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TITLE: CHARACTERIZATION OF NEW FOCUS PROJECTION AND SCAN (FPS) VIDICONS FOR SCIENTIFIC IMAGING APPLICATIONS

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Characterization of new focus projection and scan (FPS) vidicons for scientific imaging applications

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ABSTRACT

Several new photoconductors now commercially available as targets in Type 7803 Focus Projection and Scan (FPS) electrostatically focused vidicons have been characterized for use as radiometric sensors in transient illumination and single frame applications. These include Saticon (Se + As + Te), Newvicon (ZnSe), Pasecon (CdSe), and Plumbicon (PbO). Samples from several domestic and foreign manufacturers have been evaluated for photoconductive response time and responsivity at selected narrow wavelength bands, including 410 nm, 560 nm, and 822 nm. These data are compared with performance data from older target materials including Sb_2S_3 and silicon. The effect of bias lighting on sensitivity and transfer curve slopes for single-event pulsed light stimulas are presented. Dynamic range and saturation limits as functions of beam aperture, target voltage, and filament current are also discussed.

1. INTRODUCTION

The generic 7803 type focus projection and scan (FPS) vidicons are used extensively[1-3] in nuclear weapons test programs involving fast (1.6 to 16 ms TV fields of 256 scan lines) telemetry of video signals from remote underground tests. This type of vidicon, electrostatic deflection and magnetic focus was originally selected for use primarily because of the many degrees of freedom available in controlling raster size, location, format, and read-out speed.

Since 1985, several domestic and foreign manufacturers have developed prototype 7803 configuration FPS vidicons which formerly were produced exclusively by General Electric. Targets available from GE were specially-processed Sb_2S_3, and epitaxial silicon diode wafers. Target selection now includes Sb_2S_3, Silicon, and Saticon from Thomson-CSF, Sb_2S_3 and Silicon from English Electric Valve, Sb_2S_3, Saticon, and Pasecon from Heimann-MII, Sb_2S_3, Newvicon, and Plumbicon from Amperex, and Sb_2S_3 from MII-Teltron.

We have characterized photoconductive lag, spectral responsivity, and dynamic range of several vidicons from each manufacturer and have compared their performance with that obtained from GE vidicons. For the GE vidicons, improvements in sensitivity and dynamic range were investigated by studying the effects of increased beam apertures in the triode electron guns. The horizontal resolution as a function of beam aperture was measured to identify trade-offs between range and resolution.

All tests of FPS tubes described in this report were performed using a single-field fast read-out TV camera (Xedar Model XS-503) with 256 active scan lines in 3.2 ms. The amplifiers are flat (not peaked) within ± 0.5 db from ≈100 KHz to ≈25 MHz with the upper -3 db corner frequency at 30 MHz. The preamplifiers have a linear dynamic range of 250/1 with noise of 20 mV pp and saturation at 5V. The tests were performed using only pulsed light sources (100 ps to 5 μs full width at half maximum (FWHM)) at selected wavelengths to determine transient responses to spectra used in field applications. These include NE-102 fluors with peak emission at 430 nm and P-20 phosphors with a 560 nm peak.

2. BEAM APERTURE EFFECTS

In 7803 type triode gun FPS vidicons, the electron beam diverges as it leaves the crossover point and proceeds towards the target. A metallic disc with an aperture in the center is located in close proximity to the crossover. The aperture transmits only the central region of the cathode beam, acting partly as a spot-size defining aperture and partly as an aperture-stop to define the maximum divergence angle and cross sectional area of the beam. Ideally, the crossover (not the aperture) is focused at the target. Therefore, varying the beam aperture diameter should not affect image focus but should merely control the amount of electrons in the beam. In principle, the beam aperture controls the electron flux roughly analogous in operation or function to the familiar light aperture or F/number adjustment in an optical lense. Our measurements, however, indicate that most vidicons reimage a mixture or convolution of the beam crossover diameter and the disc aperture.

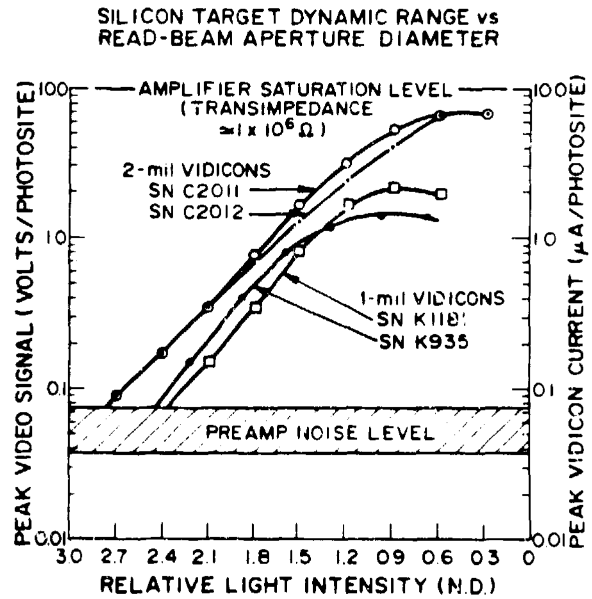

Fig. 1. Dynamic range and gain vs. read-beam aperture diameter for 1-mil and 2-mil glass faceplate silicon vidicons.

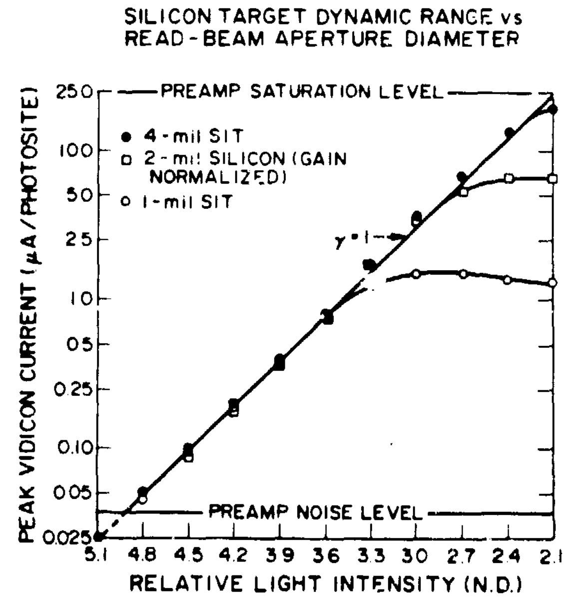

Fig. 2. Dynamic range vs. aperture diameter for 1-mil and 4-mil fiber optic faceplate SITVs.

Our studies[2] of the effects of aperture size used mostly silicon targets rather than Sb_2S_3 because of the wide variations possible in Sb_2S_3 responses such as photoconductive lag, spectral responsivity, and target capacity. Two lots of General Electric vidicons (30 silicon and 15 Sb_2S_3) with fiber optic input windows and with apertures diameters of 1, 1.5, 2, 3, or 4-mils were evaluated.

Several silicon-intensified-target vidicons (SITVs)' of various aperture size were also evaluated to provide a larger statistical base for the characterization of aperture effects.

Increases in dynamic range of ≥ 3.5X were measured for 2-mil tubes when compared with 1-mil tubes as shown in Fig. 1. This compares well with the predicted 4X increase from comparing areas for the two apertures, assuming uniform electron density in the beam and uniform charge on the target. The 2-mil tubes also showed ≈2X the sensitivity observed for the 1-mil tubes. This was attributed to scanning the target with a beam spot ≈2X larger in diameter thereby providing a larger leading edge for neutralizing a larger area of charged surface as the beam moves laterally across the target. The comparison between 1- and 3-mil vidicons again showed both gain and dynamic range increases.

Similar tests on 1- and 4-mil SITV's showed increases in dynamic range only with no changes in sensitivity as shown in Fig. 2. This, we feel, represents the ideal case where the crossover (not the aperture) is reimaged at the target. A normalized transfer curve for a 2-mil silicon vidicon is included to compare saturation limits for the three areas corresponding to the 1-, 2-, and 4-mil diameters.

The variant responses indicate that the scan beam spot size at the target is indeed a function of both the aperture and crossover images. Although all tubes were operated alike, the SITVs appeared to focus primarily the crossover (Fig. 2) while most vidicons more nearly focus the aperture (Fig. 1).

Plots of average resolution vs. dynamic range for several silicon tubes of various apertures indicates that the resolution degrades by the ratio of aperture diameters and the dynamic range increases by the ratio of aperture areas. For example the CTF at 9 lp/mm for 1-mil tubes is ≈83% while the 2- and 4-mil tubes show similar CTF, ≈79% and 85% respectively at 4.5 and 2.5 lp/mm.

The SITV tubes used in this study have 25-mm diameter photocathodes and 18-mm diameter silicon targets. Demagnifying electron optics (M = 0.72) in the image section increase the spatial frequency (of resolution bar patterns focused on the photocathode for resolution measurements) at the target. The spatial frequencies of interest for observing aperture

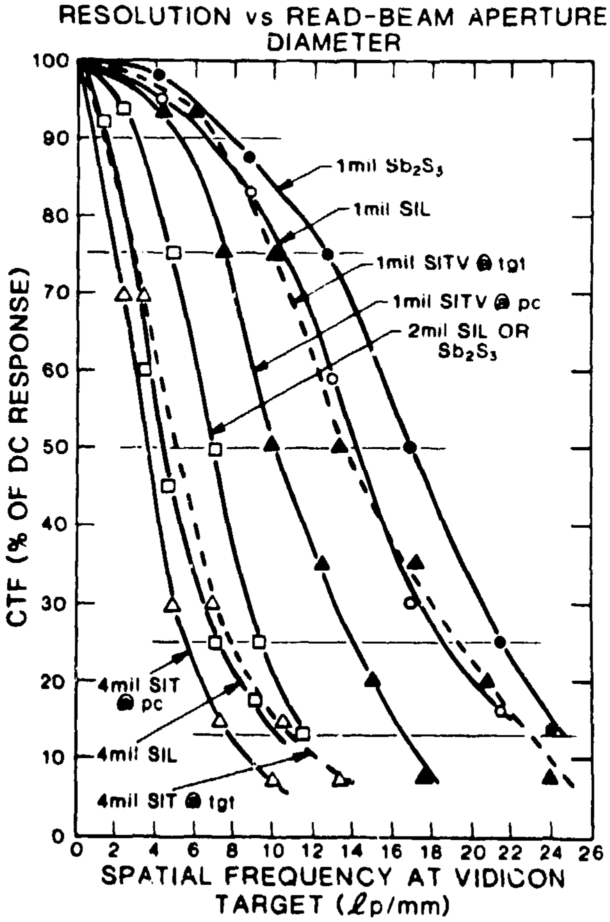

Fig. 3. CTF plots for several vidicons of various aperture size and target material.

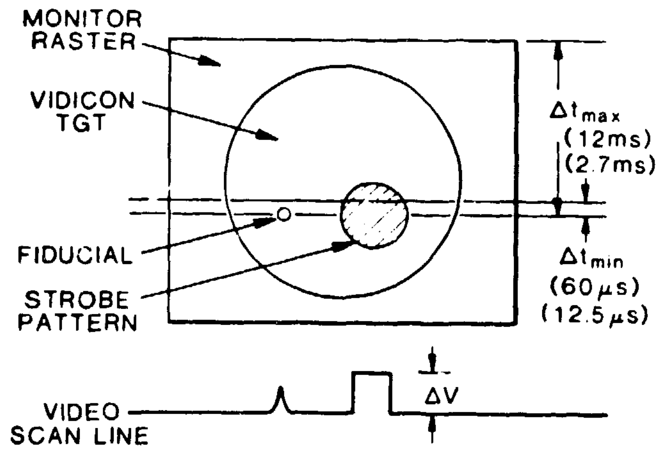

Fig. 4. Photoconductive lag or "soak" setup. A Xenon flash is imaged onto the vidicon target near the perimeter opposite the top of the raster. This allows the target soak period to be controlled by raster speed. The strobe is flashed during the vertical sync interval (scan is then at top of raster) or anytime up to one scan line before intercepting signal from the strobe. The signal (ΔV) through the strobe pattern at the fiducial location is measured to plot the photoconductive lag.

effects are those at the target, therefore the frequencies at the photocathode are corrected by the above magnification to give frequencies present at the target as depicted in Fig. 3.

The slopes of the various CTF curves vary with spatial frequency. All curves merge at the lower frequencies where the maximum beam diameter apparently is much smaller than the bar widths in the imaged resolution pattern. This indicates that all apertures adequately resolve the image. However, at higher frequencies the resolving power of the various apertures appears to follow the ratio of their diameters as expected. Table I indicates the spatial frequency required for a given CTF (as highlighted in Fig. 3) from tubes with 1-, 2-, and 4-mil apertures.

Table I. Aperture resolving power at selected CTF levels

CTF (% of DC)	Bar Frequency Resolved (ℓp/mm) 1-mil Aperture	2-mil Aperture	4-mil Aperture	Resolution Ratios 1 mil / 2 mil	1 mil / 4 mil	2 mil / 4 mil
12.5	23.0	11.5	10.5	2.0	2.19	1.10
25.0	19.0	9.5	7.0	2.0	2.71	1.36
50.0	14.0	7.0	4.5	2.0	3.11	1.56
75.0	10.0	5.0	2.5	2.0	4.0	2.0
90.0	7.0	3.5	1.7	2.0	4.12	2.06

3. PHOTOCONDUCTIVE RESPONSE TIME

As indicated in our earlier works[2,3], the photoconductive lag, response time, or soak varies with target material and operating conditions. We have thoroughly characterized the GE Sb_2S_3 and silicon targets over a period of several years (1970 to present) in our TV systems. With the advent of new sources of FPS vidicons the task of evaluating new Sb_2S_3 photoconductors resurfaced. In addition, the newer target materials required characterization under pulsed lighting conditions as well.

The amplitude as a function of soak (time between excitation of the target with a pulse of light and interrogation of the resulting signal charge) was measured with the setup shown in Fig. 4. The fiducial is a small aperture used to identify the same spatial location on the strobe pattern to minimize errors from non-uniform intensities over the strobed surface. The length of time, Δt, from excitation to interrogation was variable from one scan line to approximately three fourths of a TV field with this arrangement.

The FPS vidicons are intended for use in fast read-out applications where the line and field times are much shorter than conventional RS-170 video. The various sources of Sb_2S_3 targets, as well as new target materials in the FPS configuration, were evaluated under such conditions with a range of Δt from ≈ 12.5 μs to ≈ 2.7 ms. The absolute response-times cannot be accurately determined without longer soak intervals. However, the anticipated usage of FPS vidicons in 3.2 ms field applications require characterization in the 1 to 3 ms range. Consequently, tubes with slow photoconductive response can severely compromise sensitivity at fast scan rates. Typical Sb_2S_3 data are plotted in Fig. 5 and the non-Sb_2S_3 data are shown in Fig. 6.

4. RESPONSIVITY MEASUREMENTS FOR Sb_2S_3 VIDICONS

The Sb_2S_3 vidicons from each manufacturer were compared with one randomly selected standard GE 2-mil vidicon. (After an R&D phase with GE, special processed Sb_2S_3 with low lag, high blue response, and 1.5 and 2-mil apertures were selected as our standard FPS vidicons.)

The white light transfer curves (for pulsed light) for Sb_2S_3 FPS vidicons from the five manufacturers are shown in Figs. 7-10. The measurements were made using a Xenon strobe of ≈5 μs FWHM. All vidicons were operated with the same bias conditions. The target voltage was

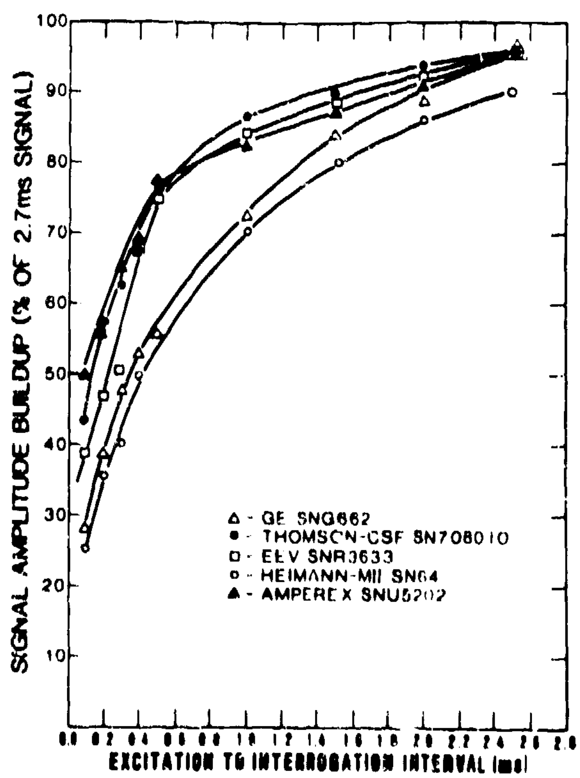

Fig. 5. Typical photoconductive lag for FPS Sb_2S_3 vidicons.

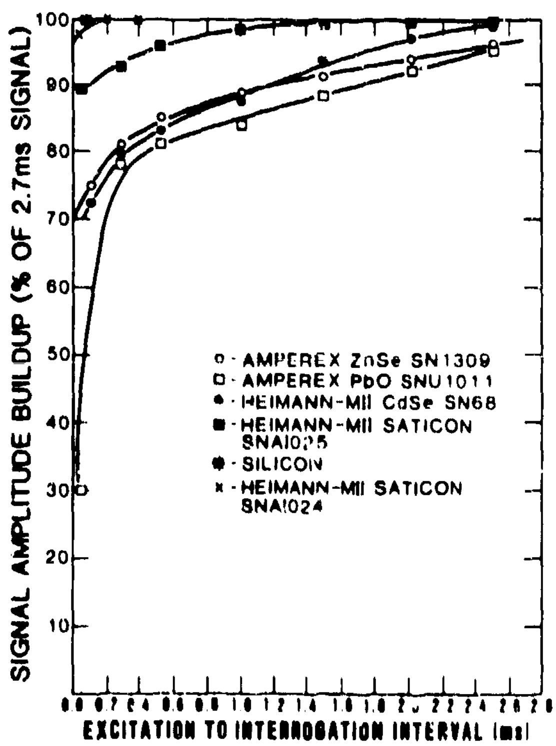

Fig. 6. Typical photoconductive lag for non-Sb_2S_3 FPS vidicons.

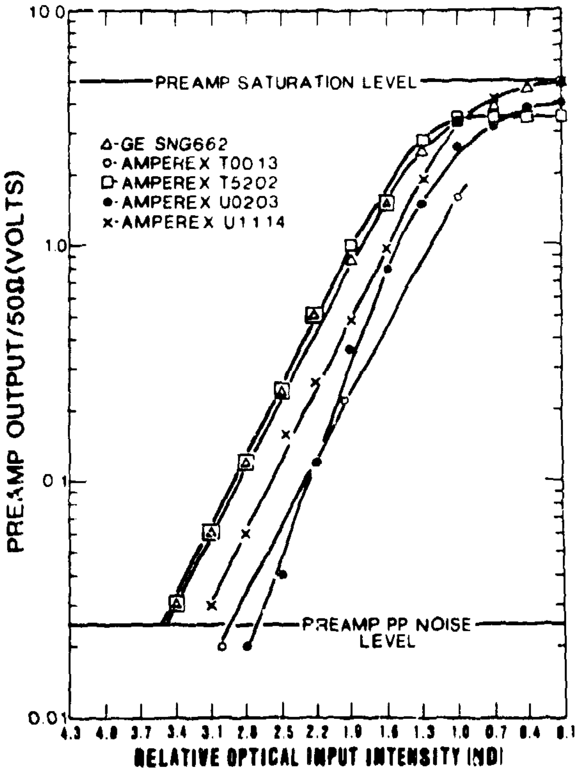

Fig. 7. Amperex Sb_2S_3 transfer curves.

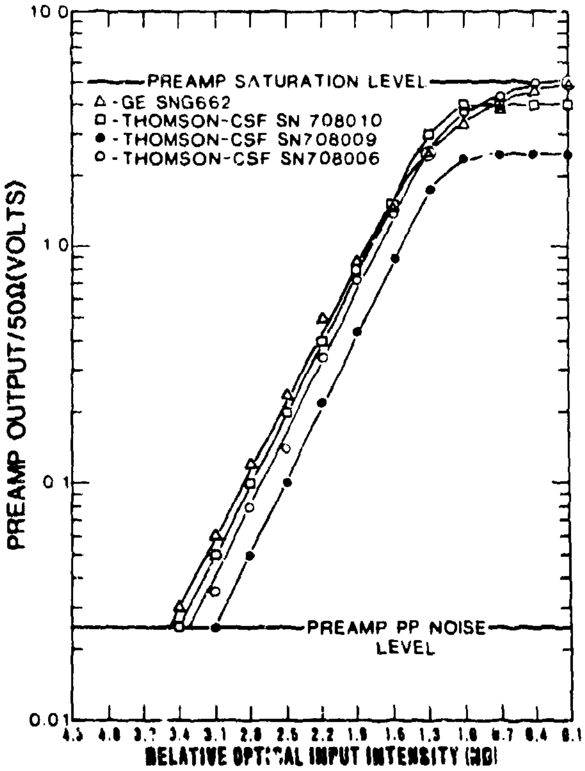

Fig. 8. Thomson-CSF Sb_2S_3 transfer curves.

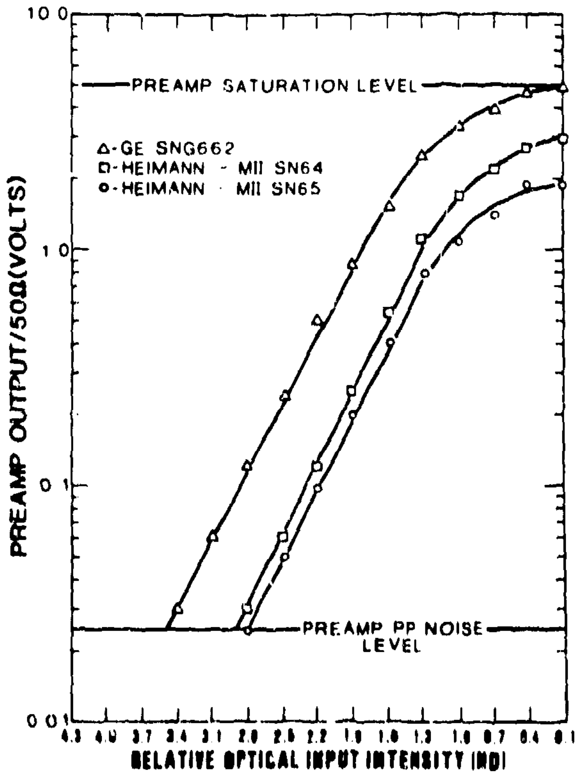

Fig. 9. Heimann-MII Sb_2S_3 transfer curves.

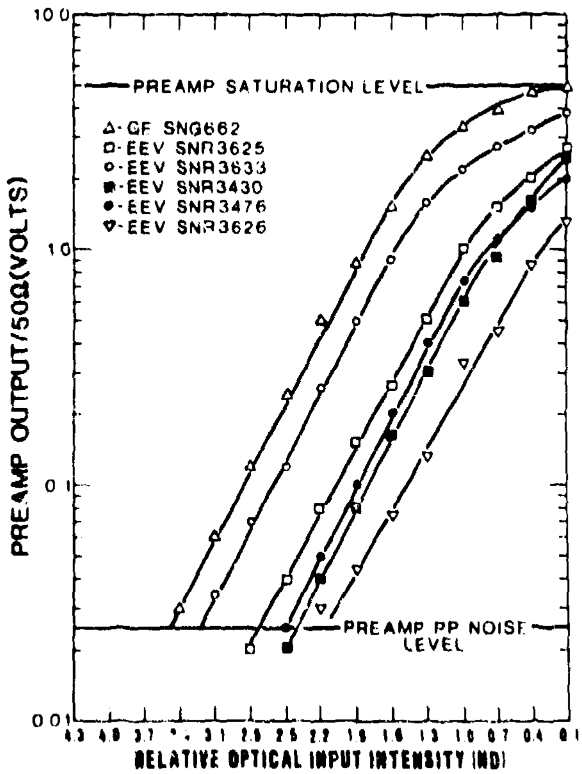

Fig. 10. EEV Sb_2S_3 transfer curves.

was +45 V with respect to the cathode, the beam current was maximum (≈0 to -5V bias on Grid 1), the targets were overscanned, the soak period was ≈2.7 ms, and the filament current was 95 mA.

The GE, Amperex, and Thomson-CSF tubes showed similar sensitivity and gain. However, the GE 2-mil tube has a much larger dynamic range, probably due to its larger aperture. Note that the preamplifier saturates before the GE vidicon reaches the limit of its transfer curve. The EEV and Heimann-MII vidicons have similar dynamic range but are approximately 2X and 4X less sensitive respectively than the GE vidicon. An Amperex 2-mil tube (SN U1114 of Fig. 7) showed dynamic range similar to the GE 2-mil tube but with slightly less gain.

To eliminate possible gains from differences in target spectral bandwidths the broad band strobe light was filtered to provide two narrow bands (≈10 nm wide) centered at 400 nm and 530 nm. The optical energy transmitted through the filters for each pulse of light was measured with an Optronic Model 730A radiometer. The 400 nm filter transmitted 0.28 ergs/cm^2 per pulse and the 530 nm transmitted 0.12 ergs/cm^2 per pulse. The video signals obtained from the 530 nm data were normalized to expected values at 0.28 ergs. These data, which indicate individual absolute responsivities, are tabulated in Table II.

Table II Spectral Responsivities

Manufacturer	Serial #	Target Type	400 nm Signal	530 nm Signal
GE	662	Sb_2S_3	680 mV	370 mV
EEV	3633	Sb_2S_3	550 mV	280 mV
Amperex	5202	Sb_2S_3	850 mV	350 mV
Thomson-CSF	708010	Sb_2S_3	600 mV	350 mV
Heimann-MII	64	Sb_2S_3	150 mV	70 mV
Amperex	U1011	PbO	1 V	920 mV
Amperex	T4704	ZnSe	350 mV	1.3 V
Heimann-MII	68	CdSe	400 mV	130 mV
Heimann-MII	A1024	Se+As+Te	1.3 V	460 mV
Thomson-CSF	10163	Se+As+Te	1.3 V	800 mV

5. RESPONSIVITY MEASUREMENTS FOR NON-Sb_2S_3 VIDICONS

The much faster photoconductive response time of the newer targets, as indicated by comparing Figs. 5 and 6 should improve responsivity at the fast FPS scan rates. Also, as found in the commercially published spectral sensitivity curves, the quantum efficiency and responsivity of several exceed that for Sb_2S_3 at the green and near infrared wavelengths.

The white light transfer curves for each target type with the green and blue responses observed for each are in Figs. 11 through 15. These data are plotted against the standard GE 2-mil Sb_2S_3 vidicon.

For these target materials that operate at very low dark current levels (compared with Sb_2S_3 targets) a steep superlinear transfer characteristic at lower light levels was observed. In some extreme cases the transfer curves terminate prematurely resulting in reduced dynamic range as observed in Fig. 12 for PbO tubes, in Fig. 13 for CdSe and in Figs. 14 and 15 for Saticon tubes. The superlinear response for silicon vidicons has been noted before[2,4]. We attributed it to light-induced charge that is used to fill trapping centers in the target material. (Normally, these are filled with random carriers from high quiescent dark current as with Sb_2S_3 vidicons.) For pulsed light applications where a single pulse of light writes the target this can be disastrous. We briefly experimented with adding CW bias light to fill traps, thereby allowing the light-induced charge to be conserved for signal. The bias light extended the dynamic range for PbO vidicons by approximately a factor of ten as indicated in Fig. 12. For ZnSe vidicons, bias lighting appears to decrease the transfer curve slope at lower light levels from nearly linear to sublinear as shown in Fig. 11. There also appears to be an effective gain increase in ZnSe from bias lighting.

The effect of adding bias light is demonstrated in Fig. 16. The signal from the pulsed light source increases in amplitude as the bias light strength is increased. With no bias light, this target shows no signal from the pulsed source. Understanding the physics associated with these phenomena as well as detailed experimentation with absolute magnitudes of bias lighting required for all targets under different operating conditions was beyond the scope of this study. It was our intent to point out that some mechanism such as bias lighting is necessary for some target materials if they are to compete effectively with Sb_2S_3 targets in pulsed light applications. Other works[5-8] reported the use of bias light to improve lag (either photoconductive or read-out components) characteristics of silicon, saticon, and PbO vidicons. However, to our knowledge, improvements in extending dynamic range

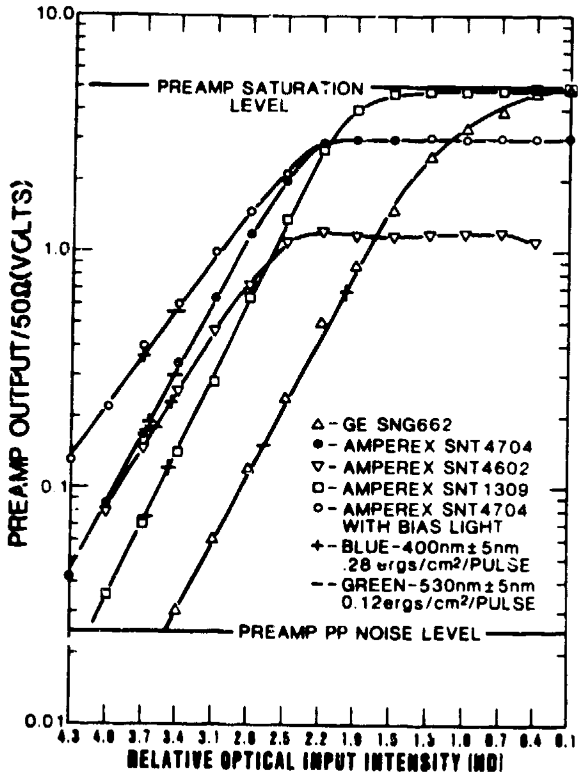

Fig. 11. Amperex Newvicon transfer curves.

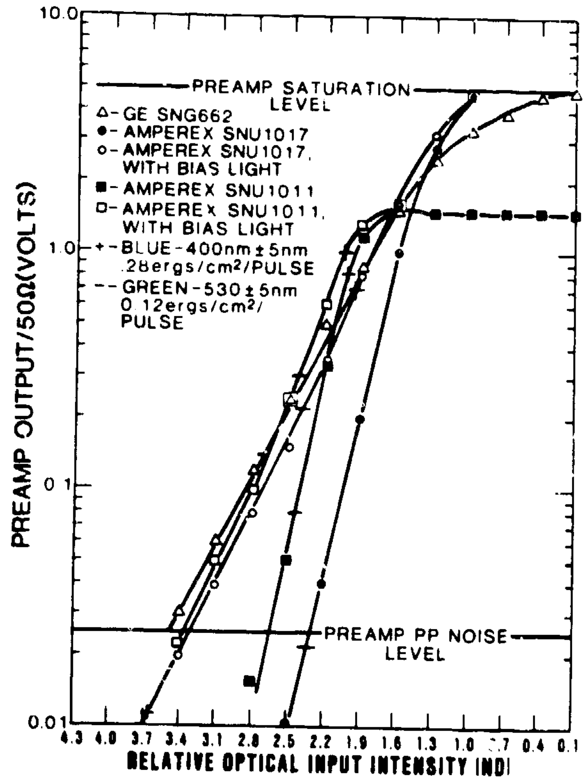

Fig. 12. Amperex Plumbicon transfer curves.

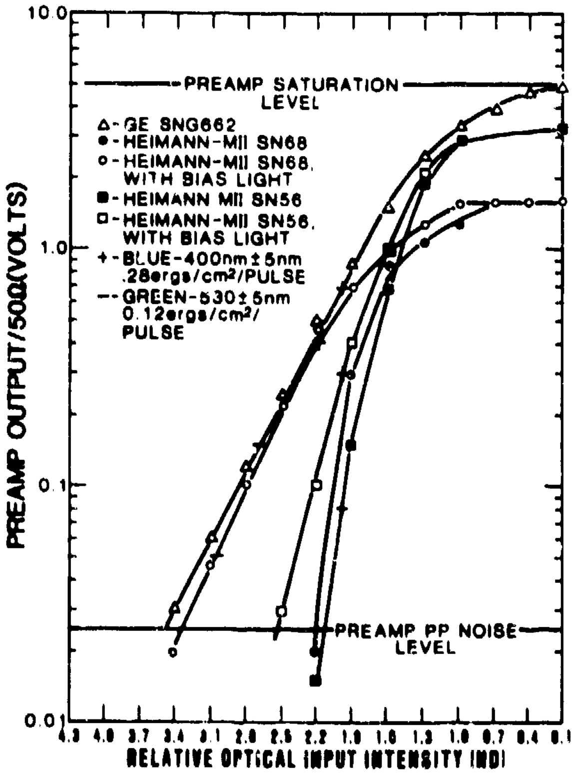

Fig. 13. Heimann-MII Pasecon transfer curves.

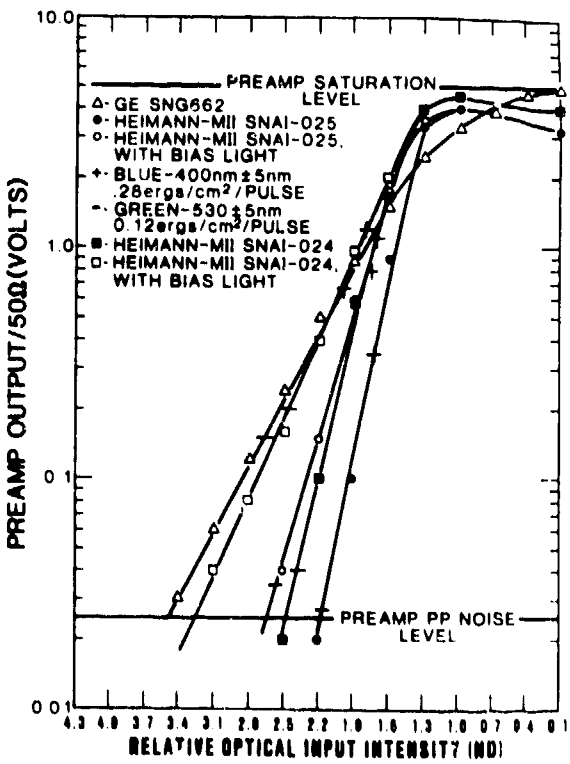

Fig. 14. Heimann-MII transfer curves.

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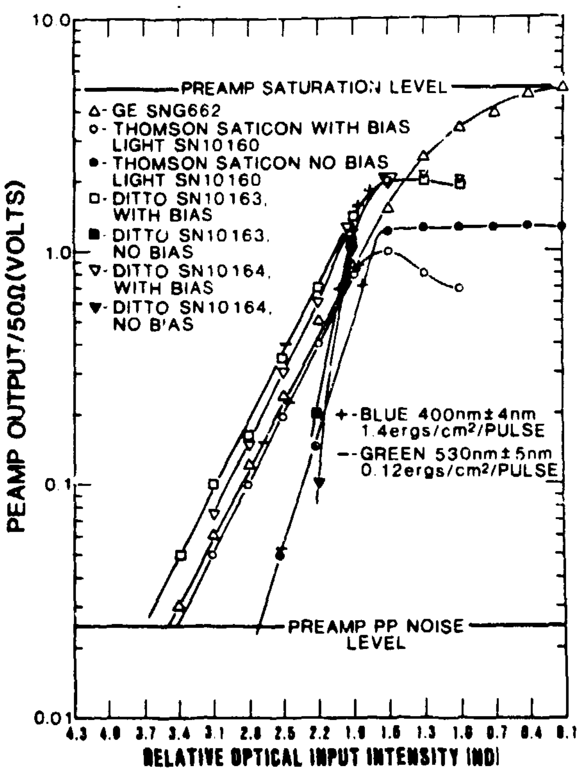

Fig. 15. Thomson-CSF saticon curves.

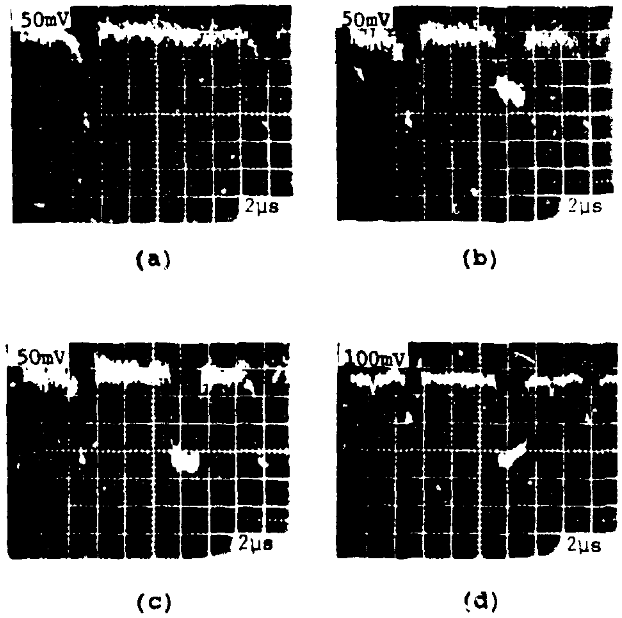

Fig. 16. Effect of CW bias lighting on single pulse (strobed) response for Heimann CdSe SN 68. No bias light is added in (a), an arbitrary bias is added in and attenuated by ND 3.1 in (b), ND 2.1 in (c), and ND 0.9 in (d).

at the lower end of the vidicon transfer curves by the use of bias lighting has not been reported elsewhere.

6. FILAMENT CURRENT EFFECTS ON SENSITIVITY AND SATURATION LIMITS

The preceding tests were conducted with filament current set to 90 mA for all vidicons. To further examine the widespread in the Sb_2S_3 vidicon performance noted (wide variations exist even among tubes from a given manufacturer), the filament current was varied and the tube output recorded.

The range selected was from 90 mA to 105 mA. Most tubes showed gradual increases in signal output as the filament current increased. However, only the EEV tubes showed marked improvement (≈3.5X the signal at 105 mA as observed for 90 mA) from the increases. The other manufacturers vidicons apparently have cathodes with flatter emission as a function of filament power. The test results for the best Sb_2S_3 vidicons from each manufacturer are plotted in Fig. 17. The voltage drops across the filaments for each of the tubes are tabulated below.

Table III Filament Current/Voltage Characteristics

	90 mA	95 mA	100 mA	105 mA
GE	6.3 V	7.0 V	7.6 V	---
Amperex	6.3 V	6.9 V	7.6 V	8.2 V
EEV	5.5 V	6.1 V	6.8 V	7.4 V
MII	6.0 V	---	7.2 V	7.9 V
Thomson-CSF	6.5 V	---	7.8 V	8.4 V

7. CONCLUSION

Beam Response

The FPS triode gun aperture influences observed for silicon target vidicons are as follows:

(A) Dynamic range is roughly directly proportional to area.

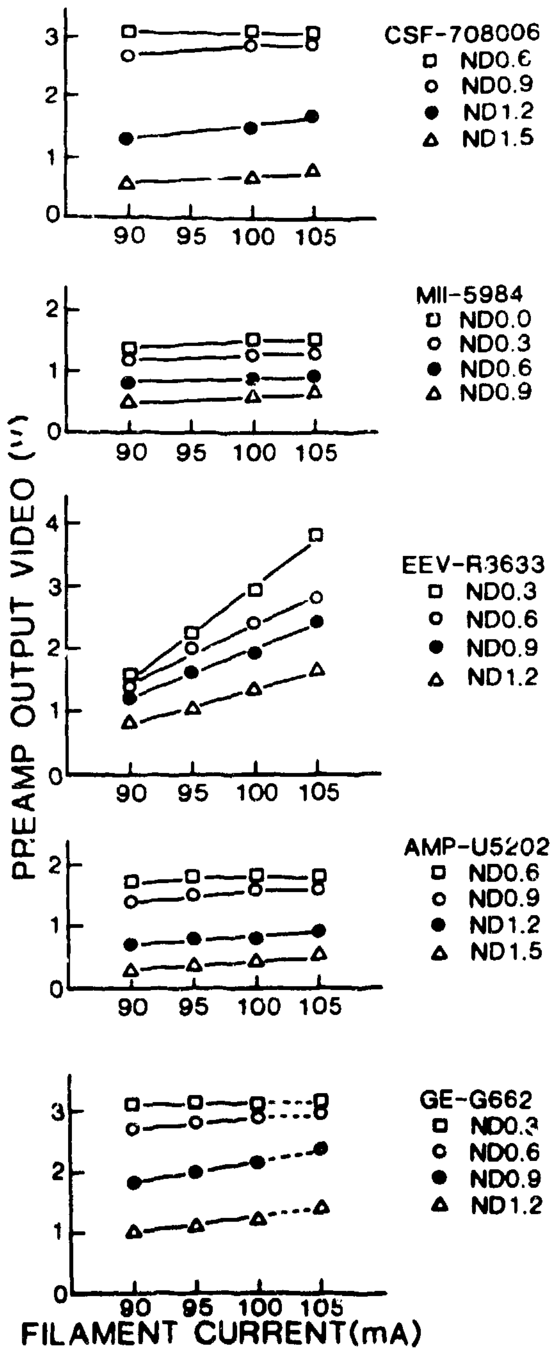

Fig. 17. Effects of filament current on vidicon saturation level. Four relative input intensities near saturation are shown for typical vidicons from each manufacturer.

(B) Resolution is roughly inversely proportional to diameter.

(C) 1-mil vidicons deliver limiting resolution of approximately 24 lp/mm and dynamic range of about 60/1.

(D) 2-mil vidicons deliver limiting resolution of approximately 12 lp/mm and dynamic range of about 240/1.

(E) No aliasing is observed with any aperture.

Soak Response

The soak performance for typical targets of each type are as follows:

(A) Silicon and saticon are the fastest, silicon requiring less than one scan line (12.5μs) and the faster saticons requiring $\approx$100μs to attain final value.

(B) ZnSe, CdSe, and PbO have similar soak curves, requiring $\approx$250μs to attain 80% to final value with 20% increase in range from 250μs to 2.5 ms.

(C) Sb_2S_3 targets require $\approx$500μs to attain 60% to final value with 40% signal increase in range from 500μs to 2.5 ms.

Filament Response

The effects of varying filament power are as follows:

(A) All vidicons showed increases in nonsaturated target signals as filament current was increased from 90 mA to 105 mA.

The EEV tube showed largest gain $\approx$200%, MII tube showed lowest gain $\approx$15%, GE, Amperex, and Thomson-CSF tubes showed $\approx$30% gains.

(B) All vidicons except the EEV tube showed saturation at higher input light intensities, even with increased filament power.

8. ACKNOWLEDGMENTS

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