlGa)As devices. This is evidenced by the extremely high reliability of long-wavelength LEDs, which have predicted lifetimes[17] of approximately $10^9$ (1 billion) hours at room temperature. Internal degradation occurs in LEDs and lasers almost identically, although LEDs are relatively immune to facet and contact degradation. The increased immunity of the long-wavelength devices to internal degradation may be fundamental in that less energy is available for the movement or creation of nonradiative defects.

In addition, mirror facets of the 1.2- to 1.7-$\mu$m lasers appear to be more resistant to damage and capable of operating at high output for longer times than the (AlGa)As lasers, without the facet-passivation coatings required for long-term reliable operation of the latter. However, the limited cw laser life-test data available so far shows predicted lifetimes that are, at best, comparable to those for (AlGa)As. This result is probably due to small amounts of any of the aforementioned mechanisms. The overall increase in cw threshold will, however, be magnified by the increase necessary to compensate for joule heating, and finally the device will fail because of a thermal runaway process as illustrated for cw operation in Fig. 7. As with (AlGa)As, the basic internal degradation mechanism is temperature sensitive, characterized by an activation energy of between 0.6 and 1.0 eV. However, due to the strong temperature sensitivity of InGaAsP lasers, it has been difficult to accelerate tests at temperatures much above 50°C. The lower threshold currents of the index-guided lasers, and lessened overall joule heating, have allowed operation at higher temperatures. Lifetime data for these lasers at the elevated temperatures are starting to become available. With better processing, mounting, materials, and uniformity, 1.2- to 1.6-$\mu$m InGaAsP lasers can probably become more reliable than their 0.85- to 0.9-$\mu$m (AlGa)As counterparts.

### *Detectors for the 1.2- to 1.7-$\mu$m spectral region*

Until recently, the only readily available detector for the 1.2- to 1.7-$\mu$m spectral region was germanium—both in *pin* form and as an avalanche detector. III-V compound *pin* detectors (InGaAs/InP) for this same spectral region have just become commercially available. These materials all suffer from one common fundamental problem: unlike silicon, they have ionization coefficients that are similar for electrons and holes. Thus, both carriers get multiplied in the avalanche process, and much excess noise is generated (in silicon, the ionization coefficient of the electrons can be 10 to 100 times greater than that of the holes so only *one* carrier gets multiplied significantly). The optimum gain for these devices[18] at higher frequencies (>100 MHz) is usually below 10. Therefore, low-noise *pin* detector/preamplifier combinations have often been proposed as the choice for a long-wavelength receiver rather than avalanche photodiodes (APDs) which, at best, only give approximately 5-dB improved sensitivity and require high voltages and careful control circuitry.

The InGaAs/InP *pin* detectors offer lower dark currents, faster response time, more uniform spectral response, and much higher operating temperature than germanium devices. Figure 8 shows a spectral yield curve for a typical device. Typical operating characteristics for 100-$\mu$m-diameter VPE InGaAs/InP detectors[19] at −10 V include leakage currents below 10 nA, quantum efficiencies of about 80 percent, pulse rise times below 300 ps, operating temperatures about 200°C, and high reliability (stable operation for more than 8000 hours at 60°C, and more than 3000 hours at 180°C). Larger-area devices will soon be available. III-V compound detectors that respond beyond 2 $\mu$m are also commercially available.

An exciting new application of the molecular-beam epitaxy technique[20] has shown that large differences in electron/hole ionization coefficients can be achieved in III-V compounds—at least for GaAs. The "superlattice photodetector" consists of fifty 500-Å layers, alternating between $Al_{.45}Ga_{.55}As$ and GaAs. The resulting discontinuities in the conduction-band energy levels aid electron (but not hole) multiplication. Electron/hole ionization ratios as high as 8 were achieved along with low-noise avalanche gain. But this device only detects light with wavelengths up to 0.9 $\mu$m; no such structure has yet been demonstrated for the 1- to 2-$\mu$m spectral region.

## LEDs versus lasers

Although best ultimate performance of a fiber optical system at *any* wavelength will be achieved with laser sources and APD receivers, many moderate data rate (<200 Mbit/s), medium distance (≤20 km) applications can be met with an LED source—especially in the 1.3- to 1.55-$\mu$m spectral range. The LED's wider spectral width (900 Å, versus 50 Å) and poorer fiber-coupling efficiency (50 $\mu$W coupled for an LED, versus 1 mW for a laser) are the limits here. Nevertheless, repeaterless transmission of 44 Mbit/s for over 23 km and 274 Mbit/s for over 7 km with a fiber-optical system using a 1.3-$\mu$m LED and an InGaAs *pin* detector has already been demonstrated.[21] The higher reliability, simpler operation, and lower cost of LEDs and *pin* detectors as compared to lasers and APDs *often* make them a favorable choice for systems at data rates below 200 Mbit/s.

## Future directions

The fundamental absorption peak of the $SiO_2$ molecule near 2 $\mu$m prevents the op-

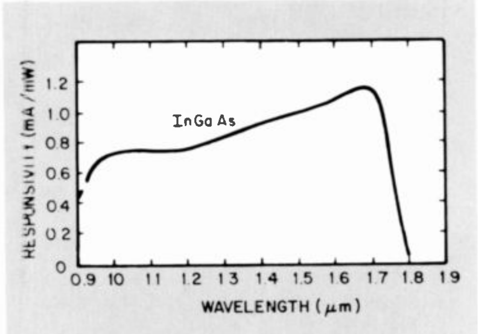



**Fig. 8. Responsivity versus wavelength for a VPE InGaAs *pin* detector.**

timal use of silica fibers at wavelengths much beyond 1.55 $\mu$m. Most fiber-optical systems will probably operate at 1.3 $\mu$m, while long-distance systems might employ 1.55-$\mu$m single-mode lasers. AlGaAs lasers are far from obsolete, however. Short, high-data-rate fiber links; data-bus fiber-distribution systems; optical recording; optical and audio disc readout; and high-speed printing will provide very large markets for lasers in the 0.7- to 0.9-$\mu$m spectral region.

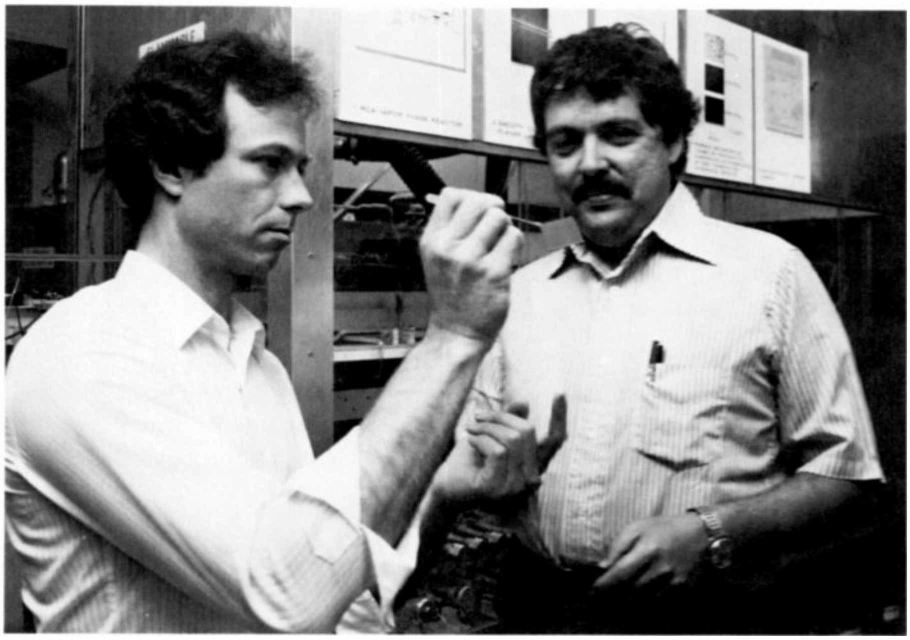
Lower attenuation losses may be attainable in other fiber materials. Certain halide and chalcogenide glasses are available in which calculated attenuation losses[22] are as low as $10^{-3}$ dB/km in the 2- to 6-$\mu$m spectral region. But these low losses have not yet been demonstrated because of impurities remaining in the fibers and a lack of a *suitable* cladding layer for such fibers. If these problems are overcome, then materials for 2- to 6-$\mu$m emitters and detectors will be needed. InGaSb and InAsSb (Fig. 1) are two materials that could meet these demands, although they would probably have to be cooled below room temperature for the longer wavelengths. Detectors in this wavelength range could similarly be made.

Eyesafe systems such as rangefinding at 1.73 and 2.06 $\mu$m will also receive much attention during the coming years.

A final note deals with efforts by various nations in this field. A recent literature survey[23] on InGaAsP showed that while, in 1979, 38 percent of all publications on InGaAsP were Japanese, 34 percent American and 20 percent European, in 1980 the percentages had changed to 47 percent Japanese, 31 percent American, and 14 percent European. These figures are probably also representative of industrial efforts on quaternary laser devices and might portend the international distribution of markets.

## References


1. M. Ettenberg and G.H. Olsen, *Laser Focus* (March 1982).
2. G.H. Olsen, *Opt. Eng.*, Vol. 20, No. 440 (1981); G.H. Olsen, *J. Opt. Comm.*, Vol. 2, No. 11 (1981).
3. T. Miya, *et al.*, *Electron. Lett.*, Vol. 15, No. 106 (1979).
4. D. Botez, *Proc. IEEE*, Vol. 68, No. 689 (1980).
5. P.F. Jacobs (private communication).
6. J.J. Hsieh, *et al.*, *Appl. Phys. Lett.*, Vol. 28, No. 709 (1976).
7. G.H. Olsen, *et al.*, *Appl. Phys. Lett.*, Vol. 34, No. 262 (1979).
8. J.P. Hirtz, *Electron Lett.*, Vol. 17, No. 113 (1981).
9. B.I. Miller, *et al.*, *Appl. Phys. Lett.*, Vol. 33, No. 44 (1978).
10. G.H. Olsen, *et al.*, *Electron. Lett.*, Vol. 16, No. 516 (1980).
11. I. Ladany (private communication).
12. I. Mito, *Tech. Dig. 3rd Int. Conf. on Integ. Optics and Opt. Fiber Comm. (IOOC)*, pp. 44 (April 1981).
13. Y. Horikoshi, *et al.*, *J. Appl. Phys.*, Vol. 18, No. 809 (1979).
14. G.H.B. Thompson, *et al.*, *Electron Lett.*, Vol. 16, No. 42 (1980).
15. D. Botez, *J. Opt. Comm.*, Vol. 1, No. 42 (1980).
16. M. Ettenberg and G.H. Olsen, *Tech. Dig. IEEE IEDM Meeting*, p. 280 (December 1981).
17. R. Yeats, *et al.*, *IEEE Electron. Dev. Lett. EDL-2*, 217 (1981).
18. C. Hurwitz, SPIE Proc., Vol. 224, No. 113 (1980).
19. G.H. Olsen, *IEEE Electron Dev. Lett. EDL-2*, 217 (1981).
20. F. Capasso, *et al.*, *Tecn. Dig. IEEE IEDM Mtg.*, p. 284 (December 1981).
21. K. Ogawa, *et al.*, *Electron. Lett.*, Vol. 17, No. 31 (1981).
22. S. Shibata, *et al.*, *Electron Lett.*, Vol. 17, No. 775 (1981).
23. A.R. Clawson, *Naval Ocean Systems Center Tech. Note #830*, San Diego, Calif. (February 1981).

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# Upgrading coal for more efficient electric-power generation

*A new process could significantly increase the amount of electric power we can get from a ton of coal.*

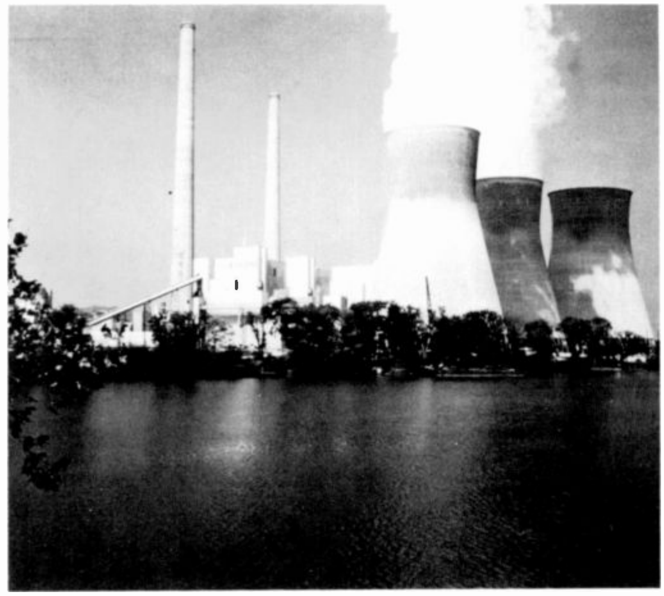

**Fig. 1. A modern coal-fired thermal generator station on the Kanawha River near Charleston, West Virginia.** It has a capacity of 2.9-million kilowatts and burns more than 7-million tons of coal a year (photo provided by American Electric Power System).

**Abstract:** *When coal is used to generate electric power, it is burned to run a steam-turbine generator. The overall generation efficiency is typically 30 percent, determined largely by the thermodynamic limitations on the performance of a heat engine. In a fuel cell, the chemical energy of a fuel can be converted directly to electric power, bypassing the conversion to heat. This can give power-generation efficiencies of 50 percent or more. Coal, in its original form, cannot be used in existing fuel cells. By carrying out a proper reaction sequence, it can be converted to products that can be used in fuel cells. This conversion can be done with little expenditure of energy and could lead to significant increases in the efficiency of electric-power generation from coal.*

Faced with dwindling national reserves of petroleum, a shortage of suitable undeveloped hydroelectric sites, uncertainties in the future of nuclear power, and a solar-power technology still in its infancy, electric utilities are turning increasingly to coal as their basic energy source. A modern coal-fired power-generating station is shown in Fig. 1. Our national reserves of coal are believed to contain more energy than all the petroleum deposits in the world. It is important that we use this resource as wisely as possible. For electric-power generation, this means we must get the maximum generation efficiency with the minimum adverse impact on the environment. One way to do this may be to convert coal into simpler fuels that can be used in fuel cells. This idea and its possible advantages are the subject of this article.

## Generation efficiency

We get most of our commercial electric power from steam- and gas-turbine generators. These are heat engines and their maximum achievable efficiency is determined by the thermodynamic limitations on the efficiency of an ideal Carnot engine. Efficiency is defined as the amount of ac power out, divided by the heat of combustion of the fuel consumed. The large generators now in use have efficiencies around 30 percent. The dominant factor is the thermodynamic limitation on the efficiency of a heat engine. For small generators the efficiency is much lower. This is illustrated in Fig. 2. For steam-turbine generators an efficiency of 30 percent can be achieved only for units having a capacity of 100 megawatts or larger. When a system gets very large, there are disadvantages. Long-distance transmission is needed and that means expensive lines, transmission losses, acquisition of transmission-line right-of-ways from an unwilling public, and problems in fulfilling power needs when a massive unit temporarily shuts down.

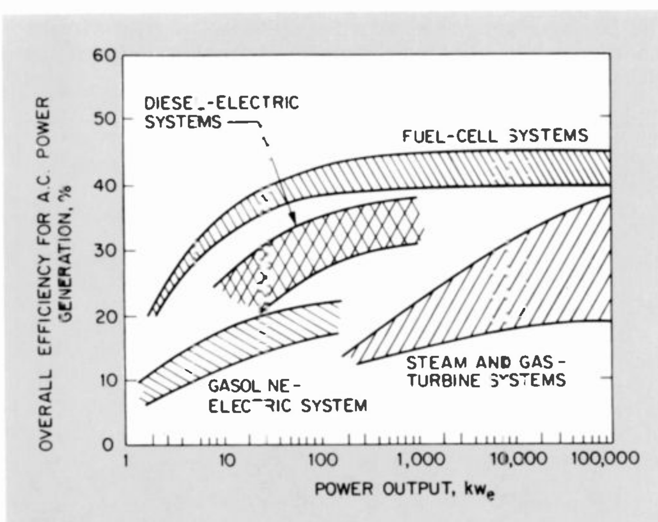


**Fig. 2. Overall generation efficiency for fuel cells and several kinds of thermal generator systems.** The achievable efficiency is a strong function of the output capacity of the unit. For steam and gas turbine generators, high efficiency is achieved only for units having a capacity greater than 10,000 kW (reproduced from "Hydrogen and Other Synthetic Fuels," U.S. Atomic Energy Commission report, TID-26136, 1972).


Final manuscript received March 22, 1982.
Reprint RE-27-4-6

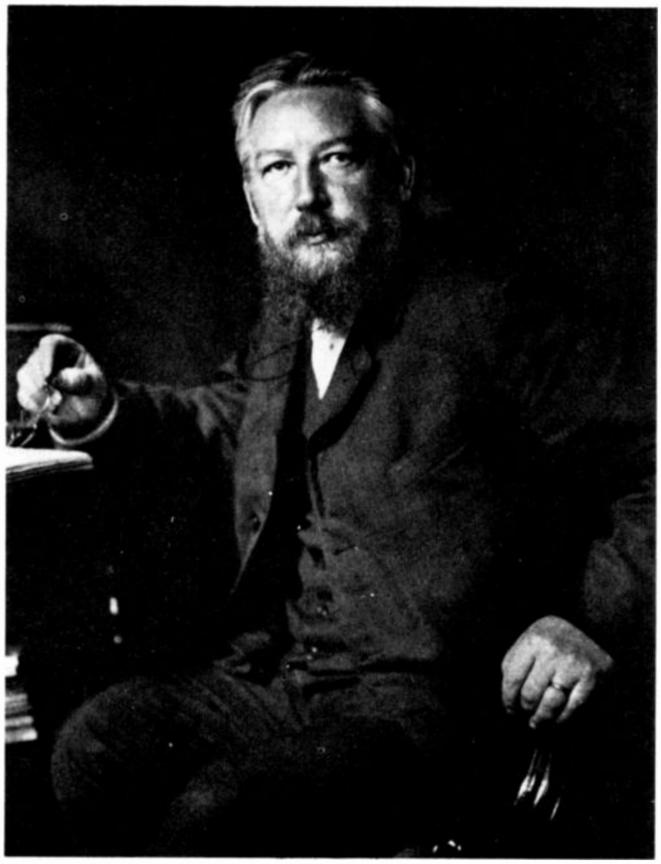

**Fig. 3. Wilhelm Ostwald, founder of physical chemistry.** He was the first to show the thermodynamic advantages of fuel cells over thermal electric generators, whose efficiency at the time was around 10 percent. In an address to the inaugural meeting of the Bunsen Gesellschaft, in 1894, he made a strong plea for the use of fuel cells to avoid the Carnot limit on efficiency. He had in mind a fuel cell that could use carbon directly. The discussions of energy questions in that period had a curious parallel to those we have today, and for good reason. Wide-scale petroleum usage was yet to come, and European coal resources were winding down. Thoughtful people were concerned about how resources could be conserved for the future. Social visionaries were alarmed; technologists were challenged (photo provided by Edgar Fahs Smith Memorial Collection, University of Pennsylvania).

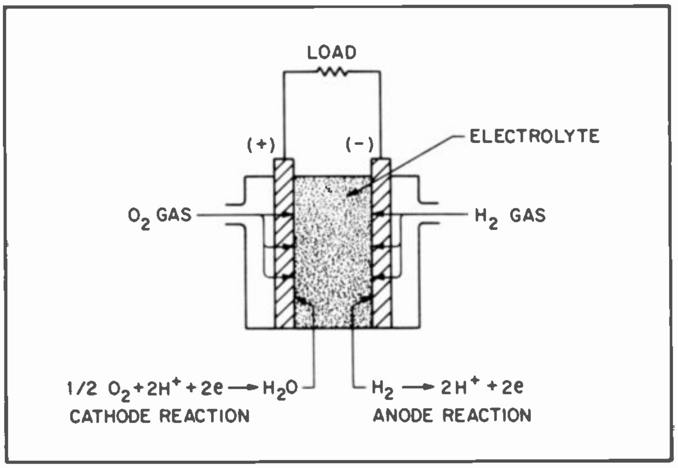


**Fig. 4. Schematic drawing of a fuel cell for use with hydrogen.** Hydrogen and oxygen flow through porous metal electrodes and undergo electrochemical reactions at the interior interface with an electrolyte solution. The overall reaction is equivalent to the combustion of hydrogen.

## Fuel cells

The main efficiency loss in thermal generators occurs because the energy of the fuel is first converted into heat and then back into mechanical energy. According to fundamental thermodynamic laws, only a fraction of the heat can be recovered as useful work. One method that has been used to avoid such losses is to convert the chemical energy of the fuel directly into electric power (Fig. 3). A fuel cell can do this. The fuel cell resembles ordinary batteries in that it consumes an energetic material in a chemical reaction and converts the energy of reaction into electric power. An important difference is that, in a fuel cell, the electrodes are not consumed during the reaction. The fuel reacts with oxygen, forming ions in an electrolyte solution and leaving charge on the electrodes that can be delivered as power to an external circuit.

Figure 4 shows a schematic drawing of a particularly simple fuel cell that uses hydrogen as the fuel. Porous metal electrodes make contact with an electrolyte solution on one side and the gases on the other. Gas flows through the electrode and reacts at the solution interface. The overall reaction is the inverse of the reaction of water electrolysis. The first fuel cell used this reaction and was made by William Grove, in England, in 1839. Practical models were pioneered by Francis T. Bacon* in the 1930s and, after further development, were used in Apollo and many later space vehicles.

Fuel cells have been made to use various fuels, usually hydrocarbons or other materials derived from petroleum. Because the working efficiencies of fuel cells can be above 50 percent (Fig. 2 is more conservative than actual achievements), they have important advantages for power generation. An additional advantage is that their efficiency can be high for relatively small units (Fig. 2). Small units allow greater flexibility in the selection of generator sites, economies in transmission systems cost, and reduced losses. Since refined fuels are used, fuel cells are also clean in operation.

Clearly, a fuel cell that could use coal directly would be perfect for electric-power generation. There have been attempts to make fuel cells that could burn carbon, that is, oxidize carbon to produce ions in solution and charge on electrodes. These attempts have not been very successful. The low volatility and inertness of carbon have proven to be insuperable obstacles. What can be done is to convert coal to simpler materials that can then be used in existing fuel cells. This is the path that I have explored and have described in a recently issued process patent, "Non-Air-Polluting, Non-Pyrolytic Upgrading of Coal for Cleaner and More Effective Electric Power Generation," U.S. Patent 4,259,414.

## Upgrading coal for use in fuel cells

Coal can be converted into many different materials. A massive effort is underway to convert coal to liquid fuels for automotive or industrial use. If the goal is greater efficiency in electric-power generation, then it is important to design a conversion process that does not, itself, use a lot of energy. A reaction

* Francis T. Bacon is a direct descendant of Francis Bacon, 1561-1626, noted philosopher and statesman, believed by some to have written the plays of Shakespeare. To avoid confusion, he refers to his illustrious ancestor as "the *great* Francis Bacon!!"

sequence that does well in this respect is one based on the well-known water-gas reaction:

$$C(s)+H_2O(g) \rightarrow H_2(g)+CO(g) \quad \Delta H = +31.4 \text{ kcal/mol} \quad (1)$$

The reaction takes place at temperatures above 1000°C and is endothermic, that is, the forward reaction absorbs energy. $\Delta H$ is the quantity of heat needed to drive the reaction. The water-gas reaction has been used for more than a century in the commercial production of gas for residential and industrial use. Until quite recently, many cities in this country and in Europe had their own gas works, making gas from coal, often using this reaction. After World War II, the national network of gas pipelines was built, allowing natural gas from Texas fields to be distributed throughout much of the country. City gas works were closed down, and the hazard of carbon monoxide in the home is now only a memory. The controversial pipeline from Siberia to West Germany involves a similar substitution of natural gas for coal gas.

What the water-gas reaction accomplishes is the conversion of coal to two gases, hydrogen and carbon monoxide. The hydrogen can be used directly in fuel cells, and the carbon monoxide could also be so used. However, if we stop at this stage, we have made a substantial expenditure of energy, more than enough to cancel out the energy benefits from the use of fuel cells. To get a feeling for how much energy has been used, we can compare it with the total energy of the combustion reaction:

$$C(s)+O_2(g) \rightarrow CO_2(g) \quad \Delta H = -94.1 \text{ kcal/mol} \quad (2)$$

Here, $\Delta H$ is negative, indicating that the reaction is exothermic, that is, it produces energy. The energy used in the water-gas reaction almost cancels out the energy advantages of fuel cells and the additional complexity cannot be justified. We can nearly compensate for the energy used in reaction (1) by following it with an exothermic reaction of the carbon monoxide, CO:

$$CO+NaOH \xrightarrow{200°C} \underset{\text{(sodium formate)}}{HCOONa} \quad \Delta H = -26.6 \text{ kcal/mol} \quad (3)$$

This, again, is a well-known reaction. It is widely used, commercially, to manufacture formic acid, HCOOH, by acidifying the formate salt produced in reaction (3). In our case the sodium formate can be used in aqueous solution in a fuel cell. Such fuel cells have been developed by two different laboratories that work in fuel-cell development. One of the motivations was to develop fuel cells for use in electrically powered automobiles.

The idea here is to combine reactions (1) and (3), and convert coal to two different materials, hydrogen and sodium formate, that can then be used in fuel cells. This involves a minimum expenditure of energy. Compare this with the present practice of burning coal according to reaction (2) and using the heat to drive a thermal generator. By combining reactions (1) and (3), we can get back nearly as much heat from reaction (3) as we use in reaction (1). The two products are then used in fuel cells to generate electric power from the oxidation reactions:

$$H_2 + \tfrac{1}{2}O_2 \rightarrow H_2O + \text{electric power} \quad (4)$$

$$HCOONa + \tfrac{1}{2}O_2 \rightarrow NaOH + CO_2 + \text{electric power} \quad (5)$$

The NaOH is a cyclic intermediate, used in reaction (3) and regenerated in reaction (5). The overall combustion of the carbon is the same, whether we have ordinary combustion, as in reaction (2), or the combined sequence of reactions (1), (3), (4), and (5) used in the present process. The advantage of the new process is that it makes it is thermodynamically possible to get as much electric power from a ton of coal as one gets from 1.5 tons of coal by conventional combustion and a thermal generator.

## Conclusions

Can processing of coal before it is used be justified on practical grounds? Any such processing means some complexity and additional costs. However, the trend for coal usage in the energy industry points to the future processing of all coal, before use, to reduce adverse effects of pollution. If processing is to be done in any case, we can offer a reward in energy efficiency and flexibility of end use to repay some costs that will be inevitable. The design and construction of suitable reactors for a new process of this kind is a substantial engineering task. It will not happen immediately, but it is a promising target for a cleaner and more economical energy future.


**Author Richard Williams** is holding an evaporation gauge he invented to provide rapid measurement of the water evaporation rate. The device has many potential applications for meteorological and agricultural studies and is expected to be especially useful in areas where moisture-sensitive materials are handled, processed, or stored. The instrument consists of a 5-inch-length glass capillary tube joined to a 4-inch-diameter round brass plate and a round piece of standard laboratory filter paper placed on the plate. When the paper becomes wet, the water that evaporates from the filter paper can be measured accurately after several minutes. The time needed for a given displacement of the column of water in the capillary tube gives a direct measure of the evaporation of water.

Richard Williams received the AB in Chemistry from Miami University and his PhD in Physical Chemistry from Harvard University. He joined RCA Laboratories in Princeton, New Jersey, in 1958, and is now a Fellow of the Laboratories. Dr. Williams has worked in the fields of liquid crystals, semiconductor-electrolyte interfaces, internal photoemission, solar cells, properties of electrons on the surface of liquid helium, and the surface properties of the VideoDisc.

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# Computer programming and systems analysis in the rapidly changing VideoDisc environment

*Want to spend $500 to set up a computer software system that would normally cost $10,000? Try FOCUS.*

**Abstract:** *Some comprehensive information needs normally satisfied by FORTRAN- and COBOL-based programs were provided quickly and cheaply by FOCUS, a database management system with a powerful and friendly user interface. Examples from "SelectaVision" VideoDisc development and testing are used, to show the system's speed, flexibility, costs and benefits, design and maintenance.*

In moving from the development phase into the manufacturing phase of the VideoDisc system, the management, engineering, and manufacturing staffs required more and better information so that a high-quality product could be released on schedule. To do this, computer programs and complete information systems had to be designed, coded, tested, and implemented in a very short time with a small programming staff and at minimal cost. Something was needed that would allow us to:

- Design and implement computer systems quickly;
- Easily debug the programs and systems;
- Spend little time maintaining the programs in the systems and easily transfer this responsibility to another person;
- Make changes to the structure of existing databases with little fuss;
- Easily link related information;
- Provide almost instant response to user requests, and answer "What if?" and "What happened?" types of questions;
- Provide rapid turnaround time for programming of new reports;
- Develop the programs and systems with minimal programming experience and training;
- Turn the day-to-day operation of systems over to nonprogramming personnel in users' groups with little training required; and
- Have data ready for statistical analyses when needed.


Final manuscript received May 26, 1982.
Reprint RE-27-4-7

We found that all of this could be done by using a database management system called FOCUS on the RCA time-sharing network at Cherry Hill, N.J. FOCUS is a member of the latest (fourth-generation) computer software. An excellent article describing fourth-generation languages in general ("Assuring MIS Success" by Read and Harmon) is available in the February, 1981 issue of *Datamation* magazine.[1] The impact of fourth-generation languages on documentation is described in the March 29, 1982 issue of *Computerworld* ("Winds of Change" by Lerner, Brownstein and Smith).[2] In general, the approach of fourth-generation languages such as FOCUS, RAMIS, and NOMAD is from the perspective of the user and the application, rather than that of the machine. Accordingly, the user interface in these kinds of products is both friendly and powerful. According to Information Builders, Inc., the developers of FOCUS, "The purpose of FOCUS is to control the entire application and thereby reduce the need for, or replace, (traditional) computer programming."[3] For us, this proved to be true.

## Speed and flexibility in response to user needs

We have found that with FOCUS, new programs, systems, and entire database structures can be put together with great speed. Usually, when something is needed, it is needed quickly. If traditional methods are used, a single program can take many days or weeks to complete. Under ordinary conditions with FOCUS, a program can be written to generate a new report within four hours of the request if the data exists in a database. In many cases, existing FOCUS programs with a selection option can be used and no programming is necessary.

Not only can programs be written quickly, an entire database can be constructed and implemented in a matter of days or, at most, a few weeks. The player system in the example[4] had about 10 man-weeks of work in its design and programming when it was turned over to the Player Product Asssurance department. The first phase was implemented three weeks after the assignment to write the system was first received. A few days after the initial implementation, the manager in charge of the lab asked for more characters in a comment field. At that

## VideoDisc-Player Product Assurance information network

The figure illustrates the network used to support the Player Product Assurance department as described by Frank Scearce in the November/December 1981 issue of the *RCA Engineer*. It shows flexibility and power as listed below:

- Each box is an independent database file with its own data maintenance programs and reports.
- An arrow pointing from one file to a second file shows that data from the first file can be read and used while accessing only the second file. These linkages can be permanently built into the network or temporarily set up at program-execution time.
- The box numbers indicate files (phases) that were designed and implemented at the same time. New database files were integrated into the network only after they had been in operation for a while. For example, the warranty database files (2) were not assigned until the CAL system (1) had been in operation for more than a month and the shipments file (7) has never been permanently integrated into the network.
- The entire network required about ten man-weeks of work and the first phase (1) was implemented three weeks after the assignment was received.
- Approximately 40 reports are generated from the network on a regular basis (daily, weekly, or monthly). However, hundreds of special studies have been conducted and the programs are still available.
- Many of the files have had changes made to their structures since implementation. These revisions of file structure would not have been economically feasible without FOCUS.

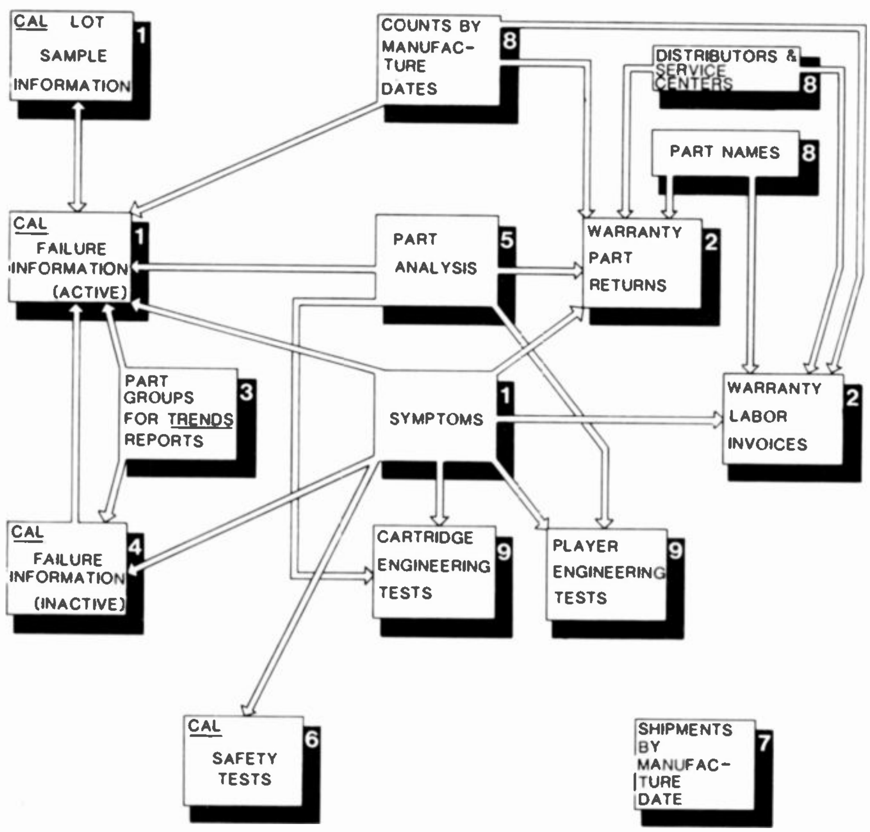



**Fig. 1. VideoDisc player product assurance information network.**

time, the system contained more than 40 programs. The comment field was increased by 12 characters and the database was rebuilt. This whole procedure took about 30 minutes. As soon as the database was rebuilt, those 40 programs "knew" about the change—they did not need to be changed or recompiled. If this had been a COBOL- or FORTRAN-based system, a program would have been written to change the file and the other 40 programs would also have been changed and retested. This would have taken days.

The flexibility of FOCUS can be typified by one of our recent systems. The department using this system has assigned a data analyst as a coordinator. This coordinator trains the rest of the personnel to enter the data and run the standard reports. She handles all of the special requests. This system contains data concerning disc production and has more than 30 standard reports. Besides the usual date-range selections, for all reports there is an option to select any part of the database and create the same report. This is done by typing as many program "IF" statements on the selection line as possible. The program then runs as if the statement were always in the program. The versatility of this procedure usually is not fully appreciated until seen in operation. For example, an engineer does not have to look through a 50-page list to find the 10 lines of detail that he needs. Using this option, he can have those 10 lines selected and printed in the order he wants. The usefulness of this feature was perceived immediately by the engineering staff. In the first six weeks of operation more than 100 special requests were run in this fashion.

Finally, because of the friendliness of FOCUS, the Product Assurance department has achieved a very high level of productivity. During the last 15 months, two staff members in our department have implemented 19 major systems containing more than 600 programs at a very low development cost, and considering the large number of special requests from the engineering and management staffs, at a low operating cost.

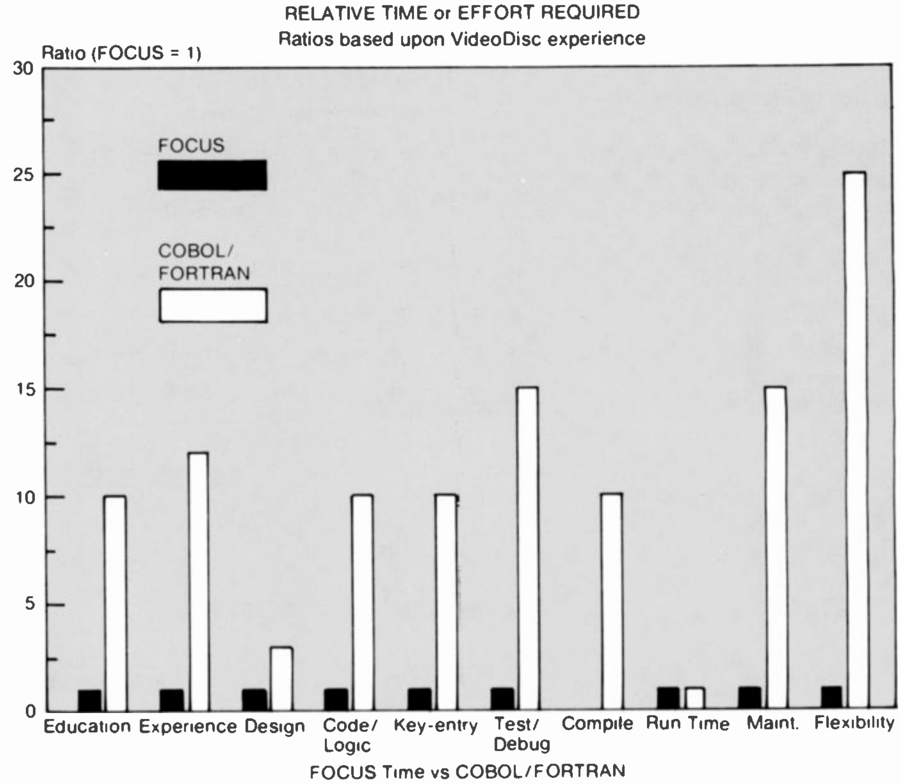
## Costs and benefits

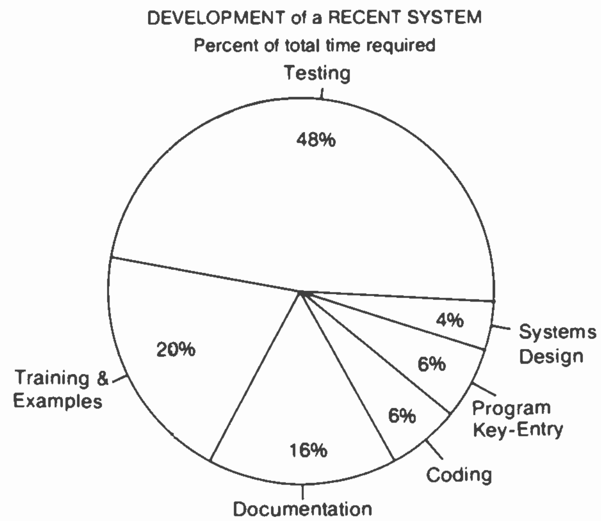
A computer project is an expense to the organization until it is implemented and used. A new FOCUS project can be imple-

## The difference between third- and fourth-generation languages

The graphs illustrate the differences between third- and fourth-generation languages. The bar graph shows the comparison of the time or effort required to do a job using FOCUS against doing the same job using COBOL or FORTRAN. The pie chart shows the breakdown of time used in the development and implementation of a recent system. The training and documentation slices in the pie chart correspond to the education in the bar chart.

Notice that testing used half of the total development time for the system and that the ratio for testing in the bar graph is 15 to 1. In other words, it would have taken fifteen times as long to test a group of COBOL programs doing the same job. The bar graph is based upon VideoDisc experience, September 1980 through 1981.




mented in less than 10 percent of the time required for a similar COBOL- or FORTRAN-based project. Therefore, it can be used sooner and will recover its development costs quickly, which with FOCUS systems are usually very small. The 30-report disc system described under "Speed and flexibility" cost less than $500 to study, program, and implement. This includes all computer charges and manpower costs, except equipment. Most of the time, a moderately complex program can be written for less than $150. Maintenance of existing programs has been reduced by about 98 percent (due to program simplicity).

FOCUS has some built-in devices to reduce costs, also. Since FOCUS can read non-FOCUS files, data can be collected by off-line devices and put into a regular file for editing and sorting by a FOCUS routine before it is added to the database.[5] One other major savings can be realized by use of an inactive file. Most daily and weekly reports that we produce do not use data more than three months old. Since FOCUS looks at every item in the file to make its report selections, older data is periodically transferred to an inactive file. If data is needed from the inactive file (as in a special engineering study), the operator only needs to tell FOCUS to use the inactive file with the active file. The program will then treat the active and inactive file as one large file. Nothing needs to be transferred back to the active file.

Even though FOCUS is a very powerful package, it does have some limitations. It cannot do a large number of very complex calculations. Occasionally, FORTRAN programs and more powerful statistical and graphics packages are needed. However, FOCUS can be used to gather the data and prepare files to be used by these routines, and the results can be easily put back into the database. There are times when this is not necessary. FOCUS can directly call FORTRAN and COBOL subroutines.

## Studies and system design

The implementation of a new computer information system, or any new product for that matter, requires a development phase and then an operations phase once the product is ready. For the development phase, schedules, programmer training, preliminary studies, system design, program coding and maintenance, and costs must be considered. For day-to-day operations, required user training, response time for reports, flexibility both for standard reports and special requests, ease of loading new data and changing existing data, and costs should be projected.

When using traditional methods, the current operations are studied, forms and reports are analyzed, costs are estimated, and the requirements for the new system are formulated. Then

## Sample cost reduction

| | COBOL/ FORTRAN | FOCUS |
|---|---|---|
| Development time: | 12 months | 1 month |
| Development cost: | $100,000 | $6000 |
| Benefits per month after implementation: | $10,000 | $10,000 |
| First year cost: | $100,000 | $6,000 |
| Return: | 0 | $110,000 |
| Net: | (-) $100,000 | (+) $104,000 |

The estimate above was based upon a COBOL or FORTRAN system against a similar FOCUS system. FOCUS is a database management system available on the RCA computer facilities at Cherry Hill. The assumption was also made that the COBOL- or FORTRAN-system design would not be changed after programming was started. No such restrictive assumption was made for the FOCUS-based system.

The benefits can be measured in dollars saved, timeliness of data, reduced manhours, and so on, above and beyond the cost of using the system. Notice also that the programmer or engineer has eleven months free to use for development of other projects.

the system itself is designed, and file and report forms are drawn. If the user agrees to the design, the program specifications are written and the system is ready to be programmed. Once the programming has started, it is usually very difficult to make any changes to the system. Even small changes to the file structures will have a major impact upon the completion date and development costs.

A new way of thinking is required when using FOCUS, beginning with the preliminary study and the system design. When using FOCUS, most of the above steps can be shortened, combined or eliminated. For a FOCUS study, the first thing is to determine exactly what data is available. Next, a preliminary file organization is decided upon. Finally, a new database is created, load programs are written, data is loaded into the database and sample reports are generated. It is easier to create the database, load data, and write sample reports than it is to draw sample-report forms. Not only does the user have the advantage of looking at final reports, but the programmer has already run a pilot project that could not have been run at all with traditional methods. If changes are requested, the programmer can easily change the reports, or if necessary, the database structure. Also, since a large FOCUS database can be split into small systems, or vice versa, it is not even necessary to know what other systems may be added later. The player system in the example on page 49 was implemented in this fashion. Each small system was written and implemented before it was incorporated into the larger database.

## Programming and maintenance

FOCUS has a report-generator and a file-maintenance function that does most of the work for the programmer. Unlike COBOL or FORTRAN programs, which may contain more than 1000 statements, FOCUS programs rarely exceed 100 statements. Most contain less than 50 statements and, at times, as few as three. According to a study done by Nanus and Farr,[6] the effort required by a programmer can be expressed by the following equation:

$$\text{Effort} = (\text{Constant}) \times (\text{Number of Statements})^{1.5}$$

Many times, FOCUS programs run correctly the first time tested. After implementation, bugs are rarely found, and if so, easily fixed. Less than two percent of our time is spent on the maintenance of implemented programs.

Responsibility for a system can easily be transferred to another person or team. As noted earlier, the Product Assurance VideoDisc-player database in the diagram was transferred to a person in the Player Product Assurance organization. The transfer was very smooth. The person taking over the system had no programming experience outside of a course in college, and had never used FOCUS. He learned FOCUS by reading the manual and took over complete responsibility for the system within two months. This was in addition to the responsibilities he still had in the Player Testing Lab.

## Training

A two-day course on FOCUS programming is available from Cherry Hill personnel, but it is not absolutely necessary. For programmers who have some basic knowledge of the IBM system (a one-day CMS course at Cherry Hill is sufficient) the manual is clear and easy to understand. There have been many instances where someone has read the manual, asked a few questions of the systems-support personnel at Cherry Hill and then set up their own database system. Most of the time, as long as someone is available to answer a few questions, the manual is sufficient. Since the use of FOCUS does not require a lot of training and experience, training costs are actually reduced and FOCUS can be used almost immediately.

As for the user, training is even easier. If the data entry and report generation is done directly by FOCUS, the user logs onto the computer, types FOCUS and executes the program.

## VideoDisc projects

Product Assurance projects for VideoDisc cover a wide spectrum of applications. All of them involve summaries for engineering analyses and management information; some also contain general historical information for various departments. Projects cover the following general areas:

- Organization and analysis of automatic-machine-collected data.
- Histories of laboratory test results (VideoDisc, Player, Caddy, Cartridge, Compound, Stampers).
- Warranty returns with analyses (VideoDisc and Player).
- Projected part-failure rates.
- Vendor quality reports.
- Schedule computation (projected completion dates).
- Project tracking.
- Production quality-control tracking.

## Advantages of FOCUS

- Systems design and programming times are small.
- Development costs are greatly reduced.
- Maintenance and debugging of implemented systems require very little time.
- New data fields may be easily added to the database, or the size of existing fields may be changed.
- Special selections, which are not built into the program, may be made at run time.
- Two or more databases can easily be linked together so that data can be used from both at the same time, if they have a common field (such as a serial number).
- A minimum amount of training is required for both the programmer and the user. No previous programming experience is necessary.
- Access to the database or individual fields can be restricted to key personnel.
- FOCUS can read non-FOCUS files and databases.
- One-time programs can be written "on the fly" (typed directly into the system).
- Programs are short and simple.
- FOCUS-generated reports are clear and concise.
- A built-in statistics package is available.
- A built-in graphics package is available.

The program will ask for all data that it needs to complete its job (more training has been required for use of the terminal than in use of the systems). The user is usually required only to decide when reports are to be issued and when data is to be loaded. For most of our systems, the user generates all routine reports and loads the data.

## Fourth-generation languages on "micros"

For those users conversant with FOCUS or other fourth-generation languages, at least one software product is currently marketed for a micro, with more on the way. NPL, implemented for the Apple computers by Desktop Software, affords the user true distributed computing. Although it uses "flat files," it does so with a FOCUS-like language. By tying the micro to the mainframe, the user may "download" extract data to the small computer for further manipulation. Conversely, input data may be collected locally and "cleansed," formatted or sorted before it is "uploaded" to a FOCUS (or other) file on the IBM mainframe. In both cases, terminal, transmission and I/O costs are minimized. In addition to NPL, FOCUS itself is under development for the IBM personal computer by the vendor, Information Builders.

## Summary

FOCUS has been a tremendous tool for Product Assurance. If it had not been available, the work could not have been done as effectively with FORTRAN or COBOL even if many more people had been hired. Time and costs for program and systems development were reduced by 90 percent. Maintenance of existing programs was reduced by 98 percent. Flexibility and response to special requests were greatly increased; the timely use of our FOCUS database systems provided significant information in many decision-making processes. Every system that we have implemented has provided unforeseen side benefits. One report revealed a situation that will impact the income of the disc operations by millions of dollars in 1982.

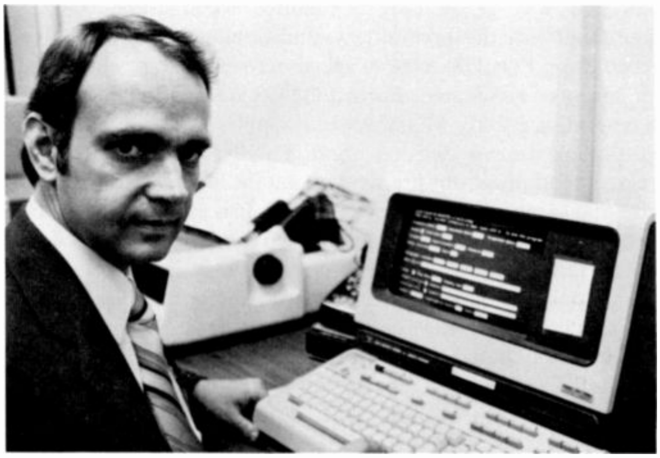
FOCUS proved to be everything that was needed and more. For the majority of projects, anyone who wants a quantum jump in programming efficiency and corresponding reduction in development costs should consider the use of a database-management system such as FOCUS. It can be used for a wide range of applications, from the collection and analysis of data for engineers, to the organization of data for the personnel department.

## Acknowledgments

Barney Milstein, Corporate Computer Services, and Tom Strauss, "SelectaVision" VideoDisc Operations, offered valuable assistance.

## References

1. Read and Harmon, "Assuring MIS Success," *Datamation*, (February 1981).
2. Lerner, Brownstein & Smith, "Winds of Change, The Impact of Fourth-Generation Languages on Documentation," *Computerworld*, (March 29, 1982).
3. Information Builders, Inc., *FOCUS Users Manual*, Information Builders, Inc. (1981).
4. Scearce, F.T., "Product Assurance for the VideoDisc Player," *RCA Engineer*, Vol. 26, No. 9 (November/December 1981).
5. Myers, W.W., "VM Line Cost Reductions with Intelligent Terminals—HP2647A," *RCA Corporate Information Systems and Services*, Vol. VI, Issue 8 (August 1, 1981).
6. Brooks, F.P., Jr., *The Mythical Man-Month*, Addison-Wesley Publishing Company, Inc. (1972).



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J.E. Fay

# Distributed system architectures for ATE

*Can suppliers provide automated equipment with true functional modularity? And can users assume the additional responsibilities involved?*

**Abstract:** *There is a strong demand for more-flexible ATE-system architectures. Users are finding that they must have the ability to meet changing requirements and to support new technologies. This demand by users is driving ATE-system design toward modular, reconfigurable architectures. This trend has wide impact on users and suppliers alike. The users will have to become more involved in the systems-engineering aspects of ATE. The suppliers will have to find ways to maintain the integrity of ATE systems, even as they are forced to relinquish total control over the design. Test-design contractors may find themselves specifying, or even designing, test instrumentation to augment customer-supplied ATE systems.*

*Finding ways to construct extendible systems is a real challenge for the ATE industry. There is no simple solution, and many approaches are being pursued. The new emphasis is on structured design with modular hardware and modular software. Partitioning a system into modules is not new. What is new is the diversity of people and organizations now involved in the process. The design of ATE systems will be more interface- and software-dominated.*

The initiatives for developing a new architecture for automated test equipment (ATE) systems have come from users. The acquisition of an ATE system requires a large investment of resources on the part of a using organization. Facilities have to be provided, people have to be trained, and test-program sets have to be produced. One very common acquisition policy for ATE is to analyze test requirements and produce customized ATE systems. Another policy is based on the common use of a general-purpose system. The first policy leads to excessive proliferation of equipments, and the second approach leads to complex adapters and programming. So neither approach is entirely satisfactory. The using organizations perceive a need that is not being met by current systems.

Users are demanding systems that are flexible and can be molded to fit evolving requirements. The challenge to the suppliers is to produce ATE systems with true functional modularity. This has to be done in a way that allows users to add or delete functions, while maintaining an integrated cohesive system. The interfaces and system concepts have to be pre-engineered for the user so that everything fits together smoothly. The difficulties are the software interfaces and the signal interface to the units under test (UUT).

Commercial ATE manufacturers have been leaders in the development of modular test systems. Commercial suppliers were quick to adopt microprocessor control and standard-interface buses. They have shown that modular systems can be easily assembled from a catalog of instruments, but many fundamental problems remain unresolved. A commercial ATE user finds that he cannot upgrade his system by putting in a better instrument unless he is prepared to rework every test program that uses the old instrument. Commercial instruments have no compatibility at the software level. The achievement of this compatibility is not easy.

## Modular design

Modular design results from software-dominated, generalized, top-down engineering. It exploits the availability of low-cost computing modules to produce functional modularity in hardware as well as software. The advantage of a modular approach is not so much in technical performance as it is in achieving system designs that are more manageable and responsive to user needs. A modular approach allows management partitioning of a system for reasons of: independent, phased development; smaller development packages; easier fault isolation and repair; and insertion of future technology.

A distributed processor network has a capability for parallel processing. Several processors can be doing useful work at the same time. It may be difficult to see the advantage of parallel processing in a test system because testing is a step-by-step sequential process. Nevertheless there are many ways to exploit parallel operations. The next stimulus can be setting up, while the last measured value is being formatted for output to the test-results


Final manuscript received May 19, 1982.
Reprint RE-27-4-8

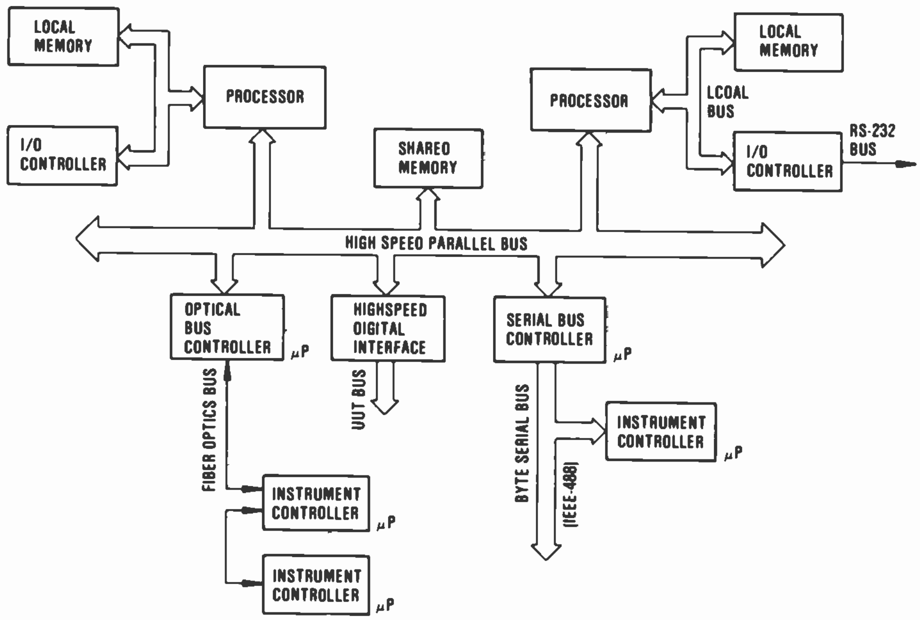


**Fig. 1. The distributed processor concept.** Some of the ways that processors can be interconnected.

record. Or several stimuli can be setting up at the same time. Several studies have shown that multiport ATE systems have distinct advantages over single-port systems. Parallel operations would be a distinct advantage in multiport systems.

Figure 1 illustrates the distributed processor concept and shows some of the ways that processors can be interconnected. Different data-bus designs are used, depending on data rates and distance. High-speed, parallel buses are used for accessing memories and high-performance devices. Byte-serial buses are effective for moderate-length buses (to 50 feet). Bit-serial buses are best for long distances. The importance is that no bus, alone, meets all requirements.

## Issues

A distributed system architecture has to address many issues. Some are common to most distributed systems and others arise from special requirements of the ATE environment. The common issues are data-bus standards, software interfaces and protocols, database access, hardware failures, and error recovery. Issues specific to an ATE system include the UUT interface, the language used for bus communications, and resource sharing (in multiport systems).

Hardware standards have been developed for many different bus systems including bit serial, byte serial, and high-speed parallel buses. It did not take long for people to realize that hardware standards were only a very small first step in achieving compatibility between the elements of a distributed system. One of the biggest problems that users have with the IEEE-488 bus is software incompatibility caused by the lack of generally accepted communications protocols.

Protocols are software formalisms used to achieve reliable communications between programs. Protocols control many essential communication functions including error detection, error recovery, synchronization of data transfers, and the establishment or removal of communication paths. Protocols can also control multiplexing of several communications paths on a single physical channel. This can be used in multiport systems to support concurrent operations. Even in a single-port system, multiplexing of communication paths can be used to simplify the handling of asynchronous errors (for example, voltage trip on a power supply).

Message content is another issue. If substitution of one instrument for another is a system requirement, then communications have to occur at a higher, more abstract level. Standard usage today is based on low-level device-specific communications. For example, "R1, F2" could mean "VOLTAGE MAX 100 V, FREQ RANGE 10 HZ TO 4 KHZ." Many systems have also used this cryptic, device-oriented language for test-program coding. Instrument interchange and program portability are prohibitively complex tasks in this kind of system. The issue here is abstraction and transparency. A reconfigurable system has to be based on the concept of hiding implementation details.

The UUT interface is an ATE subsystem that needs to be highly integrated. The ideal system configuration has a single point of interface and all system specifications must be referenced to the UUT interface. Transmission-line effects will degrade system performance if active circuits or impedance-matching networks cannot be located within inches of a UUT signal source. It is difficult to provide a single point of interface for a modular, reconfigurable system architecture. Compromises or unavoidable complexities are likely in this area.

The technical issues that we have identified so far are ones that can be managed by the ATE system designer. There is another aspect to reconfigurable expandable systems that is centered on responsibilities. Phased development with different contractors for the modular units can be the source of many problems. Responsibility must be assigned for quality assurance and configuration management of hardware and software. Document control and distribution of software updates have to be managed. Maintenance, calibration, logistics, and spares procurement are difficult to manage.

## Design considerations

For the following discussion, it is assumed that the design goal is a modular system that is reconfigurable and extendible. The system is to be designed for execution of test programs written in a higher-order signal-oriented language. Resources must be shared so that more than one test program may be executing at one time. A single point of interface is to be provided for each UUT.

The primary motivation for using distributed processing is the manageability of system-programming tasks. This is essential in a time-phased system development where different contractors may be involved, at different times, in developing test-capability modules.

ATE systems that have centralized control architectures require large monolithic test-executive programs. The test executive is the operational software that controls test equipment, and it is sometimes called the run-time system or ATE-operating system. Large executive programs can be managed by using structured design techniques, but this is difficult when more than one contractor is involved. Violation of system-design philosophies is all too common when there is a division of responsibilities. The software organization and structure has to be preserved, even under adverse circumstances. The main objective of structured software design is to produce programs that are at least conceptually modular. Physical modularity in a distributed processor system tends to reinforce and accentuate the conceptual modularity of the system software.

Expandability and reconfigurability are natural attributes of modular systems. System software has to be designed with this flexibility as a requirement. Expandability and reconfigurability add another dimension of complexity to the software-design task. Centralized executives may require recoding or a complex system-generation procedure to accommodate flexibility in the hardware configuration.

A distributed system architecture takes out much of the complexity by moving control tasks from the executive program to the local processors of "intelligent" hardware modules. The local control tasks are relatively small and easily written programs.

The flexibility of the executive software is determined by the amount of device-specific coding and the locations of this code. A major software objective is to avoid distributing device-specific coding and information. It is also necessary to minimize and localize device-specific elements within the support software (the compilers, simulators, binders, syntax checkers, and so on). In a high-order signal-oriented test programming there are many steps in the processes that occur between a source statement and execution of the statement on the test hardware:

- Check syntax.
- Check adequacy of signal specification.
- Select candidate test equipments based on capability.
- Select a specific piece of equipment from the list of candidates.
- Check validity of run-time-variable signal characteristics.
- Translate signal-characteristic values into device-specific programming data.
- Set up ancillary equipment (signal routing matrix, UUT interface unit, synchronization channels, and so on).

The system designer has to specify the software products that will be furnished. Typically the software products include a compiler, a linker, a run-time executive, and test-module firmware. The functions identified have to be allocated to the various software products. Many of the test systems used today have evolved from the first-generation punched-tape systems. In first-generation systems, there were no run-time variables and no separately compiled procedure libraries. Everything was done at compile time (or done manually by test programmers). Some computer-controlled systems are still based on doing everything at compile time.

Multiport and reconfigurable system architectures change the software trade-offs significantly. In these systems, the software is not able to allocate specific equipment until execution time. Resource management has to be done by the run-time executive. Otherwise it would be necessary to supply different program sets to every ATE configuration, and resources could not be shared effectively in multiport systems.

The character and complexity of the run-time-executive system significantly changes when the final allocation of equipment is deferred until execution. If functionally equivalent equipments can be installed in varying configurations, the translation from abstract signal-oriented descriptions to concrete device-oriented programming has to occur within the run-time environment. If the main executive is not to be cluttered with device-specific coding, then the only logical place for this coding is in the devices themselves. This leads to the conclusion that bus communications in the modular generation has to occur at a fairly abstract level, probably in an ATLAS-like format.

If the system uses high-order communications issued by a main executive, there has to be a way to accommodate nonconforming equipment. This would allow the use of commercial instrumentation and instrumentation built to other standards. The way to address this is with another layer of control. The intermediate layer of software would normalize communications with the nonconforming equipment. The software does not necessarily require an intermediate processor, although a separate processor could be advantageous in off-loading computational tasks from the executive processor. The layered software architecture is advantageous in many designs but there is less flexibility in locating code when the nonconforming module is controlled by unalterable firmware.

The system concept that emerges from all of these various design considerations is based on multiple, cooperating, software tasks. The tasks are small units of code that communicate in controlled ways. An operating system is needed to tie everything together into one cohesive entity. The operating system manages system resources, and controls task synchronization and communications. A distributed operating system is needed for complete flexiblity in a modular system, because a given capability may not always be at the same address or even on the same bus. A distributed operating system provides transparency to support reconfiguration. A task needing to communicate with another task does so via system calls that reference logical addresses. The mapping from logical to physical addresses occurs within the distributed operating system. An added benefit is flexibility with respect to the actual communications path. The system architects need to have the ability to change from one bus to another—from an electrical bus to an optical bus, for example—without serious impact on software. Confining the code that controls physical transmission of messages to a well-defined part of an operating system has many advantages.

## Conclusions

One strong motivation for developing modular ATE is the hope that standardized interfaces will encourage competition and guarantee multiple sources of supply for test-capability modules. It has become obvious that direct interchange of modules will be impossible without software-compatible bus communications. Software compatibility will not be easily achieved.The solution requires dedicated effort and strong insight into the many facets of the problem. The successful solution will likely include the following elements:

- A systems contractor for software;
- Rigorous interface definitions;
- A layered hierarchy of software; and
- A distributed, multitask operating system.

Modular ATE systems have many advantages but there are drawbacks too, so the decision to go modular has to be carefully considered. Modular systems are more readily adapted to changing requirements, but varying configurations will require carefully planned configuration management. Modular systems are easily augmented to add capability, but this can lead to a proliferation of augmentation units. Modular systems software is potentially more reliable and maintainable, but

## A glossary of ATE-system terms

**Multiport:** A system with multiple interfaces for operators, programmers, or UUTs.

**Software architecture:** The allocation of software functions to processors, programs, modules, and procedures. The design of network, protocol and data structures.

**UUT:** Unit Under Test, a generic term referring to a circuit, a board, a module or any other item test by ATE.

**Bus:** The electrical connection between communicating devices.

**Network:** Hardware and software that facilitates communications between computers.

**Protocol:** An agreement concerning messages carried by a computer network. Includes signals (ready, busy, acknowledge, etc.) and error detection/correction schemes.

**Serial bus:** A bus that transmits data serially, bit-by-bit or byte-by-byte, rather than transmitting whole computer words.

**ATLAS:** An IEEE standard language for programming test systems.

**IEEE-488:** A standard communication bus for test systems.

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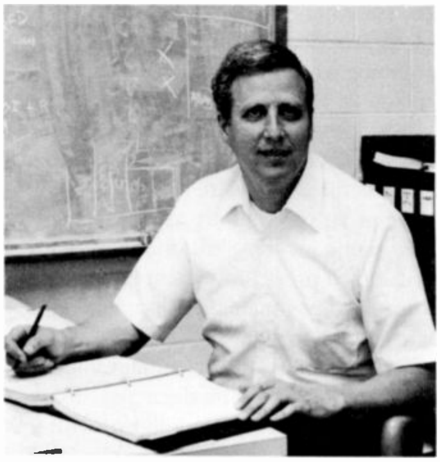

only when the basic design concepts are strong and interfaces are well defined.

Modular ATE places more responsibilities on the user for systems engineering and configuration control. For many users, a totally modular approach may not be the right answer. If a user does not have the resources or the time for systems engineering, the best approach could be a family of systems based on a well-integrated general-purpose core. Modular concepts are just as applicable to a core-based family of systems as they are to systems that do not have a well-defined common core. The advantages of a common core are stability and reliability. The common core would provide a proven set of basic test capabilities and a single point of interface that could always be relied on. Modular augmentation would be specified for meeting new demands placed on the system. The core-based system avoids many of the problems found in totally modular designs such as responsibility, reliability, repeatability, and manageability.

The modular generation could very well become a natural step in the evolution of ATE architecture rather than a radical departure from the conventional ways of constructing test systems. Users will gain new flexibility, primarily in augmentation, that will handle their unforeseen requirements. There are practical reasons for an ATE family of systems with common elements and, after all the dust is settled, it is likely that this pragmatic solution will prevail.

J. Koskulitz | M. Rosenfield

# RAMP—RCA Solid State's assembly mechanization program

*This "hands off" automated assembly process improves the quality and yield of plastic-packaged dual-in-line ICs.*

**Abstract:** *RAMP (RCA Assembly Mechanization Program) is a Solid State Division program to automate and upgrade the assembly of plastic-packaged dual-in-line integrated circuits in Kuala Lumpur, Malaysia. The authors give equipment information, quality and reliability information, key design and assembly concepts, process concepts, and other details of the system. The article includes comparisons of pre-RAMP and RAMP processes.*

In March 1981, the Solid State Division initiated a comprehensive mechanization program in Kuala Lumpur, Malaysia, for the purpose of upgrading the high-volume assembly of 8-, 14-, and 16-lead plastic-packaged dual-in-line (DIP) integrated circuits. The program, identified by the acronym RAMP (RCA Assembly Mechanization Program), has made the plastic-package assembly facility in Malaysia as modern an assembly facility as is possible with the state-of-the-art wire-bonding technologies currently available.

The RAMP program is the result of a comprehensive review begun in December 1979 into ways to reduce manufacturing costs, improve outgoing competitive quality of RCA ICs, and increase the general operational efficiency overall. The main goal of the RAMP program is a "hands-off" automated assembly process. Such a process virtually eliminates the deleterious effects, on yields and quality, of manual processing and handling. Table 1 (page 60) is a comparison of assembly-process segments, handling methods, and hardware for RAMP and pre-RAMP systems (plastic integrated circuits).

## Quality and reliability

The RAMP program was conceived and initiated with every anticipation that the quality of the product produced would be improved as a direct result of eliminating the excessive manual handling associated with the pre-RAMP process. The lack of mechanization of the pre-RAMP process resulted in product variability and difficulty in achieving a continuous, reproducible system. Analysis of pre-RAMP lot rejections and failures revealed that a majority were the result of handling damage and mixed product. In order to achieve the highest level of outgoing quality possible, it was necessary to employ lot-acceptance-and-screening techniques. This approach is not compatible with timely, direct feedback for real-time corrective action.

The mechanized RAMP process "builds in" quality as opposed to "screening" it in. The reproducible nature of a continuous mechanized process allows effective in-process quality monitoring and consequent improvements in outgoing quality. Reports from the Malaysian plant reveal significant yield improvements that can be attributed directly to the reduction of defects through the use of the RAMP process. This improvement is especially evident in the pellet processing and interconnection areas of the assembly process, the most critical areas for potential damage.

Only good quality and sound design will produce reliable product. The RAMP system of assembly mechanization, by eliminating the variables associated with excessive manual handling, results in improved consistency of reliability.

The reliability data collected to date for CMOS (Alloy-42 (ASTM F-30) frame) devices shows significant improvement in RAMP over pre-RAMP units for certain accelerated-stress tests: temperature cycle, thermal shock, and 15-psig pressure cooker. An improvement in moisture resistance is consistent with the reduced handling inherent in the RAMP system; that is, there is less potential for contamination.

Preliminary bias-life data for CMOS shows an order of magnitude lower failure rate at a 60-percent confidence level, when extrapolated to 85°C, of RAMP over pre-RAMP units. This percentage is based on a predicted value from a limited sample size tested at temperatures ranging from 125°C to 200°C.

The performance of bipolar RAMP devices compares favor-


Final manuscript received May 25, 1982
Reprint RE-27-4-9

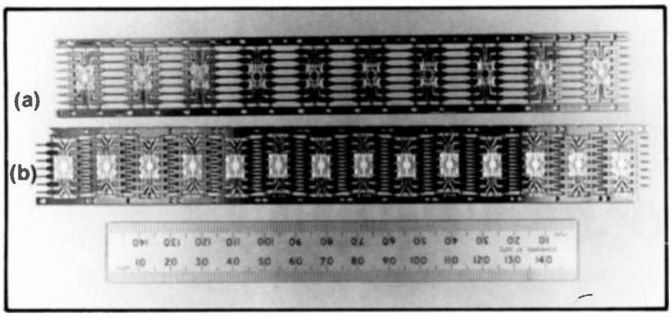


**Fig. 1. A pre-RAMP lead-frame strip with 10 unit sites per strip,** and end-to-end lead arrangement, for a 14-lead device **(a)**, and the strip used in the RAMP process **(b)**. Through interdigitation (offsetting of the leads of adjacent sites) the number of unit sites on the RAMP strip has been increased to 14.

ably with the pre-RAMP database. No statistical comparisons have been made, however, because of the relatively small sample accumulated so far. Extensive reliability evaluations will continue until the entire high-volume-output RAMP system has been thoroughly characterized.

## Key design and assembly concepts

The key design element of any IC plastic package is the lead frame. Figure 1a shows a pre-RAMP lead-frame strip with 10 unit sites per strip for a 14-lead device. Figure 1b shows the strip used in the RAMP process. Through interdigitation (ID), the number of unit sites on the strip has been increased to 14 (16-lead devices are also produced from 14-site frames). Eight-lead devices, for which there were previously only 8 unit sites per strip (Fig. 2a), are now produced from side-by-side Dual unit site strips containing 28 sites (Fig. 2b).

Figure 3 shows how interdigitation works. In the standard lead frame (Fig. 3a), leads are laid out end-to-end. In the interdigitated frames (Fig. 3b), alternate sites were displaced 0.025 inch, so that the leads from one site fit between the leads of an adjacent site. The difference in pitch (the distance between sites) in the 14- and 16-lead frames is more than 1/8 inch. Note that whereas previously 8-lead frames (Fig. 2a) were of a different width than 14- and 16-lead frames (Fig. 1a), mechanized handling throughout this RAMP process dictates that all lead-frame strips be of identical geometry (length, width, thickness, and pitch). The actual pitch dimension can vary depending on finished package requirements such as body width, lead length, and so on.

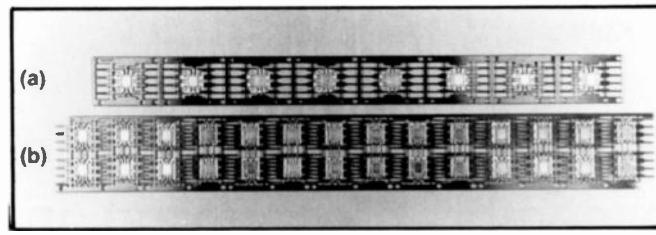


**Fig. 2. Eight-lead devices,** for which there were previously only 8 unit sites per pre-RAMP strip **(a)** are now produced from side-by-side, interdigitated, dual unit-site strips containing 28 sites **(b)**.

In addition to the ID design improvement, the 8-lead frame boasts an internal design change that improves the moisture resistance of the package, by creating longer "moisture-leak" paths and providing "lead locking," (leads anchored in the plastic of the package), features not available on pre-RAMP designs. The 8-lead RAMP frames can be made with mounting pads of either 0.080" × 0.100" or 0.110" × 0.134" dimensions; previously only the larger pad was available. This smaller pad further enhances the moisture resistance of the 8-lead package.

The savings in lead-frame raw materials and the increase in output (units per inch) for 14- and 16-lead devices under the RAMP ID design are approximately 30 percent. Savings of 50 percent in materials and increased outputs of up to 100 percent for certain process steps can be realized with the Dual-8 lead-frame design.

The lead-frame raw materials used for the RAMP units are the industry-standard Alloy-42 and a copper alloy. The amount of the material savings in dollars can be appreciated when one realizes that during the first quarter of 1982, the raw material cost for Alloy-42 strip stock was about $3.80/lb, with about 1.7 lbs required for a thousand 14- or 16-lead ID frames.

A comparison of the finished packages for RAMP and pre-RAMP devices (Fig. 4), shows that the RAMP plastic-body design has been simplified through the elimination of the ejec-

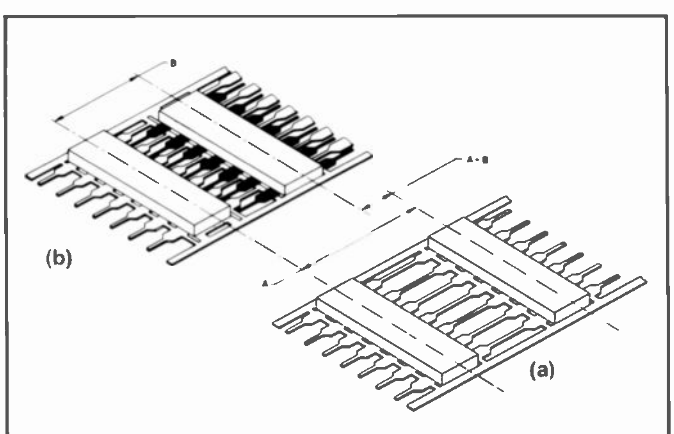


**Fig. 3. How interdigitation was accomplished.** In the standard pre-RAMP lead frame **(a)**, leads are laid out end-to-end. In the interdigitated RAMP frames **(b)**, alternate sites are displaced 0.025 inch, so that the leads from one site fit between the leads of an adjacent site. This method also improves the use of strip material. Dimension A-B indicates pitch difference.

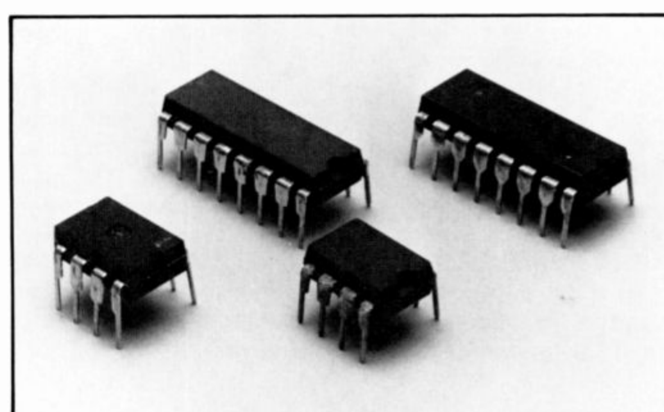

**Fig. 4. A comparison of the finished packages for RAMP and pre-RAMP devices.** The RAMP plastic-body design has been simplified through the elimination of the ejector-pin depressions and the embossed No. 1 previously used for pin-index purposes; these modifications make the branding process easier. The pre-RAMP package has a glossy finish, and the RAMP package has a matte finish.

tor-pin depressions and the embossed No. 1 previously used for pin-index purposes. The RAMP package also has a matte surface as contrasted with the glossy finish of the previous package.

## Process concepts

The assembly manufacturing processes for DIP units are segregated into four major areas: pellet processing and management; interconnection; encapsulation and finishing; and final test/ship. Again, the goal of the RAMP system is to minimize manual handling throughout the processes and to eliminate the need for individual part transfers by an operator.

A totally integrated approach to RAMP system development led to the design of input and output magazines and carriers to match equipment capability. For example, the transfer-molding equipment accepts 336 units or 24 strips-of-fourteen. Hence, the input lead-frame strip magazine was designed to hold 24 strips. Output from the molding operation, and the input to bottom branding, is by strip-stack magazine. These magazines were designed to house 144 strips of molded units, a multiple of 6 molding shots. Similar thinking was incorporated in all the other carrier designs.

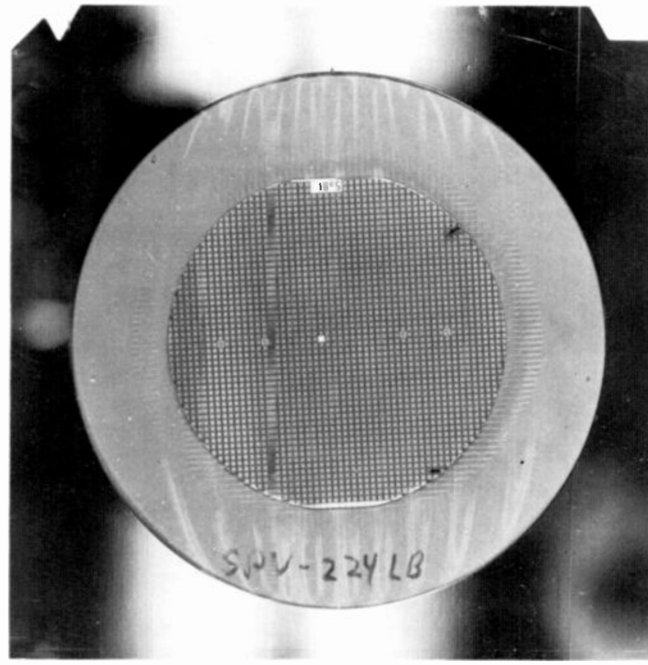

**Fig. 5. Wafers are taken from their shipping bags and laminated** with minimal heat and pressure to a PVC film with contact adhesive on one side. The film is held in a film-frame carrier, shown in the illustration, which allows for convenient transport of wafers and clean storage at any point in the pellet-processing sequence through die attach.

## Pellet processing and management

PELMAN, a pellet management system developed for RAMP that improves lot control and accurately maintains original pellet orientation, is an integrated system for processing a wafer from the point of receipt offshore through the operations of separation into discrete pellets (chip or die) and 80X pellet inspection. Wafers are received in heat-sealed nitrogen-filled shipping bags, from which they are transferred and laminated with minimal heat and pressure to a PVC film with contact adhesive on one side. The film is held in a film-frame carrier, as shown in Fig. 5; the carrier allows for convenient transport of wafers, and clean storage at any point in the pellet-processing sequence.

While still in the film carrier, the wafers are cut into individual pellets with a high-speed diamond saw, thereby eliminating wafer-breaking procedures and resulting in improved yields through the reduction of chips and cracks in the pellets. This technique also eliminates the need for individual pellet sorting, as had existed in the pre-RAMP process, since the separated pellets remain in the film carrier.

After cleaning the pellet matrix, the electrically good pellets are 100-percent visually inspected at 80X for various physical defects. The oriented, separated pellets are then passed in the film-frame carrier to the pellet-mounting operation. The visually defective pellets are identified with an ink dot that will be optically recognized by the automatic mounter.

### *Interconnections*

Lead-frame strips (Fig. 1) are positioned into the input stage of a magazine-loading machine, which fills the entire strip magazine (Fig. 6), automatically. This is an off-line operation and is the only time in the RAMP process that the unprotected strip is handled by an operator. However, because delicate wires and integrated-circuit pellets are not involved, the risk to the final product quality is minimal. The frame-strip magazine feeds the frame strips onto the track of the die-attach machine, Fig. 7. The pellet-carrying film carrier is presented to the optical pattern-recognition unit (PRU), which looks for and passes over pellets marked with an ink dot. Good pellets are automatically picked from the film and placed onto predispensed epoxy adhesive on the lead-frame die-attach pad. The completed frame strips exit into a magazine identical to the one used at the in-

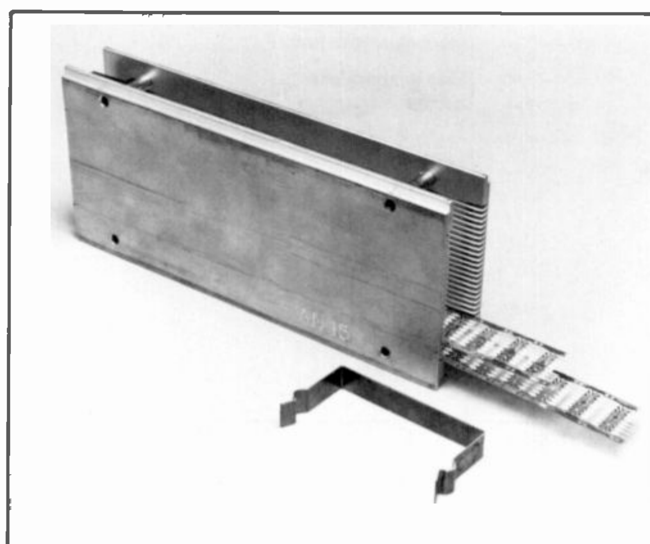

**Fig. 6. The lead-frame strips** shown in Fig. 1 are positioned into the input stage of a magazine-loading machine, which automatically fills the entire strip magazine shown above. The magazine handles assemblies from die attach into mold-plate loading. The clip in the foreground snaps over the end of the magazine to retain the strips.

**Table I. Comparison of assembly process segments, handling methods, and hardware for RAMP and pre-RAMP systems (plastic integrated circuits).**

| Standard Dual-In-Line Plastic Package | PRE-RAMP | | | RAMP | | |
|---|---|---|---|---|---|---|
| *Assembly Manufacturing Process Segments and Steps* | *Process Steps* | *Handling Hardware* | *Handling Method* | *Process Steps* | *Handling Hardware* | *Handling Method* |
| *1. Pellet Processing* | Saw scribe or diamond scribe, clean, separate by cracking<br>Sort good pellets into trays and orient<br>Pellet inspect and remove rejects | Cardboard sheets, filter paper, glass/plastic tray | Tweezer, vacuum pencil, or other manual pickup | Wafer tape mount<br>Saw-cut separation<br>Wafer cleaning<br>Pellet inspection and ink visual rejects | Film-frame carrier | X-Y tables, manual/automatic |
| *2. Interconnection* | Manual mount device with epoxy<br>Thermocompression (TC) wire bonding (manual and semi-automatic)<br>Visual inspection | U-channel slotted trays and assorted fixtures | Vacuum pencil, tweezer, or other manual pickup | Automatic pellet mount with epoxy<br>Thermosonic (TS) wire bond (fully automatic)<br>Visual inspection (hands off) | Strip magazines | Automatic strip indexers (linear) |
| *3. Encapsulation and Finishing* | Manual mold loading<br>Chase mold and manual bottom brand<br>Five temperature cycles<br>Manual finish<br>Manual solder dip<br>Manual derail | U-channel slotted trays and assorted fixtures | Tweezers or other manual pickup | Automatic mold loading<br>Aperture mold<br>Automatic laser bottom brand<br>Automatic finish<br>Automatic solder dip<br>Automatic derail | Strip stack magazines<br>Solder-dip-carrier flute magazine<br>Sticks | Automatic strip indexers (linear or shuttles); manual carrier transfer |
| *4. Final Test/Ship* | Manual test<br>Manual top brand<br>Pack and ship | Trays<br>Sticks | Some automatic; some manual | Automatic test<br>Automatic top brand<br>Pack and ship | Sticks | Automatic stick-to-stick |

feed. Compared with the pre-RAMP manual die-attach system, this automated station has increased throughput by a factor of five and has substantially improved the die-placement accuracy.

The wire connections from the integrated-circuit die to the appropriate lead-frame bond fingers are made with an automatic wire bonder. The in-feed/out-feed system is magazine-to-magazine, as in the die-attach station. The auto-index locates the strip with a die attached beneath the pattern-recognition optics. Preprogrammed data is compared with what is "seen" by the optics. Error data for $X$, $Y$ and $\theta$ are calculated and the bond head proceeds to dispense fine gold wire (that is, 0.001- and 0.0013-inch diameters) to make the appropriate connections automatically. Upon completion of interconnection, the index system automatically advances the next device into the bonding position. In addition to yield improvement, this station produces a fourfold productivity increase, bonding more than 5,000 wires per hour.

The post-bond visual inspection also makes use of a magazine-type handling system. Each device on each strip is located beneath a stereo zoom microscope at the operator's push-button command.

**Fig. 7. The die-attach machine,** a fully automatic system with pattern-recognition, adhesive-epoxy dispensing, frame-handling, and die pick/place features.

## *Encapsulation*

An important process change developed for RAMP was the replacement of a conventional "chase" mold with the "aperture" (plate) molding system. The use of aperture molding, which gets its name from the two thin plates used in the mold whose multiple apertures define the width and length of the plastic package, is gaining popularity in the industry because of its flexibility, potential for savings in molding compound, its uncomplicated nature, and the ease of maintenance and cleaning.

Figure 8 illustrates the major differences between chase and aperture mold systems. The design of the aperture system makes possible numerous package-body designs with a single press system, by simply changing plates. However, advance consideration has to be given to the types of packages desired so that the upper runner can be appropriately designed.

The aperture plate mold consists of a four part "sandwich." The uppermost element is the runner plate; the lowest element is merely a flat sheet. Both plates are securely mounted on the opposite platens of a molding press. The two innermost elements are the mold plates that define the geometry (width and length) of the body for each device. The thickness of the package body is controlled by the thickness of the plates. These plates are loaded and unloaded outside of the press, hence speeding processing time.

In the transfer molding of thermosetting epoxies, the material passes from the runner, through the gate, and into the mold cavity itself. As shown in Fig. 8, a comparison of chase and aperture molds, cavities in the aperture mold are filled from an end corner of each package cavity, whereas in the chase mold the cavities are filled from the middle of the body cavity. Filling from a top or bottom corner allows for increased density of device strips and a reduction in amount of epoxy used.

The lead-frame strips reach the encapsulation step from the post-bond visual inspection step in a magazine, from which

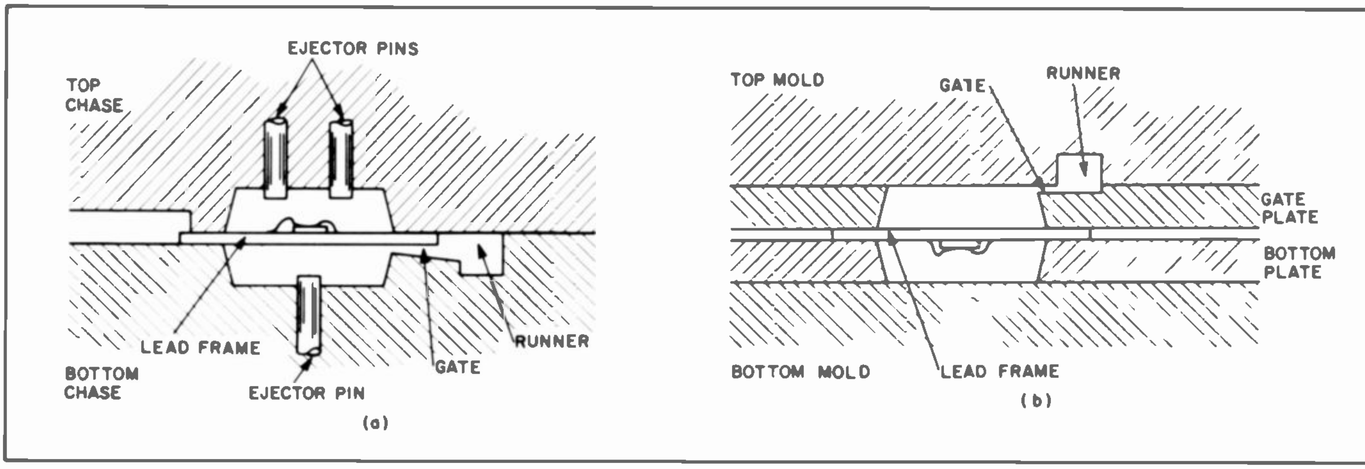


**Fig. 8. An important process change developed for the RAMP system** was the replacement of a conventional "chase" mold system **(a)** with the "aperture" (plate) mold system **(b)**. The aperture mold gets its name from the two thin plates used in the mold whose multiple apertures define the width and length of the plastic package. The chase mold produces packages with indentations made by the ejector pins and fills from a gate located in the middle of the body cavity. The aperture mold has completely flat mold surfaces, producing a package without indentations, and fills from an end corner of the cavity, a feature that increases mold density and reduces the amount of epoxy required.

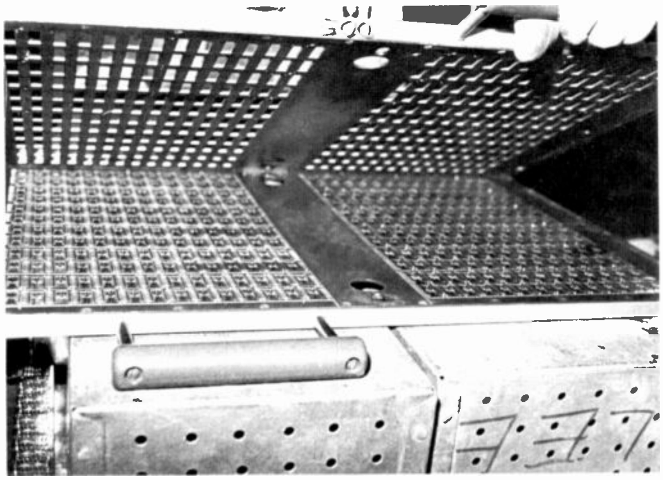

**Fig. 9. The lead-frame strips reach the encapsulation step** from the post-bond visual inspection step in a magazine, from which they are automatically unloaded onto a track. A transverse head picks up the strips and transports them to the preprogrammed location on the mold plate shown above. Note the density, the large number of strips of devices accommodated by the mold.

they are automatically unloaded onto a track. A transverse head picks up the strips and transports them to the preprogrammed location on the mold plate. This operation is continued until the mold plate is completely filled (Fig. 9). The operator then places the loaded plates into the press and closes the upper and lower platens against the plates. Preheated cylinders of epoxy molding material are then deposited into the press "pot." The operator initiates operation and awaits completion of the preprogrammed cycle.

The molded strips are automatically removed from the mold plates, after the plates have been removed from the press. A honeycomb-patterned plate is pressed against the molded units of the aperture-mold "sandwich," ejecting them from the plate onto a track. The molded strips are then loaded into the strip-stack magazine shown in Fig. 10.

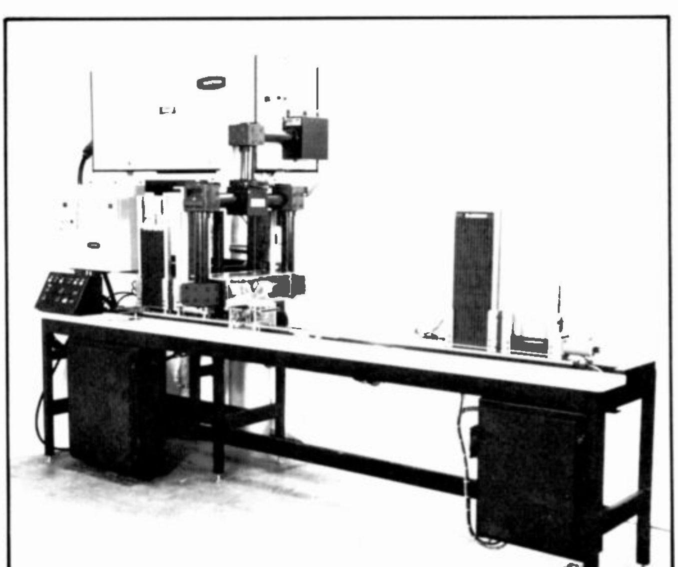

**Fig. 11. Devices are "bottom coded" after molding** by the low-energy laser brander shown. The in-feed and out-feed to this fully automatic machine is by strip magazine; the laser is triggered by the leading edge of a device body.

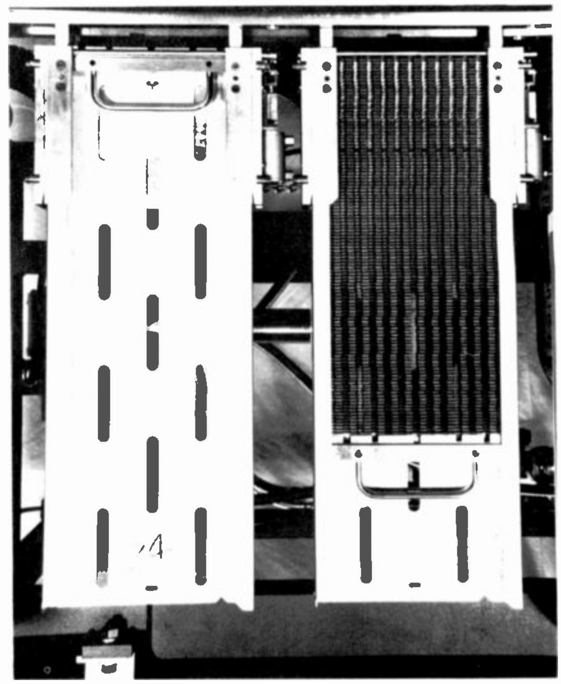

**Fig. 10. After the molding operation,** a honeycomb-patterned plate is pressed against the molded units of the aperture-mold "sandwich," ejecting them from the plate onto a track. The molded strips are then loaded into the strip-stack magazine shown. The magazine handles the strips through branding and into the finishing tool.

The encapsulation operation serves as a typical example of the improvement in productivity brought about through RAMP. As a result of the interdigitated lead-frame design and the aperture mold system, the number of units molded in a single mold cycle increased from a typical pre-RAMP 160 units to 336 units, more than twice the output. It should be noted that this increase did not require larger molding presses or more floor space. As an added feature, the number of cycles that can be performed per hour also increased since the mold plates can be cleaned outside the press. This arrangement allows one set of plates to be cleaned while another is in the press. The RAMP molding system is capable of producing ten thousand 14- and 16-lead units and twenty thousand 8-lead units per hour.

### *Branding*

After molding, the devices are "bottom coded" by the low-energy laser brander shown in Fig. 11. A very-low-energy laser was selected because only the surface of the package is treated. The in-feed and out-feed of the brander is by strip-stack magazine. The in-feed mechanism dispenses the strips onto a track that carries them to the branding position. The laser is triggered by the leading edge of each device body. The laser "looks through" a prepositioned mask that defines the characters to be branded on the device body. The track carries the branded strip into the output magazine with a machine rate of 45,000 units per hour. This contrasts with a manual branding rate of about 1000 units per hour, pre-RAMP.

### *Finishing*

Excess metal removal and lead formation is done in an automatic high-speed progressive tool (Fig. 12) that accepts the

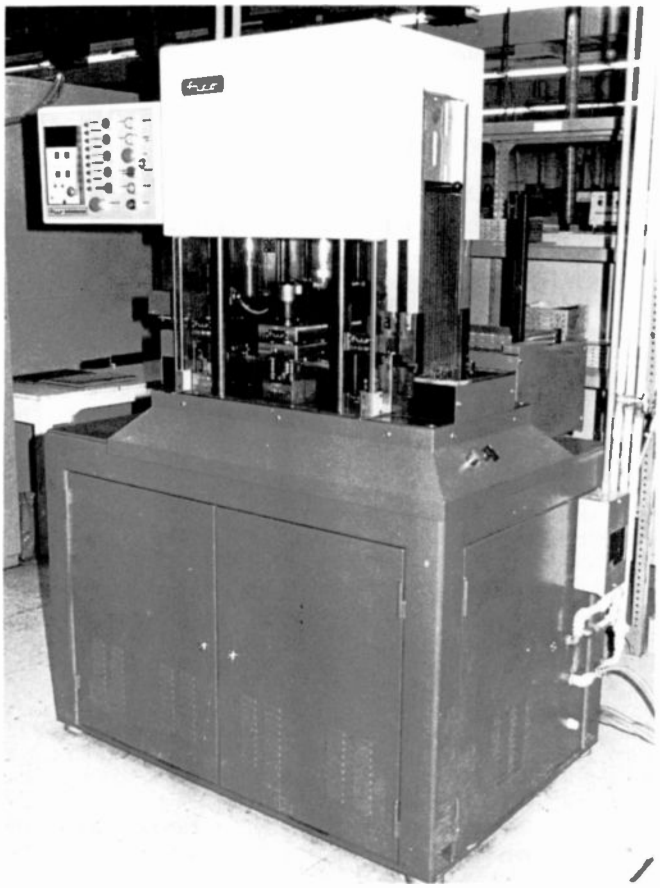

**Fig. 12. Excess metal removal and lead formation** is done in an automatic high-speed progressive tool, shown above, that accepts the strip-stack magazine at the input and discharges the formed devices, held in place by side rails, into carriers.

**Table II. Relative cost comparison of elements per unit, 1981 (pre-RAMP) versus 1982 (RAMP).** Interconnection materials include lead frame, mounting epoxy and gold wire. Encapsulation/finishing materials include molding compound and solder.

| | *8-Lead* | | *14-Lead* | |
|---|---|---|---|---|
| *Assembly Process* | *1981* | *1982* | *1981* | *1982* |
| Pellet processing | | | | |
| Labor | 2 | 1 | 2 | 1 |
| Interconnection | | | | |
| Material | 56 | 31 | 59 | 52 |
| Labor | 12 | 4 | 12 | 4 |
| Encapsulation/Finishing | | | | |
| Material | 26 | 7 | 23 | 19 |
| Labor | 4 | 2 | 4 | 2 |
| | 100 | 45 | 100 | 78 |

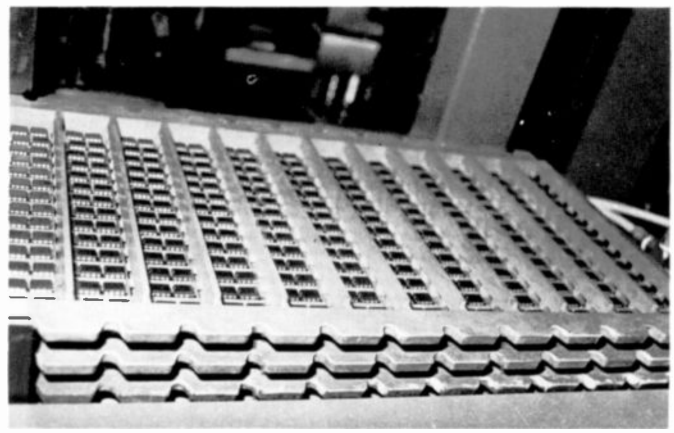

**Fig. 13. The solder-dip carriers,** specially designed so that only the side rails touch the carrier and not the device leads or body, assure complete soldering and cleanliness.

strip-stack magazine at the input and discharges the formed devices, held in place by side rails, into solder-dip carriers. The system output for 14- and 16-lead packages is approximately 40,000 units per hour; for 8-lead packages, output is 80,000 units per hour.

The solder-dip carriers with the formed strips (Fig. 13) move automatically through a system consisting of automatic fluxing, soldering, cleaning and drying (Fig. 14). The strip-carrying solder-dip carrier is then fed into the derail machine, which removes the rails from the devices and loads them into an extruded flute magazine. This magazine serves as the input for the post-soldering inspection station.

### *Final test/ship*

After post-solder inspection, the units are deposited in handling sticks. The automatic final-electrical-testing system and the automatic final-top-branding system both employ stick in-feeds and out-feeds.

## Summary

That the RAMP program has been successful in significantly reducing assembly manufacturing costs is evident from the 8- and 14-lead unit-cost data shown in Table II, a standard cost comparison of RAMP and pre-RAMP processes. Published manufacturing costs from 1981 and 1982 were used as the basis for the comparison (the final-electrical-test costs were not included because they are type dependent).

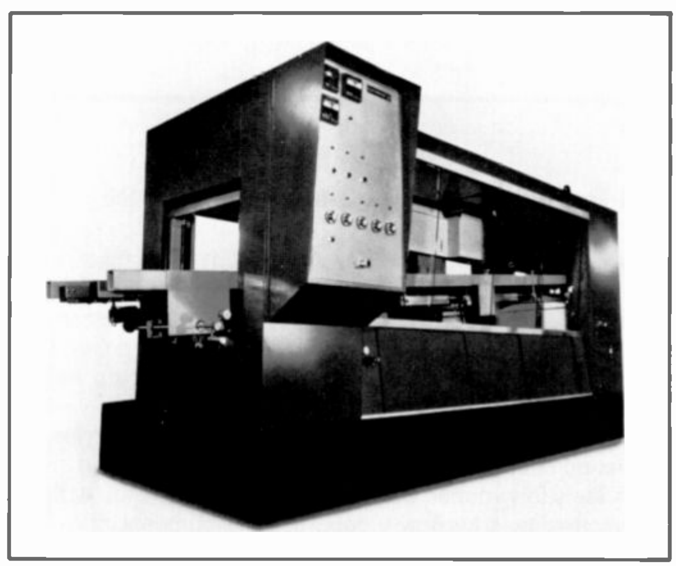

**Fig. 14. The automatic fluxing and soldering machine** accepts and feeds strip-carrying trays through fluxing and soldering operations and through the cleaning and drying module.

At this time, the volume capability of the RAMP process is also building very successfully. The 14- and 16-lead volume had approached 12 million/month by the end of the first quarter of 1982. The goal is to have an assembly capability of 18 million/-month by the end of the third quarter of 1982. The Dual-8-lead build-up was initiated in March 1982, with a plan to achieve a 5-million/month capacity by October 1982.

The RAMP concept is not restricted to 8-, 14-, and 16-lead packages; it can be adapted for virtually all dual-in-line (DIL) lead counts if sufficient volumes exist to warrant the capital expenditures. The concept will be implemented in other IC package areas in the future. Now, automated power-transistor assembly is being introduced at the Kuala Lumpur facility.

## Acknowledgments

The success of RAMP to date would not have been possible without the dedicated efforts of the many engineering and administrative personnel involved in the program both in the United States and offshore.

Authors Koskulitz (left) and Rosenfield.

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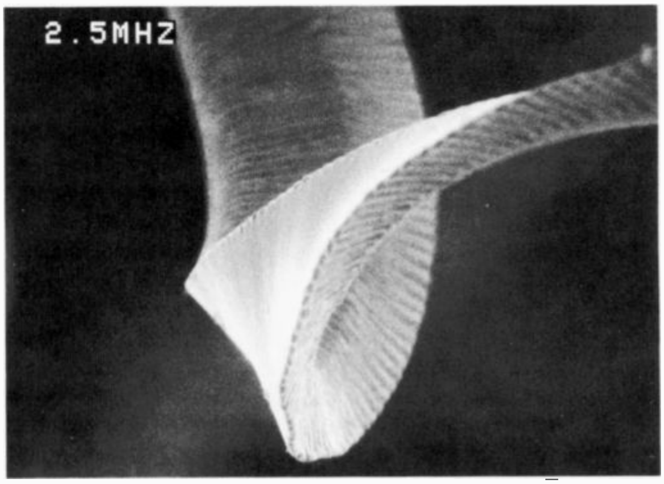
## *RCA Review* is a VideoDisc special issue

The March 1982 *RCA Review* (Vol. 43, No. 1) is the third issue devoted exclusively to the RCA VideoDisc system (see March and Sept. 1978, Vol. 39, Nos. 1 and 3). Most of the papers in this issue deal with the design of the cutter and the cutting of the VideoDisc master. These papers were written by members of J.A. VanRaalte's group at RCA Laboratories. The issue also includes papers on the stylus and pickup circuit and on the material used to make the disc. A fairly long paper, dealing with the testing setup at the Laboratories used for new VideoDisc developments, concludes the issue. Copies of the issue are available (at a cost of $5.00) by contacting the *RCA Review* office at Princeton, TACNET 226-3222.




**Fourteen km of metal "chip,"** 1/200 the thickness of a human hair, are cut from a VideoDisc master in recording an hour-long program. Pictured above, at 5000 times magnification, is a 50-$\mu$m long section of such a chip showing the minute signal undulations, whose counterpart on the master will ultimately be pressed into a disc to provide a color video program. This figure is taken from a paper in the current issue of the *RCA Review*.

R.T. Mercuri

# An Illustrated History of Computer Music

*A computer can be your "orchestra" as you create music rivaling some of the selections from the history of computer music on the attached soundsheet, between pages 72 and 73.*

**Abstract:** *Early work in computer music at RCA Laboratories and Bell Laboratories was an outgrowth of efforts toward synthesizing speech. Meanwhile, in the fifties and sixties, composers began to explore electronic- and computer-music possibilities. Computer music is defined with respect to its use in the analysis and synthesis of musical instrument tones, and in the algorithmic generation and performance of musical pieces. Music-editing possibilities are explored, and the owners of personal computers are given "starter" information on ways to create their own computer-generated music. An extensive annotated bibliography, and a soundsheet filled with musical selections, complete the package.*

Throughout history, humans in all societies have made musical instruments out of their everyday work tools. Our electronic age is no exception to this phenomenon—high-speed computers have been used both for composition and performance for well over thirty years. The computer has begun to influence every aspect of music, from the analysis of manuscripts to the construction of concert halls. These far-reaching effects can best be understood by chronicling the major developments in computer music and by describing some of the basic, underlying concepts of the field.

Long before the first electronic computers had been created, composers were establishing the groundwork for their use in composition and performance. Debussy, with experimentation in instrumental color, Mahler with the use of percussion instruments, and Schoenberg with atonal compositions, were all broadening the spectrum of "acceptable" sounds. In fact, electronic instruments such as the ondes martenot and the theremin began to be featured in major orchestral works during the 1920s.


Final manuscript received June 8, 1982.
Reprint RE-27-4-10

This paper was presented as a Colloquium at RCA's David Sarnoff Research Center in April, 1982, and is available on videotape (catalog No. 198) from RCA Corporate Engineering Education, Cherry Hill.

## The fifties and sixties: Sound synthesis

With the greater availability of tape recording equipment, in the late 1940s and early 1950s, a new school of composition emerged: *musique concrete.* The composers in this school, led most notably by Edgard Varese, used a wide range of recording techniques (splicing, variations in playback speed, overdubbing, and so on) in order to compose works from pre-recorded, natural sounds.

As an outgrowth of these efforts, Karlheinz Stockhausen and others began to build studios during the 1950s for the production of pieces that were completely electronic in origin. At this time, computers appeared on the scene, and it was quickly discovered that high-frequency pulses generated by the machines could be detected on radio receivers, thus providing the first primitive computer music. It was also during this time that Bell Telephone and RCA Laboratories began experimenting with electronic means of producing sound, primarily for the purpose of synthesizing speech. The first two selections on the soundsheet, "A Bicycle Built for Two" and "Blue Skies," were each excerpted from demonstration recordings intended to introduce sound-synthesis concepts to the general public (see page 72).

The RCA synthesizer, created by Harry Olsen and Herbert Belar, was developed at RCA's David Sarnoff Research Center during these early experiments, and was one of the first instruments to provide a mechanism for programming sound sequences. It was designed primarily as an analog device with controls over pitch, envelope and harmonic amplitudes; input of these parameters was via paper tape. Figure 1 shows Dr. Olsen in 1963 with the Mark II model synthesizer. An earlier version of this machine was used to synthesize "Blue Skies" for the 1956 recording on the soundsheet. This remarkable rendition **(selection 2)** in the style of a dance band with percussion, piano, brass and stringed instruments (even including a banjo) displays the synthesizer's ability to perform a wide range of sonorities—over twenty distinct parts may be heard in the example. The Mark II quickly gained popularity among composers as an excellent musical tool, and has been used exten-

## Computer music for the hobbyist

The activities in computer music available to the hobbyist are as many and as varied as are the specialties in the fields of computer science and electrical engineering. Projects can range from inexpensive assemblies costing less than $50, to the organization of complex systems containing intricate hardware with many megabytes of software. I will be outlining here a number of ways in which you can begin to assemble a basic, experimental computer-music system.

### *Components*

The components required for the creation of a computer-music environment must include some type of sound production hardware (along with a mechanism for amplification during playback), and a small computer system. An initial assembly can cost less than $200 and could permit experimentation with envelopes (the attack and decay characteristics of notes) and waveforms (sine, sawtooth, square...). With the addition of a display and keyboard, and some storage device (cassette tape or floppy disk), it is possible to develop a musical-note-entry system in order to use the computer as a performing instrument. As your hobby develops, you can continue to purchase or build additional hardware that could enhance the quality of the sound produced or possibly even permit you to combine or process analog-input signals.

You may wish to match the selection of your initial hobby projects to your area of technical expertise. For example, someone who already owns a personal computer might begin by writing an assembly language program that toggles the computer's output speaker at varying rates, in order to produce musical tones. The engineer could choose to experiment with off-the-shelf chips to create simple oscillators or digital-to-analog circuits.

My computer music system originally began as a home-brew project, but now mainly consists of commercially available components. The current set-up has been developed over the past eighteen months, and is comprised of the following hardware: an Apple IIplus microcomputer with 48K of memory, a 9-inch Sanyo green phosphor monitor, one 5¼-inch floppy disk drive, an RS232 serial interface card, an Epson MX80FT dot matrix printer with the graphics option, two ALF MC16 DAC boards for sound production, and a stereo amplifier and speakers. I occasionally also have access to one of several piano keyboards that interface directly to the Apple. The entire system (excluding the piano keyboard) could be purchased for approximately $3500.

My selection of the Apple as the

sively by Milton Babbitt at the Columbia-Princeton computer music center.

Computer synthesis of speech was found to be more effective than analog methods, and Bell Laboratories' work in this area produced the unique version of "A Bicycle Built for Two" **(selection 1).** This song was performed by modulating phonetic descriptors with pitch information. The result, first released in 1961, is well known because of its use in the film *2001: A Space Odyssey.* The piano accompaniment with its "stylized left hand" was subsequently added for the 1963 version reproduced on the soundsheet.

**Fig. 1. Dr. Harry F. Olson in 1963 with the RCA Mark II synthesizer.** This machine became popular with composers because it could be easily programmed, using paper tape, to produce analog sound sequences.

## Uses for computers in music

During the 1960s and 1970s researchers began to explore a wide variety of uses for computers in music, including:

- Analysis and synthesis of analog sounds for greater understanding of their physical characteristics;
- Synthesis of unique digital sounds;
- Use of the mathematical abilities of the computer to generate random strings and perform high-speed calculations for musical compositions;
- Theoretical analysis of musical compositions;
- Performance of complex music that is unplayable by humans; and
- Automatic transcription and printing of musical scores.

## Computer music: A definition

Since a proliferation of both analog and digital methods have been used for research in these areas, it is important to provide a definition for those activities that fall under the heading of central microcomputer for the system was affected heavily by its design. It incorporates eight slots for easy insertion of experimental boards or peripheral interfaces. The comprehensive hardware documentation available for the Apple has made it a perennial favorite among hobbyists. In addition, much of the early work with microcomputer music generation (most notably by Hal Chamberlin) has been done on the 6502 micro used in the Apple. Furthermore, I find the Apple's high-resolution display particularly good for musical notation (see illustration).

A considerable amount of music hardware has been created for the Apple II system. Table I, page 70, lists computer-music vendors. Sound-generation boards—available from ALF Products, Micro Music, and Mountain Computer—differ in the number of notes (voices) that can be played simultaneously,

*(Continued on page 68)*


**Soft Notes,** a musical work that can be performed identically when read upside-down, was both composed and printed by the Apple II computer.

"computer music." Sandra Tjepkema, in her *Bibliography of Computer Music*, states that only devices that are both programmable and give output in binary code may be included. Instruments such as the RCA and Moog synthesizers would not be considered, even though they may be programmable, because their output is in terms of an analog voltage and not a string of discrete numerical values.

To better understand this delineation, we must review some of the basic methods used in the production of music by computers. Hermann Helmholtz realized, in the late nineteenth century, that Fourier's law of periodic wave analysis could be extended to music in the following way: "Any vibrational motion of the air, corresponding to a musical tone, may be always, and for each case only in one single way, exhibited as the sum of a number of simple vibrational motions, corresponding to the partials of this musical tone." Complex periodic waveforms, therefore, can be broken down into a number of simple sine waves of differing frequencies and amplitudes (Fig. 2). Conversely, tones may be synthesized through the addition of such sinusoidal components.

For the computer to represent a simple or complex waveform, samples must be taken at specific intervals and stored as numeric values (Fig. 3). A digital-to-analog converter (DAC) transforms these numbers into an analog voltage, which may then be used to drive a loudspeaker system. In a similar way, an analog-to-digital converter may be used to take sound samples at high speeds (thirty thousand samples per second is quite typical), for storage by a computer system. A description of the conversion process is shown in Fig. 4.

Another parameter, called the envelope, may be manipulated

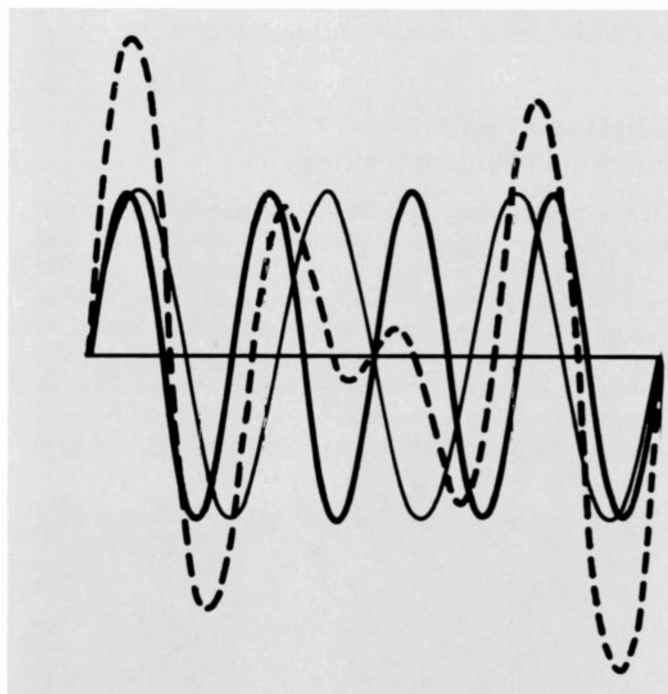


**Fig. 2. Fourier analysis/synthesis.** The combination of two equal-amplitude sine waves of three and four cycles per second produces a complex wave, which is accentuated at points where the sinusoids are in phase, and drops to zero when the two components are 180 degrees out of phase. Conversely, given this periodic, complex wave, it is possible to resolve it into its sinusoidal components. (After Howe, *Electronic Music Synthesis*, pg. 11.)

(Continued from page 67)
and also in the amount of control that can be applied over sound attributes such as the envelopes and Fourier components. Passport Designs and Syntauri Ltd. both produce piano keyboards for the Apple. The Syntauri system uses either the Mountain Computer or ALF boards for music production, and the Passport Designs system operates with either its own music hardware or, again, the Mountain Computer system. All of the aforementioned companies offer software support for their systems—most include a basic music-editing facility.

For the Apple owner whose funds are limited, a number of music programs use the computer's speaker for sound production, and therefore require no additional hardware. Insoft has created Electric Duet, which is a two-voice synthesizer with its own music-editing system. Notable Software and the Minnesota Educational Computing Consortium both produce reasonably priced, high-quality educational and recreational music-software packages that use only the built-in speaker.

Music systems are also available for many of the other popular microcomputers. Software Affair and Newtech Computer Systems both offer sound production hardware and software for TRS-80 computers. A-B Computers has a DAC board and editing system for the Commodore PET. The Atari 400 and 800 computers contain four-voice music hardware that can be accessed in BASIC. In addition, Atari offers a graphic-music-editor ROM cartridge.

Of course, it is possible to build your own sound production hardware. The SN76477N Complex Sound Generator is an inexpensive integrated circuit available from Radio Shack. A sound-effects demonstration box can be created in order to exercise the many functions of the chip. "Experimenting with a Sound-effects Generator" in the May, 1980 issue of *Popular Electronics* is an excellent source for information about the SN76477N. The chip contains various oscillators, mixers, and envelope generators. External signals may also be added to the input of the final amplifier in order to combine acoustic and electronic sounds.

Although the Radio Shack chip is compatible with most microprocessing systems, those hobbyists interested in interfacing sound hardware to computers may also wish to experiment with General Instrument's AY-3-8910 or 8912 Programmable Sound Generator. This large-scale IC can be interfaced to any bus-oriented system for software-produced sounds. The GI chip contains three independently controllable channels and operates without constant demands on the

by the computer and superimposed upon the synthesized waveshape. The envelope specifies the overall volume of a note through time. Typically, envelopes are described as distinct attack, decay, sustain and release functions (Fig. 5).

## Analysis and synthesis of musical instrument tones

In the early days of computer music, researchers believed that simple algorithms capable of synthesizing such common and naturally occurring sounds as the notes on a piano, could be developed through the use of additive and subtractive synthesis, frequency modulation, and envelopes. Analysis of sounds revealed that trivial solutions were not readily apparent. It was discovered that the overall envelope is actually constructed through the summation of separate envelopes, one for every component (partial) of the waveshape. Furthermore, there is a nonlinear variation in the waveshapes produced by differing attack and decay functions. In addition to this, the waveshape itself contains a variety of subtle, aperiodic components. Confronted with these complex issues, many researchers abandoned their work in algorithmic synthesis of natural sounds. Digital analysis has been made more attractive, however, by the recent lowering of computer memory prices, and it is hoped that continuing work in this area will provide new synthesis techniques.

James Beauchamp, of the University of Illinois, is perhaps the foremost authority on analysis and synthesis of musical

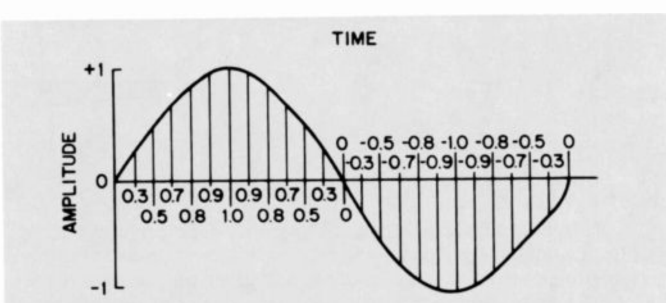



**Fig. 3. Waveform sampling.** Analog waveforms are represented in the computer as strings of digits that correspond to quantized voltage-amplitude samples taken at precise intervals.

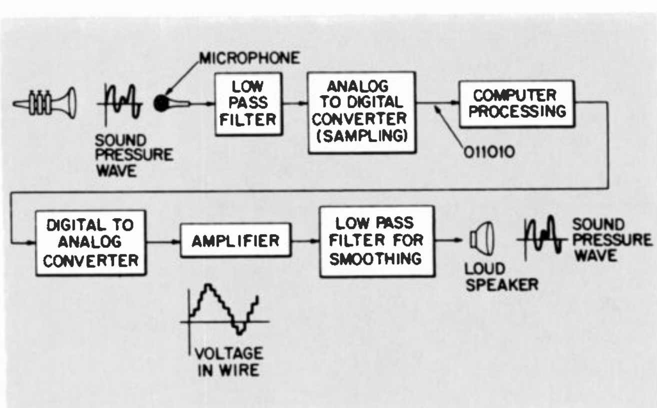



**Fig. 4. The analog-digital-analog conversion process.** A sound pressure wave is converted into an electronic signal after being picked up by the microphone. Samples of the changing voltage in the wire are taken by an analog-to-digital converter, producing binary strings that may be stored or manipulated by a computer. These numerical values can be reconverted into analog voltages and amplified in order to reproduce the sound wave. Low-pass filters are used to limit the frequency of the input signal and smooth the output of the digital-to-analog converter.

microprocessor. In addition to music synthesis, the chip can be used for sound effects, alarms, and frequency-shift-keyed modems.

### *Sound software*

Should you care to add sound to your microcomputer on a much smaller scale, it is possible to modify the ASCII control-G circuit on many computers to permit software control of the output speaker. The May 1982 issue of *Microcomputing* contains an article by Alan E. Hufnagel that details such a modification for the H-89 computer.

Once your computer is no longer mute, a whole host of programs can now be created. For example, the illustration (page 67) contains the score of Soft Notes, a two-voice canon that reads the same upside-down, generated by Michael Keith's NCC (Numerical Canon Composition) program for the Apple II. The performances of Soft Notes and the Shepard's tones on the accompanying soundsheet were realized on an Apple II system using two ALF MC16 boards. The score was printed by a music-editing program that I had written for the Apple. Further information on both the composition and editing programs, as well as many other articles of interest to the computer musician, may be found in the 1981 *IEEE Proceedings on Small Computers in the Arts.*

### *Analysis*

In addition to composition, performance, and music editing, the hobbyist may also experiment with analysis techniques. Theoretical analysis of performance and compositional styles as well as digital analysis of sounds are all possible through the use of input devices such as piano keyboards and analog-to-digital converters. Yet another field of investigation concerns the development of new graphic forms of pitch and sound specification for computer performance. The creation of music-education software is also a popular project with hobbyists, both for strengthening their own skills and for helping others.

As you have seen, the availability of reasonably priced hardware and software now makes it easy to experiment with a wide range of computer-music projects. With computer assistance, it is even possible for the hobbyist to make significant contributions and discoveries in the field of music. But no matter what scope or complexity you choose for your project, it is certain to be an interesting and exciting exploration of sound.

instrument tones. One of his early systems produced the flute and oboe pitches demonstrated on **selection 4** of the soundsheet. A brief summary of his analysis/synthesis techniques, used for this recording, is given below.

Ideally, for the analysis portion, a recording is first made of tones performed in a "dead room" or anechoic chamber. For this study, a true anechoic room was not available (background noise was measured at 19 dB). Through analog-to-digital conversion, a computer tape was produced from the original recording. This information was then used to draw three-dimensional graphs displaying the amplitude and frequency relationships through time. Algorithms that describe these parameters were generated by the computer, and a new digital tape was created. After digital-to-analog conversion, a tape recording was made of the computer synthesis.

Quality of the synthesized tones is affected, somewhat, by the sampling rate (40,000 samples per second) which limits the maximum frequency produced to 20 kHz, and by the word length of the A/D and D/A converters (10 bits) which restricts the amplitude resolution. Error is introduced through the smoothing, or deletion of phase data when the partials are combined. Although the equipment and algorithms used by Beauchamp have changed, the essential analysis/synthesis scenario has remained the same through these last twenty years. Studies of this sort continue to provide musicians with valuable information on the components of acoustical instrument sounds.

Even though there appear to be certain limitations in the synthesis of existing sounds, the computer's capabilities for the production of new sounds are boundless. Studios such as the Columbia-Princeton Electronic Music Center (Fig. 6), MIT's Experimental Music Studio, and the Institut de Recherche et Coordination Acoustique/Musique (IRCAM) in France continue to develop algorithms for sound synthesis and to describe

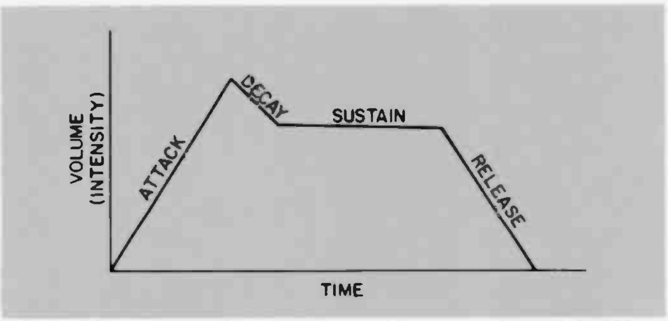



**Fig. 5. A common attack-decay envelope used in synthesizing sounds.** Envelopes produced by acoustic instruments normally consist of numerous time-dependent functions, many of which are nonlinear.

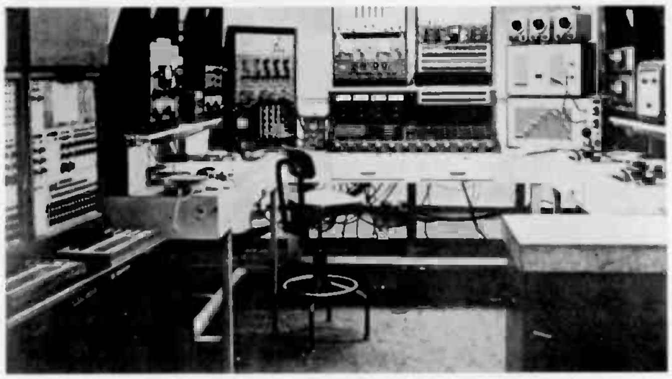


**Fig. 6. One of the studios in the Columbia-Princeton Electronic Music Center in 1971.** Equipment included a central 12-input mixing panel, four Ampex two-track stereo tape recorders, numerous sound-modifying devices (ring modulators, bandpass filters, reverberation units), and a Buchla synthesizer.

**Table I. "Micro" music hardware and software vendors.**

*For Apple II computers*

**ALF Products Inc.**

Various 3- and 9-voice music boards (reasonably priced). Some software available, including graphic music editor. 1448 Estes, Denver, CO 80215.

**insoft**

Electric Duet, a two-voice music synthesizer needing no additional hardware. 10175 Barbur Blvd., Suite 202B, Portland, OR 97219.

**Micro Music Inc.**

Four-voice music board with graphic music editor. Educational software package includes music dictation practice drills. 309 Beaufort, Normal, IL 61761.

**Minnesota Educational Computing Consortium**

Musicianship drills and other educational programs. Software marketed by Apple Computer, Inc. and Creative Computing.' Contact MECC at 2520 Broadway Drive, St. Paul, MN 55113.

**Mountain Computer, Inc.**

Sixteen-voice music board with graphic editor. Hardware compatible with Passport Designs and alphaSyntauri keyboards. 200 Harvey West Blvd., Santa Cruz, CA 95060.

**Notable Software**

Educational and recreational music software. Many programs need no additional hardware. Reasonably priced. P.O. Box 1556, Phila., PA 19105

**Passport Designs**

Piano keyboard with additional software and sound-generation hardware (optional). Marketing done by Peripherals Plus, c/o Creative Computing, Dept. C025A, One Park Avenue, New York, NY 10016.

**Syntauri Ltd.**

alphaSyntauri keyboard plus additional software. 3506 Waverly, Palo Alto, CA 94306.

*For Atari 400/800 computers*

**Atari**

Four-voice sound hardware included with computer system. ROM music-editing cartridge available. 1195 Barregas, Sunnyvale, CA 94026.

*For the Commodore PET*

**A-B Computers**

Music editor using graphics character display plus four-voice music board. 115 E. Stamp Rd., Montgomeryville, PA 18936.

*For TRS-80 computers*

**Newtech Computer Systems**

Music and percussion hardware along with editing systems. 230 Clinton St., Brooklyn, NY.

**Software Affair**

Stereo, five-voice hardware with percussion. Also includes editing facility. 858 Rubis Drive, Sunnyvale, CA 94087.

*For Sound ICs*

**General Instrument Corporation**

AY-3-8910/8912 Programmable Sound Generator. Contains three tone generators and one noise generator with amplitude and envelope control. Interfaces to most 8- and 16-bit microprocessors. 600 W. John Street, Hicksville, NY 11802.

**Radio Shack**

SN76477N Complex Sound Generator. Produces and combines noise, tone, or low-frequency sounds. Compatible with microprocessor systems. Fort Worth, TX 76102.

new techniques for combining acoustically and electronically produced sounds.

## Musical composition by computer

Considerable effort during the last 25 years has been devoted to the composition of musical works by computer. The "Illiac Suite" (**selection 3** on the soundsheet) is an example of the manner in which mathematical formulas can be used to generate strings of numerical values that specify the pitch and duration of notes. The piece was written by the ILLIAC computer (with the assistance of Lejaren Hiller) using Markov probability chains.

The compositional process assigns occurrence probabilities to each interval (distance between successive notes) from a table of values. Throughout the course of the piece, these probabilities constantly change. At the beginning of the piece, the interval of a unison is given the probability of one, and all other intervals are given the probability of zero. This causes all four intervals to remain on the same note—in this case, it is middle C. After a specified length of time, the chance of playing an octave higher is given a weight of one, and the unison a weight of two (all other notes remain at zero). The unison is therefore twice as probable as the octave, so some of the parts will move up or down an octave to another C. The interval of the fifth (C to G) is added next, and so on, until all of the 12 possible intervals have been added. Probabilities also depended heavily on the most recent choices made. For example, if the previous interval was a major third (C to E), then the chance of getting another major third (E to G#) dropped to zero. Please note that the performance of this composition on the soundsheet is presented by a traditional string quartet, and is not synthesized.

Another form of computer composition involves the input, into the computer, of rules and formulas used by composers (a technique that is of great interest to researchers in artificial intelligence). Pieces are then produced using random-number generators along with these constructs. The Numerical Canon Composition (NCC) program by Michael Keith of RCA Laboratories, operates in this manner on the Apple II computer. A canon, according to the *New College Encyclopedia of Music*, is a form of polyphonic (multivoice) composition in which the first melodic line is used to determine the subsequent parts. Various permutations are possible—staggered entrances, and transposition by fifths, thirds or other intervals. The part that imitates may be written backwards beginning at the end (this is called retrograde or crab), or the imitation portion can be written both backwards and upside down (retrograde inversion). These effects are all easily programmed into the computer. "Soft Notes" (**selection 7** on the soundsheet) is a crab canon by inversion, produced and performed by the Apple II.

Of course it is also possible to submit files of complete compositions to the computer for theoretical analysis. An excellent illustration of this type of study was presented by Kemal Ebcioglu at the 1980 International Computer Music Conference. Professor Ebcioglu originally began writing a program in LISP that would produce two-part florid counterpoint examples. After providing the computer with the rules of counterpoint, as outlined in the texts of Charles Koechlin and J.J. Fux, examples were produced that were inferior to those created by first-year music students. An analysis of counterpoint examples by master composers produced over forty "new" rules which, when added to the textbook formulas, produced examples of high quality. Studies of this sort promise to greatly assist theoreticians and students in their work.

## Computer performance

The computer's role in performance aspects of music is well known. In addition to the construction of new sounds, the computer excels in the realization of rapid-fire passages, complex rhythms, and unique tuning systems. The first movement from "Sonatina for CDC-3600" by Arthur Roberts (**selection 5** on the soundsheet) is an investigation of rapid, complex, polyphonic passages by the computer. Here only a few distinct tone colors are used with pitches of the tempered scale.

The Shepard's Tones (soundsheet **selection 8**) is another illustration of precise performance that is difficult for a human, but easy for the computer to render. The psychologist Roger Shepard discovered that weighting the volumes of notes proportional to their position in the scale, produces a seemingly endless sequence of rising (or, conversely, falling) tones. The effect is created by gradually fading out the top octave of notes as the bottom octave fades in. This illusion has its analogy in the graphics world with the continually ascending-descending staircase popularized by M.C. Escher (Fig. 7).

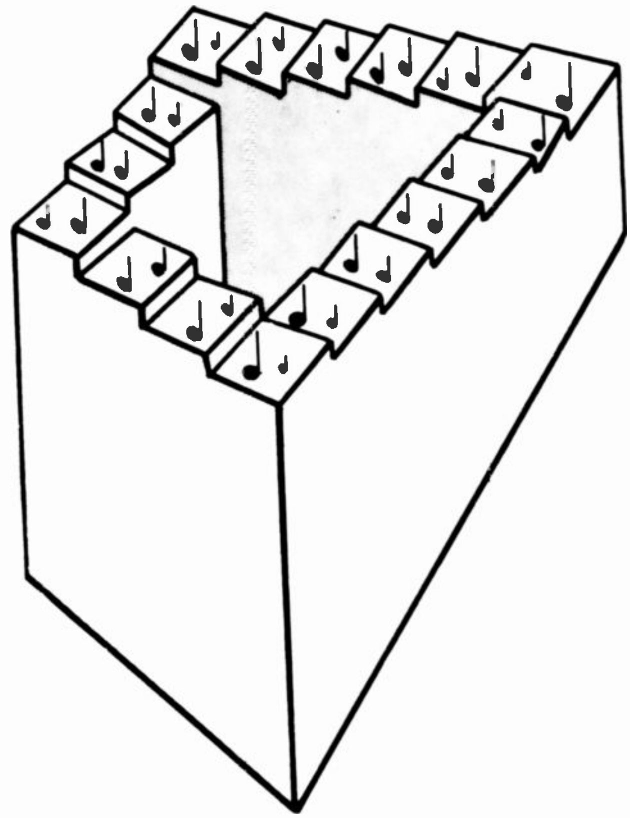


**Fig. 7. The staircase illusion is drawn here with a representation of the Shepard's Tones.** The size of each note is proportional to its volume.

## Music editing systems

Many sounds and pitches that can be synthesized cannot be represented in traditional music notation. New music editing systems have had to be created, in order to describe these items to the computer. One system is MUSIC 4BF, a sound-synthesizing program written in FORTRAN to run on the IBM System/360 computers. There exists a family of these MUSIC programs, each running on different computers, but they all follow the same general format.

In MUSIC 4BF, punched-card images are used to specify musical notes. Various fields on the cards define the instrument used (instrument sounds are separate functions, which may be predefined by the composer), and the time that the note begins, along with its duration, pitch, and amplitude. Other parameters, such as glissando and slurring, may also be added as FORTRAN subroutines and called by the note cards. The "Sonatina for CDC-3600" (**selection 5** on the soundsheet) was written in this manner, using ORPHEUS, a version of MUSIC 4BF. Once a note file has been compiled, a digital computer tape is created that is then converted into sound using a DAC. Even though many time-consuming iterations must occur before a piece can even be heard for the first time, this style of music editing has remained popular with composers because it is flexible and easily allows new sound-producing algorithms to be implemented.

Figure 8 shows the Graphic 1 console system developed by the Digital Equipment Corporation and used by Bell Laboratories during the 1960s in defining their Graphical Input (GRIN) language for music. A light pen is used with a CRT in order to "draw" a score on the screen. In addition, a terminal permits

## Notes on the soundsheet

Bound within this copy of the *RCA Engineer*, you will find a 33¹/3 rpm stereo soundsheet containing examples of electronic music from 1956 to 1981.

You may want to make a tape recording of the sheet, for personal use, as you listen to it for the first time. The sound quality of the original source materials varied widely—from a very old monophonic-acetate tape purchased at auction for two dollars, to a direct recording from the digital-to-analog converters on a microcomputer. For this reason, you may notice some background noise on certain of the selections, although every attempt has been made to keep this to a minimum. A few of the recordings are essentially monophonic—these have been mixed to produce equal signals in both the left and right channels.

The recordings, in the order that they appear on the soundsheet, are:

**1.** "A Bicycle Built for Two," ℗ 1963 Bell Telephone Laboratories, excerpted from a recording titled "Computer Speech," compiled by D.H. Van Lenten. Courtesy of Bell Laboratories.

**2.** "Blue Skies" by Irving Berlin, as performed by the RCA Synthesizer in the 1956 demonstration recording of "Synthesizer Principles." The recording is the property of RCA Laboratories.

**3.** "Illiac Suite for String Quartet of 1957" by Lejaren Hiller, excerpt from fourth movement. From "Computer Music from the University of Illinois," MGM Records, Heliodore H25053 R67-1134 12185. Reprinted by permission of the composer.

**4.** Musical Instrument Tones, real versus synthetic, A/B comparisons (flute and oboe), James Beauchamp, University of Illinois. Copyright ℗ 1969. John Wiley & Sons, Inc., New York. From an enclosure in *Music by Computers*, edited by Heinz VonFoerster and James W. Beauchamp, John Wiley & Sons, Inc.

**5.** First movement from "Sonatina for CDC-3600" by Arthur Roberts, Argonne National Laboratory. Copyright ℗1969. John Wiley & Sons, Inc., New York. Enclosure in *Music by Computers*, edited by Heinz Von Foerster and James W. Beauchamp, John Wiley & Sons, Inc.

**6.** "The British Grenadiers - Johnny Comes Marching Home" (excerpts) by Max Mathews, Bell Telephone Laboratories. Copyright ℗ 1969. John Wiley & Sons, Inc., New York. Enclosure in *Music by Computers*, edited by Heinz Von Foerster and James W. Beauchamp, John Wiley & Sons, Inc.

**7.** "Soft Notes" a crab canon by inversion, created by NCC, a canon composition program written by Michael Keith for the Apple Computer, 1981.

**8.** Shepard's Tones, an auditory illusion performed by the Apple computer with ALF music hardware.

*Tear along perforation to detach soundsheet*

alphanumeric input for the specification of frequency and amplitude scales. The scores created on this system can be translated into MUSIC IV format (the predecessor language to MUSIC 4BF), and from this a digital tape may be produced.

Once a score has been entered, it is then possible to manipulate it using the computer. "The British Grenadiers - When Johnny Comes Marching Home" **(selection 6)** was produced by the Bell Labs system during 1966 by taking the melodies to both pieces and using an averaging function to modulate from one to the other and back again (Fig. 9). What makes this transformation unusual is the fact that the "British Grenadiers" is in the key of F major and 2/4 time, and "Johnny" is in the

**Fig. 8. The Graphic 1 Console System, developed at Bell Laboratories.** Musical passages can be described in graphical notation by drawing on the CRT with a light pen. (From *Music by Computers*, John Wiley & Sons, Inc., 1969.)

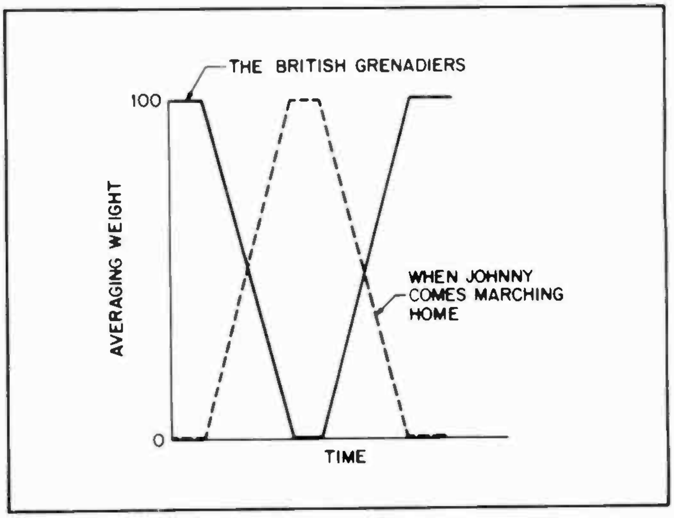



**Fig. 9. Averaging function for "The British Grenadiers—When Johnny Comes Marching Home."** A weighted average of rhythms and notes in each piece is used to specify the new melodic line.

◄ *If the soundsheet does not lay flat on your turntable, simply put an album from your collection on first, and then place the soundsheet on top of it.*

key of E minor and 6/8 time. The pitches are rounded to those in a scale consisting of all notes in both keys. The composer, Max Mathews, describes this as "a nauseating musical experience, but one not without interest, particularly in the rhythmic conversions."

Traditional music notation is also being explored with computers. Leyland Smith of Stanford University, Donald Byrd of Indiana University, and others are developing music editors that produce manuscripts of publication quality. The automatic transcription of scores from performances is also being studied in the hopes that commercial systems could someday be produced. Certain manufacturers have begun to make claims concerning the availability of such devices, but this issue is highly complex due to the subtle variations in performance speed and attack of notes. The notation of precise, metronomic renditions has been achieved, but it will probably be years before programs are perfected to accurately transcribe live performances.

## Computer music centers

Work continues in all aspects of computer music in various centers throughout the world. Barry Verco directs the MIT Experimental Music Studio, which is used primarily for composition. New sound production algorithms are constantly being developed at Stanford's Center for Computer Research in Music and Acoustics. Numerous composers remain active at Princeton University and they have been particularly successful in using techniques such as formant shifting to manipulate acoustical sounds with the computer (formants are resonance bands that determine the quality of speech sounds). At IRCAM, which is directed by Pierre Boulez, work with acoustics has led to the construction of a concert hall with movable panels that make it possible to change the reverberation time from 0.5 to 4.5 seconds.

*Tear along perforation to detach soundsheet*

## An annotated bibliography of computer music

The following references, used in the compilation of this illustrated history, constitute a survey of basic literature in the computer-music field.


Chamberlin, Hal, *Musical Applications of Microprocessors*, Hayden Book Company, Inc., Rochelle Park, New Jersey, 1980.

Analog and digital synthesis principles are covered fully, along with many examples of programs and circuit diagrams.

Griffiths, Paul, *A Guide to Electronic Music*, Thames and Hudson, New York, 1979.

An excellent synopsis of the development and use of electronic music in the 20th century, plus a comprehensive list of recordings.

Hiller, Lejaren A., "Computer Music," *Scientific American*, Vol. 201, No. 6, Dec. 1959, pgs. 109-120.*

Hiller's description of the "Illiac Suite" and other experiments in computer composition.

Hofstadter, Douglas R., *Godel, Escher, Bach: An Eternal Golden Braid*, Basic Books, Inc., New York, 1979.*

Describes the Shepard's tones and numerous other parallelisms between music, art and mathematics. Examples printed using SMUT, Donald Byrd's music-writing program.

Howe, Hubert S., *Electronic Music Synthesis*, W.W. Norton and Company, Inc., New York, 1975.*

An outstanding introductory text on the fundamental concepts of computer music—acoustics, special-effect devices, and recording techniques are covered. The MUSIC 4BF sound-synthesizing program is detailed.

Mathews, Max, *The Technology of Computer Music*, The MIT Press, Cambridge, Mass., 1969.*

An outline of fundamental principles in digital sound processing, and also a tutorial on the Music V language.

Olsen, Harry F., *Music, Physics and Engineering*, 2nd Ed., Dover Publications, Inc., New York, 1967.*

This early work (first published in 1952) provides a thorough analysis of the acoustical properties of most of the major musical instruments. Various tuning methodologies are examined. Very useful reference material for work in synthesis.

Tjepkema, Sandra L., *A Bibliography of Computer Music*, University of Iowa Press, Iowa City, 1981.

Listing of published material in computer music from 1956 to Jan. 1979.

Winston, Lawrence E., *33 Electronic Music Projects You Can Build*, Tab Books Inc., 1981 (Blue Ridge Summit, PA 17214).

Project ideas, from an electronic metronome and a singing canary, to a complete electronic organ.

*The Computer Music Journal*, Curtis Roads, Editor, The MIT Press, Cambridge, Mass.

Now in its sixth volume—published quarterly. Essential reference material for current work in the field.

*Journal of the Audio Engineering Society*, 60 E. 42nd St., New York, NY 10017.*

Thirty years of monthly publications. Numerous articles in digital sound-processing techniques and acoustics.

*IEEE Proceedings: Symposium on Small Computers in the Arts*, Nov. 20-22, 1981. IEEE Catalog No. 81CH1721-0.

Short papers on current applications of microprocessors in art and music.

*Music By Computers*, Heinz Von Foerster and James W. Beauchamp, Editors, John Wiley & Sons, Inc., New York, 1969.

Now out of print, this book is a collection of papers by Mathews, Hiller, Pierce, Beauchamp and others—all early pioneers in computer music.


* ***Publications available through RCA Technical Libraries.***

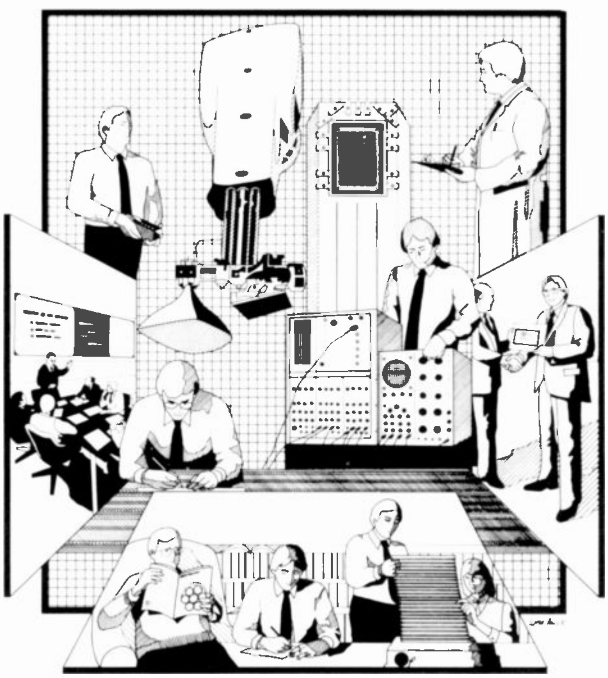
**Rebecca Mercuri** has been involved with VideoDisc research at RCA's David Sarnoff Research Center since 1980. Prior to that time she spent numerous years as an educator, teaching every age group from pre-school through college. She holds Bachelor's degrees in both Computer Science and Music, and has been writing computer music programs since 1973. Rebecca often lectures and writes on this topic—forums for her work include colleges, universities, and computer society meetings, as well as numerous computer and music publications.
Contact her at:
**RCA Laboratories**
**Princeton, N.J.**
**TACNET: 226-2998**

Computer research has made a great impact upon the musical world. The overwhelming variety of synthesized sounds has created a new vocabulary for musicians. Analysis of compositions has provided considerable insight into essential constructs of musical thought, and greater understanding of acoustical properties has been made possible through sound-analysis studies. The computer has proven itself as a valuable tool in virtually every aspect of music, and its true potential in this field will surely continue to be developed in the coming years.

## Acknowledgments

The author would like to take this opportunity to thank the numerous composers for permission to reproduce their works on the soundsheet. Z.R. Provenzano of the Pennsylvania State University, and M. Keith and C.P. Kocher of RCA Laboratories are all appreciated for their comments and suggestions during the preparation of this manuscript. Thanks are also due to P. Mercuri for narrations and technical advice on the recording. Most importantly, much gratitude must be expressed to Sam Provenzano, chief engineer at Keystone Studios, Glenside, Pennsylvania, for the donation of countless hours of studio time and patient effort, without which the soundsheet could not have been produced.

## Have you "given a stroke" to your TEC lately?



Do you know that engineers at RCA are devoting time and effort to help you in establishing and maintaining a satisfying career? They are your Technical Excellence Committee and they attempt to contribute to a stimulating working environment by determining your needs in the areas of technical education, technical information, professional activities and recognition. Once the need is established, they move on to develop and execute supportive activities.

Most of you are somewhat aware of and use the technical excellence activities. But have you paid your dues by expressing your appreciation to your TEC representative? Or even better, do you tell him your views on today's engineering climate and the career needs you perceive?

Engineers are highly skilled professionals, but all too often they keep their thoughts and needs to themselves, perhaps because they are busily engaged solving their problems. Technologies, techniques, and engineering tools—the entire supporting environment is constantly changing and better ways to do engineering work are evolving. Do you take the time to discover and master them? This is where the TEC is attempting to support you—you can help the TEC help you, by sharing your thoughts with the TEC members. Then give them credit for their efforts, every once in a while

S.M. Solomon

# RCA Glōbcom uses a new microwave communications system

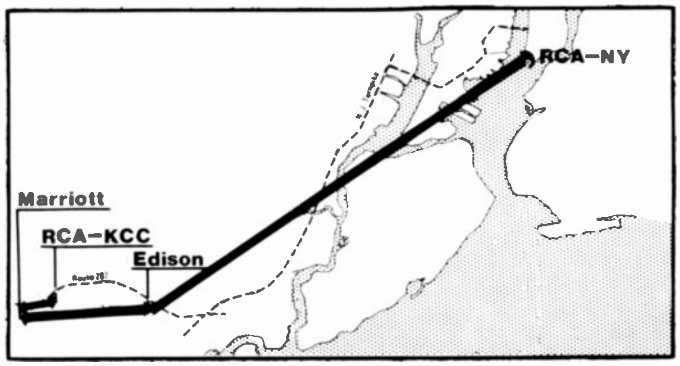



**Fig. 1. This indicates the basic 3-hops in the transmission path.** The New York-Edison hop is at 6 GHz. The Edison-Marriott and Marriott-KCC hops are at 11 GHz.

*A new high-speed data-under-voice (DUV) microwave system has been installed between RCA Globcom's major operating centers (New York City-to-Piscataway, N.J.), providing high-quality and high-reliability communications.*

**Abstract:** *A new high-speed data-under-voice (DUV) microwave system has been installed between RCA Glōbcom's major operating centers in New York, New York and Piscataway, New Jersey. The system provides end-to-end facilities for equivalent C-4 conditioned voice-grade circuits as well as 56-kilobit digital-data channels. Ease of expansion and interconnection with other transmission facilities has been engineered into the system.*

RCA Glōbcom's operating centers at 60 Broad Street, New York, and the Kingsbridge Communications Center (KCC), Piscataway, New Jersey, provide both domestic and international communications services. Overseas circuits are shared between these two locations for purposes of diversity and economy. As part of the overall system operation, it is necessary to interconnect the various services from one center to the other.

The RCA Globcom New York-to-Piscataway Microwave Communications System has replaced, to a very large extent, Bell System (AT&T, New York Telephone, New Jersey Bell) facilities formerly used to interconnect the New York City, 60 Broad Street location with the Kingsbridge Campus, Piscataway, New Jersey location.

Interconnection capability, end-to-end, consists of voice-grade circuits as well as 56 kilobit per second (kb/s) high-speed digital data circuits. The microwave system is a 3-hop system with hot-standby radio operation at each node of the system.

The system serves as a complete and separate route, and it is the primary means of interconnecting these locations. RCA Globcom has gained direct control of these transmission costs and has become less dependent upon the Bell System. RCA Globcom has leased voice-grade circuits as well as 56-kb Digital Data System (DDS) circuits from the Bell System between these locations, but both types of Bell facilities transit many of the same areas. Therefore, outages that affected one circuit frequently affected other circuits as well. In addition, costs of leasing circuits from the Bell System have nearly doubled in the last several years. Some Bell circuits have been retained only to ensure a complete path redundancy heretofore not possible. As a result, RCA Globcom is doubly protected on the crucial communications link between these centers.

The microwave system is expected to save RCA more than $2 million during the first five years at current Bell System rates. The system allows great expansion. The equipment that is in place allows for transmission of 3.156 megabits per second (Mb/s) in the digital portion (lower part) of the spectrum. Currently, less than half of that is being used. In addition, there is provision for 300 voice-grade channels in the higher part of the spectrum. Fewer than half of those channels are being used now.

Telegram, telex, and narrowband leased-channel data are sequentially multiplexed to form a high-speed digital bit stream that is fed into the digital part of the system's spectrum. Each of the voice-grade channels in the higher part of the spectrum is used to carry voice, alternate voice/data or unique data alone. Both the digital and analog signals are combined at the baseband level and transmitted via the radio system toward the distant end, where the process is reversed.

## Link descriptions

Link descriptions are given in Table I (refer to Fig. 1). Stringent design goals were set for each link of the microwave system, covering the transmitters, receivers, antenna systems, and paths in order to achieve high overall end-to-end transmission availability. The microwave radios, modems, multiplexers, and all other ele-


Final manuscript received May 26, 1982
Reprint RE-27-4-11

**Table I. Link descriptions.**

| Link | Frequency | Distance (miles) |
|---|---|---|
| N.Y. to/from Edison, N.J. | 6-GHz common carrier | 23.41 |
| Edison to/from Marriott Hotel | 11-GHz common carrir | 6.69 |
| Marriott to/from KCC Piscataway | 11-GHz common carrier | 1.20 |

ments of the system are tried and proven products, with well-established performance records.

The system, in addition, contains redundant elements of all major subsystems, so that switching to standby units can take place, thereby assuring continuity in the maintenance of communication between the two centers.

Table II (page 78) shows the major equipment located at each node of the system. The frequency-division-multiplex (FDM) terminal is wired for four supergroups (240 voice-grade circuits) but equipped initially with modules sufficient for 115 voicegrade circuits (full duplex), conditioned to C-4 quality. Further expansion is easily accomplished on a plug-in basis.

The time-division-multiplex (TDM) terminal is wired for twenty-four 56-kb/s circuits but equipped initially with modules sufficient for six 56-kb/s circuits (full duplex). Further expansion is easily accomplished.

## Radio sites

The system layout is shown in Fig. 2. Hot standby radios are employed at all four sites, with battery backup or uninterrupted power systems provided at all sites. The New York-to-Edison radios operate at 6 GHz. The Edison-to-Marriott and Marriott-to-Piscataway links all operate at 11 GHz.

All radios are solid-state baseband-to-rf analog systems with proven long-term reliability as well as major system redundancy. Independent switching of transmitters and receivers for each radio permit operation without loss of service. Each transmitter and receiver, in addition, is independently alarmed to report the continuous status of all sites to the Piscataway operating center.

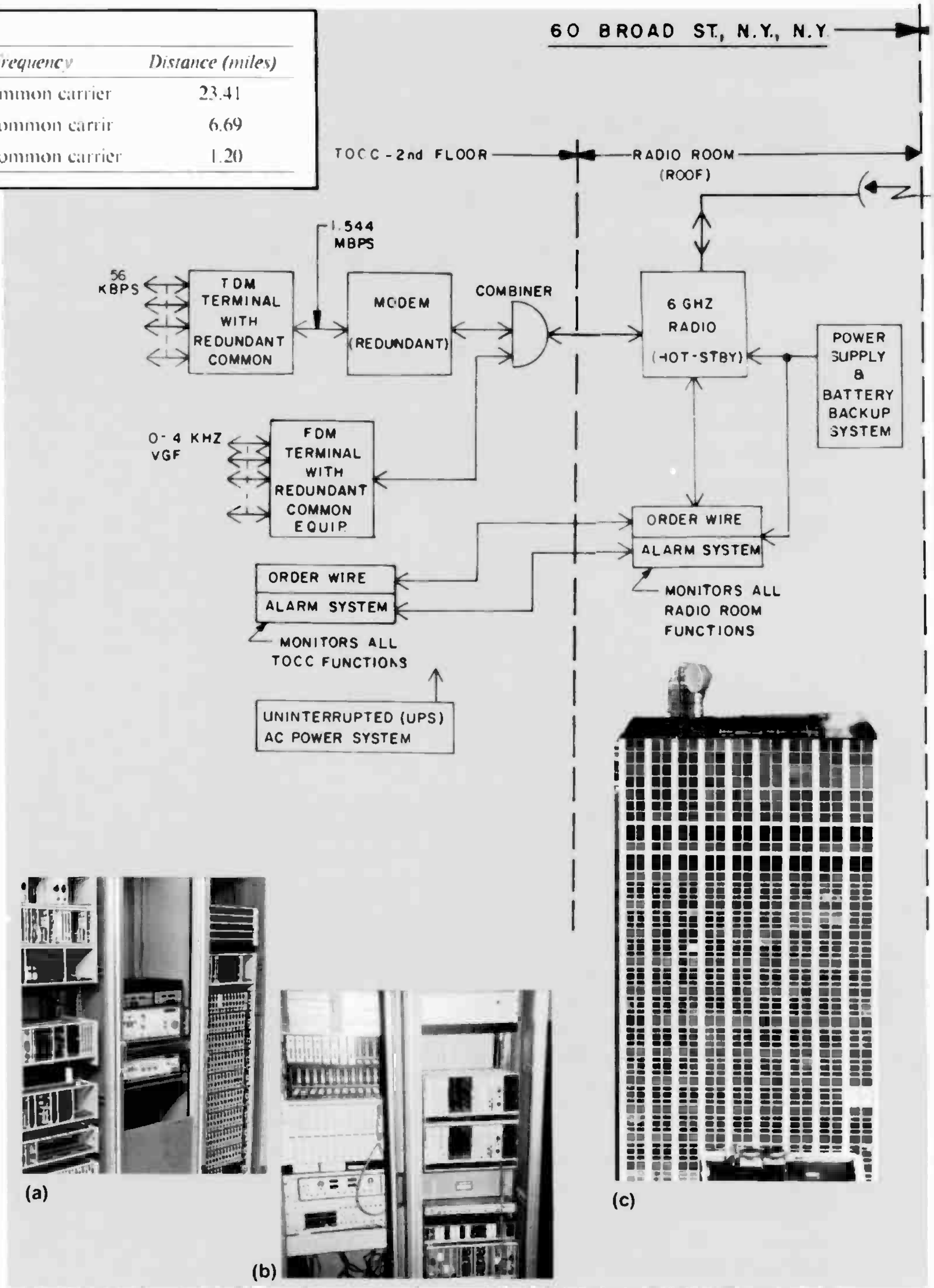



**Fig. 2. The end-to-end signal flow showing the basic system configuration and the redundancy of the subsystems.** Formation of the baseband signal is accomplished by combining the outputs of the TDM and FDM signals. The photos (left to right) show: **(a)** frequency division multiplex equipment racks; **(b)** the Technical Operating Control Center equipment racks (racks like these are at each TOCC site); **(c)** the antenna atop 60 Broad Street, New York City that faces the Edison, N.J. tower; **(d)** the antenna tower at Edison, N.J., (RCA Globcom uses the lower antenna, facing the Marriott Hotel in Somerset,

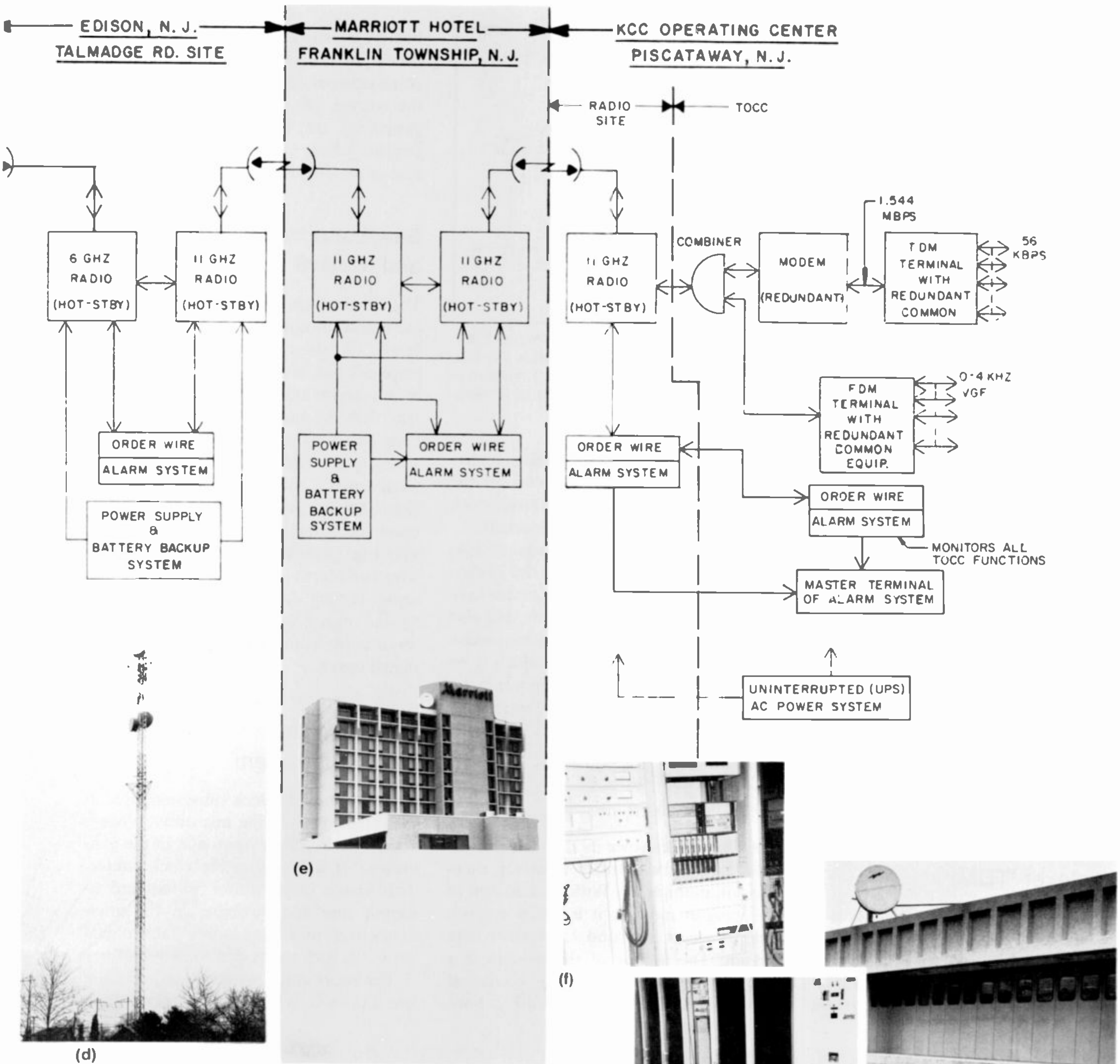
## TOCC (Technical Operating Control Center) sites

The equipment at each TOCC—New York and Piscataway—contains all the necessary multiplexing systems to form the baseband signal, which is sent to the radio for transmission to the distant end (refer to Fig. 3, page 78).

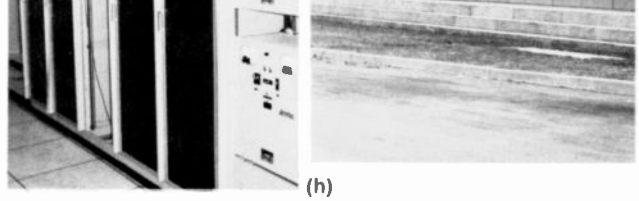
## Voice-grade (FDM) operation

One-hundred-and-fifteen voice-grade circuits (approximately two supergroups) are equipped in the initial operating system. Note that a supergroup is composed of 5 groups. A group is composed of 12 voice-grade circuits. Therefore, the supergroup contains 60 voice-grade circuits.

The basic frequency plan used for the FDM system is the CCITT-900 channel



(d) (e) (f)


(g) (h)

N.J. and the middle antenna, facing 60 Broad Street); **(e)** antennas atop the Marriott Hotel, Somerset, N.J. (the antenna at the right faces the Kingsbridge Communications Center in Piscataway, N.J., the antenna at the left faces the Edison, N.J. tower); **(f)** at the KCC, the high-stability-clock subsystem (left rack) and the time-division multiplex system (right rack); **(g)** frequency division multiplex system racks; **(h)** the antenna atop the KCC building in Piscataway, facing the Marriott Hotel in Somerset.

plan for frequency division multiplexing, starting with supergroups 11 and 12. A convenient representation of the frequency plan is shown in Fig. 3. On an end-to-end basis, each circuit has an equivalent of better than a C-4 quality Bell-type circuit.

Existing wired cabinets can accept modules to provide two additional supergroups (supergroups 13 and 14) with supergroup 15 requiring an additional expansion cabinet. Conventional CCITT multiplex arrangements are used to form channel banks, group banks, and supergroups required.

The audio (VF) interface is at four-wire, 600-ohms balanced impedance, with standard transmission level points (TLPs) of −16 TLP (transmit) and +7 TLP (receive). From the voice-frequency interface, the signals are routed to the channel modems in the FDM. All channel modems

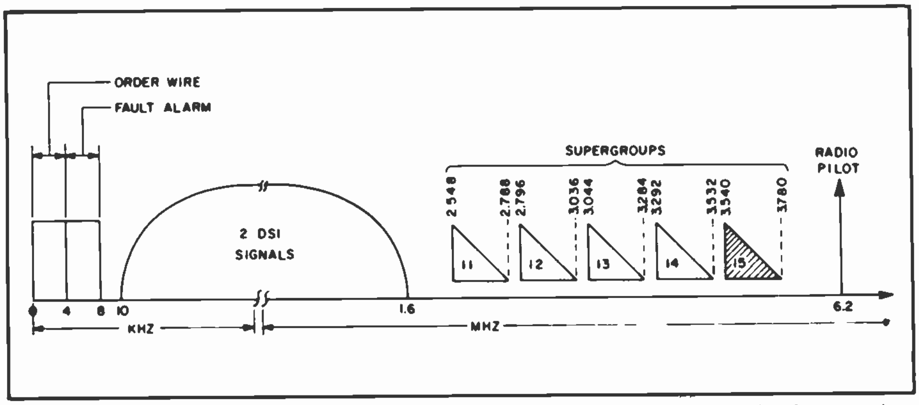



**Fig. 3. The baseband spectrum of the system.** The diagram illustrates the frequencies allocated for order-wire, fault alarm, digital transmission and FDM transmission. As the FDM part of the system grows, additional supergroups are added. Since the data modem's frequency allocation is below the allocation for the FDM portion, the system is termed "data under voice" (DUV).

are identical and can be interchanged. Twelve channels are combined into a basic group from 60 to 108 kHz. Five basic groups are then modulated to form the basic supergroup from 312 to 552 kHz. Each supergroup is then translated to the line spectrum, as shown in Fig. 3.

At the receive terminal, the inverse process is performed, where each channel is then heterodyned and filtered to provide an audio output signal. All common equipment, such as oscillators and carrier generators common to more than 60 channels, is provided in a redundant configuration.

## Time-division multiplexer (TDM)

The time-division multiplexer used is a PCM-type carrier terminal. As mentioned, it provides up to twenty-four 56-kb data channels. The 24 data channels are multiplexed to form a 1.544-Mb/s data stream and fed into the high-speed data-under-voice (DUV) modem. The clock for the TDM is provided by the Loran-C clock subsystem (covered later in this article).

At the receive side, the terminal accepts 1.544 Mb/s and demultiplexes the 24 data channels. The data channels provide synchronous information at 56 kb/s, and also provide the unique balanced transmission interface for clock and data, which is an industry standard and is commonly referred to as the "CCITT V.35" interface.

## Data-under-voice (DUV) modem

The data-under-voice modem accepts the 1.544 Mb/s data stream from the time-division multiplexer. With the addition of one plug-in module, it is easily expandable to accept a second 1.544-Mb/s data stream. The output of the modem is a 3.156-Mb/s bit stream that is converted to a unique signal called modified duobinary, which is suitable for direct application to the radio-baseband. Its spectrum occupancy is shown in Fig. 3. At the receive side, the process is reversed, generating the 1.544 Mb/s receive-data stream, which is directed to the receive side of the time-division multiplexer.

## Baseband transmit and receive

The block diagram of the generation of the baseband-transmit and the baseband-receive signals is shown in Fig. 4. Special emphasis has been achieved in the design of the receive side at each end of the system, with the use of a high-pass/low-pass filter that separates out the baseband-receive signal. The upper part of the spectrum signal is routed to the FDM-receive side. The remaining lower portion of the baseband signal is further filtered by a 10-kHz high-pass filter to remove the order-wire and alarm components. The residue signal is then data-equalized and routed to the input of the data-under-voice modem for conversion to a 1.544 Mb/s digital signal.

## High-stability clock subsystem

The high-stability clock subsystem used in the digital part of the microwave system represents a unique approach in the generation of a highly stable clock source. This stable clock source is required to permit ease and flexibility in the interconnection with other highly stable digital networks such as the Bell System DDS.

The entire clock system is derived from the Loran-C very-low-frequency (VLF)

**Table II. Major subsystems at each node of the system.**

| | *FDM with redundant common equipment* | *TDM with redundant common equipment* | *DUV (modem redundant)* | *Order wire and alarm reporting* |
|---|---|---|---|---|
| New York, N.Y. TOCC site | • | • | • | • |
| New York, N.Y. radio site | | | | • |
| Edison, N.J. radio site | | | | • |
| Marriott Hotel, N.J. radio site | | | | • |
| KCC-Piscataway, N.J. radio site | | | | • |
| KCC-Piscataway, N.J. TOCC site | • | • | • | • |

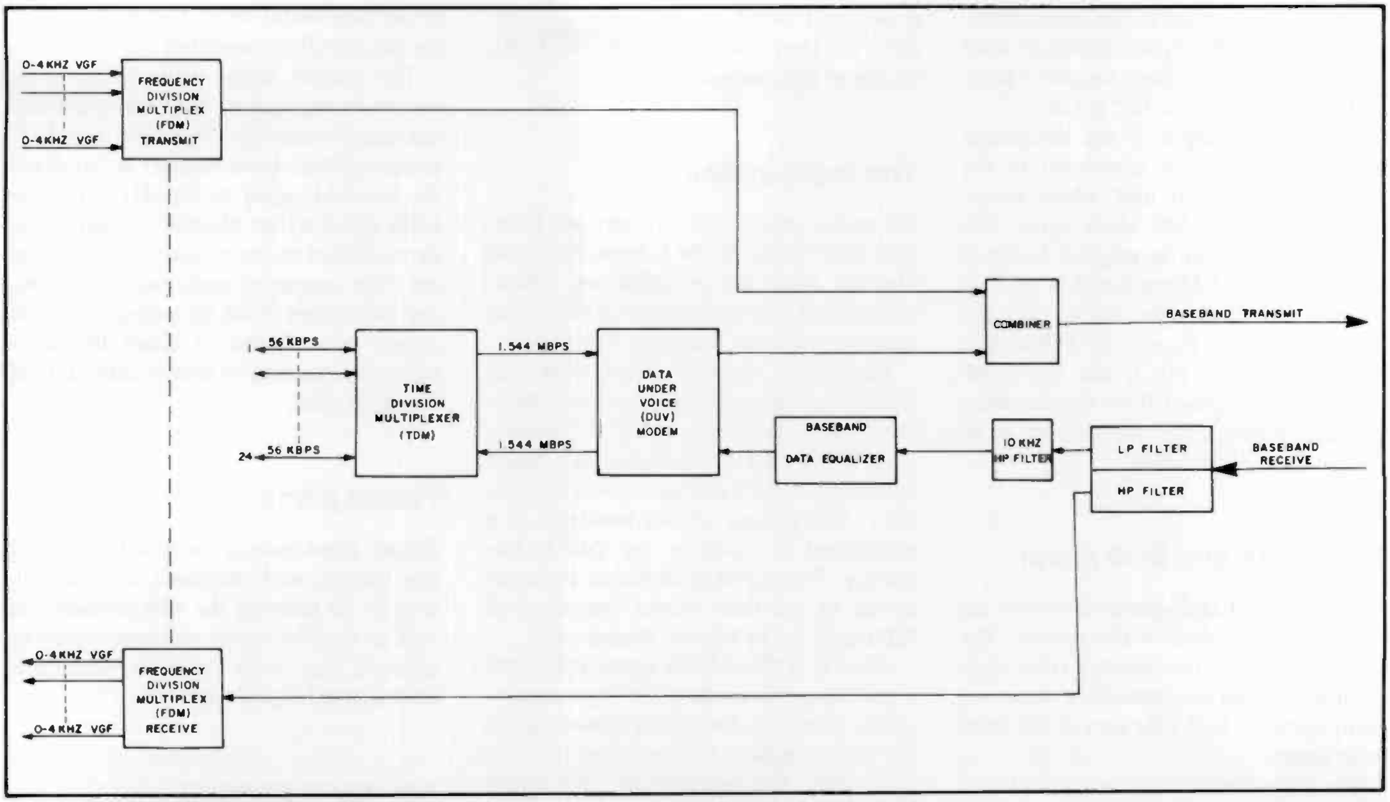



**Fig. 4. Details of the formation of the baseband-transmit signal, as well as the breakout of the baseband-receive signal.** The transmit signal consists of the combining of the outputs of the FDM and data-modem signals. The receive signal is initially filtered by a high-pass/low-pass filter. The output of the high-pass filter is applied to the FDM demultiplexer. The low-pass-filter output is further filtered to remove order-wire and alarm components, and then data equalized before being demodulated and processed by the TDM.

100-kHz transmission. The block diagram of this subsystem is shown in Fig. 5. The Loran-C system is a radio navigation system operated by the U.S. Coast Guard that is generally used as an aid for long-range navigation and frequency calibration. The Loran-C signal that is transmitted from selected sites in the Loran-C network generates a very highly stable clock signal at 100 kHz.

At the KCC-Piscataway, N.J., TOCC, a receiver is tuned to the Loran-C transmitter located at Seneca, N.Y., to receive the 100-kHz signal. The basic stability of this signal, on a 24-hour basis, is better than 5 parts in $10^{12}$. The Loran-C receiver, which internally generates a 1-MHz signal, is phase locked to the incoming Loran-C 100-kHz signal. The signal stability is passed from the Loran receiver by a 1-MHz phase-corrected output to the frequency-multiplier unit. From that point, the signals are passed to the two disciplined frequency standards (rf-oscillator units).

Reference signals must be present at the disciplined standard for approximately seven to ten days in order to allow all servo loops to obtain the maximum correction that is available from the incoming Loran signal. After that time, if the reference signal is lost for any reason, the units will maintain that frequency stabil-

*(Table II continued)*

| *Antennas* | | *Radios (all hot-standby with independent transmitter and receiver switching)* | *Power supplies with redundant backup* |
|---|---|---|---|
| | | | • |
| 12-ft.-Dia. to/fm Edison | | 6 GHz to/fm Edison | • |
| 10-ft.-Dia. to/fm N.Y. | 8-ft.-Dia. to/fm Marriott Hotel site | 6 GHz to/fm N.Y.<br>11 GHz to/fm Marriott | • |
| 8-ft.-Dia. to/fm Edison | 8-ft. Dia. to/fm KCC-Piscataway | 11 GHz to/fm Edison<br>11 GHz to/fm Piscataway | • |
| 6-ft.-Dia. to/fm Marriott Hotel | | 11 GHz to/fm Marriott | • |
| | | | • |

ity for seven to ten days. The free-running performance of the crystal oscillators used in the disciplined standards support a maximum drift of 1 part in $10^{10}$ per day.

The 1-MHz output of the disciplined frequency standard is connected to the frequency synthesizer unit, which generates the required 1.544 Mb/s signal with the same stability as the original Loran-C signal. The 1.544-Mb/s signal is used as the external-clock-input source for the TDM used at the Piscataway TOCC site. At the New York TOCC site, the 1.544-Mb/s clock is derived from the incoming data stream and is "looped around" to be used as the transmit clock.

## Order wire and fault alarm

Order-wire and fault-alarm functions are provided at all sites in the system. The order wire, which provides for voice communications and is essentially a party line, occupies the 0- to 4-kHz part of the baseband signal.

The fault alarm occupies the 4-kHz to 8-kHz part of the baseband signal. Each site contains a remote reporting unit, which is polled by a master fault-alarm terminal at the Piscataway TOCC.

Each remote unit has the capability of 24 alarm inputs. These inputs are used to display equipment status, possible loss of power, and switchover to battery backup, abnormal temperature (at unmanned sites), smoke or fire, and intrusion.

## The radio system

All radios used in the system are baseband-to-rf units. At the Edison, N.J., and Marriott locations, remodulating repeaters are used. Interconnection at these sites is accomplished at baseband level.

Each radio terminal (New York and Piscataway) accepts the composite baseband signal, as shown in Fig. 3. This signal is fed directly to the transmitter, which operates a 2-GHz crystal-controlled oscillator. The output of this oscillator is a modulated rf signal at the 2-GHz frequency. This signal is amplified and multiplied to the final output frequency (6 GHz at N.Y.; 11 GHz at Piscataway).

After it is filtered, the signal is fed into a travelling-wave-tube (TWT) power-amplifier assembly. Two TWT power-amplifier subassemblies are used, one for each transmitter. The output of the TWT amplifiers is fed into a waveguide diode switch. The main transmitter is normally switched on, with the standby transmitter switched into a dummy load. TWTs are used only at the New York and Edison sites. All other sites are fully solid-state transmitters. If a failure occurs in any component of the transmitter chain, the switchover to the hot-standby transmitter occurs.

The receive signal from the antenna system is supplied to both the main and hot-standby receivers by means of a 3-dB power splitter. Each receiver heterodynes the received signal to 70 MHz. The 70-MHz signal is then amplified, filtered, and demodulated to the original baseband signal. The output of each radio is sensed, and switchover to the hot-standby receiver occurs upon failure of either the automatic gain control or loss of continuity of the radio pilot.

## Future plans

Future plans include increased loading of this system, with emphasis on transmitting 56 kb between the two locations, as well as flexibly interconnecting the 56-kb network into both domestic and other international digital networks.

## Acknowledgments

The author wishes to acknowledge, with thanks, many discussions with the Engineering Staff at RCA Globcom. John P. Shields and Ben Kalff deserve particular mention for invaluably assisting during the planning and installation phase.

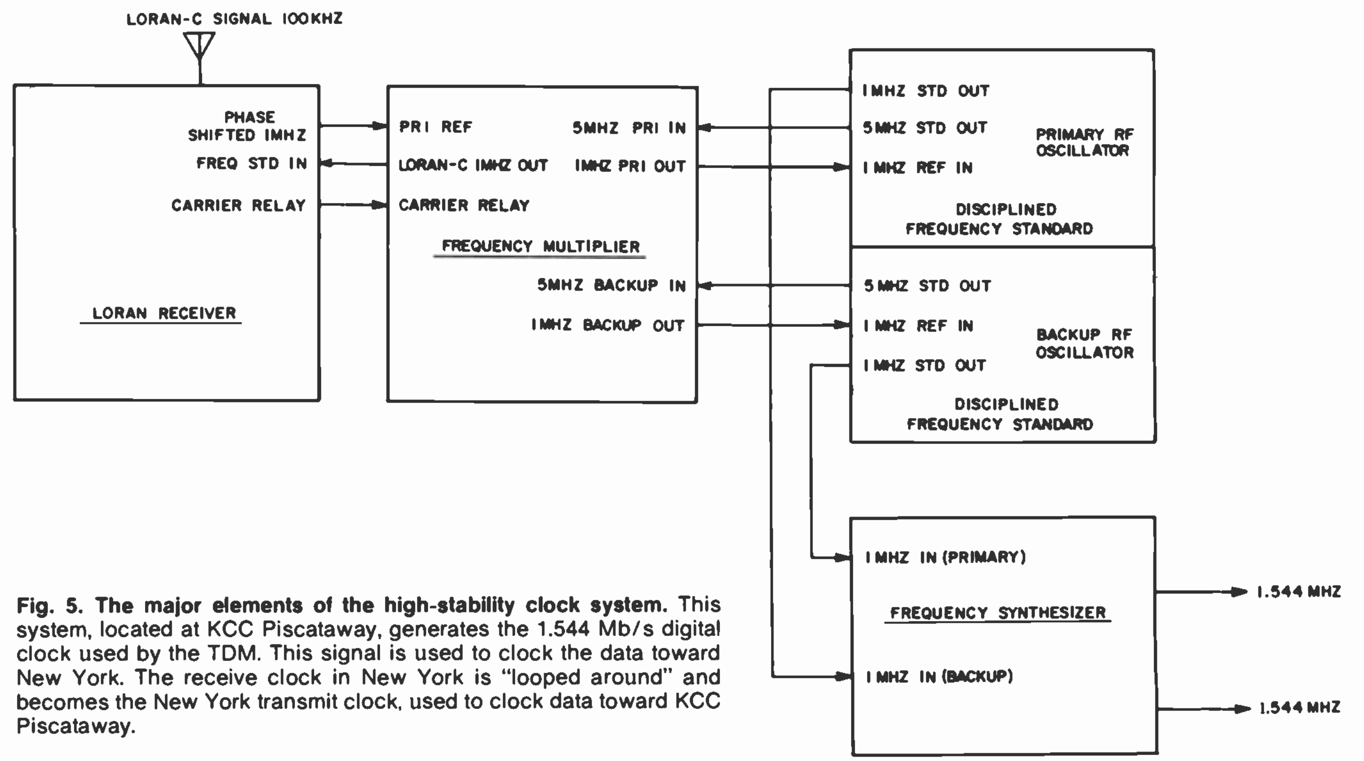



**Fig. 5. The major elements of the high-stability clock system.** This system, located at KCC Piscataway, generates the 1.544 Mb/s digital clock used by the TDM. This signal is used to clock the data toward New York. The receive clock in New York is "looped around" and becomes the New York transmit clock, used to clock data toward KCC Piscataway.

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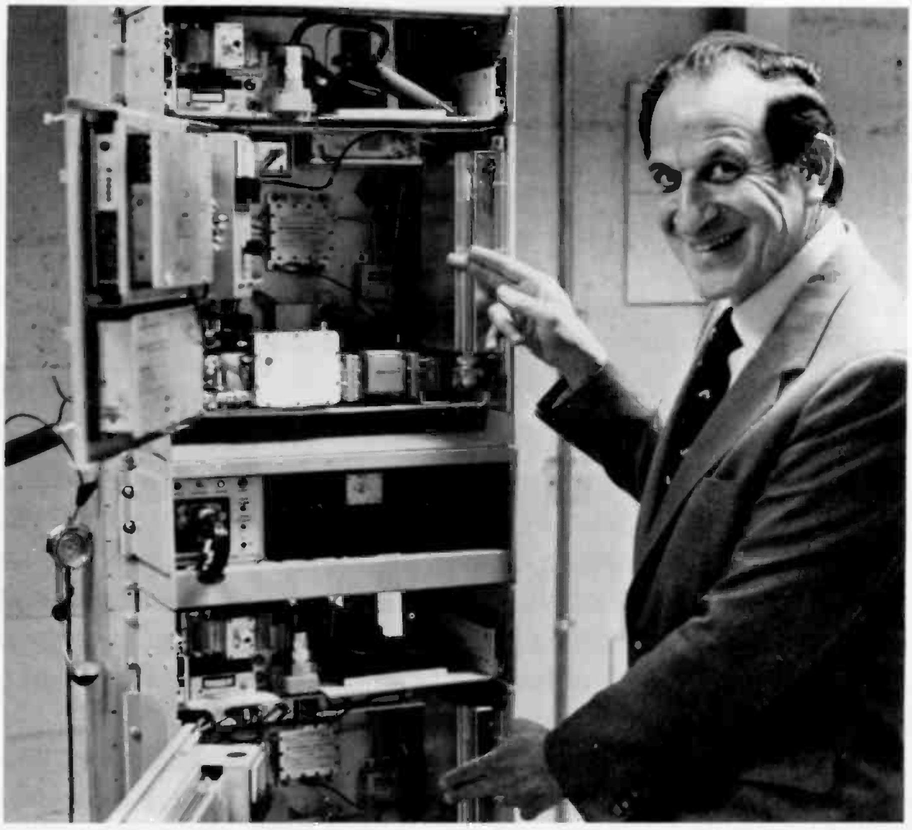

**Author Stanley Solomon** with a typical hot-standby radio transmitter and receiver, showing redundant radios and automatic switching equipment.

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J.F. Clark

# The Direct Broadcasting Satellite: Black hole or bonanza?

*Direct Broadcasting Satellite (DBS) is coming of age. What type of service will this versatile adolescent choose to provide?*

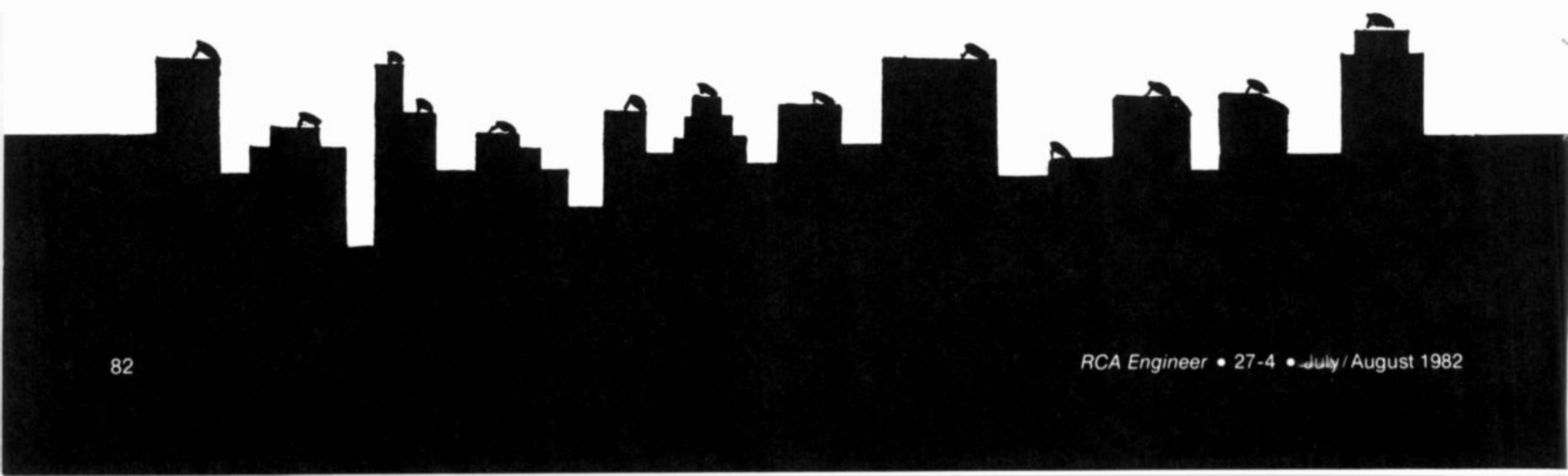
**"DBS will come to pass in more than one country within this decade. It can and should come to pass in the United States in this decade. These are the convictions with which most of us undertook our Advisory Committee tasks, based on our recognition that the technical foundations of DBS are now solid. Without such a conviction, few of us would have devoted so many hours to a 'labor of love.' While completing our work, our convictions have grown rather than diminished.**

**"In more prosaic terms, we see no technical reason why DBS should not proceed with full confidence that the required systems technology is already available or will shortly be available. To give a better feel for the present state of DBS, we list three of the most significant outstanding non-regulatory DBS challenges:**

- **To develop space-qualified high-powered (several-hundred-watt) satellite traveling-wave-tube amplifiers capable of reliable operation for 7 to 10 years;**
- **To design and mass-produce low-cost (a few hundred dollars, installed), reliable DBS home terminals, which produce high-quality TV;**
- **To provide programming sufficiently distinctive and attractive (in either standard or [high-definition television] HDTV format to develop an economically viable viewer market share.**

**"These challenges, in the opinion of this Committee, are arranged in ascending order of difficulty. We believe that the first two are well on the way to solution. The third is beyond this Committee's purview, and is a challenge to every entity which provides or would provide video entertainment and education to American families."**

**From the conclusion of the Executive Summary of the Federal Communications Commission (FCC) 1983 Regional Administrative Radio Conference (RARC-83) Advisory Committee Final Report.[1]**



**Abstract:** *DBS is a proven technical concept evolving in an increasingly favorable regulatory climate. Development of its hardware is the focus of an intensive international effort. But DBS must provide attractive programs within an efficient, profitable system concept to produce the public bonanza of which it is capable.*

If the required systems technology is indeed ready, as stated above, for what reason should Direct Broadcasting Satellite Service (DBS) *not* come to pass? This is a rhetorical question whose answer is known to each of us. Any major competitive venture based on advanced technology has a number of necessary conditions, each of which must be satisfied before proceeding.

## Condition 1. A proven DBS technical concept

The first necessary condition is the development and proof of a viable technical concept. The roots of DBS go back to 1945, when Arthur Clarke first published the geostationary orbital elements and pointed out the advantages of a worldwide communications system employing three geostationary satellites, one over each major ocean. In 1962, Donald Bond of RCA Laboratories recognized the feasibility of DBS and presented one system plan for its use.[2] In 1963, a diurnal geosynchronous orbit was first used by NASA's Syncom for communications experiments. By 1969 Comsat had placed Intelsat "birds" over each of the three major oceans, thereby fulfilling Clarke's prophesy after 24 years.[3]

NASA took the next step in 1974 with the launch of the Applications Technology Satellite, ATS-6. This was the first satellite designed to transmit a signal so powerful that a high-quality TV picture could be received using a small inexpensive home terminal antenna. Its 4-GHz TWTA had an output of only 21 W, but its space-deployed 9-m (30-ft) antenna boosted its effective isotropically radiated power (EIRP) to 51.5 dBW (140 kW) at the edge of coverage (EOC) of its 0.6° field of view. Two years later, the Canadian-U.S. Technology Satellite—CTS or Hermes—used a 200-W TWTA at 12 GHz to broadcast an EOC EIRP of 57 dBW (500 kW) over a larger area. In 1978, the Japanese launched their experimental broadcasting satellite, BSE, in a pre-operational test covering that nation's major islands. In each instance the proof of concept was successful, but long-lived space-qualified high-power TWTAs have yet to be demonstrated.

U.S. preeminence in space communications during the 1960s and 1970s is noteworthy. All four key satellites cited above were developed, built, launched, and operated by the U.S. except for Hermes, built and operated by Canada (using a U.S. TWTA and power supply), and BSE, operated by Japan. That preeminence has dissipated very rapidly with the cessation of space communications flight research by NASA after the launch of ATS-6. The expanding developments in Western Europe, Japan and elsewhere of communications satellites (including DBS-class) and launch vehicles (for example, Ariane) have accelerated that dissipation.

## Condition 2. A favorable regulatory environment

Telecommunications, whether broadcast or common carrier, is regulated domestically by the FCC, and internationally by treaty and voluntary adherence to the International Telecommunications Union (ITU). Thus, a competitive telecommunications venture can proceed only in a regulatory environment perceived to be favorable by the sponsor. The ITU has been concerned with the Broadcasting Satellite Service (BSS) since 1963, but it was only in 1979 that the regulatory environment in ITU Region 2 (the Americas and Greenland) became favorable for the development of DBS in the Americas.

Historically, BSS was formally recognized as a distinct space service by the ITU in 1963. BSS received frequency allocations in six bands, including 12 GHz, at the 1971 World Administrative Radio Conference (WARC). At the 1977 WARC-BS, a plan was developed for the BSS in the 12-GHz band. This plan allotted one of 35 orbital slots to each of 252 identified service areas of the 150 Administrations and Territories of ITU Regions 1 and 3 (Africa, Asia, Australia and Europe).[4] Detailed planning in Region 2 was postponed until RARC-83. Until then, the BSS in Region 2 is characterized as experimental. At the 1979 WARC, the ITU assigned a new band below 12.7 GHz to the BSS as the primary space service in Region 2. Its lower boundary will be set at RARC-83, probably at 12.2 GHz. It was this action at WARC-79, removing 12-GHz BSS assignments from direct competition with Fixed Satellite Service (FSS) assignments, that improved the BSS international regulatory environment in Region 2 thereafter.

Domestically, developments favorable to DBS began in 1980 when the FCC, under Docket 80-398, requested public comment on the BSS in preparation for U.S. participation in RARC-83. In 1981, the FCC ordered the establishment of an advisory committee to assist in the areas of basic service requirements, technical specifications, planning principles and procedures, and sharing criteria. Meanwhile, in 1980, the FCC, under Docket 80-603, initiated an "inquiry into the development of regulatory policy in regard to DBS . . . following RARC-83." Later in 1980, the Satellite Television Corporation, a subsidiary of Comsat Corporation, filed a five-volume application to construct an experimental DBS system. In June 1981, the FCC set an important deadline for potential applicants who wished to provide interim DBS service to the United States. All such applicants who desired to have their filings considered with the same priority afforded the 1980 STC application were required to submit their applications no later than 16 July 1981. We shall return to the regulatory environment after reviewing the resultant DBS applications and the FCC RARC-83 Advisory Committee findings.

## The regulatory environment revisited

Should the FCC adopt the Advisory Committee's recommendation regarding block frequency allotment planning, and should this become ITU policy with respect to BSS planning in Region 2, the international BSS regulatory environment would be quite satisfactory. The FCC would then have the responsibility and authority to ensure an equally satisfactory domestic regulatory

*(Continued on page 86)* ▶


Final manuscript received June 14, 1982.
Reprint RE-27-4-12.

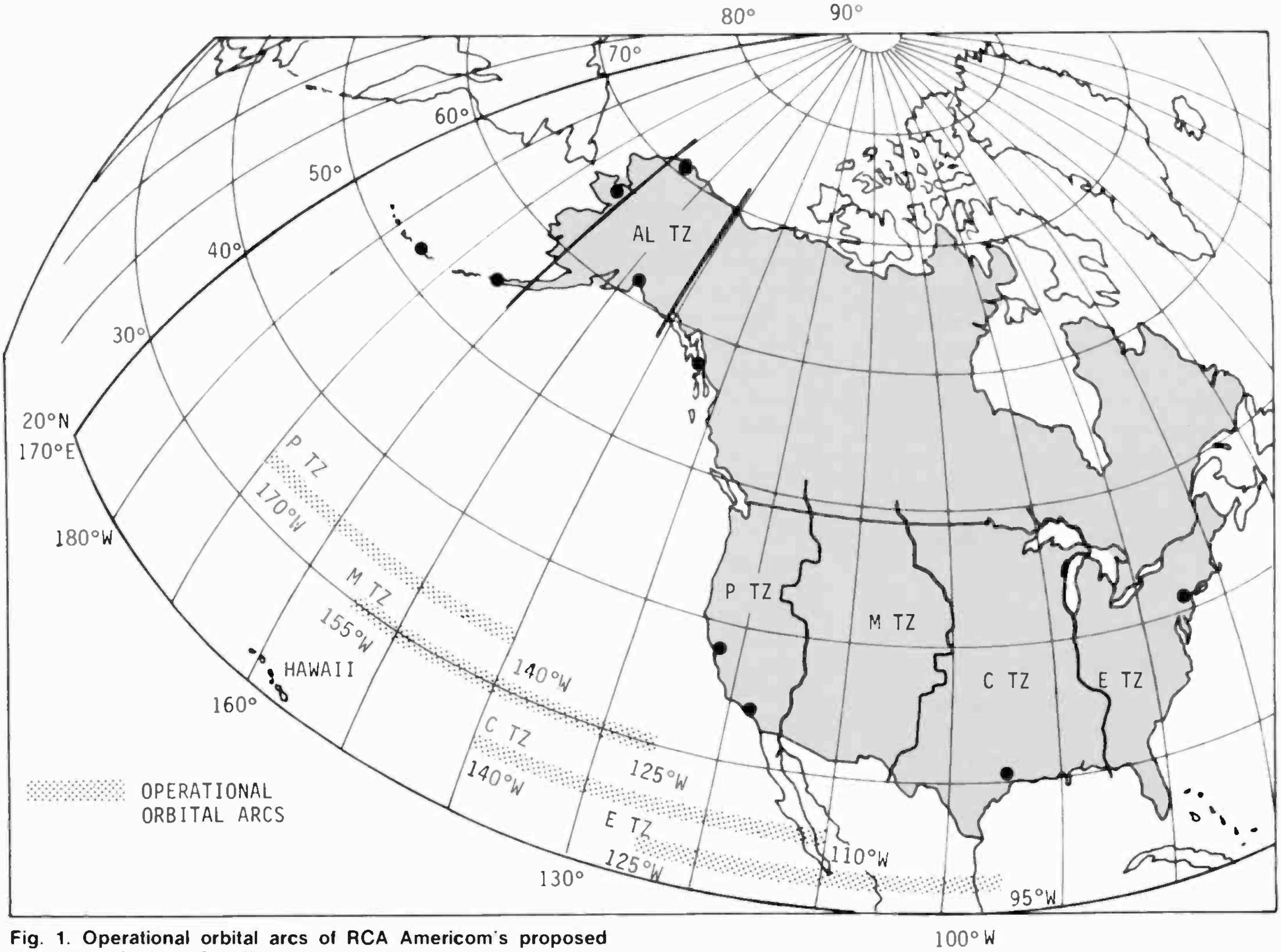



**Fig. 1. Operational orbital arcs of RCA Americom's proposed Direct Broadcasting Satellite.**

## DBS applications accepted for filing by the FCC

Before the end of 1981, eight applications to provide DBS service in the 12-GHz band had been accepted for filing. A ninth application to use Advanced Westar for BSS in the FSS band will not be considered here.

There is even more variety in the purposes of the proposed services than in their proposed methods of implementation. The major common element of purpose is DBS service to viewers in all parts of the contiguous U.S. (CONUS)—and to at least some parts of Alaska, Hawaii, Puerto Rico and the Virgin Islands—by systems which are economically viable, supported by some combination of subscriber and/or advertiser revenue. Only one of the 1981 applicants, Graphic Scanning Corp. (GSC), followed the lead of Satellite Television Corp. (STC) in providing an exclusive, multichannel, scrambled, subscription-supported DBS service. Direct Broadcast Satellite Corp. (DBSC) was alone in requesting common-carrier status for its ambitious system, which is also the only proposed system to use spot beams in addition to CONUS coverage. RCA American Communications, Inc., also proposed to lease its channels, but reserved the right to retain some capacity for its own use. Western Union Telegraph Corp. (WUTC) proposed complete control of the selection of program suppliers for its system.

U.S. Satellite Broadcasting Co., Inc. (USSB) would bridge DBS and conventional broadcasting by transmitting the unscrambled, commercially sponsored DBS programming from one terrestrial member station in each area. These member stations would share in the provision of DBS programming via their local feeder links, and share the commercial sponsorship revenue. Viewers could use either a conventional VHF/UHF receiver or a 12-GHz DBS terminal to receive the same programs. Video Satellite Systems, Inc. (VSS) also proposed to distribute free commercially sponsored programs, but its scrambled signals would be unscrambled and provided to the public only by their affiliated VHF/UHF terrestrial stations within their service areas.

Elsewhere free decoders would enable direct DBS reception by individual viewers and by CATV systems not carrying a VSS affiliate. CBS, Inc. would also encourage individual reception of their network HDTV programming directly from their DBS only outside affiliated station service areas. CBS proposed two additional scrambled HDTV subscription channels for institutional, business and residential users. More limited HDTV uses were proposed by DBSC, RCA, STC, USSB, and VSS.

Six of the eight proposed systems followed the STC lead in dividing CONUS into four service areas, which are approximately equal to the four CONUS time zones (Fig. 1). These areas are adjusted to provide stronger signals in regions of climatologically heavier precipitation at the expense of drier areas where lower signal margins are sufficient. DBSC proposed three service areas and GSC proposed only two. All of the proposed fully deployed systems feature one operating satellite (service area) at a time. USSB, VSS and WUTC would initiate service covering two time zones per satellite, while DBSC would cover all three of its CONUS service areas from its first satellite. In their fully deployed systems, GSC and VSS would provide two channels per service area throughout CONUS, CBS and STC three channels, WUTC four, and RCA, DBSC and USSB six. DBSC would also provide four channels in each of two spot beams in each of their three service areas.

WUTC proposed the only system that would provide full service during DBS satellite eclipse periods. The proposed orbital locations between 80° and 140° west longitude are almost due south of their service areas, thereby insuring high elevation angles (33° to 55°) of the home terminal antennas. DBSC proposed to place their three satellites between 103° and 143°, but with operation of only about one third of their capacity during eclipse periods. The six remaining applicants proposed to place their satellites between 110° and 175°. By providing little or no capability for operation during the delayed early-morning eclipse periods, significant satellite-battery weight savings were achieved.

All proposed DBS transponders would use TWTAs ranging from 100- to 400-W output power. After normalizing the area of coverage, most of the proposed values of EIRP at the edge of coverage fall between 56 and 58 dBW. One exception is that of GSC, which would provide less than 54 dBW because of the unusually large half-CONUS coverage per beam. The other exception is CBS, which would provide more than 60 dBW EIRP to achieve a more adequate carrier-to-noise ratio (C/N) for wider-bandwidth HDTV transmissions. Suggested channel bandwidths varied from 16 MHz (STC, USSB, WUTC) to 24 MHz (RCA) and 27 MHz (CBS-HDTV). STC proposed HDTV experiments using 28 and 100 MHz, and RCA proposed 72 MHz (three 24-MHz channels) for similar purposes.

Four proposed spacecraft (GSC, STC, VSS, WUTC) are in the Shuttle/spin-stabilized-upper-stage Delta (SSUS-D) weight class. The total power output of their operating TWTAs ranges between 300 and 600 W. Three spacecraft (CBS, RCA, USSB) are in the SSUS-A category, transmitting between 1200 and 1400 W of output power. The DBSC spacecraft would require a launch vehicle of even greater weight capability (for example, a modified Centaur liquid-propelled upper stage) because of the 14 TWTAs operating at a total output power of nearly 1400 W. Many of the proposers (CBS, USSB, VSS, WUTC) regard an appropriate model of Ariane as a possible alternative launcher.

In general, most of the applicants advocated ground terminal antennas from 0.6 to 1.0 m in diameter, a signal-to-noise ratio (S/N) of at least 42 dB, and a C/N of at least 4 dB above threshold in fair weather. Such a signal would be rated excellent by at least half of the viewers, and would be available for at least 99 percent of the worst month of the year throughout CONUS. Figure 2 illustrates a typical DBS home installation.

## FCC RARC-83 Advisory Committee findings

The work of this Committee was substantially completed on schedule in April 1982 and formally reported in May.[5] We sought "consensus without emasculation," while respecting and recording responsible minority views. The work was assigned to three subcommittees dealing with BSS service requirements, technical parameters and planning methods, and inter-service sharing. In turn, each subcommittee divided itself into from two to five specialized working groups, which in total were led by some twenty individuals as chairmen or vice-chairmen. More than 100 persons participated actively in the intensive work of these groups. The Service Requirements Subcommittee had the most difficult and controversial task—forecasting demand for a new service. Its major findings are summarized in Table I and in the following excerpts:

"Not only was there an increasing divergence of anticipated requirements as the end of this century approaches, but there was also a major division of opinion regarding the validity of using the sum of the channel requests of the eight BSS filings currently accepted by the FCC, as the baseline capacity requirement for 1985.

"Many previous forecasts assumed that the number of DBS channels would be quite limited and that they would be offered exclusively to individual households. Such forecasts

**Table I. DBS Service Requirements.** Given in equivalent standard TV channels. All estimates are inherently uncertain and will remain subject to change as the cost and market potential of DBS becomes more clearly defined.

| *Working Group* | *Service* | *1985-86* | *1990-93* | *2000* |
|---|---|---|---|---|
| 1A | Standard TV | 25-32 | 25-85 | 31-128 |
| 1B | High Definition TV[1] | 6-8 | 6-8 | 6-36 |
| 1D | Other Related Services | 1 | 16 | 26 |
| 1E | Public Service | 4-5 | 4-12 | 5-25 |
| | Totals[2] | 36-46 | 51-121 | 68-215 |

1. HDTV channels each occupy two or more standard TV channels; 6 to 8 standard TV channels equal 3 to 4 (or less) HDTV channels.

2. Expressed as standard TV channels; requirements themselves are not necessarily additive, particularly between 1A and 1E, but have been added here for convenience.

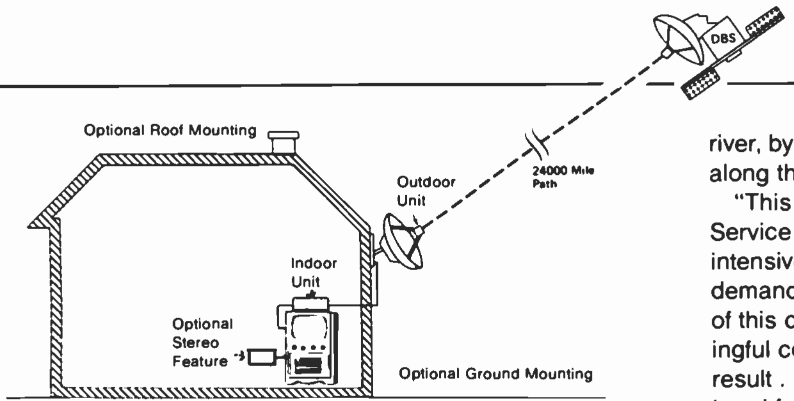



**Fig. 2. Using receiving units with receiving dishes that are one meter or less in diameter, homes will be able to receive additional TV channels.**

may be overly conservative, because DBS systems are equally capable of distributing programs to all forms of community systems (for example, cable, STV, MDS, and terrestrial broadcast). This capability leads to the possibility that some future Fixed Satellite Service (FSS) demand may be satisfied by BSS. For FSS programmers, this trade-off must balance, among other things, the additional audience to be derived from BSS viewers against the very substantial cost increase of a BSS channel compared to its FSS counterpart. For a BSS programmer, the advantages of additional community system customers are apparent.

"It is tempting to discuss in detail the pros and cons of the various demand projections, with their numerous associated minority views. Such a course is basically counterproductive, for the following reason. Forecasting the demand for a new service has always proved to be a hazardous undertaking. There is always an element of the absurd example of deriving an estimate of the demand for a vehicular bridge across a previously unbridged stretch of river, by counting the number of swimming commuters along that stretch.

"This Advisory Committee asserts that [its Standard TV Service Requirements Working Group] carried out the most intensive and extensive effort thus far to forecast BSS demand for standard TV channels throughout the remainder of this century. Fortunately, its difficulty in reaching a meaningful consensus does not detract from the value of its result . . . The capacity of the (assumed) 500-MHz BSS band from 12.2 to 12.7 GHz, using our recommended 26 MHz co-channel spacing and polarization frequency reuse, is 36 channels per satellite slot, or cluster, for each service area. This number falls in the lowest quartile of the projected standard-TV-channel demand in 1990 and beyond (Table I).

"[The] Working Group [on HDTV Service Requirements] had an even more challenging task to project demand for high definition television (HDTV) channels. The 3 to 18 channels projected for 1993 to 2000 bracketed results of a ballot of all organizations represented on [that Working Group] (one vote per organization). A 69 percent majority expected 12 to 18 HDTV channels to be utilized, 23 percent expected 3 to 15 channels, and 8 percent foresaw 3 to 7 such channels, at the end of the century. Fortunately, the FCC can provide for standard TV and HDTV, within any reasonable BSS allotment, in whatever ratio is required by the providers of each service. This happy circumstance occurs because it now appears that one HDTV wideband channel may be repackaged into two digital channels, each of the same bandwidth as a standard TV channel. . . .

"Considering [these] channel requirements, our position should favor assignment of the full BSS band to each U.S.

*(Continued from page 83)*

environment for DBS. These matters should be resolved in five discrete steps between June 1982 and mid-to-late 1983.

First is the adoption by the FCC of rules for interim DBS service, which could have occurred as early as June 1982. Meanwhile, the joint two-week early summer Conference Preparatory Meeting (CPM) of CCIR Study Groups 4, 5, 9, 10 and 11, should have given some indication of whether block frequency allotment planning would be adopted at RARC-83. Next should come FCC decisions concerning interim DBS construction permits, probably about September 1982, although such matters can always occur sooner or later than expected. Fourth should come the findings of RARC-83 in July 1983 which will probably determine the international BSS regulatory environment for the rest of the century. Finally, the FCC can then promulgate final DBS rules, issue longer-term licenses, and clarify the future of terrestrial services previously licensed to operate in the 12-GHz BSS frequency band.

## Condition 3. Available, reliable, and inexpensive hardware

The third necessary condition to be satisfied before proceeding with a consumer satellite-communications venture is the availability of space-qualified hardware for the satellite, reliable hardware for the ground control and feeder link stations, and mass-produced low-cost reliable (for minimum service in remote areas) home terminals which produce high-quality TV. The affirmative conclusions of the FCC RARC-83 Advisory Committee are cited in the opening paragraphs of this paper. These conclusions are based on hardware development in many European countries, Canada, Japan, the U.S. and elsewhere. Many of these developments, notably the high-power satellite TWTAs and the low-cost home terminals, are in response to the perceived major worldwide DBS markets. Others, such as lower-cost launch vehicles (for example, Space Shuttle, Ariane), satellite shaped-antenna-beam technology, and improved low-noise uncooled 12-GHz receiver GaAs FET rf amplifiers, have arisen from quite unrelated programs.

So DBS qualifies on three counts. It has—or should shortly have—a proven technical concept, a favorable regulatory environment, and available reliable inexpensive hardware. Does that make DBS a bonanza? Not necessarily. Some sixty years ago, radio began its spectacular growth which provided a bonanza to set manufacturers, station owners and network operators—and early radio receivers and transmitters could hardly be termed either reliable or inexpensive. The advantage possessed by early radio was that of monopoly. It was then the only real-time source of outside entertainment and information to the home. With the advent of black-and-white TV, identical considerations applied. It was then the service area, to be available for use by DBS if the Committee projections prove to be accurate. However, the FCC should retain the option to provide domestic sub-band frequency allotments for other users (for example, terrestrial fixed service). This is the best opportunity for the FCC to balance actual, demonstrated requirements of these competing services for spectrum over the next decades."

The Technical Parameters and Planning Methods Subcommittee findings are summarized in a lengthy and detailed table in the 1983 Advisory Committee Report. Its first page lists the 12-GHz BSS downlink planning parameters in the first column, WARC-77 recommended values of these parameters for ITU Region 2 in the second column, and RARC-83 Advisory Committee recommended values in column three. The recommended values of co-channel and adjacent channel protection ratios are still subject to the completion of work in progress, as cited in the last column. The recommended spacing between copolar channels is 26 MHz, which is equivalent to 13 MHz between adjacent orthogonal channels. The recommended value of home receiver figure of merit, the gain divided by the temperature (G/T) in dB/K, is better than that recommended at WARC-77, but still quite conservative compared to current technological capability. The trends in antenna patterns are toward better side-lobe suppression, shaped satellite beams for large service areas, and smaller home terminal antennas (75 to 90 cm) for better aesthetics and lower costs. Wider bandwidths than the WARC-77 value of 18 MHz (up to 24 MHz) would be permitted but not required. The tolerance on satellite rotation about its antenna beam axis would be tightened to $\pm 1°$. HDTV appears only once in the table, in connection with maximum power flux density (PFD). The recommended value of $-102$ dBW/m$^2$ for a double channel is equivalent to $-105$ dBW/m$^2$ for a standard channel in terms of PFD per unit of bandwidth.

As the countries in Regions 1 and 3 have discovered, feeder-link planning is not a simple task, particularly after the downlink planning has been solidified. The countries in Region 2 were wise to couple feeder-link and downlink planning together on the agenda for RARC-83. The minimum 5-m feeder-link transmitting-antenna size, the maximum 500-W antenna power, and the negative recommendation regarding depolarization compensation and power control use are all new contributions to RARC-83 preparations. Another contribution is the separation of nominally co-located satellites by several tenths of a degree, to achieve additional feeder-link channel isolation.

The key recommendation of this Subcommittee and its parent Committee favors block frequency-allotment planning, which relies primarily on the directivity of home terminal antennas to decouple service to contiguous service areas from DBS satellites at least 15° apart. Such planning would permit each service area to select its own values of parameters such as channel separation and type of polarization, subject to a maximum EIRP at EOC and appropriate antenna pattern roll-off beyond EOC.

The most important finding of the Inter-Service Sharing Subcommittee is its reaffirmation of "the well-documented consensus that co-channel sharing is generally not feasible, in the same service area, between the BSS and terrestrial services . . . Such considerations led to strong support for adoption of a block [frequency] allotment plan at RARC-83 as the most technically suitable way of meeting the needs of affected existing systems. Its adoption would also facilitate implementation of band segmentation between services on a domestic basis."

only real-time visual source of outside entertainment to the home. Radio, although it would prosper in different ways (for example, narrowcasting) would never again be the same. Then color TV, thanks again to General Sarnoff and RCA, not only competed with monochrome TV, but replaced the latter completely except for specialty uses (for example, small portable sets).

In the seventies, Americans enjoyed the most pervasive terrestrial TV broadcast networks in the world. It is widely believed that this success is because of, not in spite of, its free-to-the-viewer advertiser-supported basis. But in the 1970s, competitive delivery systems were starting to grow. Cable networks, formed to improve reception in areas remote from terrestrial transmitters, were transformed by satellite feeds into national program distributors. The phenomenal growth of pay cable, Multipoint Distribution Service (MDS), Subscription Television (STV) and, more recently, video cassette and video disc sales, have permanently changed the face of the home video industry and surprised many observers by the intensity of demand for all forms of "pay" (as distinguished from "free") TV.

The monopoly that radio had in the twenties and TV enjoyed in the forties, DBS will never have. If it is to bring a bonanza to its operators rather than to absorb their capital like a black hole with no return, DBS must bring its customers as good or better programs at the same or less cost than its competitors. The customer is concerned with the quality, cost and convenience of his programs, not with the method of delivery! And DBS, unadorned, is merely a delivery system, not a video service.

## Conditions 4 and 5. Where marketing and entertainment meet technology

So, in addition to a proven technical concept, a favorable regulatory environment and good inexpensive hardware, we have two more necessary conditions to satisfy: a profitable system concept; and attractive programs which are compatible with this concept.

The diversity of system concepts espoused by the eight surviving DBS applicants is testimony to the complexity of deciding on an optimum choice. In devising a profitable system concept, key issues include number of DBS home terminals, home terminal antenna size, satellite EIRP, number of customers served through other than DBS home terminals, nature of program revenue (sponsored or pay, scrambled or unscrambled, and so on), and satellite coverage area (number of coverage areas in CONUS). The provision of attractive programs in itself could be the subject of many articles in other journals.

## Conclusion

DBS has passed or appears to be passing its first three hurdles with flying colors. It is a proven technical concept, it is evolving in an increasingly favorable regulatory climate, and development of its hardware is the focus of an intensive, international, competitive effort. In many other countries, government-owned DBS systems are proceeding with little apparent concern for profitable system concepts or particularly attractive programs. In the U.S., our vaunted Yankee competitive ingenuity will hopefully continue to develop more attractive programs and more efficient distribution systems for both broadcast and narrowcast programs.

I believe DBS will be one of these.

## References


1. Clark, J.F., Chairman, *Final Report of the Advisory Committee on Preparations for the International Telecommunications Union (ITU) Region 2 Broadcasting Satellite Service Planning Conference*, p. xii (May 14, 1982).
2. Bond, D.S., "Performance Characteristics of a System for Direct Television Broadcasting from Earth Satellites," IEE International Conference on Satellite Communication, *Program and Conference Digest*, London, pp. 257-264 (November 22-28, 1962).
3. For a tutorial discussion of communications satellites and their orbits, see Clark, J.F., "Space Applications for the Benefit of Man," *RCA Engineer*, Vol. 24, No. 2, pp. 5, 6 (August/September 1978).
4. Reinhart, E.E., *et al.*, "The Impact of WARC-79 on the BSS," *IEEE Trans. Commun.*, COM-29, pp. 1193-1209.
5. From Final Report FCC RARC-83.
6. "Survey Politics of HDTV via DBS," *Broadcasting*, p. 72 (May 17, 1982).


## Two myths about DBS

### *Myth*

**Direct Broadcasting Satellite (DBS) service will have to compete against cable television (CATV), and it will lose.**

### *Facts*

- An interview of 1200 persons completed in October 1981 for Hubbard Broadcasting, Inc., by Frank N. Magid Associates[6] suggested there is broad interest in DBS. More than half of those interviewed were interested in having a home terminal to receive 30-channel DBS, and most of these were "very likely" (26%), or "somewhat likely" (20%), to spend $300 to buy a home terminal. Interest among cable TV customers was only moderately less than among unconnected homes.

  Assuming the statistical validity of extrapolating this sample nationwide yields a potential DBS audience of some 40-million homes. A more conservative DBS target might be the 20-million homes that are never expected to be passed by cable because of the expense involved (rural, low-density suburban, and old urban areas).
- DBS, used in conjunction with telephone service, can make a full range of interactive services available. Billing for these could be tied in with the telephone system.
- DBS can be used to distribute through existing services, such as cable TV, low-power TV and MDS.
- In fact, DBS and CATV can strengthen each other where cable is already in place.

### *Myth*

**RCA has the capability to participate in only a small part of the DBS spectrum of activities.**

### *Facts*

- RCA Americom is one of eight surviving FCC applicants to provide DBS service.
- RCA Astro-Electronics is well qualified to supply DBS space-segment hardware. STC has announced that RCA is one of four bidders on STC's satellite RFP (request for proposal).
- RCA Service Company installs and maintains RCA television sets and other home entertainment equipment over broad areas of the United States.
- RCA and its subsidiaries have been providing home entertainment and information for decades.
- In summary, RCA is well positioned to lead in those facets of DBS that it chooses.

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He is Chairman of the FCC RARC-83 Advisory Committee on DBS planning and a member of the U.S. delegation to the 1982 ITU Conference Planning Meeting. His professional awards include the 1974 Collier Trophy award for leadership in the LANDSAT program, and NASA medals for Distinguished Service, Outstanding Leadership, and Exceptional Service. He is a Fellow of AIAA and IEEE, and a member of Phi Beta Kappa, Tau Beta Pi, and Sigma Xi. He received his PhD in Physics from the University of Maryland in 1956.


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J.R. Staniszewski

# Expectations achieved: NOVA-1, the second-generation Navy Navigation Satellite

*NOVA-1, the newest star in the Navy's constellation of satellites, has achieved a number of technical "firsts" in its first year of orbit.*

**Abstract:** *Since its release by presidential directive in July of 1967 for commercial development, the Navy's Transit navigational system has had an enviable record of reliability and a rapid growth in navigator and surveyor use. In July of 1981, NOVA-1 was placed into service and was welcomed as a satellite navigation broadcaster, filling in a gap in coverage and reducing the satellite waiting time. NOVA-1 is the first of a limited number of improved Transit satellites authorized for production by the Navy by RCA Astro-Electronics. As it nears its first year in orbit, NOVA has demonstrated a number of firsts for an operational satellite: It achieved a precision orbit; it operates "drag-free"; it broadcasts a high-quality ephemeris; and it provides improvements in broadcast-signal strength and frequency stability at the user's receiving terminals. The satellite-design features and their applications to improved navigation and position determination are discussed.*

NOVA-1, the first of a limited production of second-generation Navy Navigation Satellites, was successfully launched from the Western Test Range at Vandenberg Air Force Base in California on May 14, 1981. NOVA joined a constellation of four OSCAR-Transit satellites whose combined on-orbit performance life exceeds 50 years. NOVA-1 is the result of an intensive technology-transfer program, which converted the prototype designs of the Transit Improvement Program of the Johns Hopkins University's Applied Physics Laboratory into the limited production of the NOVA hardware at RCA Astro-Electronics. NOVA, the newest addition in the Navy's Navigation Satellite System (NNSS), provides additional and improved navigation service to the Navy's Ballistic Missile Submarine Fleet (Fig. 1, page 90).

As NOVA passes its first anniversary of operation (it was declared operational on July 31, 1981), it is time to reflect on achievements already confirmed by its on-orbit performance. NOVA-1 has demonstrated some of the unique operational features for which it was designed. The more significant features are as follows:

- It has achieved a remarkably precise, preselected orbit, demonstrating that optimum coverage can be provided to the navigation user with reduced satellite waiting times;
- It has operated as a "drag-free" satellite since it became operational and has broadcast high-quality predicted Keplerian elements describing its orbit well beyond the accuracy and storage of predicted ephemerides (a tabulation of the orbital elements describing position in orbit) previously provided; and
- It has demonstrated that, if necessary, it can operate autonomously through a brief disruption in ground-station operation without the immediate need to refresh its stored ephemeris with newly measured and predicted orbit elements.

These demonstrated achievements stem from the following new technology systems added to the spacecraft (Fig. 2, page 91): the Orbit Adjust Transfer System (OATS); the Disturbance Compensation Subsystem (DISCOS); an expanded memory system; and an ultra-stable oscillator.

The Orbit Adjust Transfer System (OATS) is an integrated liquid stage with commandable firing times and durations used to adjust the altitude, eccentricity, and inclination to bring the spacecraft on station in its preselected orbit. The Disturbance Compensation Subsystem (DISCOS) is an ultra-sensitive electro-optical sensor and two ion-plasma, micro-pound thrusters aligned fore and aft on the spacecraft and pulsed to defeat, in real time, drag and radiation forces acting on the satellite at its operational altitude of 600 nautical miles.

An expanded memory in the spacecraft provides for up to eight days of predicted


Final manuscript received May 13, 1982.
Reprint RE-27-4-13

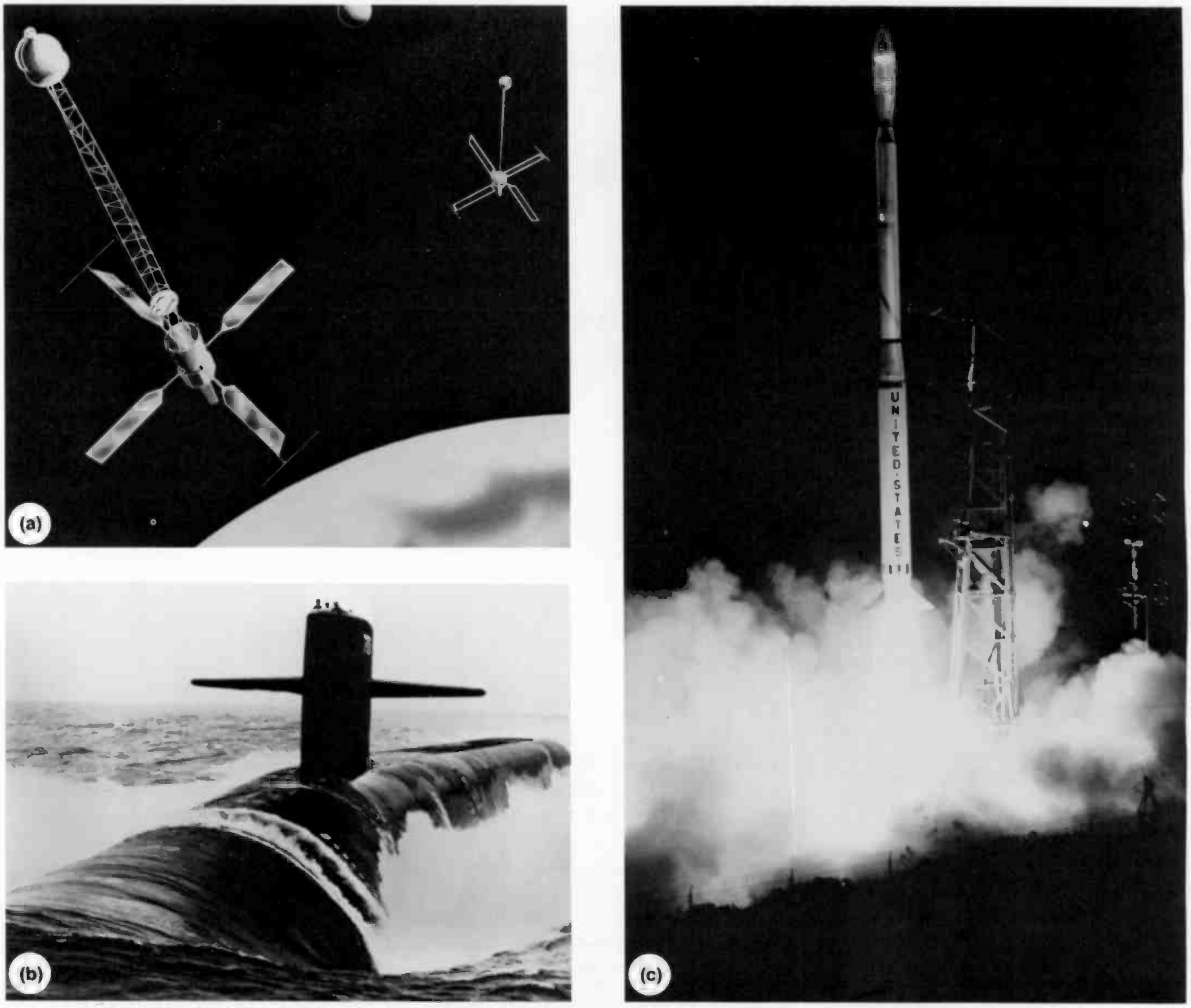



**Fig. 1. The space segment of the Navy Navigation System** consists of four OSCAR-Transit satellites and one NOVA satellite **(a)**. These satellites broadcast navigation signals to the Navy Ballistic Missile Submarine Fleet **(b)**. The satellites are lifted into their 600-nautical-mile, circular, polar orbit by the Scout, a low-cost reliable launcher **(c)**.

ephemerides. The memory is structured in magnetic core as a random-access memory for a general-purpose central-processing unit. Data stored in this memory provide navigation messages in two-minute recurring formats containing information on the satellite's orbit elements, cross-orbits (arrival times) for other satellites in the constellation, and universal time code. An ultra-stable oscillator, controlled by a ground programmable Incremental Phase Synthesizer (IPS), precisely sets the satellite clock and corrects its long-term drift characteristics, and holds the timing source constant during data recovery time. The controlled frequencies are coherently multiplied to provide rf carriers at 150 MHz and 400 MHz, thus completing the Doppler subsystem, which is the primary payload for the navigation satellite.

## The Navy Navigation Satellite System

To fully appreciate the magnitude and the essence of these achievements and the new investments in spacecraft design, it is first necessary to look back nearly 20 years to 1963[1] when the first satellite similar to the currently operating OSCAR-Transit satellites was put into operation. It is also useful to reflect on the stability and reliability of the Transit Navigation Satellite System and on the level of maturity it has achieved as a navigation and surveying system. Its universal acceptance can be measured by the remarkable explosion in the user base in recent years.[2] This latter growth was triggered by a cooperative venture of government and industry to exploit the system for commercial navigation and surveying since its broadcasted signals were first made available by presidential directive in July of 1967. Industry's contribution has been in the development of low-cost, reliable, dual- and single-frequency receiver-computers (user's growth, Fig. 3) for the ocean industries and supporting software and systems for global, all-weather precision surveys of a quality acceptable as a primary bench-mark survey.

This growth, which will be further stimulated with the entrance of NOVA into service, is due to the efforts of the Navy's Strategic Systems Project Office. With sole budgetary responsibility, SSPO's single objective has been to provide and ensure a reliable and available satellite navigation system to support the operational requirements of the Polaris, Poseidon, and Trident missile-launching submarine fleet. SSPO has fulfilled its primary objective economically and has supported the expansion of the system's user base into the commercial domain without detracting from its primary mission.

The Navy Navigation Satellite System consists of three elements: the satellite broadcaster, the ground-tracking-and-control sites, and the navigation user's receiving and computing equipment (Fig. 4). The design of the satellite broadcaster evolved quickly from experiments conducted in 1957 at the Applied Physics Laboratory (APL) of Johns Hopkins University (JHU) by W. H. Guier and G. C. Weiffenbach,[3] who established the orbits of Sputnik I and II by recording the Doppler shift of the Sputnik's transmissions at 30 and 40 MHz. F. T. McClure of APL suggested that the system be inverted; that is, that the satellite broadcast its orbit and the ground receiver record the Doppler shift that results from satellite transmissions as it passes overhead.[4] Then, using the shape of the Doppler curve and knowledge of the laws of motion, the navigator would have sufficient information to establish his location anywhere on the surface of the earth. This satellite solution would provide a global, all-weather navigation service. This JHU/APL proposal won Navy support and was developed as an essential part of the navigation system for the Polaris Ballistic Missile Submarine

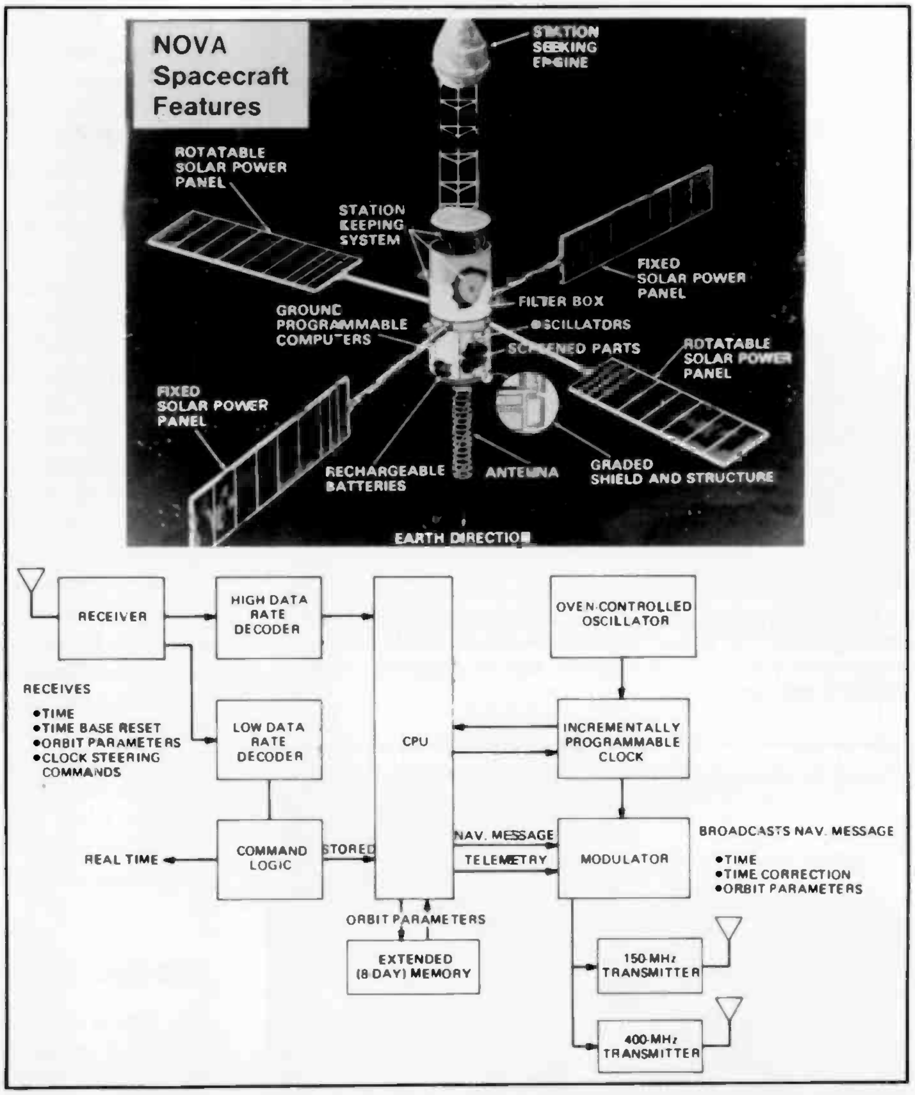
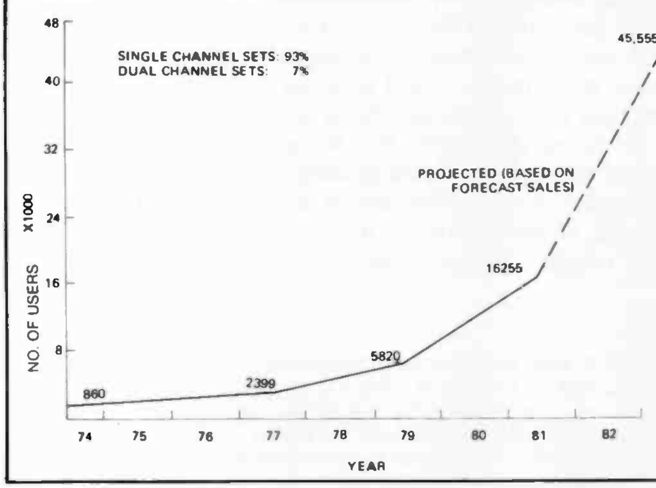



**Fig. 2. The NOVA satellite (top) features new technology** in the areas of Station Seeking: a 5-lb force thruster and 65-lb reservoir of hydrazine fuel in a Station Seeking System consisting of highly sensitive accelerometer and two solid-teflon propellant micro-thrusters and redundant ground-programmable computers each with 16,000 words of memory. The Doppler payload (bottom) provides the customary transmissions at 150 MHz and 400 MHz with high stability and higher radiated power than in the past. The larger satellite memories provide storage for up to 8 days of navigation messages.




TRANSIT-SATELLITE LONGEVITY

| SATELLITE NUMBER | LAUNCH DATE | YEARS IN OPERATION (AS OF JUNE 82) |
|---|---|---|
| 013 | MAY 18, 1967 | 15 YEARS, 1 MONTH |
| 014 | SEPT. 25, 1967 | 14 YEARS, 9 MONTHS |
| 019 | AUG. 27, 1970 | 11 YEARS, 8 MONTHS |
| 020 | OCT. 29, 1973 | 8 YEARS, 10 MONTHS |
| 048 (NOVA-1) | MAY 14, 1981 | 1 YEAR |
| | TOTAL | 51 YEARS, 4 MONTHS |

**Fig. 3. The Navy's Transit Satellite Navigation** has enjoyed remarkable longevity (above) and user acceptability (left). The curve is struck from a manufacturer's survey, with the solid line based on equipment sales and the dashed line based on projected sales.

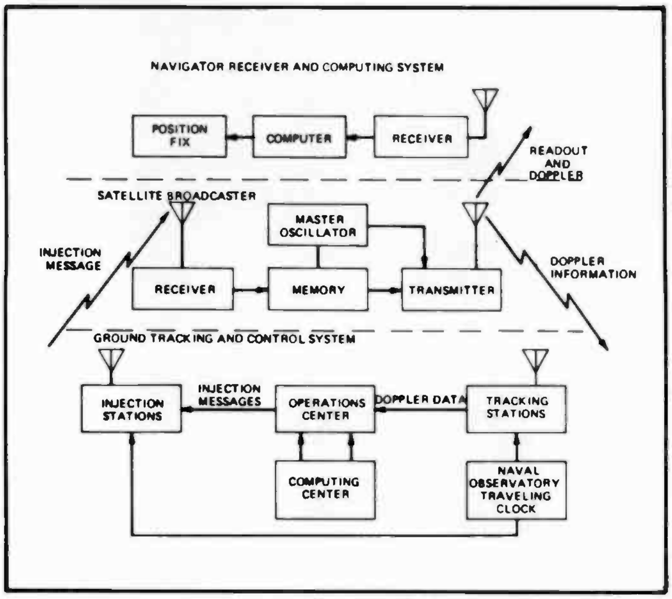



**Fig. 4. The Navy Navigation Satellite System (NNSS)** consists of three segments: the space segment or satellite broadcaster, the ground tracking and control segment, and the navigation receiver computing segment.

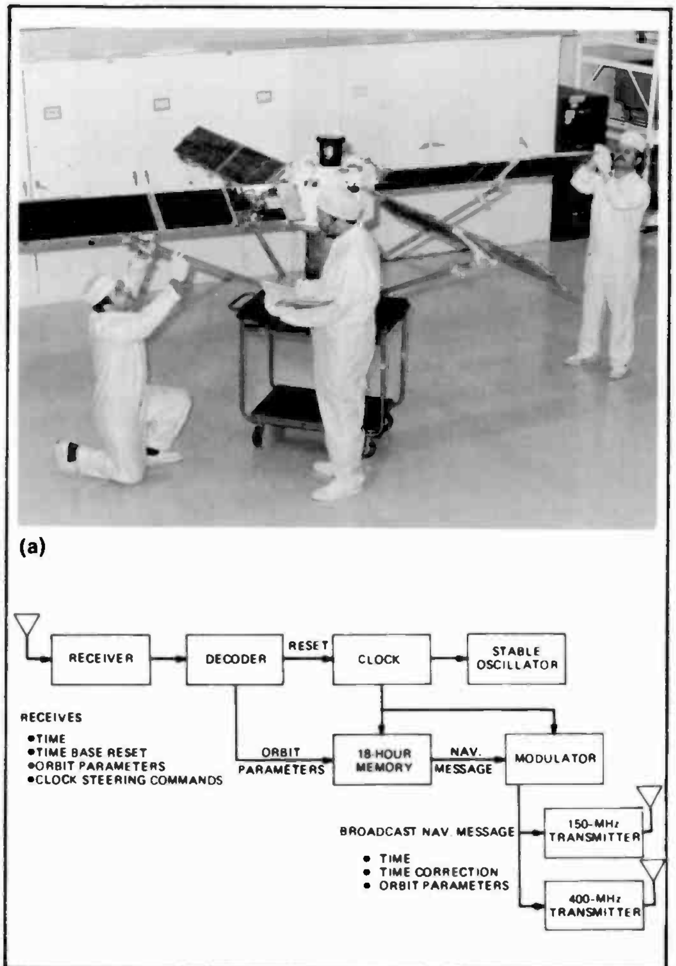



**Fig. 5. The OSCAR satellite,** shown in test at RCA Astro-Electronic's satellite assembly facility **(a),** is the workhorse of the Navy's Navigation Satellite Constellation. The OSCAR memory limits the storage of navigation messages to 18 hours and requires updating every twelve hours for effective navigation results.

Fleet. Dr. R. B. Kershner* was chosen to be the Project Manager, and, under his direction until his retirement in 1978, the system developed to its present stage of maturity. It continues to be not only an essential element in the Fleet Ballistic Missile Submarine SSBN Submarine Navigation System, but an immensely valuable positioning and surveying tool to the international community.[5]

The system operates as follows: At known ground sites located in the United States, the satellite's transmissions are tracked, and the satellite's orbit is derived from the recording of the shape of the Doppler shift. The Doppler shift is derived both for the satellite's 150-MHz carrier and its 400-MHz carrier to remove errors caused by ionospheric refraction of the radio waves.[6] The data are communicated to a central computing facility where the current orbit is established using sophisticated models of the earth's gravitational field, and future orbits or an ephemeris of the satellite are projected and injected into the satellite. These data are broadcast recurrently in 2-minute intervals until refreshed with updated ephemerides 12 hours later.

This rather elegant concept has reached its current effective use with these management policies: standardizing the satellite design at an early stage of development of the system and keeping it constant; sponsoring continuing refinements in the modeling of the earth's gravitational field with space missions devoted to geodesy; and releasing the development of low-cost, reliable, user equipment to the commercial marine-radio industry. With low-cost, reliable receivers available, the spark for the Navsat system's rapid acceptance and use by surveyors and ocean industries in the United States and internationally was assured and continues at an increasing rate to this date.

## The Scout launch vehicle

The OSCAR-Transit satellite (Fig. 5), which has become the backbone of the Navy Navigation Satellite System, was designed to be launched by the Scout booster. The Scout is a four-stage solid booster with a good record of successful launchings. It is a derivative of the earlier Vanguard Missile, a Navy development, and with its simplicity came low launch costs that were desirable for an operational system. The performance of the booster was adequate for this first phase of development. The Scout can inject a 125-pound payload directly into a 600-nautical-mile, circular-polar orbit. The early launches consistently bettered the advertised performance of a ±1.2-degree, 3-sigma, inclination error. The launch-weight limitations and heat-shield size drove the OSCAR-Transit design to a densely packaged, small-sized satellite. The dispersion errors in inclination caused orbit precession and have, on occasion, caused system operation problems as the orbital plane of one of the satellites in the constellation drifts into the plane of another, creating mutual interferences on transmitting frequencies (Fig. 6). The elimination of interference during coplanar situations requires that one of the satellites be turned off until they have drifted apart enough to resume their role in the constellation. In the

* Dr. R. B. Kershner, former Space Department Head and Assistant Director of APL, died on February 15, 1982. He was personally responsible for the development of the Transit System that permits submarines, ships, and surveyors to determine their position under any weather condition. He received the Navy Distinguished Public Service Award three times for his contributions to the Transit program and for other technical achievements.

interim, the Scout loft-weight capability has increased, and this augmented capability is useful for the heavier TIP (Transit Improvement Program) and the NOVA satellites.

## The Orbit Adjust Transfer System

Seeding a constellation with nearly invariant orbital planes clearly would enhance the developing navigation system, providing the means for optimal placing of satellites in the constellation for increased coverage and reduced waiting times. Invariant satellite orbit planes for 10-year lifetimes drove the need for the NOVA spacecraft to correct for dispersion errors due to the launch vehicle. The specifications for such an invariant target orbit are developed with the use of an analytic integrator that enables the system operators to predict the orbital elements for a NOVA-type satellite several years into the future. Initial orbit elements are selected and targeted by the Orbit Adjust Transfer System (OATS), resulting in orbit position being maintained to within 2 degrees over the satellite's expected operational life. Data gathered during the first four months of NOVA-1 operations demonstrate how well the selected target orbit has been achieved.

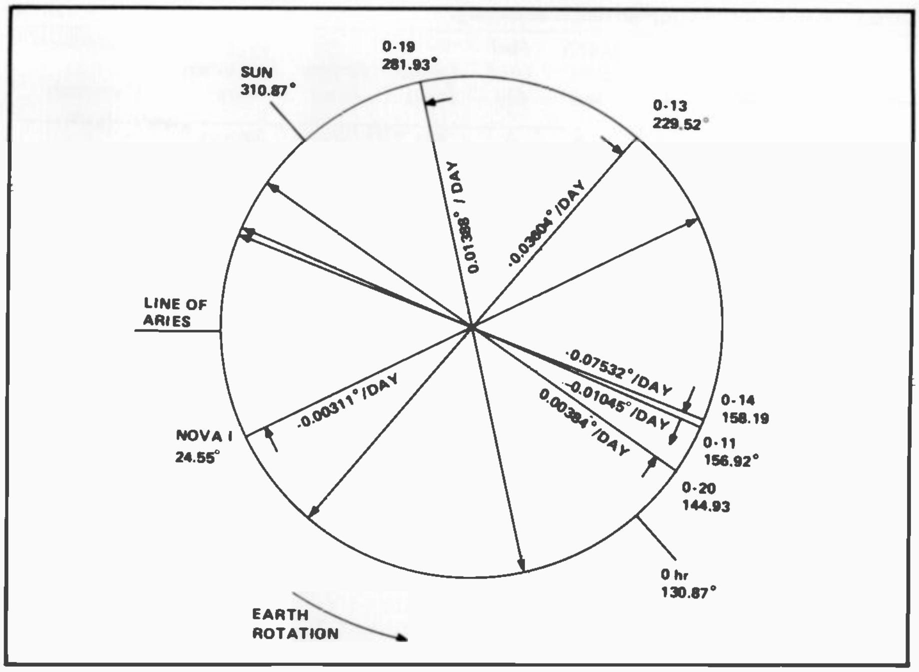



**Fig. 6. A polar view of the orbital planes of the Navy's Navigation Satellite Constellation,** four OSCARS (0-13, 0-14, 0-19, and 0-20), one Transat (0-11) and a NOVA-1. Satellite (0-11) was removed from service temporarily to avoid transmission interferences with satellite 0-14. Satellite 0-11 is a dual-payload satellite used either as a navigation satellite or used in support of the Trident test program.

The Orbit Adjust Transfer System (OATS) consists of a 20-inch diameter spherical titanium tank that contains up to 65 pounds of liquid hydrazine propellant pressurized by gaseous nitrogen ($N_2$) (Fig. 7). The gas and the liquid propellant are separated by a polyurethane bladder. The liquid hydrazine flows through a catalyst bed when the valve to the 5-$lb_f$ thruster is actuated. The valve actuation is controlled from the ground by a delayed data command that specifies when and how long the valve is to be actuated. The OATS can raise the orbit for the spinning 380-pound NOVA from the initial elliptical orbit of 200 nautical miles at perigee and 550 nautical miles at apogee, up to its final circular orbit of 634 nautical miles, while simultaneously correcting dispersion errors in inclination.

The OATS is used in a satellite whose attitude is spin stabilized and which is equipped with a Z-coil magnetic torquer

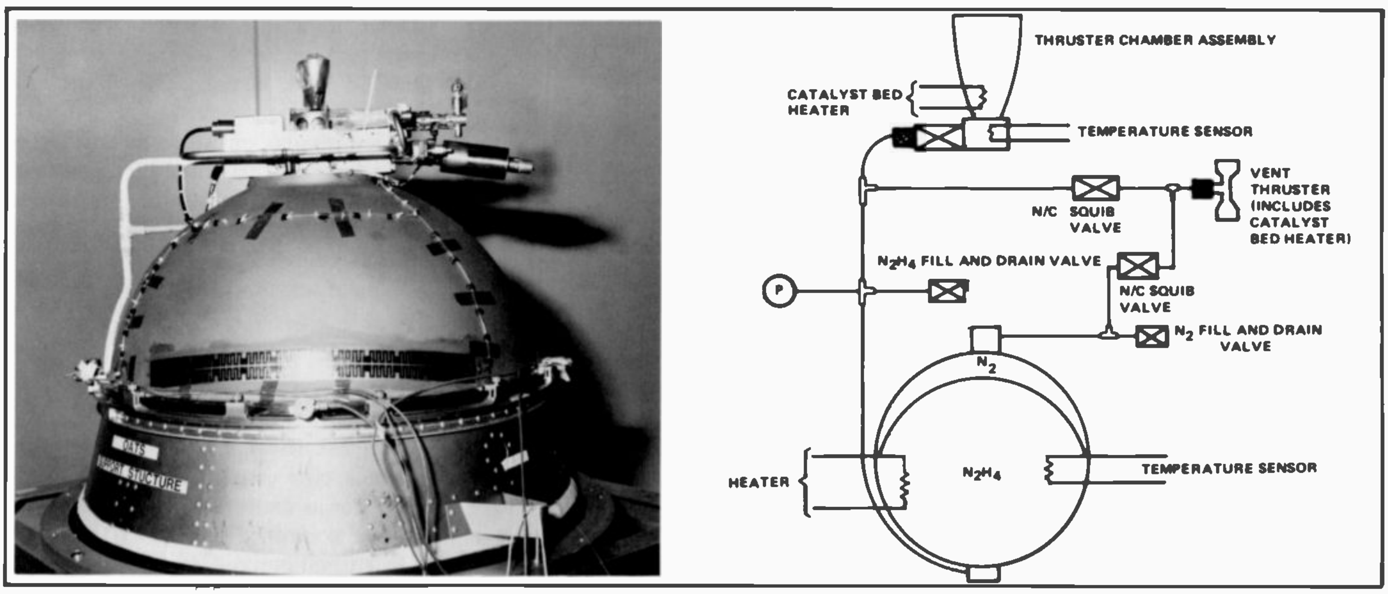



**Fig. 7. The Orbital Adjust Transfer System (OATS)** consists of a 20-inch-diameter titanium hydrazine reservoir tank and a five-lb force thruster to provide for orbit-correction manuevers.

**Table I. NOVA-1 orbit-circularization summary.**

| *Date* | *Time* | *OATS Burn (sec)* | *Fuel Used (lb)* | *Apogee (nmi)* | *Perigee (nmi)* | *Inclination (deg)* | *Comments* |
|---|---|---|---|---|---|---|---|
| 5/15/81 (Launch) | 06:07Z | 0 | 0 | 503 | 194 | 90.152 | ~59 lb. of $N_2H_4$ in OATS Tank |
| (1) 5/18/81 | 15:01Z | 132 | 3.63 | 510 | 230 | 90.146 | |
| (2) 5/18/81 | 19:47Z | 420 | 10.13 | 529 | 350 | 90.126 | |
| (3) 5/19/81 | 02:32Z | 420 | 8.5 | 574 | 426 | 90.11 | |
| (4) 5/21/81 | 07:21Z | 360 | 6.73 | 596 | 495 | 90.04 | |
| (5) 5/24/81 | 02:07Z | 360 | 5.82 | 644 | 537 | 89.99 | |
| (6) 5/27/81 | 18:18Z | 420 | 6.20 | 649 | 635 | 89.96 | |
| | | | | | | | ~18 lb. $N_2H_4$ remained |
| (7 & 8) 5/30/81 (Fuel dump at orbit normal) | 14:13Z<br>18:45Z | 840N.P.<br>840S.P. | 11.0 | 645 | 632 | | *Nodal period (sec)* |
| (9) 6/1/81 (Orbit trim) | | 360 | ~3.0 | 641 | 636 | | |
| (10 & 11) 6/2/81 (Fuel dump) | | 70 N.P.<br>148 S.P. | 2.54 | 643 | 629 | 89.97 | 6540.5 |
| (12) 6/3/81 (Orbit trim then fuel vented) | | 14 | | 642 | 629 | 89.969 | 6539.967 |

to control the orientation of the spin vector. The attitude control and stabilization subsystem also contains spin/despin magnetic torquers, digital sun-angle sensors, a 3-axis magnetometer, and passive nutation dampers. The control loops that are implemented via the on-board computer are closed through the ground control stations. Telemetered attitude data are processed in attitude determination programs. Piecewise orbit-adjust scenarios are initially tried in ground programs that provide command sequences for Z-coil torquing, time of thruster actuation in orbit, and duration of thrust. After each thruster firing sequence, the orbit-adjust scenario is completed by an update in the new orbit from the satellite tracking network. This sequence is repeated until the desired orbit is achieved. Table I is a summary of the NOVA-1 orbit-adjust phase of the mission.

As NOVA-1 neared its target orbit, nearly 20 pounds of excess hydrazine fuel remained. Inefficient thrusting near the poles was deliberately used to rapidly deplete the reservoir of residual hydrazine, leaving the orbit slightly higher in altitude than the desired target altitude and drifting toward a reference nodal-crossing time. To complete the orbit-adjust phase, the forward micro-thruster was used to tune the period until the nodal-crossing time was equal to its target value. The micro-thrusters were fired once per second for nearly 13 hours during this orbit-adjustment phase of the mission.

## The Disturbance Compensation System

Reducing system errors such as unmodeled drag forces would also enhance the NNSS value in Doppler-positioning applications. Predictable drag coefficients were introduced into the geodesy model in 1980 and resulted in improved orbit determination and consequently in improved broadcast ephemeris, reducing one of the more dominant sources of error in position determination. Clearly, if the satellite could fly "drag-free" in orbit, this source of error would be eliminated, permitting long-term storage (longer than the 12 hours of stored ephemeris in the OSCAR satellites) for the broadcast ephemeris. Fulfillment of this feature would increase the system reliability, relaxing the need for a twice-daily memory refresher.

NOVA became the first operational "drag-free" satellite with the addition of a single-axis Disturbance Compensation System (DISCOS). This subsystem has provided the means for fine tuning of the orbit period on NOVA-1 to an error on the order of 10 milliseconds in the desired 6540.5-second nodal period.[7] It has also effectively maintained a "drag-free" orbit, with test results showing less than 70 meters of in-track position error measured after 6 days of prediction span.

NOVA's DISCOS consists of an electro-optical sensor and two ion-plasma, solid-teflon-propellant, micro-thrusters operating at about $65 \times 10^{-6}$ pounds of force per pulse (Fig. 8). The heart of the DISCOS sensor is a proof-mass that is shielded from atmospheric drag and solar radiation. It is magnetically suspended and damped by a current-carrying rod that is aligned with the satellite's flight path. The proof-mass is free to move along the suspension rod and, in effect, flies the reference "drag-free" orbit to which the host satellite compares itself. An optical system senses the proof-mass position relative to the satellite and causes the micro-thrusters to fire in a closed-loop fashion, forcing the satellite to follow the "drag-free" trajectory of the proof-mass.[8]

The DISCOS system functions after the satellite has been ejected into its gravity-gradient-stabilized mode. The depleted OATS hydrazine tank becomes the tip mass and is released to a length of 26 feet by a glass-epoxy-box section mast. The mast is attached to a scissors boom that raises the DISCOS sensor 40 inches from within the satellite's cylindrical section, where it is protected during the launch and spin-mode phase. A momentum wheel aligned along the pitch axis adds sufficient momentum bias to convert the nominally two-axis-stabilized, gravity-gradient satellite to a three-axis-stabilized spacecraft with the roll axis, and hence the DISCOS axis, in the plane of the orbit and aligned to the direction of flight. The two ion-plasma thrusters are located on the roll axis so that the forward thruster can counter the drag force, and the aft thruster in combination with the forward thruster can counter the effects on the satellite of solar-radiation pressure.

## On-board processing

Redundant 16-kiloword, 16-bit-per-word, magnetic-core memories store orbital elements for as many as 8 days. The memories are controlled by one of the redundant, general-purpose, multi-access, central processors. The CPUs and memories are also used to store delayed commands and to collect selected telemetry around the orbit. These functions are essential in the orbit-adjust phase of the missions. Programs are also stored to control spacecraft equipment under program control such as temperatures of the OATS tank, manifold, and thruster catalyst bed.

The DISCOS and satellite memories complete the satellite systems required for drag-free operations and long-term storage of high-quality ephemerides. The results are a NOVA satellite that can provide continuing navigation service, even if there is a brief disruption in ground control processing or in the ground-to-satellite communications link. NOVA-1 has already demonstrated 6-day predicted orbits with errors less than 70 meters in track as compared to in-track errors in the OSCAR-Transit system that typically grow to 70 meters in an 18-hour prediction.

Short- and long-term satellite oscillator instabilities, and limitations in signal-to-noise ratio at the user's receiving terminals, are also improved in the NOVA design. Reducing these two error sources will further improve single-pass position determination for navigators and tighten the multi-pass circular-error probability for surveyors. The NOVA satellite's master oscillator, for example, has a two-stage dewar to hold its crystal precisely at its preferred tuning temperature. The improved oscillator drives a ground-programmable frequency synthesizer, which holds the satellite's clock and broadcast carriers constant and in synchronism with a master clock on the ground (Fig. 9). The result is a precise, constant frequency for the satellite's master oscillator (independent of the crystal-aging process) and with a $\Delta f/f$ noise spectrum similar to an atomic-standard type of oscillator. A dual-frequency quadrifilar antenna, with its improved pattern and gain and higher power outputs at 150 MHz and 400 MHz, provides the added signal-to-noise ratio at the ground receivers to improve the navigating and surveying solutions.

## Future plans

Two more NOVA satellites are currently in production at Astro-Electronics. One will join the Navy's Navigation Satellite constellation later this year. A minimum constellation of two NOVA and two OSCAR satellites is planned by the Strategic Systems Project Office for the remainder of this decade. Twelve OSCAR satellites are maintained in flight-ready ground

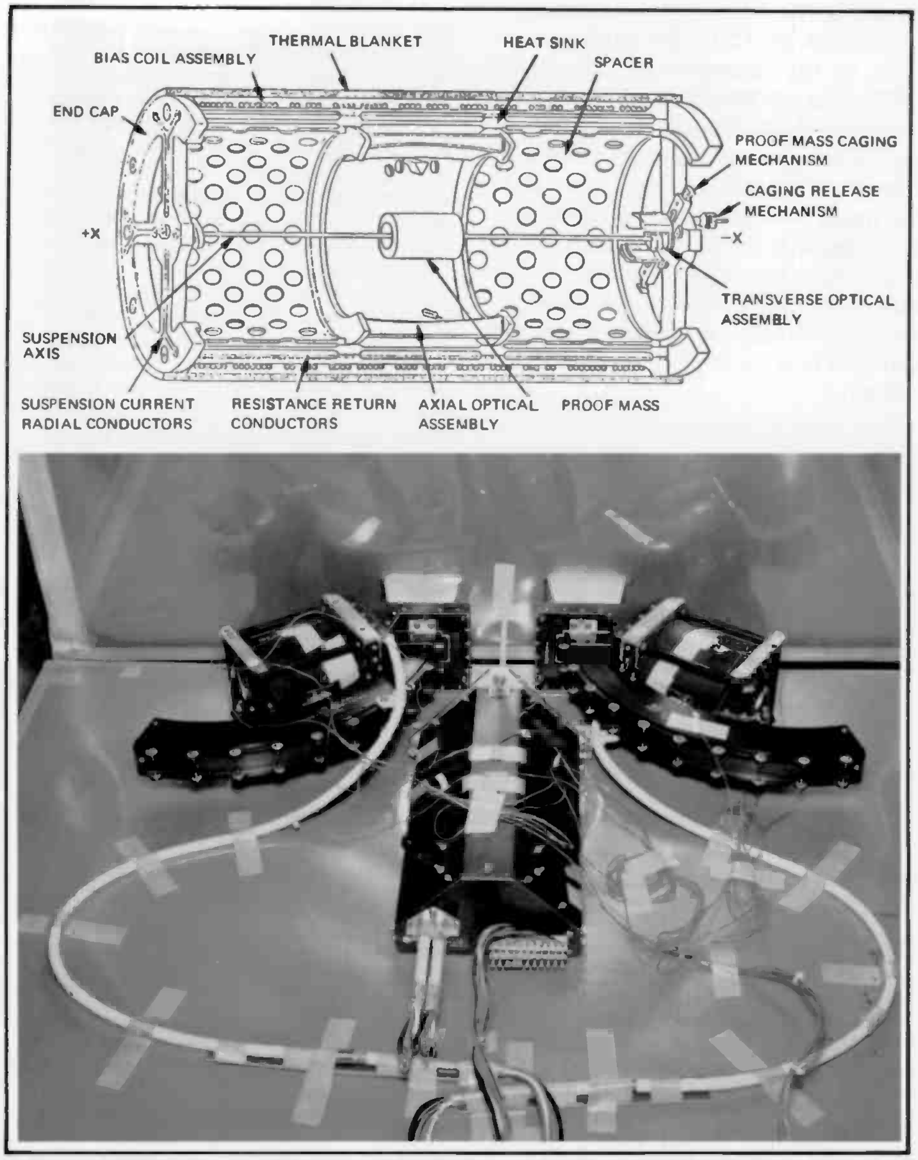



**Fig. 8. The DISCOS consists of a proof mass that provides the NOVA satellite with an attached reference drag-free orbiter.** An optical system is used to derive an error signal, a comparison of the satellite's orbit to the reference proof mass. One of the two solid-teflon propellant thrusters, located fore and aft on the satellite, is fired to drive the satellite to the reference drag-free orbit.

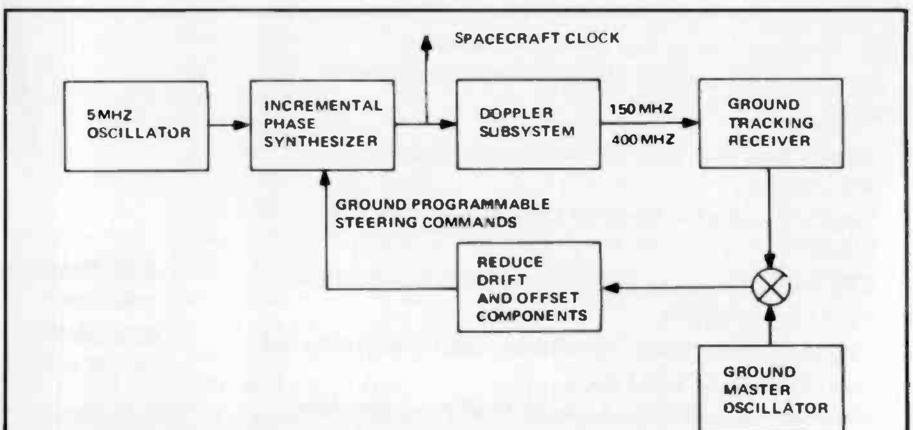



**Fig. 9. The NOVA frequency-control system** uses the crystal oscillator with the incrementally programmable synthesizer to reduce drift and bias errors.

storage at Astro-Electronics as a resource to replenish the OSCAR-Transit components of the constellation. The mix of satellites in the system should enable the navigators and surveyors to continue to exploit the proven reliability of the OSCAR-Transit series, and the improvements in the broadcast ephemeris, signal strength and constancy of the NOVA series. With a minimum constellation of four and a maximum constellation of eight satellites, the Navy Navigation Satellite System will continue to serve in its maturity until the 1990s.

**Joe Staniszewski** is the Project Manager for the NOVA Navy Navigation Satellite System Production program at RCA Astro-Electronics, Princeton, New Jersey. Mr. Staniszewski is a 30-year employee of RCA and has served in several key engineering and project-management roles during his career. Prior to his current assignment, Mr. Staniszewski managed the development of the Defense Meteorological Satellite and, earlier, the Ranger Television Subsystem delivered by RCA for the Jet Propulsion Laboratories' Lunar Surface Photographic Mission. Mr. Staniszewski has a B.S. degree in physics and is a graduate of Carnegie-Mellon University of Pittsburgh. He has taken graduate courses at Moore School of Electrical Engineering, University of Pennsylvania.
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**RCA Astro-Electronics**
**Princeton, N.J.**
**TACNET: 229-2091**

## References

1. T. Wyatt, "The Gestation of Transit as Perceived by One Participant," *JHU/APL Technical Digest*, Vol. 2, No. 1 (January/March 1981).
2. G.W. Hoskins, "Navy Navigation Satellite System Status," presented at third International Geodetic Symposium on Satellite Doppler Positioning, Las Cruces, New Mexico (February 8-12, 1982).
3. W.H. Guier and G.C. Weiffenbach, "The Early Days of Sputnik," *JHU/APL Technical Digest*, Vol. 2, No. 1, pp. 14-15 (January/March 1981).
4. F. T. McClure, "Method of Navigation," United States Patent 3,172,108 (March 2, 1965).
5. B. E. Miliken, "Surveying by Satellite in Papua, New Guinea," presented at the Third International Geodetic Symposium on Satellite Doppler Positioning, Las Cruces, New Mexico (February 8-12, 1982).
6. H. D. Black, "Satellites for Earth Surveying and Ocean Navigation," *JHU/APL Technical Digest*, Vol. 2, No. 1, pp. 3-13 (January/March 1981).
7. A. Eisner, S.M. Yionoulis, J.A. Platt, R.E. Jenkins, J.C. Ray, and L.L. Pryor, "NOVA-1: The Newest Transit Satellite," A status report presented at the Third International Geodetic Symposium on Satellite Doppler Positioning, Las Cruces, New Mexico, (February 8-12, 1982).
8. J.R. Champion, F.F. Mobley, and A.C. Sadilek, "A Low Susceptibility Proof-Mass for the NOVA Satellite," *IEEE Transactions on Magnetics*, Vol. Mag-17, No. 6, (November 1981).

## RCA Corporate Engineering Education Course Catalog Released

Eleven new video course packages and other educational services for RCA's technical staff are announced in the 1982-83 RCA Corporate Engineering Education Course Catalog. The catalog is mailed yearly to RCA engineers on the *RCA Engineer* mailing list. Additional copies are available on request, from Margaret Gilfillan, TACNET 222-5255.

Three courses have been added to the already extensive CEE computer curriculum. The effort to provide courses for manufacturing personnel has been accelerated and a "Manufacturing" category has been added to this catalog's contents section. Expansion of the range of programs in the CEE Videotape Library has enhanced its value.

Here's a quick preview of the contents of this year's catalog.

**What's New?**—*A brief summary of the new courses in this catalog.*

**What's Coming?**—*A look at CEE plans for the year ahead.*

**CEE Video Courses**—*Eighty-three video course packages now available.*

**Computer Curriculum Flowcharts**—*Help in selecting the course that's right for you.*

**CEE Resource Guide**—*Answers to all your questions about CEE services.*

**CEE Videotape Library**—*What's available and how to obtain it.*


**CEE Short Courses**—*Information about Fall, 1982 offerings.*

**CEE Staff**—*A look at some new and some familiar faces on the CEE staff.*

CEE Video Course enrollments passed the 2000 mark for the first time in 1981. You could be a part of record enrollments this year, too, after you look through CEE's new catalog and decide on the technical course for you.

# Patents

## Automated Systems

Dion, D.F.
**Sequencer for power supply voltages—4323789**

## Commercial Communications Systems Division

Bendell, S.L.
**Optical assembly for color television—4323918**

Bendell, S.L.
**Line-scan still image reproducer—4331979**

Ben-Dov, O.
**Duopyramid circularly polarized broadcast antenna—4317122**

Boyd, W.M.
**Bias adjustment responsive to signal power—43170083**

Clayton, R.W.
**Tape transducer carrier with dihedral and protrusion adjustment—4329724**

Dischert, R.A. | Walter, J.M.
**Rapid synchronization of information on separate recorded mediums—4322747**

Wolf, R.E.
**Radio transmitter energy recovery system—4319359**

## Consumer Electronics

Altenschulte, R.A.
**A.C. power line assembly—4317152**

Fernsler, R.E. | Willis, D.H.
**Two-loop horizontal AFPC system—4317133**

Fitzgerald, Jr., W.V.
**Side pincushion correction circuit—4318035**

Knight, P.R.
**Television receiver high voltage protection circuit—4321513**

Knight, P.R.
**Side pincushion modulator circuit with overstress protection—4329729**

Laux, D.E. | Meyer, K.E.
**Deflection circuit linearity coil—4331907**

Muterspaugh, M.W. | Theriault, G.E.
**IF bandpass shaping circuits—4316220**

Naimpally, S.V.
**Video blanking circuit with controlled rate of unblanking—4330792**

Nicholson, J.E. | Wilmarth, P.C.
**Institutional audio-visual system including a plural operating mode television receiver—4319277**

Parker, R.P.
**Linear high gain sampling amplifier—4331981**

Parker, R.P.
**Sample and hold circuit particularly for small signals—4331982**

Sendelweck, G.K.
**Latch-up prevention circuit for power output devices using inductive loads—4322770**

Thibodeau, L.N. | Luz, D.W. | Hicks, J.E.
**Commutated SCR regulator for a horizontal deflection circuit—4321514**

Willis, D.H.
**Linearity corrected deflection circuit—4321511**

Yost, T.D.
**Keying signal generator with input control for false output immunity—4316214**

## Government Communications Systems

Hampel, D. | Prost, K.J.
**Data classifier—4316177**

Macina, N.A.
**Multichannel frequency translation of sampled waveforms by declination and interpolation—4316282**

McMackin, J.B.
**Regulated switching apparatus—4325021**

Nossen, E.J.
**On line quality monitoring—4317206**

Nossen, E.J.
**Television signal with encoded synchronizing signals—4319273**

## Laboratories

Acampora, A.
**Color TV buried subcarrier system—4318120**

Acampora, A.
**Synchronizing transmissions from two earth stations to satellite—4320503**

Anderson, C.H. | Credelle, T.L.
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**Guided beam display device—4316118**

Avins, J.Y.
**Encoder for recording incremental changes—4328463**

Balaban, A.R. | Steckler, S.A.
**Dual phase-control loop horizontal deflection synchronizing circuit—4327376**

Bell, A.E.
**Information record—4329697**

Benyon, Jr., C.W. | O'Neill, Jr., J.J.
**Method of reducing edge current leakage in N channel silicon-on-sapphire devices—4313809**

Bloom, A. | Bartolini, R.A
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**Thick protective overcoat layer for optical video disc—4315269**

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**Baseplate assembly for flat panel display devices—4316117**

Chambers, R.W. | Cuomo, Jr., F.
**Method and apparatus for deflashing molded recorded discs—4326325**

Chang, K.K.
**System for enhancing deflection in kinecopes—4323816**

Chang, K.K.
**Horizontal deflection enhancement for kinescopes—4329618**

Crandall, R.S.
**Method for measuring the drift mobility in doped semiconductors—4319187**

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**Reversible optical storage medium and a method for recording information therein—4320489**

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**Method for end point detection in a plasma etching process—4328068**

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**High density information record lubricants—4330583**

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**Video disc player with variable offset RFI reduction circuit—4327431**

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**Technique for optimally encoding digitally encoded video signals—4320416**

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**Data rate reduction for digital video signals by subsampling and adaptive reconstruction—4323916**

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**Video disc locked groove corrector—4323998**

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## Picture Tube Division

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**Method for preparing copper-aluminum-gold-activated zinc-sulfide phosphors—4316816**

Turner, C.C.
**Carrier for rotatably holding kinescope faceplate during processing—4317427**

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G.J. Ammon | A.A. Litwak
M.S. Nigro | C.W. Reno
**Performance Measurements from Digital Optical Disc Systems**—Presented at SPIE Electro-Optic Conference, Los Angeles, Calif., published in the *Proceedings* (1/25-29/82)

W. Heagerty (ATL) | R. Smeltzer
L. Napoli (Labs) | J. Yeh (Somerville)
**4K Bit CMOS/SOS RAM Hardening**—Presented at Transient Radiation Effects on Electronics Conference, Bethesda, Md. (4/27-30/82)

A. Feller
**Custom LSI Design Using Fully Automatic Layout Programs**—Presented at IEEE Chapter on Testing and Testability, Cherry Hill, N.J. (3/25/82)

R.F. Kenville
**Optical Disc Data Storage**—Presented at IEEE Spring CompCon '82, San Francisco, Calif., published in *Digest of Papers* (2/22-25/82)

## Astro-Electronics

J. Cheng (co-author)
**Gyroless Altitude Determination and Control System for Advanced Environmental Satellites**—AIAA Guidance & Control Conference, San Diego, Calif. (8/9-11/82)

F. Chu | B. Wang
**On Changing Boundary Conditions in Structural Dynamics**—AIAA 23rd Structural & Materials Conference, New Orleans, La. (5/10/82)

M. Goldberger
**Switched Mode of DC/DC Power Converter**—BS Thesis, MIT (5/82)

J. Kara
**Dual Beam Networks for Communication Satellite Antennas**—IEEE Symposium on Advances in Antennas & Microwave

Technology, Ben Franklin Symposium, Phila., Pa. (5/15/82)

J.E. Keigler
**Development of Satellite Systems for Domestic Communication**—IEEE Atlantic Coast Section (4/21/82)

L. Muhlfelder
**Session Organizer,** AIAA Guidance & Control Conference, San Diego, Calif. (8/9-11/82)

C.E. Profera
**RF Performance of Distorted Satellite Antennas**—IEEE Symposium on Advances in Antenna & Microwave Technology (5/15/82)

C. Profera | E. Ngai
**Distortion Analysis for Satellite Reflector Antennas**—Ben Franklin Symposium, Phila., Pa. (5/15/82)
and
1982 Joint Int'l. IEEE/APS Symposium. Albuquerque, N.M. (5/24/82)

C. Profera, *et al.*
**Application Method of Steepest Descent Opt Design Shaped Beam Antennae**—1982 Joint International IEEE/APS Symposium, Univ. of N.M., Albuquerque, N.M. (5/24/82)

G. Rosol
**Multi-Frequency Antenna for TIROS-N Search and Rescue Mission**—IEEE Symposium on Advances in Antennas & Microwave Technology (5/15/82)

J.R. Staniszewski
**NOVA-1: The Newest Star in the Navy's Constellation of Navigation Satellites**—1982 RTCM Assembly Meeting, Seattle, Wash. (4/26-29/82)

T. Truong
**Design Shaped Beam Pattern Using Phase Excitation of Antenna Array**—BS Thesis, MIT (5/82)

## Automated Systems

G.R. Burton
**Schottky Barrier IR-FPA Performance in the Smoke Week IV Exercise (U)**—(4/20/82)

M.J. Cantella | J.J. Klein
(H.E. Elabd | H.G. Erhardt | J.V. Groppe
W.F. Kosonosky | F.V. Shallcross
T.S. Villani | G.M. Meray | R. Miller
F.L. Frantz - Labs)
**Design and Performance of 64 by 128 Element PtSi Schottky-Barrier IR-CCD Focal Plane Array**—SPIE Technical Symposium East '82, Arlington, Va. (5/82)

M.J. Cantella | J.J. Klein | F.F. Martin
**Results of IR Schottky Barrier Focal Plane Array in Air-to-Air Mission Test**—30th National IRIS Meeting, Naval Postgraduate School, Monterey, Calif. (5/25/82)

S.C. Hadden | J.A. Maurer
**Predicting Failure Using an On-Board Monitoring System**—Mechanical Failures Prevention Group, Gaithersburg, Md. (4/20/82)

D. Haggis | J.B. Klatskin | R.L. Camisa
**Fabrication of Lumped-Element Broadband GaAs MESFET Microwave Power Amplifiers**—*RCA Review*, Vol. 42, No. 4 (12/81)

E.A. Leblanc
**Remotely Monitored, Multichannel Magnetic and IR Intrusion Sensors**—Carnahan Conference on Security Technology, Univ. of Kentucky, Lexington, Ky. (5/12/82)

E.H. Miller
**Description of CAC Capabilities**—Old Crows Briefing, MITRE Corp., Bedford, Mass. (5/3/82)

## Government Communications Systems

P.C. Basile | R.G. Erdmann
(M. Caulton | A. Rosen | B. Stabile
A. Gombar - Labs)
**Solid-State Antenna Switching**—*RCA Review*, Vol. 42, No. 4 (12/81)

D.J. Webster
**MAROON ARCHER/ABSAP: A Large Interactive Distributed Processing System**—Presented at 1982 CISI Spring Conference NSA, Ft. Meade, published in *Proceedings* (5/26-28/82)

D.B. Wolfe
**GCS Engineering Design Automation Center—A Mini-Profile**—*TREND* (5/82)

## Laboratories

G.A. Alphonse
**A Method for the Characterization of Piezoelectric VideoDisc Recording Heads Using a Bridge Circuit**—*RCA Review*, Vol. 43, No. 1 (3/82)

G.A. Alphonse
**Power Dissipation in Piezoelectric Cutterheads**—*RCA Review*, Vol. 43, No. 1 (3/82)

R.E. Askew | H.J. Wolkstein
**A Low-Noise Peltier-Cooled FET Amplifier**—*RCA Review*, Vol. 42, No. 4 (12/82)

D.P. Barton | R.R. Barton | M. Blecker
P.W. Lyons | K.A. Pitts | P.G. Stein
J.R. Woolston
**VideoDisc Systems Testing at the RCA David Sarnoff Research Center**—*RCA Review*, Vol. 43, No. 1 (3/82)

R.L. Camisa | J.B. Klatskin | A. Mikelsons
**Lumped-Element GaAs FET Power Amplifiers**—*RCA Review*, Vol. 42, No. 4 (12/81)

D.E. Carlson
**Amorphous Thin Films for Terrestrial Solar Cells**—*J. Vac. Sci. Technol.*, Vol. 20, No. 3 (3/82)

M. Caulton | A. Rosen | B. Stabile | A. Gombar
(GCS at Camden, P.C. Basile | R.G. Erdmann)
**Solid-State Antenna Switching**—*RCA Review*, Vol. 42, No. 4 (12/81)

D.J. Channin | D. Botez | J.C. Connolly
J.O. Schroeder | J.P. Bednarz | M. Ettenberg
**High Power Optical Fiber Data Transmission Using CDH-LOC AlGaAs Laser Diodes**—IEDM '81

R.S. Crandall
**Transport in Hydrogenated Amorphous Silicon p-i-n Solar Cells**—*J. Appl. Phys.*, Vol. 53, No. 4 (4/82)

P. Datta | H. Kawamoto
**Electrical and Physical Properties of Carbon-Filled PVC for Capacitance Pickup VideoDiscs**—*RCA Review*, Vol. 43, No. 1 (3/82)

H.E. Elabd | H.G. Erhardt | J.V. Groppe
W.F. Kosonocky | F.V. Shallcross
T.S. Villani | G.M. Meray
R. Miller | F.L. Frantz
(M.J. Cantella | J.J. Klein - AS)
**Design and Performance of 64 by 128 Element PtSi Schottky-Barrier IR-CCD Focal Plane Array**—SPIE's Technical Symposium East '82, Arlington, Va. (5/82)

H. Elabd | T. Villani | W. Kosonocky
**Palladium-Silicide Schottky-Barrier IR-CCD for SWIR Applications at Intermediate Temperatures**—*IEEE Electron Device Letters*, Vol. EDL-3, No. 4 (4/82)

M. Ettenberg | G.H. Olsen
**Diode Lasers for the 1.2 to 1.7 Micrometer Region**—*Laser Focus Magazine* (3/82)

M. Ettenberg | G.H. Olsen
**The Reliability of 1.3 $\mu$m Emitters and Detectors for Fiber Optics**—IEDM 1981

K.F. Etzoid
**A Quadrature Michelson Interferometer System for Probing Surface Vibrations—Applications to VideoDisc Cutters**—*RCA Review*, Vol. 43, No. 1 (3/82)

W.H. Fonger
**Two-Constant Models of Luminescence in Particle Layers**—*Applied Optics*, Vol. 21, No.7 (4/1/82)

P.D. Gardner | S.Y. Narayan
S. Colvin | Y. Yun
**$Ga_{0.47}In_{0.53}As$ Metal Insulator Field-Effect Transistors (MISFETs) for Microwave Frequency Applications**—*RCA Review*, Vol. 42, No. 4 (12/81)

J. Guarracini | J.H. Reisner
J.L. Walentine | C.A. Whybark
**Micromachining VideoDisc Grooves and Signals**—*RCA Review*, Vol. 43, No. 1 (3/82)

L. Jastrzebski
**Origin and Control of Material Defects in Silicon VLSI Technologies: An Overview**—*IEEE Transactions on Electron Devices*, Vol. ED-29, No. 4 (4/82)

H.C. Johnson | Y. Gazit
**A Ku-Band Continuously Variable Phase/Amplitude Control Module**—*RCA Review*, Vol. 42, No. 4 (12/81)

J.B. Klatskin | R.L. Camisa
D. Haggis (AS)
**Fabrication of Lumped-Element Broadband GaAs MESFET Microwave Power Amplifiers**—*RCA Review*, Vol. 42, No. 4 (12/81)

M. Kumar
**Dual-Gate FET Phase Shifter**—*RCA Review*, Vol. 42, No. 4 (12/81)

M. Lurie | W. Barnette | I. Gorog | R. Jebens
**High Performance Optical Reader for Substrates**—*RCA Review*, Vol. 43, No. 1 (3/82)

S.Y. Narayan | J.P. Paczkowski
S.T. Jolly | E.P. Berlin | R.T. Smith
**Growth and Characterization of $Ga_xIn_{1-x}As_yP_{1-y}$ and $Ga_{0.47}In_{0.53}As$ for Microwave Device Applications**—*RCA Review*, Vol. 42, No. 4 (12/81)

R.W. Nosker | D.L. Matthies
**Basics of VideoDisc Stylus Dynamics and Interaction with Surface Imperfections**—*RCA Review*, Vol. 43, No. 1 (3/82)

L.S. Onyshkevych
**Electronic Applications of Porcelain-Metal Boards**—*Ceramic Industry* (3/82)

L.S. Onyshkevych | D.P. Dorsey
**New Life for Steel PCBs**—*Machine Design* (3/11/82)

R.C. Palmer | E.J. Denlinger | H. Kawamoto
**Capacitance-Pickup Circuitry for VideoDiscs**—*RCA Review*, Vol. 43, No. 1 (3/82)

B.S. Perlman
**Automatic S-Parameter Characterization of Microwave Devices and Circuits Using a Phase Locked Automatic Network Analyzer (PLANA)**—*RCA Review*, Vol. 42, No. 4 (12/81)

H.L. Pinch | D.A. Furst | R.T. Smith
**The VideoDisc Stylus Electrode**—*RCA Review*, Vol. 43, No. 1 (3/82)

A. Presser
**Varactor-Tunable, High-Q Microwave Filter**—*RCA Review*, Vol. 42, No. 4 (12/81)

J.H. Reisner | J. Valachovic
R.E. Simms | H.I. Moss
**Principles for the Design of Cutters for VideoDisc Recording**—*RCA Review*, Vol. 43, No. 1 (3/82)

J. Rosen | D. Rhodes
**Computer Optimized Multiple-Branch-Line Couplers**—*RCA Review*, Vol. 42, No. 4 (12/81)

A. Rosen | M. Caulton | P. Stabile
A.M. Gombar | W.M. Janton | C.P. Wu
J.F. Corboy | C.W. Magee
**Silicon as a Millimeter-Wave Monolithically Integrated Substrate—A New Look**—*RCA Review*, Vol. 42, No. 4 (12/81)

A. Rosen | M. Caulton | P. Stabile
A.M. Gombar | W.M. Janton | C.P. Wu
J.F. Corboy | C.W. Magee
**Millimeter-Wave Device Technology**—*IEEE Transactions on Microwave Theory and Technology*, Vol. MTT-30, No. 1 (1/82)

F.N. Sechi | H.C. Johnson
J.E. Brown | R.E. Marx
**Solid-State Ku-Band Radar**—*RCA Review*, Vol. 42, No. 4 (12/81)

R. Shahbender
**Thermal Analysis of VideoDisc Cutter**—*RCA Review*, Vol. 43, No. 1 (3/82)

R. Smeltzer | L. Napoli | J. Yeh (SSD)
W. Heagerty (ATL)
**4K Bit CMOS/SOS RAM Hardening**—Presented at Transient Radiation Effects on Electronics Conference, Bethesda, Md. (4/27-30/82)

F. Sterzer
**Localized Hyperthermia Treatment of Cancer**—*RCA Review*, Vol. 42, No. 4 (12/81)

G.C. Taylor | Y.H. Yun | S.G. Liu
S.T. Jolly | D. Bechtle
**GaAs Power Field-Effect Transistors for K-Band Operation**—*RCA Review*, Vol. 42, No. 4 (12/81)

R. Shahbender | K.S. Vanguri
**Approximate Resonance Spectrum of a VideoDisc Cutter**—*RCA Review*, Vol. 43, No. 1 (3/82)

R. Smeltzer | L. Napoli
W. Heagerty (ATL)
J. Yeh (Somerville)
**4K Bit CMOS/SOS RAM Hardening**—Presented at Transient Radiation Effects on Electronics Conference, Bethesda, Md. (4/27-30/82)

R.L. Truesdell
**Testing Methods for the Characterization of Cutterhead Performance in Mastering VideoDiscs**—*RCA Review*, Vol. 43, No. 1 (3/82)

L.C. Upadhyayula | R. Smith | R. Matarese
**GaAs Integrated Circuit Development for Gigabit-Rate Signal Processing**—*RCA Review*, Vol. 42, No. 4 (12/81)

J.A. vanRaalte
**VideoDisc Mastering—An Overview**—*RCA Review*, Vol. 43, No. 1 (3/82)

R. Williams | C.C. Wang
**Capillary Behavior and Lubricating Properties of the RCA VideoDisc**—*RCA Review*, Vol. 43, No. 1 (3/82)

## Missile & Surface Radar

K. Abend
**The Utility and Performance of Spectral Estimation in Radar Imaging (U)**—U.S. Army Electronics Research and Development Command, First U.S. DOD Tri-Service Combat Identification Systems Conference (Secret), *Technical Proceedings* (10/27-29/81)

P.K. Agrawal
**A Method to Compensate for Probe Positioning Errors in an Antenna Near-Field Test Facility**—1982 International IEEE/APS Symposium, Albuquerque, N.M., published in *Digest* (5/24-28/82)

O.G. Allen
**The Human Ingredient in the Quality Equation**—13th Annual Reliability Symposium, Valley Forge, Pa. (4/28/82)

J.A. Bauer
**Chip Carrier State of the Art**—Panel member and presentation; International Electronic Packaging Society (IEPS), Anaheim, Calif. (2/22/82)

J.A. Bauer
**Design Automation for Electronic Products**—NEPCON WEST, Anaheim, Calif. (2/25/82)

M. Breese | R.J. Mason
**Application of Numerically-Controlled Machining Precision Phased Arrays**—1982 International IEEE/APS Symposium, Albuquerque, N.M., published in *Digest* (5/24-28/82)

C.L. Christianson
**Next Generation Surface Radar Fire Control—Meeting Multifunction Needs with Modular Evolution**—American Institute of Aeronautics and Astronautics, Boston, Mass. (3/18/82)

L. Dewees | R.L. Schelhorn
**Porcelainized Metal Core Substrate Technology for Thick Film Multilayer Chip Carrier Circuit Fabrication**—ISHM Symposium, Baltimore, Md. (5/5/82)

A.G. Hopper
**Laser Technology and the Inverted Plumb Bob**—*Professional Surveyor*, Vol. 2, No. 2 (4-5/82)

J.O. Horsley | N.R. Snyderman
**Multiple Processor Control of Phased Array—A Signal Processor**—ELECTRO/82, Boston, Mass., published in *Proceedings* (5/25-27/82)

H.D. Lewis
**Array Radars Solve Communcation Jams**—*Microwaves* (4/82)

J.T. Nessmith
**System Engineering—Theory and Practice**—System Engineering Department Univ. of Pennsylvania, Phila., Pa. (4/15/82)

M.D. Rauchwerk
**A Low Cost Installation for Radar Data Storage and Analysis**—Southeastcon '82, Eglin Air Force Base, Fla., Conference *Proceedings* (4/4-7/82

F.E. Oliveto
**Effectiveness of Productivity Through Reliability**—13th Annual Reliability Symposium, King of Prussia, Pa. (4/21/82)

## Solid State Division

J. Yeh
R. Smeltzer|L. Napoli (Labs)
W. Heagerty (ATL)
**4K Bit CMOS/SOS RAM Hardening**—Presented at Transient Radiation Effects on Electronics Conference, Bethesda, Md. (4/27-30/82)

# Engineering News and Highlights

## Robert Miller is Chief Engineer at Astro-Electronics

Appointment of **Robert Miller** as Chief Engineer was announced by **Charles A. Schmidt,** Division Vice-President and General Manager of RCA Astro-Electronics. Mr. Miller succeeds **Dr. Warren P. Manger,** who was named Principal Scientist after having served since 1969 as Chief Engineer.

In his new position, Mr. Miller is responsible for the design and engineering of spacecraft and space systems. He had served since 1980 as Manager of Satellite Programs. A 24-year RCA employee, Mr. Miller has held various managerial and engineering positions. He was Program Manager for the TIROS series of satellites, of which 28 have been orbited and have achieved outstanding reliability in orbit.

Mr. Miller also managed the Telesat Program and directed the development of the Anik-B domestic communications satellite for Telesat Canada. Anik-B was successfully launched in December 1978. Earlier, he was Program Manager for the development of RCA Satcom domestic communications satellites. Mr. Miller received bachelor's and master's degrees in electrical engineering from the University of Delaware, and before coming to RCA, served with the U.S. Navy as an electronics officer.

## Staff announcements

### Consumer Electronics

**William A. Lagoni,** Manager, Signal Processing, announces the appointment of **Dal F. Griepentrog** as Manager, Signal Processing Modules and **James Hettiger** as Principal Member Engineering Staff.

**James A. McDonald,** Director, Display Systems Engineering, announces the appointment of **Peter R. Knight** as Manager, Deflection Subsystems.

**Charles J. Limberg,** Manager, Manufacturing Technology Center, announces the organization of the Manufacturing Technology Center as follows: **James H. Grayson,** Manager, Computer Integrated Manufacturing Systems; **David P. McCorkle,** Manager, Advanced Electronic Systems; and **Robert W. Shisler,** Manager, Automated Process Development.

**Alfred Crager,** Manager, Test Technology, announces the appointment of **Larry M. Turpin** as Manager, Systems Support.

### Laboratories

**Robert D. Lohman,** Director, Display Processing and Manufacturing Research Laboratory, announces the appointment of **Louis S. Cosentino** as Head, Display Technology Research.

### Patents

**Samuel Cohen,** Director, Patents—Electronic Systems, announces his organization as follows: **Henry I. Schanzer,** Sr. Resident Patent Counsel—Somerville; **Robert L. Troike,** Managing Patent Attorney; **Henry H. Gage,** Sr. Patent Counsel; **Allen L. Limberg,** Sr. Patent Counsel; **Raymond E. Smiley,** Sr. Patent Counsel; **William Squire,** Sr. Patent Counsel; **Joseph S. Tripoli,** Managing Patent Attorney; **Christopher L. Maginniss,** Associate Member, Patent Staff; **Robert Ochis,** Resident Patent Counsel—Camden/Moorestown; **Donald W. Phillion,** Sr. Patent Counsel; and **George Seligsohn,** Sr. Patent Counsel.

### RCA Service Company

**George D. Prestwich,** President, RCA Service Company, announces his organization as follows: **Martin J. Barnabic,** Division Vice-President, Consumer and Industry Affairs; **George J. Brennan,** Division Vice-President, Management Services and Systems Planning; **Michael F. Camardo,** Division Vice-President, Finance; **Donald M. Cook,** Division Vice-President, Government Services; **Earl A. Malm, II,** Division Vice-President, Telephone Systems and Data Services; **Philip J. Martin,** Division Vice-President, Business Development and Strategic Planning; **Melvin F. Riedberger,** Division Vice-President, Business Transition Management; **Joseph Siegel,** Division Vice-President, Industrial Relations; **Raymond J. Sokolowski,** Division Vice-President, Consumer and Commercial Services; and **Joseph E. Steoger,** Division Vice-President, Engineering.

### Solid State Division

**David S. Jacobson,** Director, Custom Large Scale Integration, Solid State Technology Center, announces the appointment of **Robert A. Donnelly** as Manager, Program Management and Business Planning.

**Richard H. Bergman,** Manager, Design, Test and Applications Custom LSI, Solid State Technology Center, announces the appointment of **Richard P. Lydick** as Leader Technical Staff, Custom LSI Design.

**H. Gene Patterson,** Manager, Large Scale Integration, Marketing and Applications, announces the appointment of **Paul K. Sferrazza** as Leader Technical Staff, Large Scale Integration Applications Engineering.

**James L. Dunkley,** Manager, Bipolar and MOS Logic Engineering, announces the appointment of **Charles Engelberg** as Manager, Test Engineering—Bipolar and MOS Logic.

**Charles Engelberg,** Manager, Test Engineering—Bipolar and MOS Logic, announces the appointment of **Peter K. Neumann** as Leader Technical Staff, Bipolar Test Technology.

## Obituary

### Harry F. Olson, an acoustical authority at RCA Laboratories

**Harry F. Olson,** a pioneer in acoustics and electronic sound recording who was associated with RCA for nearly 40 years, died on April 1 at the Princeton Medical Center. Dr. Olson was Staff Vice-President, Acoustical and Electromechanical Research for RCA Laboratories when he retired in 1967. He continued as a Consultant for the RCA Laboratories.

Born in 1901 in Mt. Pleasant, Iowa, Olson attended the University of Iowa, Iowa City, where he received the B.E. degree in 1924, the M.S. degree in 1925, and the Ph.D. degree in 1928. Dean Carl Seashore, who pioneered in the field of the psychology of musical sounds, and Professor G.W. Stewart, inventor of the acoustic wave filter, introduced Olson to the science of acoustics.

In 1928, Dr. Olson joined RCA Laboratories in New York City as a member of the Research Department. In 1932, the RCA Laboratories were moved to Camden, New Jersey, where Olson led acoustic research in 1934. In 1942, RCA Laboratories moved to Princeton, New Jersey, where Olson was Director of Acoustic Research. He was appointed Staff Vice-President of Acoustical and Electromechanical Research in 1966.

An early and important contribution of Dr. Olson's long career was the development of the velocity microphone. One of the problems in the early days of sound motion pictures was the sound pickup. He decided that a velocity microphone would have a distinct advantage over a pressure microphone in that it would be directional, and thereby discriminate against reverberant and other undesired sounds. The velocity microphone that he developed did indeed prove superior due to the directional characteristics. The velocity microphone was followed by the development of the cardioid unidirectional microphone, which Dr. Olson described in a paper delivered at the Cleveland, Ohio Meeting of the Acoustical Society of America on December 31, 1931. This microphone was an immediate success due to the unidirectional pattern. Over the years, the cardioid microphone has continued to be the universal unidirectional microphone.

He pioneered in the development of multicone and multicoil direct radiator loudspeakers, and he holds the fundamental patent on the air-suspension loudspeaker.

In 1940, when the American electronics industry was deeply involved in military projects, the Acoustics Laboratory under Dr. Olson directed their attention to underwater sound and antisubmarine warfare. They constructed underwater transducers that operated at frequencies as high as 60 MHz. During World War II, they carried out developments in sonar transducers with super directivity and an effective electroacoustic proximity fuse for depth charges.

One of the first postwar projects was the destruction of the myth that most people preferred a bandwidth restricted to 5000 Hz. Dr. Olson set up a listening room in which juries of listeners could hear live music from a small band behind a screen in the same room. In the screen was an acoustic filter that attenuated all sounds above 5000 Hz. The filter could be opened or closed and the listeners were asked to state their preference. Hundreds of listeners from all walks of life made the test and the conclusion was an overwhelming vote in favor of wide-range sound. A similar result was obtained with reproduced sound when the reproduction was free of distortion. However, when small amounts of distortion were introduced, the preference began to move toward restricting the high-frequency bandwidth, where most of the objectionable distortion products resided. These classical demonstrations, in effect, gave the green light to truly high-fidelity sound-reproducing systems and the hi-fi industry took off and burgeoned during the years following.

Dr. Olson developed the active acoustic sound absorber in the form of a specially designed microphone, amplifier and loudspeaker connected in inverse feedback condition. He pioneered in the development of the functional sound absorber. Other developments included the phonetic typewriter and speech processing system. Dr. Olson headed a team that developed the RCA magnetic tape recorder for television.

Dr. Olson, with Herbert Belar, developed the RCA Electronic Music Synthesizer. The synthesizer, after being used by several composers at the RCA Laboratories, was moved to the Columbia-Princeton Electronic Music Center in New York City. Composer Charles Wuorinen was the winner of the 1970 Pulitzer Prize for his "Times Encomium" record produced on the RCA Synthesizer—the first time the Pulitzer Prize was awarded for an all-electronic work. (This issue of the *RCA Engineer* contains a soundsheet with a musical selection made on the RCA Synthesizer; see page 72.)

A frequent contributor to professional journals, Dr. Olson has written 130 scientific papers. He holds more than 100 U.S. Patents on devices and systems in the acoustical field. He has written several books including *Dynamical Analogies, Acoustical Engineering, Musical Engineering, Music, Physics and Engineering,* and *Modern Sound Reproduction.*

Dr. Olson was elected to the National Academy of Sciences in 1959. He was a member of Tau Beta Pi, Sigma Xi, and the American Society of Swedish Engineers. He was a Fellow of the American Physical Society, the Society of Motion Picture and Television Engineers, the Institute of Electrical and Electronics Engineers, and the Acoustical Society of America. He was an Honorary Member of the Audio Engineering Society of which he was a past president. In the Acoustical Society of America, he served as Associate Editor for 30 years, on the Executive Council 1937-40, as Vice-President 1941-44, as President Elect 1951-51, and as President 1953-54. For his contribution to the field of acoustics, Dr. Olson has received many honors and awards.

*—J.G. Woodward*
RCA Laboratories

## Six receive Consumer Electronics Division quarterly awards


Benford


Shukwit


Tults


Herskowitz


Moore


McCorkle

The Consumer Electronics Division TEC has selected their first-quarter 1982 Technical Excellence Award winners. They were notified by **Dr. D. Joseph Donahue,** Vice-President and General Manager, Consumer Electronics Division. Fine efforts such as those recognized "enable RCA to continue as the leader in a very competitive marketplace," according to Dr. Donahue.

The award winners listed below will receive a plaque and a reference book of their choice. They are also eligible to receive an annual award for their work.

**John Benford**—For the development of acoustic measurement techniques, which helped find solutions to shadow-mask flutter and high-voltage-transformer noise problems.

**Stanley Shukwit**—For the suggestion and implementation coordination of a "hot-runner" system that allows the manufacture of thin-wall plastic cabinets, which resulted in considerable material savings.

**Juri Tults**—For the innovative development of synthesizer logic for the CATV version of the FS-I integrated circuit and for the FS-II integrated circuit.

**Martin Herskowitz, David McCorkle** and **George Moore**—For the development of an automatic system that measures and aligns center purity, center convergence, Z-axis edge purity, and yoke rotation while providing enough mechanical integrity to allow yoke clamp tightening without disturbing alignment.

## Mountaintop technical excellence award winners, May 1982


Burrell


Caravaggio

The Mountaintop Technical Excellence Award is designed to recognize and reward members of the technical community who have consistently exhibited qualities of initiative, leadership, technical competence, attitude and follow-up. The Technical Excellence Committee is proud to announce that **Bill Burrell** and **Tony Caravaggio** are recipients of the Mountaintop Technical Excellence Award for May, 1982.

## Technical excellence chairmen's workshop

Recently, Technical Excellence Committee chairmen met at the David Sarnoff Research Center for a one-day workshop that reviewed the various technical excellence activities. This exchange provided a source of ideas on effective activities and their execution. **H. Woll,** Staff Vice-President and Chief Engineer, gave the keynote address, in which he covered the difficulties of successfully competing in electronics today and the vital role of technical excellence. He outlined the broad concept of what technical excellence means as well as the role the TECs play in supporting both the business and the engineer's personal career.

## RCA TECs

| *Location* | *Unit* | *Chairman and Phone* |
|---|---|---|
| Bloomington | CE | Bernie Porambo 423-5181 |
| Burlington | AS | Paul Seeley 326-3095 |
| Camden | GCS | John Breen 222-2569 |
| Findlay | SSD | Mike Bankovich 425-1493 |
| Indianapolis | CE | Mike French 422-5934 |
| Indianapolis | REC | Bob Felis 424-6030 |
| Indianapolis | SVD | Ned Kiser 426-3291 |
| Lancaster | EO&D | Dave Marschka 227-2310 |
| Lancaster | PTD | Ray Marsland 227-2202 |
| Marion | PTD | Bill Harris 427-5352 |
| Moorestown | MSR | Jack O'Brien 224-3963 |
| Mountaintop | SSD | Vince Osadchy 327-1541 |
| Palm Beach Gardens | SSD | Gary Meister 722-1294 |
| Princeton | AE | Carl Voorhees 229-3494 |
| Scranton | PTD | Al Tadder 329-1476 |
| Somerville | SSD | Irv Martin 325-6204 |
| Taiwan | CE | Robert Chen 436 |

Concerns and problems in effectively carrying out the technical excellence charter were reviewed and the needed action was developed. The chairmen's reports left a strong impression that the TECs' activities contribute strongly to RCA's technical vitality and viability.

A TEC is a group of non-supervisory engineers (complemented by a management and an IR liaison representative) representing the major technical activities of their location. TECs develop and execute a variety of programs aimed at enhancing technical excellence and covering the following charter areas:

- Technical Education
- Technical Information
- Professional Activities
- Recognition

# Editorial Representatives

**Contact your Editorial Representative at the TACNET numbers listed here to schedule technical papers and announce your professional activities.**

## Commercial Communications Systems Division (CCSD)

| | | TACNET |
|---|---|---|
| **Broadcast Systems** | | |
| *Bill Sepich | Camden, New Jersey | 222-2156 |
| Krishna Praba | Gibbsboro, New Jersey | 222-3605 |
| Andrew Billie | Meadowlands, Pennsylvania | 228-6231 |
| **Cablevision Systems** | | |
| *John Ovnick | Van Nuys, California | 534-3011 |

## Consumer Electronics (CE)

| | | |
|---|---|---|
| *Clyde Hoyt | Indianapolis, Indiana | 422-5208 |
| Francis Holt | Indianapolis, Indiana | 422-5217 |
| Chuck Limberg | Indianapolis, Indiana | 422-5117 |
| Don Willis | Indianapolis, Indiana | 422-5883 |
| Byron Taylor | Indianapolis, Indiana | 426-3247 |

## Government Systems Division (GSD)

| | | |
|---|---|---|
| **Advanced Technology Laboratories** | | |
| *Merle Pietz | Camden, New Jersey | 222-2161 |
| Ed Master | Camden, New Jersey | 222-2731 |
| **Astro-Electronics** | | |
| *Frank Yannotti | Princeton, New Jersey | 229-2544 |
| Carol Klarmann | Princeton, New Jersey | 229-2919 |
| **Automated Systems** | | |
| *Paul Seeley | Burlington, Massachusetts | 326-3095 |
| Dale Sherman | Burlington, Massachusetts | 326-2985 |
| **Government Communications Systems** | | |
| *Dan Tannenbaum | Camden, New Jersey | 222-3081 |
| Harry Ketcham | Camden, New Jersey | 222-3913 |
| **GSD Staff** | | |
| *Ed Moore | Cherry Hill, New Jersey | 222-5833 |
| **Missile and Surface Radar** | | |
| *Don Higgs | Moorestown, New Jersey | 224-2836 |
| Jack Friedman | Moorestown, New Jersey | 224-2112 |
| Graham Boose | Moorestown, New Jersey | 224-3680 |

## National Broadcasting Company (NBC)

| | | |
|---|---|---|
| *Bob Mausler | New York, New York | 324-4385 |

## Patent Operations

| | | |
|---|---|---|
| Joseph Tripoli | Princeton, New Jersey | 226-2992 |

## Picture Tube Division (PTD)

| | | |
|---|---|---|
| *Ed Madenford | Lancaster, Pennsylvania | 227-3657 |
| Nick Meena | Circleville, Ohio | 432-1228 |
| Jack Nubani | Scranton, Pennsylvania | 329-1499 |
| J.R. Reece | Marion, Indiana | 427-5566 |

## RCA Communications

| | | TACNET |
|---|---|---|
| **American Communications** | | |
| *Murray Rosenthal | Princeton, New Jersey | 258-4192 |
| Carolyn Powell | Princeton, New Jersey | 258-4194 |
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| **Laboratories** | | |
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| *Nelson Crooks | Indianapolis, Indiana | 426-3164 |

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| *John Schoen | Somerville, New Jersey | 325-6467 |
| **Power Devices** | | |
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| **Integrated Circuits** | | |
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| Sy Silverstein | Somerville, New Jersey | 325-6168 |
| John Young | Findlay, Ohio | 425-1307 |
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| **Solid State Technology Center** | | |
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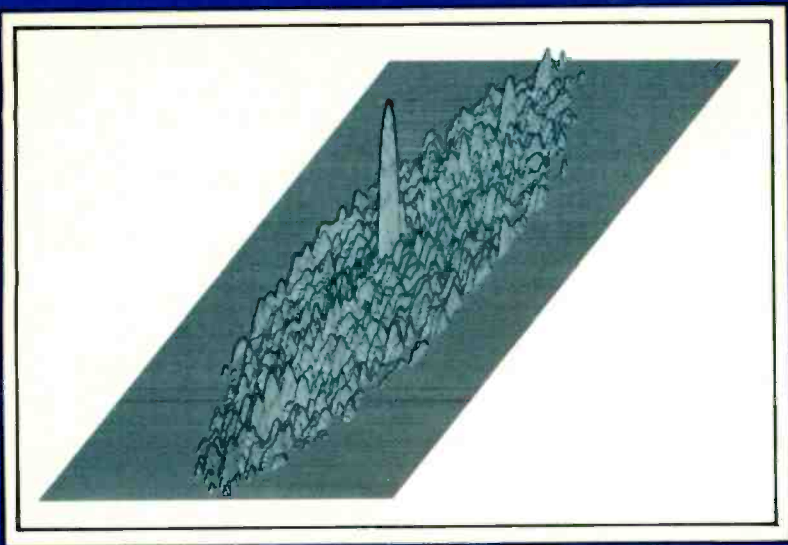

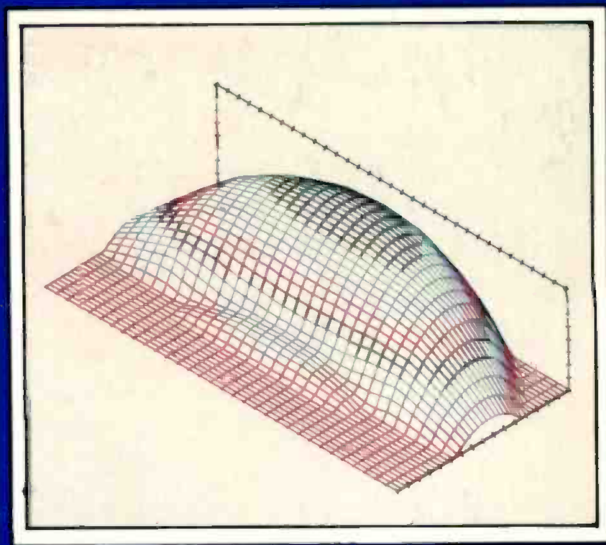


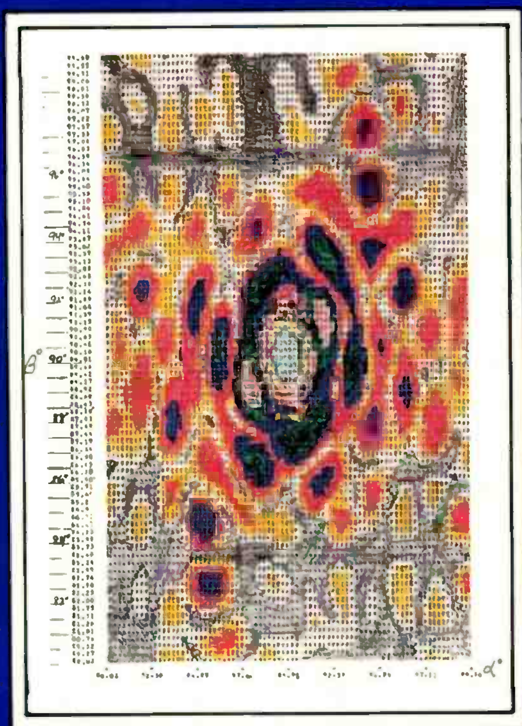

The visually interesting materials and outputs displayed here are presented and explained beginning on page 33.

**Engineering form and function: Windows on technology**

**RCA Engineer**

A technical journal published by Corporate Research and Engineering "by and for the RCA engineer"

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Printed in the U.S.A.
Form No. RE-27-4