RCA Laboratories | Princeton, NJ

1975 Research Report

Company Private

Contents

1. Introduction

W. M. Webster
Vice President, RCA Laboratories

This report is a collection of summaries of the Laboratories technical activities in 1975 prepared by the management of each of the major groupings within RCA Laboratories.

During 1975 our major programs were: VideoDisc, color television (including the initiation of a program that addresses virtually all aspects of the color kinescope), flat-panel television, a variety of programs in solid state (mainly in integrated circuits but also a substantial amount on power devices), and programs in support of satellite communications. These are discussed in greater length in the sections that follow.

About half of our total resources were directed toward current and near-term needs of the product divisions, and most of this work was joint or in close cooperation with them. Virtually all of the rest, which we classify as "New Business," was directed at products and services that address markets RCA is already in. VideoDisc, flat-panel TV, and some of the programs in satellite communications are examples of the latter.

Further details on any of our projects can, of course, be made available.

2. Systems Research

N. L. Gordon, Staff Vice President

Support of RCA's color-television business continued to be the primary task of the Systems Research Laboratory during 1975. Strong emphasis was placed on the signal processing and the power supply and deflection subsystems of television receivers. Also, support for manufacturing and service operations was provided through the development of hardware and software systems for process control and monitoring purposes. Major contributions were also made to the VideoDisc effort (our results related to VideoDisc are contained in other reports).

TV-Receiver Signal Processing

During 1975 our efforts on color-TV receiver signal-processing circuits and systems continued to be directed towards improved performance and reliability at reduced manufacturing cost. Our work was concentrated in four main areas: tuners and tuning systems; i-f amplifiers; baseband luminance and chrominance processing; and remote control. Additional efforts were directed at AGC and audio systems.

In the tuner area we continued to work exclusively on electronic tuners, which offer the best prospects for meeting FCC parity requirements, reducing costs, and providing new and unique user-tuner interfaces. A major accomplishment of 1975 was the completion of our work on the planar electronic tuner. The technology for this tuner has been transferred to CE and a product design is underway for introduction in 1977 receivers.

Work on electronic tuner addressing and control concentrated on two approaches — (1) frequency synthesis and (2) a system combining digital memory and a digital-to-analog converter. The frequency-synthesis system incorporates a new high-speed ECL divider chip and a C-MOS logic chip, both fabricated by SSTC. Several customer interfaces were developed for these systems, including capacitively sensed touch pads for rapid up-down selection of customer preprogrammed channels and a unique magnetically detented knob that provides rapid access to all 82 channels. Prototypes have been provided to CE, and marketing evaluation is underway.

The effects of i-f filter characteristics on overall transmitter-receiver transient response were studied as a guide to improved i-f filter design. The possibility of using printed i-f coils was also examined; preliminary results indicate a significant potential for cost reduction. Further work is planned for 1976.

Efforts on the use of surface acoustic wave (SAW) devices for i-f filtering continued this year with substantial assistance from SSTC in the fabrication of samples and the development of techniques for eventual mass production. The principal problems in applying SAW devices to TV i-f filtering are the high insertion loss (not inherent, but needed to eliminate triple-transit effects in the simplest configuration) and the cost of the material and the package. We have focused our work on these problems and have designed structures that use less material and fit into smaller packages. We have also designed filters that employ schemes to cancel the triple-transit signals, greatly reducing the insertion loss. At year's end we were studying the overall system tradeoffs involved in using these lower-loss, lower-cost filters.

Our principal effort on baseband processing circuits was directed at the application of charge-coupled-devices (CCD's) to TV signal processing. Using a 680-element CCD delay line developed by the Laboratories' Solid State Technology Center, we demonstrated the feasibility of using CCD's for comb filtering of chrominance and luminance and for vertical and horizontal aperture correction. We are now working closely with the Technology Center staff to integrate the clock-driver and other processing circuits on a single chip with the CCD delay line. We hope to achieve a cost-effective system that can be used in 1979 or 1980 TV receivers.

Our colorimetry program continued this year with further development of the computer analysis tools that proved so useful in the development of the ColorTrak system. When completed next year, we will have a unified computation package that will permit quick evaluation and optimization of colorimetric parameters for color TV receivers. We used the present package extensively this year in consultation with CE to evaluate a number of proposed changes in the matrix and phosphors for 1977 receivers.

Remote-control systems continued to receive attention this year with continuing effort on a highly reliable multifunction remote system utilizing a digital FSK ultrasonic transmission method. We also are working on a very low cost one- or two-function remote system for possible use in 1978 receivers. A major effort in 1975 was the cooperation with CE on a crash basis to solve a number of immediate pre-production problems on the direct-address remote system used in our top-of-the-line 1975 and 1976 receivers.

TV-Receiver Power Supply and Deflection Systems

Color receiver power-supply technology has undergone radical changes in recent years largely because of the impact of government legislation and the energy crisis.

Three different power-supply systems were developed to the prototype level during the year, all offering significant improvements over present technology in terms of efficiency and cost. One of these is based on a new ferrite material that was developed concurrently in the Process and Materials Laboratory.

Three new vertical-deflection systems were also developed. Two of these attacked the low power efficiency of conventional vertical-deflection circuits by developing the voltage pulse required for vertical retrace by a means that is independent of the normal trace supply. Efficiencies of the order of 40% were achieved with both systems. In the third system (first proposed by P. Haferl of RCA, Zurich), vertical deflection is obtained by directly driving the vertical yoke with width-modulated pulses derived from the horizontal deflection. In principle, this system can yield a power efficiency of over 80%.

The major development in horizontal deflection was the shift from SCR systems to transistor systems. This has occurred primarily because transistor technology improvements have led to ever decreasing transistor costs.

Considerable effort was devoted to devising failure-intolerant circuits for the control of x-ray radiation from the kinescope. Such radiation could result from excessive ultor voltage caused by a fault in a receiver component. These failure-intolerant circuits detect an over-voltage condition and disable the receiver. In addition, they will disable the receiver in the event of any single component failure in their own circuit. A total of three simultaneous failures is required to defeat the protection system.

In addition to the building-block work described above, three complete power-supply/deflection breadboards were developed in order to help us more fully understand the problems of system integration.

Significant progress was made in understanding the mechanism of arc tracking in printed circuit boards and in devising test procedures that give reproducible results. Close liaison was maintained throughout the year with the Product Safety Lab in Indianapolis.

The major event in deflection yoke research was the development of a nongeodesic bias-wound wire placement structure that greatly reduces the sensitivity of convergence errors to yoke position. Although experimentally realized in a toroidal configuration, this concept is equally applicable to both saddle and semi-toroidal designs.

Process Control and Monitoring Systems

These activities comprise the development and application of modern computer related hardware and software, of consumer preference testing of product alternatives, and of manufacturing inspection systems.

In early 1975, we completed the implementation of the highly automated Switching Central System for NBC-TV. Currently, the system switches all TV programs and commercials for both local (NYC) and network broadcasts from the studio equipment to the proper output channels on a full 24-hour-day schedule.

This year has seen the genesis and growth of an ambitious Process Monitoring and Control project to aid in the production of integrated circuits. The system is being designed to oversee the flow of product, to monitor important fabrication parameters, and eventually to control directly the fabrication process itself. Working in conjunction with Design Automation engineers (SSTC), a proposal for a minicomputer-based system was made to SSD and SSTC, and was approved. The hardware and data base software have been chosen, and a major user interface has been fully specified. Software development tools are being gathered for the implementation phase.

Another integrated-circuit-related activity was the development and delivery of a complete LSI mask-inspection system to Somerville. The continuously increasing complexity and decreasing size of integrated circuits has focused attention on the importance of controlling the defects in photomasks. The profitability of an integrated-circuit manufacturing operation is very strongly influenced by undetected mask defects that reduce yield. The mask-inspection system developed by us allows 100% inspection of a 4 × 4 inch mask in about one hour. Prior to the installation of our system, Somerville had no practical capability for 100% inspection of such masks.

Several approaches to improved testing techniques for CE were pursued. The project for the analysis of color TV receivers of our competitors developed new test methods that were successfully transferred to CE engineering with particular emphasis on colorimetry analysis. With the cooperation of Quality Control engineers at the Bloomington color TV factory, defect rates in the assembly process were measured, and an automated, interactive defect-analysis model was proposed to provide critical control charging parameters for evaluating proposed changes to the process.

Unification and extension of existing RCA computer aids for circuit design is the goal of a large machine CAD data-base system, which now resides at two locations: Information Services CMS, and Solid State Division TSO. It is routinely used by the Custom Monolithics Group, SSTC, and is under experimental use in SSD. It embraces logic simulation, test generation, placement and routing, artwork and logic verification, and a simple abbreviated input language. The system is being extended to include an automated method for densely packing an IC chip layout.

Within the Laboratories, an automation consulting group has aided a wide range of experimenters in choosing data collection and analysis systems. These

systems use minicomputers with modular instrumentation interfaces for real-time data acquisition and large time-sharing resources for exhaustive analysis.

We provided consultation and assistance this past year to a number of divisions developing computer-based systems. Among others, this has included database management and time-sharing problem assistance to the IS Corporate computing center, minicomputer system consultation to the Telex group within GLOBCOM, advice on microprocessor approaches for GLOBCOM's Leased Channel business, and minicomputer assistance to Broadcast Systems.

Our image-evaluation program was formulated to provide guidance in the design of products based on the perceived value of engineering changes. Our approach has been to evaluate current product designs through consumer preference testing, while simultaneously considering those psychophysical aspects of vision that apply directly to display performance. We have completed the determination of the most subjectively desirable color correction matrix and of the subjective improvement in picture quality due to the "Yale" phosphor approach. We have also noted the desire of a significant percentage of viewers to watch large-screen TV (4 × 5-1/2 feet) even though they thought the larger picture to be inferior. Experiments to determine preference with respect to kinescope geometry will be completed in 1976.

3. Technology Centers

G. B. Herzog, Staff Vice President

The role of the Technology Centers is to carry research results through to finished product. In most cases the final product is a component, but in some cases it is a system or subsystem. With the advent of LSI and developments such as the microprocessor, it becomes increasingly difficult to distinguish between a component and a subsystem. An electronic watch is at one time both an electronic component (a single CMOS chip) and a complete electronic subsystem. This close tie between components and systems requires an increasing emphasis on the smooth interaction of groups with different disciplines and the hiring of creative people with broad interests and skills. The Technology Centers now contain skills ranging from basic physics to computer architecture and programming. The resulting components range from solid-state temperature sensors to microwave devices capable of one watt of power output at 9 GHz. Subsystems produced and sold during 1975 range from military countermeasure VCO's (voltage-controlled oscillators) worth many thousands of dollars each, to automotive engine computer control systems using microprocessors that are projected to sell for under $20 when produced in quantities of a million per year. The following sections detail the activities of the individual disciplines.

3.1 Microwave Technology Center

F. Sterzer, Director

In 1975, the Microwave Technology Center continued to explore and develop new microwave technologies and to demonstrate applications of these technologies for both military and non-military systems. Significant advances were made in all aspects of microwave solid-state effort: material preparation, device design and fabrication, circuit implementations, and subsystem demonstrations. Approximately 4000 devices, circuits and subsystems were delivered to RCA product divisions and other users.

Perhaps the most dramatic results were obtained in the area of medium-power gallium arsenide field-effect transistors (GaAs FET's). In this field, major advances in both material and device processing led to the achievement of 1 watt of power

at 9 GHz, a performance milestone that placed RCA well ahead of the industry. Exploiting this achievement, power amplifiers suitable for both commercial and military communications systems were designed, fabricated, and thoroughly characterized, and the results clearly established the capability of microwave GaAs FET amplifiers to replace traveling-wave tube amplifiers in terrestrial and satellite communications systems as well as in radar and electronic warfare equipments.

Another major effort, also using gallium arsenide as the semiconductor material, is in the extremely fast signal-processing area. Work in this field, in which RCA is a recognized industry leader, is fully funded by the U.S. Government. The 1975 effort spanned the range from theoretical investigations to work on the development of a short-baseline direction-finding system module, in which time differences as small as 40-50 picoseconds will be measured. Interest in this effort continues strong not only among the service laboratories, but also in the government activities concerned with long-range research.

In our work with silicon, major advances were demonstrated in the area of p-i-n switching diodes, Units surpassing the best available commercial devices have been fabricated and demonstrated, and the suitability of the p-i-n diodes for use as elements in phase shifter and channel-switching applications has been established by the M&SR and the G&CS divisions. The p-i-n diodes are expected to play an important role in future satellite communications systems, both military and commercial, by virtue of their suitability for antenna beam-switching schemes.

Also in the area of silicon technology, we continued experiments with photovoltaic energy conversion using concentrator approaches. A 100-watt array was built with a system of lenses providing for a 1000-sun concentrating system and a built-in solar tracker. Major support of this program by ERDA is expected before the end of second quarter, 1976, and applications demonstrations on the part of government user activities are already being planned employing the arrays expected to be fabricated under the ERDA program.

An important goal of the Microwave Technology Center in 1975 was the application of advanced microwave devices and components developed by the Center to enhance the performance of important subsystem modules. Utilizing the expertise of an advanced engineering team transferred from the microwave activity of the former Electronic Components operation, we have established ourselves as one of the foremost designers and suppliers of voltage-controlled oscillators (VCO's) for sophisticated electronic warfare systems. A closely coordinated working relationship with the Automated Systems Division has been developed to exploit this expertise. Using our VCO technology, we are developing a novel, sophisticated frequency memory subsystem and are exploring its use with a microprocessor in an even more advanced system. We are also working, under a major subcontract for

the U.S. Department of Transportation, on interfacing an automobile collision-avoidance radar and an electronic dashboard using the RCA COSMAC microprocessor.

In 1975, we completed the prototype design of the ground-speed sensor for locomotive use. Developed under partial financial support of a major locomotive manufacturer, this design is now essentially frozen. A quantity of sample units will be delivered early in 1976 for exhaustive system tests (by the customer), and we expect follow-on effort for about 1000 units to be started late in 1976.

Another commercial program pursued in 1975 was the design and demonstration of a microwave ranging radar used for the measurement of the "burden" (rock-like ore, coke, etc.) in a blast furnace. Knowledge of the burden "line" is essential for the proper operation of the furnace, and the microwave ranging approach is expected to greatly increase the throughput of the furnace over that using crude mechanical measurements methods.

In the field of medical applications of microwaves, a cooperative program was established with the Montefiore Medical Center in New York City to design and test a portable solid-state microwave source using a unique applicator (electrically matched to muscle tissue) to induce highly localized heating of tumors. In experiments conducted at Montefiore on tumor-bearing mice, 100% were apparently cured by the heat treatments. We have established contact with National Cancer Institute personnel interested in these experiments and expect follow-on support from them in 1976.

During 1976 we expect record levels of government support for our work on microwave devices, circuits, and subsystems, and on photovoltaic solar generators. In the commercial area, major emphasis will be on advancing microwave technologies for satellite communications.

3.2 Design Automation

The Design Automation (DA) group creates special-purpose computer programs to reduce the cost, elapsed time, and human error inherent in integrated-circuit creation. During 1975, DA successfully developed several new software systems, and continued to refine and enhance existing systems to meet the continuing needs of the Solid State Division, the Laboratories, Government & Commercial Systems, Electronic Components, and Consumer Electronics. DA's software facilities are utilized by design and production engineers to reduce the time spent in producing artwork masks for circuit fabrication, to simulate the performance of new circuits, to pinpoint logical and mechanical errors in the design, and to evaluate the test results on these circuits once they are produced.

Artwork

Design Automation's Artwork systems transform the designer's sketch of an integrated circuit into a computer-readable representation, called a DFL file. This computer file is used to generate the actual photographic masks from which the integrated circuits are manufactured. Design Automation's artwork systems also interact in the stages between initial data entry and circuit fabrication by providing extensive editing facilities for error correction, and extensive computer validation to detect design violations.

A program, called ART, has previously been developed to provide a means for entering and manipulating data in the computer. This year the ART program was modified to allow engineers to design a basic ROM, and then *impose* any number of separate functions on this basic design, where each function represents a different ROM. Through this technique of function imposition, RCA can potentially sell any number of special-purpose ROM's, and merely impose the wanted functions on the basic design. This results in a significant savings in design and test time, since only a bit pattern must be designed and tested for each new ROM. The ROM artwork program promises to be a basis for active business during 1976.

Artwork data validation, handled by the CRITIC program, was improved to make the program twice as efficient, thereby halving its operational costs. CRITIC's ability to find design rule violations was enhanced by (1) the development of a computer language that allows engineers to specify design rules in an easy and understandable format, and (2) by the development of a new algorithm able to quickly and accurately isolate potential trouble spots in a circuit design. At year's end, the new version of CRITIC was almost 75 percent complete.

The end result of all artwork is the production of photographic masks used to manufacture each chip. The Master Artwork Program (MAP) converts computer descriptions of a circuit into commands suitable to drive the D. W. Mann Pattern Generator or Gerber Photoplotter machines. Significant improvements in MAP were realized during 1975: (1) by making artwork restrictions less severe, designers are now able to describe circuits more concisely; (2) MAP now has the ability to drive the Mann 3000 Pattern Generator, which has a resolution five to ten times better than its companion, the Mann 1600; and (3) incorporating a further design improvement into the MAP software has reduced photoplotting time by an average of 50 percent. These three MAP improvements have had an additional benefit; they have reduced overall computer running time by over 90 percent in the average case — a truly dramatic improvement.

Simulation and Testing

Circuit and logic simulation using computer software provides designers with a cost-effective computer aid for avoiding expensive circuit fabrication cycles, and for otherwise shortening the design, manufacture, and test processes.

During 1975, SSTC, G&CS, and SSD used R-CAP (the RCA Circuit Analysis Program) to simulate the diverse applications of their many integrated circuits. R-CAP's primary value rests on its ability to predict the behavior of circuits, particularly in IC technologies where prediction is impossible by means of traditional breadboarding approaches.

R-CAP's substantial benefits are the result of several technical advances:

1. By utilizing both the time-sharing and batch facilities of the large computers within RCA, R-CAP simulation results are rapidly given to the designer, minimizing delays in data evaluation to a few minutes.
2. The cost of using R-CAP has been halved.
3. In order to simulate memories using the MNOS technology a device model for that technology was developed this year.
4. Extensive consultation with our R-CAP users has led to the characterization of widely used device models, thereby improving the overall efficiency of simulation programs for these devices.

The TESTGEN and LOGSIM software programs, both developed by RCA, simulate the digital response of logic networks to input stimuli. Both TESTGEN and LOGSIM extract pertinent facts about the circuits connectivity from a logical circuit description, and mathematically simulate the functions of the circuit. Design Automation has been instrumental in encouraging computer simulation throughout SSD and SSTC through its efforts to enhance the usability and scope of both simulators. Specifically,

1. DA made the first operating version of TESTGEN available for both batch and time-sharing on the IBM/370 in Somerville;
2. DA developed both DAFTER and AFTER, which directly convert TESTGEN output into programs that drive the Datatron and Teradyne automatic testers, thereby enormously increasing the utility of computer simulation;
3. DA provided a brief listing option for the LOGSIM program, making it far easier to interpret the LOGSIM output. Redundant output results are no longer listed, reducing the volume of the output by an order of magnitude.

Automatic test program generation was widened during 1975 to include ROM test procedures. The ROMTEST program uses the actual bit pattern that specifies the contents of a customer's ROM to construct the test program, thereby eliminating *all* error-prone human intervention. Since the customer must specify the contents of his ROM, no additional labor is expended to feed this information to the ROMTEST program.

During the year, Design Automation and SSD Power Transistor Engineering departments cooperated to develop computer software to optimize device yields at final test. The developed solution predicts the yield for a manufacturing process based on the previous yield percentage for this process. These programs currently run on computers found on the factory floor in SSD's Mountaintop plant. Our pilot use of this program has demonstrated a potential yield increase of 5 percent—thus substantially increasing the potential profit margins in this high-volume production environment.

3.3 LSI System Design

The role of the LSI Systems Design group is to apply the latest semiconductor technology to useful products that can be used by the Corporation and sold to others by SSD.

In May of 1975 the COSMAC microprocessor operations were formally taken over by SSD. This represented the culmination of work begun in 1971 at the laboratories and transferred to the SSTC in 1973. By May, COSMAC microprocessor chips were in small-volume production in the SSTC Custom Monolithics pilot line; Microkits, the prototyping systems, were in factory production in Palm Beach Gardens; CSDP, the assembler/simulator/debugger package for software development, was available through commercial timeshare services or as a FORTRAN IV program; and the basic manuals were written. In July, much of the LSD group was put on loan to SSD to help further develop the microprocessor business.

During 1975, the COSMAC microprocessor chips were characterized and put into full factory production. A series of enhancements were made to the Microkit, including the design of new, bigger memory cards and an improved set of utility routines, all of which are now in production. A major accomplishment was the completion of software for the Microkit to allow "resident" assembly and editing of user programs, followed by provision of a macro capability for the assembler. Microkit demonstration systems were built. CSDP was successfully installed on a wide variety of timeshare systems, undergoing a series of enhancements throughout the year.

A number of hardware/software experiments were carried out and documented within RCA. They will emerge in 1976 as "Application Notes" and, in some cases, as I/O IC's in the COSMAC product line. These include dynamic RAM systems, time-of-day logic, a data coupler, a multiply-divide unit (as an I/O device!), keyboard logic, A/D and D/A interfaces, systems to write data into programmable ROM's, and, very important for our 1976 plans, a low-cost COSMAC-controlled floppy disc interface. We also initiated in 1975 a substantial effort to develop a new product line, to be competitive with the best of INTEL, Motorola, and others. The central issue was a new 1-chip version of COSMAC. For this we devised a new "bit-slice" approach to the layout and developed a new architecture. We breadboarded, simulated, and checked thoroughly and, as a result, it worked on the first implementation.

Complementing the new microprocessor chips, we have also designed a new ROM part, and have initiated design on several new I/O parts and a small RAM part (32 X 8), all in silicon-gate bulk CMOS. Our LSI work in memory circuits has resulted in an extensive patent position in this area.

The COSMAC MicroTutor, designed in 1974, is a small, complete microcomputer which, with its manual, allows the reader to learn the mysteries of computers and quickly to appreciate the elegance of COSMAC architecture. More than 100 have been built so far and used to train RCA engineers and SSD field men, and to convince potential customers to choose COSMAC over the competition. The MicroTutor has gone into volume production for sale by SSD.

During 1975, we initiated a program to explore the application of COSMAC in the coin-operated games business. This project led to a new concept in home entertainment systems, FRED, which is a COSMAC-based TV-display home game system. In 1975, several attaché-case FRED systems were built and demonstrated. A new approach was also developed, which replaces the previously used audio cassette input with ROM boards and partitions the software into permanently resident general-purpose subroutines separated from the plugged-in personality software. This FRED concept has been accepted by D&SP and is being vigorously pursued with a 1976 product as the goal.

A COSMAC-based system was also developed in 1975 to control a capacitance/voltage monitor in the SSTC semiconductor manufacturing line. The system is now being evaluated in the SSTC pilot line.

Our repertoire of IC sensors for automotive applications was widened in 1975. Improvements in our temperature sensor were made, and Hall-effect circuits were designed and applied as position sensors. Design work was carried out for IC sensors utilizing external on-site variable inductances and resistances.

Installation of a COSMAC system in our test vehicle to monitor and display simple speed and fuel variables, begun in 1974, was augmented in 1975. Experiments were carried out to monitor the behavior of commercial anti-skid braking systems, and then to implement our own control system. A COSMAC control system for ignition timing was designed and installed. Our systems work has allowed us to write a convincing proposal to Minicars, Inc., to provide the electronic subsystem for their "safe car of 1980". Most importantly, it has been a crucial factor in selling COSMAC to the automotive manufacturers in the face of very stiff competition. These and other customer exchanges have made automotive applications the single most promising market area for COSMAC products beginning in 1977.

3.4 Integrated Circuit Technology

J. H. Scott, Jr., Director

The Integrated Circuit Technology Laboratory resides in both Princeton and Somerville. Its role is to develop new semiconductor technologies and improve existing ones so as to make RCA competitive and profitable in the semiconductor business. Advanced technologies are developed and specialized variations, such as radiation hardening of MOS devices, are carried out for our G&CS divisions under government contract funding. These efforts nearly always lead to eventual product sales for SSD.

The following detailed descriptions of technology development reflect the joint efforts of both the Somerville and Princeton locations. In fact, many of the people have worked at both locations during the year. This interchange of personal is the most effective way of transferring new technologies.

Silicon-on-Sapphire Technology

With the introduction of SOS technology into the solid-state memory products area, work on SOS has shifted from introduction of a new business to product development, product support, and yield improvement.

In support of SSD's SOS/MOS product line a new five-transistor static 1024-bit random-access memory was designed and is being used with the bulk microprocessor.

A study of SOS/MOS device characteristics has led to new understanding of the role of substrate orientation. It has been shown that suitable performance is obtained only in two of the four possible quadrants of tilt from the major crystallographic axis.

Using high-voltage C(V) measurements, we have been able to show that changes in the surface state density of the silicon/sapphire interface have a profound effect on the performance of SOS devices. The technique allows us to analyze the contribution of each process step to the overall performance of the devices.

A new mask set for monitoring the key elements of SOS processing has been designed: we call it the Process Integrity Chip. Rather than examining the electrical properties of device and device-related structures as is done with the conventional process-control masks, this set of masks addresses the problems of manufacture from a statistical point. It is designed to provide information on the ability of the process to provide continuity and isolation where required. The mask set allows one to test, for example, the probability of obtaining n metal crossovers where n varies, in steps, from 400 to 4800. In principle, knowing the probability of performing each of the isolation/connection steps allows one to calculate an upper yield curve for this technology to directly attack the weakest process link.

Under contract to NBS, a more conventional mask set for the design, diagnosis, and manufacturing process control for SOS/MOS circuit elements has been designed. The master mask is divided into five basic subsections each of which addresses specific problems in the fabrication and design of SOS/MOS circuits. Many of the elements are unique and allow electrical and optical tests to be made rapidly during process development and production. Judicious application of these mask sets should provide the insight to realize the LSI potential of SOS.

Using a new vapor etching technique for sapphire substrates, an initial process has been developed for preparing SOS/MOS circuits that have a planar surface and stable devices. This development should allow SOS/MOS circuits to be fabricated at much higher packing densities by permitting narrower line widths and spacings to be used.

The use of positive corona discharge to determine the cleanliness of MOS oxides was shown to be useful production control technique. Demonstration of the method was made to SSD personnel at Findlay and Somerville, and a working version was delivered to Findlay.

The application of a negative corona to MOS oxides has resulted in a rapid, non-destructive way of testing various processing techniques for their radiation hardness. This technique speeds the development of radiation hard devices by eliminating the requirements for the use of expensive and slow radiation sources (e.g., SEM or Van de Graaff generators) in the initial development stages. It has yet to be made quantitative.

Metal Nitride Oxide Silicon Memory

Work on a 512-bit memory for Wright-Patterson led to the development of new, more sensitive sense amplifiers and to a new understanding of the operation of MNOS transistors in general. To answer the immediate marketplace needs, work has begun to produce PMOS/MNOS devices using bulk silicon. The initial circuits being designed in this project are intended for use in TV tuner circuits.

Charge-Coupled Devices

Analysis of buried-channel operation was continued and a computer program was developed for evaluation of the influence of fringing fields. Another program was developed for CCD design aid; it takes as input ion-implantation data such as energy and dose (including multiple implants) and prints out the potential well depth versus gate voltage. In addition, a uniform doping model, closed-form solution that includes signal charge level as a parameter was derived.

A new mode of operation for charge-coupled imagers was invented and tested. It consists of varying the available well size during the optical integration time. This results in an increase of the dynamic range and can be used for on-chip gamma correction with an improved signal-to-noise ratio over off-chip correction techniques, but at the expense of reduced sensitivity.

An IR CCD line imager, using Pd-silicide Schottky barriers as the detector elements, has been fabricated, operated, and characterized. Black-body sensitivity measurements indicated a peak quantum efficiency of 2% during CCD operation. Calculations showed that the charge-handling capability of the CCD in this mode is adequate for thermal imaging in the 3-5 μm band. A two-dimensional IR-CCD array has been designed. A number of novel techniques have been invented for extracting signals from X-Y charge injection arrays and a test chip has been designed to evaluate these concepts.

A CCD memory test array (TC-1136) was designed, fabricated using double poly Si P^+ gate construction, and successfully operated. It included novel high-density interlaced SPS loops, very narrow channel CCD registers, balanced latch charge detectors, binary charge splitters, and address decoding and recirculation logic. Based on the results obtained, a preliminary design was completed for a 65K-bit CCD memory chip. The chip will be 145 $\times$ 250 mils, fit in a standard 16-pin DIP, and operate at 200 mW power at a 5-MHz data rate. Standby power is 0.2 μW/bit.

A CCD-680 stage, 1-H delay line for television use was fabricated using buried-channel two-phase overlapping-gate technology. Performance evaluation showed that this chip meets, and often exceeds, color receiver and TV broadcast requirements.

Extensive life tests showed that the technology we developed for construction of these devices also meets the stability requirements, even in a plastic package. In the meantime, basic designs have been established for another 1-H delay line (TC-1187) that has clock drivers and other support circuitry on chip.

The luminance peaker/chroma trap chip (TC-1147, designed in 1974) was also built and evaluated in 1975. The device did not meet overall TV color receiver requirements, but the analog circuits performed well and proved the feasibility of performing these functions on-chip at the frequencies required.

The feasibility of combining buried-channel CCD's, CMOS drivers, and CMOS logic circuits on the same chip has been investigated. For this purpose, a chip (TC-1181) was laid out with a 13-bit Barker code filter and support circuits, including a novel input low-pass filter and new, improved floating-gate tap designs.

In the fall of 1975, the buried-channel CCD technology was transferred to SSTC Somerville, where CCD's for TV 1-H delay lines have been fabricated with performance characteristics that match those of devices fabricated in a research enrironment at DSRC. This work was done in collaboration with S. Graham and W. Kosonocky. Life tests with these devices are underway. The next phase of the program is the implementation of batch-fabrication and yield-improvement techniques.

This work has been expedited by the close communication and cooperation achieved between research (DSRC) and development (SSTC Somerville) personnel, which has been effected by relocation of the entire SSTC group for one year at DSRC followed by daily contact with S. Graham during the transfer to SSTC Somerville.

Accelerated life tests on buried-channel CCD's for TV 1H delay lines were successfully completed using 74 samples fabricated at DSRC.

Radiation Hardness

Improved understanding has been acquired concerning the nature of radiation-induced positive charge accumulation in SiO_2 MOS devices. Specifically, it has been established that hole trapping induces electron injection during irradiation. The number of hole traps was shown to be strongly dependent on the oxidation and anneal temperatures as well as the nature of the ambient gases. Photoconductivity experiments have provided evidence for geminate recombination in SiO_2. Vacuum-UV radiation results have shown that many holes trap within about 30 Å of the Si-SiO_2 interface and that some irreversible effects occur within the trap structure during irradiation.

A process has been established, documented, and transferred to SSTC Somerville for making radiation-resistant Si-Gate/Al_2O_3/CMOS/SOS circuits.

High-Speed Bipolar Technology

A new, very high performance, bipolar process, termed Bi-Max for advanced bipolar process for maximum performance, has been developed; it features self-alignment oxide-nitride masking coupled with non-reoxidized, ion-implanted base and emitter processing. This new process, first demonstrated in the third quarter of 1975, achieves transistor cutoff frequencies *(F_t)* of 4-5 GHz and permits transistor sizes of less than one-half that of prior state-of-the-art devices. A first technology demonstration vehicle, the TC1162 GHz counter, has been completed through first sample fabrication and evaluation. The design of a second demonstration part, the TC1171 Quad D-type Flip Flop, is also complete.

Integrated Injection Logic

A one-year program involving the analysis and characterization of I^2L within the constraints of standard bipolar processing has been completed. A firm qualitative and quantative design data base has been established and confirmed both experimentally and via computer simulation. Simple digital building-block circuits such as NAND gates, binary counters, decade counters, etc. have been fabricated and characterized. The packing density advantages of I^2L were demonstrated with circuits achieving densities greater than 170 gates/mm^2. Power/delay products of 0.1 to 1.0 picojoule were measured. Simple binary and decade counters were shown toggling at 204 MHz at power levels of 100 microwatts per gate. A comprehensive report has been issued detailing the results and conclusions of the I^2L study program.

C^2L Technology

C^2L Process Development: A novel high-speed, self-aligned silicon-gate bulk COS/MOS process was successfully introduced into the Findlay factory during 1975. This C^2L (Closed COS/MOS Logic) technology has typically 3-5 times higher performance than standard COS/MOS and is almost twice as dense. The business potential for such devices is large. Products scheduled include, among others, the 1802 microprocessor, 256-bit and 1024-bit memories, 4096-bit ROMS, and frequency synthesizers. A Signal Corps contract has been awarded to RCA to continue this successful development during 1976. This development will ensure that RCA has the highest performance bulk silicon technology in the industry.

C^2L 8-Bit Microprocessor (1802): A major undertaking during 1975 was the layout of a single chip, C^2L microprocessor. Working in this new technology, a complete layout of this 5400-transistor "random logic" circuit was prepared. The drawings for this undertaking were without error and samples delivered eight weeks ahead of the most optimistic schedule. Commercial announcement of this device is scheduled for first quarter 1976.

C^2L Memory Circuit Development: C^2L 256-bit and 1024-bit memory designs were successfully completed and tested in 1975 based on a novel memory organization. These low-cost devices have the fastest access time of any bulk CMOS device on the market and approach the speed performance of SOS designs. The 256-bit devices were sampled in 1975 and orders have been received by SSD for this type.

C^2L Linear COS/MOS: Linear COS/MOS development in 1975 continued with the goal of having a "kit" of six to eight linear COS/MOS parts suitable for commercial introduction in 1976. A technology-transfer program with SSD has been funded in 1976 for achieving this goal. Parts designed in this program are being used by RCA as the basis for bids in response to military RFQs.

NMOS Memory Development

During the second part of 1975 an intensive effort was organized in conjunction with the corresponding SSD product engineering department to develop TI type 4050 and 4060 equivalent memory parts. The process recommended and used now utilizes five mask levels (including SiO_2 scratch protect), polysilicon gates, two-level poly, and aluminum interconnect. A phosphosilicate layer is reflowed to obtain smoothing of the poly-silicon and field oxide edges. A novel dual implant process was developed that achieves higher speeds.

Surface Acoustic Wave Filters

Surface acoustic wave filters, designed by S. Perlman and J. McCusker of DSRC have been fabricated at SSTC by D. Alessandrini. The performance of these filters satisfies the complex requirements for TV i-f filters, but present designs are too large to be economically attractive for a commercial TV product. More than 300 of these filters have been supplied for evaluation. New designs are being developed to reduce chip size and improve yield.

3.5 Custom Monolithics

The role of the Custom Monolithics activity is to provide RCA equipment/systems divisions with a competitive edge. This is accomplished by making state-of-the-art custom LSI available on a quick-turnaround, high-reliability low-cost basis. Custom Monolithics provides components valued over $4 million per year to RCA divisions. The sales made by these divisions, based on these components, average more than ten times the value of the components. One example is the G&CS Tenley program where a $32 million system contract was won based on $2 million worth of components supplied by Custom Monolithics.

During the year, 94 new complex LSI arrays were designed and tooled. This total represents support provided to most of the MOU's of the Corporation in providing complex LSI design capability on a quick-turnaround basis. Other designs are supplied by our customers; e.g., the Tenley circuits. To provide quick turnaround, many of the designs were implemented using either the Universal Array family or the APAR (automatic placement and routing) techniques. To provide flexibility for systems designers in the extent to which they become involved in complex LSI designs, interfacing can be at one of several levels: logic diagram, array layout, artwork tape, or artwork. The array designs implemented in 1975 represent support provided for many end activities, both commercial and military.

Deliveries continued in 1975 of the TA6993 CMOS sync generator for use in light-weight portable TV cameras. The TCC 051-609 universal array was designed for the subminiature TV camera. A mask programmable ROM with 100-ns access time was developed in the manufacturing-methods program. Two SOS universal array designs were used to implement ranging and display logic for a laser range finder application at ASD Burlington. A complex custom array using the high-density LSI process was developed for Nippondenso. A 128-bit shift register was designed for Tenley for static low-power operation. This array is being used to replace a design by another supplier.

In addition to the above, a C^2L universal array family consisting of 168–, 276–, and 410-gate arrays was developed. These arrays will have greater density and higher performance than their standard metal-gate counterparts. Also, a C^2L APAR cell library was developed for use with the MP2D (multiport) automatic placement and routing program. Higher density and improved performance are projected for arrays designed with this approach as compared to the conventional metal-gate PR2D approach.

During the year some 850 new step-and-repeat masters were prepared and over 25,250 contact prints were delivered. The gross value of this effort was greater than $600,000 — an increase of $100,000 over 1974.

The pilot line successfully processed wafers for 84 completely new artwork designs in addition to a larger number of previously designed arrays. The LSI arrays are generally larger than 200 by 200 mils in size with some arrays exceeding 300 by 300 mils. About 44,000 packaged arrays were delivered to customers in 1975.

The delivery of 5000 COS/MOS LSI arrays for the V phase of the Tenley program was completed. These arrays consisted of 39 types of APAR arrays designed by G&CS engineers. The successful completion of the V phase was followed by the initiation of the E phase, which will require approximately 25,000 LSI arrays.

Several CD4000 series arrays were fabricated with dry oxides. These arrays exhibited radiation tolerance in excess of 10^6 Rads (Si) and passed preliminary government tests for stability and reliability. A complete COS/MOS array also processed with dry oxide was delivered to and evaluated by Sandia Laboratories. The array proved very hard, withstanding 4×10^6 Rads (Si). A triple-implant process developed by DSRC has been successfully used in conjunction with the dry-oxide technology to optimize the radiation hardness of Si-gate CMOS/SOS circuits. Total-dose hardness in excess of 5×10^5 Rads (Si) has been demonstrated.

Samples from 11 lots (159 arrays) of the CMOS/SOS 7-stage binary counters were put on life test at 125°C with 10 volts applied. No failures were encountered in the first 2000 hours. The CMOS/SOS pilot line is now operating at a rate of 100 2-inch-wafer starts per week.

Eight complex CMOS/SOS custom array types have been successfully produced for NASA's SUMC (Space Ultra-reliable Modular Computer) Program. These arrays were designed using the APAR (Automatic Placing and Routing) technique by the Advanced Technology Laboratories. The average chip size is 35,000 square mils, the smallest being 134×155 mils (includes 570 transistors) and the largest is 229×229 mils (contains 1604 transistors).

4. Information Sciences

J. A. Rajchman, Staff Vice President

Acoustic Imaging

In 1975 the great potential of diagnostic medical imaging instruments was vividly demonstrated by the spectacular success of computerized x-ray scanners that reached sales of over $100 million. Very significantly also, the sales of conventional ultrasound imaging systems was twice that of 1974, reaching $25 million. Totally harmless and non-invasive, this first generation of ultrasonic devices is already of great benefit, particularly in studying pregnancy and heart ailments. These facts confirm our previous convictions that there is a further much greater potential for ultrasound instruments capable of higher resolution and capable of localized quantitative measurements of tissue characteristics that will complement or supplant x-ray diagnostic machines. A market of several hundred millions in a few years can easily develop.

Our exploratory program, aimed at this potential, was highlighted by progress in three technical areas:

1. In ultrasonovision, our unique instrument for the visualization and measurement of wavefronts, we made larger(6″) and more conveniently usable instruments and also two basic improvements. One was the first demonstration of phase-contrast imaging ever made in acoustics, a technique that may be of great utility for differentiating tissues and their state of health. The other was the concept of a stabilization of the Michelson interferometer based on the use of two beams with a quarter-wave shift that eliminates the wiggling mirror used previously and permits more rapid and sensitive operation.

2. We invented and demonstrated large-aperture clinical instruments of very high resolution and capable of exploring the entire body. One is purely electronic and uses a simple matrix of transducers obtained on a slab of PZT by painting conducting parallel lines orthogonally to each other on the two sides. Another uses a mechanical scan to provide an instrument of utter simplicity. By the end of 1976 we expect both to demonstrate clinical usefulness.

3. Considerable progress has been made toward the realization of our original concept of an annular array instrument.

In addition, our position and reputation with pertinent government agencies and research institutes has greatly advanced. We have contracts with NSF, the Army

Medical R&D Directorate, and the Bureau of Radiological Health, a branch of the Food & Drug Administration. We have good expectation of winning on a bid that we have submitted in cooperation with Sloan-Kettering to the National Cancer Institute for comprehensive research in ultrasonic diagnosis of cancer.

Overseas Laboratories

In 1975 the shift toward applied work continued in the Zurich and Tokyo Research Laboratories.

In Zurich a significant change in that direction was the start of a project for optical testing of silicon wafers during processing. Aimed at improving manufacturing yields, the project is timely for Somerville and capitalizes on the optical and semiconductor know-how in Zurich. The project showed real promise early in the year and effort was doubled at mid-year. Short regular assignments of Zurich staff to the U.S. and vice versa were established to provide working couplings. Also in 1975 there was major progress in the zero-order-diffraction (ZOD) microfiche that provides low-cost embossable black-and-white as well as color fiche fully compatible with conventional projectors. The compatibility, as well as the high efficiency and quality of the ZOD microfiche, gives it an important commercial potential, particularly since the present microfiche business is in a period of rapid growth.

In Tokyo, the shift to applied work of preceding years brought about many interesting projects. E. O. Johnson, who took over the direction from B. Hershenov in mid-year, is planning to consolidate efforts in the few most promising ones. During 1975 noteworthy results were obtained with penetration-type cathodoluminescent phosphors, latex displays, photocatalytic solar cells, and several other projects.

4.1 Laboratories RCA Ltd., Zurich

W. J. Merz, Director

The research program of Laboratories RCA Ltd consists of five projects: Synthesis and Evaluation of Materials; Optical Studies for Silicon Device Processing; Electronic Information Recording, Storage and Display, inclusive of Electrophotography; Holography and Plastic Optics; and Optical Studies of Solids. In addition, the laboratory is engaged in consulting about new scientific and technical developments in European industrial and university laboratories.

One of the main concerns is still to maintain close coupling with Princeton and other RCA groups, including in particular the Solid State Technology Center at Somerville and the Electronic Components division at Lancaster.

In the materials activity we have refined the preparation process of various transparent electrically conducting films to be used in electro-optical devices (vidicons, liquid-crystal displays), selective filters for solar energy conversion, and photomasks. Quite a bit of effort was put into the preparation of high-quality CdSe films by chemical vapor transport and sputtering to be used in the electrophotographic project. Thin single-crystal films of $LiNbO_3$ for electro-optical applications have been prepared. Single crystals of the following materials have been grown: CaS as a host material for high efficiency cathodoluminescent phosphors; $Bi_{12}SiO_{20}$ for the study of the optical properties of two-dimensional systems; and (Ge,Sn)Te for the study of ferroelectric phase transitions. During the last few months of 1975 a very active program in preparing high-quality gratings (parallel and crossed) with grating constants as low as 1.4 μm to be used in the microfiche project was started. The methods applied are sputtering, desputtering, evaporation, and electroplating. Very encouraging results have been obtained without which the microfiche project could not have attained its present excellent performance.

A project in developing optical methods that allow testing of Si wafers during processing was started in 1975. The aim is to improve the yield and to eliminate failure modes in the Si integrated-circuit manufacturing. The methods developed will allow measurements of etch depths, undercutting, doping concentration, junction depth, epi thickness, and carrier lifetime without touching the wafers. The etch rate and undercutting problems can successfully be kept under tight control by observing the diffracted light from an optical grating that is located in a "knock-out" area in the center of the chip. The moment the grating is removed by the etchant the diffracted light beam becomes zero and the etching process is stopped automatically. The carrier concentration in Si can be measured optically by two methods. First by looking at the spectra of Raman scattered light and second by measuring the value of the refractive index. Reproducible results have been obtained with the first method; the second method is under evaluation.

Our electrophotographic system consisting of a highly sensitive photoconductive CdSe layer for detection and a well insulating foil for storage of the picture information has been developed to a point where the resolution is about 10 μm, the photographic speed 30-60 ASA, and the storage time at least several months. The picture information can be read out either by toner (hard copy) or by scanning with an electron beam or a light spot for display on TV. Experiments have been started to look into the possibility of video home recording on the

VideoDisc. Approaches analyzed are electrostatic charge pattern, piezoelectric induced deformations or changes, photoinduced deformations, and pressure-induced chemical changes. All these studies are of fundamental nature. The work on electroluminescence and electrochromism for display systems has been continued. No significant improvement in light output has been obtained yet.

The emphasis in diffraction optics (holography) continued to be on investigating techniques for recording, storage, and display of visual information, in particular with application to low-cost micropublishing systems such as black-and-white and color microfiche. First-order-diffraction microfiche shows good resolution, gray scale, and colors, but is restricted in light intensity and is not compatible with conventional projectors. A real breakthrough has been achieved with the new concept of zero-order-diffraction (on-axis) microfiche. Brightness is almost unlimited, gray scale is fine, and the color spectrum obtainable is comparable to those of color TV and Kodakchrome. The technique is based on the superposition of three mutually independent rectangular-groove gratings, which produce the three basic colors in a subtractive color scheme. Inexpensive copies are obtained by embossing the diffractive surface structure into a suitable plastic material. The main problem at the moment is to develop methods that allow perfect alignment of the three gratings or to develop methods of having all three or at least two of the gratings on one sheet. Significant progress has been made along this line with the help of the materials group. The performance of the zero-order-diffraction microfiche and its extremely low cost have made this project of potential commercial value.

The studies of optical properties of solids have been continued along three lines. First, two-dimensional materials like PbI_2, CdI_2, MoS_2 and one-dimensional materials like $K_2Pt(CN)_4Br_{0.3} \cdot 3H_2O$ have been studied in detail. The observed two dimensional effects in optical properties have become of great interest to solid-state physicists and have helped in the understanding of new classes of interesting materials. Second, the study of structural, ferroelectric or magnetic phase transitions by optical means (Raman and Brillouin scattering) has been continued on a number of materials ($K_2Pt(CN)_4Br_{0.3} \cdot 3H_2O$, SbSI, (GeSn)Te and others) which led to a better understanding of the phase transition mechanisms involved. Also acoustic sound velocity and sound attenuation measurements have been performed near the transition temperature for a number of interesting materials. Third, the luminescent properties of AgBr under extremely high excitation were further investigated. The model proposed earlier, namely a transition of the material by a Bose-Einstein condensation, has been strengthened by a number of experimental facts. This represents the first case of a Bose-Einstein condensation in a solid, a phenomenon that was predicted many years ago but never found.

4.2 RCA Research Laboratories, Inc., Tokyo

E. O. Johnson, Director

By the beginning of 1975 all work was applied and in the general area of RCA interest. In mid-year, E. O. Johnson replaced B. Hershenov as Director of the Laboratories and continued the program with few changes. The program includes devices for display, for storage, for energy conversion, and some for information processing, all emphasizing the use of non-single-crystal materials. Element costs of 10^{-1} cent, typical for single-crystal silicon devices, cannot be tolerated in these large-area devices; we are aiming at costs between 10^{-3} cent, typical of color kinescopes, and 10^{-7} cent, typical of VideoDisc.

One display device program, in cathodoluminescent phosphors is largely based on an aqueous solution technique that can controllably deposit thin and smooth phosphor layers for penetration-type kinescope screens. These are useful mostly for low-cost small-size tubes that may become popular in Japan and elsewhere. With the deposition techniques fairly well in hand, we have been primarily concerned with preventing color intermixing due to interdiffusion of the onion-skin layers during the post-bake process that anneals the phosphor grains. Intermediate onion-skin buffer layers of such materials as SiO_2 have shown promise. Another portion of the program is aimed at improving the green phosphors in conventional tubes, and is involved in the exploration of numerous promising borate-type materials.

A by-product of the phosphor research has been the discovery of photoluminescent glasses that emit visible light when activated by a UV lamp. Glasses that cover the visible color spectrum have been prepared with an efficiency as good as that of a good phosphor. Another by-product was the discovery that relatively low electric fields above a threshold switch Cd boracite crystals, and can leave them in non-zero remnant states.

Another display program involves a dispersion of micron-sized latex particles, each having an electric charge that is balanced by an equal and opposite charge of surrounding ions in a liquid solution. Depending upon charge balance and external force conditons, such as from an externally applied electric field, these particles can exist in either an ordered or disordered state. Optical effects much like those in conventional crystals are observed. During 1975 we greatly improved our ability to make particles of uniform size and behavior. Visual contrast in electric field-addressed sandwich-like display devices has been improved to nearly 10:1 by the use of segmented electrode structures that provide nonuniform fields across the particle suspensions. Switching speed has also been improved to a practical level of about 10^{-1} second. In comparison with liquid crystals, these devices promise

less critical processing, and a much wider operating temperature range, with the same power levels.

Another display program has been concerned with electrochemochromic-type displays wherein the passage of an electric current through an electrolyte causes the oxidation or reduction of dissolved chemical species with consequent change in their absorption of visible light of various wavelengths. We are now able to provide a variety of color effects, but so far all of these have suffered life-limiting, side-reaction, effects. Towards the end of 1975 a comparison of the optical efficiency of all known electrochemochromic reactions has shown them to be no higher than that of simple plating-type reactions.

Our exploratory information storage program started with the discovery during 1974 that it was possible to obtain a latent recording on a Cr-film-coated glass substrate with a laser beam of an intensity several fold below that required for evaporation. The latent picture is made visible by subsequent etching. During 1975 we tentatively explained this new effect, and found it not sensitive enough for disc-type information storage systems. In seeking other approaches, we developed a simple physical model of the energetics of information storage systems based upon electronic charges being moved from one stable energy valley to another over a potential hill. This model suggests that optimum information storage is obtained with all-electronic techniques. Also we became aware of a new piezoelectric polymer that is being developed in Japan for audio and mechanical strain applications and that we intend to evaluate in 1976. This material, polyvinylidene fluoride (PVF_2), is prepared by polarizing it by applying an electric field to it when it is mechanically stressed. The resulting piezoelectric effect is comparable to that in PZT ceramics. The material is available in a thin-film form that is inexpensive and easy to fabricate into a variety of interesting devices, particularly those based upon a bimorphytype of structure that converts low applied voltages and extremely small currents into low-mass, small-force, mechanical motion.

In another approach for the conversion of electronic signals into mechanical motion, we have explored ferroelectric domain-wall motion in $Gd_2(MoO_4)_3$ crystals and have obtained consistent motion control of the type useful for electronically controlled capacitor tuning in receivers. Though preferable to varactor capacitors, this ferroelectric capacitor is too expensive because it uses single crystals.

In the field of solar energy conversion, notable progress was made in understanding and demonstrating a photocatalytic cell that converts sunlight directly into hydrogen and oxygen gas that can be stored, transported, and reconverted into various forms of energy at some later time at the user's convenience. As a result of improved cell-contacting methods and impurity doping profiles, we have been able to demonstrate an energy-conversion efficiency that is about 80% of that theoretically possible (~5%) with the bandgap of the material (rutile) used in the cell.

Many problems remain to be overcome before practical use is possible. The most important of these is to find crystals, and eventually small crystallites, of a solution-resistant material with a more suitable bandgap, to provide energy conversion efficiencies at least as high as 10%. Our program seems to be moving faster than those of the relatively few others in this new field.

In the field of electronic information processing, one highlight during 1975 was the feasibility demonstration of a home instrument FM detection device and circuit based on the use of an acoustic wave (SAW) delay line made of single-crystal lithium niobate. It was carried out in a commercial FM receiver in a joint program with the Tokyo Engineering Laboratories. Performance was at least equivalent to that of good quality conventional commercial circuits using more cumbersome components. Less expensive PZT (polycrystal) material provided somewhat poorer electrical performance. Optimization of this approach is continuing.

In another, more fundamental project, we have made good progress in unraveling the optical properties of Co^{2+}-doped lithium niobate. Theoretically predicted strong optical rotation effects were observed experimentally and are of interest for optical communications.

5. Communications Research Laboratory

K. H. Powers, Director

The 1975 research program of the Communications Research Laboratory continued the efforts initiated in prior years in support of the communications businesses of RCA, especially the domestic satellite business of RCA Americom, and the television broadcast equipment business of the Commercial Communications Systems Division.

Much of the effort for RCA Globcom, RCA Alascom, and RCA Americom has involved close-in support of the engineering groups of those organizations, augmenting their ability to address problems requiring specialized skills in television and in systems analysis. The optical video recording and playback project initiated in 1973 has culminated in a crash joint project with Broadcast Systems to implement a feasibility model of a slide file system, representing a first potential product to utilize the new optical recording technology. This technology might possibly evolve into a new high-density recording medium for all broadcast television recording and playback apparatus.

In a midyear reorganization of the Laboratories, some of the exploratory research in optical technology and a new research program in solar energy became a part of the Communications Research Laboratory. As is consistent with our research planning strategy, we will continue to seek Government contract support for the higher risk exploratory research areas that do not have an immediate impact on RCA's current business, but can be expected to help provide new opportunities for RCA's electronics-based business in future years. At year-end, we received a notice of award of a sizable Government contract for a study of manufacturing methods for solar cell arrays.

Further details of the research program of the Communications Research Laboratory can be found in Quarterly Research Progress Reports and in various internal technical reports and memoranda.

Satellite Communications

Many new results and new signal-processing techniques were developed for application in the satellite communications business of RCA. Of particular note are new developments for television transmission by satellite as well as voice-grade and high-fidelity audio transmission. System trade-off studies have not only led to some advantageous modifications of the RCA SATCOM design but also have provided some guidelines for the specifications of future generation spacecraft systems.

1. Interface between a Satellite Earth Station and Terrestrial Microwave Systems

A project was initiated last year to develop a new technique for interfacing at i-f a single-carrier wideband FM satellite circuit with a narrower-band FM terrestrial microwave circuit without the need for demodulation to baseband and remodulation at the earth station. The technique of modulation-index multiplication and division by a factor of 3 was implemented in breadboard form emitter-coupled logic. The technique was shown to be feasible, but the detailed tests that would be required to evaluate its immunity to cross talk and other distortions have not yet been carried out. This effort has been deferred in favor of higher priority work until the need more clearly justifies a product development.

2. Television Transmission

On September 30, 1975, RCA inaugurated the service of television program distribution by satellite with the commencement of the Home Box Office (HBO) transmissions to CATV head ends. Prior to that time, RCA Laboratories personnel had worked closely with RCA Global and HBO engineers to determine the optimum technique for modulation and demodulation and to establish system and earth-station specifications. The terrestrial cable and microwave circuits between the HBO origination studio in Manhattan and the Valley Forge earth station as well as the earth station equipments themselves were carefully adjusted and measured against the established specifications. These adjustments permitted the first transmitted signals to provide top-quality TV pictures in the CATV systems participating. Test procedures were then developed to provide RCA Globcom operations personnel with detailed procedures to guarantee quality for all television distribution services.

The technique called "over deviation" for FM transmission of video was evaluated and optimized to permit the transmission of two television channels in a single satellite transponder with a modest degradation of picture quality from that achievable in a full one-channel transponder. A test of this technique over one of the transponders of SATCOM is planned for early 1976.

The same "overdeviation" technique with reduced deviation permits the transmission of a quite acceptable television picture into a small earth station (e.g., 15-ft antenna, 190° LNA) of the sort planned for installation in the small Alaskan villages. In this case, however, the full power of the transponder is required even though only half its bandwidth is utilized. A satellite test of the quality of this technique is also planned for early 1976.

3. Audio Transmission

An evaluation of several digital encoding techniques for the transmission of telephone quality audio on single-channel-per-carrier satellite transmission has been

made. It appears that an adaptive delta modulation technique at a rate of 40-56 kilobits per second will provide a high-quality telephone transmission link for private line voice circuits and have good flexibility for the multiplexing of low-bit-rate data. Subjective tests have been carried out to establish subjective equivalences of bit rate and bit error rate with signal-to-noise ratio in FM systems. These tests should permit cost trade-offs to be made between digital and analog SCPC techniques as an aid in the specification of equipments to be installed in private corporate telecommunications network demand assignment service.

Similar subjective tests have been made for digital high-fidelity transmission to evaluate the cost effectiveness of digital techniques for the networking of radio and high-fidelity stereophonic music services. It appears that a bit rate of about 250 kilobits per second is required to achieve broadcast quality high fidelity with a 15-kHz bandwidth. At this rate a fair number (10 or so) of high-fidelity channels could be packed into a single transponder for networking to small (15-ft-diameter or less) receive-only earth stations. Of course, the question of whether small receive-only earth stations will be licensed in the U.S. in the 4-6 GHz bands is not yet settled.

4. Satellite Communication System Studies

A number of system trade-off studies have been carried out to provide quick answers to specific questions that have been raised in connection with spacecraft design and system configurations. Much effort was devoted to such questions relating to the Alaskan bush telephone service and to what is the optimum satellite design for small earth station operation in Alaska. As a result of one such study, the gain of two of the transponders in SATCOM F1 were increased by about 4 dB to reduce the required HPA power in the small earth stations for the Alaskan bush. A similar study showed that an increase in the power of the spacecraft transponders from 5 watts to about 13 watts would be advantageous in the Alaskan service but not sufficiently to justify a very major modification of SATCOM. However, a slight increase in EIRP for Alaskan service could be achieved by repositioning one reflector on SATCOM F2 to provide increased EIRP on six transponders. This modification is being made.

A computerized simulation model is being developed jointly with the Operations Research group to simulate the behavior of the SATCOM business given a set of input decision parameters. The SATCOM Business Model will encompass the marketing, systems engineering, operations, and finance segments of the business. This model will be used to analyze alternatives and trade-offs by determining predicted results and their probability distributions for any set of policy decisions. It is expected that the SATCOM Business Model will be turned over to Globcom for use by mid-1976.

5. Multiple Access Transponder Utilization

A general study has been initiated to determine the best methods of multiple access (TDMA, FDMA, DAMA) to achieve maximum transponder utilization in future services.

Broadcast Systems

Work continued in 1975 on the possible application of optical recording technology to the broadcast studio recording and playback applications. Because of the potentially higher packing density possible from optical recording as compared with magnetic recording, the optical technology appears promising as a new medium that can combine into a single unit the functions now performed by the reel-to-reel tape recorder, the cartridge tape system (for 3-5 minute segments) and the slide file. It appears that a disc machine configured somewhat like a jukebox would permit the scheduling and computer control of all of the pre-recorded segments of the broadcast day.

A fairly exhaustive examination of a large number of potential recording materials for laser ablation on the surface of a disc have been evaluated. Both metals and organic dyes have been evaluated. SEM studies of the metal films showed that metals melt and pull back from the hole leaving melted material in a ring around the hole. On the other hand, the organic dyes appear to sublime leaving no material around the hole. These dyes have produced considerably higher signal-to-noise ratios than the metals. The most promising system thus far appears to be a thin metallic layer overcoated by an organic dye material. The laser beam burns away a spot in the dye leaving a clean hole into which the underlying metallic layer can reflect the light with high contrast ratio on playback. Work will continue to find a material having a sufficiently hard surface that it can be readily handled; at the same time, recording on thin and flexible substrates will be evaluated. A crash effort with the Broadcast Systems group was initiated about mid-year to implement a feasibility model of a slide-file system that might be a first product utilizing optical recording technology. The feasibility model contains a dye-coated flat glass disc, 14 inches in diameter, capable of storing fixed NTSC color-encoded images at a track density of 10,000 to the inch. The disc will rotate at 1800 rpm so that each track will play a full television frame in one revolution of the disc. Electromechanical systems for automatic focus and track access were designed. The system will include an interface to a GA minicomputer to access individual frames in accordance with either a single command from a terminal or a program time schedule. The feasibility model slide-file system is expected to be ready for demonstration at the NAB Show in March 1976.

Digital TV

The project for digital television proceeded at a reduced pace in 1975 because of the need to allocate the manpower resources to some shorter-term, urgent applications. Two members of the technical staff were sent to Camden to participate with Broadcast Systems in the development of a digital time-base corrector and a digital frame synchronizer. In addition, some of the effort devoted to digital TV was diverted to develop the preferred techniques for FM transmission of television by satellite. In spite of these diversions, measurable progress was made in the digital television project. Improvements in the analog-to-digital converter equipments and the design and construction of a *(sinx/x)* equalizer improved the quality of the basic A/D and D/A conversion systems. In addition, experimental data compression equipments were built to evaluate coarse-fine encoding techniques. The 6-4 system, which converts a 6-bit-per-sample digital signal into 4 bits per sample, did not show adequate quality for broadcast applications. On the other hand, the 8-5 system, which compresses an 8-bit-per-sample signal into 5 bits per sample, comes very close to the required quality if previous line information is used in the prediction process. With improvements in the prediction algorithm and in the encoding scheme, we hope to find an 8-4 system with adequate quality to consider for broadcast applications while achieving a 2:1 compression factor. Work will continue in data compression in 1976. This project should provide the basis for the introduction of digital LSI techniques in several TV broadcast equipment applications.

Telecommunications

Work continued in 1975 to support implementation of the digiplex system to interconnect the Princeton area computer terminals with the Corporate computer center at Cherry Hill. Consulting assistance to Corporate Telecommunications and Corporate Information Services in implementing current and future corporate data communications requirements has continued.

The study of dispersity routing was completed in 1975. Dispersity routing reduces the mean and the variance of the network delay and decreases the sensitivity of the delay to changes in link utilization, thus allowing a network to continue operating after a link or node failure has occurred. A report describing the advantages of dispersity routing was issued.

The storage and scan conversion system developed to assist in the automation of Dewline operations was completed. Transmitter and receiver terminals were shipped to RCA Service Company, Cherry Hill, for subsequent transportation to a Dewline site. On-site tests showed that the scan-conversion system could provide a remote display from a forward radar site. A technical report describing the equipment and its operation was issued.

Communication and Related System Technology

This section describes exploratory research in technology areas that have a longer-term potential impact on RCA's electronics-based businesses. Of particular note is work directed to optical communications and to solar-energy conversion. In accordance with our research strategy to seek contract support in our higher risk exploratory research, we have achieved government contract support for over half of this effort.

1. Solar-Cell Technology

Our program for the development of inexpensive photovoltaic solar cells is concerned primarily with devices that are based on silicon, either in the form of single-crystal material or in the form of amorphous material deposited on inexpensive substrates such as stainless steel.

In the area of single-crystal silicon solar cells, our program includes an extensive analysis of the applicability of existing semiconductor manufacturing technology to the manufacture of solar cells. Present silicon solar cells are a factor of 100 too expensive to represent an economic alternative to oil or coal-fired power stations. The purpose of this analysis is twofold: (1) to identify those areas that could be effectively cost reduced by the required factor using existing technology; and (2) determine areas where technological developments will have to take place before such cost reductions can be realized and to evaluate the likelihood of these developments. Up to the present time, solar-cell manufacturing has not taken advantage of automation techniques that are becoming important in the semiconductor manufacturing art. However, automation itself costs money and because of the distributed nature of the incoming solar energy, vast quantities of material must be handled. Therefore, simple automation of existing manufacturing techniques will not result in savings sufficient to make solar cells economically feasible. We are therefore evaluating several cell-design alternatives, each of which is simpler than the conventional silicon solar cell. The most interesting of these at present is the amorphous silicon Schottky-barrier solar cell developed by RCA.

These amorphous cells are deposited in thickness of 1 μm on, for example, stainless steel. In contrast to crystalline silicon devices, these solar cells can be made very thin because the optical absorption is high; furthermore the devices can be deposited on very inexpensive materials. Even at this early stage of our program, a power conversion efficiency of 4% has been achieved (compared to 12% for single-crystal cells). Because the substrate materials are inexpensive and so little silicon is used, these devices are already close to the required cost goals. An increase of a factor of two in performance will reduce the area required for a given power output to levels that are considered tolerable. Such an improvement is expected within the coming year.

In last year's report, we described work on volume holographic storage in Fe-doped $LiNbO_3$ where we had permanently stored more than 500 independent h holograms with a minimum diffraction efficiency of 2.5%. In 1975 we studied the effect of these large information storage densities on the signal-to-noise ratio of the stored information.

Noise sources intrinsic to volume phase holograms in iron-doped $LiNbO_3$ have been investigated. Intermodulation distortion, statistical noise, and scatter noise have been found to be insignificant. Cross-talk noise can be reduced to a level compatible with high-quality (S/N ratio ~40 dB) readout images at angular spacings (0.1° in air) such that large numbers of holograms can be stored in a given volume. Light-induced optical scattering during recording and readout can be reduced by proper choices of recording and readout techniques.

The development of an SiO_2 antireflection coating for $LiNbO_3$, which is stable during the heating cycles used for fixing and erasing holograms, has improved the readout image quality by eliminating multiple reflections in the crystal.

The Triode Optical Gate (TOG) liquid-crystal electro-optic device, first described in the 1974 Annual Report, has been under development as a basic element for dynamic image display. Such displays could range in sophistication from alphanumeric indicators to television. They would contain numerous TOG devices on a common substrate, and could be produced by processes now used in integrated-circuit manufacture. Previous liquid-crystal technology has lacked the speed, gray scale, and multiplexing capabilities for many such applications. The work on TOG devices has shown that in many cases these handicaps can be overcome by the use of three-terminal devices that control both the direction and magnitude of the electric fields applied to the liquid crystal.

Operation of individual TOG devices at TV frame rates has been accomplished. The key element is the use of an erase operation at the start of each frame. This removes all previous optical response and allows each frame cycle to come to its appropriate intensity level independently of whatever happened in previous frames. The gray-scale level is determined either by modulating the drive voltage or by use of a partial erase operation.

A wide variety of thin films can be produced by glow-discharge deposition, and several active programs are in progress in these laboratories, including the preparation of polymer films for record coatings and silicon solar cells. The properties of films prepared by glow discharges depend on many parameters because the reactions occur in a high energy, nonequilibrium plasma. Therefore, techniques to determine the chemical species present, to monitor, and perhaps control the

reactions, are very desirable. Analysis of the spectra of the glow itself is one such technique and is a rich source of information. Accordingly, we have begun to study the UV-visible emission spectra of various glow discharges currently used for film deposition.

We are now engaged in assembling a research facility that will be capable of high-resolution, time-resolved, UV-visible spectral measurements of various glow-discharge configurations. The emission from the glow of pure gas discharges as a function of pressure and magnetic field will be studied first, followed by studies of mixtures. The initial emphasis will be to identify species present in the gas phase and to seek correlations between the plasma composition and the composition and structure of the film deposits.

3. Optical Communications

We have made an initial demonstration of grating coupling between LNT film waveguides and optical fibers. As mentioned briefly in the 1974 Annual Report, effective couplers between the waveguide electro-optic switches we have already developed and optical fibers are an essential and heretofore missing element in realizing advanced fiber-optic communication and data systems. The difficulty is twofold. Both the large refractive index differences between the planar waveguide modulators and the optical fibers and the difference in symmetry between the guiding systems must be overcome. Our approach involves the use of gratings, ion etched into the surface of the LNT guide, that serve to overcome the refractive index difference and shape the coupled beams. The core of the fiber is embossed and directly bonded on the grating to complete the coupler. This method is consistent with the planar geometry concept and should eventually be relatively cheap to manufacture. In addition, couplers may be made to either single or multimode fibers. Our results demonstrate that the principle of operation is valid, although the observed coupling of 6% requires improvement. Some of the effects that degrade coupling efficiency have been identified and we are working to complete our understanding of the fabrication requirements and demonstrate the theoretically predicted 90% coupling.

We have also made a first demonstration of stripe-guide switching using the simple LNT fabrication technique described in last year's report. Here too, our observations establish that the principle of operation of the LNT stripe guide (coupling) switch is correct, but further improvements are required in fabrication to realize the expected operation at 2.0 V, requiring powers on the order of 10 μW/MHz. The stripe-guide switch may also be coupled to fibers using gratings. Here, however, because the stripe guides transmit only a single waveguide mode, coupling must be made to single-mode fibers. These switches are, therefore, most suitable for very high data rate applications.

6. Process and Applied Materials Research Laboratory

P. Rappaport, Director

During 1975, the major effort of the Process and Applied Materials Research Laboratory was directed toward development of a commercially viable VideoDisc system. Work continued from last year on refinement of the electron beam recorder (EBDR) for real-time recording. Also, equipment using a laser-beam recording system was developed and demonstrated. Major advances were achieved in the recording system, in disc materials, coatings and lubricants for the disc, and in the playback system. In the Materials Applied Synthesis group, emphasis was on the development of single-crystal sapphire and silicon ribbons. Work in this area is directed toward a major reduction in the complexity and, therefore, the cost of processing integrated circuits and in the potential of silicon solar cells as a major energy source. The Organic Materials and Devices Research group made significant advances in the development of optical recording media for thick-film holograms, in improving kinescope shadow masks, in classification of plastics for television cabinets (in terms of flame retardance and toxicity), and in the improvement of liquid-crystal devices. The Process Research Group, working closely with the appropriate divisions, directed itself toward analyzing and developing process techniques for integrated-circuit fabrication for the Solid State Division, printed-circuit-board manufacturing and soldering processes for Consumer Electronics, and phosphor-screen printing and mask etching for the Picture Tube Division. Of particular importance was the cooperative program setup between the Systems Research Laboratory, the Organic Materials Research Group, and the Process Research Group on all aspects of TV receiver safety. This is coordinated by the Safety and Reliability Center in Indianapolis and provides assistance to CE Engineering, Manufacturing, and Quality Control. Last, the Materials Characterization group continued to provide advanced analytical determination of materials for various Laboratories' programs and for the product divisions.

The results achieved in these five areas of Laboratories effort are described more fully in the following sections.

RCA SelectaVision VideoDisc

1. Mastering

A major effort was applied to the RCA VideoDisc to ensure that it would be recognized as a viable consumer product at the earliest possible time. Real-time recording capability, considered to be a necessary factor for an economically justifiable

system, was demonstrated. Three real-time electron-beam disc recorders were built in Princeton, two of which were sent to Indianapolis. Recording is accomplished through an electron-beam-sensitive material, the RCA Mark II', which had earlier been developed at the Laboratories and for which a patent was issued in 1975. The Video Slowdown Data Processor (VSDP) developed by the Laboratories to permit the use of either film or quadraplex tape as source material for VideoDisc at slower than real-time recording speed was transferred to Indianapolis and set up for mastering purposes there.

Systems standards for a VideoDisc system suitable for use with European television receivers (either PAL or SECAM) were established. A number or recordings were mastered at real time, demonstrating feasibility of this system.

Equipment for mastering discs at real-time exposure with a laser beam was developed and demonstrated. While the discs are not yet the same quality as those mastered with the EBDR, there are good prospects for further improvements. Optical recording has the advantage that operation in a vacuum is not required.

2. Processing

An optical defect detector was designed, built, and delivered to Indianapolis. This device uses a laser to scan across a disc surface (either EBSM master, metal master, mold, stamper, or finished record) and detect imperfections that cause anomalous dispersion of the beam. Through the use of this device, discs can be examined more completely in a matter of minutes. It has already been found to be of great importance to the Indianapolis mastering facility.

Laboratory systems were set up that simulate conditions that exist in the autocoater for deposition of metals, dielectrics, and lubricants. These were used for studies in the selection of better disc coating materials and the optimization of the procedures by which they are applied. One such material was the tri-metal coating, which solved adhesion problems of dielectrics deposited at low pressure, but later has shown signs of contributing to coating degradation with age.

A study of the thermal distortion of disc molding materials resulted in the recommendation for the use of vinyl chloride homopolymer in order that discs could withstand the required 130° F storage conditions.

A study of glow discharge polymerization mechanisms has resulted in a more thorough understanding of this process and has identified alternative starting monomers that will provide dielectric coatings of improved characteristics. Alternative lubricants that are expected to provide improved VideoDisc performance have been identified (i.e., better disc and stylus life and reduced incidence of dropouts and virus). These lubricants are compatible with the production autocoater.

Analytical techniques have been developed to more completely characterize the disc coatings by measuring oil thickness, coating hardness, adhesion, and durability; changes in dielectric properties; and the chemical nature of the coatings and of the disc substrate.

3. Playback

A new stylus, stylus arm, and cartridge were developed for use in the EM3 player that gives arm stretcher performance 10 dB better than earlier pickup designs. The low-mass spring-loaded stylus and arm provide better tracking capability, especially at the outside of the disc where disc warp is most bothersome. A separate strip-line UHF resonator was designed for use with the EM3 stylus. It provides more reproducible performance than the EM2 resonant arm as well as simplifying the design.

A study of the various trade-offs between frequency response and S/N resulted in the adoption of CCIR-type pre- and de-emphasis for recording and playback to optimize the quality of the reproduced picture. Circuitry was developed, using sample-and-hold techniques, that reduced significantly the tics and pops in the audio recovered from the disc.

Equipment for growing sapphire rod suitable for making styli was improved and made operational, so that all sapphire rod currently required by Indianapolis could be produced in Princeton. More uniform rods are now being grown with a smaller cross section than used earlier, resulting in lower weight and faster fabrication. Other stylus materials and fabrication techniques continue to be explored.

The possibility of making styli from diamond, to provide longer life, has been pursued by the purchase of sample styli from both domestic and foreign vendors, by an in-house effort to make styli, and by the use of chemical vapor-deposition techniques to apply electrodes to the diamond styli. It is possible that diamond styli will have life equal to the life of the player or, if a harder and rougher disc coating is used, that diamond will give acceptable stylus life.

Equipment was developed for the readout of VideoDisc signals by optical means. Using a helium-neon laser and novel optical processing techniques, VideoDisc signals with wavelengths of the same order as those of the laser light have been successfully read from flat recorded masters. Standard replicas or discs could be read if they could be kept flat or if a dynamic focusing system were used. This equipment (now under development) will be used in the Indianapolis mastering facility for rapid evaluation of the quality of their masters.

A disc/stylus wear test facility was set up to evaluate various disc and stylus configurations. A special team of operators has been assigned to run this facility, which was set up in June, and reports have been issued weekly.

Materials Applied Synthesis

Edge-defined film-fed grown sapphire that can be used as a substrate for heteroepitaxial grown silicon will reduce the cost of cutting silicon wafers from a boule. Yields of sapphire ribbon with acceptable silicon semiconducting properties have reached 86%. This silicon is grown in a commercial reactor using a fast/slow "burst" technique giving 0.6 μm ± 5% thick layers, which is presently the best thickness control in the industry. The surfaces of the sapphire are still too rough for standard processing of devices, and efforts are directed to obtaining a smoother surface in a 3-inch ribbon that can be cut into square wafers.

If silicon itself can be grown in ribbon geometry, the expense and waste of cutting wafers from boules can be eliminated. The problem has been the contamination of the silicon by the reaction between the wetted die defining the ribbon and the silicon. Non-wetting dies are being investigated and currently give good 20-mil ribbon. Efforts are being made to reduce the ribbon thickness to make the process more compatible for direct device fabrication.

In the area of miscellaneous new materials, rectangular-cross-section single-crystal sapphire rod for VideoDisc styli is being grown by a floating zone process using a CO_2 laser for energy input. If the correct cross section can be achieved, less stress will be introduced in the styli during shaping, giving improved yield. A ferrite has been developed that has very low dB/dT and hysteresis loss for a prototype constant-voltage TV flyback transformer. This will replace the power-consuming constant-voltage line transformer now used in some TV receiver designs. The materials used for the substrate in photomultiplier dynodes has been limited to those which will give adequate secondary electron emission. A process has been developed for depositing GaP on stainless steel permitting simpler and lower cost dynode fabrication.

Organic Materials Devices

Improved liquid-crystal displays require precise alignment of the liquid-crystal materials to the substrate. Research during 1975 demonstrated that the needed alignment could be obtained by evaporating SiO_2 at an angle to the glass substrate. Glass treatment such as ion depletion and CVD layers have shown that new classes of liquid-crystal materials with lower voltages and broader temperature ranges can be used in soft glass cells. Both of these techniques have made the liquid-crystal digital display more efficient. Liquid-crystal materials themselves have also been improved. Analyzing transition temperatures and the enthalpies of fusion, compositions of a number of eutectic mixtures have been developed. This has led to the development of several materials with wider operating temperatures at 3-volt operation. For color

displays a number of azo dyes have been added to liquid-crystal materials to use in dye guest — host systems.

Thick phase holographic materials have been developed and additives have been devised to increase sensitivity. Ablative recording media have been investigated, and layers developed that give 50 dB S/N with 13-50 mJ/cm^2 exposure from an Ar laser.

Extensive studies were made of the water-soluble resists used for kinescope mask fabrication. It was found that by adding a dye to the resist, localized defects related to corrosion pits in the steel could be seen. A chemical treatment was found that largely eliminated them. Casein was investigated as a replacement for fish glue, and methods were developed to improve sensitivity, pot life, coating life, and etch resistance.

Assistance was provided to the Consumer Electronics Safety and Reliability Center in understanding the properties of new fire-retardant thermoplastic molding materials for TV receivers. These new materials alter the melt rheology and injection molding characteristics, as well as the final product mechanical properties. An analysis of available materials and a correlation between their molding properties and laboratory physical measurements were made. Their combustion products were also studied to permit selection of optimum starting materials and to provide vendors with information on our requirements. As part of this study, the toxicological effects of these combustion products were analyzed and contact made with those working in the field of toxicology who are attempting to establish standard methods for measuring the toxic effects of combustion.

Process Research

To improve IC reliability, an investigation was made of passivation coatings; it indicated that cracks and pinholes were a major factor in aluminum metal corrosion and threshold voltage variation. The quality of the chemically vapor-deposited phosphosilicate passivation glass was analyzed and techniques for depositing low-stress films were developed.

Thick-film conducting and insulating glass frit adhesion was studied, with Government support, to define those parameters critical to thick-film hybrid-circuit fabrication. A technique was developed for pre-glazing ceramic substrates followed by firing a frit-free conducting ink that provided better adhesion than commercially available inks.

Ion-implantation techniques were developed to improve breakdown voltage of junctions. Surface doping and low emitter concentration bipolar transistors were made that showed improved electrical characteristics. New high-current ion-doping

machines were investigated and studies in critical processing areas such as silicon vidicons have shown that ion implantation can produce superior devices.

Many studies were conducted to improve the Consumer Electronics semi-additive printed-circuit-board manufacturing process. An acid sulfate plating bath with organic levelers was proposed and tested that gave smoother, lower cost plating than the present pyrophosphate plating system. Many investigations were conducted to improve the printed-circuit-board soldering process. These included analysis of flux activators, which can contribute to surface contamination, improved solder control by defining contaminants, which can effect the integrity of a solder joint, and analysis of device failure due to defective materials. Much of this work was coordinated through the CE Soldering Improvement Program Committee. In conjunction with the Systems Research Laboratory, arc tracking of electrical insulators was studied extensively and assistance given to the Safety and Reliability Center in setting up arc tracking and other combustion-testing equipment.

Materials Characterization

Auger Electron Spectroscopy (AES) has provided a better understanding of the interactions of the various materials in the VideoDisc, such as the silicone oil, styrene dielectric layer, metalized layer and the polyvinyl chloride substrate, and a determination of their adhesion, corrosion and defect structure. Sapphire rods and VideoDisc styli are also being investigated by many of these techniques to determine crystal orientation, strain, defect density and composition, and the reasons for their failure.

In the general analytical problem-solving area, Auger Electron Spectroscopy has been used to study liquid crystals, bonding problems in power transistors, Schottky-barrier devices, linear IC's, secondary-electron-emitting dynodes, glasses, Au-Ni lead frames, and many other applications. Scanning Electron Microscopy continues to be a valuable analytical tool in such diverse areas as cathodoluminescence of III-V systems, studies of silicon solar cells, electron-beam lithography, thermoelectric elements, minority-carrier diffusion length, printed-circuit-board surfaces, and others. Optical spectroscopy, mainly in the IR region, is used in a variety of problems including granular semiconductors, liquid crystals, sapphire surface quality, printed-circuit-board coatings, fire-retardant coatings, and carbon and oxygen concentrations in silicon.

Construction and evaluation of our Secondary Ion Mass Spectrometry system using quadrupole focusing was completed in 1975, enabling us to carry out studies formerly contracted outside, and the surface profilometry facilities have been improved by setting up a second instrument. A high-pressure liquid chromatograph

was ordered for work on organic polymer problems such as additives to PVC, soldering flux, plating and etching resists, and others. An electron tunneling spectrometer has been built for optical identification of monolayers of molecular species on metal or semiconductor surfaces. For processing information from these analyses, a sophisticated program was developed that permits data to be presented via the computer in a suitable coordinate system. This program has been transferred from the Princeton NTSS facility to the Cherry Hill CMS system.

7. Materials Research Laboratory

J. J. Tietjen, Director

The major emphasis of the Materials Research Laboratory programs during 1975 has been in the areas of consumer displays and semiconductor devices. Our display programs include efforts on a large-area flat television system, and expanded program on kinescopes, and studies in theoretical electron optics. The semiconductor projects emphasize silicon materials and device technologies and include a minor commitment to III-V compound injection lasers. In addition, a small exploratory effort is devoted to developing and understanding granular materials. Both the injection-laser program and the granular-materials effort receive a substantial amount of government contract support. The highlights of the Materials Research Laboratory programs are summarized in the following text.

Flat Panel TV

During 1973 a new research effort was started to develop a large-area (30″ × 40″) flat panel TV (FPTV) display that would use available cathodoluminescent phosphors to produce a bright color display for consumer applications. Several types of area electron sources and video modulation schemes have since been studied in order to identify a single, most promising FPTV system. At the start of 1975, three distinct systems approaches remained as potentially successful candidates: (1) field emission, (2) feedback multipliers, and (3) guided electron beams. During 1975 these three approaches were analyzed in detail.

The field emission approach, based on a stamping and subsequent vacuum-forming technology to produce exceedingly sharp field-emitter tips, requires that the support structure also perform the function of analog video modulation and acceleration. A detailed analysis of the structural requirements indicated that several components had submicron dimensional tolerances, which we felt would make this approach prohibitively expensive. Consequently, it was abandoned at the end of 1975. Some of the resources for the program have been redirected to explore those aspects of field-emitter technology that might be beneficial in kinescope applications.

The feedback multiplier system uses the demonstrated ability of flat electron multipliers and ion feedback in low-pressure ambients ($\sim 10^{-5}$ Torr) to provide a controllable, self-sustaining line-electron source. This FPTV system would consist of some 640 identical insulating glass vanes, each 30″ long vertically and about 1-1½″ wide, extending from the cathode back plate to the phosphor-coated front

plate of the panel. Each strip is coated with 15-20 line electrodes to provide electron multiplication, control, and acceleration. Video modulation is achieved by means of feedback control of the anode (phosphor) current. This predominantly glass technology appears to be limited to approximately 1-mil tolerances throughout.

The guided-electron-beam system selected consists of 40 modules, each of which is 1 inch wide, 30 inches long, and 3½ inches high. Each module contains three electron guides that channel electrons from the cathodes, parallel to the baseplate until they are extracted and accelerated towards the phosphor screen. Electrostatic deflection is used in each 3½ inch high module to scan the beams after extraction across a 1-inch segment of each horizontal line.

Several types of electron guides have been developed and cathode injection and extraction requirements as well as focusing criteria have been studied. Most promising are "slalom" or "bar" guides, which use precision metal-etching technologies to provide precise registration and alignment. This system requires about 0.1-mil tolerances in various metal parts and approximately 1-mil registration with most glass parts.

Based on a critical evaluation of the technologies required to accommodate the latter two systems, we intend to select a single approach during the first quarter of 1976 and subsequently focus our efforts on demonstrating a prototype FPTV display by the end of 1976.

Kinescope Research

The kinescope research effort was expanded during 1975 to provide a relatively complete program that addresses virtually all aspects of phosphor technology, aperture mask fabrication, electron-gun design, and evaluation of advanced kinescope systems. These programs are strongly coupled to the engineering activity of the Picture Tube Division (PTD).

A major contribution of our phosphor program during 1975 was the development of an improved pigmented phosphor having greater compatibility with the screening procedures used in the PTD. With this new phosphor the pigment particles are more adherent to the core phosphor due to a new latex formulation. As a result, cross-contamination of the green phosphor has been essentially eliminated and this has increased light output. This technology has now been transferred to PTD engineering for factory implementation.

In collaboration with personnel from the PTD, we have developed improved casein photoresists for aperture-mask generation and have developed a better understanding of the factors affecting the stability of these photoresist systems. In

addition we have developed improved devices for measuring and inspecting aperture masks and associated artwork.

A new electron lensing system under development will have the capability of giving greatly improved television picture sharpness, particularly under high-brightness conditions. The new system will also offer the trade-off option of cost reductions through the use of a lower-voltage power supply and more inexpensive kinescope glass. The fundamental difference between the new lens system and the conventional type is the use of solid-state materials technology to produce a more gradual — and hence less aberrative — potential gradient in the main focusing lens. The observed increase in sharpness, as defined by the width of a displayed edge, is about 25% at moderately high brightnesses in the precision-in-line configuration. The new lenses have been tested in both demountable vacuum systems and kinescopes. Further development work is in progress, and improved gun systems are planned.

In a relatively recent development, a series of advanced kinescope projects were defined to provide a thorough evaluation of several potential alternatives to the present kinescope systems. These projects will include studies of flat-faced, beam-indexed, and focus-mask kinescopes, and systems having the potential either to reduce power consumption or provide styling advantages. It is intended that these evaluative studies be completed by the end of 1977 in order to provide guidance for the selection of kinescope systems to be developed for the 1980's.

Theoretical Electron Optics

A large effort in theoretical electron optics has been established to provide the Laboratory's programs in both flat panel and conventional television with crucial theoretical design capability. Using advanced computer simulation and analytical techniques, the electron trajectories can be determined with great accuracy, enabling designs to be set without the inefficient and painful process of selecting designs only after building a large number of configurations. During the past year, the program was able to establish preliminary designs for the three flat television options, and the compatibility of these designs with other systems constraints has been a crucial factor in evaluating these options. In addition, detailed analyses of various improved kinescope gun systems were performed, pointing the way to substantial improvements in performance. In 1976, the effort will analyze various alternatives to the conventional shadow mask kinescope, including the flat kinescope, beam-index and focus-mask systems.

Semiconductor Programs

The primary emphasis of our semiconductor programs is in improving the basic materials technologies that form the foundation for manufacturing semiconductor devices. Accordingly our projects span the gamut from developing new and improved methods for epitaxial synthesis to providing on-line monitoring of processing during manufacture. Most of these programs are closely coupled to the Solid State Division engineering activity, particularly in the case of Power and Electro-Optic Devices.

Transmission electron microscope studies of silicon-on-sapphire structures have revealed detailed information about the nature of the silicon film at the sapphire interface. It was definitely established for the first time that misfit dislocations and misordered domains are present in the layer at the substrate interface. These defects are most likely the cause of the poor electrical properties of the silicon in the interfacial region. As a result of these studies, a modified growth technique has been proposed to attempt to reduce the defect density at the silicon-sapphire interface. The modification consists of interrupting the growth to anneal the initial nuclei in order to develop a preferred orientation at the substrate interface.

A prototype of a new design in silicon epitaxial reactors was constructed and put on test during the year. This new design has been shown to reduce the power consumption by a factor of 6 to 8 over our present reactors. In addition, savings of chemicals are also anticipated. The other features of this reactor are its compactness and ability to be sized for any diameter silicon wafer. Tests to establish optimum growth conditions are presently being carried out.

A major focus of the silicon research effort was on improved technologies for increased device switching speeds, reliability, and manufacturing economies. In this regard, the use of platinum as a lifetime control dopant, with properties often superior to gold, has resulted; an improved high-conductivity trimetalization system was developed in conjunction with SSD; and planar thyristors and transistors with voltage capabilities in excess of 1700 V have been evolved. A process for producing large-area glass-passivated mesa transistors with outstanding high-temperature stability was developed and transferred to SSD. In the area of process control, a program for monitoring the epitaxial deposition processes by on-line data acquisition was initiated with Mountaintop facilities to improve the control over the structures grown. Because of the more effective use of the pellet area, there is an increasing trend to integrating power devices, particularly fast-switching ones. Theoretical and experimental work has resulted in improved design concepts for Darlington circuit chips, in a novel fast switching Darlington using a Schottky barrier turn-off diode, and in a transistor structure requiring only a simple process change to incorporate a Zener protection diode.

Under NASA and National Science Foundation sponsorship, we have also contributed to the development of new solar cell structures using epitaxial configurations. These have achieved the highest open-circuit voltages reported to date with silicon solar cells.

In the area of injection-laser developments, the focus of the research has been on developing reliable laser diodes using $Ga_{1-x}Al_xAs$ structures prepared by liquid-phase epitaxy. These devices have been designed for continuous room-temperature operation, and outstanding performance has been achieved. These lasers operate with an optical emission range extending from the visible (7400 Å) to the infrared (9000 Å). As a result, they are useful in fiber communications using glass, as well as in data recording and character recognition. A commercial cw laser diode (operating at approximately 8000 Å) was announced by SSD in 1975. This is the first such device on the market with proven reliability and results from using a novel passivation technique. Life tests to date indicate more than 13,000 hours of operation. The technology has been further extended for diodes specifically designed for optical communication systems that combine modulation capability to 200 MHz and radiance values far in excess of previous results.

In other injection laser related work, results obtained using vapor-phase growth has established that it is possible to grow laser structures with properties equivalent to GaAs-$Al_{1-x}Ga_xAs$ lasers in systems not containing Al. Specifically, we have grown GaAs-$In_{1-x}Ga_xP$ heterojunction lasers with threshold current densities below 1500 A/cm^2 at room temperature. In this work, we have shown that the principle of lattice matching is pre-eminent in establishing good laser properties and that the chemical heterogeneity of the system is not a strong factor in determining lasing. This then opens the way for preparing lasers from many other material systems, if desired.

Granular Metals

Granular metals and semiconductors constitute a new group of materials that have the potential for a variety of applications in which ordinary materials cannot be employed. Primarily developed at RCA Laboratories, these materials are two-phase mixtures of very fine metal or semiconductor particles embedded in an insulating matrix. The particles are so fine that they may contain as few as 100 atoms. During the past year, RCA Laboratories research on granular materials was highlighted in *Physics 1974*, an annual report of significant developments in physics issued by the American Physical Society to science writers and reporters. The materials are currently being employed in the advanced kinescope lenses described earlier in this section. Further applications in the areas of solar energy, flat-panel television, and varistors are also being examined.

8. Technical Services

R. E. Quinn, Director

Technological Services

Technological Services consists of three groups that provide assistance to the research staff in the areas of electronic device fabrication, precision processing, and instrumentation procurement and control. The responsibility for managing the Occupational Safety and Health programs for the Laboratories also lies with Technological Services.

Glass and Vacuum Technology, the first of these three groups, provides custom evaporated films on various substrates, silk screening services for construction of electronic devices, special glassware fabrication for experimental equipment, parts preparation and assembly services for evacuated bonding and packaging of integrated circuits, laser construction and alignment facilities along with other precision welding, brazing, firing, assembly and vacuum services as required by the research staff. During 1975, this activity devoted significant effort to supporting the flat panel, laser, integrated circuit, and III-V materials programs. Our work on developing a method of bonding metal foil to glass has made a very important contribution to the overall progress of the flat panel program. New rf sealing techniques, developed in this group, have not only simplified gas laser construction, but produce a more reliable product. Improvements in the techniques used in the assembling and evacuation of experimental vacuum devices has greatly reduced the time required to evaluate new device concepts on all Laboratories programs requiring this service.

During the last quarter of 1975, emphasis was placed on adapting the equipment and manpower of this group to accommodate the needs of our expanding kinescope program. Specifically, plans were formulated and initial steps taken to construct, equip and man a pilot plant for the complete fabrication of color picture tubes. This pilot plant will allow us to incorporate any experimental advances in screening techniques, new phosphors, electron-gun designs, or tube manufacturing techniques into finished color tubes which then may be thoroughly tested and evaluated. As a result, it is anticipated that the time required to transfer new technology to the manufacturing division will be significantly reduced.

Process Technology provides precision cutting, grinding, lapping and polishing services for the Laboratories. Electroplating and bulk chemical supply services are also provided. In addition, circuit artwork generation facilities, printed-circuit-board fabrication, and integrated circuit mask making services are available from this group. Major efforts during 1975 were also directed to supporting the VideoDisc,

sapphire ribbon growth, silicon materials processing, and integrated circuit processing programs. Significant improvements were made in the fabrication of sapphire styli for the VideoDisc system. All plating of VideoDisc masters was done in this area. A unique photolithographic process for producing VideoDisc labels was developed. Finishing techniques for sapphire ribbon have been devised and continue to be perfected within this group. Very precise grinding processes for glass parts needed in the flat panel program were developed and are now routinely applied in Process Technology.

A significant reapportionment of the resources of the Process Technology group is being made to react to the new requirements of the kinescope research effort. Diamond drilling techniques for the efficient fabrication of experimental ceramic gun parts have been developed; new equipment to photographically process artwork for kinescope shadow masks is being installed in this group, and unique metal shapes and precise apertures for electron gun parts are produced ultrasonically or with electronic discharge equipment. Artwork plotting facilities are being upgraded to accommodate kinescope requirements. The efforts of this group will be closely coordinated with the Glass and Vacuum Technology group, which bears primary responsibility for kinescope fabrication.

The Instrument Center, the third organization within Technological Services, is responsible for the procurement, distribution, and maintenance of all purchased instrumentation utilized in the Laboratories. It provides a pool of commonly used equipment that may be borrowed on short notice. All records on instrumentation are maintained in this group. Because of the restrictions on the availability of capital equipment in 1975, special efforts were made to ensure the timely repair of in-house instrumentation and to implement a new system of capital equipment procurement and disbursement. The unique capital equipment system essentially consists of an equipment rental scheme that offers the user financial benefits if equipment is returned to a pool. By discouraging personnel from tying up equipment unnecessarily, existing instrumentation is more efficiently utilized and significant overall Laboratories savings are realized. In the first year since implementation, the capital system appears to be very effective.

The Occupational Safety and Health programs are managed by the Safety Administrator through the Laboratories Safety Council. Safety and accident prevention programs are extensive, well established, and well maintained at the Laboratories, as reflected in our safety statistics. Nevertheless, constantly changing Federal legislation and Corporate policy require that a continuous effort be made to ensure the safety not only of employees but of all processes, technologies, and products developed at the research center. Our programs continue to be designed to meet these objectives.

Mechanical and Instrumentation Technology

The Mechanical and Instrumentation Technology group provides broad support to the Laboratories in areas of mechanical engineering, instrumentation, and electrical engineering. Frequently, new techniques are developed that are transferred to other divisions of RCA. Since most of the work is of a support nature, it is done in collaboration with the research staff and is covered elsewhere in this report. In some cases full responsibility for the design or instrumentation has been assumed by this group. Below are some of the projects being supported by the group.

Pick-up Arm Design, VideoDisc

A major redesign of the VideoDisc tone arm was completed during the year. The object of the change was to reduce picture flutter, stylus wear, and stylus bounce damage on the record surface, and to simplify the entire assembly. The picture flutter was caused by the inability of the old design to track extreme record warp. A large reduction in arm mass eliminated this problem. The stylus wear problem was traced to vibrations in the stylus arm. The arm mass changes and additional damping increased the stylus life four times on a given record surface. Record wear caused by stylus bouncing was greatly reduced because the mass loading of the stylus in the old design was changed to predominately spring-loaded stylus force. These changes were part of a total redesign package that included a new cartridge, the electrical interface to the cartridge, and a modular electromechanical arm lifter.

Recorders, VideoDisc

Work has continued on the new electron beam column that was designed exclusively for recording VideoDisc masters. Many refinements have been added, such as a new manipulator for gun centering, new aperture designs, and fixturing designs to produce a more accurate assembly. Bench testing has been completed and four columns have been built. They are being used on real-time recorders at Indianapolis.

Another electron beam column is in the early stages of development. This unit will employ a field emission source. Test models are being built.

The present recorders that have been in use for several years have been fitted with the new columns and have been otherwise refined. A dynamic focusing system has been added to reduce the extreme flatness requirements for the masters. A Faraday cup focusing system has been added to allow focusing of the master. All of the recorders have been converted to allow recording masters for European standards.

Design is continuing on a simplified electron beam recorder. In this recorder, most of the bearings, the motor drive, and the linear traverse system are relocated outside of the vacuum system. Operating models of the long travel linear seals for the traverse system have been built and are on test.

Optical VideoDisc

Several recorder and playback systems have been built to provide optical VideoDisc capabilities. They all employ the hydrostatic oil bearing used in the electron beam recorders. A strong effort has been placed on the method of driving the table to get very accurate speed control with little vibration. The most successful method has been to build the field and rotor of a standard hysteresis synchronous motor into the oil bearing assembly so that it becomes a direct drive motor. An optical playback system has been built around this bearing-motor drive system to check the audio and video quality of video masters in the factory before replicas are made.

An optical recorder has been built to record records that can be played back on standard VideoDisc players or the optical playback system.

Flat Panel TV Display

Work continued on the field-emission cathodes using the rolling and coining technique. Models have been built of a small section of the panel to check emission quality. This approach has now been abandoned in favor of two more-promising approaches: the guided beam system and the photomultiplier system. The major effort in these approaches has been in the design of the mechanical parts so that tolerances and thermal variations do not show up in color or focus changes in the picture. The designs involve very accurately made glass and sheet metal parts with a great deal of thermal analysis work.

Defect Detector, VideoDisc

A fast scan laser defect detector for masters had been built in the laboratory. The instrumentation group designed and built the digital turntable and optical head control servos, the optical focus and position servo, the fault signal processing, and the position display. The total packaged assembly also included responsibility for operator protection interlocks.

Optical VideoDisc, TV Studio

An optical VideoDisc system for television studio use was developed and demonstrated in Canada. Circuits for this system, involving color processing and the laser driver, were designed and built.

Photomask Defect Detector

The instrument group provides the indexing control and location display electronics for a production defect detector.

±10 Kilovolt Sweep Generator

For measurement of semiconductor interfaces near thick insulators, high voltages must be used. We designed and constructed a digitally controlled sweep that is very linear and can be stopped at any point in the sweep with indefinite holding time. Linear output amplifiers were also designed and built to provide ±200 volt and ±10 kV output. We also redesigned a protective coupling arrangement to accommodate the higher voltages while preventing damage to sensitive measuring instruments.

Capacitive Distance Measuring Instrument

Stability measurements of a thin (floppy) VideoDisc while rotating requires measurement of small displacements with high-speed response. We designed and built a capacitive distance sensor with 0.01″ working distance ±0.005″ range and 0.00001″ resolution and 50 kHz response. Several of these instruments have been built for use in the Laboratories and other RCA locations. Its replication cost is about ⅓ the cost of the nearest (poorer) commercial instrument.

Video Display for Ultrasonovision

Ultrasonic imaging is a potentially important medical diagnostic tool. A high-resolution holographic ultrasonic imaging system has been designed at RCA Laboratories. However, the picture is built up slowly, and flicker and fading are troublesome. We have designed and built a digital picture storage apparatus that presents a flicker-free high-resolution display that is comfortable to view.