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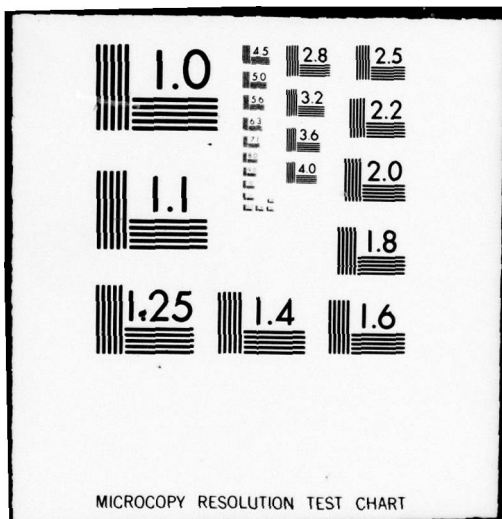
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CONTRAST ENHANCEMENT METHODS FOR VIDEO SYSTEMS

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June 1, 1979

Final Technical Report
For Period 30 May 1978 - 30 May 1979

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Methods have been studied of improving the display contrast of targets observed by TV search and tracking systems. Typical camera components can be improved upon several fold by spectral selection, lens selection, and optimum exposure of high resolution vidicons. Stationary noise can be reduced by pixel sensitivity equalization (PSE) and dynamic noise can be reduced by multiframe (Abstract continued)		

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averaging. Local area gain and brightness control (LAGBC) can be applied to raise the differential contrast of small, target-sized areas after reducing the total scene contrast. Schemes for rendering PSE and LAGBC are diagrammed.

About 70 items of technical and commercial literature are cited.

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CONTENTS

	<u>Page</u>
I. INTRODUCTION.	1
II. CAMERA COMPONENTS	6
III. AUTOMATIC VARIABLE GAIN	25
IV. OPTIONAL SYSTEM FUNCTIONS	38
V. SUMMARY AND RECOMMENDATIONS	42
VI. ACKNOWLEDGEMENTS.	44
VII. BIBLIOGRAPHY.	45

LIST OF FIGURES AND TABLES

<u>Figure No.</u>		<u>Page</u>
1	TV System with Image Enhancement Functions.	2
2	System Design Nomograph	4
3	Transfer Characteristics of Various Camera Tubes.	9
4	S/N of Several TV Camera Tubes.	10
5	Detector Compensation Amplifier	12
6	Frequency Response of Circuit in Figure 5	13
7	Log-Log Graph of Signal vs. Intensity Showing Variations in Dark Current and Responsivity	17
8	System for Taking Low-Intensity Data.	19
9	Simple System for Storing High Illumination Video Minus Low Illumination Video.	20
10	"High" Illumination Data System Including Data Difference Expansion and Frame Averaging	21
11	System Configured for Operation as a Linear Sensitivity Equalizer	22
12	System Configured for Operation as a Gamma Corrector and Equalizer	23
13	General Scheme for Local Area Gain and Brightness Control (LAGBC).	30
14	Delay Lines for Obtaining a Matrix of Pixel Data.	32
15	Two-dimensional Recursive Filter.	33
16	Two-D Recursive Averager.	34
17	Scheme for Standard Deviation or R-M-S Value	36
Table I	Estimated Contrast Enhancement Ratio.	43

I. INTRODUCTION

Purpose

The purpose of this study is to provide a base of precise information about TV systems and signal processing for target contrast enhancement from which detailed plans for system improvement programs can be made.

Approach

All stages of the image forming and signal processing system in a TV search and track set have been examined for opportunities to enhance the contrast of an image of a military vehicle, which would not be detectable by some of the present TV cameras on stabilized platforms.

Figure 1 indicates the components of a search and track set, in the sequence of flow of information. After the camera components the sequence is more variable. Several interactions need to be noted.

A TV tracker can help stabilize the image and improve the contrast for recognition of targets. On the other hand, a contrast enhanced target signal would be easier for a tracker to detect than would be the direct signal. A multiframe averager should be used prior to contrast enhancement because the allowable enhancement gain might be affected by the S/N in the video. The same applies to a sensitivity equalizer. Furthermore a recursive multiframe averager should be a part of a sensitivity equalizer so that equalizing gain factors will not be determined from noise but from average signals.

A literature survey and preliminary system study were made for each of the following processes or camera stages: spectral selection, lens, apodization (MTF filter), detector, amplifier and operating circuit, detector compensation, aperture compensation, image stabilizer, multi-frame averager, sensitivity equalizer, contrast enhancement, displays, moving target detection, instant replay, spectral detection, and autoscreening.

Definition of a Target

For the purposes of this study a TARGET is defined as an offensive weapon vehicle situated in background and under illumination such that its intrinsic contrast in the spectral band of the detector is 0.3. The target is observed through low visibility atmosphere at a range and with a certain optical power such that recognition of vehicle class would be

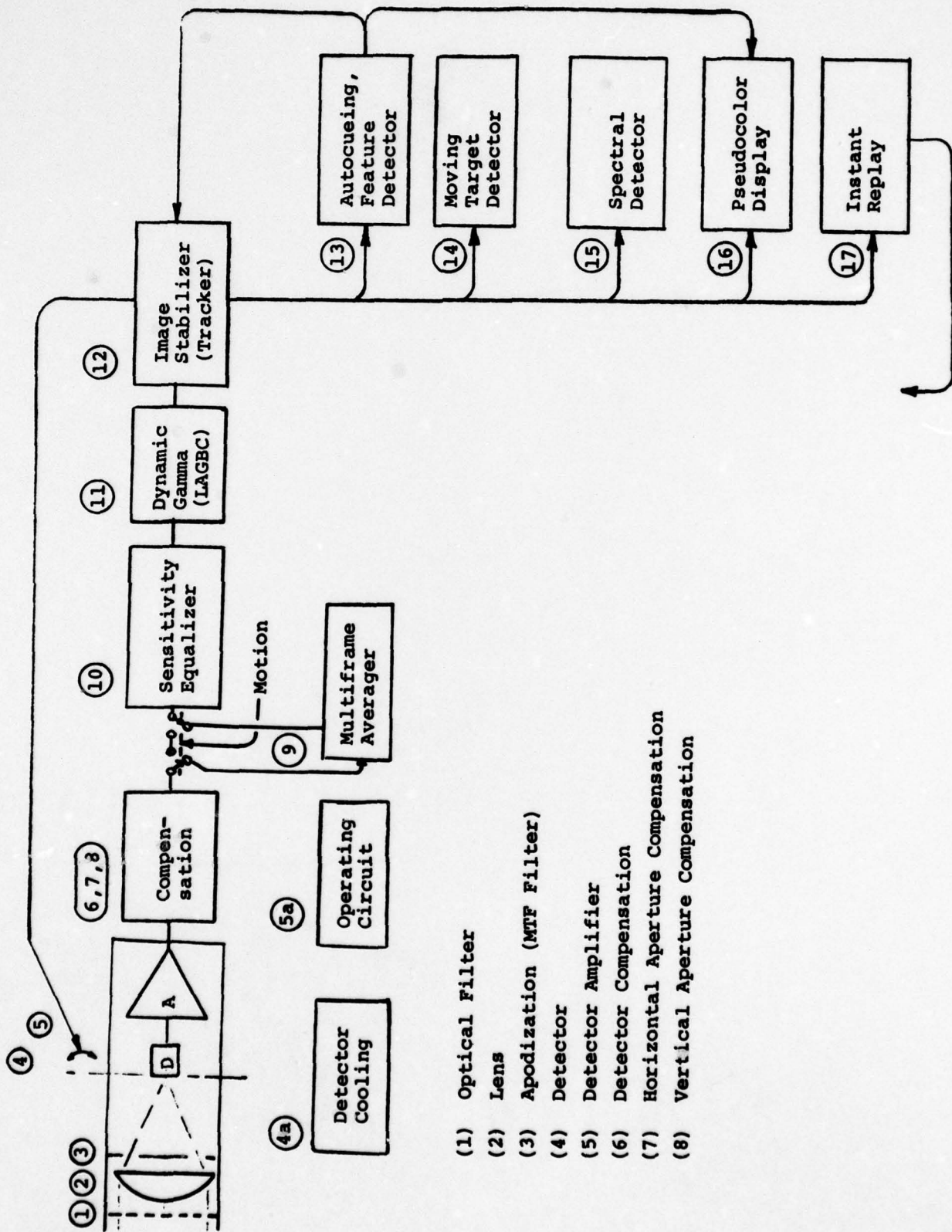


Figure 1. TV System with Image Enhancement Functions

possible if there were sufficient contrast. Low visibility atmosphere is defined as an atmosphere of that certain contrast transmission which results in a display image in which the target is just below the detection and classification threshold of a trained observer, in the absence of contrast enhancement video processing.

Ground Rules for System Consideration

In order to be useful in the systems related to this study, an approach to contrast enhancement must be adaptable to the scale of image size of a target where features are just barely detectable and it must be realizable in a package that can be incorporated into helicopter external stores. Furthermore the system must operate in real time with multi-frame processes involving no more than one-tenth second.

System Considerations

The relative importance of system parameters - lens aperture, focal length, and MTF sensor spatial response, spectral response, S/N vs. exposure - have been outlined by Pinson and Viguet.^{1*} A given set of parameters, including target and hazy atmosphere, can be tested in a program called PERTAM, by Fowler.² Data on camera components and design relations from which to refine some of the parameters are outlined in this report and collected in the project reference file.

Simplified Design Procedure

The E-O system engineer or operator has control of some parameters at the design stage and some at each application. Uncontrolled parameters include atmospheric transmission, scene illumination, and target intrinsic contrast. Ignatowski³ gives a development based on photon limited resolution, of the relations between scene illumination and reflectivity for choosing lens aperture, and target range and size for choosing focal length. Richards⁴ points out the troubles with using too large a lens. The limiting contrast lines in Figure 2 can be compared with sensor properties as given, for example, in the RCA Imaging Devices catalog.⁵

* Superscripts in the text refer to items in Bibliography.

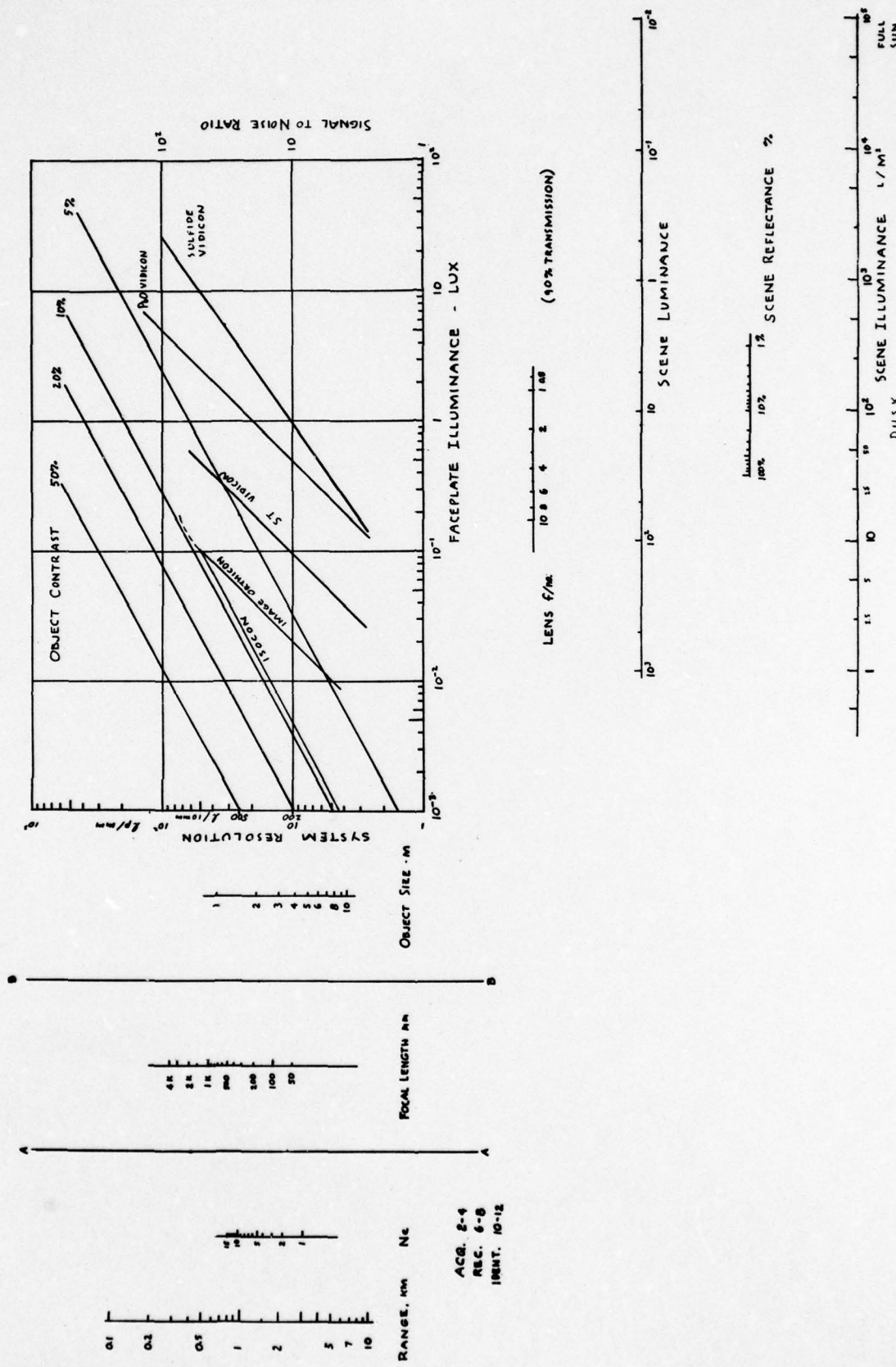


Figure 2. System Design Nomograph

The narrow range of optimum exposure for each type of sensor points out the need for correct adjustment of aperture.

An example of a system parameter selection will be given, using Figure 2. Let the problem be to determine the focal length for obtaining, at 4 km, recognition of a 2 m high tank in daylight.

Entering the nomograph at 4 km range, project to reference line A through $N_e = 6$. Then from the required system resolution of 500 lines/10 mm, or 25 lp/mm, project back to reference line B through the object height, 2 m. Connect the points on A and B and read the required focal length, 420 mm.

Consider the light level or $f/\text{no.}$ required to preserve the resolution or operate the sensor, whichever is greater. Project from 500 l/10 mm to the intersection with the 5% contrast locus, then drop down to the faceplate illuminance scale which should read 2×10^{-1} lux. Then notice that a silicon target (ST) vidicon is the most sensitive small tube, but it requires 6×10^{-1} lux for full S/N. From that point project through $f/4$ and $R = 30\%$ and read that the system will work down to a scene illuminance of 10^2 lux, which is an early sunrise or late sunset condition or very heavy overcast sky. The depth of field should be checked using the curves given by Richards.⁴

II. CAMERA COMPONENTS

Spectral Selection

There are two main objectives in restricting the spectral passband: (1) to avoid the contrast reduction due to scattering in the light path, and (2) to use a band in which there is the greatest difference between the spectral reflectivity of targets and likely backgrounds. Multiple band techniques, also mentioned, are less generally applicable because they require major equipment modification.

Given a typical item of ordnance partly concealed by foliage and camouflaged with netting, one can assume an average intrinsic contrast, C_i , of 0.2. Then the contrast at the lens, C_x , can be estimated using the range, V , at which a blackbody appears to have a contrast of 2% against the sky. From Hood⁶ $C_x = C_i \cdot \exp(-R_x \cdot \ln 50/V)$. If V is 7 miles or 11.25 km, and R_x is 4 km, then C_x would be .05, which would require enhancement. This relation assumes no change in spectral band between that used to determine the range to 2% contrast, the visibility, V , and the application band.

In general, contrast attenuation as a function of range and "visibility" decreases with increasing wavelength. Curcio⁷ took the data and Elterman⁸ graphed it. Most TV seekers use a red filter, Wratten #25,⁹ which passes above 0.6 μm . Use of a silicon vidicon allows a longer wavelength passband than that of a standard vidicon, but silicon vidicons require light level control and are more grainy, requiring blemish correction.

More sensitive silicon intensifier target (SIT) tubes would permit use of a narrower passband, but the possible improvement in transmission and contrast would not be realized because of the lower inherent signal-to-noise ratio of these tubes.

The second type of spectral improvement may come from emphasizing a spectral difference between targets and backgrounds.¹⁰ Since backgrounds vary, no single passband provides optimum contrast. Actually O.D. paint is designed to provide a reasonable match to foliage to avoid spectral discrimination. Both foliage and O.D. paint are more reflective at about 1 μm than they are in the visible band, so some of the improvement in contrast expected from raising the cut-on wavelength above 0.8 μm is not realized against O.D. painted ordnance.

The approach of multi-spectral target contrast enhancement was studied by Williamson and McCannless.¹¹ Implementation of this technique would require a synchronous filter changer, rapid detector decay, and a multifield frame grabber.^{12,13}

Lens

The lens for a TV search/track set should have a range of focal lengths and apertures optimized for the range of most likely application.⁴ Zoom lenses provide wide field, for orientation and narrow field, for examination, but suffer from reduced resolution at all fields of view, as compared with fixed focal length lenses.

In small camera systems the lens is seldom a limiting factor in determining target image contrast. However, a larger system to be used at ranges where contrast transmission is normally below the visual threshold may have several difficulties with the lens. To obtain adequate exposure the lens may be large relative to the raster. Its modulation transmission at the raster pitch should be above 85%, but often it is not. Also a large lens will have a limited depth of field. A lens designed for film photography is usually not optimum for television. The lens formula, which determines its response function, or MTF, should be optimized for the raster pitch instead of ultimate resolution. In making this optimization, the lens designer must use the raster diagonal size in determining the field of view instead of a given film size, which is usually much larger than a TV sensor.

Lenses have been designed especially for TV use by Schneider,¹⁴ Angenieux,¹⁵ Kowa,¹⁶ NYE Optical Company,¹⁷ Contraves Goerz Corporation,¹⁸ and Canon.⁷²

Apodization

If light level can be sacrificed, apodization, or the use of a central stop, can theoretically provide some contrast enhancement of image details in a certain size range as well as contrast reduction of objects in a larger size range.^{19,20}

There are several forms or degrees of apodization possible; for example: a slit, a narrow ring (large central stop), tapered central stop, and multiple rings (zone plate).

Generally, apodization requires too great a sacrifice in exposure for use under broad light level conditions. Also, the use of an iris for light level control is difficult to combine with apodization.

Detector

Selection of the detector for a searching TV camera is more important than is generally realized. Both ultimate resolution and signal-to-noise ratio can vary more than two-fold between standard and special types. Camera makers have an advantage over single system developers because they can contract with the vendors for the right to select and return inferior tubes. Therefore tubes bought from jobbers are the culls from camera makers. However, special types are available that are advertised to have at least twice the response at moderate resolution as do the most popular tubes.²¹

The very large and very slow tubes which have the greatest resolution will be omitted because of unusable camera size or excessive lag or noise.

For each range of light level there is a type of sensor that has the highest signal to noise ratio. If the iris system of the lens includes a central stop, there is little loss of resolution at small effective apertures, and two decades of intensity from the scene can be accommodated. In the case of the silicon target (ST) tubes the highlight level in the image must be accurately regulated by the iris because the response of the sensor cannot be varied by control of the target voltage.

Based on the data in Figures 3 and 4 from RCA Bulletin IMD-100,⁵ the camera tube types should be exposed such that the scene highlight has the following schedule of values, proceeding from high values downward:

Sulfide vidicon	10-20 lux
Vistacon (PbO) (or SATICON)	5 lux
ST vidicon	0.4 lux
ISOCON	5×10^{-2} lux
SIT	3×10^{-3} lux

It is noted that most vidicon camera makers claim a S/N of 40 db (100:1), but that the RCA data shows this to be likely only for the PbO types.

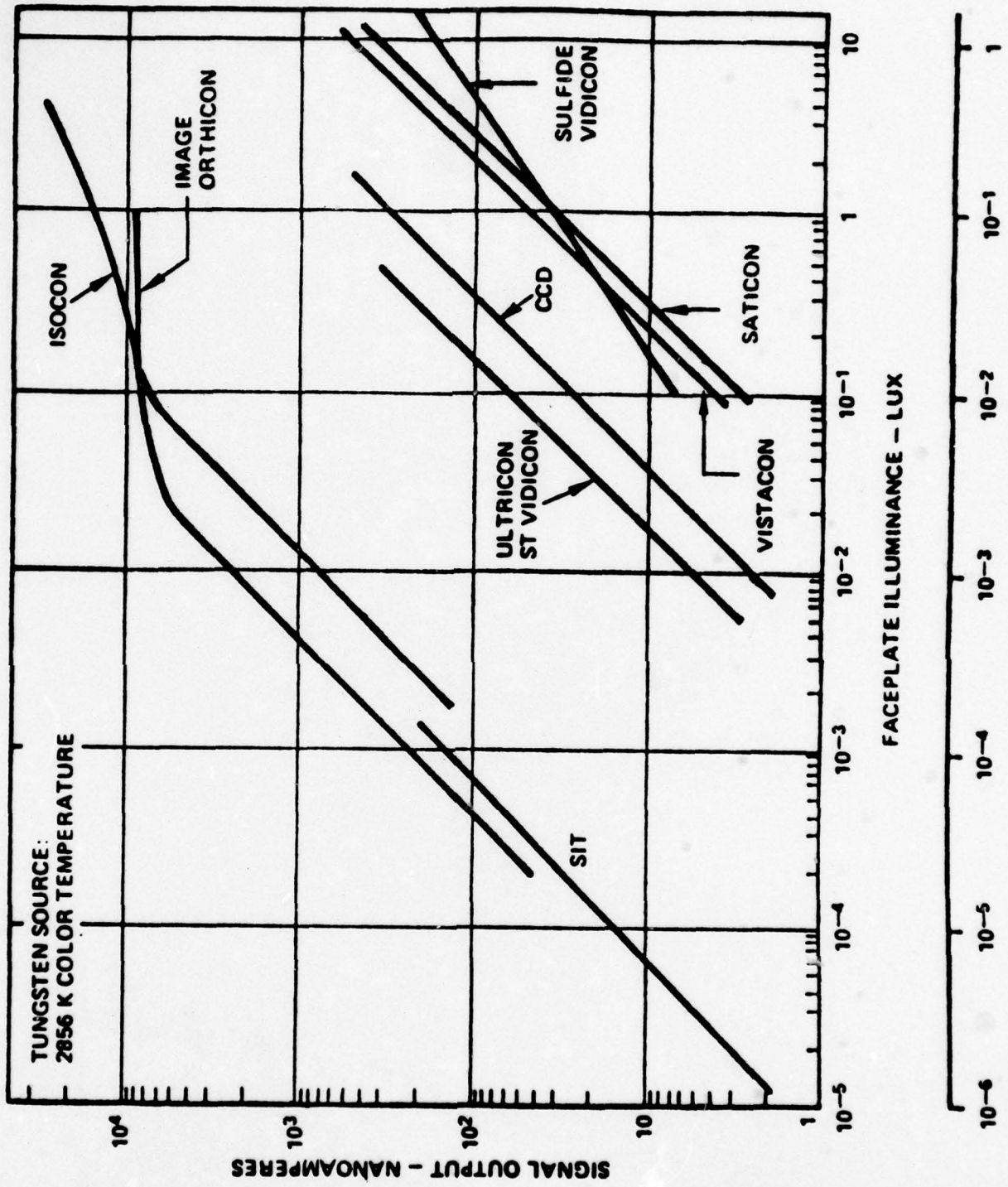


Figure 3. Transfer Characteristics of Various Camera Tubes

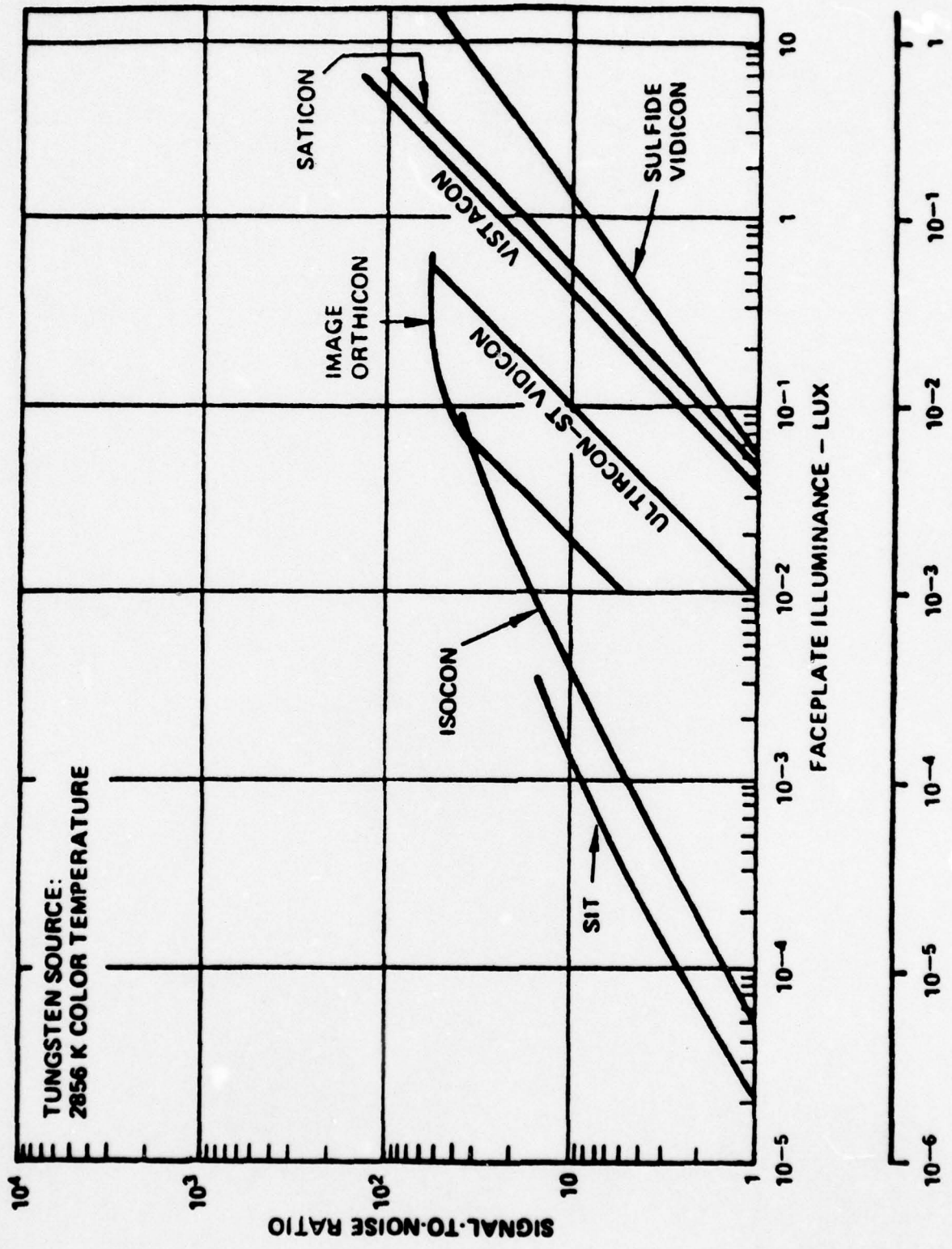


Figure 4. S/N of Several TV Camera Tubes

Below 0.05 lux, the SIT is usable but at a maximum S/N of only 15. Use of the ISOCON and IMAGE ORTHICON may be excluded by their large size and the large size of the camera circuits.

Amplifier

Every TV camera maker provides a fairly good amplifier following the detector. In the event that a particular amplifier is suspected of contributing to the noise level, either in the high frequency band or in the low frequency or 1/f band, it may be advisable to change it for a type advertised to have a significantly lower noise factor. The model 9913 by Optical Electronics, Inc.²² is one such type, which is supposed to have a noise voltage of $1 \cdot 10^{-9}$ V/ $\sqrt{\text{Hz}}$. At the upper end, 10 MHz, the noise level would be only $10^{-9} \times 3.1 \cdot 10^3$ or $3.1 \cdot 10^{-6}$ V, which is insignificant compared with beam current noise. (This comment is a suggestion, not an endorsement, and we have not confirmed the data by experiment.)

Detector Response Compensation

Vidicons, plumbicons, and CCD pictorial sensors all have some time lag associated with their intrinsic signal. Early in the amplifier train the sensing layer capacitance must be compensated. Classical video amplifier discussions have concentrated on the upper cut off frequency, but accurate compensation involves matching the onset frequency to the roll off frequency of the detector. The larger the detector time constant the lower the onset frequency must be and the greater the required ratio of maximum gain to low frequency gain. Figures 5 and 6 give an example of an operational amplifier network which provides compensation for a large, high resolution vidicon.

The upper roll-off frequency should be adjusted to the resolution and signal-to-noise ratio requirements of the system. Most camera chains include this adjustment as "high peaking".

Operating Circuit

The TV camera circuit for supplying the sensor voltages and deflection fields is often a weak link in the system. Some of the common shortcomings are focus adjustment too coarse and unstable, bright line-dark line interference from the power supply, raster position and size drift, and

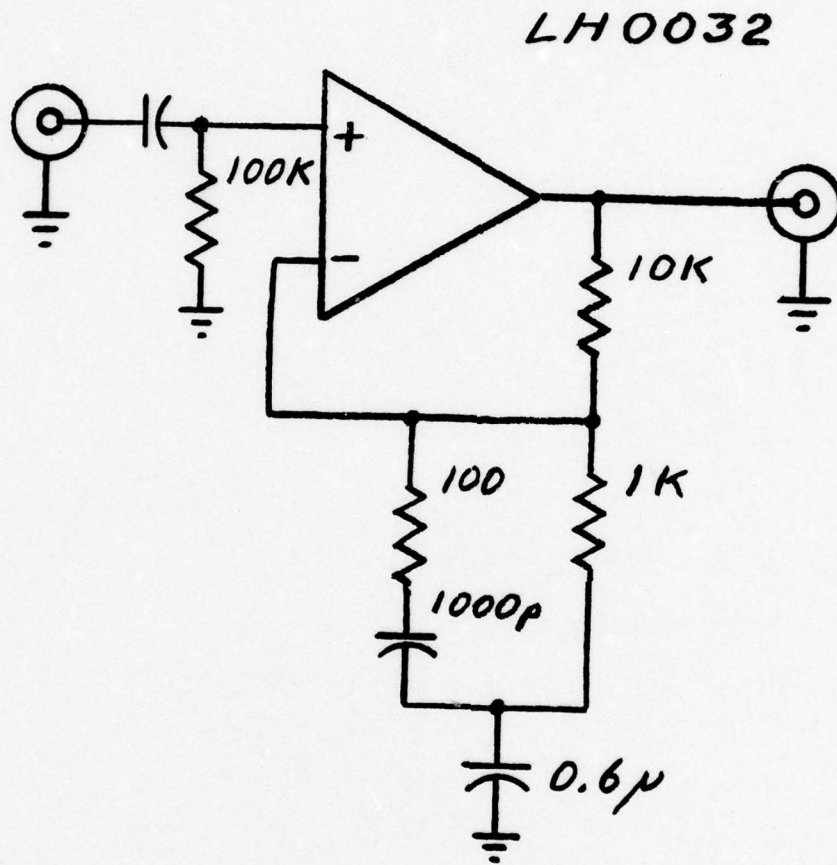


Figure 5. Detector Compensation Amplifier

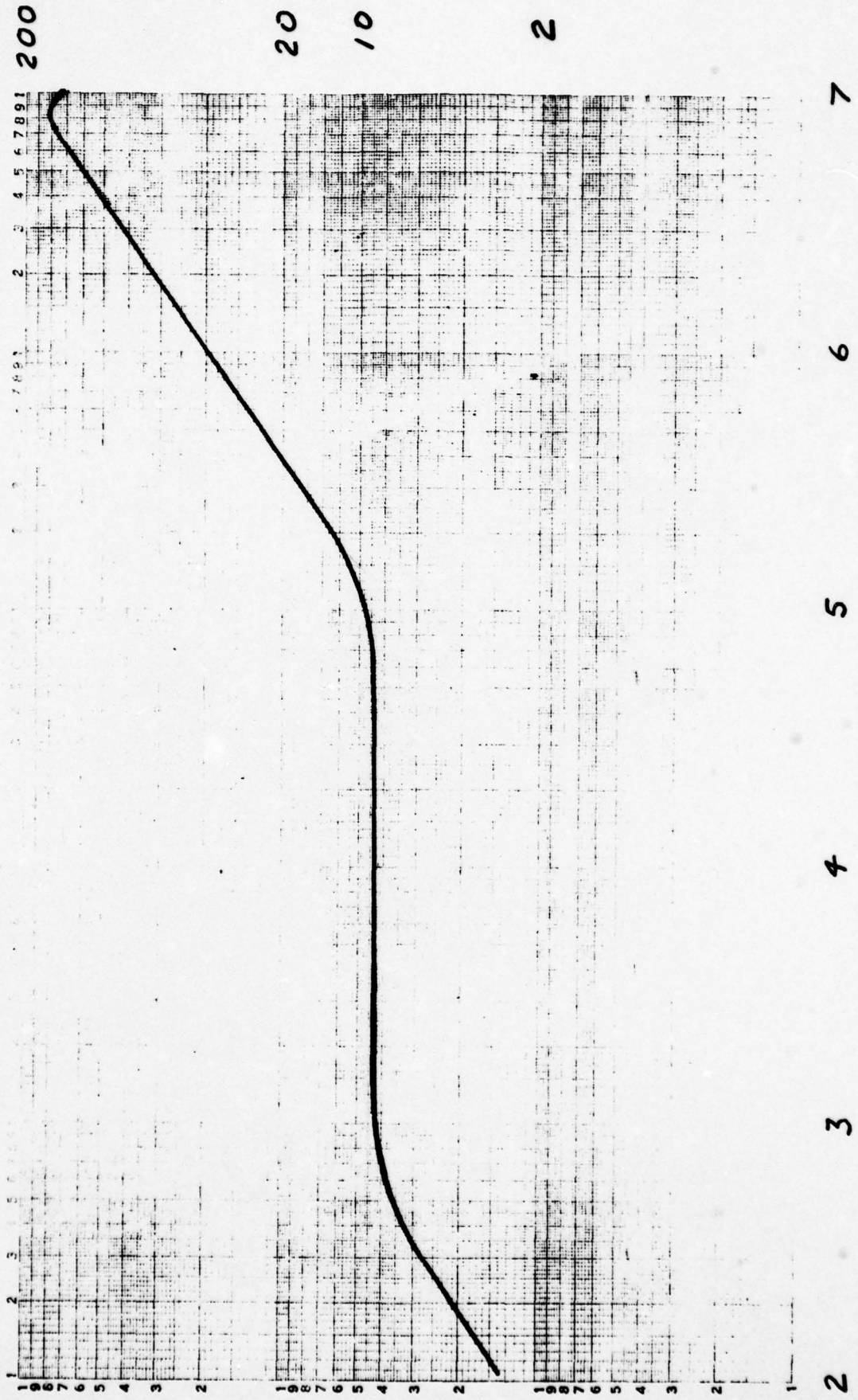


Figure 6. Frequency Response of Circuit in Figure 5

excessive or flickering target electrode voltage. Specifications defining tolerances on these factors should be added to those normally quoted by manufacturers.

Good TV cameras are available from a number of sources, some of which are listed below:

Cohu, Inc.²³
Colorado Video, Inc.²⁴
Hamamatsu Corporation²⁵
Interpretation Systems, Inc.²⁶
Sierra Scientific Corporation²⁷
SONY²⁸

Horizontal Aperture Compensation

McMann and Goldberg²⁹ explain aperture correction well. The beam size at the sensing layer is the "aperture" being compensated. Tube data indicates the beam width must be about 1/100th of the raster width, or .005 inch. A gaussian shape of electron density distribution is assumed. In a normal line rate camera (525 lines/frame), the time corresponding to the beam width would be about 0.5 μ sec.

Horizontal aperture correction can be accomplished by passing the video signal through two delays of 0.25 μ sec each, resulting in three phase related signals. A composite corrected signal then is produced by subtracting the first, or undelayed signal from the second signal and adding the third signal. The resulting signal can then be added to the second signal to obtain the desired amount of aperture correction.

Few stock TV cameras employ this complete technique, but rack mounted aperture corrector amplifiers are commercially available.

Vertical Aperture Compensation

For vertical aperture correction the same logic as for horizontal aperture correction applies except that a full and exact line of delay must be implemented.²⁹ Actually it would be desirable to have up to five lines-delay channels so that a gaussian schedule of gain factors could be applied to each line. Linear CCD delay units may make this technique feasible.

Basically the technique is similar to contrast enhancement, using a sample area of 5 x 5 pixels. The mean is subtracted from the central pixel value and the difference amplified. This results in a simple white step being displayed as a dark outline, a whiter than normal line, then the true luminance value.

Vertical aperture compensation sometimes gives odd results and must be used with moderation.

Digital aperture compensation to varying degrees was illustrated by Andrews.³⁰

Equipment for implementing vertical aperture compensation is not readily available.

Pixel Sensitivity Equalization

Sawchuk³¹ has discussed sensitivity correction in most general terms. We will consider practical methods of sensitivity correction of vidicons and solid state array sensors for the purpose of permitting greater contrast enhancement ratios. The general scheme is to test the sensor with uniform light levels, both low, or dark, and high, but not saturated, and to store two arrays of factors to be applied in real time to subsequent video signals. The low level factors would be subtracted from video and the high level factors would be divided into video to obtain uniformly dark and bright display images, upon repeating the calibration cycle.

Large area variations in sensitivity are caused by lens vignetting and vidicon beam landing angle and are usually called "Shading". Shading compensators are available commercially (Bausch & Lomb,³² Hamamatsu³³) and have been made by Southern Research Institute³⁴ for data recording TV systems. The systems will not substantially benefit a contrast enhancement processor because large area shading will be attenuated strongly by the processor whether it originates in the sensor or in the scene.

Many of Sawchuk's memory requirement calculations employ a term, a , allowing a selectable number of adjacent pixels to be corrected by the same factors. This factor is not to be greater than 1 (or left out) for the same reasons given above. The purpose of the pixel sensitivity corrector is to substantially reduce the stationary noise in the video due to localized variations in dark current and highlight current in pictorial sensors. In vidicons this is known as "wool blanket" or "eggshell" noise and in array sensors it is simply diode sensor variation and is defined as a blemish specification.³⁵

Subliminal targets are defined here as undistinguishable from blemishes, regardless of how many frames are averaged to reduce dynamic noise.

Contrast enhancement devices and digital processes that execute the function of reducing the low frequency (large area) contrast and raising the high frequency (small area) contrast worsen the signal to noise ratio in direct proportion to the gain ratio employed. When the target area contrast is as low as the noise, the gain will be increased until the noise plus target contrast fills the requirement of constant standard deviation over the sample area.

The noise in the video therefore has a direct influence on the action of the enhancement processor.

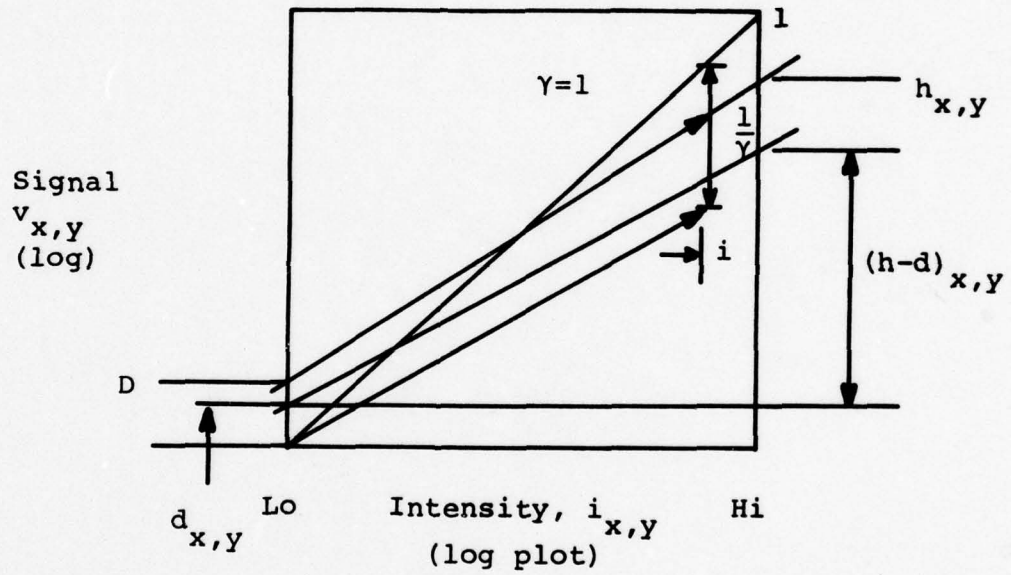
Noise in the video will usually consist of a dynamic or random component and a static component. The dynamic component can be reduced by multiframe averaging. The static component can be reduced by pixel sensitivity correction.

It appears to us that the best sequence of operations would be to apply a tracker to reduce image motion, to go through a multi-field averager to reduce the dynamic noise, to apply pixel sensitivity correction, and then to apply local area gain and brightness compensation (LAGBC).

Graphically, sensitivity variation can be represented as in Figure 7 as response curves of varying intercept (dark current) and slope (gamma). Normalized response, as represented by a curve of gamma = 1, is not as important as a constant gamma and equal intercepts. A system for equalizing intercept and sensitivity will be diagrammed in three stages.

Calibration of a pixel sensitivity corrector is plagued by pitfalls, not all of which we can anticipate. Only the most obvious ones will be avoided by the following procedure and mechanization.

First, it is necessary to know the characteristics of any gain regulating system in the sensor operating circuit. In vidicon cameras, the target (sensing layer) voltage is varied to maintain a constant signal, which may be a-c detected or d-c detected. In silicon array sensors a variable gain element is controlled to maintain constant maximum value of signal, usually a-c, amplitude. In order for any useful calibration to take place, it will be necessary to determine the control voltage for the highlight scene condition and to



$$\gamma = (h-d)/(Hi - Lo)$$

Figure 7. Log-Log Graph of Signal vs. Intensity Showing Variations in Dark Current and Responsivity

freeze it for the low light measurement. Otherwise a duplicate of the control device would have to be incorporated in the sensitivity compensation system. In making the determination of highlight sensitivity control voltage it may be necessary to use a large scale a-c target (bar chart) to activate an a-c detector. Furthermore, it will be assumed that the signal electronics will present a true d-c measure of image intensity even though the intensity is essentially uniform. A rectangular mask is sometimes necessary on the faceplate in order to create a dark border for reference purposes.

Having determined the control voltage required for highlight operation, the corresponding dark field signal can be digitized and stored in a memory, as indicated in Figure 8, a.

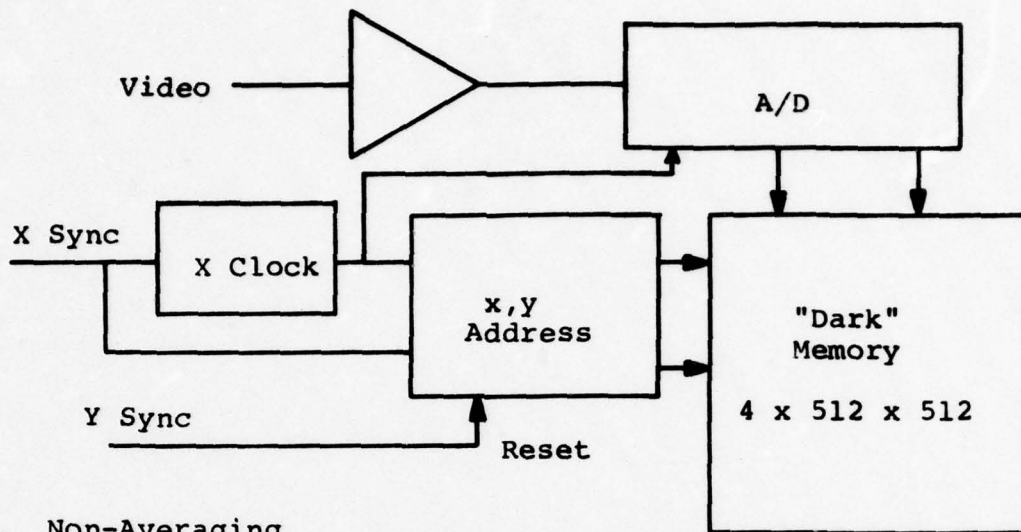
Actually the average dark signal can be stored by taking a low fraction of the new signal and adding it to a high fraction of the previous signal as read from memory, thus letting an average signal accumulate in memory, as in Figure 8, b.

Highlight Calibration. Correction for highlight sensitivity will be a division process, so the low light factor should be applied before the highlight signal measurement. The processor gain must be maintained constant for the entire calibration procedure.

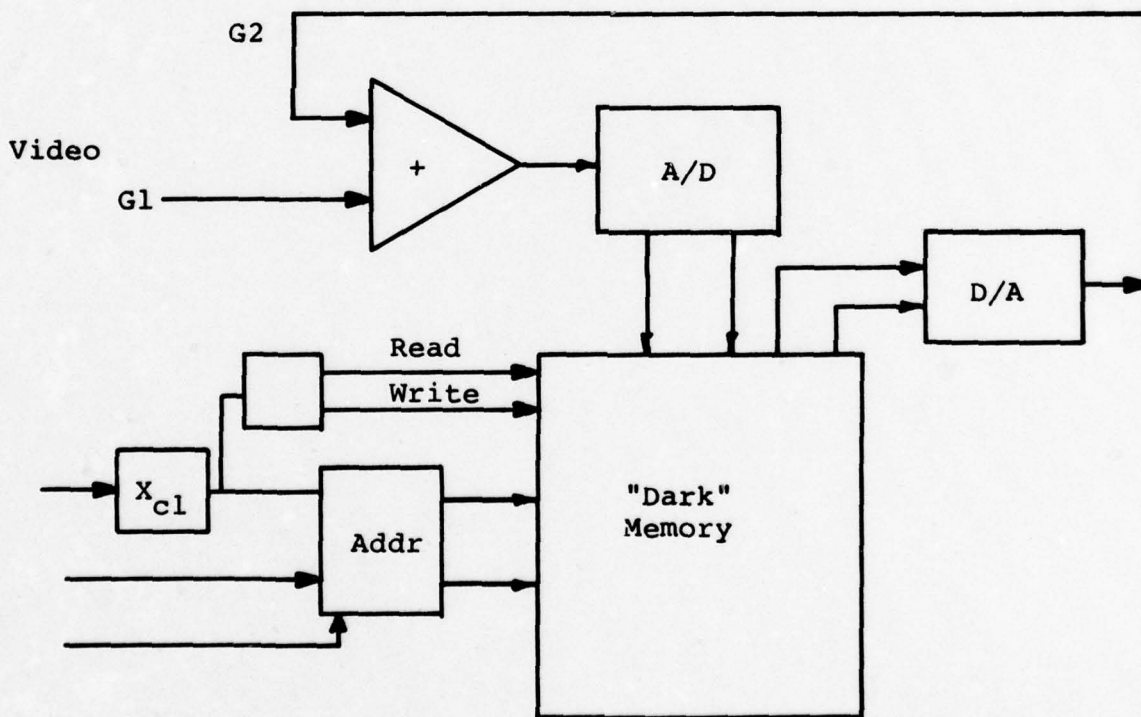
Figure 9 indicates reading the low light data from the first section of memory and subtracting it from the raw video, then digitizing the new video signal. One could achieve a scale expansion by further subtracting an average value (d-c) from the new video and applying some gain. The noise would be amplified along with video and must be averaged, as above. Figure 10 indicates both the expansion gain and the averaging.

Application. After a few fields of data accumulation, the gain factors would stabilize and the system is ready for application. The memories would be put in a read, only, mode, and the analog path would be configured as in Figure 11, in which $G5$ would be set to $1/G3$ in Figure 10 to exactly offset the gain expansion used in recording the sensitivity differences.

If the system is applied to a vidicon having a fractional gamma and true gamma correction is desired, the analog processing channel could include log and antilog stages on either side of the divider as shown in Figure 12. However, since sensitivity variations of more than a few percent would be just cause for changing sensors, it would be difficult to tell the difference between the actions of the simple and complex (log) processors.



a. Non-Averaging



b. Averaging

Figure 8. System for Taking Low-Intensity Data

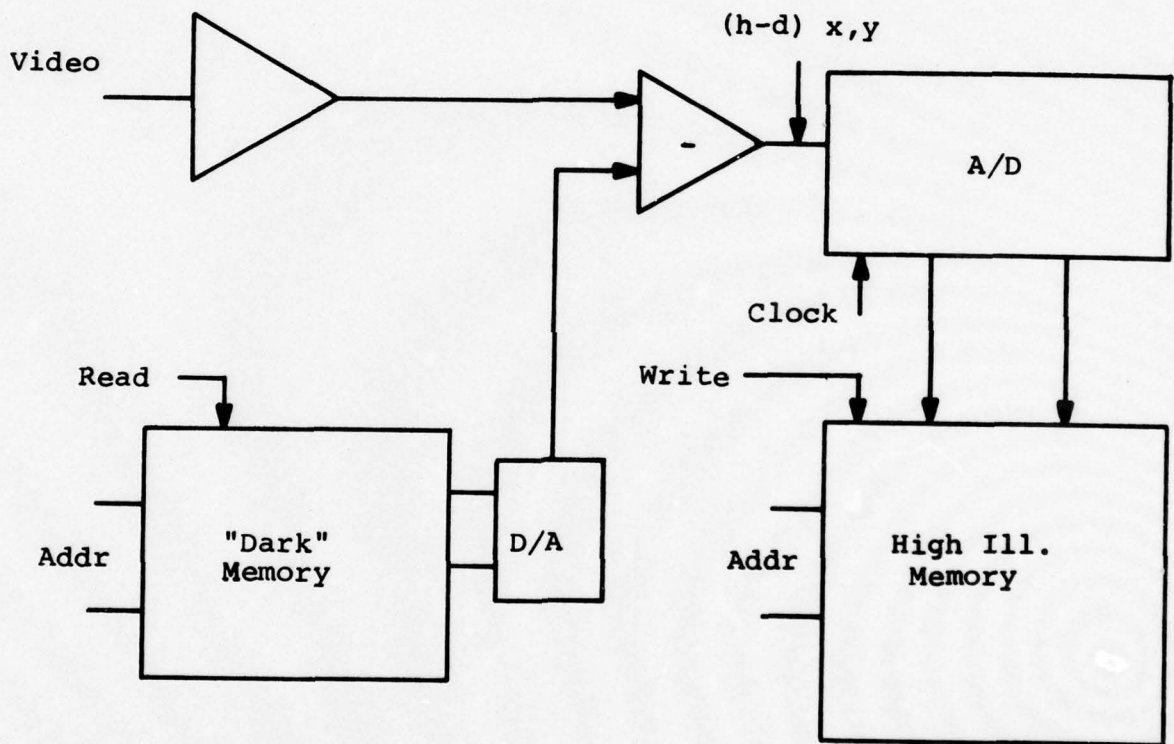


Figure 9. Simple System for Storing High Illumination Video Minus Low Illumination Video (Camera circuit gain must be held constant.)

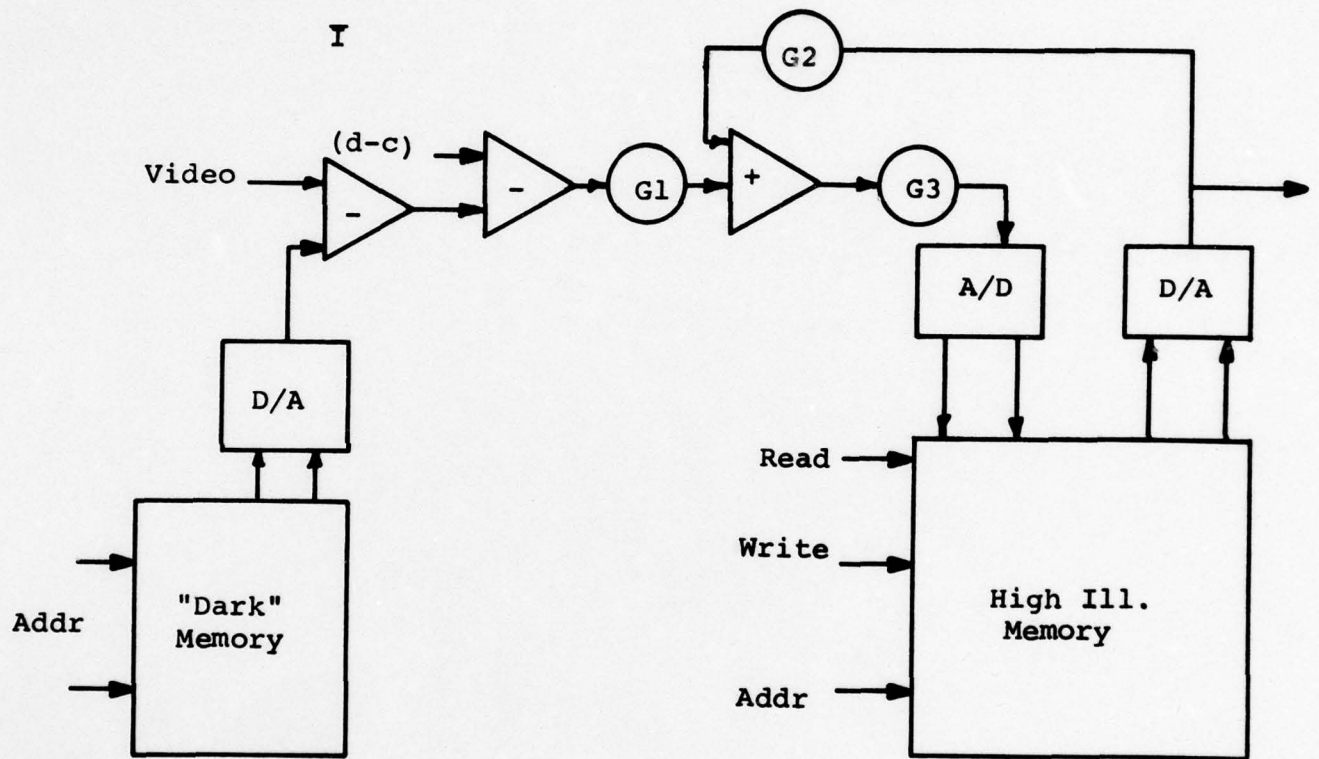


Figure 10. "High" Illumination Data System Including Data Difference Expansion and Frame Averaging

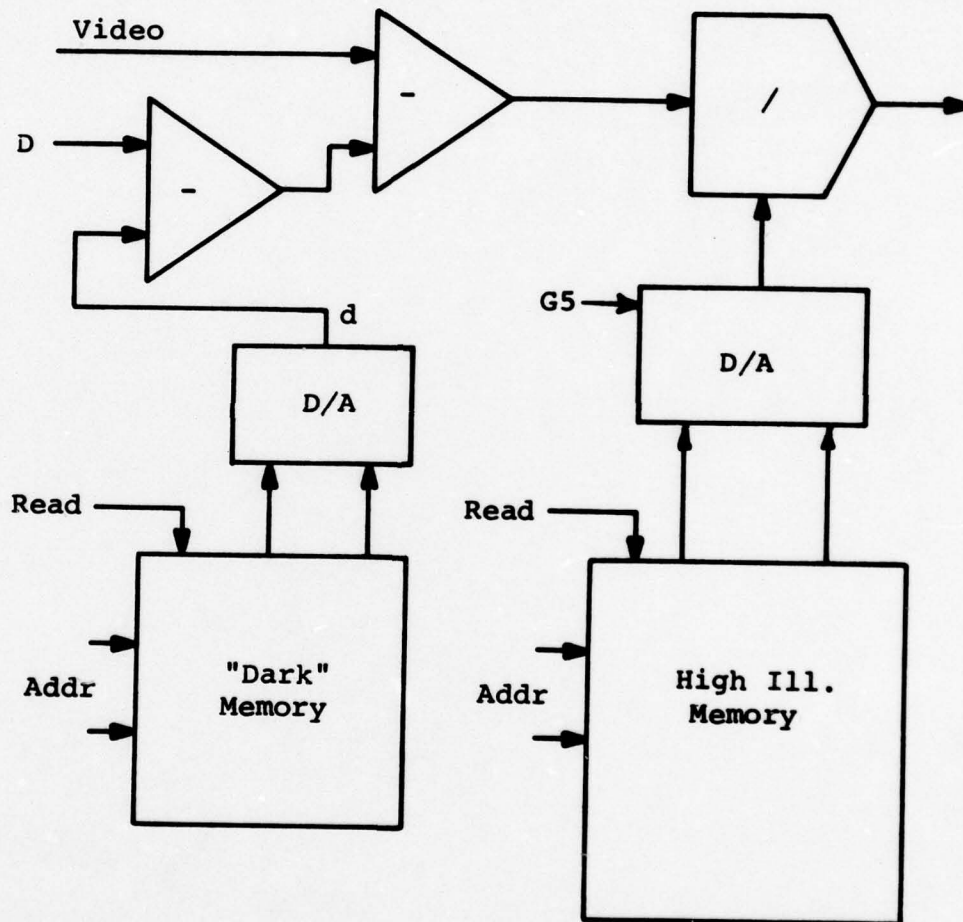


Figure 11. System Configured for Operation as a Linear Sensitivity Equalizer

$$v_1 = (v_0 - K)^{1/\gamma}$$

$$\log v_1 = \frac{1}{\gamma} \log (v_0 - K)$$

$$v_1 = \text{antilog} (\log v_1)$$

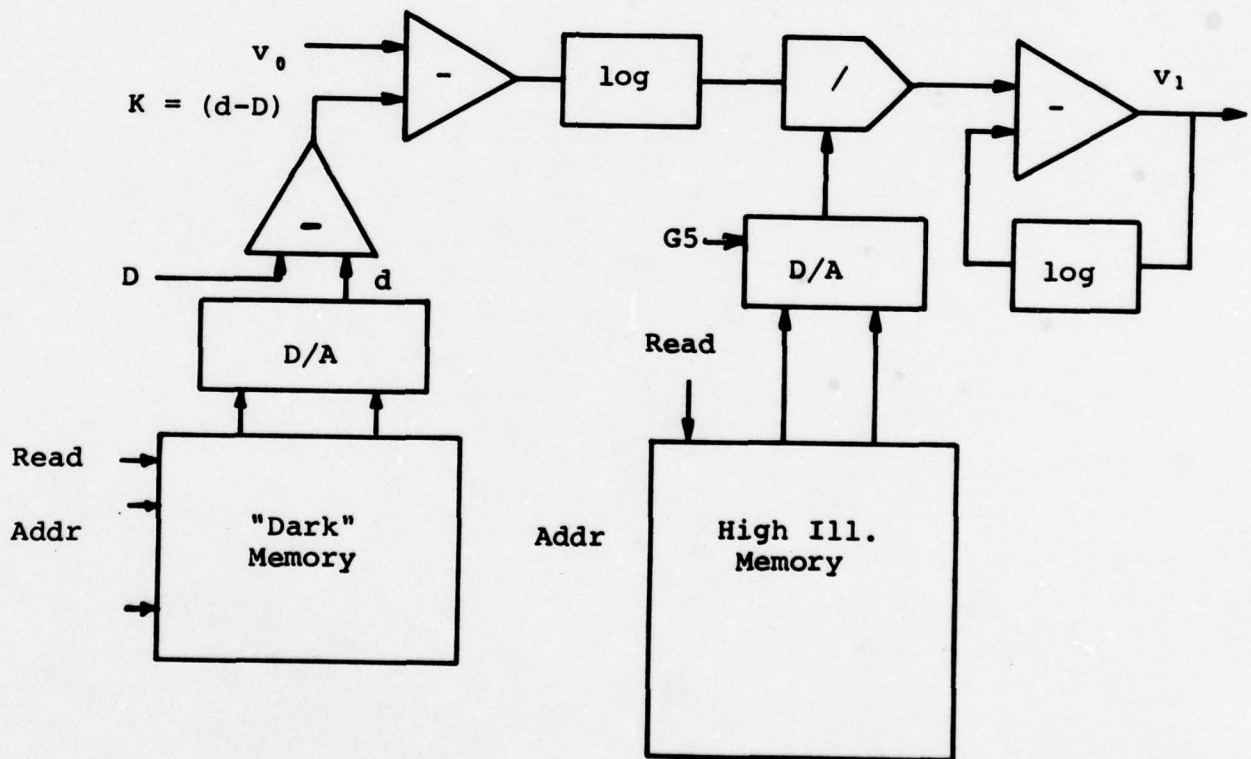


Figure 12. System Configured for Operation as a Gamma Corrector and Equalizer

Multiframe Averaging

One of the first uses of multiframe averaging was in transcribing ciné program material to video for TV broadcast. Dust and spots on film were painfully obvious. The image transform system described by Comandini³⁶ reduces the contrast of dust spots by causing four frames to be averaged in developing the video signal to be broadcast. A totally black spot then would only be 25% less bright than if there were no dust.

Adlerstein³⁷ describes a frame averager developed by CBS Technology Center using an adaptive recursive ratio. When the image is stationary, the number of fields averaged increases and when motion takes place, no averaging is employed. Mengers³⁸ makes a digital frame averager with provisions for selecting the number of frames effectively being averaged. Any form of instant write and replay pictorial memory can be connected as a recursive pictorial filter, if a small number of circuits are added.

In anticipation of frame averaging, the operator of a search TV system should scan in steps, maintaining a stationary scene for at least one-tenth second each step. This technique is known as the step-stare search method. When scanning to a new scene, the image motion can be as rapid as possible because all details will be lost during scanning and time is being wasted.

It is important to employ frame averaging when contrast enhancement will be used because the allowable gain in an area will be determined by the sum of the contrast and the noise in each area. This may be especially important when an instant replay system is the source of the video, because probably the instant replay recorder will add noise to the original camera video.

III. AUTOMATIC VARIABLE GAIN

Purpose and Objectives

Most of the studies of "Contrast Enhancement" have been directed toward evolving and testing some form of variable gain between a pictorial sensor and a pictorial display device. Some of the words used to describe the class of operations include gray-level transformation, histogram equalization, and local area gain and brightness control (LAGBC). Usually the objective is improved visual response to otherwise barely detectable images of man-made objects. Sometimes the process must compensate for display device nonlinearities, and recent improvements have considered the response of the human visual system.

Reconnaissance data used in most of the studies³⁹ has been taken from high altitude with large, non-real-time systems or with FLIR's. The present study is directed toward real-time TV systems operated at low altitude against low contrast targets obscured by haze, dust and foliage. Thus the experimental evaluations of systems reported thus far are not directly applicable to this effort.

Contrast enhancement may have different objectives depending upon whether there is an operator (man-in-the-loop), or a computer, doing the target searching or autoscreening. If the operator is to be the primary target screener, then his visual response function and noise tolerance must be considered. There are numerous variables which alter the results, but on the average an operator achieves a probability of detection (PD) of only 0.5 when the signal-to-noise ratio is down to 3.5. Frei⁴⁰ reports that observers prefer images that have been modified to favor their response, which can be simplified to the form

$$B = \log (J + C)$$

where B is the perceived brightness, and J is the display brightness.

On the other hand, a computer doing the autoscreening may have a linear response but probably requires a greater signal-to-noise ratio for a given PD because its sophistication of feature correlation would not yet equal that of a trained observer.

All of the contrast enhancement schemes which follow employ high-pass filtering and are therefore detrimental to the signal-to-noise ratio to the extent that the high frequency components of the signal become amplified more than the low frequency components of the signal. They also may involve setting a gain by measuring the average and variance for an area. Therefore it is a prerequisite that noise filtering and pixel sensitivity equalization be applied before any of the contrast enhancement processes.

Subject Perspective

Andrews³⁰ divides the activities of image processing into five categories:

- (1) Coding for data compression,
- (2) restoration and enhancement,
- (3) extraction of data,
- (4) mathematical structure analysis, and
- (5) processing system development.

The subject of this section is a part of his second group, with supporting roles from the other groups. Some of the synergistic interplay between groups should be considered when planning succeeding projects. Data compression, (1), if done without loss of significant target information, should aid development of more economical processing systems, (5). Extraction of data (3) may be a precursor of image enhancement (2,b). Structure analysis, (4), is a precursor of segmentation and feature extraction, process steps in autoscreening, which is a step beyond our subject.

Background

An extensive review of the human visual response (HVR) is given by Legault.⁴¹ Several parameters interplay: contrast sensitivity increases with spot size, contrast response is logarithmic, and probability of detection (of a low contrast area) as a function of S/N falls from 0.8 at 4.5 to 0.5 at 3.5. Some aspects of HVR are not yet adequately assessed because Legault leaves only vague recommendations. For example, it is well known that the detection of patterns in a picture of low S/N is most readily done when the pattern is of an optimum scale relative to the processing resolution of the retina and brain, not simply the largest magnification or the highest display contrast.

In 1968, Oppenheim, Shafer and Stockham⁴² reported algorithms for displaying details in otherwise saturated shadows and highlights. Implementation was by large scale computer in non-real time. Then, in 1975, Soha⁴³ described techniques for rendering details in lunar scenes where gain can be made dependent on average brightness, with useful results. Ketcham,⁴⁴ in 1976, reported a demonstration of two more general methods of relating local gain to local average brightness as well as local variance. The approach was rendered in compact hardware, but it is known that some elements of the system introduced too much noise. Further development of algorithms and small hardware has been carried out by Narendra and others⁴⁵ and will result in deliverable hardware shortly. Automatic target detection is also being advanced by at least three groups (Honeywell,⁴⁶ Westinghouse,⁴⁷ and Northrop), but they don't see fit to publish descriptions of their target detection criteria.

LAGBC has been evolved in at least five stages, the algorithms of which will be explained generally. The approach of Oppenheim, et al, involves Fourier transformation, selective multiplication of the picture spectrum, and subsequent Fourier summation to obtain the processed image. Low frequency components (signals representing large areas) are attenuated, and high frequency components are amplified. In other words, large area contrast is reduced to make room in the brightness of the display for contrast of small details within the large areas.

Fourier processing of 512 x 512 pixel picture data requires either non-real time or parallel processors, which are costly; therefore systems engineers have noticed that an approximation to the complete approach can be rendered more easily by making a high pass filter using a small area sample of the picture and extracting both mean and variance data as the sample area progresses through the picture in real time. The following equations represent the processors, successively refined.

a. $I_2(x,y) = [I_1(x,y) - \bar{I}(m,n)] \cdot [G] + [B]$

The mean, \bar{I} , of a set of samples, $m \times n$, is subtracted from the central intensity, $I_1(x,y)$. Then the difference is amplified by a factor G and the product set at a new brightness, B , such that the extremes of the displayed image range nearly from black to white.

$$b. \quad I_2(x,y) = [I_1(x,y) - \bar{I}(m,n)] \cdot g_1(\bar{I})x,y + B$$

Soha's modification, specifically for side illuminated spherical bodies, makes the applied gain a function of the mean.

$$c. \quad I_2(x,y) = [I_1(x,y) - \bar{I}(m,n)] \cdot g_1(x,y) + C \cdot \bar{I} + B$$

One of the improvements by Soland, Narendra, and Fitch⁴⁶ is to add back a portion of the mean, $C \cdot \bar{I}$, to restore realism to the scene. A typical value of C may be 0.2.

$$d. \quad I_2(x,y) = [I_1(x,y) - \bar{I}(m,n)] \cdot g_2(x,y) + C \cdot \bar{I} + B$$

$$g_2 = \alpha \cdot \bar{I}/\sigma(m,n) \quad a < g_2 < b$$

Ketcham proposed that the gain applied to the differential signal be proportional to the mean and inversely proportional to the variance, so as to raise the gain applied to the light areas and to the areas of low contrast. Notice that the determination of a given local gain could be influenced by the initial noise as well as the pictorial variance. In a further refinement the gain regulator is in a loop such that the resulting product has a constant variance. This usually results in an image having low realism and poor orientation clues.

Soland, et al,⁴⁶ like to set limits, a and b , to the range of gain, evidently to limit the display contrast or its S/N.

$$e. \quad I_2(x,y) = g_3 \cdot \log^{-1} [I_1(x,y) - \bar{I}(m,n) + D] + C \cdot \bar{I} + B$$

$$g_3 = [E]/\sigma(m,n) \quad a < g_3 < b$$

For small values of g_3 , the results are similar to that of d.

Lee⁴⁶ reports simplified digital processing that should be able to render these functions, as well as smoothing, with a compact, portable computer.

Estimation of the Gain Margin Available for Contrast Enhancement

Assume a Vistacon or Plumbicon is optimally exposed to a sunlit scene and the large area highlights are represented by a linear signal having the best rated -43 db noise per full scale signal. Next assume a target is immersed in a gray area at the .33 reflectance level. What is the noise equiv-

alent contrast (NEC) at that level? Assume the noise not to be proportional to signal but a constant voltage.

$$S/N = .33 \times 150 = 50.$$

Assuming the highlight signal can be reduced relative to the grey level of most interest, the small area differential gain could be as much as $50/3.5$, or 13.7 , to leave the S/N at a minimum of 3.5 as recommended by Legault.⁴¹ Other detectors would not provide a true enough signal for that much enhancement unless multiframe averaging were first applied.

Hardware Schemes

Figure 13 outlines a general scheme for local area gain and brightness control (LAGBC), to process a video signal according to the relations given above. First the average within a moving window must be obtained. Video is started into a half-window delay path and into a recursive low pass filter, to obtain the average over an area of $(2m + 1)$ by $(2n + 1)$ pixels. The half-window video delay is optional. The recursive filter reaches an approximate average after the passage of about half the lines and half the X-pixels have been sampled, so neither the initial video nor the present video is appropriate with respect to the average. The average value should be subtracted from the video that occurred generally near the middle of the effective local area.

The resulting differential video can be amplified (contrast enhanced) by a value, G , such that the resulting σ is a constant, except that G should be restricted to a range of values between a and b . The gain function may be linear, exponential, or hyperbolic, depending on the application and operator preference, or it may depend directly on the original average brightness (the mean). In any case, the resulting video should not saturate the display too often per picture and it should not cause a signal-to-noise ratio of less than $3.5/1$ at the gray level of the target, wherever that may end up in the gray level scale. A fraction, (B) , of the mean should be added to the amplified video to preserve realism sufficient for rapid orientation from gross features of the terrain.

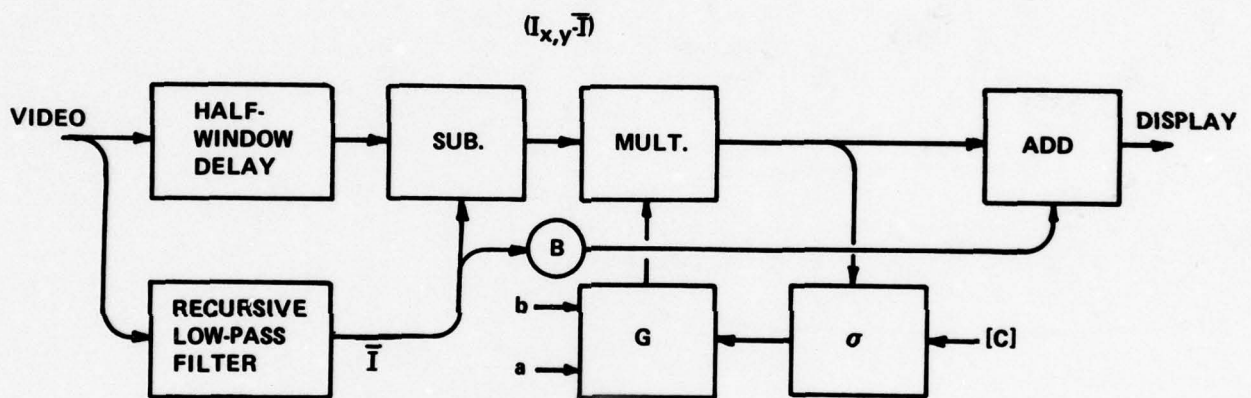


Figure 13

General scheme for local area gain and brightness control (LAGBC)

Options of Implementation

Real time processing to implement the LAGBC algorithms can be accomplished using analog, semi-digital, or fully digital electronics. Software in a high speed computer, with a pictorial memory, can possibly execute real time LAGBC, though it would probably be significantly larger than dedicated logic. Elements of both analog and digital approaches will be illustrated.

Taking an Average

The first function required of an LAGBC network is the average of a rectangular array of pixels, say $(2m + 1)$ wide by $(2n + 1)$ high. Using analog delay lines, a series of 512-stage charge coupled devices (CCD)⁴⁹ for 1-line delays, and a parallel summation, the network shown in Figure 14 gives the sum or average directly, as well as the difference between the centerpoint video and the sum. Weighted averaging can be performed by varying the summing resistors.

Similarly, a recursive filter, Figure 15, can obtain a two-dimensional average, using fewer components. The ratios γ and $1 - \gamma$ determine the effective number of lines being averaged.

Digital Hardware 2-D Filter

Since digital algebra is most readily done with only 2 operands at a time, and the results are naturally stored, serial processing (as it comes) is more straightforward than parallel (stored and then combined). First, in Figure 16, the analog video is digitized into, say, 8-bits and started into a bank of shift registers (S-R) of $(2m + 1)$ stages. The output of the S-R is complemented and added to the undelayed video resulting in a moving sample total. Division by $(2m + 1)$ is assumed. Vertical averaging could be done similarly, but it would be tedious. A recursive filter will do just as well.

The horizontal average is attenuated digitally (every pixel) by a fraction, $\gamma = 1/2n$. Then a fraction, $(1 - 1/2n)$, of the present mean is added to the new X average sample and stored into a 1-line S-R bank. Each pixel out then represents approximately the average of the pixels in an array $(2n + 1)$ by $(2m + 1)$ that passed previously. The video value should be delayed $m + n$ pixel times, also.

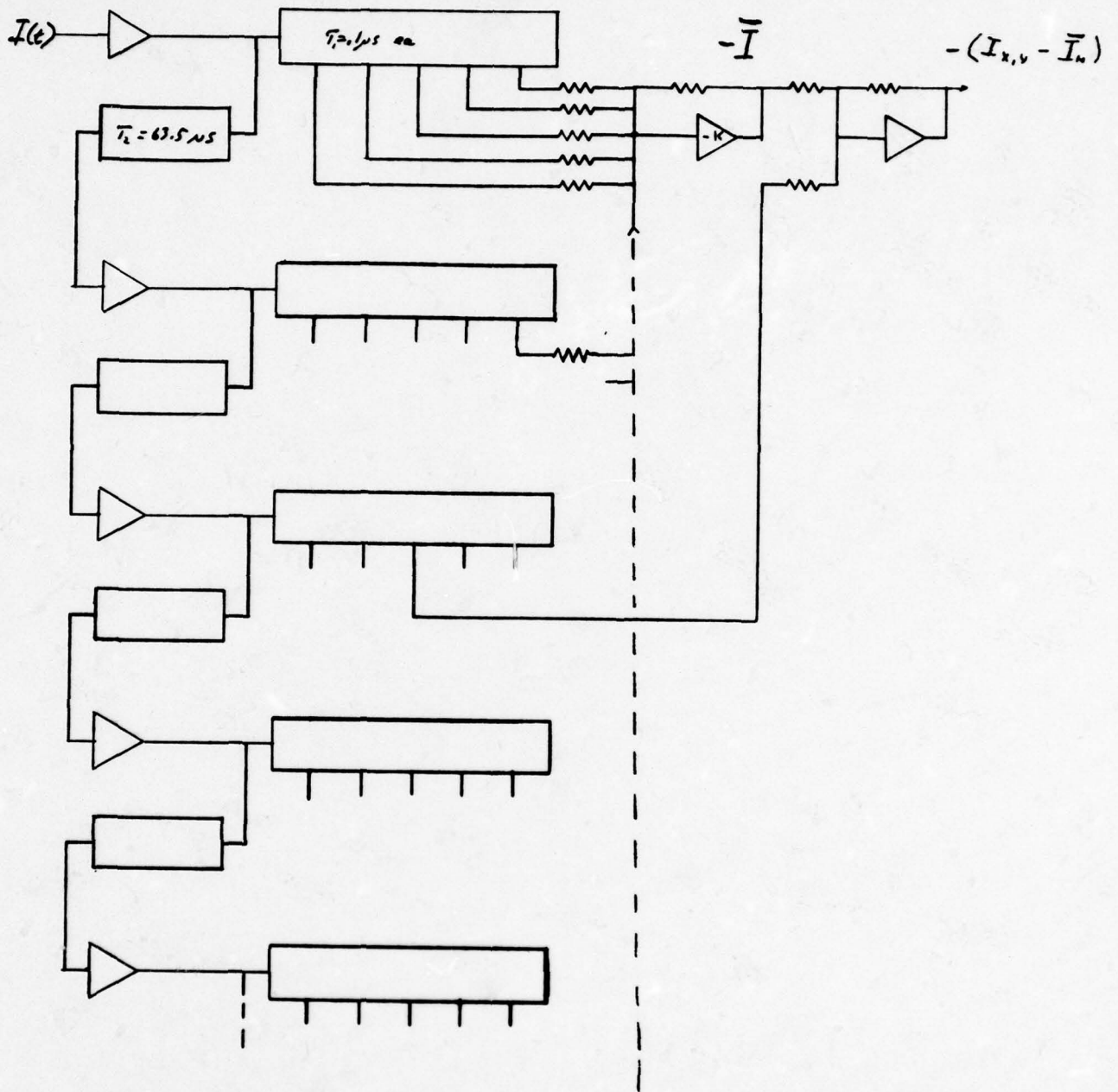


Figure 14. Delay Lines for Obtaining a Matrix of Pixel Data

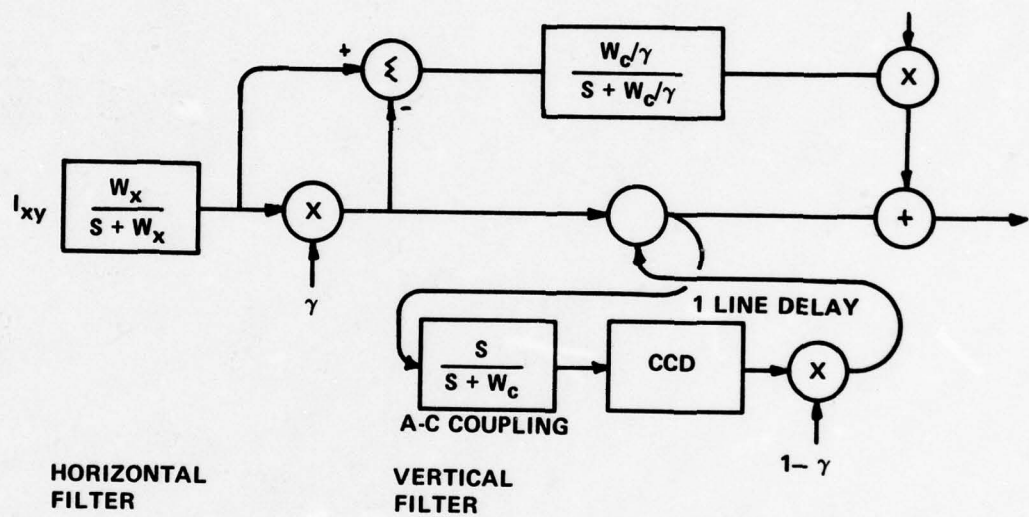


Figure 15

Two-dimensional recursive filter.

(after Soland, et al⁴⁶)

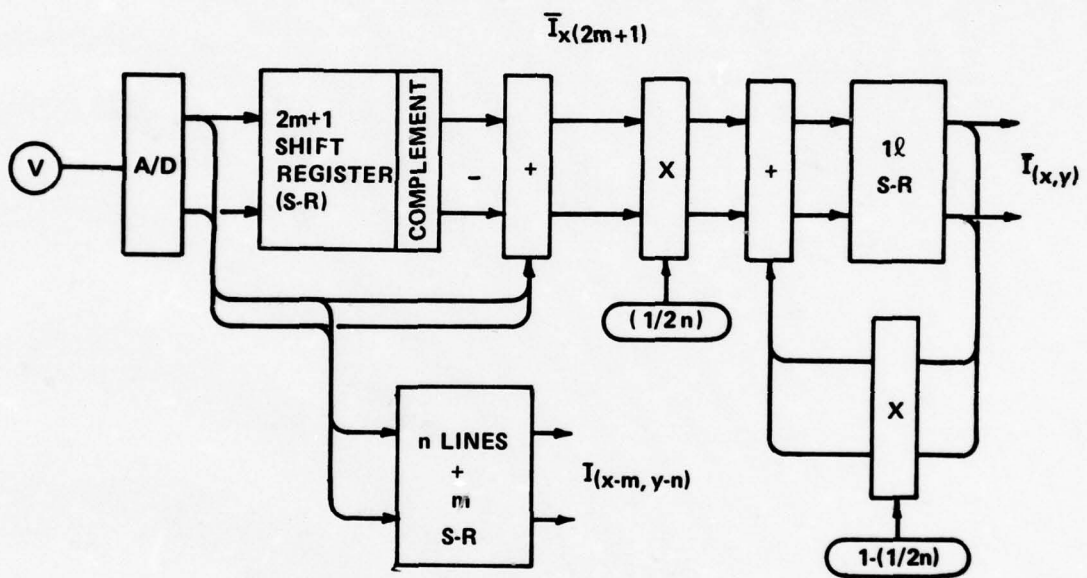


Figure 16

Two-D recursive averager.

Transients occur at the left edge and the top, because the intensity values there are likely to be different from those at the right edge and bottom of the scene. Edge mean values could be stored and inserted at retrace if necessary to preserve the whole FOV.

Similar scheming leads to a network (Figure 17), for obtaining the variance (related to the standard deviation). Having the mean from a previous scheme, the difference between the central pixel value and the mean is taken by complementing the mean and adding it to the pixel value. The difference is then applied to both inputs of a digital multiplier⁵⁰ to obtain the square of the differences. These words are then averaged recursively, as in Figure 16, to obtain the mean of the square's. Finally, the square root is taken of this mean by forcing the square of the output to equal the mean. The feasibility of this mechanization has been shown in the analog hardware but it requires iteration, in digital hardware, which takes time. A simpler scheme should be considered, such as use of the positive and negative extremes of the area brightness.

Rectification of the amplified pixel data to find the positive and negative extremes within the window is straightforward.⁵¹ Then, the values of the most positive (white) and most negative (black) peaks would be controlled to maintain optimum contrast-enhancement gain.

Hardware for Software Controlled Processing

In a recent review of digital imaging processing, Andrews³⁰ indicates schematically a typical RAM pictorial refresh station that provides stored function processing, pseudocolor and zoom options. A thinly disguised commercial comment indicates that the system is available from the Comtal Corporation, Pasadena, California. No useful details are given.

Stanford Technology Corporation⁵² also advertises an image computer which can work with a host computer to provide numerous image processing options.

Neither of these systems would be suitable for condensing into an airborne pod, but either would be useful for refining algorithms and parameters before freezing designs of dedicated hardware.

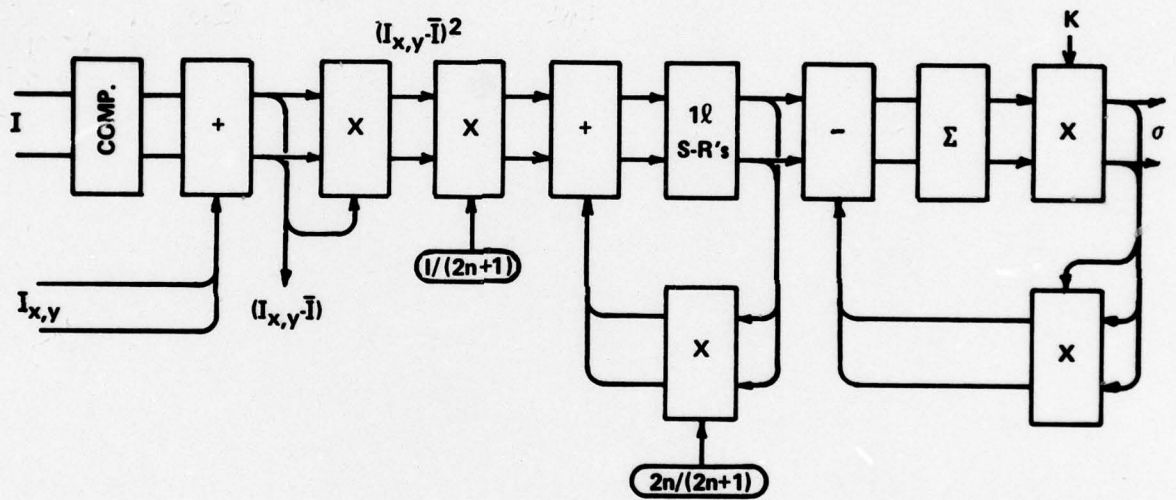


Figure 17. Scheme for Standard Deviation or R-M-S Value

Probably an array of microcomputers could be made to execute simple algorithms fast enough on a ripple phase basis. The Plessey MIPROC-16⁵³ executes four instructions per microsecond.

Smith⁵⁴ gives an adaptation to two-dimensional data of a one-dimensional digital filtering method. The method could aid enhancement of contrast by reducing the noise ratio without reducing the target-sized data content.

Narendra⁵¹ compares two dimensional filters with separable median filters both theoretically, with digital example testing, and by estimation of hardware complexity.

A direct hardware implementation of a 2-D convolution processor is analyzed and described by Jones, Burns, and Smith.⁵⁵ Weighting functions can be modified by computer control. Their reason for emphasizing the parallel, convolution approach was that it is easier to analyze, which they do well. They do not thoroughly describe the scheme.

IV. OPTIONAL SYSTEM FUNCTIONS

Multi-spectral Contrast Enhancement

In general, a painted or mud-covered vehicle doesn't have exactly the same spectral reflectivity as foliage, ground or ground cover. Therefore, it should be possible to select regions of the spectrum where the differences can be amplified. A three-band system was constructed and tested by Williamson and McCanless.¹¹ Target contrast could usually be increased, but due to AGC logic problems there were conditions found which led to false detections. To utilize a three-band approach would require incorporation of either three cameras, or a color camera, or a synchronously changing filter. None of these options appears feasible in the space limitations of present pods except at reduced resolution.

Pseudocolor

In certain applications of TV cameras it is possible to create an increase in feature awareness by converting the luminance signal levels to a trio of chrominance signals and displaying them on a color monitor. Usually the brighter colors, yellow, are used to represent higher luminance levels and the ends of the spectrum, red and violet, are used to represent lower luminance. Pseudocolor display is more realistically applied to IR scanner video than to monochrome TV.

Examples of pseudocolor display systems are ISI model VP-8²⁶ and CVI models 201 and 404A.²⁴

A word of caution: the eye has less resolution of a color image than a monochrome image because several color sensors in the fovea are required to make up a combined signal for chrominance interpretation.

Instant Replay for Visual Search

A video disc recorder with multiple read/write heads can be used for storage of search camera scenes and instant replay for target screening. An example of a flexible disc video recorder is the TRAX¹³ which can have four heads, servoed under stored program control.

In the near future it may be feasible to construct a solid state digital memory with sufficient capacity in a practical size. It would have the advantage over analog recording of no increase in noise. A scheme to keep down memory size would be to store only new scenes taken when the image is still.

Image Motion Compensation and Scene Stabilization

If the sensor optical system is on a stabilized platform, image motion can be reduced by tracking any source scene detail. Otherwise resolution will be reduced by motion. Post processing of successive scenes can restore some of the resolution,³⁰ but S/N will not be as good as would have been the case with a stationary image.

In the system diagram, Figure 1, the components used would be the tracker, or an area correlator, if available, and the platform servo, and possibly a moving target indicator (MTI).

In the case of a moving target, one would simply track the moving target, after its detection by the MTI. Then the target contrast would improve inherently because the other scene details would be blurred by the image motion.

Moving Target Indicator (MTI)

The operator's eye does a good job of moving target detection, and the improvement ratio of an artificial MTI is not known by us. However, some systems may have space and budget available for a moving target indicator.

The scheme of an MTI is simply to store one image and subtract it from the next image, amplifying the difference signal.

Several mechanizations are available, both analog and digital. The MTI may be a feature of an instant replay system, which is most likely to use analog image recording, at least in early generations. Again there are options: rigid disc or flexible disc.¹³ Probably, but not certainly, the flexible disc machine would be the more vibration tolerant. Either could be isolated from some of the vehicle vibration.

Any digital frame grabber can be augmented to form an MTI if writing the next frame can go on while reading the last frame. Examples of frame grabbers are the CVI, model 274, the Quantex, model DS-20F, ISI VDI-200, and Grinnel Systems model GMR-37.

The STEP-STARE approach to moving target detection has been analyzed by Janssens;⁵⁶ however, parts of the analysis apply to loss-less atmosphere and to a hypothetical IR detector of unknown array size rather than to a TV, of pre-determined resolution. The approach should be useful in studying pop-up, step-stare, and instant-replay systems.

Displays

Until autoscreening becomes improved and miniaturized another level, search TV systems must employ a man in the process. Therefore the display device must be optimized for the man.

Displays, or monitors, for use in airborne systems, should be improved over laboratory grade monitors in at least three ways: (1) inherent brightness ratio at full resolution, (2) reflection reduction, and (3) intensity signal transformation.

The key to high spot brightness and resolution is a combination of high beam voltage and a good, aluminized phosphor.

Examples of bright and sharp monitors are the Conrac 8" series,⁵⁷ the AF Display 60606,⁵⁸ Tektronix model 634,⁵⁹ Moniterm Corporation model VR-800,⁶⁰ and Infodex model 7715.⁶¹ There are countless others but a detailed comparison is not familiar to us at this time.

Reduction of reflection of ambient light helps preserve the inherent spot contrast under field or airborne conditions. Some shielding of sunlight is necessary, but filters will help. Examples are the green phosphor - green filter system⁶² of Hartman Systems Division of A-T-O, Inc., the microlouver system of 3M Company,⁶³ and a multilayer spectral filter system by Optical Coating Laboratories, Inc.^{64,65}

Intensity signal transformation⁶⁶ can be applied to offset nonlinearities of monitor or detector response and to offset the logarithmic visual response. However, it is not anticipated that further transformation would be necessary after application of LAGBC.

Target Autoscreening

Numerous studies are in progress on ways to eliminate the man in the loop or reduce his work load in detecting targets. This burden occurs mostly in the ground station of a two-part reconnaissance system in which the scanning part is a high resolution sensor being flown at high altitude and the analysis part, on the ground, has unlimited space for equipment. The volume of data is beyond human processing capacity.

The general technique of autoscreening is either heuristic, mathematic, or syntactic, with different sequences and criteria being tried by competing groups.

At the present time none of the techniques or approaches reported is a candidate for use in real time or instant replay, either because of size of equipment, processing time, or limited success rate. Evaluation is difficult because the viewpoint geometry mentioned above is too different from that of the helicopter at low altitude. Studies of processing for autoscreening being conducted by Dr. L. Minor of Advanced Sensors Directorate, of MIRADCOM, may change this situation. Meanwhile the literature collected will be listed without detailed analysis and ranking as to applicability.^{67,68,69,70,71}

V. SUMMARY AND RECOMMENDATIONS

Specific approaches toward developing a more successful target finding TV set have been explored. To a limited extent the performance factor of each stage of a search set multiplies with all the others.¹ Therefore, apparently the stage having the greatest margin for improvement should receive the greatest attention. Though limitations will be encountered that prevent realization of the full gain product, an estimation has been made of the possible gain in contrast or contrast range by changes in each stage of a hypothetical TV camera and display system, summarized in Table I.

It is recommended that the components, and their properties, of a given search TV set be compared with the assumed standard set to determine if there is room for direct improvement. The gain range estimated for LAGBC is based on the S/N of typical TV cameras (40 db). If a better camera or a frame averager is used, greater gain can be applied in LAGBC. Similarly, if blemishes are reduced by a pixel sensitivity equalizer, more gain can be used in LAGBC.

Prior to initiating hardware development of a pixel sensitivity equalizer or a LAGBC controller, tests should be made of the algorithms digitally, even though present systems in the Army laboratories won't process in real time. Specifically, the schemes for pixel sensitivity equalization probably can be tested at WSMR and algorithms for LAGBC can be tested in Advanced Sensors Directorate.

The digital hardware approaches to LAGBC and to pixel sensitivity equalization have been outlined in sufficient detail that demonstration hardware can be designed in a two-stage program. One stage could produce laboratory style packaging suitable for testing on piped-in video and a second stage could reduce the hardware to pod-retrofitted, flight qualified style.

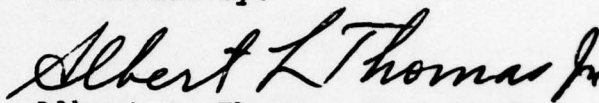
Table I. Estimated Contrast Enhancement Ratio

<u>Stage</u>	<u>Gain (all approx.)</u>	<u>Condition or Component Change (typical starting condition assumed)</u>
Spectral selection	2	600-900 nm vs. 400-900 nm
	3	800-1200 nm vs. 400-900 nm
Lens	2	70% at 50 lp/nm vs. 35% at 50 lp/nm ¹⁸
Apodization	N/A	
Detector	3.5	P8203 ²¹ vs. 4532A ⁵ vidicon (ST)
Amplifier	2-10	OEI 9913 ²² vs. typical standard
Aperture compensation	~2	Delay line method ²⁹ vs. high peaking
Image stabilizer		Use tracker with platform
Multiframe averager	2	Average 4 frames
Sensitivity equalizer	10	Blemish specs. ²¹ ignore <10% contrast. Stage should reduce 10% blemish to 1% or less.
LAGBC	~12-15	Stop gain at S/N = 3.5
Display selection	5-10	Type 60606 ³⁸ vs. typical TV monitor

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Submitted by:



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Birmingham, Alabama
June 1, 1979
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