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electro-optics systems

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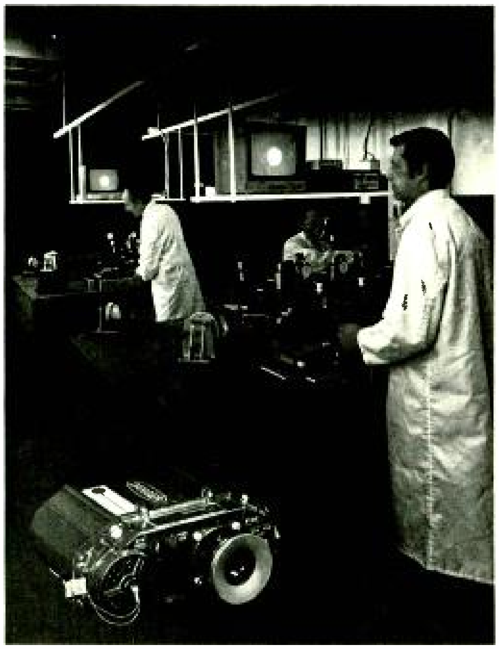

The AN/GVS-5 hand-held laser rangefinder was designed with close cooperation between engineering and manufacturing teams at Automated Systems in Burlington, Mass. Their modular rangefinder design has cut the cost and weight of the unit down to about one-fifth of previous laser rangefinders. The engineers working here in the laser alignment area are (left to right) Walter Radcliffe (technical staff), Dieter Galler (manufacturing), and Kurt Esche (manufacturing).

Photography: Dick Card and Charlie Asbrand, Automated Systems, Burlington, Mass. Special photographic techniques have been used to record the helium-neon alignment laser light.

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

E-O systems: broadening our vision

The extraordinary expansion in electronics over the past twenty-five years has pervaded all human activities—business, travel, education, family.

Man-machine interface technologies and techniques for remote sensing have been the vanguard of this expansion: connecting machine with person and allowing us to acquire better visual information about our world.

Electro-optics has extended our sensory and mental capabilities through improvements at these interfaces and through systems for acquiring, storing, and interpreting optical information. Infrared sensing, low-light-level television, position location, and automatic character recognition are familiar examples to most RCA engineers.

In the December-January issue, the *RCA Engineer* explored electro-optic technology and devices. This issue examines several RCA advances in electro-optic systems, applying the technology and devices. The benefits of these advances can be seen in improved military capability and in better and more cost-effective methods of surveying, medical diagnosis, and optical data recording.

No one can predict the future, and electro-optics is still a technology of the future. However, I am certain that RCA will continue to lead in its development and use. This activity can provide a route for our productive future growth.

E M Stockton

E. M. Stockton
Chief Engineer
Automated Systems
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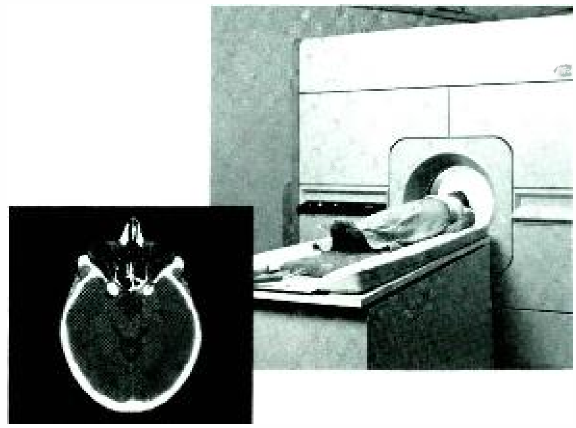
Burlington, Mass.

Electro-optic systems



tomographic X-ray scanners

Photomultiplier tubes and the solution of thousands of simultaneous equations produce cross-sectional x-rays.

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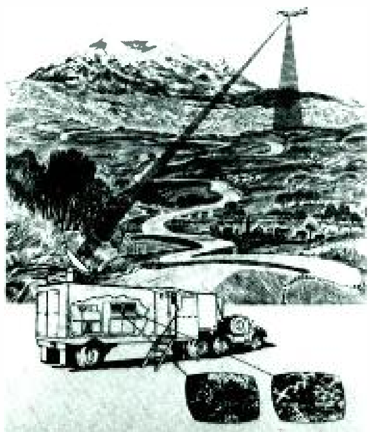

real-time reconnaissance

The return-beam vidicon tv system provides information in minutes, instead of the hours that film systems require.

30

homemade solar collector

Dean Kramer built his own experimental solar heater for under $150.

36

hand-held laser rangefinder

The device pictured on our cover can determine the range to distant objects in seconds. It is also one-fifth the weight and cost of earlier rangefinders.

45, 48

Upcoming issues

Our anniversary issue (Jun/Jul) highlights **the most important technological advances at RCA** during the past year. Among the items covered are the new low-power Xtended Life tv chassis, the microprocessor-controlled safety automobile, and the ANIK-B satellite, plus a special history of NBC engineering.

Future issues will cover **advanced communications, radar, software,** and **space technology.**

RCA Engineer

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an overview

Electro-optic products and systems

P.E. Seeley

This $3-billion market covers systems ranging from television to pollution monitoring to missile guidance.

The electro-optics (E-O) business, which covers components, devices and total systems, has been growing steadily for two decades. Closely associated with this product growth, and in many cases stimulating it, has been a buildup in E-O technology. Further evidence of E-O importance is in the increased amount of technical publishing and symposia activity; a large growth in the number of workers in the field; and the great expansion in plants, facilities, and laboratories. To indicate the size of the current E-O field, recent summary information from two consulting firms[1] gives the following—world-wide E-O sales (mainly U.S., Canada, Europe and Japan) were $2.9 billion in 1976 and will reach $3.8 billion by 1980. Also, figures show that the U.S. military spent more than $900 million in 1975 for electro-optical equipments, which makes it the biggest single customer. As an indicator of future growth, the total U.S. government electronics procurement is expected to grow at a rate of 4.0% per year for the next several years, with the E-O segment comprising 14% of that market.

Why the E-O market has grown

Several factors have nourished this impressive growth:

- The discovery and successful demonstration of the laser in the late 1950s gave the technical community a practical source of controllable, high-intensity optical energy at a single frequency. As an analogy, the laser did for the E-O field what the invention of the magnetron in 1941 did for microwave radar.
- Refinement and perfection of infrared thermal imaging techniques for remote sensing and military night vision.
- Improvements in television technology and tubes; for example, extensions of low-light-level and high-resolution performance; improvements in camera and storage tubes using silicon surfaces; fast electric shuttering technology; and new television applications such as automatic trackers, remote viewing from space, and missile guidance.
- Solid-state electronics, which made possible great advances in E-O equipment packaging, size, weight, power economy, and reliability.
- Better E-O components for displays: silicon and avalanche photodetectors; photomultipliers; fiber optics, light-emitting diodes; beam deflectors; etc.

For future growth there is also great promise in two areas: charge-coupled devices (CCDs) for solid-state imaging and signal processing; and microprocessors for system logic functions and signal processing.

What is an E-O system?

Does a better definition and description exist than "an assembly of optical and electronic components?" In looking at what an E-O system means to most engineers, one finds that it encompasses two or more of the following processes and obviously is designed to perform a useful function.

- Generating and beam-shaping uv, i-r, or visible-light energy. (For example, a light bulb, arc, LED, or laser plus optical elements in most cases.)
- Transmitting light, uv or i-r energy over controlled paths or through the atmosphere.
- Collecting and directing or focusing energy using lenses, mirrors, or holographic techniques. This energy can be: 1) man-made light, uv, or i-r energy that is received directly or via reflection and scattering; 2) energy generated as a by-product at the source—e.g., warm body, missile rocket engine, forest fire; 3) energy from the sun or stars received directly (as used by a star-tracker) or indirectly by scene reflection (as used by a

Courtesy U.S. Army

Fig. 1
Night vision goggles provide night-scene viewing under outdoor darkness with as little as starlight for illumination. RCA Electro-Optics and Devices in Lancaster manufactures image-intensifier tubes used in systems of this type.

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satellite-based or outdoor-located television camera).

- Spectral filtering to select portions of the spectrum of interest while rejecting background and other energy.
- Converting electromagnetic energy to electronic energy (photons to electrons) as with: 1) solid-state detectors or photomultiplier tubes for energy detection and radiometric purposes or optical tracking; or 2) time-sequential scanning devices such as camera tubes, CCD imagers, or detector arrays with mechanical/electronic scanning.
- Light or i-r amplification by means of either laser amplifiers or image brightness intensification (image tube) or by some form of parametric amplifier or optical up-converter.
- Electronic signal amplification by means of secondary electron multiplication (photomultiplier tube), target electron gain (silicon intensifier target tube or secondary electron conduction tube); or video signal amplification.
- Electronic and electromechanical servos and moving platforms.
- Converting electrons to photons, i.e., generating visible light from electrical signals.
- Specialized optical, electronic, or signal processing devices or functions, such as light modulators and light valves, gated intensifiers, optical analog signal processing, high-speed counting circuits for range measurement and readout, fiber optics, and holographic methods for image storage, retrieval and display.

For examples of E-O systems, see the "shopping list" at the right. Figs. 1-3 show typical E-O systems built by RCA or using RCA components.

E-O systems compared with radar

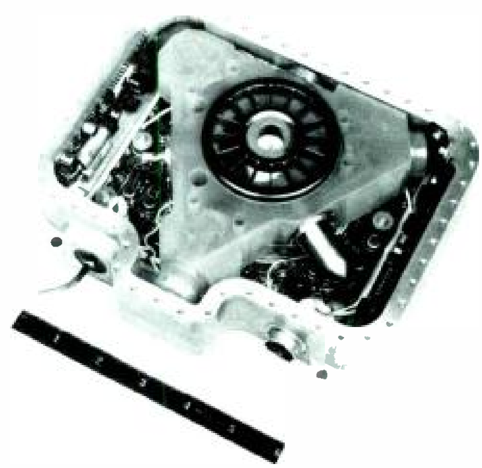
E-O systems and technology are often compared and contrasted with radar. There are many similarities and differences. For example:

A glance at a typical buyer's guide shows the following types of E-O systems:

- Angle measurements
- Automatic positioning
- Card, tape, and character readers
- Data display
- Data retrieval
- Facsimile
- FLIR (forward-looking infrared)
- Height finders
- Horizon sensors
- Image evaluation
- Infrared scanner
- Intrusion detection
- Laser communications
- Laser rangefinders
- Laser gryo
- Laser recording
- Laser designator
- Missile seeker/guidance
- Multispectral scanner
- Night vision
- Optical printers
- Pattern recognition
- Pollution monitoring
- Photo interpretation
- Star trackers
- Surveillance
- Tracking systems, tv and laser
- Television
- X-ray (using E-O processing)

- Electro-optics technology is more involved in the specialty of quantum electronics than is radar technology. This means that although the E-O systems engineer may, in one case, analyze a receiver in a similar manner to radar engineer, in another case he may be involved in statistical detection theory quite apart from

Fig. 2
RCA's ColorTrak is a good example of E-O system design.



Courtesy Honeywell

Fig. 3
Aircraft laser inertial navigation system using ring laser gyro has an MBTF of 2500 hours and drift performance under 0.01 degree/hour (equivalent to less than 1 knot of navigation error).

that applicable to typical radar receivers. (The *RCA Electro-Optics Handbook* discusses this subject in Section 8.) Also, to best understand laser transmitters (laser oscillators or laser amplifiers) and receivers, one should understand quantum physics.

• Radar systems usually must operate all-weather and E-O systems are limited to applications where visibility or i-r transmission is sufficient to maintain useful operations.

• Laser systems fit nicely into applications where range-finding is done with a single transmitted and received pulse (and using a narrow beam), whereas radars usually are better for applications where a large volume must be searched. Also, radar ranging is likely to involve pulse-to-pulse integration and processing. Electro-optical beams can provide ranging or angle tracking at low grazing angles to the ground, as long as the target (vehicle, airplane, etc.) can be seen. Radar, when used at low grazing angles, usually becomes degraded by ground-clutter echoes.

• Electro-optics work involves physical dimensions of 10^{-3} to 10^{-4} smaller than microwave radar dimensions; thus mechanical work and tolerances are much more critical in the optical analogs of microwave components, waveguides, and antennas.

• Laser work can involve pulsewidths in the region of a few nanoseconds for rangefinders and even shorter for specialized purposes. Radar transmits pulsewidths ranging from 0.1 to 100 microseconds or longer and must attain fine range resolution, if required, by pulse-compression techniques.

• E-O designs involve video bandwidths greater than typical radar bandwidths; for example, 100 MHz.

• Lasers can easily produce power densities in the transmitted beams much higher than those for a comparable-sized radar transmitter. This frequently creates materials problems (because of damage) and requires more attention to human safety, particulary eye safety.

• A few years ago, radar systems had the advantage (over laser systems) of providing coherent detection and hence deriving doppler/velocity signals from the moving object—aircraft, vehicle, satellite, etc.—being tracked. Receivers that provide excellent coherent doppler processing are now available to laser designers.

• E-O tracking systems are often called upon to track angle motions more precisely than radar systems; e.g., 5

Table I
Professional societies dealing with electro-optics.

Name	Address	Comments
SPSE (Society of Photographic Scientists and Engineers)	1330 Mass. Ave., Washington, DC 20005	More photographic in outlook than others listed below.
SMPTE (Society of Motion Picture & Television Engineers)	862 Scarsdale Ave., Scarsdale, NY 10583	Important in the fields of television, entertainment, and motion pictures.
SPIE (Society of Photo-Optical Instrumentation Engineers)	338 Tejon Place, Palos Verdes, CA 90274	A very active organization; holds many symposia, publishes and covers much government work.
SID (Society for Information Display)	654 N. Sepulveda Blvd., Los Angeles, CA 90049	Quite active in its field.
OSA (Optical Society of America)	OSA, American Institute of Physics, 335 E. 45th St., NYC, NY 10017 or OSA, 1613 19th St., Washington, DC 20009	The largest single society devoted to optics and related science.
IEEE (Institute of Electrical & Electronic Engineers)	345 East 47th St., NYC, NY 10017	No need to explain what IEEE is and does; active and publishes on television, electro-optics, lasers and solid-state imaging, signal processing, etc.
Laser Institute of America	4100 Executive Park Drive, Cincinnati, OH 45241	Very active in its field since founding in 1965.
Electronic Industries Association, Laser Section	2001 Eye St., Washington, DC 20006	Very much into laser safety and government regulation matters.
IRIS (Infrared Information Society)	Environmental Research Inst. of Mich. Infrared Information & Analyses Center, Ann Arbor, MI 48107 and ONR, 536 So. Clark St., Chicago, IL 60605	Provides a data center and information service via publications and symposia for classified government infrared and related technology fields; since 1950.

to 10 microradians, as compared to a few milliradians for radar.

- Base motion and vibration disturbances are of more concern to the E-O systems designer than they usually are to the radar designer because of the angle tracking and picture-resolution requirements. Vibration problems are also of critical concern to laser recording and holography, to mention two other E-O areas.

Leaving the comparison of radar and E-O systems, we find, within E-O, two distinct types—1) systems working only in the energy/power domain that, like a laser rangefinder or radiometer, do not produce images and 2) systems that may have energy concerns but are more concerned with image quality, such as an image transmission system, a television system, an FLIR (forward-looking infrared) system, a solid-state line array with laser beam recorder, or laser scanner and laser line display.[2]

Summary

The domain of the E-O systems designer (once mainly confined to the fields of commercial television, facsimile, and military work on i-r sensors) has so broadened and expanded that it is not possible in a short article to treat all aspects of E-O system analysis and preliminary design, let alone describe fully the status of hardware implementation and product technology.

This issue, however, presents a number of E-O system design considerations and applications. Each one has its own demands and criteria for testing and optimizing performance; in each case the results achieved must be compared to design expectations before the system engineering task is complete.

References

Tables I through IV have been included to assist the reader interested in further technical and professional information on E-O systems.

1. International E-O business estimates by A.D. Little Inc., Cambridge, MA; U.S. Government business figures by Jeff Montgomery of Gnostic Concepts, Menlo Park, CA.
2. Useful methods for analyzing imaging systems were pioneered by Dr. Otto Schade, Sr., of RCA, and his work is well recognized in this field. For example, see:
"The resolving power functions of imaging systems and of television cameras in particular,"*private correspondence* (1965).
"Image gradation, graininess and sharpness in television and motion-picture systems," Parts I, II, III, and IV, *J. SMPTE*, Feb 1951, Mar 1952, Aug 1953, and Nov 1955.
"A new system of measuring and specifying image definition," NBS Circular No. 526, Apr 1954.

Table II
Journals and magazines covering the E-O field.

Title	Comment
Applied Optics, monthly, by Optical Society of America, 2000 Penna. Ave., Wash. DC 20037.	Renowned in its field; a journal with limited advertising; more optical than electro-optical in nature; special Oct 1970 issue "Optics at RCA."
IEEE Proceedings, monthly, by Institute of Electrical & Electronics Engineers, 345 East 47 St., NYC, NY 10017	Some of the best material comes in the special issues such as: Infrared (Sep 1959); Remote Environment Sensing (Apr 1969); Digital Picture Processing (June 1972); Infrared Technology (Jan 1975); etc.
Electronics, biweekly, by McGraw-Hill, 1221 Ave. of the Americas, NYC, NY 10020.	Excellent source of electronic-circuit and device technology.
Optical Engineering, bimonthly, by Soc. Photo-Optical Instrumentation Engineers, 338 Tejon Place, Palos Verdes, CA	Provides very good articles on E-O systems and optical technology.
Optical Spectra, monthly, by Optical Publishing Co., Pittsfield, MA 01201	Their claim is "spokesman for the optical/laser industry;" a good source for state-of-the-art device information.
Electro-Optical Systems Design, monthly, by M.S. Kiver Publications, Inc., 222 West Adams, Chicago, IL 60606	Excellent source of E-O systems and component articles and "official publication of the Laser Institute of America."
Laser Focus, monthly, by Advanced Technology Publications, Inc., 385 Elliott St., Newton, MA 02164	Very good information on laser research and development, professional activities, E-O industry news, etc.; calls itself "the magazine of lasers and related technologies."
Solid State Circuits, monthly, by IEEE Solid-State Circuits Council, 345 East 47 St., NYC, NY 10017	Provides timely data on solid-state technology including CCDs (for example, special issue Feb 1976).
Journal of SMPTE, monthly, by Society of Motion Picture and Television Engineers, 862 Scarsdale Ave., Scarsdale, NY 10583	Renowned in motion pictures and television.
Information Display, bimonthly, by Society for Information Display, 654 N. Sepulveda Blvd., Los Angeles, CA 90049	The publication of SID.

Table III
Reference books on electro-optics.

Title	Author	Source	Comment
RCA Electro-Optics Handbook, EOH-11	Many contributors from technical staffs at Burlington, Lancaster, and Princeton	RCA Commercial Engineering Publications, Somerville, N.J.	A valuable *must* for E-O systems work.
Handbook of Military Infrared Technology	William Wolf, *et al*	U.S. Government Printing Office	Published in 1965 and still a valuable soruce of information on i-r, E-O systems, and optics.
SPSE Handbook of Photographic Science and Engineering	W. Thomas, Jr.	John Wiley and Sons	Excellent and extensive source on optics and photography and related science; more than 50 authors and contributors. Also contains 60 pages of data on sources of information: books, journals, societies, industrial and government sources, libraries, etc.
Laser Handbook	F.T. Arecchi, editor	American Elsevier Publishing, NYC	Includes theory and applications, published 1972.
CRC Handbook of Lasers	Robert J. Pressley, editor	CRC Press, Cleveland, Ohio	A good reference for library use and possible gift for the laser/optical scientist who "has almost everything."
Applications of the Laser	Leon Goldman, MD	CRC Press, Cleveland, Ohio	Contents range from medical to nuclear to military.
Lasers in Industry	S.S. Charschan	Van Nostrand Rheinhold	Reasonably up to date (1972); author is with Western Electric.
Laser Applications	M. Ross, editor	Academic Press	Two volumes: first on holography, communications, welding in 1971; second on scanning and tracking systems, etc., in 1974.
Advances in Image Pickup and Display	B. Kazan, editor	Academic Press	Two volumes: first on tubes and related information; second on laser displays and striped filter color television. More volumes are scheduled; author is with IBM.
Electro-Optical Systems Analysis	Khalil Seyrafi	Electro-Optical Research Co., Los Angeles	Much worthwhile information here for the E-O system designer; this book was derived from lectures given at UCLA.
Photo Electronic Imaging Devices *Vol. I, Physical Processes & Methods of Analysis* *Vol. II, Devices and Their Evaluation*	L. Biberman and S. Nudelman, editors	Plenum Press	L. Biberman is with Institute of Defense Analysis (IDA) and is heavily involved with E-O military problems and technology applications. S. Nudelman is at University of Arizona.
Handbook of Geophysics and Space Environments	Shea L. Valley, editor	Air Force, CRL, U.S. Government Printing Office	Good reference for aerospace sensor applications.
SPIE Seminar Proceedings and Books	More than 90 different titles	Write for list to SPIE	Pretty much a total picture of everything unclassified in photo-optics and electro-optics, 1963 to 1975.
Optical Engineering Handbook	J.A. Mauro, editor	GE	Published in 1966 by GE Electronics Park Lab.
Infrared Systems Engineering	R.D. Hudson, Jr.	John Wiley	R. Hudson is with Hughes Aircraft; published in 1969.
Optical Industry and Systems Directory		Optical Publishing Co., Pittsfield, Mass. 01201	Annual directory and guide to companies and vendors.

Paul Seeley has over seventeen years of experience in supervision and engineering management of electro-optical programs that have involved research, development, and equipment design for aircraft, space, and ground-based systems. Some examples are: infrared, low-light-level, and high-resolution return-beam vidicon tv; and laser rangefinders, obstacle detectors, and altimeters. He is presently Manager of Technology Planning at RCA Automated Systems.

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Automated Systems
Burlington, Mass.
Ext. 3095

Table IV
Courses in different areas of electro-optics.

Course title	Sponsored by	Date	Comment or author
Infrared Technology (1) Fundamentals (2) Advanced	University of Michigan	(1) July, one week (2) July, one week	Two excellent courses, given since early 1960s
CCDs (1) Applications (2) Physics and Technology	UCLA	(1) November, one week (2) April, one week	
Infrared Radiation Technology	UCLA	February and July, one week	
Lasers	UCLA	July, two weeks	A relatively new course
Fiber Optic Communication Systems	UC at Santa Barbara	July, one week	A relatively new course
Detection of Infrared Radiation	UC at Santa Barbara	July, one week	A relatively new course
Digital and Optical Image Processing	Inst. of Optics, University of Rochester	June, one week	One of the several excellent, one- to two-week programs given at the Institute of Optics; others are on Optical System Design, etc.
Properties and Applications of CCDs	Northeastern University	September to February	14-session evening course covers E-O and other applications of CCDs
Photoelectronic Imaging Devices	University of Arizona	August, two weeks, held at San Diego	Dr. S. Nudelman 49 lecturers
Optoelectronics	RCA Engineering Education	Available September, 1977	Dr. L. Shapiro (RCA) Dr. I.A. Miller (Drexel U.)
Others	University of Wisconsin, MIT, RPI, University of Tennessee, George Washington University, University of Colorado, and many more.		New and continuing courses are being offered each year on E-O, lasers, CCDs, optical information processing, fiber optics, coherent optics, etc.

Laser optical inspection systems

A.H. Firester

Laser-based systems can find defects in IC photomasks more quickly, more reliably, and more precisely than a human operator.

One method of determining the quality of a product is to look at it. Indeed, the word *inspection* has its roots in the Latin root for "look." The optical inspection systems that I discuss here operate by "looking" with a laser beam. What makes these systems better than simple visual inspection is that they are faster, more reliable, and more precise than a human operator. And, in some cases, they can "process" optical information in a way that would be nearly impossible for a human operator.

In this article, I briefly discuss two optical inspection systems that have been developed within RCA for corporate-wide applications. The specific examples described here are only a few of the application areas for optical inspection systems. We can anticipate that increased automation, more sophisticated products, and higher productivity will also enlarge the role of modern optical inspection systems.

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Art Firester has been involved with electro-optics for some time—his doctoral dissertation was on the modulation of light by optically pumped alkali-metal vapors. His recent research has been in nonlinear optical phenomena and their possible application to image processing; he is also working with coherent-light optical problems and holography.

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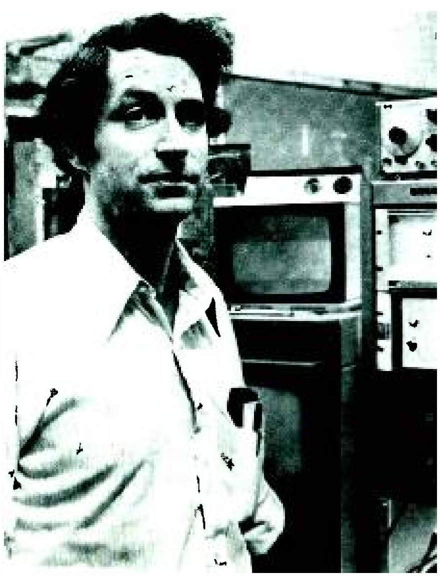


Lasers and modern optics

This article provides the reader with both a basic knowledge of the optical principles, and some techniques and areas of application of, optical inspection systems. The common thread in all these systems is the use of a laser and an approach to modern optics, which is essentially laser-based. It is appropriate, therefore, to first discuss the laser itself and the underlying optical principles upon which these inspection systems are based, and then illustrate these laser properties and optical principles by specific examples.

Lasers are ideal for these applications because of their brightness, directivity (or spatial phase coherence), monochromaticity, and availablility.

Source brightness is the amount of power emitted per unit area, per solid angle. It is a basic optical quantity that is never increased by a passive optical system.[1] Therefore, for any optical system the source brightness determines the output-signal intensity, brightness, or signal-to-noise ratio. Typically, a small HeNe laser has an output power of about one milliwatt with a beam diameter of less than a millimeter and a beam divergence of about one milliradian. This yields a brightness of more than 10^5 watts/cm^2/steradian. Furthermore, the laser output is concentrated within a very narrow spectral region.

Although high brightness alone would enable the use of the laser in inspection applications, the high intrinsic directivity caused by the spatial coherence of single transverse-mode operation further increases the laser's utility. This allows us to readily move the beam around. We need no special relay systems or large-aperture optics to prevent power loss as we move the light from the laser source to the working end of our system. Additionally, this spatial coherence means that we can efficiently obtain diffraction-limited performance with simple, small-aperture, high-f-number lenses. Finally, all these attributes would be of little practical use if these lasers were expensive, overly bulky, or extremely wasteful of power. On the contrary, the workhorse of these systems, the small HeNe laser, can be purchased for less than $200, fits in a shoebox, and consumes less than 50 watts.

The basic optical principles upon which these inspection systems are based include:

1) diffraction;

2) diffraction-limited focusing of lenses; and

3) the capability of lenses to perform two-dimension Fourier transformations.

Diffraction phenomena

If a plane wave of light impinges on an absorbing screen with an aperture as shown in Fig. 1, then the light will spread out angularly on the other side of the aperture; it will not cast a shadow of the occluding screen. As the aperture is made smaller, the light spreads further. This is the optical analog of the Heisenberg uncertainty principle. As the light location is constrained in the x-direction, the component of its momentum (or propagation vector) in the x-direction becomes more poorly defined. The relation describing this spread is

$$\sin\theta = \lambda/2d \qquad (1)$$

where θ is angular deviation of the first null in the angular radiation pattern, λ is the wavelength of the light, and d is the linear aperture dimension. At distances far from the diffracting object, the angular amplitude spectrum (the Fraunhofer diffraction pattern) of the spreading light is proportional to the two-dimensional Fourier transform of the light amplitude on a plane just after the diffracting object.

Lens focusing

The focusing of a lens (Fig. 2) is the converse of the diffracting aperture. If a lens with focal length f is illuminated by plane wave of diameter D, then at a distance f from the lens the light will be focused to a small spot of diameter d.

The size of the focused spot will depend upon both the focal length of the lens and the diameter of the illuminating wave. This dependence is the same as that given by Eq. 1 except that now θ is the focusing cone angle given by

$$\theta = \arctan D/2f \qquad (2)$$

For example, if $D = 5$ mm, $f = 25$ mm, and $\lambda = 633$ nm, then the diffraction-limited spot diameter d will be 3.2 μm; this is a very small spot for most inspection applications. Since the lens f-number ($=f/D$) for this completely filled lens is not extremely small, diffraction-limited lens performance can be obtained.

A comparison of Figs. 1 and 2 suggests an intimate relation between object diffraction and lens operation, and indeed there is. It can be shown[2] that if an object placed at the front focal plane of a lens is illuminated by a plane wave, then the light amplitude on the back focal plane of the lens is directly proportional to the two-dimensional Fourier transform of that object. This property of lenses, illustrated in Fig. 3, is the basis for Fourier optics and image processing, and, as I show later, can be used to great advantage in optical inspection systems.

Basis for optical photomask inspection

Now let us consider the use of optical inspection systems for inspecting the photomasks used in producing semiconductor integrated circuits. The increased demands of large-scale integration for further miniaturization and complexity, coupled with increasing yields and profitability, have increased the importance of 100%-inspected, defect-free photomasks. Prior to the development of these machines, it had been both technically and economically impossible for an

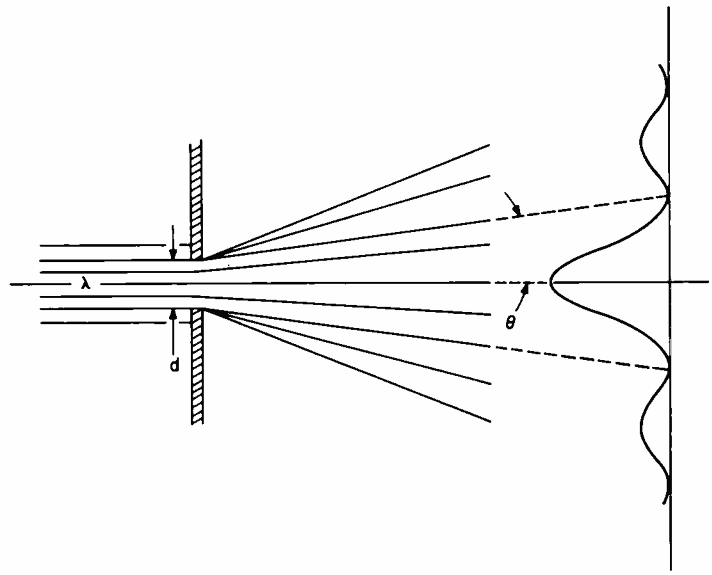


Fig. 1
Diffraction is the basis for the Fourier-optics inspection system. Light spreads out angularly as it passes through aperture in an opaque screen.

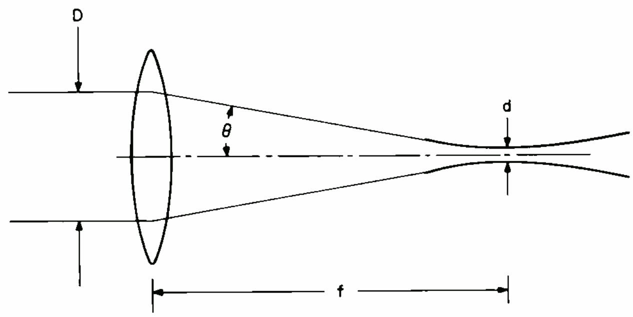
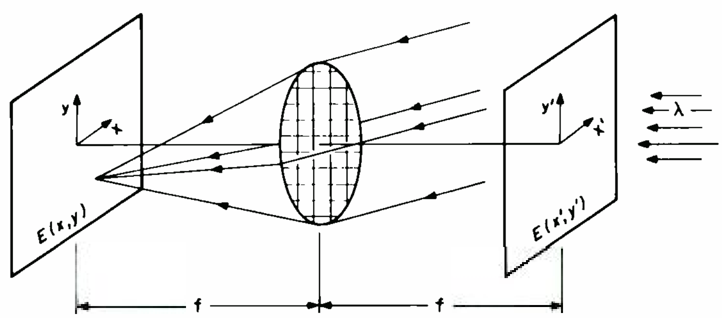


Fig. 2
Lens focusing is the converse of diffraction. Size of spot, *d*, depends on diameter of wave, *D*, and focal length of lens, *f*.



$$E(x,y) = \frac{1}{j\lambda f} \int E(x',y') \exp\{-j(2\pi/\lambda f)(xx'+yy')\}\, dx'dy'$$

Fig. 3
Fourier optics and image processing is based upon relationship between diffraction and focusing. If an object is placed a distance *f* in front of the lens, the light amplitude at *f* behind the lens is proportional to the two-dimensional Fourier transform of the object.

operator to completely and reliably inspect an *entire* photomask.

Two types of optical inspection systems have been developed at RCA Laboratories. Both are predicated on the fact that each photomask consists of a step-and-repeat array of identical patterns; each pattern corresponds to a single IC. Thus, to find random defects in these patterns, each one can be compared with its neighbor; any discrepancies found are defects. The first IC mask-inspection system described here uses a differential laser scanning technique and the second uses Fourier-optics image-filtering.

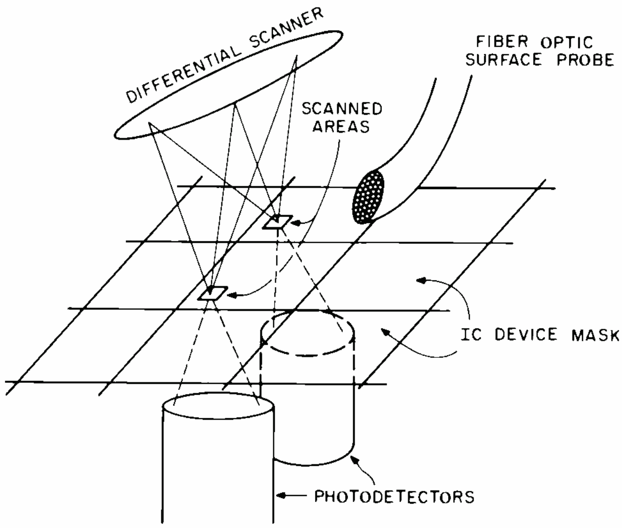


Fig. 4
Differential laser scanning system scans adjacent areas of photomask and compares respective photodetector outputs. Surface probe is used to discriminate between actual mask defects and surface contamination.

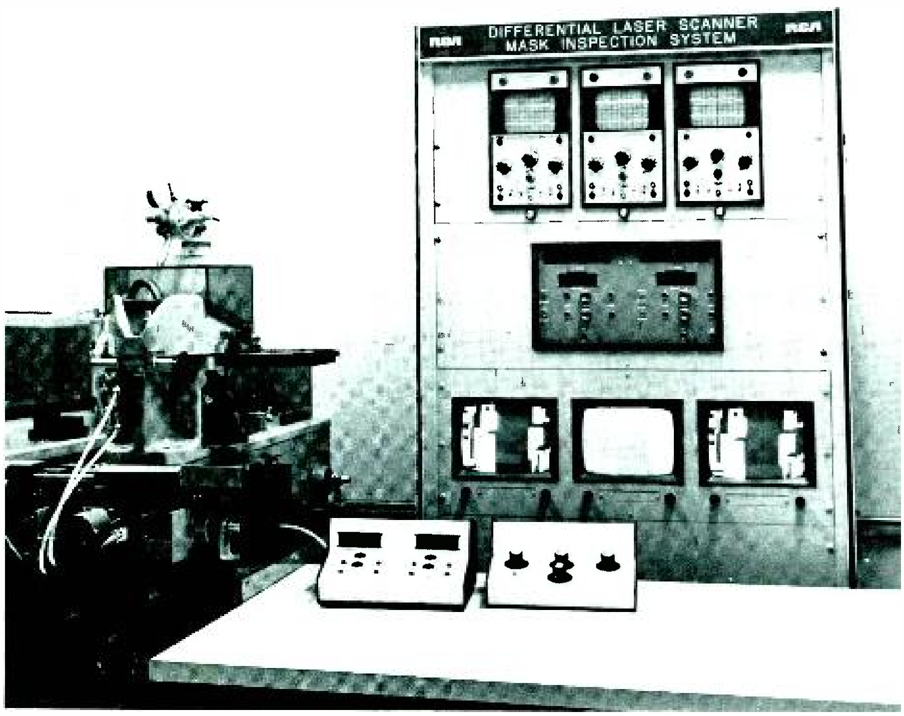


Fig. 5
Differential laser scanner mask-inspection system detects defects as small as two micrometers in diameter.

Differential laser scanning system

This method scans and compares adjacent portions of the photomask.

The heart of the differential laser scanning system[3,4] is the laser beam deflection system.[5] This system forms a two-dimensional scan pattern by utilizing a solid-state acousto-optic deflector and an electromechanical galvanometer scanning mirror. The acoustic deflector is constructed from paratellurite and is sequentially scanned at tv line rates for the fast-axis scan. The light deflection along the other axis is from the galvo-driven mirror also being sequentially scanned at tv-field rates. With both optical scanners properly synchronized and incorporated within a beam-deflection optical system, the result is a tv-raster-type scan pattern. By incorporating a beam splitter in a symmetrical optical arrangement, the differential system scans two identical optical fields in a one-to-one ratio over adjacent portions of the repetitive structure of the mask. This is illustrated in Fig. 4, where the dotted lines represent the step-and-repeat circuit patterns comprising the integrated-circuit mask. Fig. 4 also illustrates the optically scanned fields that represent the corresponding portions of the mask pattern being scanned by the laser beam.

As the laser beams are scanned over the surface of the mask, the light is transmitted through the mask and intercepted by two photodetectors, whose outputs are then processed and compared. Since the laser beams scan identical patterns, random defects are indicated by pattern differences. When this difference signal is displayed on a tv monitor, the result is a mask defect pattern with the mask pattern itself subtracted out. The problem that arises most often with this system is in discriminating between real mask defects and surface contamination, such as dust. To circumvent this problem, a fiber-optic surface probe is used to collect the light scattered from the mask surface. By looking at both the transmitted light and the surface scatter, it is possible to accurately distinguish real defects from dust or surface contamination.

The differential laser scanner mask-inspection system shown in Fig. 5 can detect defects as small as 2 μm while providing a tv image of the circuit magnified by about 400 times. Using this system, the operator needs only to classify defects; the scanner does the more difficult work of locating them.

Fourier-optics systems

This approach to defect detection is based upon the diffraction of light by the integrated-circuit photomask itself.

The basic optical system in this method (Fig. 6) consists of two identical lenses separated by twice their focal length. As discussed earlier, if an object is illuminated by a plane wave, then the light amplitude at the mid-focal plane is proportional to the two-dimensional Fourier transform of the object. In this case, the object is the integrated-circuit photomask located at the focal plane of the first lens.

Let us consider the construction of the light pattern in this focal plane—the Fourier transform of the step-and-repeat photomask. Because of the periodic nature of the step-and-repeat photomask, the Fourier transform or diffraction pattern consists of a two-dimensional array of bright spots. The spacing of these bright spots depends only on the step-and-repeat spacing of the photomask, not on the individual device pattern being repeated. On the other hand, the amplitude of these spots does depend upon the individual device pattern.

In the optical system depicted in Fig. 6, the light pattern in the mid-focal plane is Fourier-transformed by the second lens to form an image of the original photomask in the final detector plane. However, if a mask consisting of an array of opaque spots is placed at the mid-focal plane, and if these spots block each of the bright spots in the Fourier transform of the photomask, then no light passes through the second lens for a perfectly periodic photomask. If, on the other hand, there are a number of defects in the photomask, the diffraction pattern or Fourier transform of these defects is not confined to the array of bright spots, but, depending on the defect, will generally cover the Fourier-transform plane. Accordingly, the light diffracted by these defects is not blocked by the array of opaque spots and is imaged by the second lens on the detector plane. Thus, the defect is imaged at its geometric image location as a bright spot on a generally black field. Furthermore, the defect will appear bright whether it is an opaque area in the normally clear part of the pattern or a clear area where the photomask should be opaque.

An actual Fourier processor for integrated circuit photomask inspection[6] is shown in Fig. 7. The processor consists of a collimated laser source, two high-quality lenses specially designed for this application, a spatial filter consisting of an array of opaque spots, and a tv camera. The spatial filter is specially made for each particular step-and-repeat spacing. Fourier processors are parallel processors (they operate over their entire field of view instantaneously); this system can operate over a field of view two inches in diameter with a defect resolution of slightly less than 10 μm. Defect detection is done by placing a tv camera at the defect-image plane and displaying the defects occurring in a 0.5″ × 0.5″ area on a tv monitor. The photomask under test is then translated so that the entire useful area of the photomask is scanned on the tv monitor.

Conclusions

This article has discussed two optical inspection systems. There are more that could have been mentioned and there will be more applications in the future where laser optics can play a useful role. We can expect that, based upon further progress in lasers, optics, and detectors, more and more optical inspection systems will be developed. Simple optical techniques will be more easily implemented and more sophisticated techniques will become practicable. This article has attempted to introduce some concepts, techniques and present applications with the hope that they will suggest new solutions to future problems.

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5. Gorog, I.; Knox, J.D; Goedertier, P.V.; and Shidlovsky, I.; "Television Rate Laser Scanner—Parts I & II," *RCA Review*, Vol. 33, No. 4 (Dec 1972).
6. This system was developed by A. Firester, M.E. Heller, and W.R. Roach of RCA Laboratories, Princeton, N.J., and F Caprari, of the Solid State Technology Center, Somerville N.J.

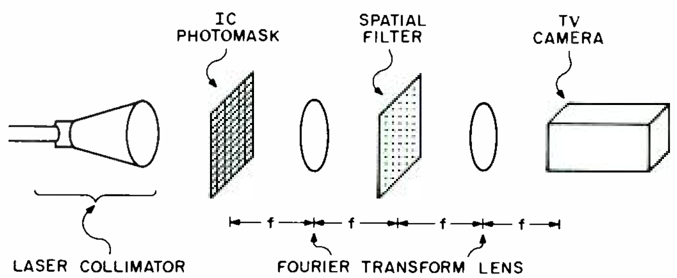

Fig. 6
Fourier-optics approach starts by Fourier-transforming the light pattern passing through the IC mask; result is an array of bright spots, associated with a perfect mask, plus a second pattern if there are any defects present. Spatial filter of opaque spots is arranged to block out the "perfect-mask" array in the Fourier transform, leaving only the defect images on the tv monitor background.

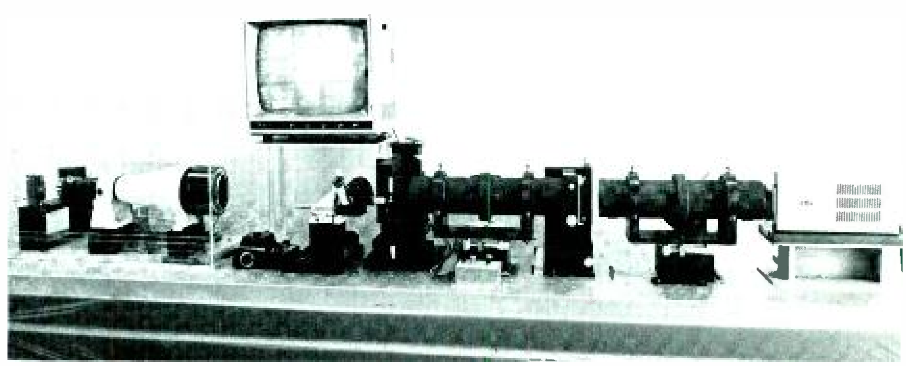

Fig. 7
Fourier-optics photomask inspection system, which has a defect resolution of ten micrometers, can operate over a field of view two inches in diameter.

Inspecting IC masks with a differential laser scanning system

J.D. Knox
P.V. Goedertier
D.W. Fairbanks
F. Caprari

With increased integrated-circuit miniaturization, defect-free masks become increasingly important. Laser scanning can provide 100% mask inspection quickly.

One of the major disadvantages of using the standard microscope for inspecting mask patterns, especially complex ones, is eye fatigue. Mask-inspection groups at the factories are becoming increasingly concerned about operator fatigue with the inspection of the latest high-density arrays. Even under the best of conditions, time constraints limit the inspection to only a portion of the IC mask. In addition, many defects are overlooked because of the high pattern-density of these masks. All of these factors lumped together form a bottleneck in the IC manufacturing process and greatly reduce production yields.

Differential mode overcomes limitations

The differential laser scanner mask inspection system[1,2] overcomes these limitations through its inherent differential operating mode, allowing the operator to quickly locate and classify all defects on the IC mask. The heart of the system is the laser-beam deflection arrangement[3] that uses a solid-state acousto-optic deflector and an electromechanical galvanometer scanning mirror to form a two-dimensional raster-type scan pattern. Briefly, the IC mask-inspection system works by scanning a split optical field in a one-to-one ratio over corresponding portions of the repetitive structure of the IC mask. An x-y positioning table translates the mask past the scanning beams. The laser deflection system is used as a flying-spot scanner and the optically scanned fields are viewed on tv monitors in the image-pickup mode. This arrangement allows the operator to compare adjacent IC patterns one on the other for random-type defects.

A few remarks about the IC mask itself should be made before going into the details of the IC mask-inspection system. As shown in Fig. 1, the IC mask takes the form of a matrix where each element, commonly called a pellet, represents the integrated-circuit pattern. The pattern images are formed by a precision step-and-repeat exposure process. That is, adjacent IC patterns are uniformly spaced on precision centers and oriented in the same manner. This precision is required since a number of these masks comprising a set must be superimposed and registered to within very close tolerances (typically one micrometer) in the IC fabrication process.

The system works by scanning two identical optical fields over adjacent portions of the repetitive structure of the mask.

This is accomplished by incorporating a precision beam-splitter in a symmetrical optical arrangement, and is illustrated in Fig. 2. Fig. 3 gives a little more detail about the laser-scanned optical fields. The area in each field is covered by 525 interlaced tv scan lines; each area typically measures 0.020″ × 0.025″. Again, this scan pattern is

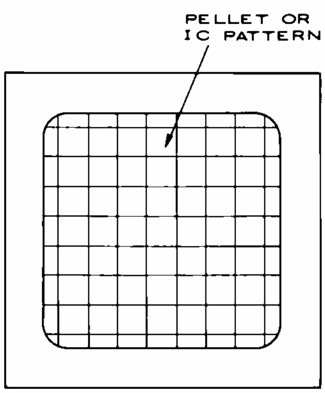

Fig. 1
An IC mask takes the form of a matrix, with each element or "pellet" representing the IC pattern. All elements are uniformly spaced, oriented in like manner, and located on precision centers.

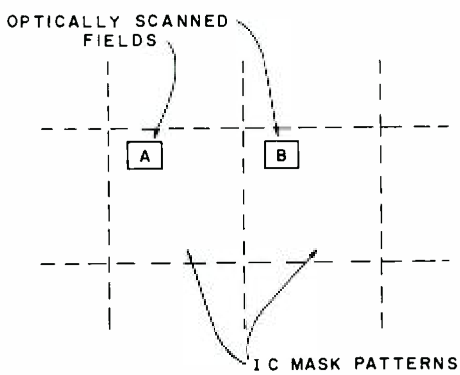

Fig. 2
Step-and-repeat patterns (dashed lines) make up the integrated-circuit mask. Fields *A* and *B* are the corresponding areas of the mask being scanned by the laser beams.

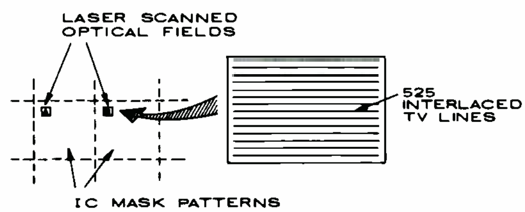

Fig. 3
Laser-scanned optical fields consist of 525 interlaced tv lines generated by the sequentially scanned horizontal and vertical light deflectors.

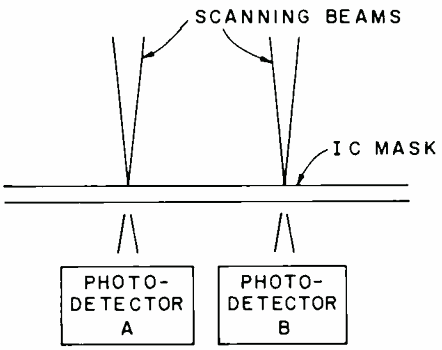

Fig. 4
As the laser beams are scanned over the surface of the IC mask, the transmitted light is intercepted by photodetectors *A* and *B*.

generated by a solid-state acousto-optic deflector and a galvo-driven scanning mirror. The acoustic deflector is constructed from tellurium dioxide and is sequentially scanned at tv line rates, providing the fast axis scan. The light deflection along the other axis is derived from the galvo-driven mirror being sequentially scanned at tv field rates. Both optical scanners, properly synchronized, will generate a tv raster-type scan pattern.

As the laser beams scan over the surface of the mask, the light transmitted through the mask is intercepted by two photodetectors.

This is illustrated in Fig. 4. When the beams scan over the IC mask, the transmitted light is interrupted, which modulates the output of the photodetector according to the mask-pattern geometry. The resulting output signals from the photodetectors are then processed and compared. Since the laser beams scan identical precision patterns, defect-free patterns will produce identical outputs from the photodetectors, and so a null-signal output from the differential comparator. However, random defects will produce a difference indication. When this difference signal is displayed on a tv monitor, the result is a mask-defect pattern with the mask pattern itself subtracted out. This method significantly reduces the burden of locating the defects within these complicated pattern structures, allowing the operator to find all the defects.

The integrated-circuit patterns themselves, magnified about 400 times, can be viewed when the photodetectors are displayed on two tv monitors.

Fig. 5 shows how the monitors and photodetectors are arranged, and Fig. 6a is a photograph of a typical defect map displayed on the defect monitor. The actual

Joseph Knox has worked extensively in the design and development of optical scanning systems. In addition to the one described here, these systems have been used for laser deflection displays, light valve displays and information scanning. Dr. Knox's other activities include the design and fabrication of acousto-optic deflectors, modulators, and cavity dumpers for visible and infrared lasers.

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Peter Goedertier was the co-discoverer of the He-Ne "cascade" laser and a pioneer in the development of the cross-pumped YAG:Nd:Cr laser. His other research projects have ranged from ion physics and early gaseous and solid-state optical masers to electro-optics and the development of various optical systems.

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David Fairbanks was responsible for the mechanical design of the laser scanner mask-inspection system described here. He has also done mechanical design work on SelectaVision player systems, photovoltaic tracker, and other in-house and production equipment.

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Fausto Caprari joined the SSTC in 1975, with the responsibility of transferring the mask-inspection-system technology from RCA Laboratories to SSD. Before that, he had an active part in the system's development at RCA Laboratories. His other electro-optics experience includes a system for soft-contact and proximity printing that is now being used at a number of RCA photomask operations.

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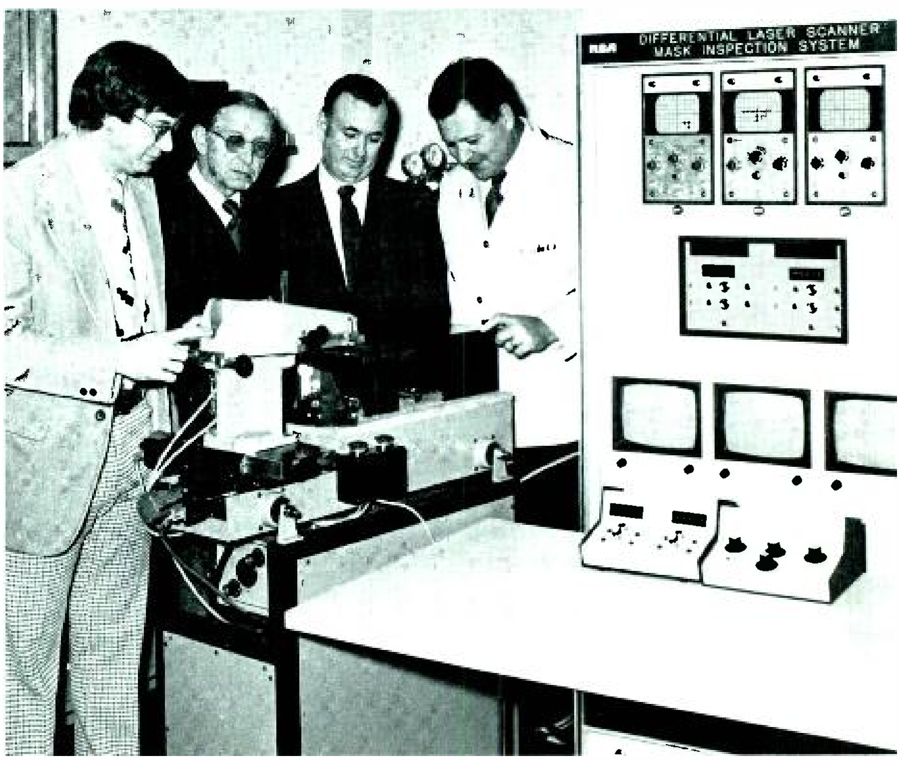
Left to right: **Knox, Goedertier, Fairbanks,** and **Caprari**



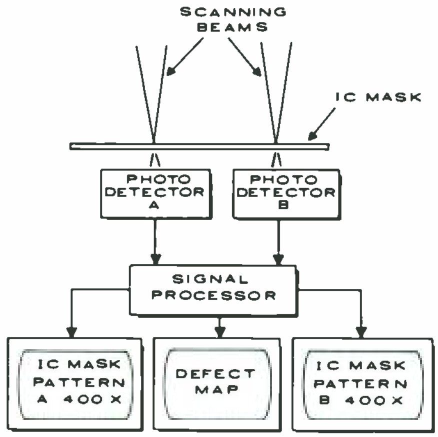


Fig. 5
Signal outputs from photodetectors *A* and *B* are processed in a differential comparator, then displayed on the center tv monitor showing the defect map. Monitors *A* and *B* show the respective IC mask patterns magnified about 400 times.

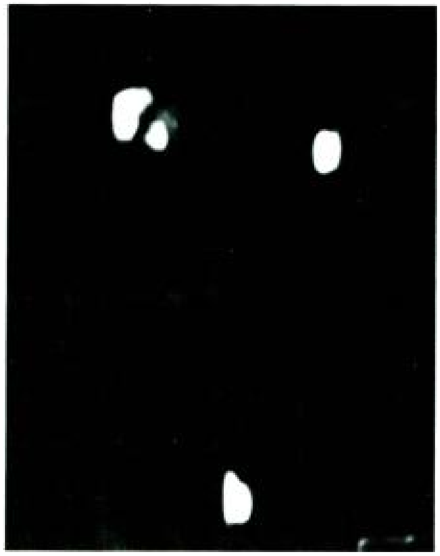


Fig. 6a

Fig. 6b

How defects appear to the operator. Defects can be located quickly on the defect monitor (left), then have their locations on the IC pattern established on the pattern monitor (right). Note that the defect at tne upper right on the defect monitor would be very difficult to identify using the pattern monitor alone.

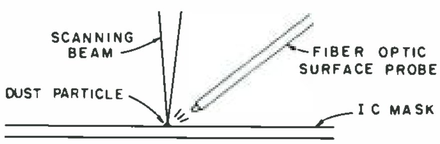


Fig. 7
Fiber-optic probe is placed at a shallow angle to collect the side-scattering caused by dust or similar contamination.

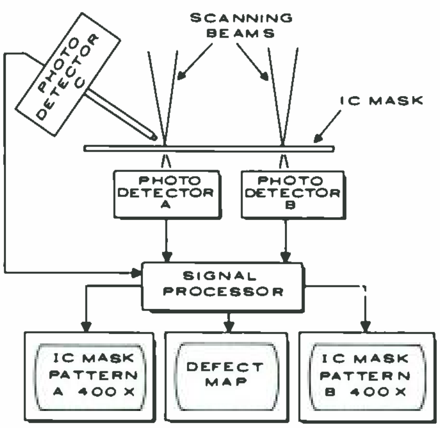


Fig. 8
Entire light-collection arrangement allows the operator to look at transmitted and surface-scattered light.

pattern defects can be viewed on one of the pattern monitors (Fig. 6b). These irregularities can be quickly located by comparing the defect map to corresponding locations on the monitor displaying the IC pattern with the defect. The defects here range in size from about 6 μm to 12 μm. The defects at the upper left and lower right of Fig. 6 represent either pattern irregularities, such as broken leads, or surface dust. However, the defect shown in the upper right of Fig. 6 represents an emulsion stain. This defect type is very difficult, and many times impossible, to detect using a standard microscope. In this particular example, the defects are easily located on the pattern monitor. Many times, however, the defect may be quite small and well nested within the complicated mask pattern, making it nearly impossible to locate; but with the aid of the defect map (Fig. 6a) the operator is able to pinpoint the defect location on the mask pattern (Fig. 6b) and record its presence.

It is important not only to find all defects, but also classify them to have a complete picture of the usability of the IC mask.

For example, a given defect level may mean mask rejection; however, if many of the defects are a result of surface contamination, then simply cleaning the mask will restore it to a useful condition. Also, defect classification gives diagnostic information pointing to possible processing problems.

Therefore, to further speed the inspection process, an optical means of distinguishing the various defect types is highly desirable. To circumvent the problem of discriminating between chrome spots and surface contamination, a surface detector has been incorporated into the system to collect scattered light from the mask surface. This is illustrated in Fig. 7, where the fiber-optic probe* is placed at a shallow angle so it collects only the scanning-beam light that is reflectivity-scattered from the dust particles on the surface. In effect, the surface probe suppresses the pattern information by collecting only the strong preferential scattering from the dust particles.

Fig. 8, a schematic of the entire light-collection system, demonstrates the operator's capability of looking at both the transmitted and surface-scattered light and so accurately classify almost all mask-defect types. Fig. 9 demonstrates the effectiveness of this optical system. The pattern-monitor photograph of Fig. 9a shows how a group of mask defects (in the upper right-hand corner) appears without the surface probe activated. The defects here range in size from about 4μm to 8μm.

*Four probes placed at 90° angles is a more desirable light-collection arrangement.

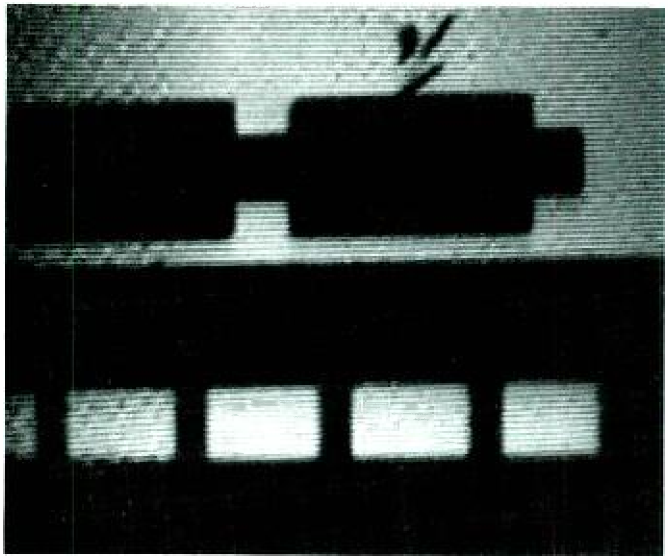


Fig. 9a

How the operator classifies defects. Pattern-monitor photograph at left shows a group of mask defects in the upper right-hand corner. At this point, defects remain unclassified.

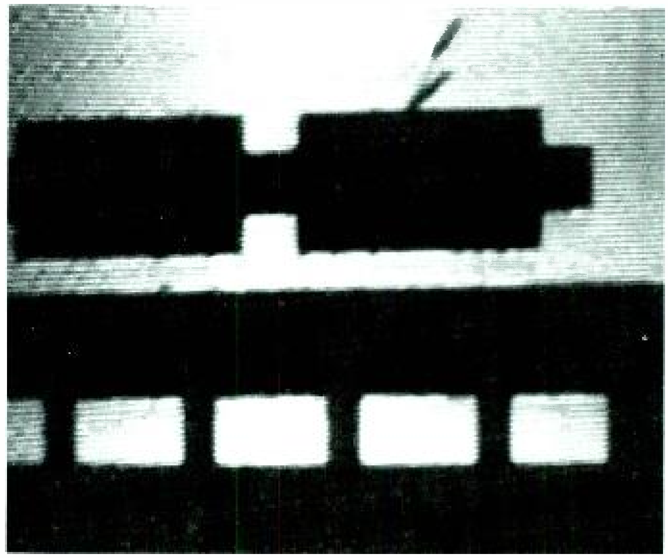


Fig. 9b

With surface probe activated, one of the defects appears as a white spot, identifying it as surface dust.

At this point, the operator cannot be sure whether the defects are chrome spurs, surface dust, or a combination of the two. However, by activating the surface probe (Fig. 9b), the operator can determine that the defect group consists of two chrome spurs and one dust particle.

System performance

An experienced operator can thoroughly inspect an entire 4" X 4" high-density mask, both recording and classifying all defects, in a little over an hour.

For inspection, the operator places the mask on an x-y scan table that moves the mask past the scanning laser beam in a zig-zag fashion. The operator observes the center monitor, which displays the IC mask defect map. This enables the operator to quickly pinpoint the defects, which can be observed on the pattern monitors magnified about 400 times. With the aid of the surface detector, the operator can then classify the defect according to type.

The inspection system has proved to be especially suitable for investigating masters before subsequent submasters are made from them. In addition, the mask-inspection system has also been used to look at actual integrated circuits on sapphire wafers to correlate electrical performance with observed physical aberrations found in the circuit structure. This system has also proved to be a powerful diagnostic tool. For example, it detects step-and-repeat runout errors and pattern irregularities, alerting the operator to possible processing problems somewhere within the production chain.

Resolution is about five micrometers.

The mask-inspection system itself is inherently capable of detecting defects as small as 2 μm, which is commensurate with the spot size of the focused scanning beam. However, this applies only where the defects are out in the open, such as chrome spots, dust particles or pits in the substrate. For edge defects, considerations such as step-and-repeat errors and dimensional variations in the mask limit the resolution of the differential laser scanner to about 5 μm. We must thus assume this level to be the overall resolution capability of the mask-inspection system. As higher-precision masks generated by electron-beam exposure systems come into use in the near future, we anticipate more precise and efficient use of the differential laser scanner as a mask-inspection tool.

Summary

The tedious task of integrated-circuit mask inspection has been greatly simplified by using laser-beam scanning and associated optical techniques. State-of-the art systems range from the semi-automated type of system described here to fully automated systems.[1] There is an interesting compatibility relationship between the machine and operator. The machine quickly locates the defects, which is difficult for the operator to do. However, the operator classifies the defects, which is difficult for the machine to do. Based on this consideration, it may still be wise to keep the operator in the loop, regardless of the degree of automation desired.

Acknowledgments

The authors are deeply indebted to J. Csercsevits, J. Martin, W. Mitchell, S. Bus, and W. Young for their technical assistance. The authors are especially grateful to J.Y. Avins for the later addition of a digital readout for IC pellet location. The support, encouragement, and helpful discussions of Dr. I. Gorog are also greatly appreciated.

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Computerized tomographic x-ray scanners

R.W. Engstrom

Computerized tomographic scanners show the internal organs of the body in cross section and thus are extremely valuable for diagnosis. They also represent a large potential market for RCA's photomultiplier tubes.

A new diagnostic medical instrument, the computerized axial tomographic (CAT) X-ray scanner, is causing great excitement in medical circles where it is viewed as the most revolutionary development since Roentgen discovered X-rays in 1895. Concurrently, it represents a challenging business opportunity for medical-equipment suppliers such as EMI, Ohio-Nuclear, General Electric, American Science and Engineering Inc., Phillips, Searle, Picker, and Pfizer. For the RCA Electro-Optics and Devices activity, the CAT scanner also presents a unique opportunity: photomultiplier tubes are used in large numbers in these equipments. RCA is presently a leading supplier of photomultiplier tubes for the medical imaging market, and is in an excellent position to capitalize on this promising development.

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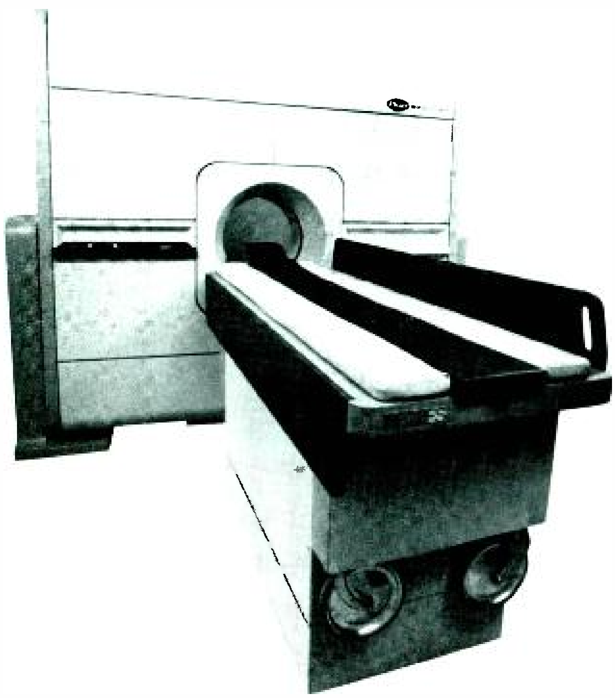
The CAT scanner produces an X-ray image in an entirely different manner from that of conventional radiography.[1] The standard X-ray picture is a shadowgraph; thus a chest X-ray produces an overlay of shadows from the rib cage and internal body structure. Interpretation is frequently difficult because of the interfering images. The CAT scanner, on the other hand, provides a density image which represents a cross section of the patient—a tomograph. Thus, a CAT scan of the head would show the outer bone structure, the folds of the brain, and possibly a tumor inside the skull as though a complete thin slice had been taken through the middle of the head. This tomographic image is produced by exposing the head to X-rays at many different angles of entrance. The multiplicity of shadow-type images thus formed are analyzed by a computer, which produces a reconstructed cross section density image.

Early scanners

The first commercial CAT scanner was developed by EMI in England and was largely the work of Godfrey Hounsfield. The unit was called the EMI scanner; it was first introduced to this country at the Mayo Clinic in June, 1973. Hounsfield had been doing developmental work at the Central Research Laboratories of EMI on business computers and pattern-recognition techniques when he recognized the possibility of applying computerized storage and retrieval to X-ray data taken from many different angles. His first machine was developed with the support of the British Department of Health and Social Security and installed in Atkinson Morley's Hospital in September, 1971.

The original EMI equipments were brain scanners. In operation (see Fig. 1), the head



CAT scanner built by Pfizer Medical Systems, Inc. (Photo credit: Pfizer Medical Systems, Inc.)

This "slice" of the thoracic cavity clearly shows the lung tissue, blood vessels, air passages, ribs, and spine. (Photo credit: Pfizer Medical Systems, Inc.)

is positioned in a frame with the plane of scan selected by the physician. A pencil beam of X-rays passes through the head and is detected by a NaI(Tl) scintillator, which converts the X-ray energy to light scintillations that are measured by a photomultiplier tube. The photomultiplier output current thus provides the basic information on the density distribution through the head. The X-ray tube and the detector system traverse the head and provide 160 readings of transmission through the head. The scanning system is then rotated 1° around the head and the process is repeated. Rotation through 180° provides the complete input data of 160 × 180 = 28,800 readings. From these data, and by specially developed algorithms, the computer in effect solves 28,800 simultaneous equations. Tissue density is thus derived for 6400 separate points in the cross section of the head.

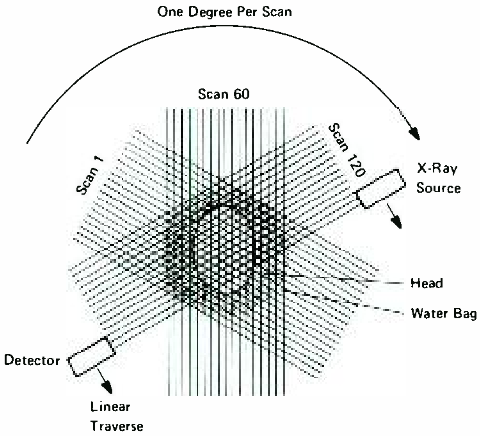


Fig. 1
Original EMI CAT head scanner. The equipment scans through 180° in 1° increments, with 160 readings at each position.

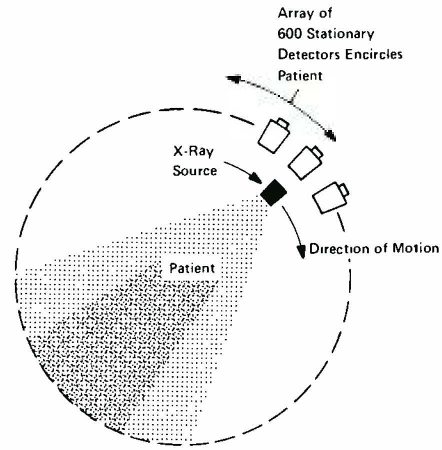


Fig. 2
Body scanner currently being marketed by American Science and Engineering, Inc. This equipment uses 600 RCA photomultiplier tubes.

Medical impact

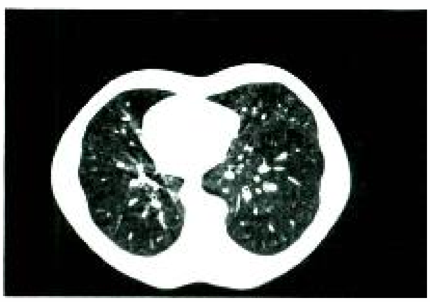
Although CAT scanners have now been developed for application to the torso as well as the head, the original EMI scanner was specifically for diagnosis of brain disorders: tumors, strokes, infection, epilepsy, injuries, and senility. The tomograph provides fine contrast rendition and precise spatial location information and, thus, is more useful than previous techniques. Because the technique is non-invasive, and is of relatively short duration, hospitalization is not required.

In other diagnostic procedures, the patient may spend several days in the hospital and be subjected to considerable discomfort. In angiography, for example, a high-contrast liquid is inserted by means of a catheter in the artery leading to the brain. A rapid series of X-ray pictures is taken as the dense material enters and leaves the brain. Besides considerable discomfort and headaches, the patient may be subject to convulsive seizures. In pneumoencephalography, fluid from the ventricles of the brain is withdrawn through a spinal tap and replaced with air. The patient is placed in various aspects to move the air bubble around while radiograms are being made. When the patient recovers from the anesthesia he may have severe headaches!

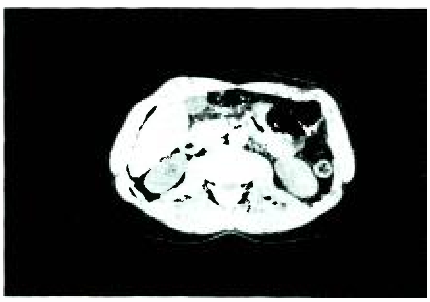
Whole-body CAT scanners are now becoming available and with them experience in using this new diagnostic tool for a variety of medical problems. Preliminary evaluations indicate considerable usefulness in accurately locating and differentiating tumors and cysts from normal tissue. New developments promise to provide scans fast enough for dynamic imaging of the heart.

CAT equipment development

Since the introduction of the EMI scanner, numerous companies in this country have entered the market with scanners of various



This 4-mm slice through the mid thorax was done with a different type of CAT scanner. Note that the blood vessels (light spots) can be clearly differentiated from the air passages. (Photo credit: American Science and Engineering, Inc.)



The right and left lobes of the liver are clearly distinguishable in this 4-mm section of the abdomen. Also distinguishable are the gall bladder, duodenum, pancreas, colon, spine, and ribs. (Photo credit: American Science and Engineering, Inc.)

This 3-mm high-resolution slice shows the skull (white outline), ethmoid sinuses (white ellipses at the root of the nose), and the extra-ocular muscles and optic nerves attached to the eyes (Photo credit: American Science and Engineering, Inc.)

kinds. Companies such as Ohio Nuclear, who already had entry in the medical diagnostic field with gamma camera equipment, were a natural to extend their product lines to this related medical-instrument field. Improvements have been made, particularly in the speed and precision of the measurement. The original experimental scanner required 2-½ hours on a large computer. Later, this time was reduced to 5 minutes, which was comparable to the scan time. Improvements in computer time are being made by hard-wiring and by using better algorithms.

American Science and Engineering Inc. has developed a considerably improved whole-body scanner that uses 600 RCA photomultiplier tubes surrounding the patient as illustrated in Fig. 2. Each photomultiplier tube is optically coupled to a bismuth germanate crystal. This scintillator was selected because of its effective stopping power for X-rays (high Z number), and because of its mechanical and chemical durability. It is non-hygroscopic in contrast to NaI(Tl)—a very common scintillator used extensively in nuclear medical equipment.

In the AS&E CAT scanner, a fan beam of X-rays is produced and rotated around the patient. A rotation of somewhat more than 360° corrects for body motion during the process. As in other scanners, the data are fed into a minicomputer which provides a tomographic image one minute after the scan. Scanning time may be varied from 5 to 20 seconds depending upon the need for greater resolution or upon the degree of subject immobilization.

Other manufacturers have also entered the market, and new machines are expected to proliferate rapidly. These equipments require from 27 to as many as 600 photomultiplier tubes each. The success in the market will be determined by reliability, availability, resolution, process time, and price—in the range from $200,000 to $700,000. In 1975, $100 million of CAT scanners were shipped, mostly to the U.S. market. By 1980, it is estimated the world market will approach $1 billion. For photomultiplier tubes, this means a total sales of $10 million in 1980.

Photomultiplier requirements

Two photomultiplier types—with half-inch- or three-quarter-inch-diameter photocathodes (Fig. 3)—are currently being used in CAT scanners. These tubes are smaller than the typical two- or three-inch photomultipliers used in large numbers in nuclear medical equipment. The demand for smaller tubes is a response to the need for higher resolution in a reasonably sized detector circle. The ¾-in. photomultiplier being used is a 10-stage tube with a bialkali photocathode; it has a gain of 7.7×10^6 at 1000 V, very low dark current, and a very high blue sensitivity to match the spectral emission from the BGO crystal. The ½-in. tube is almost identical except for size.

Obviously, photomultiplier tubes will be required in large numbers, especially for instruments with hundreds of tubes. In 1977, the facilities in Lancaster will be expanded in an effort to supply as much as possible of the predicted demand.

References

1. For a more detailed discussion, see the cover article in *Scientific American*, October, 1975, p. 56, "Image Reconstruction from projections," R. Gordon, G.T. Herman, and S.A. Johnson.

Ralph Engstrom, as Staff Consultant, is involved with most of the photosensitive devices developed by RCA's Electro-Optics and Devices activity. Since joining RCA in 1941, Dr. Engstrom's work on such devices has included photomultipliers, image tubes, and camera tubes.

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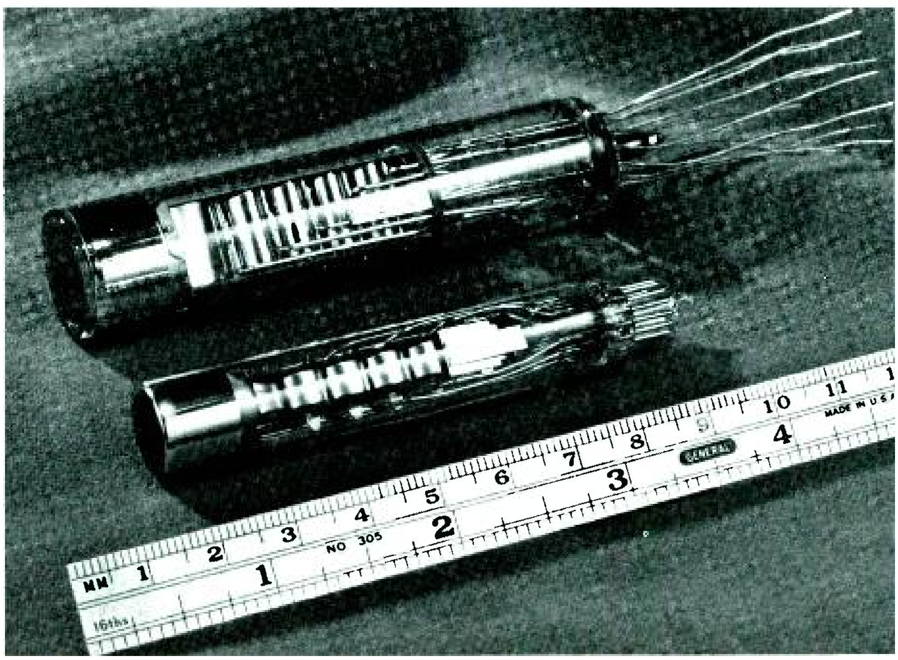
Fig. 3
Photomultiplier tubes used in CAT scanners. These ¾-in.- and ½-in.-dia. tubes have high gain, low dark current, and high blue sensitivity.



Producing tv displays from audio cassettes

W.J. Hannan

This book-sized box of electronics takes encoded information from a stereo cassette player and displays it as alphanumeric and graphic information on a tv set. Voice, music, or sound effects accompany the tv display.

The ability to display graphic and alphanumeric information on a television screen is valuable in many situations, but has generally been limited to videotape systems. The audio-cassette system described here, tentatively called "the electronic book," could have many applications in the following areas:

Business—electronic mail, business reports, and conference tv;

Education—foreign-language lessons, elementary and speed reading, mathematics, industrial instructions, and music-minus-one;

Entertainment—sing-a-long, quiz games, and sound patterns.

Functional description

The system can be divided into five subsystems: casette interface, refresh memory, video generator, tv sync generator, and rf circuitry. Figs. 1 and 2 show the "electronic book" in its final color-tv form.

The system receives precorded data from a cassette tape played on an ordinary home tape player.

The first model of the "electronic book" used FSK (frequency shift key) modulation at a bit rate of 2880 baud, but the latest model uses PSK (phase shift key) modulation at 3000 baud. In the PSK system, no phase shift represents a zero bit and a 180-degree shift represents a one bit. Tests show that this modulation scheme is a substantial improvement over the FSK tech-

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Final manuscript received May 11, 1976.

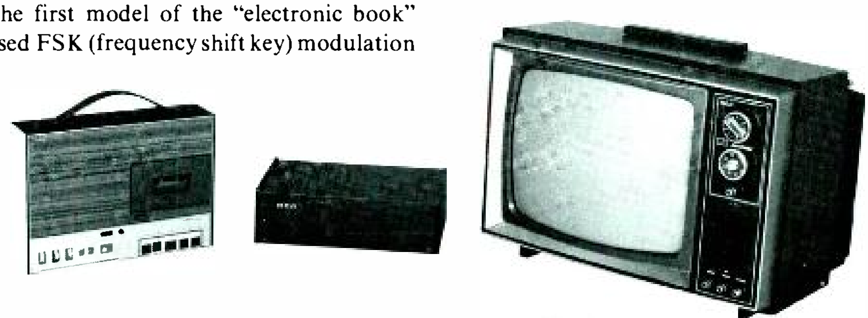

Fig. 2
Color version of display system. Display electronics take up much less space than audio cassette or television set.

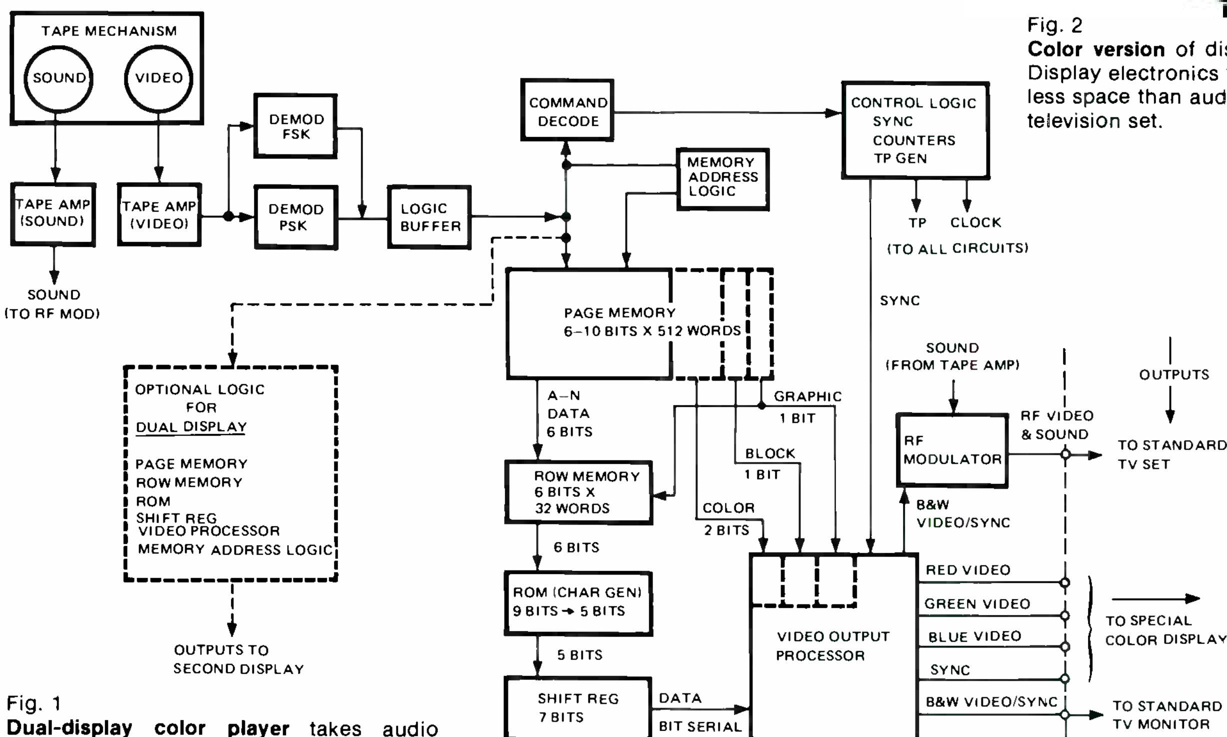

Fig. 1
Dual-display color player takes audio cassette input and uses demodulation, refresh memory, video generator, tv sync generator, and rf subsystems to produce alphanumeric and graphic displays.

Bill Hannan was Chief Engineer at RCA's Palm Beach Gardens operation when the work described in this article was done. His involvement with electro-optics also includes laser and holography research; his group won a David Sarnoff award for their holographic prerecorded video system in 1972. He is presently Manager of Radiation Systems Engineering at RCA Automated Systems.

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nique; it is more tolerant of signal-amplitude variation, tape-speed change, and poor amplifier frequency-response characteristics. Also, its higher data rate improves display animation.

Data to be displayed is contained in the refresh memory, which includes a page memory and a row memory.

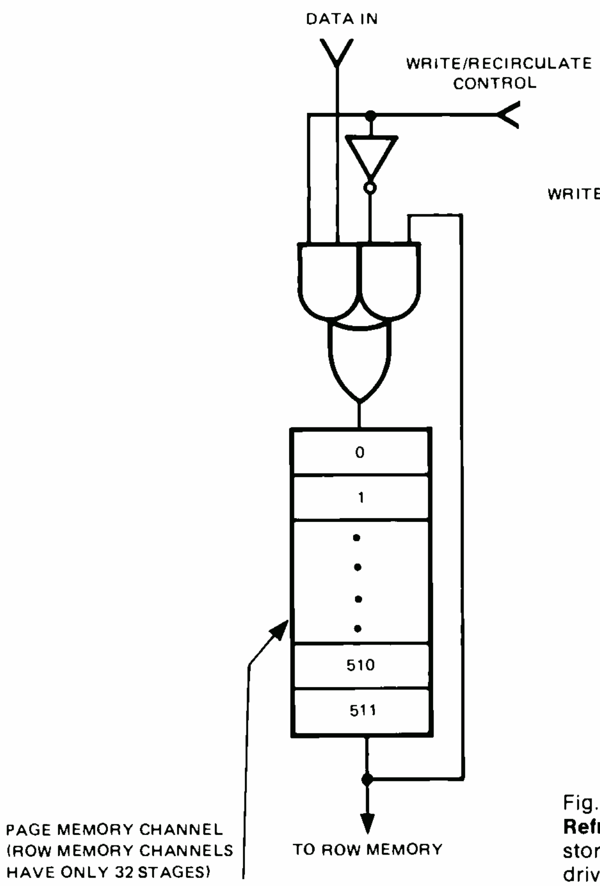
Data from the cassette is stored in the page memory and, at the appropriate time, is extracted and loaded into the row memory. (See Fig. 3.) The row memory is used as a buffer memory, its output driving a character-generating ROM from which television video is developed. The screen is refreshed at the standard 60-Hz rate.

Because of the repetitive nature of television frames, a recirculating shift register is used for the basic memory element. The Page Memory Address Register (PMAR) allows the page memory to be selectively addressed, permitting selected portions of a display to be altered without rewriting a complete frame.

As previously mentioned, the page memory contains 512 locations for storage of the 16 lines of 32 characters. Each character location in memory requires 6 bits to define the codes for 64 alphanumeric characters. Adding two more bits defines a color for each character, so they can be displayed in red, green, or yellow on a blue background.

A dot-matrix technique generates alphanumeric characters for the tv display.

Dot patterns for all characters are stored in the read-only memory (ROM), which has access provided by a two-part code: one part identifies the character and the other the line address. Data accessed from the ROM is output in byte-parallel form; serializing this data produces the video signal.



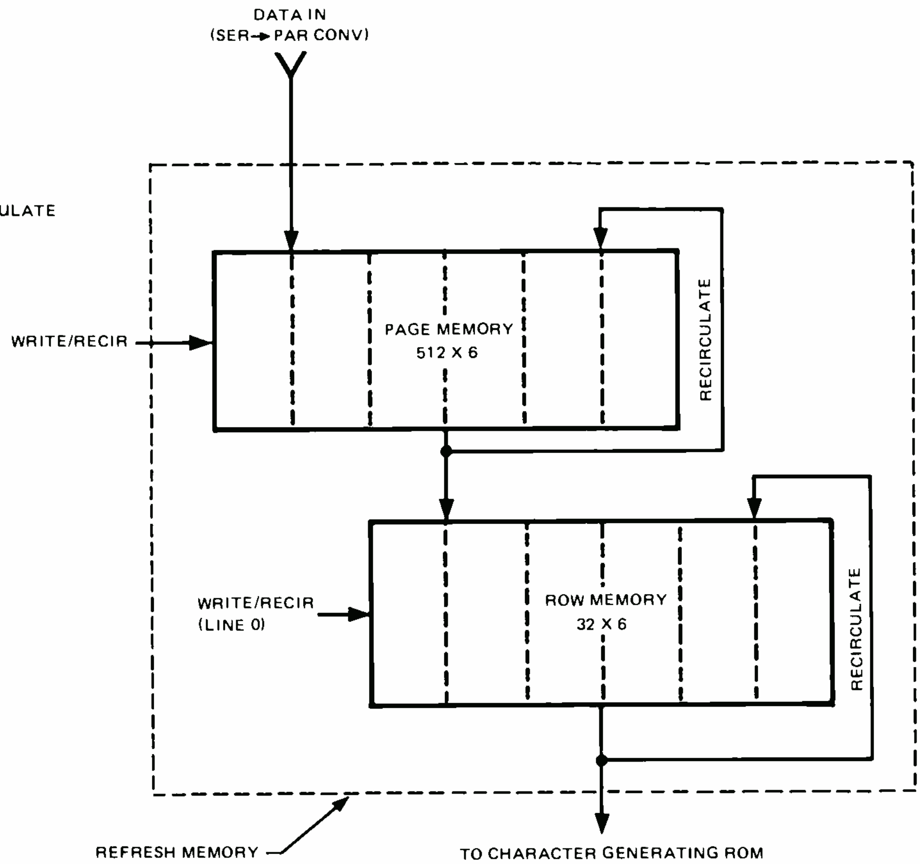


Fig. 3
Refresh memory uses a recirculating shift register as its basic memory element. Data is stored in page memory, then loaded into row memory, which is used as a buffer memory that drives a character-generating ROM.

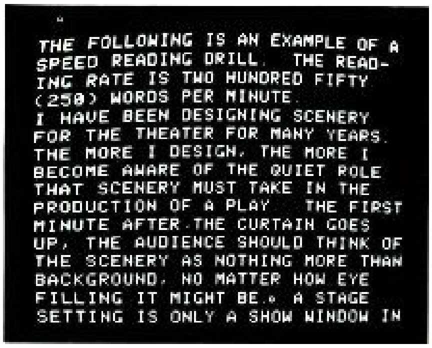


Fig. 4
Typical alphanumeric display generated (photographed on the tv screen here) has 16 lines of 32 characters.

Fig. 5
Operator enters information into system via the composer. Editing can also be done here.

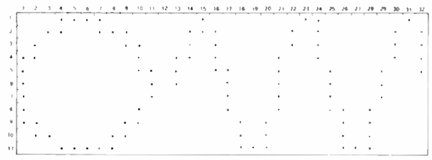


Fig. 6a

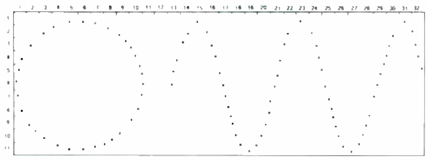


Fig. 6b

Graphic displays:
(a) using 512 allowable dot positions; (b) using dot-ROM technique allowing dot locations to be varied within the 512 positions.

A total of 256 horizontal lines are scanned in a noninterlacing pattern every 16.67 ms to provide a sharp, flicker-free tv image.

Although the line rate is slightly lower than that of broadcast tv (15,360 Hz compared to 15,750 Hz), it is well within the pull-in range of a standard tv set. A master oscillator is counted down to derive the horizontal and vertical sweep frequencies. The 5.8060-MHz dot frequency is divided by seven to obtain the character rate, which is divided by 54 to obtain the line rate (i.e., the horizontal sweep frequency). The line rate in turn is divided by 256 to obtain the vertical sweep frequency. The alphanumeric display is centered on the tv screen by using vertical and horizontal sync pulses as references, with appropriate time allowed for retrace, overscan, and page margins.

The serialized ROM output is mixed with sync and used to amplitude modulate a vhf carrier. This signal drives the antenna terminals of a standard tv set, producing a display with 16 rows of 32 characters. Fig. 4 shows how a typical display appears on the tv screen.

The composer

The equipment for composing "electronic-book" tapes includes an RCA Series 400 Miniprocessor, a color tv monitor, the "electronic book," an alphanumeric keyboard, and two standard cassette recorders, all packaged in an office desk (Fig. 5).

The composer performs three basic functions: video generation; audio and video recording; and tape duplication. The Series 400 Miniprocessor is programmed to help the operator compose tapes. The operator enters information through the alphanumeric keyboard and views the resulting frames on the tv monitor. When completed, each frame is stored in the processor memory and may be called out in the desired sequence for reviewing or recording on tape.

Graphics

Simple graphics can be displayed by using dots to produce sampled pictures.

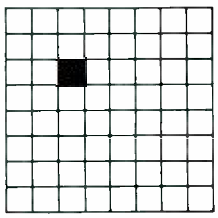
Because only 512 dot (or sample) positions were available, the quality of our first graphic displays left much to be desired. One obvious way to improve quality is to increase the number of samples (or dots) per picture. However, this approach calls for an increase in the size of the page memory in direct proportion to the number of dots per picture, and consequently a corresponding increase in hardware costs. Another serious drawback to this approach is the increased "write-in" time associated with a larger page memory. Writing a frame into the present "electronic book" from an audio cassette player takes about one second; any increase in write-in time would degrade animation effects.

Fig. 6a shows how typical figures appear on a tv screen when only 512 sampling positions are avilable to "draw" figures. Note that image quality is poor, not only because of the limited number of dots available to "draw" pictures, but also because each dot is located at a fixed character position (one of the 32×16 array of character positions).

The dot-ROM system improved image quality without increasing the number of dots per frame.

One way to avoid the "fixed character position" restriction involves adding another ROM and associated drive circuitry to the "electronic book" to allow the location of each dot to be varied within each of the 512 character positions. In effect, the new ROM performs essentially the same function as the character-generating ROM previously mentioned, but generates dots instead of alphanumerics.

As an example, consider the case in which the area normally occupied by each character is subdivided into 64 parts to form an 8×8 array of available dot positions, as illustrated here. In effect, this



makes $512 \times 64 = 32{,}768$ dot locations available. Note, however, that although the maximum number of dots that can be displayed per frame is still restricted to 512, the individual dots can be positioned more accurately. Fig. 6b, which is Fig. 6a redrawn with each dot now allowed to occupy any one of the 32,768 positions, clearly illustrates the improvement. Thus, adding a dot-generating ROM and associated drive circuits can significantly enhance the quality of graphic tv displays without degrading animation performance or prohibitively increasing hardware costs.

A redundancy-reduction scheme promises a significant improvement in image quality without a prohibitive increase in hardware cost.

One graphic display/transmission concept that is related to the "electronic book" project is a redundancy-reduction scheme that involves encoding pictorial data into a set of nonredundant symbols so as to shorten required transmission time.

The video signal from the tv camera (Fig. 7) is sampled so as to divide the tv picture into a large number of equal sections, each of which is further sampled to define a large number of dot positions. To simplify this description, assume that the picture is divided into an array of $32 \times 16 = 512$ sections and that each section contains an array of $7 \times 11 = 77$ dot positions. (Nothing is sacred about these particular values, however.)

The 512 sections of the picture are scanned sequentially, starting with the section in the upper left-hand edge of the picture and proceeding down to the lower right-hand edge, at the standard 30 frames/s rate. As each section is scanned, the video signal is gated into a 7×11 buffer memory cell, which stores the symbol in that section and serves as an intermediate storage point for each symbol. If the symbol in the buffer cell is not identical to a symbol previously stored in one of the RAM (random-access memory) cells, then the contents of the buffer memory are transferred to the next available cell in the RAM and the corresponding address of that RAM cell is stored in the memory. On the other hand, if the symbol happens to be identical to one previously stored, then it is not transferred to the RAM; however, the RAM memory address of the identical symbol (which was previously stored in the RAM) is stored in the next location of the page memory. This process continues until all picture sections are scanned. Thus all nonredundant symbols are stored in the RAM and their addresses are stored in the page memory.

Upon completing the page-memory writing cycle, the system transmits data stored in the RAM and page memories to the receiving terminal, where it is written into identical RAM and page memories via standard synchronizing techniques. Upon completion of the memory write cycles, the receiving terminal cycles the page memory at the tv field rate, and the symbols it addresses in the RAM are fed to the tv display, thus reconstructing the original image.

Fig. 8 compares the quality of the images produced by these three graphic systems; more information is available in Ref. 1.

Applications

A number of applications for the "electronic book" have been developed, including a block-diagram generating scheme, large-screen tv projection, electronic chess, and other games. The conference tv system described here is an example of these application capabilities.

The display system makes conference tv possible via conventional voice-grade telephone lines.

Our experimental system included the following features:

—Two-way transmission with voice return signals suppressed by hybrids

—Dual-frame display

—Recording facility for capturing the complete proceedings of a meeting

—Time-shared digital signals for speaker identification and pointer display at the remote terminal

—Frame "grabbing" circuit, which prevented tape readout from stopping until a complete frame of information was stored.

—Remote pointer for tv display

The outputs from multiple directional microphones triggered a light display (at the remote terminal) that identified each speaker. The remote pointer provided a light rectangle on the video display. It was controlled by a hand-held box that contained the pointer position-encoding electronics.

By adding a redundant page memory, row memory, ROM, and associated logic circuitry, we demonstrated a dual-frame system. Dual displays are commonly used for business presentations to ensure continuity of information flow. For example, one screen might show a table of contents with the particular subject under discussion highlighted in a different color, while the other screen shows a sequence of frames related to that subject. Test results verified that this mode of operation greatly enhanced business presentations.

One of the important applications for the "electronic book" is in presenting "canned" reports. For this application, the people giving the report create rough sketches of the displays they want to appear on the tv screen, indicating desired colors and animation, and then record the sound track they want to accompany the display. The sketches and recorded sound track are then given to a secretary or technician who employs the composing machine to produce a cassette recording of the canned presentation. These canned presentations may undergo many reviews and cassette editings before the final presentation to insure that they convey the proper message.

The main benefits of most meetings usually come from the comments and questioning that occurs during or immediately after the formal presentation. In this regard, the complete proceeding (i.e., the canned presentation plus all comments, questions, and answers) can be captured simply by rerecording the canned presentation during the meeting and adding the output of a microphone that picks up the meeting's audio responses.

Conclusions

The advent of low-cost LSI circuits provides a practical means for storing alphanumeric and graphic tv displays. Using such frame-storage circuitry, the "electronic book" creates tv displays from encoded signals stored on audio cassettes. Experimental results have shown that:

1) the data-handling capacity of a conventional cassette player enables a frame containing 512 characters to be completely refreshed in less than 2 seconds;

2) frame "freeze" can be achieved simply by stopping tape drive;

4) a dot-generating ROM enables reasonably good graphic displays to be generated without sacrificing refresh time;

4) four-color displays call for only a modest increase in hardware complexity; and

5) encoded signals can be transmitted over standard telephone lines.

Acknowledgments

The "electronic book" was developed by the Palm Beach Division over a period extending from 1972 to 1974. Major contributors to this program were J. Bordogna, F. Brooks, G. Hopkins, R. Hopkins, W. Matthews, and R. Saenz.

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1. Hannan, W.J.; *private communication.*

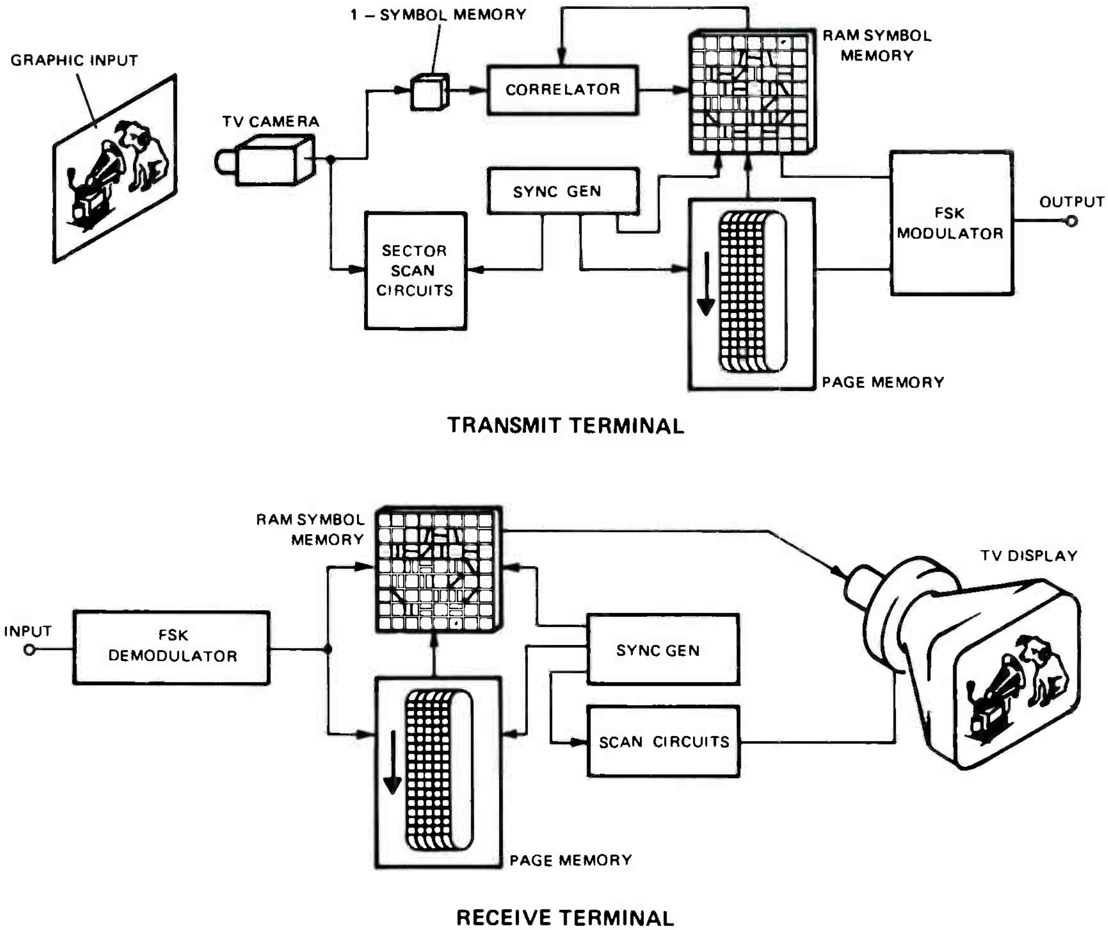


Fig. 7
Redundancy-reduction pictorial encoding scheme reduces storage and transmission requirements by storing each nonredundant symbol in RAM, and each address of its occurrence in page memory.

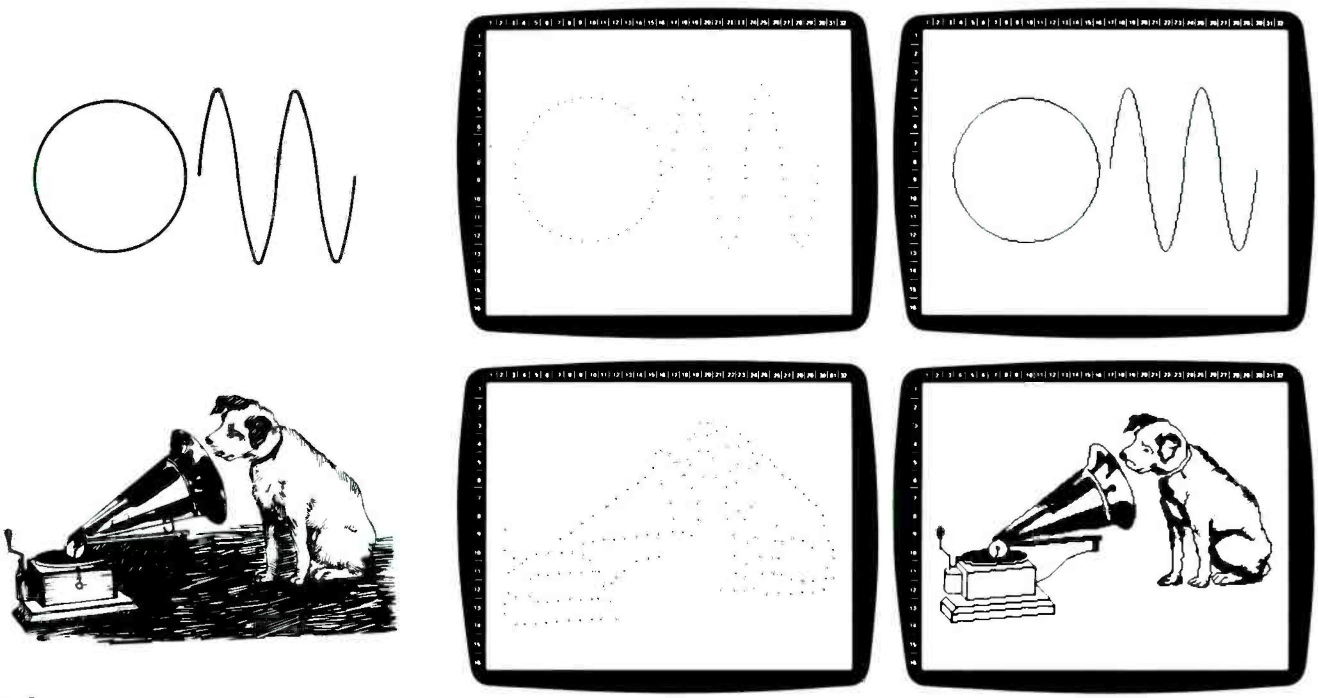
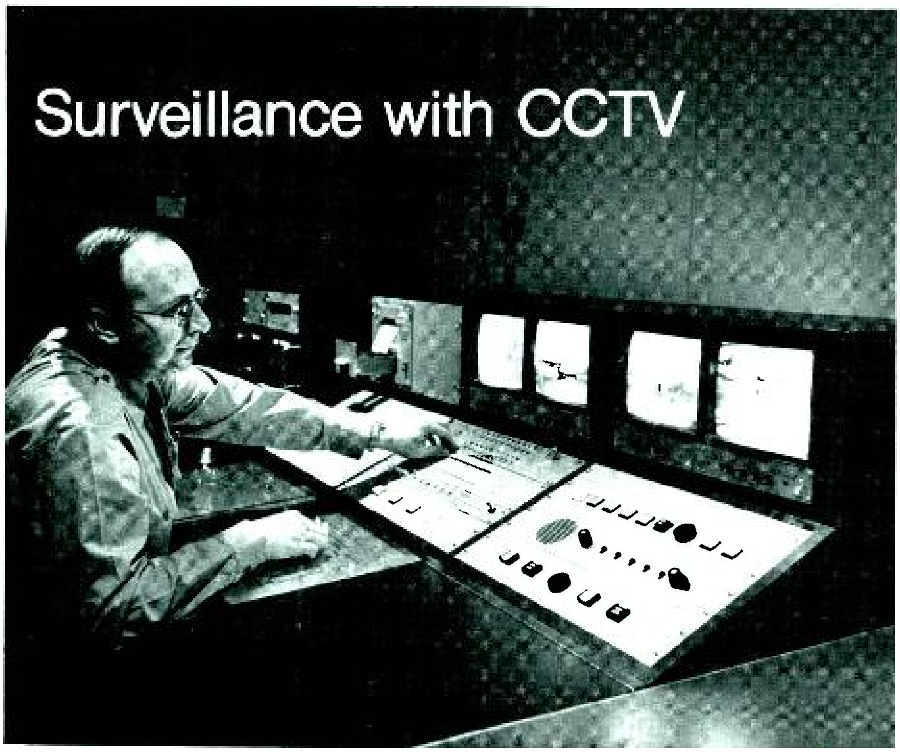


Fig. 8
Comparison of graphic display techniques—original material (left) and its reconstructed image via dot-ROM (middle) and redundancy-reduction (right) methods.

Surveillance with CCTV



The CCTV industry is growing rapidly with products for almost every need. The trick is to learn to select those products best suited for the job to be done.

V.C. Houk

Closed-circuit television (CCTV) recently has experienced a significant boom that should continue as the technology moves into many phases of our lives. Actually, CCTV has been around for many years, but it has taken a lot longer than forecast a decade ago for it to become a part of our everyday living. The recent economic slump, with belt tightening by industry, government, and business, has emphasized the need for lower cost ways of maintaining security and improving control of operating efficiency. As a result, the trend in surveillance CCTV ran contrary to the economy during the slump.

The heart of every CCTV system is the camera, the input source that provides information to the system and determines to a large extent system performance.

Random-interlace camera

Random-interlace cameras, because of their inherent lower cost, have become the workhorses of CCTV. These cameras provide an output signal that contains the minimum sync signals necessary to lock up with the monitor and provide a stable picture. The combination of video signal and the necessary sync information is referred to as composite video. The video information represents about 70% of the total signal, normally one volt peak-to-peak, while the horizontal and vertical sync pulses account for 30% of the signal. The video information is positive, and the sync pulses are negative.

An explanation of random interlace requires a momentary digression to discuss broadcast standards.

CCTV standards are largely an outgrowth of tv broadcasting, which requires high performance to assure a quality picture. Although some of these broadcast standards are not required in CCTV, many have been carried over.

Television signals for transmission on the air were established so that a full frame of picture video is made up of two fields of information; each field is transmitted in 1/60th of a second. To minimize picture flicker and crawl, the designers specified that these two fields of picture information be superimposed with their horizontal scan lines interlaced. Thus, the second field fills in the information missing between the scan lines of the first field. A picture field is made by scanning approximately 262 horizontal lines. The lines in the second field are synchronized so that they fall in the gaps between the horizontal lines of the first field, thus producing one completely interlaced frame. The requirement that the scan lines of the second field fall exactly between the lines of the first field results in the 2:1 interlace terminology associated with broadcast-type systems.

A frame of picture information consists of approximately 512 lines of useful information, with the 525-line picture system. The additional lines are needed for the vertical blanking interval during which the retrace occurs as the beam moves from bottom to top to start a new field. Unlike broadcast cameras, random-interlace cameras do not provide complete synchronization between the first and second fields. The horizontal and vertical scan frequencies are not locked together in a manner that assures that the horizontal scan lines of the two fields interlace. While this can be considered as a free-running or floating system, the results are a picture of completely acceptable CCTV quality. In fact, it is often difficult to tell if a system is using a random-interlace camera. Moreover, horizontal resolution, which is the basis for most resolution specifications, is not degraded with a random-interlace system.

RCA's random-interlace surveillance camera is a high-quality, high-performance reliable product.

The RCA TC1000 random-interlace camera employes integrated circuits in an all solid-state construction; the only active component not solid state is the vidicon pickup tube. This camera is a general-purpose product that supplies pictures with better than 550 tv lines of horizontal resolution, considerably more resolution than seen on a home-broadcast tv receiver (a good home tv set is limited to about 250 lines of resolution).

These low-cost cameras are quite versatile and have a number of desirable features, including sensitivity that makes possible usable pictures with as little as 0.5 fc of scene illumination—a fairly low-light condition similar to that of the subdued lighting in the home. Automatic light-control (ALC) circuits permit these cameras to work over a wide dynamic light range (10,000:1) from bright sunlight to dim interiors. These cameras can be extremely reliable and operate for long periods of time without adjustment. The only normal wearout mechanism is related to the vidicon pickup tube. As with any electron tube, there is a finite life; RCA quotes an average life of the vidicon used in its TC1000 of approximately 15,000 to 20,000 hours, or about two years of 24-hour-a-day operation.

While a camera with all solid-state circuitry has an extremely long life expectancy, it can be adversely affected by the environment in which it is operated. Extremely high temperatures encountered in hot industrial areas or outdoors in sunlight where the camera temperature can rise beyond its rated operating range can cause premature failure. Extreme cold can also damage the camera, but the damage is more likely to result in reduced performance than permanent failure.

Manufacturers go to considerable trouble to test and adjust cameras in the factory so that they will produce the best possible picture under normal operating conditions. There is a common misconception among users that target-voltage and beam adjustments should routinely be set for each situation. This is not true; the factory set-up covers a wide range of operating conditions and is optimized for best performance under most conditions. The only time when adjustment could improve the picture would be in abnormal situations, and then the improvement would be limited. Often field adjustment leads to setting the beam and/or target controls too high. A high target setting usually causes excess sticking or vidicon burn while an over-beamed vidicon reduces resolution and can shorten vidicon life.

Special CCTV cameras

From the basic low-cost random-interlace camera, one can move in several directions depending upon the requirements. Cameras are available with higher resolution, 2:1 interlace, external drive options, and more sensitivity. These cameras provide advantages in situations where standard-camera performance would be marginal or unsatisfactory.

A one-inch vidicon can improve resolution and sensitivity.

Many cameras use one-inch vidicons as opposed to the 2/3-inch vidicon used in the majority of the lower-cost random-interlace cameras. One-inch vidicons provide high resolution, in excess of 800 lines. Also, the one-inch vidicon is slightly more sensitive because of the greater area of the photoconductor; this normally results in about one lens stop more sensitivity for a one-inch camera as compared to the same camera with a 2/3-inch vidicon. However, this comparison between one-inch and 2/3-inch vidicon sensitivity should not be taken too literally, since camera design can often affect sensitivity to an even greater degree.

Synchronization needs often affect camera selection.

A camera that is locked to a master sync generator can be used with special-effect generators so that portions of pictures from different cameras can be presented on portions of the same screen. As an example, one portion of a split image shown on a single screen might be used for identification of an individual while textual or badge information verifying the individual's identity is presented on the other half of the same screen. Sync-lock between cameras is also desirable when the camera is used with tape recorders, particularly time-lapse recorders. While video tape recorders (VTRs) can handle a wide variety of video signals, they may have some difficulty in providing a picture free of vertical or horizontal instability. When a number of cameras are sequentially recorded by a VTR, it is best to lock them together by a 2:1 sync generator. This arrangement improves the stability of reproduction and helps to eliminate annoying picture roll, jitter, or tearing. If random-interlace cameras are used with time-lapse recorders, the cameras should be locked together vertically by precision line-lock in the cameras. 2:1 interlace cameras provide little advantage when used with time-lapse recorders unless they are locked together vertically.

Another important aspect in selecting a camera is matching it to available light level.

One of the biggest problems in CCTV systems has been the practice of using standard vidicon cameras where the light levels are too low to give satisfactory results. Under such conditions, a standard vidicon camera is overtaxed, so that the automatic light-control circuit elevates the vidicon target voltage to a point where the camera produces pictures with excessive lag or image burn. This condition is evident when moving objects in the picture appear to have a trailing after-image or when fixed subjects burn a permanent or semi-permanent image into the vidicon photoconductor; this image may or may not disappear after a period of time. Highlights in dimly lit scenes may burn to such a degree that permanent damage is done to the vidicon photoconductor. For this reason, conventional vidicon cameras should not be used if light levels are below the limits specified, or where there are bright highlights in the viewed area.

Silicon target cameras are better for low-light-level application.

The correct approach is to use a more sensitive camera, such as one with a silicon-target vidicon.[1] Silicon-target vidicons are much the same as conventional vidicons except that they use a target structure of silicon diodes rather than the conventional photoconductor of antimony trisulphide. The silicon-target vidicon has a sensitivity that varies from 5× to 10× more than a conventional vidicon, depending upon the type of lighting on the scene. The best conditions for realizing the full sensitivity of silicon-target vidicons is with incandescent lighting or other sources where the spectral distribution contains red or infrared. Under fluorescent or mercury-vapor lights, the silicon vidicon is still more sensitive, but to a lesser degree, and avoids the image-burn problem. In fact, the silicon vidicon is essentially impervious to burn, even if pointed directly at the sun, while conventional vidicons can be destroyed by a bright light from the sun, arc welders, or flash bulbs.

A basic characteristic of the silicon vidicon, and for that matter all extra-sensitive vidicons, is that they do not permit automatic light control within the camera by control of vidicon target voltage. The silicon vidicon is operated at a fixed target voltage, and use over a wide dynamic light range requires a lens with an adjustable iris. Many silicon cameras use motorized iris lenses to automatically control the lens opening. Most auto-iris lenses detect the video output signal and adjust the iris for a constant output level. Auto-iris lenses do a commendable job, although mechanical wear does take place over extended periods. For the auto-iris to be effective over a wide light range, such as encountered between sunlight and twilight, the lens must also include a filter. This filter often takes the form of a spot filter on the

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CCTV accessories and cameras. Some of the components of a typical CCTV installation are shown above. From left to right, a pan-tilt drive, various lenses, a switcher/date time generator combination, a monitor, a VTR camera, the TC1005/S01 premium high-performance camera with a 1-inch silicon intensifier target vidicon, the TC1005/05 premium camera with a 1-inch standard vidicon, and the TC1000—the standard "workhorse" camera, which costs about $280.

center of a lens element, so that its primary influence occurs when the lens is closed down by the iris. The filter extends the effective *f*-number range of the lens from what normally would be *f*/1.5 to *f*/22 to as high as *f*/360 and *f*/500.

Conventional vidicon cameras cost less.

Silicon-vidicon cameras have been relatively expensive in the past. Whereas conventional vidicon cameras cost in the range of $300 to $400 (user price *with* lens), silicon-target-vidicon camera costs are often in the range of $700 to $1200 (user price *without* lens). The added price of a spotted fixed-focal-length auto-iris lens is in the order of $300, which brings the total price to between $1000 to $1500 depending on the combination of camera and lens. It is easy to see why there has been pressure to use conventional vidicon cameras at lower light levels than intended by the manufacturers.

Recently, RCA announced a new, lower-cost silicon camera, the AutoVu camera.

The AutoVu camera makes use of a novel concept, an integral variable-focal-length lens with its own built-in light control. This 2/3-inch camera is a self-contained package that carries a user price of $965. The AutoVu camera's integral lens is adjustable from 14mm to 38mm, providing coverage from slightly wide-angle viewing to approximately 2× telephoto. The lens is set at installation and can be changed if the viewer desires a different field of view. The unique automatic light-control system does not have the motors and gears found in conventional auto-iris lenses. It uses, instead, an automatic aperture opening controlled by a taut-band meter movement that is essentially free from wear and almost as fast as the electronic ALC in conventional cameras. The AutoVu camera should find many applications where the higher sensitivity and other characteristics of silicon vidicons are desirable.

There are special cameras that fulfill specific needs and that simplify installation.

Most manufacturers provide their cameras in 24-V ac versions. This simplifies installation by eliminating the need for costly 120-V wiring, which often requires installation in conduit by union labor.

The 24-V camera can be operated from a standard Class II bell-type transformer using low-voltage wiring such as lamp-type zip cord or the new Siamese cable, which contains the RC59U and a pair of low-voltage wires with a ground shield in one sheathing. An even newer concept in supplying power to the camera is now being marketed by several manufacturers. Called a VidiPlex by RCA, this type of camera receives its power through the same cable that takes the video signal from the camera; thus, the installation requires only one coaxial cable.

An example of a more sophisticated CCTV camera that provides premium performance is the RCA TC1005.

This camera is available with either 2/3- or 1-inch vidicons, the difference being primarily in resolution and sensitivity—both in favor of the one-inch size. These premium-performance cameras provide broadcast-type sync with crystal-controlled 2:1 interlace and meet the requirements of EIA RS170 specifications. This sync specification assumes optimum stability and compatibility.

The sync in the TC1005 camera is generated by a new RCA CMOS integrated circuit and has a number of outstanding features. The camera has input provisions that allow all cameras in the system to be synchronzied with a master sync generator. This arrangement is accomplished by feeding individual horizontal and vertical sync signals into each camera; the camera will also "genlock" onto either composite sync or composite video. Horizontal and vertical sync drives can also be taken from a camera and used as a master sync generator to lock up other cameras or components within a system. A novel feature of the TC1005 camera is the second isolated video output, so that there are two independent 75-ohm video outputs on each camera.

An outstanding feature of these premium cameras is their ability to handle an extremely wide dynamic light range.

A 100,000:1 automatic light-control range is achieved through a two-stage ALC circuit. One stage controls the vidicon target voltage and the second provides automatic video-gain control. A full understanding of this system is important to a user, but in this article, it is sufficient to say that the automatic light range is achieved by controlling the vidicon target until it reaches an upper level, where a further increase would cause excessive lag or burn in the vidicon. At that point, the AGC in the video amplifier takes over, increases the video gain, and provides additional sensitivity. The increased sensitivity achieved through the video AGC is equivalent to using a super-fast lens; i.e., there is an increase in sensitivity equivalent to approximately 3.0 lens stops.

Very- and ultra-low-light-level cameras

No discussion of CCTV would be complete without mention of the sophisticated cameras available for producing pictures in extremely low light. These cameras can be listed as very-low-light and ultra-low-light cameras. The very-low-light cameras produce pictures under light levels as low as 1/4 moonlight, and ultra-low-light cameras can provide usable pictures on a heavily overcast night without benefit of any supplemental lighting. Many of the very-low-light cameras use a silicon intensifier target (SIT) tube,[2] which combines a silicon-target-vidicon structure with a stage of light amplification in front. The tube is built as one unit with the electrons generated in the image stage focused directly on the silicon target. This arrangement avoids the losses inherent in tubes such as single and double intensified vidicons (IV and I^2V) where one or two image sections are coupled to a conventional vidicon through fiber optics. The sensitivity and resolution of the IV and I^2V tubes are lower than those of the SIT tube.

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The SIT and ISIT cameras make ideal 24-hour-a-day surveillance cameras when used with an automatic lens-filter system that allows the camera to operate under sunlight conditions. In the past, these low-light-level cameras have been extremely expensive, but today their price is decreasing. The RCA TC1030 SIT camera has a user price of approximately $6000 plus lens, and the RCA TC1040 ISIT camera has a user price of approximately $8000 plus lens. For someone who has not seen one of these low-light cameras in operation, it is quite startling to see the pictures that can be produced in darkness so complete that the eye cannot distinguish the objects.

CCTV accessories

There are a number of accessories that aid in the design and installation of CCTV systems. Many of these accessories are conventional products, such as mounting brackets, scanning heads, and pan tilt units—all used to make cameras flexible in their viewing capability. In addition, CCTV switchers are now produced for almost every conceivable situation. Switchers range from low-cost passive types, which simply connect individual camera outputs through the switcher to a single monitor, to the more elaborate sequential or remote switchers, which can automatically sequence from one camera to another while allowing any camera to be by-passed or manually held on-screen.

Video motion detectors can also be used to detect changes in scene content in a secure area. The motion detector then automatically brings the picture of the area of interest up on the monitor and sounds an alarm. An example is RCA's VidAlert Motion Detector, which is available as either a 2- or 4-channel detector. It can be coupled to a sequential switcher that allows automatic call-up to provide security personnel with several forms of alarm.

CCTV monitors

Monitors for CCTV installations are rather conventional in their design; their packaging, however, has been adapted to the need of the surveillance market. The 9-inch monitor represents the backbone of the surveillance industry. It provides a convenient size for viewing at distances from 3 to 9 feet and is suitable for desk top use; two units can be mounted side-by-side in a 19-inch rack. Smaller monitors, such as a triple 6-inch version, are becoming increasingly popular because of their size. On the other end of the scale are 12- and 17-inch monitors; the latter is most often used for distant viewing.

It is important to recognize that monitors can become the limiting element in a CCTV system. Some monitors are simply conventional home-type black-and-white tv sets in an industrial cabinet. These monitors do not provide resolution capability commensurate with even the lowest-cost CCTV camera. Not only do they limit the resolution, but their sync stability is often lacking and their reliability uncertain. While it is true that no CCTV picture can be better than the camera, it is just as true that no CCTV picture can be better than the monitor. Monitors become even more critical when they are used in conjunction with time-lapse recorders, which put a heavy demand on the monitor. Unless the monitor's horizontal and vertical sync circuits are designed to handle time-lapse recorder inputs, the pictures may show vertical jitter, horizontal tearing, or both. While not all of these symptoms are caused by the monitor, they can be aggravated by a poor one. The highest quality pictures can only be obtained through the combined use of a good time-lapse recorder, a good monitor, and good cameras.

Conclusion

Specifications cannot replace experience in the installation of CCTV systems. Even then, an experienced person cannot always accurately judge which camera and lens are best suited to an application, particularly if it is a difficult low-light-level application. The best way to determine the camera for the job is to take one on site and test it under actual conditions. Often the pressure is on to cut costs or to meet competition, but in the final analysis, only an adequately designed system can do the job expected.

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Real-time aerial reconnaissance using the return-beam vidicon

M.J. Cantella | R.J. Gildea

This television system can resolve 1-ft objects from 10,000 ft.

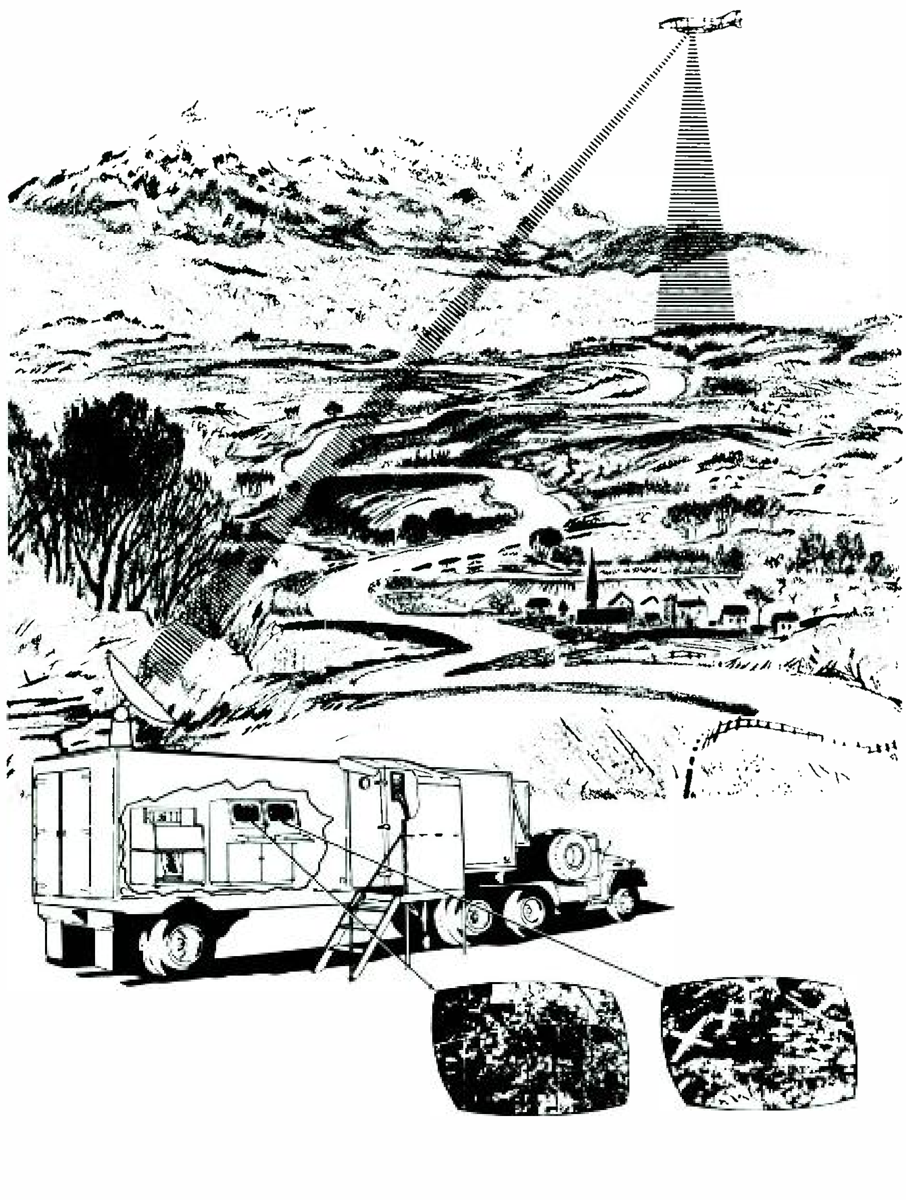

Fig. 1
Return-beam vidicon camera system transmits televised real-time reconnaissance data back to ground station, where it is interpreted immediately and stored. Film-based reconnaissance systems have delays of hours before information can be studied.

The high mobility associated with modern warfare accentuates the need for real-time aerial reconnaissance, since acquiring and interpreting imagery quickly permits rapid action. The feasibility of a complete real-time reconnaissance system has been established recently on the Air Force contract for the AN/UXD-1 Electronic Camera for High Performance Aircraft (ECHPA).[1] This program included the development of a complete electronic/camera pod for use on an RF-4 aircraft and a ground station to provide real-time display and hard-copy recording of the remote video data.

Operational concept

This new real-time system uses an airborne electronic camera to take a series of high-resolution "snapshots" and, with slow-scan readout, relay the images over a data link to a ground station for real-time photo-interpretation. (See Fig. 1.) CRT monitors capable of scan-converting the incoming information to high-quality, flickerless displays are used to assess data rapidly. The ground-station operator can display either the camera's full field of view or a magnified, selected portion of this field. Thus, the status of military activities can be ascertained within seconds, compared with typical delay times of hours in more conventional photographic reconnaissance systems.

This new system depends largely on the outstanding performance of the return-beam vidicon (RBV), which required several important departures from commercial television techniques, including:

- "snapshot" operation, in which exposure, readout, and erasure time intervals are separated;
- short exposure time to minimize image smear caused by motion;

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Fig. 2
RBV camera mounted in pod of an RF-4.

- high sensor resolving power under low-contrast conditions;
- slow-scan readout for data-link compatibility;
- rapid camera frame rate for contiguous coverage and stereo overlap;
- scan conversion and real-time display of received information;
- electronic zoom, mensuration, and annotation of displayed imagery.

The RBV has played a triple role in this system. Not only is it used as a sensor, but variations of the device are used as a display scan converter and as a CRT recorder. Using the same basic hardware in these three key roles should be a cost-effective approach for future systems.

The electronic reconnaissance system

The basic reconnaissance system consists of an airborne pod, mounted at the centerline of an RF-4C aircraft, and a photoidentification van.

Fig. 2 shows the pod while airborne, and Table I lists the system design and performance parameters.

Table I
Design and performance parameters for the AN/UXD-1 electronic camera system.

Photo surface resolution	55 line pairs/mm
Ground resolution on film	1 ft @ 10,000 ft
Display resolution	3.5 ft (normal) 2 ft (3:1 zoom)
Cycle time	14 s
Mission time	> 2 hr
V/H compensation	Slewable mirror
Focal plane shutter speed	1/2000 to 1/125 s
Lens	180 mm $f/2.8$
Signal/noise @ 190 lm/ft^2 scene	25/1
Video bandwidth	2.5 MHz
Data-link range	1-150 Nmi
Pod and equipment	
Size	22" dia. × 18' long
Weight	1100 lb
Power	2000 W

A lower-resolution television viewfinder camera, boresighted with the high-resolution camera, is used to select the scene to be transmitted from the airborne system. The two cameras have 54° × 42° and 16° × 16° fields of view. When targets of interest are encountered, the high-resolution system is activated and the scene is imaged on the 4½" RBV through a snapshot mode of operation similar to conventional framing film photography.

The tube is exposed by a focal-plane shutter, and a light sensor establishes the proper exposure automatically by adjusting the lens iris and shutter speed. Shutter times are between 1/2000 and 1/125 second. After exposure, readout occurs. The cycle is then completed by preparing the tube electrically for the next exposure.

The cycle time given in Table II is determined primarily by the data-link transmission bandwidth. The electronic camera in the baseline application uses a slow-scan readout of 6000 lines in ten seconds. Scenes are transmitted to the ground terminal, where the video signal is annotated and applied simultaneously to the hard-copy reproducing media and to a scan-converter display console for visual observation. In the normal search mode, the scene is displayed for 4 seconds before the next scene is received, but the operator may extend viewing time to 18 seconds. Constant brightness and contrast are maintained on the display by automatic black-level and gain-control circuits in the scan converter.

The camera head assembly is mounted in the forward section of the airborne pod. Relative motion of the ground image is compensated by a forward-motion compensation mirror for V/H input signals from 0 to 0.33 radian/second. A spring isolation system accommodates motion caused by vibration and the high-speed focal-plane shutter further minimizes motion effects. Thus, at altitudes between 3000 and 30,000 feet, no stabilization is required.

Table II
Performance parameters for the RBV electronic camera.

Resolution	6,000 tv lines/height (60 lp/mm)
Sensitivity	0.01 foot-candles
Contrast enhancement	No S/N losses due to haze down to 5% contrast
Cycle time	3 s to 30 s

As with high-resolution photography, the high-resolution tv camera requires an environmentally controlled atmosphere for optimum operation.

The on-board thermal control unit provides temperature control for the optics and tube with gaseous N_2 for cooling and internal heat blankets for heating. Following an initial cool-down or heat-up cycle, optimum equipment performance is maintained with mission profiles between 3000 and 30,000 feet altitude.

The reconnaissance system used a standard AFWET (Armed Forces Weapons Evaluation and Test) pod. The prime design area in adapting the pod to accommodate the ECHPA equipment related to the payload. In particular, since the payload was to be mounted in the nose area, turbulence considerations dictated the nose configuration, window mountings, fairing, sealing, and structural integrity.

In order to maintain reliable system operation and eliminate the formation of condensation ice on the equipment and optical windows, the forward portion of the pod was sealed and a bottle mounted within the tail cone supplied 2-3 psi of dry N_2. The

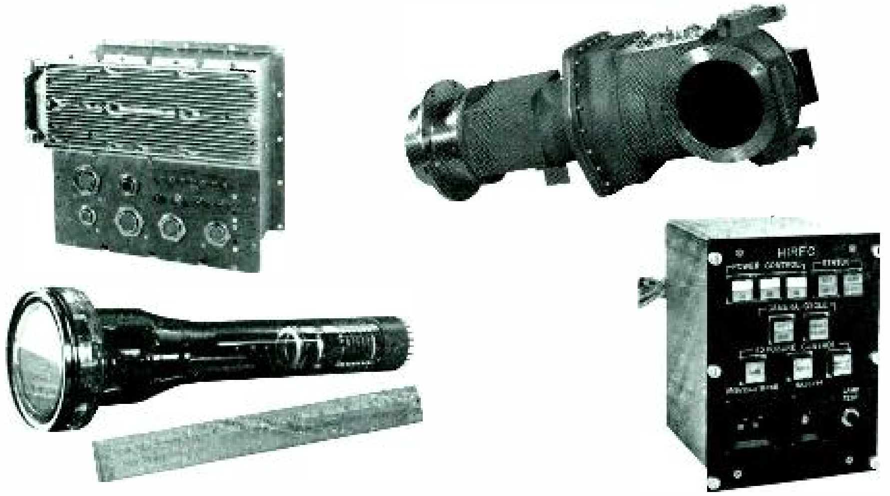

Fig. 3
Flyable camera components are grouped around the RBV tube (lower left), the heart of the electronic camera.

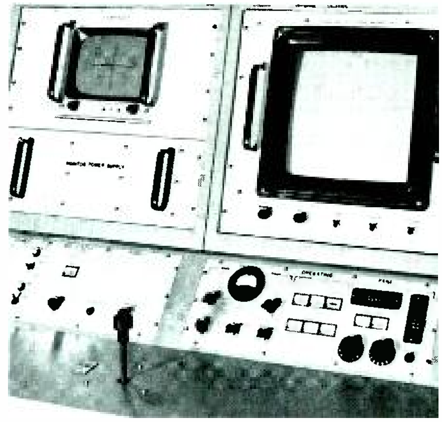

Fig. 4
Display console also uses an RBV for image storage. Operator can magnify selected portions of the image, since display has 1/3 the resolution of the RBV.

leak rate of the pod enables the onboard nitrogen gas reservoir to maintain the desired internal pressure for at least 46 hours at the severe condition of 30,000 ft.

The electronic camera

A principal subsystem of the ECHPA is the AN/UXD-5 electronic camera developed for the Air Force. Its RBV tube and flyable camera components are presented in Fig. 3; principal performance parameters are listed in Table II. The hardware configuration was chosen to fulfill the operational and environmental requirements of a pod-mounted test bed.

The key assembly is the camera head, which consists of the tube assembly, yoke, focal-plane shutter, lens assembly, forward-motion compensation mirror, heat exchanger, electronics, high-voltage supply, and the basic structure. For optimum performance, the electronic camera system uses power-supply and deflection circuits of high precision and stability, plus special circuits for exposure control and black-level correction.

The unique black-level correction technique is based on the fact that atmospheric haze appears as a uniform potential on the RBV photoconductor, upon which the scene detail is superimposed.

During readout, the photoconductor electrode is biased so that only the scene detail is read out. Clipping the haze in the readout process improves video signal-to-noise ratio and is far more effective than performing this function in a video processor. In the AN/UXD-5 design, the readout is adjusted automatically to an optimum level for every exposure.

Michael Cantella was project engineer for the development of the ultra-high-resolution return-beam vidicon and storage tube. He is presently responsible for developing new systems for surveillance and real-time information acquisition, transmission, retrieval, and recording.

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Authors **Cantella** (left) and **Gildea** with an RBV tube.

Ground station

The main function of the ground station is to convert the video received from the airborne camera systems into soft- and hard-copy imagery for photointerpretation and recording. The main hardware components of the station are a display console and a hard-copy recorder.

The display console contains a CRT display, a scan converter, and operator controls.

Fig. 4 shows the display console. An RBV is used for image storage and scan rate conversion. Its electron beam is used for writing. Readout, at 2000 lines/frame, 15 frames/second 3:1 interlace, is presented on a long-persistence display kinescope. Since the display has one-third the resolution of the RBV, areas of the image may be selected for magnification with a force stick

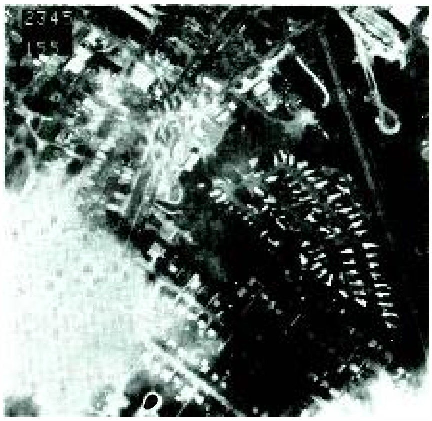
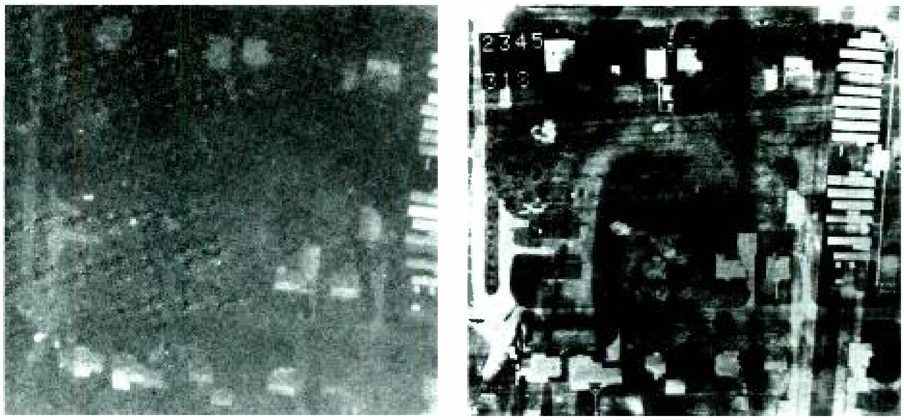


Fig. 5
RBV produces high-quality images under good atmospheric conditions.



Film system

RBV system

Fig. 6
Comparison of images made under very poor visibility conditions. RBV system provides significant detail because of its basic low-contrast imaging capability and designed-in automatic contrast-enhancement.

and magnified by underscanning the RBV scan converter during readout.

For high-fidelity reproduction, the received video information is key-clamped for dc restoration and the gain is controlled to maintain a constant peak-to-peak video signal. Two simultaneous feedback loops are required for these functions. The loops include control of the RBV target and multiplier electrodes, and loop parameters are optimized for each electronic zoom ratio selected by the operator, which produces a multiframe readout display of constant brightness and gamma.

In a real-time reconnaissance system, hard-copy recordings of video data are desirable for long-term storage and more detailed photointerpretation.

In the ECHPA system, the primary recorder uses an electron beam to record on 5-inch film. In future systems, this could be replaced by a laser-beam recorder. A second experimental recorder of the high-resolution CRT type was also used successfully. This CRT was designed as an extension of the RBV and employs essentially identical electron optics and associated mechanical and electronic components. Its output is imaged on 5-inch film. The total resolution obtained initially with this approach was not as high as with the direct film-recording method. However, it did demonstrate the potential for a low-cost future recording capability. Since the RBV is used as a sensor and as a scan converter in other portions of the system, the resulting simplification of equipment procurement, spares, and maintenance procedures could yield minimum life-cycle costs in a three-RBV system.

Image quality

The AN/UXD-1 electronic camera flight test demonstrated its potential for providing useful near-real-time information for reconnaissance.[2] In the course of 57.2 flight hours, it demonstrated an ability of acquiring quality imagery at altitudes from 820 to 41,600 feet while flying at speeds form 160 to 633 knots, giving V/H values from 0.012 to 0.26. The system demonstrated a ground resolution of 2.25 feet from an altitude of 16, 670 feet based on the evaluation of images of a 5:1 contrast-resolution target.

Adequate performance was achieved at illumination levels as low as 1000 foot-candles and visibilities as poor as 2 nautical miles. The AN/UXD-1, under poor visibility, produced higher-resolution, better-contrast images than a standard KS-87 aerial reconnaissance camera. Under good visibility, the KS-87, with 2½ times the format size, gave a ground-resolved distance half that of the AN/UXD-1.

The electronic camera can "see" in poor-visibility conditions.

Fig. 5 shows an RBV image obtained in good visibility; Fig. 6 compares the images obtained with the RBV system and a standard film system under very poor (2½-mile) visibility conditions.Note that while the image recorded by the film camera is almost completely obscured, significant detail is observable in the RBV image. At the time this image was obtained, the pilot could not see the ground. In addition, the 1-inch vidicon viewfinder camera could not provide an image because of the low contrast. This imagery illustrates the RBV's extraordinary low-contrast imaging capabilities and the automatic contrast-enhancement technique designed into the AN/UXD-1 equipment.

RBV imaging and storage characteristics

The return-beam vidicon is a unique, high-performance device designed especially for real-time reconnaissance missions. Because of its crucial role in this system, we will discuss it at some length. Its characteristics include:

- High resolution over the entire image area
- Optical and electrical data input
- Large storage capacity
- Efficient erasure
- Low spurious signals
- Electronic zoom
- Controllable transfer function

The RBV can provide image sensing and electrostatic storage with a standard antimony sulfide oxysulfide (ASOS) target.[3] Readout can be done continuously with a steady-state optical exposure or in near-real time with a discrete input consisting of a shuttered exposure or electrical write-in. With discrete input, the information can be read out in a variety of modes, including slow, single-frame scan or fast, multiframe scan for display on a tv monitor. In multiframe readout, a continuous high-quality display can be obtained for up to about one minute. All readout modes permit electronic magnification (typically ten to one) through raster steering and zoom.

The RBV tube and external magnetic electron optics that produce these high-

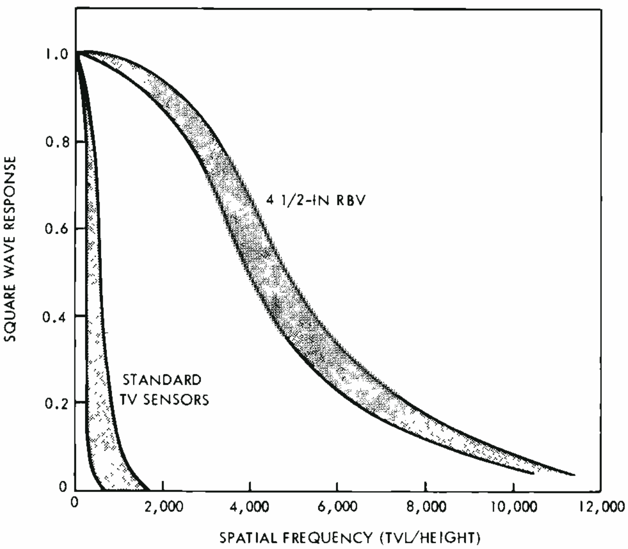


Fig. 7
Measured RBV response has approximately ten times the spatial frequency of standard tv sensors.

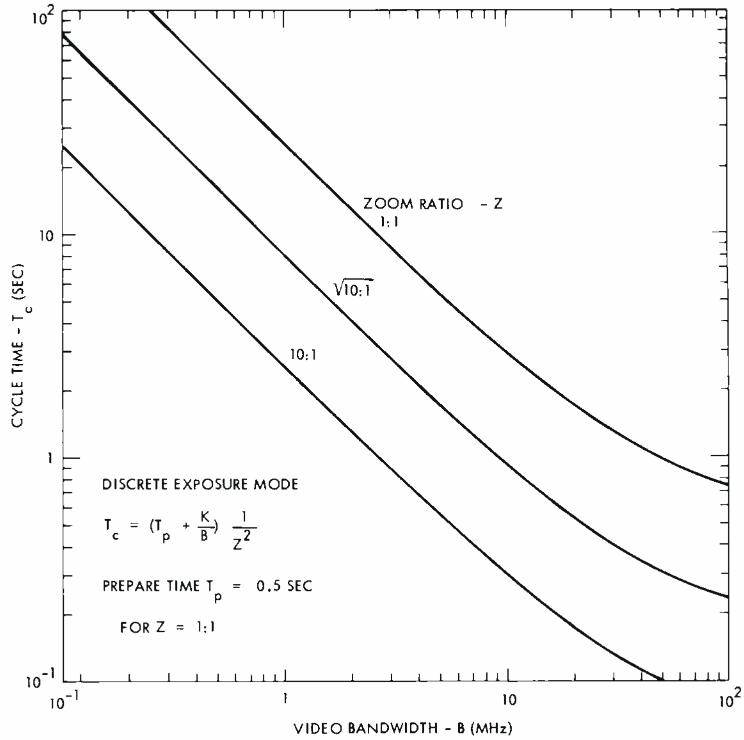


Fig. 8
Cycle time is essentially determined by readout time, which is bandwidth-limited, and prepare time, which is one-half second with RBV's special gun design.

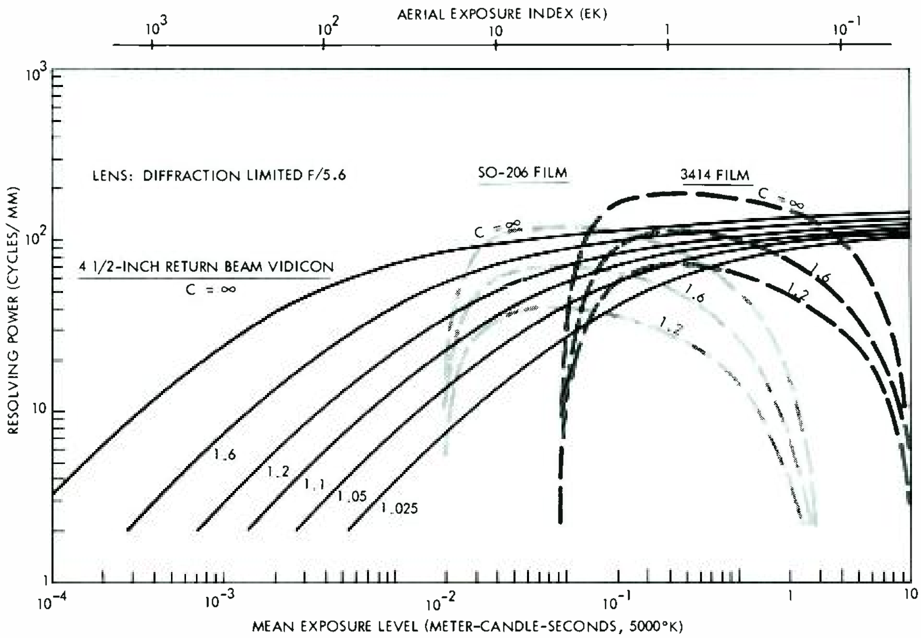


Fig. 9
Resolving power of the RBV compared with films'. RBV excels in low-contrast conditions, is equal to or slightly less than film in high-contrast conditions.

resolution electronic images are the result of several years of development sponsored by the Air Force Avionics Laboratory and performed by RCA under the technical guidance of O.H. Schade, Sr. The RBV contains a large (50 mm × 50 mm) photoconductive sensing layer and a high-gain return-beam readout that permits high sensitivity, wide video bandwidth, and long-term multiframe readout. A two-inch RBV of similar design containing a 25 mm × 25 mm sensing layer is also available.

The electron optics of the RBV have provided outstanding aperture response over the entire sensing layer.[4] Fig. 7 presents a typical 4½-inch RBV square-wave response characteristic and also includes, for comparison purposes, a region of performance associated with standard tv sensors. The RBV provides approximately 10 times the linear (equivalent to 100 times the area) resolution of standard tv sensors. The high resolving power of 100 line pairs/mm (10,000 tv lines per height) has been demonstrated over the entire sensing layer.

Snapshot exposures are best for aerial reconnaissance; typical exposures of one millisecond minimize image smear caused by aircraft motion.

For effective reconnaissance, it is important to repeat the snapshot cycle fairly rapidly to permit contiguous and stereo overlap coverage. Since the exposure and erase sequences require only a fraction of a second, cycle time is determined essentially by the readout time (bandwidth limited) and the prepare time (gun-current limited). A special gun design permits adequate preparation in only one-half second.[5] A typical cycle time (T_c) characteristic for a 6000 × 6000 tv-line/height system is presented in Fig. 8. Note that cycle time varies inversely with bandwidth over most bandwidths of interest. In addition, cycle time can be shortened significantly in the electronic zoom mode.

Fig. 9 shows resolving power of the RBV as compared with film; these characteristics have been extrapolated from work accomplished by O.H. Schade, Sr.[6] The methodology used for this comparison combines modulation transfer functions including an assumed diffraction-limited *f*/5.6 lens, signal-to-noise characteristics, and gray-scale transfer functions to provide an upper limit of performance as a function of mean exposure and scene contrast. Note that the RBV operating range extends over the range of all film types. The RBV camera performance equals SO-206 film and is slightly less than 3414 film at high contrast, but exceeds the performance of both films at low contrast.

Excellent imagery is achievable with the RBV even at contrasts lower than the limits associated with film and with human vision. This outstanding capability is made possible by the high-capacity target of the RBV and by the contrast-enhancement technique employed during the readout interval. This capability is especially important in acquiring aerial imagery under adverse atmospheric conditions.

The RBV can also operate as an electrical write/read storage tube.

A standard ASOS photoconductor target can be used and overall resolution performance is essentially as good as that obtained with optical input. Both electrical and optical inputs can be superimposed. Readout can be accomplished, as with optical input only, with a slow-scan single frame or with fast-scan multiple frames. In multiframe readout, information can be displayed in a flickerless manner for about one minute even though readout is basically destructive. Information stored on any portion of the target can be magnified with electronic zoom.

The electrical-storage characteristics of the RBV can be enhanced even further if the readout process is inherently nondestructive. This has been accomplished by using a new RBV storage target[5,7] consisting of 7000 SiO_2 stripes on a Si substrate and measuring 50 mm × 50 mm. This structure is similar to that used on many current nondestructive readout storage tubes. This device has an aperture response nearly as good as the RBV sensor, and 5000 to 6000 tvl/height limiting resolution has been observed.

Signal transfer and gray scale can be optimized mainly by adjusting target bias during readout. For linear transfer, at least ten$\sqrt{2}$ gray shades have been observed. This provides excellent display of halftone imagery.

The performance of the high-resolution storage tube permits a number of unique applications in a real-time reconnaissance system. In a high-resolution image frame, areas of particular interest can be examined in detail by using the electronic zoom. Alternatively, a large number of frames of moderate resolution can be stored. Each frame can then be selected for readout. Other reconnaissance applications include scan conversion for interface between communication links, magnetic and hard copy recorders, and computers.

Conclusions

The high-resolution RBV has been established as a feasible real-time reconnaissance sensor. The AN/UXD-1 camera system, configured as a pod for mounting on the RF-4 aircraft, has been deployed successfully under a variety of flight profiles and visibility conditions. Accessory equipment for automatic exposure and contrast control, forward-motion compensation, and environmental control worked well. The imagery obtained in flight tests was comparable to film's at high contrast and exceeded film's at low contrast.

Based on recent RBV developments, future hardware systems of this type are expected to have faster frame rates, near i-r spectral response, and stereo overlap. For these faster frame-rate systems, requirements for cooling can be relaxed, which will permit a significant reduction in the size and weight of support equipment for environmental control. The use of long-focal-length lenses combined with the outstanding low-contrast capability of the RBV should provide excellent long-standoff capability.

The application of this new real-time reconnaissance system is expected to have significant impact on future military operations. In addition, nonmilitary applications such as earth-resources surveying, environmental protection, law enforcement, and forest-fire control could use this type of equipment to advantage.

Acknowledgments

Since the initiation of the RBV program in 1963, many competent people have contributed toward its recently demonstrated success. O.H. Schade, Sr. is due the highest level of acknowledgment, not only for his design of the RBV and associated electron optics, but for his many innovative methods for tube and special-circuit operation and for overall electronic-reconnaissance system design. In the course of tube development, significant technical contributions have been made by RCA Laboratories in Zurich and by C.W. Mueller and E.C. Douglas of Princeton. F.D. Marschka and R.E. Hoffman of EO&D, Lancaster provided tube-fabrication and production-engineering skills. Within Automated Systems, Burlington, particular acknowledgment is due to J.J. Klein, S.V. Piccirillo, P. E. Seeley, and their supporting teams for AN/UXD-1 hardware design and flight-test support. This effort was accompanied by valuable design recommendations made by Astro-Electronics personnel who have successfully used the 2-inch RBV in space.

Special acknowledgment is also due to the Air Force Avionics Laboratory for its continued financial support. Individuals who made significant contributions in monitoring the various contracts and in design and field test efforts include J. Huckabye, R. Rang, M. St. John, and N. Rowe.

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Building a homemade solar energy collector

D.A. Kramer

The benefits of a solar energy collector for the average home need not await a breakthrough in technology. Inexpensive materials and simple techniques are available now to permit you to supplement your home heating requirements and save some money.

In November, 1974, I constructed an experimental solar collector to test the feasibility of solar house heating. The motivation for this project dated back about a year earlier when I realized that our traditional energy sources were being rapidly depleted and that increasing fuel costs would be the necessary consequence.

During the first six months of 1974, I searched the available literature on solar energy. Of the works read, I consider the late Farrington Daniels' book[1] outstanding for a layman. Actually, much of the work on solar energy seemed to date back to 1955.[2] Since then there has been a great proliferation of publications in the field. *Solar Energy*, the journal of the International Solar Energy Society, and books by Duffie and Beckman[3] and Meinel[4] are necessary tools for those with a serious interest in solar energy applications.

The literature seemed in general agreement that about one square foot of solar energy collector is needed for each two square feet of living area for "optimum" solar heating. Optimum is about 80% and is synonymous with cost effectiveness, because overdesign has severe cost penalties. In the area of New Jersey where I live, it is economically impractical, at present, to supply more than 70 to 80% of the heat load with solar energy.

Ed note: The energy "crisis" is becoming a thing of the past. It is now a way of life. Whatever courses are taken by industry and government—conservation, increased production, or development of new sources of energy—fuel is going to cost us more.

In this article, Dean Kramer of RCA Laboratories relates his experiences in building an experimental solar energy collector for his home in Cranbury, N.J. Dean's motivation, back in 1973, for investigating a direct application of solar energy to his home was mainly pragmatic—as traditional energy sources were being rapidly depleted, the costs of fuel were rapidly rising. He decided to do something, and a year later had his first solar energy collector operating.

For further evidence of the growing interest in harnessing energy from the sun, readers should take a look at Edmund Scientific Co.'s latest catalog. Eight pages in the catalog offer solar energy experimenters a collection of items ranging from solar cells to solar furnaces to complete plans for building a solar house. Edmund Scientific Co. is located at 124 Edscorp Building, Barrington, New Jersey 08007.

—F.J.S.

Heat load analysis

To fully understand the problem, I needed to know the heating requirements of the house. The actual fuel consumption would tell the amount being used and hence the "experimental" heat load. A calculation of the heat loss factor (HLF) would determine the "theoretical" heat load. A comparison would act as a cross check.

Because our home is heated by gas, it was a simple matter to ascertain heating requirements by examining past utility bills. First, gas consumption patterns during summer months were determined. I found that a "base" (non-heating) load of 2.8 million BTU (MBTU) per month existed, a figure which respresented cooking and hot water. It should, of course, be recognized that during winter months, gas for cooking (and to a somewhat lesser extent, hot water) offsets the need for space heating. The actual gas consumption for heating (after subtracting this base load) represented 88.8 MBTU per heating season, based on a 10-year average.

Estimates of the HLF were not as easily obtained. Fortunately, we had the blueprints and specifications of our house. From these, and standard tables of heat loss coefficients, the HLF was estimated to be 434 BTU/h/°F. Using the coefficients of Whillier[2] gave 512 BTU/h/°F as the HLF. Both estimates were later found to be low. The most refined method[5] gave a value of 691 BTU/h/°F. (None of these values takes into account the effect of wind, which significantly increases heat losses.)

Choosing a collector

The final stage of planning involved the selection of a type of collector appropriate to our hot-air heated, split-level home. I chose a "flat-plate" collector as a starting point, because this design was sufficiently simple in construction and has been adequately researched.

Flat-plate collectors are of two general types—those that extract the collected heat by liquid and those that use air flow. Fig. 1 shows a cross-section of a liquid-type collector. This type is somewhat more efficient, can be used in summer for heating water, and in principle may be used as a source of energy for air conditioning. However, its design, fabrication, and cost, ruled against its use for my feasibility study.

Dean Kramer joined RCA Laboratories in 1957 and has been primarily involved in optical spectroscopy. For the past ten years, he has been a part of the Materials Characterization Group and is currently engaged in making measurements in support of the VideoDisc program. He has been a member of the International Solar Energy Society since 1975, and is presently part of the Passive Systems Division of the American Section.

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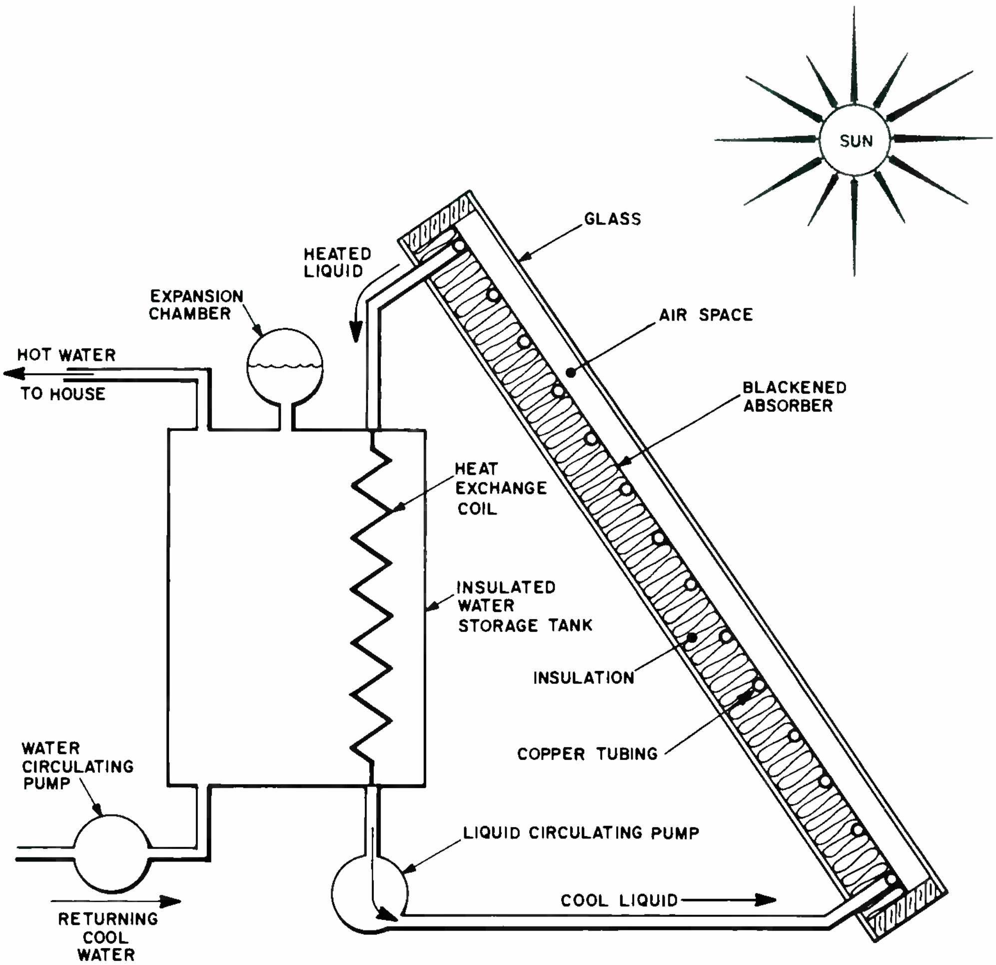

Fig. 1
The liquid-type collector has several advantages over the hot-air type, including its greater efficiency and its possible use as a supplementary hot-water source. However, the materials and components needed in such a system—plumbing, storage tank, heat exchanger, and pumps—make it much more costly and difficult to fabricate.

The air-flow collector, on the other hand, can be constructed of readily available materials that are inexpensive and easy to work with. Fig. 2 shows the application to my house of the air collector I selected. In operation, cool air is taken from the basement, heated in the "greenhouse" area between the blackened aluminum plate and the glass covering, and forced by the fan into the lower living level of the house. The heated air is then diffused by convection currents throughout the house. In practice, this diffusion is quite efficient, there being only a 2°F temperature differential from level to level.

Solar collector panels are usually mounted on the roof of a building. However, I decided to place the collector panel at the rear of the house, rather than on the roof, because:

a)The back of the house faced south,

b)Casement windows for ducts existed in basement and recreation rooms,

c)The roof pitch of 4/12 was improper for winter solar heat collection, and

d)An experimental collector needs to be where it can be readily modified.

Regarding point c) above, a pitch of 4/12 gives an angle of less than 19°. For best results, however, a solar collector should be tipped at an angle near 15° plus the latitude. Consequently, my collector was set at an angle of 55° from the horizontal.

Building the collector

The necessary stimulus leading to actual construction of a collector came about when I was able to obtain inexpensive, used storm sash. The size of the sash was such that an 8 x 10-foot frame of 2- x 4-inch lumber could accomodate them. The net glass area was 65 ft^2, which determined the fan size. The "rule-of-thumb" generally calls for about 1.5 CFM fan capacity for each square foot of collector. A "muffin" fan of 100 CFM matched this requirement closely.

The surface material used in my original collector was simply the foil facing of the insulation, painted flat black.

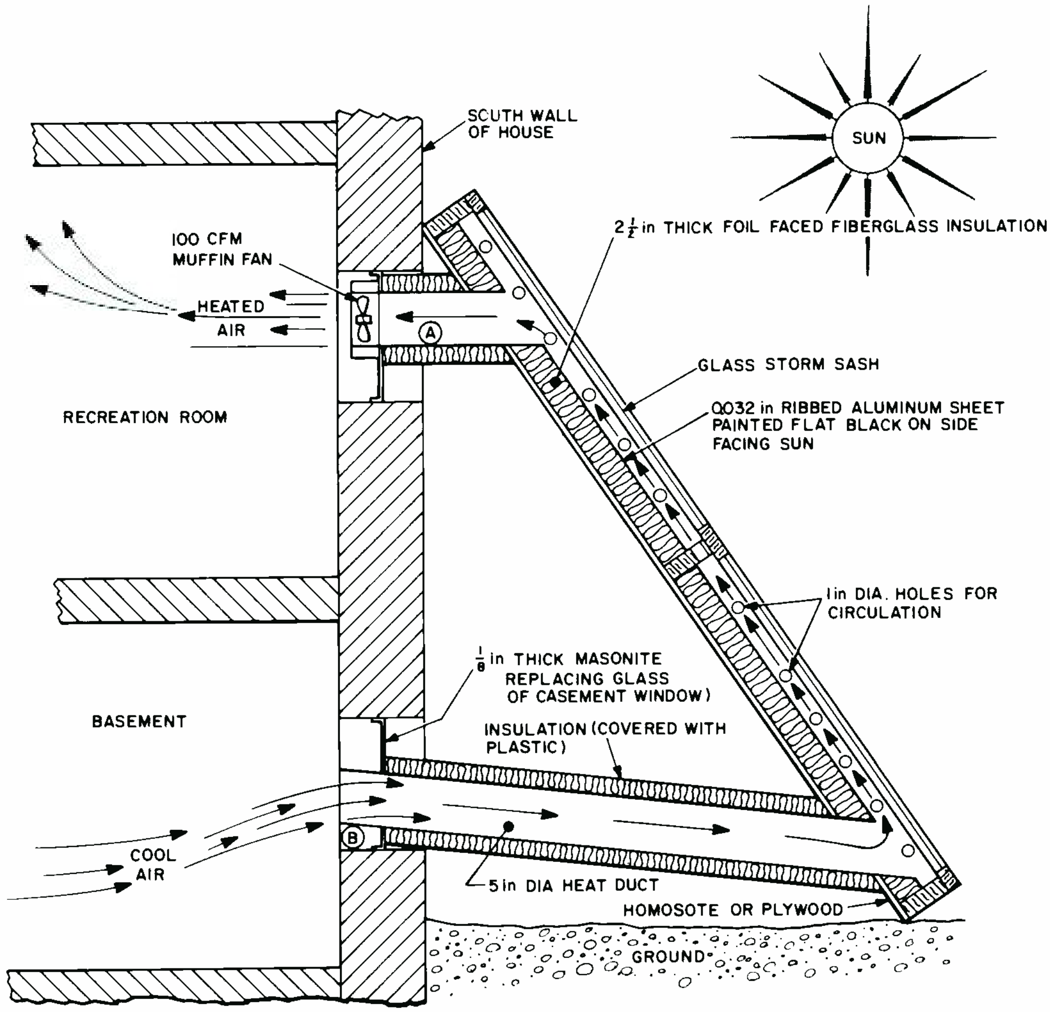

Fig. 2
The hot-air type collector selected by the author for use in his home is relatively simple to construct and requires no expensive components. Air circulation is controlled by a differential thermostat with sensors at points A and B. The sun does the rest.

This was backed by polyethylene sheeting in an effort to trim costs. Unfortunately, both of these choices proved to be inadequate. The high temperature to which the foil facing is subjected (in excess of 180°F) causes the paper backing to crumble after about one year. The ultraviolet rays of the sun cause the polyethylene to disintegrate in a similar time period.

In my present collector, the surface material is 0.032-in-thick ribbed aluminum sheet, painted flat black. Homosote is used as the backing, but 0.5-in-thick-plywood would be equally as good.

In the second year of the system's operation, I added a differential temperature thermostat.[6] The device uses two thermistors, as indicated by points A and B in Fig. 2. When the temperature at A exceeds that at B by 10°F, the fan turns on. When the temperature differential is less than 5°F, the fan shuts off. Because the collector would supply only a relatively small fraction of the heating load (estimated to be between 5 and 10%), a heat storage system was deemed an unnecessary expense. Rock bins are, however, the normal method used with hot-air systems.

During the months of May and September, when the total heating load is carried by solar energy, the indoor temperature varies by about 10°F. The proponents of "passive" solar energy systems (where solar heat is stored in the masonry of the structure) accept 20°F variations; and they claim it to be a healthier situation. In operation, I found that the outlet air temperature from the solar panel approximated 130° near mid day. (It has been measured as high as 170°F.) An output of 50,000 BTU on a clear day is not unusual.

My efforts to determine effectiveness of the collector on a sunny day vs. a cloudy day were frustrated by the "thermal inertia" of the house. Estimates indicated the heat capacity of the interior structure of the house to be in the range of 30,000 to 40,000 BTU for each degree change of internal temperature. Thus, heat that was being "stored' in the structure on sunny days was being used on cloudy days. While this was desirable from a heating standpoint, it caused large deviations when I attempted to make correlations of BTU/degree-day averages. Application of the method of Nash and Williamson[7] showed a significant difference in the fuel consumed. This same method gave HLF values ranging from 794 to 694 BTU/h/°F, which is in reasonable agreement with the calculated value of 691 BTU/h/°F mentioned earlier.

Use of total fuel consumption for the 1974-75 heating season gave a value of 821 BTU/h/°F, while net (heating) consumption gave 598 BTU/h/°F. These values represent fuel consumptions of about 400,000 BTU/day on a typical January day in central New Jersey. When heat loss from 100 gal of cold water brought into the house represents approximately 30,000 BTU/day, or heat gain from the six residents for a 12-hour period is about the same, it may be seen that the agreement is quite good.

Calculating HLF

As a result of the foregoing, I suggest the following method as an easy means of finding the HLF for a residence:

$$HLF = Q/24DD \text{ in BTU/h(°F)}$$

where Q = MBTU for heating season

DD = degree-days for the same season

The 24 in the denominator converts the daily units for HLF to hourly units. This HLF may then be used to determine the adequacy of insulation and the percentage of the heating load that could be expected to be carried by a solar energy collector of given size. For example, Nash and Williamson[7] indicate that with an HLF of 830 BTU/h/°F, only 65% of the heat requirements in January would be met for a 1500 ft^2 house, with a 500 ft^2 collector.

Conclusion

During the first year of operation, my solar collector supplied about 8% of the heating load. This figure was based on a reduction in fuel consumption of 6.25 MBTU over the previous year (1973-74). Based on BTU/degree-day, the savings were about 13%. However, I believe the lower figure to be more realistic. Since our home has 1300 ft^2 of living area, the optimum size for a solar collector would be 650 ft^2 as stated earlier. This size could be expected to supply around 80% of the heating needs.

The cost effectiveness of a homemade solar collector of this type is significantly greater than present commercially available types. Total cost of my collector (excluding my labor) was less than $150, or $2.30/$ft^2$ of net glass area. Commercial panels run around $10.00/$ft^2$ without controls or installation and are at best 25% more efficient.

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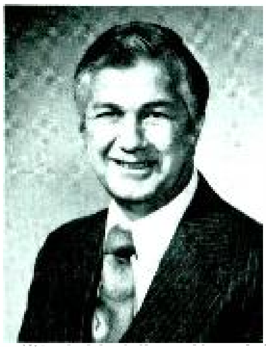
The 1977 David Sarnoff Awards for C

RCA's highest technical honors have been announced for 1977. Each award consists of a gold medal and a bronze replica, a framed citation, and a cash prize.


Borman


Byers


Olson


Turpin


Luedicke

Bennie L. Borman, Larry J. Byers, Larry A. Olson, Larry M. Turpin
Consumer Electronics, Indianapolis, Ind.

Eduard Luedicke
RCA Laboratories, Princeton, N.J.

For team effort in the design, construction and installation of automated test equipment used in the assembly of color tv chassis.

The minicomputer-controlled automated system designed by this team tests tv-chassis subassemblies at the point of their manufacture. The 100% testing in a self-contained console required the development of unique signal sources and measurement methods for testing. Examples of the systems and techniques developed include: a 10-ns waveform sampler that permits rapid and accurate testing of any desired waveform in a color tv receiver; a frequency counter capable of measuring a broad range of frequencies within milliseconds with extremely high precision; a method of measuring phase relationships of color tv signals objectively; a control-system interface that allows half-rack attachment to a master signal stand; time-optimized control software; and the establishment of new test methods for automated testing, rather than subjective oscilloscope waveform analysis.

Leopold A. Harwood
Consumer Electronics, Somerville, N.J.


Harwood

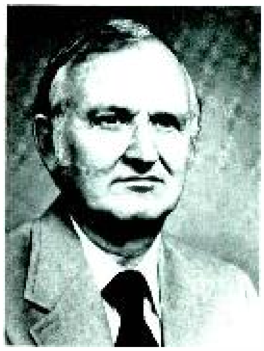
For the invention, development, and application of chroma processing integrated circuits used in color television.

During his 25 years of service with RCA, Leo Harwood has received 36 patents, many of which have been used in RCA color television products. His chroma-processing integrated circuits have been used from the first-generation XL-100 in 1969 to the new third-generation single-chip chroma IC introduced in the 1977 CTC-85 Xtended Life chassis. He has been responsible for introducing sample-and-hold circuits in color control loops, chroma overload control, and dynamic flesh correction—all ColorTrak features that have become the standard of the industry. RCA has manufactured over 20 million integrated chroma circuits of his design.

Jutstanding Technical Achievement

James L. Sullivan

Missile and Surface Radar, Moorestown, N.J.



Sullivan

For conceptual contributions and technical leadership in the development and implementation of advanced signal-processing systems.

James Sullivan has been in the forefront of advanced radar signal-processing technology for more than 20 years. His inventiveness and technical direction have brought RCA to a position of leadership in this important technological area through the development of systems of increasing sophistication and capabiltiy on programs such as BMEWS, TRADEX, hand-held tactical radars, over-the-horizon systems, and more recent computer-controlled equipments such as the digital instrumentation radar and the AN/SPY-1 phased array radar sensor for AEGIS. In 1976, Mr. Sullivan's achievements assumed a special significance with the award of a contract providing for a communications signal-processing system of unparalleled capacity and performance.

Lucas J. Bazin, Sidney L. Bendell, John J. Clarke, Donald C. Herrmann, Cydney A. Johnson, Anthony H. Lind, Mark R. Nelson, Dennis M. Schneider, Alexis G. Shukalski, Harry G. Wright

Broadcast Systems, Camden, N.J.

For team effort leading to the highly successful TK-76 electronic newsgathering tv camera.

The TK-76 camera developed by this team weighs only 20 pounds (plus a 6-pound battery belt), and has many advantages over the previously used 16-mm film systems or tv cameras not specifically designed for newsgathering. The TK-76 has been highly popular, largely because of its technical features and performance compared with competitive offerings. For example, 150 were ordered before the first camera was shipped, and the current shipping rate is 50 cameras per month. This team carried through the TK-76 design program, from concept to start of product deliveries, in record time. The project began in late 1974, a developmental model was shown in April 1975, and full-scale production deliveries began in April 1976.

Bazin

Bendell

Clarke

Herrmann

Johnson

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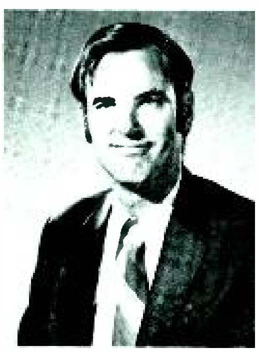
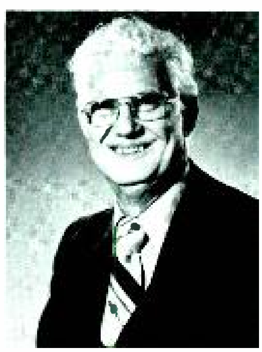
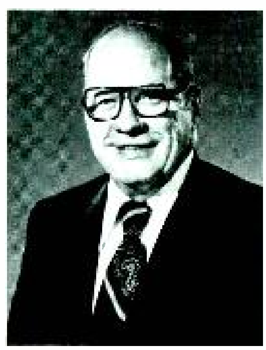
Nelson



Schneider



Shukalski



Wright

Professionalism

E.W. Herold

An engineer who acts like a professional is more apt to be treated as one.

Engineers employed by large companies sometimes lose sight of those aspects of their career that identify them as professionals. They are usually subject to similar rules, benefits, and working hours as nonprofessionals. Thus, engineers sometimes view themselves as routine employees with few distinguishing characteristics. Is this the way it should be? I believe not.

First a word on the definition of professional. Although the dictionary may show as broad a meaning as "someone following an occupation as a means of livelihood," I am addressing a more select portion "requiring a base of specialized intellectual and practical knowledge acquired through education and experience"—specifically, that group of "technical professionals" in science and engineering. During the past years, it has become increasingly clear that rapid advances have placed an additional heavy burden of "keeping up with technology" on the technical professional.

The high price of entry and upkeep in the profession justifies expected rewards substantially higher than those of many other workers.

Challenging job assignments, substantial freedom in job execution, job security, and financial reward are prime expectations; yet, self-esteem resulting from success, reenforced by the prestige a professional attains among his colleagues, friends, and community, is also very important.

These were my expectations when I encountered a shocking experience early in my career. A neighbor, who was a non-engineering top executive of another company, gave me his opinion of engineers in a moment of candor. "They are a purchasable human commodity," he said. "I buy them when I need them, fire them when I don't. Engineers are a 'dime a dozen,' in no way different from unskilled labor."

It was a devastating characterization for me, a young entrant in a field that had appeared to be so important, so challenging, and so different from the ordinary occupations. It's true, this happened in the 1930s when so many engineers were unemployed and available. It's also true that such an attitude did not prevail during two periods since: World War II and in the post-Sputnik years, when engineers were in a seller's market. Nevertheless, over most of my own 50-year career, many engineers did not attain the status of other professionals, and it seems to me this is, in part, a result of their own behavior and attitudes. It is my thesis that if an engineer acts like a professional, he or she is more apt to be treated as one. The present text is an endeavor to suggest a few steps which would help make the technical professional more distinguishable.

Outstanding performance is the basic professional characteristic.

The engineer employed by a large company, if he begins to lose his identity as an individual professional, also begins to lose the reenforcing prestige to his self esteem. What should his behavior be to prevent this? There are many answers. Foremost, the engineer must perform outstandingly at his job. If he is inventive, he surpasses others in writing down and promoting his ideas. If he is highly analytical, he uses this skill in evaluating ideas of others. The tenacious engineer persists when others are discouraged, and the impatient engineer takes advantage of this converse quality to move fast in trying many, many potential solutions in a short time. The person who is less brilliant or inventive simply works harder on the ideas of others, so that his performance remains outstanding. The one sure way to build up self-esteem is success as proven by performance. All other professional characteristics support, and are supported by, outstanding job performance. Three such characteristics are:

1) The need for *continuing education* in new fields and other disciplines has been stressed so often that it needs no amplification.

2) The engineer should *communicate often* and freely with his peers. Within his organization, he finds individuals with all the special qualities needed for outstanding group performance. By using their help, and by

helping them, he enhances his individual prestige as well as that of his company. Outside his organization, the engineer should publish his work, attend technical meetings in his field, and make personal contacts with as many as possible in environments other than his own.

3) The engineer should *support his profession* by joining and participating in his own professional society as well as in those of related disciplines. Far too many engineering employees of large corporations view the professional society as a journal subscription service, instead of as the representative body of his profession. The result is that the society loses its representative status, but the engineer loses even more: an important distinction between himself and the nonprofessional.

The above list is by no means all-inclusive. The present discussion will be limited to an expansion of items 2 and 3.

Publishing

I have already mentioned the welfare of others as a professional responsibility.

First, let's consider the publication of one's own work. Free publication of results helps many others, because it expands knowledge, saves time, and minimizes duplication of effort. But such considerations are not the most important reasons. For every result which an individual publishes, there are thousands of results published by others for him to use. He is part of a vast system, in which he contributes a little and is given, in return, access to a tremendous quantity of knowledge contributed by other professionals. There aren't many instances in life in which the return on investment is so high. However, this return will not happen if individuals, collectively, do not make their small donation.

In the case of research and development, of course, there is an additional reason for writing up one's work, and that is that otherwise there's not much point to doing the work at all. In R&D, there isn't any product if there isn't any record; one of the key products of research and development is paper with information on it. This situation is so well understood that technical publications are replete with R&D papers. But not all is communicated. There are the lazy fellows who just never find the time to do the writing. Then there are the overly industrious engineers who are so busy on the next project that data on the former ones remain in crude original notes, never again to be interpretable by anyone but the originator. Finally, there are the deadbeats who are going to beat the game by using everyone else's published work, but who purposely withhold their own. All three types defeat the system, lose prestige and self-esteem, and rarely end up among the more successful R&D workers.

For professionals who are not in research or development, such as the manufacturing engineer, the quality expert, the sales engineer, and many others, the question of communication and publication is equally important. Unfortunately, one does not find in these areas as many prestigious outlets for publication or presentation, nor has there been as great a system built up whereby the "return on

investment" is measured in high powers of ten. This state of affairs is entirely the result of so little input to the system. If all the non-R&D engineers communicated as freely and widely as did the R&D workers, the return would build up quickly. I have often been dismayed to find the great reservoir of professional knowledge and talent within a large company that lies hidden and unknown except in the immediate environment of the individual possessing it. Small wonder that, with such disregard of the professional's obligation to help others, many engineers are viewed as just another bunch of employees.

Presentations

The presentation is an entirely different medium.

So far, I've talked of publication, but this is only one form of communication. It's an especially useful form because it permits archival storage, and to the reader it allows detailed personal study and repetition. Every sentence can be read and reread, a page can be returned to and re-studied, and every figure and diagram is available for later use. But there's another way to communicate which is remarkably effective, the oral presentation. In my own experience, I have often been surprised, after hearing a talk on a subject I had already seen in written form, to suddenly find I could see something significant that had eluded me. The reason is, of course, that the speaker requires the listener to follow linearly a train of thought. The listener can't stop and reflect, or jump to some other part of the material, or go back to repeat. The good speaker, who knows exactly the message he wants to convey, moves the listener along the track directly to the conclusion. Far too many engineers fail to see this distinction and they fail both to use the technique to advantage for themselves, and, more commonly, fail to go to meetings and talks, on the ground that they can read about the subject. The two media are not equivalents and, again, the engineer possibly has failed to utilize fully the means at his disposal to enhance his performance and that of his profession.

The professional society

A professional society is useless without active member support.

What of the professional society and the role it plays? Clearly, one of the chief functions is to provide publication media and forums for oral presentation. But success in these two endeavors requires more than the dedication of small bands of volunteer editors, program chairmen, and committee members. The society must be supported actively by the professionals it is intended to serve. The engineer has many temptations to freeload on his obligation. His company library provides journals, and his employer often permits expense account travel to meetings, so that a higher registration fee for nonmembers is not inducement to join. However, no professional society can survive on library subscriptions and registration fees and remain a fraternity of professionals who organize to help themselves. Failure to belong to your professional society (often, to several different societies) is like failing to feed yourself properly: you starve the very source of your welfare, and reduce the "return of investment" mentioned above, which is potentially many powers of ten.

Most professional societies do much more for the profession they serve than act as a communication medium. They become official spokesmen for the profession in local, national, and international affairs. The successful society serves its members by dissemination of general news, by surveys of membership views and of the status of the profession in society, and by setting up engineering standards of measurement and definitions of terminology. By establishing criteria for various levels of performance, including a hierarchy of membership grades, they maintain the professional standards without which professionalism has no meaning. The membership directory of the society is a valuable source book for personal communication and solicitation of help. In most societies, an award system provides incentives to perform over and beyond the normal rewards provided by other parts of society and by one's own self-esteem. Again, none of these factors can be highly successful unless the qualified professionals are members.

The society appropriate for most RCA engineers is, of course, the IEEE. Yet, in my own experience, this largest engineering society in the world has never been supported by the profession to the extent one might expect. Perhaps as many as half of the professionals whose livelihood depends on the electrical and electronic sciences are not members at all, and, of the members themselves, many fail to use the advantages of membership to the extent they could. I hear criticism of the organization, its aims, and its policies; but much of the IEEE's problems can only be ascribed to apathy and lack of ambition on the part of the members.

In my own case, I joined the IRE in 1930 and so have been a member for 47 years. Truthfully, there has probably never been a year in which there wasn't some Institute policy that needed change or improvement. Yet, in integrating everything that IRE, AIEE, and IEEE have done over these years, the positive so far outweighs the negative that I cannot conceive what my own career would have been like without the Institute.

Ed Herold was Director of Technology in he RCA Research and Engineering organization at the time of his retirement in 1972, after 37 years with RCA in research and development. He is a Fellow and former Director of the IEEE, and a member of Phi Beta Kappa, and Sigma Xi. He was awarded the IEEE Founder's Medal in 1976

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Furthermore, I have not seen many instances in which the nonmember has contributed much to improve the Institute. Thus, I have always resented the engineer who fails to join or to renew his membership on the ground that the IEEE should be better. Of course it should, but the way to make it do so is to support it, first with membership and second by participating actively in all the functions in which the Institute can or should serve him. To be practical about it, he can't make a better investment!

Conclusion

As stated earlier, there are a wide variety of ways in which engineers can act in a professional manner. Communicating through publications and presentations and active involvement in professional groups are but two. I would like to challenge you, the RCA engineer, to take stock of your professional activities. What are the various ways in which you act as a professional? If my thesis is correct, that you will be regarded and treated as a professional only to the extent that you demonstrate your professional credentials, then the means to a professional goal are at your disposal.

Success story: the AN/GVS-5 design-to-unit-production-cost program

Establishing a cost goal for a product before its development begins is one way to produce an on-target cost. The AN/GVS-5 contract marks the first time that this has been done on a government development contract at ECOM.

F.F. Martin

The contract for the AN/GVS-5 hand-held laser rangefinder* program was awarded to RCA by the U.S. Army Electronics Command (ECOM) in June 1974. It included, among other items, Design-To-Unit-Production Cost (DTUPC) and Producibility Engineering and Planning (PEP) tasks. This contract was a milestone for RCA and ECOM because it was the first that incorporated DTUPC and PEP into a development contract.

DTUPC is the cost goal established before development begins for a product that is to be manufactured in a specified quantity and rate. The manufacturing quantity and rate can be specified by the customer, as in the GVS-5 program, or by corporate or division management, based upon a product selling price that includes a profit objective. DTUPC includes the nonrecurring costs for factory tools and test equipment as well as the recurring costs of materials and labor. PEP, Producibility Engineering and Planning, is the development of a production plan that includes production-engineering requirements on the drawings.

Team approach

As early as the proposal phase, we decided that a multidisciplinary team was required to effectively plan and implement the

*See "The AN/GVS-5 hand-held laser rangefinder," by Jason Woodward, *this issue*.

perspective

The development and product work of the hand-held laser rangefinder has produced more than $18 million of business to date for Automated Systems. The largest contract is for over $13 million (to date) for a total of 1500 units with an option for 1000 more. This contract is believed to be the largest quantity order for field-portable laser rangefinders in the world. Later this year, the U.S. Army plans to negotiate for a quantity of 1500 production units; total product potential for this laser rangefinder is now over 10,000 units. In addition, this program has provided a technical and business base for developing other applications of this and simlar laser rangefinders. The Electronics Command of the Army is taking steps to standardize on the use of the GVS-5 modules for almost all of the various laser rangefinders planned over the next several years. Results of this work have placed RCA in a competitive position for the tank and helicopter rangefinder business.

Key to the successful application of this laser rangefinder technology was the design-to-cost program described here. The design team worked closely with production specialists from the beginning, rather than building an engineering model-shop version and then passing it to manufacturing with the comment; "we've done our part, now it's up to you to produce it." This close cooperation meant that before designs were frozen, or changed to solve problems, the impact on the production cost was immediately reflected and examined by manufacturing and management personnel. The program resulted in a laser rangefinder produceable for $3500 and weighing only 5 pounds, compared with the previous $30,000 unit weighing 25 pounds. The GVS-5 program has opened up a market at least 100 times greater than that available with earlier rangefinders.

—Editors

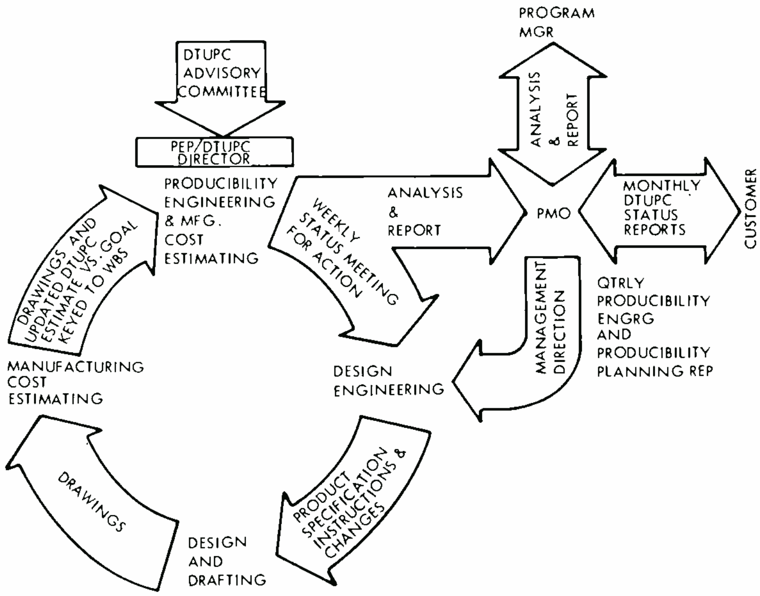

Fig. 1
Work flow for the PEP/DTUPC program involved testing the economic impact of design decisions long before they were "cast in concrete," then keeping the customer informed of the alternatives.

Ferd Martin is Manager of the AN/GVS-5 program described here. He has also managed several other large electro-optical programs, including Project Night Life, the Integrated Observation System, and the Cobra Night Fire Control System. His work has also included managing a number of programs in the area of reconnaissance and strike systems.

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DTUPC and PEP tasks. The team, comprised of members of the engineering, materials, manufacturing, and finance staffs, was chaired by the program manager.

The team developed the following approach for conducting the DTUPC task:

- Set goals by work breakdown structure
- Develop tradeoff matrix
- Obtain estimates and reevaluate
- Alter design and reestimate
- Freeze design after iteration

Essentially, we divided the overall DTUPC goal into modular elements through a work breakdown structure.

These modular elements included all the major subassemblies or modules of the AN/GVS-5 for which a specific engineer had design responsibility. The goal for each modular element was assigned to the engineer responsible for that module; it became another specification item that he had to consider in his design. For example, the rangefinder display module was assigned the electrial engineer responsible for that item, and the control panel module was assigned to the mechanical engineer responsible for that item. We then developed detailed tradeoff matrices based upon design alternatives, obtained detailed cost estimates for each alternative, iterated the design as a result of the cost estimate, and finally froze the design after we decided that we had met the goal or achieved the best result we could in the available time. Fig. 1 shows how the team implemented this approach as a practical operation.

The program manager had overall responsibility for the program, but a PEP/DTUPC director, functionally reporting to the program manager, was responsible for the implementation and control of the PEP/DTUPC tasks. A technical director, also functionally reporting to the program manager, was responsible for design engineering.

We organized our work plan in such a way as to avoid disturbing the normal and effective close ties between design engineering and drafting. Both design engineering and the PEP/DTUPC director received guidance on their parallel responsibilities directly from the program manager.

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We were determined to test the economic impact of design decisions long before they were cast in concrete.

This called for compiling more or less finished drawing packages at an earlier stage than was usually required on other programs. Therefore, manufacturing personnel, buyers, and vendors could respond with reliable intelligence on the cost to produce these designs early in the design process.

The DTUPC/PEP director then analyzed and fed this production-cost information to the program manager and the design group. Finally, the program manager decided whether: the current design could be accommodated into total program objectives, both functional and economic; redirection of design effort might be required; or higher management should be informed of a potential problem.

The customer was also brought into the picture early and regularly.

We advised him through formal and verbal reports on progress and areas where a specific specification item was adding substantial cost. He then could decide whether to relax the specification or keep it as it was. This interaction was particularly important to the customer and RCA.

One serious problem that we had to resolve immediately after contract award was how to handle inflation. For the period from the submittal of our proposal to ECOM and award of the contract, the U.S. economy experienced the worst short-term inflation rate in our history—over 20% in a nine-month period. Our solution to this problem was to use a government index that closely tracks the inflation rate—the "All Industrial Commodities" portion of the "Wholesale Price Index" published in *Economic Indicators*, a monthly government publication. We then used this index on a monthly basis to adjust the various targets of the work breakdown.

Table I

Final status report of the DTUPC program. Current target column takes 20% inflation into account over original target. Current estimate, slightly over target cost, represents cost/performance tradeoffs accepted by customer.

Period ending July 31, 1976

Item	June 3, 1974 target	Current target	Current estimate	Delta (over)/under target	
AN/GVS-5 set	$2,572.55	$3,096.66	$3,551.06	($454.40)	(14%)
Program mgm't.	43.75	52.37	52.37	—	
Transit case	97.73	120.70	149.18	(28.48)	
Carrying case	34.88	42.08	37.14	4.94	
AN/PVS-4 bracket	16.25	20.86	33.83	(12.97)	
AN/TAS-2 bracket	15.34	18.82	—	18.82	
Batteries (3)	89.50	107.11	107.11	—	
External power cable	52.84	65.91	291.37	(225.46)	
Cold weather kit	8.13	9.89	—	9.89	
HHLR, MX-9838	2,214.13	2,658.92	2,880.06	(221.14)	(8%)
Housing assy.	199.31	238.54	418.24	($179.70)	
Optical assy.	595.33	717.33	838.01	(120.68)	
Receiver assy.	537.11	642.86	461.05	181.81	
Transmitter assy.	557.86	669.96	755.61	(85.65)	
Pwr supply assy.	226.06	272.38	250.88	21.50	
Integ. and test	98.46	117.85	156.27	(38.42)	

Results of the program

Table I is a summary of the final result of the DTUPC effort on the GVS-5 program. The June 3, 1974 unit-cost target of $2,572.55 accounted for a 22% inflation factor from the time of the proposal submission to contract award. The current target of $3,096.66 accounted for an additional 20% inflation factor that occurred from contract award to the completion of the final DTUPC effort on the contract. The "delta" of $454 is the true cost differential of the final DTUPC estimate compared to the corrected target goal. It is 14% over target, but acceptable to the customer.

Analyzing the results provides a good insight into the overall achievement. The receiver assembly, which includes all the electronic circuitry for the receiver subsystem, came in at $182 under target. The overages of $180 and $121 respectively in the housing assembly and optical assembly were caused almost entirely by a severe weight limitation in the laser rangefinder specification. In this case, we advised the customer early of the DTUPC problem and told him the production cost could be reduced if he would grant a very small increase in rangefinder weight. He chose not to grant the weight increase. The total rangefinder itself (MX-9838) was only 8% over target in spite of the cost increases caused by weight limitations. The other significant item causing the DTUPC final estimate to be over target was the external power cable, where a tight specification was also the principal cause for the increased cost. Again the customer was advised early on alternatives to reduce the production cost for this item. He chose not to relieve the specification and to accept the higher production cost.

Conclusions

We are convinced that the DTUPC/PEP effort on the GVS-5 program was successful. A major factor was starting the DTUPC effort during the preproposal phase. Because of that effort, we presented a believable story in the proposal and evolved a concept that remained essentially unchanged. As a result, we could concentrate on the design details during the subsequent phases.

A multidisciplinary team dedicated to the DTUPC/PEP concept and a great deal of hard work are essential to a successful effort. Many tradeoffs are necessary, as well as rapid feedback of information and ideas. This effort, however, does produce a lower-cost product and justifies the work put into the effort.

Acknowledgments

Many people at Burlington contributed to the planning and execution of the DTUPC/PEP tasks on the AN/GVS-5 program. The lead people were Frank McGurk, the DTUPC/PEP director, Jay Woodward, the technical director, and Sam Waldstein, the mechanical manager.

The AN/GVS-5 hand-held laser rangefinder

In one second, this five-pound device can determine the distance to an object 10 kilometers away, accurate to 10 meters.

Fig. 1
Hand-held laser rangefinder resembles a standard binocular. Easy to use, its only controls are power on/off, minimum range on/off and adjustment, reticle brightness adjustment, and "fire."

J.H. Woodward

The AN/GVS-5 laser rangefinder is the most recent in a series of laser rangefinders designed for ground use by infantry and artillery obervers. All have been designed by RCA Automated Systems under U.S. Army Electronics Command contracts.

The hand-held laser rangefinder (HHLR), shown in Fig. 1, is held in a manner similar to a pair of binoculars and sighted upon the desired target through its seven-power telescope. Depressing and holding its "fire" pushbutton has the range to the target measured and displayed in the lower portion of the sighting telescope reticle.

To make the range measurement, the laser transmitter emits a single, six-nanosecond infrared "light" pulse in a one-milliradian-diameter beam directed at the target.

A portion of the energy reflected by the target is detected by the silicon avalanche diode in the HHLR receiver, and the elapsed time between transmitted and received pulses, directly proportional to range, is measured by a binary-coded decimal counter using a quartz-crystal clock. The range, in meters to the nearest ten meters, is shown directly on a light-emitting diode (LED) display. The HHLR is powered by an internally housed replaceable, rechargeable nickel-cadmium battery.

A minimum-range gate can be set to preclude ranging to interfering objects near to the user.

The gate setting, adjustable from 200 to 5000 meters, can be displayed on the range display and is controlled by a potentiometer. An adjustable reticle light for dusk or night use is also available. A power switch enables the other functions, although no power is consumed unless one of the three pushbuttons (fire, minimum range, and reticle) is held down. The telescope eyepiece has a diopter adjustment to accommodate each operator's eye.

The rangefinder provides range to targets between 200 and 9990 meters under most conditions when the targets are visible within the one-mil central field of the sighting telescope. A multiple-target light indicates if more than one object is within the one-mil field during ranging. A second light warns of a battery in need of recharging. The HHLR may also be operated from external power supplied by a military-vehicle electrical system.

Modular design

The AN/GVS-5 contract required it to be a high-production-rate design using design-to-cost and producibility engineering and planning programs during the design phase. (See Martin's article in this issue on this aspect of the design.) The stringent performance and environmental specifications, five-pound weight limit, human-engineering, safety, reliability, and maintainability constraints combined with the low design-to-cost goal to pose a challenging design problem.

One of the design requirements was modular construction, to facilitate repair by replacement. To achieve the maximum benefit of modularity, the cost, reliability, feasibility of isolating problems to a specific module, and ease of replacement all had to be considered.

For example, the optical assembly has no internal electrical parts or connections.

All items with electro-optical functions couple optically through windows or lenses, so they may be replaced without violating the pressure sealing of the optical assembly. The laser transmitter module, another separate and replaceable subassembly, mounts to the optics with a simple, precision mechanical interface. In compliance with an Army specification, all laser modules are interchangeable so that they can be replaced without optical alignment or boresighting.

The other replaceable modules include the electrical functions—the detector-preamplifier, video-amplifier, range-counter, power-supply, and laser-trigger circuits—all shown in Fig. 2, plus the

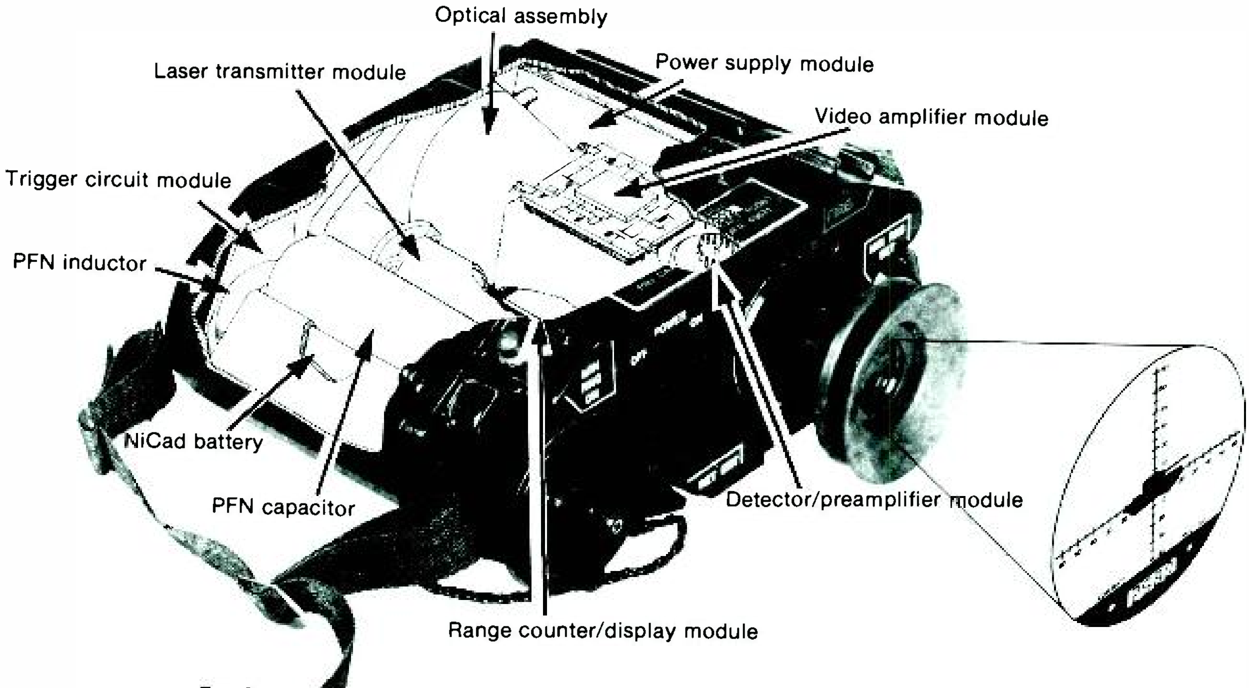

Fig. 2
Modular design allows field replacement. Laser transmitter modules are interchangeable so they can be replaced without optical alignment or boresighting.

control-panel assembly and cover. The pulse-forming-network inductor, capacitor, and diode, the panel controls, and the interlock switches are replaceable discrete electrical parts.

The configuration, method of construction, and degree of repairability of the modules were all subjects of tradeoff analyses, constrained by the design-to-cost goal and the fact that the performance requirements, weight limit, power consumption, and MTBF could not be compromised. A tradeoff decision made early in the design phase eliminated internal connectors for modules because their weight was critical and the failure rate of the connectors could significantly increase the frequency of module replacement. Instead of connectors, the designers chose pins on 0.1-inch centers along module edges, soldered to pads on custom-designed flexible printed-wiring harnesses.

Two types of electronic modules resulted from the tradeoff studies—hybrid and discrete. Hybrid microelectronics assembly technology was used for the high-frequency and high-density circuitry—the detector-preamplifier, video-amplifier, and range counter-display units. Etched-board, discrete-component construction was used for the trigger circuit and the dc-dc converter power-supply because the size of the magnetic elements, the relatively high voltages, and the large high-voltage parts made effective hybrid circuits impossible.

The *detector-preamplifier* module consists of a ceramic substrate that supports the silicon avalanche photodiode and the unity-gain preamplifier chip components. This assembly is mounted on a 12-pin, TO-8 header, then sealed with a cover containing the optical input window. The principal consideration in selecting this type of packaging was achieving optimum detector performance by minimizing capacitance and interconnections, while providing adequate shielding and decoupling from external fields.

The *video amplifier* uses a rectangular ceramic substrate with all active devices (IC chips, transistors and diodes) within a hermetically sealed volume formed by a square Kovar cover soldered to the substrate. Thick-film resistors requiring functional trimming, plus most of the capacitors, are mounted on the substrate outside of the sealed area. External connections are made with pins on 0.1-inch centers along one edge of the substrate, which is cemented to an aluminum mounting plate.

The *range counter-display* module is supported by a rectangular substrate. The counting logic and strobing circuitry for the LED display is distributed between two custom CMOS/SOS LSI chips of the GUA variety. Two round Kovar seal covers protect these active devices. A hybrid display subassembly, holding two discrete LEDs and a 4-digit, 7-segment numeric indicator, mounts in a plane perpendicular to the main substrate face. Also mounted on the main substrate external to the sealed cans are thick-film resistors, chip capacitors, and the quartz crystal for the clock.

The *trigger circuit* is for the most part conventional, with discrete components mounted to an etched board. The high-voltage trigger transformer and associated capacitor are attached to the board by a metal bracket.

The *power supply* module consists of a larger double-side-etched board with a smaller board mounted above one end. This high-density package of discrete components derives all of the HHLR dc voltages from the nickel-cadmium battery or other prime power source. The high-density packaging and comparatively low unit cost of the power supply suggest that it should be considered a nonrepairable item.

The precision aluminum housing of the *optical assembly* is the supporting structure for the three microelectronic modules, the power supply, and the laser transmitter module. The sighting and receiving functions share a common objective lens assembly and erecting prism cluster. A beam-splitting cube diverts laser return energy to the detector optical path and passes visible light to the viewing eyepiece. A display lens and periscope are used to image the range-display LEDs within the optics assembly in the lower portion of the reticle plane; a separate telescope contained in the casting reduces the beam divergence of the laser transmitter output.

An innovation in the design of the *laser transmitter* module is the use of the laser rod to support the Q-switch and rear reflector of the resonator. The rod is in turn held at the laser output end by a mounting flange that also supports the pump cavity housing containing the flashlamp and trigger electrode. By incorporating a saturable absorber in a solid as the Q-switch, an extremely simple resonator results. The complete laser transmitter module, capable of over two megawatts output, is 3.5 inches long and weighs approximately 0.1 pound. The output beam is factory-aligned normal to the mounting flange to permit module replacement without optical boresighting.

The *control panel* is the main supporting structure of the laser rangefinder. It consists of a precision aluminum investment casting to which the molded polycarbonate battery well is bonded. The operating controls for the rangefinder are all mounted to the control panel with immersion-proof seals on shafts and actuator buttons. The pulse-forming network protective diode mounts on the control panel, with the pulse-forming-network capacitor, inductor, trigger circuit module, and interlock switches mounted on the battery well. The optical assembly flange is bolted to the control panel and has an O-ring seal.

The *cover assembly* is the remaining structural module of the rangefinder. A ribbed aluminum casting, with the open end flanged for panel mounting interface, it contains two windows for protecting the optical-assembly objective lenses.

The control panel and cover are investment castings, chosen as the best compromise of uniform structural properties, light weight, precision, and cost. Die castings could not be obtained with the 0.040-inch-thick wall needed to minimize cover weight, nor with similarly thin sections in portions of the control panel. Machining through the skin of the die casting could result in poor mechanical characteristics and leakage due to porosity, so this potentially inexpensive casting process was reluctantly abandoned.

Table I
Typical characteristics of the AN/GVS-5.

Maximum range	9990 m
Minimum range	$\leqslant$200 m
Range resolution	±10 m
Range accuracy (R.S.S.)	10 m
Minimum-range gate continuous adjustment range	$\leqslant$200 m to $\geqslant$5000 m
Sight field of view	7°
Resolution	7 arc-sec., on axis
Receiver field of view	1 mil
Receiver bandwidth	20 nm
Receiver sensitivity	2 nW/cm^2
False-alarm rate (internal noise)	<0.01
Transmitter power	2 MW in 1.0-mil beam
Transmitter pulse width	6 ns
Ranging duty cycle	96/hr (continuous)
Recycle time	1 s
Ranges per battery charge	400-700
Weight	$\leqslant$4.7 lb. w/battery

The battery that powers the AN/GVS-5 is a 20-cell sealed nickel-cadmium unit that has a 150 milliampere-hour capacity and weighs one-half pound. Its weight is included in the five-pound requirement for the AN/GVS-5.

Performance characteristics

Table I gives typical characteristics of the laser rangefinder. Engineering development models of the HHLR having these characteristics and incorporating the modularity concept described above have been fabricated, tested and delivered to the U.S. Army Electronics Command under contract DAAB07-74-C-0270 for testing. All of the items destined for infantry use have completed test at RCA and demonstrated compliance with the environmental requirements of the ECOM specification. This includes water-immersion, exposure to humidity, salt fog, fungus, EMI testing, and radiation environment, plus operation at −50F, +160F, and 10,000-foot altitude.

Performance has equalled specification requirements, and design goals have been or surpassed. Specifically,

- The rangefinder weighs 4.7 lb., well within the 5-lb. design requirement.
- The number of rangings per battery charge is 400 to 700, as compared to the specified "100 required, 250 desired."
- During acceptance testing, no false alarms were observed in a total of 2000 rangings at 9980 meters (100 each on 20 units). The false-alarm rate is specified as less than 1%.
- No range readings differing from the programmed range by more than 10 meters were recorded in the acceptance testing. This included three range measurements at each of ten different ranges, plus the 100-range false-alarm test on each of the rangefinders.
- The predicted receiver sensitivity of 2×10^{-9} W/cm^2 has been verified by range testing against a diffuse target at 1750 meters with a number of different rangefinders. The tests were performed with a 35-dB absorption filter covering the transmitter exit aperture and with the receiver aperture reduced by an iris diaphragm for additional attenuation of 4 to 8 dB.
- The average energy output of the units has been 12 mJ within a 1-mil-diameter beam, with typical pulsewidth of 6 ns, corresponding to a 2-MW output.
- The AN/GVS-5 must range to a target subtending 1 mil (in diameter) and having 10% diffuse reflectivity, at a distance of 5 km when the atmospheric visibility is 5 km. The latter requirement has been established as yielding an equivalent 1% round-trip transmission at 1.065 nm. This requires a ratio of peak transmitter

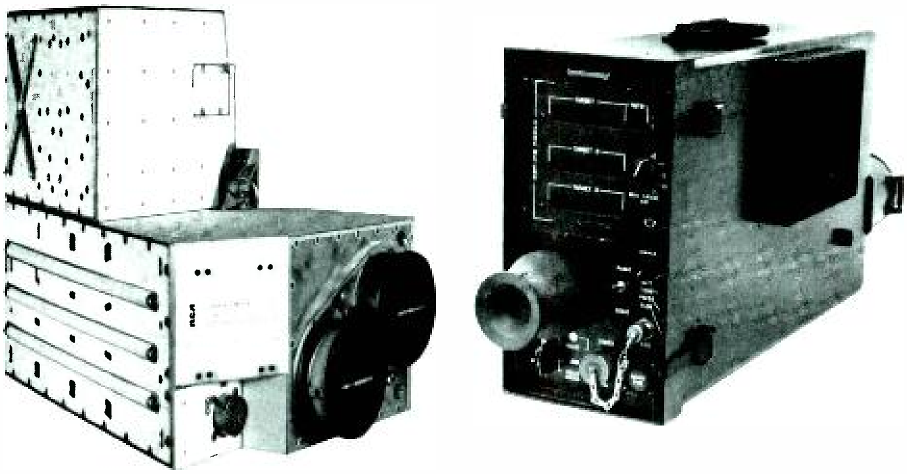

Fig. 3
Earlier laser rangefinders were quite bulky in comparison with the AN/GVS-5. The Apollo laser altimeter (left), which had 1-meter range resolution over its 40-80 nautical mile range, weighed 50 lb and also needed an external power source. The AN/UAS-9 (right) weighed 60 lb and required an external 24-V supply.

power (in a 1-mil beam) to receiver sensitivity of approximately 10^{15} cm^2, which corresponds to the system's 2-MW transmitter power and 2 nW/cm^2 sensitivity.

Previous rangefinders

A comparison of the AN/GVS-5 with earlier rangefinders[1] indicates the progress that has been made. For example, the AN/GVS-1 rangefinder designed and built by RCA ten years ago provided similar ranging performance to the AN/GVS-5, but weighed nearly 30 lb with its internal nickel-cadmium battery. The ruby laser input was over 200 J, with output of about 6 mW peak at 0.6943 nm, but the 4.7-lb. AN/GVS-5 requires only 7 J input to a neodymium YAG laser with 2-MW output at 1.065 nm. The S20 photomultiplier used in the AN/GVS-1 had a quantum efficiency an order of magnitude lower than the AN/GVS-5 silicon avalanche detector. The nickel-cadmium battery assembly in the AN/GVS-1 weighed about 4 lb. and provided 100 to 150 ranging operations per charge, as compared to the half-pound GVS-5 battery that provides 400 ranges per charge.

Another early ruby laser rangefinder was the Apollo laser altimeter[2] (Fig. 3a). This 50-lb unit determined altitude above the lunar surface for the Apollo 15, 16, and 17 vehicles. Its range was 40 to 80 nautical miles (74 to 148 km) and range resolution was 1 meter. Its power was supplied by the Apollo.

The AN/UAS-9 laser rangefinder-designator (Fig. 3b) was a 60-lb. neodymium YAG unit capable of operating at rates to 10 pulses per second. It provided range to 30 km with 5-meter resolution. The digital range readout simultaneously displayed range to as many as three targets, depending upon the number of targets within the field of view. It required an external 24-V dc source.

Conclusions

The AN/GVS-5 met or exceeded its performance, reliability and maintainability requirements. The HHLR "design-to-cost" goal established at contract award and subsequently adjusted for economic factors was exceeded by a small percentage. This difference was largely because cost-versus-weight tradeoffs were generally resolved in favor of reducing weight, which was lower than the specification limit by a similar percentage! The hardware was completely documented for procurement and has been physically audited to assure conformance of drawings and hardware.

Acceptance of the AN/GVS-5 by potential users has been generally enthusiastic. This has been in part because the first RCA demonstration unit has been operating for two years with no failures. It has been demonstrated and tested in many areas under widely varying conditions. On each occasion its performance has fully demonstrated RCA specifications and has met or exceeded customer requirements.

Acknowledgments

The Automated Systems technical effort was accomplished by a team of engineering, manufacturing and material operations personnel collaborating to meet the program technical and cost objectives. The Solid State Technology Center (Somerville), RCA Ltd. (Canada), and Central Engineering Materials (Camden) activities all made significant technical contributions to the program.

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Final manuscript received July 9, 1976.

Jason Woodward was responsible for the the technical direction of the AN/GVS-5 laser rangefinder set design. This is the latest in a series of laser rangefinder programs under his design management, starting with the AN/GVS-1 in 1962. He has also served as program manager and technical director for the MBT-70 tank laser rangefinder program and the Apollo lunar laser altimeter program.

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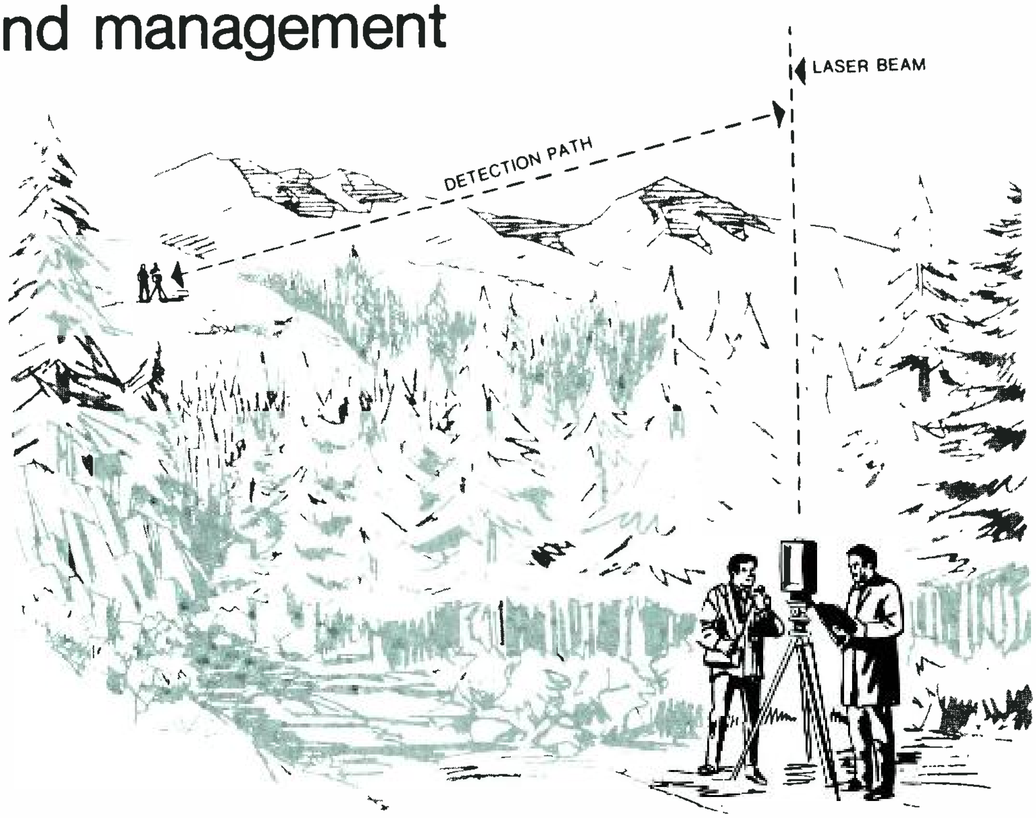
The laser range pole—a surveying aid for forest land management



E.E. Corey

Laser-aided surveying could help the Forest Service survey its mountainous boundaries in less than half the normal time and at one-third the cost.

In surveying, accurate heading information is usually obtained by sighting through a standard theodolite mounted above one point to a range pole extending vertically above the other point. Obstructing hills, trees and other obstacles in the direct line of sight between the two points, however, often prevent a simple one-step heading determination. An RCA laser-based system provides a vertical range-pole extension in the form of a tall, straight column of light that is visible to photodetector "eyes" in a theodolite at the distant point.

The U.S. Forest Service has used models of the laser range pole since 1973 and found it to be a reliable instrument and a great asset in the heavily backlogged task of boundary-line surveying. Although the system was designed specifically for cadastral (boundary-line) surveying, it can be used for many other applications that require an accurate heading determination between points where one point can't be seen from the other. By eliminating tedious random transitting operations, the laser range pole has reduced the total time to determine and post a boundary line by 2/3. Also, accuracy has been significantly increased—three inches over a mile of heavily forested and hilly terrain is typical with the equipment in field use. The equipment is transportable by backpacks, permitting rapid long-range transiting through rugged terrain and over obstacles not possible with other techniques.

Need for an improved surveying system

The Cadastral (legal boundary) Survey Department of the U.S. Forest Service has been concerned in recent years with a rapidly increasing backlog of unposted boundary lines, especially those that separate U.S. Forest Service land from privately owned land. The American public's growing interest in remote resort areas for summer and winter vacations has stimulated the development of these pockets of land, many of which intermingle in complex patterns with the National Forest lands.

The boundary system needs work, especially in mountainous terrain.

The Ordinance of 1785 established a rectangular system of surveys for the public lands to provide an orderly settlement of the land west of the original colonies. Even though this has generally proven to be an

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excellent system, it is plagued with defective and irregular surveys, especially in mountainous areas.

More than 272,000 miles of property lines comprise the National Forest system, and over 1,160,000 property corners are required to legally define and identify National Forest boundaries. Markers called "monuments" have been placed at most of these sections and quarter-section corners during the past 190 years. Many of them have been lost as a result of normal forest growth, and some have been destroyed by heavy logging and road-building equipment.

In all cases, however, a search must be made for the controlling "corners" prior to property-line surveying, since they define and control the legal property boundary. The legal boundary is the straight line between two of these corner markers, and the difficulties encountered in surveying this line are why the laser range pole system was conceived and developed.

The purpose of the laser range pole system is to determine an exact heading from one corner marker to an adjacent marker, typically located either a half-mile or mile away.

A line-of-sight heading determination is possible in only a very few cases; trees and hills normally obstruct the line of sight between the two points. A long straight "range pole" is used to project a reference point on the ground to a reasonable height to allow a line-of-sight heading to be established with a transit or a theodolite. The maximum height of the range pole is, for practical purposes, limited to about six or eight feet.

Fig. 1
Laser transmitter establishes a laser beam "range pole" rising a mile above reference point or boundary marker. Radio transceivers are used for voice communications and signaling between laser transmitter and receiver electronics.

The laser range pole uses a laser beam as a pole, and so is not limited in height.

Assuming a cloudless path, the laser pole will produce a detectable line of light greater than a mile vertically above the reference point on the ground. The receiver, a half-mile or mile away, can be elevated to an angle above the terrain and then establish an accurate heading to the thin line of laser light-scatter projecting vertically from the laser transmitter.

Principle of operation

The tripod-mounted laser transmitter subsystem (see Fig. 1) is placed precisely above one marker and leveled so that the pulse of laser light will travel vertically from the marker. (Vertical tolerance is ±7 seconds of arc; beam divergence is 0.7 milliradian.)

The receiver theodolite subsystem (Fig. 2) is located on the adjacent marker a half-mile or a mile away. Mounted on a tripod precisely above its respective corner marker, it is carefully leveled and then aimed through a clearing above the terrain in the direction of the laser transmitter. The coarse direction to the transmitter is determined with a compass. (There is generally a ±5° tolerance on compass bearings.)

The receiver theodolite's field of view requires that the receiver must be aimed within ±0.5° of the correct heading before its photodetectors will detect the laser light-scatter in either the left-half or right-half field, so successive one-degree adjustments must be made until the signal is acquired. Once it is received, one of three indicator lights on the front panel will tell whether corrections should be made to the left or right of the aiming direction. After a number of successive trials and corrections, the CENTER light will indicate that the receiver is aimed directly at the laser beam (typically within twelve arc-seconds of the correct azimuth to the distant marker.)

The receiver theodolite may then be lowered in elevation and used by the surveying team to determine where to set the first stake on a true line between the two markers.

Design considerations

The major concern at the onset of this project was whether a relatively small receiver system could detect the sidescatter from a laser pulse a mile away under a broad range of weather and daylight background conditions. Although much data has been accrued on backscatter throughout a decade of pulsed-laser rangefinder development, very little has been published on sidescatter.

In 1972, when the development of the laser range pole began, the ruby laser/photomultiplier detector system was the most economical and safest approach. Avalanche detectors had not been fully accepted for neodymium systems and frequency-doubling lasers were too expensive and inefficient. The ruby laser's wavelength also appeared to be the best compromise for all weather conditions.

The effective range does not continue to increase as the scatter-producing haze or fog becomes denser.

This is because the same particles that are enhancing the scatter have an adverse affect on transmission. A curve plotting

Fig. 2
Receiver theodolite subsystem is coarsely aimed at the transmitter's laser-light "pole" a mile or half-mile away, then adjusted in azimuth until the signal is acquired. Indicators tell which way to adjust aim until the receiver is aimed at the light pole within twelve arc-seconds.

maximum range vs. range of visibility for a ruby system peaks at a surprisingly typical visibility range (six or seven miles). It then begins to slowly drop off as the scatter becomes more dependent on the clear-air Rayleigh or molecular scatter contribution. The same plot for a neodymium laser (10,648 Å) would peak at a shorter visibility range; a doubled neodymium green laser (5324 Å) peaks at a longer visibility range.

Other counterbalancing effects tend to stabilize performance over a broad range of conditions.

One of these, which had not been anticipated during the development, was discovered when the first prototype was tested in the thin air high in the Colorado Rocky Mountains. The lack of scatter-producing aerosol there was mostly compensated for by the increased gain of the system working into the deep-blue sky background that is typical at these altitudes (10,000 to 12,000 feet). Note: The nature of the signal (a vertical line) plus the need to search for the signal necessitates a large-enough field of view (0.5° × 1.2°) so that the system, with a 10-Å spectral bandpass filter, is still background-limited under any daylight conditions. An AGC circuit is used to maximize the gain for an acceptable false-alarm rate. The dark-blue sky background at high altitudes therefore significantly increases daytime sensitivity.

Another counterbalancing effect results from the geometry of the system (Fig. 3). Neglecting atmospheric attenuation, the range equation for a laser rangefinder shows that the received signal is proportional to $1/R^2$. The geometry of the laser range pole system shows that the length of the signal-producing scatter within the field of view increases proportionally with range. Therefore, if you consider the improvement in the electronic processing factor due to the change in signal length, the normalized received signal approaches being proportional to R/R^2 or $1/R$.

Command radio link

Because the laser transmitter is not continuous, but only pulses on command, it is necessary to have voice communication between the receiver and transmitter operators. Two RCA TACTEC radios are used.

It is also desirable to use these same radio transceivers for communication between the two subsystems. Ideally, the receiver's processing electronics would be gated to operate only during the instant that the laser pulse is present, which would permit the receiver to operate at a lower threshold for an acceptable false-alarm rate. This is implemented to the degree limited by the audio bandwidth of the radio. A 2-kHz audio tone is automatically generated at the transmitter 250 ms prior to lasing. The receiver's audio signal discriminator recognizes the tone after it has been on for 60 ms. Four milliseconds prior to lasing, the transmitted tone automatically stops; this generates a 2-ms gate in the receiver during the laser firing time. The audio discriminator prevents the creation of gates during normal voice communciations.

The audio tone has additional value in that the receiver operator can hear it very distinctly, so he knows when to expect an indicator light.

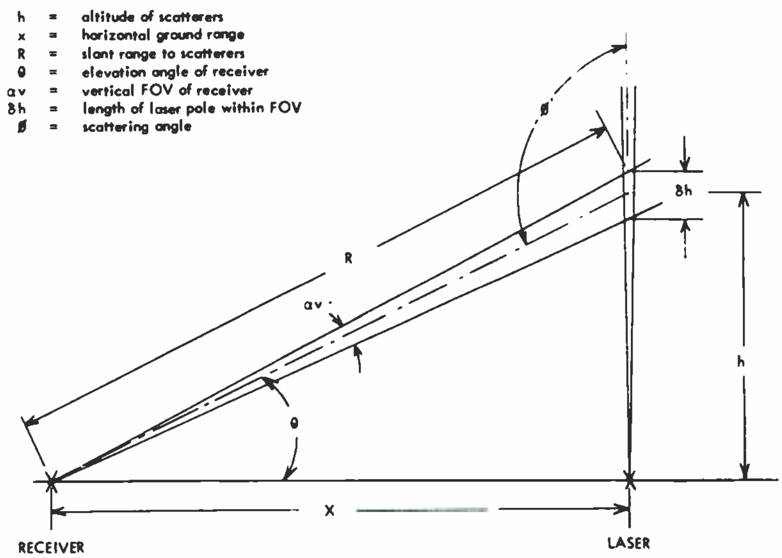

Fig. 3
System geometry helps stabilize performance over a wide range of conditions. The received signal is proportional to $1/R^2$, and signal-producing light scatter within the field of view increases with *R*. Normalized received signal therefore approaches $1/R$.

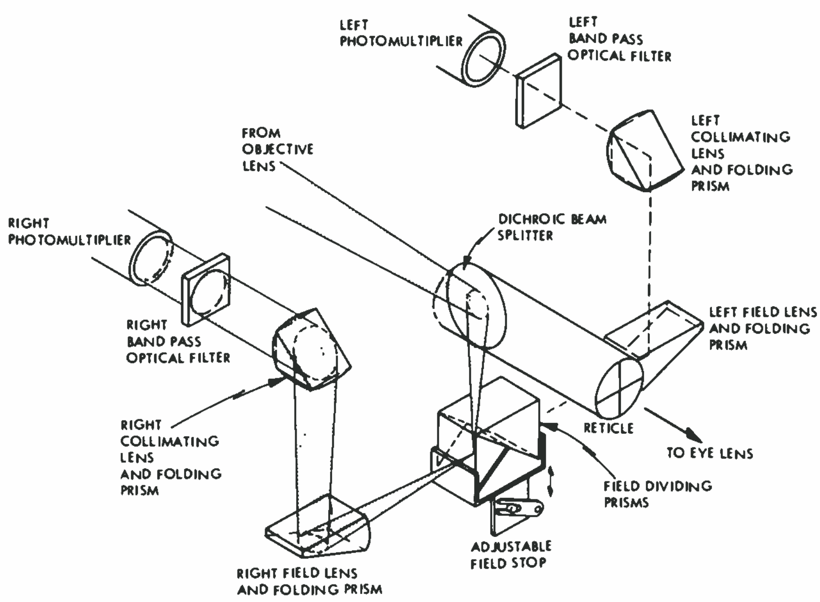

Fig. 4
Receiver optical design is simple but precise, resulting in a lightweight system.

Fig. 5
Receiver resembles a standard theodolite. Indicators *R*, *C*, and *L* (for right, center, and left) tell which way to adjust receiver to center it on laser "pole."

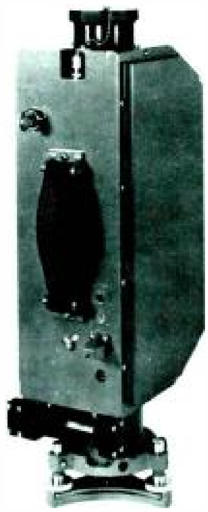

Fig. 6
Transmitter package contains all power converters and electronics except battery. Extra safety interlock prevents laser from transmitting unless it is aimed within seven degrees of vertical.

Both subsystems are nickel-cadmium battery operated and, since they are only powered for four or five seconds during each trial, relatively small batteries will run the system for a day without recharging.

Receiver theodolite design

The present system incorporates a modified Kern DKM2A theodolite, chosen because of its superior quality and adaptability for this application. The optical design, shown in Fig. 4, is a simple but very precise and well engineered. The final instrument (Fig. 5) is lightweight, attractive, and looks quite similar to a standard theodolite. All of the electronics were designed and packaged by RCA Automated Systems in Burlington. The photomultiplier detectors are standard C70042K types produced by RCA Electro-Optics and Devices in Lancaster.

Laser transmitter design

The laser transmitter is an extension of the designs made over the past decade for the U.S. Army ECOM and for NASA on the Apollo laser altimeter. The pulsed ruby laser is Q-switched by a motor-driven rotating prism and transmits 200 mJ in a single 35-ns pulse. Besides the usual high-voltage safety interlock features, it has a safety interlock "tilt" switch that prevents operation unless the transmitter is aimed vertically within seven degrees. With the exception of the battery, all of the required power converters and electronics are contained within the single transmitter package (Fig. 6).

Present status

All three systems produced thus far are in operation with the U.S. Forest Service. The two second-generation systems recently delivered to the Forest Service far exceed the basic performance requirements—the daytime range has proven to be over 2½ miles under sunlight conditions, and the specifications require one mile. Nighttime range is over 5 miles. Automated Systems has recently been awarded a sole-source contract from the Bureau of Land Management for four of these systems to be used principally for surveying oil-shale land boundaries.

Product improvement considerations

The successful field evaluation of the first prototype laser range pole (then called the long-range laser traversing system) proved conclusively that the product was an extremely useful tool for the cadastral surveyor. Since then, efforts have been directed toward cost reduction. The first step was a major modification in the receiver subsystem. Using a smaller, more economical theodolite halved the receiver weight, improved sensitivity, and resulted in a lower-cost receiver subsystem.

Another improvement being considered is changing the detectors from photomultipliers to silicon avalanche diodes. Analysis has shown that using avalanche diodes results in a forty-percent increase in daylight range. This would have no immediate effect on cost, but the long-range potential cost improvement is better with silicon avalanche detectors.

The major cost improvements on the laser subsystem will only be realized through quantity builds. A significant portion of the cost in small quantities is the fabrication (machining) costs, which can be substantially reduced through automation.

Acknowledgments

The author gratefully acknowledges the professional contributions of the small group of RCA engineering people who made the laser range pole a successful product and a credit to RCA wherever it is used. These people are: Robert Guyer, Mechanical Design; Michael DeFlumere, Laser Design; Robert Dearborn, Engineering Technician; and Paul Mednis, Design Drafting.

Also a special acknowledgment is due to the U.S. Forest Service and their representatives—Bernie Hostrop, Tom Patterson, Gerry Larson, and Heyward Taylor—for their excellent field evaluation and continued support in promoting the use of this equipment.

Earl Corey joined RCA in 1957 and has specialized in designing electro-optical systems, particularly laser systems, during the past seventeen years. Prior to his recent role as lead Development Engineer on the laser range pole, he was Project Engineer on several Army laser rangefinder programs.

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Two-dimensional digital correlation for optical tracking

L. Weinberg
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Image correlation tracking compares the difference between successive images of the tracked object. It is a highly accurate tracking method, but is more complex than quad, edge, or centroid tracking.

Harald Pschunder joined the Advanced Electronic Technology group at MSR in 1974. While at RCA, he has worked on various projects related to the computation and applications of orthogonal transformations, including simulation of portions of an advanced solid-state radar system, reduced bandwidth image encoding, and space radar signal processing.

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Len Weinberg joined the Advanced Electronic Systems and Technology group at MSR in 1970. He has designed, specified, and simulated the radar scheduler function to be implemented in the AEGIS radar system. Among his other responsibilities have been the design and performance estimates of signal processors and the sizing of various digital implementations. He holds a patent on a technique to reduce target range smearing in radar and is a coholder of a patent in the area of digital interpolation.

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Authors **Weinberg** (left) and **Pschunder.**

Among the techniques available for tracking objects, perhaps the best known is radar. Radars search for, detect, and then track objects of interest, using some method of generating error signals to keep the radar directed at the target as it moves in azimuth and elevation. As an example, the monopulse radar tracker uses a single pulse with four offset antenna beams as the basis for generating error signals to drive the antenna's target-tracking servomechanism.

Optical tracking systems, though not as well known, operate in much the same fashion. Their popularity for short-range tracking derives from their increased resolution and accuracy over radar in both range and angle, a result of their higher operating frequencies. For example, optical systems have been widely used in RPVs (remotely piloted vehicles), an application which requires the high-accuracy tracking representative of similar ground and shipborne tracking systems. In such systems a television camera views the terrain and the video signal is transmitted to a control center. These systems can be used for guidance control, target detection, intelligence gathering, and even precise aiming of a laser beam.

For automatic tracking, when fast response times are required, an on-board automatic tv tracker can be used as the primary tracking source. This tracker can be electro-optically locked onto a predominant terrain feature or other specified target to provide the error signals required to control a gimballed platform. Although requirements vary with the mission, automatic optical systems are capable of tracking accuracies well above those of standard radar trackers.

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Present automatic tracking methods

These performance levels, of course, depend in part on the accuracy of the error signals, which may be generated by any of several methods that vary in complexity and performance. Three of the most widely used types of automatic i-r and tv trackers generate corrective error signals from single frames of data. These are known as the quad, edge, and centroid trackers.

- The *quad tracker* most resembles the radar monopulse technique, and like monopulse it integrates the video signal from four sections of a scene and compares amplitudes to generate *x-y* corrective error signals.
- The *edge tracker* uses the signal contrast between the target edge and adjacent space, employing either single- or multiple-threshold detection. This technique is commonly implemented in a leading-edge tracker. The multiple-edge tracker, often used for high-contrast targets, can track the top, bottom, left, and right edges of the target.
- The *centroid tracker* computes the center of mass in the *x* and *y* dimensions of the tv field of view as a basis for generating corrective error signals to track the target.

Table I summarizes the principal characteristics of these trackers and the correlation tracker described in this paper.

Correlation tracking

Although the quad, edge, and centroid techniques are popular in automatic optical trackers, even greater accuracy can be obtained from a correlation tracker, which functions with two frames of data rather than one. Higher accuracy is obtained, but at a cost of system complexity. Although correlation trackers have been built, tested, and simulated in the last few years, the published data on the subject is sparse and the number of variables that come into play are many.

Correlation tracking involves comparing two images of an object field taken by the same sensor at different times.

In such systems a sensor (for example, a vidicon tv tube) receives two-dimensional video inputs containing the object to be tracked and passes them on in digital form to a track processor. Fig. 1 is a block diagram of an automatic tv tracking system, showing the location of the digital track processor. A tv-formatted system produces a video signal in a sequential manner. The scanning format depends upon the sensor design, but most sensors scan each line left to right, continuing line by line down through the scene until the end of the frame. For each scene, analog-to-digital converters generate the *x-y* coordinate matrix of digitized video pixels* that make up a frame of data. Two frames of data are then processed in a correlation tracker to provide *x-y* error signals to drive a servomechanism that keeps the object in the center of the optical field of view.

*Pixel stands for picture element, or one digitized amplitude in the matrix.

In correlation tracking, two frames of data, each containing the target, are used to generate error signals. The first frame of data serves as a reference for the second and the tracker estimates the displacement of the target within the field of view between frames. This target displacement, or error signal, is fed back to the servo electronics so that the target is kept at the same location within the field of view as in the reference frame.

The target displacement between frames can be estimated by the location of the peak of the correlation function. The basic assumption in correlation tracking is that the computed correlation function between

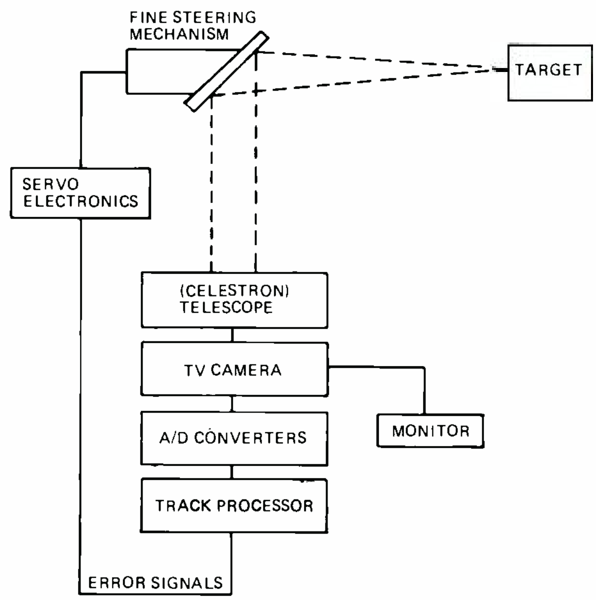

Fig. 1
Television tracker block diagram. Track processor may be of correlation, centroid, quad, or edge type, but storage is generally required in all types.

Table I
Comparison of tracker types.

Tracker type	*Performance vs. point target*	*Performance vs. expanded target*	*Positive features*	*Negative features*
Quad	Fair	Good	Simple processing	Resolution generally no better than one resolution element
Edge	Poor	Target-shape dependent	Clutter rejection good, depending upon target-to-background voltage ratio	Tracking inhibited when edge passes completely through field of view
Centroid	Good	Good	Independent of target shape	Noise at scene edge contributes heavily
Correlation	Fair to good	Very good	Uses maximum scene information; glint-and amplitude-insensitive	Relatively complex processing

the two data frames will be maximum when the targets within the fields of view coincide.

A sample point of the correlation function can be computed by displacing the second frame relative to the first, multiplying aligned points, and summing.

When this is repeated for many displacements in x and y, a sampled two-dimensional correlation function is generated, and an estimate of the peak, and therefore target displacement, can be made. Tracking a target over many frames of data requires establishing a reference data frame and computing the peak of the correlation function between the reference and each new data frame.

The use of the correlation function to estimate target displacement may be illustrated in a simplified, one-dimensional example. Fig. 2 shows two frames of one-dimensional data (e.g., azimuth). In Frame 1, a target of amplitude A is shown at a location between 0 and 1. Frame 2 data, taken at a later time, shows the same target displaced three resolution units to the right, at a location between 3 and 4. As Frame 1 is displaced, and the amplitude values are multiplied point-by-point and summed, a peak in the correlation function corresponding to amplitude A^2 is obtained, as shown. The location of the peak then indicates the number of resolution units of target displacement between Frames 1 and 2. Although the two-dimensional case is more complex, this basic approach holds.

Correlation tracking was simulated using photographs of a model drone (15 inches long, 10-inch wing span) suspended by calibrated four-point rigging on a light background (Fig. 3). The pictures were digitized to 200 pixels per inch in each dimension and the results stored on magnetic tape. A complete digitized photograph measured 520 × 420 pixels, with 13-bit pixel amplitudes (0 to 8191).

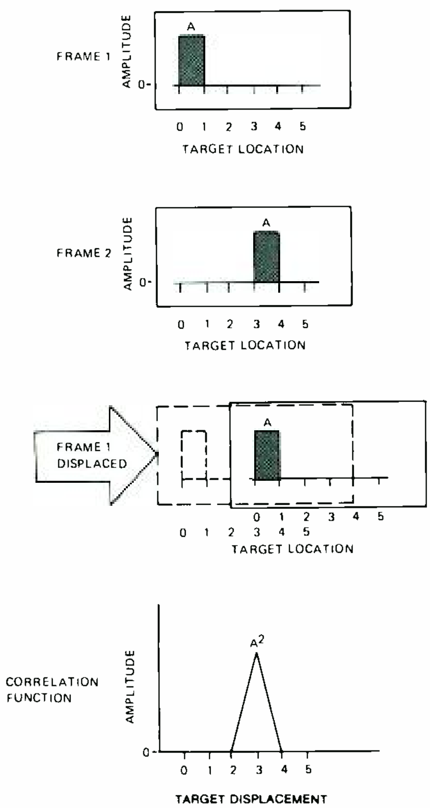

Fig. 2
Applying the correlation function to one-dimensional target displacement. Note that Frame 2 could have been shifted left to accomplish correlation, resulting in an identical correlation-function amplitude.

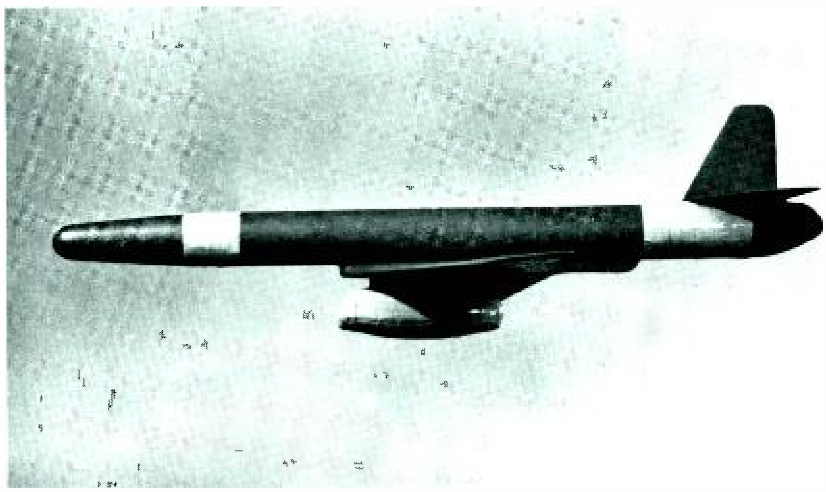

Fig. 3
Drone model used for simulating correlation tracking techniques.

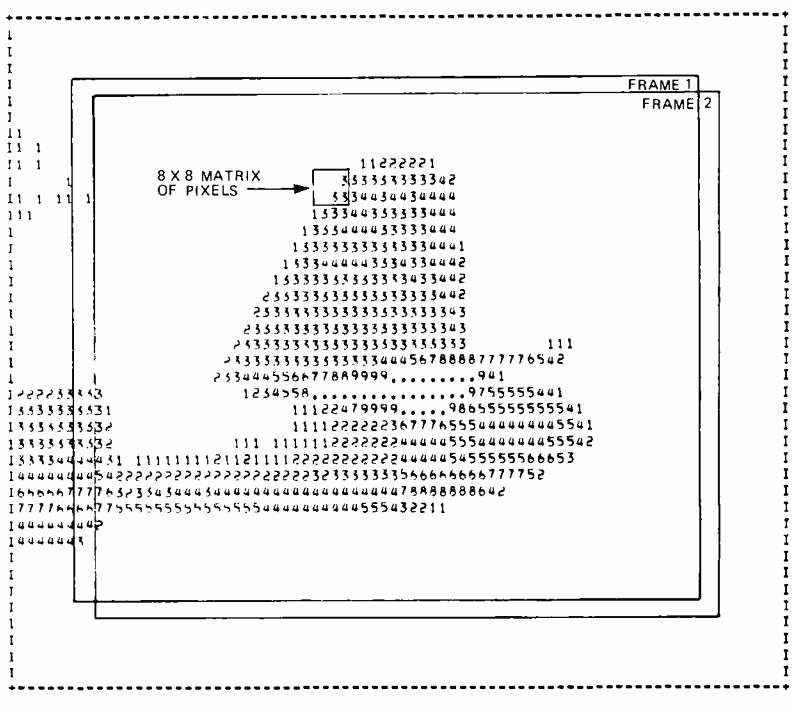

Fig. 4
Digitized tail section of drone pictured in Fig. 3, showing target displacement for two separate data frames. Symbols within frames represent amplitude values.

Although in some applications it is useful to include the entire target in the correlation tracker, other applications are satisfied by using only a portion of the target. Since the memory requirements and computation time of the correlation track processor increase with the number of pixels (and this is also true for a simulation), only the tail section of the drone was used in the simulation work described in this paper. In our simulations, 16×16-point frames of data were used. However, performance is predicted for larger numbers of resolution elements by means of a derived general formula.

Two digitized frames of the drone tail section are shown in Fig. 4. The difference between them is that the tail section in Frame 2 is displaced to the left and up by four pixels in each dimension relative to its location in Frame 1 (in the illustration, the tail section remains stationary as Frame 2 shifts down and to the right). These two frames of data, with different sets of noise added, are used to compute the correlation function and estimate the target displacement between data frames. The frame displacement that results in aligning the target in the two data frames will give the peak value of the correlation function. This technique is the basis for the simulation description.

The location of the peak of the correlation function is used as an estimate of the target displacement.

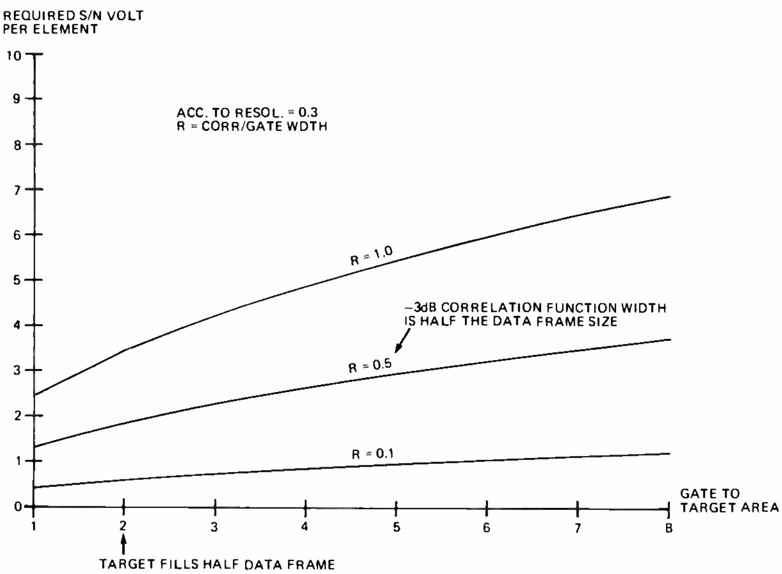

Fig. 5
Performance curves for correlation tracker of 0.3 resolution-element accuracy. Signal/noise voltage is plotted against ratio of gate to target area.

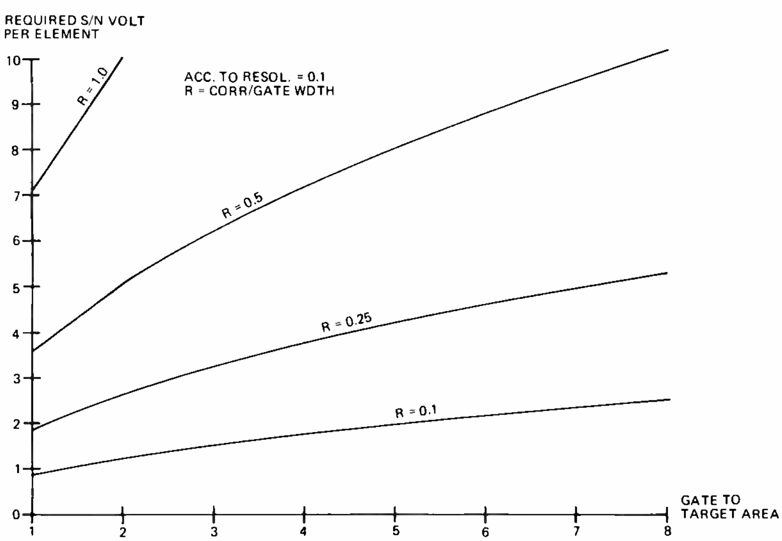

Fig. 6
Performance curves for correlation tracker of 0.1 resolution-element accuracy. High S/N ratios and wideband target signals provide optimum performance.

The mechanism for computing the correlation function for a displacement of (r,s) points between frames, $C(r,s)$, is:

$$C(r,s)=\frac{1}{(2m+1)^2}\sum_{i=-m}^{m}\sum_{j=-m}^{m} f_1(i,j)f_2(i+r,j+s) \quad (1)$$

where

$(2m+1)^2$ is the number of points in a data frame

$f_{1,2}(i,j) = S_{1,2}(i,j) + N_{1,2}(i,j)$ is the signal amplitude in Frame 1 or 2 at the $(i,j)^{th}$ point

$S_{1,2}(i,j)$ is the sampled target signal amplitude at the $(i,j)^{th}$ point in Frame 1 or 2

$N_{1,2}(i,j)$ is the independent noise added to the $(i,j)^{th}$ point of Frame 1 or 2.

By computing the correlation function betweeen two frames for several values of (r,s), a precise estimate of the target shift may be made. Although complicated, correlation tracking offers greater accuracy than any of the standard methods—quad, edge, or centroid tracking—against targets such as those shown in Figs. 3 or 4.

Predicted correlation tracker performance

A performance formula for a correlation tracker was derived as a means of predicting the accuracy of the target-displacement estimate. Displacement estimate accuracy may be expressed as:

$$\frac{\sigma_{\Delta\psi}}{\zeta}=\frac{\rho}{(2m+1)}=\frac{1}{1-[(C(\rho,0)/C(0,0)]}\cdot\left[\frac{1}{2}\frac{\eta^2\sigma_N^2}{A^2}\left(\frac{1}{2}\frac{\eta^2\sigma_N^2}{A^2}+1\right)\right]^{1/2} \quad (2)$$

where

$\sigma_{\Delta\psi}/\zeta$ is the ratio of the accuracy of the displacement estimate to the distance between resolution elements

$C(\rho,0)/C(0,0)$ is the relative value of the correlation function amplitude for the noise-free target signal for a displacement of ρ resolution elements in one dimension between frames to the peak of the correlation function

$2m+1$ is the number of resolution elements on one side of a square data frame

A^2/σ_N^2 is the signal-to-noise power ratio at a single resolution element

η^2 is the ratio of total number of resolution elements in the data frame to the number in the target

Implicit in the derivation of Eq. 2 is a three-point parabolic interpolation (Eq. 3) for the peak of the correlation function described in the section on the simulation.

Performance curves of a correlation tracker are presented in Figs. 5 and 6, using Eq. 2. It is clear from Eq. 2 that the accuracy of the correlation tracker improves as the data-frame target signal-to-noise ratio increases $[A^2/\eta^2\sigma_N^2]$ and as the ratio of correlation-function width to frame size $[2\rho/(2m+1)]$ decreases.

The performance curves relate the required signal-to-noise voltage ratio (A/σ_N) per resolution element to the frame (gate) to target area (η^2) for different −3 dB spreads of the correlation function $[C(\rho,-)/C(0,-) = 0.5$ and 2ρ is the 3-dB width of the noise-free correlation function]. The term $R = 2\rho/(2m+1)$ is the ratio of the −3 dB spread of the correlation function to the frame width in one dimension. The curves in Fig. 5 reflect an accuracy of 0.3 resolution element; Fig. 6 shows an 0.1-resolution-element accuracy.

These performance curves suggest the following:

- The optical system should provide the highest signal-to-noise ratio possible.
- The data frame about a tracked object should be placed for maximized target signal. Although this approach tends to generate asymmetrical correlation functions resulting in interpolation errors, this problem may be alleviated by means such as weighting the edges of the gate where the target signal is passing out of the gate from frame to frame.
- The selected target signal should have the narrowest correlation function or the largest bandwidth possible. A scene with nearly equal amplitudes would have a large correlation-function spread and a small (or dc) bandwidth, whereas large variations in pixel amplitudes represent scenes with large bandwidth. Two-dimensional high-pass filtering can be applied to narrow the width of the correlation function.[1] The data frame size should be the largest practical, as this increases the target signal bandwidth as more object detail is included in the data frame.

Operational systems face a number of other error sources in addition to independent additive noise discussed here. Optical distortion, low target-to-background contrast, target rotation, and mismatched interpolation formulas for the the peak of the correlation function are some of these error sources.

For the correlation tracker, the best performance is obtained when the target image fills the gate and when the narrowest correlation function is obtained for a given S/N. Because the correlation tracker uses more of the detailed image amplitude data, it can be expected to provide increased tracking accuracy over quad, edge, and centroid trackers when "large" (nonpoint) targets are being tracked.

Simulation of correlation tracker accuracy

The accuracy of a correlation tracker has been estimated by means of a computer simulation and the results compared with predicted performance. The tail sections of the drone (Fig. 4) were used with Rayleigh-distributed noise added to each point to generate a specific signal-to-noise ratio. The simulation program used data frames of 16×16 points (Fig. 7). Each point is the average of the pixels in an 8×8 region of the original digitized photograph shown in Fig. 4.

Frame 1 with noise added (Fig. 8) provides the reference data frame, and Frame 2 with a different set of noise represents the new data frame to be correlated against Frame 1. The tail of the drone in Frame 2 has moved one-half a point to the left (minus x) and one-half a point up (minus y) relative to its location in Frame 1. In the simulation, all 31×31 possible nonzero values of the correlation function were computed using a two-dimensional FFT (fast Fourier transform) algorithm.[2]

The samples of the correlation function taken between Frames 1 and 2 are shown in Fig. 9. The largest correlation-function amplitude was used to normalize all points. Therefore, 1.000 represents the largest correlation-function sample, and its location indicates no shift of Frame 1 relative to Frame 2. The asymmetry of the surrounding points, however, indicates that the peak value falls betwen pixels. The solid line indicates the −3 dB spread of the correlation function.

Additional accuracy within a few tenths of a resolution element is obtained by interpolating independently in the x and y directions. A simple three-point parabolic interpolation formula is used for estimating the shift, P_X and P_Y, where

$$P_X = \frac{1}{2}\,\frac{C(1,0) - C(-1,0)}{2C(0,0) - C(1,0) - C(-1,0)} \qquad (3)$$

and similarly for P_Y, where the peak correlation-function value is assumed to occur at (0,0).

A comparison of simulation results and those predicted from the formula is given in Table II. The accuracy obtained in the simulation is close to predicted performance. The simulation result is an average of ten computer runs, with a three-point

Table II
Simulation results were close to predicted performance.

	Pixel S/N voltage ratio = 2	*Pixel S/N voltage ratio* = 5
Accuracy of simulation runs (resolution elements)	0.269	0.099
Accuracy predicted by Eq. 2 (resolution elements)	0.304	0.107

parabolic interpolation formula assumed. The results apply to

$R = 2\rho/(2m + 1) = 0.437$

$\eta^2 = 2.85$

Conclusions

Simulation results have confirmed the validity of a formula for predicting correlation tracker performance when independent noise is added to each resolution element in a frame. Performance curves indicate that the accuracy of a correlation tracker improves as the total target signal-to-noise power ratio increases and as the width of the correlation function of the target signal decreases. These curves will be important in comparing predicted correlation tracker performance with that of quad, edge, and centroid trackers.

In particular, when the target signal fills half the data frame, and the width of its correlation function is half the frame width, a signal-to-noise voltage ratio of 1.9 per resolution element results in an accuracy of 0.3 of the resolution cell. With nothing else changed, a signal-to-noise of 5.2 results in an accuracy of a tenth of a resolution cell.

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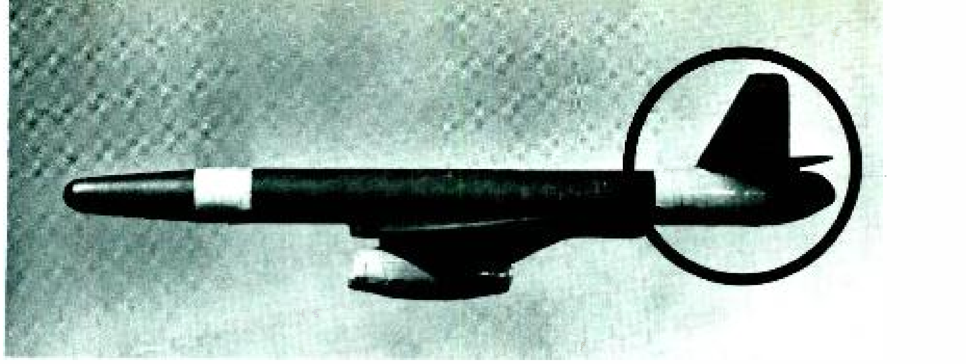


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	1102	1175	896	0	0	0	0	0	0
4	0	0	0	0	0	0	1161	1957	1962	1711	0	0	0	0	0	0
5	0	0	0	0	0	0	1766	2007	1979	1900	0	0	0	0	0	0
6	0	0	0	0	0	1194	1958	1973	1967	1970	0	0	0	0	0	0
7	0	0	0	0	813	1759	1937	1915	1927	1985	0	0	0	0	0	0
8	0	0	0	0	1337	1899	1894	1878	1868	1928	0	0	0	0	0	0
9	0	0	0	819	1823	1935	2232	2702	3267	3790	3604	2629	1486	0	0	0
10	1161	0	0	805	1807	3438	5271	6333	6516	6472	4453	2480	1257	0	0	0
11	1573	0	0	0	0	0	1033	2177	4140	4461	3111	2591	2931	805	0	0
12	2038	837	909	957	969	1016	1165	1257	2332	3086	3432	3780	2580	0	0	0
13	4140	1953	2100	2213	2231	2268	2545	2674	4064	4339	3261	1551	0	0	0	0
14	2515	1438	1295	1223	1123	956	952	1041	844	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Fig. 7

Tail section of drone from Fig. 4 (Frame 1) reduced to 16x16 points by averaging pixel amplitudes within an 8x8 square. Numbers represent relative amplitudes of points.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	401	1987	2775	4187	627	3133	1489	2135	1720	1940	1313	1203	42	5381	4277	3091
2	1245	856	2254	1843	1685	1483	1695	1987	1812	920	3605	940	2986	1845	2246	1940
3	2358	1687	2859	453	1630	3712	851	3164	1844	3654	2757	3001	937	2699	478	2854
4	1131	1635	1811	1314	2414	1956	2217	4500	3865	4420	841	1118	900	398	4618	2322
5	3465	2913	2788	2000	1521	1903	4911	4694	5601	5966	2220	4361	2259	3375	3431	1890
6	3985	1846	1289	1929	2289	2611	3610	4311	3359	2918	1570	2999	2302	1971	2061	2665
7	2139	3676	1938	2767	1568	5687	4719	2484	4414	3886	3367	4340	338	1863	2133	1131
8	1332	3029	1690	1030	3277	3519	5332	5777	4567	6102	1241	3262	4048	601	3502	2793
9	2052	1794	3587	2800	5722	2763	3690	5960	4613	4264	6590	4310	2723	3622	1383	2335
10	2052	1286	1540	3743	4154	6075	7745	8192	8192	7088	6550	4898	1543	1504	3187	509
11	4577	1600	387	3721	1231	1119	1759	5036	7031	7343	5682	3785	3931	5443	1765	2733
12	4310	1039	3529	1832	2867	3554	4465	1648	4332	6017	4358	7037	5650	1300	1344	1492
13	6126	2675	2614	4172	4291	5065	5405	6023	5522	5238	8192	4612	3288	3257	1770	4024
14	5823	3873	2429	2943	3449	1399	3590	4809	1869	2864	579	1968	1810	1105	1228	2493
15	3546	1638	1272	818	1844	2605	916	2194	1084	5564	1444	3420	1926	407	3485	369
16	1197	840	2643	1077	2853	3649	2248	1702	800	611	1788	5932	926	3313	3397	2063

Fig. 8

With noise added to Fig. 7, tail section takes this form (signal-noise voltage ratio = 2). This is a data frame used in simulation to generate the correlation function and thereby estimate known target displacement.

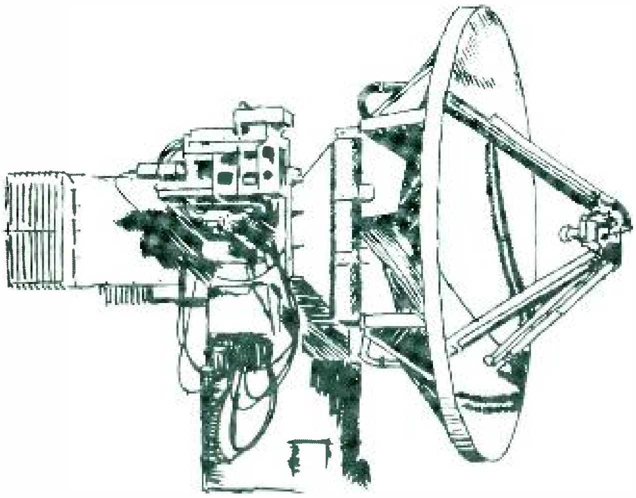
→ x

	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	1
-15	0.000	0.000	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.000	0.000	0.000	0.0
-14	0.005	0.005	0.005	0.010	0.010	0.010	0.010	0.010	0.010	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.010	0.010	0.010	0.005	0.005	0.0
-13	0.010	0.016	0.016	0.021	0.021	0.026	0.031	0.031	0.036	0.041	0.041	0.041	0.041	0.041	0.036	0.036	0.031	0.026	0.026	0.021	0.016	0.0
-12	0.016	0.021	0.031	0.041	0.047	0.057	0.062	0.067	0.078	0.078	0.083	0.083	0.083	0.083	0.083	0.078	0.067	0.057	0.047	0.036	0.036	0.
-11	0.026	0.041	0.052	0.067	0.083	0.093	0.104	0.109	0.114	0.114	0.130	0.130	0.130	0.135	0.130	0.119	0.109	0.093	0.073	0.057	0.052	0.
-10	0.036	0.062	0.083	0.098	0.119	0.130	0.145	0.150	0.161	0.171	0.187	0.181	0.181	0.181	0.176	0.166	0.145	0.119	0.098	0.073	0.057	0.
-9	0.057	0.083	0.104	0.130	0.161	0.187	0.212	0.238	0.244	0.249	0.259	0.244	0.238	0.238	0.233	0.218	0.192	0.155	0.124	0.088	0.062	0.
-8	0.067	0.098	0.124	0.161	0.197	0.233	0.275	0.300	0.311	0.316	0.326	0.311	0.300	0.300	0.285	0.275	0.244	0.197	0.155	0.109	0.083	0.
-7	0.083	0.119	0.155	0.202	0.249	0.295	0.342	0.373	0.399	0.409	0.409	0.389	0.363	0.352	0.337	0.316	0.275	0.228	0.181	0.130	0.088	0.
-6	.093	0.140	0.181	0.233	0.290	0.347	0.399	0.446	0.477	0.487	0.487	0.456	0.425	0.404	0.383	0.358	0.321	0.275	0.223	0.161	0.109	0.
-5	.104	0.155	0.207	0.264	0.321	0.383	0.446	0.497	0.534	0.565	0.575	0.554	0.513	0.492	0.466	0.430	0.383	0.326	0.264	0.202	0.140	0.
-4	114	0.171	0.233	0.300	0.373	0.451	0.523	0.591	0.648	0.684	0.705	0.668	0.617	0.585	0.539	0.492	0.446	0.378	0.306	0.233	0.161	0.1
-3	130	0.197	0.269	0.347	0.435	0.518	0.596	0.679	0.741	0.772	0.782	0.720	0.668	0.632	0.575	0.518	0.461	0.404	0.332	0.249	0.166	0.11
-2	140	0.207	0.285	0.368	0.466	0.554	0.642	0.725	0.777	0.813	0.839	0.788	0.725	0.674	0.606	0.534	0.471	0.394	0.332	0.254	0.176	0.12
-1	155	0.228	0.311	0.394	0.487	0.588	0.689	0.793	0.876	0.948	0.990	0.912	0.819	0.720	0.627	0.549	0.466	0.383	0.321	0.244	0.171	0.11
Y ↓ 0	.171	0.254	0.337	0.414	0.497	0.585	0.694	0.798	0.886	0.953	1.000	0.917	0.839	0.741	0.637	0.539	0.451	0.368	0.300	0.228	0.155	0.109
1	.181	0.259	0.321	0.394	0.471	0.539	0.627	0.699	0.762	0.808	0.850	0.813	0.762	0.694	0.606	0.523	0.430	0.337	0.264	0.202	0.145	0.104
2	.176	0.254	0.332	0.409	0.477	0.534	0.591	0.648	0.694	0.741	0.788	0.762	0.715	0.653	0.570	0.487	0.404	0.321	0.244	0.181	0.135	0.098
3	0.161	0.238	0.311	0.394	0.471	0.528	0.575	0.622	0.663	0.689	0.710	0.684	0.642	0.591	0.513	0.440	0.373	0.295	0.223	0.161	0.114	0.078
4	0.135	0.197	0.259	0.321	0.389	0.446	0.492	0.539	0.565	0.585	0.591	0.575	0.549	0.508	0.446	0.378	0.321	0.254	0.192	0.140	0.093	0.062
5	0.104	0.150	0.212	0.269	0.332	0.389	0.435	0.466	0.482	0.508	0.528	0.513	0.471	0.430	0.378	0.326	0.275	0.218	0.166	0.119	0.083	0.057
6	0.098	0.145	0.192	0.244	0.295	0.342	0.383	0.404	0.420	0.446	0.466	0.446	0.414	0.378	0.326	0.285	0.244	0.202	0.155	0.109	0.073	0.04
7	.088	0.124	0.171	0.212	0.254	0.280	0.311	0.337	0.347	0.368	0.378	0.368	0.347	0.316	0.280	0.249	0.212	0.166	0.130	0.098	0.062	0.0
8	.073	0.104	0.140	0.181	0.218	0.233	0.259	0.280	0.285	0.290	0.300	0.285	0.269	0.249	0.223	0.202	0.181	0.145	0.114	0.088	0.057	0.0
9	057	0.083	0.109	0.140	0.166	0.181	0.202	0.218	0.223	0.223	0.228	0.212	0.197	0.176	0.161	0.155	0.140	0.124	0.098	0.073	0.047	0.
10	052	0.067	0.083	0.098	0.114	0.130	0.140	0.155	0.161	0.166	0.166	0.150	0.140	0.135	0.124	0.119	0.109	0.093	0.073	0.052	0.036	0.
11	41	0.057	0.067	0.078	0.088	0.098	0.109	0.119	0.119	0.114	0.119	0.109	0.109	0.104	0.093	0.083	0.073	0.062	0.052	0.036	0.026	0.
12	26	0.031	0.041	0.047	0.057	0.062	0.067	0.067	0.067	0.067	0.073	0.067	0.067	0.062	0.057	0.052	0.047	0.036	0.031	0.021	0.016	0.
13	010	0.016	0.016	0.021	0.021	0.026	0.026	0.031	0.036	0.036	0.036	0.036	0.036	0.036	0.031	0.026	0.026	0.026	0.021	0.016	0.016	0.0
14	005	0.010	0.010	0.010	0.010	0.016	0.016	0.016	0.021	0.021	0.021	0.021	0.021	0.021	0.016	0.016	0.016	0.010	0.010	0.010	0.010	0.00
15	.000	0.000	0.000	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.000	0.000	0.00
16	.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Fig. 9

Sampled correlation function between Frames 1 and 2 (noise added for $S/N = 5$ per pixel). Solid line represents -3 dB amplitude profile. Nearest point to peak of correlation function is represented by "1.000."

The laser-radar tracker: coupling complementary technologies



Neither the great range and versatility of radar nor the short-range, low-angle precision of the laser can meet all of today's demanding range instrumentation requirements. A combined laser-radar system offers the best of both worlds in precision tracking.

Herb Schlegel joined RCA Moorestown in 1970 in a special projects group assigned to the analysis and definition of the laser systems described in this paper. He subsequently became the responsible engineer for development and delivery of these systems for NASA-Wallops and the White Sands Missile Range. His current responsibilities include analysis work on adapting limited-scan phased arrays to existing RCA instrumentation radars.

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Don Dempsey joined the MSR engineering staff as a design development engineer in 1958 and has been associated with a wide range of radar development programs. He headed the special projects team that developed the laser systems described here and served as program manager for the first system installed at NASA Wallops Flight Center. His current assignments include consultation with NASA on application of radar to the GEOS-C Program, and advanced radar application development.

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D.J. Dempsey | H. Schlegel

The rate of expansion of laser applications over the past decade has been spotty, with exciting advances in some areas and disappointing setbacks in others. In any event, electro-optic devices clearly have grown far beyond their early status as instruments in the sheltered environment of laboratory research. Today lasers are functioning effectively and reliably in both industrial and medical instrumentation. Moreover, the laser is showing very real promise of practical utility in field operation under outdoor environmental conditions. One such area of particularly large potential is that of precision laser-tracking systems.

The laser tracker offers significant potential improvements over instrumentation radar under certain operational conditions.

In particular, the narrow pulsewidths and high peak powers of pulsed lasers imply greater ranging precision and resolution than is attainable with the wider-pulsewidth radar systems. Again, for angle tracking precision, the well-formed, narrow laser beamwidths can be obtained in small, lightweight systems, whereas equivalent narrow-beam radars must either operate at very short wavelengths or use very-large-aperture antennas. Still another attribute of laser systems is their

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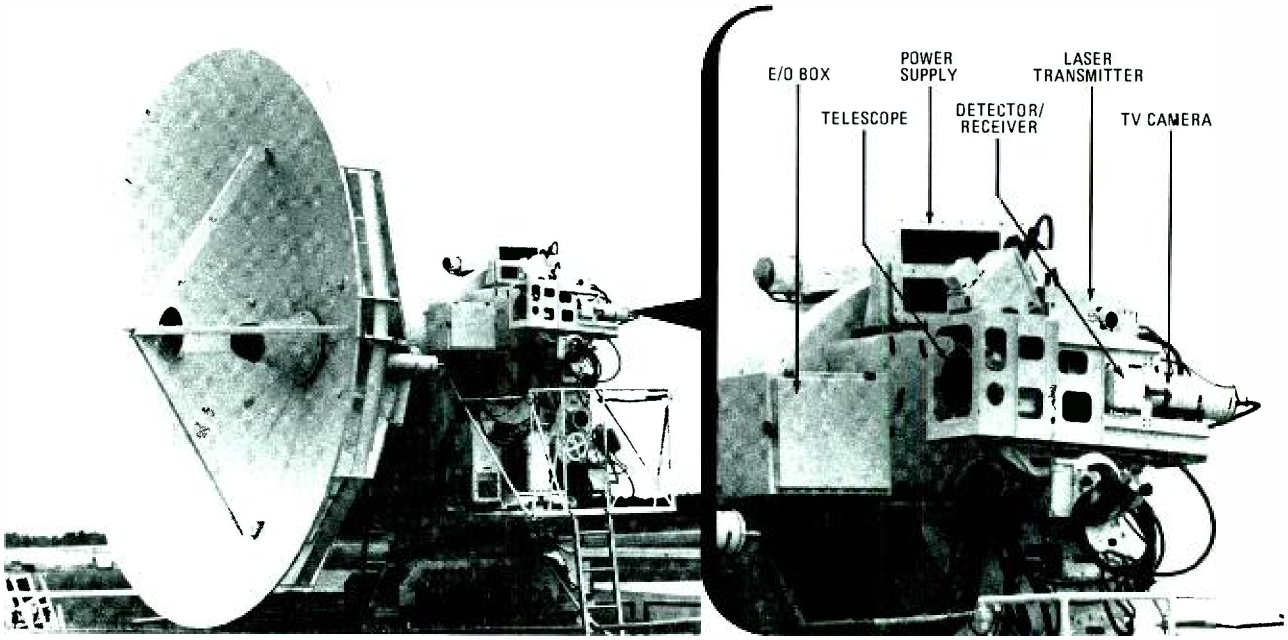

Fig. 1
Laser tracker modification to AN/FPS-16 radar at NASA-Wallops. On-mount equipment provides laser tracker augmentation without degrading radar system performance.

virtual immunity from clutter and multipath effects, enabling them to track targets at very low elevation angles (and even below the horizon) without the signal degradation encountered in radar systems.

Among the several disadvantages of electro-optical tracking instruments, the most serious are those associated with atmospheric effects. The atmosphere, even under relatively clear weather conditions, introduces substantial attenuation at optical wavelengths (from 0.5 dB/km in a clear atmosphere to more than 20 dB/km in light fog). These losses limit the maximum range and restrict practical system use to good weather. The atmosphere also introduces pulse-to-pulse amplitude variations and waveform distortions that limit precision in range and angle tracking.

Another problem lies in the reflectivity of normal targets of interest. These include oxidized- or painted-aluminum aircraft, flame-coated artillery shells, and painted mortar rounds, rockets, and bombs. Very-high-power lasers are required for even short-range tracking of such target surfaces, leading to the need for target-enhancement devices. Fortunately, optical retroreflectors and highly reflective paints and materials are available to provide signal-strength enhancement from cooperative targets. However, the small size of the test article or adverse aerodynamic effects may preclude using these enhancement methods.

The offsetting characteristics of high peak powers and high atmospheric attenuation limit laser systems to fair weather and to relatively short (20-mile) slant ranges when both range and angle tracking are desired.

Range-only tracking out to several hundred miles can be obtained with a combination of high-gain photomultiplier tubes and the use of high-directivity retroreflectors on the targets. Angle-position data, however, is most economically obtained with solid-state quadrant photodetectors, which have much lower gain than photomultiplier tubes, and so sharply limit the maximum range-tracking capability of angle trackers.

Clearly, electro-optic devices offer exciting possibilities for precision tracking, even with their well-known limitations. RCA's exploratory work in this area has taken the form of operational field systems in range instrumentation environments. This paper describes two such system developments and discusses the performance results of operational laser trackers.

RCA's role

Engineers at Missile and Surface Radar have been deeply involved in range-instrumentation technology for many years. The laser tracker, when it is developed to its full potential, will become a complementary system to microwave radar, and may replace the need for a new radar in some instances. The implications of this kind of competition to both new and ongoing business are a continuing spur to MSR engineers to maintain a working knowledge and experience level in the field.

The approach MSR has chosen combines the best features of both laser and radar tracking systems—a laser tracker mounted on, and integrated into, an existing instrumentation radar.

This approach combines the proven all-weather, long-range features of instrumentation radars with the potentially more precise low-angle, short-range capability of lasers. Over the past several years MSR has developed, installed, and extensively tested two laser systems incorporating full three-coordinate tracking integrated into existing instrumentation radars at NASA Wallops Flight Center, Va. (Fig. 1) and at White Sands Missile Range, N.M. Also, a third range-only, high-power unit has been deployed at NASA-WFC for special satellite-tracking missions.

This compromise approach, using a combined laser and microwave radar tracking system, has accumulated a large body of knowledge and practical experience for both customer and contractor. It has also provided an opportuntiy for multilevel corporate cooperation in a technology area in which several RCA divisions have special capability. Some examples:

- Missile and Surface Radar provided specific familiarity with the radar

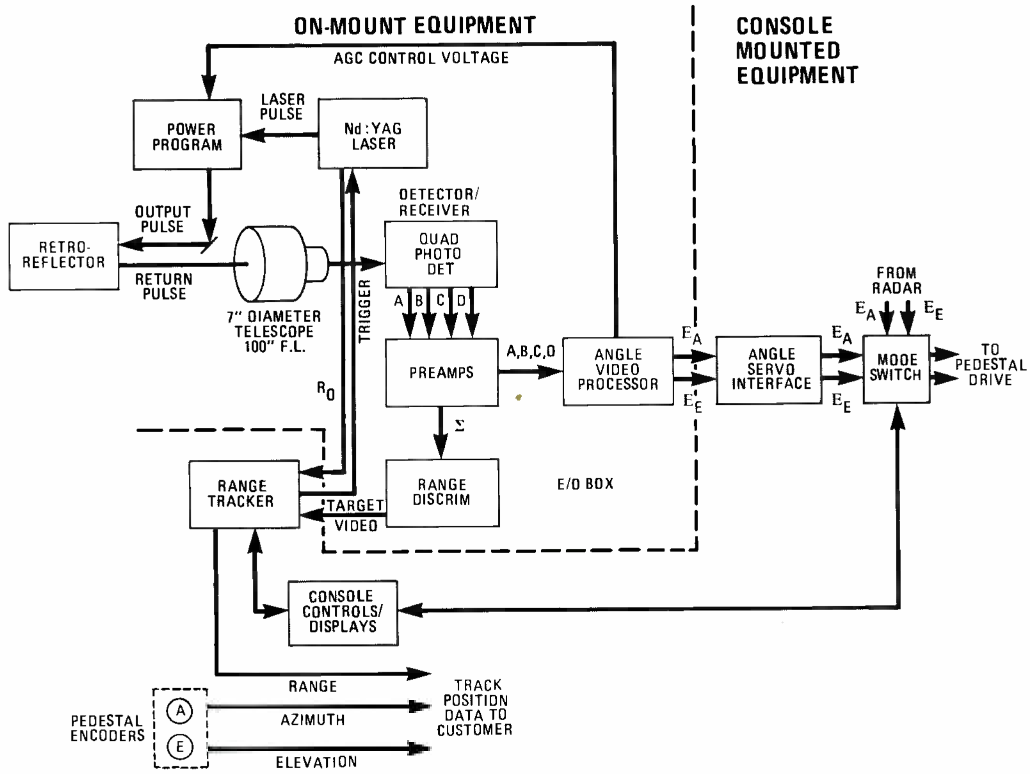

Fig. 2
Laser tracking system mounted on radar pedestal provides closed-loop angle tracking through the existing pedestal drive system and independent ranging data on retroreflector-equipped targets.

environment as well as the system design constraints imposed by that environment. Range and angle tracker development also fell within MSR design experience. The purchased optics system (modified 7-inch Questar telescope) was based on a three-port coaxial configuration previously developed at MSR under an independent research and development task.

- Advanced Technology Laboratories contributed heavily, not only during initial proposal efforts, but also in applying previous laser signal-processing experience to the development of the transimpedance amplifiers and angle video processor equipments used in the system.
- Aerospace Systems provided the Nd:YAG laser source for the system. This device used an interferometer design originally developed by a joint ATL-AS group under a previous R&D effort.
- RCA Ltd (Montreal) contributed the fully depleted PIN quadrant photodiode that is used as the angle error detector.
- RCA Laboratories optics specialists provided continuous consultation and support throughout the program.

The success of these integrated laser-tracker system developments was the result of a truly multidivisional effort. Details of the systems developed and the results of their application are outlined in the following sections.

Laser tracker system development

The two three-coordinate trackers (range, azimuth, and elevation) delivered to date are designed to provide highly precise angle and range tracking data on high-performance aircraft. The first system was incorporated into an AN/FPS-16 instrumentation radar (SN49) at the NASA Wallops Flight Center. The second is installed on an AN/MPS-36 mobile instrumentation radar (SN13) at the White Sands Missile Range, New Mexico. These two radar systems represent both ends of a four-generation family of precision instrumentation radar trackers. The AN/FPS-16, developed by RCA in the late 1950s, was the first radar specifically designed for instrumentation use and was one of the first tracking radars to offer accuracies within 2 meters rms in range and 0.1 mrad rms in angle tracking. A product of the early 1970s, the RCA AN/MPS-36 provided very nearly equivalent precision in a compact, flexible, highly mobile system. The operational characteristics of the two radar systems and their associated laser trackers are so similar that a single description essentially covers both units. Accordingly, the following paragraphs use the NASA Wallops Flight Center system as a basis for discussion and then explain the minor differences between the two systems.

The major features of the laser tracking system are:

- Optics mounted on radar-pedestal elevation axis
- Independent closed-loop range tracker
- Control panel integrated into radar console
- Laser angle errors used to drive existing radar angle servos

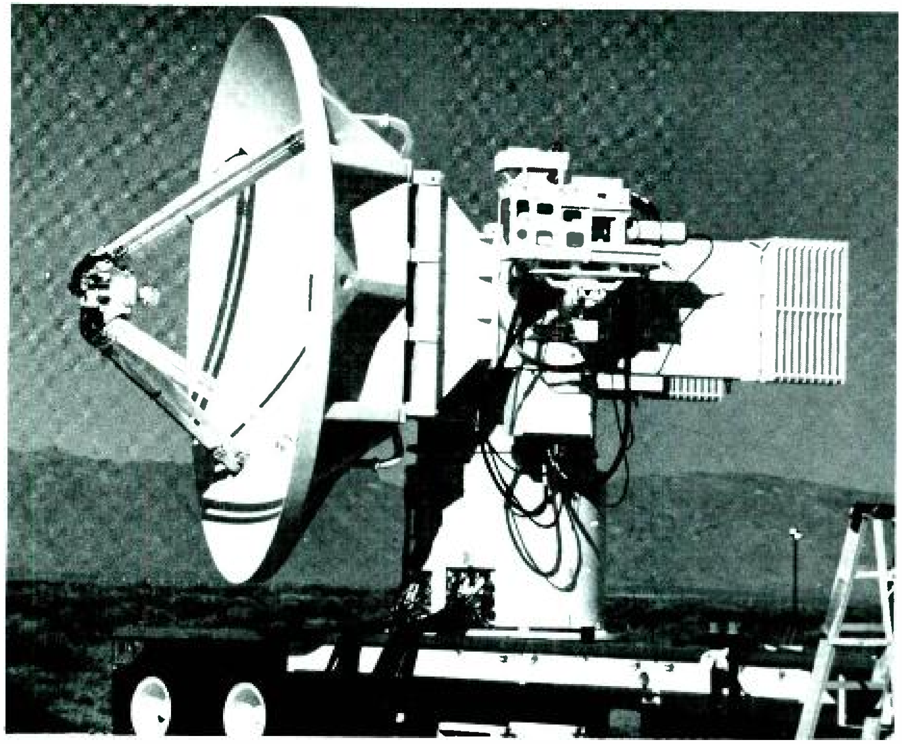

Fig. 3
Laser tracker mounted on the AN/MPS-36 radar at White Sands Missile Range. On-mount equipment is identical to that shown in Fig. 1 except for an optical receive-power programmer (not visible in this view) and mechanical interface differences between the two different types of radars.

- Automatic/manual laser-radar handover
- Automatic/manual transmit power programming
- Eyesafe design
- Retroreflector assembly provided (if desired)
- Coaxial three-port lens system

Fig. 1 provides a view of the system as installed on the AN/FPS-16 radar at NASA-WFC. The major on-mount equipments are identified in the photograph, and the simplified block diagram of Fig. 2 shows their interrelationship with the radar electronics.

System operation

When a 40-pulse/s laser trigger is generated within the range tracker and sent to the laser head, the laser transmits a 20-ns, 40-mJ, 1.06-μm pulse in response. The pulse passes through a power programmer, where it is attenuated by varying amounts, depending on range and receive signal strength. This power programmer is incorporated in the system for two reasons. First, it assures that the optical energy densities impinging on the target never exceed a specified "eyesafe" level. Thus at no time are the pilot or crew of a tracked aircraft subjected to optical energies that might cause eye damage. To meet these standards, the system inserts minimum levels of optical attenuation as a function of target range (10 dB for 6000 feet and 30 dB for 2000 feet). In addition, the system is constrained to use a maximum level of attenuation (greater than 50 dB) whenever a verified measurement of target range is lacking (i.e. during acquisition). The maximum attenuation can be manually overridden by the laser operator once it has been determined that all eye-safety criteria have been met.

The second reason for using the power programmer is to provide the system with a means of compensating for large variations in receiver signal strength as a function of target slant range. The system is required to track targets at slant ranges from 350 to 120,000 ft, which would place an unrealistic dynamic-range requirement on the receiver AGC response if no optical attenuation were available. Thus the power programmer serves as both an eye-safety system and a narrow-bandwidth optical AGC system.

After the signal passes through the programmer, it strikes a right-angle mirror in front of the telescope and travels to the target where it is reflected by the retroreflector. The return signal is captured by the 7-inch telescope, reflected by a frequency-selective (dichroic) right-angle mirror, and then passed through an interference filter to the face of the quadrant photodetector. The video output pulses from each quadrant pass through a transimpedance amplifier into the angle video processor, where they are peak-detected and combined to form azimuth and elevation error voltages. A signal representing the sum of the quadrant detector outputs is also generated and sent to the range discriminator. The angle errors, after passing through interface circuits, are used to drive the pedestal in angle by means of existing angle servos. The range discriminator output pulse is passed to the range tracker where, together with an R_0 pulse (sample of transmitted pulse) from the laser, it is used as a measure of round-trip transit time to the target. A closed-loop range tracker uses this measured transit time to update its output range measurement after first processing the data through a variable-bandwidth, all-digital, Type-2 servo loop.

The WSMR tracker

The second three-coordinate laser tracker system has been integrated into an AN/MPS-36 radar system on the White Sands Missile Range (see Fig. 3). The WSMR tracker is identical in configuration to the previously described NASA-WFC system except for the incorporation of a receive-power programmer (a variable optical attenuator) and the use of a modified, high-power laser.

The receive-power programmer was installed to provide optical attenuation with a faster response time than the narrow-bandwidth transmit programmer can provide. In this revised configuration, the transmit programmer is normally controlled only as a function of target range and thus serves primarily as an eye-safety attenuator. The transmit attenuator also provides a gross control of receive-signal strength to maintain it within the dynamic range of the vernier receive attenuator. The receive programmer is controlled only by

Laser satellite tracking

In addition to the full three-coordinate laser tracking sysems, MSR has also developed a range-only laser tracker for the retroreflector-equipped GEOS-III satellite. This system is integrated into the AN/FPQ-6 instrumentation radar at Wallops Flight Center. NASA applies the ranging data to obtain highly accurate orbits for the satellite as a means of calibrating the satellite's altimeter. The altimeter readings, in turn, provide data on the earth's geoid, ocean currents, and sea state.

The laser system is pointed at the target by the radar (which is performing a simultaneous track of the satellite). The radar tracker uses a satellite-borne transponder, which introduces a ranging error caused by the uncertainty of the exact transponder delay. This transponder-induced error is not present in the more precise laser ranging data.

The satellite laser ranging system operates in a similar manner to the ranging portion of the other laser tracking systems. The major differences lie in its use of a gated, high-gain photomultiplier tube as the optical detector and in the direct output of the round-trip propagation time (coupled with a time-of-day measurement) as range information instead of filtered data from a closed-loop tracker.

The range-only system uses a high-power, narrow-pulse ruby laser that delivers up to 5 J/pulse in the 20-ns normal Q-switched mode, or 0.5 to 1 J at 5 ns in the pulse-slicer mode. The satellite ranging system has the following characteristics:

Range precision	50 cm
Repetition rate	1 pulse/s
Wavelength (ruby)	6943 Å
Energy output per pulse	0.5 J (nom)
Pulse width	5 ns
Power output, peak	100 MW
Optical beamwidth	1 mrad (nom)
Receive bandwidth	12 Å

For approximately one year, the system has been delivering satellite ranging data with a precision of 30 to 50 cm rms at a nominal orbital range of 400 nautical miles.

the receive-AGC level and thus serves as an optical adjunct to the more limited dynamic-range electronic AGC loop. This revised configuration removes the eye-safety constraints from the optical AGC function and provides the system with a greater flexibility in responding to variations in atmospheric attenuation. The receive attenuator also minimizes the possibility of range-dependent, range-systematic errors occurring when tracking high-performance, short-range targets.

The higher-energy (80 mJ/pulse) laser was incorporated into the WSMR system in response to a minimum output energy requirement in the system specification. The RCA-designed unit uses the same basic optical cavity design as did the earlier, lower-energy laser, but the overall mechanical configuration of the device was changed to accommodate a beefed-up cavity cooling system.

A significant feature of both systems is the ability to align and collimate the optical transmit/receive paths with the radar rf axis.

When properly collimated, the system can be automatically or manually switched between laser and radar tracking modes without interrupting tracking data. Thus the laser can be used as long as a satisfactory signal level is present, with automatic transfer to radar track mode whenever the optical track is interrupted. Such an interruption could occur if aircraft maneuvers obstruct the retroreflector or the aircraft passes through a cloud bank. Automatic return to the optical track mode then occurs when the system senses that a useful laser return is once again being received.

This handover capability between the laser and radar systems assures the data user of the best possible tracking data from the combined instruments.

The radar, with its wider beamwidths and long-range tracking capabilities, can be used to assist in automatic laser acquisition, after which the system will automatically (if desired) transfer track over to the laser for precision tracking at shorter ranges and at low elevation angles. This combined laser/radar tracking capability is unique to RCA-designed laser tracking systems.

Laser tracker performance

The three-coordinate laser tracking system performance characteristics are presented in Table I. A better indication of actual system performance capabilities can be obtained from Fig. 4 (from the NASA Wallops trackers) and Fig. 5 (from the White Sands system).

Fig. 4 shows typical measured range and angle errors for the NASA WFC tracking system. The precision of the range and angle tracks on a dynamic target are well within the specified limits of 0.5 foot rms and 0.1 mrad rms.

Fig. 5 depicts range calibration data obtained using the WSMR system. These data were taken during October and November 1975. Surveyed optical retroreflector targets were set up at various ranges and azimuth angles to check the day-to-day calibration accuracy and stability of the laser tracking system. The system provided stable ranging data over the one-month interval and the ranges agreed closely with the known survey range to the targets. The plotted data have not been refraction-corrected; such corrections, if applied, should produce improved results.

In general, the systems have provided consistent tracking precisions of 0.5 foot rms or less in range and 50 microradians rms or less in angle, over the system's entire range.

Both customers for these instrumentation lasers are currently evaluating the accuracy and operational readiness of the systems. The accuracy evaluations conducted thus far have used a multitheodolite network as the reference for comparison purposes on dynamic targets, and surveyed ground targets for static tests. Results have been encouraging. Static target tests have shown excellent agreement between laser-measured and surveyed positions, with no apparent systematic errors. During the dynamic tracking tests, the difference in target position as determined by the laser and by the theodolite data has been less than the position-measurement uncertainities of the theodolite measurements.* Thus, the lasers are performing very well, and a quantitative determination of their actual accuracy must await development of more accurate reference systems.

The only area where a performance problem has been encountered with these laser trackers is in consistently meeting the 120,000-ft maximum slant-range specification. This requirement has been met by the

*Real y Vasquez, R., Jr. "AN/MPS-36 laser tracking systems's precision and accuracy performance evaluation," WSMR Technical Memorandum NR-DR-76-Z. 7 Jun 1976.

WSMR system, which is operated in a semi-arid environment with very clear atmospheric conditions. The NASA system, on the other hand, is deployed very near the ocean on the eastern shore of Virginia—an area of hazy, vapor-laden atmospheric conditions. Nonetheless, the NASA system has demonstrated an acquisition and track capability out to slant ranges of 60,000 ft at aircraft altitudes from 5,000 to 10,000 ft, with an occasional track out to the maximum instrumented range of 120,000 ft.

Conclusions

Tests performed to date on two fully integrated laser/radar systems have verified that such systems do indeed provide much more versatile instrumentation than radar-only systems. Low-elevation tracks of landing aircraft at NASA-WFC and "pop-up" tracks of helicopters during tactical warfare exercises at WSMR have provided tracking data that would have been unavailable with standard radar.

Test results show that track precisions of 0.5 ft rms in range and 50 μrad rms in angle are routinely achieved. Accuracy-evaluation tests indicate that the systems are capable of providing absolute measurement accuracies commensurate with the data precision.

An important, but sometimes overlooked, attribute of the combined systems is their ability to support both radar and laser missions with the same operating and maintenance personnel and facilities previously used for the radars alone. Thus, the user obtains the added laser tracking capability with essentially zero impact on the present radar-only O&M costs. This factor is especially important today when the effective operating budgets of the national ranges are being reduced by reductions in appropriations and the effects of inflation.

RCA's work in combining lasers and radars in instrumentation range trackers tends to confirm the expected: the laser cannot replace the long-range all-weather tracking capability of radar; neither can radar compete with lasers in the realm of short-range, high tracking precision, especially at low elevation angles. The development effort has, however, established the practicality of combining electro-optics and radar in a single unit of great versatility and performance.

Table I
Performance characteristics of the combined system.

Radar performance	unchanged
Tracking range	350 to 120,000 ft
Angle track rate	450 mrad/s max
Angle K_V	5300 s^{-1} max
Angle K_A	195 s^{-2} max
Range track rate	$\geqslant$10,000 ft/s, 2500 ft/s^2
Optical beamwidth	4 mrad
PRF	40 pulses/s
Power output, peak	2.0 MW
Energy output, per pulse	40 mJ
Pulse width	20 ns
Wavelength	1.06 μm
Optics diameter	7 in.
Laser range granularity	0.5 ft (radar: 2.0 yds)
Laser range precision	<0.5 ft rms ($S/N \geqslant 20$ dB)
Laser angle precision	<50 μrad rms ($S/N \geqslant 20$ dB)

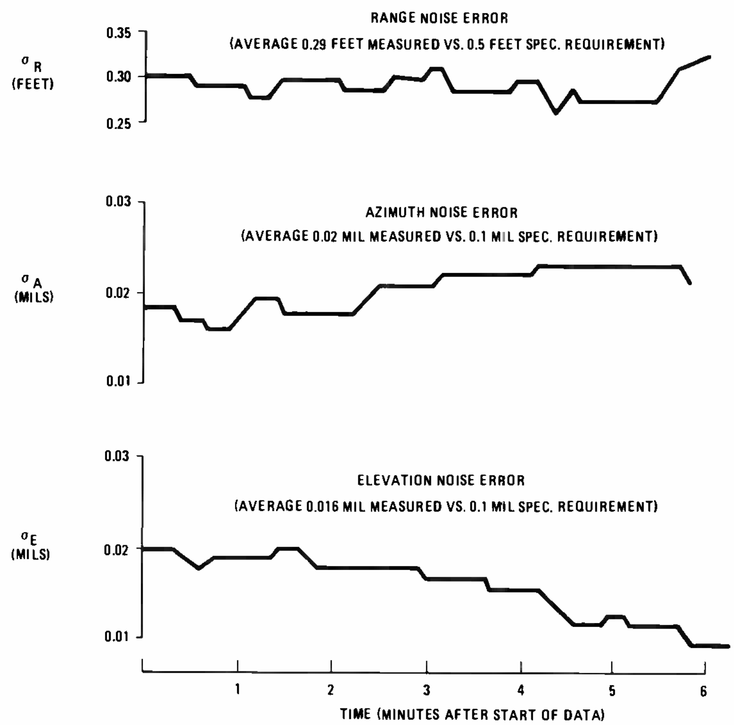

Fig. 4
Tracking performance characteristics of the Wallops Flight Center laser tracking system. Errors are well within the specification limits of 0.5 ft in range and 0.05 mil in angle.

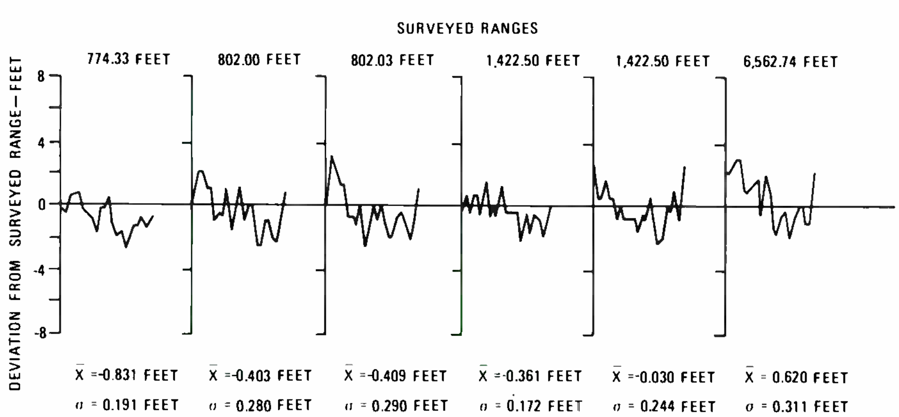

Fig. 5
Relative day-to-day range stability of the White Sands laser system as measured against surveyed optical targets at various slant ranges on the test range.

Pen and Podium Recent RCA technical papers and presentations

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Automated Systems

J. G. Bouchard| D.R. Bokil
Automatic assembly of hybrid circuits on a ceramic substrate—American Defense Preparedness Assoc., Coronado, CA (3/77)

J.G. Bouchard| D. Bokil
Automatic assembly of hybrid circuits on a substrate—Keystone and Metropolitan Chapter of the Intl. Soc. of Hybrid Microelectronics, Princeton, NJ (4/20/77)

G.T. Burton
Electronic solid state wide angle camera system (ESSWACS)—SPIE/SPSE Technical Symp., Reston, VA (4/18/77)

M.L. Johnson
Reliability of the AN/GVS-5 hand held laser rangefinder—15th Spring Reliability Seminar, Lynnfield, MA (4/28/77)

A. Muzi
Sensor selection for automatic diagnosis of vehicles—SAE 1977 Intl. Eng. Congress, Detroit, MI (2/28 - 3/4/77)

W.C. Neuman
How to optimize digital design for checkout on automatic test equipment—IEEE Boston Section Education Group, MIT, Cambridge, MA (3/24/77)

Advanced Technology Laboratory

W.A. Clapp
CMOS LSI arrays for system applications—Workshop on Microprocessors, JPL, Pasadena, CA (4/28/77)

W.A. Clapp
Trends in technology and microcomputers—U. of Penna. Eta Kappa Nu Initiation Dinner, Philadelphia, PA (4/6/77)

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Laboratories

M. Ettenberg| C.J. Nuese| G.H. Olsen
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L.J. French| J. Hilibrand
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W. Kern| R.B. Comizzoli
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R.U. Martinelli| E. Jetter
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Optical transmission of liquid crystal field effect cells—*J. Appl. Physics*, Vol. 48 No. 3 (3/77) pp. 1179-1185

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N.S. Klein| D.W. Fairbanks| D.J. Tamutus
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O.R. Mesker| E.A. James
Extremely high stress in graded interfacial layers: Hf on sapphire—23rd Natl. Vacuum Symp., Chicago, IL (9/22/76) *J. Vacuum Sci. & Tech.*, Vol. 14 No. 1 (Jan/Feb 77) pp. 85-88

C.E. Weitzel
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R.E. Daniel| A.R. Triano

Electrical properties of a-Si solar cells—*Technical Digest* of the 1976 IDEM Mtg., Washington, DC (12/6/76) p. 75

Missile and Surface Radar

J.A. Bauer

Use of chip carriers for high packaging density, high reliability, high performance products—*Proc.*, NEPCON/WEST '77, Anaheim, CA (3/1-3/77)

M.W. Buckley

Project management—Education for Business and Industry seminar, London, England (3/29-30/77)

B. Fell

Radar identification and tracking of birds—Adult Education Program, Lenape Senior High School, Medford, N.J. (3/29/77)

J.R. Foglebock

Book review of "Frequency synthesizers: theory and design"—*IEEE Spectrum* (2/77)

J.W. Hurley

Industrial logistics management—logistics methods & techniques—Garden State Chapter, Logistics Engineers Symp., Temple U., Phila., PA (4/14/77)

S.M. Sherman

Complex angles of arrival— *Proc.* IEEE Southeastcon, Williamsburg, VA (4/4-6/77)

Dates and Deadlines

Upcoming meetings

Ed. Note: Meetings are listed chronologically. Listed after the meeting title (in bold type) are the sponsor(s), the location, and the person to contact for more information.

JUN 20-22, 1977—**Design Automation Conf.** (ACM, IEEE) New Orleans, LA **Prog Info:** Harry Hayman, Design Automation Conf., POB 639, Silver Spring, MD 20901

JUN 20-24, 1977—**Laser 77 Opto-Electronik: 3rd Intl. Congress and Intl. Exhibition,** Munich, Germany **Prog Info:** Munchener Messe-und Ausstellungs-gesellschaft GmbH. Messegelande, Munchen

JUN 20-24, 1977—**Intl. IEEE/AP Symp. and USNC/URSI Mtg.** (IEEE et al) Palo Alto, CA **Prog Info:** J.B. Damonte, 1716 Hillman Ave., Belmont, CA 94002

JUN 21-23, 1977—**Intl. Microwave Symp.** (MTT, IEEE) Sheraton Harbor Island Hotel, San Diego, CA **Prog Info:** David Rubin, 3528 Quimby St., San Diego, CA 92106

JUN 21-25, 1977—**World Electrotechnical Congress** (USSR Acad. of Sci., IEC, IEEE, et al) Moscow, USSR **Prog Info:** A.K. Antonov, Organizing Comm., WEC, Kalinin Prospect 19, Moscow G-19, USSR

JUN 22-24, 1977—**Joint Automatic Control Conf.** (IEEE et al) Hyatt Regency, San Francisco, CA **Prog Info:** J.S. Meditch, Dept. of Elec. Eng., U. of Wash., Seattle, WA 98195

JUN 27-29, 1977—**1977 Device Research Conf.** (IEEE) Cornell U., Ithaca, NY **Prog Info:** E.I. Gordon, Bell Telephone Labs., Room 2A 330, Murray Hill, NJ 07974

JUN 27-29, 1977—**Conf. on Fluid and Plasma Dynamics** (AIAA) Hilton Hotel, Albuquerque, NM **Prog Info:** AIAA Meetings Dept., 1299 Ave. of the Americas, New York, NY 10019

JUL 10-15, 1977—**Intl. Colour Association: Color 77, The 3rd Congress** Rensselaer Polytechnic Institute, Troy, NY **Prog Info:** Dr. Fred W. Billmeyer, Jr., Dept. of Chemistry, RPI, Troy, NY 12181

JUL 11-14, 1977—**Intersociety Environmental Systems Conf.** (ASME et al) Jack Tar Hotel, San Francisco, CA **Prog Info:** Technical Affairs Department, ASME, 345 E. 47th St., United Engineering Center, New York, NY 10017

JUL 11-15, 1977—**Infrared Technology: Fundamentals & Systems Application,** U. of Michigan **Prog Info:** Anthony J. LaRocca, Chairman, U. of Michigan, College of Engrg., Continuous Engineering Education, 300 Chrysler Center, N. Campus, Ann Arbor, MI 48109

JUL 12-15, 1977—**Nuclear & Space Radiation Effects Conf.** (IEEE, NASA, JPL) Coll. of Wm. & Mary, Williamsburg, VA **Prog Info:** Harold Hughes, Naval Research Lab., Code 5216, Washington, DC 20375

JUL 17-22, 1977—**Intersociety Transportation Conf.** (ASME) McCormick Inn, Chicago, IL **Prog Info:** Technical Affairs Department, ASME, 345 E. 47th St., United Engineering Center, New York, NY 10017

JUL 17-22, 1977—**Power Engineering Society Summer Meeting** (IEEE) Maria Isabel, Sheraton, Camino, Mexico City, Mex. **Prog Info:** Ing. Francisco Hawley, N. CONDUMEX, SA, Poiniente 140 No. 720, Mexico 16, D.F.

JUL 18-22, 1977—**CCD and SAW: Basic Theory & Application to Communications, Radar & Signal Processing** (Rensselaer Polytechnic Inst.) Lake George, NY **Prog Info:** Course Director, Prof. Pankaj Das, RPI, Troy, NY 12181

JUL 28-30, 1977—**Electromagnetic Compatibility Symp. & Exhibition,** Congress Bldg., Montreux, Switzerland **Prog Info:** F.E. Borgnis, EIDG, Tech. Hochscule, Sternwartsi 7, 8006 Zurich, Switzerland

AUG 2-4, 1977—**Electromagnetic Comp. Symposium** (IEEE) Olympic, Seattle, WA **Prog Info:** B.L. Carlson, Jr., POB 88062, Seattle, WA 98188

AUG 2-4, 1977—**New Options in Energy Technology** (AIAA/EEI/IEEE) Fairmont Hotel, San Francisco, CA **Prog Info:** Martin Newman, Director, Public Information, AIAA, 1290 Sixth Ave., New York, NY 10019

AUG 16-18, 1977—**Active Microwave Semiconductor Devices and Circuits,** Cornell U., Ithaca, NY **Prog Info:** Prof. L.F. Eastman, Program Chairman, 316 Phillips Hall, Cornell University, Ithaca, NY 14853

AUG 21-26, 1977—**Soc. of Photo-optical Instrumentation Engineers Symp.** (SPIE) Town and Country Hotel, San Diego, CA **Prog Info:** SPIE, P.O. Box 1146, Palos Verdes Estates, CA 90274

AUG 26-SEP 4, 1977—**Intl. Radio and TV Exhibition 1977 Berlin,** Berlin, W. Germany **Prog Info:** Intl. Radio & TV Exhibition, Press Center, Mr. Bodo H. Kettelhack, P.O. Box 19 17 40, D-1000, Berlin 19, W. Germany

AUG 28-SEP 2, 1977—**Intersociety Energy Conversion Eng. Conf.** (IEEE et al) Sheraton Park, Washington, DC **Prog Info:** Glen A. Graves, Office of Energy R&I Policy, NSF, 1800 G St., N.W., Washington, DC 20550

SEP 18-21 1977—**American Ceramic Soc. Fall Mtg., Electronics Div.** (ACS) Queen Elizabeth Hotel, Montreal, Que. **Prog Info:** Henry M. O'Bryan, Jr., Bell Telephone Laboratories, Inc., Room 6D-307, Murray Hill, NJ 07974.

Calls for papers

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SEP 6-9, 1977—**COMPCON Fall** (IEEE) Washington, DC **Deadline Info: 6/30/77 to** COMPCON FALL '77, POB 639, Silver Spring, MD 20901

OCT 10-14, 1977—**Annual Mtg. Optical Soc. of America,** Royal York Hotel, Toronto, Ont. **Deadline Info: (ab) 7/8/77 to** OSA, Suite 620, 2000 L St., N.W., Washington, DC 20036

JAN 29-FEB 3, 1978—**1978 IEEE Power Engineering Soc. Winter Mtg.** (IEEE) Statler Hilton Hotel, New York, NY **Deadline Info:** Immediately request an author's kit from Technical Conf. Services Office at IEEE Headquarters, 345 E. 47th St., New York, N.Y. 10017

MAR 22-24, 1978—**Vehicular Technology** (IEEE) Regency, Denver, CO **Deadline Info: 7/21/77 to** John J. Tary, U.S. Dept. of Commerce, OT/ITS, 325 Broadway, Boulder, CO 80302

APR 10-12, 1978—**1978 IEEE Intl. Conf. on Acoustics, Speech, & Signal Processing** (IEEE) Camelot Inn, Tulsa, OK **Deadline Info: (ab) 9/22/77 to** Thomas H. Crystal, Inst. for Defense Analyses, Thanet Rd., Princeton, NJ 08540

JUL 16-21, 1978—**Power Engineering Soc. Summer Meeting** (IEEE) Los Angeles, CA **Deadline Info: 2/1/78 to** G.A. Davis, Southern Calif. Edison Co., POB 800, Rosemead, CA 91770

Patents

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V. Auerbach
Error cancelling scanning optical angle measurement system—3992106

J.F. Balceqicz
Minimum shift keying communications system—3993868

D.S. Bond
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W.L. Cable
Spacecraft structure—4009851

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Fast acquisiton circuit for a phase locked loop—3993958

T.D. Michaelis
Solar torque compensation for a satellite—RE29177

L. Muhlfelder| N.U. Huffmaster
Backup wheel for a three-axis reaction wheel spacecraft—3999729

R.A. Newell| J.H. Bacher
H.W. Bilsky| P.J. Callen
Satellite battery reconditioning system and method—3997830

K.J. Phillips
Minimization of residual spacecraft nutation due to disturbing—3997137

J.S. Pistiner
Minimization of spacecraft attitude error due to wheel speed reversal—3998409

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Digital-to-synchro converter—3993993

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Charge-coupled device input circuits—4010485

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A.G. Dingwall| B.D. Rosenthal
Current mirror amplifier—4010425

W.G. Einthoven| W. Hulstrunk
Semiconductor device with solder conductive paths—3997910

J.G. Endriz
Modulation mask for an image display device—4001620

J.G. Endriz| C.A. Catanese
Modulation mask for an image display device—4001619

D.W. Fairbanks
Overhead signal pickup device—3993316

B.W. Faughnan| R.S. Crandall
Electrochromic device having a dopant therein to improve its color center absorption characteristics—4009935

A.H. Firester
Electro-optic Q-switching system for a laser—3965439 (assigned to U.S. Government)

A.H. Firester
Optical element for a laser—4011524

A.H. Firester
Polarization-selective laser mirror—4009933

R.A. Gange
Holographic recording medium—4012253

D.M. Gavrilovic
Liquid crystal compounds and electro-optic devcies incorporating them—4013582

I. Gorog
Optical communication and display system—4004078

I. Gorog| J.D. Knox
Acousto-optic modulated laser—4019155

W.E. Ham
Edgeless transistor—4015279

J.M. Hammer
Fiber-optic to planar-waveguide optical coupler—4018506

K.G. Hernqvist
Gas laser optical system—3996527

K.G. Hernqvist
Ultra-violet gas laser—4008445

K.G. Hernqvist
Laser alignment system—4010363

K.G. Hernqvist| A.H. Firester
Method of aligning a laser device—3999858

P. Ho| A. Rosen
Frequency tunable microwave apparatus having a variable impedance hybrid idler circuit—4005372

A.C. Ipri
Method of simultaneously forming a polycrystalline silicon gate and a single crystal extension of said gate in silicon-on-sapphire MOS devices—4016016

E.O. Johnson
Electronic timepiece—4007583

H.C. Johnson
Stabilizing and calibration circuit for fm-cw radar ranging systems—4008475

G.S. Kaplan| A.S. Clorfeine
Respiration monitor—3993995

G.S. Kaplan| A.D. Ritzie
Binary rate multiplier with means for spacing output signals—4017719

H. Kawamoto
Comb filter appratus for video playback systems—3996610

E.O. Keizer
Recording apparatus and methods for a color picture/sound record—4005474

E.O. Keizer
Video disc playback apparatus—4018987

E.O. Keizer
Video disc record having spirally aligned sync storage locations—4018984

H.P. Kleinknecht| H.G. Kiess
Apparatus for making a recording of an electrostatic charge pattern—4005436

M.A. Leedom| J.C. Bleazey
Disc record groove skipper—3999386

A.W. Levine| M. Kaplan
Electron beam recording medium comprising 1-methylvinyl methyl ketone—4012536

A.W. Levine| M. Kaplan
Electron beam recording comprising polymer of 1-methylvinyl methyl ketone—4018937

P.A. Levine
Smear reduction in CCD imagers—4010319

H. F. Lockwood| M. Ettenberg
H. Kressel| J.I. Pankove
Light emitting diode with reflector—3991339

R.U. Martinelli| H. Kressel
Lateral current device—4005451

R.M. Mehalso
Method of making a metallized video disc having an insulating layer thereon—4018945

D. Meyerhofer
Controlled angle viewing screens by interference techniques—3996051

R.S. Mezrich| D.H. Vilkomerson
Ultrasonic wave radiation pattern display system incorporating phase contrast means—3997717

C.S. Oh| E.F. Pasierb
Alkoxybenzylidene-aminobenzonitriles—3996260

G.H. Olsen| M. Ettenberg| R.U. Martinelli
Electron emitting device and method of making the same—4019082

J.T. Oneil, Jr.| A. Pelios
A.H. Simon| F.G. Nickl
Article carrying coded indicia—4004131

H.L. Pinch| B. Abeles| J.I. Gittleman
High resistance cermet film and method of making the same—4010312

H.L. Pinch| H.I. Moss
Video disc stylus—4013830

E.S. Poliniak| R.J. Himics| H. Wielicki
Olefin-SO_2 copolymer film adhesion to a substrate—4007295

A. Presser| E. Mykietyn
Variable tuning and feedback on a high power microwave transistor carrier amplifier—3999142 (assigned to U.S. Government)

D.H. Pritchard
Comb filter for video processing—3996606

W.F. Reichert
Method of forming raised electrical contacts on a semiconductor device—3993515

W. Phillips
Method of preparing optical waveguides—3997687

R.M. Rast
Programming unit for a television tuning phase locked loop—4009439

G.H. Riddle
Probe forming electron optical column having means for examining magnified image of the probe source—4010318

G.H. Riddle| R.R. Demers
Mechanically adjustable electron gun apparatus—3997807

W.R. Roach
Deformable mirror light valve and method of operating the same—4013345

A.D. Robbi
Low energy switching circuit—4011464

A.D. Robbi
Variable range automotive radar system—4011563

P.H. Robinson| R.S. Ronen
Method of treating semiconductor device to improve its electrical characteristics—4007297

L.R. Rockett, Jr.
Surface potential stabilizing circuit for charge-coupled devices radiation hardening—4011471 (assigned to U.S. Government)

J. Rosen
Semipassive responder utilizing a low voltage, low power drain reflective varactor phase modulator—3996587

B.D. Rosenthal| A.G. Dingwall
Voltage amplitude multiplying circuits—4000412

W. Rosnowski
Diffusion of conductivity modifiers into a semiconductor body—3997379

D.L. Ross| L.A. Barton
Method of recording information in which the electron beam sensitive material contains 4,4-bis(3-diazo-3-4-oxo-1-naphthalene sulfonyloxy) benzil—4005437

J.R. Sandercock
High resolution, high contrast Fabry-Perot spectrometer—4014614

J. Schiess| T.E. Bart
Color correction circuit for video recorders—4001876

F.N. Sechi
Linear amplifier utilizing adaptive biasing—3996524

F.N. Sechi
Linear high power transistor amplifier—3991381

I. Shidlovsky
Hafnium pyrophosphate phosphors and methods of preparation—4014813

D.L. Staebler
Recording assembly for volume holography—4017144

F. Sterzer
Electronic license plate for motor vehicles—4001822

F. Sterzer| G.S. Kaplan
Dual mode automobile collision avoidance radar—4003049

Z. Turski
Microwave bulk acoustic delay device having two transducers on the same surface and method of making same—3996535

C.L. Upadhyayula
Planar transferred electron logic device—3991328

J.L. Vossen, Jr.| F.R. Nyman
D.G. Fisher| G.F. Nichols
Metal coating for video discs—4004080

C.C. Wang| T.C. Lausman
Photosensitive camera tube target primarily of lead monoxide—4001099

P.K. Weimer
Signal processing circuits for charge-transfer image-sensing arrays—4001501

P.K. Weimer
Charge transfer color images—4001878

P.K. Weimer
Charge transfer readout of charge injection device arrays—4016550

M.H. Woods| R. Williams
Method of treating a layer of silicon dioxide—4007294

M.H. Woods| R. Williams
Method of radiation hardening semiconductor devices—4014772

C.T. Wu
Self-clocking, error-correcting low bandwidth digital recording system—4003085

Distributor and Special Products Division

F.R. Dimeo| W.J. Bachman
Antenna construction—4010473

S.L. Knanishu
Alternating current meter circuit—3993951

SelectaVision Project

A.L. Baker
Squelch circuit for a video record player—4017677

A.L. Baker
End-of-play control system—4017678

B.K. Taylor
Disc record locked groove escape apparatus—3997716

Automated Systems

D.A. Gore
Binary-coded Fraunhofer hologram recording technique—3990773

S.C. Hadden| L.R. Hulls
Sampling and dilution method—3965749

W.J. Hannan| E.M. Fulcher
R.D. Rhodes| R.G. Saenz
Credit card containing electronic circuit—4004133

R.E. Hanson
Acceleration burst test apparatus and method for internal combustion engines—3994160

E.M. Sutphin, Jr.
Fast automatic gain control circuit with adjustable range—3995224

R.E. Tetrev
Detection system for spatially-distributed set of radiation beams manifesting multibit binary code—3995146

Missile and Surface Radar

M.E. Breese
Monopulse radar system—3996589

R.P. Perry| H. Urkowitz
Constant false alarm rate (CFAR) circuitry for minimizing extraneous target sensitivity—3995270 (assigned to U.S. Government)

L. Weinberg
Target detection method and apparatus for reducing range-smearing error caused by relative target motion—4014022 (assigned to U.S. Government)

O.M. Woodward
Frequency selective reflector system—4017865

Picture Tube Division

S.B. Deal| D.W. Bartch
Method for adhering components platform to cathode-ray tube and product thereof—4016363

R.C. Demmy
Shadow mask cathode ray tube shield—4002941

G.E. Eiwen
Method for devacuating a vacuum tube—4010991

R.W. Etter
Silver plating bath—4003806

T.F. Simpson
Method of measuring color purity tolerance of a color display tube—4001877

R.P. Stone
Method of setting cathode-G1 spacing—4015315

E.S. Thall
CRT with thermally-set getter spring—4006381

M. Vanrenssen| M.H. Wardell, Jr.
Electron tube socket having spring-wire contacts—4012094

P.W. Wolverton
Article positioning apparatus—3990692

RCA Records

J.B. Halter
Triangular piezoelectric transducer for recording video—RE-29113

RCA Ltd., England

L.R. Avery
Drive pulse generator for a television deflection circuit—3992648

L.R. Avery
Automatic noise gate for a synchronizing signal amplifier—4008370

B. Crowle
Phase-splitter circuits—4004240

Consumer Electronics

D.R. Andrews
Tape cartridge player with cartridge pull-in mechanism—3992919

J.B. Beck
Magnetic recording and reproducing system with tape-to-head speed control—4003090

L.A. Cochran| L.A. Harwood
Controllable gain signal amplifier—3999141

L.A. Harwood
Hue correction apparatus having a restricted range—3996608

L.A. Harwood
Third harmonic signal generator—4019118

L.A. Harwood| E.J. Wittmann
Bias circuit for junction diodes—4019152

H.E. Haslau| W.E. Rigsbee
Coil winding machine—4007881

R.S. Packman
Panel edge fastener clip—3999729

Solid State Division

A.A. Ahmed
Biasing current attenuator—4019071

L.R. Avery
Amplifier suitable for use as a color kinescope driver—3996609

R.R. Brooks
GTO circuits—4016433

R.R. Carbonetta, Jr.
Gas laser—4001720

J.C. Coffin
Photodetector non-responsive to Cerenkov radiation—4002901

W.F. Dietz
Drive circuit for a gate semiconductor device—4001607

W.G. Einthoven
Semiconductor device having parallel path for current flow—3999217

R.D. Faulkner| R.E. McHose
Phototube having improved electron collection efficiency—4006376

G.M. Harayda| W.M. Austin
Heat-sink assembly for high-power stud-mounted semiconductor device—4004195

V.E. Hills| L. Wu
Proximity sensing circuit—4001613

F.R. Hughes| R.C. Crissman
Improved processes for activating S-1 cathode—3992071

P.J. Kannam| W.P. Bennett
Transistor having integrated protection—4017882

L.A. Kaplan
Phase control circuit including an operational transconductance amplifier suitable for use in audio frequency signal processing apparatus—3995235

P.W. Kaseman
Electron discharge image tube with electrostatic field shaping electrode—4001618

H. Khajezadeh
High-reliability plastic-packaged semiconductor device—4001872

T.W. Kisor
Carrier for semiconductor components—4015707

M.B. Knight
Current amplifiers—3992676

A.G. Lazzery
Liquid crystal module—4012117

A.J. Leidich
Cascaded transistor amplifier stages—4007427

A.F. McDonie| C.M. Tomasetti
Method of sensitizing electron emissive surfaces of antimony base layers with alkali metal vapors—4002735

L.D. Miller| H. Popp
Method for extending cathode life in vidicon tubes—4018489

D.K. Morgan
Keyed comparator—4004158

P.L. Myers
Automatic assembly of semiconductor devices—3992770

J. Ollendorf| F.J. Cestone
Semiconductor wafer chuck with built-in standoff for contactless photolithography—4006909

J.S. Radovsky
Bias current circuit—3999140

L.R. Salvatore
Transistor circuits—4010418

O.H. Schade, Jr.
Dynamic current supply—4004244

O.H. Schade, Jr.
Current limiting circuit and method—3996498

O.H. Schade, Jr.
Current amplifier—4008441

O.H. Schade, Jr.
Voltage regulator circuit with FET and bipolar transistors—4012684

H.D. Scheffer
Ultrasonic wire bonding chuck—3995845

A.C. Sheng| M.E. Malchow
Oscillator circuits—4001723

A.C.N. Sheng
Amplifier with current gain inversely proportional to transistor Hfe—4004243

A.C. Sheng
First timing circuit controlled by a second timing circuit for generating long timing intervals—4017747

H. Sorkin
Liquid crystal devices—4003844

R.G. Stewart
Rectifier structure for a semiconductor integrated circuit device—3999205

D.R. Tshudy| T.W. Edwards
Method of selective growth of microcrystalline silicon—4004943

C.F. Wheatley, Jr.
Apparatus for supplying symmetrically limited bidirectional signal currents—4004242

H.A. Wittlinger
Oscillator circuit whose frequency is voltage controllable which contains a comparator—3996531

H.A. Wittlinger
Ground fault and neutral fault detection circuit—4012668

B. Zuk
ECL switching circuit for producing noncomplementary, time coincident signals—4001608

Broadcast Systems

O. Ben-Dov
Circularly polarized, broadside firing, multihelical antenna—4001567

W.J. Derenbecher, Jr.
Blanking generator for PAL sync signals—4009487

H.G. Seer, Jr.
Negative color film mask correction—4009489

H.G. Seer, Jr.
Negative gamma circuit—4018988

RCA Ltd., Canada

M.P. Mills
Method of fabricating large area, high voltage pin photodiode devices—4009058

Globcom

N. Disanti| F. Oster
Narrow-band eight-phase modem—4011407

RCA Service Co.

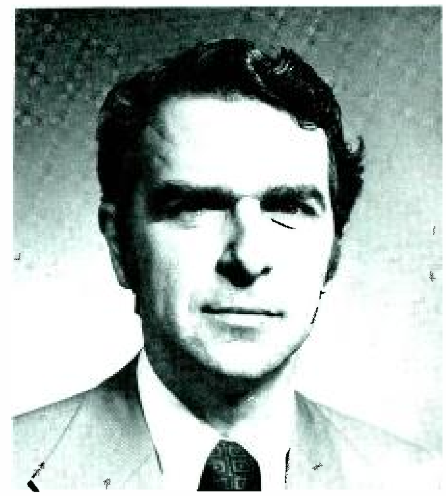
E.L. Crosby, Jr.
Tethered balloon mooring means—3976268 (assigned to U.S. Government)

E. L. Crosby, Jr.
Toroidal tail structure for tethered aerofoam balloon—3993269

Four new *RCA Engineer* Ed Reps appointed

Editorial representatives are responsible for reviewing and approving technical papers; for coordinating the technical reporting program; and for promoting the preparation of technical papers and presentations. (See inside back cover for a complete listing of Ed Reps.)

Fred Foerster is the new Ed Rep for Integrated Circuits at Solid State Division. He is Manager, Engineering Specifications, at Somerville. Fred was an engineer in the Receiving Tube Division for nearly 20 years before his transfer to SSD in 1972.



Jack Friedman is the new Ed Rep for Missile and Surface Radar. He is Leader of the Proposals and Contract Reports Group at Moorestown. Jack has 21 years of experience in various engineering and editing positions.

Staff announcements

President and Chief Executive Officer

Edgar H. Griffiths, President and Chief Executive Officer, announced executive responsibility for the Major Operating Units will be as follows: **Howard R. Hawkins**—Executive Vice President, with responsibility for Random House, Inc. and RCA Records Division. Mr. Hawkins will also act as Communications advisor to the President and Chief Executive Officer. **Julius Koppelman**—Group Vice President, with responsibility for Distributor and Special Products Division, Picture Tube Division, RCA Alaska Communications, Inc., RCA American Communications, Inc., RCA Global Communications, Inc., and RCA Service Company. **Paul Potashner**—Group Vice President, with responsibility for Banquet Foods Corporation, Coronet Industries, Inc., and Oriel Foods Group.

Solid State Division

Frank J. DiGesualdo, Manager, Palm Beach Gardens—Solid State Operations, announced the organization as follows: **William B. Allen,** Manager, Industrial Relations; **Charles E. Godfrey,** Manager, Operations Services; **John A. Kucker,** Manager, Manufacturing—Wafer Fabrication; **Ernest T. Prigge,** Manager, Manufacturing—Assembly & Test; **Gordon S. Putnam,** Manager, Financial Operations; and **Richard B. Tyler,** Manager, Quality & Reliability Assurance.

John E. Schaefer, Manager, Findlay Operations, appointed **Alco D. Brown** Manager, Manufacturing—MOS Wafer Fabrication.

Gerald K. Beckmann, Director, MOS Logic Products, appointed **Henry L. Pujol** Manager, Applications Engineering; and **Michael D'Agostino** Manager, Timekeeping Products.

Henry L. Pujol, Manager, Applications Engineering—MOS Logic Products, announced the organization as follows: **Richard E. Funk,** Leader, Product Performance Engineering; and **Henry L. Pujol,** Acting Leader, Customer Support Engineering.

Julius Litus, Jr., Manager, Design Engineering—MOS Logic Products, announced the organization as follows:

Engineering News and Highlights

Maucie Miller is the new Ed Rep for Americom. He is Administrator of Technical Publications at the Piscataway facility. During his career at RCA, Maucie has been involved in all aspects of technical publications.

Leslie Schmidt is the new Ed Rep for the Solid State Technology Center. She joined RCA in 1976 as Engineering Administration Coordinator shortly after graduating from Bucknell University where she received the BA, magna cum laude, in Physics and English.

Marconi International Fellowship

The Marconi International Fellowship commemorates Guglielmo Marconi's creative contributions to scientific discovery, engineering, and technology. Twenty-two major organizations concerned with the communications industry, representing ten ten countries, sponsor the Fellowship. RCA has been a sponsor since the award was initiated in 1974 to commemorate the centenary of the inventor's birth. The Fellowship recognizes and inspires achievements of living men and women whose efforts in the fields of communications sciences and technologies, like Marconi's, are characterized by a profound commitment to human betterment.

The Fellowship, a $25,000 grant, enables the recipient to undertake or complete a project or study which has as its ultimate objective the well-being of mankind. Learned societies, academies and universities from all countries as well as individuals in industry and public life are invited to propose candidates for the Fellowship. All candidates must be proposed by July 31, 1977. For further information on this fellowship, contact:

Doris E. Hutchison
Adm., Technical Information Systems
RCA Corporate Engineering
Building 204-2
Cherry Hill, N.J. 08034

Richard P. Fillmore, Leader, Standard Circuit Design—Hi-MOS; **Orest Harasymowych,** Administrator, Design Engineering; **Robert C. Heuner,** Leader, Standard Circuit Design—COS/MOS; and **Nicholas Kucharewski,** Leader, Custom Circuit & Timekeeping Design.

Louis V. Zampetti, Manager, Silicon Materials, announced the organization as follows: **Daniel A. August,** Superintendent, Manufacturing—Silicon Materials; and **W. Robert Guerin,** Leader, Technical Staff—Silicon Materials.

Frederick P. Lokuta, Manager, Wafer Fabrication, announced the organization as follows: **Eugene J. Chabak,** Leader, Technical Staff—Wafer Fabrication; **Roy P. Petersen,** Superintendent, Manufacturing—Pellets; and **Edmund A. Vancavage,** Superintendent, Manufacturing—Diffusion.

Fred G. Block, Manager, Central Engineering, announced the organization as follows: **Anthony J. Bianculli,** Manager, Engineering Standards, and Acting Administrator, Data Base Systems; **Stuart N. Levy,** Manager, Computer Aided Manufacturing, and Acting Leader, Advanced Computer Aided Manufacturing; **Vincent J. Grobe,** Manager, Computer Aided Manufacturing—Power; **James J. Rudolph,** Leader, Computer Aided Manufacturing—IC's; **Raymond A. McFarlane,** Manager, Equipment Technology; **Alva B. Hom,** Leader, Assembly Equipment; **Dieter G. Krawitz,** Manager, Equipment Technology Shop; **Robert C. Shambelan,** Leader, Wafer Fabrication Equipment; **William J. VanWoeart,** Leader, Electronic & Electrical Systems; **George J. Pulsinelli,** Administrator, Engineering Administration; **Harold S. Veloric,** Manager, Materials & Processes Laboratory; **Robert N. Epifano,** Leader, Defect Analysis, Analytical Technology and Polymer & Photoresist Technology; **Carel W. Horsting,** Leader, Metallurgical Technology; and **Ural Roundtree, Jr.,** Leader, Crystal Technology.

Stanley Rosenberg, Director, High Speed Bipolar, IC Operations, announced the organization as follows: **Patrick L. Farina,** Manager, Operations Control and Administration—High Speed Bipolar; **Marvin E. Mendelson,** Administrator, Facilities—High Speed Bipolar; and **Harold Miller,** Manager, Operations Control—High Speed Bipolar.

Carl R. Turner, Division Vice President, Solid State Power Devices, announced the organization as follows: **Dale M. Baugher,** Manager, Power Applications, Test & Technical Planning; **Melvin Bondy,** Manager, Operations Planning & Administration—Power; **Ralph S. Hartz,** Director, Power Development & Type Engineering; **John E. Mainzer,** Director, Power Manufacturing Operations; **Robert E. O'Brien,** Manager, Technology Transfer Program—Power; and **Donald Watson,** Director, Product Marketing—Power.

John E. Mainzer, Director, Power Manufacturing Operations, announced the organization as follows: **George W. Ianson,** Manager, Power Manufacturing Operations Support; **Henry A. Kellar,** Manager, Device Fabrication; **Frederick P. Lokuta,** Manager, Quality Reliability; **Vincent J. Lukach,** Manager, Quality & Reliability Assurance; **Richard M. Marshall,** Manager, Financial Operations; **Joseph R. Spoon,** Manager, Industrial Relations; **Juan C.J. Suarez,** Manager, Manufacturing—Belo Horizonte; **Eric Van-Vooren,** Manager, Manufacturing—Liege; **Henry C. Waltke,** Manager, Operations Services; and **Louis V. Zampetti,** Manager, Silicon Materials.

Ralph S. Hartz, Director, Power Development & Type Engineering, announced the organization as follows: **Donald E. Burke**, Manager, Device Development Engineering; **Edward A. Czeck**, Manager, Type Engineering; and **Robert J. Satriano**, Manager, Equipment/Package Engineering.

Consumer Electronics Division

Roy H. Pollack, Vice President and General Manager, announced the appointment of **D. Joseph Donahue**, Vice President, Operations.

D. Joseph Donahue announced the organization as follows: **Harry Anderson**, Division Vice President, Manufacturing Operations; **Jay J. Brandinger**, Division Vice President, Engineering; and **Leonard J. Schneider**, Director, Product Assurance.

Roy H. Pollack, Vice President and General Manager, Consumer Electronics Division, announced the organization of Product Assurance as follows: **Leonard J. Schneider**, Director, **Clyde W. Hoyt**, Manager, Product Safety and Reliability Center; **Thornley C. Jobe**, Manager, Technical Support; and **James R. Smith**, Manager, Quality and Reliability.

Jay J. Brandinger, Division Vice President, Engineering, announced the organization as follows: **J. Peter Bingham**, Manager, Engineering Development; **Cortland P. Hill**, Manager, Product Design and Test Technology; **Eugene Lemke**, Manager, Display Systems; and **John M. Wright**, Manager, Engineering Services.

Loren R. Wolters, Vice President, Operations, RCA Taiwan, announced the organization as follows: **T.T. Chang**, Manager, Plant Quality Control; **Gary Chen**, Manager, Manufacturing Engineering; **James Chua**, Manager, Engineering; **David M. Dew**, Manager, Resident Engineering; **James Shu**, Manager, Manufacturing, Plant II; and **James Yang**, Manager, Manufacturing, Plant I and Satellite Plants.

Business Systems and Analysis

Franz Edelman, Staff Vice President, Business Systems and Analysis, announced the organization as follows: **Paul Berger**, Manager, Systems Design; **Michael A. Cofone**, Manager, Systems Support; **Denis J. Foley**, Manager, Systems Implementation; **N. Newton Garber**, Manager, Operations Research; and **John T. O'Neil, Jr.**, Director, Systems Planning.

Telecommunications and Computer Services

John P. Macri, Staff Vice President, Telecommunications and Computer Services, announced the organization as follows: **Allen M. Fleishman**, Manager, Computer Services; **Harry A. Freedman**, Manager, Computer Systems Planning; **Charles E. Hurd**, Manager, Telecommunications Customer Services; **Anthony V. Isaia**, Manager, Computer Operations; **William B. Noyovitz**, Manager, Operations Analysis; **Forrest R. Smoker**, Manager, Telecommunications Systems Planning; and **Edward J. Tomko**, Manager, Telecommunications Operations.

Picture Tube Division

Joseph H. Colgrove, Division Vice President and General Manager, Picture Tube Division, announced the following appointments: **Donald R. Bronson**, Division Vice President, International; and **William G. Hartzell**, Div. Vice President, Engineering.

RCA American Communications, Inc.

Andrew F. Inglis, President, RCA American Communications, Inc., announced the organization as follows: **A. William Brook**, Vice President, Engineering; **Carl J. Cangelosi**, General Counsel; **John Christopher**, Director, Program and Space Systems Management; **Dennis W. Elliott**, Director, Finance; **Paul W. Gaillard**, Vice President, Marketing; **Donald E. Quinn**, Director, Public Affairs; **Harold W. Rice**, Vice President, Operations; **Charles H. Twitty**, Director, Industrial Relations; and **Jack F. Underwood**, Vice President, Communications Services.

National Broadcasting Company

Oden Paganuzzi, Director, Broadcast Systems Engineering, appointed **John P. Gillen** Manager, Broadcast Systems Engineering.

Robert J. Butler, Director, Technical Development appointed **Miguel A. Negri** Senior Staff Engineer, Technical Development.

RCA Laboratories

William M. Webster, Vice President, announced the organization as follows: **Nathan L. Gordon**, Staff Vice President, Systems Research; **Gerald B. Herzog**, Staff Vice President, Technology Centers; **Charles A. Hurford**, Manager, Industrial Relations; **Kerns H. Powers**, Staff Vice President, Communications Research; **Richard E. Quinn**, Staff Vice President, Administration; **Thomas O. Stanley**, Staff Vice President, Research Programs; and **James J. Tietjen**, Staff Vice President, Materials and Components Research.

Richard E. Quinn, Staff Vice President, Administration, announced the organization as follows: **Emil V. Fitzke**, Manager, Technological Services; **George C. Hennessy**, Director, Marketing and Technical Information Services; **Richard E. Honig**, Head, Materials Characterization Research; **Jerome Kurshan**, Manager, Administrative Services; and **Ralph H. Myers**, Manager, Finance.

James J. Tietjen, Staff Vice President, Materials and Components Research, announced the organization as follows: **Henry Kressel**, Director, Materials and Processing Research Laboratory; **Robert D. Lohman**, Director, Display Systems Research Laboratory; and **Brown F. Williams**, Director, Energy Systems Research Laboratory.

Brown F. Williams, Director, Energy Systems Research Laboratory, announced the organization as follows: **David E. Carlson**, Head, Photovoltaic Device Development; **Bernard Hershenov**, Head, Energy Systems Analysis; **David Richman**, Head, Semiconductor Materials Research; and **Brown F. Williams**, Acting Head, Optical Materials and Devices Research.

Robert D. Lohman, Director, Display Systems Research Laboratory, announced the organization as follows: **Roger W. Cohen**, Head, Physics and Chemistry of Solids Research; **P. Niel Yocom**, Head, Luminescent and Electro-Optic Materials Research; **John A. Van Raalte**, Head, Displays and Device Concepts Research.

Henry Kressel, Director, Materials and Processing Research Laboratory, announced as follows: **Glenn W. Cullen**, Head, Materials Synthesis Research; **Richard Denning**, Manager, Advanced Power Engineering (SSD); **Leonard P. Fox**, Head, Applied Process Research; **Charles J. Nuese**, Head, Semiconductor Device Research; and **Daniel L. Ross**, Head, Organic Materials and Devices Research.

Nathan L. Gordon, Staff Vice President, Systems Research Laboratory, announced the organization as follows: **David D. Holmes**, Director, Television Research Laboratory; and **Alfred H. Teger**, Head, Advanced Systems Research.

Kerns H. Powers, Staff Vice President, Communications Research, announced the organization as follows: **Guy W. Beakley**, Head, Image Processing Research; **Istvan Gorog**, Head, Optical Electronics Research; **Eugene O. Keizer**, Head, Micro Topographics Research; **Bernard J. Lechner**, Director, Video Systems Research Laboratory; and **Daniel A. Walters**, Head, Satellite Systems Research.

Bernard J. Lechner, Director, Video Systems Research Laboratory, announced the organization as follows: **John K. Clemens**, Head, Signal Systems Research; **William D. Houghton**, Head, Special Projects Research; and **Charles B. Oakley**, Head, Broadcast Systems Research.

Joseph H. Scott, Director, Integrated Circuit Technology, announced the organization as follows: **Norman Goldsmith,** Head, Integrated Circuit Process Research; **Israel H. Kalish,** Manager, Integrated Circuit Design and Process Development (SSTC); **George L. Schnable,** Head, Solid State Process Research; and **Karl H. Zaininger,** Head, Solid State Device Technology.

Fred Sterzer, Director, Microwave Technology Center, announced the organization as follows: **Erwin F. Belohoubek,** Head, Microwave Circuits Technology; **Ho-Chung Huang,** Head, Microwave Process Technology; **S. Yegna Narayan,** Head, Microwave Components Technology; and **Markus Nowogrodzki,** Manager, Division Liaison.

Promotions

Astro-Electronics

T.J. McKnight from Senior Engineer to Manager (Specialty) Engineering (R. Packer)

Solid State Division

Frederick P. Lokuta from Leader Technical Staff to Manager, Wafer Fabrication (John Mainzer, Power Manufacturing Operations, Mountaintop)

Consumer Electronics

Robert F. Shelton from Leader Liaison Engineer to Manager, Resident Engineering-Bloomington (Eldon L. Batz, Resident Engineering)

Awards

An authors' reception held by Advanced Technology Laboratories of Government and Commercial Systems on March 24 in Camden honored 30 members of the technical staff who presented or published papers or received patents over the past year. Host for the reception was Paul Wright, Director of ATL.

NASA honors Freedman and Kravitz

Larry Freedman and **Marvin Kravitz,** members of the Space Shuttle TV technical staff, Astro-Electronics, Princeton, were awarded by NASA for development of new technology applicable to the Space Shuttle program. They were presented the NASA Technical Brief Awards for development of a "TV Cursor/Special Effects Generator," which can be used as an alignment aid in the Space Shuttle TV system, enabling astronaut pilots to position, align, install and remove payloads from the Shuttle cargo bay.

Licensed engineers

When you receive a professional license, send your name, PE number (and state in which registered), RCA division, location, and telephone number to: *RCA Engineer*, Bldg. 204-2, RCA, Cherry Hill, N.J. New listings (and corrections or changes to previous listings) will be published in each issue.

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William Beckett, Moorestown, N.J.; PE-23495, N.J.

Solid State Division

Kenneth R. DeRemer, Somerville, N.J.; PE-22832, N.J.

Obituary

Henry D. Harmon, an engineer at Astro-Electronics, died April 1. He was 51. Mr. Harmon received the BS in Electrical Engineering from the University of Pennsylvania in 1952 and the MS in Electrical Engineering from Stevens Institute of Technology in 1956. During his nearly 25 years with RCA, he worked in several different activities. From 1952 to 1959 he worked as a semiconductor device development engineer in the Semiconductor and Materials Division. From 1959 to 1963, Mr. Harmon was a member of the Central Engineering Group in the Defense Electronics Division where he specialized in transistors—evaluating, consulting, and troubleshooting. In 1963 he joined Astro-Electronics where, as a member of the Space Power Group, he tested and analyzed solar cells and arrays. Then from 1965 to 1968 he was a transistor applications specialist for AED's Engineering Reliability Group. From 1968 to 1972 Mr. Harmon worked on RF devices at Missile and Surface Radar. He returned to Astro Electronics where he worked as semiconductor specialist until his death. Mr. Harmon was a member of the IEEE and the Professional Group on Electron Devices.

Professional activities

Harry J. Woll elected Chairman of Moore School Board of Trustees

Harry J. Woll, Division Vice President and General Manager, RCA Automated Systems, Burlington, Mass., was recently elected Chairman, Board of Trustees, for The Moore School of Electrical Engineering, University of Pennsylvania. The Moore School prepares undergraduate and graduate students for careers in Computer Science and Engineering, Electrical Engineering and Science, and Systems Science and Engineering. Dr. Woll is also a member of the Board of Overseers of the University's College of Engineering and Applied Sciences.

Nossen on NSIA

Edward J. Nossen, leader, Communications Systems, Government Communications, Camden, has been appointed to the National Security Industrial Association (NSIA) Subcommittee dealing with matters relating to Anti-Jam communications systems.

Lind on SMPTE Board

Anthony Lind, Manager of New Products Engineering, Studio and Control Equipment, Broadcast Systems, Camden, has been elected to the Society of Motion Picture and Television Engineers Board of Governors for the 1977-78 term. SMPTE is a key organization in the fields of television and motion picture engineering; its major functions are standardization activities, a technical journal and technical conferences.

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