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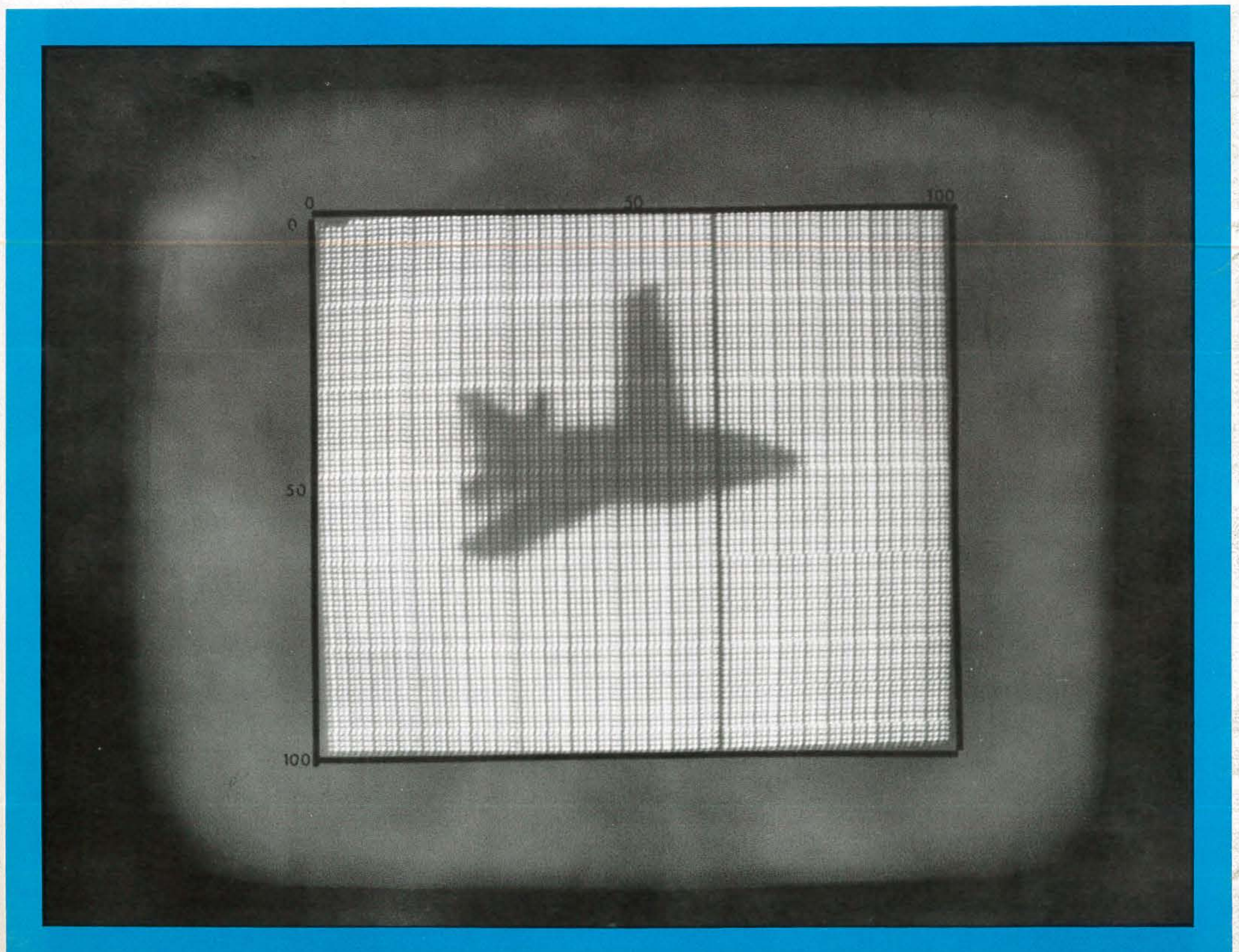
SID JOURNAL

The Official Journal of the Society For Information Display

SOLID STATE IMAGING

VOLUME II, NUMBER 6



Information Display

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Publisher
Erwin A. Ulbrich

Editor
Erwin Vodovoz

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Ron Thorstenson

COVER:

Our apparent two front covers of this issue is just our way of saying that we have reverted to the original name of this magazine, **Information Display**. The officers of SID feel that this is a more descriptive title for this publication.

The front cover (the one in color) is courtesy of General Electric (pg. 8) and the back cover is an actual display from the system described on page 5.

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DEPARTMENTS

THE OFFICIAL JOURNAL OF THE SOCIETY FOR INFORMATION DISPLAY.

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PRESIDENT'S MESSAGE

Those of us who attended the General Membership meeting of the Society, which was held in Washington, D.C. on April 22, 1975 in conjunction with the 1975 SID International Symposium, were privileged to participate in the annual award ceremonies of the Society for Information Display.

This year, Special Recognition Awards went to Joseph E. Bryden, George H. Heilmeir, Peter Seats, Otto H. Slade, Sr., and Donald A. Shurtleff. Elected to Fellow were William E. Good, Lucien M. Bieberman and H. Gene Slottow. Harold B. Law received the Frances Rice Darne Memorial Award.

It is not my purpose here to heap further accolades upon these so honored. I could not add thereby to the concrete achievements which earned them these signal honors. Rather, at the suggestion of Richard Wright, SID's Director from New England, this forum is being used to call your attention to the significance of SID's awards and to solicit your participation in the process.

Under our bylaws, a Fellow is a SID member, elected by the Honors and Awards Committee from nominations at large made annually of outstanding engineers and scientists in the information display field who have made widely recognized and significant contributions to the advancement of that field. Historically, the Society elects not more than three Fellows in any one year. The Frances Rice Darne Memorial Award is awarded periodically, but not more than one each year, to a Society member for an outstanding technical achievement in, or contribution to, the display field. Special Recognition Awards are given to members of the technical and scientific community, not necessarily SID members, for distinguished and valued contributions to the field of information display.

In all cases, the SID Honors and Awards Committee, which operates all year, solicits nominations for these honors. The names and supporting documentation on all nominees are sent to the Chairman, this year Phil Damon, who distributes these without editorial comment to the other Committee Members. Using this material, and with encouragement to obtain outside opinions from those in various organizations who might know the work of the candidate personally, the Committee Members rate the nominees on a predetermined set of criteria.

Those proposed by the committee are truly individuals of stature having contributed significantly to the advancement of information display.

Every one of you is urged to assist the Honors and Awards Committee in the selection of the most worthy candidates for these honors. You can do so by nominating exceptional individuals and supplying substantiating information to help the committee in its difficult but rewarding task.

ROBERT C. KLEIN
President — SID

CHARGE COUPLED SENSOR ARRAY APPLICATION TO TRACKER SYSTEMS

By JAMES L. RIEDL
McDonnell Douglas Astronautics Company
Huntington Beach, CA

Charge Injection Array Devices (CID) have the potential for a wide variety of military orientated uses. One such use is in trackers, opto-electronic systems which guide a weapon in on a target. Present day trackers utilize SWIR (short wave length infrared) and LWIR optical detectors to sense a target. In the tracker, one to four detectors are arranged such that the target energy sweeps or nutates across the detectors. The resultant signal from the detector is de-coded or de-modulated to produce guidance signals which steer the weapon to the target. Many trackers steer to a target utilizing the targets exhaust energy. Countermeasure ejected by the target can simulate exhausts which confuse the tracker, resulting in escape. Future targets will likely have a more sophisticated mix of tracker

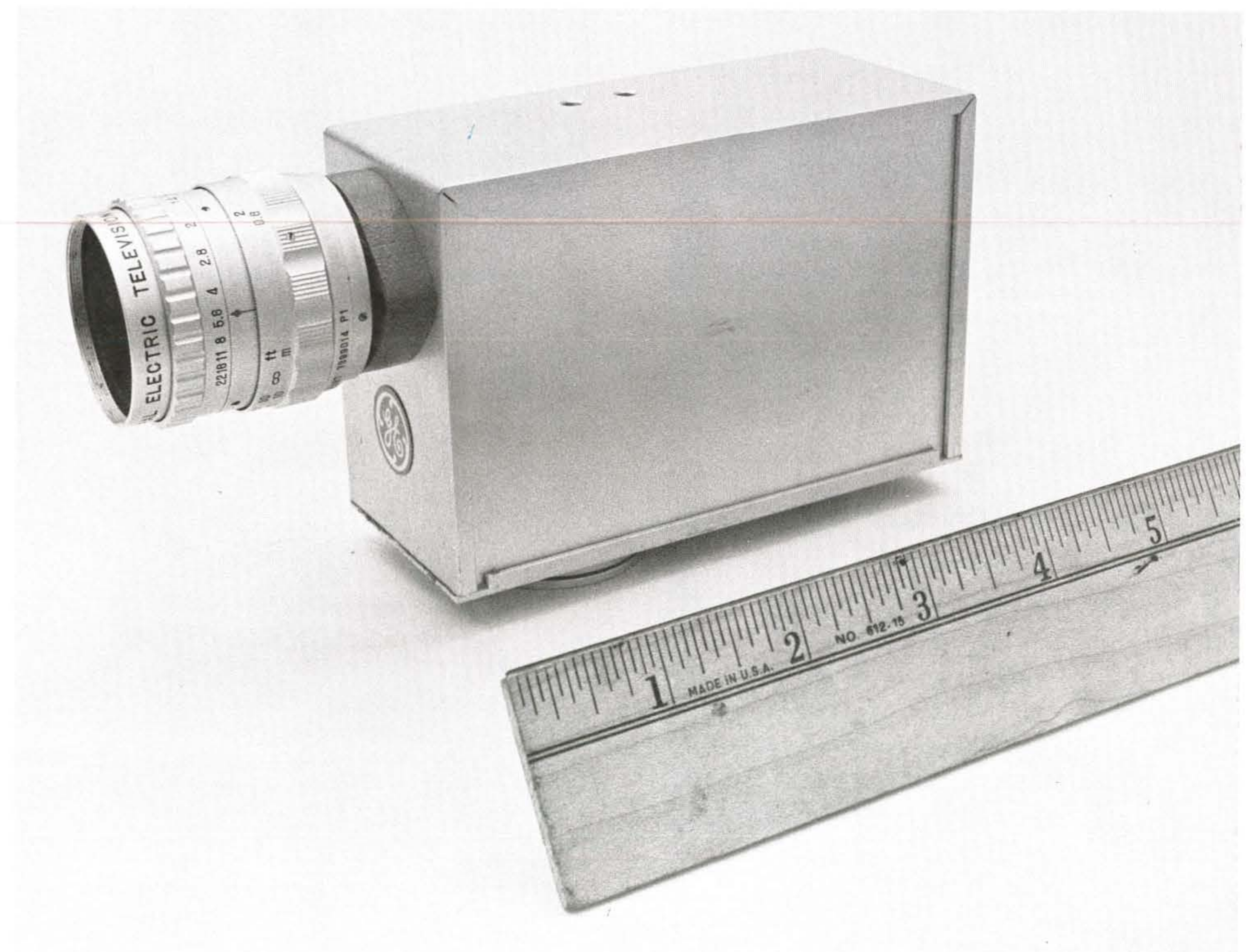


Fig. 1. CID Sensor used to evaluate this system.

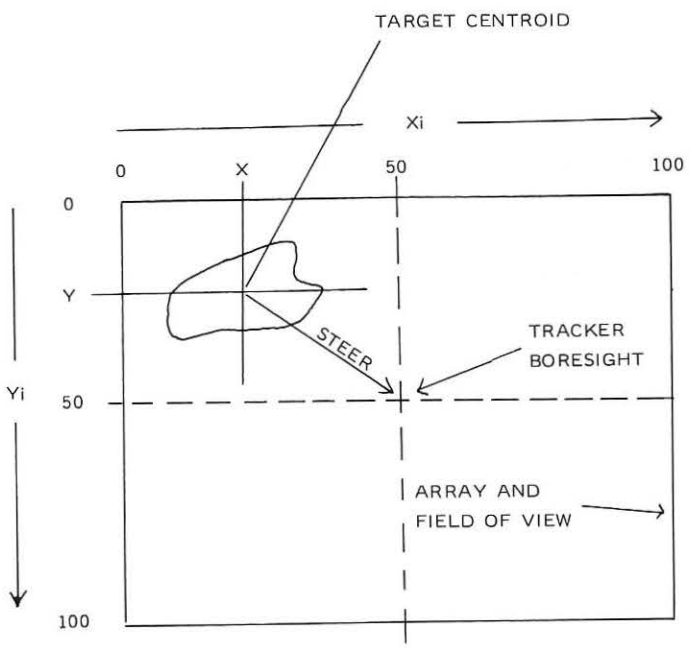


Fig. 2
Mathematical model upon which this sytem is based.

countermeasures. Countermeasures can be successful if the tracker is not intelligent. One approach to an intelligent tracker appears to be an array tracker.

An array tracker images the target on a 2-dimensional array of photo-sensors that statistically can provide better measurements as compared to point source target measurements. It can be used for multiple target discrimination, selective aim pointing, track-while-scan, identifying friend or foe, and fuzing.

Investigations into array trackers have provided a new tracker system. This tracker uses a 100 x 100 (10,000 sensors) array of CID sensors (General Electric Co., Syracuse, New York – *Figure 1)*. A lens focuses the target image onto the array which is electronically read-out and the image detected. Detection occurs if the signal from each sensor exceeds a threshold. The threshold information essentially is the target; most high level noise being removed by the threshold setting. A digital computer then calculates the mathematical centroid of the target utilizing the following algorithm.

$$(1) \quad X = \frac{\sum_{j=1}^{m} \sum_{i=1}^{n} \mu_{ij} x_i}{\sum_{j=1}^{m} \sum_{i=1}^{n} \mu_{ij}}$$

$$(2) \quad Y = \frac{\sum_{j=1}^{m} \sum_{i=1}^{n} \mu_{ij} y_i}{\sum_{j=1}^{m} \sum_{i=1}^{n} \mu_{ij}}$$

μ_{ij} = $\begin{cases} 0 \text{ if sensor signal is below threshold} \\ 1 \text{ if sensor signal is above threshold} \end{cases}$

x_i = number of ith sensor in the X direction

y_i = number of jth sensor in the Y direction

m = number of resolution elements in the Y direction.

n = number of resolution elements in the X direction.

This algorithm is derived from the classic definition of the center-of-mass of a uniformly dense blob. Uniformity is guaranteed by the threshold.

The centroid algorithm provides X and Y date, and from this, the tracker steers to the target centroid *(Figure 2)*.

The steering commands are derived to cause the target centroid to coincide with the weapon boresight, that is, the center of the array. The steering commands are:

$$(3) \quad Y_{rate} = K_1 J_y (Y_{m/2} - Y)$$

$$(4) \quad X_{rate} = K_1 K_2 J_x (X_{n/2} - X)$$

Y_m = 100 detectors in this case,

Y = centroid vertical coordinate

$K_1 = \theta \dfrac{\text{degrees}}{\text{detector}}$, θ is based on focal length of the imaging optics and detector spacing.

$K_2^* = \text{scruntch factor} = \dfrac{\text{array X dimension}}{\text{array Y dimension}}$

J_x and J_y = open loop gain required in the overall servo system hardware.

The threshold can be made adaptive based on a Markov or ad-hoc trainable automata theory. Adaptive thresholding is useful against countermeasures.

The complete tracker system was mechanized in a real time tracking scenario at McDonnell Douglas, Huntington Beach. Rotating targets were moved on the inside of a 30-foot hemispherical dome. A CID array mounted on a 3-axis CARCO gimbal *(Figure 3)* tracked the rotating, moving target. The rotating target provided different target aspects which caused the tracker to continuously calculate a centroid. Outputs from the CID array were read-out at various clock rates. Presently, the array is read-out 60 times a second producing centroid steer commands that are calculated 60 times a second. Calculations are accomplished by a hard-wired computer. The fast frame rate of 60 frames/second precludes almost any target from out-steering the tracker. □

*Note that some arrays are not square but rectangular. Thus the distance moved across the array is different for the X and Y direction.

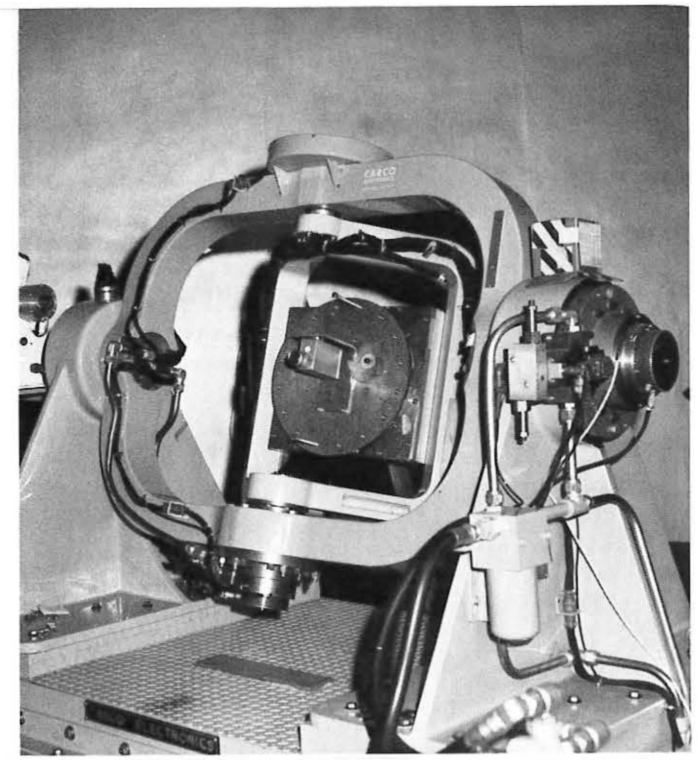


Fig. 3
CARCO gimbal fixture used to test the tracker system.

about the author

James L. Riedl has fifteen years of experience in guided missile systems and is employed by McDonnell Douglas Astronautics Company in Huntington Beach, CA. Mr. Riedl holds an M.S.E. degree in pattern recognition and image processing from the University of California at Irvine and is a consultant to the North American Schools Inc. Additionally, Mr. Riedl is president of the Riedl Rifle Co., manufacturers of specialized small arms, a field in which Mr. Riedl holds patents and has published.

CID —A Unique Approach to Solid-State Imaging

By FRED A SACHS and JOHN M. HOOKER
Optoelectronic Systems Operation,
Tube Products Department,
General Electric Company

Dramatic advances have recently taken place in the task of accomplishing imaging through the use of solid state devices. General Electric's approach to the Charge Injection Device (CID) has responded very favorably to the evolution and improvement of this technology.

With the introduction of the 100 x 100 CID imager in 1973, it became apparent that this device, or a CID in another format, could serve the existing imaging market as well as serving to create new markets. To this point, imagers of 132 x 192 and 244 x 188 sizes have been implemented.

Uses presently envisioned for the CID system are outlined in *Figure 1*. Many of these applications are presently served by products utilizing tube type imagers. The advantages of CIDs in these applications are small size and weight, reliability, maintainability, and most significantly, the lack of any degradation mechanisms which virtually eliminates maintenance cost. New applications are limited only by one's imagination.

Market Segment	Typical Applications	Pertinent CID Features
Security/Surveillance	Remote Sampling Mode	Slow Scan Random Access Address
	Hazardous Area Viewing	Ruggedness Burn Resistant
	Law Enforcement	
Broadcast	Chroma Channels	Broad Spectral Response High Sensitivity
Process Control	Measurements	Geometric Accuracy Near IR Sensitivity
Military	Missile Sensor	Low Power Requirements Ruggedness
	Remotely Piloted Vehicles	Random Access Address Small Size Reliability
	Fire Control	Geometric Accuracy Ruggedness
Instrumentation	Spectrometer	Broad Spectral Response Selective Scanning
	Microscopy	Sensitivity Small size
	Laser Detector	Broad Spectral Response
Optical Character Reading	Automatic Point of Sale	Small Size Reliability
Computer	Card Readers	Reliability Readily Converts to Digital Form
Medical	Patient Monitoring	High Sensitivity Near IR Sensitivity Low Maintenance

Figure 1. Here's how the CID Imager can be used.

Basic Theory

Despite its similarity to existing CCD (Charged Coupled Device) technology, the CID is a unique approach to solid-state imaging. The device consists of an X-Y addressed array of charge storage capacitors which store photon-generated charge in MOS inversion regions. Readout is effected by sequentially injecting this stored charge into the substrate and detecting the resulting displacement current to create a video signal. This technique has a number of basic advantages, among which are simple mechanization, tolerance to processing defects, avoidance of charge transfer losses, and minimized blooming. The approach taken in CID development has been aimed at producing an efficient device with a wide dynamic range. Performance results obtained from 100 x 100 CID imagers will be discussed, together with advances in charge collection and readout techniques that have greatly increased the operating speed and application potential of this approach.

Performance Highlights

Dark Current — The CID approach permits significantly more silicon area to be used for photon charge generation than for charge storage. This results in an advantageous dark current situation because the thermal charge generation rate in non-depleted bulk silicon is orders of magnitude less than the generation rate in the depleted storage region. Consequently, each image sensing site collects and stores photon-generated charge from essentially the total site area but generates dark current only in the storage area.

The use of bias charge in the storage area results in an additional reduction in dark current. The surface thermal generation rate in MOS structures is much smaller under inversion conditions than under depletion conditions. The use of bias charge maintains essentially all but the periphery of the storage area inverted.

In the 100-line imager, these factors result in an order of magnitude reduction in dark current below that achievable had the entire photosensitive area been depleted.

Sensitivity — Sensitivity as a function of wavelength is plotted in *Figure 2*. The sensitivity maximum for the structure occurs at a wavelength of 0.67 microns.

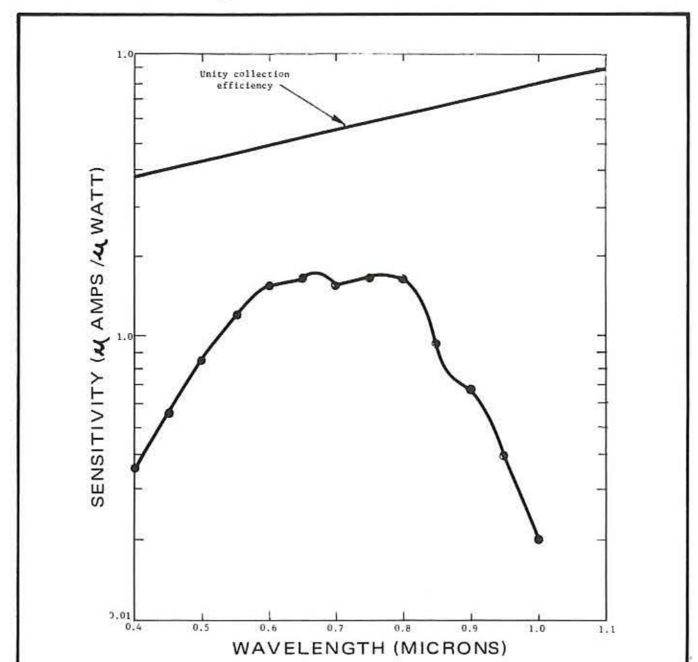


Figure 2. Spectral sensitivity

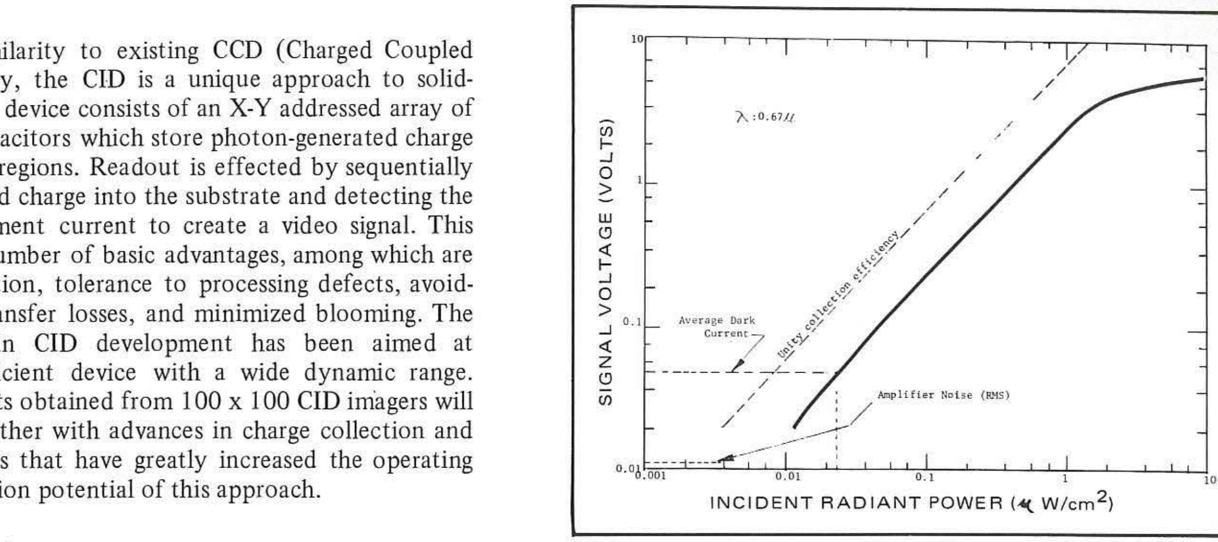


Figure 3. Transfer characteristics

The transfer characteristics are shown in *Figure 3*. Output signal voltage is a linear function of input radiant power for two orders of magnitude. Some non-linearity is caused by depletion capacitance loading on the injected charge signal, and as such, is predictable and repeatable. The important performance factors demonstrated by this data are:

Dynamic Range > 500-to-1

Peak Signal to RMS Noise > 1200-to-1

Peak Sensitivity ($\lambda = 0.67\ \mu$) 160 $\mu A/\mu W$

The dark current level noted in *Figure 3* amounts to 6 nA/cm^2 average at 25°C. Although local regions with high dark current (bright spots) have been observed in a number of imaging devices, it has been possible to obtain low, relatively uniform dark current.

Modulation Transfer Function (MTF), as measured in both the horizontal and vertical directions, is plotted in *Figure 4*. The high level of modulation can be attributed to a low level of cross-talk between sensing sites and recapture by adjacent sites during injection.

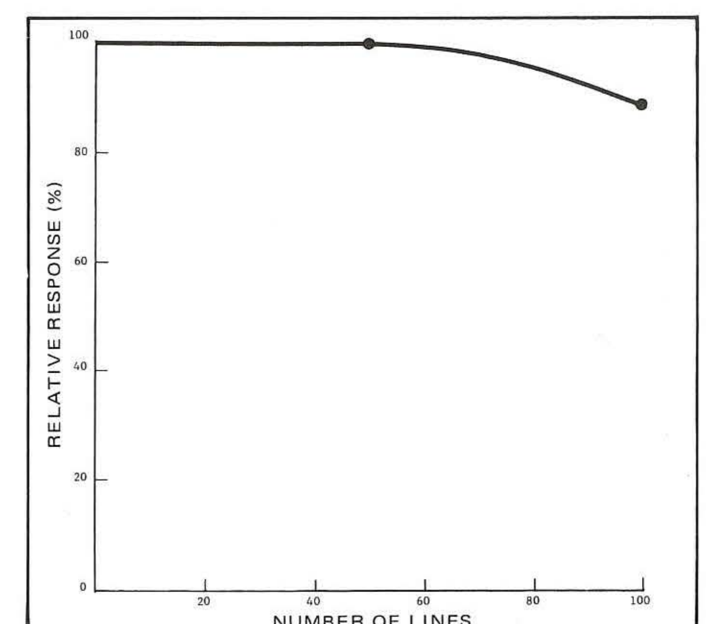
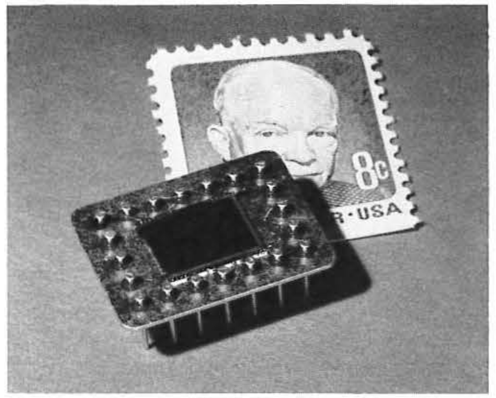


Figure 4. Horizontal and vertical amplitude response



Sensor Self Scan Flexibility – The CID array format provides a highly flexible self-address capability. The charge storage capacitor pair at each CID sensor site performs a logical "AND" function with respect to the injection of the "image charge" stored at the site. Thus, a site is addressed only when logical 1 states exist on both the row and column electrodes of the site. This means, that in principle, a CID imaging array can be addressed or scanned in any manner whatsoever.

Practical constraints are imposed by dark current and the fact that one electrical lead is required for each column and row of the array. To reduce electrical interconnects to the CID semiconductor ship, address decoding circuits are implemented "on chip" with the CID array.

For the more generally used raster scan addressing format, two shift registers are used, one register for the array rows and one for the columns. As a result, the number of interconnections required to achieve address is reduced from 201 for a 100 x 100 CID imager to 10 or less. Furthermore, frame times as short as .0167 seconds, or as long as 1 second, have been realized. Frame times can, and have been, extended further by cooling CID arrays. This is not a difficult task when the compact size and low thermal mass of the sensor is considered.

Random address can also be achieved in the CID. Using suitable binary decoding circuitry, "on chip" with the CID array, any specific array site can be addressed. Thus, the high degree of address and frame rate flexibility inherent in the CID approach will make CID imagers highly attractive in interactive systems where higher resolution is required but not in the full field.

Current Status

Present level of development allows General Electric to offer two camera systems, one utilizing a 100 x 100 CID device, and the other utilizing a 244 x 188 device.

100 x 100 Cameras are available in two basic forms. The first type provides video output in a 2:1 interlaced format, with two 50-line fields. Separate horizontal and vertical drives are provided that may be used in conjunction with X-Y displays. Horizontal line frequency and frame rate is determined by the frequency of the master clock, thus allowing operation over a range of frame rates from 1/30 sec. to one sec. The video output is in the form of a "box-car", sampled and held signal, with a p-p amplitude of 0.5 volt at a data rate corresponding to the master clock frequency. Cameras of this type, operating at a 30 hz frame rate, have been demonstrated to have a dynamic range of > 500-to-1. This camera may also be modified to provide a straight non-interlaced scan, with 100-line fields.

The second type of 100 x 100 camera provides a composite video output signal which is compatible with conventional 525-line TV monitors. This is accomplished by scanning each line of the CID imager (100 elements) in the 52 μsec alloted for the active portion of a standard TV line scan with one line scan of the CID taking place for every five line scans on the monitor (the other 4 lines are blanked). The resulting video signal is structured as follows:

- 262.5 lines-per-field
- 50 active lines-per-field equally spaced
- 525 lines-per-frame
- 100 active lines-per-frame equally spaced.

The 244 x 188 camera currently being offered will also provide a composite video output signal (2:1 interlaced) which is 525-line TV compatible. The format will consist of two 262.5 line fields, each with 122 equally spaced active lines, combined into a 525-line frame, with 244 equally spaced active video lines. The camera will feature greatly improved anti-blooming capability. □

Fred A. Sachs is the marketing manager of the Optoelectronic Systems Operation of the General Electric Company in Syracuse, NY. He previously held positions as Manager of Application Engineering for Imaging Devices, also with GE in Syracuse. Prior assignments with GE were associated with Broadcast and Closed Circuit Television Engineering, totaling fifteen years of service with GE.

John M. Hooker is the engineering manager of solid state imagers at the tube products department of the General Electric Company. He received his BSEE from Vanderbilt University in 1959 and the MS in Engineering Physics from Western Kentucky University in 1969. In his position as development engineer at GE, he was responsible for product development of new electronic devices, such as CdS photoconductors, magnetic reed switches, high density matrix-type electron lens structures, vacuum and plasma-type displays of various types with associated drive circuits. Since 1969 he has acted as the project engineer responsible for product development and production of vacuum fluorescent display devices, including drive and scan circuitry design. This product line covered complete display modules with associated decode/drive electronics. In 1972, he assumed project responsibility for the development of solid state imaging products for the Optoelectronic Systems Operation, and has held his present position since October 1973.

Charge-coupled imager for 525-line television

By R.L. RODGERS, III

The operation and performance parameters are described for a CCD image sensor having 512 x 320 elements (163,840 individual storage sites). The device is designed and fabricated for use in the standard 525-line television system. This solid-state imager is capable of performance superior to that of camera tubes with regard to signal-to-noise ratio, freedom from lag, and absence of microphonics. Additional features include its small size, light weight, low power, and precision image characteristics.

Considerable effort went into the development of a TV system that would make an acceptable picture utilizing all of the eye-brain visual perception principles. Factors such as the visual acuity of the eye and critical flicker frequency effects were considered. This effort led to the development of the U.S. Standard 525-line television system. For a solid-state image sensor to obtain its greatest market potential it should be compatible with and meet the minimum performance parameters of this standard system. Many approaches have been taken toward achieving this goal. The most promising approach thus far is a charge-coupled imager which has the potential for meeting both performance and manufacturing requirements. The production experience with silicon vidicon targets will provide a base for the manufacture of solid-state charge-coupled image sensors[1].

A 512 x 320 element CCD imager containing 163,840 individual analog storage sites has been designed and fabricated for the requirements of the standard 525-line television system. In this paper, the requirements for this system are defined and the resultant imager performance is described. Several smaller size vertical frame transfer CCD imagers were developed prior to the 512 x 320 imager[2,3,4]. These devices demonstrated that the required device performance parameters could be obtained.

IMAGE SENSOR REQUIREMENTS FOR 525-LINE TV COMPATIBILITY

The television system used for almost all broadcast and closed circuit television in the United States is the system described by the National Television System Committee (NTSC). This standard is described in EIA standards RS-170 for broadcast and RS-330 for closed circuit industrial applications. For the purpose of the following discussion, the requirements are the same.

The standard RS-170 system consists of two 262.5 line fields each 1/60 second long (1/59.939 second for color), interlaced 2:1 to form one complete frame every 1/30 second. Approximately 23% of each frame is devoted to blanking time for the display. This time is used to transfer charge from one register to another in a CCD.

Vertical Cell Count

The RS-170 vertical blanking interval is .075 ±.005 of the field interval yielding 241.5 to 244.125 (243 nominal) active display lines per field. This places a requirement of a minimum of 242 lines to be generated by the imager for *each* field. The maximum number of lines in each field is 262 to enable all of the cells for that field to be read out before the next field starts. One row of cells is required for each line in the display. The RS-170 sync pulses cause the display to interlace each field with the preceding field. This causes a display with approximately 486 active lines per frame. The same 243 line positions generated on one field may be repeated on the next field giving a 486 active line display, with the resolution of 243 lines, or a new interlaced set of 243 elements may be supplied by the sensor (each field) for a total of 486 lines of vertical resolution per frame.

Horizontal Cell Count

The RS-170 standards call for a horizontal line frequency of 15,750 lines/s (15,734 lines/s for color). The line time is therefore 63.49 microseconds. The nominal horizontal blanking interval is 17% of the horizontal line time leaving 52.7 microseconds active display time. In closed circuit applications, the horizontal video bandwidth is unlimited. In monochrome and color broadcast, the luminance bandwidth is 4.2 MHz. Filling this bandwidth requires approximately 450 cells. A composite color signal has the color information modulated on a 3.58 MHz subcarrier. Unless the video monitor or receiver uses an expensive comb filter to remove the chroma information from the luminance signal (not commercially used), the color subcarrier beats with the luminance signal causing an annoying *edge creep*. It is therefore common practice to limit the luminance video bandwidth to 3 MHz. Most present-day video tape recorders are also limited to 3 MHz video bandwidths for luminance information. This leads to a practical minimum number of cells for the 3 MHz bandwidth of 320 cells. The corresponding video data rate is 6 MHz. *Table I* summarizes the 525-line system requirements.

<u>Vertical Parameters</u>
Frame Time (1/30 Second)
2 Interlaced Fields (1/60 Second Each)
Total Number of Lines Per Field (262.5)
Vertical Blanking Interval (.075 ±.005 V)
Active Scan Lines Per Field (Nominal/243)
Required Vertical Cell Count:
242-262 Each Field (Repeated or Interlaced)
<u>Horizontal Parameters</u>
Luminance Electrical Bandwidth (4.2 MHz)
Color Receiver and VTR Practice (3 MHz Bandwidth)
Required Cell Count:
4.2 MHz (Approx. 450 Cells)
3 MHz (Approx. 320 Cells)
<u>Format Parameters</u>
Picture Aspect Ratio (4:3)

Table I Summary of 525 line television system requirements (RS-170)

Picture Format Considerations

There are several factors affecting the choice of picture format. *Table II* lists the most popular formats used in television, movie film, and still photography. Most movie film and TV formats have the 4:3 aspect ratio which is required for the standard TV system. There has been a general trend toward smaller formats through the years in all three media. This has been the result of improvements in the resolution of lenses and photosurfaces as well as the need for more compact and lightweight equipment. The most popular lenses are the "C-mount" variety. There are two basic subdivisions of C-mount lenses. These are the designs for the 16 mm format of one inch vidicons and 16 mm movie film. Any of the 16 mm vidicon lenses can however be used for the smaller formats. The 11-12 mm formats seem very attractive because of their small size and ready availability of inexpensive interchangeable lenses. Lenses for 8 mm and Super 8 mm have low MTF's in the TV line ranges of interest and the small format requires extremely small CCD cell dimensions – beyond the state of the art for fabrication and device operation considerations to achieve standard TV resolution (240 television lines per picture height). An additional drawback of very small formats is the inability to achieve selective focus special effects with normal fields of view due to the inherent very large depth of focus.

Movie Film	Format (Diag.)	Aspect Ratio
8 MM	5.46 MM	4:3
Super 8 MM	6.68 MM	4:3
16 MM	12.0 MM	4:3
35 MM	25.5 MM	4:3
Television		
2/3" Vidicon	11.0 MM	4:3
1" Vidicon	15.9 MM	4:3
1.2" Vidicon	21.2 MM	4:3
1.5" Vidicon	25.0 MM	4:3
Still Film		
110	21.2 MM	4:3
126	39.2 MM	1:1
135	43.3 MM	3:2

Table II Popular image formats

512 x 320 CCD IMAGER PERFORMANCE PARAMETERS

A 512 x 320 element CCD array has been designed and fabricated for the standard 525-line TV system as described above. It is capable of generating the full resolution requirements of broadcast color receivers and tape recorders. *Figure 1* shows the layout of this vertical frame transfer imager. The imager is composed of three sections. The lower section contains 256 x 320 cells which can be interlaced on alternate fields to generate 512 x 320 picture elements per frame[5]. In actual use, only 486 lines (243 per field) are displayed as described above. The extra elements are provided to allow variations in system blanking and timing and to avoid nonuniformities at the picture edges. The middle section contains a 256 x 320 cell storage area to provide format conversion to a sequential horizontal readout. The top section shows the 320-element readout register which shifts the video out at 6 MHz data rate. The cell size is 1.2 x 1.2 mils resulting in a 12-mm image format. The overall chip size is 500 mils x 750 mils.

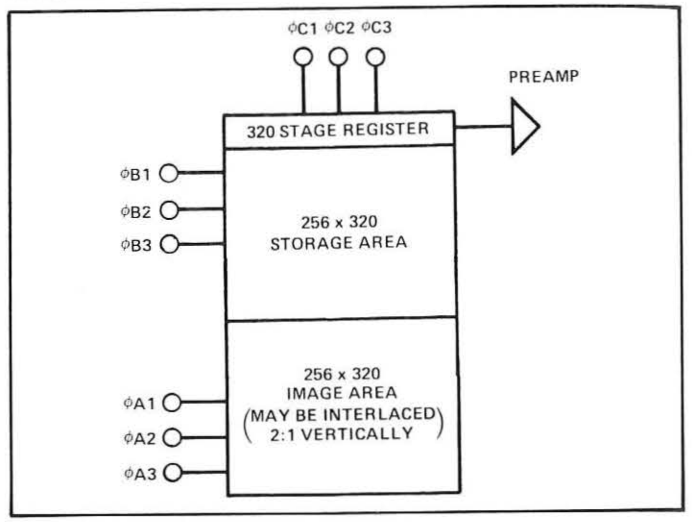


Fig. 1. 512 x 320 Element CCD Imager

Spectral Response

The spectral response of a CCD is similar to the spectral response of a silicon vidicon. The spectral response extends

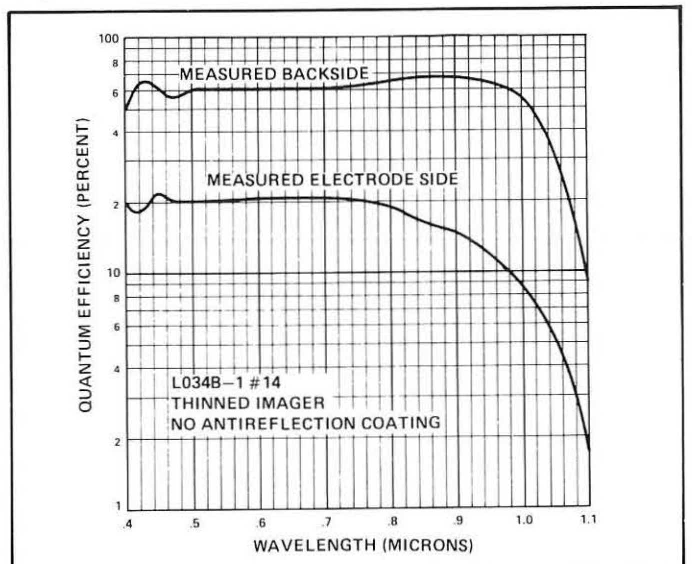


Fig. 2. CCD Imager spectral response

from a .4μm to 1.1μm. *Figure 2* shows the spectral response for a thinned area imager test device. Absorption of light in the transfer electrodes reduces the available light to the substrate when an image is formed on the electrode side. When the light is incident on the backside (side opposite transfer electrodes), the deviation in sensivity from 100% quantum efficiency is caused primarily by reflection losses and incomplete absorption in the infrared. The magnitude of light loss in electrode side imaging varies with process variations and wavelengths, and can differ somewhat from that shown in *Figure 2*, particularly in the blue end of the spectrum. The backside illumination is basically independent of electrode details.

SIT-CCD

A vertical frame-transfer CCD imager processed for backside illumination that has good blue response may be fabricated into a new type of high-sensitivity CCD imager. This device is the CCD version of the Silicon Intensifier Target (SIT) Camera Tube[6]. The SIT-CCD imager consists of a photoemissive cathode, electron-optical focusing section, and CCD imager in an evacuated envelope. The photoelectron image is injected into the silicon at high energy, forming many secondary hole-electron pairs. This current gain greatly increases the sensitivity of a CCD by raising the output signal above background signal variation limitations. Interline-transfer CCD imagers cannot use this method of low-light-level sensitivity enhancement.

Resolution

The most basic limitation on limiting resolution is the number of cells contained in the imager. In the horizontal direction, the number of cells is determined by the number of channels formed by the channel stop diffusions (320 for the 512 x 320 device). In the vertical, the number of resolution elements is determined by the number of different storage cell configurations formed by the transfer electrodes in the image area (256 actual cells electronically interlaced 2:1 to achieve 512 sample positions in the vertical direction).

Resolution is usually defined in terms of Television Lines/Picture Height (tvl/ph). In the horizontal direction, this number is 3/4 of the horizontal cell count or 240 tvl/ph due to the 4:3 aspect ratio. In the vertical direction, only 486 resolution samples are displayed out of the 512 possible, and the finite line structure in the display is often quoted as reducing the effective useful resolution to approximately 350 tvl/ph due to the *kell factor* even though actual resolution may be seen to the 486 sample limit with proper pattern phasing. In the horizontal, the video is smoothed into a continuous waveform and the finite cell (moire) effects are not as severe.

Another factor affecting picture sharpness is the reduction of MTF (sine wave response) due to resolution loss mechanisms in the image formation and readout processes. These losses are tabulated in *Table III* for a 1.2 mil cell dimension. The lens is the first contributor to the loss of resolution in image formation. The lateral diffusion of electrons in the imager before collection is the second mechanism. It is a Sech function of the optical spatial frequency and field-free diffusion length in the bulk. The numbers shown are representative of typical geometries. The third loss is the Sin X/X loss due to the finite cell sampling process. All of these effects are also present in silicon vidicons[1]. The resolution losses in the readout process are given by the equation in *Table III*. N_ϵ is the transfer loss and f_o is the frequency of one cell. This resolution loss mechanism

Image Formation Losses		
Mechanism	1/2 Cell Limit (2 Cells/TVL)	Cell Limit (1 Cell/TVL)
(1) Lens MTF	.94	.88
(2) Sin X/X Cell Sampling MTF	.90	.63 $(\frac{2}{\pi})$
(3) Lateral Diffusion MTF	.95	.90
MTF Product 1,2,3	.80	.50
Image Readout Losses		
Readout MTF = $\exp[-N\epsilon(1-\cos(2\pi f/f_o))]$		

Table III Resolution loss mechanisms

is analogous to the resolution loss of a scanning electron beam in a silicon vidicon. The overall MTF is the product of the image formation MTF and the readout MTF. The squarewave response CTF is larger than the sine-wave response MTF. The actual measured responses depend on the phasing of the light pattern with respect to the cell pattern. If the black-and-white bars are lined up with the cells in an in-phase condition, the response is greatest. If the bars are lined up with half a white bar and half a black bar contained in each cell, the response at the cell limit will be zero.

Transient Response

In the vertical frame transfer design, the picture is integrated for one field (16.66 milliseconds). The picture is then read out completely each field. There are therefore no smearing effects due to *lag* during panning except for resolution loss due to image motion during exposure as in any movie film camera. Some other types of solid-state sensors integrate for a full frame (33.3 milliseconds) and have twice the panning resolution loss because of the longer exposure time.

Dark Current

During the operation of a CCD imager, a two-dimensional charge pattern replica of the light pattern is formed inside the CCD. Thermally generated charge partially fills the potential wells and generates a background signal known as dark current. There are three basic dark-current generating mechanisms[1]. These sources are illustrated in *Figure 3*. The

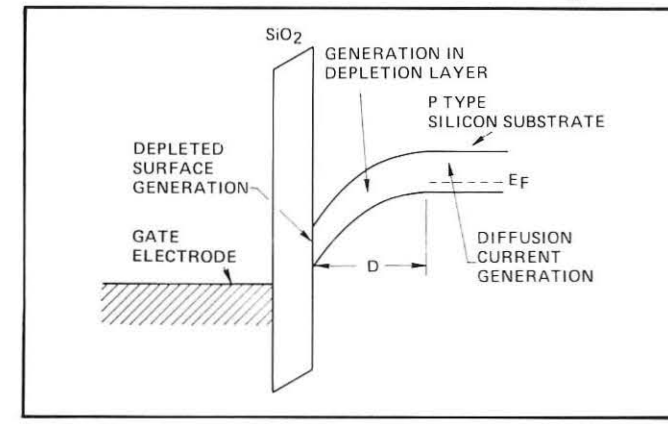


Fig. 3. Dark current sources in CCD Imagers

first source is diffusion current from the substrate. This current source can be neglected. The second source of dark current is from the depleted layer between the SiO_2 interface and the substrate. A simplified equation for this current density is $J_{Dep} = eN_iD/2\tau$ where τ is the effective lifetime and N_i is the intrinsic carrier concentration. The effective lifetime is a complex function of the actual hole and electron lifetimes and the energy level of the generation centers. If CCD's are processed to remove most of the generation centers near the center of the bandgap, this component of dark current is less than the third dark-current source.

The third dark-current source is generation current from surface states at the silicon S_iO_2 interface. A simplified equation for the surface-generation current density is $J_s = e\,N_iS/2$. S is the effective surface generation velocity and is proportional to the surface-state density N_{ss} near the middle of the bandgap. The value of N_{ss} near the center of the band may differ significantly from the density of surface states nearer the band edges which affect transfer efficiency. Actual dark current measurements have yielded dark current densities of 5 nA/cm^2. This results in a dark current of about 4 nA in the image sensing area of a 512 x 320 cell device.

The second and third dark-current sources depend on the temperature variation of N_i. This results in the standard silicon dark-current variation of a factor of 2 for every $9^o - 10^oC$ temperature change around room temperature.

Blooming

CCD's exhibit unique problems of charge containment when overloaded with light. Charge is fairly well confined from spreading sideways by the channel stop diffusions. However, excess charge can spill up and down the channel. A special mode of operation has been developed to greatly reduce the spreading of charge down the channel under overload conditions. This low-blooming mode is accomplished by maintaining the phase fingers adjacent to a charge integrating phase finger at a voltage that maintains the surface under these fingers in light accumulation. This forms a temporary extension of the channel stop around each charge integration collecting site minimizing charge spread down the channel.

On-Chip Video Processing

The charge signal in a CCD is manipulated around without touching a finite electrode until it is extracted at the output. A floating diffusion is used as a charge detector. The voltage on the floating diffusion is reset to a fixed potential once each clock period by a reset transistor. When each charge packet reaches the floating diffusion, the charge changes the voltage on the capacity at that node. This voltage is sampled by a sampling transistor operating as a source follower. These circuits are shown in *Figure 4* The very low node capacity of the floating diffusion results in a significant improvement in signal-to-noise ratio over a silicon vidicon operating at the same light level. In fact, at normal signal levels, no noise is visible in a displayed picture generated by the CCD imager.

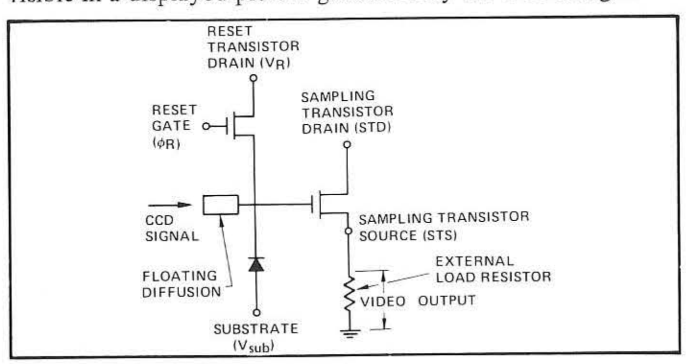


Fig. 4. On chip video processing

Fig. 5. Prototype camera described above.

Developmental Camera

A developmental black-and-white camera has been fabricated for the 512 x 320 CCD imager. *Figure 5* shows a picture

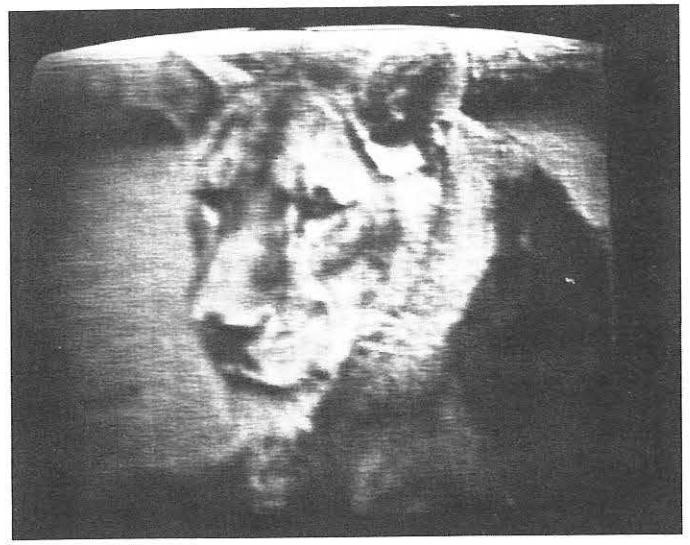


Fig. 6. Sample photo made by CCD camera.

of this camera. The camera is approximately the size of a pack of cigarettes and has a *C-mount* for lens interchangeability.

Fig. 7. Sample photo made by CCD camera.

Figure 6 and *Figure 7* show 525-line monitor pictures made by this camera with a 512 x 320 CCD imager.

(1) Spectral Response Similar to Silicon Vidicon
(2) Operable in SIT-CCD Mode
(3) 500 Nanoamp DC Maximum Signal
(4) 4 Nanoamp DC Dark Current at 25° C
(5) Compatable With Standard 525 Line TV
(6) Supplies Full Resolution of Color TV (240 TVL/PH)
(7) No Lag – Picture Erased in One Field

Notes:
3φ, N-Channel Vertical Frame Transfer
163, 840 1.2 x 1.2 Mil Cells
6 MHz Data Rate, 16.66 ms Integration
12 MM Image Format
500 x 750 Mil Chip Size

Table IV Summary of developmental 512 x 320 CCD imager performance parameters

SUMMARY AND CONCLUSIONS

A CCD imager has been developed that will offer an attractive alternative to camera tubes for many 525-line television applications. It is capable of supplying the full resolution of color TV (240 tvl/ph). The features of CCD imagers that are superior to camera tubes are signal-to-noise ratio, freedom from lag, and absence of microphonics. The small size, light weight, low-power consumption, and precision image characteristics are additional benefits. *Table IV* summarizes the performance parameters for this developmental 512 x 320 CCD imager. □

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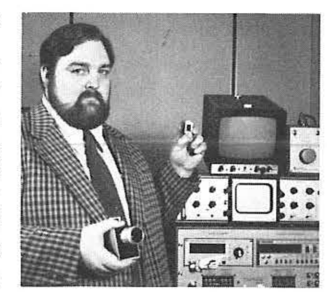
about the author



R.L. Rodgers III, Manager, CCD Manufacturing and Engineering, Electro-Optic Products, Lancaster, Pa., received his training in physics and electrical engineering at the Polytechnic Institute of Brooklyn. He has been working on electro-optic imaging devices since joining RCA Laboratories in 1964. He was instrumental in the conception and design of RCA's Silicon Vidicon and Silicon Intensifier Target (SIT) camera tubes. He transferred to the Electro-Optic Products Advanced Technology area in Lancaster in 1969 to continue work on silicon camera tubes and LLLTV cameras using these tubes, resulting in the development of a photoelectron noise limited I-SIT camera. He was responsible for the development of an effective non-blooming silicon target design and new lower cost fabrication techniques for silicon targets. Most recently he has been involved with Charge Coupled Devices (CCDs) for imaging and memory applications. He was promoted to his present position early in 1974. Mr. Rodgers has presented many technical papers and received an RCA Laboratories Achievement Award in 1968.

Editor's Note

Since this article was received, RCA has made additional progress with their CCD camera.

They have demonstrated two all solid state, tubeless black-and-white TV cameras and said they plan to make developmental samples available to the electronics industry beginning in the second quarter of 1975.

The CCD image sensor produces standard television pictures with a resolution comparable to images made from a two-thirds inch silicon vidicon tube now used in many TV applications.

The first CCD product to be introduced by RCA is a 512 x 320 element device capable of producing fully standard 525-line compatible video for use in either color or black-and-white TV cameras. RCA calls this sensor a Silicon Imaging Device, which has been dubbed "SID" for short, and will carry type number SID51232.

Two versions of the black-and-white TV camera designed around the SID have been announced and are shown in figure 1.

Of particular importance to equipment manufacturers is the fact that CCD imager can be used in conventional 525-line TV systems without the need to provide special equipment or to modify standard equipment.

The two cameras are models TC1150 and TC1155. The TC1150 has a built-in lens which is part of an automatic light control system that can quickly adapt over a wide range of scene illumination. Its focal length is adjustable from 12 mm to 38 mm. This camera is best suited for general purpose use, especially where varying light levels are encountered.

The TC1155 will accept standard "C" mount interchangeable lenses to allow flexibility. A wide selection of focal lengths is available. This camera can be tailored for a large variety of specialized applications such as industrial process control or scientific instrumentation.

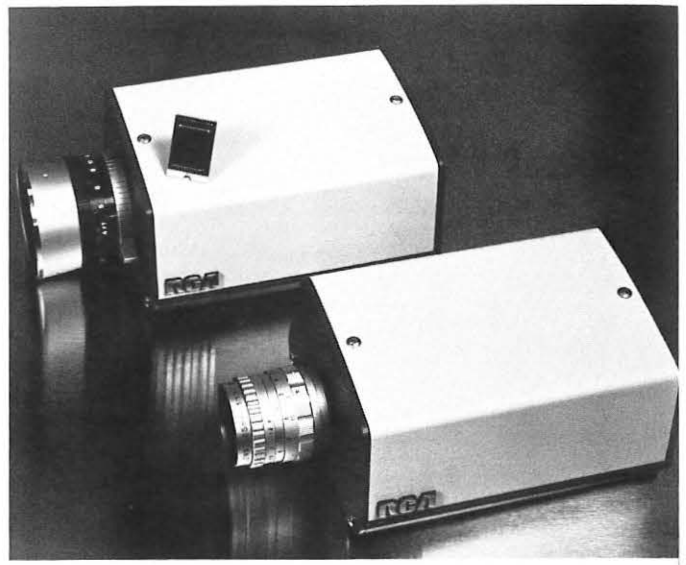


Figure 1
The RCA all solid-state black-and-white TV cameras are the TC1150 (top) and TV1155 (bottom). The TC1150 has a built-in lens which is part of a unique automatic light control system that can quickly adapt over a wide range of scene illumination. The TC1155 will accept standard "C" mount interchangeable lenses to allow for the greatest possible flexibility.

The SID51232 will be offered as a basic imager in two grades that differ with respect to some electrical parameters, but the primary difference is with regard to the stringency of blemish screening criteria. The SID51232BD, intended for the more critical applications is priced at $2,300 each. The SID51232AD for use where budgetary considerations are paramount is priced at $1,500 each.

Either the TC1150 or TC1155 may be purchased with either grade of sensor. Using the SID51232BD, the cameras are priced at $3,800 each. If the SID51232AD is chosen, the cameras are priced at $3,000 each.

Deliveries of the SID sensor and both cameras are scheduled to begin on a developmental basis in the second quarter of 1975. Commercial product announcements will be made shortly thereafter.

Development of a special custom CMOS IC which will generate complete vertical clocking waveforms is being completed for use in the TC1150 and TC1155 cameras. RCA does plan to offer this custom IC as a separate product in the future to make it easier for system designers to use the SID sensor.

How soon the volume can build and the CCD realize its low cost potential is difficult to pinpoint with great accuracy. RCA believes that it can happen reasonably quickly and an image sensor like SID should be selling in the $30 region by the early 1980's – perhaps sooner.

Additionally, RCA has also demonstrated a color TV camera using three of the 512 x 320 element CCDs. The color camera produced a RGB 525 line picture that could be transmitted by U.S. broadcast stations after NTSC encoding. However, these color pictures are not yet of broadcast quality and the cameras lack adequate sensitivity.

The all solid state color TV camera is still a few years off.

HIGH GAIN SPECULAR SCREENS

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An illustrated description and discussion of the characteristics of the surfaces of aluminum, silver, and pearl screens.

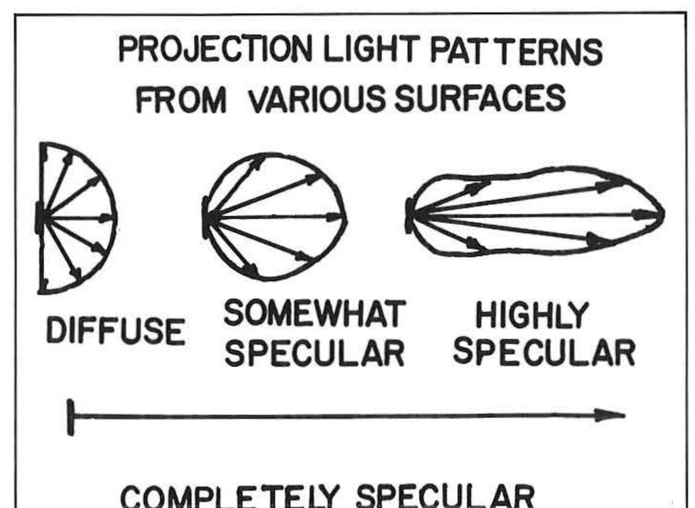


Figure 1. Typical diagrams of light reflection distributions.

High gain screens with specular surfaces may be designed to reflect light from a projector to a specific audience area. Some of the projector's light in a system utilizing matte white screen material is wasted on areas where there is no audience.[1,2]

Figure 1 illustrates the characteristics of four types of screens; diffuse, a somewhat specular or a semi-specular, a highly specular and a completely specular. The incident ray that illuminates these surfaces comes from the right in each case. The length of the arrows or vectors indicates the brightness or magnitude and direction of the reflected light. The vectors are contained in the shape of the polar outline. The diffuse surface reflects the same brightness or luminance in all directions. A completely specular surface reflects a ray in only one direction. When the incident light beam is perpendicular to a completely specular surface, the light is reflected back towards the source, as indicated by the arrow at the bottom of *Figure 1.* The other two surfaces in the figure indicate various combinations of diffusion and specularity in their surface.

Figure 2 illustrates in theory how a lenticular specular surface can control light. In theory, no light is to be reflected outside of the envelope containing the representative vectors. Note: other things being equal, the gain is higher when the subtended audience angle is narrow as indicated by the increased length of the vectors when the subtended angle is smaller.[1,2]

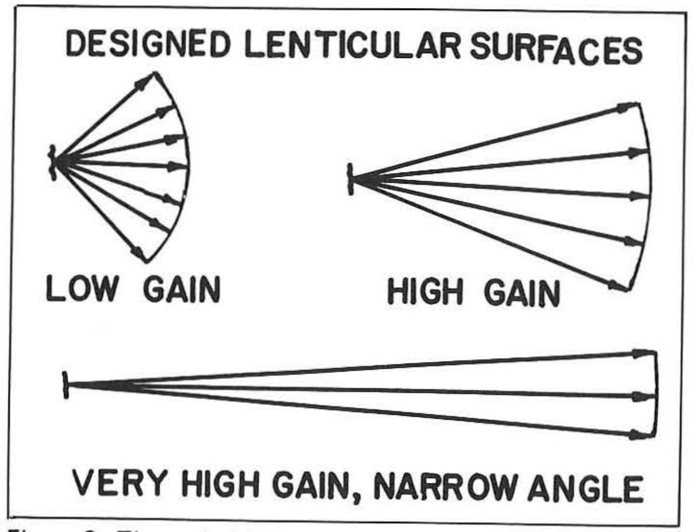


Figure 2. Theoretical light distribution patterns from designed lenticular screen elements.

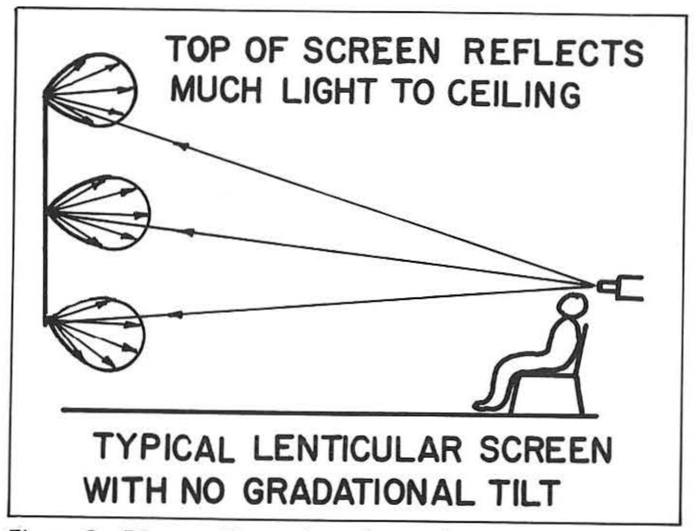


Figure 3. Diagram illustrating why semi-specular screens may be darker at the top than the rest of the screen.

Front projection aluminum, silver, or pearl screens contain some specularity and diffusion on the surface of their lenticules or elements. *Figure 3* illustrates why a semi-specular screen reflects wasted projection light to the ceiling in a typical installation with a vertical screen. This is indicated by the relative size of the light vectors reflected to the viewer aimed back at the viewer are shorter than the vectors aimed at the viewer from the bottom and center of the screen. Therefore, other things being equal, the top of the screen will be darker than the rest of the screen.

Semi-Specular Lenticular Screens

Front projection screens which do not have specially designed lenticules produce "hot spots" similar to many rear projection systems. *Figure 4* shows a diagram indicating the reason why a rear projection screen with a semi-diffusing surface has a "hot spot". The vector is longest in a light diffusion pattern that is on a line between the projector and the viewer.

Lenticular screens designed to eliminate wasted reflected light were described in a 1925 patent by Clark, No. 1535985. This is a "containment" type of screen.[3] In practice, compromises are usually made because of practical technical problems in the manufacture and installation of these screens.

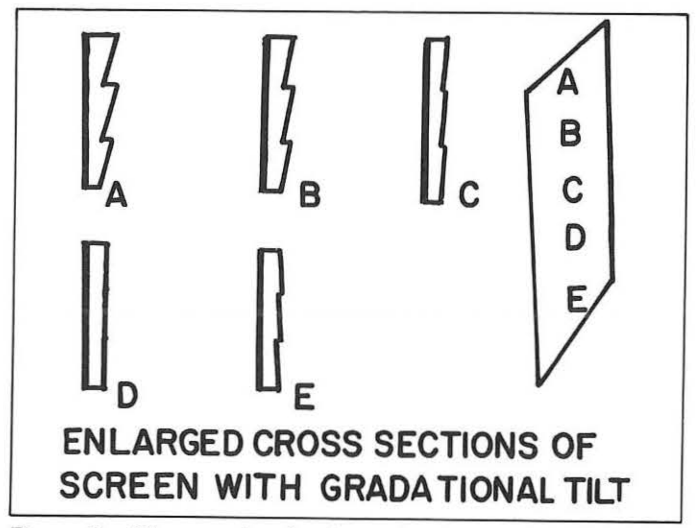


Figure 5. Diagram showing how elements may be gradually tilted from top to bottom of a screen.

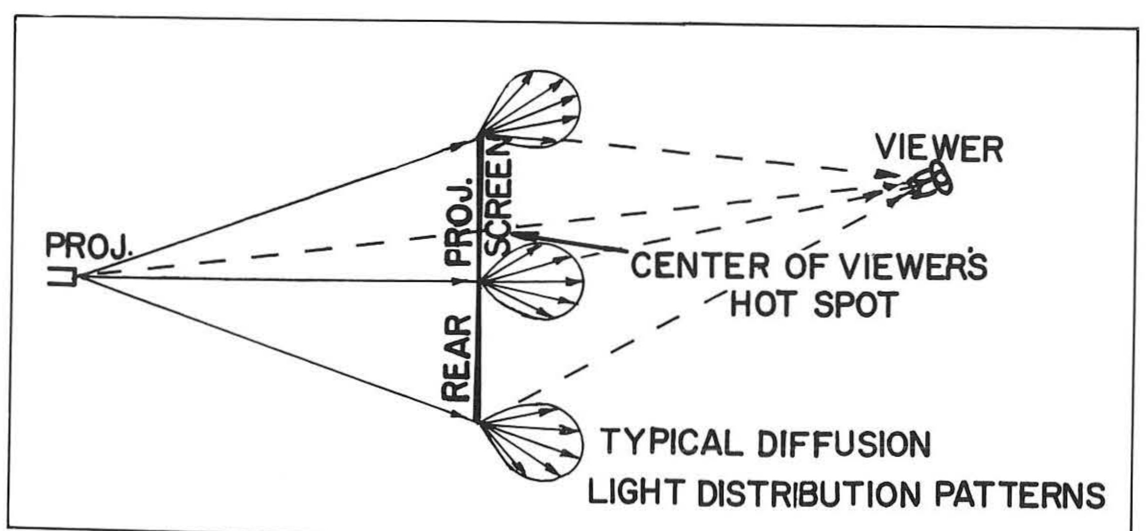


Figure 4. Rear projection diagram which illustrates why rear projection screens have "hot spots."

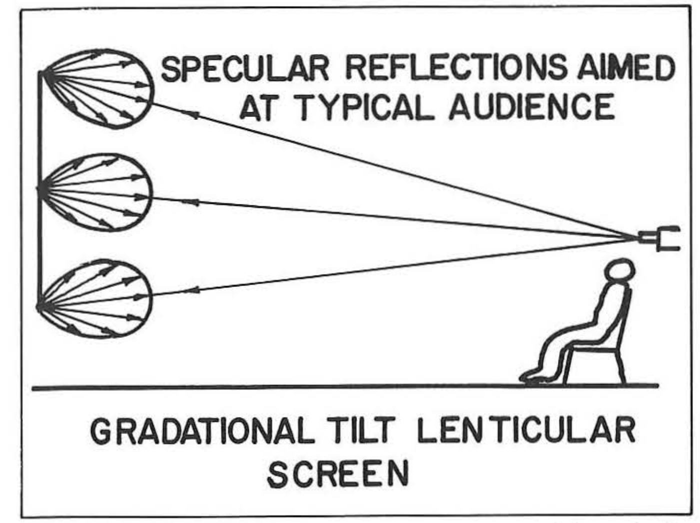


Figure 6. Diagram illustrating that a screen with gradually changing tilt of elements or lenticules can be of more uniform luminance than the typical lenticular screen illustrated in Fig. 3.

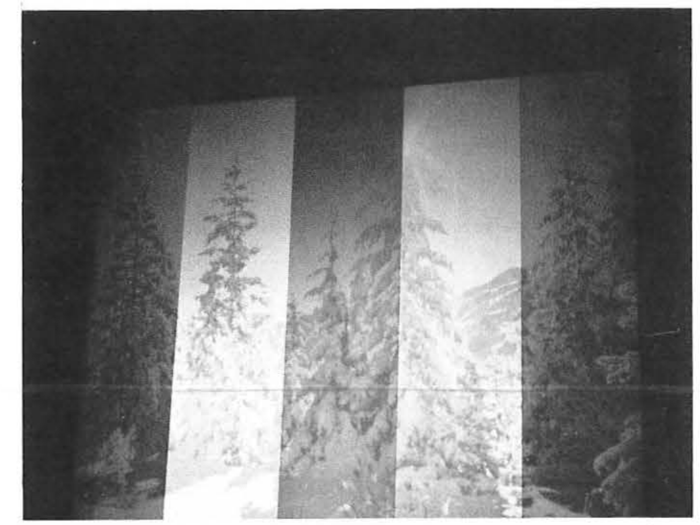


Figure 7. Photograph of a composite screen, taken 20° to right of the projector. Left panel – typical matte white brightest panels – prototype gradational tilt lenticular. Center panel – typical aluminum lenticular screen. Right panel – typical glass beaded screen.

Figure 5 indicates how lenticules can be tilted gradually from the top "A" of a screen to the bottom "F". The lenticules are so small that they cannot be resolved by the eye at normal viewing distances. *Figure 6* demonstrates that if the viewer is looking at a screen with the elements gradually tilted from top to bottom as shown in *Figure 5*, the viewer will see a screen more uniformly illuminated from top to bottom. The photograph in *Figure 7* shows a composite screen made of four different types of screen materials. The first panel on the right is a typical white screen material, the second and fourth panels are gradationally tilted screen material, the picture brightness is fairly uniform from top to bottom, the center panel is a typical commercial lenticular screen which has a loss of brightness at the top of the screen when used in a typical installation. If the pictures were in color, when the sky is blue and the luminance is low, the sky would look almost grey and dark, but when the screen luminance is high at the top of the screen, it will appear to be a bright blue. The fifth panel on the right is a oeaded screen. It will look bright from top to bottom when viewed within 10° of the projector beam from top to bottom, and the projectionist and the audience close to the projector will see a nice bright picture, but at the sides, the viewers will see only a picture equal to white. High gain specular screens should have a gain in brightness or luminance for a typical audience at least greater than white. "High" is a relative word in this paper and these semi-specular screens do not have as high a gain as the highly specular surfaces, but they are brighter than white and may be considered to be "high" gain in a manner of speaking.

Specular screens will also lose brightness uniformity when they are hung flat as shown in *Figure 8*, the viewer will see the near side of the screen brighter than the far side. This fact can be tested by locating a viewer on either side and drawing lines

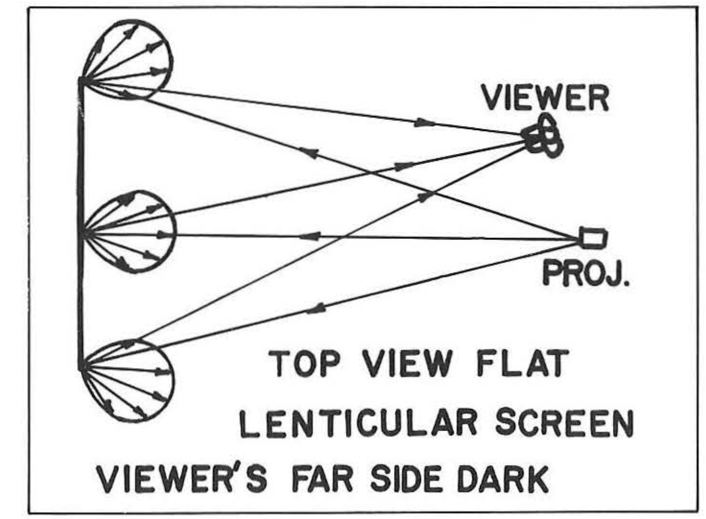


Figure 8. Diagram illustrating why the near side of a flat lenticular screen is brighter than the far side.

to the reflected light distribution vector diagrams at the sides of the screen. The vectors will be longer on the near side of the screen than they are on the far side of the screen.

The uniformity of the light could be greatly improved by manufacturing the screen with lenticules that are gradually tilted from top to bottom as indicated in *Figure 5* and also gradually tilting them from side to side. *Figure 9* indicates how concave or convex elements could be gradually tilted from side to side and from top to bottom. It should be pointed out that

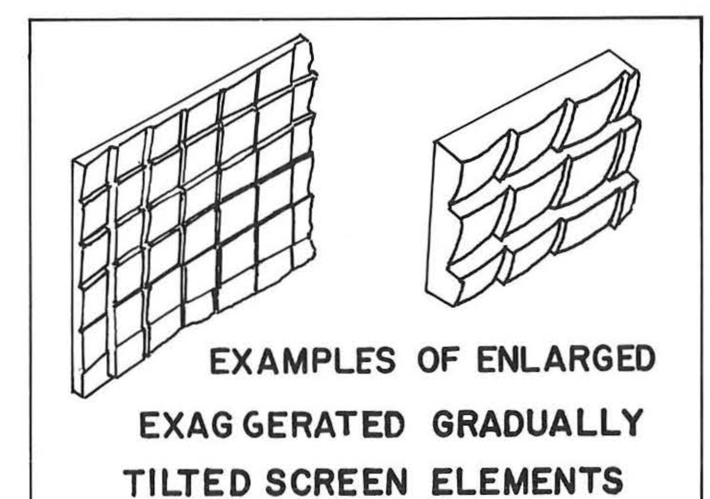


Figure 9. Drawing of enlarged screen lenticules, concave or convex, that are tilted more at the edges of a screen than they are at the center.

in theory this can be done, but in practice these elements should be so small that they cannot be resolved at normal viewing distances and that each element must be aimed at just a tiny different angle than all the other elements. The precision required is imposing and there have been failures. One approach has been to make a concave screen such as Kodak's Ektalite. This requires making a large concave screen, hard to handle and store. Another approach would be to use a screen with a gradational tilt and a curve as indicated in *Figure 10*. This can produce a more uniform screen brightness for more of the typical viewing audience, and can be rolled up for shipment.

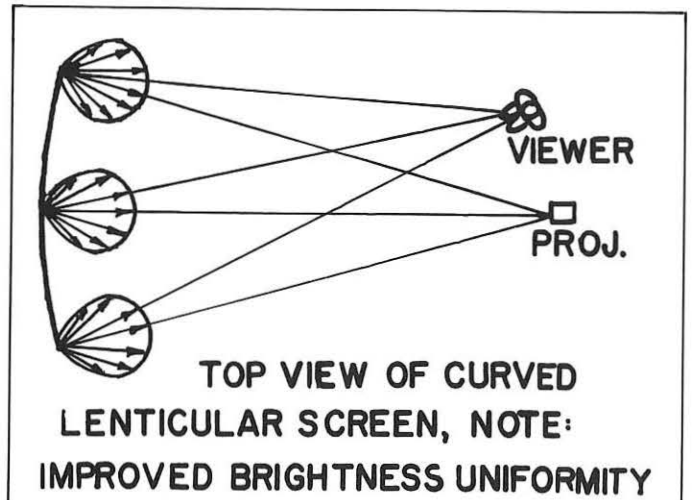


Figure 10. Diagram illustrating why a screen curved with a radius equal to the projection distance will produce a more uniform screen luminance for a typical viewer.

Highly Specular Screens

When the diffusion of the lenticular screen surface is decreased, the surface of the screen elements become more specular of shiny. The gain of the screen also increases and can approach the theoretical gain possible for a prescribed audience area.[1,2] The design of the lenticule determines the solid angle of the reflected light. *Figure 11* shows how two images can be projected onto a highly specular screen at the same time and not interfere with each other. In order to demonstrate this, a composite screen compound of three materials was made up and is shown in *Figure 12*. The darker top panel was a typical aluminum powder lenticular screen available commercially. The center is a prototype evaporated aluminum lenticular screen material with some diffusion. The bottom brighter panel is a prototype evaporated aluminum lenticular surface which is highly specular. There was white light projected on the screen for this picture.

Figure 13 is a series of three pictures taken of the *Figure 12* composite screen with two slides projected onto the screen as shown in *Figure 10*. Projector "A" projected a slide of *Figure 10* and Projector "B" projected a slide of an astronaut walking on the moon. The photograph on the left in *Figure 13*, is what the viewer would see on the composite screen when viewed from the left, a little in front of projector "B". From the left there is a slight indication of the moon picture on the two top panels, but *none* on the highly specular screen panel on the bottom. There is high ambient light on the left picture. The image is so bright that it caused some flare in the camera lens for the image on the bottom panel. The center picture was taken head-on between projectors "A" and "B". Note the double exposure effect on the top two panels. On the bottom panel, note the rejection of the astronaut picture on

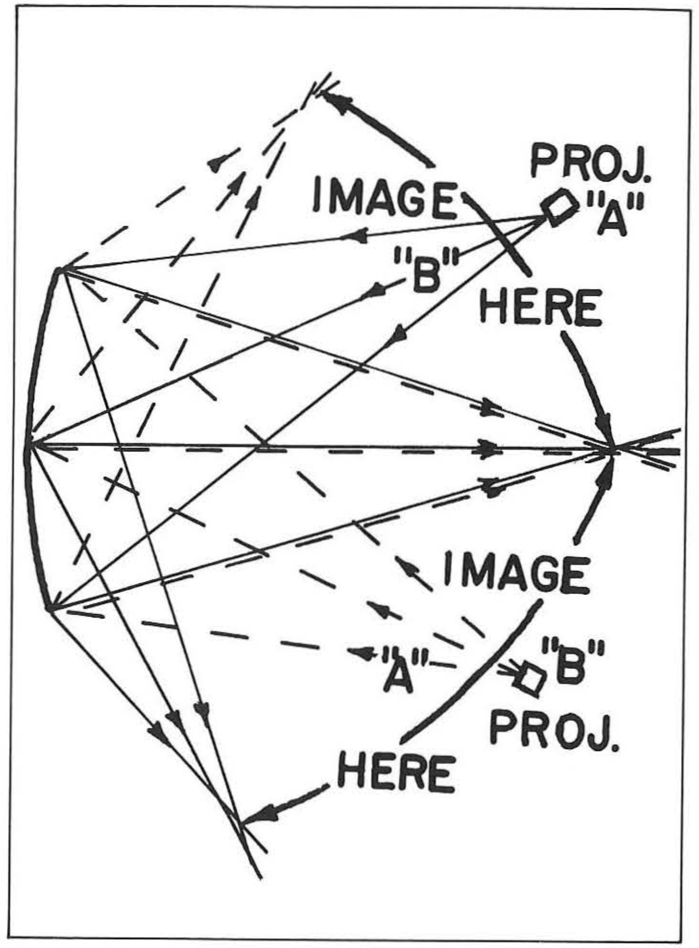


Figure 11. Diagram indicating how two images can be projected onto the same very specular lenticular screen and provide for two viewing areas that see the image from only one projector.

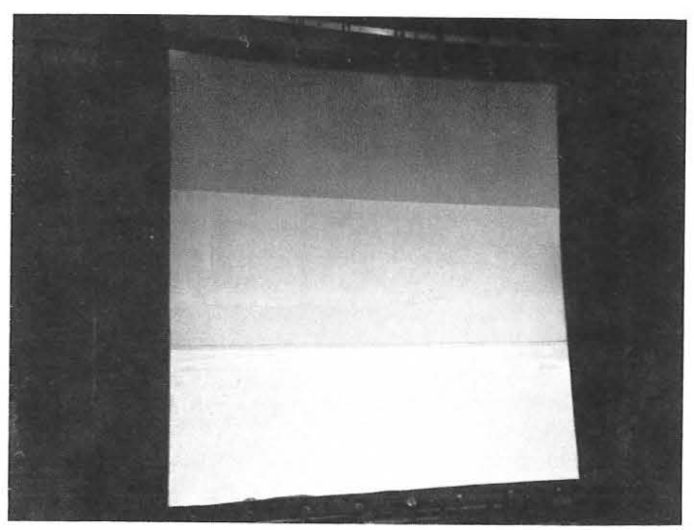
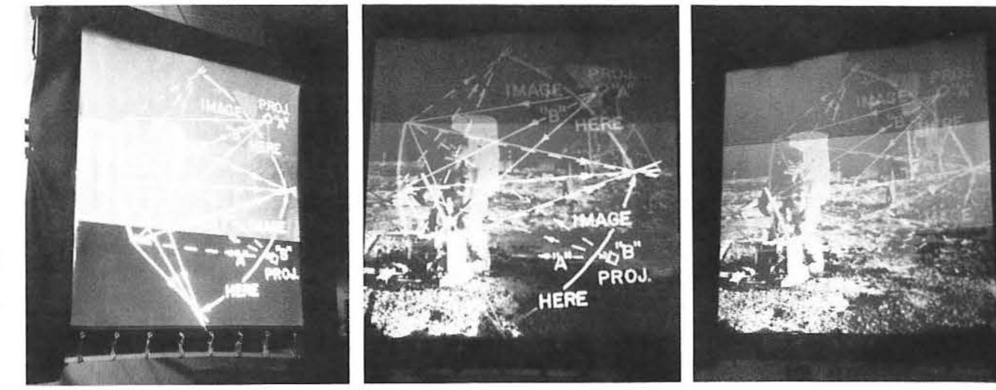


Figure 12. Photograph of the composite screen used in Fig. 11. Top panel — typical aluminum lenticular. Center panel — semi-to-highly specular prototype lenticular. Bottom panel — very specular prototype lenticular.

Figure 13. A setup shown in Fig. 10 on the composite screen shown in Fig. 12. Proj. "A" used a slide of Fig. 10. Proj. "B" used a slide of an astronaut on the moon. Left photograph is a view from in front of Proj. "A". Center photograph is a head-on view of the composite screen. Right photograph is a view from in front of Proj. "B". With the room lights on, left photograph has more ambient light and a little longer exposure than the other two photographs.



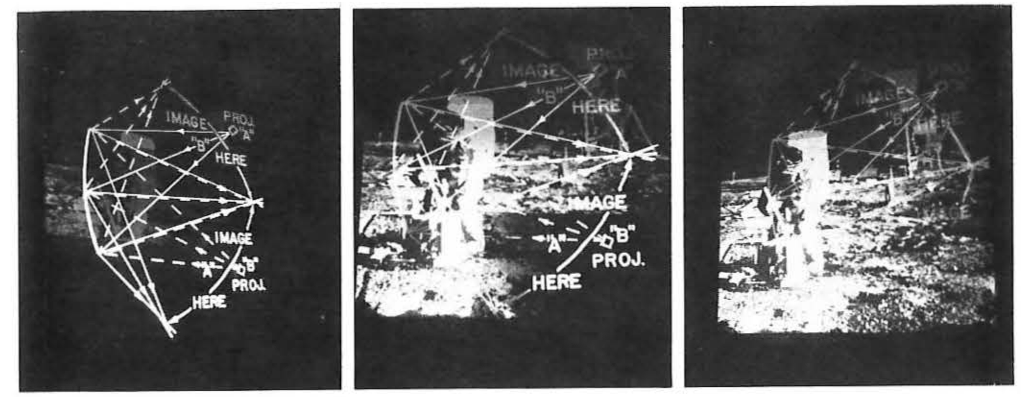


Figure 14. Same setup as in Fig. 13, but room lights off; i.e. no ambient light.

the right, and the rejection of the drawing on the left. The cutoff is sharp and the images could be said to be "contained". The picture on the right was taken from a location near project "A". There is some ambient light, approximately 5-foot candles looking back at the projector, 25-foot candles from the left and 10-foot candles looking up. Note again the double exposure effect on the top two panels and the complete rejection of the *Figure 10* slide on the very specular bottom panel.

Figure 14 shows pictures similar to *Figure 13*, but with the room lights off. Again note the double exposure effect on the top two panels, but excellent "containment" of the picture on the bottom very specular material.

On high gain prototype screen materials, one notes a scintillation or sparkle diffraction effect which may be objectionable to some observers. The scintillation may be reduced by adding diffusion at the expense of gain and the material's ability to reject ambient light. One might suggest washing out a very faint image not wanted at the sides of a "containment screen" in a dark surround by side ambient lights or by the projection of pictures that are much brighter than the main picture to be contained when viewed from outside the desired audience area.

It should be stressed that tight tolerances are required in the manufacture of screen material. Coating non-uniformity and embossing defects may be masked in poor screen material, but often even small defects are objectionable when everything else is good.

Specular screen seams must be of a butt type, because if the screen material curves or changes plane even slightly, the seam will be objectionable to many observers. In addition, when the seam is good, the material must be uniform in the degree of embossing, the amount of diffusion, the thickness, and the total reflectance of the coating in order to make an acceptable screen.

High gain specular screens present the possibility of displaying information under conditions that would not be satisfactory when using other types of screens. For example, a narrow, solid angle highly specular screen material might display several scores for different lanes in a bowling alley at the same time.

Conclusions

In practice, high gain screens always have a little diffusion and as the diffusion is increased, the gain and scintillation go down. High gain screens require high precision in manufacture and installation to produce uniform screens, but the high gain screens' ability to reject ambient light and provide a brighter, higher luminance image make them worth considering. ☐

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about the author

Yorick G. Hurd, physicist, has been plant superintendent of the Design & Roller Division, L.E. Carpenter & Co., Norwalk, CT. since 1961. Previously, he was a physicist for 12 years with Twentieth Century-Fox Films in New York, and has worked with the Navy and the aerospace industry. Mr. Hurd holds a Master of Science degree from Tufts University where he also took his bachelor's degree in 1946. He holds several patents, has published numerous articles and is a member of many professional societies.

Positional Color Coding - A Color Identification System That Combines Color And Intensity

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The design of dynamic, high resolution, display systems for command and control, surveillance, or simulation applications has progressed through the monochrome stage to provision of full color. Efficient binary storage and manipulation of picture element color and luminance numbers is necessary in display generators and refresh memories. Traditional color numbering systems are seriously deficient in their ability to perform this function. A new positional notation technique has been placed in use at Philco-Ford which not only meets the necessity, but provides new insight into the true shape of the three-primary color solid and the two-primary color diagram.

THE NEED FOR A NEW CODE

When designing dynamic, high-resolution color display systems having the capability to show a choice of hundreds of colors, it is necessary to compute the usability of a color for a given function such as, for example, false color coding, annotation, or identifying a cursor. Similarly, the display system user must be able to compute the usability of a color for his specific application. Wide use of such computations has been held back because of lack of ability to identify each color by a number which has the following properties:

1. The number should allow a display designer or user to look at the number and immediately know what color is represented.
2. The number should allow a display designer or user to immediately determine color brightness on the display.
3. The number should have mathematical properties which allow adding or subtracting of the numbers to result in new numbers which represent the true effect of adding or subtracting the actual color sources in the display.
4. The number should allow a display designer to obtain the number for the complementary color by taking the complement of the number.
5. The number should be extremely efficient with regard to number of digits or bits so as to minimize storage requirements for picture element codes.
6. The number should tie-in to physical reality in generating and using displays.

More than one system of coding numbers are now in wide use for such tasks as allowing the government to buy standard military paint, allowing scientific experiment correlation, and specifying display colors. The ones most often thought of as applicable for display designers and users are the Munsell system and the related Inter-Society Color Council-National Bureau of Standards (ISCC-NBS) system which ties to the CIE diagram. This latter system is based upon the Munsell definition of any color as a set of numbers representing "hue", "value", and "chroma". Hue is designated by a number from zero to 100 through the visible color range, where very low numbers represent reds, medium numbers represent greens, and high numbers represent blues and purples. Value is designated by a number from zero to ten representing color "lightness' where black equals zero and white equals ten. Chroma is designated by a number from zero to "fourteen plus" representing color "saturation" where zero equals gray (no apparent color) and higher numbers represent "purer" colors. The CIE chromaticity diagram results from an artificial transformation of hue, saturation, and brightness numbers into two-dimensional coordinates, some of which are negative.

It should be apparent from the definitions that a color system of the Munsell type is not well suited to the combination of needs listed as necessary to design and program the use of multicolor displays. For example, it is common to produce colors by additively mixing various amplitudes of red, green, and blue primary colors from discrete red, green, and blue image sources. A color numbering system should assist in designing and specifying components for this common situation. It is not sensible to mix the outputs from a separate "hue generator", "value generator", and "chroma generator" to produce a display such that a Munsell - type system is helpful in the design. Similarly, the related derived "chromaticity coordinates" found in color literature can be negative in sign and are not directly interpretable as relative intensity settings of real display image generators.

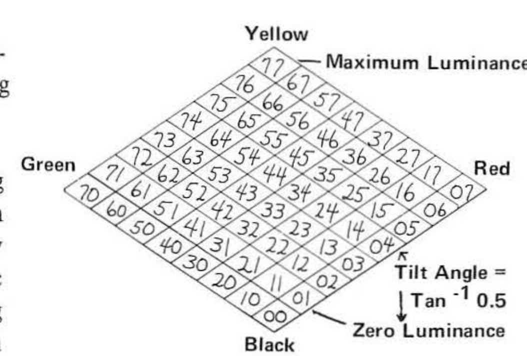


Figure 1.
A two-primary color diagram that uses three bits per primary (octal coding).

THE CONCEPT OF POSITIONAL NOTATION NUMBERS

The triumph of modern numbering systems over, for example, Roman numerals was the positional notation which allowed each digit position to have a weight and be the multiplier of a power of the base number. This property allows mathematical functions to be easily performed with "carries" or "borrows" readily handled using simple rules.

After careful study, it seems apparent that a similar concept should be applied to numbering colors. The concept explained herein is based on using one "digit number" for red, one "digit number" for green, and one "digit number" for blue.

USE OF WHITE LIGHT TO DEVELOP THE COLOR NUMBER BASE

The digital color coding must correctly indicate the performance of displays as seen by normal human eyes under various ambient light conditions as well as indicating quantitatively the visual experience achieved by additive or subtractive color mixing. If properly done, the same numbering scheme will be applicable to color filters in subtractive systems as to light generators in additive systems. One key to it all is the definition of "white" light. In the CIE system, colorimentry is performed by combining monochromatic lights of green and blue wavelengths easily obtainable as prominant lines in the spectrum of the mercury arc plus an uncritical though tightly specified red wavelength. More recent research on color rendering capabilities of white light by W.A. Thornton appears to demonstrate that a better set of three unique spectral colors to produce "pure white" when additively mixed are a blue near 450 nm, a green near 540 nm, and an orange-red near 610 nm. Other experimenters have worked to determine the ft-candle or ft-lambert contribution of various red, green, and blue primaries to match Illuminant "C", the NTSC reference white. For NTSC television receiver primaries, the brightness contribution of NTSC primaries to matching Illuminant "C" is 58.7% green plus 29.9% red plus 11.4% blue. The references cited clearly indicate the highly subjective nature of "white light". However, the ratios of luminance contribution of the three NTSC primaries for Illuminant "C" seem not only to be a law of nature for additive color, but to be an independent law of nature for digital display video synthesizer memories. The proper ratio of the amount of the most significant color (green) to the second most significant color (red) is two to one, the same ratio as represented by the weights of the binary most significant and second most significant bits storing the color codes in a digital memory.

The highly subjective nature of what is defined as white plus the NTSC ratio of green to red (58.7%/29.9% = 1.97) makes the use of a binary or octal digit system seem most appropriate for a weighted positional notation for color numbering. The minor contribution of the third most significant color (blue) to Illuminant "C" (11.4%) indicates that a weight for blue equal to one-half that of red is more than sufficient to be able to define a workable binary color numbering system.

While the weighted positional notation color number base is exactly two, the coefficient of the corresponding series can be subdivided as finely as desired to represent any color. The examples and diagrams which follow represent each color as a set of three numbers, where the most significant number represents green and carries four units weight, the second most significant number represents red and carries two units weight, and the least significant number represents blue and carries one unit weight.

PRACTICAL EXAMPLES OF THE VALUE OF THE SYSTEM

Assume that a three primary additive color mixing display system can produce up to 50 ft-lamberts of white light and that the capability exists to divide the luminance contribution of each primary into eight luminance steps having equal increments as measured directly with a human-eye-corrected spot brightness meter. In this case, it makes sense to use "octal" digit numbers for the color numbering. Obviously the number for numeric white is 777 corresponding to 50 ft-lamberts. The number for black is 000 corresponding to zero ft-lamberts.

Typical problems which might be solved are as follows.

- Q1. What color is 077 and what will the spot brightness meter read if the color brightness is measured?
- A1. Since red and blue digits are maximum, the color is a highly saturated magenta. Since:

  777 = 7(4) + 7(2) + 7(1) = decimal 49, the value of 49 decimal corresponds to 50 ft-lamberts.

For the number in question:

$077 = 7(2) + 7(1) = 21.$

$21 \times \frac{50}{49} = 21.4$ ft-lamberts meter reading

- Q2. For the same system, what is the number code for a cyan color of the same brightness as 077?

- A2. Cyan has equal digits for green and blue.

$X(4) + X(1) = 5X = 21.$

$X = 4.2.$

Therefore, with eight levels per primary, it is not possible to have a fully saturated cyan have exactly the same brightness as 077.

One can choose 404(brightness $= 20 \times \frac{50}{49} = 20.4$ ft-lamberts) or choose slightly bluer 405(brightness = 21.4 ft-lamberts).

- Q3. For the same system, what is the number code for Illuminant "C" and how bright is it?

- A3. As shown above, the ratio of blue to red in Illuminant "C" is 11.4% to 29.9%. The blue number digit can be calculated as:

$7 \times \frac{.114}{.299} = 2.67 = 3$

Therefore in this display system, a close approximation of Illuminant "C" will be produced by creating color 773. The brightness will be:

$7(4) + 7(2) + 3(1) \frac{50}{49} = 45$

$\frac{50}{49} = 45.8$ ft-lamberts

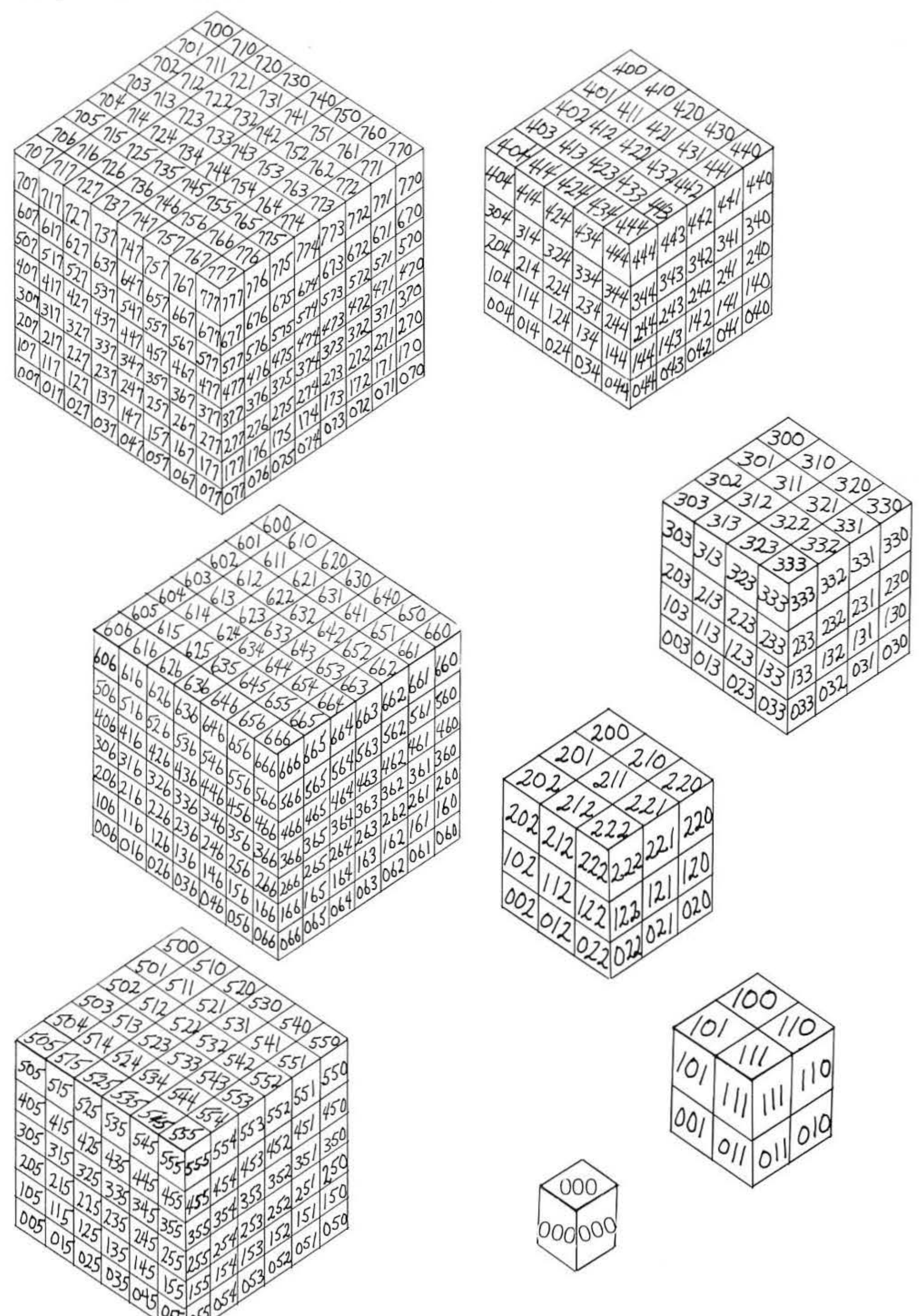
THE COLOR SOLID

A study of the color solids based on Munsell numbering shows that while one can choose to have a solid with color value numbers chosen to allow surfaces of constant luminosity to be parallel planes, the resultant Munsell color solid is in the form of a difficult to comprehend asymmetric shape.

Since the weighted positional notation concept of color numbering has such fundamental mathematical properties, it is no surprise that the corresponding color solids are regular, symmetrical, and easily learned. To evolve the three-primary binary color solid, it will be beneficial to consider first the related two-primary binary color diagram shown in Figure 1. The two primaries chosen for the example are green and red, the pair which can best be combined to provide a useful variety of different and vivid colors. Study of this figure will show that each color is accurately positioned with regard to all others with regard to color and luminance. Since there are only a discrete number of steps per primary (eight) in this example, luminance variations are also present in discrete steps with the luminance value corresponding to the position of the center of each square.

Figure 2.

A three-primary binary color solid (exploded view) using three bits per primary (octal coding).



The overall square has been tilted as shown so that the centers of squares for all colors of equal luminance are on the same horizontal line. For example, it can easily be seen from the color diagram that colors 70, 62, 54, and 46 have equal luminance. It can also be seen that complementary colors have complementary numbers.

Once the two-primary binary color diagram is shown to be a tilted square, it is seen that the three-primary binary color solid is a tilted cube having the color numbers distributed as shown in an exploded view in Figure 2. The exploded view was chosen for illustration so that the color numbers for all 512 elemental color cubes which make up the complete color solid could be shown simultaneously. As can be seen by study of this color solid, adding another available luminosity step to each primary has the effect of adding another layer of elemental cubes to the basic color solid. Because the digits chosen were octal, the exploded view shows eight such layers.

In the even simpler case of a "seven color" system having only one bit per primary, the entire color solid consists of only the bottom two layers shown in Figure 2. It can be seen that the solid in this simple case consists of eight elemental cubes with complementary colors occurring at opposite corners and that the numbers for these complementary color pairs are also complementary as follows:

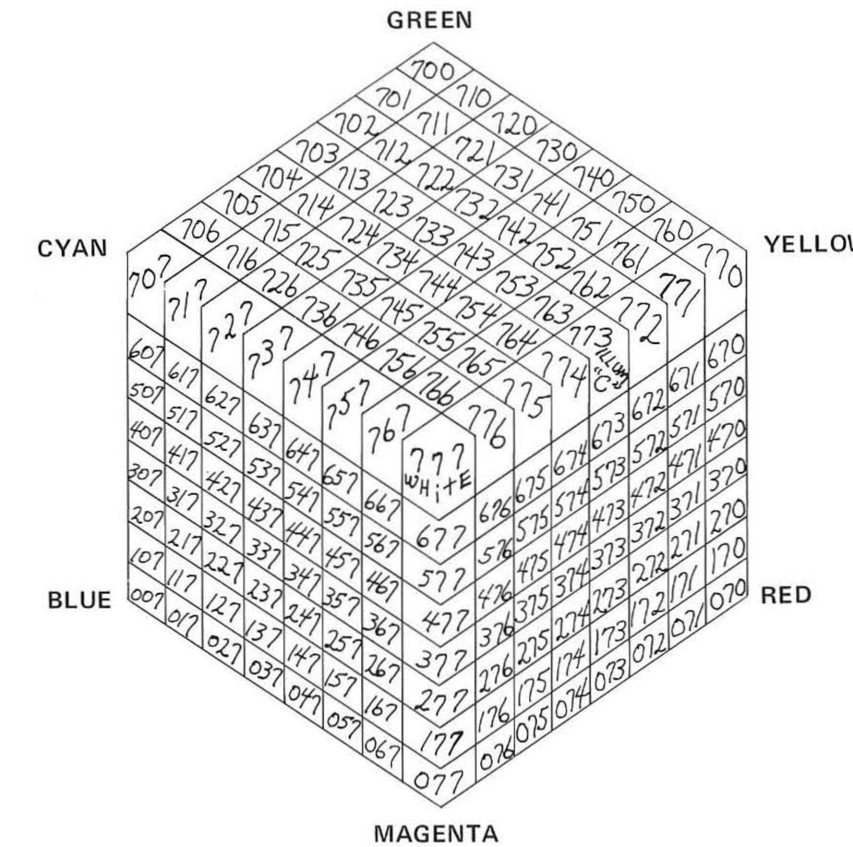
- WHITE = 111, BLACK = 000
- GREEN = 100, MAGENTA = 011
- RED = 010, CYAN = 101
- BLUE = 001, YELLOW = 110

The properties of complementary colors being opposite and intermediate colors and intensities being intermediately spaced and uniformly numbered are preserved in the color solid, no matter how complex it becomes with finer subdivisions of color steps.

It is also true that the cube can be rotated to a position such that all colors of the same luminance are in the same horizontal plane. For example if the cube is aligned such that centers of cubes representing colors 507, 347, and 603 are in the same horizontal plane, all colors of equal luminance are in horizontal planes.

Figure 3.

A two-dimensional color diagram derived from the three-primary color solid with three bits per primary (octal coded).



CREATION OF A TWO-DIMENSIONAL COLOR DIAGRAM FROM THE THREE-PRIMARY BINARY COLOR SOLID.

As has been described, it is difficult to comprehend the location of colors in the asymmetric Munsell color solid. As an attempt to help this so that color mathematics are somewhat reduced in complexity, and elaborate transformation was previously agreed upon to create a two-dimensional related representation known as the CIE diagram. This often seen diagram allows users a means to identify numbers with colors, but only with great difficulty because color boundaries are badly asymmetric and irregularly configured.

The function of visualizing the relationship of colors from their position on a two-dimensional representation of the three-dimensional color solid is of sufficient use to merit a description of how to do this for the binary color solid. It is recommended that a very fine representation be achieved by looking at the color solid cube from a point directly above the white corner when the black corner is aligned behind the white corner. This view yields a beautiful and symmetric hexagon as the color diagram as shown in Figure 3. The color zones in this diagram can be subdivided into as fine a mosaic as desired by the user. Color zones of lesser luminance representing lower layers in the cube can either be shown as accompanying diagrams of proportionately reduced size and complexity (similar to the exploded view of Figure 2) or as a mosaic of nested zones.

CONCLUSIONS

Since practical color display synthesizers can be readily constructed from the additive or subtractive primary color sources and since practical color display synthesizers cannot be readily constructed from hue, value, and chroma synthesizers, it seems sensible for display system designers to use the above described positional color coding system to understand and quantize synthesized colors. □

WORLDWIDE INFORMATION DISPLAY DEVELOPMENT PROGRESS HIGHLIGHTED AT 1975 SID INTERNATIONAL SYMPOSIUM

The growing international activity in display technology was again underscored at the annual SID Symposium, with significant development/design reports presented this year by more than 100 authorities from here and abroad – Germany, Finland, Norway, Switzerland, France, England and Japan.

During sessions which attracted over 1000 people, speakers discussed projection displays, digital image generation and image processing, electrochromic and gas discharge devices, matrix addressing and multiplexing, plasma displays and computer graphic systems and applications. An invited paper session featured four major addresses on the present and future of video communications, the capacitive-sensing video display system – the first comprehensive disclosure of this development, dithervision – a new display technique, and perceived information content of displayed information.

During four evening-discussion periods, more than 20 global experts assessed electroluminescent layers and displays and microprocessor/memory technology, now being widely researched for an assortment of applications. Also on the agenda was an appraisal of the potentials of displays for physicians.

At the luncheon, a sparkling illustrated talk on Information Display and the Radical Revitalization of Society, was delivered by T.H. Nelson, author of Computer Lib, and currently at the University of Chicago.

The popular seminar tutorials, introduced at SID during the 1972 meeting, were held again, with cosponsorship this year by SID and the Electrical Engineering Department of the University of Maryland. Eight 1-1/2-hour in-depth lectures covered such topical areas as liquid crystal technology, ac and dc plasma displays, holography and information display, display technology and applications in Japan; also digital image processing, interactive computer graphics, colorimetry and its application to color TV and visual display system human factors.

Author interviews, another SID first, affording face-to-face chats with supporting operational models, were also timetabled, following the day sessions. And as in the past, the get togethers were extremely well attended.

SID honors/awards ceremony during opening session. Top, fellow awards presentations by P. Damon (center) to W.E. Good, L.M. Biberman and H.G. Slottow, left to right, respectively. Bottom, special recognition awards – left to right – to D.A. Shurtleff, O.H. Schade, Jr. (representing his father), P. Damon, J.E. Bryden, P. Seats and G.H. Heilmeier.

THE SID board of directors meeting held in Washington, DC, during the SID 75 symposium. Above, left to right: B.J. Lechner, secretary; J. Markin, symposium chairman; B. Kazan, Proceedings editor; S. Mito and T. Inoguchi, representing the recently-formed SID chapter in Japan and G. Miyazaki, advisor for Japanese speakers. At head of the conference table, R.C. Klein, president of SID. Below, left to right: I. Chang, representing Mid-Atlantic chapter; R.C. Thoman, director/Western region; T.V. Curran, publications committee chairman; A.D. Hughes, director/Northeastern region; P. Damon, honors and awards chairman, and P. Dupuis, treasurer.

Harold B. Law, receiving the Francis Rice Darne Memorial Award, for his contributions to the development of the color picture tube which resulted in practical color TV.

Certificate of Appreciation being presented to T.V. Curran, right, by R.C. Klein, SID president, for his services as secretary.

During a formal opening, outstanding scientists were cited by the society for their pioneering information display developments and five authors and co-authors of papers presented last year, were also honored for their efforts.

The Francis Rice Darne Memorial Award was presented to Harold B. Law, RCA Corporation, for his outstanding contributions to color picture tube development resulting in practical color TV. For technical leadership and contributions to the literature on sensors and the perception of displayed information, Lucien M. Biberman, Institute for Defense Analyses, was named a Fellow of the Society. William E. Good, General Electric Co., was also cited as a Society Fellow for pioneering efforts in color TV receivers and standards, and his prime contributions to a practical and efficient light valve for projection color TV. For outstanding contributions to plasma display technology and the Society, H. Gene Slottow, University of Illinois, was honored too, and named a Fellow of the Society.

Special recognition Society awards were also presented to five: George H. Heilmeier, Department of Defense, Advance Research Project Agency; Joseph E. Bryden, Ratheon Company; Otto H. Schade, Sr., RCA Corporation; Peter Seats, Thomas Electronics and Donald A. Shurtleff, MITRE Corp.

Tung H. Jeong, Lake Forest College, and Hal Snyder, University of Chicago, received symposium best-paper plaques for their 1974 talk on The Integration of Motion Pictures Into Holograms.

Citations for outstanding 74 papers were also presented to Paul Tenczar, University of Illinois, and Robert G. Carlson and E. Timothy Fitzgibbons, Rockwell International Corporation.

Another highlight event at SID 75 was the annual exhibition, featuring operational systems, components and accessories, valued at over $10-million. On view were such new developments as four-color direct writing picture displays programmed by computers, large-screen color-TV projection, dimensional color displays and infrared cameras.

Distributed, too, at the meeting was the DIGEST of TECHNICAL PAPERS with 800-1000 word illustrated condensations of all talks – invited and contributed – plus day-evening session overview editorials. Additional copies are now available through the SID office, 654 N. Sepulveda Boulevard, Los Angeles, CA 90049, at $15.00 for members and $20.00 for nonmembers.

The executive committee of the 75 meeting included Joseph Markin, Zenith, general chairman; Robert Glusick, General Electric, secretary; Vernon Fowler, GTE Labs, program chairman, and John van Raalte, RCA Labs, secretary; also John B. Flannery, Xerox, treasurer; John L. Simonds, Eastman Kodak, awards; Roger L. Johnson, University of Illinois, special events; Reinhard Ennulat, ECOM, local arrangements. Others were Rudi Engelbrecht, RCA/Zurich, overseas advisor for Europe; Sanai Mito, Sharp Corp., overseas advisor for Japan; Leonard S. Taylor, University of Maryland, seminar coordinator; Bernard J. Lechner, SID liaison, and Lewis Winner, consultant for the sessions and exhibition.

T.J. Jeong (right) Lake Forest College and H. Snyder, University of Chicago, with their awards for the best paper presented at SID 74 on the Integration of motion pictures into holograms.

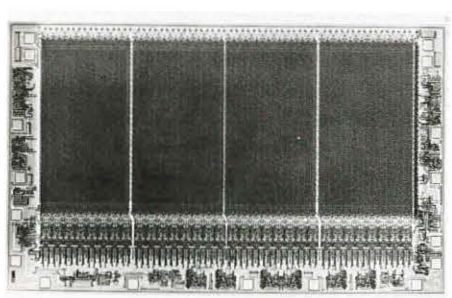
NEW PRODUCTS

16-KILOBIT CCD MEMORY

A 16-kilobit CCD memory circuit manufactured as a standard commercial product has been introduced by Intel Corporation.

The Intel 2416 CCD serial memory is a single silicon chip in a standard 18-pin package less than an inch long. The chip is an array of 64 shift registers, each 256 bits long, and I/O (input/output) control logic similar to a RAM. This configuration gives the CCD the high operating speed and data storage versatility of an assembly of small registers while providing a total data storage capacity of 16,384 bits per package.

The 16-kilobit capacity allows bulk memories with a system storage density of at least a megabit (1,048,576 bits) per circuit card to be built into equipment at low cost. Such systems will also improve overall operating efficiency of the equipment, since they can operate at many times the speed of rotating peripheral memories.



One such system, built by Intel to demonstrate the CCD, operates at a maximum access time less than 200 microseconds and reads or writes data at rates greater than 64 megabits per second. This speed would be sufficient to keep the fastest computer I/O channel completely occupied during a "program swapping" operation, for example.

The CCD chip is fabricated with basically the same silicon-gate n-channel MOS (metal-oxide-silicon) technology that Intel has used to produce n-channel MOS products since 1972.

The Intel 2416 is available from stock in two packages: 18-pin plastic DIP (dual in-line package) and 22-pin ceramic packages. The package options allow system manufacturers to test and assemble the CCDs with existing equipment designed to handle standard IC dual in-line packages.

Intel Corporation
3065 Bowers Ave.
Santa Clara, CA 95051

Circle Readers Service Card No. 101

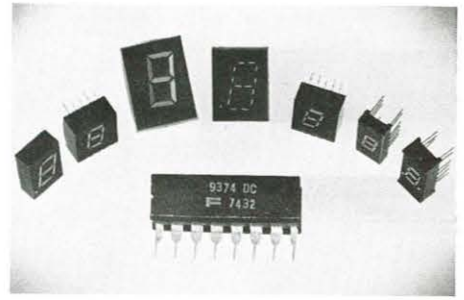
DECODER DRIVES 7-SEGMENT LED DISPLAYS DIRECTLY

Fairchild Camera & Instrument Corporation has added a new 7-segment LED Decoder/Driver to its 9300 TTL family.

The 9374 is a BCD to 7-segment decoder with constant current-sink outputs. The decoder features low-power latched inputs which can be driven easily from all TTL, and most MOS and CMOS devices. The 15 mA constant-current outputs drive common anode LED displays directly without need for external resistors.

The input latch and low input load currents permit simplified multiplexed display systems. The 9374 can take multiplexed BCD data directly from complex MOS or CMOS devices like calculator, DVM, or panel meter chips, and convert it to static 7-segment LED drive current. Since the low-power inputs represent zero load to the line when the latch is disabled, many 9374s can be driven from one MOS or CMOS device by strobing (enabling) one digit at a time.

The constant-current output feature allows the LED anode supply voltage to be varied between 2.5 and 10 volts without affecting display brightness. This feature permits a number of power and cost-saving applications. By using a separate LED anode supply voltage of 2.5 volts, the total display power can be cut in half. Also, because the 9374 outputs



will maintain a constant current with varying output voltages, unregulated full-wave or half-wave rectified LED anode supplies can be used.

The 9374 is available now in either a ceramic or plastic DIP package.

Digital Products Division
Fairchild Camera & Instrument Corp.
464 Ellis Street
Mountain View, CA 94042

Circle Readers Service Card No. 102

ECONOMY GRAPHICS TERMINALS

Tektronix, Inc., has announced two new economy computer graphics terminal models. They are the E4010, and E4010-1 or hard copy compatible version.

The E4010 is priced at $3,795 which is $400 less than the present 4010 terminal. The E4010-1 is priced at $3,995, $700 less than the present 4010-1.

The E4010 models have all features of the popular 4010's except thumbwheels to control the cross-hair cursor. Graphic input is through the keyboard.

The E4010 and E4010-1 have 11-inch flicker free storage tubes, 63 character ASCII set (Upper case), and 1024 x 1024 addressable points.

All Tektronix interfaces, options and peripherals (with the exception of 4952 Joystick) will be compatible with the terminals. This includes peripherals such as 4953 and 4954 Graphics Tablets, 4921 and 4922 Disc Memory Units, and 4631 Hard Copy Unit.

In addition, Tektronix software will be compatible with the E4010 and E4010-1 with one modification. The command to turn on the cross-hair cursor must be disabled.

Tektronix, Inc.
Box 500
Beaverton, OR 97005

Circle Readers Service Card No. 103

LOW-COST MICROPROCESSOR

National Semiconductor Corp. has entered the market for low-cost microprocessors with a four-bit machine that it calls "FIPS" for Four-bit Integrated Processor System.

The FIPS machine, designed as a pin-for-pin replacement for an Intel microprocessor, features a CPU that sells for less than $10 (100 quantity). National claims power dissipation in typically 20 percent lower than that of the Intel microprocessor.

The "FIPS" chip set consists of a four-bit central processing unit (model INS4004), a 256 x 8-bit mask-programmed read-only memory combined with a four-bit input-output port (model INS4001), a 320-bit random-access memory with a four-bit output port (model INS4002), and a 10-bit serial-in parallel-out shift register (model INS4003).

An eight-bit address latch memory interface (model INS4008), and eight-bit instruction and input-output transfer device (model INS4009), are included in the chip set. Together they permit the use of the standard MM1702AQ 2,048-bit erasable PROM (programmable read-only memory).

The CPU contains all of the control logic needed to request, decode, and execute the program instructions stored in the main memory. (The main memory consists of INS4001 read-only memories.)

The CPU consists of a four-bit arithmetic logic unit, sixteen four-bit index registers, a 12-bit program counter with a three-level stack, and miscellaneous control logic. Communication with the other chips in the system is accomplished over a time-multiplexed four-bit data bus.

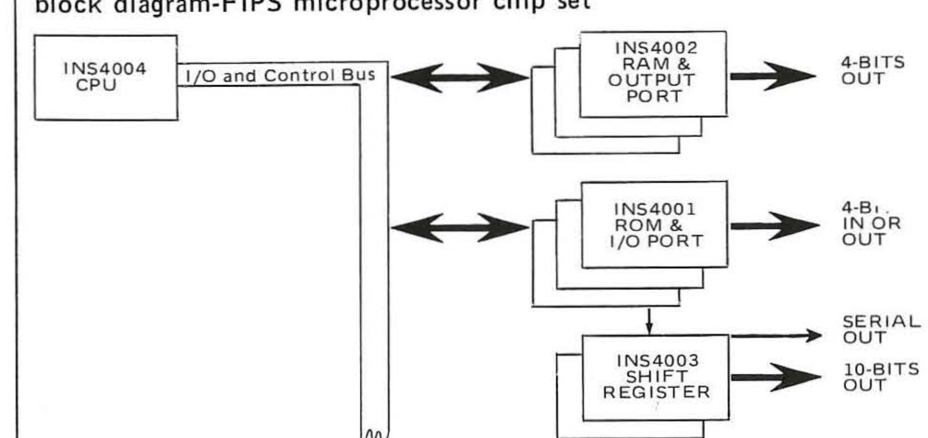
In operation, the CPU sends a sync pulse to the systems read-only memories and random-access memories to select the next instruction to be executed. The pulse is followed by 12 bits of address data during the subsequent three clock cycles.

The selected ROM sends back eight bits of instruction during the following two clock times, and this information is stored in registers within the CPU. During the subsequent three clock times, the CPU executes the instruction.

The INS4001 ROMs, which store the CPU's instructions, are arranged in banks of sixteen. Switching between banks is done under control of the program, with the CPU selectively enabling the appropriate bank of ROMs to fetch an instruction.

The CPU provides a "conditional jump" instruction which is used to test an external input pin. A reset signal can be given to the CPU to clear all registers and flip-flops. After the reset signal has been received, the program will start from step "0", executing program instructions. A total of 45 program instructions are provided by the CPU.

block diagram-FIPS microprocessor chip set



National Semiconductor Corp.
2900 Semiconductor Drive
Santa Clara, CA 95051

Circle Readers Service Card No. 104

LED RECEPTOR EXPANDS TESTING CAPABILITY

Photo Research Division of Kollmorgen Corporation announced the introduction of its new Light Emitting Diode (LED) Receptor accessory for use with its line of Spectra® Photometers and Radiometers. This device will enable users to expand the light measuring capabilities of the company's 1980 Pritchard®, Spot-Meter and SpectraSpot™ models to include the measurement of axial luminous (or radiant) intensity of LED's. The

12-inch long tube mounts on the front of the photometer's objective lens. After an LED is inserted in the entrance port on the end of the tube, the photometer will measure LED output in intensity units (candelas, millicandelas or watts/steradian, depending on calibration).

A stock item, the new LED receptor sells for $250 and includes a single-wavelength calibration.

For the direct measurement of luminance of LED's, optional "macro" lenses are available from the company.

Photo Research Corp.
3000 North Hollywood Way,
Burbank, CA 91505

Circle Readers Service Card No. 105

CRT DISPLAY WITH STORAGE, VARIABLE PERSISTENCE

A new high-resolution CRT display, Model 1335A from Hewlett-Packard, has both variable-peristence and storage capability, and it is remotely programmable. Aimed mainly at instrumentation and medical OEM users, the 1335A is UL listed for use in medical and dental patient care systems. The display is offered with a long list of factory options to tailor it to particular uses.

The 8 x 10 cm display fills much of the front panel of the half-rack-width instrument, which is 5-1/4 inches high. It is adaptable to form full rack-width horizontal, or vertically-stacked OEM instruments when combined with matching empty modules, also offered.

Resolution in conventional mode is approximately 100 lines per inch (40 lines per cm); the spot size is relatively independent of intensity setting, so drive levels need not be tightly controlled and intensified parts of the display stay focussed.

Persistence is continuously variable from about 0.2 second to full storage; signals with slow refresh rates thus can be shown without flicker by matching persistence to rep rate. In storage mode, dots as brief as 1 μs can be displayed against a completely dark background for 30 minutes. For shorter periods and at reduced trace-to-background ratio, 0.05 μs events can be stored. Stored resolution is over 50 lines per inch (20 lines per cm) and stored traces retain sharp details.

ERASE, STORE, WRITE, VARIABLE PERSISTENCE, and CONVENTIONAL operating modes may be remoted, the front panel knobs disabled. A single control line is needed for each function, including disable.

Identical 5-MHz X and Y amplifiers have 70 ns risetime. Differential inputs are optional. The time required for any size movement on the CRT, including response time for the amplifiers to settle within one spot-diameter of final position, is under 300 ns. Thus thousands of vectors and characters can be written on the display without flicker or annoying distortions.

Factory-installed options, checked out with the instrument before shipment, include: 1) for the X-Y amplifiers, deflection factor (sensitivity), polarity, and input impedance, 2) for the Z-axis amplifier blanking range, polarity, input impedance, gain, gamma correction, and digital input, 3) for the CRT graticule, contrast filter, and 4) for the package, controls, covers, line voltage, line tolerance, and special ac cords.

Hewlett-Packard Company
1501 Page Mill Rd.
Palo Alto, CA 94304

Circle Readers Service Card No. 106

PROGRAMMABLE LED TESTER

VIM Model 2000 LED test system performs comprehensive parametric electrical and optical tests of discrete, 7 segment, and alphanumeric displays automatically under programmable control without computer assistance, software, or peripherals.

Designed for low-cost, high speed production testing, engineering analysis, and end-user receiving, this compact bench-type tester provides accurate testing in any ambiant light. It interfaces with any automatic wafer probe machine or device handler.

Preprogrammed memory (Erasable PROM) simplifies repetitive testing. Memory accommodates test programs for two displays with different parameters (standard), nine displays (optional).

The system tests segment and intersegment continuity, and up to ten current levels ranging from ten microamperes to 100 milliamperes (1 microampere to 1 ampere optional) at a 10 volt compliance for forward voltage, reverse voltage breakdown, brightness, and intersegment uniformity comparison of brightness within programmed range. Test program also allows for visual comparison by operator.

Each V_F test requires 300 microseconds, so a complete 7 segment and decimal test requires only 2.4 milliseconds. A complete test, including brightness and categorizing, of 7 segment and decimal display is performed in less than 100 milliseconds.

To change test parameters or update, a key-locked auxiliary memory can be programmed via control panel thumbwheel switches. Console digital display allows testing of inputs.

Console displays "Pass-Fail", individual category accumulation for statistical analysis, device-type under test, and test number. Display also serves as digital voltmeter.

In semi-automatic data logging mode, system stops after brightness and uniformity test, allowing visual evaluation and manual recording of test data. In automatic data logging with optional printer, special interface, or handler, test data for each device or wafer is stored in memory until called for print-out. An inking sub-system, compatible with various data logging systems, is available to categorize wafer die.

Photometric brightness is measured by ultrastable photodiode and CIE correction glass filter matched to CIE luminosity response at better than 2% point by point from 630 to 680 nanometers. Force and sensing adjust for line drop in voltage.

Self-diagnostics are performed on all functional operations as the wafer probe steps from one die to the next. Self-diagnostics test accuracy of programmed constant current source levels for all ranges, accuracy of voltage measurement, and accuracy of brightness amplifier output against calibrated LED. Alarm light and coded diagnosis are displayed on the console.

Versatile Integrated Modules
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ELECTRO-OPTICS HANDBOOK

The second edition of RCA's Electro-Optics Handbook is now available from RCA distributors, technical bookstores, or directly from RCA Electronic Components.

This carefully edited, 256-page Second Edition provides general extensive reference material with dozens of tables, charts and graphs on the rapidly expanding field of electro-optics. The RCA ELECTRO-OPTICS HANDBOOK, EOH-11, has an optional list price of $4.95 each.

The index of over 500 items is a valuable time-saving adjunct to finding information contained in the 13 seconds of the EOH-11: 1)-Radiometric Quantities and Units 2)-Photometric Quantities, Units and Standards 3)-Physical Constants, Angle Conversion Factors and Commonly Used Units 4)-Blackbody Radiation 5)-Eye Response and Luminous Efficacy 6)-Sources of Radiation 7)-Atmospheric Transmittance 8)-Detection, Resolution and Recognition 9)-Lasers 10)-Detector Characteristics 11)-Image and Camera Tubes 12)-Optics 13)-Photographing E-O Displays. Direct orders should be mailed to RCA Commercial Engr., Harrison, NJ 07029

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