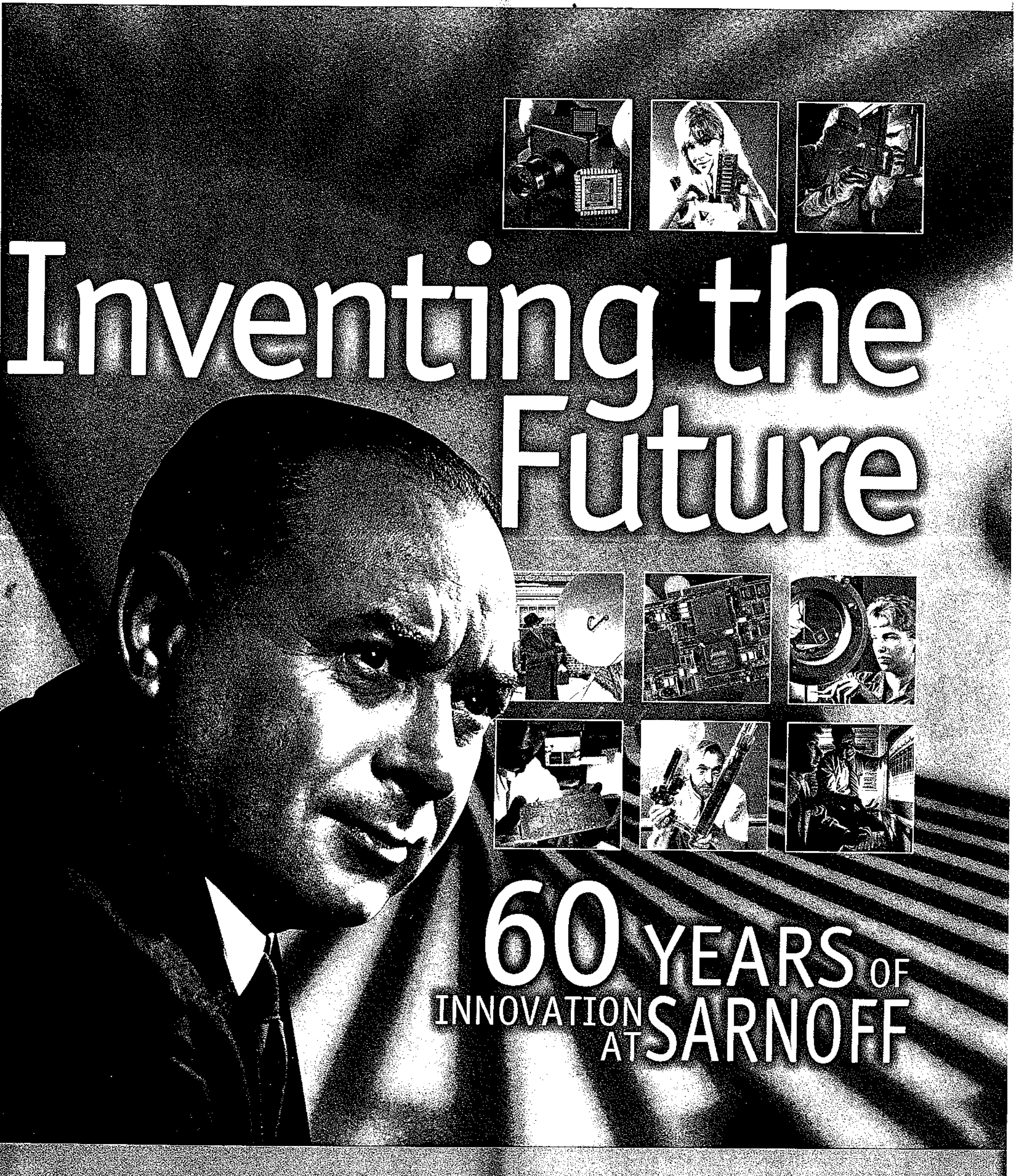
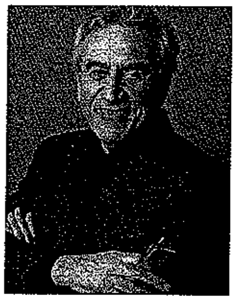

Inventing the Future
60 YEARS OF INNOVATION AT SARNOFF



Productive Science

Preface

Dr. Henry Kressel
Managing Director,
Warburg Pincus

Dr. Henry Kressel is a managing director at Warburg, Pincus & Co, LLC, a diversified venture capital firm. Prior to 1983 he was vice president at RCA Laboratories, responsible for worldwide R&D in optoelectronics, power devices, integrated circuits and associated software. Dr. Kressel holds 31 U.S. patents for electronic and optoelectronic devices, and pioneered the first practical semiconductor lasers. He was the founding president of the IEEE Laser and Electro-Optics Society (LEOS) and is a member of the National Academy of Engineering.

The achievements described in this book are testimony to the productivity of a unique organization, one that has mastered the art of creating industrial innovations and managing their commercial realization.

RCA Laboratories, the predecessor of Sarnoff Corporation, opened its doors in 1942. Its formation reflected David Sarnoff's total focus on building RCA around innovative electronic technologies.

The results surpassed even his expectations. During its first 45 years, when it was RCA's corporate research center, the Labs pioneered many of the innovations that comprise the foundation of our modern world infrastructure. As an independent company, Sarnoff Corporation has continued this tradition of major innovations on behalf of government and industrial partners.

The organization's success is based on a few basic operating principles that have guided its management since the beginning. These include market focus, product involvement, breadth of expertise, strategic vision, and rapid assimilation of new developments.

Market focus is the most important of these. History has shown that industrial research laboratories that are divorced from market reality eventually fail. The management of the Laboratories was acutely aware of this pitfall.

They avoided it by creating a unique culture and management style that successfully matched the individual's freedom to innovate with the strategic direction of the company. While the scientific specialists in various disciplines at the Labs were among the best in the world, their contributions went beyond research and discovery. They were also expected to help bring concepts from the laboratory to the market.

It was not unusual to see scientists working on the floor of RCA factories to help in a product launch. I remember working the night shift to train factory personnel during the introduction of the early silicon transistors, and later during production of semiconductor lasers.

Management also understood that excessively narrow specialization is the enemy of creativity. An important factor in the success of the Laboratories was its ability to develop talent over time to meet changing technological and commercial requirements. It was not unusual for scientists to change fields every few years to develop new areas.

This had an important advantage: the experience gained in one field could be transferred to a new area, thus providing new insights. In my case, for example, over the years I had the opportunity to move my research work from transistors to microwave devices, then to semiconductor lasers and light emitting diodes, from there to solar cells, and finally to integrated circuits. At each stage I was able to apply lessons from one field to problems in another. The experience with semiconductor materials and processes helped me find ways to produce commercially viable laser diodes.

Scientists were also involved in product strategy. Management frequently initiated programs to build applications so that researchers could demonstrate the commercial potential of their innovations. For example, in the early 1970s we created prototype fiber optical systems to show how our newly developed RCA commercial semiconductor lasers might be used in communications.

This culture of flexibility was the direct result of having managers with broad knowledge of both technologies and markets. It was expected that senior technical staff members would be fully cognizant of any developments in their fields that might impact the company's business, and be ready to launch programs to address new market opportunities.

Thanks to its flexible management structure, the Labs could react very quickly to external developments. For example, the development of digital television was launched at the Laboratories in the late 1970s, years ahead of most competing efforts.

Now, in this book, this record can finally speak for itself. The hundreds of breakthrough technologies and products listed in these pages show how creative and productive the organization has been over the past 60-plus years.

Yet even this is only part of the story. As the central corporate research organization for RCA, the Labs had amassed a portfolio of over 20,000 patents when the General Electric Company acquired RCA in 1985. It is interesting to note that this intellectual property brought GE annual licensing revenues in excess of $250 million per year.

You could not ask for more convincing proof of the success of RCA Laboratories and Sarnoff Corporation in combining good science with commercial savvy. That is the best kind of innovation.

Innovation Goes Global

Introduction

Satyam C. Cherukuri, PhD
President and CEO
Sarnoff Corporation

Dr. Satyam Cherukuri joined Sarnoff as a researcher in 1989. In 1998 he was named Managing Director of the company's Life Sciences and Systems unit, which he was instrumental in developing. He became Sarnoff's Chief Operating Officer in 2001, and President and CEO in 2002. Dr. Cherukuri is Chairman of the Executive Council of the Conference Board. He also sits on the Board of Directors for Ness Technologies, Inc. (NASDAQ: NTSC), a global provider of IT services and solutions.

It is now possible to source new ideas, new technologies, and new products worldwide. The technology supply chain has been realigning, making it critical for companies to be connected into the global innovation network. Those that don't engage now are doomed to watch helplessly as the competition passes them by.

Major corporations are struggling to adapt before it's too late. They are looking for ways to reap the benefits of this commercial revolution rather than fall behind in the race to develop successful new products.

Investing in the Future

Sarnoff has developed a highly effective approach to innovation on a global scale. We've established subsidiaries and affiliates in Europe and Asia to build a global innovation supply chain with human capital worldwide.

Through this international network we can act as a conduit between our clients and a pool of innovators, partners, and potential customers around the world.

Sarnoff has continually adapted to changing market conditions. Our breakthrough technologies and products were usually created with international markets in mind. This book summarizes these achievements.

R&D Decentralized

The corporate R&D model, invented by Edison over 100 years ago and embodied by Sarnoff and other renowned laboratories, was responsible for generating fundamental breakthroughs in electronics, communications, computers, pharmaceuticals, materials — in fact, every industry.

For 45 years after its founding in 1942, Sarnoff's innovations helped RCA, our parent company, revolutionize the electronics and communications industries. The outcomes included color TV and CRTs, lasers, color LCDs, the CMOS process, silicon solar cells, and computer vision.

In the 1970s, companies met the increased demand for innovation by looking beyond corporate R&D. They licensed new technology, or bought small, entrepreneurial companies with promising products.

In the 1990s venture capital-funded entrepreneurial companies drove the stock market to dizzying heights while they created new products and services for a seemingly insatiable market.

A new model, distributed innovation, has emerged with Sarnoff as an early pioneer. Having spun out from RCA in 1987, we became a contract research provider, developing technology for government and commercial clients in such areas as satellite broadcasting, computational drug design, and HDTV. We also founded over 20 start-up companies, often in partnership with our clients, to bring innovations to market.

The Global Opportunity

It all came to an abrupt and sobering halt in 2001 with the collapse of the Internet bubble. The economic crisis accelerated a growing trend toward internationalization. The flood of foreign-born scientists and entrepreneurs to U.S. centers of innovation began to ebb. The worldwide communications infrastructure that came out of Silicon Valley and other U.S. innovation centers made it possible for innovators to stay home, yet stay in touch. It helped create a global ecosystem for creating and consuming technology. The internationalization of technical skills and business operations has helped eliminate the cost of production facilities as a barrier to innovation.

The story has now come full circle. As this book shows, Sarnoff Corporation has long been a vital international force for innovation, working at the forefront of technology and its commercial application for over 60 years.

We have operated in, even pioneered, each of the three innovation modes: corporate R&D, distributed services, and global collaboration. This first-hand experience is a tremendous asset as we help clients face the challenge of transitioning to a global innovation model.

We look forward to putting our international network of resources at the service of our partners to create tomorrow's successful products.

Video

SARNOFF INVENTS AN INDUSTRY

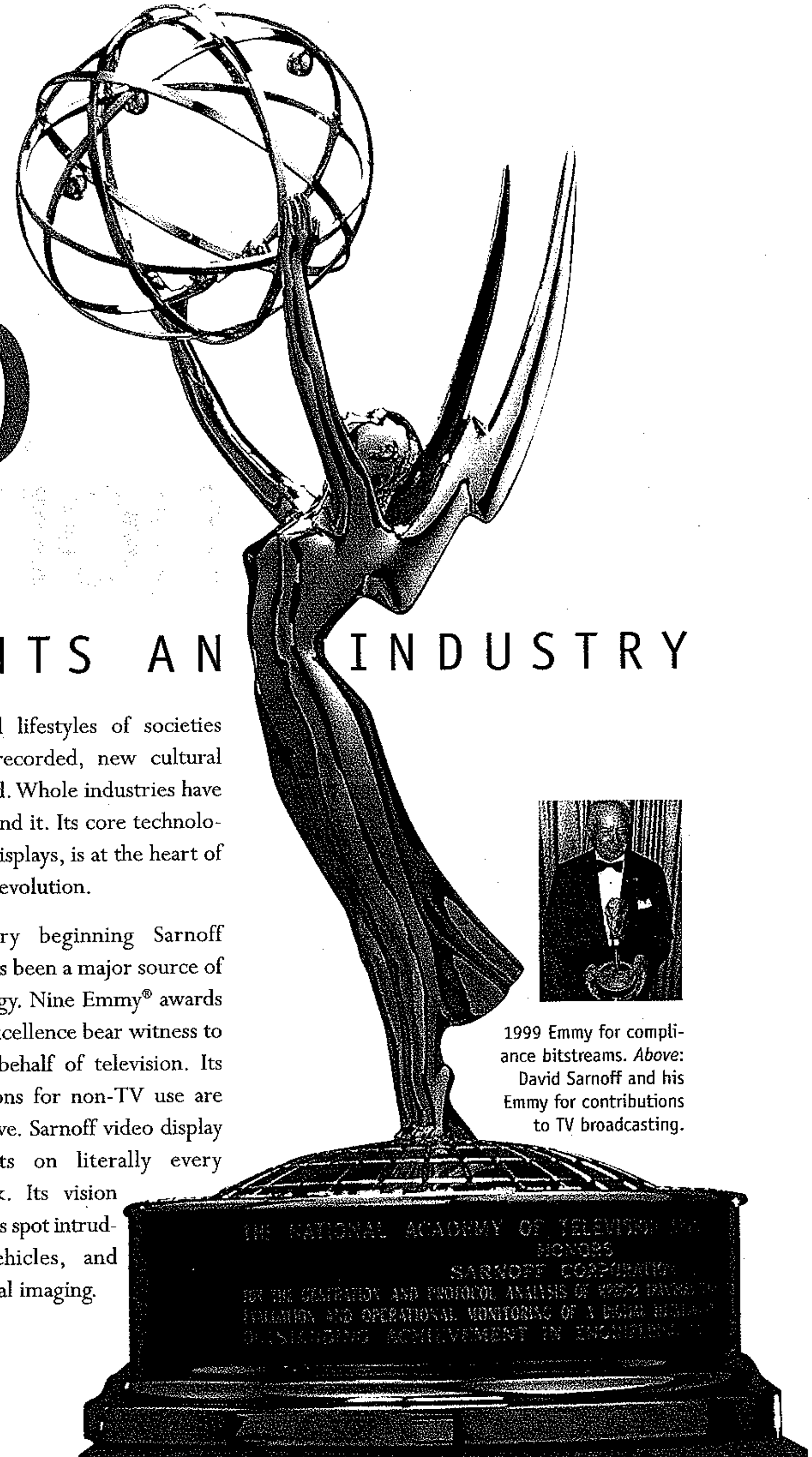
"Now we add sight to sound."

The year was 1939, the occasion was the New York World's Fair, and the event was the announcement of RCA's all-electronic television system. The speaker? David Sarnoff, RCA's president and the namesake of Sarnoff Corporation.

His words were the precise distillation of a much larger vision. Television would totally change how people perceived the world. Even though no one could have foreseen TV's full impact at its introduction, David Sarnoff understood its significance.

Today hardly any aspect of life is untouched by television. Wars have been fought on TV, elections contested, the values and lifestyles of societies revealed and recorded, new cultural artifacts created. Whole industries have sprung up around it. Its core technology, electronic displays, is at the heart of the computer revolution.

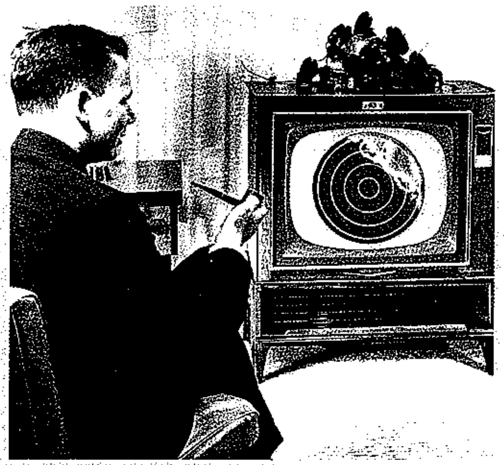
From the very beginning Sarnoff Corporation has been a major source of video technology. Nine Emmy® awards for technical excellence bear witness to its efforts on behalf of television. Its video innovations for non-TV use are equally pervasive. Sarnoff video display technology sits on literally every computer desk. Its vision technology helps spot intruders, guide vehicles, and improve medical imaging.



1999 Emmy for compliance bitstreams. *Above*: David Sarnoff and his Emmy for contributions to TV broadcasting.

SIGNIFICANT SARNOFF VIDEO INNOVATIONS

1944 Video camera tube for guided missiles, later used in TV studios.
1947 Proposal for an electronic, monochrome-compatible color television system, the basis of the NTSC standard.
1950 Shadow mask CRT, the first color television picture tube.
1953 FCC approval of the NTSC color television standard; Sarnoff created the fundamental technology and design of the color-encoding system, cameras, CRT (including phosphors), receivers.
1968 LCD technology, including basic chemistry and first commercial applications for today's dominant flat-panel display.
1974 CCD image sensor, adapting an existing technology to commercial use.
1981 RCA introduces CED VideoDisc product into consumer market.
1984 Pyramid-based image processing, the basis for vision technology and real-time processing of video.
1986 Stereo sound for broadcast television.
1991 Advanced Digital HDTV, a predecessor of the ATSC digital TV standard approved by the FCC five years later.
1992 Digital direct broadcast satellite TV, at that time the fastest growing consumer electronics product in history.
1993 Real-time insertion of images into live video.
1996 FCC approves ATSC system as the standard for U.S. digital television. Sarnoff was a leader of the Grand Alliance, a seven-member consortium that developed the new system.
1997 VideoBrush, commercial software for PCs to turn live video into panoramic still images for display and printing.
1999 Integrated circuit chipset designed in collaboration with Motorola to receive digital TV signals and convert the images for display on analog TVs.
2000 Acadia® I, world's fastest vision processing chip for real-time video processing in desktop PCs and other consumer products.
2003 Watermarking for digital cinema that survives compression, encoding, and Internet distribution.



GLOBAL IMPACT

Television has become a force in the world economy. A major consumer electronics manufacturing industry arose around it. In 1948 there were 350,000 TV sets in American homes; in 2000 there were 100 million. There is one set for every four people in the world, or nearly 1.8 billion televisions.

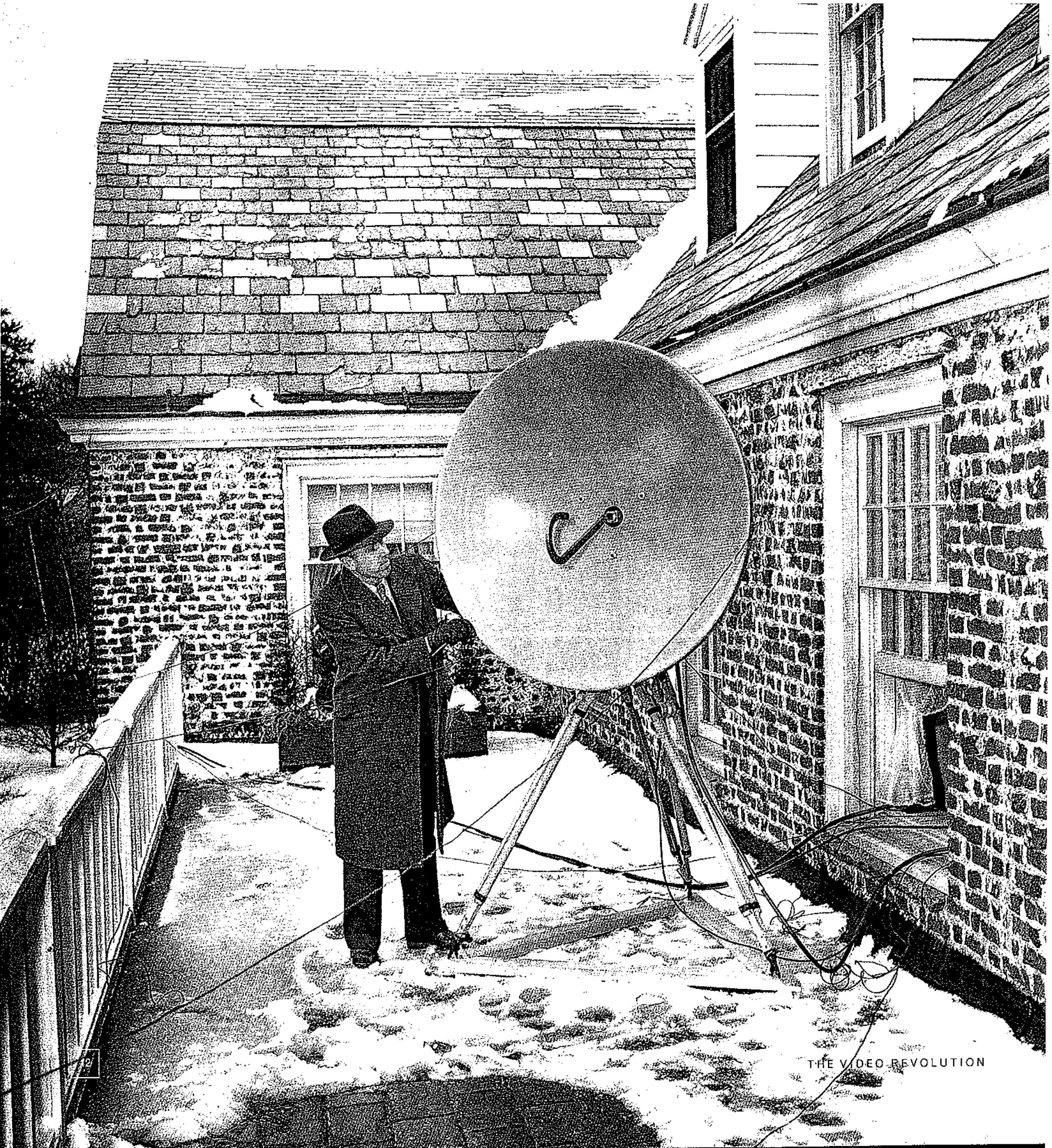
It has generated new growth in related businesses. The most obvious example is advertising. In 1941, in the first commercial broadcast in the U.S., Sarnoff's NBC-TV ran a 10-second commercial for a Bulova watch and netted $7. Sixty years later advertisers paid $24 billion for spots on TV.

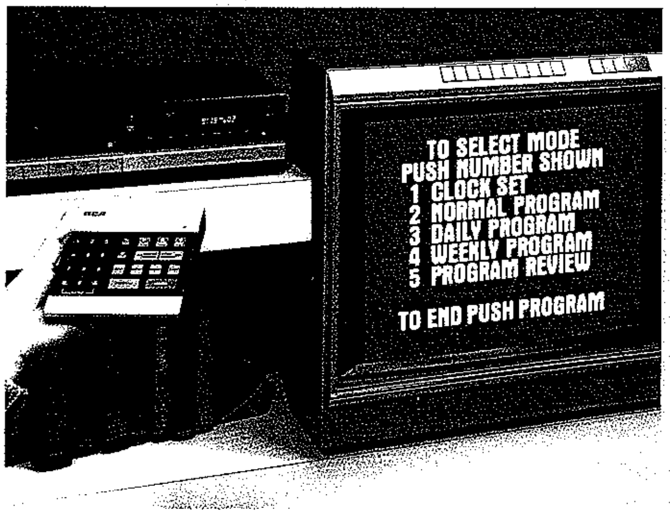
As with any successful new system, television stimulated technology spinoffs such as video displays, video cameras, video recorders, recordable video media, and cable and satellite delivery systems. Many of these found important applications outside of television, such as medical diagnostics, security and surveillance, and scientific and technical imaging.

RELATED TOPICS

CRT, LCD, Flexible Plastic Displays: see *The World on Display*
CCD Image Sensor: see *Extending the Power of Sight*; also see *Information on a Beam of Light*
Pyramid Processing, VideoBrush, Acadia I: see *Teaching Computers to See*
Digital TV chipset: see *The Microelectronics Miracle*

ABOVE: Demonstration of TV weather channel, 1958, combining Labs expertise in television and airborne radar systems.



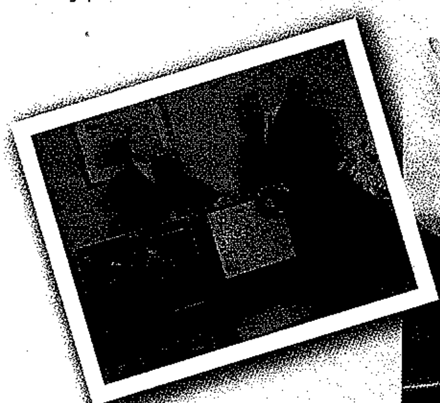


TOP LEFT: On-screen menu for video-cassette recording, 1982. The helical-scan head used in all VCRs was developed at Sarnoff.

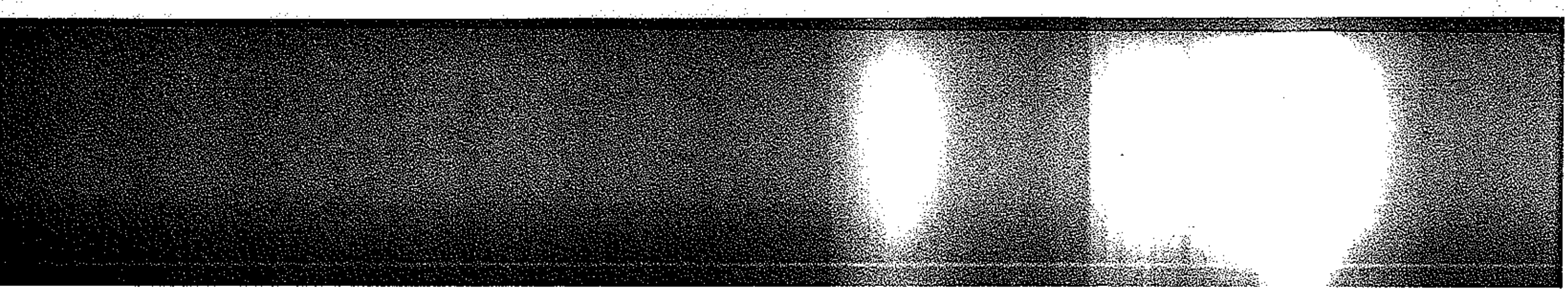
TOP RIGHT: Paul Weimer demonstrates his vidicon camera in 1950. The vidicon, a simple, inexpensive, and effective imager, was used in industrial, military, and closed-circuit video systems into the 1980s.

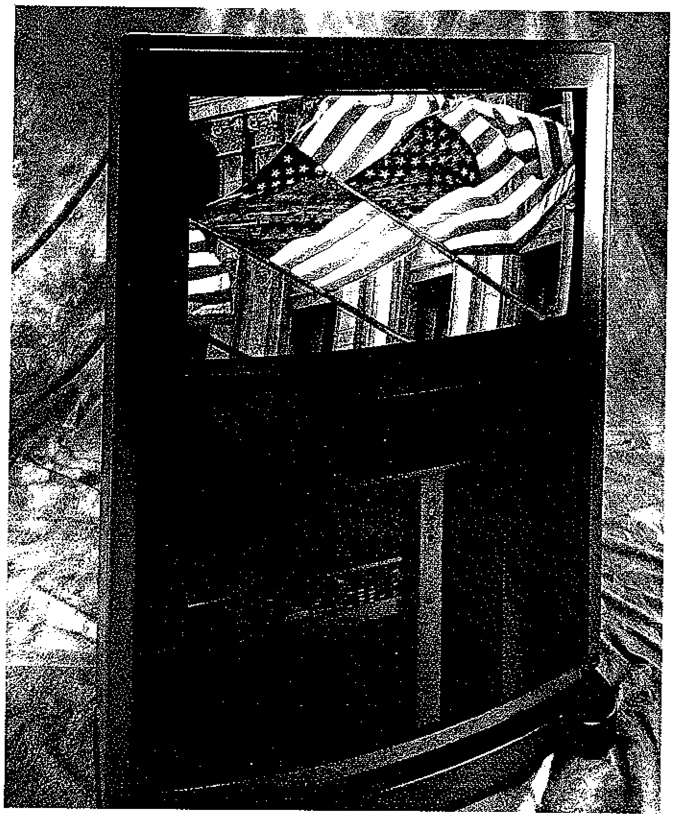
RIGHT: Paul Mitnaul demonstrates RCA's VideoDisc, a predecessor of the DVD, in 1980.

BELOW: Harry Olson shows David Sarnoff the world's first videotape player for the home, developed as a 65th"birthday present" to Sarnoff in 1956.



LEFT: Setting up a microwave antenna at Princeton University's Graduate School in 1946 to receive an all-electronic color television signal from the Labs, two miles away.



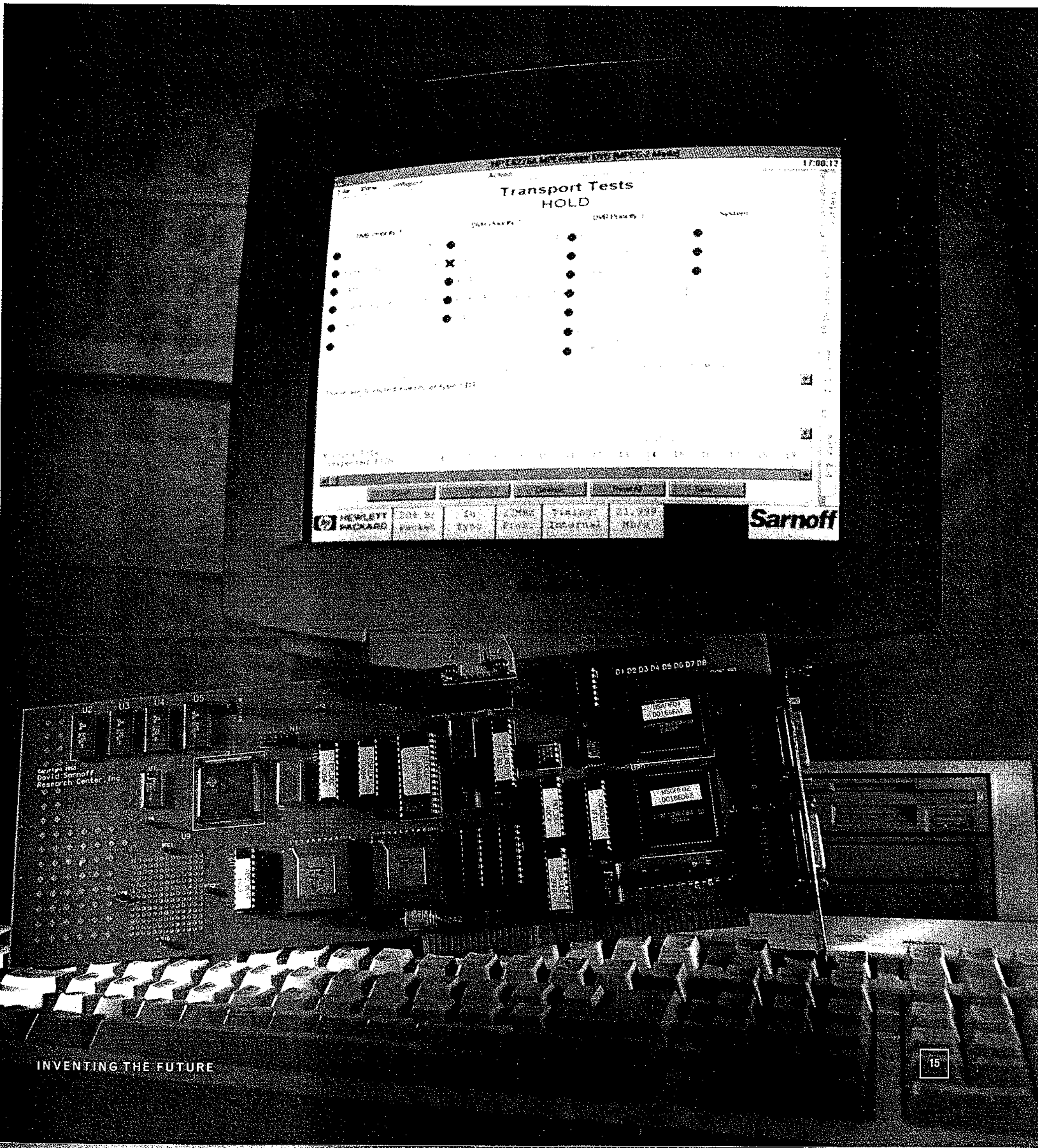


LEFT: Sarnoff was a leader of the seven-member Grand Alliance that developed the HDTV standard in 1995.

BELOW LEFT: Sarnoff digital video interactive (DVI) technology was simple enough for a child to use (1986).

BELOW RIGHT: The DVI team that pioneered the first interactive CDs. Sarnoff spun off the DVI technology to Intel in 1988.

RIGHT: Sarnoff Compliance Bitstreams are the de facto U.S. standard for verifying that receivers will reliably decode and display digital TV and HDTV signals.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HEWLETT PACKARD
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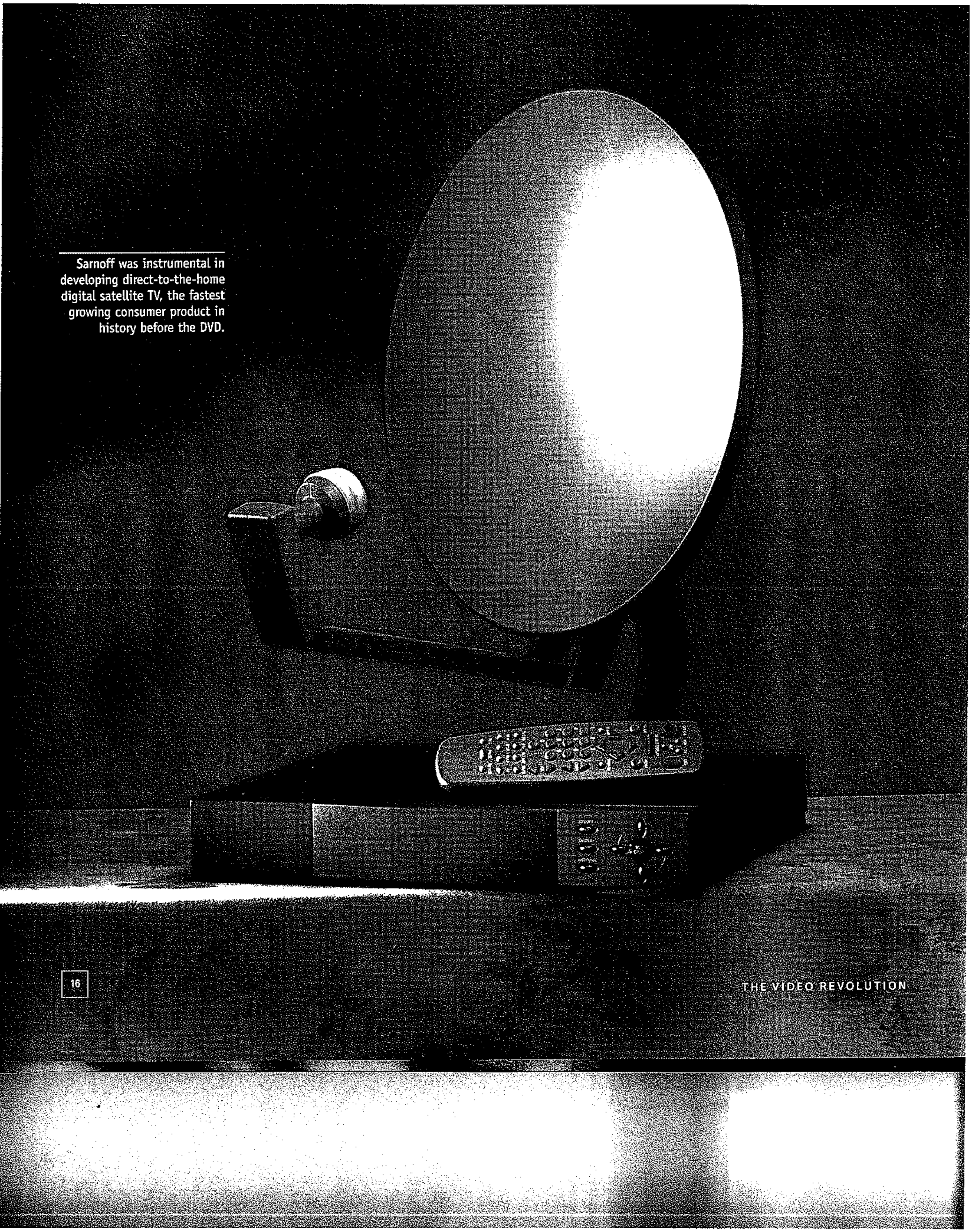
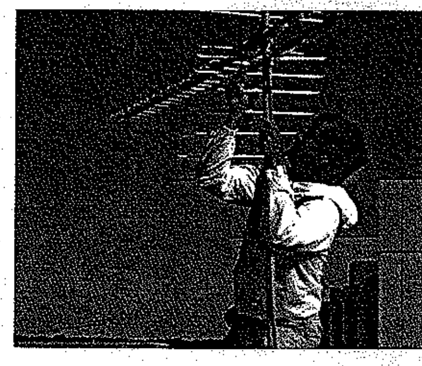
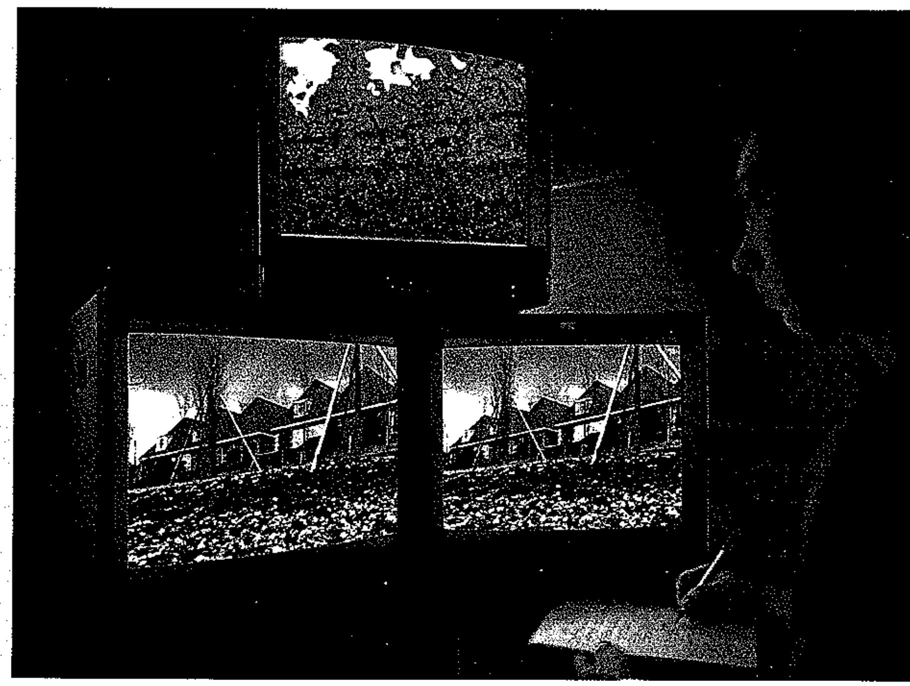
Copyright 1995
David Sarnoff
Research Center, Inc.



Sarnoff was instrumental in developing direct-to-the-home digital satellite TV, the fastest growing consumer product in history before the DVD.



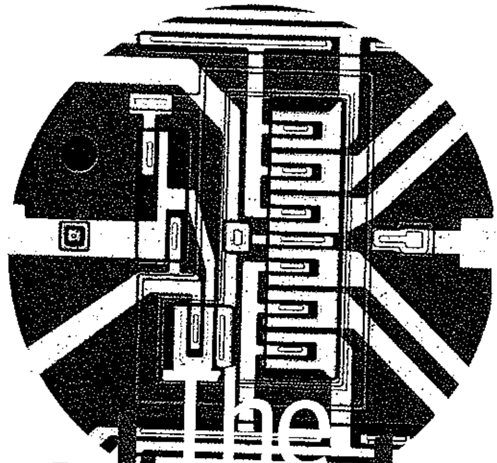


ABOVE LEFT: The technical leaders of the Grand Alliance pose in Sarnoff's field lab: standing L-R: Wayne Luplow (Zenith), Glenn Reitmeier (Sarnoff), Bob Rast (General Instruments), Terry Smith (Sarnoff); seated L-R: Ralph Cerbone (AT&T), Jae Lim (MIT), Aldo Cugnini (Philips).

ABOVE: Al Acampora with Sarnoff's priority processor board for MPEG picture information, part of the advanced digital high-definition TV (ADHDTV) system, a forerunner of the Grand Alliance digital TV system that became the official U.S. standard.

Frank Lang adjusts an antenna during DTV tests in Washington, D.C.

LEFT: JNDmetrix™ technology predicts how humans will react to digitally processed video or other images, allowing program originators to adjust the processing for highest perceived quality.



The Microelectronics Revolution

TRANSISTORS, ICs, CMOS PROCESS

Power is no longer synonymous with size.

In the early 1950s you could buy a "portable" radio, but it was bulky, required frequent battery changes, and its vacuum tubes let it double as a foot-warmer. Five years later the world was carrying a transistorized radio in its shirt pocket.

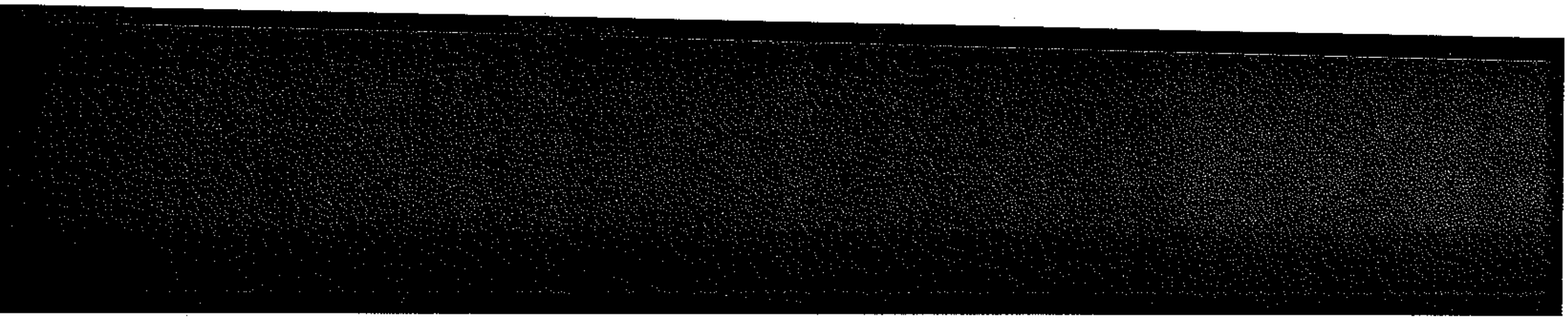
In the 1960s a computer filled a climate-conditioned room and was limited to basic number-crunching. Today people carry computers in their briefcases that can create graphics, encode video, and communicate over the Internet, all almost instantly.

The astonishing evolution of electronic devices during the last 40 years has transformed the way people live, work, play, communicate, and relate to their world. It all grew out of the microelectronics miracle, driven in large part by Sarnoff innovations.

In the early days, working with RCA's Semiconductor Materials Division, Sarnoff developed better materials and processes for transistors and diodes, including defect-free crystals and better doping and cleaning methods. That's when radios and TVs abandoned vacuum tubes in favor of smaller, cooler, more reliable solid-state devices.

But the biggest breakthrough came in 1964: the development of the standard complementary metal oxide semiconductor (CMOS) process at Sarnoff. CMOS ultimately gave manufacturers a way to create low-power digital "computers on a chip," or integrated circuits (ICs) containing millions of transistors. Today CMOS is used to make over 90% of the world's microprocessors and memory chips.

Building on its historical leadership in IC design, processes, and materials, Sarnoff continues to advance the state of the art in semiconductor technology. Its silicon intellectual property (IP) adds functionality to countless ICs; TakeCharge® technology puts more chips on each wafer at many of the world's leading foundries. Sarnoff also designs new chips for IC makers.



SIGNIFICANT SARNOFF MICROELECTRONICS INNOVATIONS

1952 Demonstration of high-frequency transistors for use in radios, television, and other consumer electronics.

1959 Development of tunnel diodes for use in computers and communication equipment.

1962 Thin-film transistor (TFT), widely used as drivers for liquid crystal displays (LCDs).

1962 Metal oxide semiconductor field effect transistor (MOSFET), the basis of C (complementary) MOS process.

1964 Development of the CMOS process, which later became the technology used to manufacture the vast majority of the world's ICs and DRAM chips.

1966 Invention of vapor-phase epitaxy, a standard technique for semiconductor fabrication.

1970 Development of Standard Clean 1 and Standard Clean 2 to remove metallic contaminants during semiconductor oxide growth.

1976 Charge-coupled device (CCD) adapted to commercial use.

1977 Silicon-on-sapphire (SOS) ICs, used extensively in space applications circuits due to their inherent resistance to radiation.

1982 Gallium arsenide (GaAs) microwave devices, the first solid-state power amplifiers (SSPAs) to be used in communications satellites.

1986 GEM technology to create form, fit, and function replacements of no-longer-available ICs in Department of Defense electronic systems with current Bi-CMOS techniques, without having to redesign entire systems.

1992 Ultra-low-power A/D converter, using deep submicron CMOS technology to achieve a hundredfold reduction in power requirements.

1997 CMOS Active Pixel Sensor (APS) imager, a "camera-on-a-chip" with outstanding dynamic range.

1999 Digital TV demodulator and decoder chips, designed with Motorola, to adapt analog TVs for the new digital and HDTV standard.

2000 TakeCharge® technology for IC design, substantially reduces manufacturing costs for ICs by shrinking dies, eliminating reworks, and fitting more chips per wafer.

2003 Prototype of uncooled CMOS infrared (IR) sensor based on MEMS technology demonstrated.

2004 Silicon IP for MPEG-4 based video on cell phones, other devices and for ATSC digital TV demodulation and decoding offered for licensing.

GLOBAL IMPACT

Sales of semiconductors topped $215 billion worldwide in 2004. The business is broadly international, with the 10 largest firms headquartered across the U.S., Europe, and Asia.

At the finished product level, manufacturer-to-dealer sales of consumer electronics products in the U.S. alone exceeded $125 billion for 2004.

But even economic facts as impressive as these only begin to suggest the titanic transformation of our world by the electronics revolution.

It gave new life to existing technology. Electronics gave the auto industry the engine controls it needed to meet tougher emissions standards in the 1970s, and opened the way for many other safety and convenience features. Everything from wristwatches to harbor dredges have gained new precision and performance from the replacement of mechanical controls with electronics.

The electronics revolution also gave birth to new industries. The manufacture of the components is just the starting point. Personal computers, cell phones, and numberless consumer products all owe their existence to the ICs that pack 100 million devices in a volume of less than 0.004 cubic inches.

As the circuits within these tiny devices get smaller, and their power and speed increase, Sarnoff Corporation continues to play a major role in their development and application.

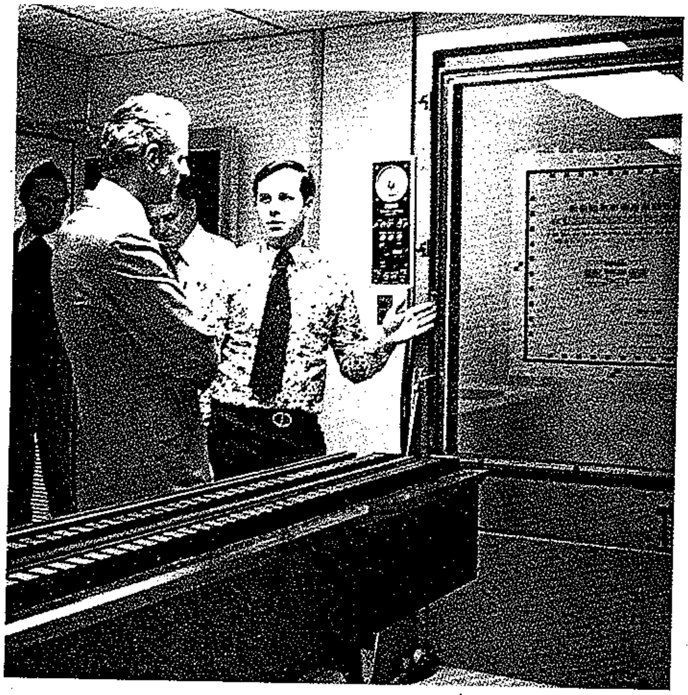
RELATED TOPICS

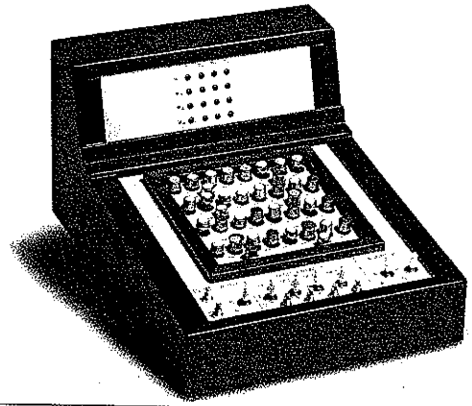
Electronic materials: see *Elements of Innovation*
Television and video: see *The Video Revolution*
Optoelectronics: see *Information on a Beam of Light*
Cameras: see *Extending the Power of Sight*

ABOVE: Gerry Miller probes the connections on a new integrated circuit, c1995.

LEFT: c1967 close-up of RCA's CMOS integrated circuit, the first in the market when released in 1968.

A technician probes the first thin-film transistors in the world. Invented as camera sensors by Sarnoff's Paul Weimer in 1961, TFTs are used today to control liquid crystals in LCD panels.



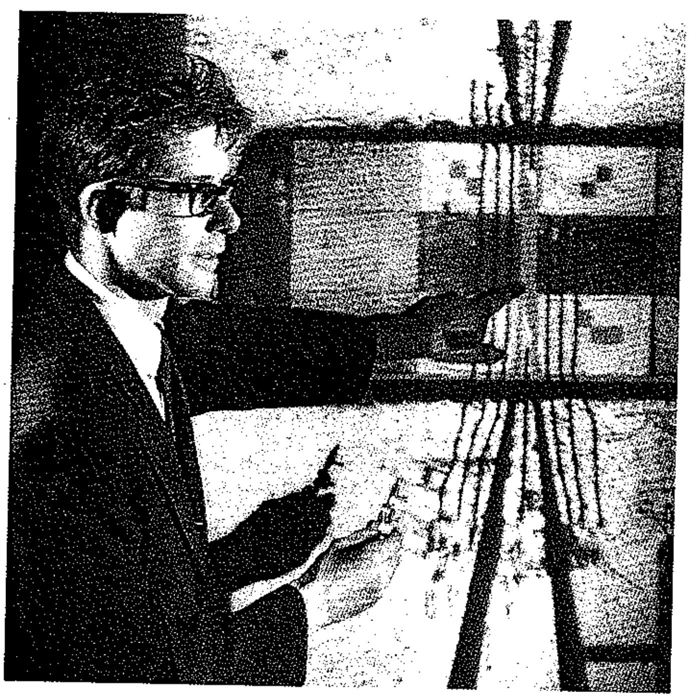


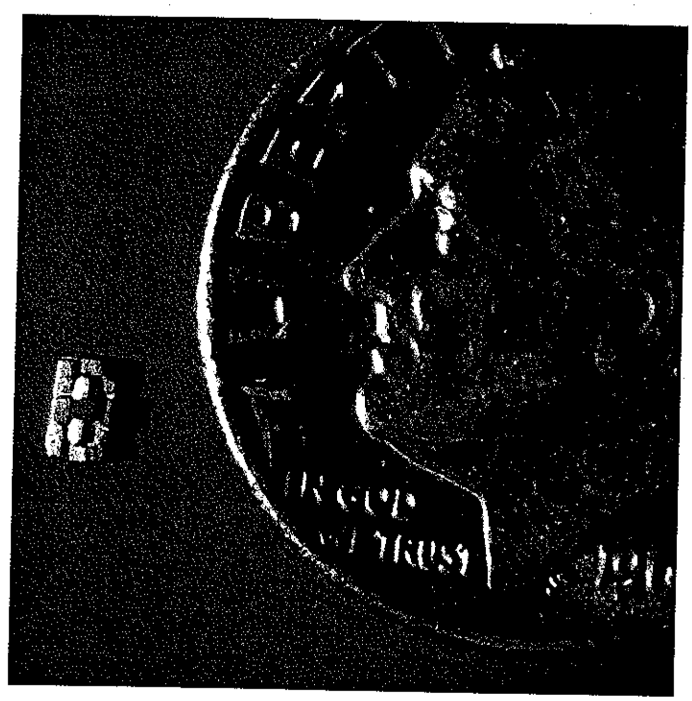
ABOVE: Breadboard model of RCA's CMOS 4, a 4-bit/word memory circuit, in 1966. Based on this work RCA's Solid-State Design Center in Somerville, NJ designed and made the first CMOS IC in 1968 and the first CMOS microprocessor in 1976.

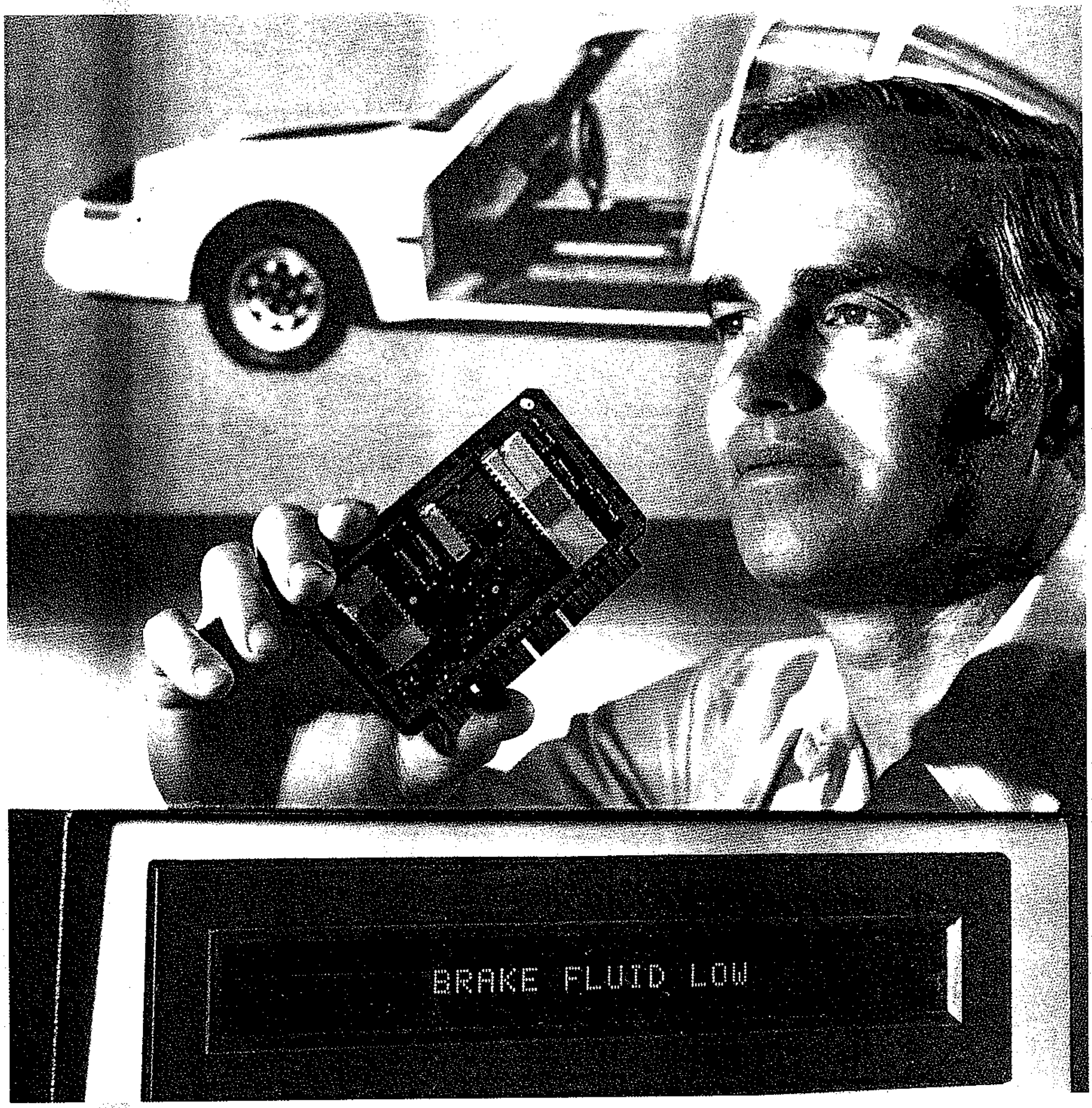
LEFT: Greg Zak demonstrates a new photoreduction camera for the preparation of IC masks at Sarnoff in 1978.

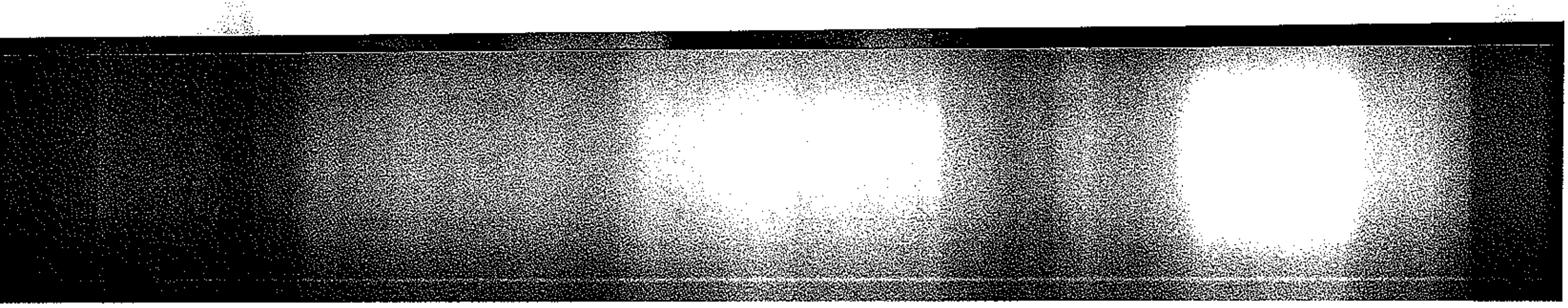
BELOW LEFT: Raymond Dean explains the Labs' gallium-arsenide (GaAs) microwave amplifier in 1967. Based on the Gunn Effect, it was the first solid-state amplifier to reliably generate 10 to 40-gigahertz. It was used for high-definition radar and satellite communications.

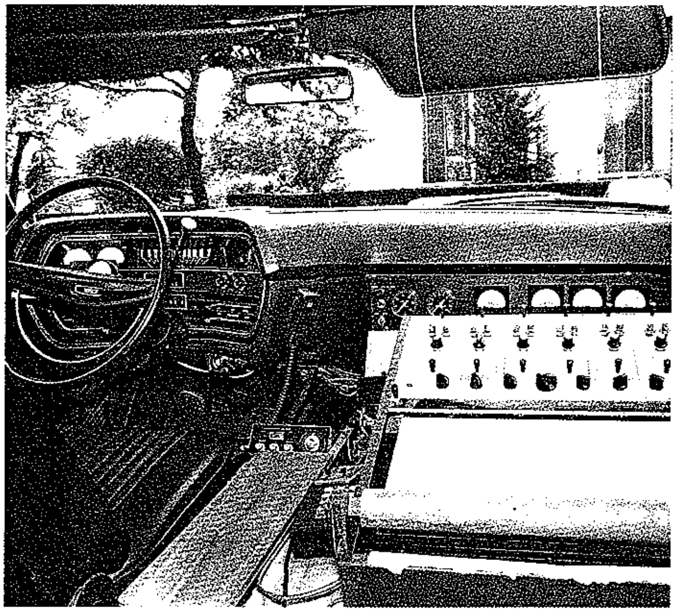
BELOW RIGHT: GaAs field-effect transistor, c1976. RCA's Fred Sterzer pioneered this efficient microwave device.

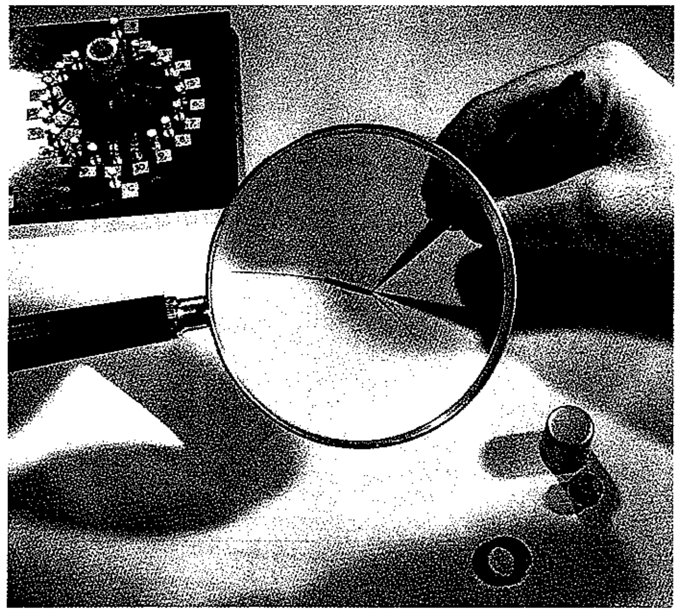





BRAKE FLUID LOW





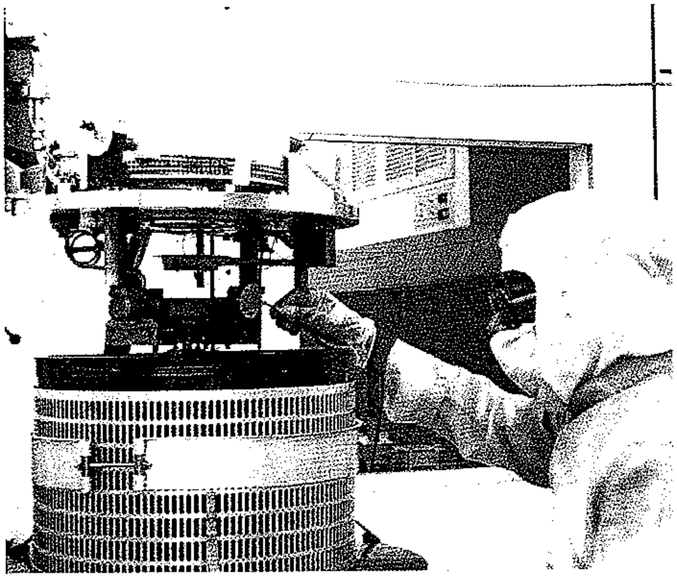


ABOVE LEFT: Equipment incorporated into a Chrysler car for testing RCA's 1802 microprocessor in 1976. The 1802 supplied electronic ignition controls in three model years of Chryslers and Cadillac Sevilles from GM.

ABOVE RIGHT: 1958 photo of the Labs' integrated circuit (IC) shift register, incorporating active and passive electronic components shown upper left. Torkel Wallmark and his staff lost the race to create the first working microprocessor to Robert Noyce and John Kilby. In the 1960s RCA continued to pioneer techniques and devices fundamental to the microelectronics revolution.

LEFT: Steven Hofstein holds up the first MOSFET circuit in 1964, just two years after he explained the technology in his lab notebook.

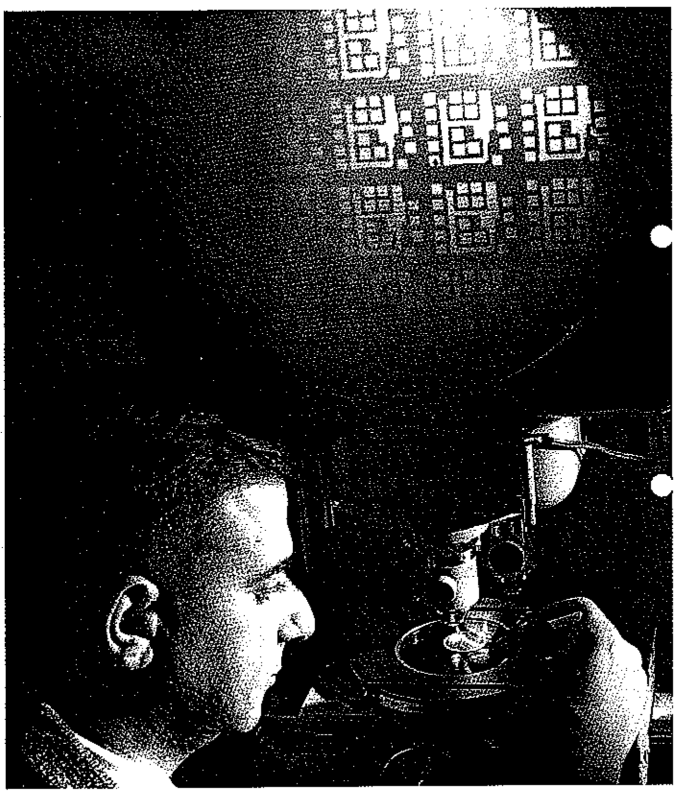
FAR LEFT: Eugene McDermott holds the 1802 CMOS microprocessor, which controlled electronic ignition in the Research Safety Vehicle in 1976. A number of auto safety and efficiency features in use today were developed at the Sarnoff labs.

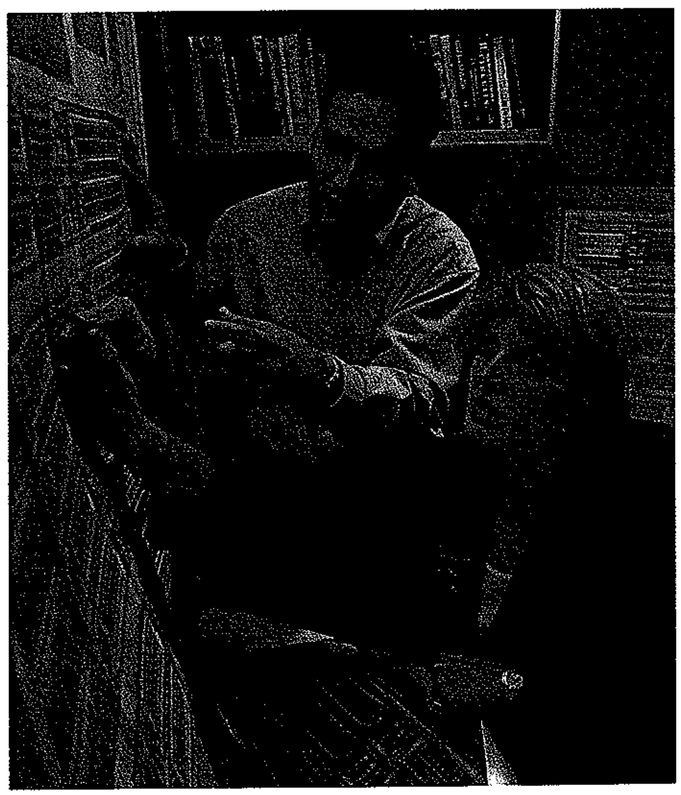


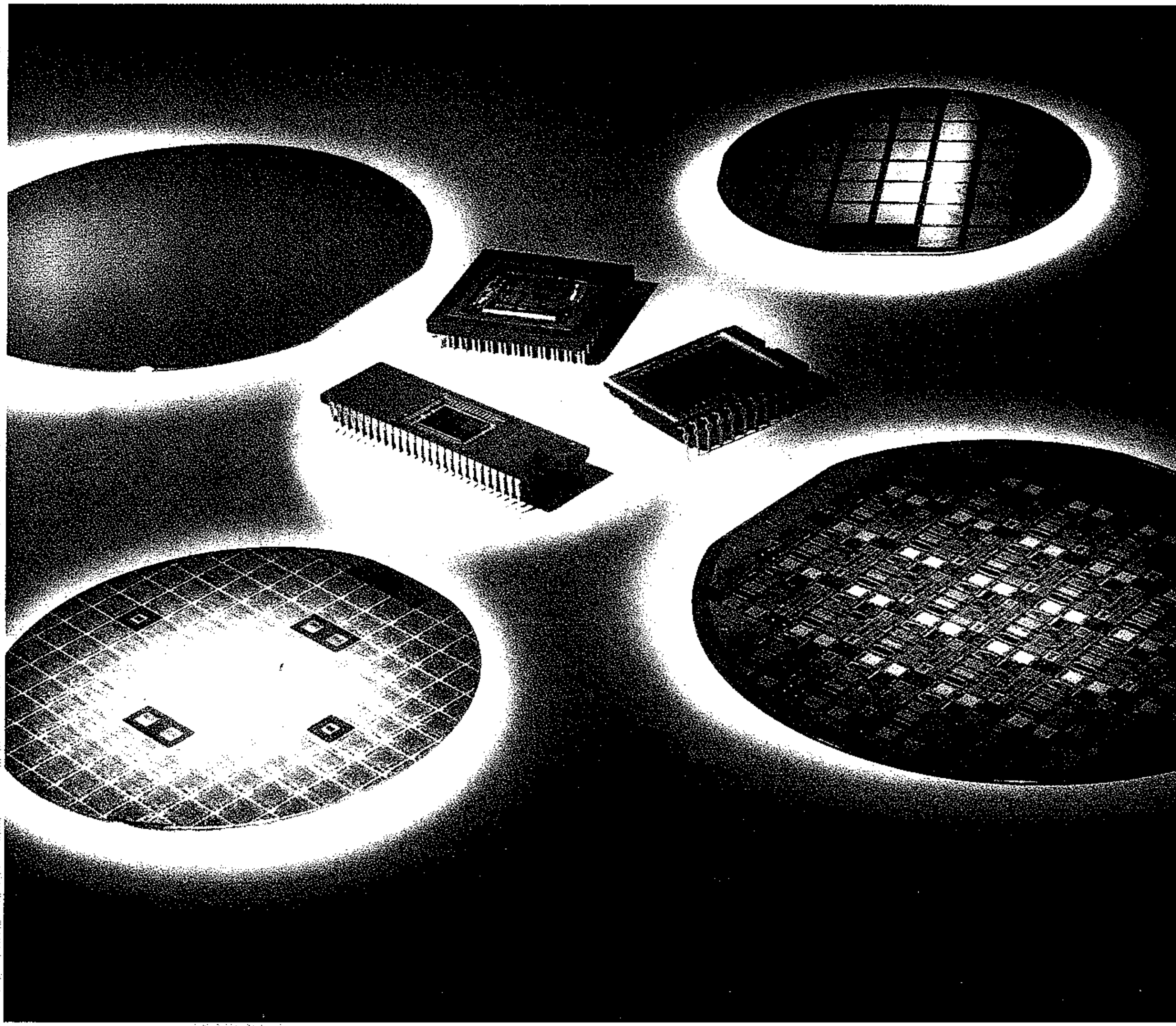
LEFT: Sarnoff technician places a wafer in an epitaxial deposition device.

BELOW LEFT: Art Stoller probes an integrated circuit under the microscope in 1965.

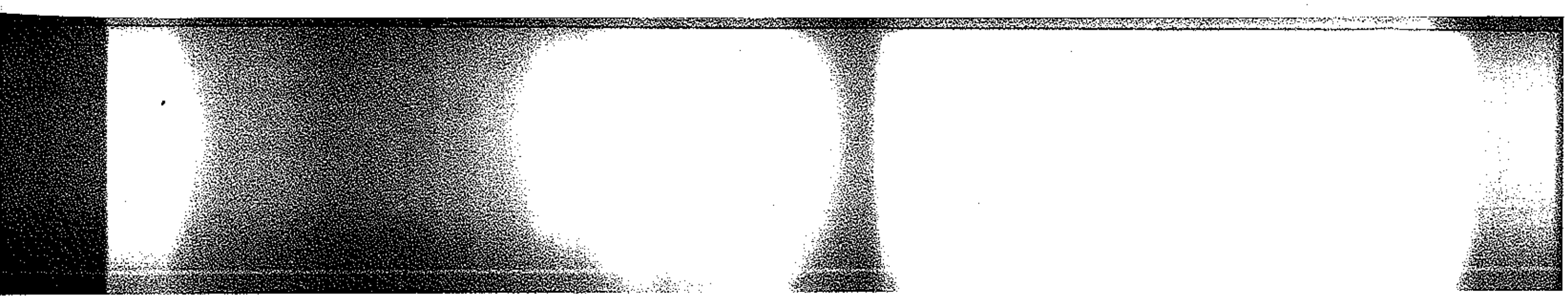
BELOW RIGHT: Rakesh Kabra and Laura Housel of Sarnoff's Microelectronics staff review the design of a new chip in 1995.

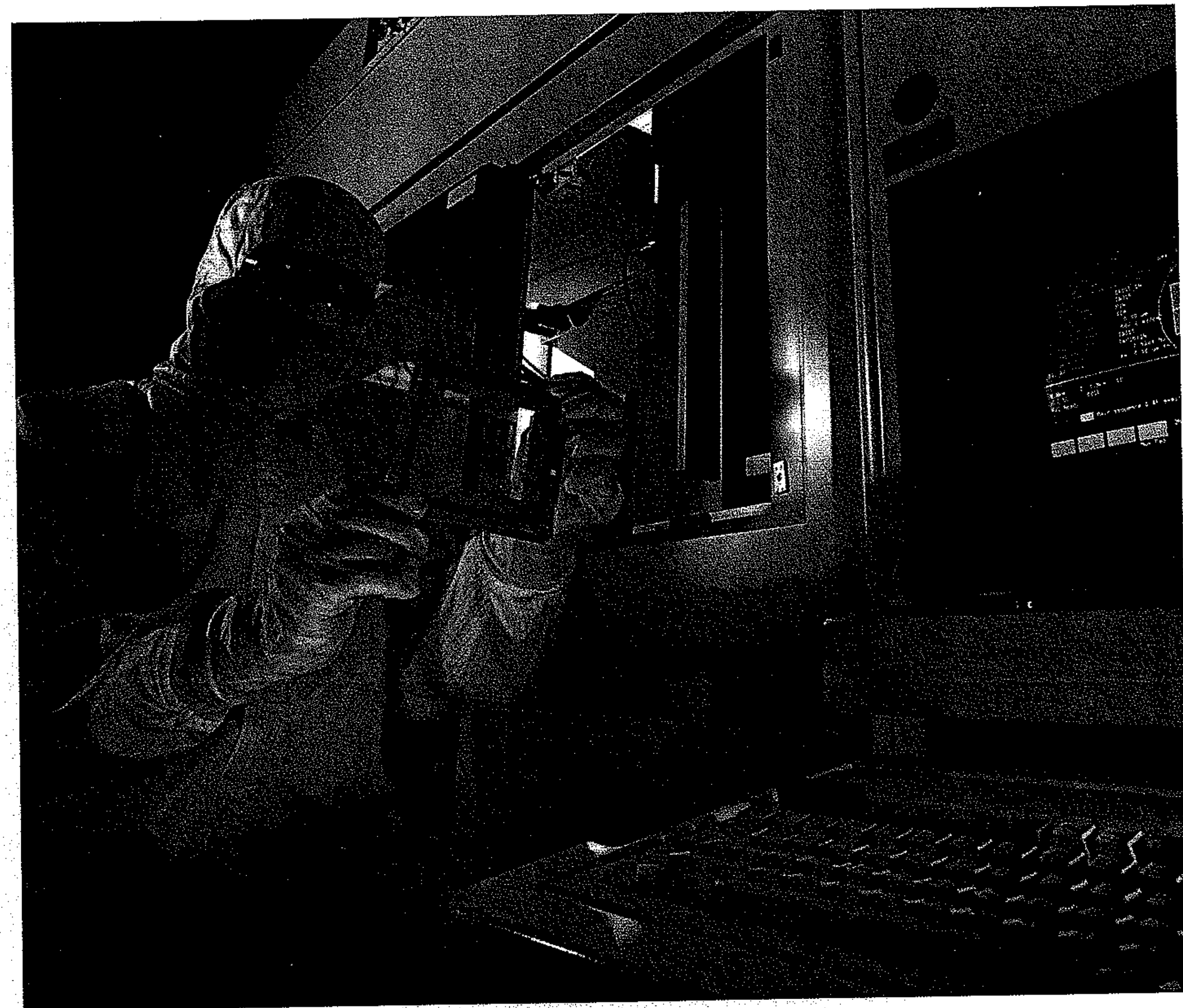






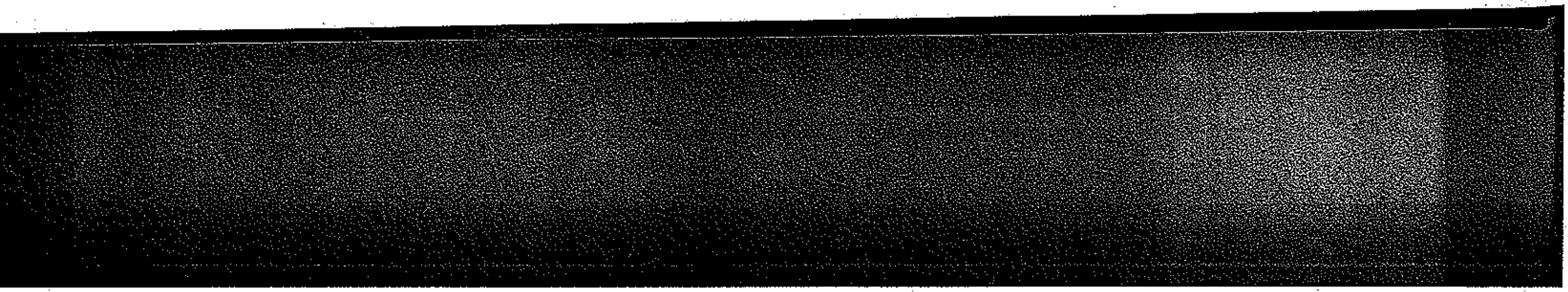
ABOVE: Wafers for imager chips and the finished imagers. Sarnoff's pioneering work includes CCD mass production, broadcast quality CCDs, back-illuminated CCDs for high sensitivity, and uncooled MEMS IR imagers. It designs and fabricates CCD, CMOS, and CMOS/CCD imagers and arrays covering the deep ultra-violet, visible, and infrared spectra.

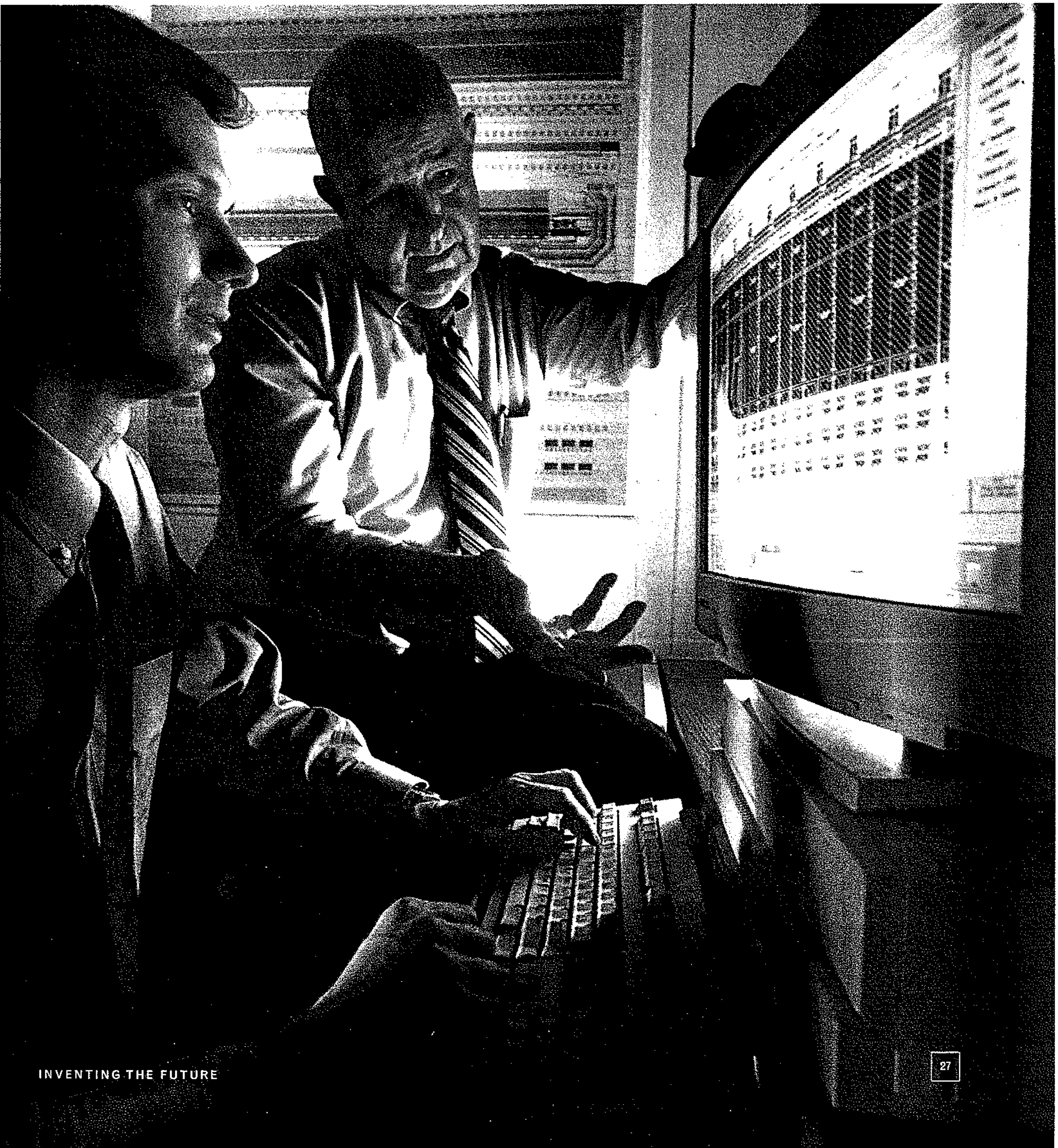


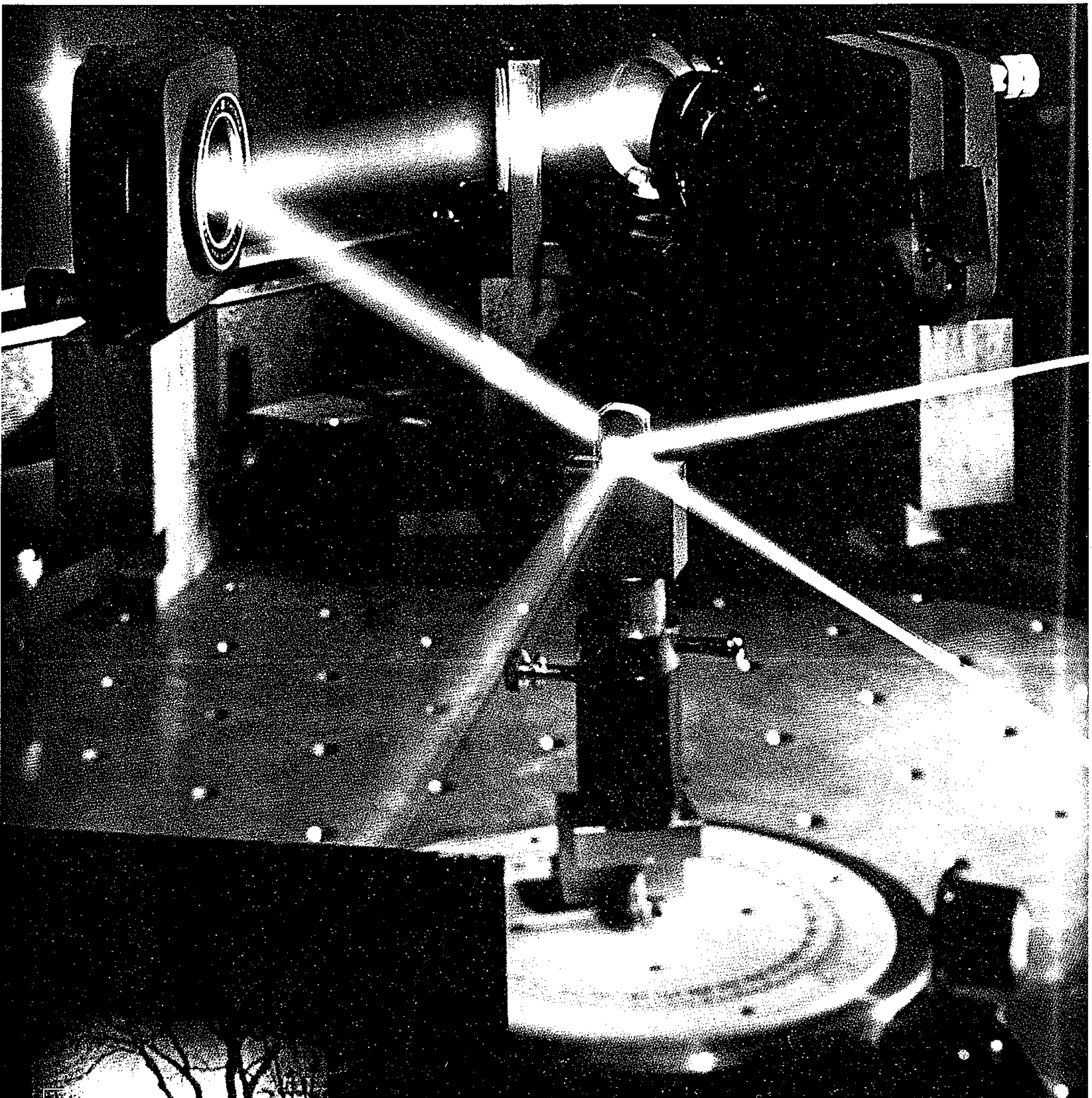


ABOVE: Photolithograpy technician David Stout shows a mask for a chip in Sarnoff's highly productive GEM program, c1995.

RIGHT: Robin Dawson and Steve Connor review a CCD chip design, c1995.







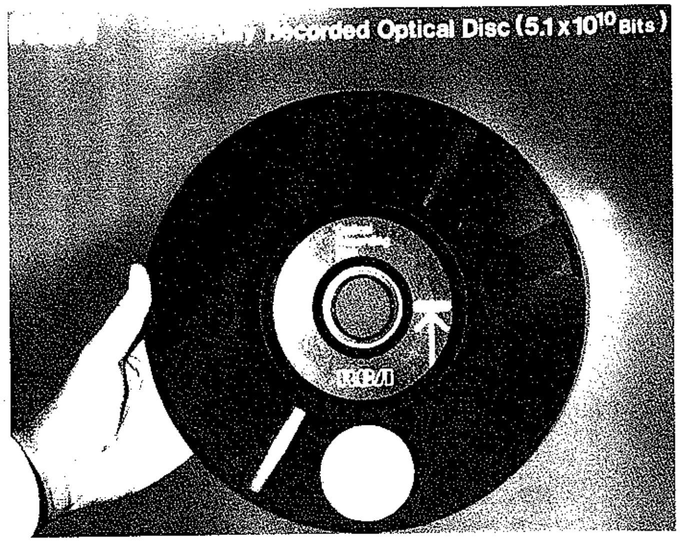
INFORMATION ON A BEAM OF LIGHT

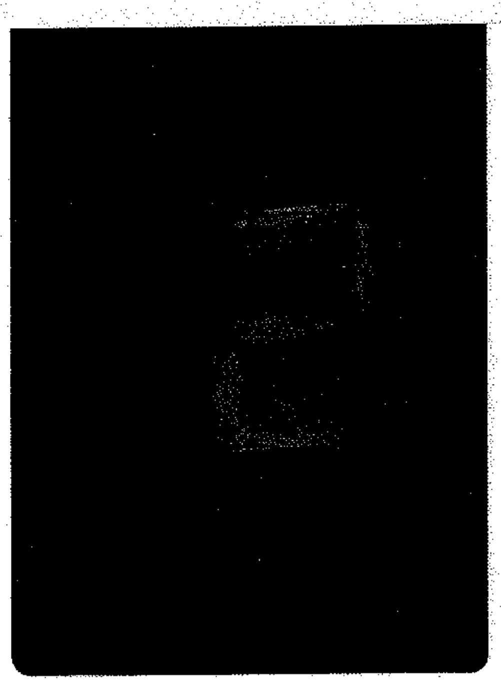
LEFT: As part of a research project to develop atomic-level holographic data storage in crystals, a laser beamed through a lithium-niobate crystal in 1971 reveals an image of the David Sarnoff Research Center.

RIGHT: RCA's 1980 optically rewritable laser disc can store over 6GB on a 12-inch side.

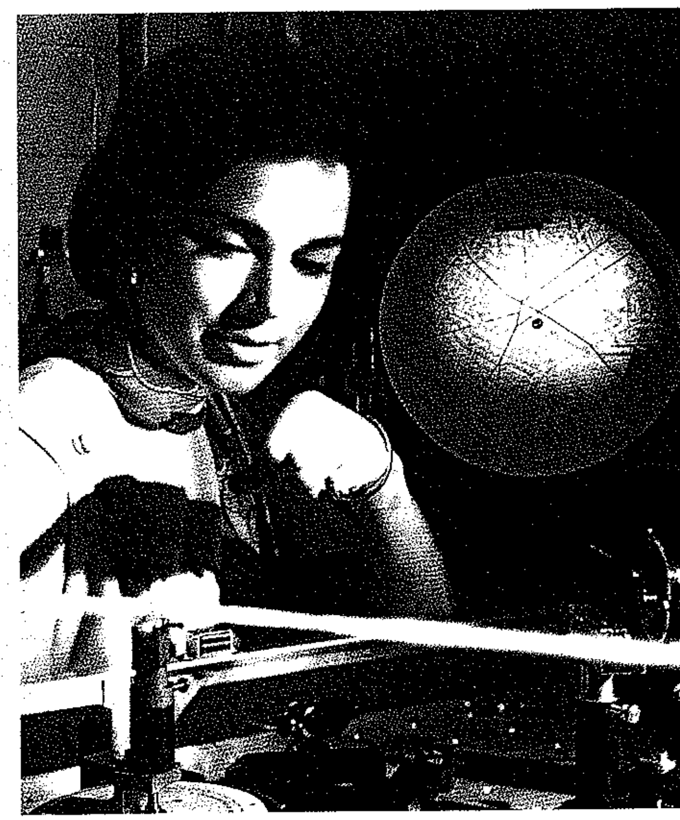
BELOW LEFT: Working with Ed Miller, Jacques Pankove demonstrated the world's first blue light-emitting diode using gallium nitride in 1972, drawing on GaN photoluminescence research started by Herbert Maruska to fulfill James Tietjen's idea of a color, flat-panel LED display.

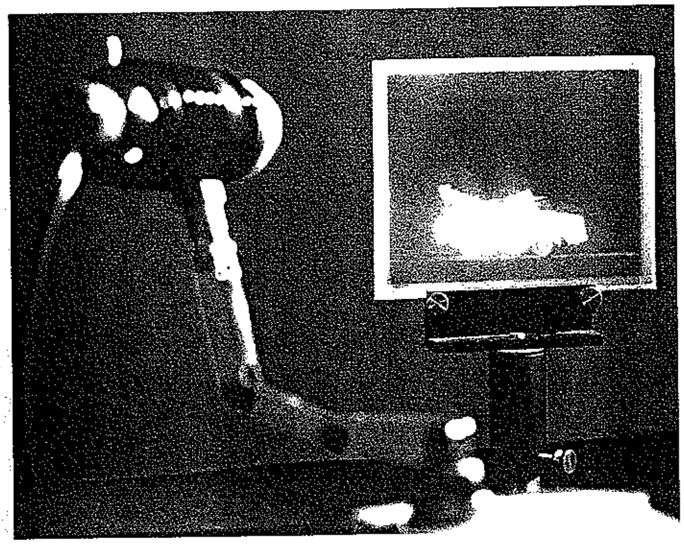
BELOW RIGHT: Patricia Cullen points to the crystal cube a laser is reading to show a map of Mercerville, NJ in 1971.

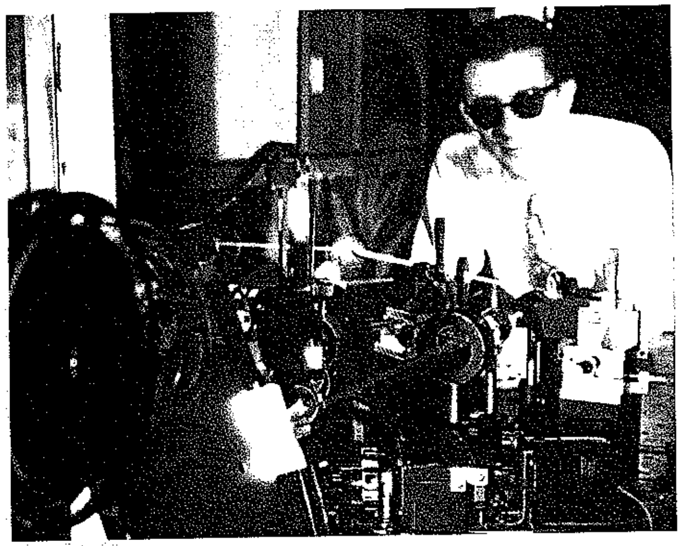


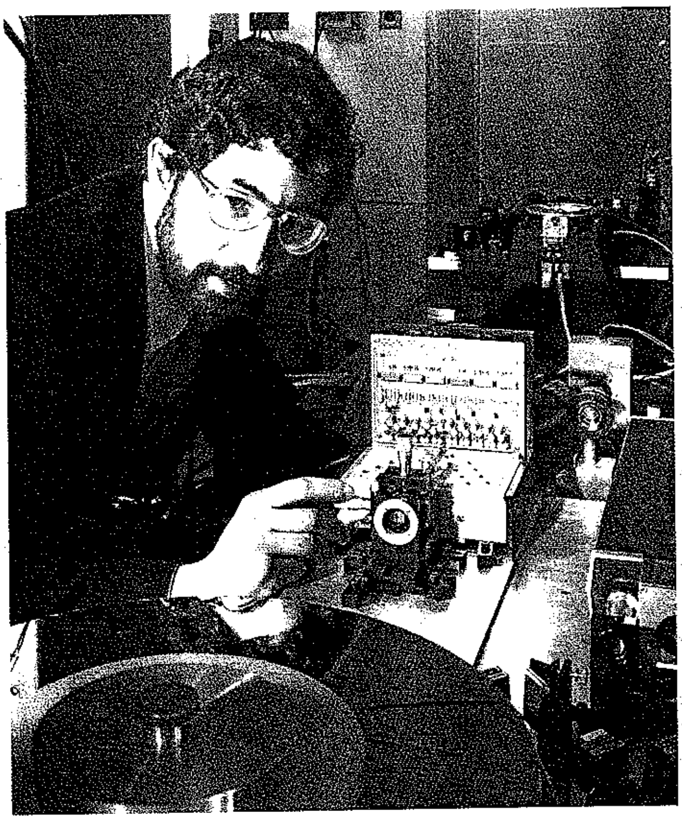


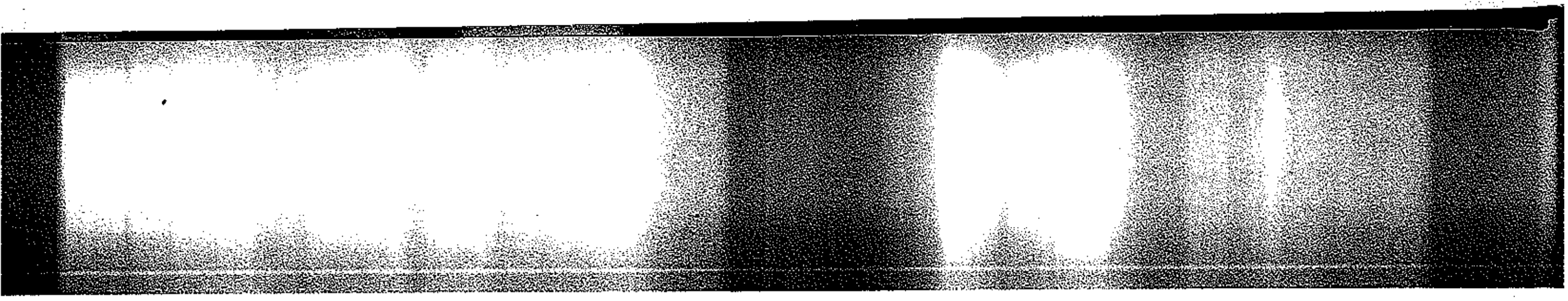
GaN ELECTROLUMINESCENCE COUNTS
November 1972

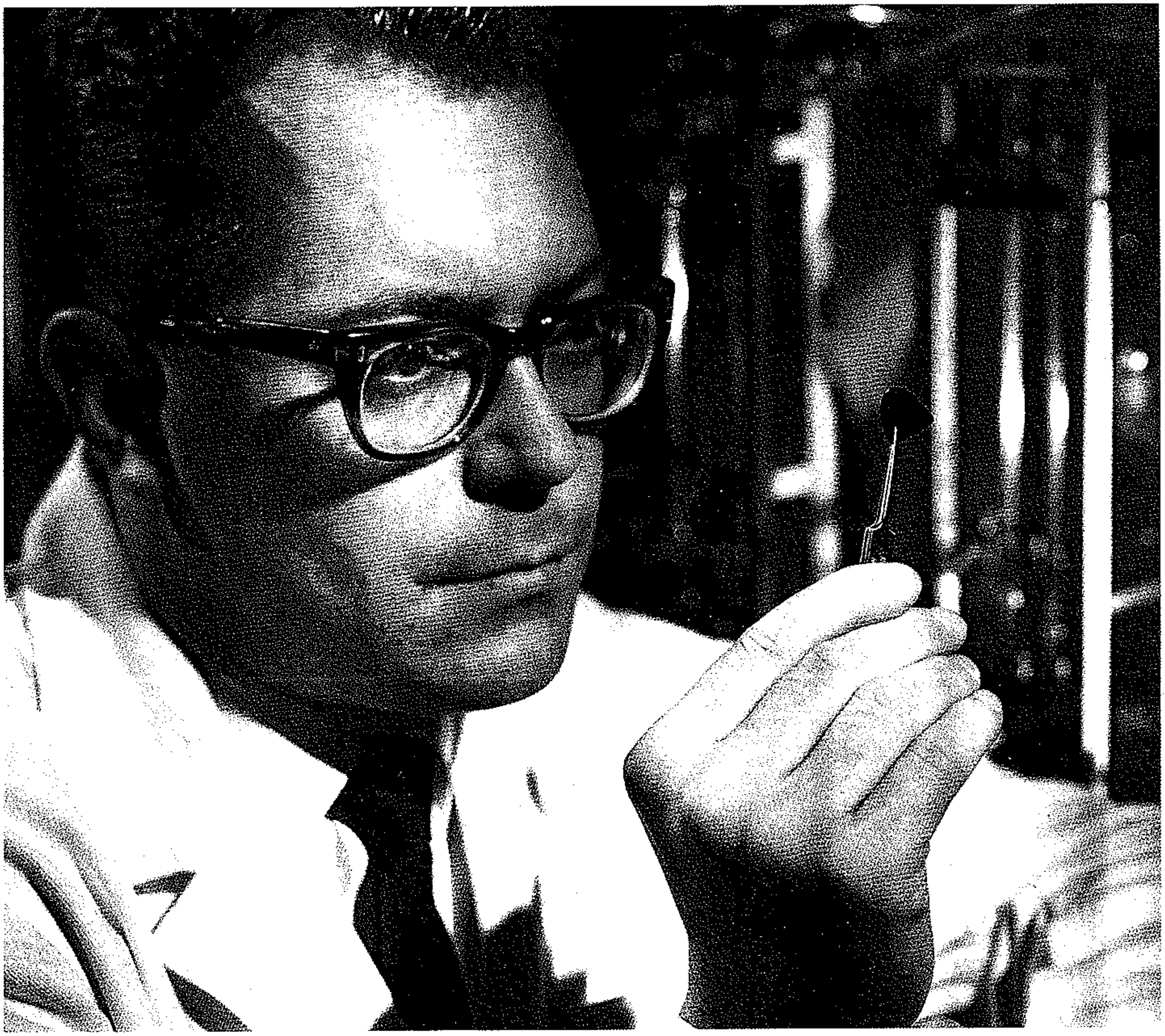






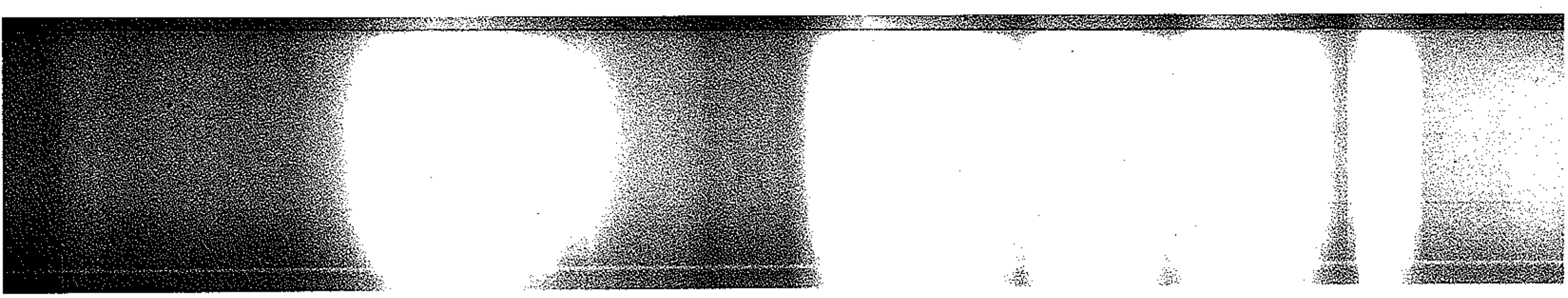


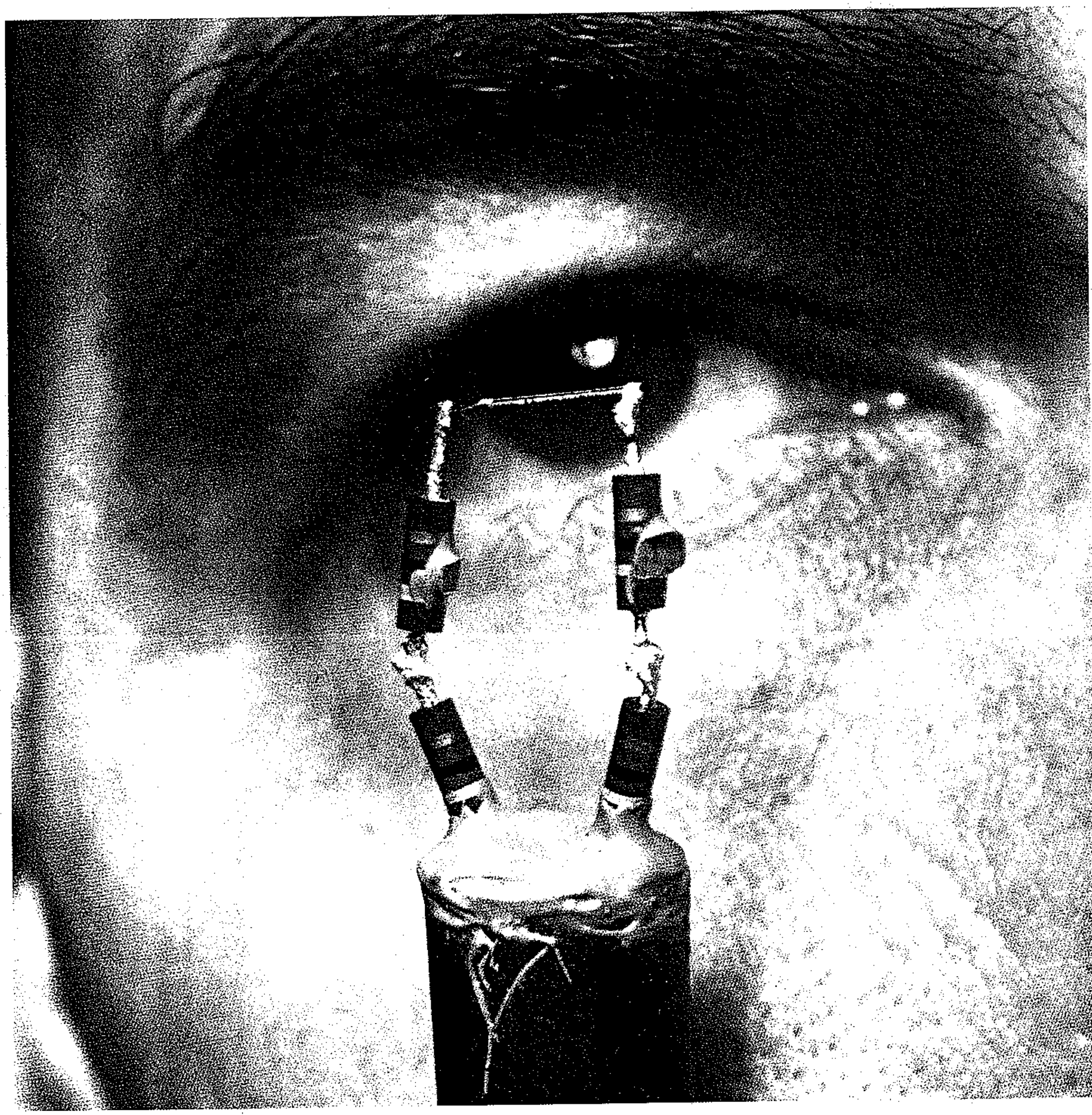




ABOVE: James Tietjen holds a gallium-arsenide (GaAs) wafer made with the vapor-phase epitaxial growth technique that he pioneered at the Labs in 1966.

LEFT (CLOCKWISE): 1) Laser hologram, 1972. **2)** Robert Bartolini oversees laser research that ultimately leads to breakthroughs in optical recording. **3)** Robert Duncan and Zoltan Kiss measure output of a calcium-fluoride laser doped with dysprosium in 1962. **4)** Don Carlin demonstrates optical recording on a 14-inch disc in 1984.



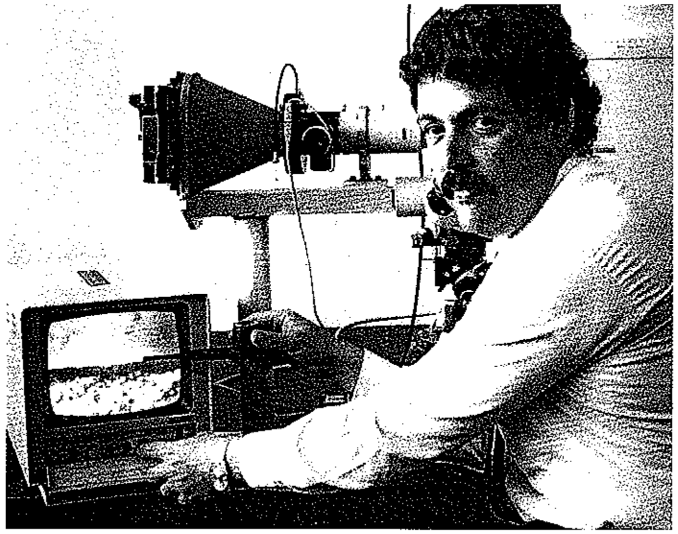


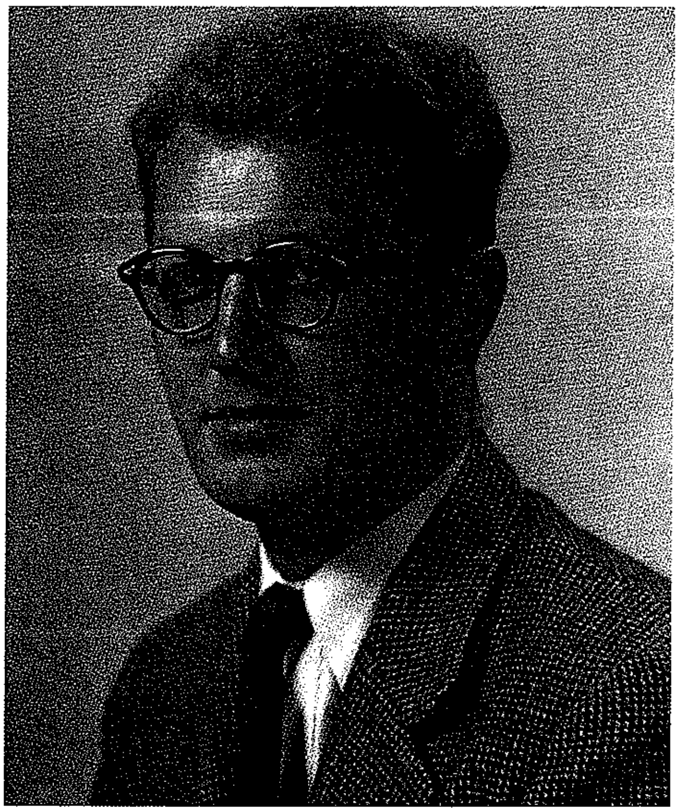
LEFT: GaAs light-emitting diode, c1966.

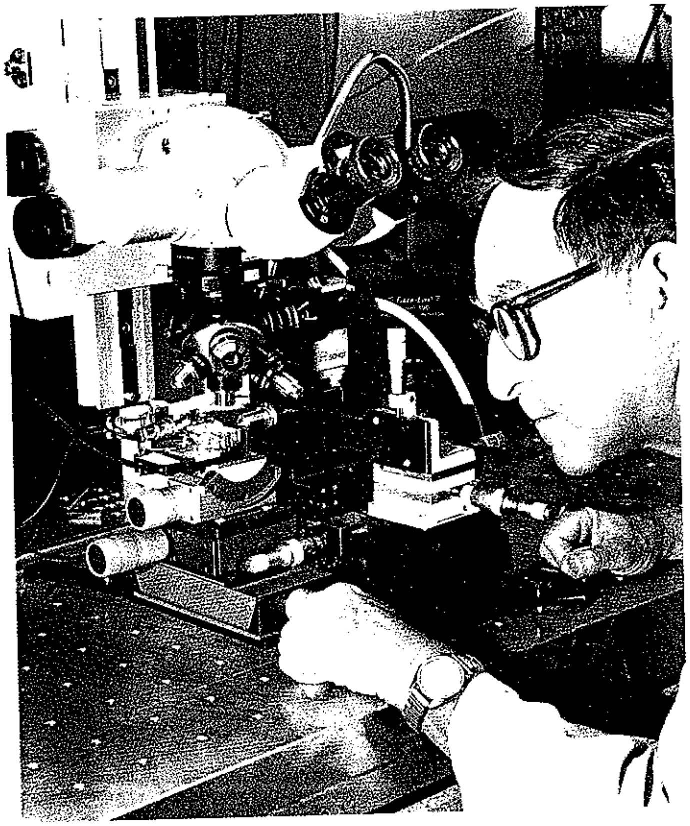
RIGHT: Michael Ettenberg shows a solid-state laser with the multilayer reflector that he invented in 1978. By nearly doubling the laser's output, the reflector extended the laser's operating lifetime while reducing its power consumption.

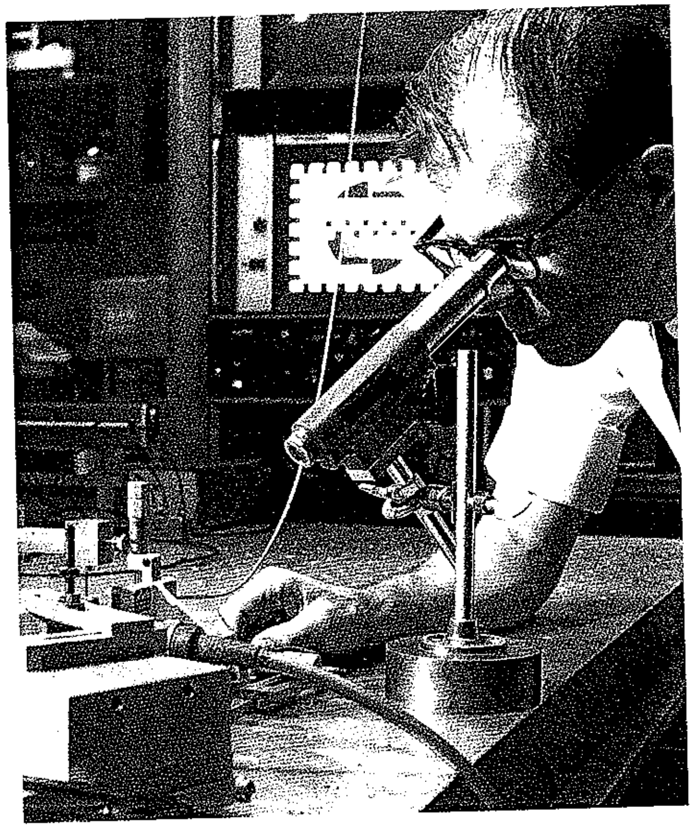
BELOW LEFT: Nobel laureate Herbert Kroemer began his career at Sarnoff in 1954. In his three years in Princeton Kroemer commercialized the drift transistor and published his first article on the benefits of wide-bandgap heterogeneous semiconductors.

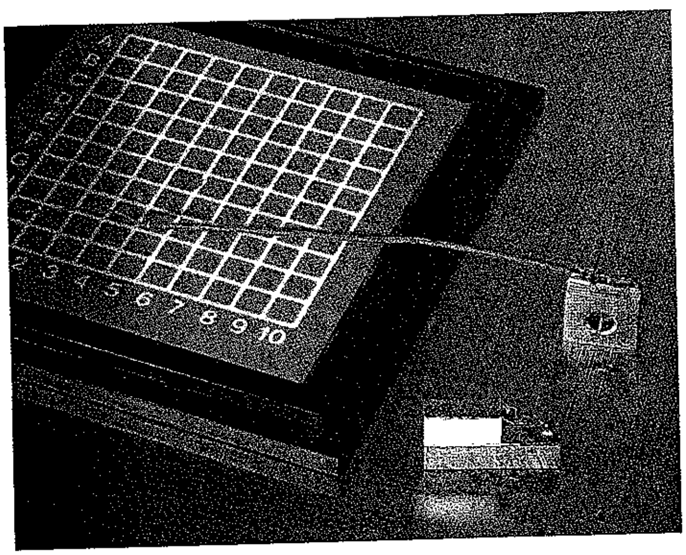
BELOW RIGHT: Grating surface emitter array, c1989.

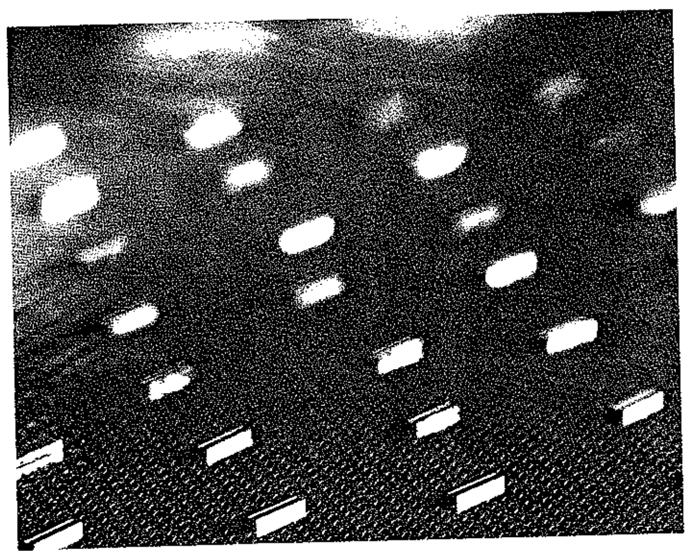


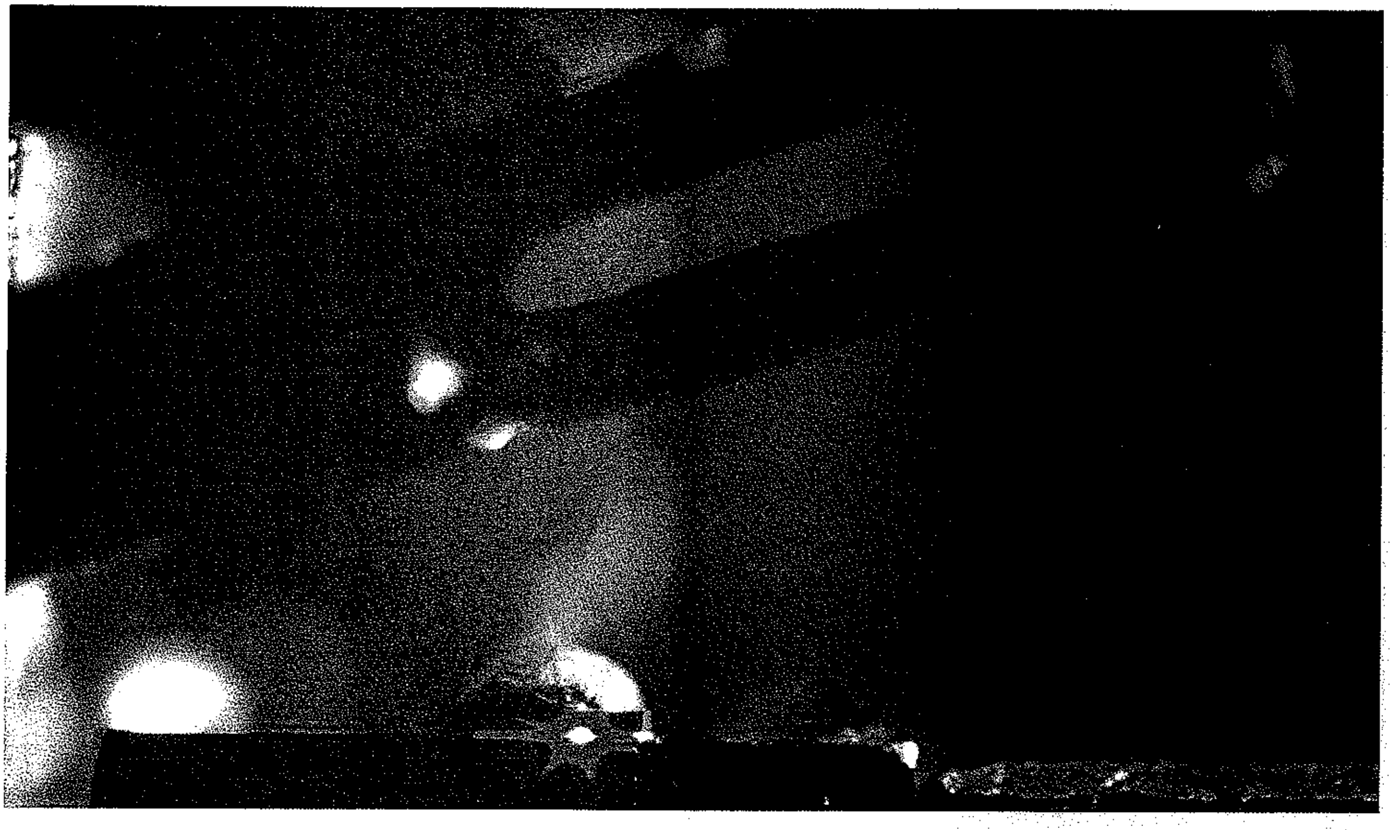


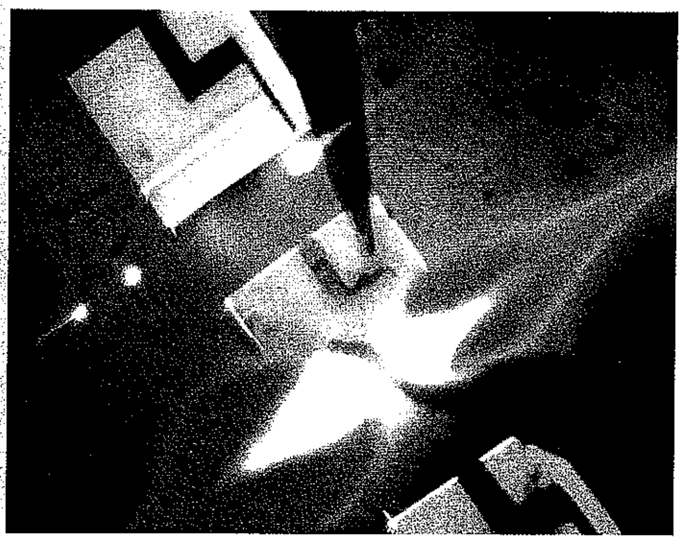












LEFT PAGE (CLOCKWISE):
1) Jacob Hammer examines an external Bragg reflecting laser in 1985. The device simplified the production of single-wavelength lasers used in space and fiber-optic communications.
2) James P. Wittke adjusts the coupling of an LED to a fiber-optic cable during experiments on the quality of analog television signal transmission over fiber optics in 1973.
3) Close-up of semiconductor laser diode chips on the tray in photo at left.
4) Tray of laser diode chips, ready for mounting in headers (right) to create laser assemblies, 2004.

ABOVE: Aluminum Gallium Arsenide (AlGaAs) laser diode is smaller than the eye of a needle.

LEFT: A laser diode emits a single-frequency red beam during testing.