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# SIGNAL-TO-NOISE RATIO FOR THE WIDE FIELD/PLANETARY CAMERA OF THE SPACE TELESCOPE

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16. ABSTRACT

Signal-to-noise ratios for the Wide Field Camera and Planetary Camera of the Space Telescope have been calculated as a function of integration time. Models of the optical systems and CCD detector arrays were used with a 27th visual magnitude point source and a 25th visual magnitude per arc-second$^2$ extended source. A 23rd visual magnitude per arc-second$^2$ background was assumed. The models predicted signal-to-noise ratios of 10 within 4 hours for the point source centered on a single pixel. Signal-to-noise ratios approaching 10 are estimated for approximately 0.25 x 0.25 arc-second areas within the extended source after 10 hours integration.

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# TECHNICAL MEMORANDUM

## SIGNAL-TO-NOISE RATIO FOR THE WIDE FIELD/PLANETARY CAMERA OF THE SPACE TELESCOPE

The signal-to-noise ratio has been estimated for the wide field camera (WFC) and the planetary camera (PC) as a function of integration time. The following paragraphs describe the effective flux, effective polychromatic point spread function, and noise calculations.

The total number of CCD signal electrons from the whole point spread function (PSF) or from a square arc-second solid angle for an extended source was determined as follows. First, the energy flux received from a solar type star of visual magnitude m was taken as [1]:

$$I(m) = 3.72 \times 10^{-9} \times 10^{-0.4m} \text{ erg cm}^{-2} \text{ Å}^{-1} \text{ sec}^{-1}$$

near 5500 Å. Then the spectral distribution was assumed to be that of a blackbody at 6000°K. (The results are not very sensitive to the assumed temperature since the bandwidth of the visual filter is narrow compared to that of the blackbody.) Then the number of signal electrons in the entire PSF or square arc-second solid angle for an extended source is

$$N = AtI(m) \int_{(\text{all } \lambda)} (\lambda/hc) B(\lambda) Q(\lambda) T(\lambda) d\lambda \quad ,$$

where

$A$ = unobscured aperture area [2]

$t$ = integration time

$\lambda$ = wavelength

$(\lambda/hc)$ = photons per unit energy

$B(\lambda)$ = blackbody spectrum at 6000°K normalized to 1. at 5500 Å

$Q(\lambda)$ = quantum efficiency of system [3]

$T(\lambda)$ = transmission of visual filter F306 [4] .

The WFC and PC designs [5] were ray-traced; it was found that they are basically perfect optical systems from the OTA through the central axis of each of the WF/PC telescopes (rms wavelength error < $\lambda/300$). For this study, several samples of $\lambda/13$ rms random wave front error were applied (here $\lambda$ = 6328 Å). The random distributions were smoothed by a gaussian distribution so that there were about 5 cycles per aperture diameter. The aperture was assumed to be a circle of 1200 mm radius with a central obscuration of radius 396 mm. "F" numbers of 12.9 and 30.0 were assumed for the WFC and PC, respectively. The polychromatic PSF's were represented by 6 monochromatic PSF's weighted by the spectral distribution of signal electrons. An assumed jitter of 0.007 arc-seconds rms was simulated by convolution with a gaussian distribution of the appropriate width. The smearing effect of charge transfer inefficiency in the CCD at the center of the 800 x 800 array was included by assuming a typical value for charge transfer efficiency of 0.99996 [6,7,8]. (A central pixel's charge must be transferred 1200 times in the three-phase device). Finally, smearing by charge carrier diffusion in the CCD was taken into account with a theoretical model [9,10] of a rear illuminated CCD 10 microns thick with a 4.5 micron thick depletion region and with 5500 Å incident light. The temperature of the CCD was assumed to be -95°C. The theoretical model is supported by measurements up to 33 cycles/mm spatial frequency for sample devices [7,8]. Formally, the fraction of the total number of signal electrons in a given CCD detector area is

$$\frac{\underset{\text{(given area, all }\lambda)}{\iiint} \lambda B(\lambda)Q(\lambda)T(\lambda)NPSF(x,y,\lambda)\,dx\,dy\,d\lambda}{\underset{\text{(all }\lambda)}{\int} \lambda B(\lambda)Q(\lambda)T(\lambda)\,d\lambda}$$

where

$$\underset{\text{(all area)}}{\iint} NPSF(x,y,\lambda)\,dx\,dy = 1$$

and $NPSF(x,y,\lambda)$ is the continuous form of the effective polychromatic PSF at the CCD surface before weighting by the spectral distribution of signal electrons.

The rms noise in the signal was calculated as follows:

$$\Sigma = (N_S + N_B + i_D t n_p + \sigma_R^2 n_p)^{1/2}$$



where:

$\Sigma$ = rms noise electrons

$N_S$ = signal electrons

$N_B$ = background electrons

$i_D$ = dark current = $6 \times 10^{-3}$ electrons/pixel/sec at -95°C [7]

$t$ = integration time

$n_p$ = number of detector pixels considered

$\sigma_R$ = rms readout noise of CCD = 17.8 electrons/pixel [3] .

Then the signal-to-noise ratio is $N_S/\Sigma$ .

Figures 1 and 2 show sample effective point spread functions after integration over wavelength for the WFC and PC models, respectively. The full width of a pixel is $0.6 \times 10^{-3}$ in. or 0.100 and 0.043 arc-seconds for the WFC and PC, respectively.

Figures 3 through 6 show sample signal-to-noise ratios calculated for the WFC and PC models for a single CCD pixel exposed to a point source of 27th magnitude. The background was assumed to be 23rd magnitude per square arc-second. The cases with the PSF centered on the pixel and centered on the pixel's corner are shown. Figures 7 through 9 show the signal-to-noise ratio calculated for groups of pixels exposed within an area of 25th magnitude per square arc-second source and 23rd magnitude per square arc-second background. At the edge of an extended source area the signal-to-noise ratios would be smaller due to smearing by the effective point spread functions.

In the present model a 27th magnitude point source centered on a pixel with a 23rd magnitude per square arc-second background would result in a signal-to-noise ratio of 10 in less than 4 hours for both the WFC and PC. The cases with the PSF on a corner would not meet that specification with a single pixel. The WFC model would have a signal-to-noise ratio of 10 in 10 hr for 2 x 2 pixels exposed within an area of 23rd magnitude source and 27th magnitude background. However, at the edge of an extended source area the signal-to-noise ratio would be smaller due to smearing by the effective point spread function. The PC model would achieve a signal-to-noise ratio of about 9 over 6 x 6 pixels under similar conditions.

REFERENCES


1. Allen, C. W.: Astrophysical Quantities. Third edition, The Athlone Press, London, 1973, p. 197.

2. Updated Characteristics of the SI-to-OTA Optical Interfaces, Perkin Elmer Report No. PR-706, May 1982.

3. Westphal, J. A.: The Wide Field Planetary Camera. NASA Report No. CP-2244, August 1982, pp. 28-39.

4. LMSC Report No. D931340, p. 60.

5. WFPC Flight Equipment Optical System Detail Specification, Jet Propulsion Laboratory, September 1980; Optical Schematic WF/PC System, Jet Propulsion Laboratory, revised November 1979.

6. Barbe, D. F.: Imaging Devices Using the CCD Concept. Charge-Coupled Devices: Technology and Applications, IEEE Press, New York, 1977, equation (82), p. 147.

7. Landauer, F. P., Janesick, J. R., Knapp, S. L., Blouke, M. M., and Hall, J. E.: An 800 x 800 CCD Imager for Space-Borne Scientific Imaging. Proc. 1978 Gov. Micro. Applications Conf., Monterey, CA, November 1978, p. 394.

8. Blouke, M. M., Janesick, J. R., Hall, J. E., and Cowens, M. W.: Texas Instruments (TI) 800 x 800 Charge-Coupled Device (CCD) Image Sensor, in Solid State Imagers for Astronomy, SPIE Vol. 290, 1981, pp. 6-15.

9. Crowell, M. H., and Labuda, E. F.: The Silicon Diode Array Camera Tube, Bell System Technical Journal 48, 1969, pp. 1481-1528.

10. Seib, D. H.: Carrier Diffusion Degradation of Modulation Transfer Function in Charge Coupled Imagers, IEEE Trans. ED21, 1974, pp. 210-217.

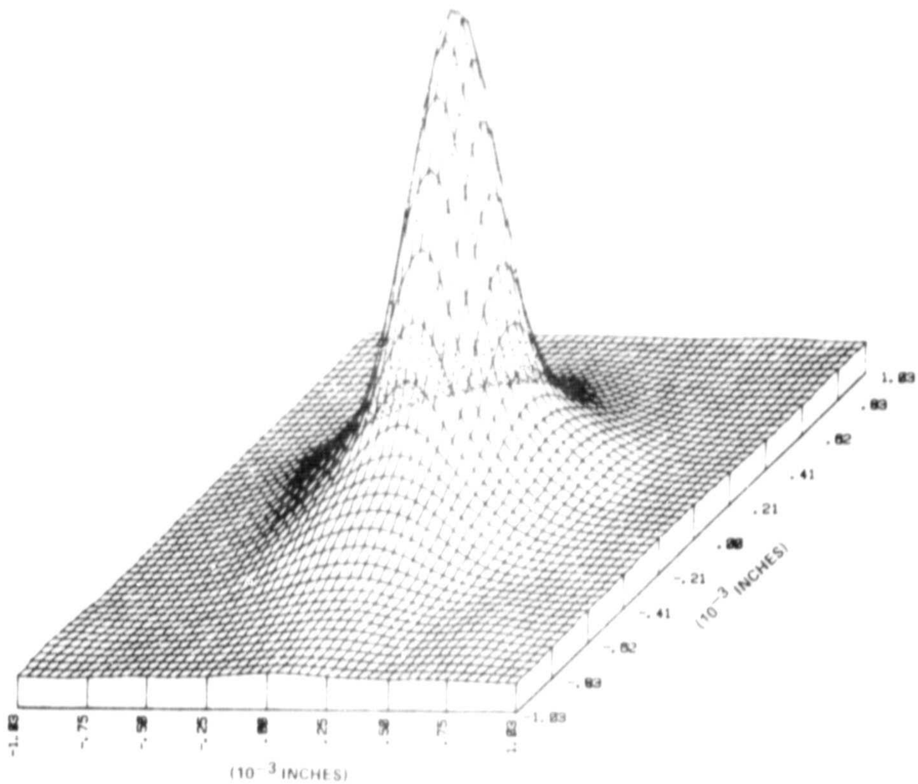


Figure 1. WFC, effective point spread function.

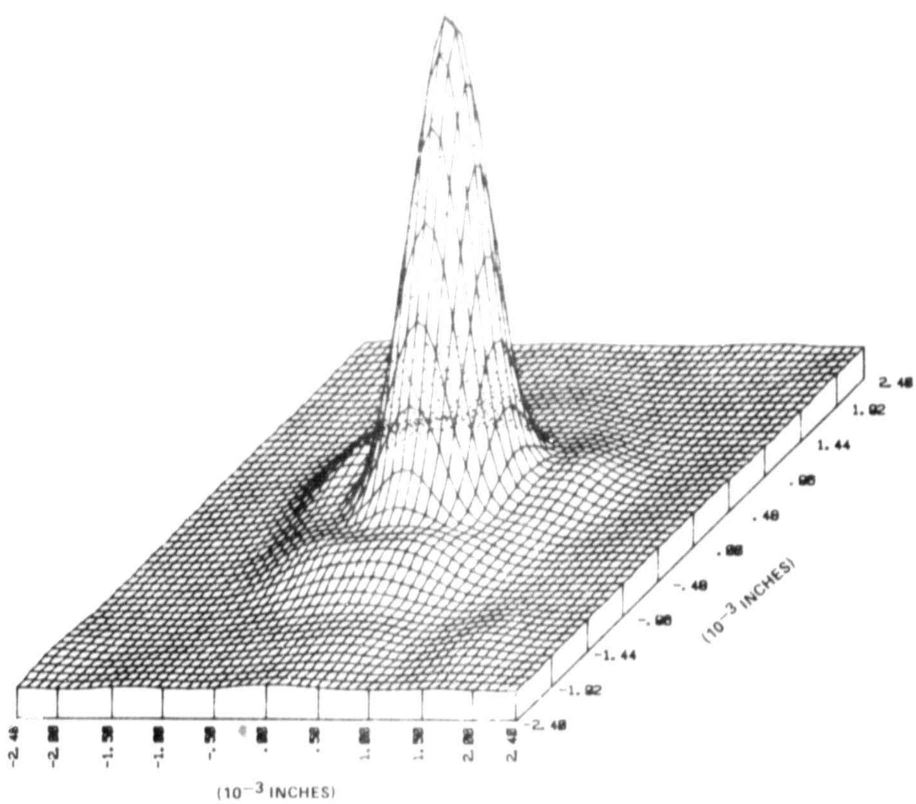


Figure 2. PC, effective point spread function.

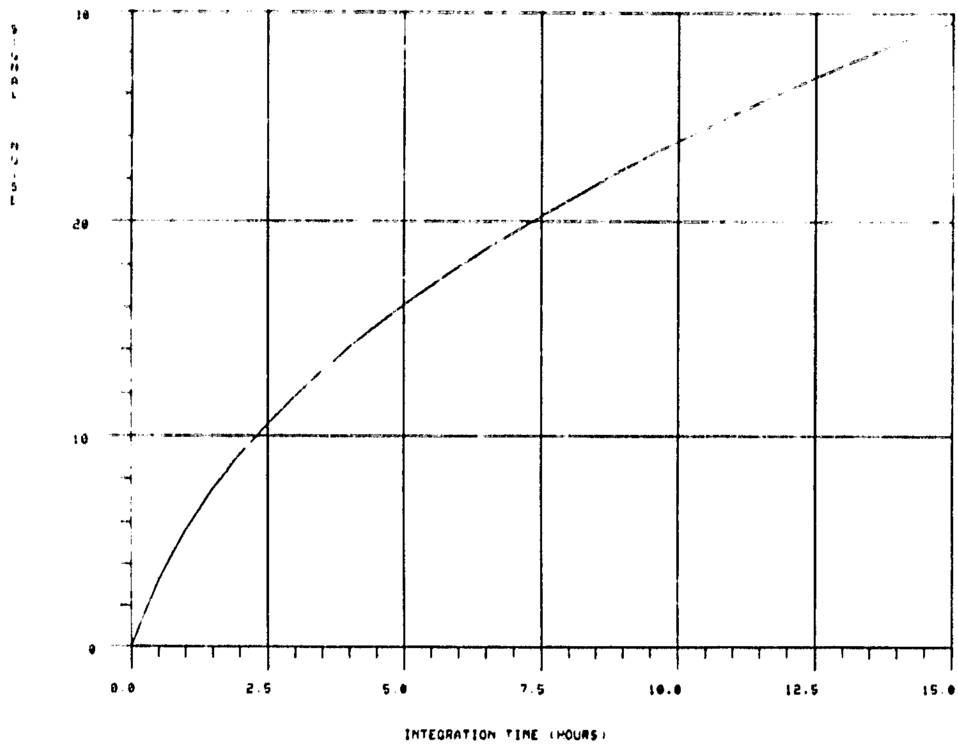


Figure 3. WFC, 27th magnitude point source centered on pixel, 23rd magnitude per arc-sec$^2$ background.

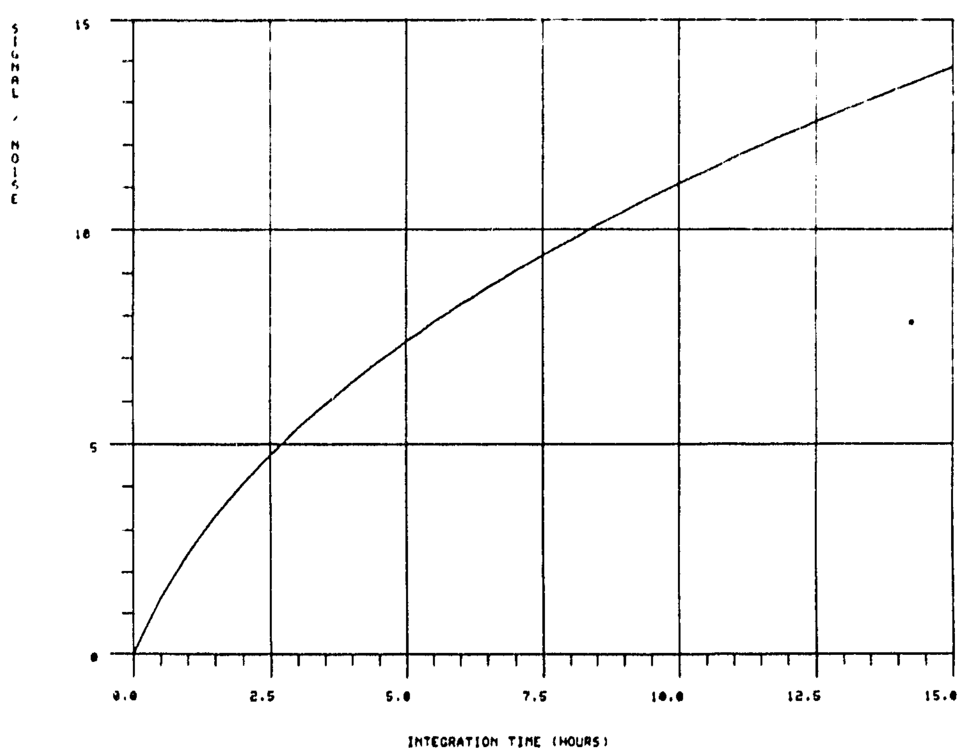


Figure 4. WFC, 27th magnitude point source centered on pixel's corner, 23rd magnitude per arc-sec$^2$ background.

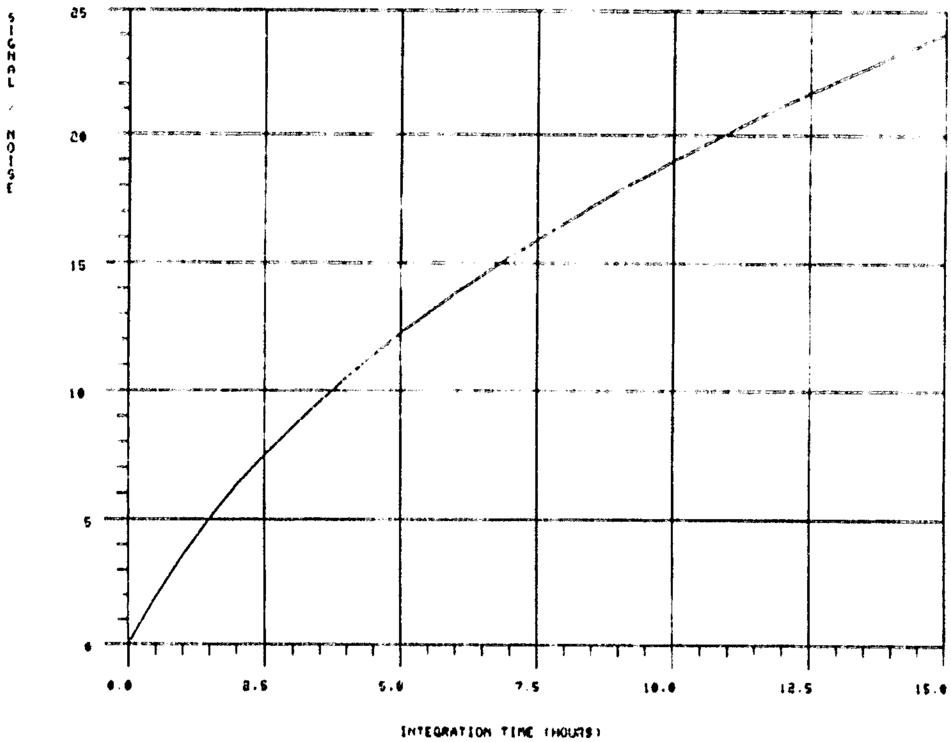


Figure 5. PC, 27th magnitude point source centered on pixel, 23rd magnitude per arc-sec$^2$ background.

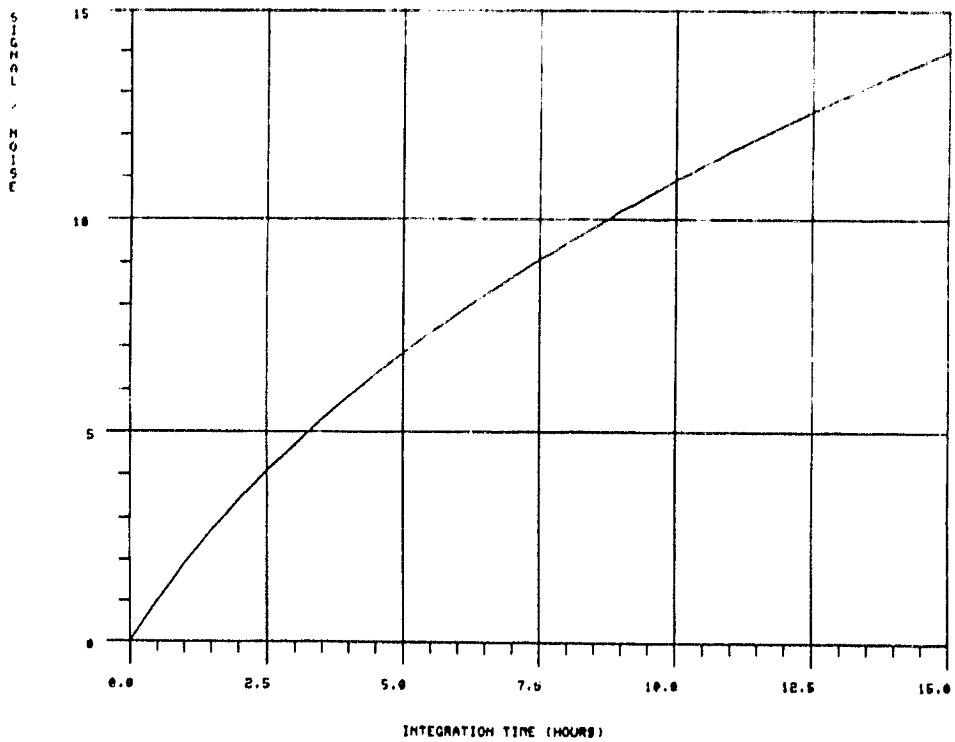


Figure 6. PC, 27th magnitude point source centered on pixel's corner, 23rd magnitude per arc-sec$^2$ background.

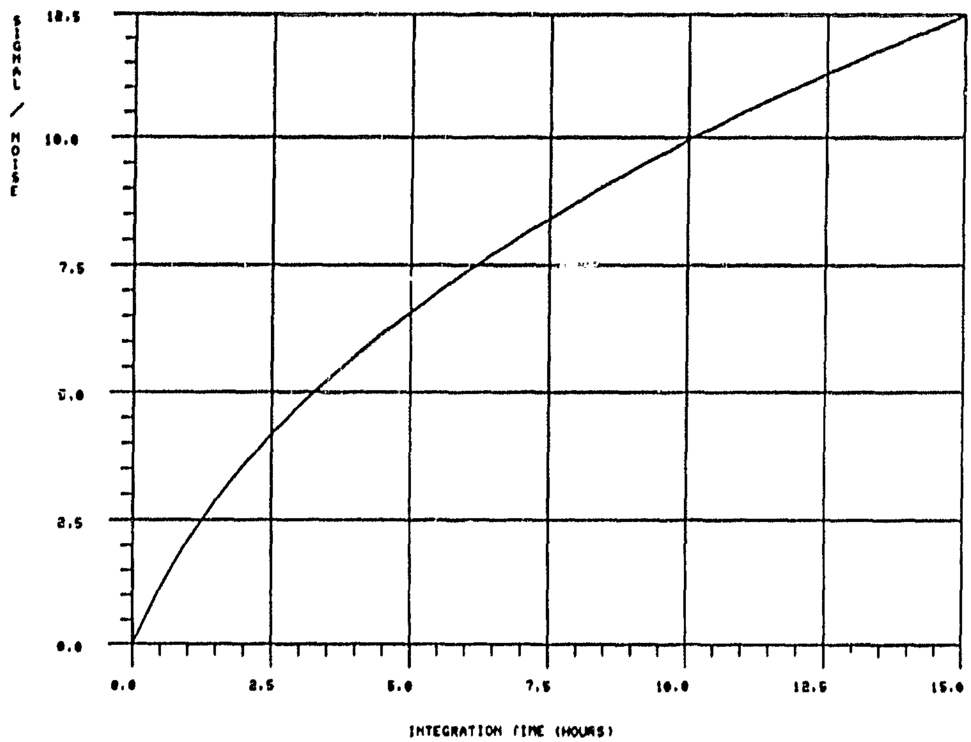


Figure 7. WFC, 25th magnitude per arc-sec$^2$ source on 2x2 pixels, 23rd magnitude per arc-sec$^2$ background.

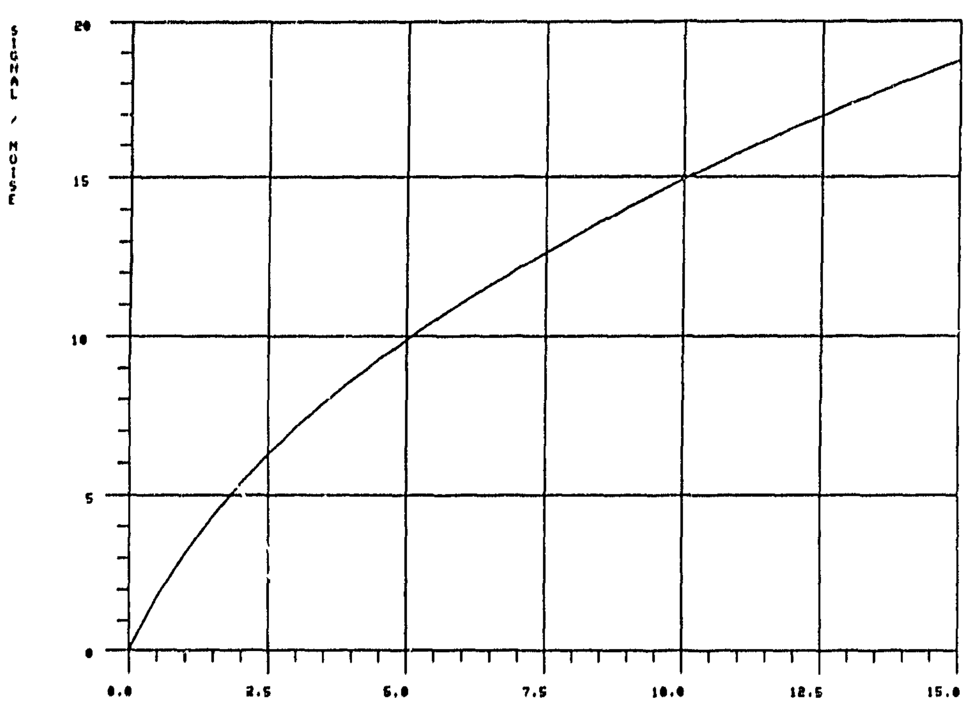


Figure 8. WFC, 25th magnitude per arc-sec$^2$ source on 3x3 pixels, 23rd magnitude per arc-sec$^2$ background.

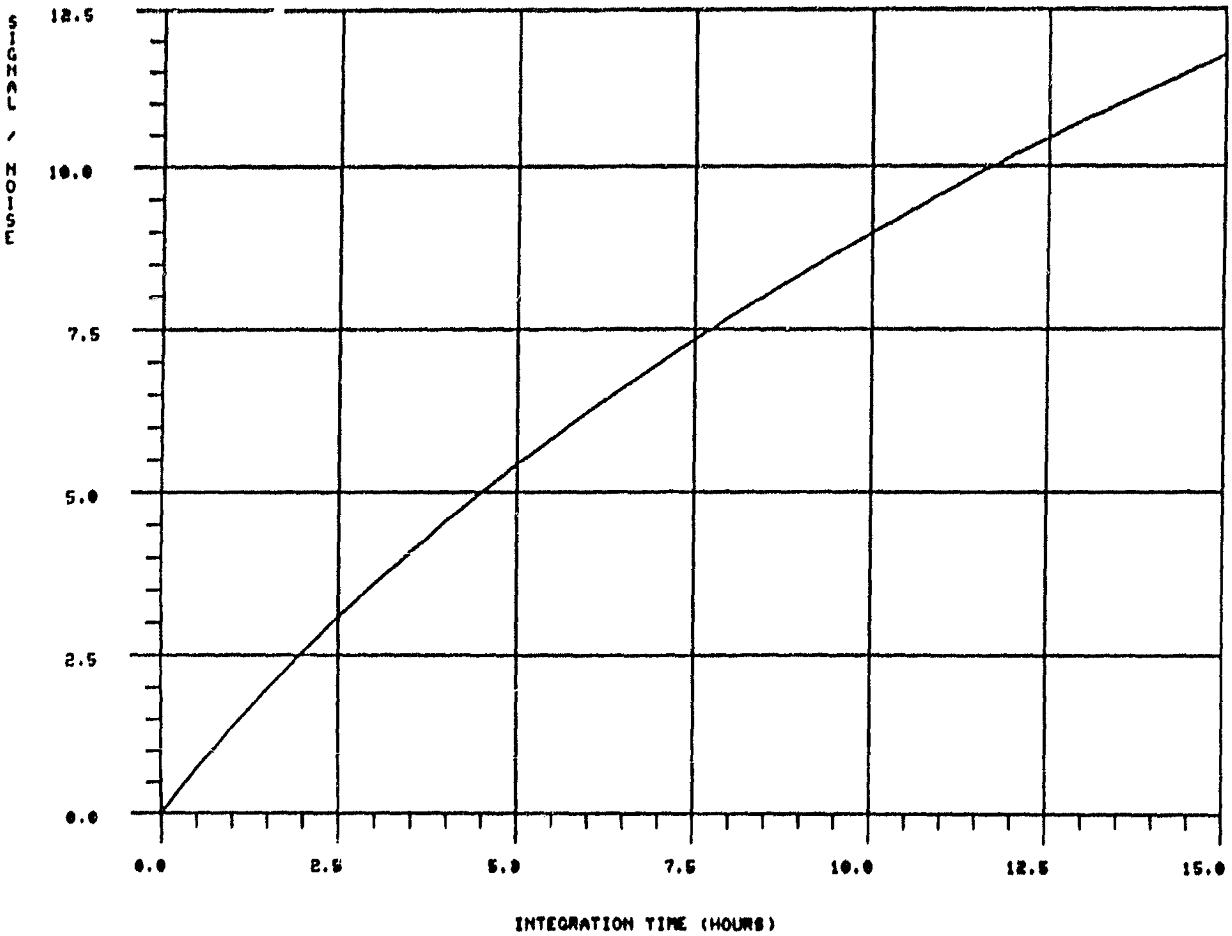


Figure 9. PC, 25th magnitude per arc-sec$^2$ source on 6x6 pixels, 23rd magnitude per arc-sec$^2$ background.