CHAPTER 3: BEAMSPLITTER AND PMT

Beamsplitter and PMT Mount

The beamsplitter and position sensor (PMT) are mounted to a 3" x 1/2" steel plate located above and slightly behind the slit as shown in Figure 16.

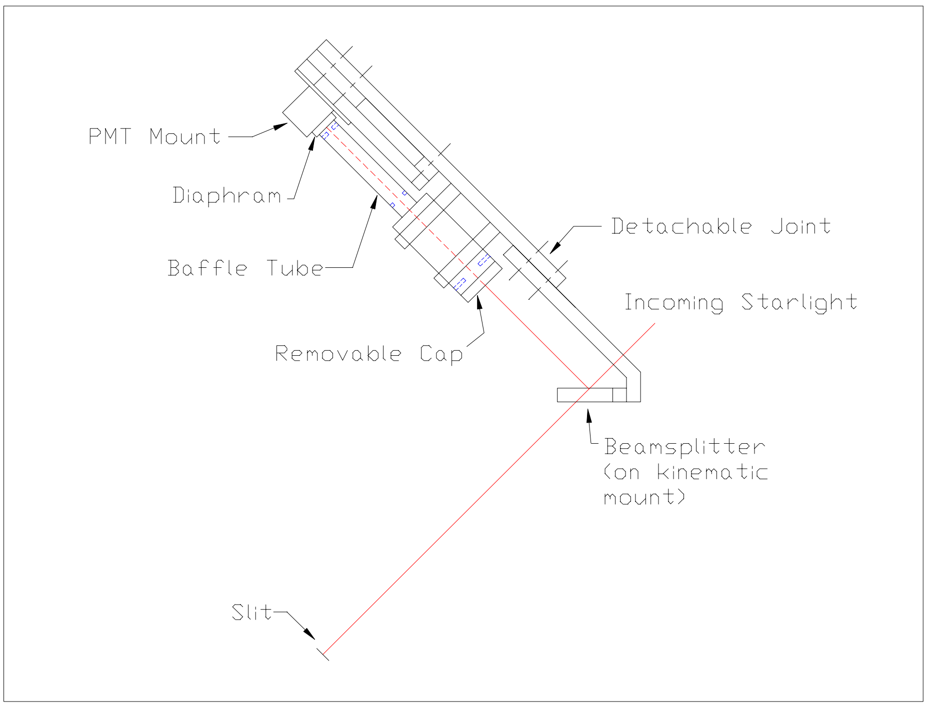

Figure 16. Beamsplitter and PMT Mount Assembly. The beamsplitter reflects a small amount of the incoming light to the PMT. A baffle tube is used to help eliminate scattered light and a diaphragm is used to keep the PMT covered when not in use.

This mount "sandwiches" the steel plate in order to avoid modifications to the structure and is equipped with a pinned, detachable joint for easy removal of the beamsplitter mount when not in use and for repeatable reinstallation.

Beamsplitter

The beamsplitter, provides a 4% reflected sample of the beam across the entire visual spectrum at an incident angle of 45°. The surfaces are finished to a flatness of better than $\lambda/10$. The second surface is coated with a highly efficient AR (anti-reflectance) coating with a reflectance of less than 0.5%. This virtually eliminates ghost images. At an incident angle of 45° and a beamsplitter thickness of 5mm, any ghost images that do occur will be offset from the actual beam by 7mm. This displacement is large enough to insure that none of this light will enter the slit. Some of the light caused from ghost imaging will be sensed by the PMT. The proportion of light, as well as position, will be constant, resulting in a simple offset in the position of the image centroid at the PMT relative to the position of the real image at the slit. This offset has no effect on the position calculations as the alignment of the system is made by centering the image on the slit while simultaneously illuminating each PMT quadrant with an equivalent amount of light, both from the actual image and the ghost image.

The beamsplitter is mounted on a kinematic stage using an L-shaped mount, allowing the light to pass without interference. This mount (see Figure 17) has an angular range of 10° with a resolution of 6 arcseconds about two axes. The adjustment knobs face outward allowing easy access and full adjustability of the beamsplitter. With the use of the kinematic mount, the beamsplitter is fully adjustable for easy alignment of the system.

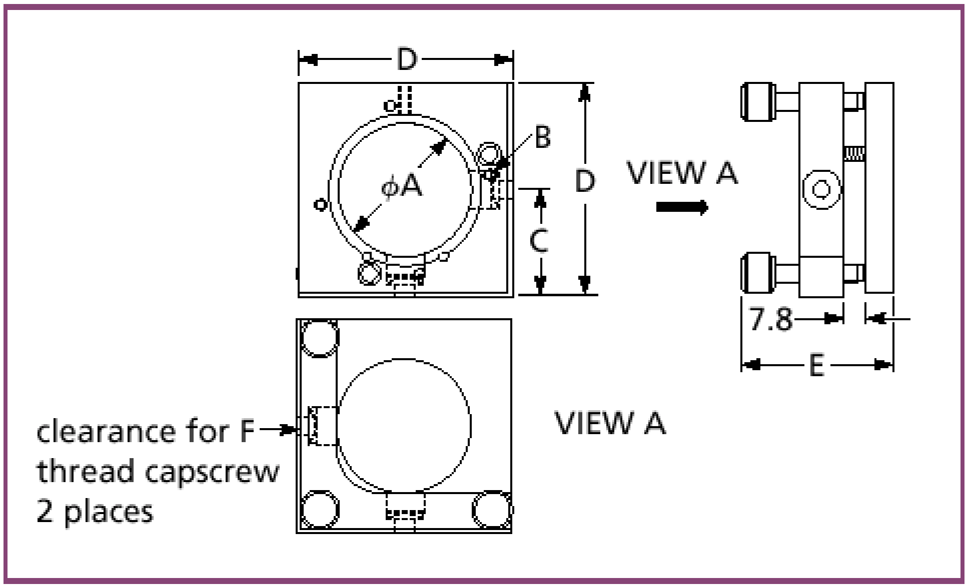

Figure 17. Kinematic Stage Type Beamsplitter Mount. The “L” shaped rear mount allows the light to pass through without interference.

PMT Baffle

The reflected light from the beamsplitter passes through a baffle tube before reaching the PMT. The PMT is very sensitive and will pick up light from any LEDs in the slitroom. The purpose of the baffle tube is to eliminate the resultant noise from these LEDs and reduce the surface area of the PMT. By limiting the surface area, the background light of the night sky is also limited, further reducing the external noise of the sensor. The baffle is constructed from black anodized lens holders and extension tubes available from Edmund Scientific. The lens holders are used to hold baffles, which are similar to washers with the correct baffle hole sizes.

The baffle was designed by first determining the required surface area of the PMT. It is very important that the image not completely stray from the PMT surface. Should this occur, the PMT will send purely noise signals, dark current and background light, to the controller. This results in the chaotic corrections at the tip/tilt mirror and the star being completely lost. To avoid this, the baffle must be large enough to keep the star on the PMT for any sudden motion of the image. Large wind gusts can cause the image to wander as far as five arcseconds from the slit. This value is not well known, so a safety factor of 2 will be used, resulting in a required area of ±10 arcseconds. During bad seeing conditions, the stellar image can have a diameter of up to 2 arcseconds. The surface area should have at least enough room to accommodate worst case conditions, resulting in a circular surface area of 11.5mm, ±11 arcseconds, on the PMT.

The secondary mirror of the telescope has a 1m diameter and is located 36m from the slit. The baffle should then block out an area outside of straight lines between the outer edges of the secondary mirror and the active PMT surface. The positions and diameters of the baffles are shown in Figure 18.

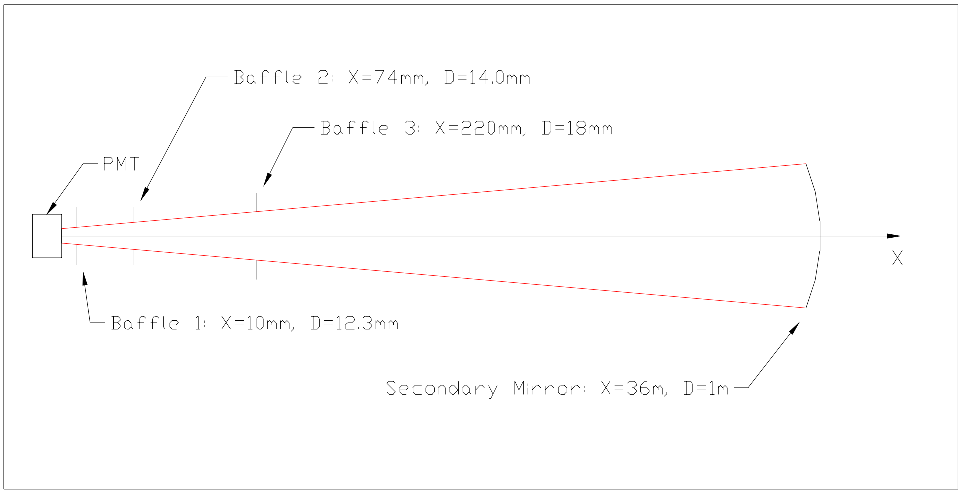

Figure 18. Baffle Layout. The baffle will constrain the PMT field of view to an area within the lines connecting the diameter of the secondary to the diameter of the PMT active area.

PMT Housing

The baffle tube threads into a diaphragm which is epoxied to the PMT housing. This allows no external light to enter the PMT except for the light that passes through the baffle. The diaphragm can be used to further limit the PMT surface area if necessary and also acts as an additional cover for the PMT when not in use. The PMT housing completely seals the PMT from external light sources. The PMT is held securely in the housing using set screws as shown in Figure 19.

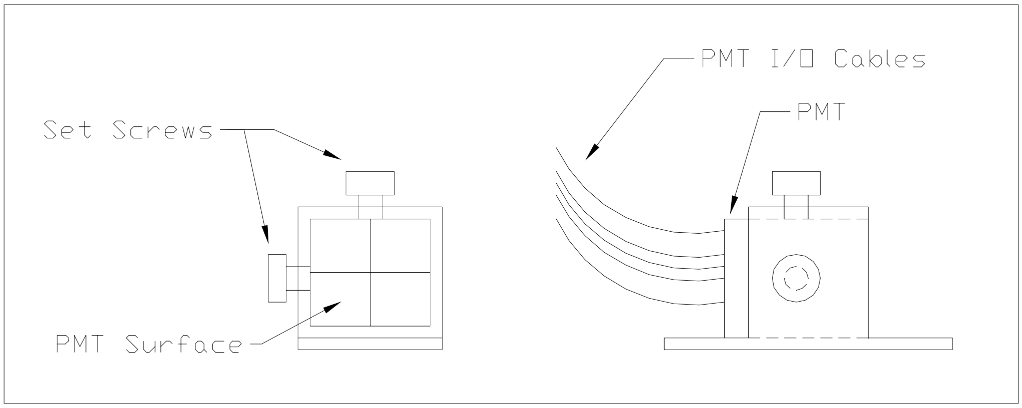

Figure 19. PMT Mount. PMT is held in place using the two set screws.

PMT

The active surface of the PMT is divided into four anodes, or quadrants, as shown in Figure 20. The position of the stellar image on the PMT surface is measured relative to the center (origin) of the active surface by measuring the output currents from each quadrant. When the image lies directly on the center, the output currents will be equal, corresponding to the actual image lying directly on the slit. If the image is not centered on the slit, there will be more current from the quadrants corresponding to this offset.

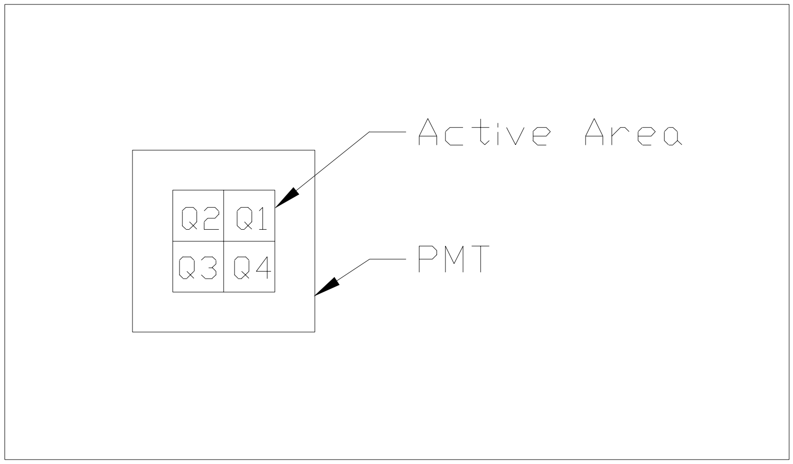

Figure 20. Photomultiplier Tube Surface. The PMT surface is made up of four anodes in a quadrant format.

Each anode, quadrants Q1 through Q4, outputs a signal in the form of a current, I_n, with amplitude proportional to the amount of light seen by the corresponding anode. The position of the light spot on the active surface, (X,Y), can be determined in rectangular coordinates by taking the ratio of the amount of light on each side of each axis and the total light on the surface. The normalized ideal positions can be found as

$$X = \frac{(I_1 + I_4) - (I_2 + I_3)}{\sum_{n=1}^{4} I_n} \qquad (24)$$

and

$$Y = \frac{(I_1 + I_2) - (I_3 + I_4)}{\sum_{n=1}^{4} I_n}. \qquad (25)$$

The solutions to (24) and (25) will meet one of the three criteria listed below.

$$X,Y = -1 \tag{26}$$

$$-1 < X,Y < 1 \tag{27}$$

$$X,Y = 1 \tag{28}$$

Ideally, condition (27) will be met. This will allow an absolute position to be determined, resulting in a single step correction. Should condition (26) or (28) occur, all that is known is that the light spot is located completely on one side of the X or Y axis. In this situation the tip/tilt mirror must correct in increments until condition (27) is satisfied. The light spot can then be moved to the origin in a single step.

Unfortunately, dark current and background light will cause each anode to always output a finite amount of signal. Dark current, output signal while no incoming light is present, is constant and can be subtracted out with a DC offset. The amount of background light will vary with cloud cover and positioning of the telescope. If the telescope is pointed directly over San Jose or near the moon, more background light is present. With non-zero signals from quadrants that do not see the light source, the solutions to (24) and (25) will never reach unity. This is not a problem as the corrections are made by multiplying the position errors by a gain coefficient with the largest steps occurring at the extreme values of X and Y. These large steps will be repeated until the position is known.

When the optimal condition (27) is met, the absolute position depends on the diameter of the light spot. This diameter varies with seeing conditions, so the gain coefficient used is the value found for the smallest stellar image that will be seen. This will insure against overcorrecting and oscillating during observations of larger images. The best gain was found by experimentally adjusting the gain during actual observations.

The PMT requires a power supply of up to 900 Volts. This will enable the PMT to reach the maximum gain of 50×10^6 photoelectrons/photon if necessary. At this gain, the dark current is still only at a nA level. The relationships between supply voltage versus gain and dark current are shown in Figure 21. The power supply is enabled through the control system, allowing power to the PMT only during closed loop operation. To protect the PMT from sensing high levels of light at large gain levels, the system will have redundant safety mechanisms. An external SiPD (Silicon PhotoDiode) will be connected to the controller to shut down power to the PMT should a flashlight or room lights be turned on in the slitroom. If a large amount of light is focused up the baffle, i.e. focusing the telescope on a bright object, the controller will shut down the PMT power before the PMT signal becomes too large. The PMT threshold feature is currently in operation, but the SiPD feature has not yet been installed. Details of these sub-systems are discussed in the control section.

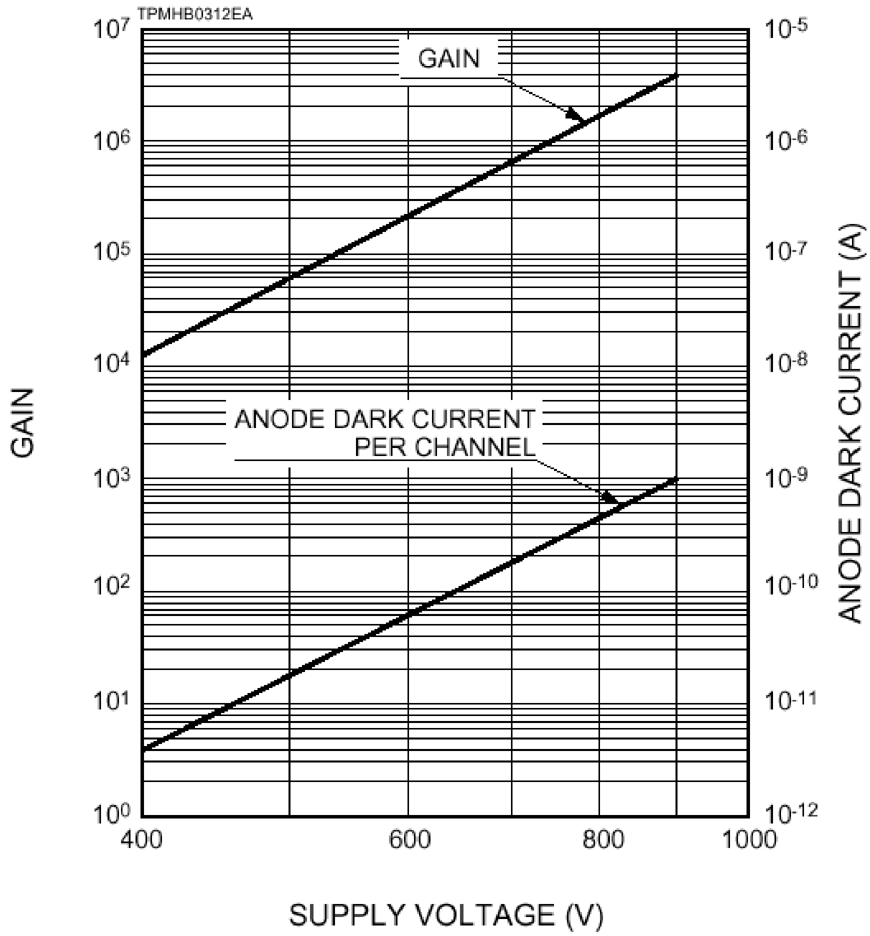

Figure 21. PMT Supply Voltage Versus Gain and Dark Current.

The photocathode material chosen for this application is an S-20 multialkali. As shown in the curve below (Figure 22), the spectral response, for the 500k curve, is best between 300 and 600 nm, with a QE and responsivity of approximately 20% and 60mA/W, respectively. The majority of our stars (V=~7) will then get a theoretical response of ~10^{-7} A, about two orders of magnitude higher than the noise levels.

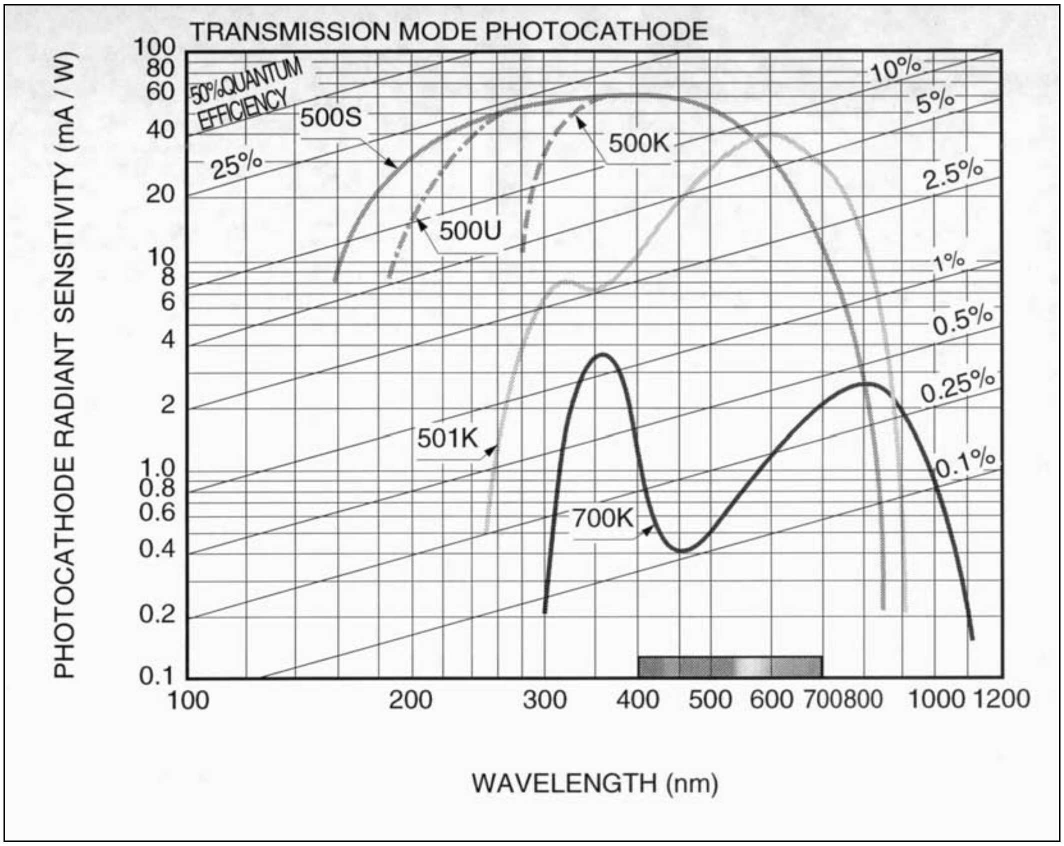

Figure 22. Photocathode Sensitivity and QE Vs. Wavelength. The S-20 photocathode material is designated by the 500K line and peaks at a sensitivity of 60mA/W at 20% quantum efficiency.

Beamsplitter Alignment

Proper alignment of the beamsplitter will allow the position of the light spot on the slit to correspond with it's reflected image being located at the center of the PMT. Alignment of the beamsplitter must be done with the laser used earlier for the optical table alignment still in place, but using a neutral density filter to protect the PMT. With the laser pointed at the slit, the PMT will sense the position of image centroid on its surface. If it is not already centered, closing the loop on the controller will cause the tip/tilt mirror to make a false correction and the image will move off the slit. The beamsplitter can be adjusted until the image is back on the slit, while the controller holds the reflected image at the center of the PMT. This procedure gets the alignment very close, and may require a very slight adjustment when observing an actual star. The same procedure can be used with a star. By aligning first with the laser, the alignment is close enough for the fine adjustment with a star to take only a couple of seconds.