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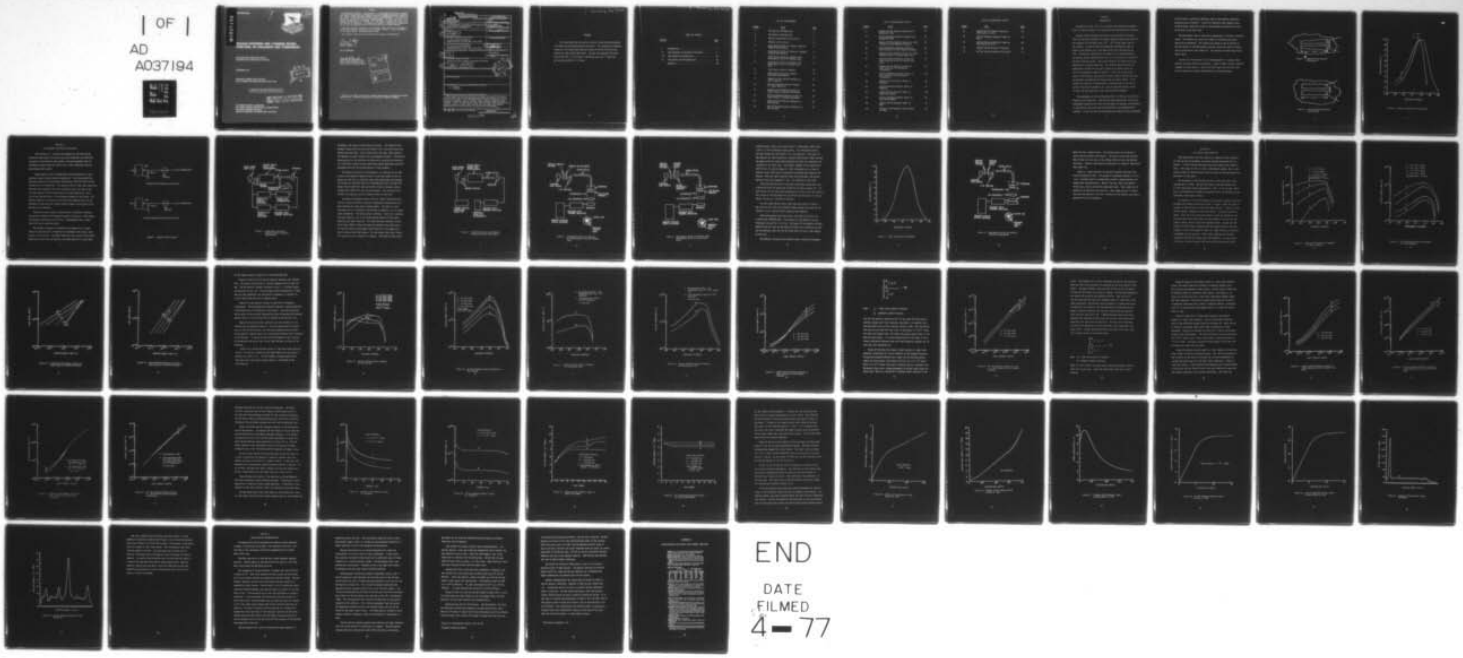

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GALLIUM PHOSPHIDE AND CADMIUM SULFIDE DETECTORS, AN EVALUATION AND COMPARISON

ELECTRO-OPTIC DETECTORS GROUP
ELECTRO-OPTICS TECHNOLOGY BRANCH

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Larry F. Reitz

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Project Engineer

FOR THE COMMANDER

Donald J. Peacock

DONALD J. PEACOCK, Actg. Chief
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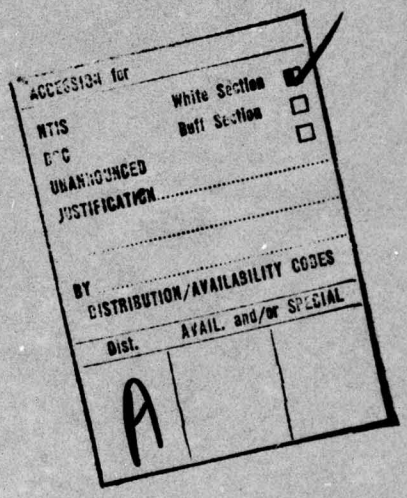
Electro-Optics Technology Branch



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This report describes the results of a series of tests performed on both a cadmium sulfide and a gallium phosphide photoconductive detector and how the test results compared. The tests performed were detector impedance, speed of response, uniformity, spectral response, signal response linearity and pulse response. Also a variable added to these tests was light signal magnitude. The general conclusion of this report was that the GaP detector had superior characteristics to the CdS device, but required more development.

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FOREWORD

This report describes the results of tests on both gallium phosphide and cadmium sulfide photoconductive detectors. This program was conducted inhouse by the Electro-Optic Detectors Group of the Air Force Avionics Laboratory under project 2001-03-05. The test was conducted from March 1975 to May 1975. The principal investigator was Larry F. Reitz who was assisted by Melvin R. St John.

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SECTION I

INTRODUCTION

The purpose of this report is to describe and compare the characteristics of gallium phosphide and cadmium sulfide photoconductive detectors.

Cadmium sulfide detectors have been in use for about 10-12 years. Their use has been principally in systems requiring high sensitivity for the detection of low light levels, 10^{-8} - 10^{-12} watts range, such as star sensors. Of course there are commercial CdS detectors used in cameras, door openers, etc., but these units are of low quality and cost. The detector described in this paper is of a high sensitivity and quality and was fabricated for use in a star sensor for a satellite attitude reference system. This device consists of a thin film of CdS deposited on a sapphire substrate. The contacts (made with tin) are deposited on the CdS film in such a manner as to leave a strip or a slit of CdS exposed as shown in Figure 1. This slit is the active region of the detector and measures 9 microns wide by 3300 microns long. The detector configuration was dictated by the sensor design. In the sensor, the long axis of the detector is perpendicular to the axis of motion of the stars; therefore, as a star crosses the sensor's field-of-view, the star image will cross the slit and be detected.

The development of Gallium Phosphide began in 1972 as an alternative detector to CdS detectors. While CdS has high sensitivity, it has many undesirable characteristics such as slow speed of response, non-uniformity in sensitivity, non-stable gain characteristics, and reproducibility problems. It was felt that the processing and doping of gallium phosphide

could be better controlled; therefore, some of the problems associated with CdS could be eliminated. It was also theorized that trapping levels could be better controlled in GaP so that detector characteristics could be tailored to the users need.

The GaP detector used in this set of experiments is strictly a research device. The detector was made from a wafer of solution grown copper doped gallium phosphide. The contacts are placed on top of the GaP in the same manner as the CdS detector with the active slit being 12 microns wide by 1270 microns long (Figure 2). The contacts are made using silver doped indium.

In order for these devices to be interchangeable in a system, their spectral responses should be comparable. Figure 3 shows a typical spectral response for both devices. The rest of this paper deals with the side by side comparison of other characteristics of these detectors.

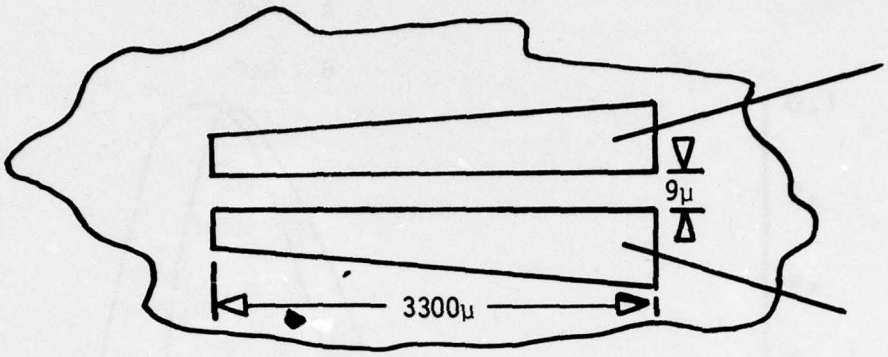


Figure 1. Cadmium Sulfide Detector Configuration

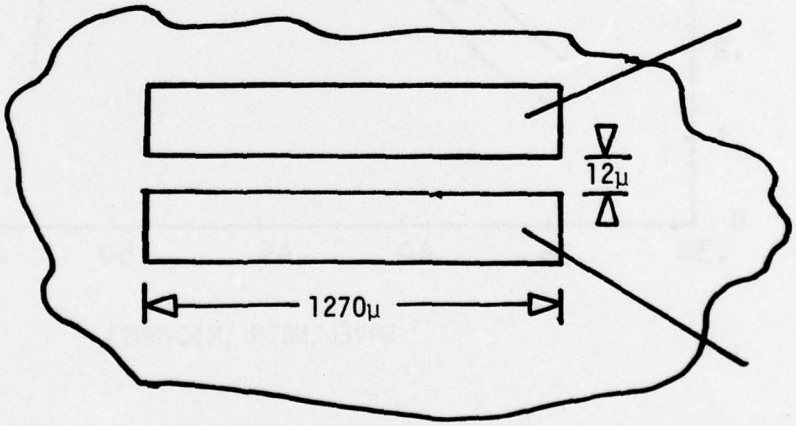


Figure 2. Gallium Phosphide Detector Configuration

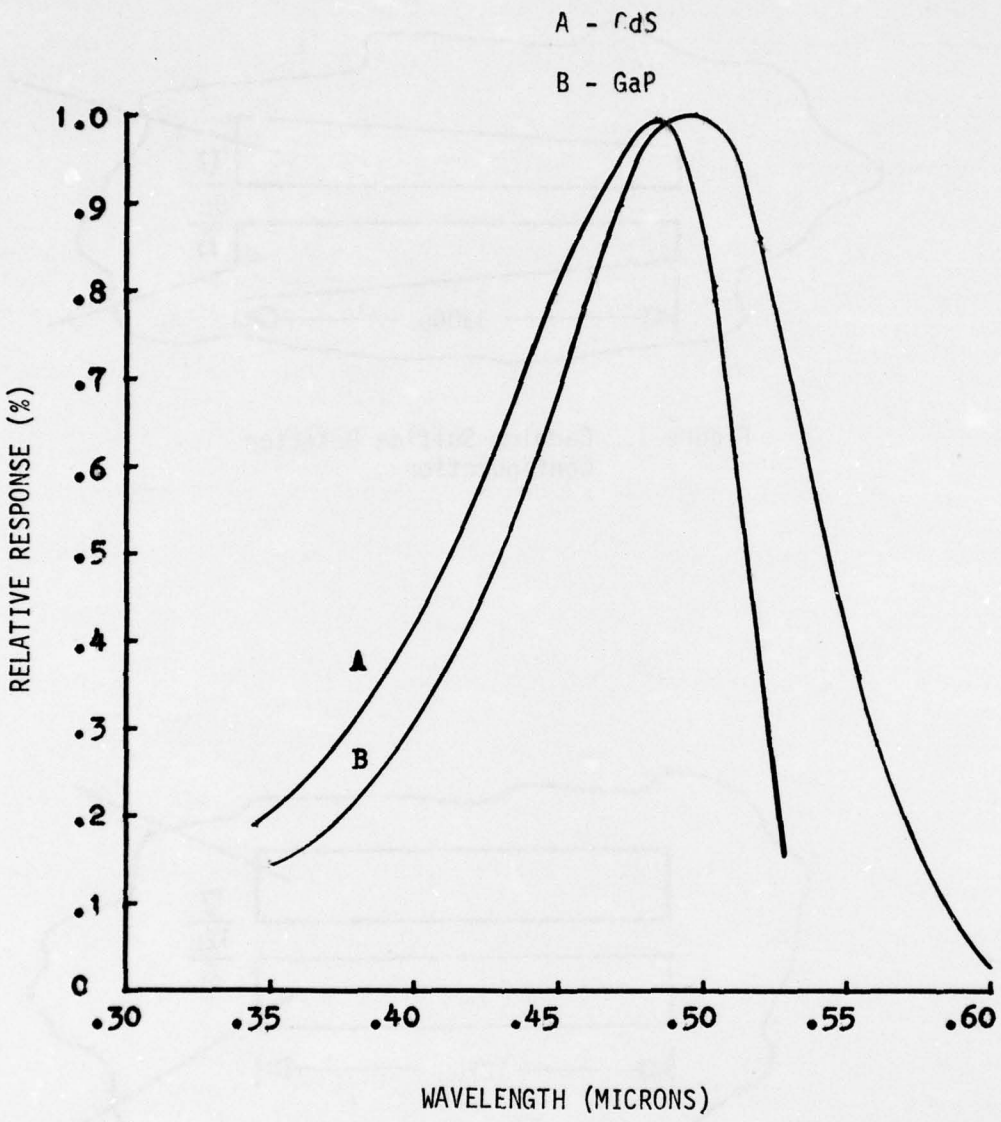


Figure 3. Spectral Comparison of CdS and GaP

SECTION II

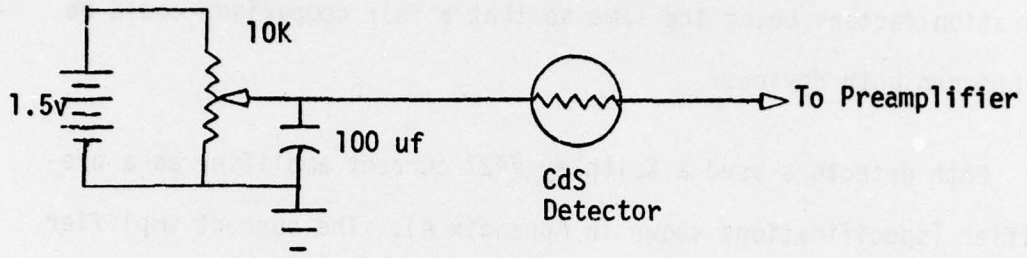
TEST EQUIPMENT AND DETECTOR EVALUATION

This section will present block diagrams of the test set-ups along with descriptions of how the tests were conducted and calibrated. In general, both detectors were tested on the same equipment with all calibration factors being the same so that a fair comparison could be made between both devices.

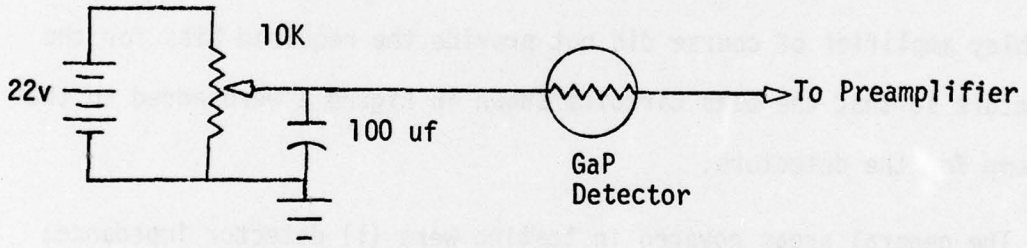
Both detectors used a Keithley #427 current amplifier as a pre-amplifier (specifications shown in Appendix A). The current amplifier was chosen because in most detector applications, dual FET input current preamplifiers are being used. The reason for this is that these amplifiers have low input impedance (less than 4 megohms) which cuts down on the R-C time constant of the detector-amplifier input combination, which can be the limiting factor in the frequency response of the system. The Keithley amplifier of course did not provide the required bias for the detectors so that the bias circuits shown in Figure 4 were added to the pre-amp for the detectors.

The general areas covered in testing were (1) detector impedance; (2) spectral response; (3) frequency response; (4) gain vs. input energy; (5) detector uniformity; and (6) noise. The equipment used in these tests will now be described below.

The spectral response of the detectors was measured on a system (Figure 5) consisting of a Hilger-Engis spectrometer which used a xenon lamp as a light source. The output light went into a quartz fiber optics bundle which split into two bundles, one bundle going to a Hilger-Watts



Cadmium Sulfide Detector Bias Circuit



Gallium Phosphide Detector Bias Circuit

Figure 4. Detector Bias Circuits

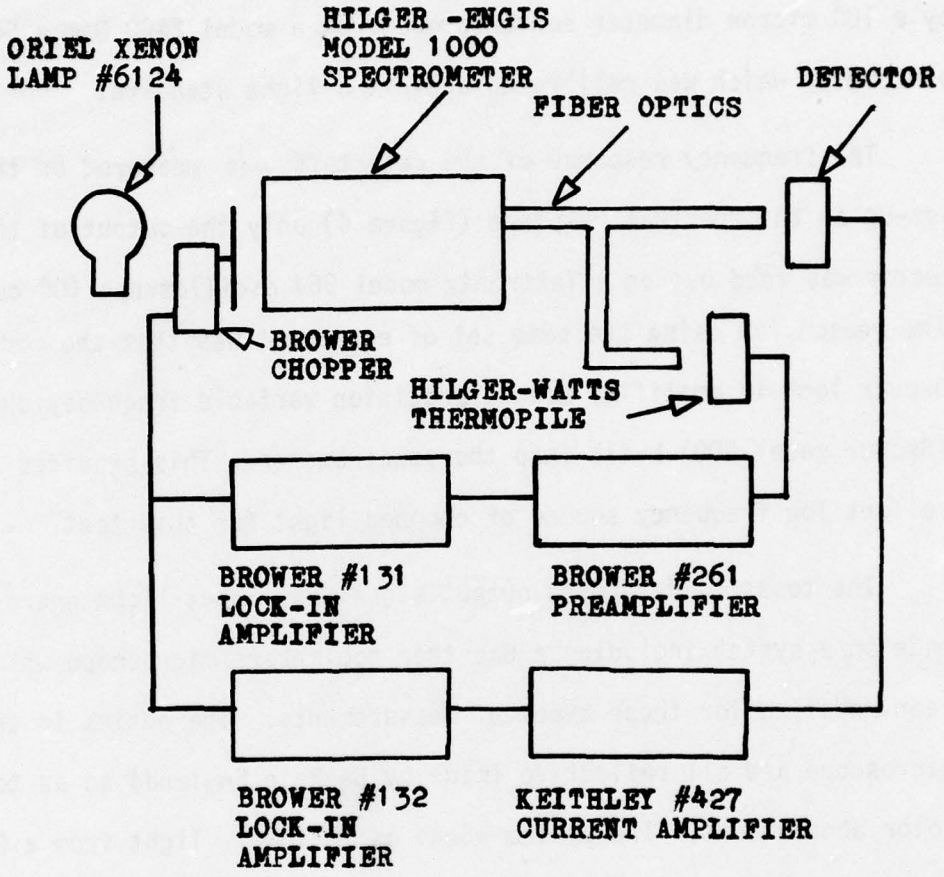


Figure 5. Experimental Set-Up for Detector Spectral Response Measurements

thermopile, the second illuminating the detector. The thermopile and detector signals were both fed into Brower lock-in amplifiers where the signals were monitored. During these tests, the input light energy to the detector was kept constant (via the thermopile output). The absolute energy density at the detectors was measured by replacing the detectors by a 100 micron diameter sensor probe from a model 2400 Gamma Scientific photometer which was calibrated against a light standard.

The frequency response of the detectors was measured on the same set-up as the spectral response (Figure 6) only the output of the detector was read out on a Tektronix model 564 oscilloscope (DC coupled). The reason for using the same set of equipment was that the model 132 Brower lock-in amplifier used a precision variable frequency chopper (Brower model 500) built into the spectrometer. This provided an excellent low frequency source of chopped light for this test.

The tests to determine output signal vs. input light energy were made on a system including a Gaertner toolmakers microscope which had been modified for these types of measurements. The optics in this microscope are all reflective (made by Beck in England) so as to reduce color aberrations. The system works as follows: light from a Gaertner lamp goes through a set of calibrated neutral density filters which determine the light intensity. The light then goes through a Corning color filter #9782 to shape the spectral content of the light source. For the gain tests using chopped light (Figure 7) a 2Hz chopper was used in front of the light source. For the pulsed light tests (Figure 8) a shutter was used instead of a chopper. The light was then trans-

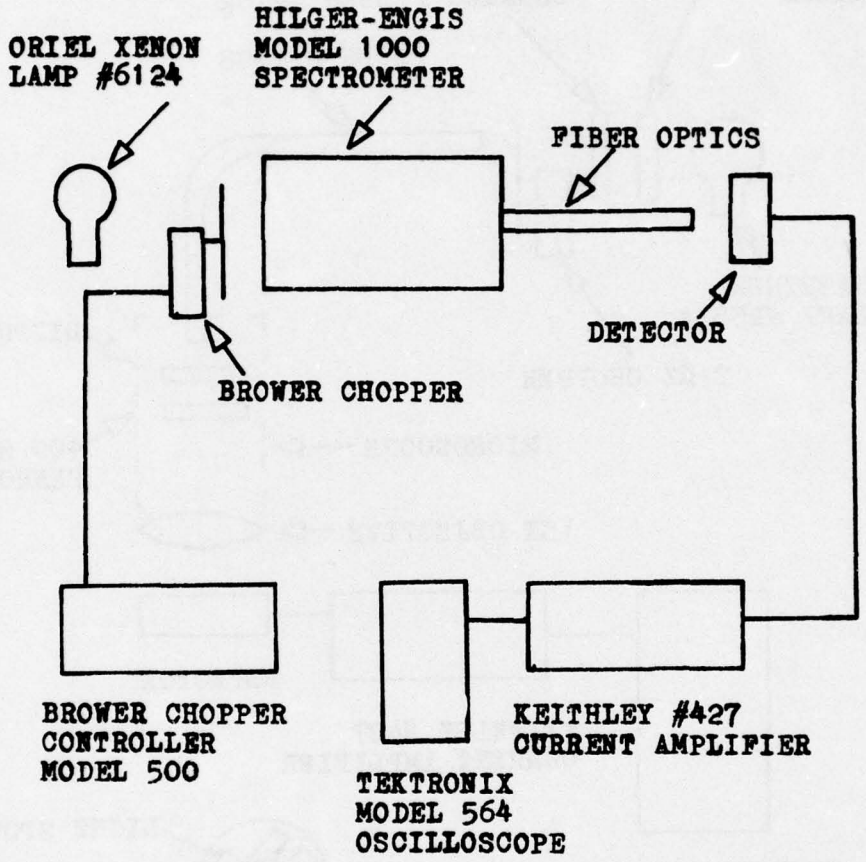


Figure 6. Experimental Set-Up for Detector Frequency Response Measurements

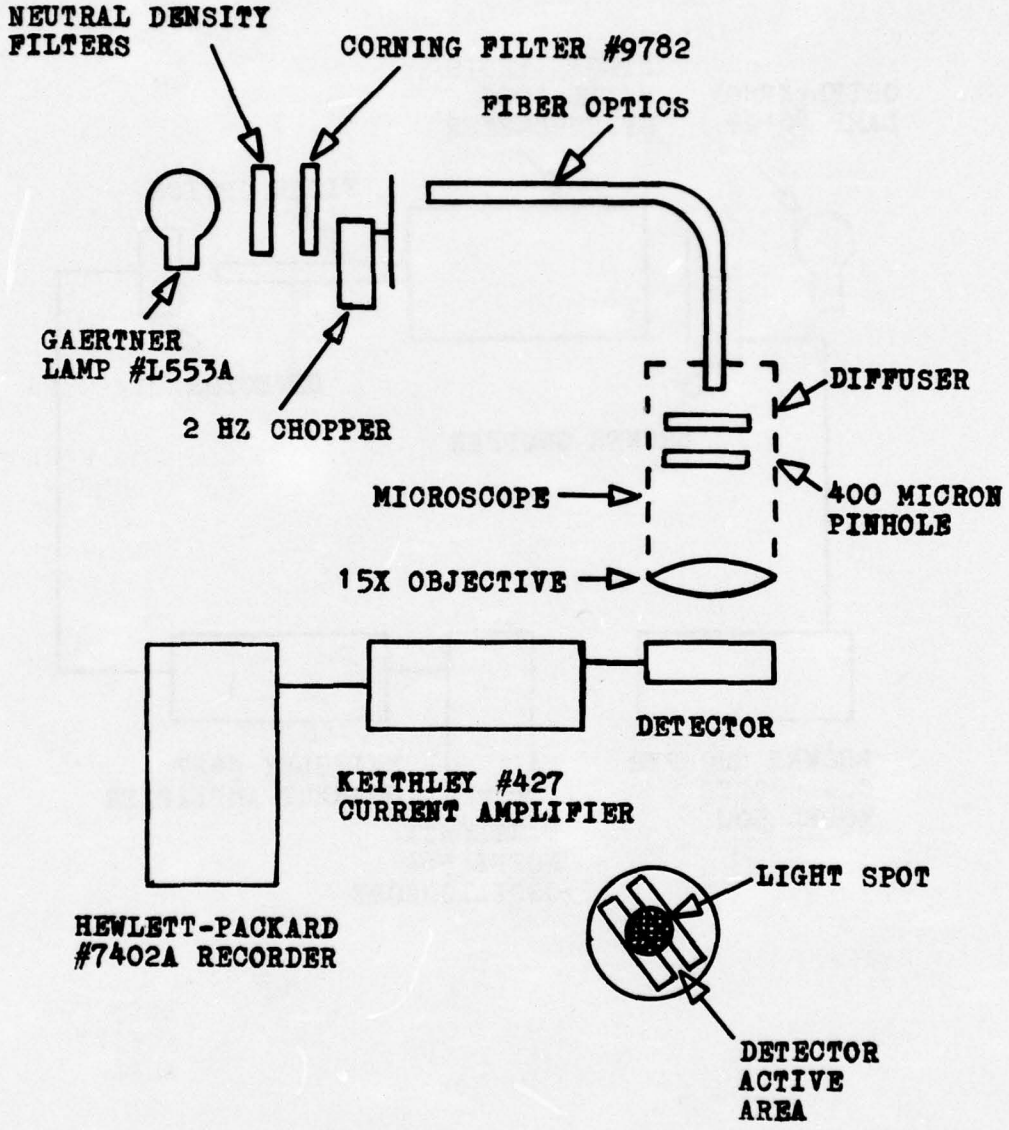


Figure 7. Experimental Set-Up for Detector Gain Measurements Using 2Hz Chopped Light

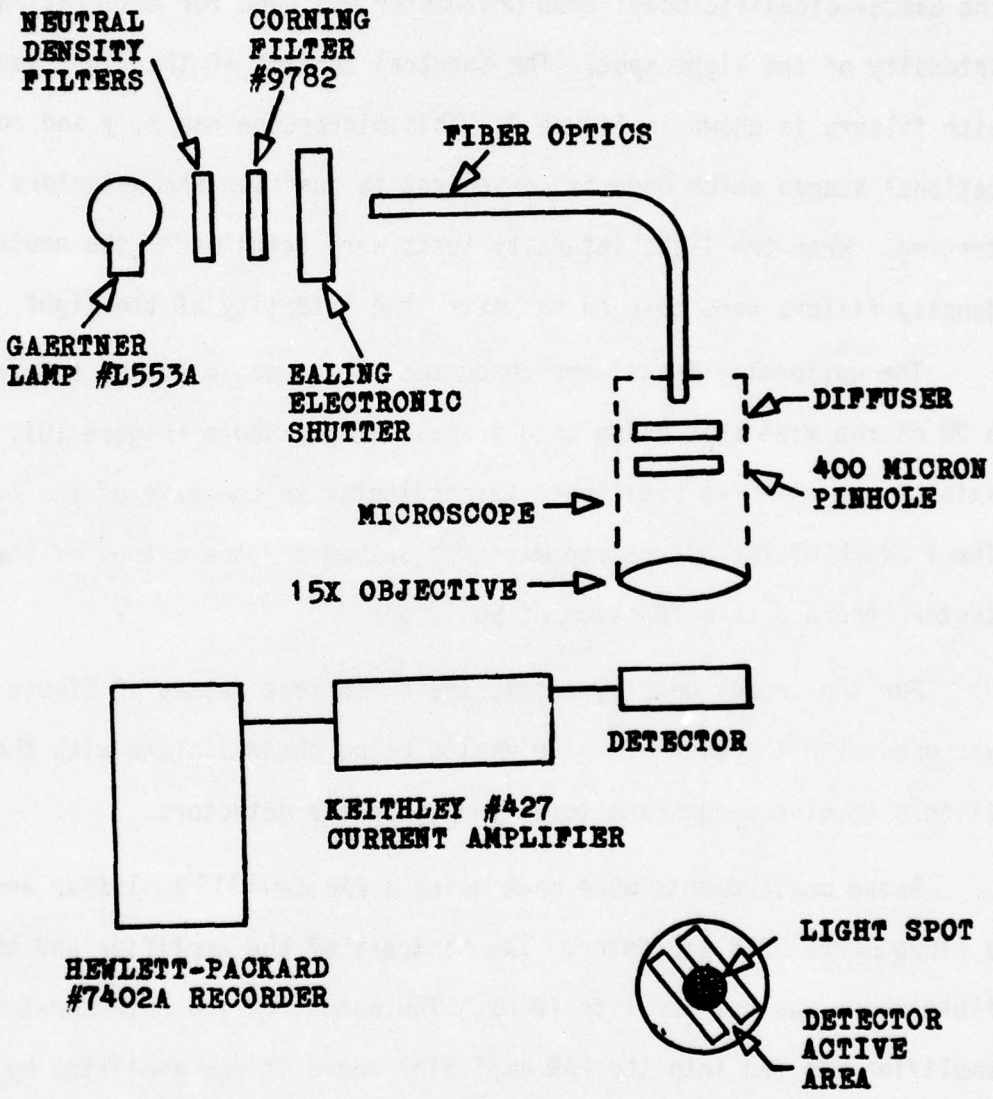


Figure 8. Experimental Set-Up for Detector Gain Measurements Using 1/4 Second Light Pulse

mitted through a fiber optic bundle where it illuminated a 400 micron pinhole in the microscope's object plane. The illuminated pinhole was then imaged onto the detector via a 15X objective. The output of the detector was then recorded on a Hewlett-Packard model 7402A recorder. The Gamma-Scientific model 2400 photometer was used for calibrating the intensity of the light spot. The spectral content of the light source with filters is shown in Figure 9. This microscope had x, y and rotational stages which made it convenient to position the detectors for testing. When the light intensity tests were being made, the neutral density filters were changed to vary the intensity of the light

The uniformity tests were conducted on the above set-up only with a 30 micron wide slit being used instead of a pinhole (Figure 10). The axis of the slit was positioned perpendicular to the axis of the detector. The Y stage of the microscope was then driven and the output of the detector recorded as a function of position.

For the energy density tests, again the test set-up of Figure 7 was used with the size of the pinholes being changed along with the ND filters to give a constant total energy on the detectors.

Noise measurements were made using a PAR model 113 amplifier and a Fluke model 931B RMS meter. The bandpass of the amplifier and the Fluke meter was set for 1 to 10 Hz. The output of the detector-Keithley amplifier was fed into the PAR amplifier where it was amplified by 100X and narrowbanded, then fed into the Fluke meter to give an RMS reading of the noise.

The detector resistance was measured using a Keithley picoammeter

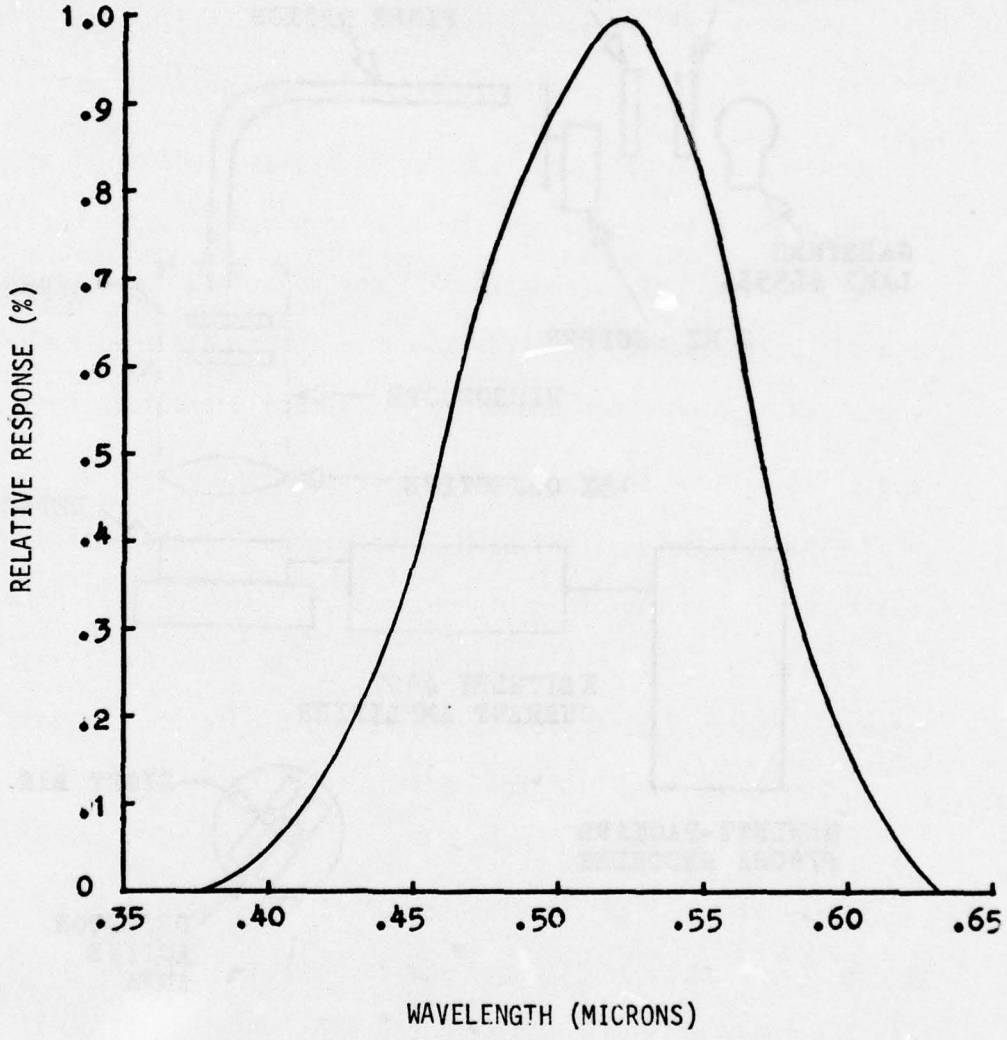


Figure 9. Light Source Spectral Response

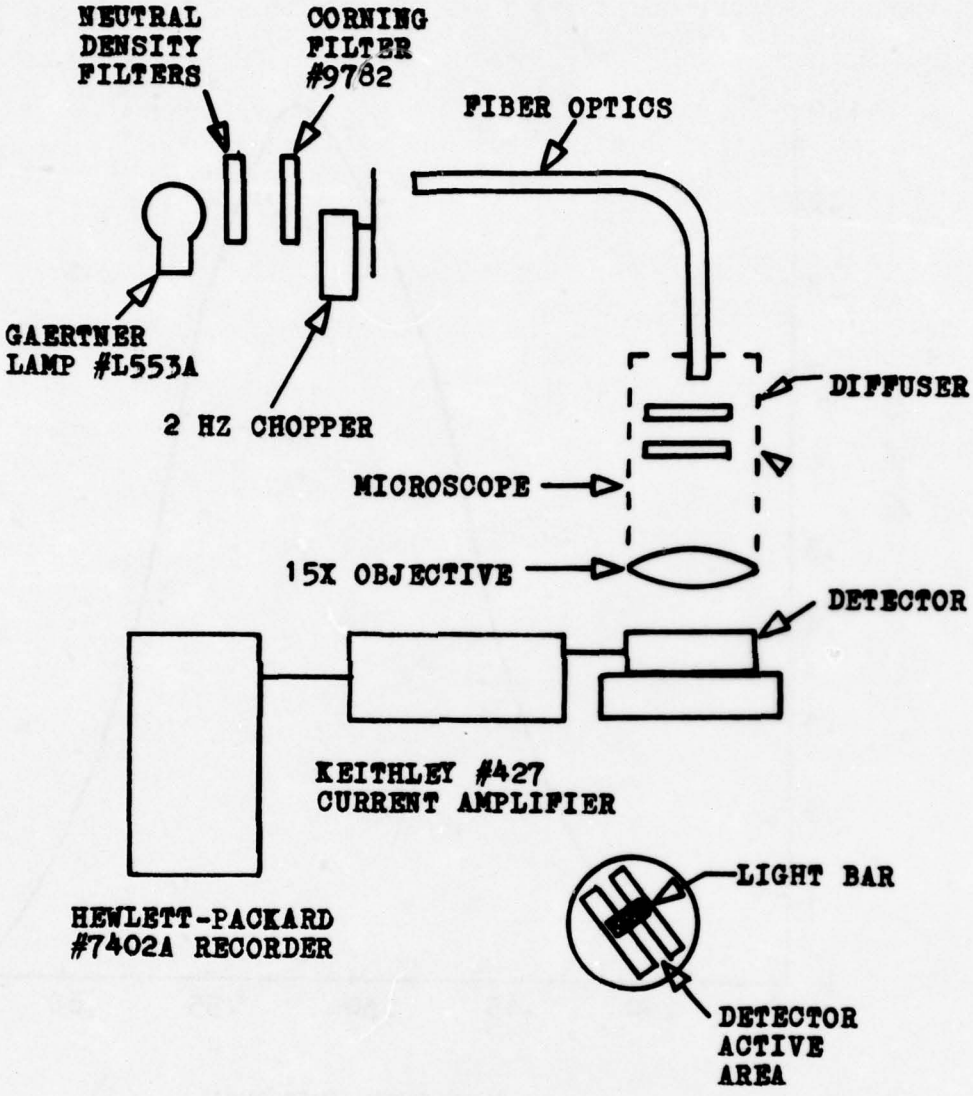


Figure 10. Experimental Set-Up for Detector Uniformity Measurements

model 417 and a voltage source. The voltage source was connected in series with the detector and ammeter. The series current was measured, then divided into the value of the voltage source to give the detector resistance. Detector capacitance was measured on a Tektronix capacitance meter model 130.

Signal vs. light intensity and spectral response tests were also run with background light. The purpose of background lighting is to saturate trapping levels or recombination levels in photoconductors and change their characteristics. Mercury "Pen Ray" lamps with spectral filters were used to provide the background light. These lamps were DC powered to do away with light pulsing. These lamps were set 12 inches away from the detectors with their radiation at the detector plane being measured first by a photometer.

SECTION III

TEST RESULTS AND COMPARISONS

This section deals with the results of a number of tests conducted on both the gallium phosphide and cadmium sulfide photoconductive detectors. It will be noted that these tests were mostly small signal AC tests. The reason for this is that in operational systems, this is the operating mode for these devices, therefore these are the most meaningful parameters to talk about.

The resistance of the CdS detector was 5×10^8 ohms with a shunt capacitance of 1.4 pfd. The dark resistance of the GaP detector was 3×10^{12} ohms with a shunt capacitance of 1 pfd. As can be seen, there was a vast difference in detector resistances which was reflected in the magnitude of the signal currents.

As referred to in the Introduction, the spectral response of gallium phosphide and cadmium sulfide are similar. Figure 11 shows the spectral response of CdS and how it shifts with light intensity. Figure 12 shows the GaP spectral response and intensity shifts. Two things should be noted. First due to test equipment design, it was not possible to get the exact same light intensities into the detectors, but just the same range of values, which is the more important factor. Second, the CdS detector shifted spectral response much more drastically than the GaP. (Figures 13 and 14 are graphs of signal vs. light intensity at constant wavelengths for CdS and GaP.) These Figures show how the spectral response of CdS and GaP change with light intensity. As can be seen, the spectral response shape of GaP stays fairly constant while that

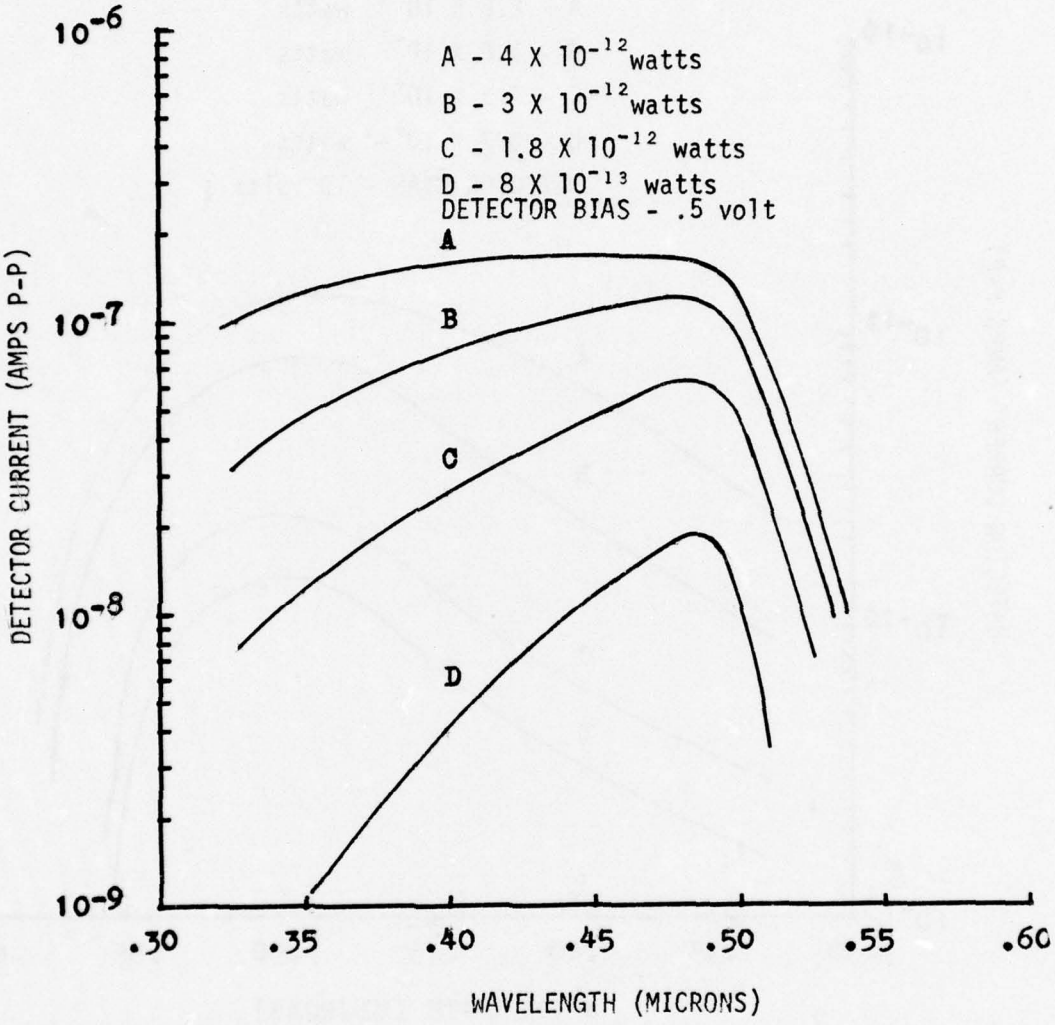


Figure 11. Cadmium Sulfide Spectral Response vs. Light Intensity

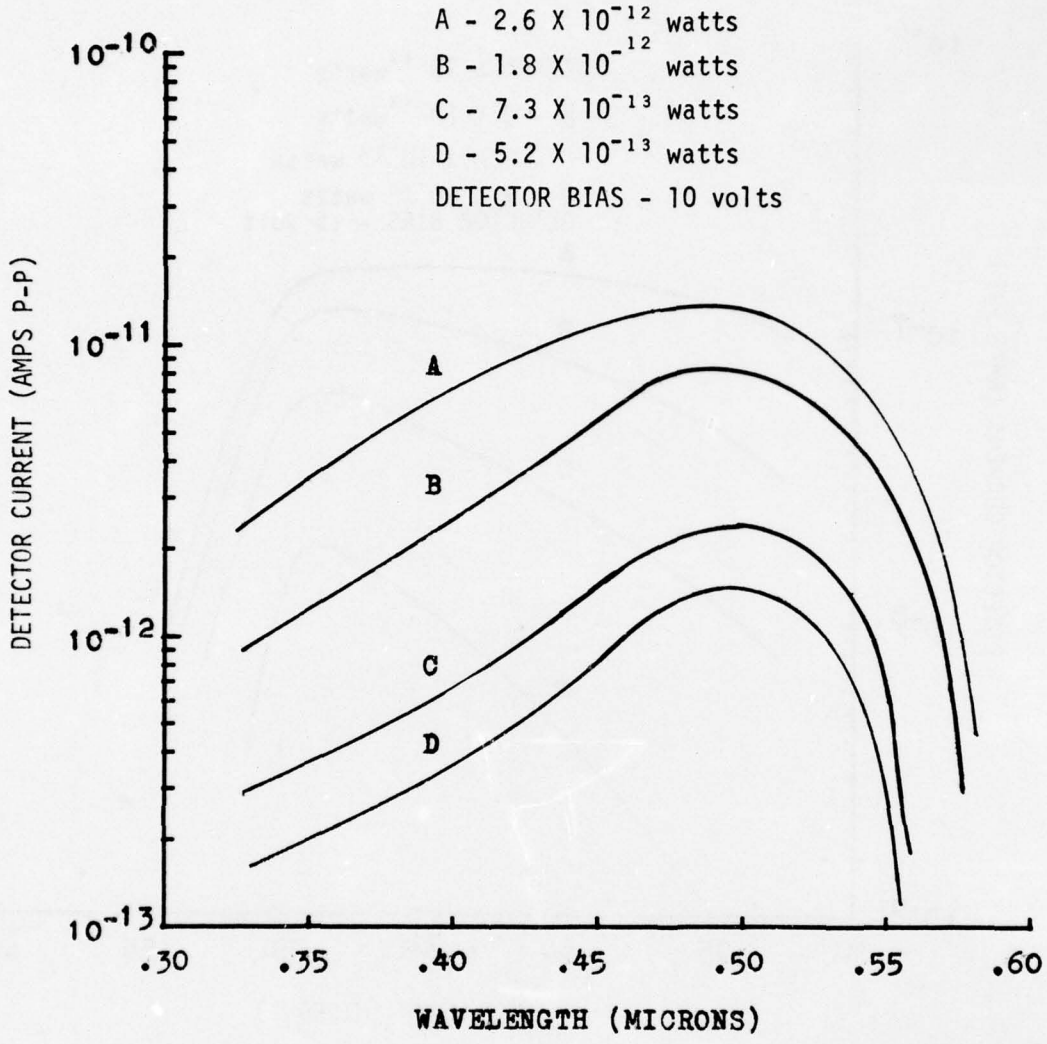


Figure 12. Gallium Phosphide Spectral Response vs. Light Intensity

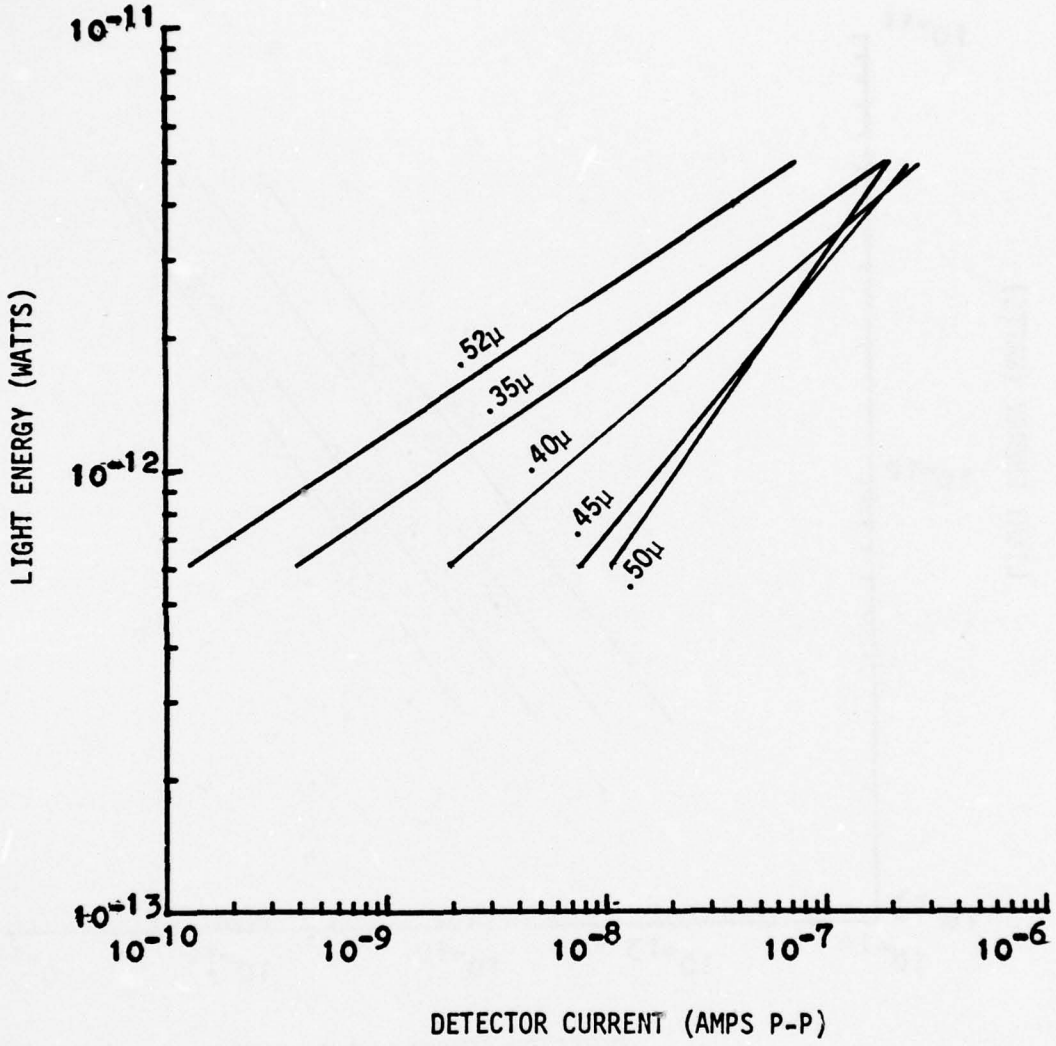


Figure 13. Cadmium Sulfide Detector Current vs. Light Energy at Constant Wavelength

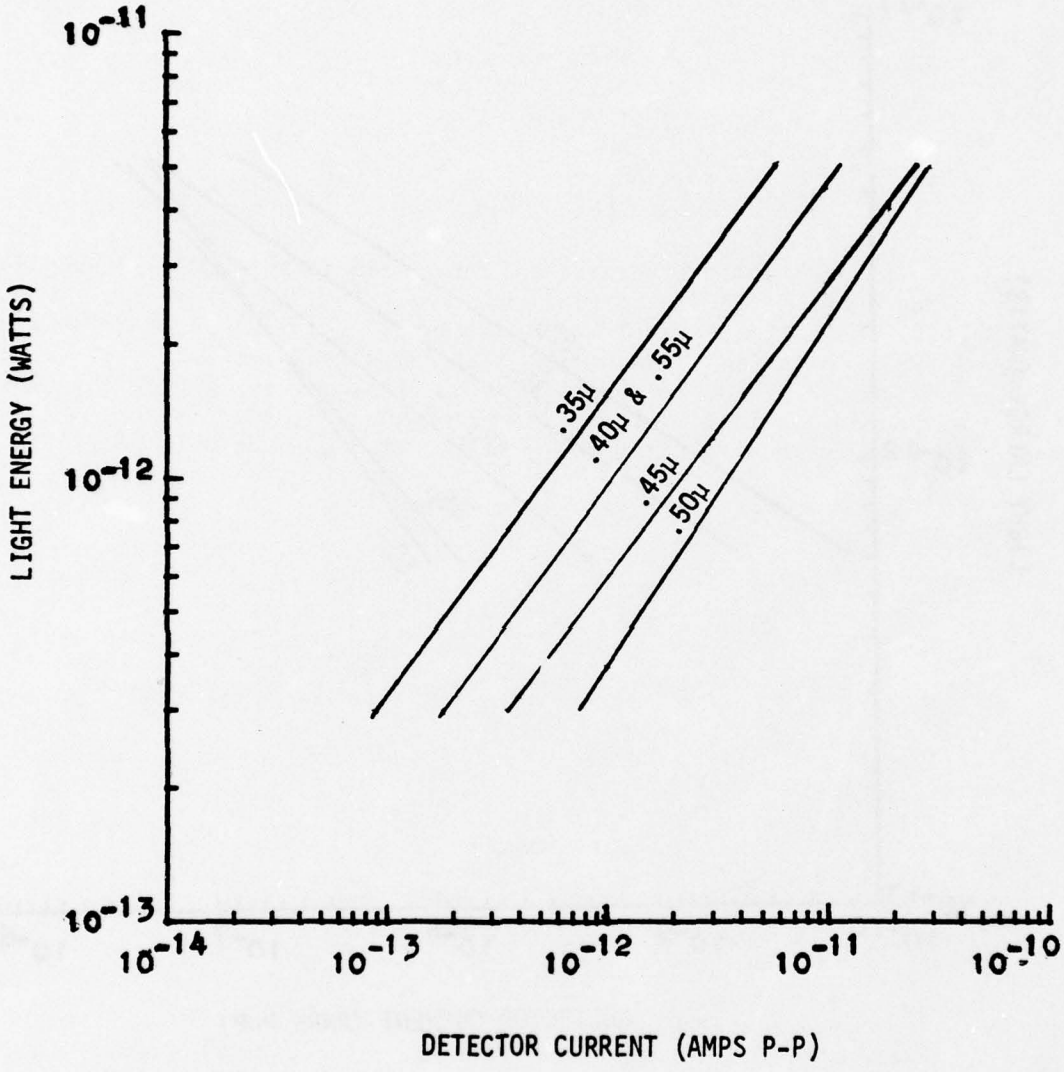


Figure 14. Gallium Phosphide Detector Current vs. Light Energy at Constant Wavelength

of CdS changes greatly, especially in the ultraviolet (UV).

Figures 15 and 16 are CdS and GaP spectral responses with changing bias. Here again the CdS spectral response changes much more than the GaP. The CdS spectral response increases in the .3 - .4 micron region and decreases in the .45 - .5 micron region with increasing bias. Under the same test conditions, the GaP spectral response at .5 microns increases faster than the rest of response curve.

Figure 17 is the spectral response of CdS with DC background illumination. The two background conditions used were a green background (.54 microns) and a UV background (.40 microns). The green background had no effect on the spectral response while the UV depressed the detector output signal, but also reduced the UV response of the detector also.

Figure 18 has the same test conditions as used in Figure 17, but with the gallium phosphide detector. Much the same results were found here as with the CdS detector, for the green background had no effect on the spectral response while the UV background depressed the UV response of the detector. It should be noted that both detectors had a greater DC current with the green light so the light did have an effect on the detectors.

Figure 19 is the CdS detector signal vs. the input light intensity at 2Hz. The spectral response of the input light source was shown in Section II of this report. The CdS detector converted about 40% of the input light into output current signal as calculated on the following page.

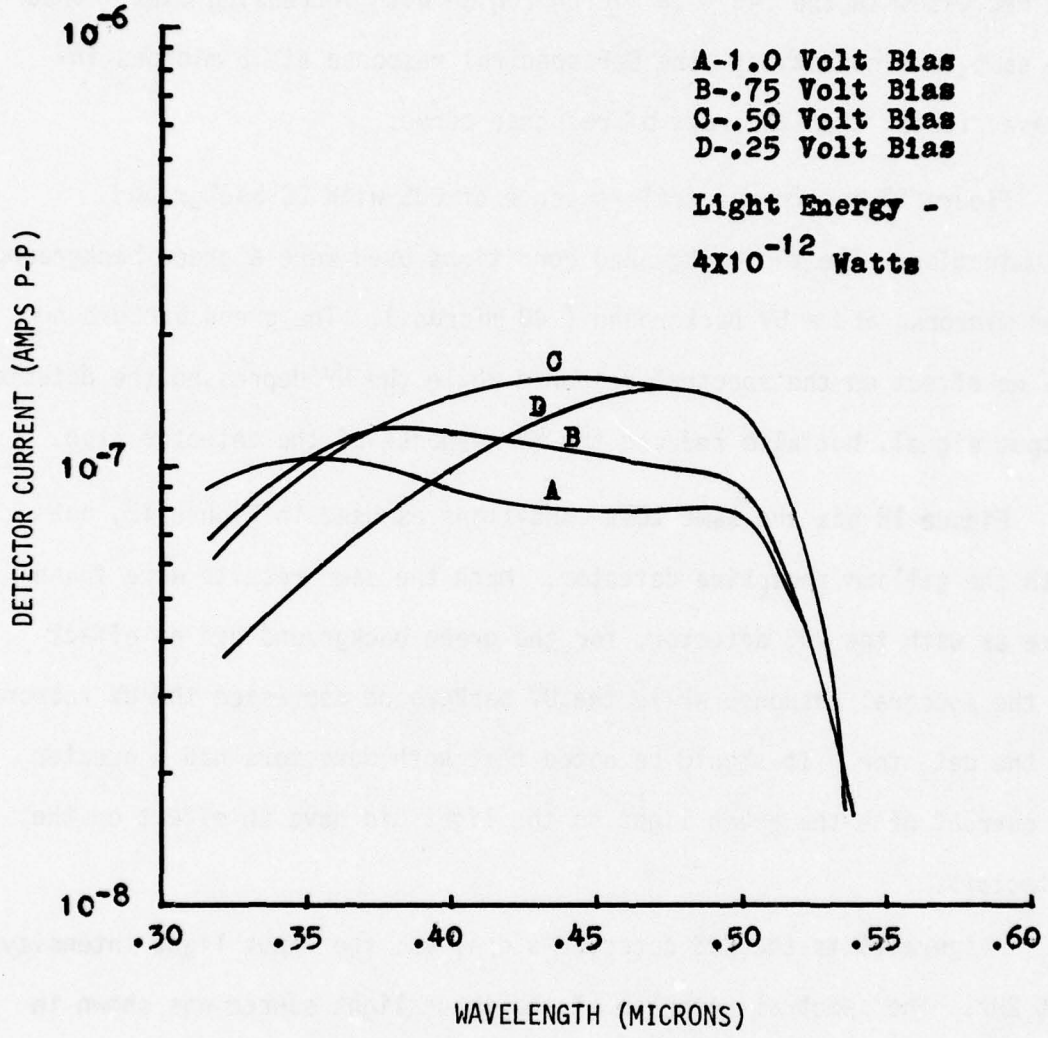


Figure 15. Cadmium Sulfide Spectral Response vs. Bias Voltage

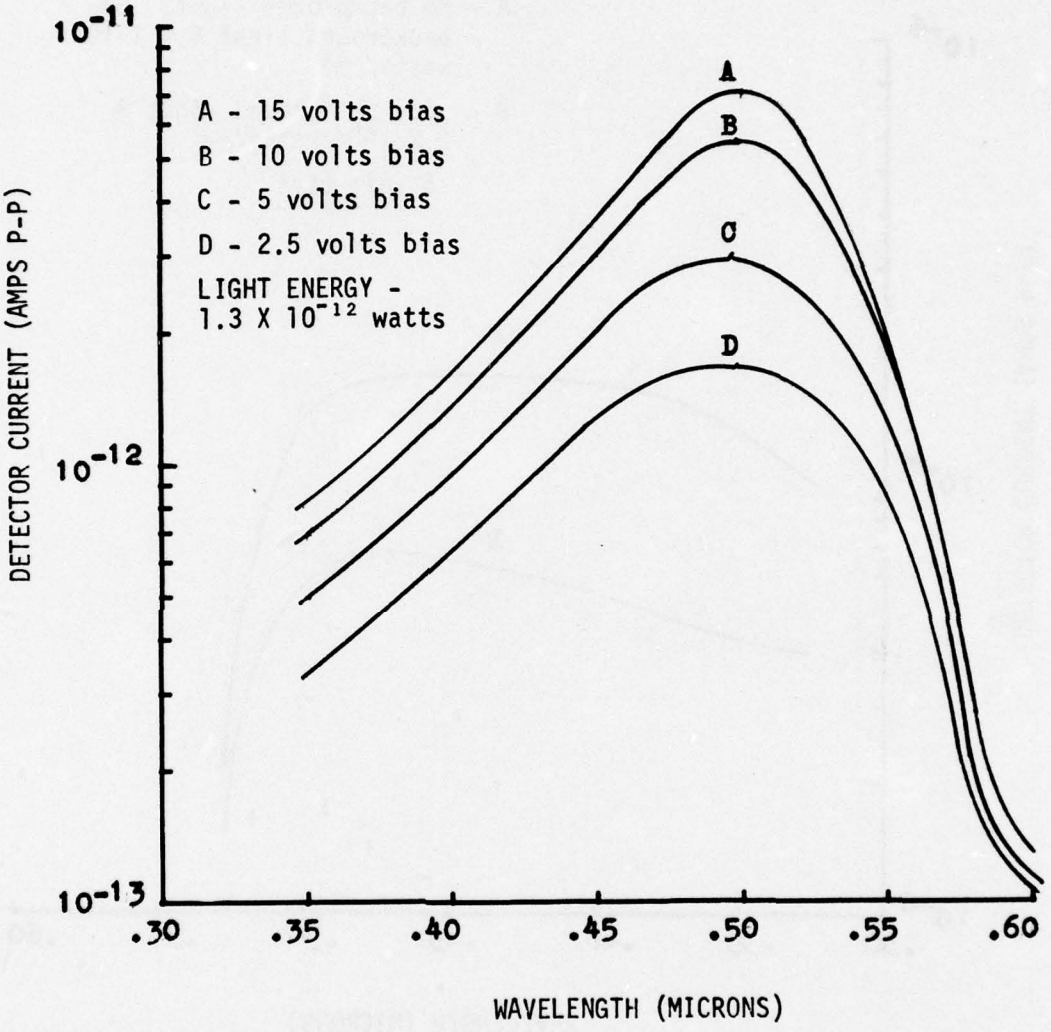


Figure 16. Gallium Phosphide Spectral Response vs. Bias Voltage

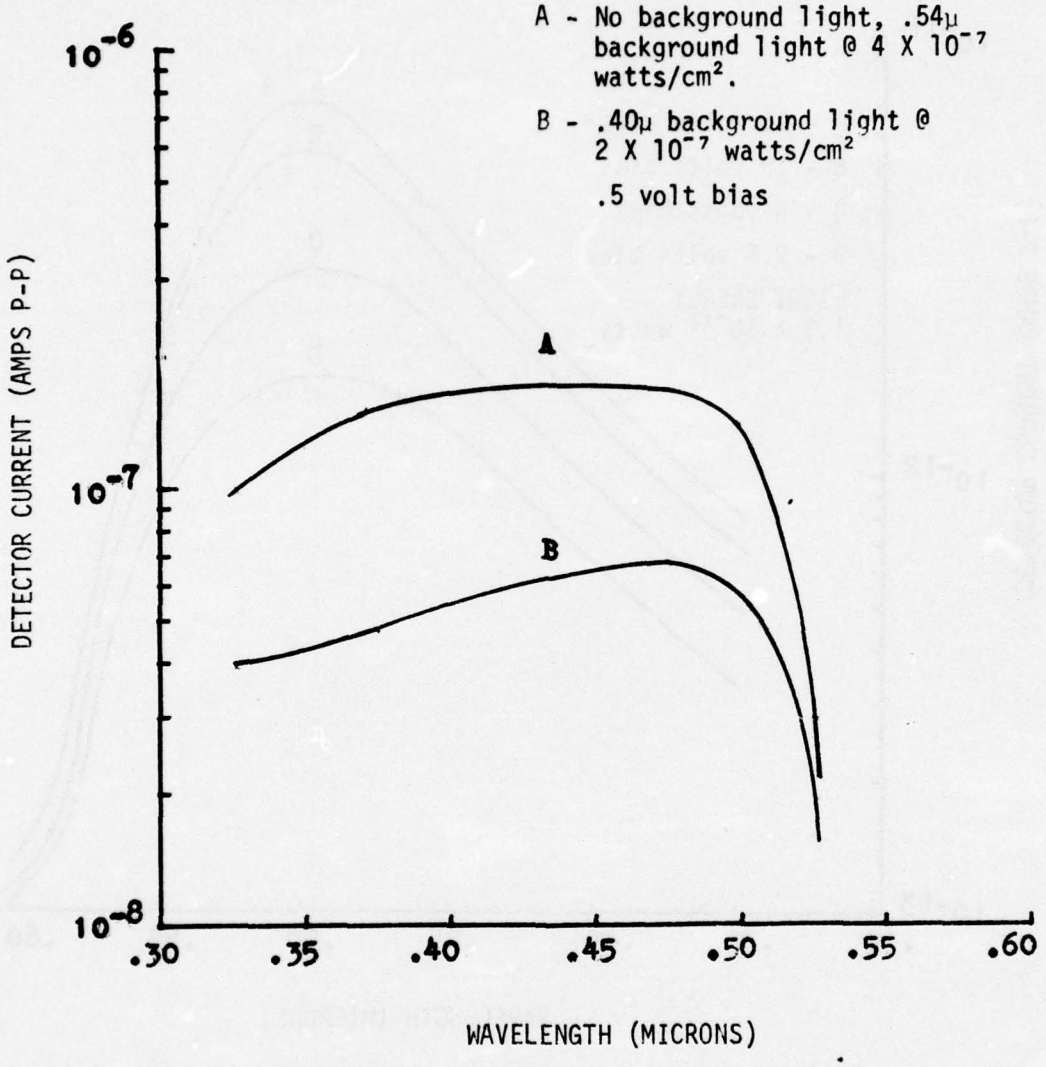


Figure 17. Cadmium Sulfide Spectral Response with Background Light

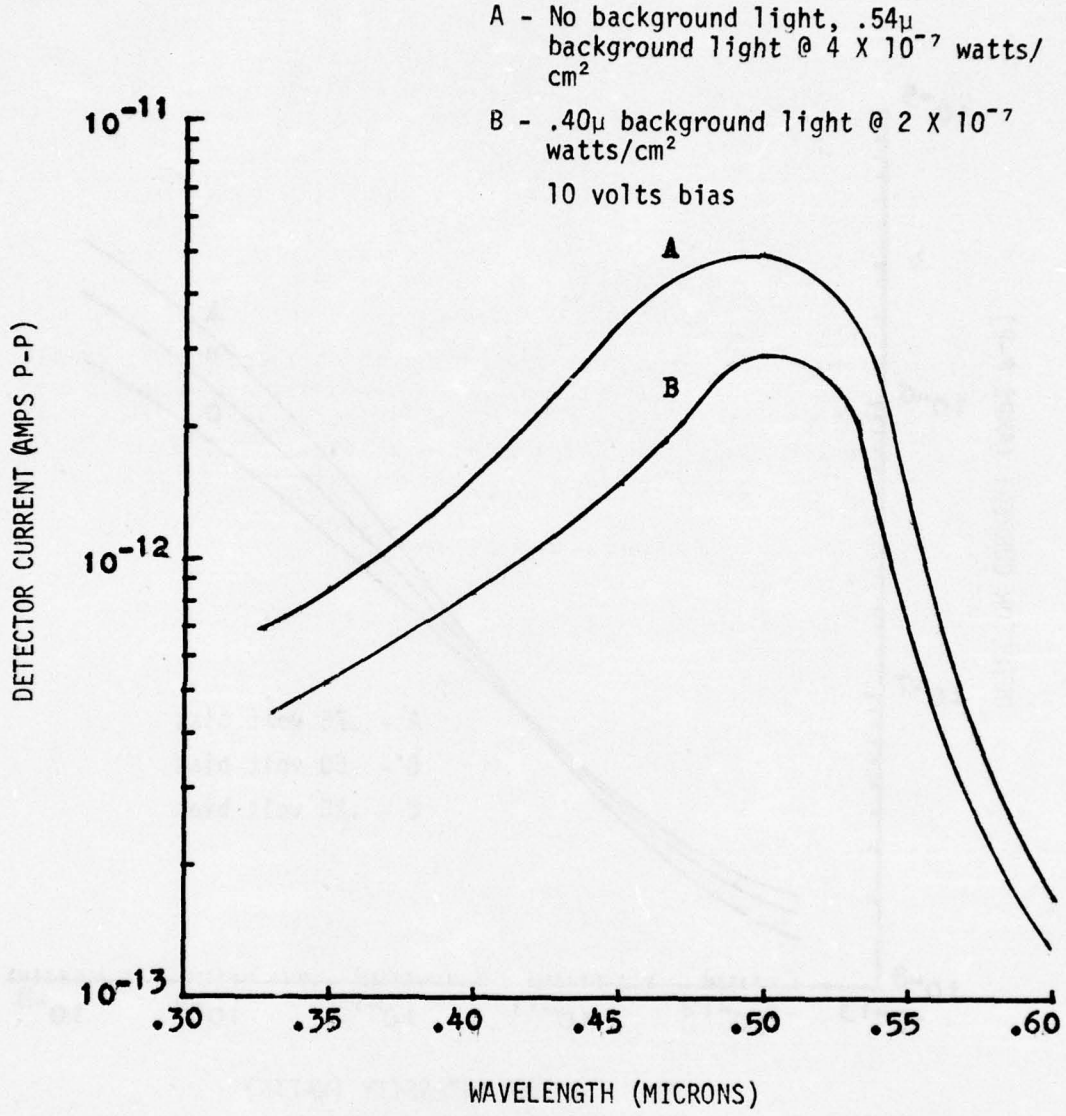


Figure 18. Gallium Phosphide Spectral Response with Background Light

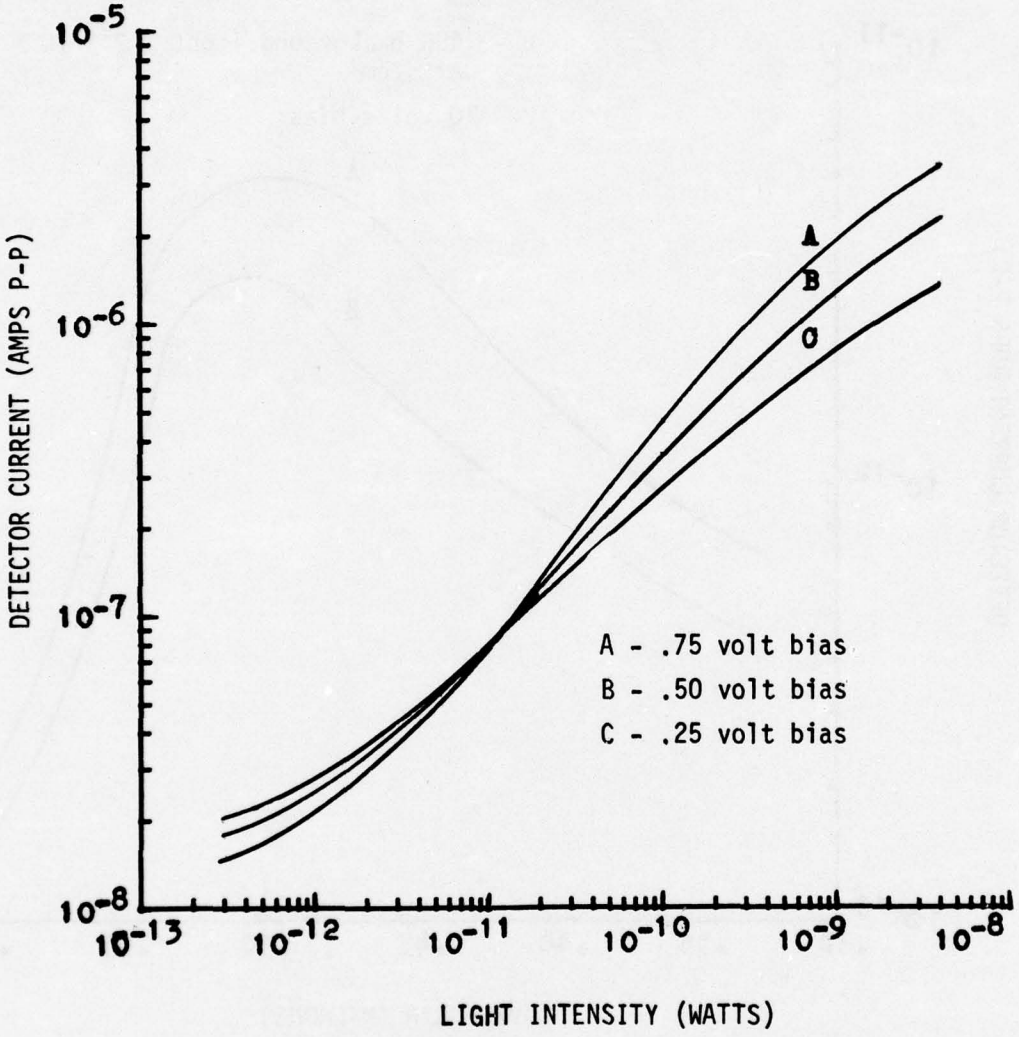


Figure 19. Cadmium Sulfide Detector Current vs. Light Intensity at 2Hz Chopping Frequency

$$\frac{\int_{.2\mu}^{.8\mu} L_\lambda D_\lambda \, d\lambda}{\int_{.2\mu}^{.8\mu} L_\lambda \, d\lambda} = 40\%$$

where L_λ = light source spectral response

D_λ = detector spectral response

From the CdS spectral response curves, it was shown that the spectral response changes with light intensity, therefore it is doubtful that the conversion factor of this detector remains at 40%. One interesting fact that can be noted from this curve is that below 1.5×10^{-11} watts, the lower the detector bias, the higher the output signal, which is not what one would expect. It can be observed that for CdS there is not a linear relationship between signal and light intensity although the .25 volt bias curve approaches it.

Figure 20 indicates the detector signal current vs. input light intensity relationship for the GaP detector at 2Hz chopping frequency. The gallium phosphide detector has a power law relationship between signal and input energy, with breaks occurring near 1.5×15^{-10}watts. Above 1.5×10^{-10} watts, the signal increases, but at a sublinear rate. The dashed lines show a strange phenomenon in the GaP signal above the break point. There is a transient or overshoot effect observed in the

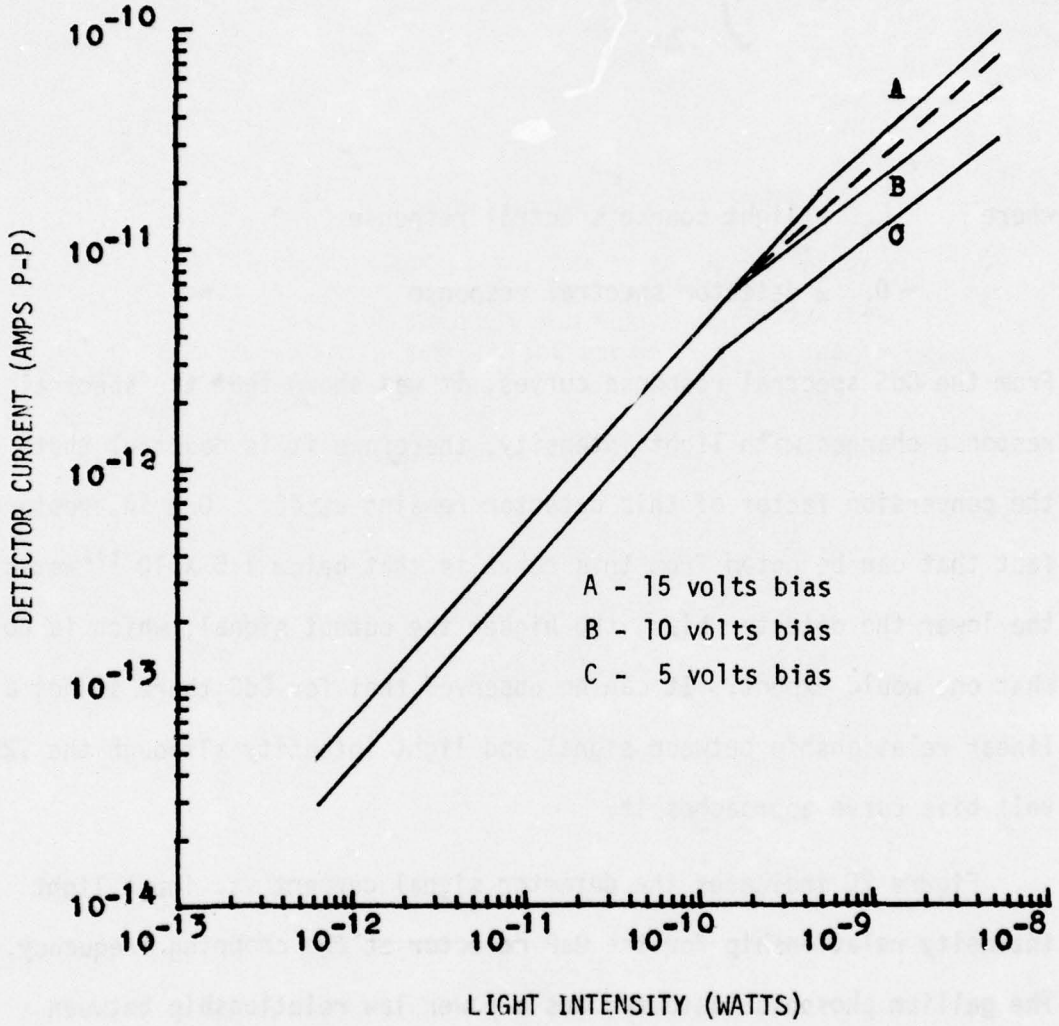


Figure 20. Gallium Phosphide Detector Current vs. Light Intensity at 2Hz Chopping Frequency

signal. The dashed line of curve B represents the peak of the overshoot, while the solid line represents the amplitude of the flat portion of the signal. The peak overshoot values are left off the rest of the curves of Figure 20 and Figure 22 for ease of reading. The overshoot phenomenon was found to be caused by the Keithley amplifier. When on the 10^{11} V/A scale and with the input load impedance above 10^{11} ohms with a small shunt capacitance, the amplifier would overshoot on a square wave input. The amplifier was tested for the characteristic by connecting high impedance Victorian resistors (10^{11} and 10^{12} ohms) across the amplifier input with gain set at 10^{11} V/A. A Hewlett-Packard square wave pulse generator was connected in series with the resistors and various small capacitors were put across the resistors. The size of the overshoot was found to be dependent on input resistance, shunt capacitance, and signal level. The GaP detector converted about 60% of the input light into a signal current as calculated below:

$$\frac{\int_{.2\mu}^{.8\mu} L_\lambda \; D_\lambda \; d\lambda}{\int_{.2\mu}^{.8\mu} L_\lambda \; d\lambda} = 60\%$$

where L_λ = light source spectral response

D_λ = detector spectral response

Below 1.5×10^{-10} watts, the same signal level was obtained at both 10 volts and 15 volts bias. Above the break point, the signal levels differed.

Figure 21 shows the CdS detector signal vs. input light intensity using a 1/4 second light pulse instead of continuous chopped light. This test was done because in many systems, a single pulse of light must be detected instead of continuous light signals. Here again, as in Figure 19, CdS does not have a linear type relationship between signal and light intensity. The curves of Figure 19 and Figure 21 do differ in magnitude indicating that it makes a difference whether a continuous train of 1/4 second pulses (2Hz chopped light) or a single 1/4 second pulse is used.

Figure 22 shows the 1/4 second signal response from the GaP detector vs. input light intensity. The first thing that should be noted is the difference between Figure 22 and Figure 20. Again the use of single or continuous light pulses makes a difference in signal magnitude. Figure 22 in contrast to Figure 21 is a series of sublinear straight line relationships. The first break points in the curves occur at 7×10^{-12} watts, with 5 v bias curve having a second break point at 7×10^{-10} watts. The signal overshoot occurred again in this test and occurred over a wide range of values.

Figure 23 indicates the CdS signal vs. light intensity relationship with .40 and .54 micron DC background light. The .54 micron background had no effect on the original curve but the .40 micron background decreased the output signal for low input light intensities. Figure 24 shows the signal vs. light intensity with background for the GaP detector. In this case, the low intensity end of the curve remained the same with and without background, but at higher intensities, the signal was

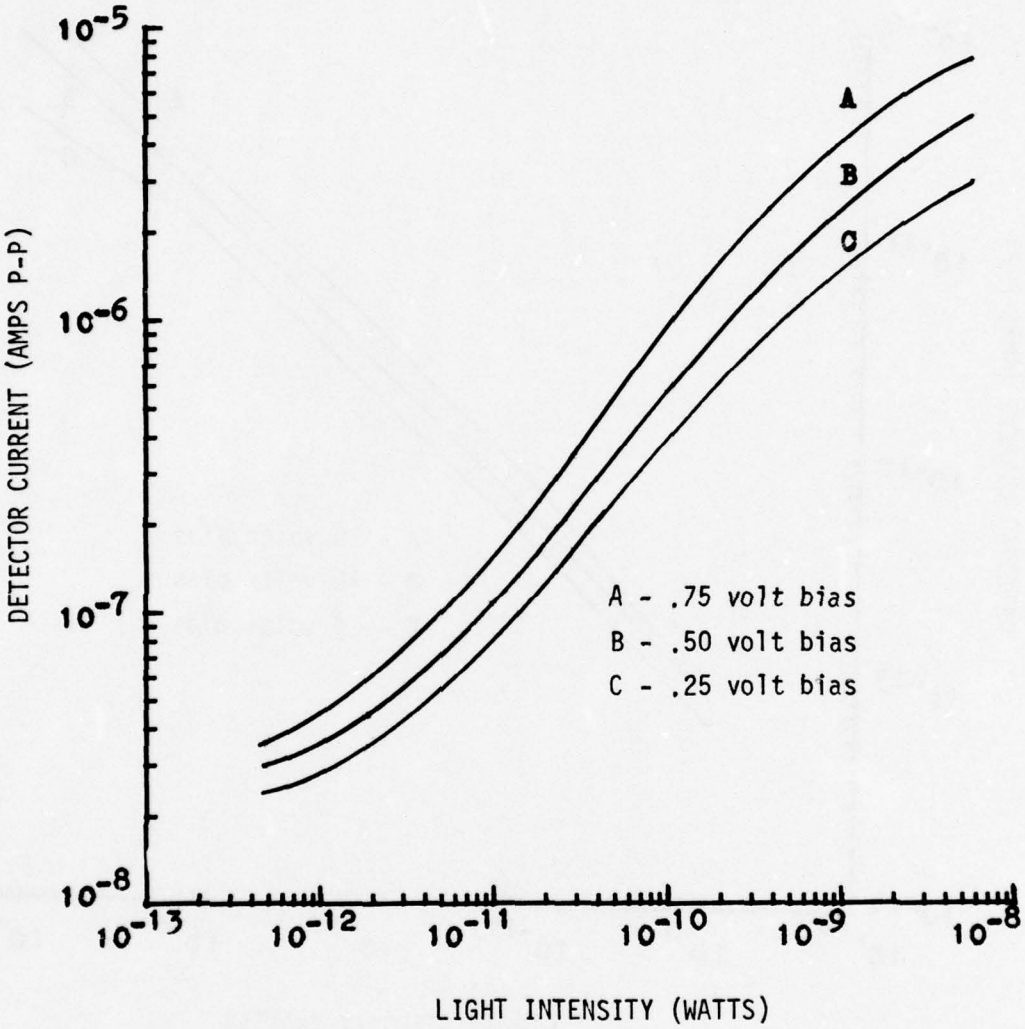


Figure 21. Cadmium Sulfide Detector Current vs. Light Intensity Using 1/4 Second Light Pulse

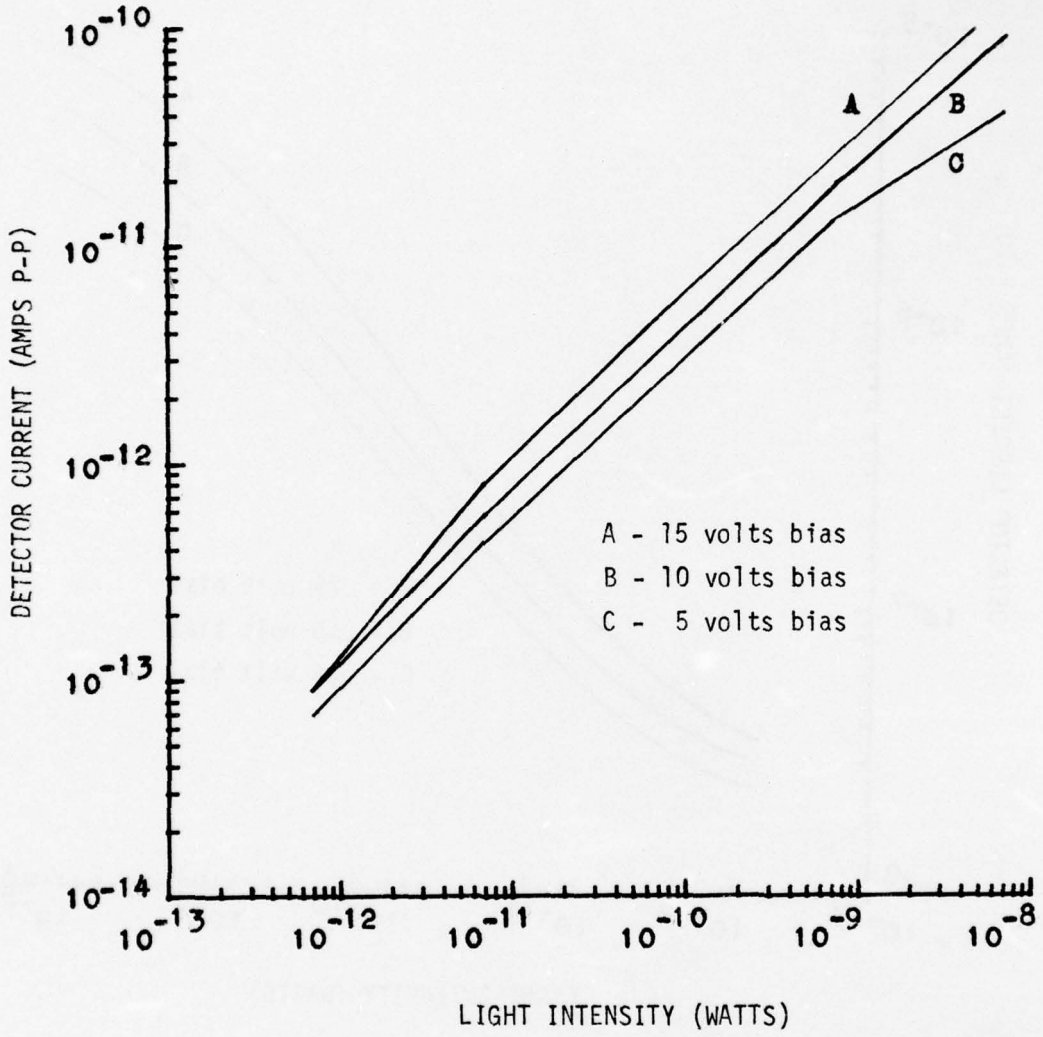


Figure 22. Gallium Phosphide Detector Current vs. Light Intensity Using 1/4 Second Light Pulse

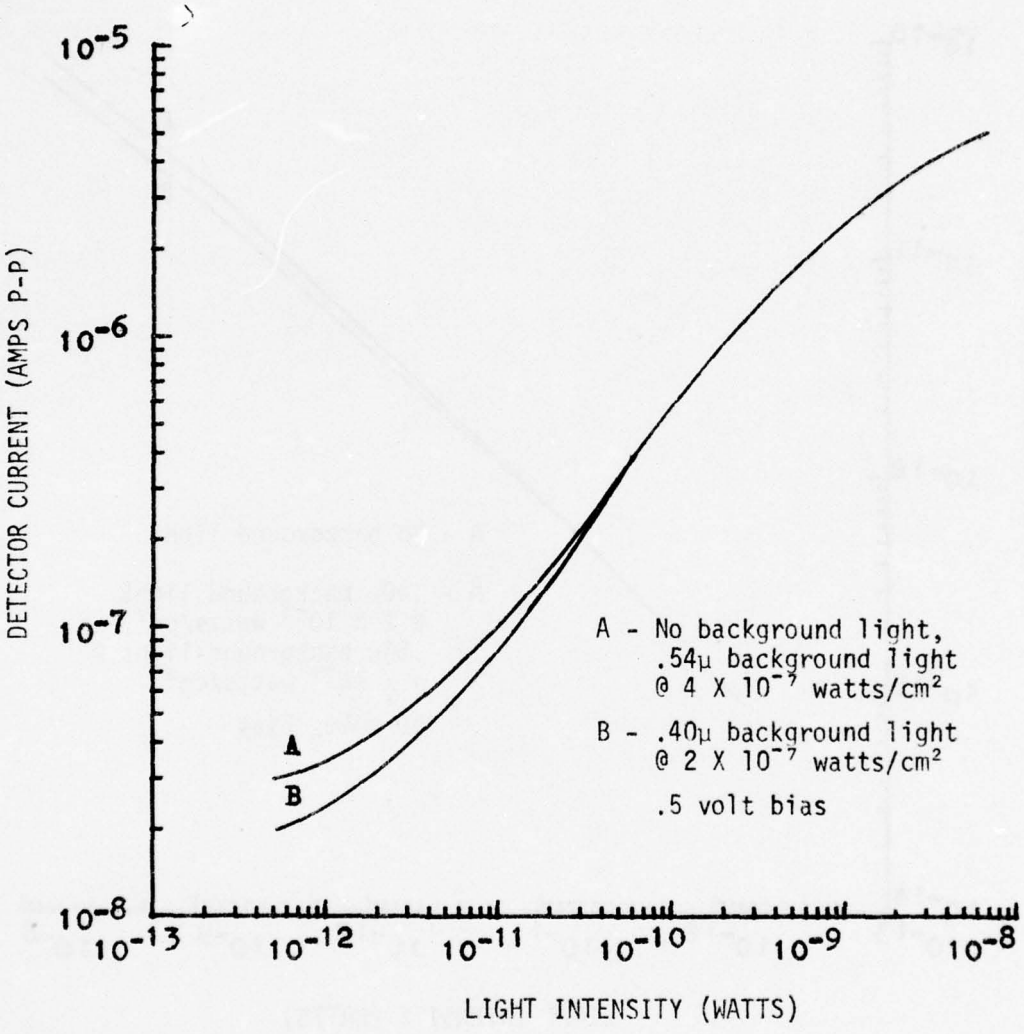


Figure 23. Cadmium Sulfide Detector Current vs. Light Intensity with Background Illumination

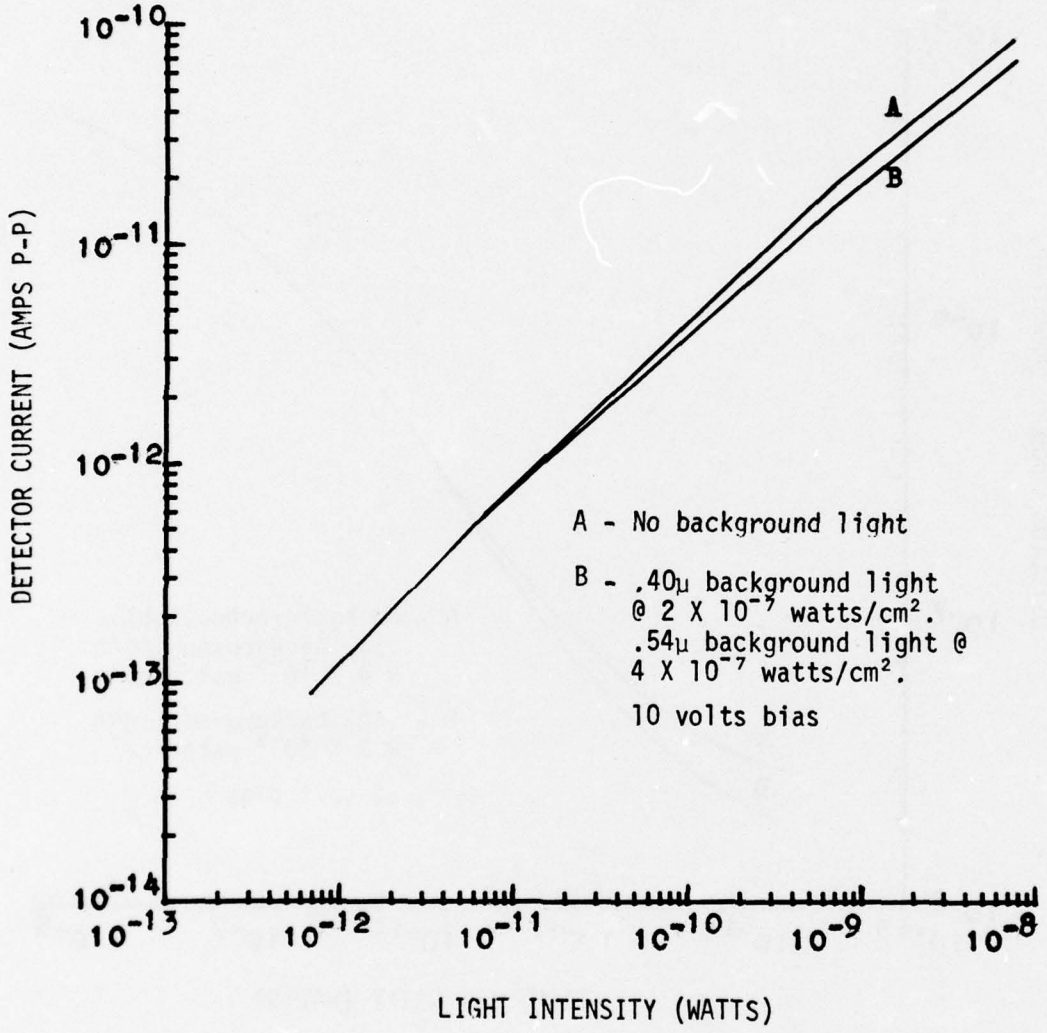


Figure 24. Gallium Phosphide Detector Current vs. Light Intensity with Background Illumination

depressed with both the .54 and .40 micron background. The signal overshoot values were left of this figure to avoid confusion but it was found that the percentage overshoot for the .54 micron background was the same as with no background (Figure 22), but for the .40 micron background, the percentage overshoot was twice the no-background case.

Figures 25 and 26 show the frequency response of the CdS detector and the GaP detector. In comparing the two figures it can be seen that the GaP detector has a much better frequency response. As an example in going from 2 Hz to 14 Hz, the CdS signal decreased by a factor of 5 while the GaP detector signal decreased by a factor of 1.5. The frequency response of the GaP detector could not be measured at higher frequencies due to the limited preamplified response and chopper range.

The next figure (Figure 27) shows the growth of the CdS signal if a light is pulsed onto the detector at specific intervals after the detector has been in the dark for a number of hours. In the past, this phenomenon has caused serious signal processing problems in systems. As can be seen, the faster the light is pulsed, the more the signal grows. At the 1 second pulse rate, the signal grows by a factor of 2.4.

Figure 28 shows the results of the same test on the GaP detector, only here the detector signal decreased slightly. The decrease is small enough that it should not affect system operation. If the pulse is not repeated in less than 5 seconds, there is no decrease in the GaP signal.

The next three figures deal with signal vs. bias (Figure 29), noise vs. bias (Figure 30) and finally signal-to-noise ratio vs. bias (Figure 31)

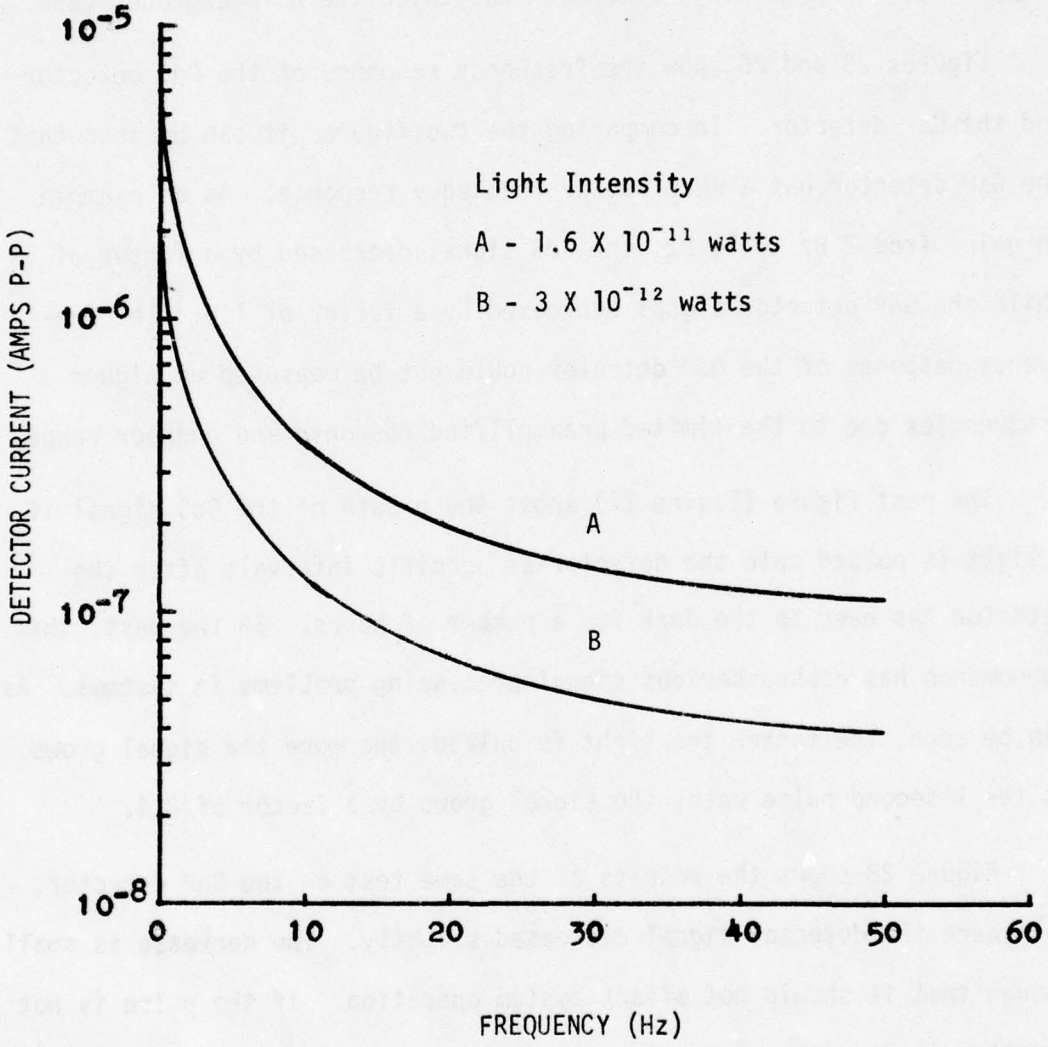


Figure 25. Cadmium Sulfide Detector Signal vs. Frequency

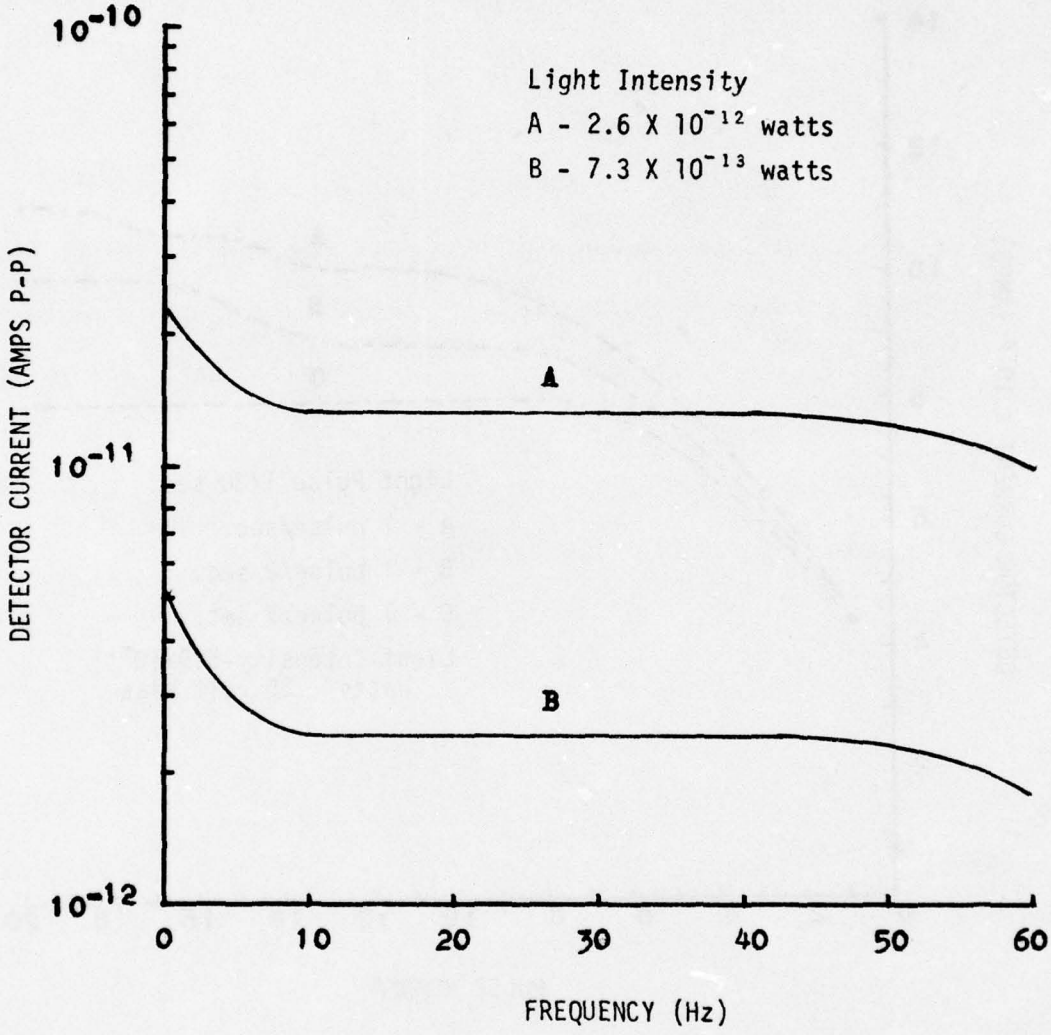


Figure 26. Gallium Phosphide Detector Signal vs. Frequency

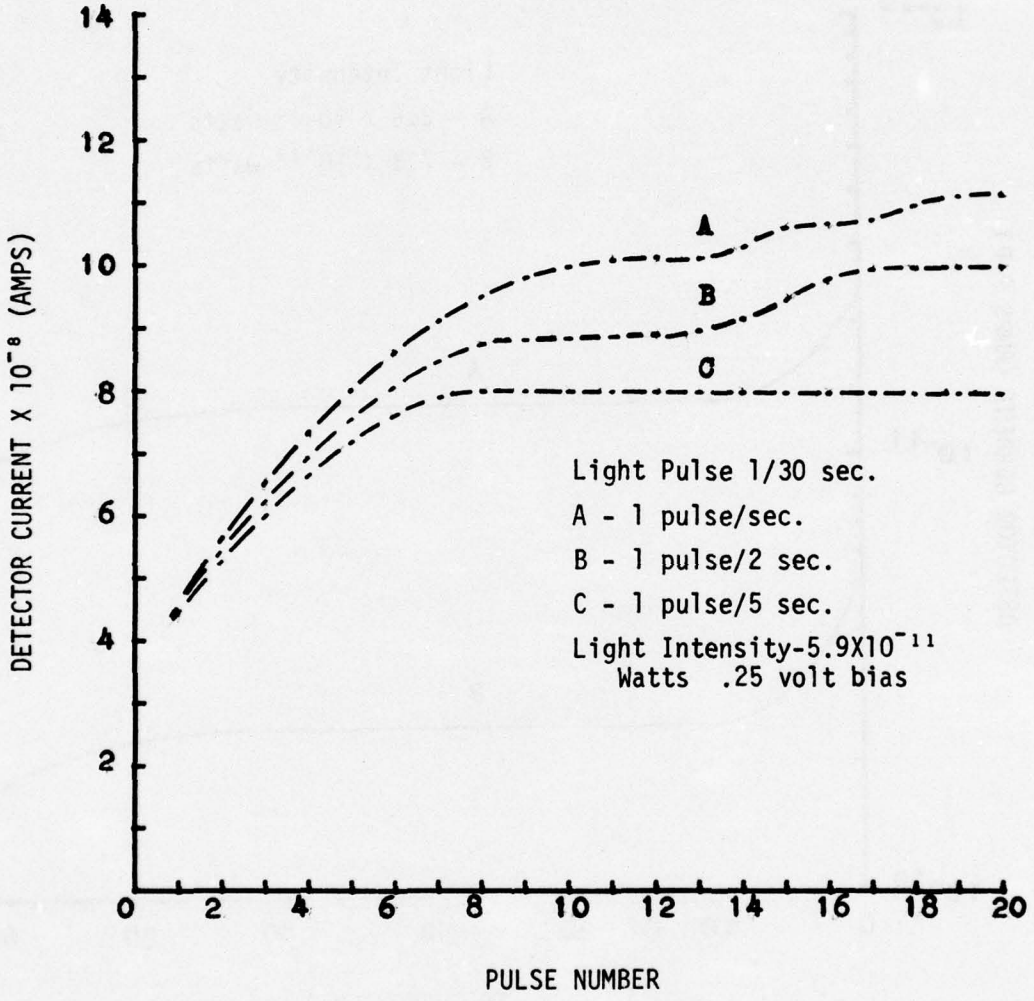


Figure 27. Cadmium Sulfide Detector Signal vs. Light Pulse Number

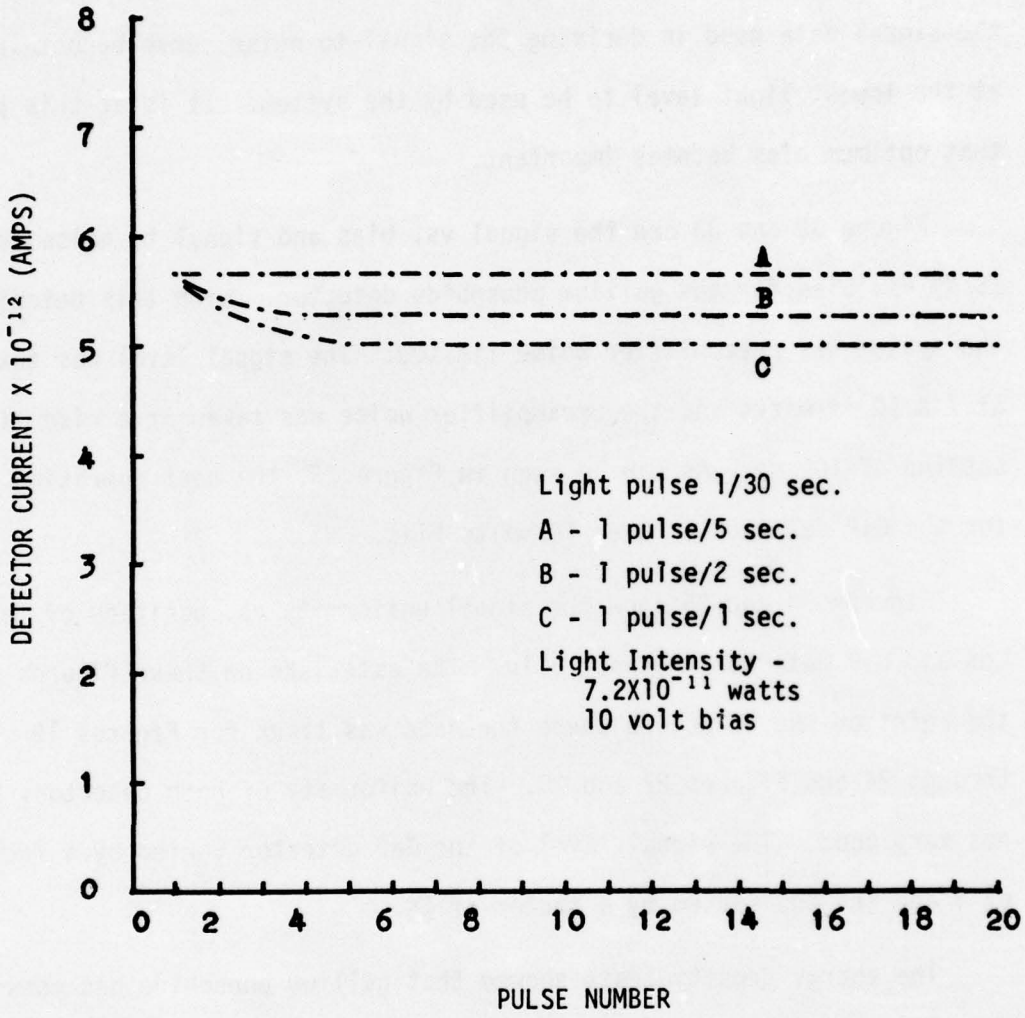


Figure 28. Gallium Phosphide Detector Signal vs. Light Pulse Number

for the cadmium sulfide detector. In Figure 29, the signal data was taken using 1/4 second light pulse at 5 X 10^{-13} watts. The rationale for the selection of this data point was made from typical system requirements. The peak of the signal-to-noise curve shows the optimum bias point for this detector-preamp is .1 volt. It is important that the signal data used in deriving the signal-to-noise curve be obtained at the lowest light level to be used by the system. It is at this point that optimum bias becomes important.

Figure 32 and 33 are the signal vs. bias and signal to noise ratio (S/N) vs. bias for the gallium phosphide detector. With this detector, the system was preamplifier noise limited. The signal level was taken at 7 X 10^{-13} watts and the preamplifier noise was taken at a rise time setting of 100 ms. As can be seen in Figure 33, the best operating point for the GaP detector is over 10 volts bias.

Figures 34 and 35 show the signal uniformity vs. position of the CdS and GaP detectors respectfully. The asterisks on these figures show the point on the detectors where the data was taken for Figures 19 through 24 and Figures 27 and 28. The uniformity of both detectors is not very good. The signal level of the GaP detector varied by a factor of 9 and the CdS varied by a factor of 34.

The energy density tests showed that gallium phosphide had constant signal as the energy was spread out over the length of the detector. For cadmium sulfide, the signal increased about 10% every time the illuminated area doubled. The one restriction on the above data is that the detector must be illuminated from contact to contact or these results become invalid.

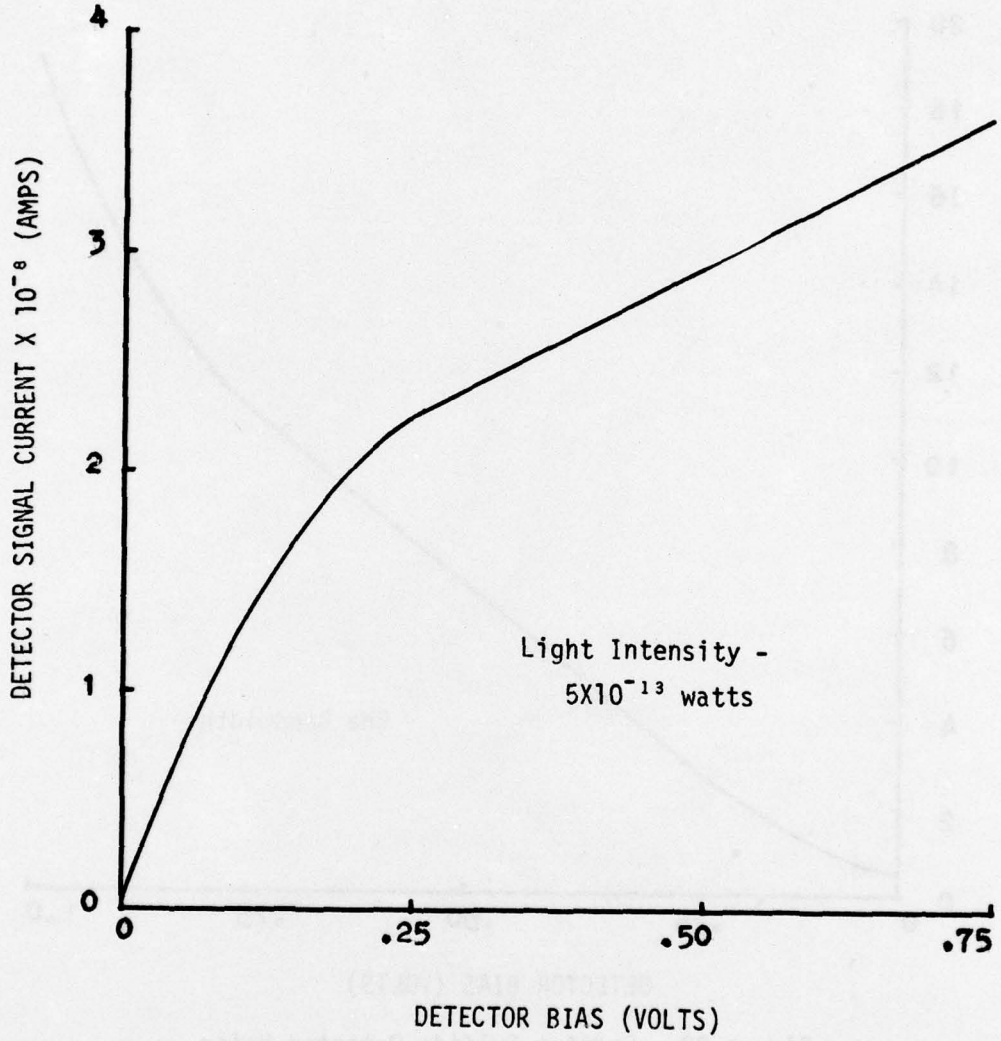


Figure 29. Cadmium Sulfide Detector Signal Current vs. Bias

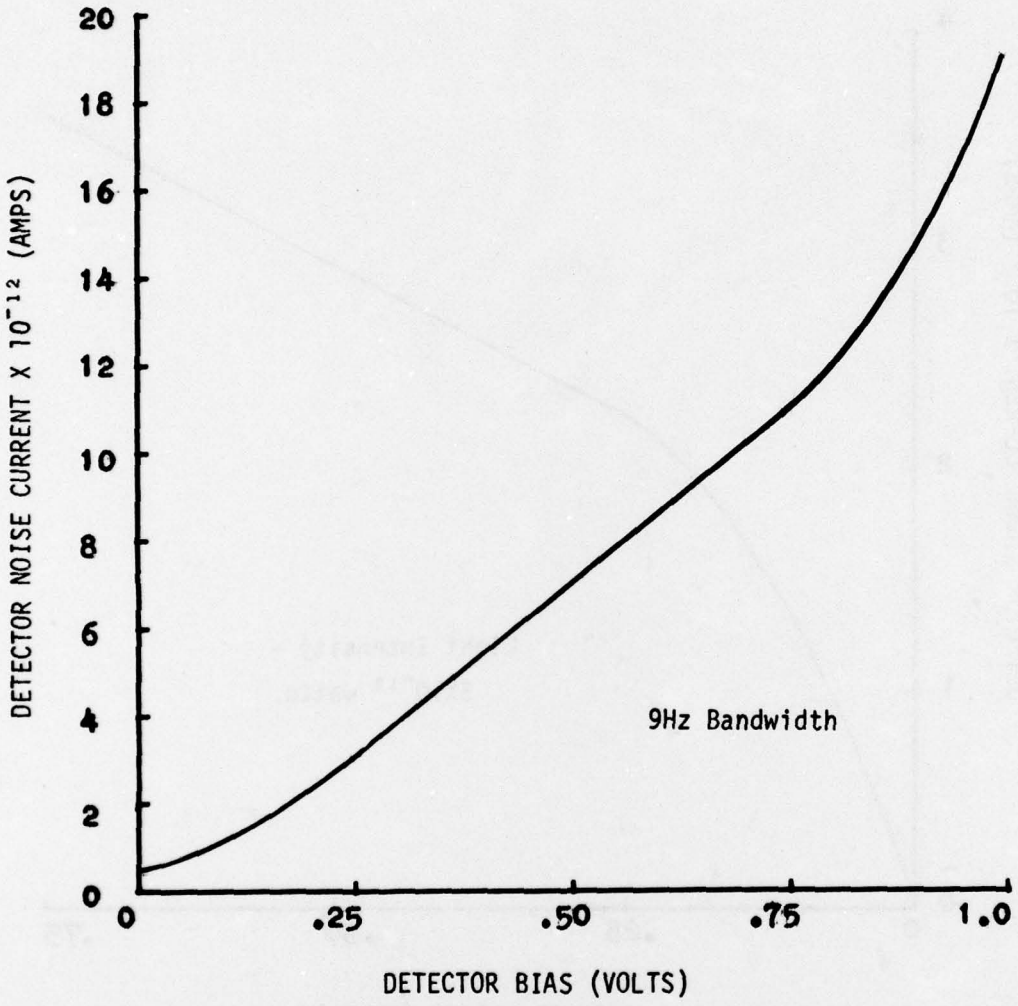


Figure 30. Cadmium Sulfide Detector Noise Current vs. Bias

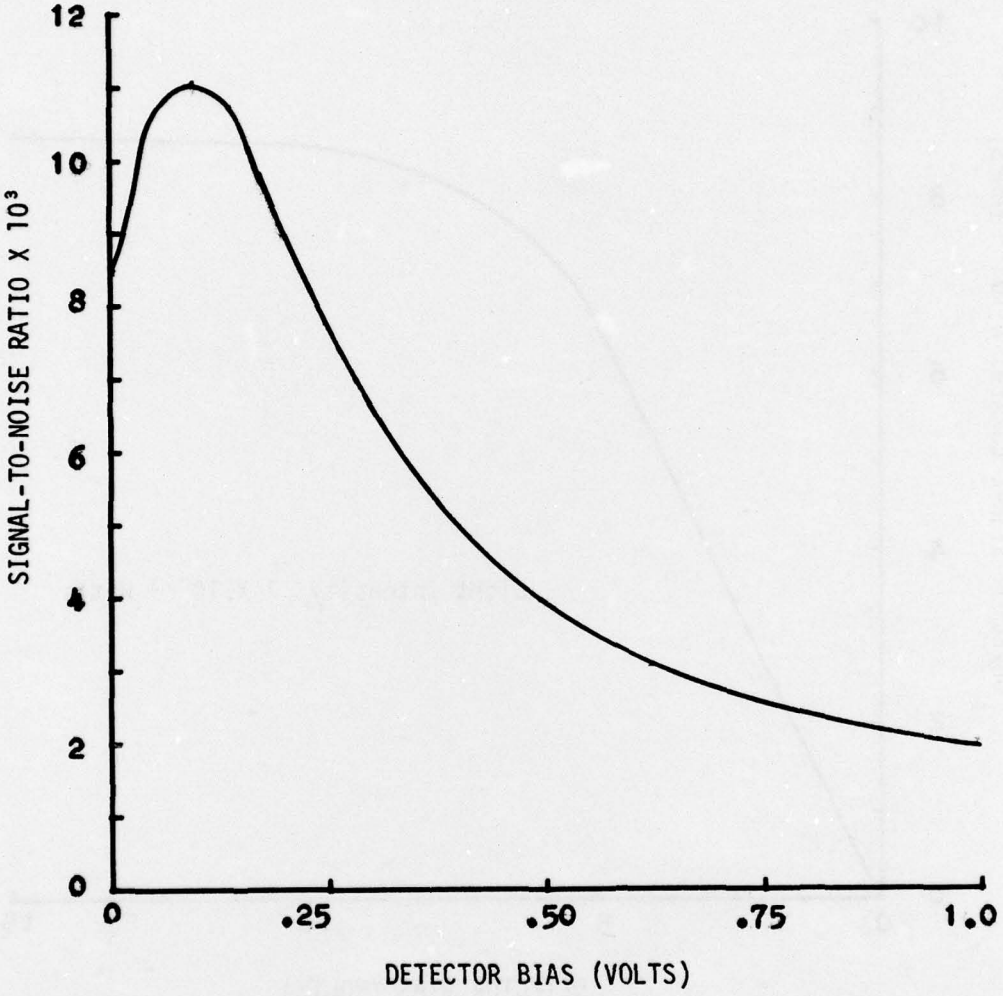


Figure 31. Cadmium Sulfide Detector Signal-to-Noise Ratio vs. Bias

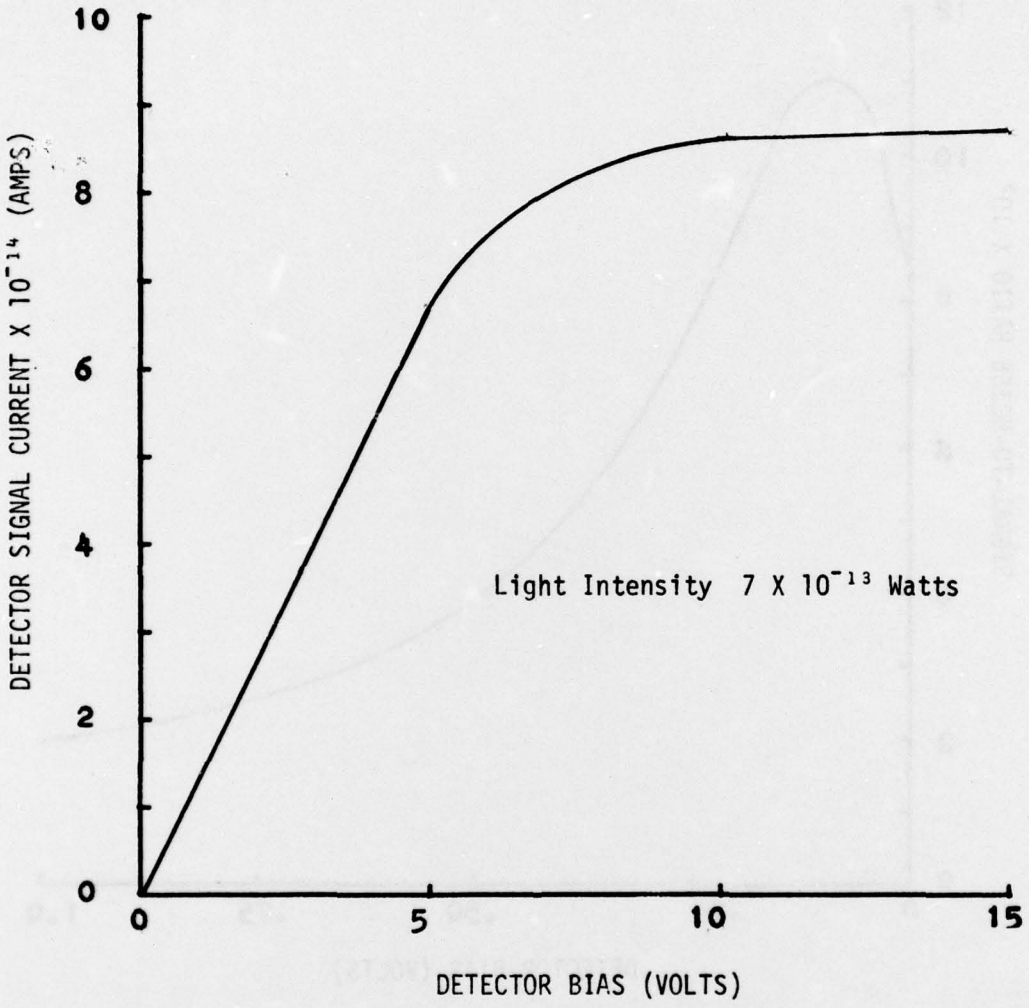


Figure 32. Gallium Phosphide Detector Signal Current vs. Bias

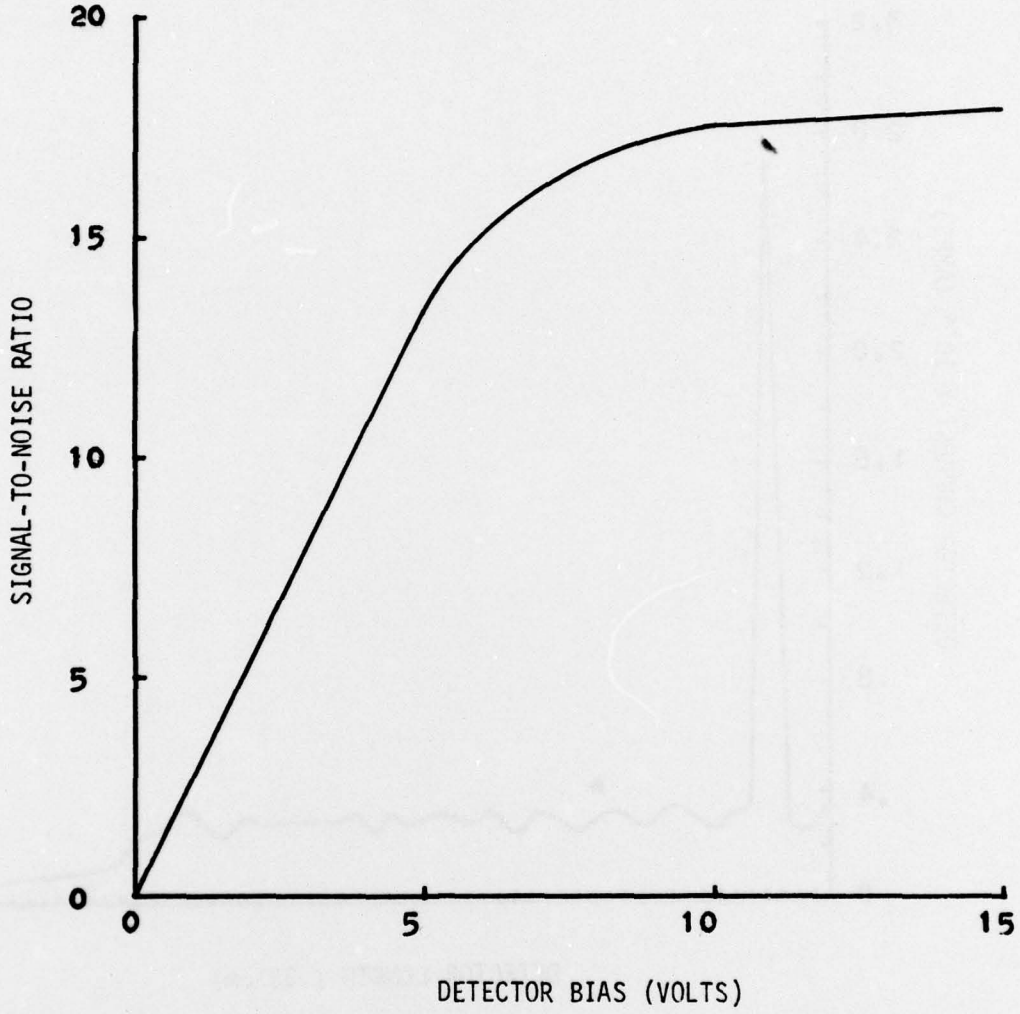


Figure 33. Gallium Phosphide Detector Signal-to-Noise Ratio vs. Bias

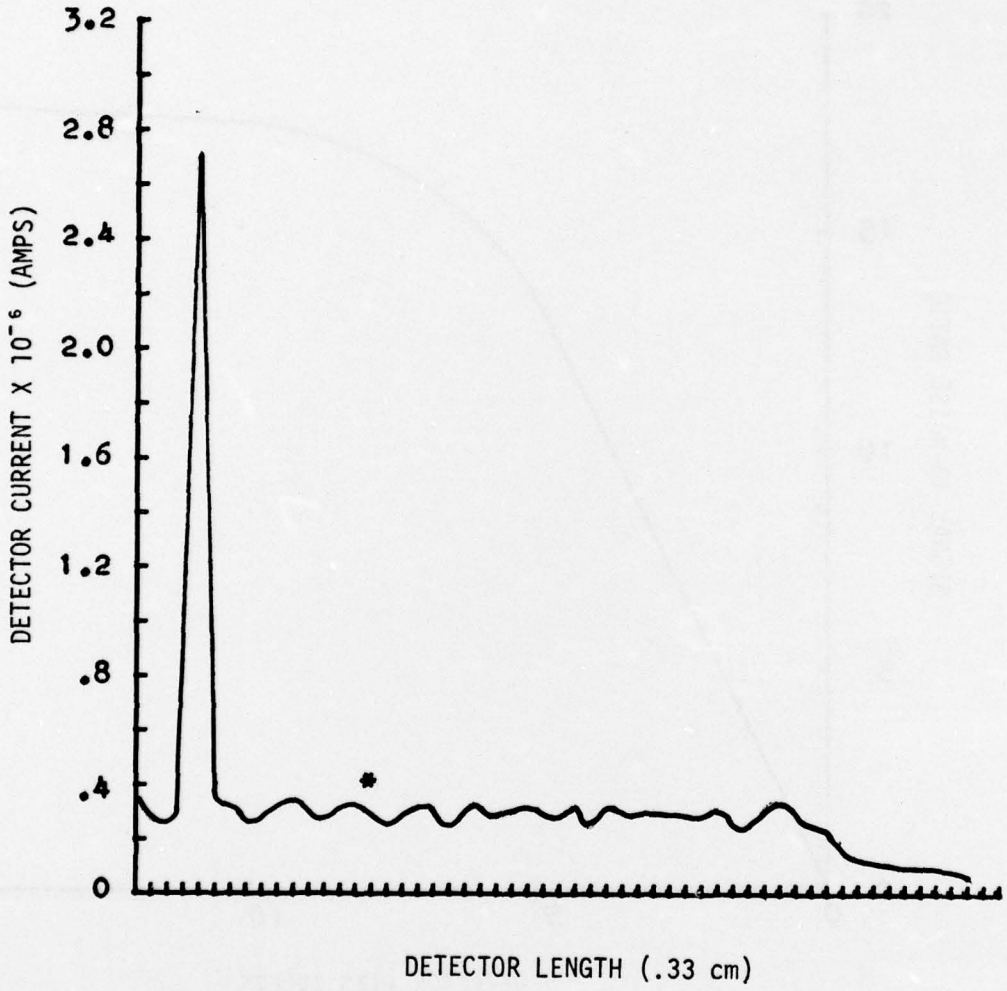


Figure 34. Cadmium Sulfide Detector Signal Uniformity

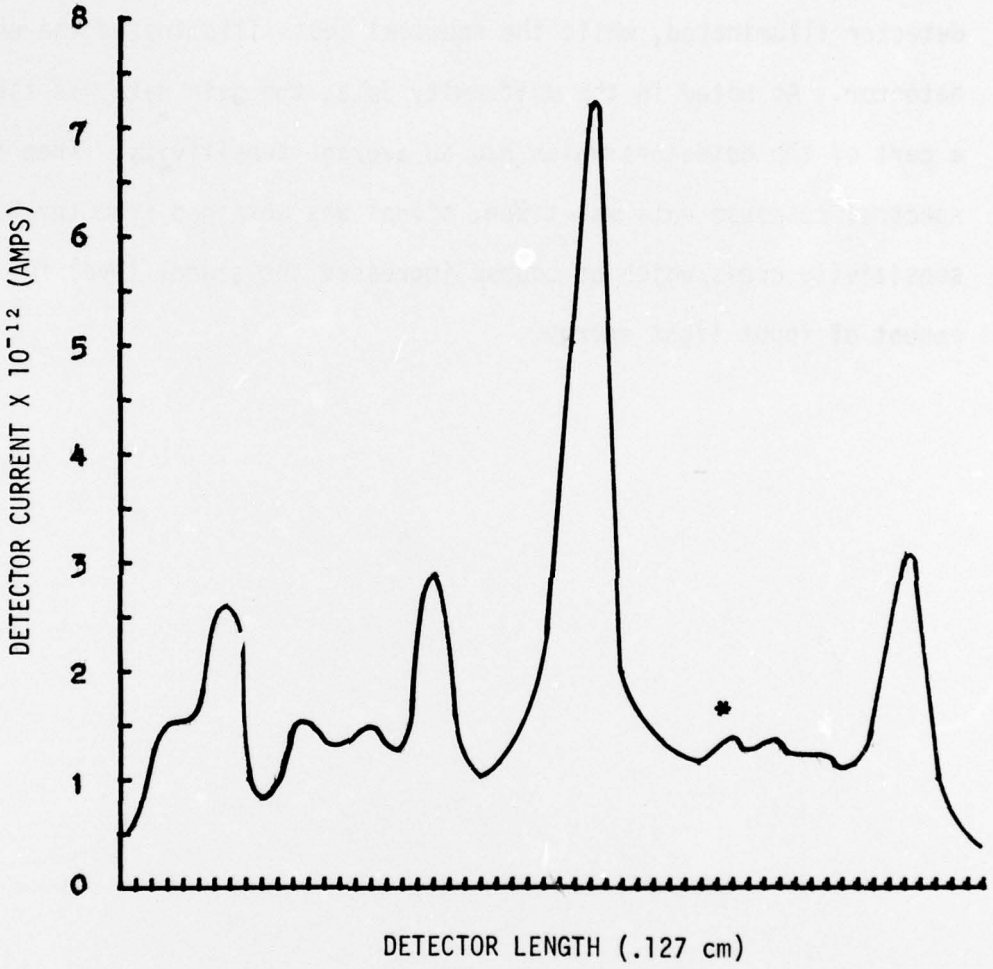


Figure 35. Gallium Phosphide Detector Signal Uniformity

One final comment should be made on the tests results. If one compares the spectral response data (Figures 11 and 12) and the detector gain curves (Figures 19 and 20) there appears a discrepancy in the signal level for amount of input light energy. This discrepancy comes about from the method of testing. The gain tests had 33 microns of the detector illuminated, while the spectral tests illuminated the entire detector. As noted in the uniformity data, the gain data was taken in a part of the detectors which had an average sensitivity. When the spectral response data was taken, signal was obtained from the high sensitivity areas, which of course increased the signal level for the amount of input light energy.

SECTION IV

CONCLUSIONS AND RECOMMENDATIONS

In comparing the gallium phosphide and cadmium sulfide detectors a number of conclusions can be made. This section of the report will list some of the conclusions along with recommendations for future work in this area.

The first conclusion is that GaP has a wider frequency response than CdS. The CdS signal is down 50% from its DC level at .5 Hz, but GaP is still above the 50% point at 50 Hz.

The resistance of the GaP detector is greater than that of CdS by a factor of 10^4. This helps decrease the dark current and dark noise, but it also creates problems in preamplifier front end design. The GaP detector impedance was one factor that caused the test system to be preamplifier noise limited. From the data, it will be noted the signal currents of the GaP detector were usually lower by a factor of 10^5 than those of CdS. This was mainly due to the large difference in detector resistance. If one calculates the percentage resistance change for a given light level, the percentages come out about the same; for example a 10^{-12} watt light signal changes both the GaP and CdS resistances by about 3%. The signal situation would be improved if a voltage mode preamplifier were used; then at low frequency, both CdS and GaP would produce about the same signals, but the higher frequency response of the GaP detector will be lost due to the RC time constant of the detector and preamplifier front end.

The GaP detector has a better characteristic when subjected to

repetitive pulses than CdS. The CdS detector signal can grow to twice the original signal, which in a system can cause problems especially if signal amplitude is one of the parameters being measured.

The gain characteristics of the GaP detectors has a power law relationship for various ranges of light intensities. In most cases, the constant relationship would extend over a sufficient range of input intensity for an electro-optical system. The CdS detector has a non-uniform gain relationship. Depending on how a low light level system is designed, this may cause signal processing problems.

The background illumination produced interesting results, the .4 micron background light decreased just the lower part of the CdS gain curve (Figure 23), but it lowered the upper portion of gain curve of the GaP detectors (Figure 24). The .4 micron background depressed both detector spectral response curves in the .3 to .5 micron regions. The .54 micron background had no effect on the CdS gain curve while the basic gain signal for the GaP detector was the same as with the .4 background light. The .54 background had no effect in either case on the spectral response of the detectors. The .4 micron background light did change the percentage overshoot value of the detector signal for the GaP detector at the higher signal levels. This would seem to indicate a basic change in detector impedance, either the resistance or capacitance or both.

The CdS spectral response changes both with bias and light intensity. This will cause problems in calibration of a system. The GaP spectral response does have some spectral peak shifts with bias and intensity,

but these are not large and therefore would not cause the problems found with the CdS detector.

Bias affects the signal-to-noise ratio of both detectors. For the GaP detector, since the system was preamplifier noise limited, the bias should be over 10 volts. Above 10 volts however, very little signal gain is obtained with increasing bias. The CdS had its best signal-to-noise ratio at about .1 or less volts. Above that bias level, the noise increased faster than the signal level.

Detectivity[1] (D^*_λ) values were not calculated or compared in the test results due to not being able to obtain noise data for the GaP detector. There have been D^*_λ values calculated for both CdS and GaP based on both theory and reported data. Calculated D^*_λ peak for GaP[2] is 2×10^{14}cm $Hz^{\frac{1}{2}}$/watt. D^*_λ peak calculated for CdS[1] is 5×10^{14}cm $Hz^{\frac{1}{2}}$/watt. D^*_λ peak measured for CdS was 2.5×10^{14}cm $Hz^{\frac{1}{2}}$/watt.

The gain curves for both CdS and GaP changed slightly when a single 1/4 second pulse was used instead of the 2 Hz chopped light, but both detectors did keep their general gain characteristics.

Uniformity was poor for both devices. The CdS detector, for which the fabrication process was supposed to be under good control, had a factor of 33 change in signal level along the active area of the detector. The GaP detector had a factor of 9 change in signal but since this was

[1]Physics of Semiconductor Devices, Sze, pg 657.

[2]Honeywell Radiation Center.

a new device with processing problems, this was not a surprise. The GaP detector was found to have some semitransparent spots in the contacts. These thin spots would let light into the detector material where it was not desired; therefore the actual detection area was larger in certain areas than it should have been. Not all of the GaP uniformity problems therefore were due to the detector material. Both devices need substantial work to obtain better uniformity.

One factor not covered in these tests is that of environmental characteristics of these devices. The general conclusion of environmental tests[4] has been that the GaP detectors can withstand much higher temperatures and humidity than the CdS devices.

General recommendations for future work are primarily aimed at the GaP detector technology. Research in CdS area has yielded very few encouraging results so that it is hard to justify additional effort in the area. The GaP technology, however, does show promise. Initial efforts should continue on materials growth and doping. It is felt that if research and development are done in this one area, many of the problems noted in these test results, such as nonuniformity, will be eliminated. Also considerable work should be done in studying the trapping levels and recombination centers in this material but only after the materials problem is under better control.

[4]Conducted by Honeywell, Inc.

APPENDIX A

SPECIFICATIONS FOR KEITHLEY #427 CURRENT AMPLIFIER

RANGE: 10^4 to 10^{11} volts/ampere in eight decade ranges. (10^{-13} ampere resolution to 10^{-3} ampere full output).

OUTPUT: ±10 volts at up to 3 milliamperes.

OUTPUT RESISTANCE: Less than 10 ohms dc to 30 kHz.

OUTPUT ACCURACY: ±2% of reading to the 10^9 volts/ampere range, ±4% of reading on the 10^{10} and 10^{11} volts/ampere ranges exclusive of noise, drift and current offset.

RISE TIME (10% to 90%): Adjustable in 1x and 3.3x steps from "Fast Rise Time" listed below to 330 msec.

NOISE VS. RISE TIME*:

	FAST RISE TIME			WIDE DYNAMIC RANGE		
Gain V/A	Rise Time (10%-90%)	Dynamic Range	Noise (ampere rms)	Dynamic Range	Noise (ampere rms)	Rise Time (10%-90%)
10^{11}	1.5 ms	100	$4x10^{-13}$	$1.3x10^4$	$3x10^{-16}$	330 ms
10^{10}	400 µs	200	$2x10^{-12}$	$2x10^4$	$2x10^{-14}$	100 ms
10^9	220 µs	400	$1x10^{-11}$	$2x10^4$	$2x10^{-13}$	10 ms
10^8	60 µs	800	$5x10^{-11}$	$2x10^4$	$2x10^{-12}$	1 ms
10^7	40 µs	2000	$2x10^{-10}$	$2x10^4$	$2x10^{-11}$	100 µs
10^6-10^4	15 µs	2000	–	$2x10^4$	–	100 µs

*With up to 100 pF input shunt capacitance. Noise and/or rise time increase as input shunt capacitance increases (1000 picofarads maximum).

STABILITY: Current offset doubles per 10°C above 25°C. Voltage drift is less than 0.005% per °C and less than 0.005% per day of full output after 1-hour warmup.

OFFSET CURRENT: Less than 10^{-12} ampere at 25°C and up to 70% relative humidity.

CURRENT SUPPRESSION: 10^{-10} ampere to 10^{-3} ampere in eight decade ranges with 0.1% resolution (10-turn potentiometer). Stability is ±0.2% of suppressed value per °C ±0.2% per day.

INPUT VOLTAGE DROP: Less than 400 µV for full-scale output on the 10^6 to 10^{11} volts/ampere ranges when properly zeroed.

EFFECTIVE INPUT RESISTANCE: Less than 15 ohms on the 10^4 and 10^5 volts/ampere ranges, increasing to less than 4 megohms on the 10^{11} volts/ampere range.

MAXIMUM INPUT OVERLOAD: Transient: 1000 volts on any range for up to 3 seconds using a Keithley (or other 10 mA-limited) high-voltage supply. Continuous: 500 volts on the 10^{11} to 10^7 volts/ampere ranges, decreasing to 200 on the 10^6, 70 on the 10^5 and 20 volts on the 10^4 volts/ampere ranges.

OVERLOAD INDICATION: Lamp indicates pre-filter or post-filter overload.

DYNAMIC RESERVE: 10 (20 dB).

CONNECTORS: Input: (Front) BNC. Output: (Front and Rear) BNC.

POWER: 90-125 or 180-250 volts (switch selected), 50-60 Hz, 5 watts.

DIMENSIONS; WEIGHT: Style M 3½" half-rack, overall bench size 4" high x 8½" wide x 12⅛" deep (100 x 217 x 310 mm). Net weight, 7 lbs. (3,0 kg).

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