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August 1994

ACOUSTO-OPTIC BEAM STEERING STUDY

Harris Corporation

Sponsored by
Ballistic Missile Defense Organization

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ACOUSTO-OPTIC BEAM STEERING STUDY

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13. ABSTRACT (Maximum 200 words)

This is the final report for a 21 month study investigating the use of acoustic-optic beam steering for inter-satellite laser communications (lasercom). The basic technique is demonstrated in a breadboard that uses a customized 2-dimensional acoustic-optic Bragg cell deflector and a magnifying optical system comprised entirely of off-the-shelf components. The breadboard was designed to steer a laser over a range of 360 x 36 degrees. Important characteristics of the acoustic-optic Bragg deflector include high angular resolution, fast switching speed, high electrical and optical efficiency, and high reliability with no moving parts.

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1.0 Introduction

This is the final report for a 21 month study investigating the use of acousto-optic beam steering for inter-satellite laser communications (lasercom). The basic technique is demonstrated in a breadboard that uses a customized 2-dimensional acousto-optic (AO) Bragg cell deflector and a magnifying optical system comprised of all off-the-shelf components. Important characteristics of the AO Bragg deflector include high angular resolution, fast switching speed, high electrical and optical efficiency, and high reliability with no moving parts.

The breadboard was designed to steer a laser over a range of 360° x 36°. Several unique capabilities are provided by the AO deflector which are not possible with conventional steering mirrors. For example, multiple simultaneous beams can be independently steered anywhere within the total steering range. Also, the AO deflector can produce variable defocus or "zooming" that increases the divergence of the transmitted beam anywhere from 1 to over 10 times the diffraction-limited beam width. A direct-digital-synthesizer (DDS) was fabricated for the breadboard to produce ultra-stable and fast switching frequencies for input to the AO deflector. All of the beam control and diagnostic functions for the breadboard are provided by a menu-driven PC486-33 computer program.

The potential for reducing the overall size of an AO-based lasercom transmitter was also investigated. Using customized optical components and miniaturized packaging techniques an optical system equivalent to the breadboard demonstration could be reduced to the size of a "shoebox" with no sacrifice of performance.

2.0 Executive Summary

This section briefly summarizes the significant results of the effort. An analysis was performed that determined AO technology could meet or exceed all of the desired beam steering specifications for a given "hypothetical" lasercom system (derived from the SDI Brilliant Pebbles concept). Then the technology was experimentally demonstrated in a breadboard using the hypothetical system specifications as design goals. The goal specifications and the final breadboard results are listed in Table 2-1. Overall, the conclusion is easily made that acousto-optic technology is a very effective beam steering technique for use in lasercom transmitter applications.

Table 2-1 illustrates that all of the goal specifications were met by the breadboard with the exception of end-to-end optical efficiency. As explained in Section 5.3 this was partly due to poor spectral quality of the infrared laser diode used in the breadboard (which reduced the Bragg cell deflection efficiency), but mostly due to several optical components that were not designed to operate at the 830 nm wavelength of the laser diode, which resulted in approximately 70% reflection losses. The projected efficiency of a customized optical system with a much lower lens count and properly coated optics using a high quality laser diode source is at least 70%, as discussed in Section 4.2.2.

Table 2-1. Breadboard Goal Specifications and Results

Goal Specification	Breadboard Result
• steering range: approx. 180° x 45°	• implemented 360° x 36° (2 sectors)
• transmit beam size: 0.36° round	• successfully demonstrated
• zoom factor: minimum 10X (3.6°)	• successfully demonstrated
• multiple beam generation: min. 4	• successfully demonstrated (can "simulate" many more)
• end-to-end optical efficiency: min. 50%	• 13% demonstrated (limited by laser and >70% losses in "off-the-shelf" optics)
• steering response time: 30 microsec	• successfully demonstrated

3.0 Background and Overview

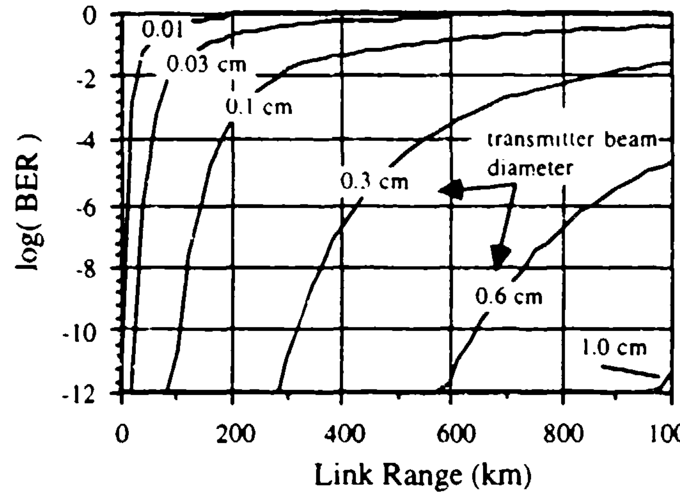
In many communications scenarios lasercom has been shown to have significant hardware advantages over traditional RF/microwave approaches: smaller apertures, lower power consumption, and lower weight. These advantages can be directly related to the high carrier frequency of the light which produces narrower beamwidths. In addition, there are significant systems advantages including higher data rates, EMI immunity, jam resistance, and easy frequency allocation. The component technology in lasers, detectors, and modulators is continuing to advance at a rapid pace, leading to increased interest in lasercom for terrestrial and space-based applications. However, the narrow beamwidths that help make lasercom attractive also increase the burden on acquisition, pointing, and tracking (APT) functions.

The motivation for the present effort arises from the need to quickly steer a communications laser over a very wide steering range using relatively small apertures and short link ranges. These requirements were derived from the SDI Brilliant Pebbles scenario. In this scenario traditional opto-mechanical approaches to beam steering become complex and expensive to implement, and reliability becomes a concern. In this report the design and development of a demonstration transmitter subsystem using acousto-optic (AO) technology is presented that meets or exceeds the beam steering requirements for many lasercom applications.

AO deflector technology is very mature and proven reliable in many applications. AO deflectors may also have utility as angular and wavelength discriminators for wide-angle lasercom receivers. Although the present effort was primarily concerned with lasercom transmitter applications there are numerous other related applications for AO deflectors including image processing, robotic scanning/inspection systems, RF antenna processing, laser printing/marking, visual displays, laser radar (LIDAR), and remote sensing. Closely related AO tunable filters (AOTF) provide high resolution spectral analysis capability for LIDAR, remote sensing, and in the analysis of covert optical communications or threat laser beams (warning sensors) in tactical environments.

An analysis was performed to determine the minimum transmitter apertures (beam diameter) required for various link ranges. For example, Figure 3-1 shows link performance as bit error rate (BER) versus link range for various beam diameters. The assumptions used in developing this trade analysis are listed directly below Figure 3-1. This analysis was not concerned with the performance of specific lasercom systems, but only with determining approximate beam diameters for the design of the AO beam steering subsystem.

Figure 3-1. Example Link Performance Analysis



<u>Assumptions:</u>

- Laser: λ = 830 nm, Power = 1 watt
- Receiver: D_r = 25 cm, APD gain = 40
- Data: Rate = 100 Mbps, 2-ARY, no error corrections
- Other: no background noise, no path attenuation, no pointing/tracking errors

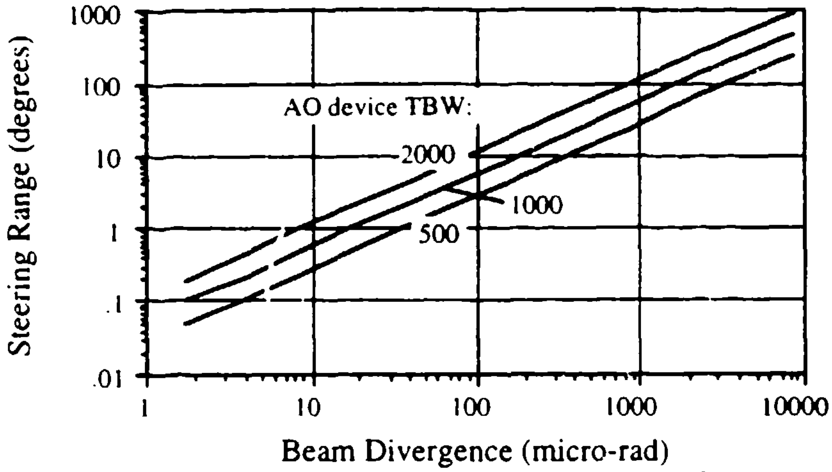
It may be seen in Figure 3-1 that for link ranges out to 1000 km an optical aperture as small as 1 cm may provide good BER performance. This result forms the basis for using very wide field-of-regard (FOR) optics and beam deflection by a Bragg cell to achieve steering of the transmit beam. The maximum steering range and transmitted beam size is related to the Bragg cell by

$$\Theta_{range} \approx TBW \cdot \Theta_{beam} \tag{3-1}$$

where Θ_{range} is the desired transmitter steering range, Θ_{beam} is the beam divergence (chosen to meet BER requirements), and TBW is a performance measure of the Bragg cell called the "time-bandwidth product", or also known as the "spot resolution number". In general, Bragg cell efficiency deteriorates with increasing TBW, making it harder to achieve high optical throughput.

The important result of Eq. (3-1) is that the available transmitter steering range is ultimately limited by the Bragg cell performance for a given transmitter beam size, as shown in Figure 3-2.

Figure 3-2. Beam Parameters vs. Acousto-optic Device Performance



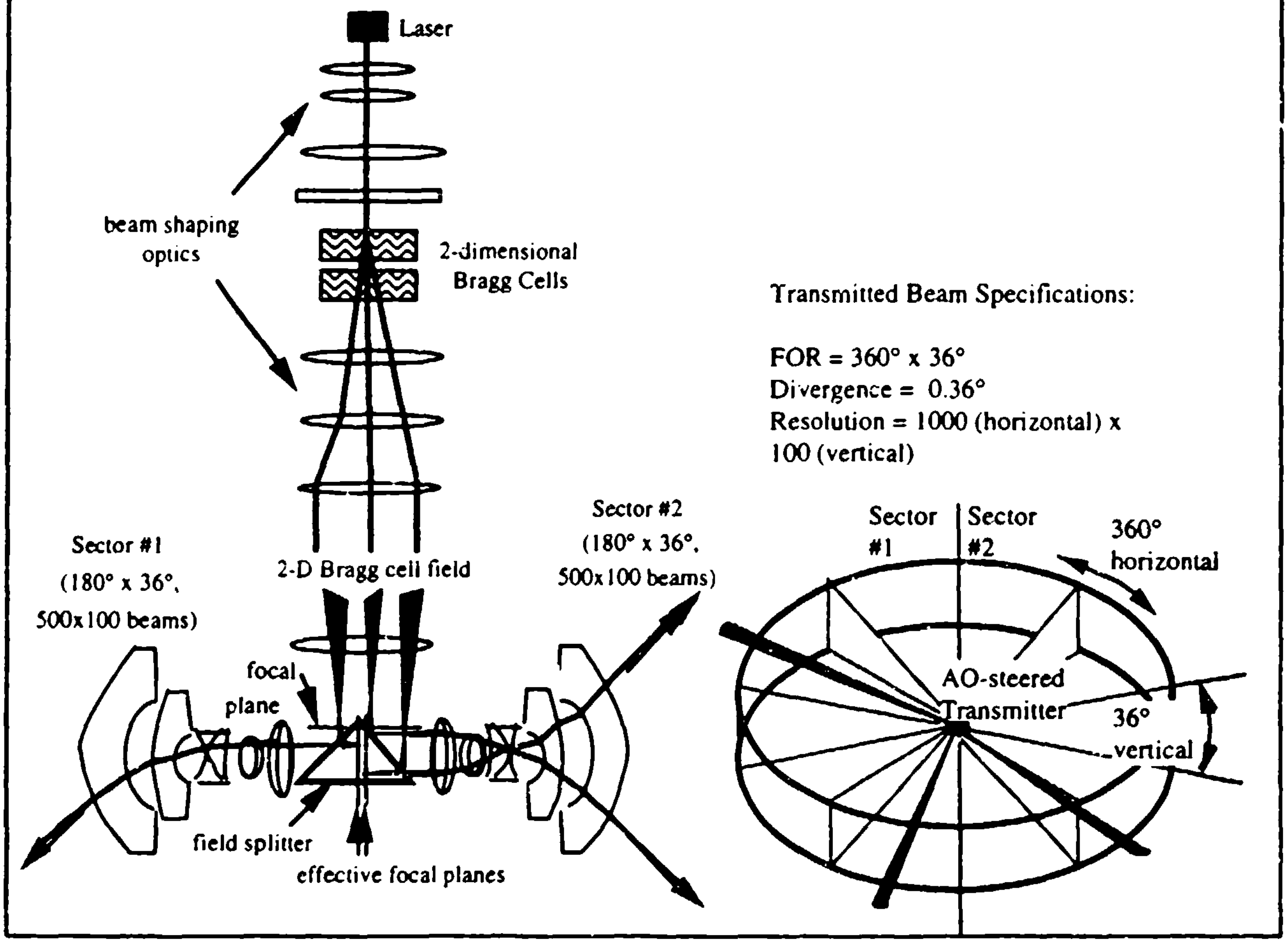
Three different values of Bragg cell TBW's are plotted in Figure 3-2, with a TBW of 500 representing an "easy" Bragg cell design and a TBW of 2000 representing a state-of-the-art design. To obtain a full 360° steering range it may be seen that a moderately complex Bragg cell design with a TBW of 1000 may be used with a beam divergence of about 6 milliradians (upper right hand corner of plot). The maximum link range can then be determined based on specific link parameters such as laser power, path loss, desired BER, background noise, etc.

Figure 3-2 suggests some interesting alternative applications for lasercom AO Bragg steering. For example, in certain applications such as terrestrial or space data relays it is not necessary to steer the beam over a very wide range, and larger transmit apertures may be required. Also, when very fast steering speeds are not required over a wide steering range one may employ auxiliary mechanical gimbals for coarse pointing. In these types of applications an AO Bragg deflector can provide high performance "fine-tune" beam steering in association with the larger beam sizes. For example, as shown in the lower left hand corner of Figure 3-2, a Bragg cell design of TBW = 1000 and a beam divergence of 2 microradians can provide a fine-tune steering range of 0.1°. Therefore, AO Bragg steering also has utility in lasercom systems requiring transmit beams 10 cm or more in diameter and link ranges well beyond 1000 km (referring to Figure 3-1).

The trade analysis presented in Figure 3-2 is not limited just to lasercom transmitters, but is also valid for receivers. In other words, an AO deflector may be used in an optical receiver employing wide FOR optics in order to select the desired angle of arrival to the photodetector. This uses the AO device in the reverse sense from the transmitter: here one wishes to hold a constant deflected angle (onto the detector) for various chosen input angles. In this application there is no actual change in the Bragg cell itself, but only a change in the way that it is utilized. Since lasercom receivers require somewhat larger apertures for low BER communication the lower left hand corner of Figure 3-2 is generally the applicable region for receiver operation. As in the long range transmitter case, for large receiver apertures the AO device serves primarily as a very fast fine-tuning element with a courser steering assist from slower gimbal mechanisms as needed.

For the purpose of technology demonstration a breadboard lasercom transmitter was developed that provides a 360° x 36° optical steering range. This is achieved optically by a field splitter that divides the beam space and routes the Bragg cell output field to two optical magnification sectors that each cover a 180° x 36° FOR. This concept, illustrated in Figure 3-3, can be easily extended to provide three or more output sectors as required.

Figure 3-3. Breadboard Transmitter Optical Concept

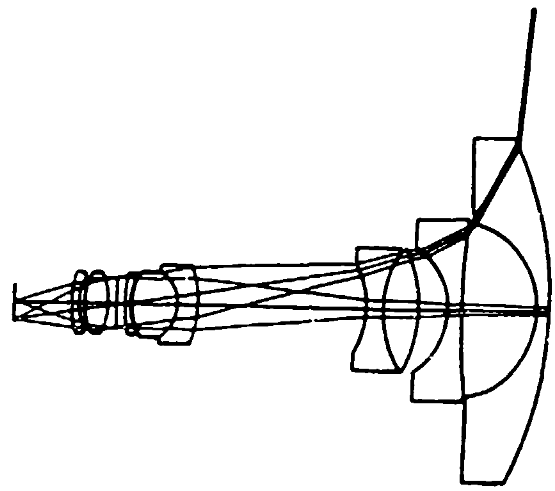


In order to achieve two axes of beam steering two Bragg cells turned orthogonal to each other are required. The time-bandwidth TBW, or spot resolution, required for the Bragg cells can be determined from the ratio of total steering range to far-field beam width: 1000 (360°/0.36°) in the horizontal axis and 100 (36°/0.36°) in the vertical axis. However, this would result in two highly asymmetric Bragg cell designs, and since the optical field can be divided as shown in Figure 3-3, a more equitable solution is to implement a 500 (horizontal) x 200 (vertical) spot Bragg cell pair and optically split the field in half along the 200 spot axis. In the end, this approach produces the optical equivalent of a 1000 x 100 spot Bragg cell pair.

The relatively small steering range that the Bragg cell inherently produces must be angularly magnified in order to meet the lasercom transmitter requirements. The 1.2° steering range of the

500 Spot Bragg Cell must be magnified to 180° as it exits the lasercom terminal, so an optical magnification factor of 150X is required. Angular magnification results in an effective decrease in the beam diameter, which in this case becomes 25 mm / 150 = 165 microns. For the 200 Spot Bragg Cell the optical magnification factor required is approximately 70X. Due to the relatively small beam sizes a simple wide angle 35mm camera lens was employed to achieve the required optical magnification. Figure 3-4 illustrates the concept of the wide angle camera lens. The breadboard optical design has been extensively modeled on CODE V® analysis software and shown to have wavefront quality near $\lambda/10$.

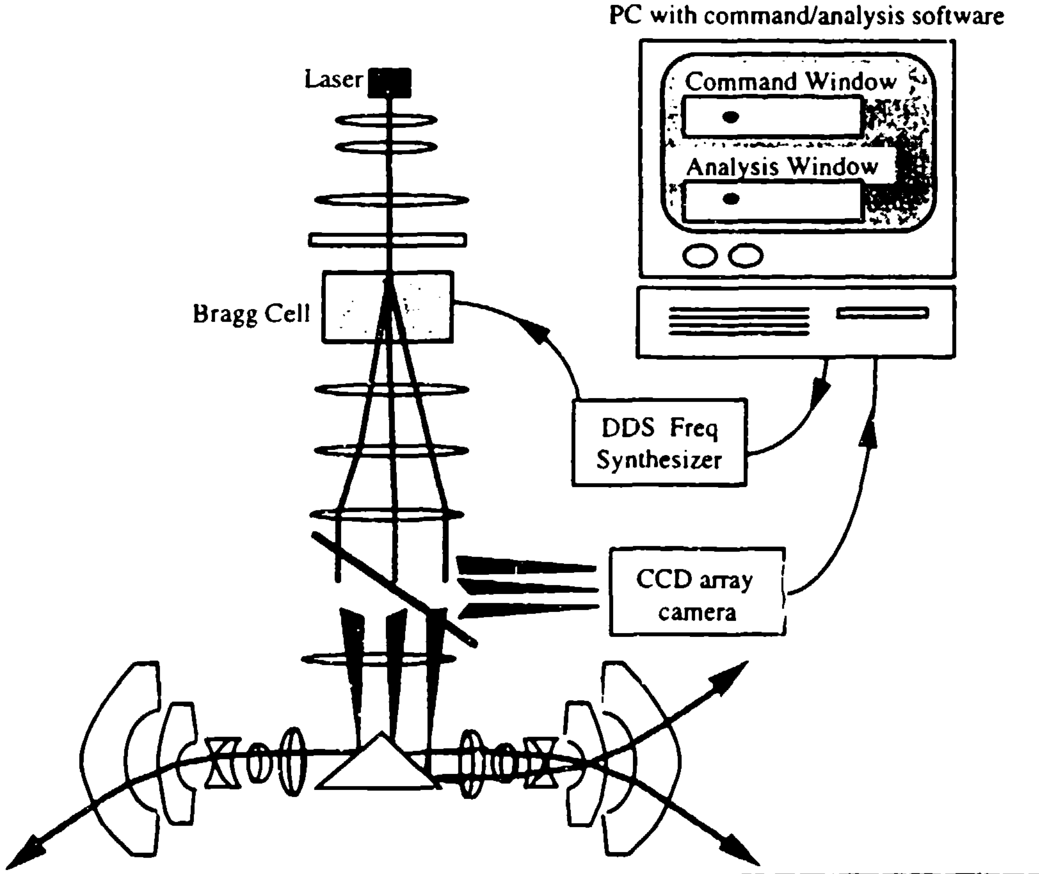
Figure 3-4. Optical Magnification Concept with Wide Angle Lens



To drive the Bragg cells an electronic subsystem was developed that uses direct-digital-synthesis (DDS) to generate the required frequencies. Since the DDS system can switch frequencies up to 50 times faster than the response time of the Bragg cells one can use time-division-multiplexing of several frequencies in order to produce multiple simultaneous deflected beams or similarly to create higher diverging beams for lasercom acquisition or close-range communication purposes. The DDS system provides phase noise, spurious signal, and drift specifications well within the requirements of the breadboard. The output of two DDS channels is amplified before insertion to the two Bragg cells.

The breadboard control is implemented in a turn-key fashion with a 486-33 PC as the central controller. A very user-friendly menu-driven software interface was developed in Visual Basic®. The PC opens two windows on the monitor screen - the "command" and "analysis" windows. In the top half of the monitor the command window shows a flat representation of the 2-D beam steering space (360° x 36°) with a small dot that indicates the current intended beam steering direction. The angular coordinates of the intended steering direction are displayed next to the window. Directly below the command window is the "analysis" window, which displays a real-time image from the CCD array camera that is mounted at an intermediate focal plane of the Bragg cell output. The analysis window thus provides a direct visual check on where the beam is actually being steered vs. the intended direction displayed in the command window. The actual pointing coordinates can be calculated and displayed using a centroiding algorithm that operates on the CCD image data. Figure 3-5 shows a simplified schematic of the demonstration breadboard hardware.

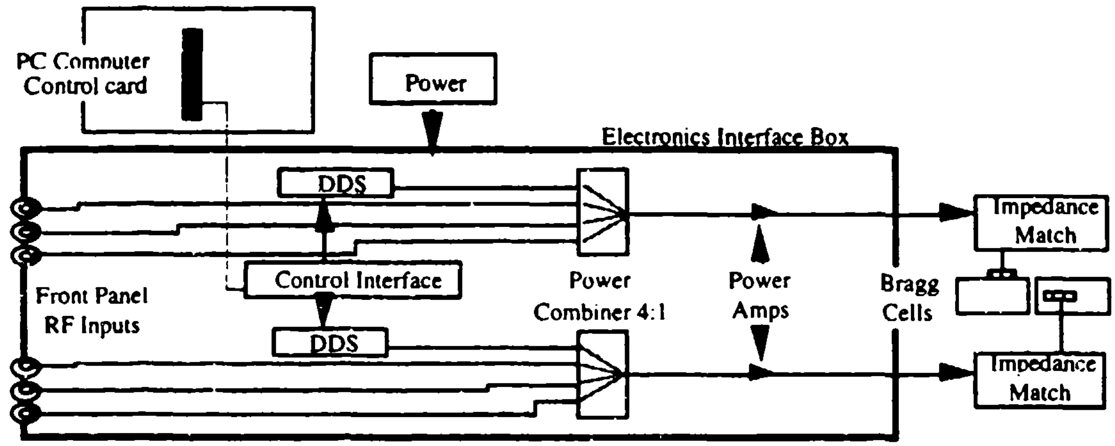
Figure 3-5. Simplified Breadboard Schematic



The CCD camera and image analysis software serve as a built-in diagnostic system for the breadboard. Performance parameters that can be directly measured include beam size, beam shape, beam location, scan range, scan linearity, optical efficiency, zoom factor, and multiple beam generation. The CCD camera does not respond fast enough to measure the 30 microsecond switching response.

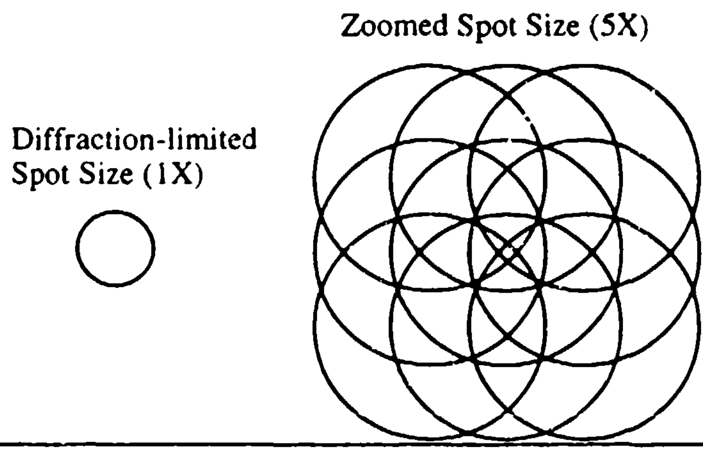
The PC converts intended steering directions selected in the command window into new horizontal and vertical frequencies for the DDS frequency generator that feed into the Bragg cells. 16-bit frequency data words are loaded into 4096-word FIFO (first-in first-out) memories on a custom digital interface board, and the FIFO memory is continuously cycled to the DDS at the rate of 400 nsec/word. Therefore, to completely fill the 40 microsecond (25 mm) aperture of the 500 Spot Bragg Cell only 100 of the 4096 available FIFO words need to be occupied. In other words, if the FIFO contents are forced to change more rapidly than 100 words at a time then only partially developed deflection beams will be produced by the Bragg cells due to subaperture fill times. A simplified schematic of the electronics subsystem is shown in Figure 3-6.

Figure 3-6. Simplified Electronics Schematic



Optical defocus or "zooming" of the beam is executed from a pull-down menu in which zooms from 1X to 11X may be selected. The nominal beam steering direction is unchanged by the zooming function. Specific zoom ratios are accomplished by a combination of multiple frequencies switched at specific duty cycles. The different frequencies will deflect beams in different directions, and the abbreviated duty cycles (less than the full Bragg cell aperture) create smaller diffraction apertures and hence wider divergence angles. The combination of these two effects can be tailored to produce infinitely varying zoom ratios. The FIFO memories are loaded with the appropriate frequency data and duty cycles such that all the required frequencies are always present within the Bragg cell aperture. For example, Figure 3-7 illustrates the spot pattern that results in a 5X beam zoom using 3 frequencies per acoustic axis switched at a duty cycle of 1/3 the Bragg cell aperture of each axis.

Figure 3-7. Example Beam Pattern of 5X Zoom



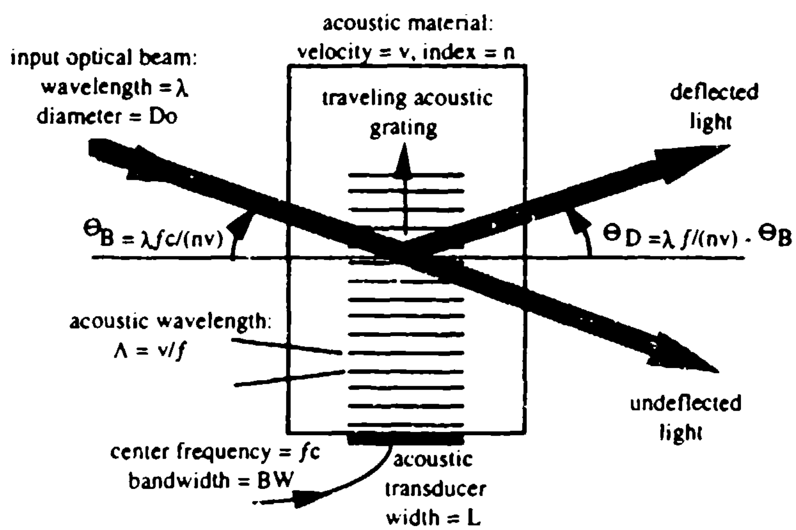
4.0 Subsystem Components

4.1 Acousto-optic Bragg Cell Design and Test

The design of Bragg cells requires a detailed understanding of the fundamental processes illustrated in Figure 4.1-1, which will not be discussed in detail here since many references have covered this in the past. Briefly, an input sinusoidal electrical signal is converted to traveling acoustic waves in the Bragg cell by a piezoelectric transducer.

The acoustic waves produce a refractive index grating through the photoelastic effect, by which the incident light beam is angularly deflected according to the standard theory of diffraction from periodic gratings. The grate spacing will be an inverse function of frequency, and to first order the deflected optical beam angle will be a linear function of the input frequency.

Figure 4.1-1. Fundamental Acousto-optic Process



It may be seen in Figure 4.1-1 that the AO material parameters that determine the deflected beam angle, Θ_D, are the acoustic velocity, v, and optical index, n. Material parameters that determine the amount of light that is deflected include the acoustic attenuation coefficient Γ [dB/m/GHz^2] and the deflection figure-of-merit $M_2 = n^6 p^2/(\rho v^3)$ [s^3/kg], where ρ is the mass density and p is the photoelastic constant. The time-bandwidth parameter, TBW, is defined as the product of: 1) the time that it is required for the acoustic signal in the Bragg cell to traverse the width of the input optical beam, D_o, and 2) the bandwidth of the electrical stimulus, BW. This is expressed as

$$TBW = (D_o / v)\,BW \qquad (4.1\text{-}1)$$

where (D_o / v) is the acoustic transit time. From Eq. (4.1-1) it appears that a large TBW can be obtained by simply choosing a material with low velocity and by using a large electrical bandwidth for a fixed beam width. However, there are other practical limitations, since one must also consider the effects that a large bandwidth may have on the deflection efficiency. One limitation to the bandwidth arises due to the increase of acoustic attenuation, Γ, with frequency. For most acoustic crystals the intrinsic attenuation varies with approximately the square of the operation frequency. A simple derivation shows that TBW is limited by acoustic attenuation according to

$$\mathrm{TBW} \approx 10^{17} / (\nu\, \Gamma\, \mathrm{BW}) \tag{4.1-2}$$

where the assumption is made that the fractional bandwidth (BW / f_c) is approximately 0.5 for ease of impedance matching to the acoustic transducer. Performance vs. material trades can therefore be made by solving Eq. (4.1-2) for BW and then Eq. (4.1-1) for D_o until an overall optimum Bragg cell design is achieved.

There is, however, another major consideration for the choice of acoustic material: the potential wavefront distortion of the deflected beam due to thermal gradients in the material. The thermal gradients arise due to the imperfect conversion of the input electrical signal into acoustic waves by the transducer, and also to some degree by acoustic attenuation within the Bragg cell. A thermal distortion figure-of-merit can be defined for acoustic materials as

$$M_{th} = n\, M_2\, k / \zeta \tag{4.1-3}$$

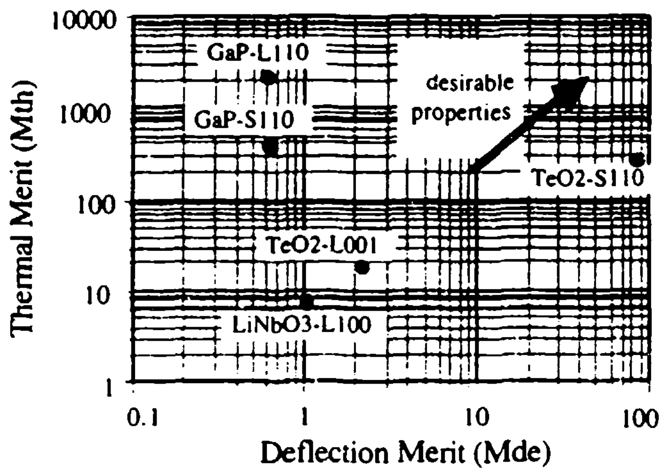
where k [W/m/°C] is the thermal conductivity and ζ [1/°C] is the temperature dependence of the acoustic velocity. The appearance of n and M_2 in this definition reflects the fact that materials with higher diffraction potential require less drive power for a given level of optical efficiency and hence earn a better Figure of merit for thermal distortion. If thermal distortion is a problem, selective heat sinking of the Bragg cell can often alleviate the situation by predominantly forcing only easily correctable linear and/or quadratic distortion terms to occur. Similarly, a figure-of-merit for optical deflection efficiency is given by

$$M_{de} = M_2 / (\nu\, \Gamma^{1/2}) \tag{4.1-4}$$

where the acoustic attenuation parameter, Γ, and velocity, ν, account for the practical limitations imposed on the actual design of high time-bandwidth Bragg cells. A material trade for high TBW Bragg cells can then be made by plotting M_{th} versus M_{de} as shown in Figure 4.1-2 for six common Bragg cell materials. The shear-wave <110>-mode in Tellurium Dioxide (TeO_2) is seen to have the best overall combination of features for this type of application. The <110>-mode of TeO_2 has been well explored in the literature due to it's very slow velocity of 617 [m/sec] and very high $M_2 \approx 1.2 \times 10^{-12}$ [s^3/kg], and is commonly referred to as "slow-shear" TeO_2. The rather high value of $G \approx 22000$ [dB/m/GHz^2] in slow-shear TeO_2 severely limits it's bandwidth range via Eq. (4.1-2), but does not typically degrade optical efficiency at smaller bandwidths due to the offsetting effects of the very high M_2 via Eq. (4.1-4). There are, however, numerous complications involved in properly utilizing slow-shear TeO_2 in practice, especially due to it's acoustic anisotropy and optical birefringent properties.

With TeO_2 as the chosen acoustic material the bandwidth can be found from Eq. (4.1-2) to be about 14 MHz for the 500 spot (horizontal) acoustic axis. The beam diameter D_o can then be found from Eq. (4.1-1) to be 22 mm. This results in a 100% switching response time of $D_o/\nu \approx$ 36 microsec. If the beam diameter for the 200 spot axis is chosen to be 11 mm (in order to produce a 2:1 aspect ratio corresponding to the output of many laser diodes) then the bandwidth from Eq. (4.1-1) is 12 MHz, which is well below the maximum limit imposed by Eq. (4.1-2).

Figure 4.1-2. Acoustic Material Figure-of-Merit Trade

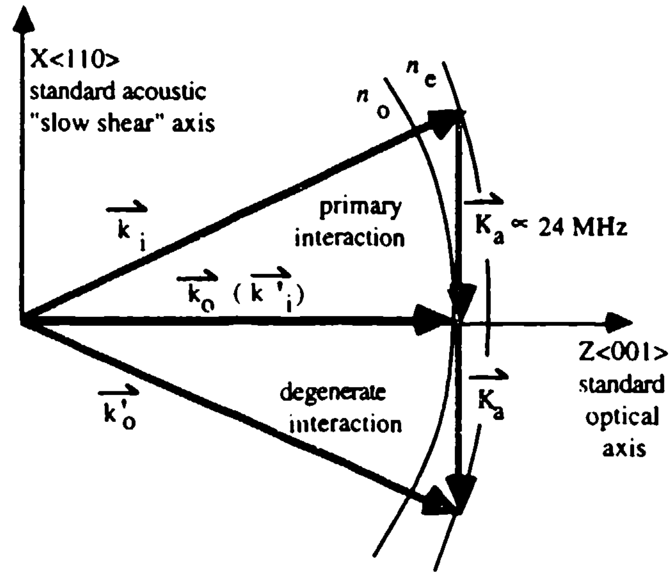


As mentioned previously, the choice of center frequency is somewhat complicated by the birefringence in TeO_2. A low center frequency is typically desired in order to reduce acoustic attenuation, and a fractional bandwidth of less than 60% is also desired for piezoelectric transducer and impedance matching requirements. In the pure <110> "slow shear" mode of TeO_2 the inherent center frequency is fixed at about 24 MHz for an optical wavelength of 830 nm. This would result in a marginal fractional bandwidth of 58%. A Bragg cell designed at this frequency, however, will have a severe degenerate notch in the deflection response when driven to high optical efficiency centered at the 24 MHz frequency.

The explanation for this "self" or "1-tone" degeneracy is illustrated in the momentum-matching diagram of Figure 4.1-3. The incident and deflected output light vectors, $\mathbf{k}_i$ and $\mathbf{k}_o$ respectively, are defined by $2\pi n_x/\lambda$, where the extraordinary index (n_e) is used for the incident light and the ordinary index (n_o) is used for the output light. For a Bragg interaction to occur these two vectors must form a triangle with the acoustic vector $\mathbf{K}_a$, defined by $2\pi f/v$. Due to the symmetry of the pure-mode <110> interaction it is seen that the deflected beam may be re-deflected to the outer index along $\mathbf{k}'_o$ at the 24 MHz center frequency. The degenerate interaction, denoted by the primed k's in Figure 4.1-3, does not have as much bandwidth due the non-tangential nature of the interaction, leading to the notch formation in the response band of the primary interaction.

The degeneracy may be removed, and/or the center frequency increased, by rotating the acoustic mode slightly off of the pure-mode <110> slow-shear axis. Alternatively, the center frequency could be increased by utilizing a phased array piezoelectric transducer. In other applications it may also be advantageous to rotate the optical axis of the Bragg cell. For the present application a simple acoustical rotation is the logical choice based on a trade of electrical drive power and size of the TeO_2 crystal. However, in a 2-D deflector it is not possible to acoustically rotate both axes in a single crystal without also inducing unwanted optical rotations. The easiest solution to this dilemma is to use two separate crystals that are each acoustically rotated. These can then be brought together, or even glued together, to form a quasi-monolithic single Bragg cell. This approach also serves to reduce the fabrication complexities of a 2-D single crystal Bragg cell.

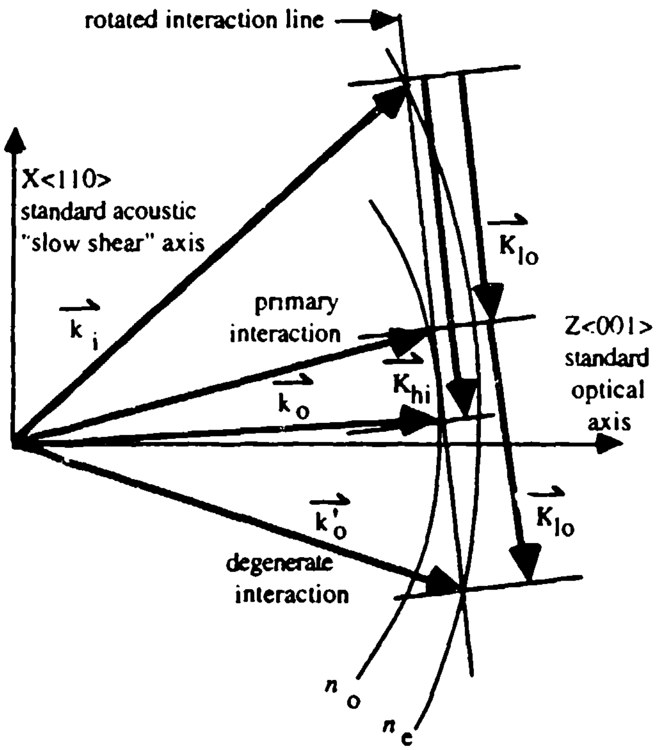
Figure 4.1-3. Degenerate Response in On-Axis TeO_2



Several primary issues must be addressed in acoustically rotating a TeO_2 crystal: the center frequency and bandwidth of the interaction, the "walkoff" of the acoustic energy in the crystal due to anisotropy of the velocity, and the conjugate frequency pair at which secondary interactions occur. These secondary interactions are actually split manifestations of the degenerate 1-tone interaction that occurs in the <110> pure-mode, and may be considered as "2-tone" degeneracies since two frequencies are involved. For applications where only one frequency is introduced into the Bragg cell at a time then 2-tone degeneracy is not a concern. For the lasercom demonstration system, however, it is desired to use discrete simultaneous frequencies to produce multiple deflected beams, so if a 2-tone degeneracy exists then it would likely be encountered in operation.

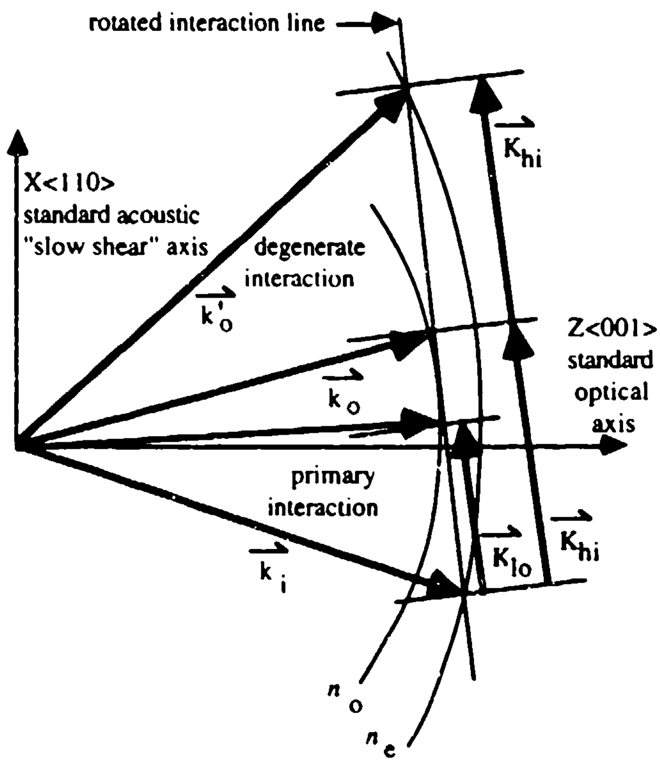
Figure 4.1-4 illustrates the concept of acoustic rotation and the usable bandwidth region where 1- and 2-tone degeneracy can be avoided. In this configuration the 1-tone degeneracy is prevented as long as the bandwidth does not extend below the frequency corresponding to $\mathbf{K}_{lo}$. This also happens to be the condition for preventing 2-tone degeneracies since it can be seen that frequencies higher than that corresponding to $\mathbf{K}_{lo}$ cannot re-match to the outer index. The only practical limitation to the upper end of the bandwidth is how well the line of interaction matches to the inner index. For maximum bandwidth the interaction line should not be perfectly tangent to the inner index but should be slightly "de-tuned" by the input $\mathbf{k}_i$ angle so as to bisect the inner index in two places with a small offset mismatch at the center frequency.

Figure 4.1-4. Rotated AO Interaction in TeO_2: High-Band Mode



Note that the rotated AO interaction illustrated in Figure 4.1-4 may be reversed in operation such that the degenerate interaction is utilized as the primary interaction, as shown in Figure 4.1-5. In this case 1- and 2-tone degeneracies are prevented as long as the bandwidth does not extend above the frequency corresponding to K_{hi}. It can be seen in Figure 4.1-5 that the acoustic vectors are shorter than in the previous case, so this orientation is referred to as the up-shifted low frequency interaction, or "low-band" mode. The advantage of the low-band mode is less acoustic attenuation and, more significantly, a wider bandwidth due to the fundamental $1/f_c$ dependence of interaction bandwidth for a given transducer size.

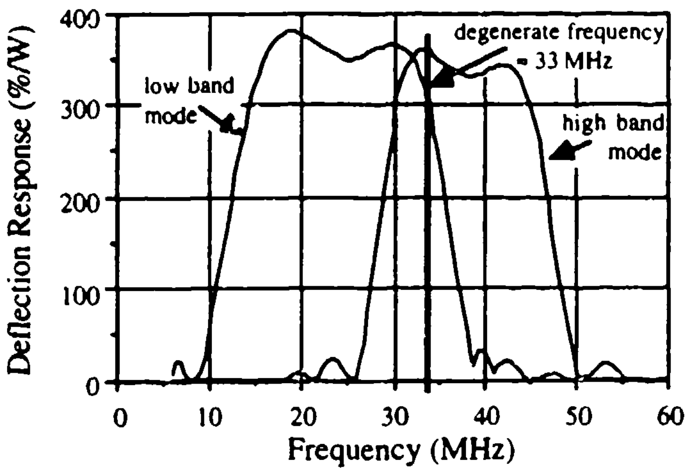
Figure 4.1-5. Rotated AO Interaction in TeO_2: Low-Band Mode



The theoretical small-signal deflection response of both the high- and low-band modes is shown in Figure 4.1-6, normalized to 1 watt of electrical drive power. Here the acoustic rotation is 2° and the optical aperture is 22 mm as required for the 500 Spot Bragg Cell axis. It can be seen that the center frequency of the low-band mode is hardly changed from the non-rotated case of ≈ 24 MHz due to the circularly-symmetric nature of optical activity in the vicinity of the <001> axis, but the high-band mode center frequency has moved significantly upward to nearly 40 MHz. Degenerate effects are not included in the responses shown in Figure 4.1-6.

In order to obtain the required 14 MHz bandwidth for the 500 Spot Bragg Cell axis it is seen from Figure 4.1-6 that only the low-band interaction mode is practical. The 1-tone degeneracy occurs at about 33 MHz, and since the degenerate notch width is about 10% of the total interaction bandwidth then the upper bandwidth limit of the low-band mode should not exceed 31 MHz. Therefore the 500 spot acoustic axis can be satisfied with a 14 MHz bandwidth centered at 24 MHz on the low-band interaction mode. The resulting fractional bandwidth is 58%.

Figure 4.1-6. Theoretical Deflection Response of Low- and High- Band Interactions in 2° Acoustically Rotated TeO_2



The same center frequency of 24 MHz was chosen for the 200 spot acoustic axis in order to use duplicate and interchangeable electronic frequency generation circuits for the two Bragg cell axes. The deflection response of the 200 spot axis is essentially the same as that shown in Figure 4.1-6 for the 500 spot axis. For acoustic rotation angles less than 4° the energy walkoff angle due to anisotropy is about 10 times greater, so for a 2° acoustic rotation the crystal must be sized properly for a 20° beam propagation over the optical aperture length. The approximate dimensions of the 500 Spot Bragg Cell are shown in Figure 4.1-7. Acoustic reflection interference from the back surface of the Bragg cell is almost completely eliminated by appropriately beveling and coating the back surface with a proprietary acoustic absorbing material.

RF impedance matching circuits were designed and constructed for the Bragg cells. The schematic of these circuits is shown in Figure 4.1-8. Relatively simple LC "pi"-type circuits were used for the matching, and were they constructed with discrete micro-chip components (inductors and capacitors) due to the relatively low frequencies involved. The starting point impedance for the 200 Spot Bragg Cell and the final matched impedance are shown in Figure 4.1-9, in Smith Chart form. Similar data for the 500 Spot Bragg Cell is shown in Figure 4.1-10.

Figure 4.1-7. Dimensions of 500 Spot (Horizontal) Bragg Cell

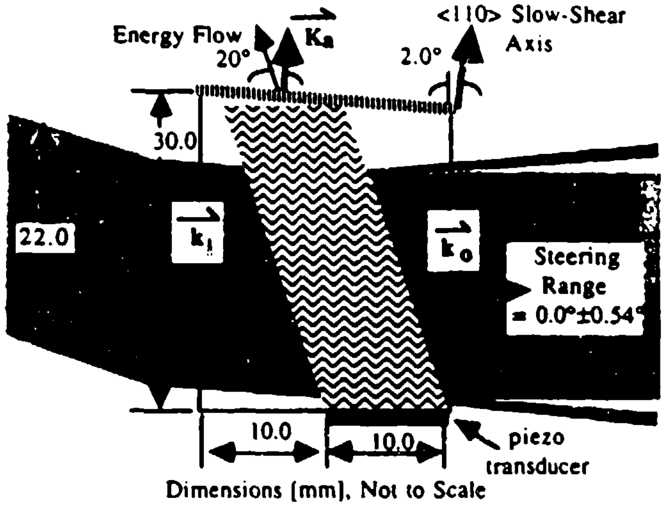
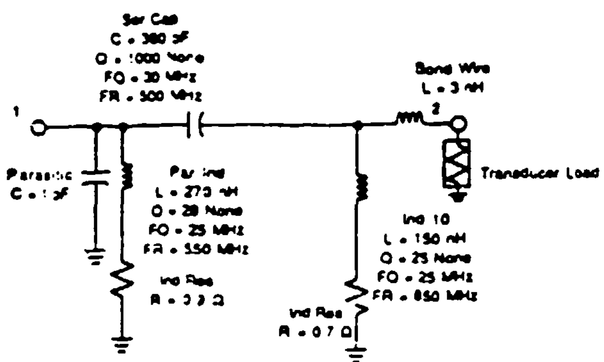


Figure 4.1-8. Bragg Cell Impedance Match Circuits

200 Spot Cell Circuit



500 Spot Cell Circuit

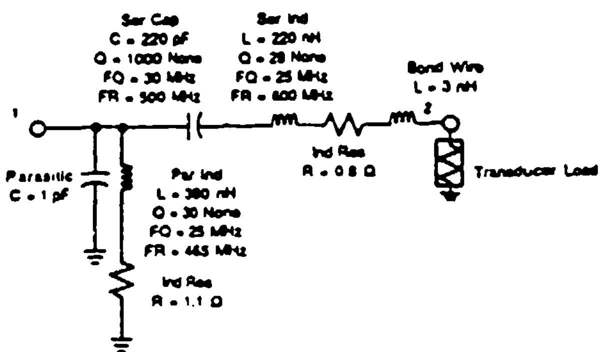


Figure 4.1-9. Starting and Finishing Impedance for 200 Spot Bragg Cell

Starting Impedance — Finishing Impedance

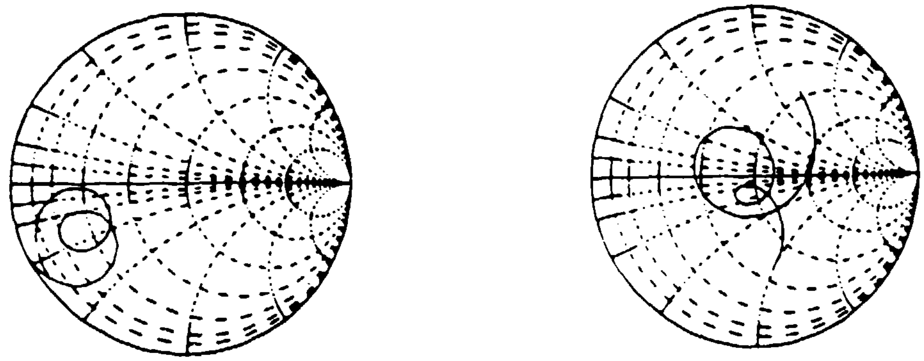
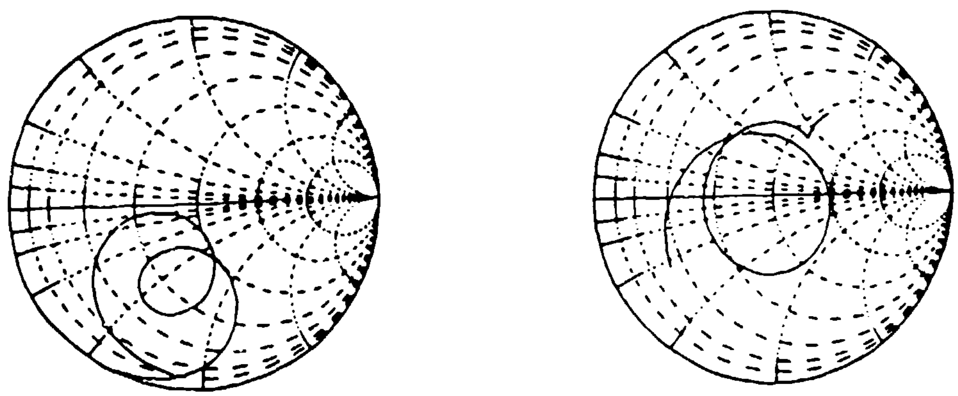


Figure 4.1-10. Starting and Finishing Impedance for 500 Spot Bragg Cell

Starting Impedance — Finishing Impedance



The resulting VSWR for the 200 and 500 Spot Bragg Cells is shown in Figure 4.1-11. The frequency range in Figures 4.1-9 through 4.1-11 ranges from 15 to 35 MHz, although only 17 to 31 MHz is actually used during operation of the Bragg cells. The VSWR values over the range of operation are are no worse than 2.5:1, corresponding to an electrical insertion loss of less than 1.0 dB (≈ 20% power transmission loss). All subsequent Bragg cell performance references to deflection efficiency vs. drive power (i.e., expressed as %/Watt) include this RF matching loss.

The small-signal deflection efficiency response of the 500 Spot Bragg cell is shown in Figure 4.1-12. The theoretical response is shown on the left-hand side, assuming a flat matching VSWR of 2.0. On the right-hand side of Figure 4.1-12 is the experimentally measured response, which has a match VSWR of about 2.0 at 20 MHz as was shown in Figure 4.1-11. The small-signal response is a commonly used measurement for acousto-optic devices because it avoids the issue of the non-linear deflection response with increasing RF drive power. In other words, it is a convenient method for comparing the efficiency performance of different AO devices without having to state the exact drive power that was used. The peak response, measured at about 20 MHz, is seen to be ≈700%/W. The slight deviation from the theoretical response at frequencies greater than 20 MHz can be seen to be at least partially due to the rising VSWR in Figure 4.1-11. Very similar results were obtained for the 200 Spot Bragg cell, except the peak efficiency was measured to be about 400 %/W.

Figure 4.1-11. Matched VSWR for 200 and 500 Spot Bragg Cells

200 Spot Cell VSWR | **500 Spot Cell VSWR**

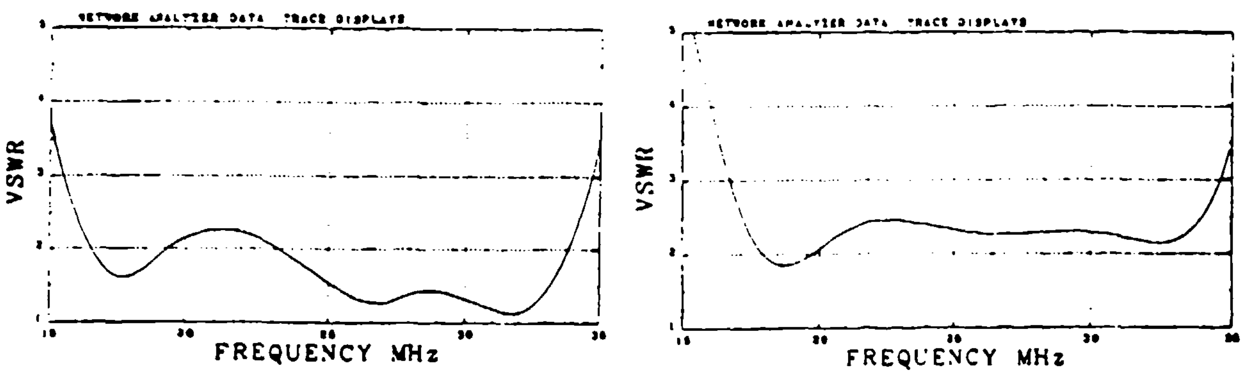
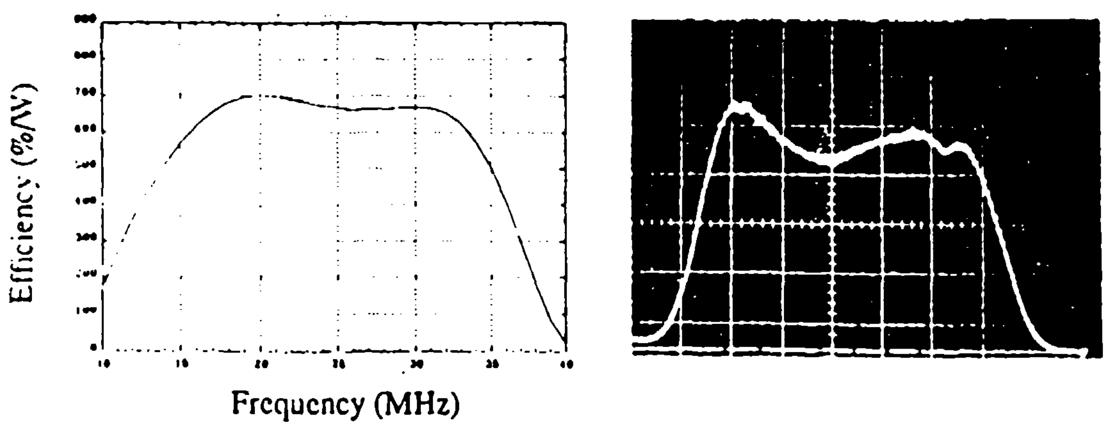


Figure 4.1-12. Theoretical vs. Experimental Deflection Efficiency of the 500 Spot Bragg Cell

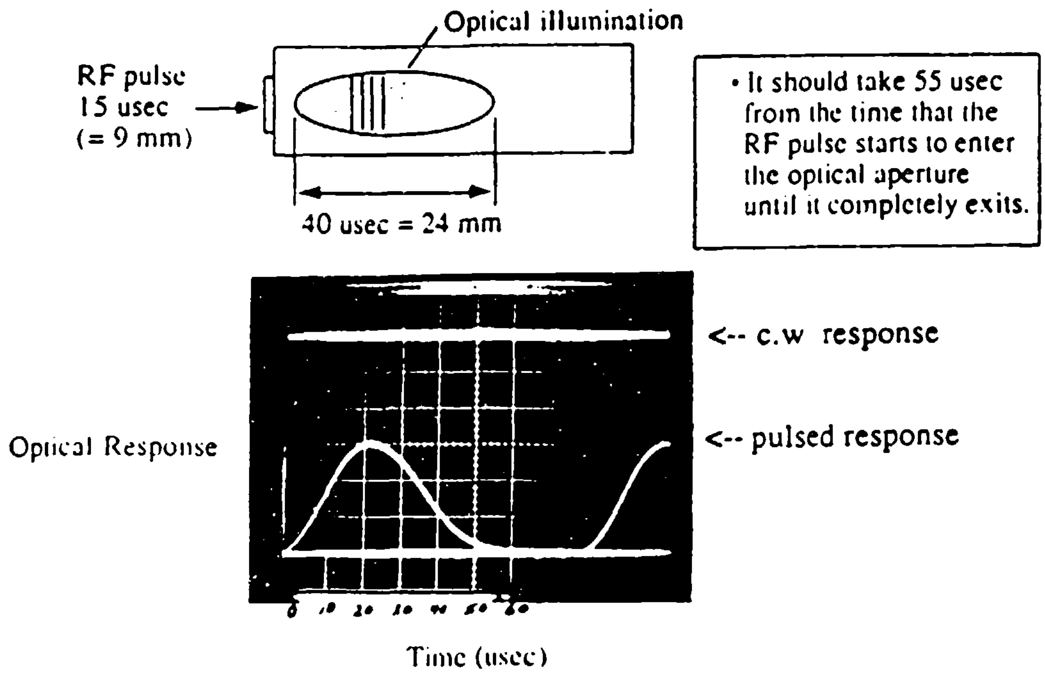
Theoretical:
assumes flat 2.0 VSWR

Experimental:
VSWR ≈ 2.0 @ 20 MHz, then rising



The optical switching response, or steering speed, of the 500 Spot Bragg Cell was measured using a pulsed input RF signal. Since the optical deflection angle is a function of the RF frequency that is inserted into the cell, then the speed at which the angle can be changed depends on how fast the frequency content of the cell can be changed. The switching speed will therefore be determined by the ratio of the illumination beam width over the acoustic velocity. For this test the 500 Spot Cell was illuminated with an accurately measured 24 mm wide optical beam, which should correspond to about 40 µsec of acoustic aperture if the acoustic velocity is 620 m/sec in the slow-shear TeO_2. For a given beam width the switching speed is solely determined by the acoustic velocity, so this test is really a verification of the acoustic velocity of the Bragg cell. Therefore, if an RF pulse of 15 µsec duration is input to cell then it should require a total of 55 µsec from the time that the pulse first enters the illumination aperture until it completely disappears. If the deflected beam is monitored on a photodetector then the response should be seen to correspondingly rise and fall within the same 55 µsec. This test and the experimental results are illustrated in Figure 4.1-13.

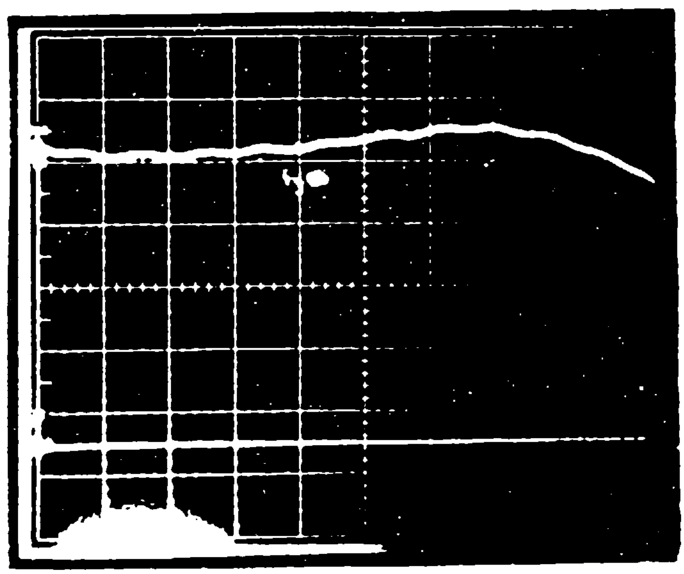
Figure 4.1-13. Switching Response Test



The illumination for the test in Figure 4.1-13 was a Gaussian intensity profile; had the illumination been uniform then the response would have had a flat "plateau" between about 15 and 40 µsec. The response is seen to correctly rise and fall at the 55 µsec interval, confirming that the 100% switching response time is 40 µsec for the 500 Spot Bragg Cell. Note that the response peaks at about half the c.w. response simply due to the fact that the RF pulse always occupies less than half of the illumination aperture. The 200 Spot Bragg Cell similarly would have a 200 µsec switching speed due to it's smaller 20 µsec aperture.

Figure 4.1-14 illustrates the "saturated" response of the 500 Spot Bragg Cell. At about 400 mW of input RF power the deflection response peaks on this cell and will actually start to decline with increasing drive power. This saturation effect will cause the frequency response of the cell to flatten out to a large degree as shown in Figure 4.1-14. The saturated response is seen to deviate about ±5% around the nominal value.

Figure 4.1-14. Saturated Response of the 500 Spot Bragg Cell



A thermal analysis was performed on the Bragg cells to investigate the potential wavefront distortion effects caused by temperature gradients inside the cells. Imperfect conversion of the input RF drive power at the piezoelectric transducer is the source of thermal heating, and additional heating occurs due to absorbed acoustic energy at the end of the cell and acoustic attenuation along the length of the cell. The resulting temperature gradients can cause optical distortions due to thermal expansion of the width of the Bragg cell (W) and the temperature dependence of the acoustic velocity (v)and index of refraction (n). The optical phase, ϕ_B, at position "l" from the transducer end of the cell along the exiting face is given by

$$\phi_B(l) = 2\pi \{ f \int_0^l \frac{1}{v}\, dx + \frac{n(l)W(l)}{\lambda_o} \} \qquad (4.1\text{-}5)$$

where f is the RF frequency of excitation (i.e., ≈24 MHz) and λ_o is the optical wav length.

Figure 4.1-15 shows the parameters and geometry of the heat sinking used in the thermal analysis, and Figure 4.1-16 shows the results of the analysis. The top of Figure 4.1-16 shows the optical wavefront contours that would result from the temperature gradients, and the bottom of Figure 4.1-16 shows the "corrected" wavefront contours when the simple tilt and quadratic focus terms have been removed. The focus correction can be easily implemented by adjusting the appropriate spherical lens in the breadboard optics, and the tilt term is simply an angular deflection offset. This shows that heatsinking at the back face of the cell produces a very large region of the Bragg cell that is predominantly free of optical aberrations to less than λ/10 peak-to-valley. This occurs because the symmetry of the temperature gradients along the acoustic axis of the cells lend themselves to well behaved optical distortions that are of low enough order (spherical and linear) to be easily corrected.

Figure 4.1-15. Geometry and Parameters for Thermal Analysis

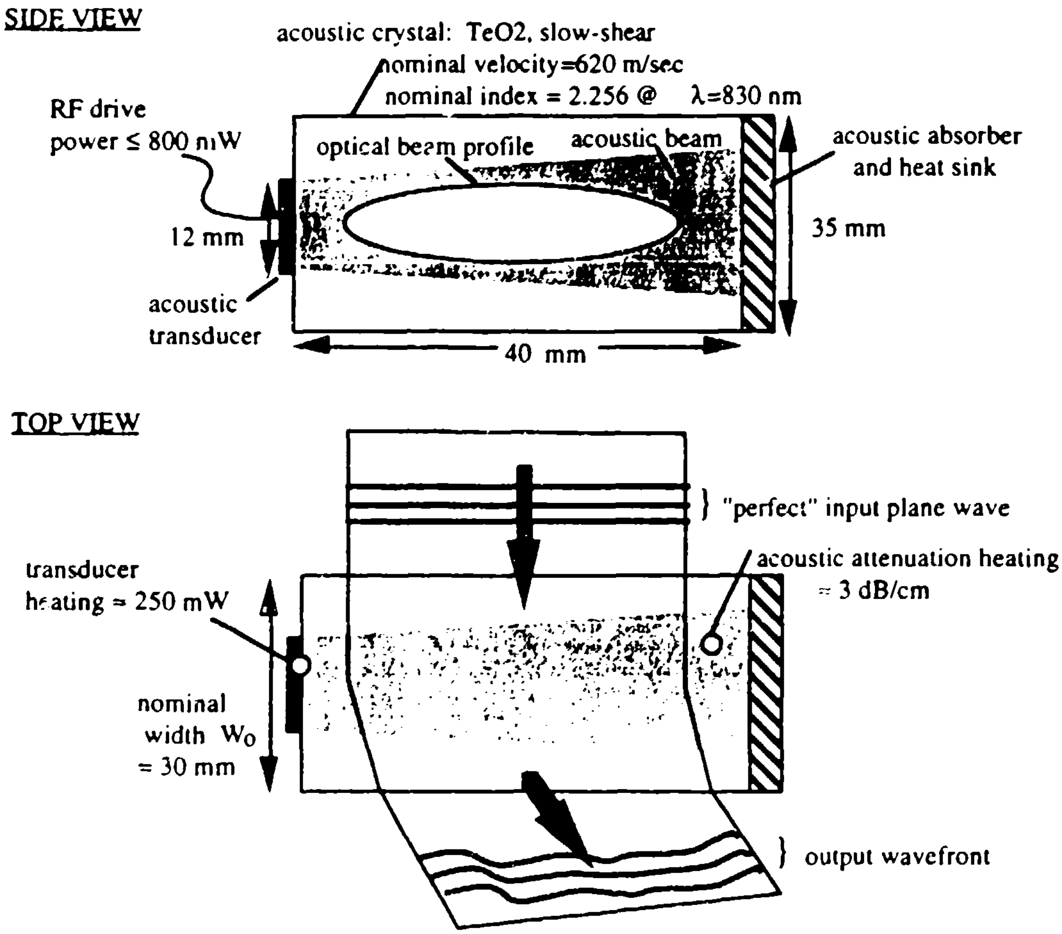
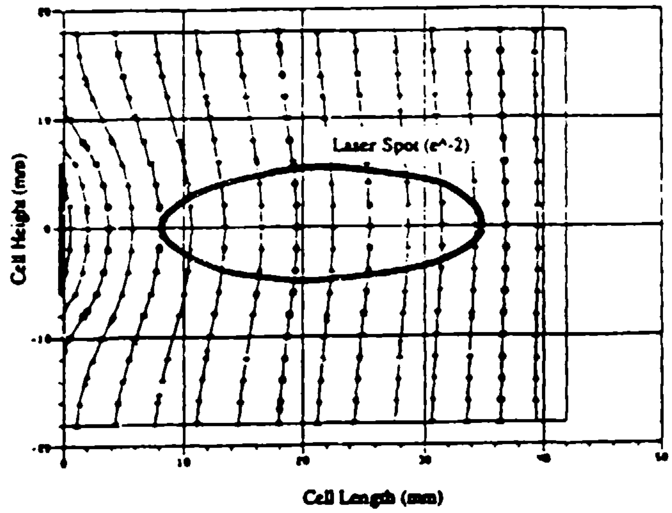


Figure 4.1-16. Raw and Corrected Wavefront Contours

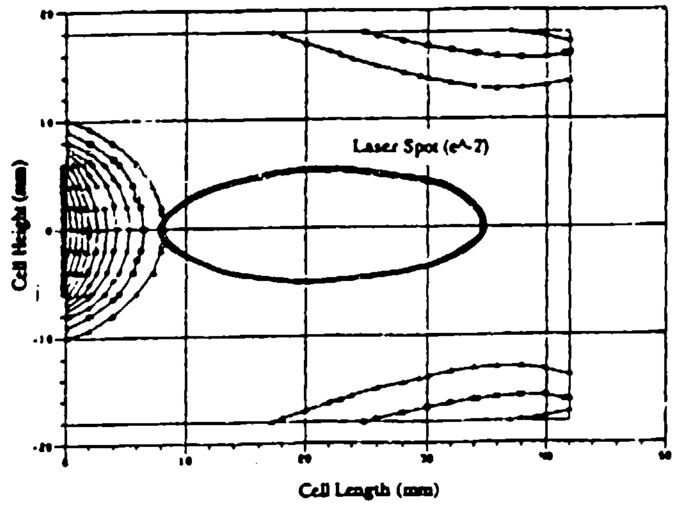
Raw Wavefront Analysis

- integrated wavefront at exit face of cell
- λ/2 per contour, 8.2 λ total deveiation



Corrected Wavefront Analysis

- corrected for linear (tilt) and quadratic (focus) terms
- λ/10 per contour



4.2 Optics

4.2.1 Demonstration Optics Design

The purpose of the demonstration optics was to show proof of concept without the expense of building a custom system. Figure 4.2.1-1 illustrates the layout of the demonstration optics. All off-the-shelf optical components were used (except for the Bragg cells) in the breadboard design.

Figure 4.2.1-1. Demonstration Optics Layout

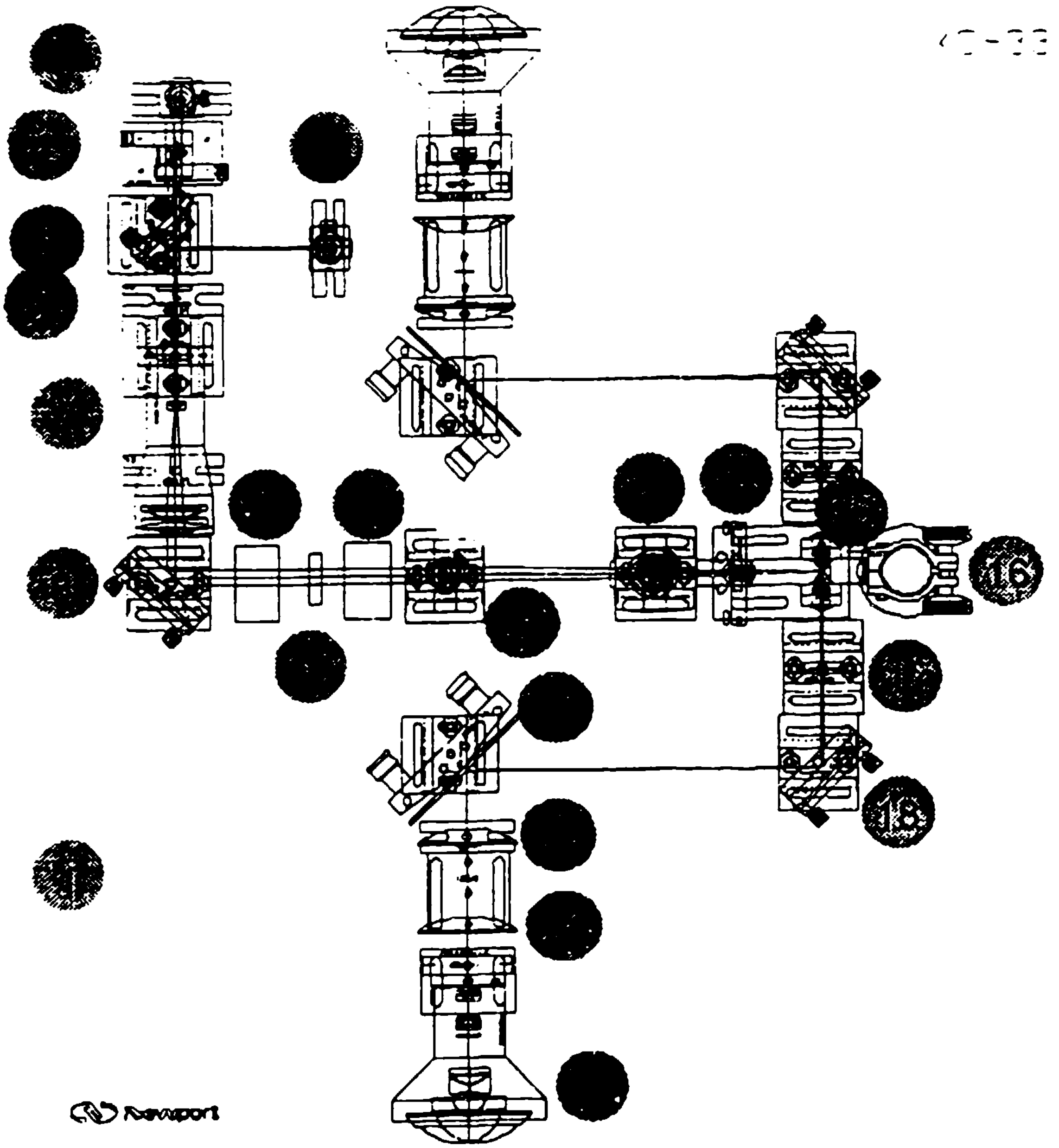


Table 4.2.1-1 contains a list of parts in the Lasercom system illustrated above. Only one 180 degree field is enumerated, with the other field identical.

Table 4.2.1-1. Demonstration Optical Hardware List

1) The base plate is a 2 inch thick 3 foot square optical table with a one inch 1/4-20 hole grid pattern.
2) The 25 mW 830 nm laser and collimator.
3) The 10 mW 670 nm laser and collimator.
4) A 2X anamorphic corrector prism pair.
5) Hot mirror beam combiner (reflects IR, passes visible).
6) A half wave plate and a quarter wave plate.
7) A 6X beam expander.
8) A 2 inch Folding Mirror.
9) The Horizontal Bragg Cell.
10) A half wave plate.
11) The Vertical Bragg Cell.
12) The Horizontal Fourier Transform Lens (300 mm).
13) The camera pickoff beam splitter, the camera's Vertical Fourier transform lens, and CCD camera suspended above.
14) Holds the Vertical Fourier Transform Lens (80 mm) for the projection legs.
15) The image divider mirrors, and two 40 mm Lenses (one for each half field).
16) Camera support post.
17) 100 mm lens.
18) A 2 Inch fold mirror.
19) A 3 Inch fold mirror.
20) 150 mm lens.
21) 150 mm lens.
22) 8 mm Nikon Fisheye lens.

The optics consist of several sections. The first part is the illumination optics (2-8), followed by the Bragg cells that do the beam steering (9-11). Next come the Fourier transform optics that form the beam waists (12-14). The beam waist field is then divided in half and each half reimaged to the input field of the fisheye lenses (15-21). Finally, the fisheye lenses project the beams out to free space (22).

This system was optimized for an 830 nm laser. However, to provide a visible demonstration capability, a 670 nm laser was also provided. With the 670 nm laser however, the bandwidth of the Bragg cells is only half that for the 830 nm laser. The power to the laser is provided by a BNC connector on the back panel of the system control box. This connector supplies 5 volts to the two laser drivers. Inline on the power cable is a switch that selects either the RED laser or the IR laser. Only one laser can be used at a time to avoid spot confusion at the CCD camera plane. The aspect ratio required at the Bragg cells is 2:1 with the long axis in the horizontal direction. The aspect ratio out of the RED laser is 4:1, so a 2X prismatic beam expander is used to form the correct ratio. The output of the IR laser is about 2:1, so no correction is required.

The beams are combined using a hot mirror. A hot mirror is a dichroic surface that reflects IR (above 700 nm) and transmits visible light. The beam sizes at this point are about 2 by 4 mm. A 6X beam expander is used to create a 12 by 24 mm beam to illuminate the Bragg cells. The

Fourier Cylinders then form a scan plane with a field of 500 spots by 200 spots. A beamsplitter reflects a small portion of the light to the CCD TV camera for spot position monitoring. The top half and bottom half of the fields are divided by a mirror pair into the left field and right fields, each with 500 by 100 spots. These fields are then reimaged and magnified to fill the input aperture of the fisheye lens. The fisheye then projects the spots to fill each half field of 180 degrees horizontally by +/- 18 degrees vertically.

The alignment procedure listed in Table 4.2.1-2 assumes that all the optical mount holders are in their normal positions (see Demonstration Optics Layout, Figure 4.2.1-1). The optical axis should be aligned to be 5 1/2 inches above the optical table. At all times observe laser safety precautions! Useful tools not supplied are an infrared viewer, an IR sensitive viewing card, a power meter, and an oscilloscope.

Table 4.2.1-2. Alignment Procedure

1) Place 830 nm laser with collimator into holder (2).
2) Rotate the laser beam to a clear area of the table.
3) Adjust laser until near and far field of beam is at 5 1/2 inches above the table.
4) Aim the beam at the center of the dichroic splitter (5).
5) Adjust the splitter angle to maintain the 5 1/2 inch height and project the beam along the line of components (6), (7), and (8).
6) Center the half wave plate and the quarter wave plate (6) on the beam.
7) Center the 6X beam expander (7).
8) Before inserting turning mirror (8), use the collimation tester (supplied) to adjust the collimation out of the 6X beam expander. Rotate the focus ring until the fringes on the view screen are parallel to the shadow of the wire.
9) Insert turning mirror (8) centered on the beam and folding 90 degrees toward the horizontal Bragg cell.
10) Position the horizontal Bragg cell (9) in the center of the beam.
11) Place a 300 mm lens (supplied) after the cell, and project the spot onto a detector with the detector output displayed on a scope.
12) Energize the cell by starting the software. Select Scan Horizontal from the menu.
13) Adjust the position and angle of the cell to maximize the output on the detector and maintain a flat bandshape.
14) Iteratively adjust the rotation of the halfwave and quarterwave plates (6) to maximize the output of the horizontal cell. Greater than 80% throughput efficiency can be obtained.
15) Remove the 300 mm lens.
16) Position the halfwave plate (10) in the center of the diffracted beam.
17) Position the vertical Bragg cell in the center of the diffracted beam.
18) Place a 300 mm lens (supplied) after the cell, and project the spot onto a detector with the detector output displayed on a scope.
19) Energize the cell by starting the software. Select Scan Vertical from the menu.
20) Adjust the position and angle of the cell to maximize the output on the detector and maintain a flat bandshape.
21) Iteratively adjust the rotation of the halfwave plate (10) to maximize the output of the vertical cell. Greater than 80% throughput can be obtained.
22) Select Scan Diagonally from the software menu and check the composite deflection efficiency. Greater than 60% should be available across the band.

Table 4.2.1-2. Alignment Procedure (Continued)

23) Remove the 300 mm lens.
24) Place the 300 mm cylinder lens in position (12). This focuses the scan horizontally.
25) Place the beamsplitter (13) so that the diffracted light passes through and is reflected upward.
26) Position the vertical Fourier lens (14) into position, centered on the beam.
27) Position a second cylinder lens above the beamsplitter, supported off vertical post (16).
28) Suspend the CCD TV camera also from post (16).
29) Center diffracted light on the camera.
30) Select Scan Vertically from the software and focus the line of light on the camera by moving the camera position up and down.
31) Select Scan Horizontally from the software and focus the line of light on the camera by moving the suspended cylinder lens.
32) Select Multibeam, 8 beam demo from the software menu.
33) Center the pattern on the TV camera by moving the camera.
34) The TV camera setup may have to be repeated after the projected beams are set up.
35) Focus cylinder lens (12) and (14) to form an image in front of folding and splitting mirrors (15).
36) Position splitting mirrors (15) to deflect the top half of the image to the left and the bottom half of the image to the right.
37) Choose the pattern file RIGHT0.PTN from the File Open menu.
38) Position the 40 mm lens (15) for a straight projection of the beams.
39) Position the 100 mm lens (17) in the center of the beam.
40) Position mirror (18) to direct the beams toward mirror (19).
41) Observe the image at position (19). Individual spots should be observed.
42) Position Mirror (19) to center the image in the center of the following lens positions.
43) Center lens (20) on the beam.
44) Center lens (21) on the beam.
45) Insert the Nikon Lens (22) into its holder.
46) Focus lens (17) to obtain clean spots on the screen.
47) Position mirror (19) to center the array of spots in the vertical direction and horizontally.
48) Finely adjust the position of lens (22) along the beam path to set the outer spots at the outer edge of the observation screen.
49) Iterate any adjustments out of tune.
50) Repeat for the other projection leg.

Note: The system can only be nominally adjusted for one wavelength laser at a time. If the 670 nm laser is used for alignment, then the 830 nm laser will no longer be aligned.

The following sections provide the CODE V® design data for the breadboard system. Table 4.2.1-3 and Figure 4.2.1-2 cover the Front-end Demonstration Optics Design and Layout, from laser to Bragg cells. The CODE V® design tool works better when starting from an infinite object, so the data below starts with the collimated beam in the Bragg cells and works backward toward the Aspherical lens in the laser collimator.

Table 4.2.1-3. Front-end Demonstration Optics Design

Code V® design data, from Bragg cells to laser diode.

```
                 RDY              THI      RMD        GLA           CCY   THC
 OBJ:          INFINITY         INFINITY                            100   100
 STO:          INFINITY        35.000000           'TEO2'           100   100
   2:          INFINITY        25.000000                            100   100
   3:          INFINITY         3.000000           BK7_SCHOTT       100   100
   4:          INFINITY        25.000000                            100   100
   5:          INFINITY        35.000000           'TEO2'           100   100
   6:          INFINITY        50.000000                            100   100
   7:          INFINITY         0.000000   REFL                     100   100
    XDE:       0.000000    YDE:     0.000000    ZDE:      0.000000  BEN
    XDC:        100        YDC:      100        ZDC:       100
    ADE:      45.000000    BDE:     0.000000    CDE:      0.000000
    ADC:        100        BDC:      100        CDC:       100

   8:          INFINITY       -50.000000                            100   100
   9:        -125.26610        -7.997000           SK11_SCHOTT      100   100
  10:         115.19900        -4.205000           SF5_SCHOTT       100   100
  11:         555.66760        -0.748000                            100   100
  12:         -73.85900        -5.776000           SF11_SCHOTT      100   100
  13:        -110.00000       -87.180000                            100   100
  14:          INFINITY        -2.080000           SF11_SCHOTT      100   100
  15:         -31.67600        -2.080000                            100   100
  16:          INFINITY        -2.080000           SF11_SCHOTT      100   100
  17:         -31.67600       -50.000000                            100   100
  18:          INFINITY        -3.000000           BK7_SCHOTT       100   100
  19:          INFINITY       -25.000000                            100   100
  20:          INFINITY        -3.000000           BK7_SCHOTT       100   100
  21:          INFINITY       -50.000000                            100   100
>  22:         INFINITY         0.000000   REFL                     100   100
    XDE:       0.000000    YDE:     0.000000    ZDE:      0.000000  BEN
    XDC:        100        YDC:      100        ZDC:       100
    ADE:      40.000000    BDE:     0.000000    CDE:      0.000000
    ADC:        100        BDC:      100        CDC:       100

  23:          INFINITY        50.000000                            100   100
  24:           3.03022         3.000000           SF57_SCHOTT        0   100
    ASP:
    K  :     -0.233433     KC :        0
    IC :        YES        CUF:     0.000000    CCF:       100
    A  :-.452234E-03       B  :-.407418E-04     C  :-.112171E-05    D
:-.562827E-06
    AC :        0          BC :        0        CC :        0       DC :        0

  25:           9.29061         1.000000                              0   100
  26:          INFINITY         1.200000           BK7_SCHOTT       100   100
  27:          INFINITY         0.695980                            100   PIM
 IMG:          INFINITY         0.000000                            100   100
```

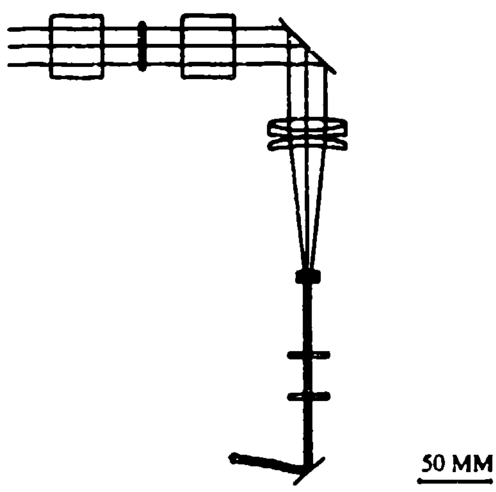
Table 4.2.1-3. Front-end Demonstration Optics Design (Continued)

```
SPECIFICATION DATA
   EPD          25.00000
   DIM                MM
   WL             830.00
   REF                 1
   WTW                 1
   XAN           0.00000
   YAN           0.00000
   VUX           0.00000
   VLX           0.00000
   VUY           0.00000
   VLY           0.00000

APERTURE DATA/EDGE DEFINITIONS
   CA
   CIR S1                       20.000000
   CIR S2                       20.000000
   CIR S3                       15.000000
   CIR S4                       15.000000
   CIR S5                       20.000000
   CIR S6                       20.000000
   CIR S7                       25.000000
   CIR S9                       25.000000
   CIR S10                      25.000000
   CIR S11                      25.000000
   CIR S12                      25.000000
   CIR S13                      24.000000
   CIR S14                       7.000000
   CIR S15                       5.500000
   CIR S16                       7.000000
   CIR S17                       5.500000
   CIR S18                      12.500000
   CIR S20                      12.500000
   CIR S21                      12.500000
   CIR S22                      12.500000
   CIR S24                       2.500000
   CIR S25                       2.500000

PRIVATE CATALOG
   PWL               830.00
   'THIN'          1.010000

   PWL               830.00
   'TEO2'          2.200000

REFRACTIVE INDICES
    GLASS CODE                     830.00
   SF57_SCHOTT                   1.821707
   SF11_SCHOTT                   1.763120
   SF5_SCHOTT                    1.657453
   SK11_SCHOTT                   1.556411
   BK7_SCHOTT                    1.510206
   'TEO2'                        2.200000

SOLVES
   PIM
```

Table 4.2.1-3. Front-end Demonstration Optics Design (Continued)

```
This is a decentered system.  If elements with power are
decentered or tilted, the first order properties are probably
inadequate in describing the system characteristics.

INFINITE CONJUGATES
  EFL          26.9927
  BFL           0.6960
  FFL        7102.4964
  FNC           1.0797
  IMG DIS       0.6960
  OAL         -64.9460
  PARAXIAL IMAGE
   HT           0.0000
   ANG          0.0000
  ENTRANCE PUPIL
   DIA         25.0000
   THI          0.0000
  EXIT PUPIL
   DIA          0.0950
   THI          0.7986
```

Figure 4.2.1-2. Front-end Demonstration Optics Layout



Input to Cell from Laser Diode HAR 6-JUL-93

The data for the Back-end Demonstration Optics Design, Table 4.2.1-4 and Figure 4.2.1-3, covers the demonstration optics from the output of the Bragg cells through to the output of the Fisheye lens. Because Nikon does not release design data for their lenses, the CODE V® description of the Fisheye lens is an approximation. This approximation was obtained by having CODE V® optimize the performance of the lens until it matched the published lens data such as focal length, field, nodal positions and lens count.

Table 4.2.1-4. Back-end Demonstration Optics Design

Output From Bragg Cell.

	RDY	THI	RMD	GLA	CCY	THC	GLC
OBJ:	INFINITY	INFINITY			100	100	
STO:	INFINITY	45.000000			100	100	
2:	155.61000	5.000000		BK7_SCHOTT	100	100	
CYL:							
RDX:	INFINITY	CCX: 100					
3:	INFINITY	220.505101			100	0	
4:	INFINITY	5.000000		BK7_SCHOTT	100	100	
CYL:							
RDX:	41.49600	CCX: 100					
5:	INFINITY	97.612781			100	0	
6:	69.12100	2.000000		SF5_SCHOTT	100	100	
7:	17.13750	3.500000		SK11_SCHOTT	100	100	
8:	-25.58640	60.308441			100	100	
9:	177.46180	3.000000		SF5_SCHOTT	100	100	
10:	42.40620	7.000000		SK11_SCHOTT	100	100	
11:	-63.41870	424.559359			100	100	
12:	77.80500	14.000000		BK7_SCHOTT	100	100	
13:	INFINITY	62.278121			100	100	
14:	77.80500	14.000000		BK7_SCHOTT	100	100	
15:	INFINITY	8.330962			100	100	
16:	INFINITY	0.100000		BK7_SCHOTT	100	100	
17:	INFINITY	-0.007790			100	100	
18:	INFINITY	37.600000			100	100	
19:	45.73557	2.000000		621412.600145	100	100	100
20:	300.00000	0.100000			100	100	
21:	51.80390	2.500000		753909.286741	100	100	100
22:	19.87530	8.500000		487000.704000	100	100	100
23:	-71.69472	8.000000			100	100	
24:	INFINITY	4.600000			100	100	
25:	39.76499	3.000000		744000.447000	100	100	100
26:	21.68338	6.500000		487000.704000	100	100	100
27:	-70.75049	0.100000			100	100	
28:	300.00000	2.500000		648227.447629	100	100	100
29:	-154.23737	3.000000			100	100	
30:	INFINITY	2.000000		755000.276000	100	100	100
31:	INFINITY	28.500000		AIR	100	100	
32:	-60.00000	12.000000		755000.276000	100	100	100
33:	-23.00000	1.300000			100	100	
34:	-21.00000	7.000000		604179.611411	100	100	100
35:	60.00000	17.000000			100	100	
36:	-16.00000	3.000000		487000.704000	100	100	100
37:	-110.00000	22.000000			100	100	
38:	-28.00000	3.000000		487000.704000	100	100	100
39:	-68.00000	10.000000			100	100	
40:	INFINITY	60.000000			100	100	
IMG:	-150.00000	0.000000			100	0	

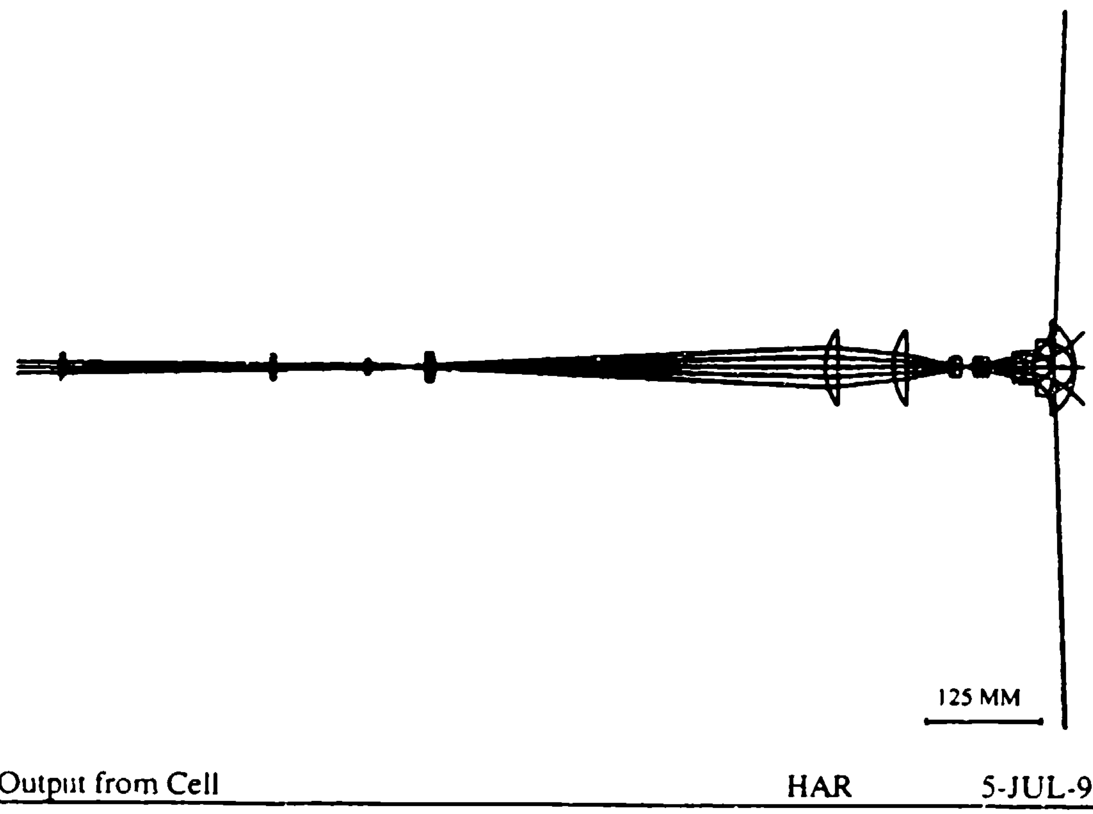
Table 4.2.1-4. Back-end Demonstration Optics Design (Continued)

```
SPECIFICATION DATA
  EPD       12.50000
  AFI       60.00000
  DIM             MM
  WL          830.00
  REF              1
  WTW              1
  XAN        0.00000        0.00000        0.00000        0.00000
0.00000
  YAN        0.00000        0.12000        0.24000        0.36000
0.48000
  VUX        0.00000        0.00000        0.00000        0.00000
0.00000
  VLX        0.00000        0.00000        0.00000        0.00000
0.00000
  VUY        0.00000        0.00000        0.00000        0.00000
0.00000
  VLY        0.00000        0.00000        0.00000        0.00000
0.00000

APERTURE DATA/EDGE DEFINITIONS
   CA
   CIR S2                         15.000000
   CIR S3                         15.000000
   CIR S4                         13.000000
   CIR S6                          7.500000
   CIR S7                          7.500000
   CIR S8                          7.500000
   CIR S9                         15.000000
   CIR S10                        15.000000
   CIR S11                        15.000000
   CIR S12                        40.000000
   CIR S13                        40.000000
   CIR S14                        40.000000
   CIR S15                        40.000000
   CIR S19                        10.000000
   CIR S20                        10.000000
   CIR S22                        10.000000
   CIR S23                        10.000000
   CIR S24                        10.000000
   CIR S25                        10.000000
   CIR S26                        10.000000
   CIR S28                        10.000000
   CIR S29                        10.000000
   CIR S30                        10.000000
   CIR S31                        10.000000
   CIR S33                        16.000000
   CIR S34                        16.000000
   CIR S35                        17.000000
   CIR S36                        16.000000
   CIR S37                        30.000000
   CIR S38                        30.000000
   CIR S39                        55.000000
```

Table 4.2.1-4. Back-end Demonstration Optics Design (Continued)

```
REFRACTIVE INDICES
   GLASS CODE                          830.00
  BK7_SCHOTT                         1.510206
  SF5_SCHOTT                         1.657453
  SK11_SCHOTT                        1.556411

INFINITE CONJUGATES
  EFL       22851.2167
  BFL         345.3854
  FFL      -1.1008E+07
  FNO        1828.0973
  IMG DIS      60.0000
  OAL        1156.3870
  PARAXIAL IMAGE
   HT         191.4424
  ANG           0.4800
  ENTRANCE PUPIL
   DIA         12.5000
   THI          0.0000
  EXIT PUPIL
   DIA          0.2835
   THI       -172.8578
CODE V> in fl

output from cell

 Elem    Surfs    Focal Length
   1      2- 3     304.994317 Cylinder in Y direction
   2      4- 5     (81.3 mm Cylinder in X direction)
   3      6- 8      40.000048
   4      9-11     100.000046
   5     12-13     152.497158
   6     14-15     152.497158
   7     16-17     Flat
   8     19-20      87.753893
   9     21-23     122.109272
  10     25-27      73.581878
  11     28-29     160.193088
  12     30-31     Flat
  13     32-33      44.591933
  14     34-35     -25.275186
  15     36-37     -39.318677
  16     38-39    -101.392848
```

Figure 4.2.1-3. Back-end Demonstration Optics Layout



4.2.2 Custom Optics Design

For a spaceborne application, small size and light weight are very important. One program goal was to produce an optimized design for space using custom, instead of off-the-shelf, optics. Optimizing for size and weight meant redesigning the breadboard optics to include the fewest components possible. On the output side, the Fourier transform lenses were retained as a pair of cylinders. The output lens system however was changed from seventeen elements (scaling system consisting of six elements in four groups, and a fisheye of eleven elements in nine groups) to an output fisheye lens with five elements total, a savings of twelve optical components. Table 4.2.2-1 is the Code V® design for the custom output fisheye lens, starting from the output and working back to the lens input. Figure 4.2.2-1 illustrates the layout of the custom back-end optics.

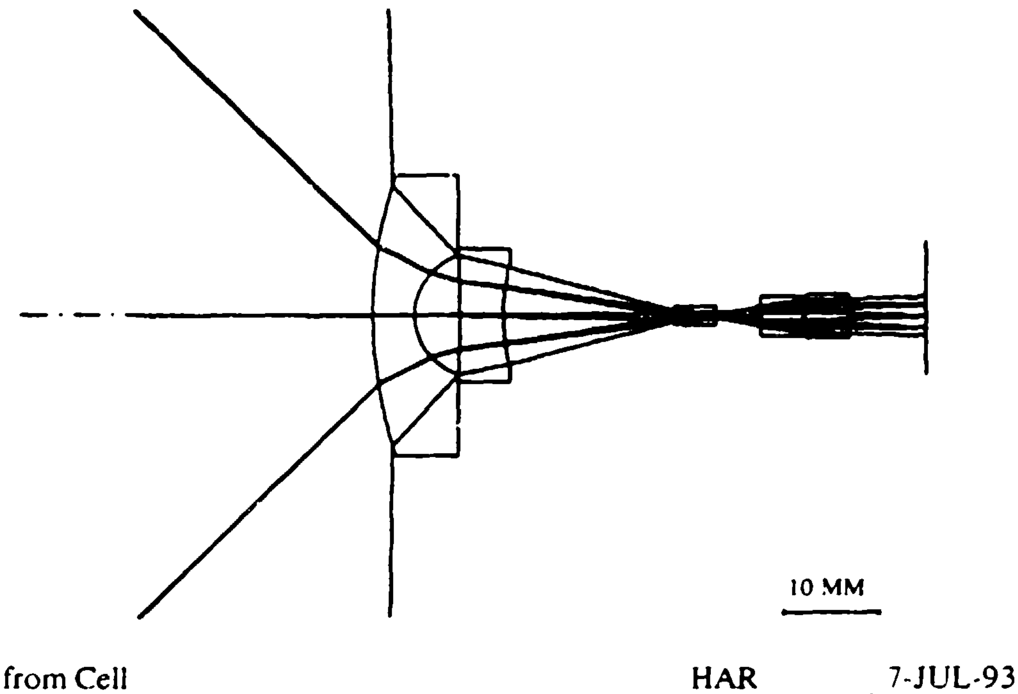
Table 4.2.2-1. Back-end Custom Optics Design

Small Fisheye Lens.

	RDY	THI	RMD	GLA	CCY	THC
GLC						
> OBJ:	INFINITY	INFINITY			100	100
1:	INFINITY	25.000000			100	100
2:	49.45403	4.400000		SFL57_SCHOTT	0	0
3:	6.87256	4.676532			0	0
4:	-100.84273	4.400000		SFL57_SCHOTT	0	0
5:	26.52705	18.238627			0	0
6:	-47.69870	4.406043		SFL57_SCHOTT	0	0
7:	-33.85776	0.100000			0	0
STO:	INFINITY	4.558435			100	0
9:	-258.23597	4.531052		SFL57_SCHOTT	0	0
10:	-15.98231	0.100000			0	0
11:	13.92418	4.589311		SFL57_SCHOTT	0	0
12:	-76.55846	7.600000			0	0
13:	INFINITY	0.414966			100	PIM
IMG:	INFINITY	-0.039060			100	100

```
SPECIFICATION DATA
  NA          0.04167
  DIM              MM
  WL           830.00
  REF               1
  WTW               1
  XAN        0.00000     0.00000     0.00000     0.00000     0.00000
  YAN      -89.00000   -45.00000     0.00000    45.00000    89.00000
REFRACTIVE INDICES
   GLASS CODE               830.00
  SFL57_SCHOTT            1.821500
SOLVES
  PIM
INFINITE CONJUGATES
  EFL          1.7000
  BFL          0.4150
  FFL         34.3550
  FNO         12.0000
  IMG DIS      0.3759
  OAL         82.6000
  PARAXIAL IMAGE
   HT         97.3952
   ANG        89.0000
  ENTRANCE PUPIL
   DIA         0.1417
   THI        34.4024
  EXIT PUPIL
   DIA         5.0782
   THI       -60.5239
```

Figure 4.2.2-1. Back-end Custom Optics Layout



On the input side to the Bragg cells, the design takes seven elements and reduces the count to three, a savings of four lens components. Table 4.2.2-2 lists the Code V® output for this part of the design. Figure 4.2.2-2 illustrates the Front-end Custom Optics Layout.

For the custom optical design, the mid-section optics layout is shown in Figure 4.2 2-3. The mid-section transforms the Bragg cell output, and is implemented using two cylinder lenses. The Code V® output design data for this section is shown in Table 4.2.2-3.

Table 4.2.2-2. Front-end Custom Optics Design

Custom Beam Shaping Optics.

```
                    RDY              THI        RMD         GLA            CCY     THC
GLC
  OBJ:          INFINITY         INFINITY                                  100     100
    1:          INFINITY         3.000000              BK7_SCHOTT          100     100
    2:          INFINITY         5.000000                                  100     100
    3:          INFINITY         3.000000              BK7_SCHOTT          100     100
    4:          INFINITY         5.000000                                  100     100
>   5:          INFINITY        15.000000                                  100     100
      XDE:      0.000000    YDE:     0.000000    ZDE:      0.000000    REV
      XDC:       100        YDC:      0          ZDC:       100
      ADE:      0.000000    BDE:     0.000000    CDE:      0.000000
      ADC:       100        BDC:      100        CDC:       100

    6:          INFINITY        12.000000              SF11_SCHOTT         100     100
    7:          INFINITY         0.000000                                  100     100
      XDE:      0.000000    YDE:     0.000000    ZDE:      0.000000    DAR
      XDC:       100        YDC:      100        ZDC:       100
      ADE:      0.000000    BDE:     0.000000    CDE:      0.000000
      ADC:       100        BDC:      100        CDC:       100

  STO:          INFINITY        20.0'                                      100     100
    9:          45.84068        13..                   507578.598075       100     100
100
      XDE:      0.000000    YDE:     0.000000    ZDE:      0.000000
      XDC:       100        YDC:      100        ZDC:       100
      ADE:      0.000000    BDE:     0.000000    CDE:      0.000000
      ADC:       100        BDC:      100        CDC:       100
      GP1: FK5_SCHOTT SPG:                      PRC:

   10:         -18.44596         1.500000              SFL57_SCHOTT        100     100
   11:         -58.40115         0.100000              AIR                 100     100
   12:          21.47053        13.000000              SFL57_SCHOTT        100     100
   13:          INFINITY        14.122865              AIR                 100     PIM
  IMG:          INFINITY        -0.029505                                  100       0

SPECIFICATION DATA
   EPD        25.00000
   XZF
   DIM              MM
   WL           830.00
   REF               1
   WTW               1
   XAN         0.00000
   YAN         0.00000
   VUX         0.00000
   VLX         0.00000
   VUY         0.00000
   VLY         0.00000
APERTURE DATA/EDGE DEFINITIONS
   CA
   CIR S1                  15.000000
   CIR S3                  15.000000
   CIR S6                  15.000000
   CIR S7                  18.000000
```

Table 4.2.2-2. Front-end Custom Optics Design (Continued)

REFRACTIVE INDICES

GLASS CODE	830.00
SF11_SCHOTT	1.763120
507578.598075	1.500766
SF157_SCHOTT	1.821365
BK7_SCHOTT	1.510206

DEPARTURES FROM CATALOG INDICES

GLASS CODE	830.00
507578.598075	0.019036

SOLVES

PIM

ZOOM DATA

	POS 1	POS 2
EPD	25.00000	12.50000
ADE S5	0.00000	-6.04460
ADC S5	100	100
ADE S7	0.00000	-29.43000
ADC S7	100	100
YDE S9	0.00000	7.38661
YDC S9	100	0
ADE S9	0.00000	19.88279
ADC S9	100	0
YDE S5	0.00000	3.82850
YDC S5	0	0

This is a decentered system. If elements with power are decentered or tilted, the first order properties are probably inadequate in describing the system characteristics.

	POS 1	POS 2
INFINITE CONJUGATES		
EFL	23.4006	23.4006
BFL	14.1229	14.1229
FFL	40.7117	40.7117
FNO	0.9360	1.8721
IMG DIS	14.0934	14.0934
OAL	90.6000	90.6000
PARAXIAL IMAGE		
HT	0.0000	0.0000
ANG	0.0000	0.0000
ENTRANCE PUPIL		
DIA	25.0000	12.5000
THI	35.7791	35.7791
EXIT PUPIL		
DIA	118.6018	59.3009
THI	125.1371	125.1371
STO DIA	25.0000	12.5000

Figure 4.2.2-2. Front-end Custom Optics Layout

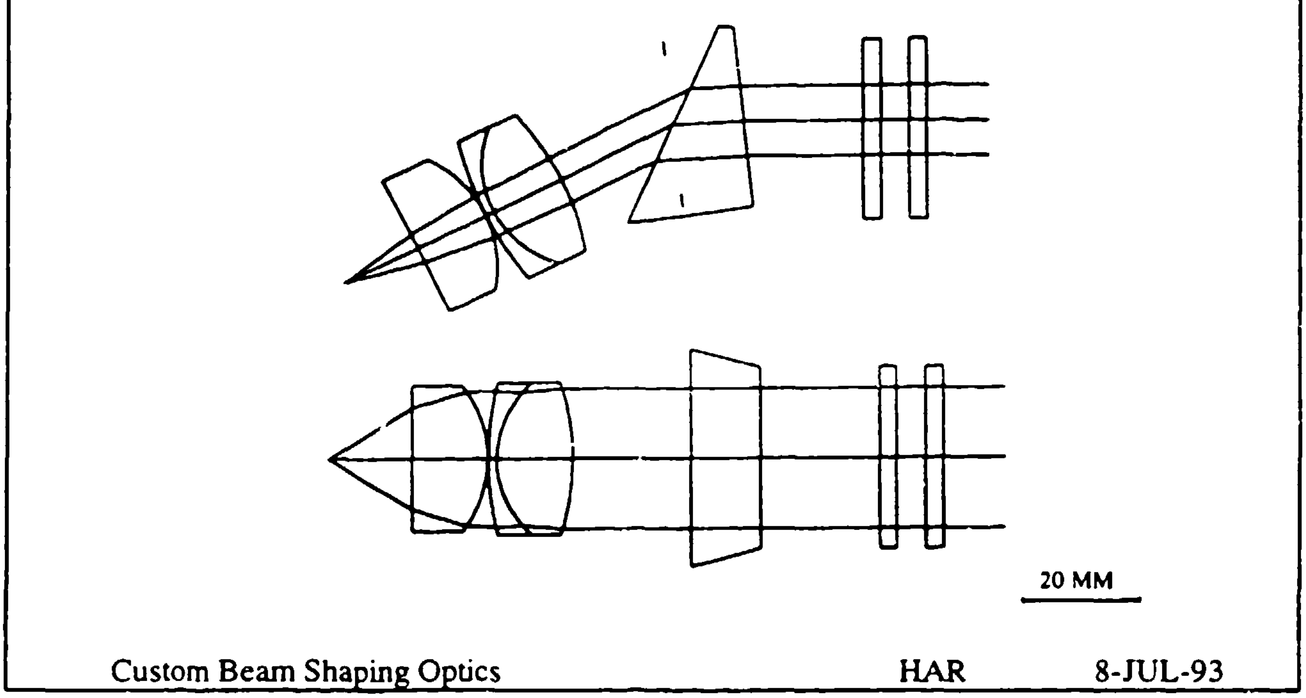


Figure 4.2.2-3. Mid-section Custom Optics Layout

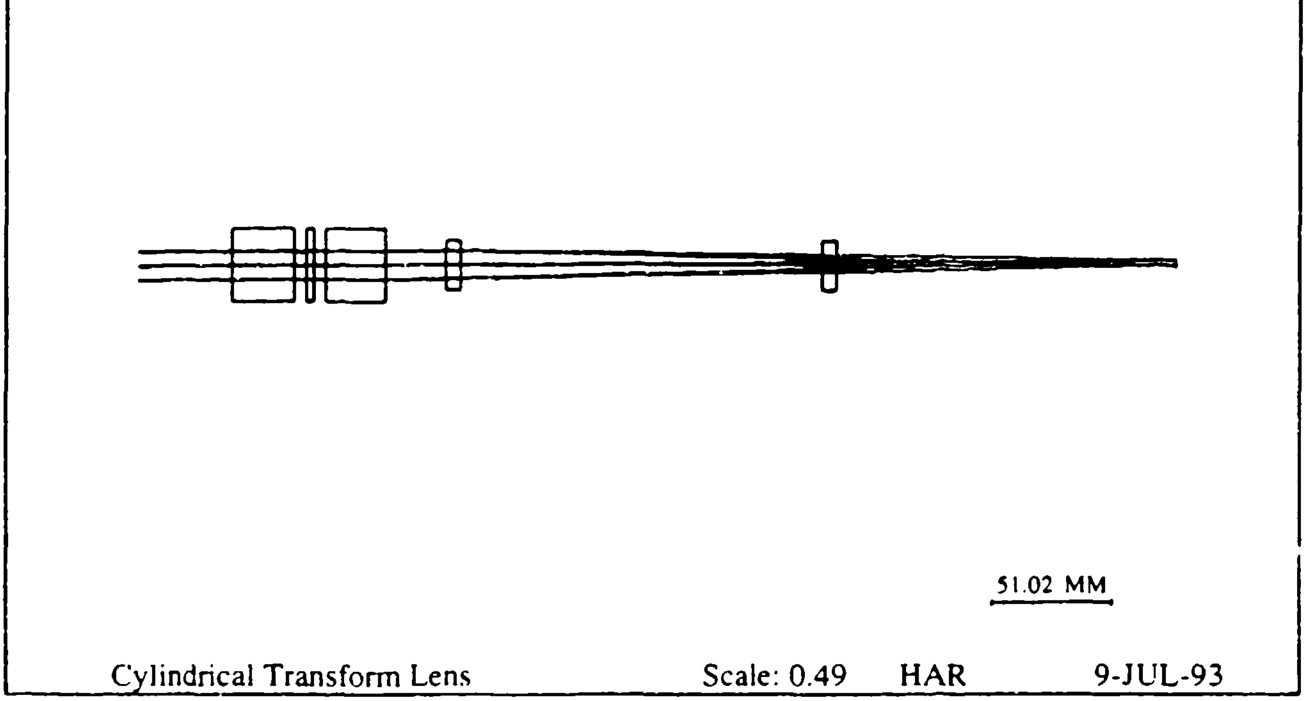


Table 4.2.2-3. Mid-section Custom Optics Design

Cylindrical Transform Lens.

```
                 RDY              THI      RMD       GLA              CCY   THC
GLC
> OBJ:        INFINITY         INFINITY                               100   100
    1:        INFINITY        25.000000            'TEO2'             100   100
    2:        INFINITY         5.000000                               100   100
    3:        INFINITY         3.000000            BK7_SCHOTT         100   100
    4:        INFINITY         5.000000                               100   100
    5:        INFINITY        25.000000            'TEO2'             100   100
  STO:        INFINITY        25.000000                               100   100
    7:       155.04000         6.000000            BK7_SCHOTT         100   100
      CYL:
      RDX:    INFINITY     CCX:     100
    8:        INFINITY       152.535673                               100     0
    9:        INFINITY         6.000000            BK7_SCHOTT         100   100
      CYL:
      RDX:    75.20000     CCX:     100

   10:        INFINITY       143.418412                               100   PIM
  IMG:        INFINITY        -0.104780                               100     0
 SPECIFICATION DATA
   EPD       12.50000
   PUX        0.50000
   PUY        0.50000
   PUI        0.13500
   XZF
   DIM             MM
   WL          830.00
   REF              1
   WTW              1
   XAN        0.00000        0.00000        0.21300        0.21300
   YAN        0.00000        0.50900        0.00000        0.50900

APERTURE DATA/EDGE DEFINITIONS
   CA
   CIR S1                  15.000000
   CIR S3                  15.000000
   CIR S5                  15.000000
   CIR S7                  10.000000
   CIR S9                  10.000000

PRIVATE CATALOG
   PWL              830.00
   'TEO2'         2.200000

REFRACTIVE INDICES
    GLASS CODE                    830.00
   BK7_SCHOTT                   1.510206
   'TEO2'                       2.200000
```

Table 4.2.2-3. Mid-section Custom Optics Design (Continued)

```
SOLVES
   PIM

 NFINITE CONJUGATES
   EFL          147.3914
   BFL          143.4184
   FFL           68.8310
   FNO           11.7913
   IMG DIS      143.3136
   OAL          252.5357
   PARAXIAL IMAGE
    HT            0.5479
   ANG            0.2130
   ENTRANCE PUPIL
    DIA          12.5000
    THI          34.7138
   EXIT PUPIL
    DIA          54.0018
    THI         780.1700
```

Figure 4.2.2-4 represents the entire custom system from end to end. It is much smaller and more compact than the breadboard. The custom optics consists of the laser output going through a three element 25mm F1 collimator, followed by an 1.5X prismatic beam expander. This system of input optics takes the 3:1 aspect ratio of the laser and forms it into a 12.5 by 25mm output beam. This is followed by a halfwave plate and a quarterwave plate to adjust the polarization to the elliptical orientation necessary to get maximum diffraction efficiency from the Bragg cells. Between the two Bragg cells is another halfwave plate that corrects for the polarization change due to the birefringence of the first cell. After the cells are the two orthogonal cylinder lenses, 300mm for the horizontal output and 145mm for the vertical. These lenses Fourier transform the scan angles into a real image plane at the back focal plane of the fisheye lenses. A splitting mirror directs half the vertical field to each of the two fisheye lenses, which image the focal plane to infinity with a .36 degree beam divergence.

Table 4.2.2-4 below shows the predicted optical throughput for the custom system. With custom optics, designed and coated for 830 nm, and using a Spectra-Diode Labs laser, the output can easily exceed the requirement of 50% throughput. In the Section 5.3, Breadboard Performance Summary, the Custom design expected results are further contrasted with the actual measurements for the breadboard.

Figure 4.2.2-4. Complete Custom Optics Layout

Custom System could be folded into
approximately 4 X 4 X 8 inch package

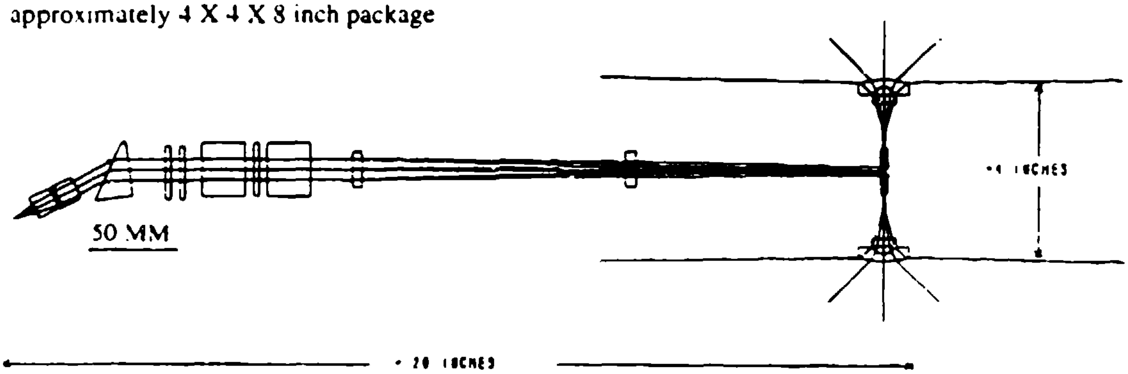


Table 4.2.2-4. Optical Efficiency of the Custom System

Lasercom Light Budget — Custom System

COMPONENT	COMPONENT POWER OUT (mW)	THROUGHPUT
Laser Output	150.0	-
Laser Collimator	145.5	0.97
Wave Plates (1/2 AND 1/4)	139.6	0.96
Horizontal Cell (DC)	136.8	0.98
Horizontal Diffraction	130.0	0.95
Wave Plate (1/2)	127.4	0.98
Vertical Cell (DC)	124.8	0.98
Vertical Diffraction	118.6	0.95
300 mm Cylinder	117.4	0.99
145 mm Cylinder	116.2	0.99
Turning Mirror	115.1	0.99
Fisheye Lens	109.3	0.95
TOTAL	109.3	0.73

4.3 Electronics Design and Test

Figure 4.3-1 shows a simplified block diagram of the electronics subsystem. The electronic subsystem uses direct digital synthesis (DDS) to generate a tunable 18 to 32 MHz frequency output bandwidth. The electronics interface box consists of a control interface card, two DDS cards, and an RF section, all self-contained including a power supply. The breadboard PC computer controls the electronics box via a digital output card.

Figure 4.3-1. Electronics Subsystem Block Diagram

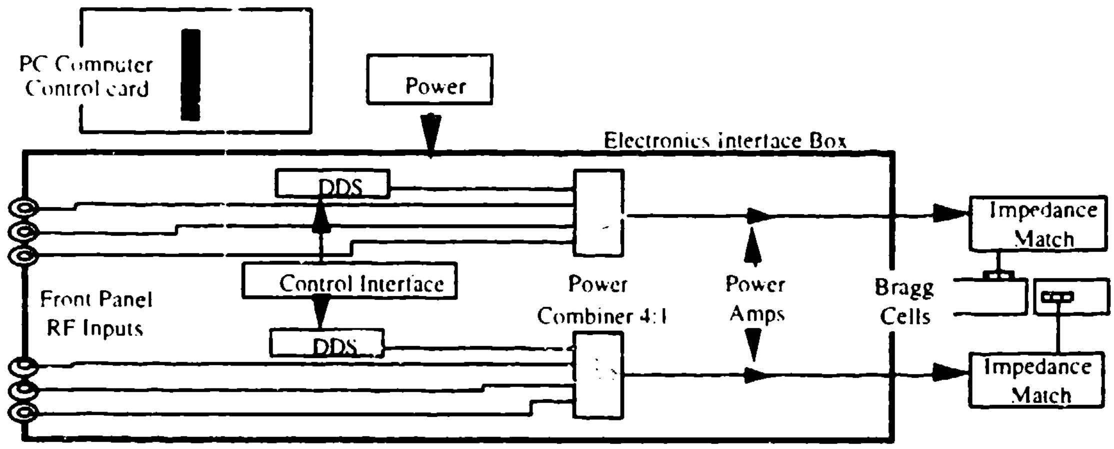
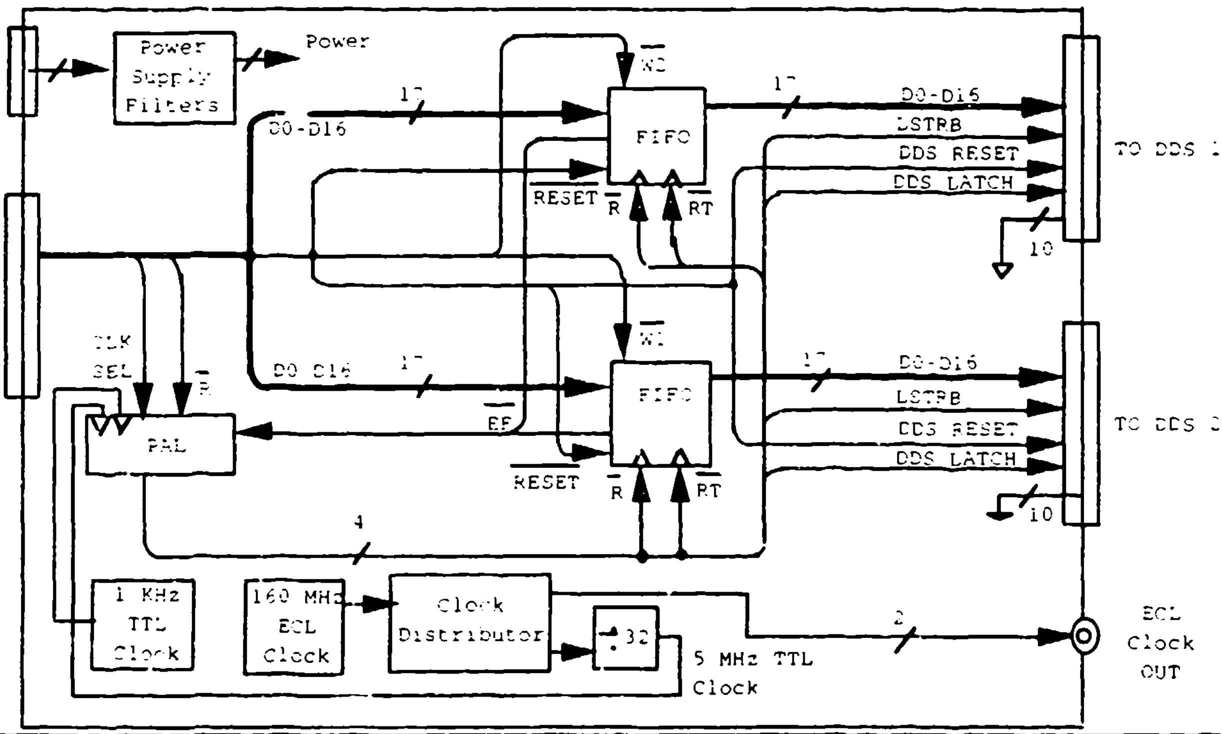


Figure 4.3-2 shows a block diagram of the Control Interface Board. The Control Interface Board buffers digital frequency and control data between the controlling PC and the two DDS cards, strobes this information into the DDS cards upon a read request from the PC, and generates the required clocks for the these processes to take place. Appendix C contains a schematic of the Control Interface Board.

The Control Interface Board receives 24 parallel data bits from the controller PC consisting of 17 data bits of frequency data, and 7 data bits of control logic. The frequency data (D0-D16) is latched into four 4096X9-pin FIFO's (CY7C433), two FIFO's per channel, upon a write request (W1, W2) from the PC. A read enable (READ EN) command from the PC enables the FIFO's to read data into the DDS cards via a read (R) command from the PAL (32VX10). The PAL also transmits a DDS latch command (DDS LATCH) to the DDS cards to latch the frequency data into buffers on the DDS card and a DDS load strobe (LSTRB) command to load the information into the DDS chip. Once all the data has been read from the FIFO's an empty flag (EF1, EF2, EF3, EF4) will signal the PAL. The PAL will then send a retransmit command (RT) to the FIFO's requesting the FIFO to loop through the frequency data.

Figure 4.3-2. Control Interface Board Block Diagram



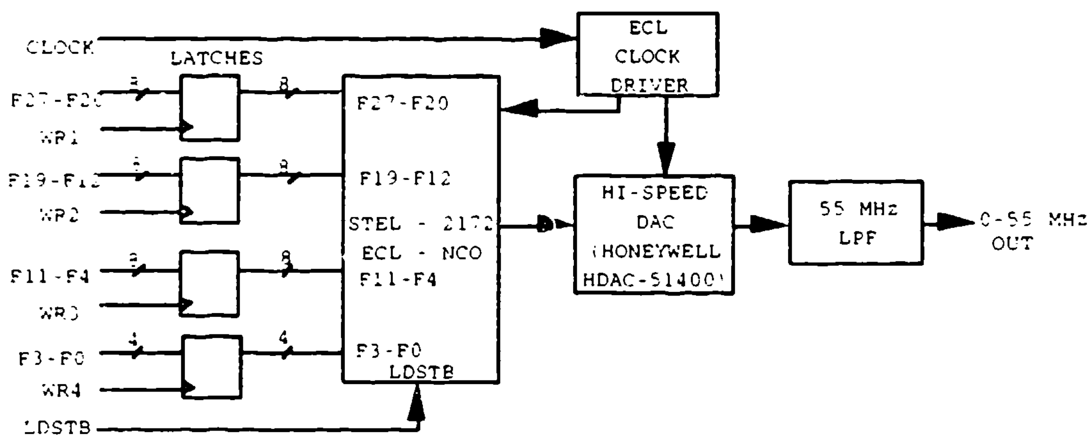
The sequence of operation is as follows:

1. Initial reset of FIFO's and DDS card (RESET, DDS RESET) at turn on.
2. Write to the FIFO's (W1, W2)
3. Read all FIFO's.
   a. READ EN from PC to PAL.
   b. R from PAL to FIFO's.
   c. DDS LATCH from PAL to DDS card.
   d. LSTRB from PAL to DDS card.
4. FIFO's will continuously loop until a RESET or write command.
   a. Empty flag (EF1-EF4) from FIFO to PAL.
   b. Retransmit (RT) from PAL to FIFO.

The Control Interface Board generates a 160 MHz ECL clock, a 5 MHz TTL clock, and a 1 KHz TTL clock. The 160 MHz ECL clock is used as the clock for the DDS boards. The 5 MHz and 1 KHz clocks are clock selected (CLK SEL) by the PC for either fast or slow operation and are used for FIFO read and write operations. The FIFO write rate is determined by the PC and the FIFO read rate is 400ns.

Figure 4.3-3 shows a block diagram of the DDS board. The DDS boards are off-the-shelf Stanford Telecom STEL-2272A single output direct digital synthesizer boards with a maximum output frequency of 110 MHz and a maximum clock speed of 300 MHz. The output frequency changes 33 clock cycles after a LSTRB command. This application uses a 160 MHz clock for a frequency change rate of 206 nsec.

Figure 4.3-3. DDS Card Block Diagram



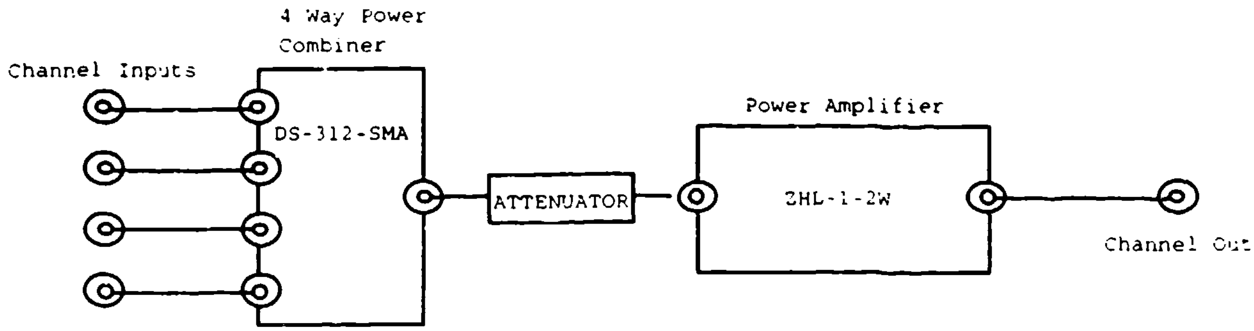
The frequency information from the Control Interface Board is buffered into four 8-bit latches with a DDS LATCH command. A LSTRB command initiates a serial input of the frequency data bits into the STEL-2172A chip at the DDS board clock rate (160 MHz). The DDS chip bounces the data bit information against a look-up table in ROM to translate to a corresponding frequency using the following equation:

$$fout = (phase\ change) * fclk / 2^N \qquad (4.3\text{-}1)$$

where *phase change* = data bits from PC, *fclk* = 160 MHz, N = 18, and *fout* = 18 to 32 MHz. For example, if *fout* = 18 MHz, then *phase change* = *fout* * 2^N / *fclk* = $(18 * 10^6) * (2^N)/(160 * 10^6) = 2.9491 * 10^4$ = 000111001100110011 (bin). Frequency calculations were made using 18 bits of frequency data to improve frequency resolution to 610 Hz. The two MSB's of the frequency data are always 0 between 18 and 32 MHz.

Figure 4.3-4 shows a block diagram of the RF section. The RF section contains two identical RF paths, one for each channel, containing a power combiner, an attenuator and a high power amplifier. A 4-way power combiner (Anzac, DS-312-SMA) combines the RF from the DDS card with up to three additional frequencies. The attenuator is SMA packaged and can be selected for a desired output power. The high power amplifier (Mini-Circuits, ZHL-1-2W) is a 2 watt device with a minimum gain of 29 dB.

Figure 4.3-4. RF Section Block Diagram



The electronics subsystem was thoroughly tested to verify that the goal specifications were met. The following paragraphs summarize the results per test performed.

Test #1. Frequency Tuning

The Channel X (horizontal) and Channel Y (vertical) were tuned from 18 to 32 MHz. A HP5328B frequency counter was used to measure frequency resolution across the band. A random sampling of 20 frequencies compared to the expected frequency achieved a resolution in both channels of less than 610 Hz.

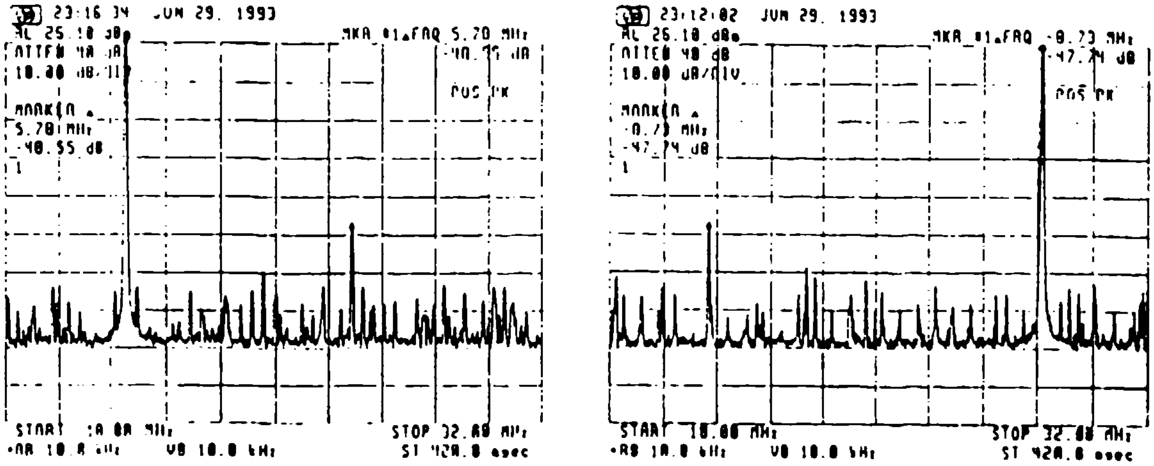
Test #2. Spurious Tones

This test was performed to verify that spurious tones were at least 40 dBc down.

Channel X - Figure 4.3-5a shows spurious tones across the frequency band at < -40 dBc. The frequency band was swept to annotate worst case dynamic range.
Channel Y - Figure 4.3-5b shows spurious tones across the frequency band at < -40 dBc. The frequency band was swept to annotate worst case dynamic range.

Figure 4.3-5. Spurious Tones Test Results

a. Channel X (horizontal) b. Channel Y (vertical)



Test #3. Phase Noise

This test was performed to verify that phase noise was no greater than -70 dBc/Hz maximum, 20 KHz from the carrier.

Channel X - Figure 4.3-6a shows a CW signal centered at 18 MHz and at an output power of +27 dBm. The SSB phase noise at 20 KHz offset is approximately -93 dBc/30 Hz or -108 dBc/Hz.
Channel Y - Figure 4.3-6b shows a CW signal centered at 18 MHz and at an output power of +26.5 dBm. The SSB phase noise at 20 KHz offset is approximately -93 dBc/30 Hz or -108 dBc/Hz.

Test #4. Settling Time

This test was performed to verify that the settling time was no more than 200 nsec. Figure 4.3-7 shows the test setup used to check the settling time at turn on and turn off of frequencies generated by the DDS card. A Merrimac quadraphase modulator was used as a phase detector with 90 degree phase shift reference. The output of the DDS card was split with one signal entering the modulator at the 90 degree quad and the other at the in-phase combiner. The signals were then combined 90 degrees out of phase to produce a voltage reference. The output of the DDS card was then toggled. The settling time is the time measured 10 to 90 % in amplitude.

Channel X - Figure 4.3-8a shows a rise time of less than 100 nsec. Figure 4.3-8b shows a fall time of less than 75 nsec.
Channel Y - Figure 4.3-9a shows a rise time of less than 100nsec. Figure 4.3-9b shows a rise time of less than 75 nsec.

Figure 4.3-6. Phase Noise Test Results

a. Channel X (horizontal) b. Channel Y (vertical)

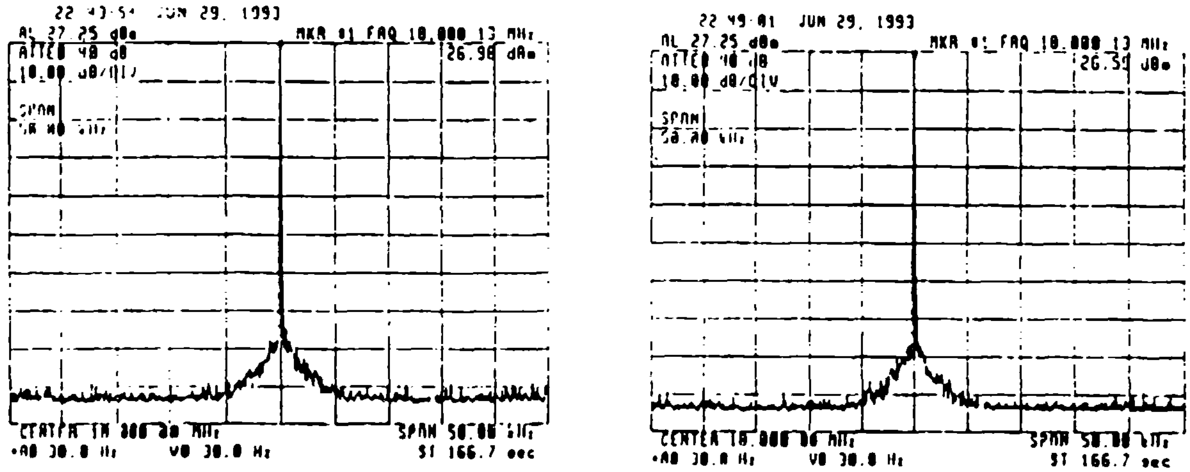


Figure 4.3-7. Settling Time Test Setup

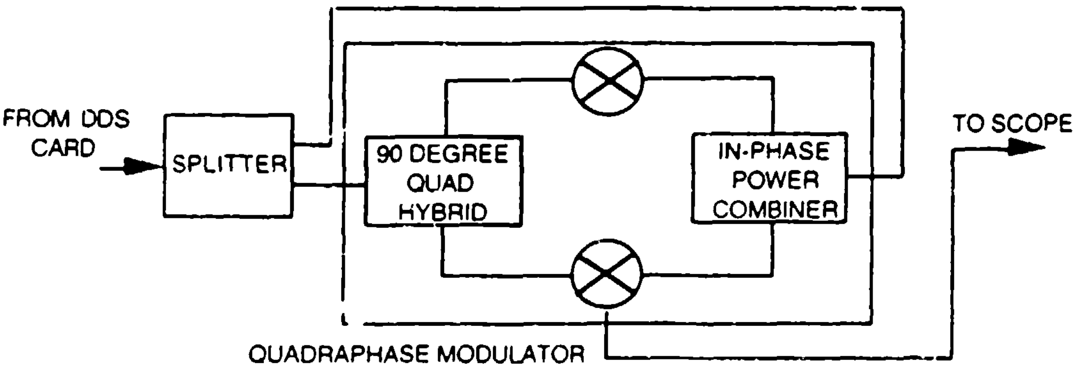
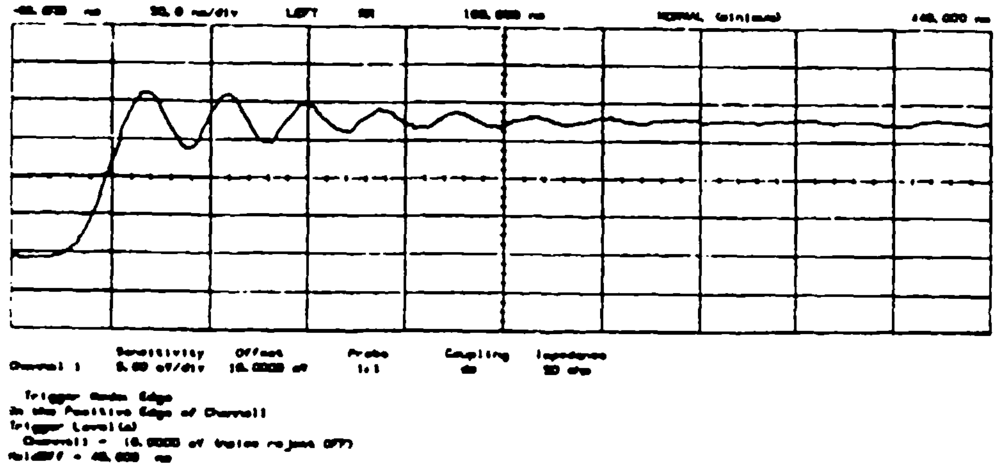
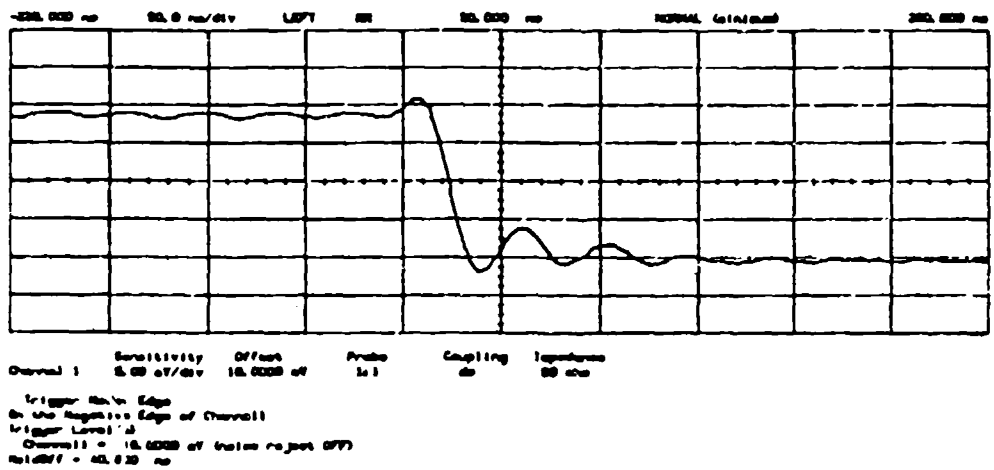


Figure 4.3-8. Channel X (Horizontal) Settling Time Test Results

a. Rise Time



b. Fall Time

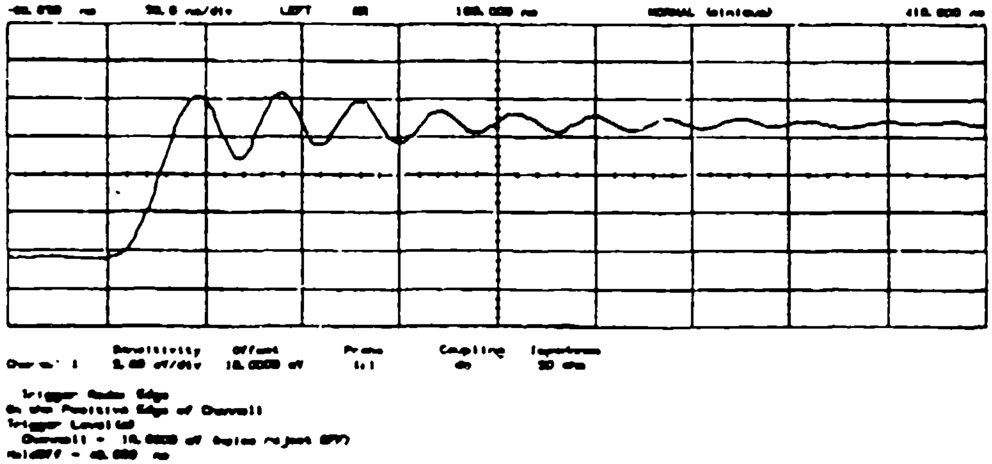


Test #5. Frequency Drift:

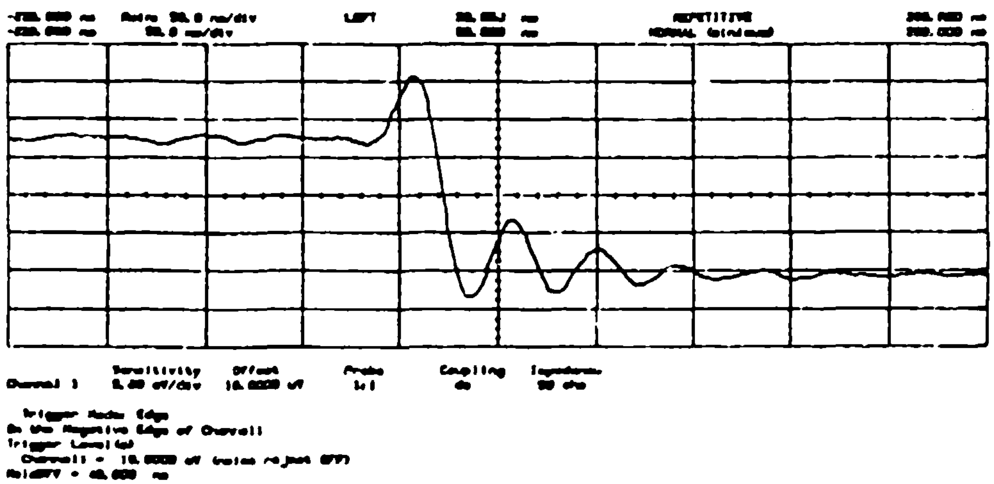
This test was performed to verify that the frequency drift was no more than 10 Hz/minute, and less than 50 Hz maximum long term. The test monitored both channels at turn on for 5 minutes with an HP5328B frequency counter, and the achieved drift was less than 10 Hz. The long term test monitored both channels over a twelve hour period, and achieved the same results.

Figure 4.3-9. Channel Y (Vertical) Settling Time Test Results

a. Rise Time



b. Fall Time



Test #6. Third Order Intercept

This test was perfonned to verify that the third order intercept was +42 dBm minimum.

Channel X - Figure 4.3-10a shows a two tone test for intermodulation distortion across 18 to 32 MHz. The tone on the left was generated by the DDS card and the other tone was generated by an external signal source combined in the RF section of the electronics subsystem. Both tones were adjusted to +26 dBm output power at the output of the electronic subsystem. The external signal source was swept across the band to generate the worst case intermod tone. The figure shows the intermod +42.63 dBc. The third order intercept point is calculated as follows:

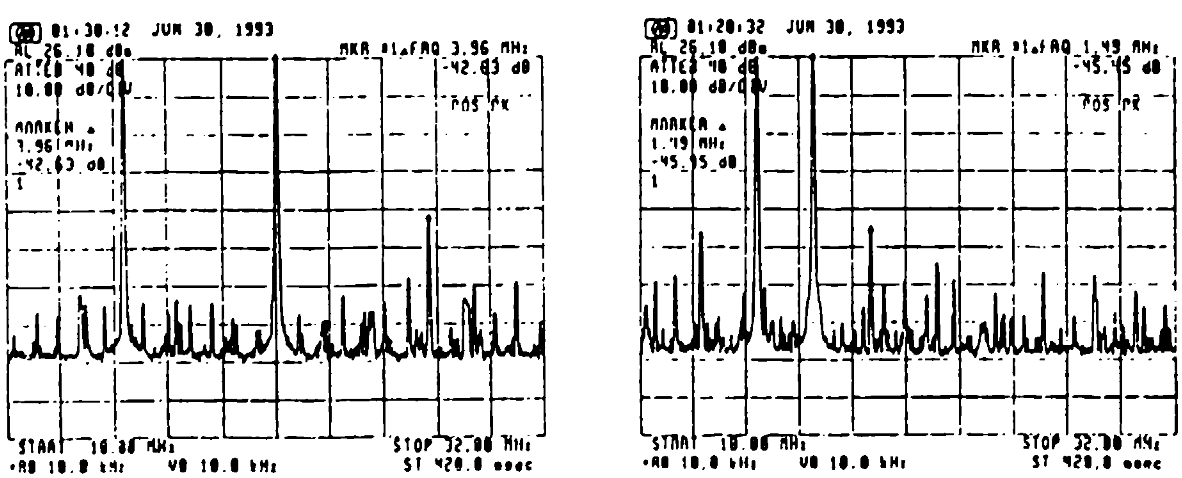
IP3 = Pout + A/2 where A is the difference of output power and intermod level, therefore, IP3 = 26 + 42.63/2 = 47.3 dBm.

Channel Y - Figure 4.3-10b shows a two tone test for intermodulation distortion across 18 to 32 MHz. The tone on the left was generated by the DDS card and the other tone was generated by an external signal source combined in the RF section of the electronics subsystem. Both tones were adjusted to +26 dBm output power at the output of the electronic subsystem. The external signal source was swept across the band to generate the worst case intermod tone. The figure shows the intermod +45.45 dBc. The third order intercept point is calculated as follows:

IP3 = Pout + A/2, where A is the difference of output power and intermod level, therefore, IP3 = 26 + 45.45/2 = 48.7 dBm

Figure 4.3-10. Third Order Intercept Test Results

a. Channel X (horizontal) b. Channel Y (vertical)



5.0 Breadboard Demonstration

5.1 Breadboard Hardware Description

This section briefly describes the breadboard hardware setup. Figure 5.1-1 shows the major components of the breadboard: the controller PC computer (on the left), the electronics interface box (middle background), and the optics bench (foreground) which contains the lasers, Bragg cells, CCD camera, and the various lenses.

The breadboard is self-contained, requiring no additional lab equipment to operate (other than tables on which to place the computer, electronics box, and optics bench). Once the computer and electronics box are plugged into the AC wall outlet the breadboard is ready to run, and all other components are powered via software control: the lasers, Bragg cells, and CCD camera. The breadboard control software and operational procedure will be discussed in detail in Section 5.2 (see also Appendices A and B). Table 5.1-1 lists the PC computer specifications.

Table 5.1-1. PC Computer Specifications

• Motherboard:	486-33DX with AMI BIOS
• Cache:	64K SRAM
• RAM:	8 Megabytes
• Hard Disk:	120 Megabytes (IDE)
• Floppy Drives:	3.5" (1.44 Meg) and 5.25" (1.2 Meg)
• I/O ports:	2 serial and 1 parallel, 2 IDE and 2 FDC
• Graphics Card:	ATI-VGA Wonder XL-24 (1 Megabyte)
• Monitor:	14" SVGA 1024 x 768 non-interlaced
• Video Overlay Card:	Super Video Windows
• I/O Card:	National Instruments DIO-24
• Software:	DOS 5.0, Norton Desktop 2.0, Windows 3.1, Visual Basic 2.0

Figure 5.1-2 shows a perspective view of the optics bench. The two laser diodes (670 nm and 830 nm wavelength) are in the far left corner of the bench. The Bragg cells are located where the input coax cable terminates in the left central portion of the bench (Note: the mount shown for the Bragg cells is an earlier mount not used in the final breadboard). The CCD camera is suspended vertically at the top of Figure 5.1-2, and the two wide-angle output lenses can be seen at the left and right sides of the bench. The optics bench (TMC Model #77-133-02) has a 3 x 3 foot surface area (9 ft.^{2}), is 2 inches thick, and weighs approximately 135 lbs. (without optics). The Bragg cell design was discussed in detail in Section 4.1.

One side of the electronics box is shown in Figure 5.1-3 with the cover removed. This shows the custom developed interface board containing the programmable array logic (PAL) devices and the first-in-first-out (FIFO) memories. In the upper center this picture shows the heat sink on one of the two signal output amplifiers, and to the left of this is one of the 4:1 signal combiners (3 front panel input ports and 1 internal DDS generator channel). The power supply for the box electronics is on the right side of the box, and a cooling fan is located directly above.

Figure 5.1-1. Photograph of Breadboard Hardware

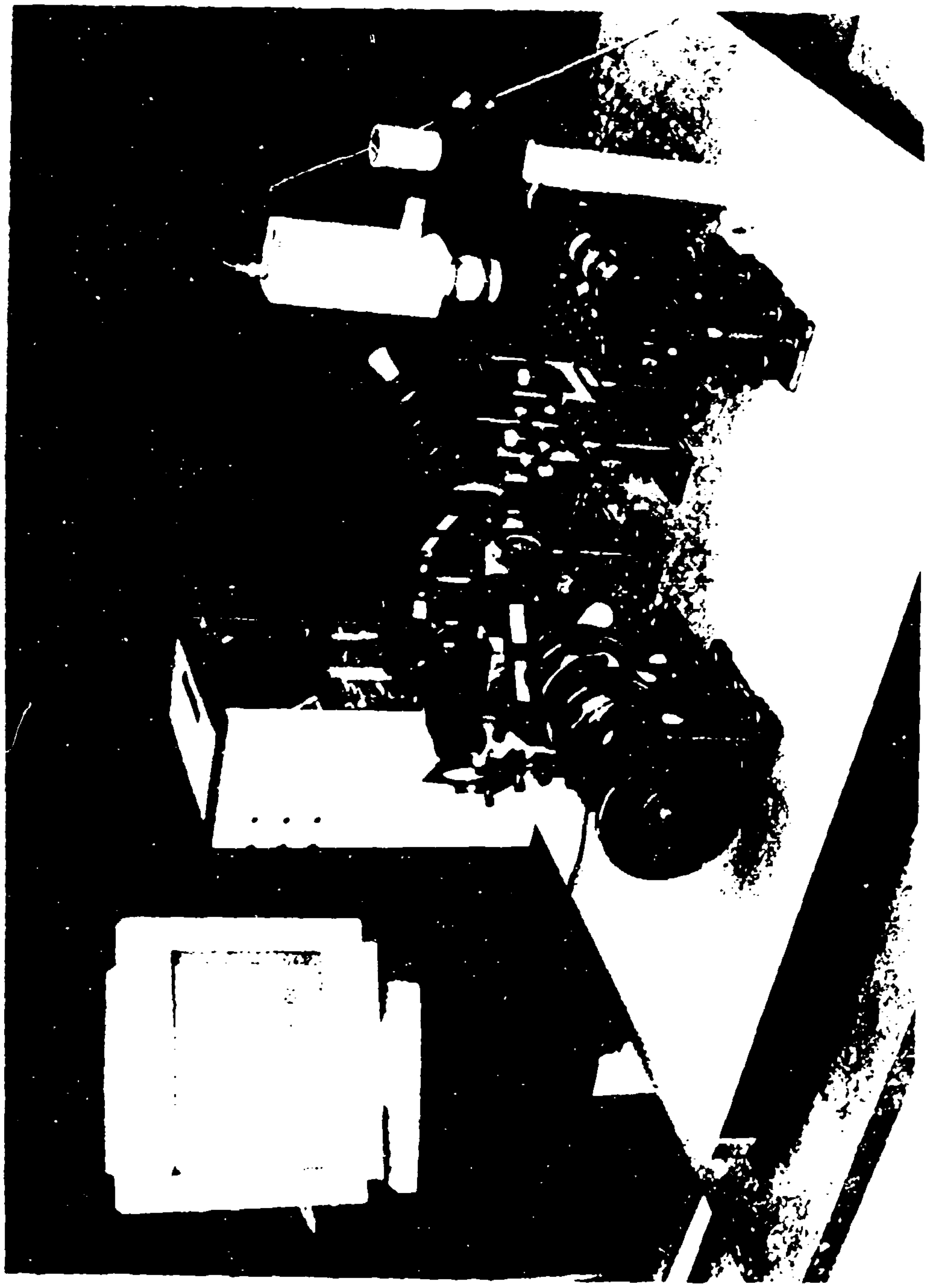


Figure 5.1-2. Photograph of Optics Bench

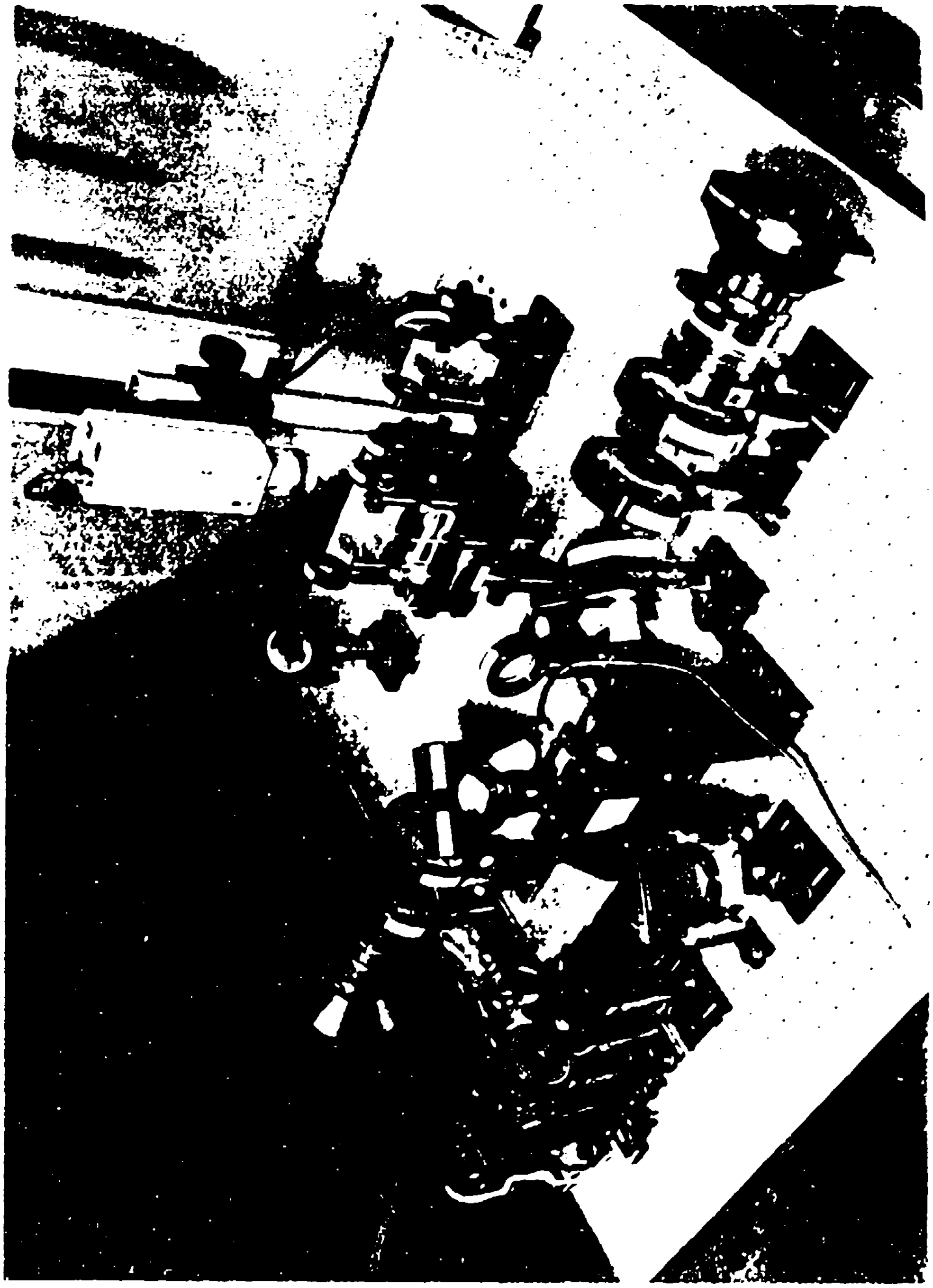


Figure 5.1-3. Photograph of Electronics Box (Interface Board Side)

Figure 5.1-4 shows the other side of the electronics box. This view shows the two DDS generator boards on the right side of the box (Stanford Telecom Model #STEL-2272). The other power amplifier is located in the upper central region of the box, and the other signal combiner can be seen in the upper right hand corner. The CCD power transformer is located at the bottom.

5.2 Control and Analysis Software Description

The Lasercom system was designed for ease of use. When the computer boots up, it automatically loads Windows and runs with Norton desktop. To start the Lasercom system, simply double click the left mouse button with the cursor sitting on the Lasercom Icon, in the Applications group. This starts the software and turns on the hardware.

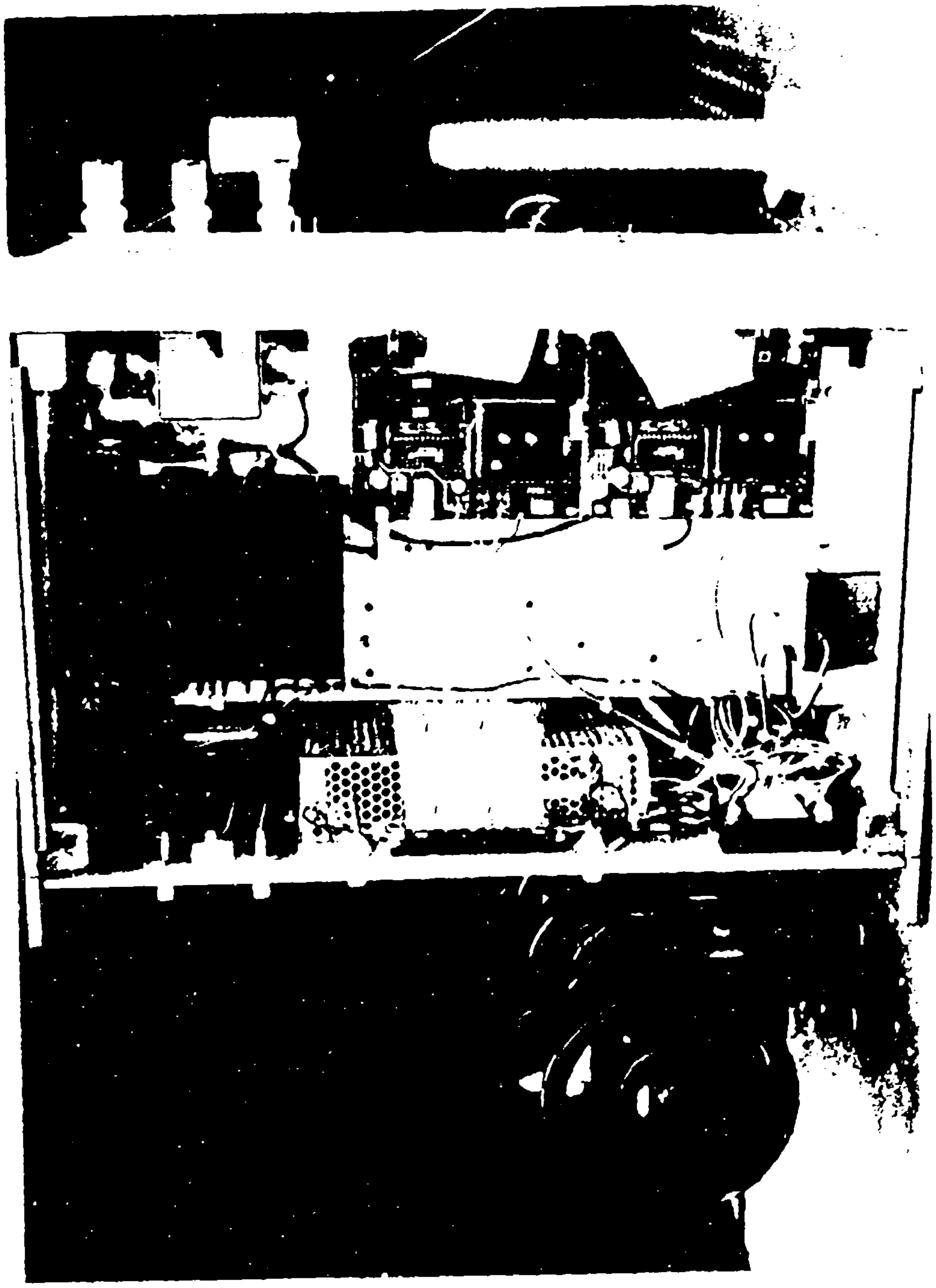
The software was written in Visual Basic 2.0 and is fully commented. Appendix A attached is a printout of the source code. Appendix B is a printout of the Help file, which explains the system operation and control in greater detail.

When the program first loads, a warning dialog box is displayed that explains about laser safety. Then the control window appears. In the top part of the screen is a white control area, in the bottom is the live TV camera output. The laser spot initial condition is on, with the spot centered in the right half of the display area, with the beam exiting the system in the center of the right-hand fisheye lens.

The spot can be moved to a new position by three different methods. The spot can be positioned by placing the mouse cursor antwhere on the white control area and clicking the left mouse button. The spot will then appear at that point. The white display area represents 360 degrees of horizontal positions and +/- 18 degrees of vertical positions. The line in the center defines the split in the system between the left-hand fisheye and the right-hand fisheye output. The live TV output is split vertically, with the bottom half mapped to the left area and the upper half corresponding to the right half. Another way to manipulate the spot position is to place the mouse cursor on the spot and, while holding down the left mouse button, dragging the spot to a new location. The third method of spot positioning is to grab the slide bar with the mouse and drag it to a new location. This gives you independent control of the horizontal and vertical positions. The bars and the bar arrows can also be clicked on for coarse and fine position control, respectively. The position of the spot can only be controlled for a single spot. In order to control the position of multiple output spots, either independent frequency sources can be plugged into the front panel, or a pattern file can be written for time division multiplexing the spot positions. See the Help menu for details on writing a pattern file.

Along the top of the program is a menu bar. This lets you control things like displaying pattern files, zooming the spot, displaying multiple spots, scanning the spot, centroiding the spot, and calling on the Help files. To exit the program, either double click in the upper left corner or choose the File - Exit menu.

Figure 5.1-4. Photograph of Electronics Box (DDS Side)



5.3 Breadboard Performance Summary

The primary objectives of the breadboard demonstration were to correlate theoretical predictions of Bragg cell performance (such as efficiency, switching speed, multi-beam generation, and beam zooming) with experimental data and to gather other data concerning system-level operations such as overall steering range, beam divergence, and throughput efficiency. All of the objectives of the breadboard were met, and with the one exception of throughput efficiency, all of the technical goals were achieved. The overall throughput efficiency was found to suffer for two reasons which will be explained in greater detail later: poor laser diode spectral quality and several uncoated (or wrongly coated) optical lens elements. The itemized compliance of the breadboard performance versus goals is given in Table 5.3-1.

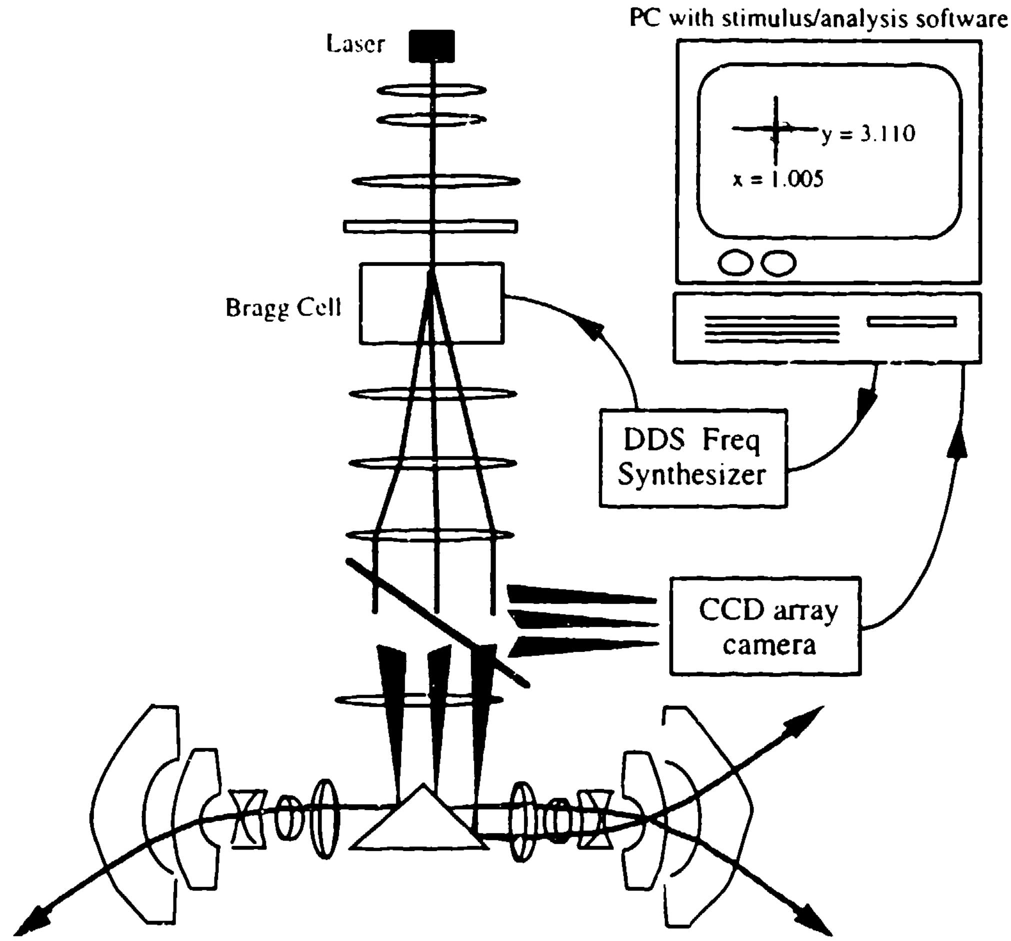
Table 5.3-1. Itemized Compliance of Breadboard to Goals

SOW Goal Specification	Breadboard Result
• steering range: approx. 180° x 45°	• implemented 360° x 36° (2 sectors)
• transmit beam size: 0.36° round	• successfully demonstrated
• zoom factor: minimum 10X (3.6°)	• successfully demonstrated over 11X
• multiple beam generation: min. 4	• successfully demonstrated (can "simulate" many more)
• end-to-end optical efficiency: min. 50%	• 13% demonstrated (limited by laser and >70% losses in "off-the-shelf" optics)
• steering response time: 30 microsec	• successfully demonstrated

The majority of the breadboard performance parameters can be measured by a diagnostic system that is built into the breadboard itself: a CCD camera array interfaced to the PC control computer with custom analysis software. This particular combination of hardware and software is hereafter referred to as the Built-in Test Set, or BTS. Several tests, however, required initial calibration tests separate from the BTS due to their unique demands. The BTS block diagram is illustrated in Figure 5.3-1. Note that the BTS is a self-contained analysis system that requires no additional laboratory equipment.

The optical design wavelength of the demonstration breadboard is 830 nm (infrared), although a 670 nm (red) laser is also incorporated into the breadboard for purposes of visual (naked eye) demonstration. All test descriptions and results in this Section are assumed to occur at the 830 nm design wavelength. No minimal specifications were implied for the 670 nm wavelength; in fact, it was found to be very difficult to optically align both the 670 and 830 nm lasers to the Bragg cells simultaneously through the same optics. As a result the 670 nm laser does not have the desired visual impact when the optical system is optimized for the 830 nm laser. In hindsight a better solution would have been to provide separate input optics for the two lasers so that they could be optimized individually.

Figure 5.3-1. Breadboard Built-in Test Set (BTS) Block Diagram



A test plan was developed for the breadboard and implemented with only some minor changes. The tests that were described in the test plan and performed on the breadboard are summarized in Table 5.3-2. The following paragraphs explain how the performance measurements were made and the data that was obtained for each of the SOW performance goals.

Table 5.3-2. Test Plan Summary

Test ID	Test Name	Specifications	Test Setup	Comments
A	Steering Range	360° x 36°	• Special • BTS	• Initially measured with "curved screens". • Measured on CCD after initial calibration.
B	Beam Divergence	0.36°	• Special • BTS	• Initially measured with beam profiler. • Measured on CCD after initial calibration.
C	Divergence Zooming	10:1	• Special • BTS	• Initially measured with beam profiler. • Measured on CCD after initial calibration.
D	Multiple Beams	qty. 4	• Special • BTS	• Visually observed on "curved screens". • Measured on CCD prior to exit lens.
E	Optical Efficiency	50%	Special	Measured with discrete photodetector
F	Response Time	40x 20 microsec	Special	Measured w/ APD detector & oscilloscope.

Test A. Steering Range

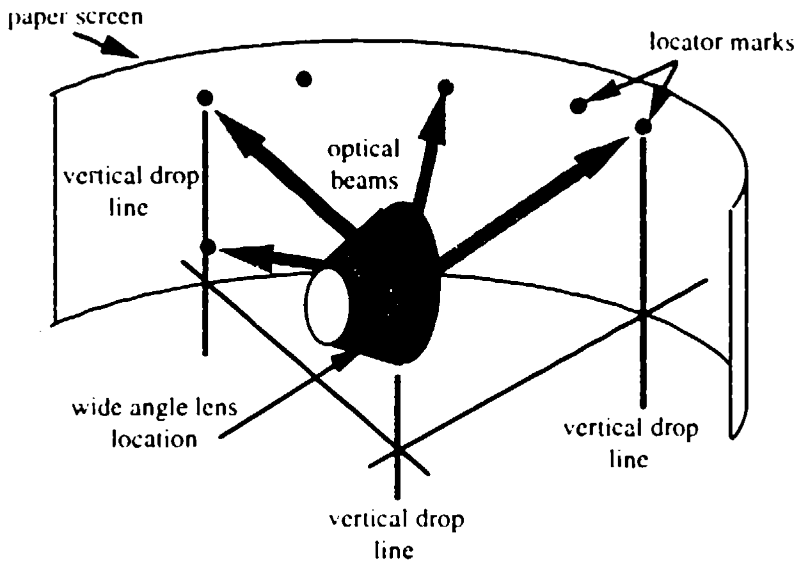
This test was performed by measuring the maximum angular steering range of the optical output at the exit of the wide-angle Nikon output lenses. Specifically, the limits of the horizontal and vertical steering range were determined by physically locating the steered beam on a curved screen placed approximately 1 foot from the output lens, as shown in Figure 5.3-2. A hand-held IR viewer was used to locate the beam position on the screen, and at the limits of the beam steering a pencil mark was made on the screen corresponding to the exact beam location. The beam was then incrementally steered by commands from the PC computer until the beam steering limits are reached (where clipping or vignetting of the beam occurs to a level no greater than 1 dBc). The locator marks on the screen were then used to geometrically determine the angular beam steering range as discussed below.

Horizontal range: Drop vertical lines to the bottom of the screen (i.e., to the bench top) from the maximum horizontal extent locator marks. Draw a line that intersects these points with the vertical drop point on the bench top that corresponds to the center of the wide angle lens. After doing this for both left and right steering limits the horizontal steering range can be determined directly from the angle between these lines.

Vertical range: The vertical angular steering range was measured by triangulation between two maximum extent locator marks lying on a vertical drop line and the distance to the wide angle lens.

The results of this test successfully confirmed that the total breadboard steering range is 360° horizontal by 36° vertical.

Figure 5.3-2. Test A - Beam Steering Range



Test B. Beam Divergence

This test was performed using a newly purchased beam profiler system, the Spiricon Model #LBA-100A. Placed after the wide angle exit lens, the Spiricon makes very accurate beam profile measurements including beam diameter at both the 1/2 (FWHM) and e^{-2} (Gaussian) power points. By taking a measurement at one axial location and then another at a further axial location the Spiricon can automatically calculate the divergence of the beam. This test confirmed that the diffraction-limited beam divergence was 6.29 mrad, or 0.36°. Therefore, the number of resolvable beams is 1000 in the horizontal axis (360°/0.36°) and 100 in the vertical (36°/0.36°).

Test C. Divergence Zooming

This test is intended to confirm that the optical beam will effectively enlarge or "zoom" by a factor of at least 10 in both axes, or to increase to about 3.6° from the 1X value of 0.36° in both the horizontal and vertical axes. Note that the amount of actual divergence can be varied continuously anywhere between a factor of 1X to 20X or more by commanding the proper number and spacing of frequencies into the Bragg cells. The pull-down "Zoom Menu" in the PC control software has pre-programmed data for generating 1X, 3X, 5X, 7X, 9X, and 11X zooms. This test was performed using the previously mentioned Spiricon beam profiler, and the results are shown in Table 5.3-3. It is seen that very good agreement was obtained between the desired and actual measured zoom ratio. It would have been a simple matter to adjust the frequency programming to the Bragg cells to obtain even better correlation, but it was deemed unnecessary since the primary intent was merely to demonstrate a minimum of 10X zooming.

Table 5.3-3. Beam Zooming Test Results

Desired Zoom Ratio	Measured Zoom Ratio
1 X	1 X
3 X	2.66 X
5 X	4.66 X
7 X	6.59 X
9 X	9.17 X
11 X	10.80 X

Test D. Multiple Beam Generation

The goal of this test is to produce a minimum of four independently steered beams from the Bragg cells. True multiple beam generation requires that frequencies be simultaneously combined before insertion into the Bragg cells. Each Bragg cell therefore has been supplied with four input channels each: 1 internal DDS channel and 3 front panel ports for externally applied signals. We have inserted signals into the front panel ports and confirmed the true multiple beam generation.

This test can also be "simulated" using BTS capability. The procedure is very similar to the previous zoom approach in Test C, except here full-aperture beams are generated in a time-multiplexed fashion. The PC commands the Bragg cells to vary between 4 frequencies that correspond to the desired steering directions. The frequencies are switched at the fastest switching speed of the 500 Spot Bragg Cell (40 microsecond aperture). The simulation occurs due to the fact that the beam is being steered faster than the CCD camera can respond, and therefore 4 statically steered beams "appear" to occur. Note that the steering frequencies can be arbitrarily chosen and that more or less than 4 unique beams may be steered by commanding the proper number of frequencies into the Bragg cells. In fact, this the same technique that is used to generate special scans and patterns from the pull-down "File Menu" and "Scan Menu".

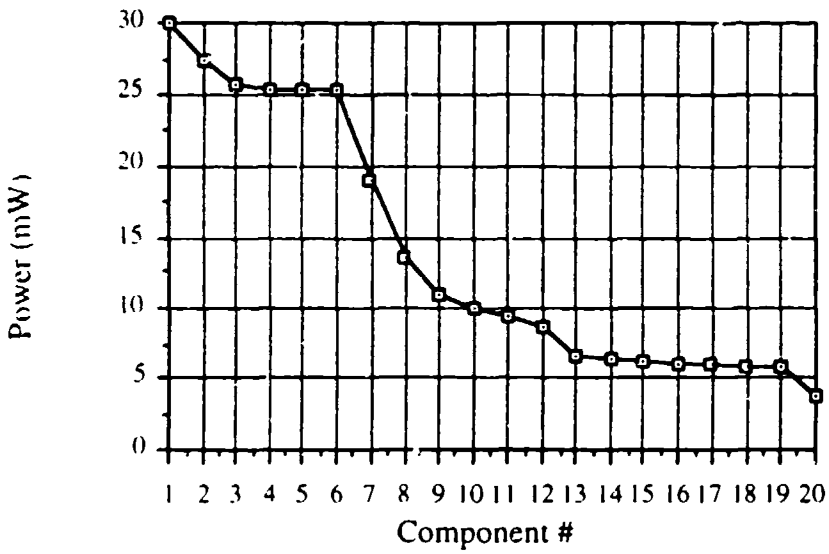
The result of this test is that the generation of at least 4 simultaneously and independently steered beams was successfully demonstrated. The divergence angle of each beam is the same as for a single CW steered beam. Note that ghost beams are also be generated in this process since any steering frequency in one Bragg cell interacts optically with any steering frequency in the other Bragg cell. For example, 2 frequencies input to each cell in order to generate N=2 unique beams also produces 2 ghost beams. In general, N^2 total beams are formed, of which N are primarily sought and N^2-N are ghost beams.

Test E. Optical Efficiency

The purpose of this test is to measure the end-to-end optical efficiency of the overall demonstration breadboard, defined as the optical power difference between the output of the source laser diode and the beam that finally exits the wide-angle lens. The optical efficiency of the Bragg cells is a function of their drive power, so this test was performed after the saturation drive power (i.e., maximum efficiency) of the Bragg cells had first been determined. The test was performed by placing a photodetector in the path of the optical beam at various locations between the laser source and the final wide-angle exit lens.

The result of this test is that the overall optical efficiency of the demonstration breadboard is about 13% (-9 dB), instead of the goal 50% (-3 dB). Figure 5.3-3 presents the component-by-component breakdown of the optical power through the system.

Figure 5.3-3. Measured Optical Power through Breadboard

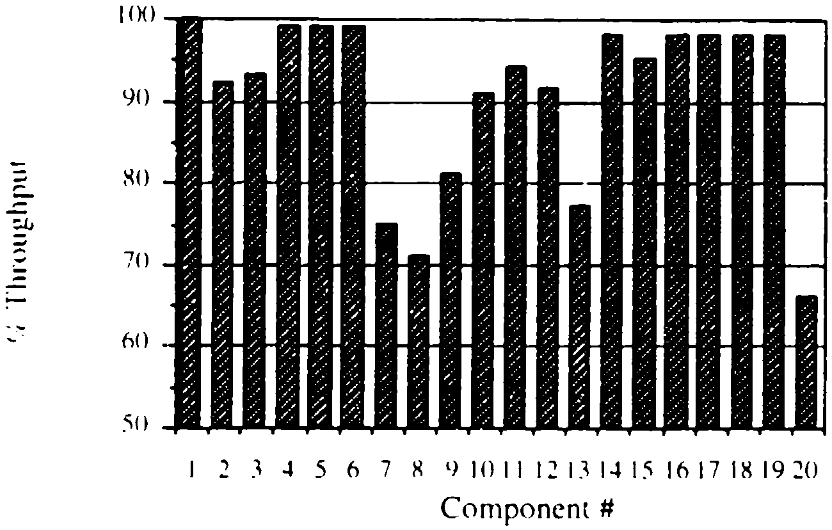


Component Definition:

1. Laser Diode	6. Mirror	11. Splitter	16. Mirror
2. Collimator	7. Horiz. Bragg cell	12. 80mm Cyl lens	17. Mirror
3. Mirror	8. Wave Plate	13. Mirror	18. 150 mm lens
4. 2 waveplates	9. Vert. Bragg cell	14. 40 mm lens	19. 150 mm lens
5. 6X Beam Expander	10. 300mm Cyl. lens	15. 100 mm lens	20. Nikon wide lens

Another way to view the optical power losses is on a component-by-component throughput percentage, as shown in Figure 5.3-4. It can be seen in Figure 5.3-4 that five of the 20 breadboard components failed to meet at least 90% optical throughput efficiency: #7 Horizontal Bragg Cell, #8 Wave Plate, #9 Vertical Bragg Cell, #13 Mirror, and #20 Wide Angle Lens. The lack of a proper 830 nm anti-reflection coating is the reason that #8 Wave Plate (which had to be ordered quickly without time for coating delays) and #20 Wide Angle Lens (which is an off-the-shelf 35mm camera lens coated for visible only) performed poorly. The reason that the #13 Mirror performed poorly is due to the fact that unprotected aluminum-coated mirrors do not reflect well at a 45° angle of incidence at 830 nm wavelength. A gold or silver coated mirror would do a much better job in this location.

Figure 5.3-4. Component Throughput Percentage



Component Definition:

1. Laser Diode	6. Mirror	11. Splitter	16. Mirror
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3. Mirror	8. Wave Plate	13. Mirror	18. 150 mm lens
4. 2 waveplates	9. Vert. Bragg cell	14. 40 mm lens	19. 150 mm lens
5. 6X Beam Expander	10. 300mm Cyl. lens	15. 100 mm lens	20. Nikon wide lens

The remaining two components that performed less than expected are the #7 Horizontal Bragg Cell and #9 Vertical Bragg Cell. This was somewhat of a surprise given the excellent initial measurements that were made on the Bragg cells after fabrication. As discussed in Section 4.1 the Horizontal Bragg Cell (500 Spot Cell) had a small signal response of 700%/W, and was expected to approach 95% efficiency or more at approximately 300 mW of drive power. Similarly, the Vertical Bragg Cell (200 Spot Cell) had a small signal response of 400%/W, and was expected to approach 95% efficiency or more at approximately 400 mW of drive power. This led to an investigation of the cause of the performance degradation.

The impressive small-signal responses reported in Section 4.1 are noted to have been made using a very high quality Spectra-Diode Labs laser diode Model 5400 (100 mW, index-guided, single mode). This raised the question as to the quality of the laser diode that was purchased for the breadboard, which is a Sharp laser diode packaged by D. O. Industries (DOI), Model 1-9280-SHAC. The spectrum of the laser had been measured at delivery and found to be "adequate", but was remeasured again in light of the efficiency problems. It was found to have degraded significantly. The results are given in Figure 5.3-5, where on the left hand side is the initial measurement and on the right hand side is the latest measurement. It is clear that substantial degradation in longitudinal mode structure has occurred, and the laser is now running with a large number of wavelengths. The spatial profile was also measured using the Spiricon beam profiler, as shown in Figure 5.3-6. This also confirmed that the laser had a degraded transverse mode structure, probably directly related to the degraded longitudinal mode structure.

Figure 5.3-5. Laser Diode Spectral Quality Measurements

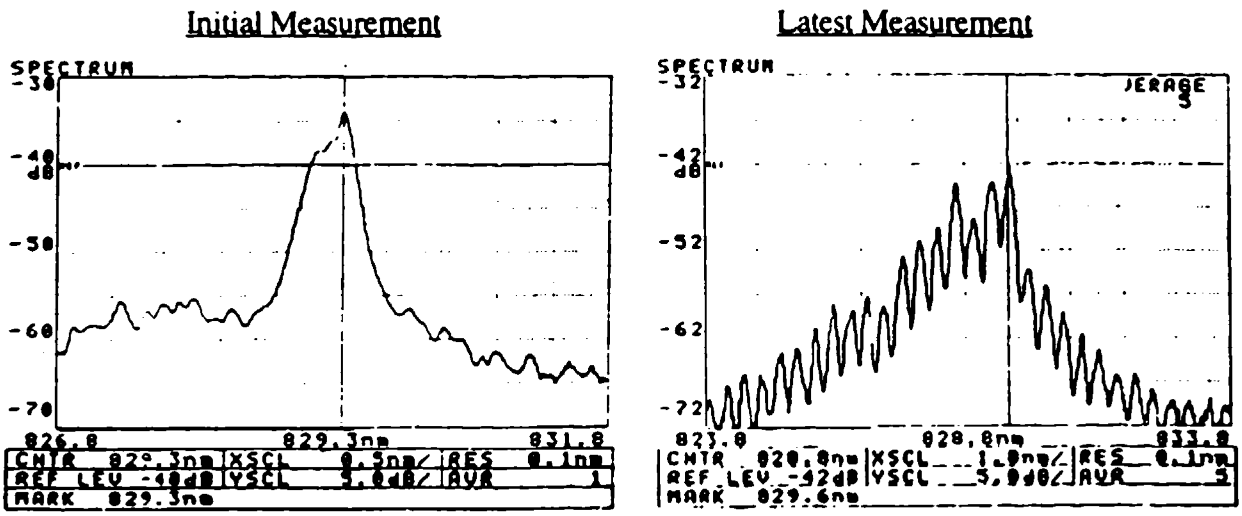
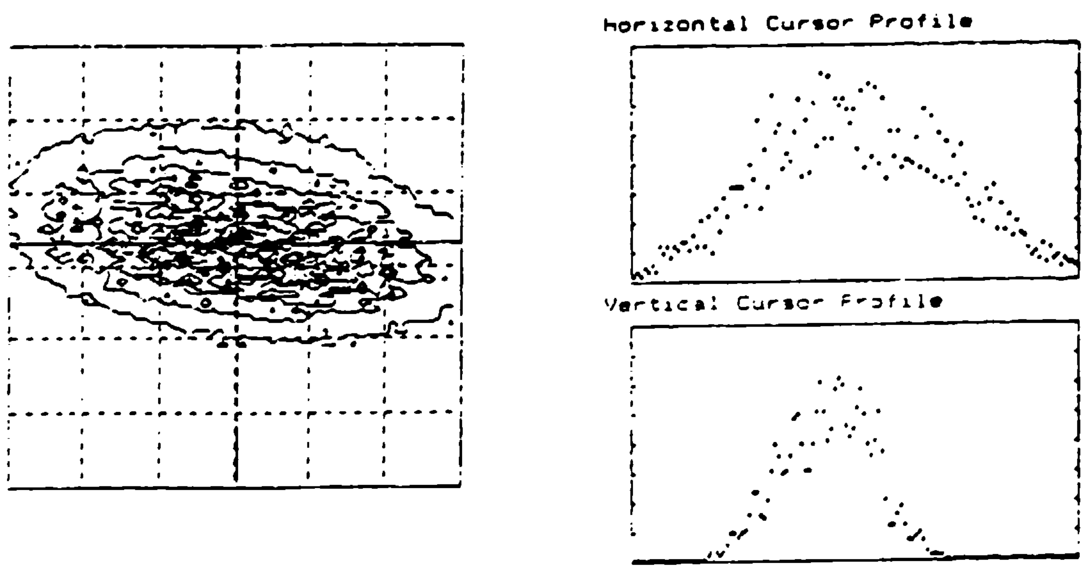


Figure 5.3-6. Laser Diode Spatial Profile Measurement



Due to a lack of time and funds at the end of the program the laser diode problem could not be corrected. It is surmised that the poor laser quality directly contributed to the lower than expected Bragg cell performance since the acoustic/optical phase matching requirements inside the Bragg cell are rather stringent. In other words, not all of the multiple wavelengths from the laser can be properly phase-matched simultaneously inside the Bragg cell to produce a high deflection response. Therefore, some of the light from the DOI breadboard laser is being "wasted" since the Bragg cell cannot properly deflect it. The small-signal response was also measured using the DOI laser and found to be about half the response measured previously with the SDL laser.

Test F. Response Time

The purpose of this test was to determine the response time limit for switching of the optical beam steering direction. Since this is completely determined by the Bragg cell response time, the results of this test were given in Section 4.1, Figure 4.1-13 as part of the Bragg cell checkout testing. The response time was measured by pulsing or time-gating a signal through the Bragg cell and observing the rise, dwell, and fall time of the resulting deflected optical beam. This test successfully verified that the 60% response time of the Horizontal (500 Spot) Bragg Cell was 30 microseconds, and 15 microseconds for the Vertical (200 Spot) Cell. The 100% response time for the Horizontal and Vertical Cells is 40 and 20 microseconds, respectively.

6.0 Conclusions

As a result of this effort it has been proven that acousto-optic Bragg cells can perform very useful and unique functions for controlling the transmitted beam in a laser communications system. Analytical tools were developed to model the performance of Bragg cells for this application, and other design trades were made which led to the choice of the optimum Bragg cell material (TeO_2), fabrication geometry, and heat sinking techniques. A breadboard lasercom transmitter was developed which successfully demonstrated that Bragg cells can be used to steer the transmit beam over a very wide range (in this case, 360° x 36°) and with very fast speed (< 40 μsec). The steered beam was shown to have a diffraction limited beam divergence (0.36° in this case). Several complications led to an overall optical efficiency of about 13% for the breadboard, as explained in Section 5.3, but convincing evidence is provided that the overall optical efficiency of a customized optical system can be greater than 70%, as explained in Section 4.2.2. Also, it is shown that the overall package size for a customized system can be on the order of 128 in^3, including lasers, Bragg cells, and all optical components.

Some unique attributes of Bragg cells were demonstrated by the breadboard, including multiple simultaneous beam steering (> 4 simultaneous beams) and variable beam divergence (> 10:1 beam spreading). Significantly, all these capabilities are provided by Bragg cells which are rugged, long-life components that have no moving parts. Bragg cells are, therefore, very attractive components from a systems application point-of-view.

A custom electronics box including frequency generators was developed for the breadboard using direct digital synthesis (DDS) to provide ultra-stable and fast frequency switching for the Bragg cells. These electronics can be significantly miniaturized for flight applications.

In summary, acousto-optic beam steering technology has been proven as a viable approach for lasercom beam steering at the breadboard level. The next step for development is to produce brassboard-level hardware which implements miniaturized packaging techniques and to obtain performance data under simulated or real environmental loading conditions.

Appendix A. Breadboard Control PC Source Code

The following pages present the listing of the source code that exists on the breadboard PC computer for all of the control and diagnostic functions. The code is written in Visual Basic®, which is a registered trademark of the Microsoft Corp. The code has been extensively commented; however, it is suggested that any desired changes not be made before contacting the author first to avoid potential complications: Lee Burberry, Harris Corp. HISD, M/S 13-7747, P. O. Box 98000, Melbourne, FL, 32902, phone (407)727-5317.

```
Sub BOARDINIT ()
  'SETUP DIGITAL I/O BOARD FOR 24 BITS ALL OUTPUT
   For I = 0 To 2
     status = DIG_Prt_Config%(ByVal 1, ByVal I, ByVal 0, ByVal 1)
   Next I
   'set all bits ports 0,and 1 to zero
   portout(0) = 0
   portout(1) = 0
   portout(2) = (2 + 4 + 8 + 16)
   '2 = HARDWARE ON 4=RESET 8=W1 16=W2 INITIALIZED TO SET
   For I = 0 To 2 'send out initial states
   status = DIG_Out_Port%(ByVal 1, ByVal I, ./Val portout(I))
   Next I
   XFreqOut = Val(form1!Text2.Text)'read initial state from screen text
   YFreqOut = Val(form1!Text4.Text)'read initial state from screen text
   Call Freqout 'initialize Y and Y frequencies
End Sub


Sub CENTROIDING () 'routine to find weighted average of spot location

Dim DeqreeX, DegreeY As Single  'local X and Y holders
Dim Pix As Single               'Pixel Grey Level
Dim I, J As Integer             'local counters
Dim SumX, SumY, SumW As Double  'Sum holders
Dim XLower, ZUpper, YLower, YUpper As Integer 'box size holders
Dim ymax, Ymin, YDelta As Integer    'Vertical scale holders
Dim XHalf As Integer                 'which half
Static Region As AVrect                'define a region variable for partial frame capture

Const XOff = 10                      'extent of centroid area in X
Const YOff = 30                      'extent of centroin area in Y
Const XMax = 210                     'Global size of x area for scaling
Const XMin = -30                     'Global size of x area for scaling
Const PixThreshold = .1              'if grey level below this, don't count it

If CentroidOn = True Then       'only do it when button pushed
   form1!Picture2.Visible = True 'Picture2 hold data for centroiding
   form1!AvControl1.Visible = False 'hide real time vidio
   form1!avoverlay.Visible = False 'hide overlay window
   form1.Timer5.Enabled = False  'turn off timer so no reentry
  OldMouse = Screen.MousePointer'save old mouse pointer shape
  Screen.MousePointer = 11      'set to hourglass while centroiding
  SumX = 0                      'initialize Sum X
  SumY = 0                      'initialize Sum Y
  SumW = 0                      'initialize Weighted Sum
  YDelta = -47
  'where to centroid around in degree space
  DegreeX = Val(form1.Text1)'get position from screen text
  If DegreeX >= 180 Then      'Which half?
    Ymin = -160 + YDelta
    ymax = 210 + YDelta
    DegreeX = DegreeX - 180  'X mod 180
    XHalf = 180 'remember to add 180 to output
  Else
    Ymin = -160
    ymax = 210
    XHalf = 0
  End If
  'Form1!Picture2.Scale (-30, 25)-(220, -25)'scale the data
  form1'avoverlay.Scale (XMin, ymax)-(XMax, Ymin)'scale the data
  DegreeY = Val(form1.Text3) 'get position from screen text
  'set limits
  YLower = DegreeY - YOff
  If YLower < Ymin Then YLower = Ymin
  YUpper = DegreeY + YOff
  If YUpper > ymax Then YUpper = ymax
  XLower = DegreeX - XOff
  If XLower < XMin Then XLower = XMin
  xupper = DegreeX + XOff
  If xupper > XMax Then xupper = XMax
```

```
  'draw box around spot
  form1!avoverlay.Line (DegreeX - XOff, DegreeY - YOff)-(DegreeX + XOff, DegreeY + YOff), white
, B
  'grab video to picture box to get access to pixel data
  a$ = "d:\temp.bmp" 'file to hold bitmap on ramdrive
  'define the region of the video field to grab
  Region.Left = 50
  Region.Top = 130
  Region.Right = 530
  Region.Bottom = 270
  'LResult = AVgrabtofile(AvControl1.AvVideoHandle, a$, File_windows8gray, Region)'save REGION
OF video to Ramdisk
  LResult = AVgrabtofile(AvControl1.AvVideoHandle, a$, File_windows8gray, ByVal 0&)'save ALL vi
deo to Ramdisk
  form1!Picture2.Picture = LoadPicture(a$)'get video from disk so can be accessed
  form1!Picture2.Scale (XMin, ymax)-(XMax, Ymin)'scale the data after screen size dynamically a
djusted
  'centroid by waited average
  For I = YLower To YUpper
    For J = XLower To xupper
     'get pixel value (b/w camera)
     Pix = (form1!Picture2.Point(J, I) And 255) / 255'keep numbers small so no overflow
     If Pix < PixThreshold Then Pix = 0
     SumX = SumX + Pix * J 'set up sum of POSITION wieghts
     SumY = SumY + Pix * I 'set up sum of POSITION wieghts
     SumW = SumW + Pix     'set up sum of PIXEL wieghts
    Next J
  Next I
  If SumW > 0 Then 'If Sum of all the pixels is nonzero then
   XCentroid = SumX / SumW + XHalf 'calculate the X centroid
   YCentroid = SumY / SumW   'calculate the Y centroid
  Else                 'If all zero then centroid is zero
   XCentroid = 0
   YCentroid = 0
  End If
  If Calibrated Then    'use calibration table to calculate location
'  find calibration box upper left coordinates and frequencies

   uxd = Val(form1.Text1) / 30          ' demand x-frequency in array coordinate space
   uyd = (18 - Val(form1.Text3)) / 3    ' demand y-frequency in array coordinate space

   nx = Int(uxd)            ' box left array coord
   If nx = 12 Then nx = 11
   ny = Int(uyd)            ' box top array coord
   If ny = 12 Then ny = 11

   dx00 = nx * 30           ' demand box left frequency
   dy00 = 18 - ny * 3       ' demand box top frequency

'  find box corner frequencies
   x00 = XCentroids(nx, ny)
   x10 = XCentroids(nx + 1, ny)
   x01 = XCentroids(nx, ny + 1)
   x11 = XCentroids(nx + 1, ny + 1)
   y00 = YCentroids(nx, ny)
   y10 = YCentroids(nx + 1, ny)
   y01 = YCentroids(nx, ny + 1)
   y11 = YCentroids(nx + 1, ny + 1)

'  estimate "Should-Have-Been" frequencies xfr, yfr
   a1 = x10 - x00
   a2 = y10 - y00
   b1 = x01 - x00
   b2 = y01 - y00
   dtrm = a1 * b2 - a2 * b1 'matrix determinant
   c1 = x11 + x00 - x10 - x01
   c2 = y11 + y00 - y10 - y01
   d1 = XCentroid - x00
   d2 = YCentroid - y00
   xxx = 0
   yyy = 0

  'use successive aproximation to find location
```

```
    For I = 1 To 5
        e1 = d1 - c1 * xxx * yyy
        e2 = d2 - c2 * xxx * yyy
        xxx = (b2 * e1 - b1 * e2) / dtrm
        yyy = (a1 * e2 - a2 * e1) / dtrm
    Next I
    'These are the calibrated values
    XCentroid = dx00 + 30 * xxx
    YCentroid = dy00 - 3 * yyy
End If
   'Picture 2 is visible, show area of centroiding
   form1!Picture2.Line (DegreeX - XOff, DegreeY - YOff)-(DegreeX + XOff, DegreeY + YOff), white,
  B
   'Display Cetroid results as text on the screen
   form1.Label6.Caption = Format$(XCentroid, "0.00")
   form1.Label8.Caption = Format$(YCentroid, "0.00")
   form1.Refresh 'update display
   form1.Refresh 'update display
   form1.Timer5.Enabled = True  'turn on again for next centroid
   Screen.MousePointer = OldMouse  'set back to before state
   'erase box with another Xor draw
   form1!avoverlay.Line (DegreeX - XOff, DegreeY - YOff)-(DegreeX + XOff, DegreeY + YOff), white
 , B
 Else  'centroider is off
   form1.Label6.Caption = "  Off" 'status output if centroid off
   form1.Label8.Caption = "  Off"
  End If
End Sub


Sub TIMER6_Timer ()
End Sub

Sub TVFRAMESETUP ()  'set up form1 control sizes
h = form1.Height 'get the vertical size of the form
w = form1.Width  'get the horizontal size of the form
                 'scale all displays to those sizes
form1.Hide 'turn off the form while resizing
'setup the video frame grabber
form1!AvControl1.Top = h * .25
form1!AvControl1.Left = w * .02
form1!AvControl1.Height = h * .65
form1!AvControl1.Width = (3 / 2) * form1!AvControl1.Height
'setup the video frame grabber overlay window
form1!avoverlay.Top = h * .25
form1!avoverlay.Left = w * .02
form1!avoverlay.Height = h * .65
form1!avoverlay.Width = (3 / 2) * form1!AvControl1.Height
'set up a picture box to hold the data for centroiding
form1!Picture2.Top = h * .25
form1!Picture2.Left = w * .1
form1!Picture2.Height = h * .65
form1!Picture2.Width = (3 / 2) * form1!AvControl1.Height
'put a yellow bar in the middle of the video window to show split halves
form1!Sepbar.Height = form1!AvControl1.Height * .005
form1!Sepbar.Top = form1!AvControl1.Top + (form1!AvControl1.Height / 2) - (form1!Sepbar.Height
/ 2)
form1!Sepbar.Left = form1!AvControl1.Left
form1!Sepbar.Width = form1!AvControl1.Width
'set up point display windows
form1!Picture1.Top = h * .05
form1!Picture1.Left = w * .1
form1!Picture1.Width = w * .65
form1!Picture1.Height = h * .1
'set up horizontal scroll bar
form1!HScroll1.Top = h * .17
form1!HScroll1.Left = w * .1
form1!HScroll1.Width = w * .65
form1!HScroll1.Height = h * .01
'set up veritcal scroll bar
form1!VScroll1.Top = h * .05
form1!VScroll1.Left = w * .77
form1!VScroll1.Width = h * .025
```

```
form1!VScroll1.Height = h * .1
'set up X degree text display
form1!Text1.Top = h * .2
form1!Text1.Left = w * .3
form1!Label1.Top = h * .2
form1!Label1.Left = w * .38
'set up X Frequency text display
form1!Text2.Top = h * .2
form1!Text2.Left = w * .5
form1!Label2.Top = h * .2
form1!Label2.Left = w * .58
'set up Y degree text display
form1!Text3.Top = h * .06
form1!Text3.Left = w * .8
form1!Label3.Top = h * .07
form1!Label3.Left = w * .88
'set up Y Frequency text display
form1!Text4.Top = h * .12
form1!Text4.Left = w * .8
form1!Label4.Top = h * .13
form1!Label4.Left = w * .88
'set up centroid Label
form1!centroidlabel.Top = h * .45
form1!centroidlabel.Left = w * .78
'set up X centroid text output
form1!Label6.Top = h * .63
form1!Label6.Left = w * .78
form1!label7.Top = h * .63
form1!label7.Left = w * .85
'set up Y centroid text output
form1!Label8.Top = h * .53
form1!Label8.Left = w * .78
form1!Label9.Top = h * .53
form1!Label9.Left = w * .85
'turn the form back on
form1.Show
'put an initial spot on the screen
SPOTDRAW
End Sub

Sub ABOUT_Click ()
AboutBox.Show 'if requested tell about program origan
End Sub

Sub CALIBRATE_Click ()
'Routine to Calibrate the Centroider
Dim I, J As Integer'Local counters
Dim X, Y As Single 'local Degree inputs

Title = "Calibration of Centroider" 'Message Box Title
Msg = "This Will Take a While.  "      'set up message
Msg = Msg & " Do you want to continue?"  'more message
DgDef = MB_OKCANCEL + MB_ICONQuestion ' Describe dialog buttons
Response = MsgBox(Msg, DgDef, Title)    ' Get user response.
If Response = IDOK Then     ' Evaluate response
   Screen.MousePointer = 11 'set to Hourglass
   CentroidOn = True 'set the global variable
   For J = 0 To 12    'step through Y
   Y = (J - 6) * -3   'Get Y from J (18 to -18 step -3)
    For I = 0 To 12   'step through X
      X = I * 30      'Get X from I (0 to 360 step 30)
      HScroll1.Value = X * 10#          'set scroll bars, causes
      VScroll1.Value = (VMax / 20# - Y) * 10#  'spot to be output
      Call CENTROIDING 'Find Spot centroid
      form1.Timer5.Enabled = False'turn timer off(cetroid turned it on)
      XCentroids(I, J) = XCentroid 'save the position
      YCentroids(I, J) = YCentroid 'save the position
   Next I
  Next J
  CentroidOn = False 'set the global variable
  Screen.MousePointer = 1 'set to Arrow
  Calibrated = True 'set global variable
  form1.centroidlabel = "Calibrated Centroid Position"
```

```
  Timer5.Enabled = False'turn timer off
  form1!Picture2.Visible = False  'turn off picture2 when done
  form1!AvControl1.Visible = True'show real time vidio
  form1!avoverlay.Visible = True'allow overwriting on window
  form1.Label6.Caption = "  Off" 'status output if centroid off
  form1.Label8.Caption = "  Off"
End If
End Sub

Sub CENTOFF_Click () 'Turn centroindong Off
CentroidOn = False   'set global variable
Timer5.Enabled = False'turn timer off
form1!Picture2.Visible = False  'turn off picture2 when done
form1!AvControl1.Visible = True'show real time vidio
form1!avoverlay.Visible = True'allow overwriting on window
form1.Label6.Caption = "  Off" 'status output if centroid off
form1.Label8.Caption = "  Off"
End Sub

Sub CENTON_Click () 'Turn centroiding On
CentroidOn = True 'set the global variable
Timer5.Enabled = True'turn timer on
End Sub

Sub CONTENTS_Click ()
Dummy = Shell("c:\windows\winhelp.exe lasercom.hlp")'start windows help on help
End Sub

Sub DIAGONAL_Click () 'draw a diagonal line of light
Dim IncrementX As Single   'x step size
Dim IncrementY As Single   'y step size
Dim FreqX As Single        'local x frequency holder
Dim FreqY As Single        'local y frequency holder
Dim J As Integer           'local counter
Call TURNZOOMOFF 'turn off the zoom if on
'leave enable line on to watch the drawing be created
Call RST                   'TOGGLE RESET LINES to clear Fifo
IncrementX = (MaxXFreq - MinXFreq) / 249 '250 x steps
IncrementY = (MaxY1Freq - MinY1Freq) / 249 '250 Y steps
FreqY = MinY1Freq                      'set to initial step
For FreqX = MinXFreq To MaxXFreq Step IncrementX 'step through frequencies
 For J = 0 To 7    'eight occurrences in the fifo for each freq  (8*250=2000)
  Call DOSENDING(FreqX, FreqY) 'mid value for y freq
 Next J
 Call DRAWMULTI(FreqX, FreqY) 'draw each spot on the screen without erasing old spots
 FreqY = FreqY + IncrementY   'increment Y frequencies with X
Next FreqX
IncrementY = (MaxY2Freq - MinY2Freq) / 249  'another 2000 fifo location
FreqY = MinY2Freq                      'reset Y for second half
For FreqX = MinXFreq To MaxXFreq Step IncrementX
 For J = 0 To 7    'eight occurrences in the fifo for each freq
  Call DOSENDING(FreqX, FreqY) 'mid value for y freq
 Next J
 Call DRAWMULTI(FreqX, FreqY) 'draw each spot on the screen without erasing old spots
 FreqY = FreqY + IncrementY   'increment Y frequencies with X
Next FreqX
End Sub

Sub DONE_Click () 'Ready to terminate program run
    Call TURNZOOMOFF             'turn off zoom and centroider if on
    form1!Timer5.Enabled = False 'turn off centroider timer
    Call ONOFF(False)
    End
End Sub

Sub EIGHTBEAM_Click () 'display one spot in each corner of the two halves
Dim FreqX As Single    'local frequency holder
Dim FreqY As Single    'local frequency holder
Call TURNZOOMOFF       'turn off the zoom if on
Call ENABLE(0)         'TURN OFF READ
Call RST               'TOGGLE RESET LINES
 FreqX = MinXFreq      'set frequencies to Left half, lower left
 FreqY = MinY1Freq
```

```
'1
 For J = 0 To 199 '200 occurrences in the fifo for each freq(2 fill times)
  Call DOSENDING(FreqX, FreqY) 'mid value for X & Y freq
 Next J
 Call DRAWMULTI(FreqX, FreqY)  'draw the spot
'2
 FreqY = MaxY1Freq          'Left half, Upper left
 For J = 0 To 199 '200 occurrences in the fifo for each freq(2 fill times)
  Call DOSENDING(FreqX, FreqY) 'mid value for X & Y freq
 Next J
 Call DRAWMULTI(FreqX, FreqY)  'draw the spot
'3
 FreqX = MinXFreq
 FreqY = MinY2Freq               'Right Half Lower Left
 For J = 0 To 199 '200 occurrences in the fifo for each freq(2 fill times)
  Call DOSENDING(FreqX, FreqY) 'mid value for X & Y freq
 Next J
 Call DRAWMULTI(FreqX, FreqY)  'draw the spot
'4
 FreqY = MaxY2Freq               'Right Half Upper Left
 For J = 0 To 199 '200 occurrences in the fifo for each freq(2 fill times)
  Call DOSENDING(FreqX, FreqY) 'mid value for X & Y freq
 Next J
 Call DRAWMULTI(FreqX, FreqY)  'draw the spot
'5
 FreqX = MaxXFreq                'Left half, lower right
 FreqY = MinY1Freq
  For J = 0 To 199 '200 occurrences in the fifo for each freq(2 fill times)
 Call DOSENDING(FreqX, FreqY) 'mid value for X & Y freq
 Next J
 Call DRAWMULTI(FreqX, FreqY)  'draw the spot
'6
 FreqY = MaxY1Freq               'left half, Upper Right
 For J = 0 To 199 '200 occurrences in the fifo for each freq(2 fill times)
  Call DOSENDING(FreqX, FreqY) 'mid value for X & Y freq
 Next J
 Call DRAWMULTI(FreqX, FreqY)  'draw the spot
'7
 FreqX = MaxXFreq
 FreqY = MinY2Freq               'Right half, Lower Right
 For J = 0 To 199 '200 occurrences in the fifo for each freq(2 fill times)
  Call DOSENDING(FreqX, FreqY) 'mid value for X & Y freq
 Next J
 Call DRAWMULTI(FreqX, FreqY)  'draw the spot
'8
 FreqY = MaxY2Freq               'Right Half, Upper Right
 For J = 0 To 199 '200 occurrences in the fifo for each freq(2 fill times)
  Call DOSENDING(FreqX, FreqY) 'mid value for X & Y freq
 Next J
 Call DRAWMULTI(FreqX, FreqY)  'draw the spot
Call ENABLE(1)                 'TURN READ LINE BACK ON
End Sub

Sub ELEVENX_Click () 'zoom spot 11 X
threex.Checked = False
fiveX.Checked = False
sevenX.Checked = False
nineX.Checked = False
elevenX.Checked = True  'check the correct menu Item
ZOOMOFF.Checked = False
IsZoomed = SMALLSPOT * 11  'set spot to 11 X size
SPOTDRAW                   'draw the spot
Freqout                    'send out the spot
End Sub

Sub FIVEX_Click ()   'zoom the spot to 5 X
threex.Checked = False
fiveX.Checked = True   'check the correct menu Item
sevenX.Checked = False
nineX.Checked = False
elevenX.Checked = False
ZOOMOFF.Checked = False
IsZoomed = SMALLSPOT * 5  'set the spot size
```

```
SPOTDRAW                    'draw the spot
Freqout                     'send out the spot
End Sub

Sub FOPEN_Click () 'choose to open a picture file
Load filebox        'get the dialog box
filebox.Show        'show the dialog box
End Sub

Sub FORM_GotFocus () 'whenever the Form is on top
SPOTDRAW             'redraw the spot
End Sub

Sub Form_Load () 'When the program starts this form is loaded first
  APP.HelpFile = "lasercom.hlp"'define the help file for the F1 key
  form1.Hide          'hide the main form until it is resized
  Safety.Show 1       'warn about laser 1 for modal
  Call ONOFF(True)    'TURN HARDWARE BOX ON
  IsZoomed = SMALLSPOT  'initialize the spot size
  OldIsZoomed = IsZoomed 'Remember it for latter
  CentroidOn = False 'centroid off to start
  Calibrated = False 'Not calibrated yet
  MaxCounter = 10  'number of warmup Intervals for timers
  OnCounter = 0    'initially all off for timers
  form1!Text2 = Format$(MidXFreq, "##0.000") 'set start Freq
  form1!Text4 = Format$(MidY2, "##0.000")'set start Freq
  Call TVFRAMESETUP 'Set up Form 1
  form1.Refresh      'force display to update
  Call BOARDINIT     'Initialize the hardware
  Timer1.Enabled = True'in one second turn on spot
End Sub

Sub FORM_MouseMove (Button As Integer, Shift As Integer, X As Single, Y As Single)
Screen.MousePointer = 1  'When mouse is on Form, let it be an ARROW POINTER
End Sub

Sub Form_Paint () 'when the form need refreshing
If Not Fancy Then
  SPOTDRAW   'draw a single spot if not in multispot mode
  Freqout    'SEND SPOT OUT
End If
End Sub

Sub FORM_Resize ()  'If form size changes
If form1.Width > 600 Then TVFRAMESETUP 'dynamically scale all the screen elements if not an Ico
n
End Sub

Sub FORM_Unload (Cancel As Integer)  'When program is terminating
    Cancel = True 'Yes this is the end of the program
    form1!Timer5.Enabled = False 'turn off centroider
    Call ONOFF(False)
    End
End Sub

Sub FOURBEAM_Click () 'four simulataneous beams
Dim FreqX As Single   'local frequency holder
Dim FreqY As Single   'local frequency holder
Call TURNZOOMOFF 'turn off the zoom if on
Call ENABLE(0)                          'TURN OFF READ
Call RST                                'TOGGLE RESET LINES
 FreqX = (MaxXFreq - MinXFreq) / 3 + MinXFreq 'left half, 1/3
 FreqY = MidY1                               'middle Y
 For J = 0 To 199 '200 occurrences in the fifo for each freq(2 fill times)
  Call DOSENDING(FreqX, FreqY) 'mid value for X & Y freq
 Next J
 Call DRAWMULTI(FreqX, FreqY)  'Draw spot on screen without erasing others
 FreqY = MidY2                               'Right half middle
 For J = 0 To 199 '200 occurrences in the fifo for each freq(2 fill times)
  Call DOSENDING(FreqX, FreqY) 'mid value for X & Y freq
 Next J
 Call DRAWMULTI(FreqX, FreqY) 'Draw spot on screen without erasing others
 FreqX = (MaxXFreq - MinXFreq) * 2 / 3 + MinXFreq  'left half, 2/3
```

```
 FreqY = MidY1                                            'middle Y
 For J = 0 To 199 '200 occurrences in the fifo for each freq(2 fill times)
  Call DOSENDING(FreqX, FreqY) 'mid value for X & Y freq
 Next J
 Call DRAWMULTI(FreqX, FreqY)  'Draw spot on screen without erasing others
 FreqY = MidY2                                            'right half middle
 For J = 0 To 199 '200 occurrences in the fifo for each freq(2 fill times)
  Call DOSENDING(FreqX, FreqY) 'mid value for X & Y freq
 Next J
 Call DRAWMULTI(FreqX, FreqY) 'Draw spot on screen without erasing others
Call ENABLE(1)                 'TURN READ LINE BACK ON
End Sub

Sub HORIZONTAL_Click () 'draw horizontal Line
Dim increment As Single 'X frequency step
Dim Freq As Single      'local X frequency holder
Call TURNZOOMOFF        'turn off the zoom if on
'leave enable line on to watch the drawing be created
Call RST                'TOGGLE RESET LINES
increment = (MaxXFreq - MinXFreq) / 249 '250 steps across each half
For Freq = MinXFreq To MaxXFreq Step increment    'do steps  for left half
 For J = 0 To 7    'eight occurrences in the fifo for each freq
  Call DOSENDING(Freq, MidY1) 'mid value for y freq
 Next J
 Call DRAWMULTI(Freq, MidY1)  'draw the spots on the screen without erasing old ones
Next Freq
For Freq = MinXFreq To MaxXFreq Step increment   'do steps for right half
 For J = 0 To 7    'eight occurrences in the fifo for each freq
  Call DOSENDING(Freq, MidY2) 'mid value for y freq
 Next J
 Call DRAWMULTI(Freq, MidY2)  'draw the spots on the screen without erasing old ones
Next Freq
End Sub

Sub HSCROLL1_Change ()                             'when bar or buton is clicked
DEGX = HScroll1.Value / 10#                        'get X text and convert to degrees
DEGY = -(VScroll1.Value / 10# - VMax / 20#) 'get Y text and convert to degrees
Call DEGtoFREQ(DEGX, DEGY)                         'convert degrees to frequencies
Text1.Text = Format$(DEGX, "##0.0")                'redisplay degree X text
Text2.Text = Format$(XFreqOut, "##0.000")          'display new X frequency as text
Text4.Text = Format$(YFreqOut, "##0.000")          'display new Y frequency as text
SPOTDRAW                                           'draw the new spot
End Sub

Sub HSCROLL1_Scroll ()                             'The bar button is being dragged
DEGX = HScroll1.Value / 10#                        'get X text and convert to degrees
DEGY = -(VScroll1.Value / 10# - VMax / 20#) 'get Y text and convert to degrees
Call DEGtoFREQ(DEGX, DEGY)                         'convert degrees to frequencies
Text1.Text = Format$(DEGX, "##0.0")                'redisplay degree X text
Text2.Text = Format$(XFreqOut, "##0.000")          'display new X frequency as text
Text4.Text = Format$(YFreqOut, "##0.000")          'display new Y frequency as text
SPOTDRAW                                           'draw the new spot
End Sub

Sub NINEX_Click () 'Set zoom to 9 X
threex.Checked = False
fiveX.Checked = False
sevenX.Checked = False
nineX.Checked = True  'check only the correct menu Item
elevenX.Checked = False
ZOOMOFF.Checked = False
IsZoomed = SMALLSPOT * 9    'set spot size to 9 X
SPOTDRAW                    'draw the spot
Freqout                     'send the spot out
End Sub

Sub NOBEAMS_Click ()
Call TURNZOOMOFF        'turn off zoom if on
RST 'reset FIFO turns all beams off
form1!Picture1.Cls    'and clear the display window
'redraw vertical separator line on screen
form1!Picture1.Line (.5 * form1!Picture1.ScaleWidth, 0)-(.5 * form1!Picture1.ScaleWidth, form1!
Picture1.ScaleHeight), Black
```

```
End Sub

Sub PICTURE1_MouseDown (Button As Integer, Shift As Integer, X As Single, Y As Single)
PMOUSE = True         'Set the global variable to MOUSE IS DOWN
HScroll1.Value = (X / form1!Picture1.Width) * hmax  'set the scroll bar to match the mouse posi
tion
VScroll1.Value = (Y / form1!Picture1.Height) * VMax 'a change in the scrollbars will update the
 text output
End Sub

Sub PICTURE1_MouseMove (Button As Integer, Shift As Integer, X As Single, Y As Single)
Screen.MousePointer = 2 'while mouse is moving in the picture window, set it to crosshair shape
If PMOUSE = True Then 'if the mouse button is pressed...
  form1.Timer5.Enabled = False 'turn off timer while moving
  h = (X / form1!Picture1.Width) * hmax  'get the mouse X Coor.
  v = (Y / form1!Picture1.Height) * VMax 'get the mouse Y Coor.
  If h < 0 Then    'limit the value to within the Picture1 size
    h = 0
  Else If h > hmax Then h = hmax
  End If
  If v < 0 Then
    v = 0
  Else If v > VMax Then v = VMax
  End If
  HScroll1.Value = h    'set the scrollbars to refloxt tha mouse position
  VScroll1.Value = v    'a change in the scrollbars will update the text output
End If   'is mouse button pressed
If CentroidOn Then form1.Timer5.Enabled = True 'turn it on again
End Sub

Sub PICTURE1_MouseUp (Button As Integer, Shift As Integer, X As Single, Y As Single)
PMOUSE = False 'set the Global variable to reflect that the mouse button is no longer presued
End Sub

Sub SEVENX_Click ()  'Seven X menu option chosen
threex.Checked = False
fiveX.Checked = False
sevenX.Checked = True  'make sure only seven X menu item is checked
nineX.Checked = False
elevenX.Checked = False
ZOOMOFF.Checked = False
IsZoomed = SMALLSPOT * 7 'set spot size to 7 X
SPOTDRAW                 'draw the spot
Freqout                  'send out the spot
End Sub

Sub TEXT2_Change () 'when the X screen text is changed, output the new spot
Call Freqout    'SEND FREQUENCY DATA TO FIFO #1
End Sub

Sub TEXT4_Change () 'when the Y screen text is changed, output the new spot
Call Freqout' SEND FREQUENCY DATA TO FIFO #2
End Sub

Sub THREEX_Click ()   'Three X menu option chosen
threex.Checked = True 'make sure only Three X menu item is checked
fiveX.Checked = False
sevenX.Checked = False
nineX.Checked = False
elevenX.Checked = False
ZOOMOFF.Checked = False
IsZoomed = SMALLSPOT * 3 'set spot size to 3 X
SPOTDRAW                 'draw the spot
Freqout                  'send out the spot
End Sub

Sub TIMER1_TIMER () 'initialize output
Call Freqout 'send out spot after program starts
Timer1.Enabled = False'after doing it turn self off
End Sub


Sub TIMER5_Timer ()
```

```
Call CENTROIDING 'used to periodically do centroiding
End Sub

Sub TWOBEAM_Click ()      'Menu Item for two out beams chosen
Dim FreqX As Single       'local Frequency holder
Dim FreqY As Single       'local Frequency holder
Call TURNZOOMOFF          'turn off zoom if on
Call ENABLE(0)            'TURN OFF READ
Call RST                  'TOGGLE RESET LINES
 FreqX = MidXFreq         'set mid left half
 FreqY = MidY1            'set mid Y
 For J = 0 To 199 '200 occurrences in the fifo for each freq(2 fill times)
  Call DOSENDING(FreqX, FreqY) 'mid value for X & Y freq
 Next J
 Call DRAWMULTI(FreqX, FreqY)  'draw each spot without ereasing old ones
 FreqY = MidY2                 'set mid right
 For J = 0 To 199 '200 occurrences in the fifo for each freq(2 fill times)
  Call DOSENDING(FreqX, FreqY) 'mid value for X & Y freq
 Next J
 Call DRAWMULTI(FreqX, FreqY)  'draw each spot without ereasing old ones
 Call ENABLE(1)                'TURN READ LINE BACK ON
End Sub

Sub USING_Click ()
Dummy = Shell("c:\windows\winhelp.exe WinHelp.hlp")'start windows help on help
End Sub

Sub VERTICAL_Click ()     'Draw a vertical line in each half, was chosen from the menu
Dim increment As Single 'step size holder
Dim FreqY As Single       'local Frequency holder
Dim FreqX As Single       'local Frequency holder
Call TURNZOOMOFF          'turn off zoom if on
'leave enable line on to watch the drawing be created
Call RST                  'TOGGLE RESET LINES
FreqX = MidXFreq          'middle Of X
increment = (MaxY1Freq - MinY1Freq) / 249    '250 steps
FreqY = MinY1Freq                             'start at left bottom
While FreqY < MaxY1Freq                       'doit
 For J = 0 To 7     'eight occurrences in the fifo for each freq
   Call DOSENDING(FreqX, FreqY) 'mid value for y freq
 Next J
 Call DRAWMULTI(FreqX, FreqY)  'draw each spot without ereasing old ones
FreqY = FreqY + increment      'next step up
Wend
increment = (MaxY2Freq - MinY2Freq) / 249    'reset for right half
FreqY = MinY2Freq                             'skip unused verticle bandwidth
While FreqY < MaxY2Freq                       'doit
 For J = 0 To 7     'eight occurrences in the fifo for each freq
   Call DOSENDING(FreqX, FreqY) 'mid value for y freq
 Next J
Call DRAWMULTI(FreqX, FreqY)  'draw each spot without ereasing old ones
FreqY = FreqY + increment     'next step up
Wend
End Sub

Sub VSCROLL1_Change ()                             'The bar of arrows are being clicked on
DEGX = HScroll1.Value / 10#                        'convert the screen text to X degrees
DEGY = -(VScroll1.Value / 10# - VMax / 20#)        'convert the screen text to Y degrees
Call DEGtoFREQ(DEGX, DEGY)                         'convert the degrees to frequencies
Text2.Text = Format$(XFreqOut, "##0.000")          'display the new X Frequency
Text3.Text = Format$(DEGY, "##0.0")                'display the new Y Degrees
Text4.Text = Format$(YFreqOut, "##0.000")          'display the new Y Frequency
SPOTDRAW                                           'draw the new spot
End Sub

Sub VSCROLL1_Scroll ()                             'the button on the bar is being dragged
DEGX = HScroll1.Value / 10#                        'convert the screen text to X degrees
DEGY = -(VScroll1.Value / 10# - VMax / 20#)        'convert the screen text to Y degrees
Call DEGtoFREQ(DEGX, DEGY)                         'convert the degrees to frequencies
Text2.Text = Format$(XFreqOut, "##0.000")          'display the new X Frequency
Text3.Text = Format$(DEGY, "##0.0")                'display the new Y Degrees
Text4.Text = Format$(YFreqOut, "##0.000")          'display the new Y Frequency
SPOTDRAW                                           'draw the new spot
```

```
End Sub

Sub ZOOMOFF_Click () 'zoom off menu Item chosen
Call TURNZOOMOFF     'turn off the zoom if on
SPOTDRAW             'draw the spot
Freqout              'send out the spot
End Sub
```

```
Sub OK_Click ()
safety.Hide 'continue with program
End Sub

Sub cancel_click ()
End            'end  the program before it starts
End Sub

Sub Form_Paint ()
OKButton.SetFocus 'highlight button as default
End Sub

Sub OKbutton_Click ()
safety.Hide 'when OK continue with program
End Sub
```

```
Sub DIR1_Change () 'if the selected directory changes, rflect the change
    File1.Path = Dir1.Path
End Sub

Sub DRIVE1_Change () 'if the selected directory changes, rflect the change
    On Error GoTo DriveIError  'make sure no error on reading drive
    Dir1.Path = DRIVE1.Drive   'if no error, get data
Exit Sub
DriveIError:                   'handle error
    Beep
    If Err = 68 Or Err = 71 Then  'print error message
        Msg$ = "Error #" + Str$(Err) + "  No Floppy in the Drive!"
        MsgBox Msg$, 48
    Else
        Msg$ = "Error #" + Str$(Err)    'print generic error message
    End If
    Resume                         'go back to program
End Sub

Sub ExitDemo_Click ()
Filebox.Hide 'if filebox canceled, get rid of window
End Sub

Sub FILE1_DblClick () 'allow double clicking the name to load the file
Call LOADFILE_Click  'If double clicked then load file
End Sub

Sub LOADFILE_Click ()
' Routine do get a data file and use it to display a line pattern
 Dim Filename As String  'The file containing the data
 Dim Commnd As String    'The first item command on each data line
 Dim FirstParm As Single 'The second item on each data line (if needed)
 Dim SecondParm As Single'The third item on each data line (if needed)
 Dim ThirdParm As Integer'The forth item on each data line (if needed)
 Dim I As Integer        'local counter
 Dim J As Integer        'local counter
 Dim NTIMES As Integer   'The number of fifo locations for each point
 Dim OldDX As Single     'temporary parameter holder
 Dim OldDY As Single     'temporary parameter holder
 Dim DegX As Single      'Spot position holder
 Dim DegY As Single      'Spot position holder
 Dim StepX As Single     'increment of next spot position
 Dim StepY As Single     'increment of next spot position
 Filebox.Hide            'get ride of the File Open Dialog Box
 form1.Refresh           'Repaint the display
If File1 <> "" Then       'a name was chosen
 'make the file name with full path specified
 If Right$(Dir1, 1) = "\" Then  'root filenames end in slash
    Filename = Dir1 + File1
    Else
    Filename = Dir1 + "\" + File1 'subdirectories need slash added
 End If
 Open Filename For Input As #1    'open the file
 Input #1, Commnd                 'check the first statement
 If UCase$(Commnd) <> "START" Then  'If not "start" then file not in correct format
    Beep                            'beep and do nothing
 Else                               'file is OK to start
   Call TURNZOOMOFF 'turn off the zoom if on
   Call RST   'TOGGLE RESET LINES   'Clear the Fifo
   form1.Picture1.Cls               'clear the Display area
   Input #1, NTIMES                 'Get the number of location to fill the fifo for each point
displayed
   While (Not EOF(1))               'Keep getting data until the end of the file
     Input #1, Commnd               'get the next command
     Select Case UCase$(Commnd)     'Act on the command
       Case "POINT"                 'If it is a point
        Input #1, FirstParm, SecondParm 'Get X and Y Coordinates, in Degrees
        OldDX = FirstParm           'save it for latter
        OldDY = SecondParm          'save it for latter
        Call DEGtoFREQ(FirstParm, SecondParm) 'convert degrees to frequencies
        For J = 0 To NTIMES - 1     'for Ntimes
```

```
          Call DOSENDING(XFREQOUT, YFREQOUT) 'Fill the Fifo
        Next J
        Call DRAWMULTI(XFREQOUT, YFREQOUT)  'Display location on screen
       Case "LINE"                    'If it is a line
        Input #1, FirstParm, SecondParm, ThirdParm 'Get the X, Y and number of steps
        StepX = (FirstParm - OldDX) / (ThirdParm - 1) 'Calculate the X step size
        StepY = (SecondParm - OldDY) / (ThirdParm - 1) 'Calculate the Y step Size
        DegX = OldDX + StepX  'take one step from starting point
        DegY = OldDY + StepY  'take one step from starting point
        For I = 1 To ThirdParm - 1  'for number of step do...
        Call DEGtoFREQ(DegX, DegY)  'convert to frequencies
        For J = 0 To NTIMES - 1     'for NTimes
           Call DOSENDING(XFREQOUT, YFREQOUT) 'Fill the Fifo
        Next J
        Call DRAWMULTI(XFREQOUT, YFREQOUT)    'Display the point
        DegX = DegX + StepX                   'increment to the next point
        DegY = DegY + StepY                   'increment to the next point
        Next I                                'Take the next step
        OldDX = FirstParm                     'Remember where we left off
        OldDY = SecondParm                    'Remember where we left off
       Case "CLEAR"                 'Start new picture
        Call RST    'TOGGLE RESET LINES to clear the Fifo
        form1.Picture1.Cls         'clear the display
       Case "END"
        'does nothing, but looks good at end of the file
       Case Else
         Beep     'Anything else is not a valid command.
     End Select
     Wend
 End If     'End of Valid data file
 Close #1   'close the file
Fancy = True 'set the Mode varible to multypoint display
End If'no file name chosen
End Sub

Sub TEXT1_KeyDown (KeyCode As Integer, Shift As Integer)
    If KeyCode = 13 Then     'If Enter key is hit
       File1.Pattern = Text1.Text 'select text
    End If
End Sub
```

```
'Lasercom Software, Version 1.01, June 1993
'Writen By Lee Burberry, Staff Engineer
'Harris Corp., Information Systems Division
'PO Box 98000, Melbourne Fl, 32902
'
Global PMouse As Integer              'IS MOUSE DOWN IN PICTURE1
Global OldX As Single                 'PRIVIOUS X IN PICTURE1
Global OldY As Single                 'PRIVIOUS Y IN PICTURE1
Global IsZoomed As Integer            'ZOOM TOGGLE
Global OldIsZoomed As Integer         'ZOOM STATE STORAGE
Global XFreqOut As Single             'X OUTPUT FREQUENCY IN MHz
Global YFreqOut As Single             'Y OUTPUT FREQUENCY IN MHz
Global Upperhalf As Integer           'WHICH HALF OF SPLIT
Global PortOut(0 To 2) As Integer     'PORTA=0, PORTB=1,PORTC=2
Global Status As Integer              'RETURN FROM DIGITAL BOARD
Global CentroidOn As Integer          'on off place holder
Global Fancy As Integer               'Is more than one spot being drawn
Global XCentroid, YCentroid As Single'weighted average inside box
Global XCentroids(0 To 12, 0 To 12) As Single'array of calibration offsets
Global YCentroids(0 To 12, 0 To 12) As Single'array of calibration offsets
Global Calibrated As Integer          'state of calibration
Global Const SMALLSPOT = 15           'Number of Pixels to draw for spot Radius
Global Const Hmax = 3600              'Horizontal scale for 360 degrees
Global Const Vmax = 360               'Vertical scale for 36 degrees
Global Const Black = 0                'Color number
Global Const White = &HFFFFFF         'Col : number
Global Const Magenta = &HFF00FF       'Color number
Global Const MinXFreq = 18            'Horizontal bragg cell band minimum in MegaHertz
Global Const MaxXFreq = 30            'Horizontal bragg cell band maximum in MegaHertz
Global Const MidXFreq = (MaxXFreq - MinXFreq) / 2 + MinXFreq'Horizontal bragg cell band middle
Global Const MinY1Freq = 18           'Vertical cell band minimum in MegaHertz
Global Const MaxY1Freq = 23.25        'Vertical cell band maximum in MegaHertz for lower mirror
Global Const MidY1 = (MaxY1Freq - MinY1Freq) / 2 + MinY1Freq 'middle of lower vertical bandwidt
h
Global Const MinY2Freq = 24.75        'Vertical cell Upper band minimum in MegaHertz
Global Const MaxY2Freq = 30           'Vertical cell band maximum in MegaHertz
Global Const MidY2 = (MaxY2Freq - MinY2Freq) / 2 + MinY2Freq 'middle of upper vertical bandwidt
h
Global Const OffsetY = MinY2Freq - MinY1Freq  'Seperation of the two vertical Bands
Global Const NumBits = 262144         '2^18 BITS for DDS board resolution
Global Const DDSClock = 160           '160 MHZ CLOCK TO DDS BOARDS
Global Const EnableHi = 32            'BINARY 00100000 ENABLE HIGH     (OR IN)
Global Const EnableLo = 223           'BINARY 11011111 ENABLE LOW      (AND IN)
Global Const ABMask = 255             'BINARY 11111111
Global Const CMask = 3                'BINARY 00000011
Global Const ClearC = 252             'BINARY 11111100
Global Const ResetHi = 4              'BINARY 00000100
Global Const ResetLo = 251            'BINARY 11111011
Global Const ResetDDSHi = 128         'BINARY 10000000
Global Const ResetDDSLo = 127         'BINARY 01111111
Global Const Wrtln1Hi = 8             'BINARY 00001000
Global Const Wrtln1Lo = 247           'BINARY 11110111
Global Const Wrtln2Hi = 16            'BINARY 00010000
Global Const Wrtln2Lo = 239           'BINARY 11101111
Global Const RelayOn = 2              'BINARY 00000010
Global Const RelayOff = 253           'BINARY 11111101
Global Const MB_OK = 0                'Define buttons
Global Const MB_OKCANCEL = 1
Global Const MB_YESNOCANCEL = 3
Global Const MB_YESNO = 4
Global Const MB_ICONSTOP = 16
Global Const MB_ICONQUESTION = 32
Global Const MB_ICONEXCLAMATION = 48
Global Const MB_ICONINFORMATION = 64
Global Const MB_DEFBUTTON2 = 256      'Define other.
Global Const IDOK = 1                 'OK button selected.
Global Const IDCANCEL = 2             'Cancel button selected.
Global Const IDABORT = 3              'Abort button selected.
Global Const IDRETRY = 4              'Retry button selected.
Global Const IDIGNORE = 5             'Ignore button selected.
Global Const IDYES = 6                'Yes button selected.
Global Const IDNO = 7                 'No button selected.
```

```
'The following three lines declare the functions that control the I/O card
Declare Function DIG_Out_Port% Lib "atwdaq.dll" (ByVal slot%, ByVal port%, ByVal pattern%)
Declare Function DIG_Prt_Config% Lib "atwdaq.dll" (ByVal slot%, ByVal port%, ByVal latch_mode%,
 ByVal direction%)
Declare Function DIG_Prt_Status% Lib "atwdaq.dll" (ByVal slot%, ByVal port%, Status%)
'The following is for the Vidio Frame Grabber Card
''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
''''''''''''''''''
'Global Declarations For SVW CIL (Common Interface Library)
'New Media Graphics (c) 1992
'Modifications:
'   Release 1.3b Supplemental (1:33 pm)
'   gek 22-Jun-1992 Add support for Still Frame Compression board
'   gek 17-Jun-1992 Change FrameGrab Structure to accept pointers
'                   Change AVputToBitmap and AVgetFromBitmap graphicsRect to
'                   use As Any instead of As AVrect
'                   Add Window's SendMessage declaration
'



'Function Declarations

'-----------------------------------------------------------------------
' From Av_ctrl.h
'-----------------------------------------------------------------------

' Private Window Messages Start Here (0x400) :
Global Const WM_USER = 1024


'
' Define New Messages that can be sent to the AV Control
'
'           Message ID                            wParam          lParam
'           ----------                            ------          ------
'
Global Const AVM_GETVIDEO = (WM_USER + 1)       '
Global Const AVM_FADEIN = (WM_USER + 2)         ' FadeMask        Duration
Global Const AVM_FADEOUT = (WM_USER + 3)        ' FadeMask        Duration
Global Const AVM_FREEZE = (WM_USER + 4)         ' True/False
Global Const AVM_LISTSOURCES = (WM_USER + 5)    ' Buffer Length   Buffer Pointer
Global Const AVM_GETSOURCE = (WM_USER + 6)      ' Buffer Length   Buffer Pointer
Global Const AVM_SETSOURCE = (WM_USER + 7)      '                 Buffer Pointer
Global Const AVM_SETCOLORKEY = (WM_USER + 8)    ' Hardwa.e color index
Global Const AVM_GETCOLORKEY = (WM_USER + 9)    '
Global Const AVM_SETCOLOR = (WM_USER + 10)      '                 COLORREF
Global Const AVM_SETDISPLAY = (WM_USER + 11)    ' Video Parameter Value
Global Const AVM_GETDISPLAY = (WM_USER + 12)    ' Video Parameter
Global Const AVM_SETAUDIO = (WM_USER + 13)      ' Audio Paramter  Value
Global Const AVM_GRAB = (WM_USER + 14)          ' AV_GRAB command LPFRAMEGRAB
Global Const AVM_PUT = (WM_USER + 15)           ' AV_PUT command  LPFRAMEGRAB
Global Const AVM_FITMODE = (WM_USER + 16)       ' Fit Mode
Global Const AVM_AUTORESIZE = (WM_USER + 17)    ' True/False
Global Const AVM_NOTIFY = (WM_USER + 19)        '
Global Const AVM_GETFITMODE = (WM_USER + 20)
Global Const AVM_TUNE = (WM_USER + 21)          ' channel  loword=finetune, hi=standard
Global Const AVM_GETAUDIO = (WM_USER + 22)      ' Audio Parameter
Global Const AVM_SETPOSITION = (WM_USER + 23)   '                 AVrectPtr
Global Const AVM_GETPOSITION = (WM_USER + 24)   '                 AVrectPtr
Global Const AVM_MAP = (WM_USER + 25)           '
Global Const AVM_UNMAP = (WM_USER + 26)         '
Global Const AVM_GETCOLOR = (WM_USER + 27)      '

'
'  List of normal window messages WM_ that are used by the AV control
'
'   Message         Additional use in AV Control
'
'   WM_ENABLE       This will enable/disable the Video
'   WM_SIZE         Resizes the video to fit the window
```

```
'   WM_MOVE          Moves the video to fit the window
'


'
' Commands & Data structures involved in FrameGrabbing
'
Global Const AV_GRAB_FILE = 0      ' uses filename field to name dest file
Global Const AV_GRAB_BITMAP = 1    ' uses bitmap field to hold result
Global Const AV_GRAB_CUT = 2       ' uses Windows Clipboard to hold result
Global Const AV_GRAB_COPY = 3      ' uses Windows Clipboard to hold result

Global Const AV_PUT_FILE = 0       ' uses filename field to hold source file
Global Const AV_PUT_BITMAP = 1     ' uses bitmap field as the source
Global Const AV_PUT_PASTE = 2      ' uses Windows Clipboard as the source
Global Const AV_PUT_CLEAR = 3      ' Puts all black to the framebuffer


'*****************************************************************
'*                                                               *
'* Copyright (C) 1992 New Media Graphics Corp.                   *
'*                                                               *
'* Module:       avsys.h                                         *
'* Description: Visual Basic definitions for AV CIL              *
'*                                                               *
'*              M S - W I N D O W S   3 . 0   E D I T I O N      *
'*                     Compiled under Visual Basic 1.0           *
'*                                                               *
'*****************************************************************


' Name of configuration file (does not specify location)

Global Const CONFIGFILE = "VIDEO.INI"  ' Filename of Configuration file

' Define the strings for graphics mode configuration

Global Const INI_GRAPHICS_MODE = "Mode"
Global Const INI_WALIGN_LEFT = "Wleft"
Global Const INI_WALIGN_TOP = "Wtop"
Global Const INI_VALIGN_LEFT = "Vleft"
Global Const INI_VALIGN_RIGHT = "Vright"
Global Const INI_VALIGN_TOP = "Vtop"
Global Const INI_VSTART = "Vstart"
Global Const INI_SHIFT = "Shift"
Global Const INI_GDELAY = "Gdelay"
Global Const INI_RED = "Red"
Global Const INI_GREEN = "Green"
Global Const INI_BLUE = "Blue"


' Maximum length of a source name
Global Const SRCNAME_LEN = 16


'* This structure defines what a vidport looks like.  It
'* is used by AVdefineVidport.

Type Vidport
    X1 As Integer
    Y1 As Integer
    x3 As Integer
    y3 As Integer
End Type

Type Winport
    X As Integer
    Y As Integer
    Width As Integer
    Height As Integer
End Type

Type DisplayAttr
```

```
    bright As Integer
    sat As Integer
    contrast As Integer
    hue As Integer
    sharp As Integer
    Flags As Integer                        ' Black and white flag
End Type

' Describe a unit configuration

Type UnitConfig
    unit_type As Integer        ' Type of video unit, from UNIT_ below
    total_vins As Integer       ' Video inputs
    total_ains As Integer       ' Audio inputs
    window_mode As Integer      ' Reserved
    locks As Integer            ' Number of open handles
    key_mode As Integer         ' Current color keying mode KEY_ below
    key_value As Integer        ' Parameter for color key mode
    active As Integer
End Type

' Describe a source configuration

Type SrcConfig
    srctype As Integer          ' See SRC_* below
    sigtype As Integer          ' See SIG_* below
    active As Integer           ' TRUE or FALSE
End Type

'  Describe a connection.  Both of these are numbered 1..n.
'  These are logical numbers, not physical, so the private bus
'  would simply be considered some ordinally numbered input.

Type ConConfig
    video_input As Integer
    audio_input As Integer
End Type

' Misc defines
Global Const AV_UNDEF = -1
Global Const AV_FILLIN = -2

' Error returns from video module
Global Const AV_OK = 0                  ' Everything hunky dory
Global Const AV_FAIL = 1
Global Const AV_NOMEM = 2               ' No memory left
Global Const AV_SYSERR = 3              ' The system returned an error
Global Const AV_INTERNAL = 4            ' Internal error
Global Const AV_NULLVID = 5             ' Null video handle passed
Global Const AV_ILLARG = 6              ' Illegal argument
Global Const AV_RANGE = 7               ' Argument out of range
Global Const AV_TIMEOUT = 8             ' Timeout - no response from hardware
Global Const AV_OVERRUN = 9             ' Data overrun

Global Const AV_NOTFOUND = 10           ' Entry not in configuration file
Global Const AV_NOCONFIG = 11           ' No configuration file
Global Const AV_NOUNITS = 12            ' No video generators on this system
Global Const AV_BADCONFIG = 13          ' Bad entry in configuration file
Global Const AV_DUPNAME = 14            ' Attempt to add a duplicate name
Global Const AV_BADINPUT = 15           ' Illegal connection description
Global Const AV_SPLIT = 16              ' Can't split audio/video across units
Global Const AV_SIGNAL = 17             ' Unknown signal description
Global Const AV_NOCONTROL = 18          ' No control line available for device
Global Const AV_INUSE = 19              ' Device is active
Global Const AV_NOTSUPT = 20            ' Feature not supported
Global Const AV_NOTACTIVE = 21          ' Device requested is not active
Global Const AV_NOCONNECT = 22          ' Device not connected

Global Const AV_BADLOC = 23             ' Attempt to move to bad location
Global Const AV_BADSIZE = 24            ' Attempt to create window with bad size
```

```
Global Const AV_BADFIT = 25             ' Window won't fit on screen
Global Const AV_WMODE = 26              ' Can't in this windowing mode
Global Const AV_ALMOST = 27             ' The winport values were adjusted

Global Const AV_NOTREADY = 28           ' Device not ready
Global Const AV_DEVICE = 29             ' Wrong device type for operation

Global Const AV_BADFORMAT = 30          ' Format not allowed for this operation
Global Const AV_BADFILENAME = 31        ' Filename was not allowed
Global Const AV_BADREGION = 32          ' Error in framegrabbing region

Global Const AV_NOTCOMPLETE = 33        ' Used in framegrabbing.
                                        ' Operation went fine but is NOT
                                          finished yet. It should be called
                                        ' again

Global Const AV_BADIOADDR = 35         ' Bad SVW I/O address
Global Const AV_BADMEMADDR = 36        ' Bad framebuffer address


' Masks for AVconfigure
Global Const AV_QUERY = 1

' Return values from AVgrabToBand and AVputFromBitmap
Global Const XFR_CMPLT = &HA0
Global Const XFR_NCMPLT = &HA1
Global Const XFR_START = &HA2

'
' * Useful Audio constants
' * These constants are documented to be these ranges and will not change.
'
Global Const AV_MINVOL = 0
Global Const AV_MAXVOL = 100
Global Const AV_MINBAL = -100
Global Const AV_MAXBAL = 100
Global Const AV_MINBASS = 0
Global Const AV_MAXBASS = 100
Global Const AV_MINTREBLE = 0
Global Const AV_MAXTREBLE = 100

Global Const AV_VOLUME = 1
Global Const AV_VOLUME_UP = 2
Global Const AV_VOLUME_DOWN = 3
Global Const AV_VOLUME_MUTE = 4
Global Const AV_BALANCE = 5
Global Const AV_BALANCE_LEFT = 6
Global Const AV_BALANCE_RIGHT = 7
Global Const AV_BASS = 8
Global Const AV_BASS_MORE = 9
Global Const AV_BASS_LESS = 10
Global Const AV_TREBLE = 11
Global Const AV_TREBLE_MORE = 12
Global Const AV_TREBLE_LESS = 13
Global Const AUDIO_USRDEF = &H1000              ' Load user defined default

' Flags for DisplayAttr.flags
Global Const DISP_FLAG_BNW = &H1

' AVsetDisplay parameters
Global Const DISP_HUE = 1
Global Const DISP_SATURATION = 2
Global Const DISP_BRIGHTNESS = 3
Global Const DISP_CONTRAST = 4
Global Const DISP_SHARPNESS = 5
Global Const DISP_MFILTER = 6
Global Const DISP_BNW = 7
Global Const DISP_RED = 8                        ' Internal use only
Global Const DISP_GREEN = 9                      ' Internal use only
Global Const DISP_BLUE = 10                      ' Internal use only
Global Const DISP_USRDEF = &H1000               ' Load user defined default
Global Const DISP_SYSDEF = &H2000               ' Load system defined default
```

```
Global Const DISP_MIN_HUE = 0
Global Const DISP_MAX_HUE = 100
Global Const DISP_MIN_SAT = 0
Global Const DISP_MAX_SAT = 100
Global Const DISP_MIN_BRIGHT = 0
Global Const DISP_MAX_BRIGHT = 100
Global Const DISP_MIN_CONT = 0
Global Const DISP_MAX_CONT = 100
Global Const DISP_MIN_SHARP = 0
Global Const DISP_MAX_SHARP = 100

' Types of sources
Global Const SRC_UNKNOWN = "U"
Global Const SRC_LASERDISC = "L"
Global Const SRC_TUNER = "T"                         ' TV Tuner
Global Const SRC_VCR = "V"
Global Const SRC_CAMERA = "C"
Global Const SRC_TUNER_PLUS = "I"                    ' Jr + Tuner (inboard)

' Types of video units
Global Const UNIT_HIRES = "H"              ' Workstation product
Global Const UNIT_SVW = "S"                ' Super VideoWindows
Global Const UNIT_SVW_SL = "J"             ' Super VideoWindows SL
Global Const UNIT_SVW_TV = "P"             ' TV VideoWindows (on one card)
Global Const UNIT_SVW_CM = "C"             ' Super VideoWindows w/Compression
Global Const UNIT_SVW_MCA = "M"            ' Super VideoWindows Microchannel

' Video source types
Global Const SIG_NONE = 0
Global Const SIG_AUTO = "a"                          ' Automatically detect
Global Const SIG_NTSC = "n"
Global Const SIG_PAL = "p"
Global Const SIG_RGB = "r"                           ' Not supported by SVW
Global Const SIG_SVHS_NTSC = "v"

' Fade flag
Global Const FADE_IN = 1
Global Const FADE_OUT = 0

' Fade masks -- Not supported in this release
Global Const FADE_VIDEO = 1
Global Const FADE_AUDIO = 2
Global Const FADE_SCREEN = 4

' Various modes for AVfitMode
Global Const FIT_STRETCH = &H10          ' 16 decimal
Global Const FIT_COMPRESS = &H20         ' 32 decimal
Global Const FIT_CROP = &H40             ' 64 decimal - not supported
Global Const FIT_CENTER = &H21           ' 33 decimal
Global Const FIT_GRAB = &H11             ' 17 decimal
Global Const FIT_ONETOONE = &H12         ' 18 decimal

' Color key modes
Global Const KEY_NONE = 0
Global Const KEY_COLOR = 1                 ' Single color
Global Const KEY_MASK = 2                  ' Set of colors-not implemented yet
Global Const KEY_LOGICAL_PALETTE = 3
Global Const KEY_PHYSICAL_PALETTE = KEY_COLOR

' Op codes for AVcvtRGBtoKeyColor
'
' * BGR888 or COLORREF are intended to accept a Windows COLORREF structure

Global Const CVT_BGR888 = 1
Global Const CVT_COLORREF = 1

'
' * BGR666 is intended to accept the Microsoft C6 constants such
' * as _RED and _GREEN that appear in graph.h.

Global Const CVT_BGR666 = 2
```

```
' * Flags for AVgetDevices.  The active and inactive modifiers
' * are mutually exclusive.  Asking for both of them gives you nothing.

Global Const GET_SOURCES = &H1
Global Const GET_UNITS = &H2
'Global Const GET_ALL         = (GET_SOURCES | GET_UNITS)
Global Const GET_ONLYINACTIVE = &H10
Global Const GET_ONLYACTIVE = &H20
'Global Const AVgetSources(index,buf,n) = AVgetDevices(GET_SOURCES|GET_ONLYACTIVE,index,buf,n

'
' * Various definitions for how to parse video.ini
' * These are case insensitive

Global Const INI_VIDEO_CONNECTION = "VideoOut"
Global Const INI_AUDIO_CONNECTION = "AudioOut"
Global Const INI_ACTIVE_SOURCE = "Active"
Global Const INI_CONTROL_LINE = "Control"
Global Const INI_CONTROL_SETTINGS = "CtrlCfg"
Global Const INI_SIGNAL_TYPE = "Signal"
Global Const INI_SOURCES = "Sources"
Global Const INI_DRIVER_NAME = "DLL"            ' For Microsoft Windows 3.0
Global Const INI_UNITS = "VideoUnits"
Global Const INI_IOADDR = "IOaddr"              ' For SVW, Tuner
Global Const INI_MEMADDR = "MemAddr"            ' For SVW
Global Const INI_SYNC = "AlignSync"
Global Const INI_CONTRAST = "Contrast"
Global Const INI_HUE = "Hue"
Global Const INI_SAT = "Saturation"
Global Const INI_BRIGHT = "Brightness"
Global Const INI_SHARP = "Sharpness"
Global Const INI_VOLUME = "Volume"
Global Const INI_BASS = "Bass"
Global Const INI_TREBLE = "Treble"
Global Const INI_BALANCE = "Balance"
Global Const INI_SOURCE_DEFAULT = "DefaultSource"
Global Const INI_SOURCE_NONE = ""

Global Const DEV_LASERDISC = "Laserdisc"
Global Const DEV_VCR = "VCR"
Global Const DEV_TUNER = "Tuner"
Global Const DEV_TUNER_PLUS = "TunerPlus"
Global Const DEV_CAMERA = "Camera"
Global Const DEV_UNKNOWN = "Unknown"
Global Const DEV_SVW = "SVW"
Global Const DEV_HIRES = "Hires"

'
'* Laserdisc stuff

Global Const PLAY_FORWARD = 0
Global Const PLAY_REVERSE = 1

Global Const AUDIO_NONE = 0
Global Const AUDIO_LEFT = 1
Global Const AUDIO_RIGHT = 2
Global Const AUDIO_BOTH = 3

Global Const PLAYER_AUDIO = 1
Global Const PLAYER_DIRECTION = 2
Global Const PLAYER_SPEED = 3
Global Const PLAYER_FRAME = 4
Global Const PLAYER_DISPLAY = 5

'
' Frame Grabbing Stuff
'/* Rectangle */
Type AVrect
    Left   As Integer
    Top    As Integer
    right  As Integer
    bottom As Integer
End Type
```

```
'/* Framegrab Structure */
Type FrameGrab
    format   As Integer
'   filename As String * 30
    filename As Long
    bitmap   As Integer
'    region   As
    region   As Long
End Type

'****************************************************************
' *
' * Data structures describing an image currently being framegrabbed
' *
' ****************************************************************
' FGB format flags
Global Const AV_BITMAP = 1
Global Const AV_FILE = 0
Global Const AV_PUT = 2
Global Const AV_GRAB = 0
Global Const AV_BOTTOMUP = 4
Global Const AV_TOPDOWN = 0


'****************************************************************
'*
'* Data structures describing a FGB format installed in the CIL
'*
'****************************************************************
'
' Native Format IDs
Global Const AV_SVW = 1

' Supported features of a framegrab format
Global Const AV_GRABBITMAP_SUPT = 1
Global Const AV_PUTBITMAP_SUPT = 2
Global Const AV_GRABFILE_SUPT = 4
Global Const AV_PUTFILE_SUPT = 8
Global Const AV_PRESCAN_SUPT = 16
Global Const AV_APPLGLOBAL = 32

Global Const FILE_REVISION = 1

'****************************************************************
' *
' * Format IDs
' *
' ****************************************************************

' Band Formats
Global Const BAND_SVW_NATIVE = 1
Global Const BAND_WINDOWS24 = 2
Global Const BAND_TARGA16 = 4
Global Const BAND_TARGA24 = 5
Global Const BAND_TARGA32 = 6
Global Const BAND_PCXGRAY = 7
Global Const BAND_PCX256 = 8
Global Const BAND_WINDOWS8 = 9
Global Const BAND_WINDOWS8GRAY = 10
Global Const BAND_JPEG = 11

' Bitmap Formats
Global Const BITMAP_SVW_NATIVE = BAND_SVW_NATIVE
Global Const BITMAP_WINDOWS24 = BAND_WINDOWS24
Global Const BITMAP_WINDOWS8 = BAND_WINDOWS8                ' Grab Only
Global Const BITMAP_WINDOWS8GRAY = BAND_WINDOWS8GRAY        ' Grab Only

' File formats
Global Const FILE_SVW_NATIVE = BAND_SVW_NATIVE       ' read/write
Global Const FILE_WINDOWS24 = BAND_WINDOWS24         ' read/write
Global Const FILE_TARGA16 = BAND_TARGA16             ' read/write
Global Const FILE_TARGA24 = BAND_TARGA24             ' read/write
```

```
Global Const FILE_TARGA32 = BAND_TARGA32           ' read/write
Global Const FILE_PCXGRAY = BAND_PCXGRAY           ' Write Only
Global Const FILE_PCX256 = BAND_PCX256             ' Write Only
Global Const FILE_WINDOWS8 = BAND_WINDOWS8         ' Write Only
Global Const FILE_WINDOWS8GRAY = BAND_WINDOWS8GRAY' Write Only
Global Const FILE_JPEG = BAND_JPEG                 ' read/write


' Standards for the AVtuner call
Global Const USA_BCST = 0
Global Const USA_CATV = 1
Global Const JAPAN = 3

'Still Frame Compression Framegrabbing Literals

Global Const FGC_ALL = 0
Global Const FGC_HIGH = 1
Global Const FGC_MED = 2
Global Const FGC_LOW = 3
Global Const FGC_CUSTOM = 4
Global Const FGC_DIALOG = 5
Global Const FGC_PUT = 6
Global Const FGC_LAST = 7


'#endif

Declare Function AVdefineAudio Lib "Video" (ByVal vid As Long, ByVal volume As Integer, ByVal b
alance As Integer, ByVal bass As Integer, ByVal treble As Integer) As Integer
Declare Function AVsetAudio Lib "Video" (ByVal vid As Long, ByVal parm As Integer, ByVal Value
As Integer) As Integer
Declare Function AVgetDisplay Lib "Video" (ByVal vid As Long, ByVal parm As Integer) As Integer
Declare Function AVgetAudio Lib "Video" (ByVal vid As Long, ByVal parm As Integer) As Integer
Declare Function AVcvtBGRtoKeyColor Lib "Video" (ByVal op As Integer, ByVal Value As Long) As I
nteger
Declare Function AVcvtRGBtoKeyColor Lib "Video" (ByVal R As Integer, ByVal g As Integer, ByVal
b As Integer) As Integer
Declare Function AVgetPlayerStatus Lib "Video" (ByVal vid As Long, ByVal parm As Integer) As Lo
ng
Declare Function AVpausePlayer Lib "Video" (ByVal vid As Long) As Integer
Declare Function AVplayPlayer Lib "Video" (ByVal vid As Long, ByVal end_frame As Long) As Integ
er
Declare Function AVseekPlayer Lib "Video" (ByVal vid As Long, ByVal frame As Long) As Integer
Declare Function AVsetPlayer Lib "Video" (ByVal vid As Long, ByVal parm As Integer, ByVal Value
 As Integer) As Integer
Declare Function AVstepPlayer Lib "Video" (ByVal vid As Long, ByVal incr As Long) As Integer
Declare Function AVstopPlayer Lib "Video" (ByVal vid As Long) As Integer
Declare Function AVcolorKey Lib "Video" (ByVal vid As Long, ByVal mode As Integer, ByVal Value
As Integer) As Integer
Declare Function AVfitMode Lib "Video" (ByVal vid As Long, ByVal mode As Integer) As Integer
Declare Function AVcreate Lib "Video" (ByVal source As String) As Long
Declare Sub AVdestroy Lib "Video" (ByVal vid As Long)
Declare Function AVsetDisplay Lib "Video" (ByVal vid As Long, ByVal parm As Integer, ByVal Valu
e As Integer) As Integer
Declare Function AVmap Lib "Video" (ByVal vid As Long) As Integer
Declare Function AVunmap Lib "Video" (ByVal vid As Long) As Integer
Declare Function AVenable Lib "Video" (ByVal vid As Long) As Integer
Declare Function AVdisable Lib "Video" (ByVal vid As Long) As Integer
Declare Function AVfreeze Lib "Video" (ByVal vid As Long, ByVal flag As Integer) As Integer
Declare Function AVconfigure Lib "Video" (ByVal vid As Long, frame As Winport, ret_wp As Winpor
t, ByVal mask As Integer) As Integer
Declare Function AVmove Lib "Video" (ByVal vid As Long, ByVal X As Integer, ByVal Y As Integer)
 As Integer
Declare Function AVsize Lib "Video" (ByVal vid As Long, ByVal width1 As Integer, ByVal Height A
s Integer) As Integer
Declare Function AVfade Lib "Video" (ByVal vid As Long, ByVal flag As Integer, ByVal mask As In
teger, ByVal delay As Integer) As Integer
Declare Function AVisFaded Lib "Video" (ByVal vid As Long, ByVal mask As Integer) As Integer
Declare Function AVvideoWindow Lib "Video" (ByVal src_name As String, ByVal X As Integer, ByVal
 Y As Integer, ByVal width1 As Integer, ByVal Height As Integer) As Long
Declare Function AVgetKeyMode Lib "Video" (ByVal vid As Long) As Integer
Declare Function AVgetKeyValue Lib "Video" (ByVal vid As Long) As Integer
Declare Function AVdevice Lib "Video" (ByVal vid As Long, ByVal device As String) As Integer
```

```
Declare Function AVtuner Lib "Video" (ByVal vid As Long, ByVal channel As Integer, ByVal fine A
s Integer, ByVal standard As Integer) As Integer
Declare Function AVgrabtofile Lib "Video" (ByVal vid As Long, ByVal filename As String, ByVal f
ormatl As Integer, graphicsRect As Any) As Integer
Declare Function AVputFromFile Lib "Video" (ByVal vid As Long, ByVal filename As String, ByVal
formatl As Integer, graphicsRect As Any) As Integer
Declare Function AVgrabToBitmap Lib "Video" (ByVal vid As Long, ByVal formatl As Integer, graph
icsRect As Any, bitmapPtr As Long) As Integer
Declare Function AVputFromBitmap Lib "Video" (ByVal vid As Long, ByVal formatl As Integer, ByVa
l bitmap As Integer, graphicsRect As Any) As Integer
Declare Function AVclear Lib "Video" (ByVal vid As Long, graphicsRect As AVrect) As Integer
Declare Function AVinit Lib "Video" (ByVal fnam As String) As Integer
Declare Sub AVend Lib "Video" ()

'Windows 3.x functions
Declare Function sendmessage Lib "User" (ByVal hWnd As Integer, ByVal wMsg As Integer, ByVal wP
aram As Integer, lParam As Any) As Long


'Still Frame Compression Framegrabbing functions
Declare Function FGCinstall Lib "Fgc.dll" (ByVal formatl As Integer) As Integer
Declare Function FGCremove Lib "Fgc.dll" (ByVal formatl As Integer) As Integer
Declare Sub FGCsetImageQuality Lib "Fgc.dll" (ByVal quality As Integer, ByVal sharpness As Inte
ger)
Declare Function FGCqualityDialog Lib "Fgc.dll" () As Integer
Declare Function FGCgetSharpness Lib "Fgc.dll" () As Integer
Declare Function FGCgetQuality Lib "Fgc.dll" () As Integer
Declare Function FGCsetAddress Lib "Fgc.dll" (ByVal address As Integer) As Integer
Declare Function FGCgetAddress Lib "Fgc.dll" () As Integer
Declare Function FGCaddressDialog Lib "Fgc.dll" () As Integer


Sub DEGtoFREQ (ByVal X As Single, ByVal Y As Single)
'Routine to convert from degrees to output frequencies
'X AND Y PASSED IN DEGREES
'X ->0 TO 360 DEGREES
'Y +/- 18 DEGREES
Dim SclX As Single  'X scale (horizontal)
Dim SclY As Single  'Y scale (vertical)
SclX = (MaxXFreq - MinXFreq) / 180  'x always goes 0 to 180
If X < 180 Then
  SclY = (MaxY1Freq - MinY1Freq) / 36 'Y has two regions
  Upperhalf = False
Else
  X = X - 180  'WRAP SPACE MOD 180 DEGREES
  SclY = (MaxY2Freq - MinY2Freq) / 36  'if x>180 then use upper half
  Upperhalf = True
End If
  XFreqOut = X * SclX + MinXFreq 'REQUIRED FREQ OUTPUT
  YFreqOut = Y * SclY + MidY1 - Upperhalf * OffsetY
  'RETURN FREQ FOR TWO DIFFERENT REGIONS
End Sub

Sub DOSENDING (XOut As Single, YOut As Single)
'This routine converts frequencies to the numbers required by the dds board
Dim Number As Long 'holds the number to send to the Fifos in the dds card
Dim Midd As Long   'number is 18 bits, mid is middle byte
Dim Hi As Integer  'hi is most significant byte

' do the X frequency
Number = (NumBits / DDSClock) * XOut + 1 'calculate number for dds board
PortOut(0) = Number And ABMask     'ABMASK is Lower 8 bits only
Midd = Number \ 256                'SHIFT RIGHT 8 BITS
PortOut(1) = Midd And ABMask       'set up middle 8 bits
Hi = Midd \ 256                    'SHIFT RIGHT 8 BITS
                                   'set up two msbs, (never used)
' 2 msb's are never set in used frequency range
' msb changed to control hardware on-off relay
' portout(2) = (portout(2) And CLEARC) Or (HI And CMASK)

'SEND THEM OUT
   For I = 0 To 2
     Status = DIG_Out_Port%(ByVal 1, ByVal I, ByVal PortOut(I))
```

```
   Next I
'AND STOBE WRITE LINE to advance fifo counter
   Call WRTLN(1)                'FIFO 1 OR 2

' do the Y frequency
Number = (NumBits / DDSClock) * YOut + 1  'calculate number for dds board
PortOut(0) = Number And ABMask      'ABMASK is Lower 8 bits only
Midd = Number \ 256                 'SHIFT RIGHT 8 BITS
PortOut(1) = Midd And ABMask        'set up middle 8 bits
Hi = Midd \ 256                     'SHIFT RIGHT 8 BITS
                                    'set up two msbs, (never used)
' 2 msb's are never set in used frequency range
' msb changed to control hardware on-off relay
' portout(2) = (portout(2) And CLEARC) Or (HI And CMASK)

'SEND THEM OUT
   For I = 0 To 2
     Status = DIG_Out_Port%(ByVal 1, ByVal I, ByVal PortOut(I))
   Next I
'AND STOBE WRITE LINE to advance fifo counted
   Call WRTLN(2)                'FIFO 1 OR 2
End Sub

Sub DRAWMULTI (ByVal X As Single, ByVal Y As Single)
'routine to draw more than one spot on Picture1 frame for fancy outputs
Dim Q As Single 'x position on display window
Dim R As Single 'y position on display window
'draw but don't erase
'calculate and scale the X postion
Q = ((X - MinXFreq) / (MaxXFreq - MinXFreq)) * Form1!Picture1.Width * .494
'is it in left half or right half
If Y > MaxY1Freq Then  'right half
  Q = Q + Form1!Picture1.Width * .5 'jump to right half
  Y = Y - OffsetY 'reduce to in picture range
End If
'calculate and scale the y position
R = Form1!Picture1.Height - ((Y - MinY1Freq) / (MaxY1Freq - MinY1Freq)) * Form1!Picture1.Height
 * .95 - 40
'Output spot to screen
Form1!Picture1.Line (Q - IsZoomed, R - IsZoomed)-(Q + IsZoomed, R + IsZoomed), Black, BF
'draw vertical screen separator line
Form1!Picture1.Line (.5 * Form1!Picture1.ScaleWidth, 0)-(.5 * Form1!Picture1.ScaleWidth, Form1!
Picture1.ScaleHeight), Black
End Sub

Sub ENABLE (I As Integer) '0 FOR LOW, 1 FOR HI
'READ ENABLE IS DISABLED WHEN LO, ENABLED WHEN HI
'set up port 2 with bit pattern for enable and leave other bits intact
If I = 0 Then
  PortOut(2) = PortOut(2) And EnableLo 'PORT C
Else
  PortOut(2) = PortOut(2) Or EnableHi 'PORT C
End If
'send it out
Status = DIG_Out_Port%(ByVal 1, ByVal 2, ByVal PortOut(2))
End Sub

Sub Freqout ()  'parameters passed as global variable XFreqOut, and YFreqOut
'routine to output a single spot to the DDS Fifo and update the screen
Dim I, J, K, N As Integer  'local counters
Dim XOut As Single         'Local version of XFreqOut
Dim YOut As Single         'Local version of YFreqOut
Dim ZoomFactor As Integer  'amount of Zoom
Dim Delta As Single        'SPACING OFFSET FACTOR
Const XOffset = .025       'MHz .025
Const YOffset = .1        'MHz .05

ZoomFactor = IsZoomed / SMALLSPOT  'How much to zoom

Call ENABLE(0)                      'TURN OFF READ
Call RST                            'TOGGLE RESET LINES

Select Case ZoomFactor
```

```
 Case 1:                            'NO ZOOM
    XOut = XFreqOut                 'LOCAL STORAGE
    YOut = YFreqOut                 'LOCAL STORAGE
   Call DOSENDING(XOut, YOut)       'send one spot
 Case 3:                            'USE 4 SPOTS
    Delta = 1                       '1 full pixel position stagger
    N = 103                         'about one total fill time for all spots
    Do While N >= 0                 'set up 16 spot array
     I = Int(N / 26) - 1.5          '1.5, .5 ,-.5,-1.5
     J = Int((N Mod 52) / 13) - 1.5   '1.5, .5 ,-.5,-1.5
     'each spot is offset one pixel spacing
     XOut = XFreqOut + I * Delta * XOffset
     YOut = YFreqOut + J * Delta * YOffset
     Call DOSENDING(XOut, YOut)  'send out spots to fifo
     N = N - 1
    Loop  'next n
 Case 5:                            'USE 4 SPOTS
    Delta = 1.5                     '1.5 full pixel position stagger
    N = 103                         'about one total fill time for all spots
    Do While N >= 0                 'set up 16 spot array
     I = Int(N / 26) - 1.5          '1.5, .5 ,-.5,-1.5
     J = Int((N Mod 52) / 13) - 1.5   '1.5, .5 ,-.5,-1.5
     'each spot is offset one pixel spacing
     XOut = XFreqOut + I * Delta * XOffset
     YOut = YFreqOut + J * Delta * YOffset
     Call DOSENDING(XOut, YOut)  'send out spots to fifo
     N = N - 1
    Loop  'next n
 Case 7:
    Delta = 2                       '2 full pixel position stagger
    N = 103                         'about one total fill time for all spots
    Do While N >= 0                 'set up 16 spot array
     I = Int(N / 26) - 1.5          '1.5, .5 ,-.5,-1.5
     J = Int((N Mod 52) / 13) - 1.5   '1.5, .5 ,-.5,-1.5
     'each spot is offset one pixel spacing
     XOut = XFreqOut + I * Delta * XOffset
     YOut = YFreqOut + J * Delta * YOffset
     Call DOSENDING(XOut, YOut)  'send out spots to fifo
     N = N - 1
    Loop  'next n
 Case 9:
    Delta = 2.5                     '2.5 full pixel position stagger
    N = 103                         'about one total fill time for all spots
    Do While N >= 0                 'set up 16 spot array
     I = Int(N / 26) - 1.5          '1.5, .5 ,-.5,-1.5
     J = Int((N Mod 52) / 13) - 1.5   '1.5, .5 ,-.5,-1.5
     'each spot is offset one pixel spacing
     XOut = XFreqOut + I * Delta * XOffset
     YOut = YFreqOut + J * Delta * YOffset
     Call DOSENDING(XOut, YOut)  'send out spots to fifo
     N = N - 1
    Loop  'next n
 Case 11:                           'USE 4 SPOTS FOR 7,9,11
    Delta = 3
    N = 103                         'about one total fill time for all spots
    Do While N >= 0                 'set up 16 spot array
     I = Int(N / 26) - 1.5          '1.5, .5 ,-.5,-1.5
     J = Int((N Mod 52) / 13) - 1.5   '1.5, .5 ,-.5,-1.5
     'each spot is offset one pixel spacing
     XOut = XFreqOut + I * Delta * XOffset
     YOut = YFreqOut + J * Delta * YOffset
     Call DOSENDING(XOut, YOut)  'send out spots to fifo
     N = N - 1
    Loop  'next n
End Select
  Call ENABLE(1)                  'TURN READ LINE BACK ON
End Sub

Sub ONOFF (I As Integer) 'FALSE FOR OFF, TRUE FOR ON
' THIS ROUTINE CONTROLS THE ON-OFF RELAY IN THE HARDWARE
' BIT 1 ON PORT 2 USED TO BE MSB OF DATA
' SINCE IN USED FREQ RANGE MSB WAS NEVER SET,
' LINE WAS CHANGED (2/2/93) TO CONTROL SYSTEM ON -OFF
```

```
If I = False Then 'turn it off
  PortOut(2) = PortOut(2) And RelayOff 'PORT C
Else            'turn it on
  PortOut(2) = PortOut(2) Or RelayOn 'PORT C
End If
  Status = DIG_Out_Port%(ByVal 1, ByVal 2, ByVal PortOut(2))
End Sub

Sub RST () 'routine to reset hardware box,  Reset clears Fifo
'FLIP RESET BAR AND DDSRESET THEN RESTORE
  PortOut(2) = PortOut(2) And ResetLo 'PORT C
  PortOut(2) = PortOut(2) Or ResetDDSHi 'set both reset and dds reset
  Status = DIG_Out_Port%(ByVal 1, ByVal 2, ByVal PortOut(2))
  PortOut(2) = PortOut(2) Or ResetHi  'set back the other way
  PortOut(2) = PortOut(2) And ResetDDSLo  'transition
  Status = DIG_Out_Port%(ByVal 1, ByVal 2, ByVal PortOut(2))
End Sub

Sub SPOTDRAW () 'This routine prints the dot on the User Interface
If Fancy Then   'If the previous mode was a many spot draw then
   Fancy = False  'reset mode to single point
   Form1!Picture1.Cls   'and clear the display window
End If
'Set the X and Y scale so that all of the small spot are displayed at the edges
X = Form1!HScroll1.Value * .994 * Form1!Picture1.Width / Hmax
Y = Form1!VScroll1.Value * .95 * Form1!Picture1.Height / Vmax
'erase old spot
Form1!Picture1.DrawWidth = 1      'one pixel linewidth
Form1!Picture1.FillColor = White  'WHITE TO ERASE
Form1!Picture1.FillStyle = 0      'SOLID FILL, spot is a small box
Form1!Picture1.Line (OldX - OldIsZoomed, OldY - OldIsZoomed)-(OldX + OldIsZoomed, OldY + OldIsZ
oomed), White, BF
'redraw it at new location
Form1!Picture1.FillColor = Black   'BLACK
Form1!Picture1.FillStyle = 0       'SOLID FILL, spot is a small box
Form1!Picture1.Line (X - IsZoomed, Y - IsZoomed)-(X + IsZoomed, Y + IsZoomed), Black, BF
'redraw vertical separator line on screen
Form1!Picture1.Line (.5 * Form1!Picture1.ScaleWidth, 0)-(.5 * Form1!Picture1.ScaleWidth, Form1!
Picture1.ScaleHeight), Black
'remember spot location so next time it can be erased
OldX = X
OldY = Y
OldIsZoomed = IsZoomed 'remember old size of spot
End Sub

Sub TURNZOOMOFF ()  'when no zoom is wanted
   IsZoomed = SMALLSPOT 'Set zoom to one spot size
   Form1!threex.Checked = False
   Form1!fiveX.Checked = False
   Form1!sevenX.Checked = False
   Form1!nineX.Checked = False
   Form1!elevenX.Checked = False
   Form1!ZOOMOFF.Checked = True 'set the zoomoff check on the pulldown menu
   Form1!Picture1.Cls 'clear the screen display
   Fancy = True       'set mode to multi spot
   'also turn off centroiding
   CentroidOn = False   'set global variable
   Form1!Picture2.Visible = False  'turn off picture2 when done
   Form1!AvControl1.Visible = True'show real time vidio
   Form1!avoverlay.Visible = True'allow overwriting on window
End Sub

Sub WRTLN (I As Integer)    'Toggle the Hardware Fifo Write line
'channel 1 OR 2 FOR CHOICES
If I = 1 Then                    'CHANNEL 1
  'SEND THEM LO THEN BACK TO HIGH
  PortOut(2) = PortOut(2) And Wrtln1Lo 'PORT C
  Status = DIG_Out_Port%(ByVal 1, ByVal 2, ByVal PortOut(2))
  PortOut(2) = PortOut(2) Or Wrtln1Hi 'PORT C
  Status = DIG_Out_Port%(ByVal 1, ByVal 2, ByVal PortOut(2))
Else                             'CHANNEL 2
  'SEND THEM LO THEN BACK TO HIGH
```

```
  PortOut(2) = PortOut(2) And Wrtln2Lo 'PORT C
  Status = DIG_Out_Port%(ByVal 1, ByVal 2, ByVal PortOut(2))
  PortOut(2) = PortOut(2) Or Wrtln2Hi 'PORT C
  Status = DIG_Out_Port%(ByVal 1, ByVal 2, ByVal PortOut(2))
End If
End Sub
```

Appendix B. Breadboard Control PC Help File Listing (User's Guide)

The following pages present the listing of the on-line help files that are available to the operator via the breadboard control software (see also Appendix A, Section 5.2). These help files contain a brief overview of the breadboard system and therefore constitute a User's Guide of sorts that should be reviewed by anyone who is preparing to operate the breadboard.

 # Table of Contents

CONTENTS_MAIN

* Index to General Information

* CONTENTS_OVERVIEW

[*] Index to Menus

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[*] CONTENTS_MENUS

* Index to Technical Information

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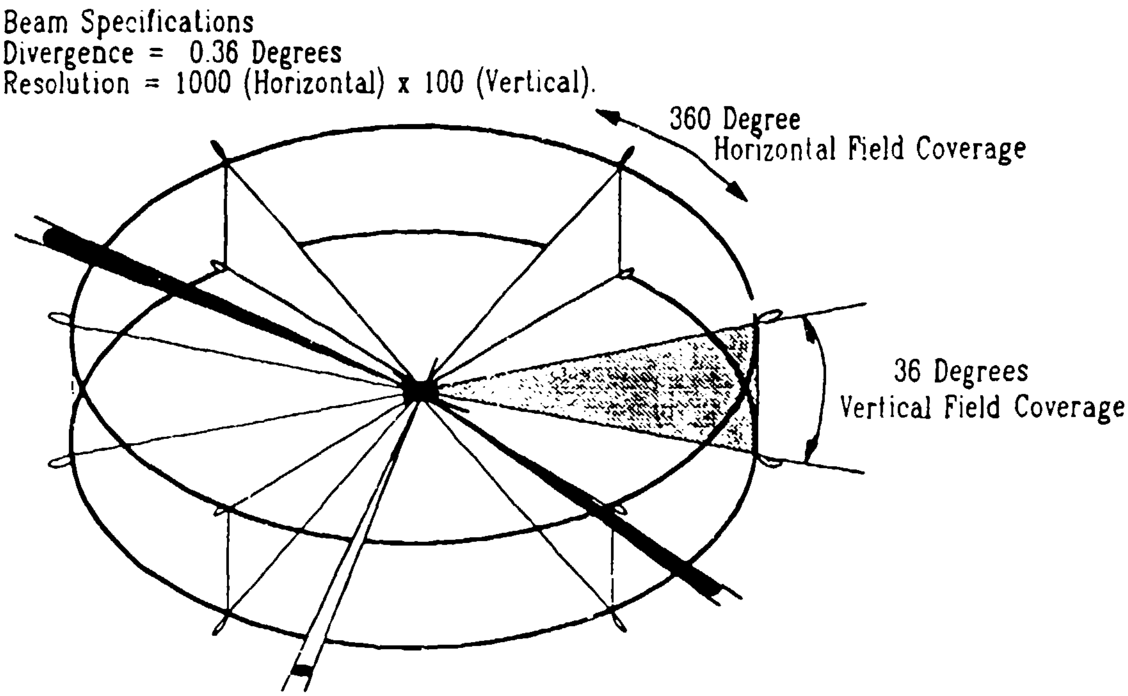
* CONTENTS_TECHINFO

[#][K][$] Program Overview

Lasercom is a system designed to output an 830 nm laser beam in any direction within a cylinder of space that ranges from 0 to 360 degrees in the horizontal direction by +/- 18 degrees in the vertical direction. The size of the beam is designed to cover an angular spread of 0.36 degrees. The purpose of this system is to demonstrate beam steering for low orbit satellite optical communication with no moving parts.

This software is the control interface needed to operate the breadboard. The beam can be positioned by clicking the mouse on a new position on the beam positioning control area, dragging the beam spot from one position to another, or by adjusting the position slide controls.

System Optical Field Coverage.



[#] GENERAL OVERVIEW

[K] OVERVIEW;LASER TYPE;SCAN RANGE;BEAM STEERING;SATELLITE OPTICAL COMMUNICATION;CONTROL INTERFACE;BEAM POSITION;

[$] PROGRAM OVERVIEW

[a] [K] [S] Release History

Version 1.01
June 1993

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[a] GENERAL_HISTORY
[K] RELAEASE HISTORY,VERSION;DATE
[S] RELEASE HISTORY

[#] [K] [$] Know Bugs and Limitations

There are as yet, no known bugs.
Please keep us informed of any bugs found during use.

This program is limited to a single instance. Only one working copy can be run at a time.

[#] GENERAL_BUGS
[K] BUGS;LIMITATIONS
[$] KNOW BUGS AND LIMITATIONS

#K$ Copyright Notice

Sponsored By SDIO and Directed by Rome Laboratories under Contract No. F30602-91-C-0131

GENERAL_COPYRIGHT
K BURBERRY;LASERCOM;HARRIS;ROME;SDIO;CONTRACT NO.;SPONSORED BY
$ COPYRIGHT NOTICE

#K$ File Menu

Open
Pops up a file open dialog box to select pattern files.
Pattern files draw pictures with the output light beam.

Select a file name and click OK to display the picture.
Or double click the filename to display the picture.

Select CANCEL if you do not want to display a picture file.

Exit
Ends the program.
The program terminates after a one minute cooldown period.

MENU_FILE
K FILE MENU;OPEN;EXIT;PATTERN FILE
$ FILE MENU

#K$ Zoom Menu

Off

Turn zoom off and returns the output laser beam to is normal size covering 0.36 degrees of field

3 X

Enlarges the output laser beam to 3 times it normal size to cover a 1.08 degree field

5 X

Enlarges the output laser beam to 5 times it normal size to cover a 1.80 degree field

7 X

Enlarges the output laser beam to 7 times it normal size to cover a 2.52 degree field

9 X

Enlarges the output laser beam to 9 times it normal size to cover a 3.24 degree field

11 X

Enlarges the output laser beam to 11 times it normal size to cover a 3.96 degree field

---

MENU_ZOOM

K ZOOM MENU;OFF;3X ;5 X;7 X;9 X;11X;ENLARGE

$ ZOOM MENU

#KS Multibeam Menu

0 No Beams
This clears the system FIFO of all output frequencies. This will turn off all the output beams.

2 Beam Demo
Displays two simultaneous beams, one in the center of each field. These two beams define the centered output of each fisheye lens and can be used as an aid to system alignment. The coordinates of each beam in space is; 90 degrees horizontally by 0 degrees vertically, and 270 degrees horizontally by 0 degrees vertically.

4 Beam Demo
Displays four simultaneous beams. The coordinates of each beam in space is; 60 degrees horizontally by 0 degrees vertically, 120 degrees horizontally by 0 degrees vertically, 240 degrees horizontally by 0 degrees vertically, and 300 degrees horizontally by 0 degrees vertically.

8 Beam Demo
Displays eight simultaneous beams, one in each corner of each field. These beams define the limits of each field and can be used to scale the data to cover the output field of each fisheye lens. The coordinates of each beam in space is; 0 degrees horizontally by -18 degrees vertically, 0 degrees horizontally by 18 degrees vertically, 179.9 degrees horizontally by -18 degrees vertically, 179.9 degrees horizontally by 18 degrees vertically, 180 degrees horizontally by -18 degrees vertically, 180 degrees horizontally by 18 degrees vertically, 359.9 degrees horizontally by -18 degrees vertically, 359.9 degrees horizontally by 18 degrees vertically.

MENU_MULTIBEAM
K MULTIBEAM; NO BEAMS, 0 BEAMS;2 BEAM,4 BEAM,8 BEAM;ALL BEAMS OFF;TURN OFF BEAMS
$ MULTIBEAM MENU

#K$Scan Menu

Horizontally
Draws a Horizontal line from 0 degrees to 360 degrees horizontally, 0 degrees vertically.

Vertically
Draws two vertical lines from -18 degrees to +18 degrees vertically, 90 degrees horizontally, and 270 degrees horizontally.

Diagonally
Draws two Diagonal lines from 0 degrees horizontally by -18 degrees vertically to 179.9 degrees horizontally by +18 degrees vertically, and 180 degrees horizontally by -18 degrees vertically to 359.9 degrees horizontally by +18 degrees vertically.

MENU_SCAN
K SCAN MENU;HORIZONTAL;VERTICAL;DIAGONAL
$ SCAN MENU

#KS Centroid Menu

On
Turns centroiding on. When a single beam is output, this function periodically finds the position of the beam as seen from the reference CCD camera. The detected coordinates are displayed alongside of the camera display output. With centroiding on, the system pauses for a few seconds each time the centroiding takes place. Centroiding dramatically slows down the system.

Off
Turns off the centroiding function.

Calibrate
This function is used to create a lookup table between the desired beam output locations and the actual location as seen on the CCD camera. It takes a few minutes to operate and should only be used if an exact correlation between desired and actual beam output is required.

MENU_CENTROID
K CENTROID MENU;CENTROID ON;CENTROID OFF;CENTROID CALIBRATE;CALIBRATE
$ CENTROID MENU

#K$ Help Menu

Contents
Activates this Help File

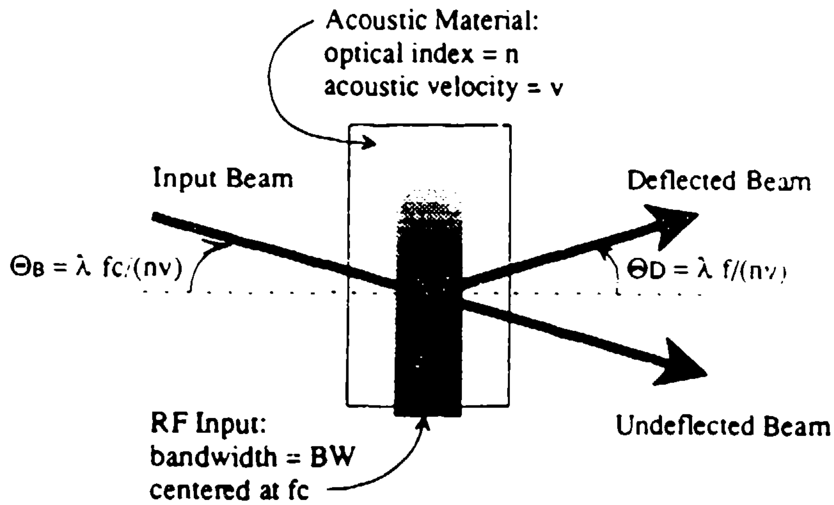
Using Help
This Opens the Help File on how to use a Help File.

About
The About choice pops up a Dialog Box with the Version number, Copyright Information and Sponsorship of this software.

MENU_HELP
K HELP MENU;CONTENT;USING HELP;ABOUT
$ HELP MENU

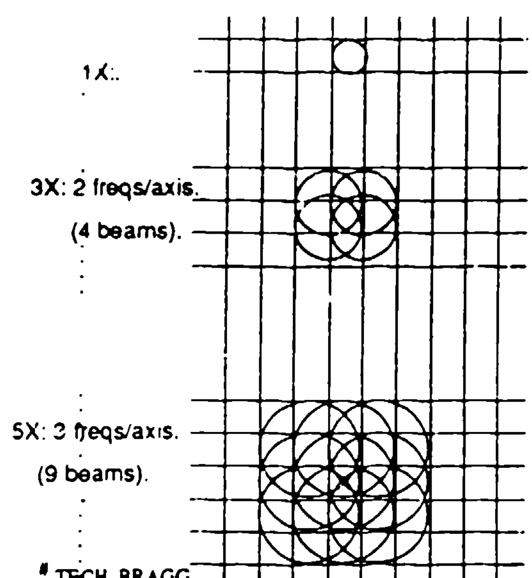
[#KS] Description of Bragg Cells

Basic Theory



The Bragg cells are the key component in the beam steering system. The direction of light passing through the Bragg cells is changed to an angle that is a linear function of the RF frequency that is used to stimulate the cells. Inside the Bragg cells an acoustic grating (compressional wave) is propagated at the frequency of the RF stimulus in the transverse direction of the optical beam path. The time that it takes for the acoustic wave to propagate over the width of the input optical beam is referred to as the "time aperture" of the cell. This corresponds to the time that it takes to uniquely change the angle of optical deflection from the cells.

How Zooming is performed



An interesting result can be obtained by switching the RF stimulus frequencies faster than the time aperture of the Bragg cells. The deflected optical beam can be made to effectively expand, or "zoom", in divergence angle by repetitively cycling several closely spaced frequencies within the time aperture of the cells. Each unique frequency steers the deflected beam to a slightly different direction, and the sub-aperture fill time of each frequency causes each deflected beam to spread more due to diffraction and hence overlap the neighboring beams. The result of these two effects is that the net (composite)

TECH_BRAGG
K DESCRIPTION OF BRAGG CELLS;BRAGG CELLS;STEERING;ZOOMING;MULTIPLE BEAMS;MAX RF POWER;RF POWER
$ DESCRIPTION OF BRAGG CELLS

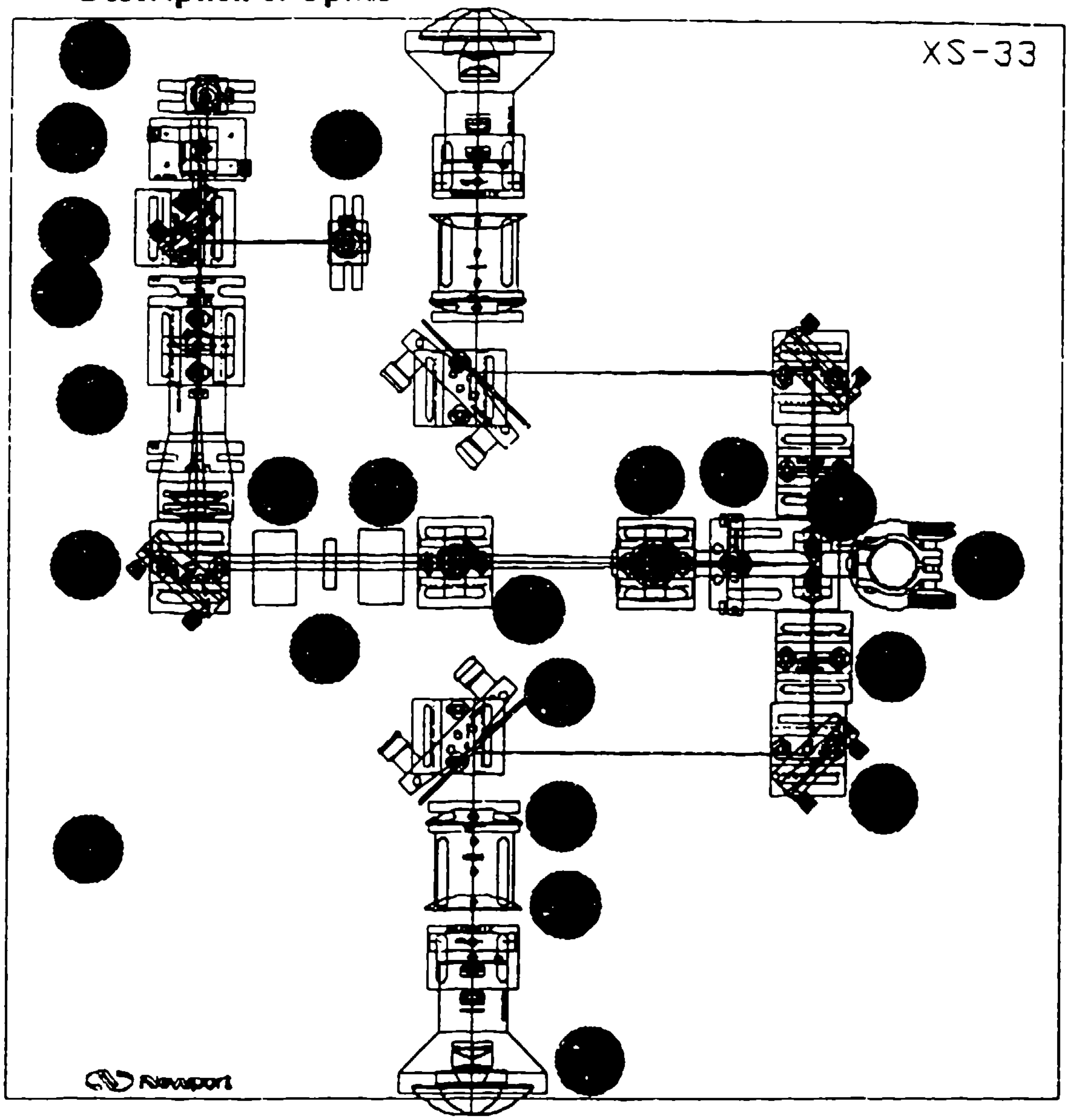
deflected beam appears to have increased in size over that of the uncycled (cw) beam size. The zoom factor can be continuously varied by programming the correct frequency spacings and cycle times to the Bragg cells. The demo software (under ZOOM MENU) has been pre-configured to provide zoom factors of 1X (cw), 3X, 5X, 7X, 9X, and 11X.

How Multiple Beams are performed

As mentioned above, Bragg cells operate by transforming a particular input RF stimulus frequency into a specific optical deflection angle. Multiple simultaneous deflection beams can therefore be generated by inserting simultaneous RF stimulus frequencies into the Bragg cells. The demo electronics/interface box has 3 additional input ports per Bragg cell for this purpose. Since the electronics/interface box provides only one frequency source per Bragg cell (DDS synthesizer) then a different approach is used to "simulate" the effect of multiple beams without using the additional input ports. The approach used is to time-division-multiplex the frequencies rapidly between the different beam locations (i.e., faster than the CCD camera can respond) so that the illusion of multiple beams is created. However, the true generation of multiple beams can only occur by simultaneously summing frequencies into the Bragg cells via the front panel input ports.

WARNING: the total combined RF power (the summed power of all input frequencies) into each Bragg cell should not exceed 400 mW due to potential thermal damage to the cells. NOTE: the DDS frequency synthesizer in the electronics/interface box has a gain pot that has been pre-adjusted to a produce 400 mW to each Bragg cell. If the front panel input ports are used to provide additional frequencies then one of the following options should be executed: 1) the DDS outputs should be attenuated appropriately with in-line pads, or, 2) the DDS outputs should be disconnected and terminated with 50 ohm load, or, 3) the gain pots on the DDS boards should be adjusted to appropriately reduce the power.

K $ Description of Optics



The following is a list of parts in the Lasercom system illustrated above. Only one 180 degree field is enumerated, the other field is identical.

1) The base plate is a 2 inch thick 3 foot square optical breadboard with a one inch 1/4-20 hole pattern grid.
2) The 25 mW 830 nm laser and collimator.
3) The 10 mW 670 nm laser and collimator.
4) A 2X anamorphic corrector prism pair.
5) Hot Mirror beam combiner (reflects IR, passes visible)
6) A half wave plate and a quarter wave plate

TECH_OPTICS
K DESCRIPTION OF OPTICS;PARTS;COMPONENTS
$ DESCRIPTION OF OPTICS

7) A 6 X beam expander.
8) A 2 Inch Folding Mirror
9) The Horizontal Bragg cell
10) A half wave plate
11) The Vertical Bragg Cell
12) The Horizontal Fourier transform Lens (300 mm)
13) The camera pickoff beam splitter, the cameras Vertical Fourier transform lens, and CCD TV camera suspended above.
14) Holds the Vertical Fourier transform Lens (80 mm) for the projection legs
15) The image divider mirrors, and two 40 mm Lenses (one for each half field)
16) Camera support post
17) 100 mm lens
18) A 2 Inch fold mirror
19) A 3 Inch fold mirror
20) 150 mm Lens
21) 150 mm Lens
22) 8 mm Nikon Fisheye Lens

The optics consists of several sections. The first part is the illumination optics(2-8), the next part is the Bragg cells that do the beam steering(9-11). Then comes the Fourier transform optics that form the beam waists(12-14). The beam waist field is then divided in half and each half reimaged to the input field of the fisheye lenses(15-21). The fisheye lenses then project the beams out to free space(22).

This system was optimized for an 830 nm laser. However, to provide a visible demonstration c bility, a 670 nm laser was also provided. The power to the laser is provided by a B.C connector on the back panel of the system control box. This connector supplies 5 volts to the two laser drivers. Inline on the power cable is a switch that selects either the RED laser or the IR laser. Only one laser can be used at a time to avoid spot confusion at the CCD camera plane. The aspect ratio required at the Bragg cells is 2:1 with the long axis in the horizontal direction. The aspect ratio out of the RED laser is 4:1, so a 2X prismatic beam expander is used to form the correct ratio. The out of the IR laser is about 2:1 so no correction is required. The beams are combined using a hot mirror. A hot mirror is a dichroic surface that reflects IR (above 700 nm) and transmits visible light. The beam sizes at this point are about 2 by 4 mm. A 6X beam expander is used to create a 12 by 24 mm beam to illuminate the Bragg cells. The Fourier Cylinders then form a scan plane with a field of 500 spots by 200 spots. A beamsplitter reflects a small portion of the light to the CCD TV camera for spot position monitoring. The top half and bottom half of the fields are divided by a mirror pair into the left field and right fields, each with 500 by 100 spot. These fields are then reimaged and magnified to fill the input aperture of the fisheye lens. The fisheye then projects the spots to fill each half field of 180 degrees horizontally by +/- 18 degrees vertically.

K $ Alignment Procedure

This alignment procedure assumes that all the optical mount holders are in their nominal positions (see Description of Optics). The optical axis should be aligned to be 5 1/2 inches above the optical table. At all times observe laser safety precautions! Useful tools not supplied are an infrared viewer, an IR sensitive viewing card, a power meter, and an oscilloscope.

1. Place 830 laser with collimator into holder (2).
2. Rotate the laser beam to a clear area of the table.
3. Adjust laser until near and far field of beam is at 5 1/2 inches above the table.
4. Aim the beam at the center of the dichroic splitter (5).
5. Adjust the splitter angle to maintain the 5 1/2 inch height and project the beam along the line of components (6), (7), and (8).
6. Center the half wave plate and the quarter wave plate (6) on the beam.
7. Center the 6 X beam expander (7).
8. Before inserting turning mirror (8), use the collimation tester (supplied) to adjust the collimation out of the 6 X beam expander. Rotate tne focus ring until the fringes on the view screen are parallel to the shadow of the wire.
9. Insert turning mirror (8) centered on the beam and folding 90 degrees toward the horizontal Bragg cell.
10. Position the horizontal Bragg cell (9) in the center of the beam.
11. Place a 300 mm lens (supplied) after the cell, and project the spot onto a detector with the detector output displayed on a scope.
12. Energize the cell by starting the software. Select Scan Horizontal from the menu.
13. Adjust the position and angle of the cell to maximize the output on the detector and maintain a flat bandshape.
14. Iteratively adjust the rotation of the halfwave and quarterwave plates (6) to maximize the output of the horizontal cell. Greater than 80 throughput efficiency can be obtained.
15. Remove the 300 mm lens.
16. Position the halfwave plate (10) in the center of the diffracted beam.
17. Position the vertical Bragg cell (11) in the center of the diffracted beam.
18. Place a 300 mm lens (supplied) after the cell, and project the spot onto a detector with the detector output displayed on a scope.
19. Energize the cell by starting the software. Select Scan Vertical from the menu.
20. Adjust the position and angle of the cell to maximize the output on the detector and maintain a flat bandshape.
21. Iteratively adjust the rotation of the halfwave plate (10) to maximize the output of the vertical cell. Greater than 80 % throughput efficiency can be obtained.

TECH_ALIGNMENT

K ALIGNMENT PROCEDURE;TOOLS

$ ALIGNMENT PROCEDURE

22. Select Scan Diagonally from the software menu and check the composite deflection efficiency. greater than 60 % should be available across the band.
23. Remove the 300 mm lens.
24. Place the 300 mm cylinder lens in position (12). This focuses the scan horizontally.
25. Place beamsplitter (13) so that the diffracted light passes through and is reflected upward.
26. Position the vertical Fourier lens (14) into position, centered on the beam.
27. Position a second cylinder lens above the beamsplitter, supported off vertical post (16).
28. Suspend the CCD TV camera also from post (16).
29. Center diffracted light on the camera.
30. Select Scan Vertically from the software and focus the line of light on the camera by moving the camera position up and down.
31. Select Scan Horizontally from the software and focus the line of light on the camera by moving the suspended cylindrical lens.
32. Select Multibeam, 8 beam demo from the software menu
33. Center the pattern on the TV camera by moving the camera.
34. The TV camera setup may have to be repeated after the projected beams are set up.
35. Focus cylinder lens (12) and (14) to form an image in front of folding and splitting mirrors (15)
36. Position splitting mirrors (15) to deflect the top half of the image to the left and the bottom half of the image to the right.
37. Chose the pattern file RIGHT0.PTN from the File Open menu.
38. Position the 40 mm lens(15) to project the beams straightly.
39. Position the 100 mm lens (17) in the center of the beam.
40. Position Mirror (18) to direct the beams toward mirror (19).
41. Observe the image at position (19) . Individual spots should be observed.
42. Position Mirror (19) to center the image in the center of the following lens positions
43. Center Lens (20) on the beam.
44. Center Lens (21) on the beam.
45. Insert the Nikon Lens (22) into its holder.
46. Focus lens (17) to obtain clean spots on the screen.
47. Position mirror (19) to center the array of spots in the vertical direction and horizontally.
48. Finely adjust the position of lens 22 along the beam path to set the outer spots at the outer edge of the observation screen.
49. Iterate any adjustments out of tune.
50. Repeat for the other projection leg.

Note: The system can only be nominally adjusted for on wavelength laser at a time. If the 670 laser needs to be used than the 830 laser will no longer be in adjustment.

#K $ The Centroiding Algorithm

To display and centroid the optical spot, a CCD TV camera is used in conjunction with a NEW MEDIA GRAPHICS Super Video Windows, video display and capture board. During normal operation, only the real-time video is displayed on the screen. During centroiding, the real time video is hidden and only the frame grabbed image is displayed. The frame grabbed picture is used as a holding place for the video data. Each pixel of video holds the 8 bit gray level value of the data (only upper 7 bits are significant). An area that surrounds the expected position of the spot is selected and the average of the pixels, times the position, is taken, and divided by the average of the pixel values to get the weighted average. From this data, the located spot data is obtained. However, in order for this data to be valid, the system must be calibrateJ. The calibration routine, creates of grid of know spot location and their associated centroided positions. Using this data, a four point interpolation is used to find the calibrated centroid positions.

TECH_CENTROIDING

K CENTROIDING ALGORITHM;FRAME GRABBER;VIDEO

$ THE CENTROIDING ALGORITHM

#K $ Pattern File Format

Triangle.PTN

EXAMPLE
START,33
POINT,90,15
LINE,120,-10,40
LINE,60,-10,40
LINE,90,15,40
END

This is a spot based drawing routine. However, since the fill time of the Bragg cell is 100 locations in the FIFO and the FIFO has 4096 total locations, only 40 totally independent spots may be displayed. Up to 4096 position may be specified, but under filling the Bragg cells will cause the beam to grow.

The First command in a Pattern file must be the START command followed by a comma, and the number of FIFO locations used for each spot draw. The other commands may be mixed or repeated in any order. An END command at the conclusion of the file is optional but is included for clarity. Other commands consist of 'POINT',X,Y (where X,Y are the coordinates of a spot location in degrees horizontal (0-360) by degrees vertical (-18 - +18)) and 'LINE',X,Y,NUM (which draws a series of points from the present location to the specified X,Y coordinates, with the number of steps indicated by NUM-1 (a NUM of 2 produces just the two endpoints). 'CLEAR' will erase the present drawing in the FIFO and allow for multiple successive pictures in one file, used for animation purposes.

TECH.PATTERN

K PATTERN FILE FORMAT;START;POINT;LINE;CLEAR;END;*.PTN;FIFO

$ PATTERN FILE FORMAT

#K$ How to Write a Pattern File

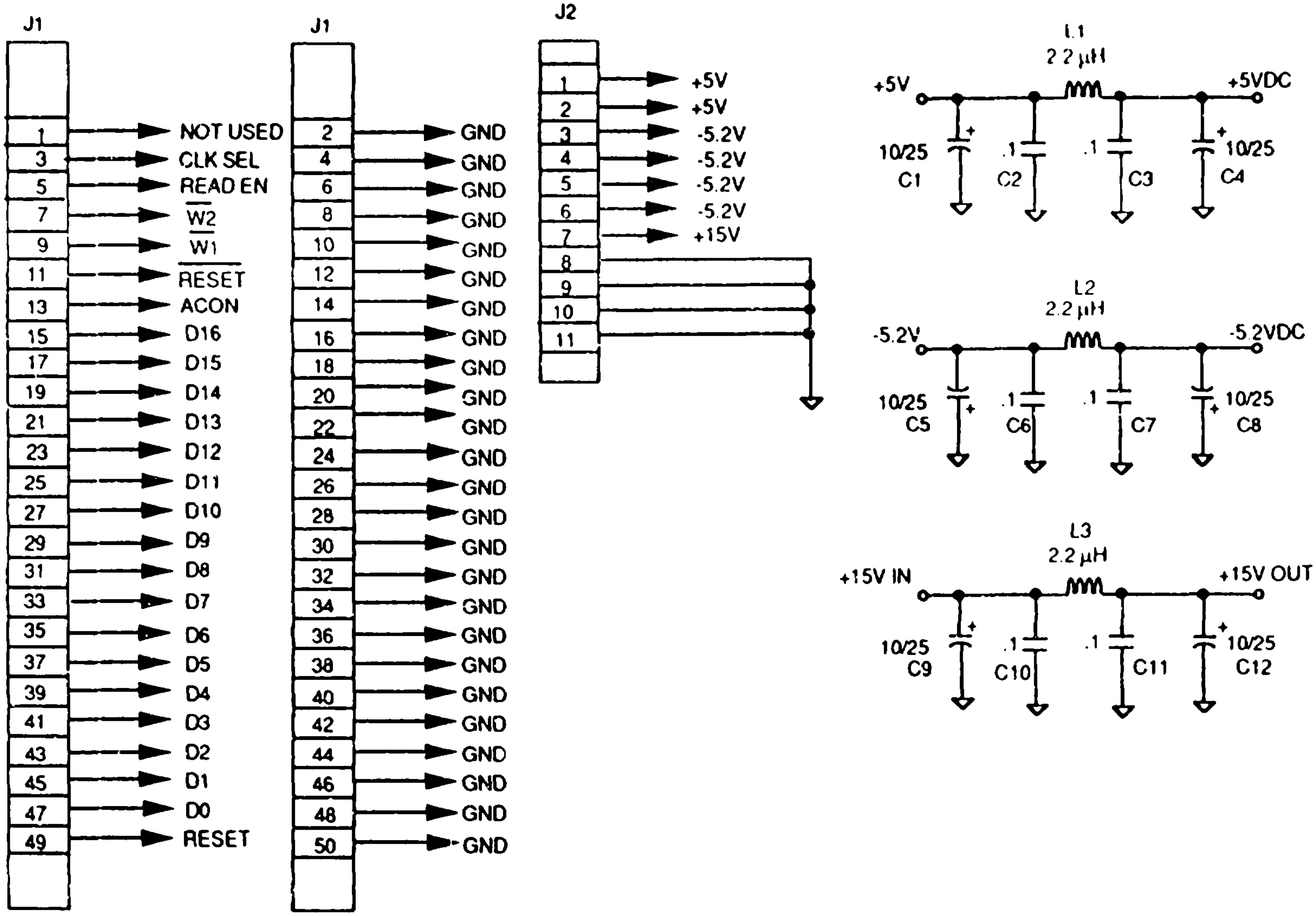
Pattern files can be written with any text editor that can save files in ASCII format. Each Line must start with a keyword, with parameters following separated by commas. One command per line must be used. Illegal commands will cause the program to BEEP when the bad line in the file is accessed. The file will continue to run, however.

TECH_WRITE
K HOW TO WRITE A PATTERN FILE;TEXT EDITOR;ASCII;BEEP
$ HOW TO WRITE A PATTERN FILE

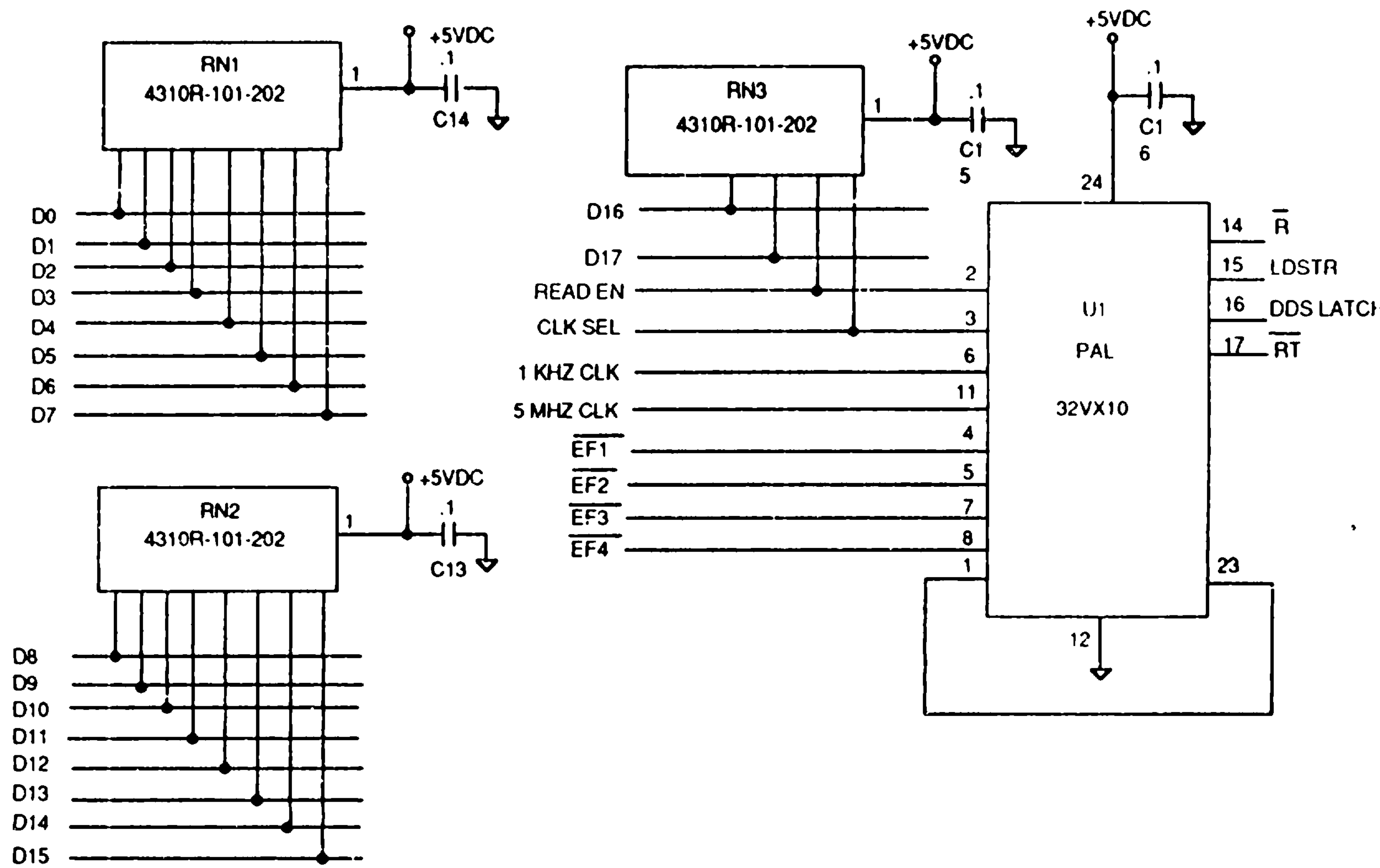
Appendix C. Electronic Interface Board Schematics

The following pages present the electrical schematics for the Electronic Interface Board.

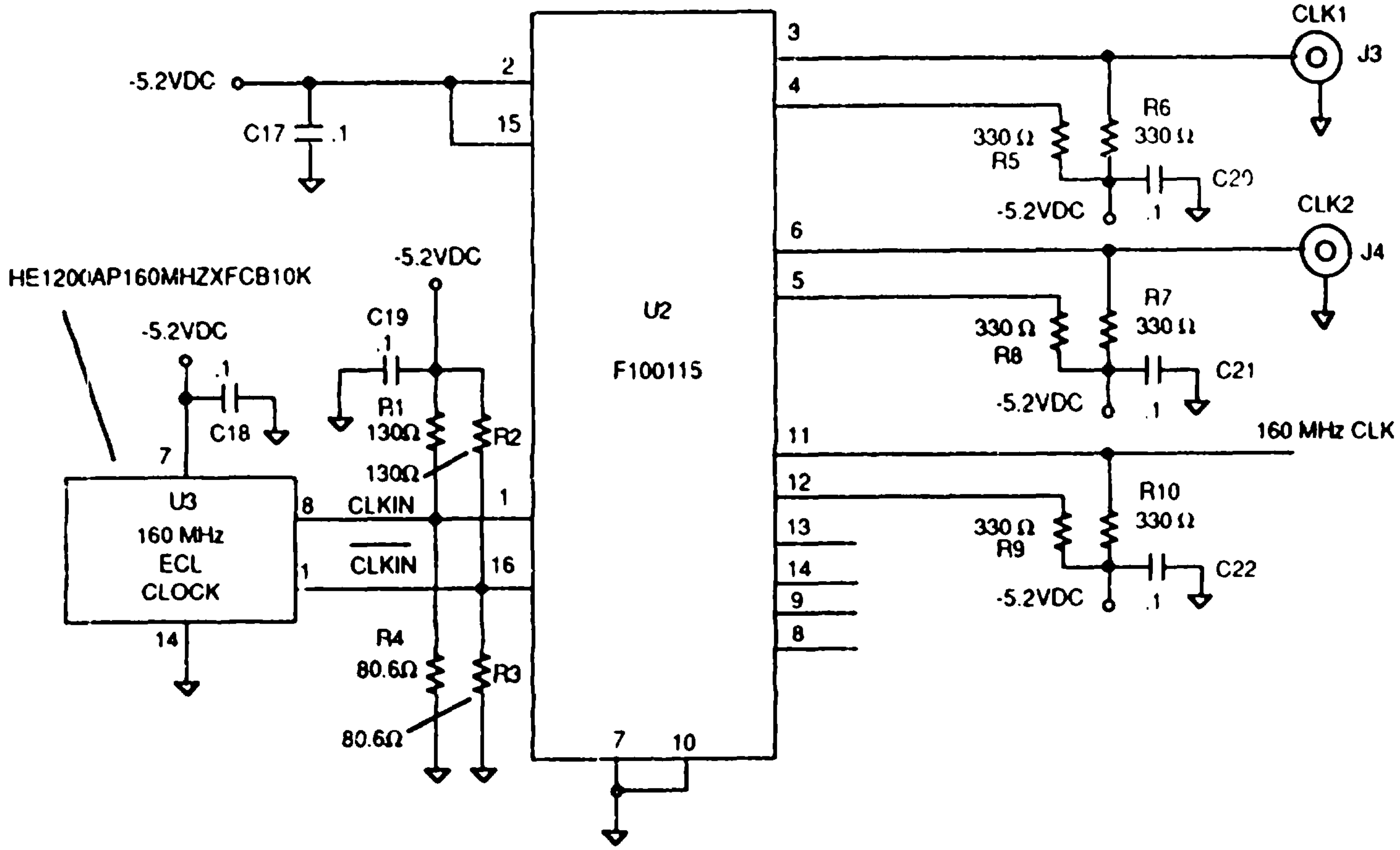
Control Interface Schematic



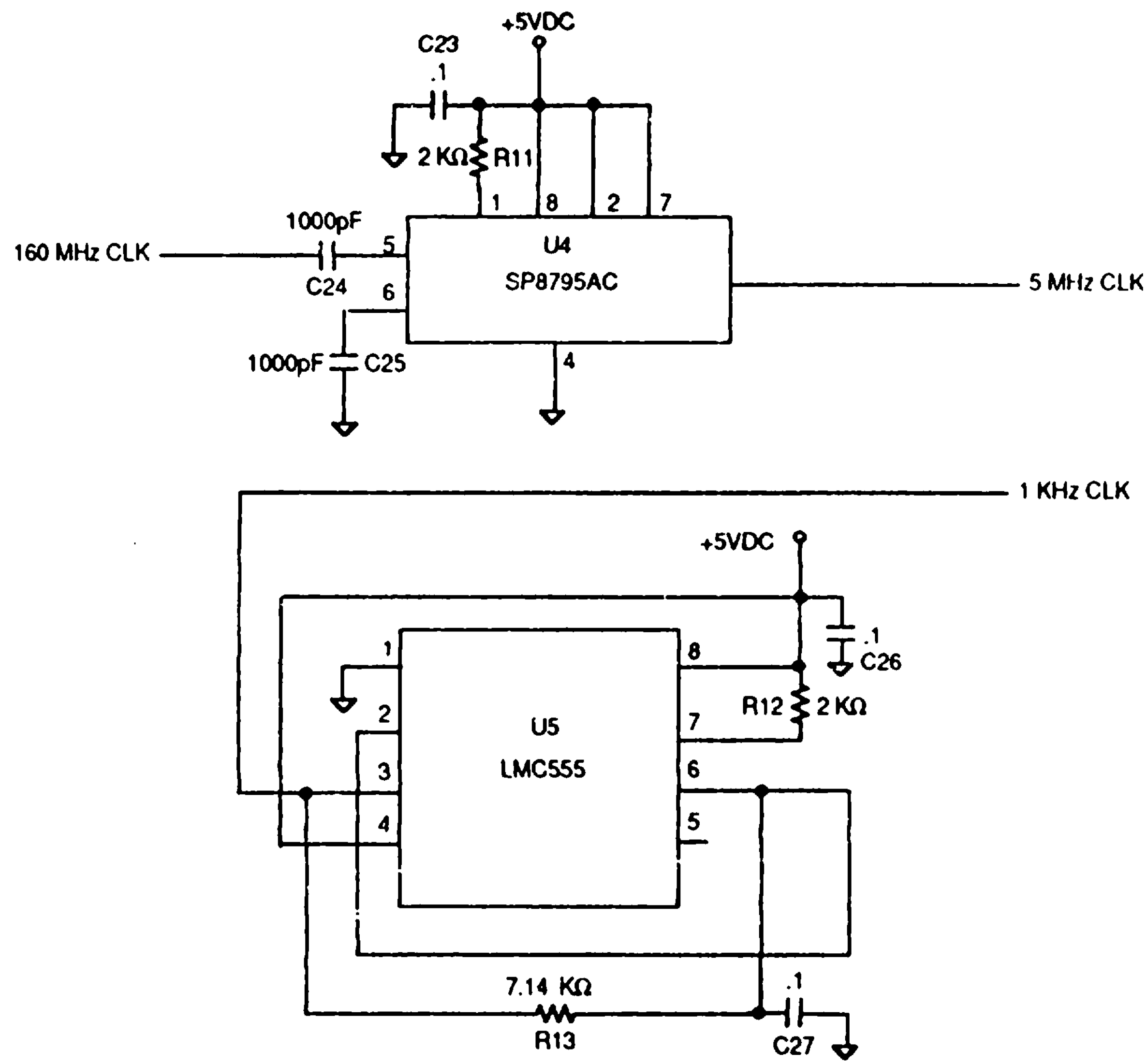
Control Interface Schematic



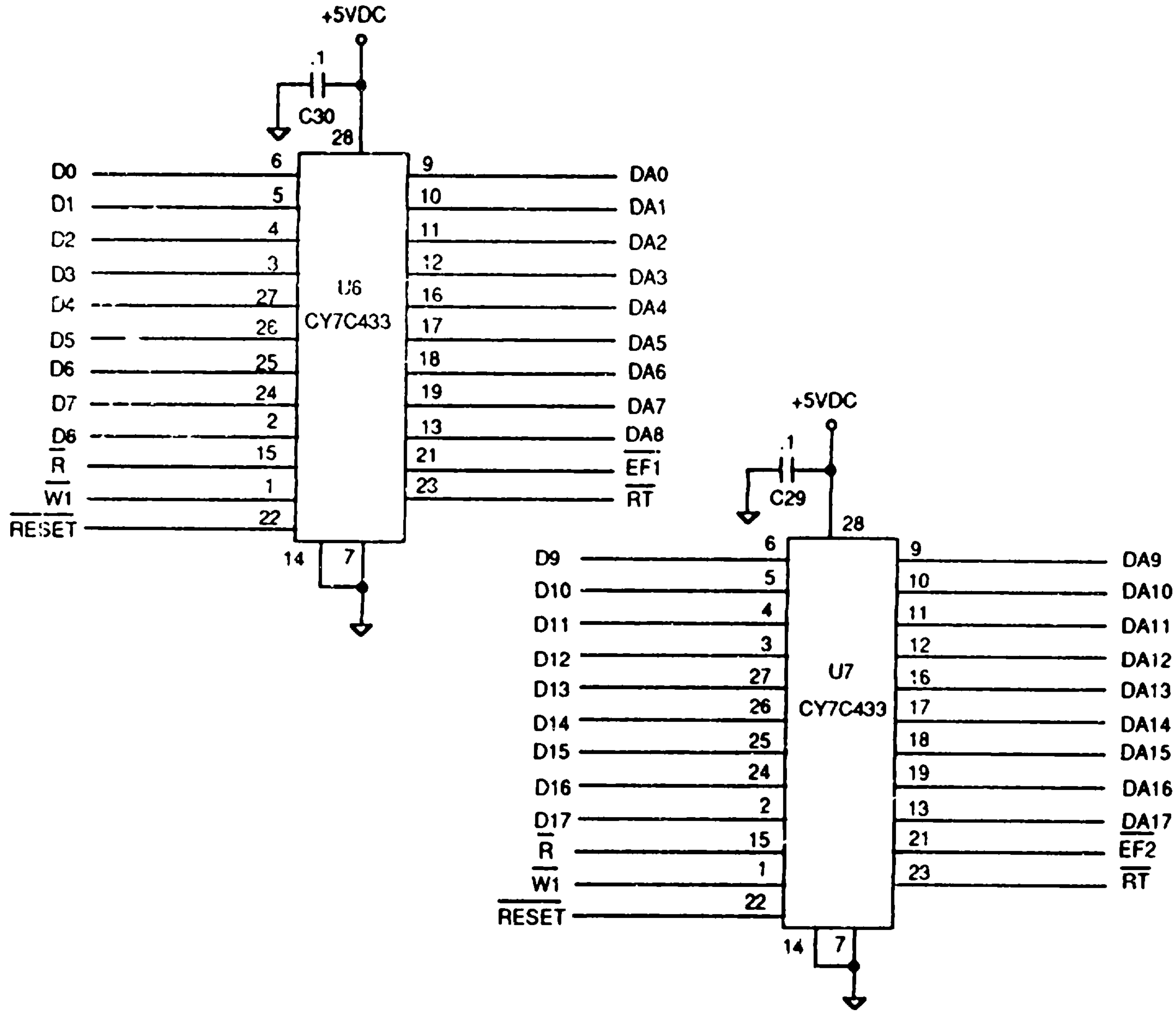
Control Interface Schematic



Control Interface Schematic



Control Interface Schematic



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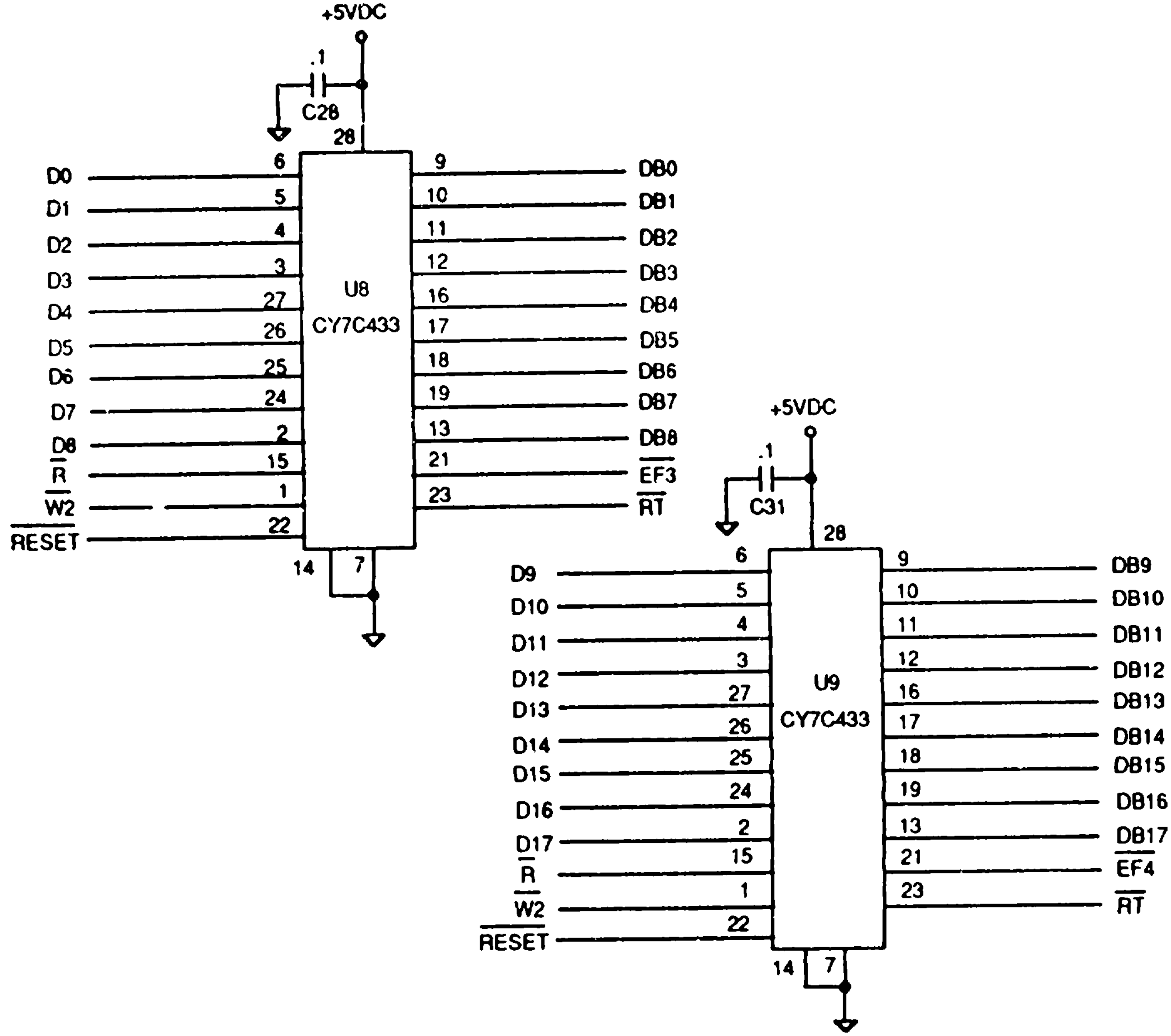

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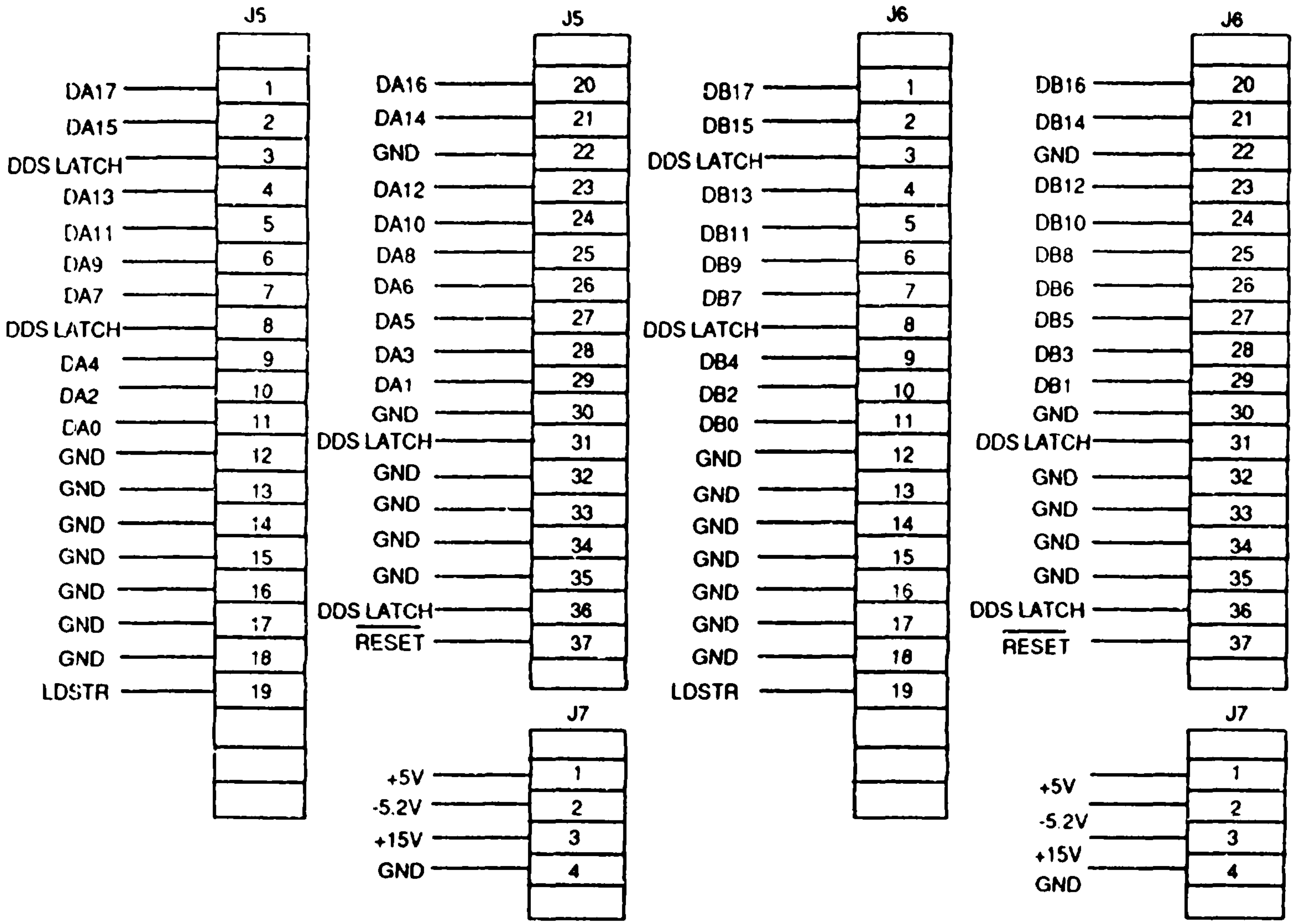

Appendix D. List of Acronyms and Frequently Used Abbreviations

AC	Alternating Current
AO	Acousto-Optic
AOTF	Acousto-Optic Tunable Filters
APT	Acquisition, Pointing, Tracking
BER	Bit Error Rate
BTS	Built-in Test Set
BW	Band Width
°C	Degrees Centigrade
CCD	Charge Coupled Device
cm	centimeter
CW	Continuous Wave
dB	decibel
dBc	decibel relative to carrier
dBm	decibel relative to 1 mW
DC	Direct Current
DDS	Direct Digital Synthesis
DOI	D. O. Industries
EMI	Electro-Magnetic Interference
FIFO	First In, First Out
FOR	Field Of Regard
GHz	GigaHertz
Hz	Hertz
I/O	Input/Output
IR	Infra Red
KHz	KiloHertz
Km	Kilometer
LIDAR	Laser Radar
m	meter
Mbps	Megabits per second
MHz	MegaHertz
mm	millimeter
mrad	milliradians
µsec	microseconds
mW	milliWatts
nm	nanometer
ns, nsec	nanosecond
PAL	Programmable Array Logic
PC	Personal Computer
RAM	Random Access Memory
RF	Radio Frequency
SDI	Strategic Defense Initiative
SDL	Spectra Diode Laboratories
sec	seconds
SOW	Statement of Work
TBW	Time Band Width product
TeO_2	Tellurium Dioxide
TV	Television
VSWR	Voltage Standing Wave Ratio
W	Watts

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