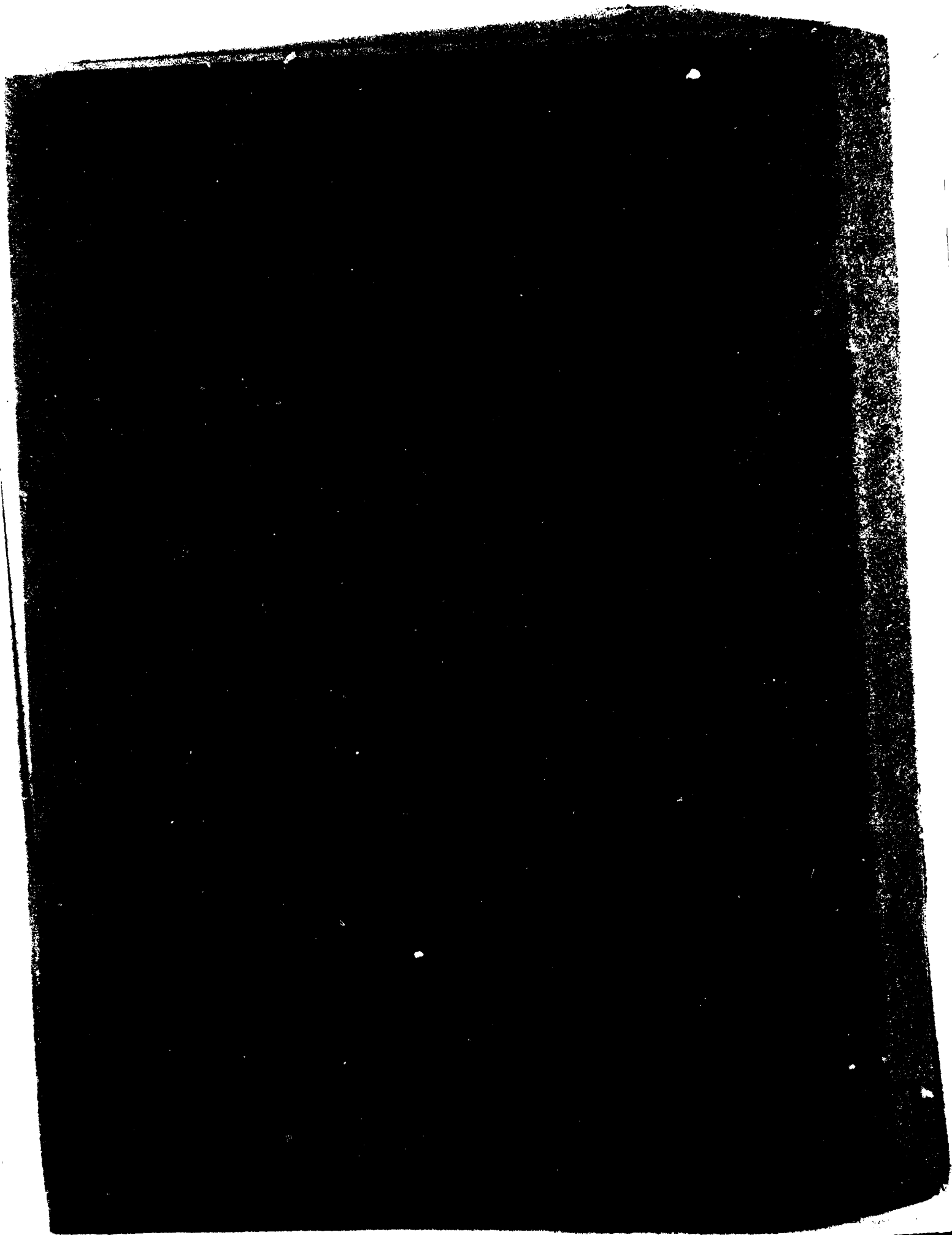




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SECTION I

INTRODUCTION

This report describes the optical design of a feasibility model of a laser projector helmet mounted display for visual simulation in flight training. The feasibility model was designed to evaluate the laser projection concept and to serve as a test bed to determine required performance parameters for an advanced development technology demonstration. The feasibility model provides a single, monochrome laser raster display projected from the observer's helmet onto a one meter radius spherical screen. The advanced development model is planned to provide two full color laser rasters projected onto a 3 meter radius spherical screen. Both models are designed to interface to an existing Computer Image Generation (CIG) system at the Visual Technology Research Simulator (VTRS) facility at the Naval Training Equipment Center. The VTRS CIG system is capable of providing raster imagery at a line rate of 1023 lines per frame and a frame rate of 30 Hz with a two to one field interlace. The projected field of view for the feasibility model is approximately 50°H by 40°V.

The feasibility display system consists of the following components:

1. A laser, which provides the display light;
2. An acousto-optic modulator (AOM), which modulates the laser light in response to an analog video signal from the CIG;
3. Beam shaping optics, to relay and shape the laser beam for proper interface to the line scanner;
4. An acousto-optic beam deflector (AOBD), which provides the high speed line scan;
5. Optics to image the scanned line onto a fiber optic relay;
6. A flexible fiber optic array to relay the scanned line to the observer's helmet;
7. A projection lens which images the scanned line image onto the display screen after reflection from a frame scanner; and
8. A galvanometer frame scanner which provides the 60 Hz scan to convert the line into a full raster on the display screen.

This report discusses the design and specification of the feasibility model components. Some of the components, such as the laser, acousto-optic modulator and the fiber optic bundle were available in the laboratory and therefore are not necessarily optimum for the system. The acousto-optic beam deflector and frame scanner were purchased to evaluate their feasibility prior to specifying in an advanced feasibility model.

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SECTION II

COMPONENTS

The active components in the interim system are the:

- (a) Argon laser
- (b) Acousto-optic modulator (AOM)
- (c) Acousto-optic beam deflector (AOBD)
- (d) Fiber optic bundle, and
- (e) Mirror galvanometer.

Each of these components will be discussed in the following subsections. The system arrangement is shown in Figure 1.

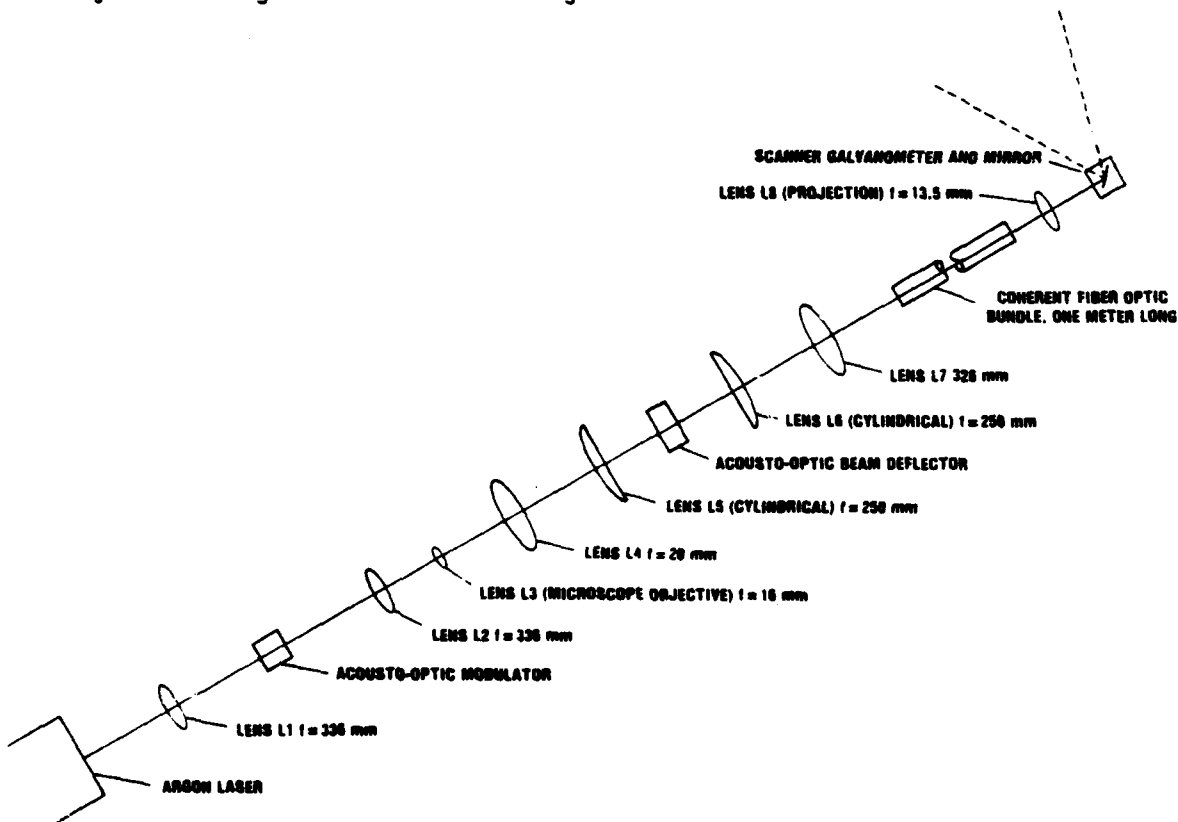


Figure 1. System Optical Arrangement

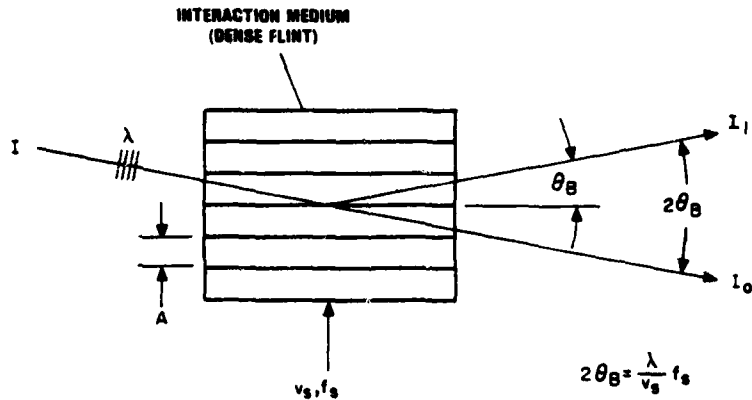
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THE ARGON LASER

The argon laser is a Control Laser Corporation of Orlando, FL, Model No. 553. The laser is rated at 6 watts (all lines) in the TEM<sub>00</sub> mode. The single wavelength 514.5 nm line is used in this system. The laser has a beam diameter of 1.6 mm and a divergence of 0.4 mr.

THE ACOUSTO-OPTIC MODULATOR

The AOM, shown in Figure 2, is a Model 125 manufactured by the Intra-Action Corporation of Bensenville, IL, and is used to intensity modulate the laser beam. The AOM is a solid state device using dense flint as the interaction medium. The transducers that generate the acoustic waves in the crystal are indium bonded lithium niobate. The unit has a usable range of 430 nanometers (nm) - 700 nm. The AOM uses an RF carrier frequency of 125 MHz to generate the acoustic waves and requires a driving power of three watts. When operating, the RF input frequency is held constant and the video input signal



$\theta_B$  = BRAGG ANGLE

$\lambda$  = OPTICAL WAVELENGTH

$A, v_s, f_s$  = ACOUSTIC WAVELENGTH, VELOCITY, FREQUENCY



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Figure 2. Acousto-optic Modulator

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used to vary the amplitude which causes intensity modulation of the laser beam. The optical transmission loss through the device is less than 2 percent and the extinction ratio is greater than 1000 - 1. The Bragg deflection angle, diffraction efficiency, and bandwidth are a function of the optical wavelength ( $\lambda$ ) and the laser beam spot size.

#### THE ACOUSTO-OPTIC BEAM DEFLECTOR (AOBD)

The AOBD, shown in Figure 3, is manufactured by the Harris Corp. of Palm Bay, FL. The interaction medium is tellurium dioxide ( $\text{TeO}_2$ ). The active aperture is 22 mm wide by 0.4 mm high. The scanning bandwidth is 250 - 500 MHz with a center frequency of 375 MHz. The unit requires an input power of 1.2 watts and has a maximum light diffraction efficiency of 15 percent. When the 514.5 nm line is used, the beam is deflected through an angle of 30.6 mr. An extremely precise voltage controlled oscillator is required to maintain a line focus of the scanned laser beam.

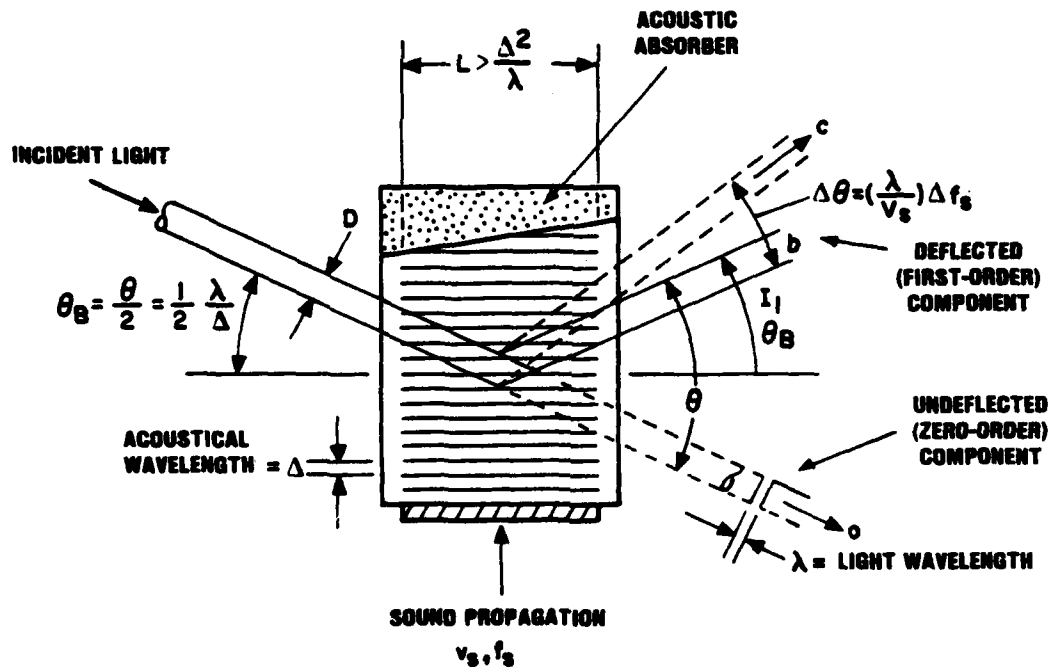


Figure 3. Acousto-optic Beam Deflector

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### THE FIBER OPTIC BUNDLE

The fiber optic bundle is manufactured by the American Optical Company, Southbridge, MA. The individual fibers are  $10\mu$  in diameter arranged in  $6 \times 6$  arrays. These arrays are then arranged into linear or rectangular groupings. The particular bundle used in this interim system is one meter in length, and has a  $10 \text{ mm} \times 8 \text{ mm}$  face with a numerical aperture of 0.56.

### THE MIRROR GALVANOMETER SCANNER

The scanner, shown in Figure 4, is the 10OPD manufactured by General Scanning, Inc., Watertown, MA. It is a moving iron galvanometer with a position transducer designed for closed loop operation. The scanner can drive mirrors with inertias up to  $0.05 \text{ GM-CM}^2$  and has a rotation range up to  $20^\circ$  ( $40^\circ$  of optical scanning). The transducer has a linearity of  $\pm 0.3$  percent of the total excursion. The signal response time is  $10\mu\text{s}$ . The scanner is used with servo controller CCX-102 which provides a ramp into the galvanometer. With the mirror used, this system's flyback time is on the order of 2 ms. This scanner provides the vertical scan for the raster image.

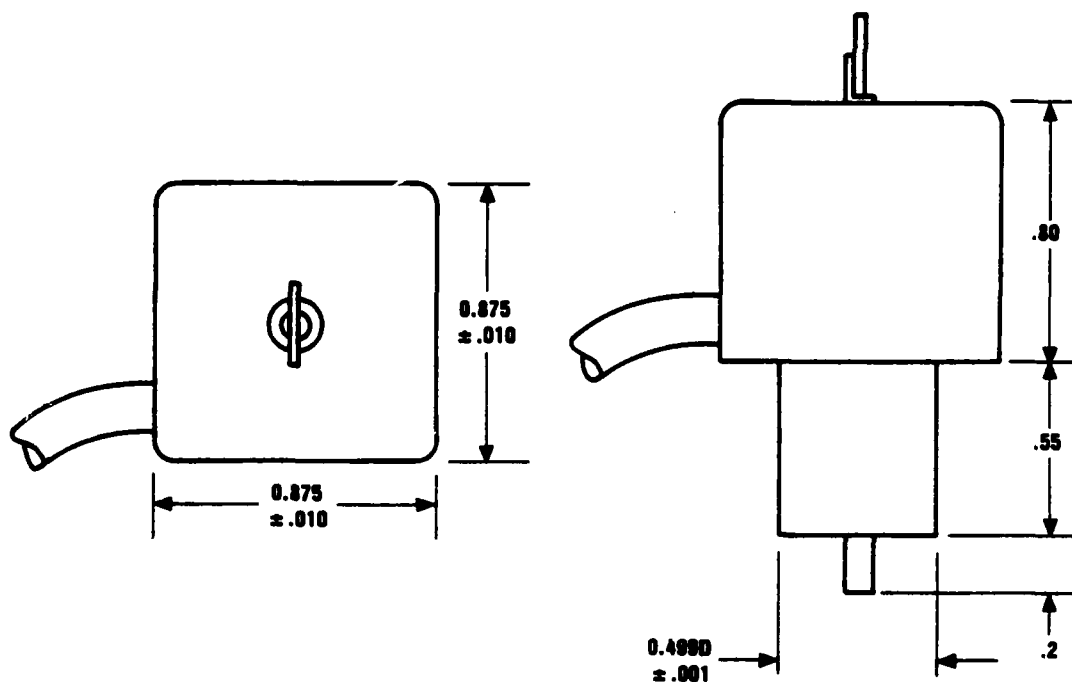


Figure 4. Scanning Galvanometer

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SECTION III

THE OPTICAL DESIGN

THE ACOUSTIC-OPTIC MODULATOR

The manufacturer, Intra-Action Corp., recommends a spot size of 0.14mm to obtain maximum bandwidth modulating and minimum rise time. The laser beam diameter is 1.6 mm ( $\lambda = 514.5$  nm). The laser, operating in the TEM<sub>00</sub> mode, provides a Gaussian beam whose diameter is the distance between the  $1/e^2$  power points (the points where the power is 86 percent of the central peak power). The expression for the Gaussian spot formed by a diffraction limited lens is:<sup>1</sup>

$$d = 4\lambda f / \pi D$$

where:  $d$  = the required 0.14 mm spot,  
 $\lambda$  = 514.5 nm,  
 $D$  = 1.6mm, and  
 $f$  = focal length of lens  $L_1$  required to produce the proper spot size.

Solving the expression for  $f$ :

$$f = \frac{d \pi D}{4 \lambda} = \frac{0.14 \text{ mm} \times \pi \times 1.6 \text{ mm}}{4 \times 0.5145 \times 10^{-3}} = 341.94 \text{ mm}$$

The lens is an off-the-shelf 336mm doublet which gives a spot size of:

$$d = \frac{4\lambda f}{\pi D} = \frac{4 \times 0.5145 \times 10^{-3} \text{ mm} \times 336 \text{ mm}}{\pi \times 1.6 \text{ mm}} = 0.138 \text{ mm}$$

This is the spot size focused in the crystal. The deflection angle between the zero order (I<sub>0</sub> undeflected beam) and the defracted first order I<sub>1</sub> is:<sup>2</sup>

$$2 \sin \theta = \frac{\lambda}{V} F.$$

<sup>1</sup> H. G. Heard, Laser Parameter Measurements Handbook, J. Wiley and Sons, Inc., New York, 1968, P58.

<sup>2</sup> Driscoll, W.G., Handbook of Optics, McGraw-Hill, New York, 1978, Chap. 17, pp 18-20.

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where:  $\theta$  = the Bragg Angle,  
 $\lambda$  = 514.5 mm, and  
 $V$  =  $3.91 \times 10^3$  MHz (the carrier frequency of the modulator driver).

Substituting these values in the above equation gives  $\theta = 8.23$  mr or a deflection angle of  $2\theta = 16.45$  mr.

The diffraction efficiency is calculated by using equations provided the AOM instruction manual. The diffraction efficiency is expressed as:

$$P_1 = P (1 + \alpha^2)^{-1/2}$$

where:  $P$  = the maximum optical power that can be diffracted into the first order, and

$\alpha$  is related to the interaction geometry by:

$$\alpha = 2L \sin \theta / d$$

where:  $L$  = the width of the acoustic beam (in this case 8 mm),  
 $\theta$  = the Bragg Angle (8.23 mr), and  
 $d$  = the beam spot size (0.138 mm).

Substituting these values into the equation gives  $\alpha$  equal to 0.95. Substituting  $\alpha = 0.95$  into the expression for diffraction efficiency gives an efficiency of 72.4 percent (Figure 5).

The depth of modulation is determined by:

$$M = e^{-(f/f_e)^2}$$

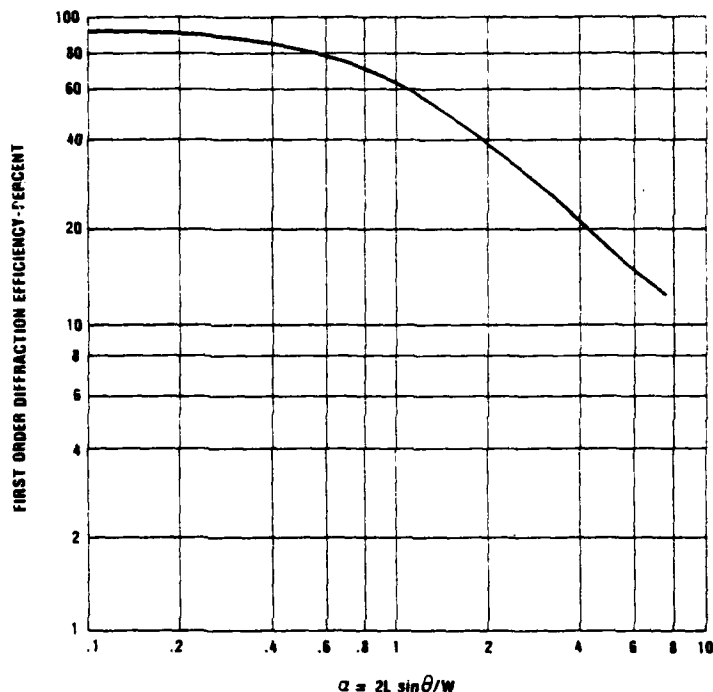
where:  $f$  = the frequency at which the modulation is to be determined, and

$f_e$  =  $3.51/D$  MHz ( $D$  is the spot diameter).

The number 3.51 has been empirically determined through experimentation by the manufacturer. The video bandwidth of a 1023 line system is 30 MHz. Using this figure and substituting into the above equation for  $M$  gives:

$$M = \exp - (f/f_e)^2 = \exp - \frac{(30/3.51)}{0.138} = 0.31.$$

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**Figure 5. First Order Diffraction Efficiency as a Function of the Geometrical Factor .**

The depth of modulation at 30 MHz will be 31 percent. The modulation can be increased if necessary by decreasing the spot size. However, this will cause a corresponding decrease in diffraction efficiency as well as increasing the energy density of the beam spot within the crystal. For example: going through the above calculation for a spot size of 0.1 mm will give a depth of modulation of 43 percent and a diffraction efficiency of 60 percent. The last element of the modulator system is a lens (L2) to collimate the exiting laser beam. This lens is identical to the one used to focus the beam into the AOM so that the output beam diameter is 1.6 mm, the same as the input beam diameter. This confocal AOM system will make it easier if the spot size should have to be changed. The two identical lenses now being used would be replaced with two other identical lenses with the required focal length to give the desired new spot size. The input and output beam diameter of the AOM will still be 1.6 mm so that the optics after it will not have to be changed.

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SECTION IV

THE AOBD AND ASSOCIATED OPTICS

The AOBD has an active aperture of 22 mm horizontally and 0.4 mm vertically. The AOBD only interacts with the laser beam in the horizontal direction.<sup>3</sup> The laser beam on the input side of the AOBD is expanded so that its diameter between the  $1/e^2$  power points is 22 mm in the horizontal direction and compressed in the vertical to less than 0.4 mm in order to get maximum energy through the AOBD. On the output side, the beam is reshaped into a circle. A beam expander with a magnification of 13.8X is required to increase the 1.6 mm beam to 22 mm. Two lenses with a focal length ratio of 13.8 provide the required expansion. Lens L3 is a 10 power microscope objective with a focal length of 16 mm. Using L3 with a doublet, L4 with a focal length 220 mm, will give a magnification of 13.8 (Figure 6).

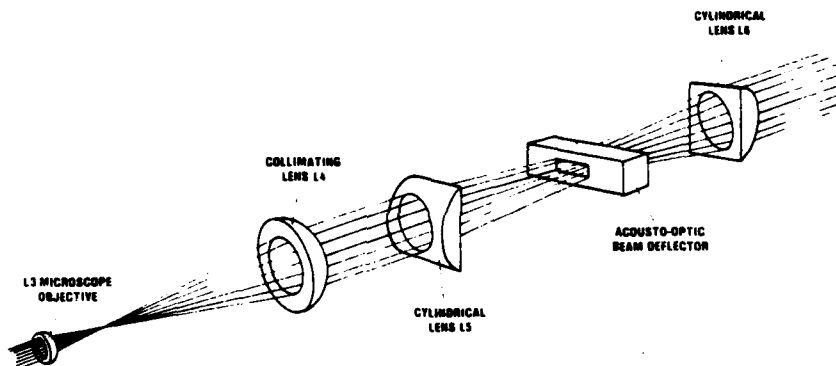


Figure 6. Laser Beam Shaping for the Acousto-optic Beam Deflector.

When expanding a Gaussian beam with a Keplerian expander the new beam waist (22 mm) occurs at the focal point of the lens<sup>4</sup> (220 mm to the right) and at that point it is a plane wave. The 16 mm microscope objective forms a spot of radius:

$$r_0 = \frac{f\lambda}{\pi r} = \frac{16 \times 0.5145 \times 10^{-3}}{.8\pi} = 3.28 \times 10^{-3} \text{ mm}$$

<sup>3</sup> Dickson, Leroy D., OPTICAL CONSIDERATIONS FOR AN ACOUSTO-OPTIC DEFLECTOR, Applied Optics, Vol. 11, No. 101, Oct. 1972, pg 2196.

<sup>4</sup> Dickson, Leroy D., CHARACTERISTICS OF A PROPAGATING GAUSSIAN BEAM, Applied Optics, Vol. 9, No. 81, August 1970, pgs 1854-1858.

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where:  $f$  = 16 mm focal length,  
 $\lambda$  = wave length of laser light in nm, and  
 $r$  = entrance radius of the laser beam.

The general equation for the spot size is:<sup>5</sup>

$$r^2 \text{ min} = r_0 f / [(D_1 - f)^2 + f_F^2]^{-1/2}$$

where:  $r_0$  =  $3.28 \times 10^{-3}$ ,  
 $f$  = 220 mm,  
 $d$  = the distance of  $r_0$  from the lens, and  
 $f_F$  =  $\pi r_0^2 / \lambda$ .

If  $r_0$  is at the focal point of  $f$  then  $(D_1 - f) = 0$  and the equation reduces to:

$$r^2 \text{ min} = \frac{f \lambda}{\pi r_0}$$

Substituting the above values into the equation gives:

$$r^2 \text{ min} = \frac{220 \times 0.5145 \times 10^{-3}}{\pi \times 3.28 \times 10^{-3}} = 10.98 \text{ mm}$$

or, a diameter of approximately 22.00 mm for the beam waist. The location of the waist ( $d_2 \text{ min}$ ) is given by the expression:

$$d_2 \text{ min} - f = (d_1 - f) f^2 / [(d_1 - f)^2 + f_F^2]$$

Again,  $(d_1 - f) = 0$  and the equation reduces to  $d_2 \text{ min} - f = 0$  or  $d_2 \text{ min} = f$  so that the waist is located at the focal point. The divergence of this spot is given by:

$$\sigma_0 = \frac{2 \lambda}{\pi r^2 \text{ min}} = \frac{2 \times 0.5145 \times 10^{-3} \text{ mm}}{\pi \times 10.98} = 29.8 \text{ } \mu\text{r}.$$

The divergence is measured from the center of  $r^2 \text{ min}$ .

The expanded beam must now be reduced in vertical size to less than 0.4 mm so that it will be accepted by the AOB aperture. The usual way to do this is with a cylindrical lens (L5). Since this will be a single element and

<sup>5</sup> OPCIT; Dickson, Leroy D., Applied Optics, August 1970, pgs 1857-1858.

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uncorrected, it should have a large f/number in order to minimize aberrations. The one chosen has a focal length of 250 mm which, with the 22 mm beam diameter, gives an f/number of f/11.4. This lens must be placed as close as practicable to the previous lens in order to keep the optical chain as short as possible. The line width produced by the lens is:

$$d = \frac{4\lambda f}{\pi D} = \frac{4 \times 0.5145 \times 10^{-3} \times 250}{\pi \times 21.96} = 7.4 \mu\text{r}$$

where: f = 250 mm focal length,  
 D = entrant spot size 21.96 mm, and  
 λ = 0.5145 × 10<sup>-3</sup> mm (wavelength of laser light).

The AOB<sub>D</sub> has a 22 mm × 0.4 mm aperture; the crystal is TeO<sub>2</sub>. The acoustic wave velocity is 4200 m/s; the scanning bandwidth is 250 - 500 MHz with a center frequency of 375 MHz. The total deflection angle is 30.63 mrad and the diffraction efficiency is 16 percent.

When the laser beam passes through the AOB<sub>D</sub> there is no effect on the beam in the direction that is normal to the scan. In the direction of the scan the entering beam is truncated by the AOB<sub>D</sub> aperture. This truncation affects the divergence of the emerging beam.<sup>6</sup> If r<sub>e</sub> is the 1/e<sup>2</sup> radius of the beam and W is AOB<sub>D</sub> aperture length, then:

$$P_t = \frac{W}{2r_e}$$

is defined as the truncation ratio (Figure 7a and 7b). From Figure 7a, σ<sub>0</sub> is 1/e<sup>2</sup> divergence of the untruncated beam, E<sub>e</sub> = σ<sub>e</sub>/σ<sub>0</sub> is the ratio of divergences. Further, σ<sub>e</sub> may be expressed as:

$$\sigma_e = (4/\pi) E_e P_t (\lambda/W).<sup>7</sup>$$

In this case, P<sub>t</sub> = 1 (the beam is truncated at 1/e<sup>2</sup> points) and from Figure 7b, E<sub>e</sub> = 1.3, substituting into the above equation gives:

$$\sigma_e = \left(\frac{4}{\pi}\right) (1.3) (1) \left(\frac{0.5145 \times 10^{-3} \text{ mm}}{22}\right) = 38.8 \mu\text{r}.$$

There are two modes of operation for the AOB<sub>D</sub><sup>8</sup>, the random access and FM linear modes. In either mode, there is a time which is required to address a particular location of the AOB<sub>D</sub> with the deflected beam. This time is

<sup>6</sup> OPCIT; Dickson, Leroy D., Applied Optics, Oct. 1972, Pg 2197.

<sup>7</sup> IBID; Pg 2197.

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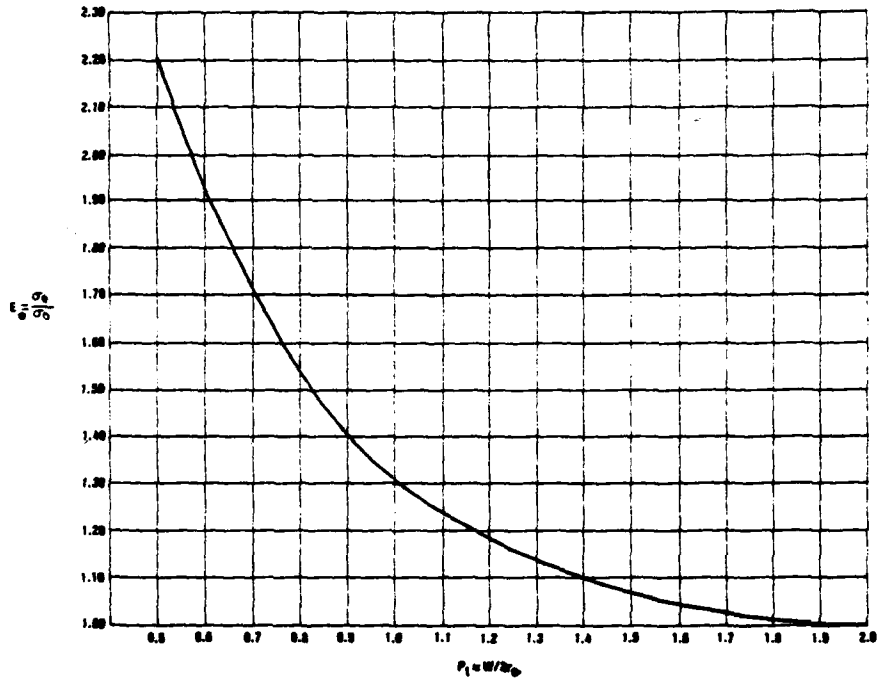


Figure 7a. Normalized  $1/e^2$  Divergence as a Function of Truncation Ratio

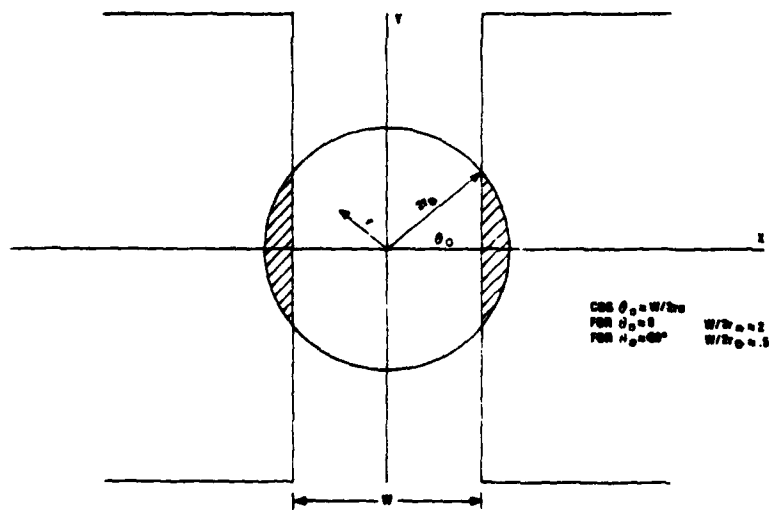


Figure 7b. SHT Truncated Gaussian Beam  $r_0 = 1/e^2$  Radius.

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called the random access  $T_a$  and is the time needed to remove the old acoustic signal from the AOBD and to replace it with a new one.  $T_a$  is expressed as:

$$T_a = W/v = \frac{22}{4.2 \times 10^6} = 5.24 \mu s$$

where:  $W$  = the AOBD aperture length, and

$v$  = the acoustic wave velocity in the AOBD crystal.

The static spot resolution  $N$  for the AOBD is expressed as the ratio of the total angle of deflection to divergence angle:

$$N = \Delta\theta/\sigma_e$$

The  $N$  for the AOBD being used in this mode is:

$$N = 30.63 \text{ mr}/38.7 \mu r = 791 \text{ spots}$$

However, when the AOBD is operated dynamically, this resolution is reduced. In this case the AOBD is used in the FM linear mode. In the FM linear mode the acoustic frequency is swept and the scanned spot moves in an analog fashion as the acoustic frequency is continually swept. When operated in this mode, there is a sweep time  $T_s$  which, in this case, is equal to that of a 1023 line video system,  $T_s = 26.58 \mu s$ . In order to avoid a continuous distortion of spot size (Figure 8) the AOBD must be blanked for the period  $T_a$  in which the acoustic wave is filling the aperture. When this is done, a portion of the bandwidth equal to  $T_a/T_s \Delta v$  is lost for scanning and the number of resolvable spots is reduced by the factor  $T_a/T_s$ . The usable amount of resolvable spots is expressed as  $(T_s - T_a)/T_s$ .

The expression for the number of resolvable spots for an AOBD operating in the FM linear mode is:<sup>9</sup>

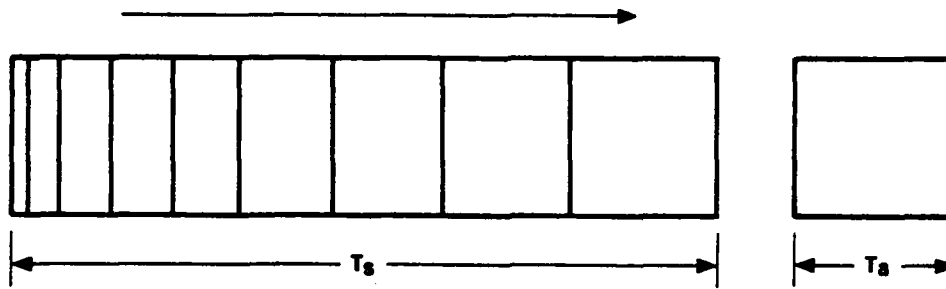
$$N_e = [(m-1)/m](\pi/4E_e P_t) \Delta v T_a$$

where:  $m = T_s/T_a$ .

In the above equation,  $N_e$  is a function of the product of  $E_e P_t$ ,  $P_t$  being the truncation ratio and  $E_e$  the ratio between the input and output divergence of the beam passing through the AOBD. From Figure 7a, it is seen that  $E_e$  is a function of  $P_t$  and that as  $P_t$  increases the product

8 OPCIT; Dickson, Leroy D., Applied Optics, Oct. 1972, Pgs 2198 - 2000.

9 OPCIT; Dickson, Leroy D., Applied Optics, Oct. 1972, Pg 2199.



**FIGURE 8. LINEAR FM MODE DEFLECTOR**

**NOTE:**

- (a) The acoustic beam is viewed as a block of linear FM acoustic waves being swept through the aperture.
- (b) The dimensions of the aperture and FM block are given in terms of  $T_a$  and  $T_s$ .

$E_e P_t$  increases which causes a decrease in  $N_e$ . In this case it would seem best to make  $P_t$  as large as possible or not truncate the beam at all. However, it can be shown that decreasing  $P_t$  improves the MTF<sup>10</sup> (Figure 9) of the AODB output and increasing  $P_t$  or eliminating truncation will seriously reduce the MTF.  $P_t$  can be reduced only so far to improve MTF and  $N_e$  before light loss through the AODB becomes excessive. A  $P_t = 1$  appears to be a good compromise between light loss due to truncation (Figure 10) and MTF (there is little gain in MTF for  $P_t > 1$  and light loss increases rapidly for  $P_t > 1$ ).

Substituting into the preceding equation for  $N_e$ :

$$N_e = \left[ \left( \frac{26.58}{5.24} - 1 \right) \div \frac{26.58}{5.24} \right] \left( \frac{\pi}{(4)(1.3)(1)} \right) (250 \text{ MHz})(5.24 \mu\text{s})$$

$$N_e = 635 \text{ useable resolved spots}$$

<sup>10</sup> Randolph, J. and Morrison, J., "Modulation Transfer Characteristics of an Acousto-Optic Deflector," Applied Optics, Vol. 10, No. 6, June 1971, Pgs 1383 - 1385.

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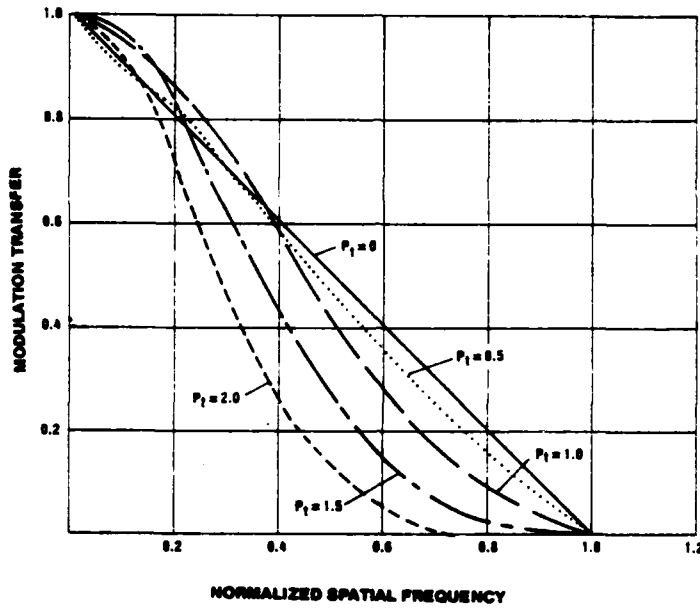


Figure 9. Modulation Transfer vs. Normalized Spatial Frequency (Aperture Width is Constant).

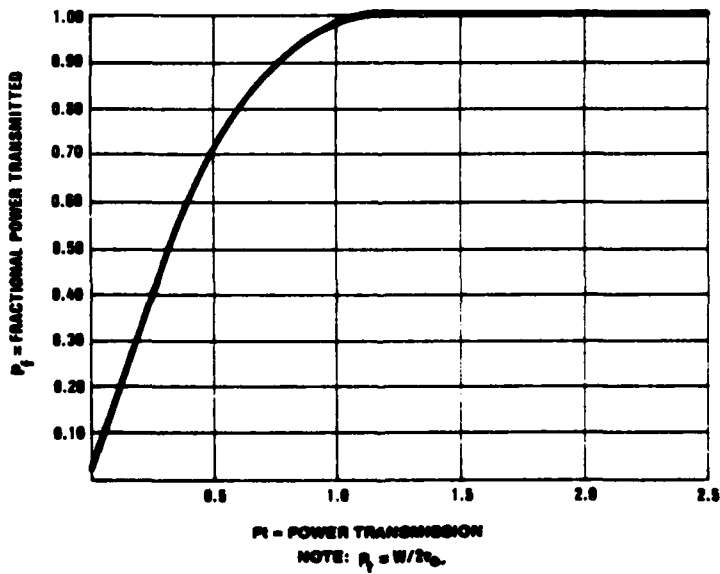


Figure 10. Fractional Power Transmitted vs. Power Transmission

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The laser beam is now reshaped into a circle. This is accomplished by placing a second 250 mm cylindrical lens (L6) after the AOB D at a distance equal to that of the first. However, the beam is not restored to a perfect circle. The divergence of the beam is changed in the horizontal scanning direction from 29.8  $\mu$ r to 38.7  $\mu$ r due to diffraction when passing through the AOB D. There is no change in the vertical direction. After passing through the second cylindrical lens, the vertical direction is collimated at 22 mm. With its divergence restored to 29.8  $\mu$ r, the horizontal direction is not affected by the cylindrical lens, it is 22 mm in diameter with a divergence of 38.7  $\mu$ r.

The AOB D sweeps the deflected spot through an angle of 30.63 mr. The required line sweep on the fiber optic bundle is 10 mm. Using the maximum resolution of 791 resolvable spots gives a spot size of 12.6 microns. The focal length needed to give the proper spot diameter is obtained from the equation:<sup>11</sup>

$$D_e = \sigma_e f$$

where:  $D_e$  = the spot diameter,  
 $\sigma_e$  = the divergence, and  
 $f$  = the focal length of the lens (L7) required.

The required spot diameter in the horizontal scan direction is 12.6 microns. The divergence in this direction is 38.7  $\mu$ r. The required focal length is:

$$f = \frac{D_e}{\sigma_e} = \frac{12.6 \times 10^{-3} \text{ mm}}{38.7 \times 10^{-6}} = 325.6 \text{ mm}$$

In the vertical direction the spot size will be:

$$D_e = 29.8 \times 10^{-3} \times 325.6 \text{ mm} = 9.70 \text{ microns}$$

<sup>11</sup> OPCIT; Dickson, Leroy D., Applied Optics, Oct. 1972, pg 2197.

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The 10 mm line sweep is focused onto the face of the fiber optic bundle (Figure 11).

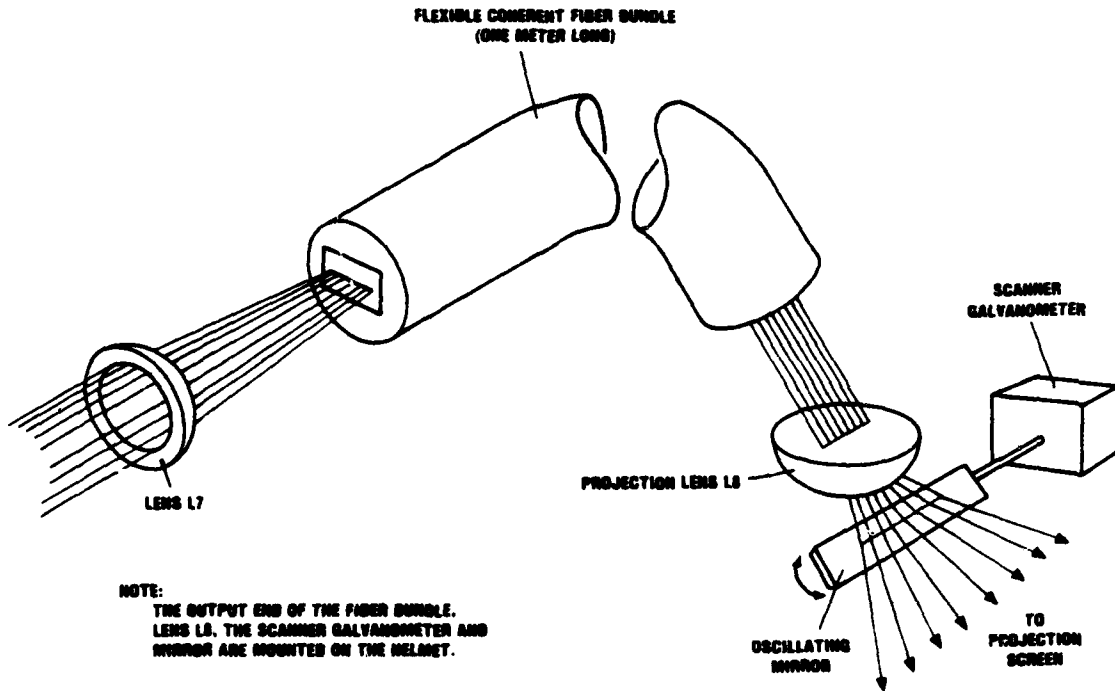


Figure 11. Fiber Optic Bundle and Projection Optics.

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### SECTION V

#### THE PROJECTION LENS AND VERTICAL SCAN

L8, the final lens in the system, is a 13.5 mm focal length lens that projects the 10 mm horizontal scan line on the output face of the fiber optic bundle onto the projection screen. The horizontal field of view is  $43^\circ$ . However, immediately upon exiting this lens the scan line is intercepted by the vertical scanner. The vertical scanner is a mirror-galvanometer that scans the horizontal line in an angle and is adjustable up to  $20^\circ$  ( $40^\circ$  optical). The required aspect ratio for the final image, vertical to horizontal, is  $3/4$ . With horizontal scan subtending  $43^\circ$ , the vertical scan is set at  $16^\circ$  ( $32^\circ$  optical). The vertical scanner is a moving iron galvanometer with a position transducer for closed loop operation. It will work with mirror inertia up to  $0.05 \text{ gm-cm}^2$ . The mirror used on the system has an inertia of  $0.002 \text{ gm-cm}^2$  and is 36 mm X 4 mm X 1 mm thick with a ceramic substrate. The linearity of the scanner is greater than  $\pm 0.3$  percent of the excursion. Its signal response time is 10  $\mu\text{s}$  and, with the mirror being used, the flyback time is on the order of 2 ms. The galvanometer control unit may be driven by an external source, however, it has an internal adjustable ramp generator with frequency variation between 1 Hz and 600 Hz. The dead time between ramps is 40  $\mu\text{s}$ . For external trigger the ramp is completed and then waits for the next start signal. The ramp slope is adjustable.

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SECTION VI

CONCLUSION

This report covers the design analysis of a laser with a Gaussian profile, thus it assumes that the laser is operating in the TEM<sub>00</sub> mode which closely approximates this profile. Further, it is assumed that the optics are diffraction limited. This is not difficult where the beam diameter is small and the f/number is greater than 10, in those sections cemented doublets or even simple lenses can be used. However, where the beam diameter is large (greater than 15 mm) or the f/number is less than 10, a good quality laser beam expander should be used. In the first instance, the beam expander will have surface irregularities less than  $\lambda/4$  to prevent any significant wave form distortion and in the second instance, because it will be a highly corrected air space doublet, it will be diffraction limited over its whole aperture. In order to avoid problems due to diffraction when designing for a Gaussian beam, the lens aperture to beam diameter ratio of the lenses used should be greater than  $2.8 r_e$ , where  $r_e$  is the radius of the laser beam at the lens aperture. The elements in the system described that will probably degrade performance the most are the cylindrical lenses (unless custom designed and manufactured) and the fiber optics bundle. The cylindrical lenses are simple off-the-shelf items and, although their f/numbers are greater than 10, the quality of the surface may not be good enough to prevent waveform distortion. Further, the lenses must be precisely aligned with each other or a significant amount of astigmatism is introduced into the system. The fiber optics bundle may destroy the Gaussian profile of the beam since fibers are known to generate higher order modes as the beam passes through. There are single mode fibers but their core diameters are on the order of 3 microns. The core diameters of the bundle fibers are 10 microns. Also, the fibers tend to increase beam divergence. There is one other point to make - this design is based on a laser beam diameter measured between the  $1/e^2$  power points and the beam is truncated at these points. However, if, after the beam passes through the AOBD, the beam is truncated at the half power points the spot resolution of the AOBD can be increased (with a corresponding decrease in light). This might be worth considering if AOBD is the limiting component of resolution and the extra loss in light transmission can be tolerated.

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LIST OF SYMBOLS

$\lambda$	=	wavelength of light
$d$	=	Gaussian spot diameter
$f$	=	focal length of lens
$D$	=	laser beam diameter
$\theta$	=	Bragg angle
$V$	=	acoustic wave velocity
$F$	=	carrier frequency of acousto-optic modulation driver
$P_1$	=	diffraction efficiency
$P$	=	maximum optical power that can be diffracted into first order
$L$	=	width of acoustic beam
$M$	=	depth of modulation
$r_o$	=	laser spot radius formed by a lens
$r_{2 \text{ min}}$	=	laser beam waist radius
$P_t$	=	laser beam truncation ratio
$\sigma_o$	=	laser beam divergence before truncation
$T_a$	=	random access time for AOBD
$T_s$	=	sweep time for AOBD
$N$	=	number of resolvable spots of AOBD
$D_e$	=	spot diameter after truncation
$\sigma_e$	=	beam divergence after truncation

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