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RPV ACTIVE BORESIGHT INVESTIGATION.(U)

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RPV ACTIVE BORESIGHT INVESTIGATION

International Laser Systems, Inc.
3404 N. Orange Blossom Trail
Orlando, Florida 32804

15 December 1978

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Prepared for

NIGHT VISION AND ELECTRO-OPTICAL LABORATORY
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Analytic and experimental studies were performed to generate design approaches for a miniature Remotely Piloted Vehicle (RPV) electro-optical sensor system. The RPV has a stringent weight limitation; therefore the emphasis was on approaches that would increase precision laser designation performance while reducing size and weight. Laser designator to silicon vidicon boresight is a critical parameter for precision laser designation and passive design approaches usually employed increase the weight of the sensor. Automatic active boresight

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20. ABSTRACT (Continued)

techniques that tolerate a lighter and less rigid mechanical structure can significantly decrease weight and improve performance. Common laser/TV optics designs were investigated because they yield the smallest total clear aperture and permit the introduction of automatic active boresight techniques.

The analytic portion of the study produced eight common optic layouts with complete lens prescriptions for two and several autoboresight options. A breadboard of one of the common optic designs was assembled and experimentally evaluated. The breadboard was flexible enough to evaluate several of the boresight techniques. Two important side-issues were also studied: 1) narcissus and 2) irises and other attenuators. The breadboard optical system worked perfectly, and actually improved TV resolution slightly, when compared to the camera lens alone. The narcissus analysis was verified by one lens surface which caused a reflection image on the TV. An internal retro-reflector system provided autoboresight via both a reticle projector and the direct laser beam. Two 40-dB attenuators which avoid diffraction problems were demonstrated. One, based on tapered wedge filters, had unique advantages. Baffling the TV from stray laser radiation was also very rewarding: small, selective baffles were completely adequate.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

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I. INTRODUCTION

A. SCOPE AND PURPOSE

Analytic and experimental studies were performed to generate design approaches for a miniature Remotely Piloted Vehicle (RPV) electro-optical sensor system. The RPV has a stringent weight limitation; therefore the emphasis was on approaches that would increase precision laser designation performance while reducing size and weight. Laser designator to silicon vidicon boresight is a critical parameter for precision laser designation and passive design approaches usually employed increase the weight of the sensor. Automatic active boresight techniques that tolerate a lighter and less rigid mechanical structure can significantly decrease weight and improve performance. Common laser/TV optics designs were investigated because they yield the smallest total clear aperture and permit the introduction of automatic active boresight techniques. A breadboard system was designed and fabricated to demonstrate the validity of the most promising design approaches.

B. RESULTS AND RECOMMENDATIONS

The program can be considered a complete success. The common optic study resulted in eight viable layouts. The auto-boresight study resulted in a list of choices, techniques, and components, several of which were examined in depth. One fallout of the studies was the need for a 40-dB attenuator free of objectionable diffraction effects. Many viable techniques are listed, and two are analyzed in some detail.

The breadboard was designed, built, and tested, using one of the study layouts (a complete prescription is included in this report). Optical performance was, if anything, a little better than expected. The 10X laser collimator was almost perfect, exhibiting only a few seconds of aberrations. The 2.5X TV Galilean seemed to improve the camera lens performance slightly. (This makes sense, since it flattened the field and was corrected for the proper spectrum.) The auto-boresight retro assembly proved to be very versatile, when used with a selection of filters and irises. It was used to demonstrate a variety of boresight techniques, plus some of the pros and cons of each. The transparent retro was also demonstrated, with spectacular results.

The narcissus analysis was validated very well experimentally: one surface of one of the objective lenses was too close to normal to the laser beam and gave a visible back-reflection on the TV, exactly as predicted. Also as predicted, the reticle projector could be made visible under all background conditions, as could the retro-reflected laser spot.

No baffles were included in the original breadboard, and the inevitable stray laser light upset the TV image. It was discovered that only a small amount of strategically located tape was required to do a complete clean-up. This was very encouraging, since baffling is often a serious problem.

Of those attenuator techniques examined, two were fabricated and tested. The results were as expected. Both techniques will work well, but the one employing tapered wedge filters holds special promise. It should be seriously considered for this application, since it solves the 40-dB problem smoothly, completely and compactly. A main feature is that the effective aperture never drops below the f/10 requirement of the 2:1 TV underscan.

The 2.5-inch diameter common aperture (NFOV), with a speed of f/4 at the vidicon, is believed to be necessary. Broadening the laser beam commensurate with the (WFOV) TV field size is strongly recommended. A reticle projector integral with the laser is the recommended auto-boresight technique. Finally, some version of the opposing wedge iris appears mandatory if the scene brightness and TV resolution specs are to be met simultaneously.

C. REPORT ORGANIZATION

Sections II through IV will present the theoretical studies and analyses, followed by the experimental results in Section V. The experimental test plan, which was followed only roughly, is included as an appendix.

Section II covers the common-optic techniques studied, including prescriptions for the breadboard and one of Wright Scidmore's* designs. Last in this section is a narcissus analysis which should be studied carefully by anyone designing common-optic lenses.

In Section III, the auto-boresight problem is studied. Many approaches, rational and otherwise, are listed, and several are evaluated in more detail.

Section IV is the result of attenuation problems encountered while doing the other two studies. This problem should be addressed in detail by the sensor designers, but two viable techniques were developed, analyzed and tested.

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*An independent optical design consultant, formerly with Frankford Arsenal.

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II. COMMON OPTICS STUDIES

A. THIN LENS DESIGNS

1. General

In any optical design effort, the first two steps are problem definition and thin-lens layouts. Taking first things first, the problem here is to design optics for the sensor package of an RPV. Volume, weight, and aperture must be minimized. The laser transmitter, laser receiver, and two television fields of view must be accommodated. For study purposes, the design parameters given in Table 1 were selected.

Some results of the design parameters are rather immediately apparent. The 10X laser divergence ratio implies a 2.5-inch collimator output diameter. The 250-mm, f/4 NFOV lens will also have an aperture of very nearly 2.5-inches. These lenses must, therefore, be combined into a single aperture. Whether or not the laser divergence should change with the TV field is open to question. There are strong arguments both ways and both will be examined. The WFOV lens must be installed totally on the TV side of the combining beamsplitter if laser divergence is to be maintained. Easiest to implement would be a completely separate lens mounted beside the laser/NFOV optics.

The laser receiver needs very little aperture for the short ranges involved — an inch or less would generally be adequate. One possible location is attached to the laser transmitter, as is done in GLLD, ALLD, TADS, and other transceiver-type ILS laser rangefinders. This location would, however, place severe restrictions on some of the reflective auto-boresight techniques. More desirable would be in combination with the separate (0.5-inch aperture) WFOV lens, if indeed that lens is separate. A third alternative is a completely separate lens. For this tudy, a transceiver arrangement will be assumed.

TABLE 1. COMMON-OPTIC DESIGN PARAMETERS

Laser:	100-mJ	minimum output energy
	20-nsec	nominal pulse width
	25-pps	maximum repetition rate
	0.25-inch	raw laser beam diameter
	1.5-mrad	raw laser beam divergence
	0.15-mrad	required output divergence
Receiver:	Silicon-Avalanche	detector type
	20 nwatt	detection threshold (at detector)
	6 Km	maximum range requirement
Television:	Silicon vidicon	Sensor type
	1-inch	tube size
	16-mm	scan diagonal (nominal)
	3:4	raster size ratio (9.6 x 12.8-mm)
	525-line	nominal scan
	30-Hz	scan rate (non-interlaced)
	8-MHz	video bandwidth
	f/4	maximum lens speed (rather arbitrary)
	250-mm	lens effective focal length (NFOV)*
	50-mm	lens effective focal length (WFOV)**
	2:1	underscan capability
	10^5 -lux	maximum scene brightness***
	200-lux	minimum scene brightness***
	0.65 to 0.95-micron	useful spectrum

*Narrow field of view - nominally 3.67° full diagonal

**Wide field of view - nominally 18.18° full diagonal

***Typical data - not needed for thin-lens study

2. Roberts Designs

The problem, then, is to combine the laser and NFOV lenses as much as possible, while permitting the inclusion of a switchable WFOV lens for the TV. Many designs are possible; the eight shown in the figures are some of the more plausible. Figure 1 shows the original design proposed. This and the next three were done by Al Roberts of International Laser Systems, while Wright Scidmore was responsible for the designs in Figures 5 through 8.

The configurations in Figures 1 and 2 are very similar, the primary difference being the manner of switching to the WFOV. In Figure 1 the laser divergence is also changed, while in Figure 2 the laser is untouched. The "reversible Galilean" in Figure 1 may, in fact, pose severe narcissus (back-reflection) problems. Both 1 and 2 have the dichroic splitter in collimated space, which is very desirable.

The configuration in Figure 3 is the one chosen for the breadboard, and is described in detail later on in this report. This differs from Figure 2 in that the splitter is moved into convergent space, eliminating one lens and a potential narcissus problem. Figure 4 moves the flip-mirror into convergent space also. This has the fewest optical elements of any of the designs, but poses several serious mechanical problems, such as the retention of WFOV boresight and focus in spite of the moving element.

The configurations in Figures 5 through 8 are described by Wright Scidmore in the following paragraphs. Of these, only Figure 5 involved a dual aperture. Figure 6 widens laser and TV fields simultaneously.

3. Scidmore Designs

a. Concept A (Refer to Figure 5)

Lens L1 is a common objective lens for the NFTV and the laser transmitter. Light is transmitted through lens L1, beam-splitter plate M1, iris diaphragm D1, folded by mirror M2, transmitted through lens L2, reflected from a second folding mirror M3, and transmitted through filters F, and field flattener lens L3 and focussed at the vidicon face plate. Laser energy is transmitted through lens L6, folded as required by mirrors including mirror M5, reflected at beam-splitter plate M1 and collimated by the common objective lens L1. The laser receiver energy follows the same path as the laser transmitted energy in the reverse direction, being split off in the

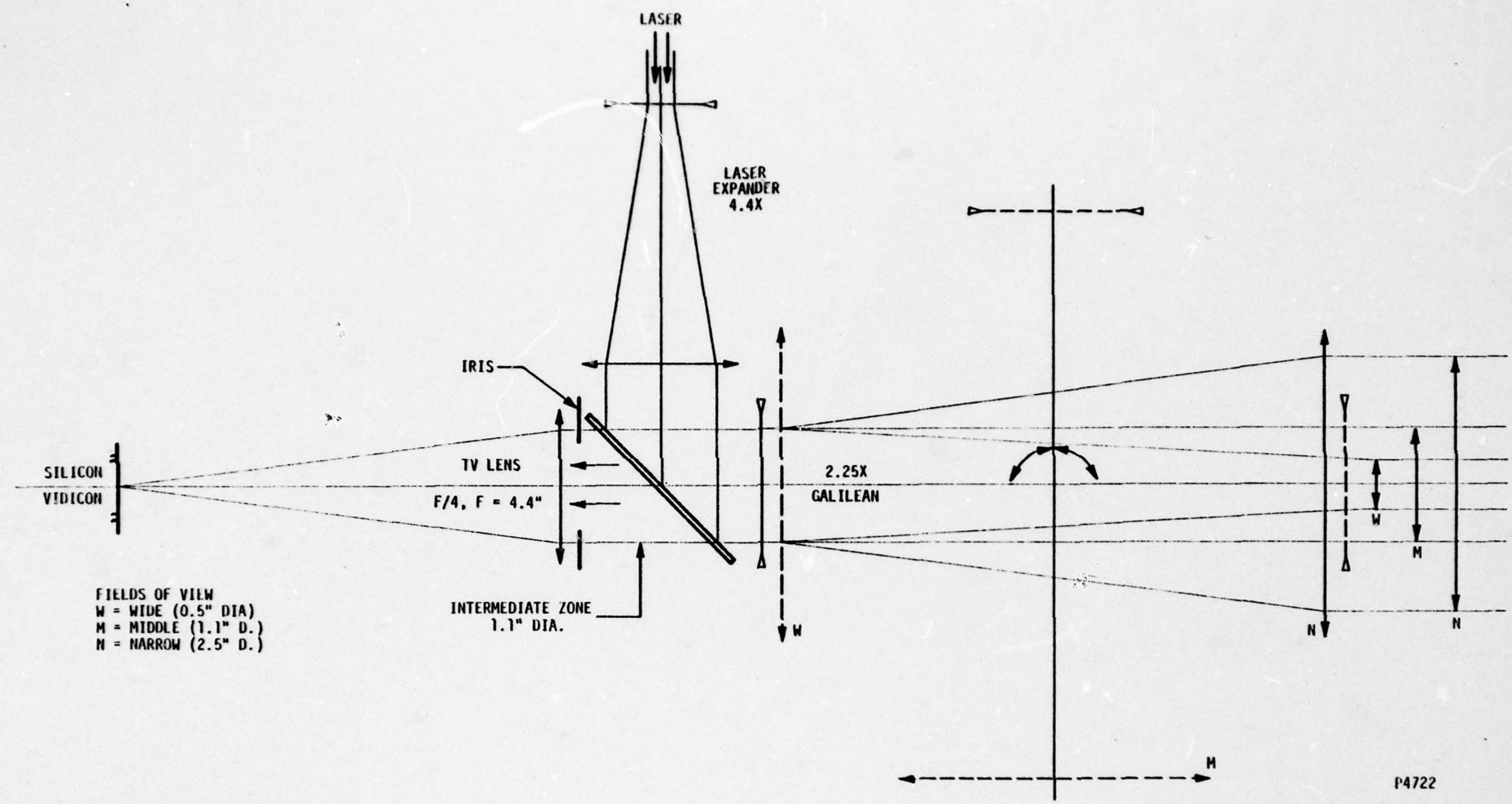


Figure 1. Rotating Galilean Design

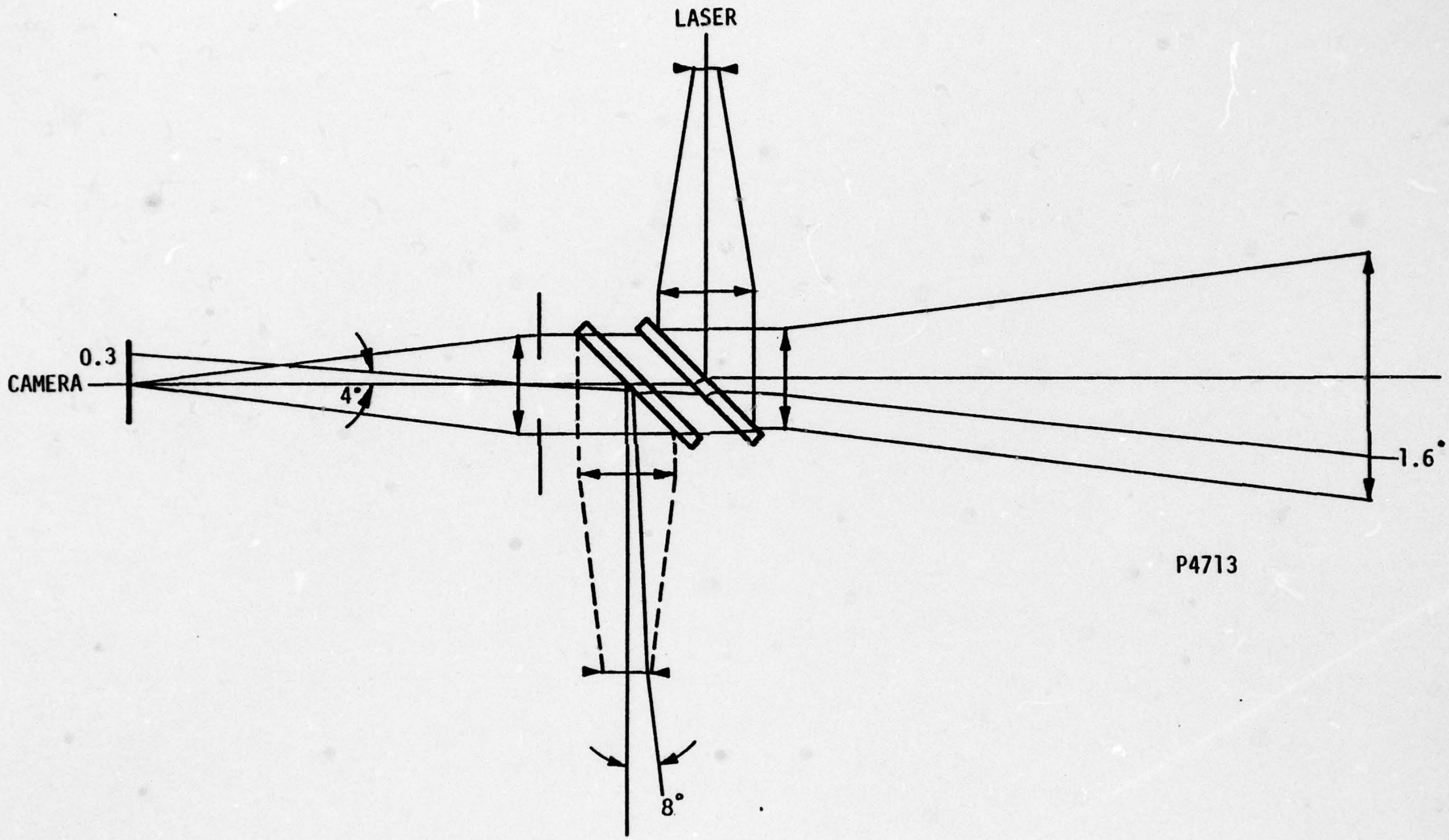


Figure 2. Afocal Splitter and Separate WFOV

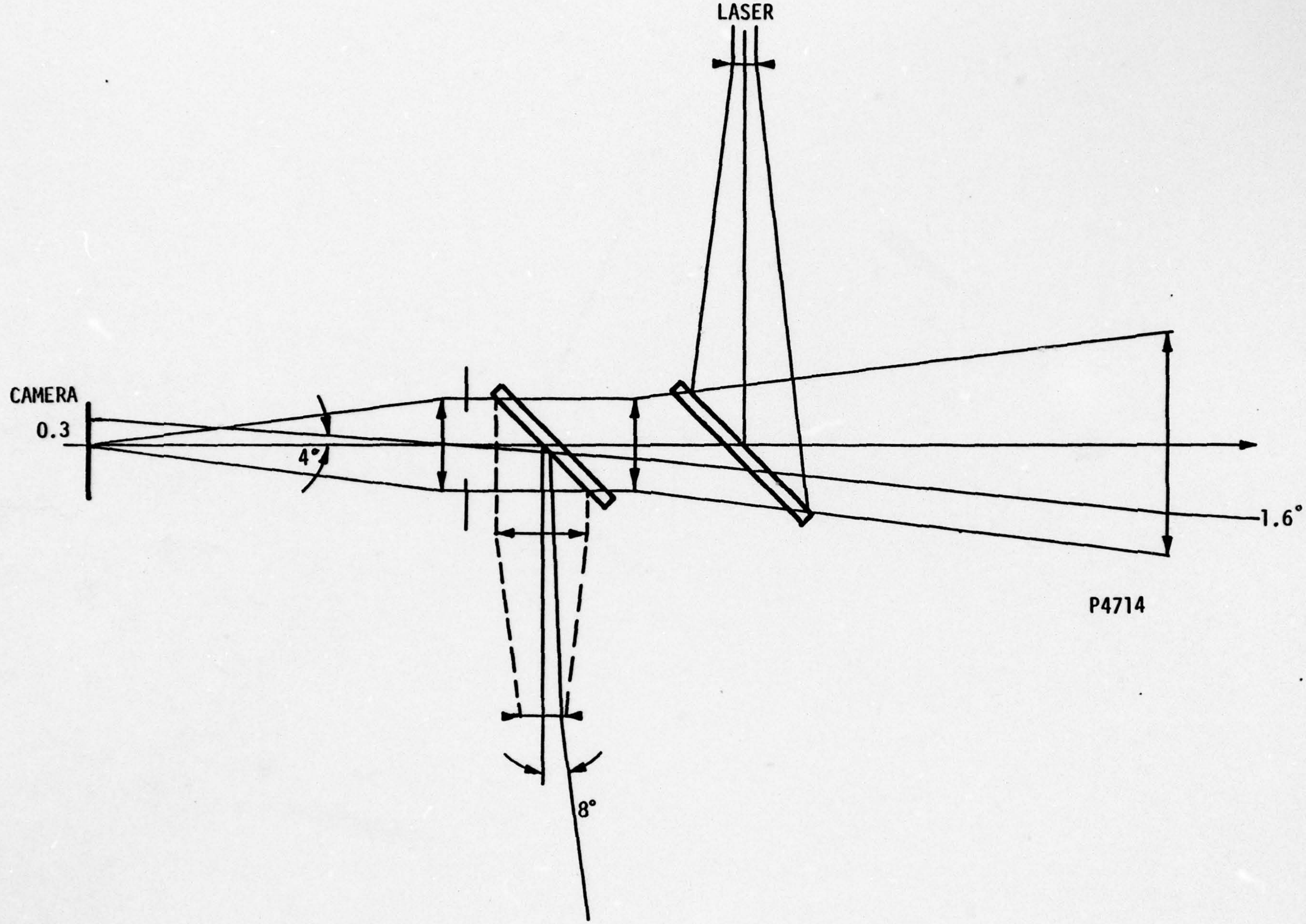


Figure 3. Design with Splitter in Convergent Beam

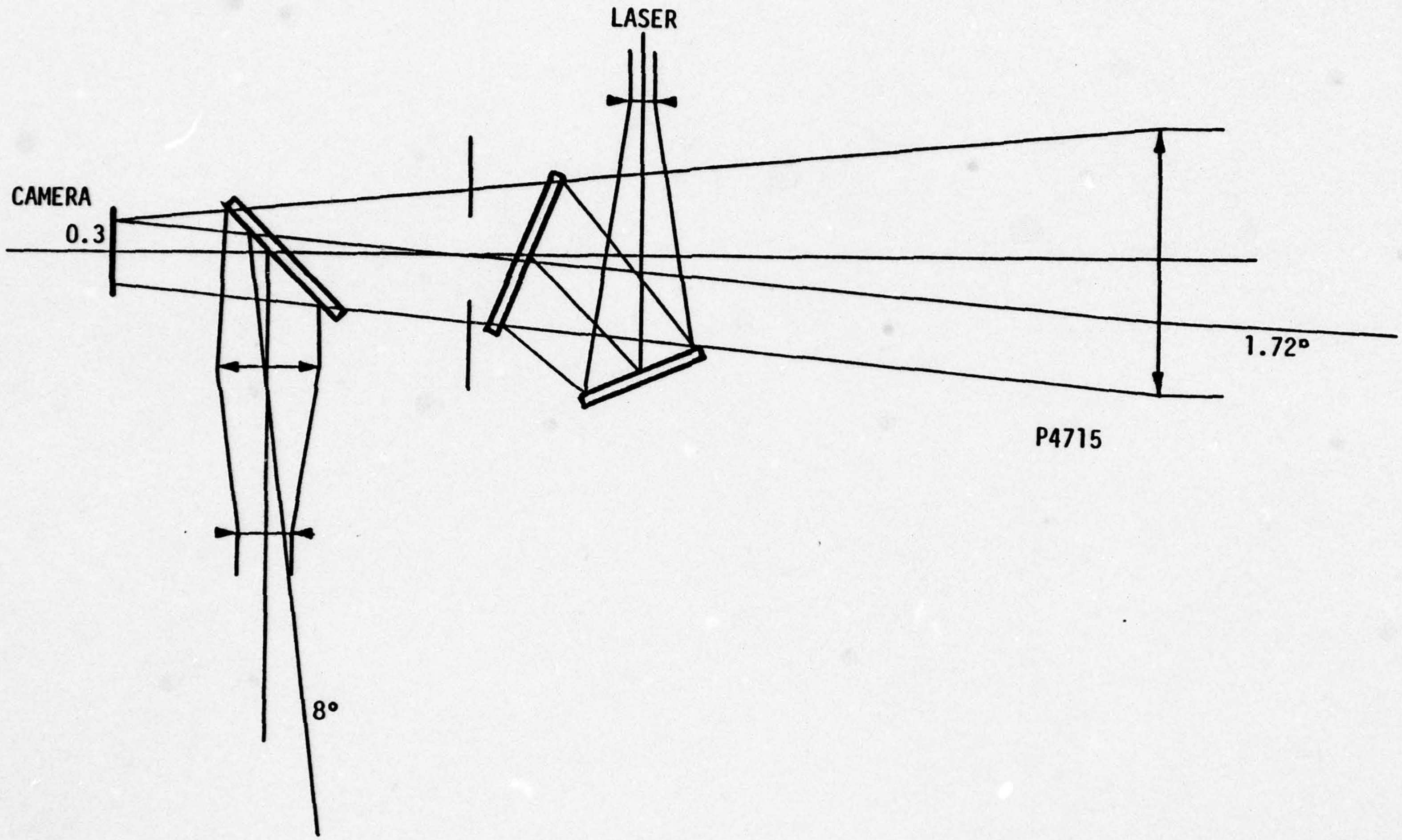
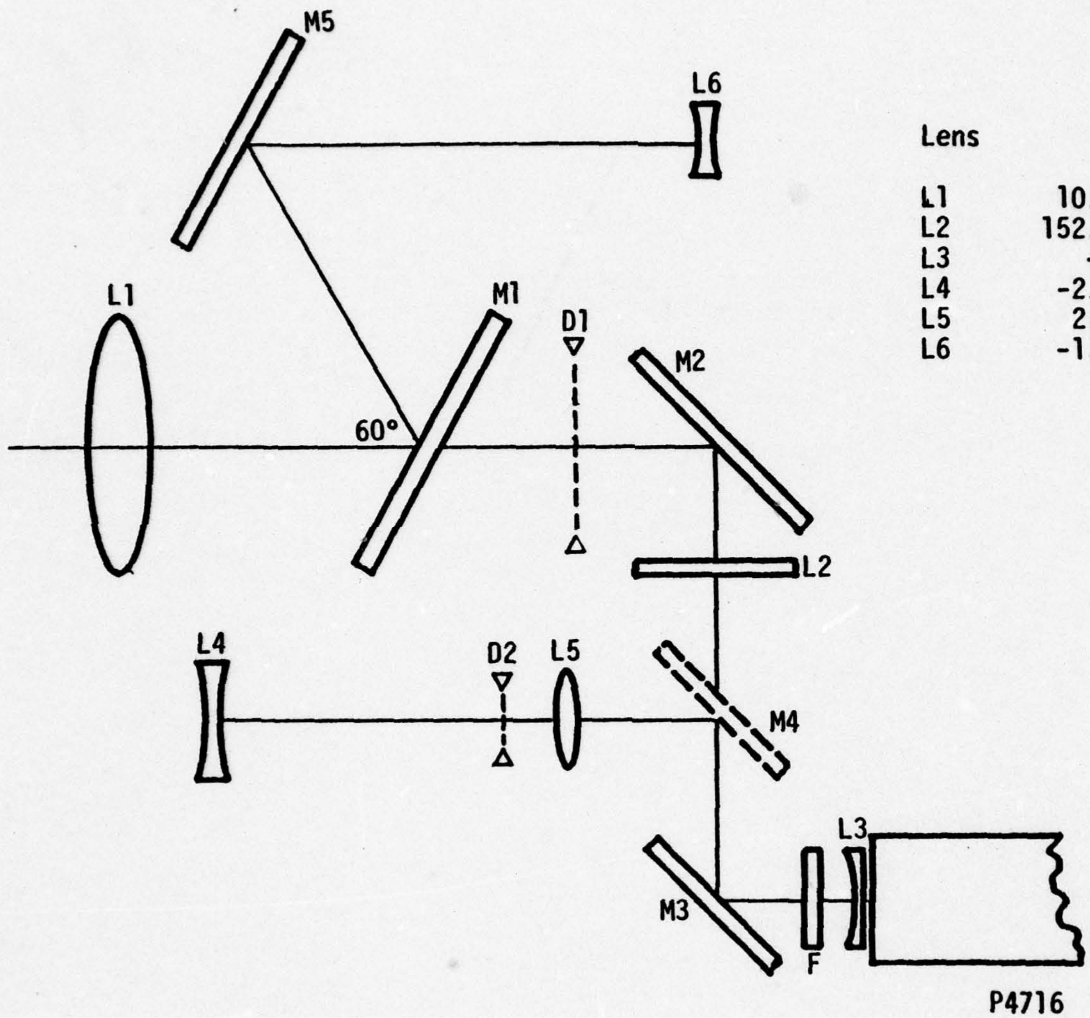


Figure 4. Minimum Parts Design



Lens	f	C.A.
L1	10.108	2.5
L2	152.30	1.24
L3	-	0.62
L4	-2.907	0.80
L5	2.384	1.08
L6	-1.011	0.254

Figure 5. Scidmore Concept A

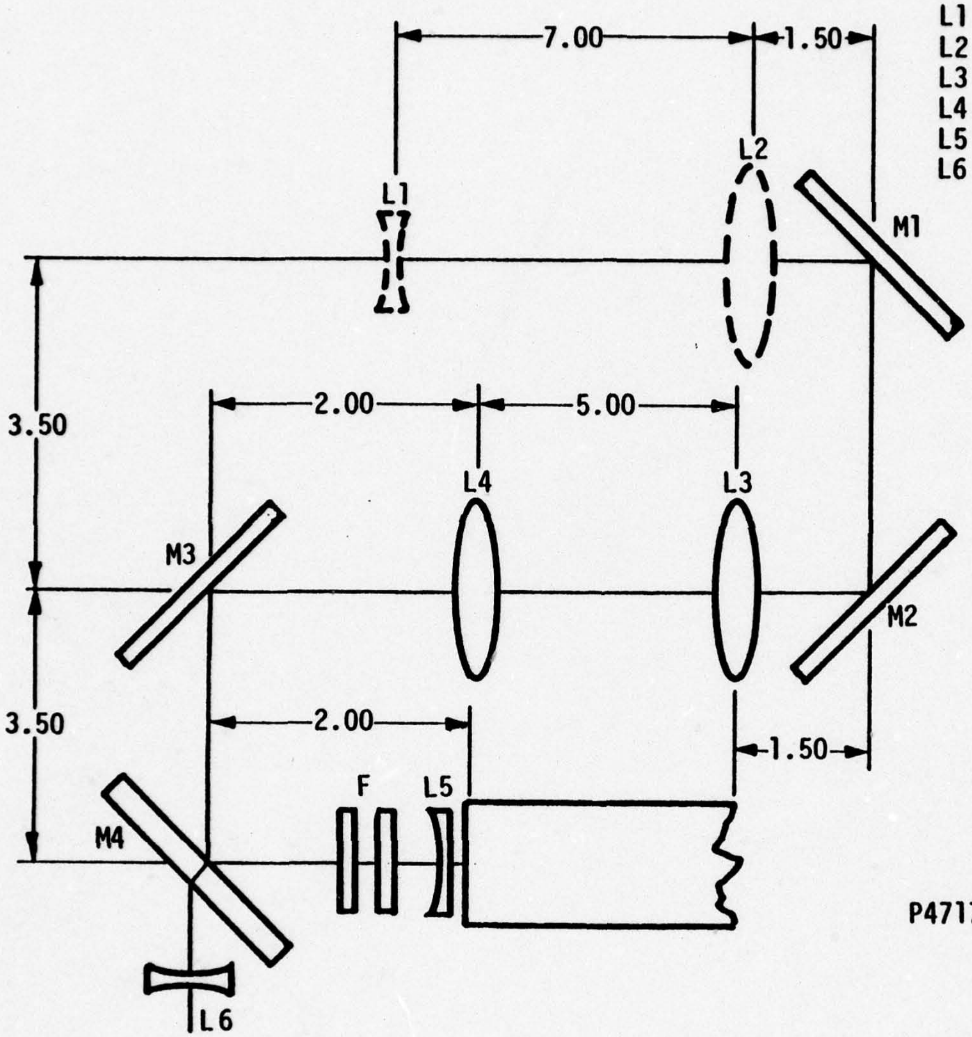
laser module. The wide field TV energy enters the system through negative lens L4, iris diaphragm D2, positive lens L5 and is reflected by select mirror M4, folding mirror M3, transmitted through filters F, and field flattener lens L3 and focussed at the vidicon face plate.

A major disadvantage of this concept is the poor boresight integrity of the WFTV due to the displacement of its axis with respect to the laser axis on the dome. It is estimated that three elements (a singlet and doublet) would be required for lens L1, a cemented doublet for L2, a singlet for L3, a cemented doublet for L4, three elements (a singlet and doublet) for L5 and two singlets for L6.

b. Concept B (Refer to Figure 6)

Light for the NFTV, WFTV and laser enter along a common axis. Lenses L1 and L2 comprise an afocal assembly (reverse Galilean telescope) which is in position for WFTV and out of the optical path for NFTV. Light is then reflected from folding mirrors M1 and M2 and transmitted through the common Petzval objective (L3 and L4), folded from mirror M3 and from beam-splitter plate M4 and transmitted through a light control (filter) assembly F and field flattener lens L5 and focussed at the vidicon faceplate. Laser energy is transmitted through lens L6, beam-splitter plate M4, mirror M3, lenses L4 and L3, mirrors M2 and M1, to object space. In the low power mode (wide field), the laser energy is also transmitted through the afocal assembly comprised of lenses L2 and L1 prior to being transmitted to object space.

This concept provides excellent boresight integrity for both the narrow field and wide field TV sensors with respect to the laser. The number of optical elements in separate paths which affect boresight are reduced to a minimum and boresight is unaffected by the magnification change assembly. It is pointed out, however, that in-flight boresight correction of the reticle for NF will introduce a boresight error in the wide field in the same manner as for all other concepts. This concept provides a challenge in regard to minimizing narcissus effects but a satisfactory solution is considered achievable. This scheme does not satisfy the present requirement that laser beam divergence be the same for WF and NF modes. A disadvantage of this scheme is the inability to provide an iris diaphragm for light control since it would affect the transmitted (and received) laser energy. Light control must be provided therefore by filter wheels or by variable density plates. This should



LENS	f	C.A.
L1	-1.750	0.75
L2	8.750	2.50
L3	21.01	2.50
L4	14.111	2.22
L5	-	0.62
L6	-2.100	0.25+

Figure 6. Scidmore Concept B

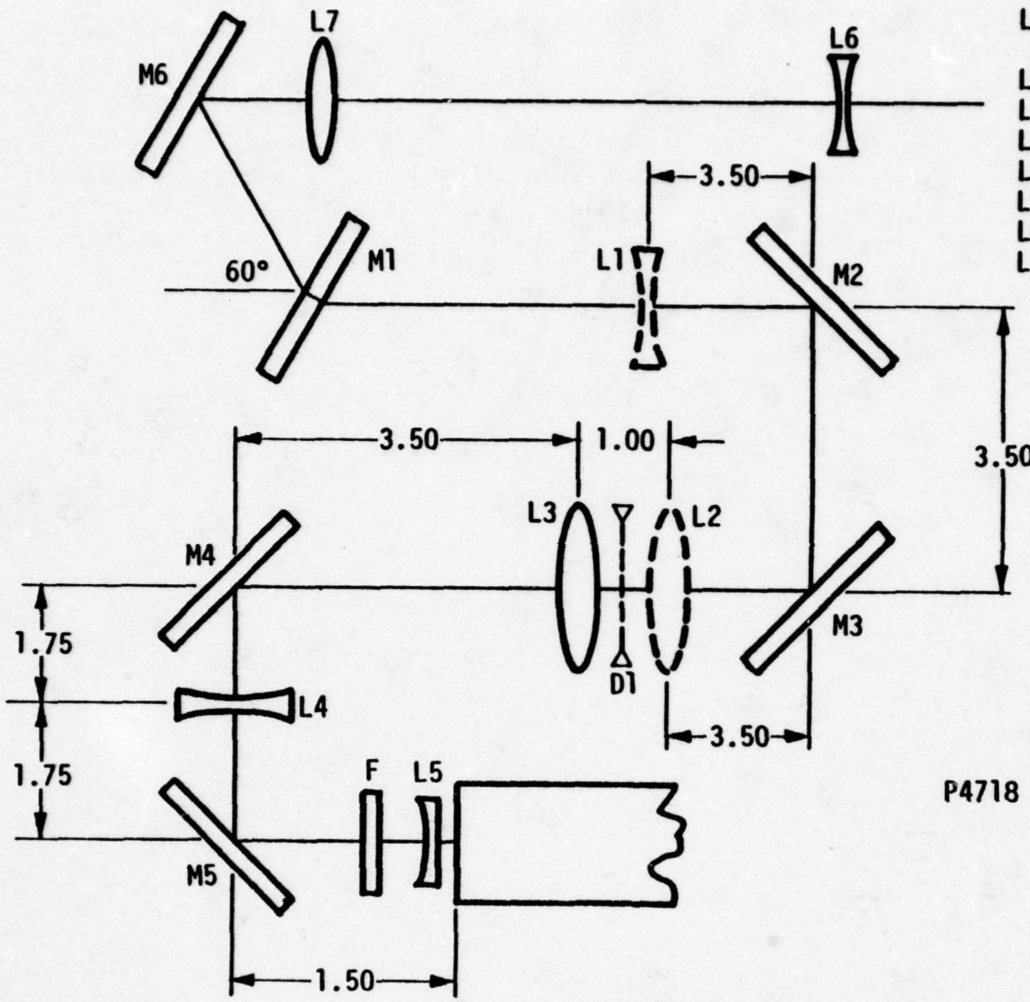
not necessarily be considered a disadvantage since the resolution will not be affected appreciably by filters. This scheme is shown using a beam-splitter plate to transmit the laser energy to minimize number of components. This plate would have a wedge angle to minimize axial astigmatism. A beam-splitter plate or prism could be embodied in the general concept to reflect laser energy if the added complexity is considered warranted.

It is estimated that three elements (a singlet and cemented doublet) would be required for lens L1, three elements (a singlet and cemented doublet) for L2, an air-spaced doublet for L3, a cemented doublet for lens L4, a singlet lens for field flattener L5 and two singlets for the laser diverging lens L6.

c. Concept C (Refer to Figure 7)

The NFTV, WFTV and laser transmitter all use a common entrance aperture. Light for the NFTV is transmitted through beam-splitter plate M1, reflected from folding mirrors M2 and M3, transmitted through iris diaphragm D1 and lens L3, reflected from mirror M4, transmitted through lens L4, reflected from mirror M5, transmitted through filters F and field flattener L5 and focussed at the vidicon faceplate. Changing from NF to WF is accomplished by flipping in a reverse Galilean telescope assembly containing lenses L1 and L2. The laser energy is transmitted through diverging lens L6 and collimating lens L7 and reflected by folding mirror M6 and beam-splitter plate M1 into object space.

Advantages of this system are minimum narcissus problems in lens design, and the use of a single iris diaphragm for both the NFTV and WFTV modes. Disadvantages include relatively poor boresight integrity due to the number of optical elements in separate TV/laser paths and the need for a separate large objective for the laser beam expander assembly. It is estimated that three elements (a singlet and doublet) would be required for lens L1, three elements (a singlet and doublet) for lens L2, three elements (all air-spaced) for lens L3, a cemented doublet for lens L4, a singlet for lens L5, two singlets for lens L6 and three elements (a singlet and doublet) for lens L7.



LENS	f	C.A.
L1	-2.625	0.97
L2	13.125	2.5
L3	7.838	2.5
L4	-12.709	1.17
L5	-	0.62
L6	-1.00	0.25+
L7	10.00	2.5

Figure 7. Scidmore Concept C

d. Concept D (Refer to Figure 8)

The NFTV, WFTV and laser transmitter all use a common aperture. Light for the NFTV is transmitted through common lens L1, laser beam-splitter plate M1, iris diaphragm D1, reflected from folding mirror M2, transmitted through lens L2, reflected from mirror M3, transmitted through filters F, field flattener lens L3 and focussed at the vidicon faceplate. Light for the WFTV is transmitted through lens L1 and beam-splitter plate M1, but is then reflected by prism P1 through negative lens L4, iris diaphragm D2, lens L5 and reflected by prism P2 through filters F and field flattener L3 and brought to a focus at the vidicon faceplate. The field of view change is effected by translating prisms P1 and P2 into the optical train for WF. The laser energy is transmitted through the negative diverging lens L6, reflected by folding mirror M4 and beam-splitter plate M1 and collimated by the common objective lens L1.

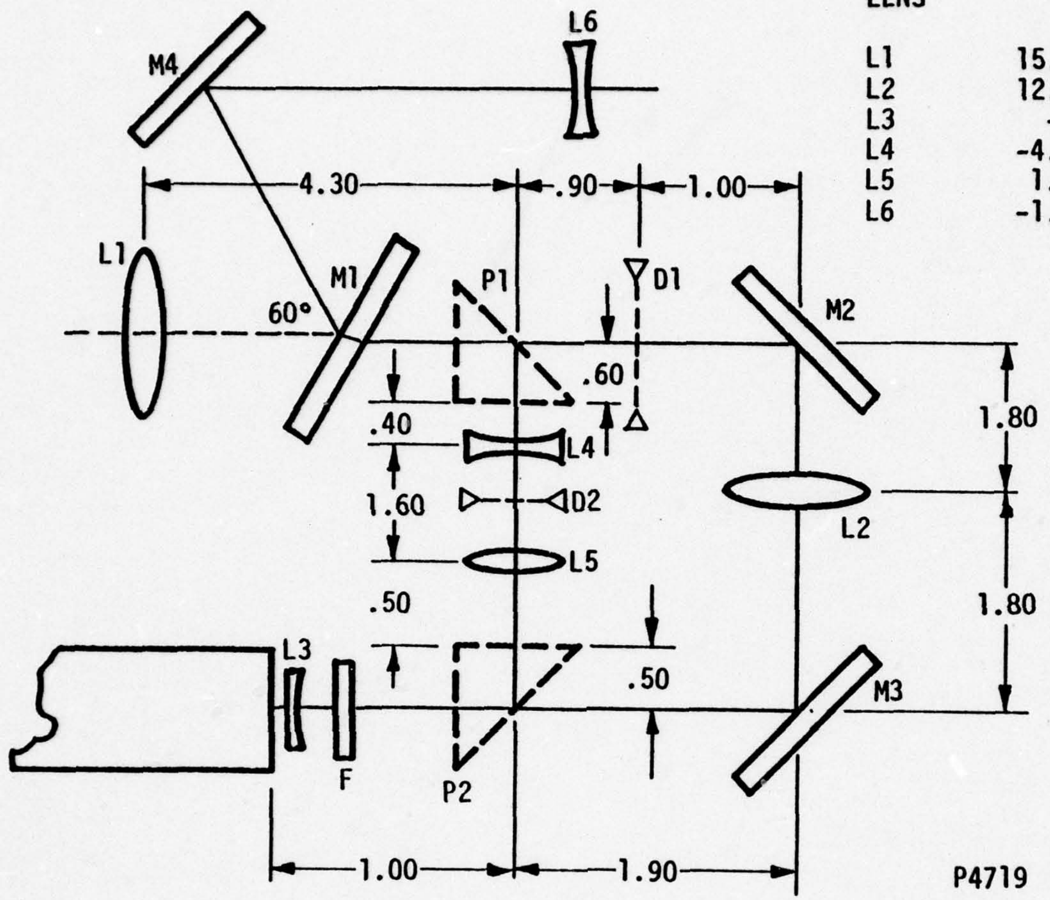
The principal advantage of this general concept is its compactness. No narcissus problems are anticipated using the beam-splitter plate as shown. A disadvantage is the need for separate iris diaphragms for the NF and WF (unless light control is provided entirely by filter wheels or variable density plates). Also, boresight integrity is not optimum due to the large number of optical components in separate paths for the laser and NFTV.

The number of lens elements required for the NFTV and WFTV has been determined for the same basic concept with some minor modifications in power distribution and laser beam-splitting method. It is believed that the same number of elements will apply to this first order design. Two singlet elements should suffice for lens L6 with an appropriate number of folding mirrors to project the laser beam from the resonator and to satisfy space requirements.

B. TEST LENS DESIGN

1. General

A layout of the complete test setup is shown in Figure 9. The laser was GFE and the TV camera is ILS test equipment. The (100-mm focal length, f/2.8) lens directly in front of the camera is a purchased item; in the final system it should be designed to be compatible with the RPV sensor (saving volume, weight, and complexity while improving performance.) Five lens groups, two dichroic beam splitters (one of them wedged), and a mirror had to be designed. The resultant breadboard system has (as can be seen in the figure) a neat layout with access to all parts for adjustment purposes.



LENS	f	C.A.
L1	15.551	2.50
L2	12.588	1.40
L3	-	0.62
L4	-4.311	0.47
L5	1.380	0.79
L6	-1.555	0.25+

Figure 8. Scidmore Concept D

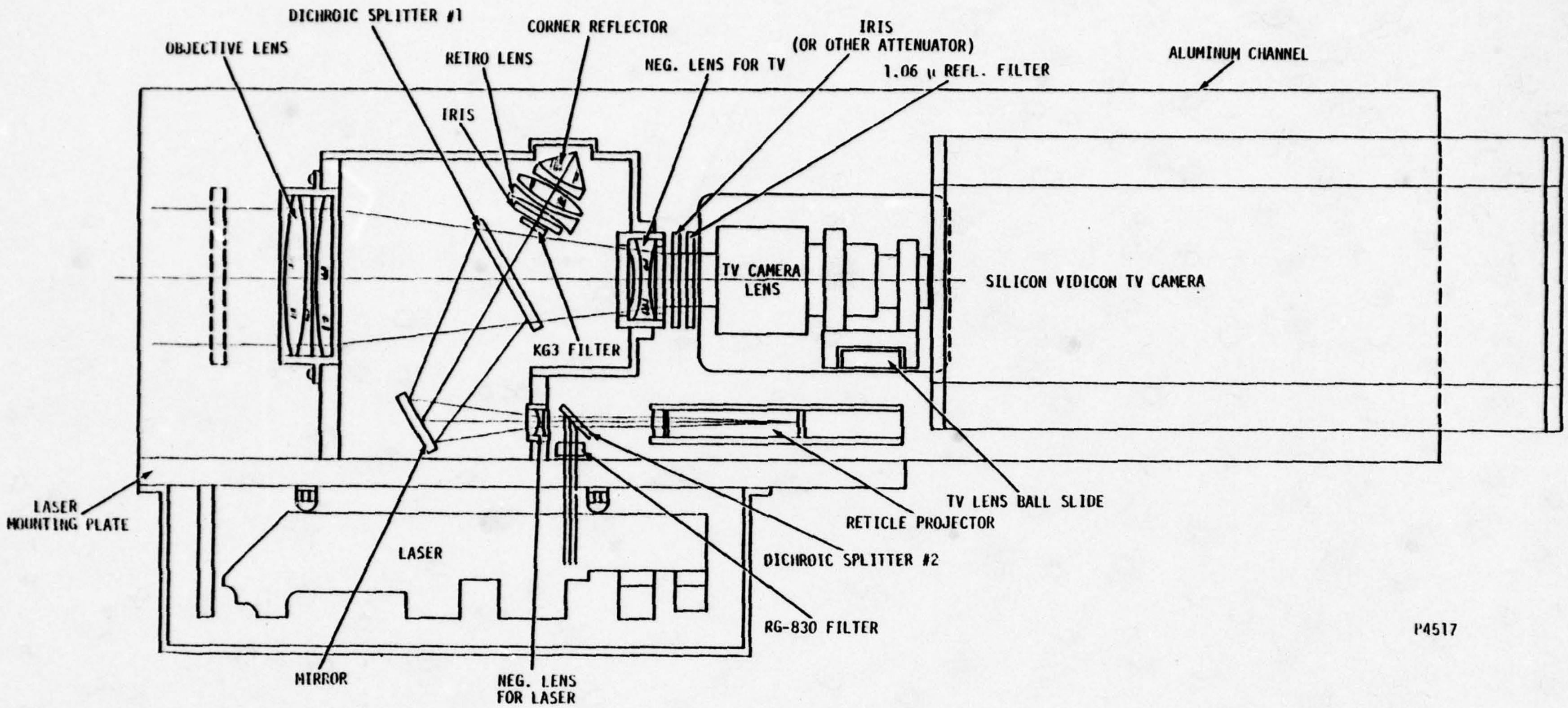


Figure 9. RPV Sensor Test Layout

The elements shown form a very versatile test bed. In the first place, it is possible that (except for the folding required for compactness) this will be the best general configuration. Secondly, it permits demonstration and debugging of all currently envisioned boresight techniques. Finally, the elements can be reconfigured into several of the other layouts described in the previous section with very little rework required.

The design is relatively self-explanatory. The objective and TV negatives lenses act as a 2.5X Galilean telescope on the 100-mm camera lens to give the desired 250-mm focal length. Dichroic splitter #1 combines TV and laser in the objective lens only, giving the common 2.5-inch aperture while minimizing the number of elements that the TV and laser have in common. This splitter is wedged to remove the axial astigmatism introduced by its 30° tilt. Some residual axial coma can be removed via a second plate in the remote event that it becomes important.

The laser output reflects off dichroic splitter #2 and then goes through the laser negative lens which, in combination with the objective, constitutes a diffraction-limited 10-power telescope. The laser itself is mounted outboard on a plate such that any available laser interferometer may be used by simply drilling new mounting holes.

The reticle projector generates a collimated beam which is combined with the laser beam by dichroic splitter #2. In practice, this would be mounted directly to the laser bed in order to minimize the possibility of relative boresight shifts, but they are separated here to increase the versatility of the test bed. The reticle is two concentric circles, 0.005" and 0.030" diameter, illuminated by a #328 lamp in near contact with the reticle (no condenser is necessary). The reticle is in a dark-field format, so that only the two bright rings are projected. A specially-designed 2.5-inch focal length doublet is used to project the reticle; the two rings therefore subtend 2 and 12 mrad respectively at splitter #2. These angles correspond to 0.2 and 1.2 mrad in target space. The center circle is used for alignment, but it is very difficult to see on a TV monitor so the larger circle is employed purely to help find the small one. These sizes may, in fact, be too small. The center circle is a dot on the TV. Better might be 0.6 and 3.0 mrad, referred to target space, or even larger.

In an operational system, an RG-830 filter (light-blocking) would be used between splitter #2 and the laser negative lens. The combination of elements limits the projector to the 0.83-0.95 μ spectrum. This should provide a more than adequate amount of energy from the projector, and it has the distinct advantage of simplifying the color correction problem. Splitter #1 will be only partially reflective (10-20%) in this spectral region, so most of the projector energy goes through the splitter, is collimated by the retro lens, and then returns via the retro prism. On the way back, 10-20% is reflected into the TV to provide a more-than-adequate image. Since nothing is perfect, splitter #1 will also "leak" some 1.064 μ laser energy which will also be retro-directed into the TV. Thus, both self- and projector-boresight techniques were tested and compared.

2. Diffraction Effects

While the calculations are rather simple, it is necessary to know what theoretical limits there are to system performance. Both laser and TV will be examined.

The laser is limited, in the optimum case, by the Airy disc. The angular diameter of the first dark ring, which contains 84% of the total energy, is (in object space)

$$\beta_L = \frac{2.44\lambda}{D} = (2.44)(1.064 \times 10^{-6})/(63.5 \times 10^{-3})$$

so β_L = 41 microradiams.

A system requirement of, for example, 120 μrad is thus only three times the theoretical limit.

The TV is a little more complex. Probably the easiest approach (not necessarily the the best) is to simply equate the Rayleigh limit to the scan line spacing and determine the resultant f-number. A little mathematic manipulation gives f-number = F/D = S/1.22λ where S is the physical line spacing. For 525 lines in 9.5 mm, S = 18.1 microns (720 micro-inches). If we use λ= 0.78 micron (the approximate center of the useful band), then F/D = (18.1)/(1.22 X 0.78) = 19.1. Thus any lens speed faster (smaller f-number) than f/19 will provide aberration- and scan-limited operation. Any speed slower than f/19 will generally be diffraction-limited. This reduces to f/9.5 for a 2:1 underscan.

Based on a 100-mm focal length TV lens, the angular equivalent of the TV line spacing is easily seen to be 181 μrad at the beamsplitter , or 72 μrad in object space (outside the 2.5X Galilean). Thus, it is compatible with the previous laser calculations: more than the laser diffraction limit, but less than the real laser beam. These numbers are also halved, to 91 and 36 μrad respectively, if a 2:1 underscan is employed.

3. Breadboard Lens Design

Figure 10 is an accurate schematic of those optics which were designed specifically for this breadboard system. As can be seen, there are five lens groups which perform four separate functions: (1) TV expander, (2) laser collimator, (3) reticle projector and (4) retro-reflector. The design was performed, and will be discussed, in that order.

Central to the design is the 2.5X Galilean telescope for the TV camera. Two controlling factors in this design are (1) the dual function of the objective (lenses D, E, F), and (2) the terrible iris location just to the camera side of lens A. Galilean telescopes are, by nature, problem children anyway when (unlike laser collimators) a finite field-of-view is required. Vignetting is a common technique for controlling off-axis aberrations (especially coma) in such systems.

The design started with a selection of the doublet plus singlet objective configuration. An air-spaced doublet would probably have sufficed for the TV, but experience has shown such lenses to be unworkable as laser objectives because of excessive high-order spherical aberration. A cemented doublet negative lens (elements A + B) appeared adequate, and experience has shown this orientation to be superior to the reverse (positive on left). Surface 6 was vignetted to the 2.41-inch axial bundle diameter, which permitted it to be used as the aperture stop for design purposes. The two most difficult aberrations to remove were high-order coma and lateral color. The final prescription, given in Table 2, is better than necessary for the fully scanned TV, and the center of the field can even handle the 2:1 underscan at full aperture. Aberration curves are given in Figure 11, and the effect of vignetting can be seen in Figure 11C. The aperture of lenses A+B was increased so that, along with the f/2.8 TV lens, the system would operate at f/4: the aperture stop would be surface 6 and there would be no vignetting. As the iris is closed to 1-inch, about 25% vignetting is encountered as shown but the system is still at f/4. At about

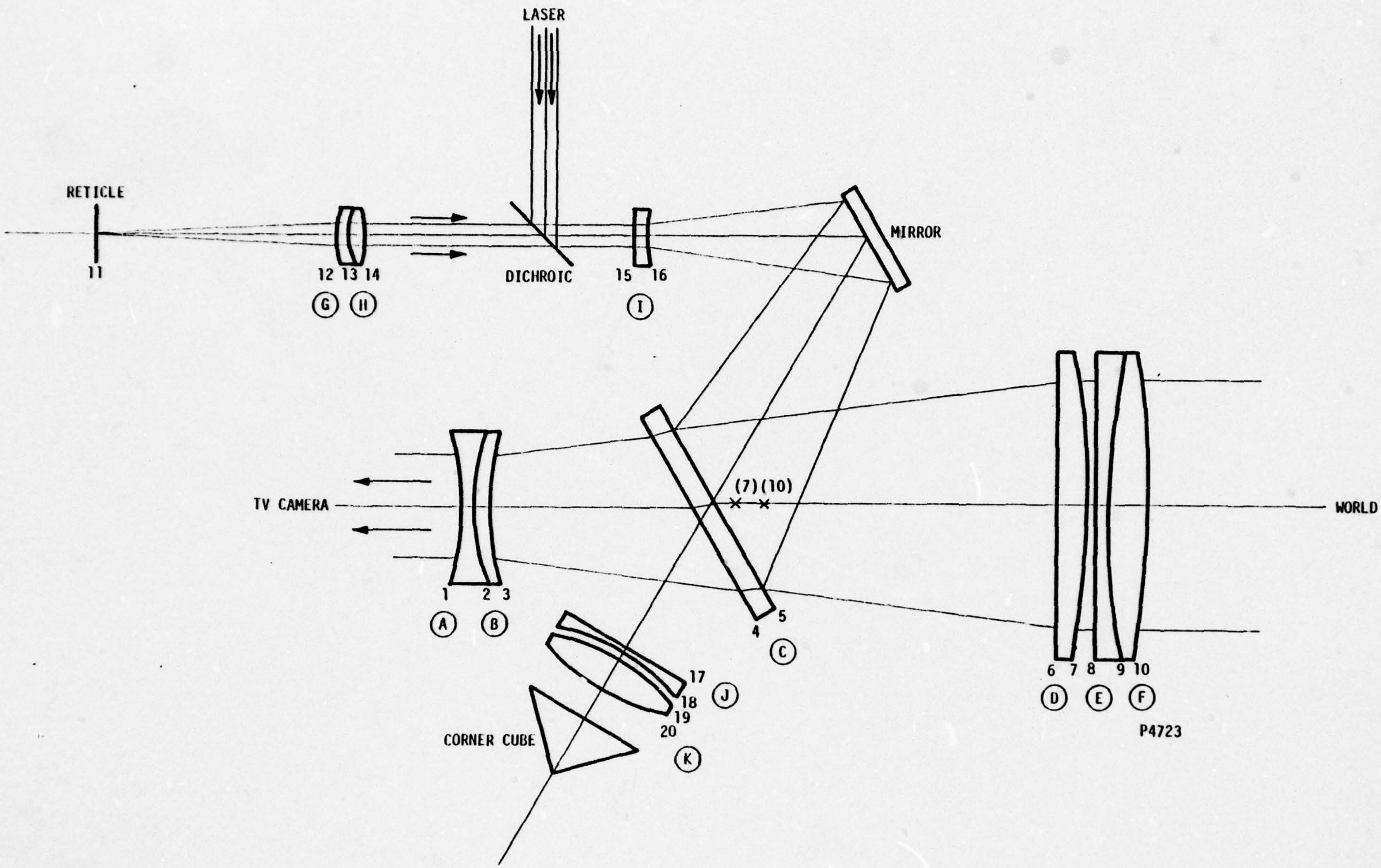


Figure 10. Breadboard Optics

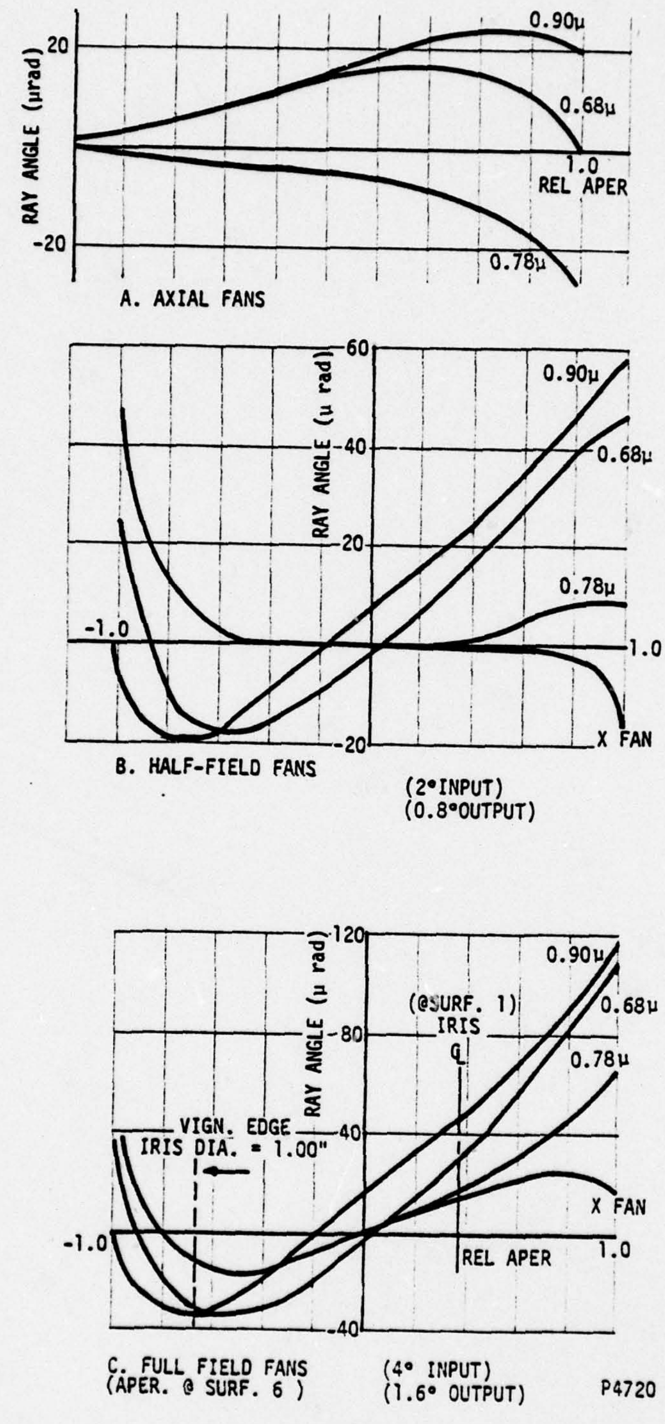


Figure 11. 2.5X Galilean Ray Fans

TABLE 2. BREADBOARD 2.5X GALILEAN FOR TV

Lens	Material (Shape)	Outside Diam.	Clear Aper.	Thickness	Surf.	Radius	Air Space	Comments
A	SK-16	1.500	1.35	0.150	1	-3.909		
	(DCc)				2	2.047		
							Cemented	
B	SF-56	1.500	1.35	0.200	2	2.047		
	(P-Men)				3	4.719		
							1.970	focus TV (1)
C	BK-7	1.90x	1.75x	0.200	4	∞		Rectangular
	(Plano)	2.30	2.15		5	∞		Tilted 30°
							3.400	Wedged 10'30"
D	SK-16	3.000	2.75	0.300	6	33.960		
	(DCx)				7	-9.043		
							0.100	
E	SF-56	3.000	2.75	0.150	8	∞		
	(PCc)				9	7.944		
							Cemented	
F	BK-7	3.000	2.75	0.350	9	7.944		
	(DCx)				10	-10.658		

f/6.5 vignetting again disappears. The curves in Figure 11 plainly shown secondary color and field curvature as the most significant remaining aberrations. The field curvature is of opposite sign to that usually present is camera lenses and ought to actually help some.

The wedge splitter was then examined (element C). A plane parallel plate design injected about 190 μrad of axial astigmatism which was completely removed with about 10.5 arc-minute wedge (narrow end toward objective).

The laser collimator now requires only lens "I" to be complete. This can be made of almost any glass which is modestly damage-resistant and transparent to 1.064 μ. An initial attempt with Silica gave 2-μrad diameter spherical aberration with an unacceptable back reflection off surface 15. It later turned out that a very dispersive, high index glass would help the projector color-correction, so SF-56 was chosen with the prescription shown in Table 3 and , again, a 2-μrad blur.

Next, the reticle projector was designed using the main objective (lenses I, D, E, F) as a collimator. A focal length of 2.5 inches was chosen to generate reasonable-sized TV images from the 0.005 and 0.030 inch-diameter reticle circles. The only real design problem was axial color, since the 0.83-0.95 μ spectrum is not easy to correct. The resultant lens had spherical and coma problems which were partially solved by compromising the color correction. The net result, given in Table 3, has (related to the "world" side of the objective) only 60 μrad of axial blur and 0.3 mrad blur of the outer ring. This last is bad, but reduces to 80 μrad when restricted to half-aperture by the retro lens.

Lastly, the retro lens (elements J + K) was designed to collimate the projector onto the corner cube (the return path should take care of itself). A cemented doublet was tried and would not work for any pair of real glasses, so a small air-space was used. The result, at 1.3-inches diameter on the prism (about 2/3 of the laser aperture) is only 40-μrad of axial chromatic aberration for the projector and 14-μrad spherical for the laser.

The experimental results have completely justified this design.

TABLE 3. BREADBOARD RETICLE AND LASER PROJECTOR

Lens	Material (Shape)	Outside Diam.	Clear Aper.	Thickness	Surf.	Radius	Air Space	Comments
Reticle	-	-	-	-	11	∞		
							2.331	focus reticle (4)
G	SF-56	0.560	0.500	0.100	12	1.724		
	(N-Men)				13	0.549		
							Cemented	
H	SK-16	0.560	0.500	0.150	13	0.549		
	(DCx)				14	-2.500		
							(≈ 2.7)	not critical
I	SF-56	0.560	0.500	0.100	15	25.800		
	(N-Men)				16	0.757		
							5.241	focus laser (2)
C	BK-7	(see 2.5X		0.200	5	∞		
	(Plano)	Galilean)			4	∞		
							1.479	focus retro (3)
J	SF-5	1.375	1.250	0.100	17	-39.370		
	(DCc)				18	3.150		
							0.108	
K	BK-7	1.375	1.250	0.250	19	3.333		
	(DCx)				20	-2.838		

C. SCIDMORE COMMON-APERTURE DESIGN

Figure 12 and Tables 4 and 5 show the results of lens design for the NFTV and WFTV systems for this basic concept. The image quality of both systems is considered excellent for the entire spectral range and for all fields of view. The wavelengths used for the design cover the entire spectral range of interest (0.78, 0.63, and 0.9 micron). Considerable effort was expended in selecting glasses which would give good secondary color correction while not placing too great a burden on manufacture. Much of the work done on this design should be applicable to the evolvement of a final design when the configuration is firmed up.

The general concept is discussed previously as Concept D (Figure 8). Lens L1 consists of two elements, lens L2 also consists of two air-spaced elements (though it might be possible to make this component a cemented doublet), lens L3 is a singlet, lens L4 consists of two elements, and lens L5 consists of four air-spaced elements. A two-reflecting 45° prism is used to transmit TV energy and reflect the laser transmitter energy instead of the beam-splitter plate shown in Concept D.

Unfortunately, this design suffers from reflected laser energy focussing in the middle of the laser beam-splitter prism. This problem can be eliminated by one of the following methods:

(1) Changing the power distribution and using a beam-splitter plate instead of the beam-splitter prism as shown in first order design of concept D (Figure 8).

(2) Use of longer focal length TV lenses (reduced fields of view) would permit objective lens to be displaced from laser beam-splitter prism without introducing excessive vignetting of wide field — the reflected energy being focussed harmlessly in space between objective and beam-splitter prism.

The objective (lenses A + B) will probably have to be increased to three elements in any case because of its use in the laser collimator. As discussed in the previous section, the high-order spherical aberration of such a lens usually is very difficult to overcome. In this case, even at the f/5.6 speed of the front lens group, a preliminary design effort could only reduce the spherical residual to 25-μrad diameter. This is unacceptably high for even a 200-μrad output requirement because it places an unnecessary extra burden on the laser design.

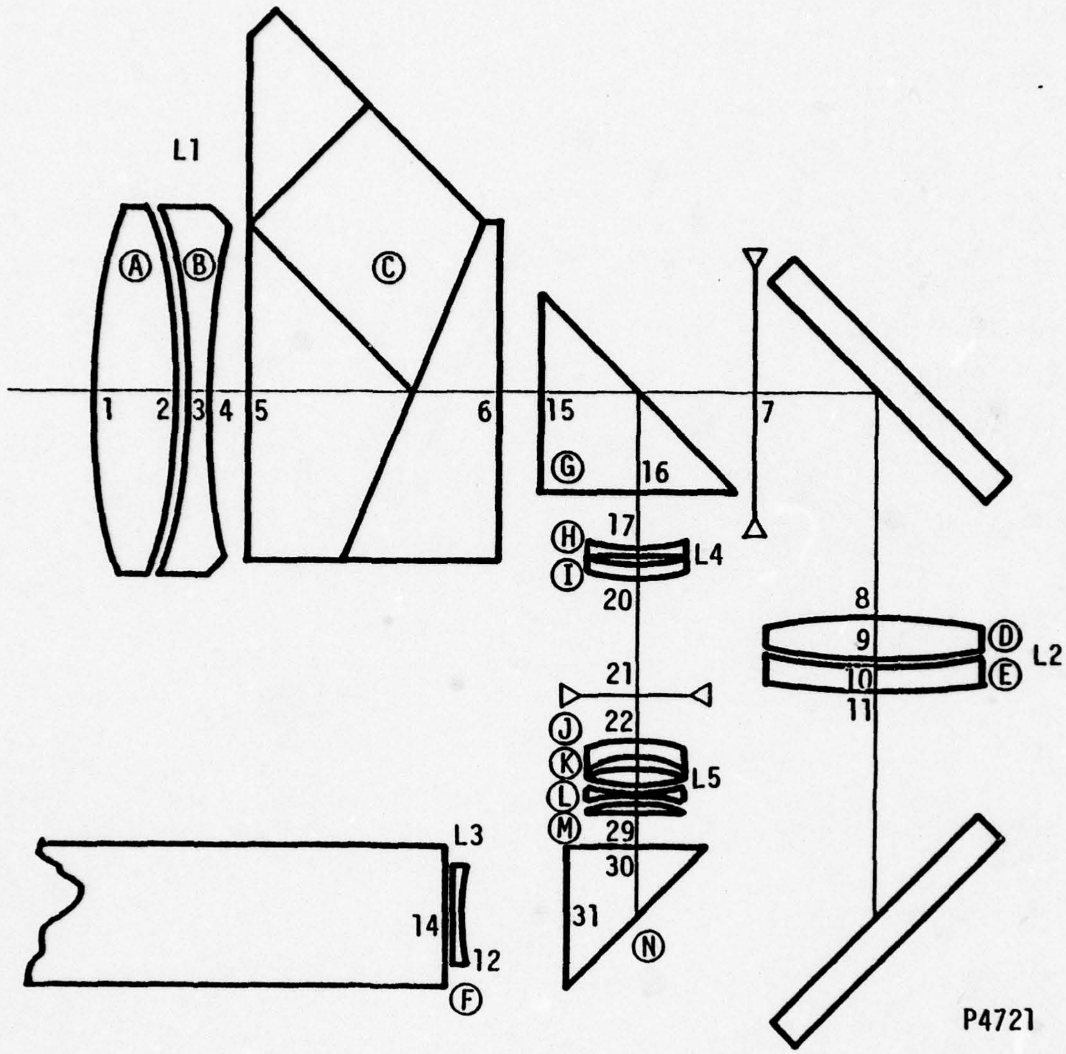


Figure 12. Scidmore Design D

TABLE 4. SCIDMORE DESIGN "D" - NFOV PATH

Lens	Material (Shape)	Thickness	Surf	Radius	Air Space	Axial Ray	Edge Ray	Comments
A	SK-7	0.600	1	5.282		1.250	1.408	
	(DCx)		2	-4.415		1.197	1.386	
					0.064			u = 0.305
B	KZFS4	0.200	3	-4.192		1.177	1.358	RARE GLASS
	(DCc)		4	15.562		1.160	1.302	
					0.206			u = 0.090
C	BK-7	1.850	5	∞		1.142	1.281	LASER COMBINER
	(Prism)		6	∞		1.032	1.116	
					1.850			
IRIS	-	0	7	∞		0.865	0.865	44-mm Dia.
					2.500			(Rather Large)
D	SK-2	0.300	8	11.270		0.640	0.751	
	(DCx)		9	-4.226		0.617	0.740	
					0.020			
E	SF-11	0.150	10	-3.945		0.612	0.736	
	(N-Men)		11	-13.055		0.604	0.731	
					4.642			u = 0.128
F	SK-2	0.080	12	-4.217		0.009	0.316	FIELD FLATTENER
	(PCc)		13	∞		0.003	0.314	
					0.020			
TUBE	-	0	14	∞		0	0.313	16-mm Diag.

TABLE 5. SCIDMORE DESIGN "D" — WFOV PATH

Lens	Material (Shape)	Thickness	Surf	Radius	Air Space	Axial Ray	Edge Ray	Comments
A	SK-7	0.600	1	5.282		0.250	1.264	Uses Full
	(DCx)		2	-4.415		0.239	1.211	2.5" Lens
					0.064			
B	KZFS4	0.200	3	-4.192		0.235	1.173	
	(DCc)		4	15.562		0.232	1.097	
					0.206			
C	BK-7	1.850	5	∞		0.228	1.053	
	(Prism)		6	∞		0.206	0.740	
					0.300			
G	BaK1	1.400	15	∞		0.201	0.662	
	(Prism)		16	∞		0.185	0.434	
					0.400			
H	SK-2	0.080	17	-1.053		0.178	0.345	
	(N-Men)		18	-16.901		0.182	0.342	
					0.033			
I	SF-11	0.100	19	-1.489		0.184	0.343	
	(P-Men)		20	-1.040		0.194	0.349	
					0.866			
IRIS	-	0	21	∞		0.219	0.219	11-mm Dia.
					0.300			
J	SF-11	0.140	22	2.209		0.227	0.286	
	(N-Men)		23	1.093		0.223	0.296	
					0.026			
K	SK-2	0.120	24	2.584		0.226	0.297	
	(DCx)		25	-1.273		0.230	0.307	
					0.010			
L	SF-11	0.060	26	-8.011		0.230	0.312	
	(DCc)		27	3.573		0.229	0.319	
					0.010			
M	SK-2	0.124	28	0.895		0.229	0.332	
	(P-Men)		29	14.666		0.219	0.331	
					0.231			

TABLE 5. SCIDMORE DESIGN "D" — WFOV PATH (continued)

Lens	Material (Shape)	Thickness	Surf	Radius	Air Space	Axial Ray	Edge Ray	Comments
N	BaK1	1.000	30	∞		0.189	0.326	
	(Prism)		31	∞		0.107	0.314	
					0.762			
F	SK-2	0.080	12	-4.217		0.009	0.299	
	(PCc)		13	∞		0.003	0.300	
					0.020			
TUBE	-	0	14	∞		0	0.301	Not Quite 16-mm

D. NARCISSUS ANALYSIS

1. General

Narcissism — the art of staring at one's own reflection — can be as devastating for laser systems as it was for Narcissus himself. Even if not physically damaging, the reflections can be enough of a nuisance to compromise system performance. The problem occurs because no anti-reflection coating is perfect. The small amounts of laser energy reflected from (usually curved) lens surfaces is enough to damage other optical elements if focussed "properly". The receiver in a transceiver system is especially sensitive to surfaces which are normal to the laser beam, as is the silicon vidicon in a common-optics arrangement. Laser-only problems will be discussed next, followed by the TV-imposed limitations placed on lens design.

2. Laser Considerations

Most dramatic of the laser problems is component damage, and the most vulnerable component is the receiver detector in a transceiver. Next in vulnerability are multi-layer dielectric coatings, followed by the bulk optical materials themselves. In many cases non-optical hardware can also be damaged by stray laser radiation. As an example, look at Figure 10. Notice the pair of "x"'s on the optical axis just to the right of splitter C. These are the paraxial reflection foci from surfaces 7 (lens D) and 10 (lens F). When examined in detail, these foci turn out to be quite soft (fuzzy) and strongly divergent. If this were not the case, they would need to be located at a much greater distance from surface 5.

Most subtle, and deadly, are those reflections which are only slightly convergent so that they focus inside the laser, to the left (optically) of lens I . These foci are always very sharp and can damage almost any part of the laser interferometer. Perfectly collimated reflections can also act as etalons and cause premature or erratic lasing action.

One must also be aware of the assembly procedure. Lens spacings, for example, often change drastically in the process of focussing the system. A reflection which is designed only slightly divergent can be made dangerously convergent by a change in lens spacing (lenses used in testing must also be evaluated carefully in this light).

The lens designer must therefore (1) avoid surfaces normal to the laser beam, (2) keep "hard" reflection foci away from everything (especially the laser), and (3) keep soft foci away from coated surfaces. Parenthetically, a burn at the center of splitter C in Figure 10 would certainly not be fatal. In fact, the effect is almost (in this case) totally cosmetic and might not have any noticeable effect on system performance.

3. TV Considerations

The laser and the TV camera should not be on speaking terms under any conditions or via any routes: electrical, mechanical, acoustical, or optical. Optically, the laser emits broad-band light from the flashlamp and narrow-band fluorescence in addition to the primary laser output. These can be controlled and minimized, but never completely eliminated.

Internal shields and an RG-830 filter usually are adequate to suppress the flashlamp. The fluorescence is less well organized than the Q-switched pulse, so those techniques which eliminate direct reflection problems invariably also control the fluorescence. The remaining optical problem, then, is the control of that laser energy which is reflected off common optical elements into the TV camera.

The analysis is not too difficult. Using the symbols in Table 6, the reference power density is

$$F = I/A\eta_Q. \quad (1)$$

The laser output must be referred to the vidicon plane and scan rate. Thus, for a laser prf of less than the scan rate,

$$P = (E/T)\ \eta_R\ \eta_T\ \eta_O, \quad (2)$$

and, if this power is spread over a diameter D at the vidicon plane,

$$F_r = P/(\tfrac{\pi}{4}\ D^2). \quad (3)$$

The problem now becomes one of reducing F_r so that $F_r \leq F$, by either increasing D or decreasing one or more of the η's.

TABLE 6. NARCISSUS ANALYSIS SYMBOLS

Symbol	Typical Value	Meaning
I	2 na	Minimum permitted photocurrent
A	123 mm^2	Scanned photo surface area
F	0.27 nw/mm^2	Minimum photo surface power density
T	1/30 sec	Scan frame time
E	100 mJ	Laser output energy
η_R	0.002	Lens surface reflectivity
η_T	0.002	Beamsplitter transmission @ 1.06μ
η_O		Optics transmission (including filters)
η	60 ma/watt	Vidicon conversion efficiency @ 1.06μ
D		Reflection diameter @ vidicon plane
W	12.8 mm	Scan width
F_r		Reflection power density @ photosurface
P		Laser power at vidicon plane
K		D/W ratio
N		Refractive index preceding refl. surface
i		Paraxial axial ray incidence angle
Y		Paraxial axial ray height
f		Lens speed at vidicon

Setting $F_r = F$ results in

$$\frac{P}{\frac{\pi}{4} D^2} = \frac{I}{A\eta_Q} \qquad (4)$$

and since (for a 3 x 4 scan) $A = \frac{3}{4} W^2$,

$$(\frac{\pi}{4} D^2)/(\frac{3}{4} W^2) = P\eta_Q/I$$

or $$(D/W)^2 \approx (E/TI)\ \eta_R\ \eta_T\ \eta_O\ \eta_Q. \qquad (5)$$

This, then, defines the minimum permitted D/W ratio, which we shall call K. It is possible to show, via the "optical invariant" that this means

$$|\ N\ y\ i\ | \geq \frac{K\ W}{8\ f} \qquad (6)$$

This equation controls the optical design by restricting surface curvatures even more severely (in many cases) than the laser considerations.

For a bright (800 na) scene, the minimum detectable signal will be about 16 na. If $\eta_O = 1$ is assumed and the other tabulated values are used, equation (5) gives $(D/W)^2 = 45$ or $K = 6.7$. For surface 10 (for example), $N \approx 1.6$, $y \approx 32$ mm, and $f = 4$ so the incidence angle i (from equation 6) must be greater in magnitude than 0.052 radian or 3°. This surface meets this criterion easily, as do all the others except surface 8, where i = 1.14°. Experimentally, this was the only surface which produced a bothersome reflection. Since N = 1 at this surface, and $y \approx 30$ mm, equation 6 says a value of $i \geq 5.1°$ is needed.

There is no provision for control of incidence angle in most lens design programs. The best bet is to first use filters to reduce η_O as much as possible. Then the design must be iterative, forcing recalcitrant surfaces to acceptable shapes and possibly adding a compensatory element or two. A 1.064 μ multi-layer mirror ($\eta_O \approx 0.005$) was used as a filter in the breadboard to completely solve the surface 8 problem with only a modest impact on sensitivity. This filter had other effects on the system, however, such as the elimination of most auto-boresight techniques employing the direct laser beam.

E. PACKAGING CONSIDERATIONS

1. General

Space on an RPV is severely limited, and a design is therefore not truly viable unless it is capable of being folded into a restricted volume. Wright Scidmore was therefore assigned the task of evaluating at least two designs from the packaging viewpoint. Ground rules were: (1) that the system must meet all the specs in Table 1 (Section II); (2) it should fit in half of the 12-inch sphere used on the Aquila/POISE program; and (3) auto-boresight should be included internally rather than externally. Two designs were evaluated which were minor variations of Scidmore designs B and C (Section II.A.3). The first, employing a 2.2X Galilean telescope in a rotating turret as the output lens assembly, changes both TV field and laser divergence. The second, using a flip-in power changer, is less tractable physically but maintains the narrow laser beam. One result of the study was a third design, derived from the second, which should be much easier to package.

2. Rotating Galilean Design

a. First Order Concept

This scheme (See Figure 13) is basically a modification of Concept B (Figure 6). Lenses L1 and L2 comprise an afocal Galilean telescope having a magnification of $\sqrt{5}$X. This assembly is common to the laser and TV and rotates 180° to change from NFOV to WFOV. If desired, a third IFOV (4.9° x 6.5°) can be provided with a 90° rotation of the assembly to remove the lenses L1 and L2 from the optical train. Light from this assembly is then transmitted through a beam-splitter plate (BS), a Wedge Filter/IRIS Assembly (F-1), and focussed at the vidicon by Petzval lenses L3 and L4 with appropriate folding being provided by mirrors M1 and M2. Translation of L4 provides the necessary focus for NFOV and WFOV. The laser beam is transmitted through lens L6, reflected from folding mirrors M5, M4 and M3 and recollimated by lens L5. The energy is then reflected from the beam-splitter plate (BS) and transmitted through the common afocal objective (L2 and L1). The 4.472X magnification provided by L6 and L5 combined with the afocal objective provides a beam expander magnification of 10X in the NFOV position and a magnification of 2X in the WFOV position keeping the apparent size of the beam impact area constant for the two fields of view. A tapered filter

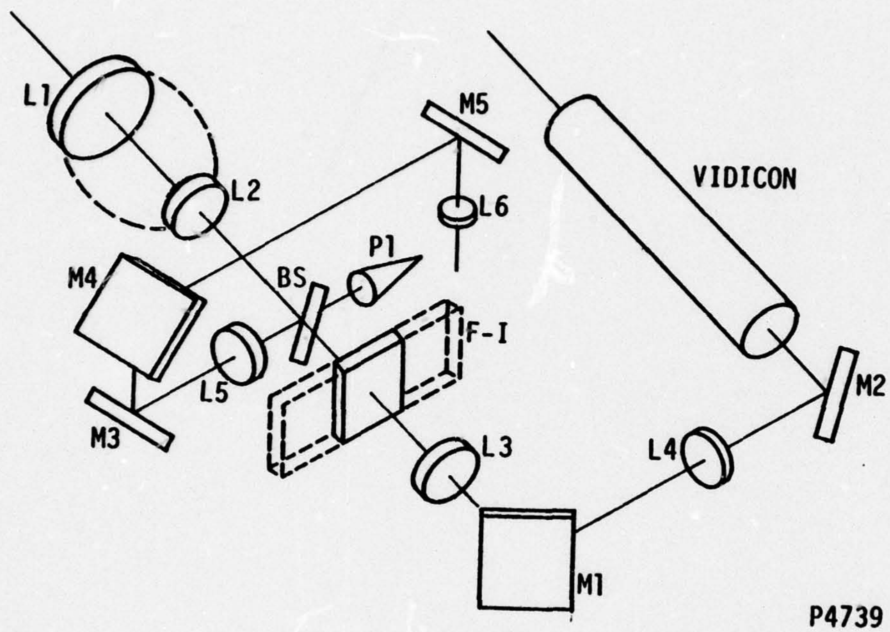


Figure 13. First Design (Scheme A)

wedge light control assembly (F-I) which has an open aperture of 1.118 inch is provided. The narcissus problems in the design of this system are considered challenging but amenable to correction. A beam-splitter plate was incorporated in lieu of a beam-splitter prism to avoid glass at possible Narcissus focus points.

A simple reliable boresight check system is provided by placing a corner cube prism (P1) in line with the laser axis. In this manner, a collimated reticle in the laser module which is coincident with the laser transmitter/receiver axis is transmitted through the same optics which transmit the laser energy (L6, M5 M4, M3 and L5), the beam-splitter plate (BS), reflected back 180° by the retro prism (P1), reflected from the beam-splitter plate and brought to a focus at the vidicon by Petzval lens (L3 and L4) after being transmitted through the filter assembly (F-I) and reflected from mirrors M1 and M2. Laser energy is blocked during normal operation by placing either a fixed blocking filter or a mechanical shutter between the beam-splitter plate and the retro prism.

This scheme provides excellent boresight integrity in that the components in separate paths which could affect boresight can be packaged compactly, the field of view change assembly and reticle boresight assembly do not affect boresight of either field of view, and any boresight error which may occur in between boresight check/alignment will be reduced by the $\sqrt{5}$ in the NFOV by the afocal objective assembly. Other advantages offered by this scheme are minimum size, weight and complexity — the full 36 dB attenuation of light being provided with a simple mechanism without impacting the open transmission of the TV system.

The only shortcoming of this system is the failure to keep the beam divergence constant for the different fields of view. It is believed that this is a small price to pay for the increase in boresight integrity and reduced size, weight and complexity. In fact, it is quite likely that an increase in beam divergence might be helpful when operating at short ranges in the wide field of view to spread the beam over a reasonable portion of the target — especially so in schemes where boresight integrity of the WFOV might not be as good as desired and/or expected.

b. Optical Packaging

This scheme was configured to fit easily within half of a 12-inch sphere, and could easily be compacted even further.

Figure 14 is a top view of this configuration. Table 7 tabulates the X, Y, and Z coordinates of the various points shown in Figures 14 and 15 and clearances of these points to a 12 inch diameter sphere. R is the radius to the closest point on the sphere whereas R* is the approximate clearance in the X, Z plane to the surface of the sphere. Contour lines are shown in Figure 14 for heights of Y=1.5 and Y=3.0.

Figure 15 is a rear elevation view of Scheme A. Contour lines are shown for X=1.5, 2.0, 3.0, 4.0, 4.5 and 5.0.

The approximate focal length and clear apertures of the lenses are shown in Table 8.

The location of the laser axis at I was selected arbitrarily. This axis location could be relocated if desired to best suit the laser configuration. Also, axis GB could be made vertical if desired and one folding mirror could be eliminated. These are details which can best be effected together with mechanical design personnel to effect optimum opto-mechanical design.

3. Flip-in Lens Design

a. First Order Concept

This scheme (See Figure 16) is an updated version of Concept C (Figure 7). Light for the NFTV is transmitted through the beamsplitter prism P1, reflected from folding mirrors M1 and M2, transmitted through the iris diaphragm (I), and focussed at the vidicon by the telephoto objective L3 and L4 after being reflected by folding mirrors M3 and M4 and transmitted through the filter control mechanism F1 and F2. The field of view is changed to wide field by insertion of lenses L1 and L2 into the optical train thereby reducing the focal length of the system by a factor of 5 to 1. Focusing of both the NFTV and WFTV systems is effected by longitudinal translation of lens L4. The laser beam is transmitted through lens L6, reflected from folding mirrors M7, M6 and M5 and collimated by lens L5. The energy is then reflected from the beamsplitter prism P1 through the entrance window to the target.

A simple, reliable boresight check system is provided in the same manner as described for Scheme A by placing a corner cube P2 in line with the laser axis as shown in Figure 16.

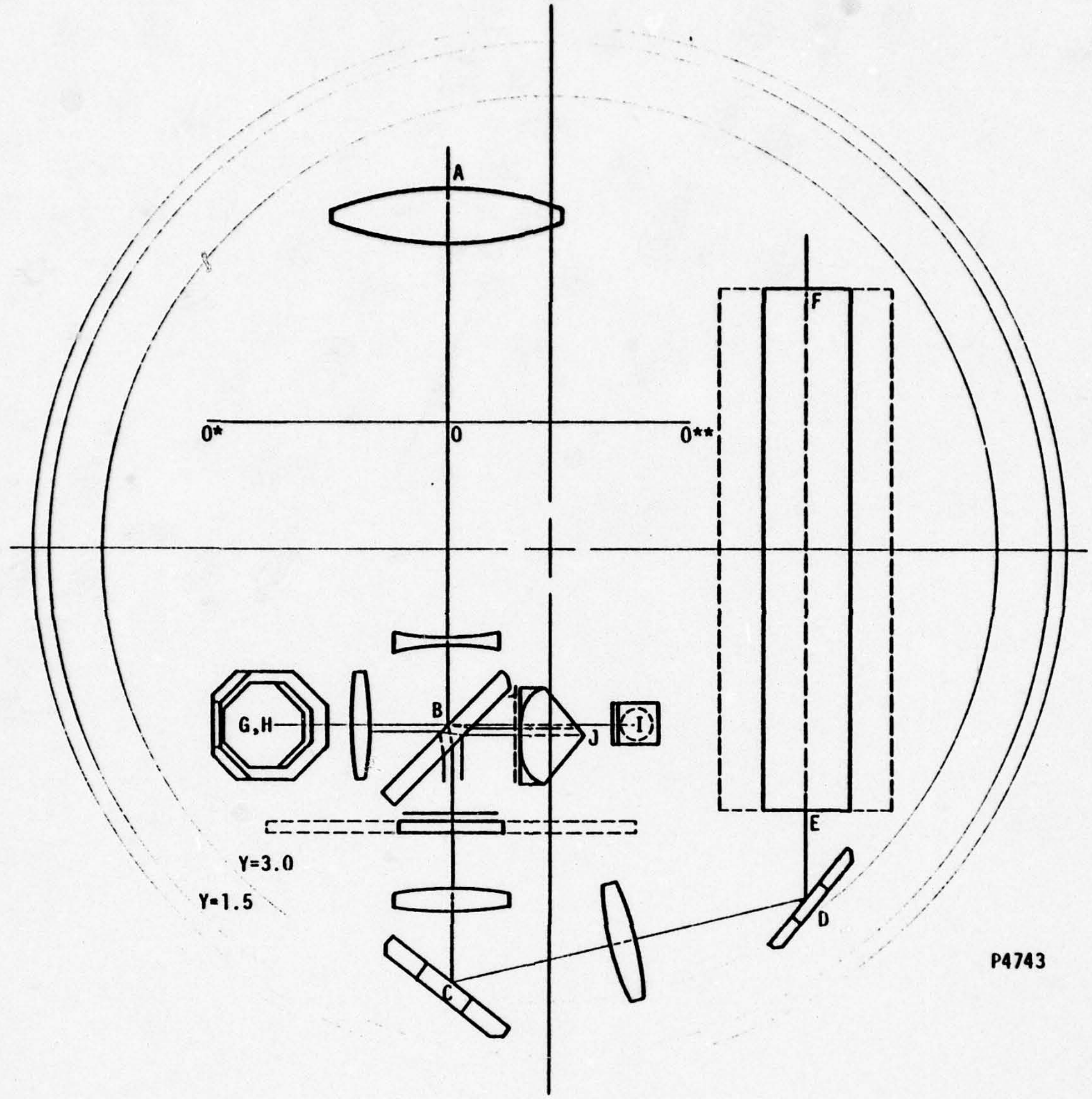


Figure 14. First Design (Side View)

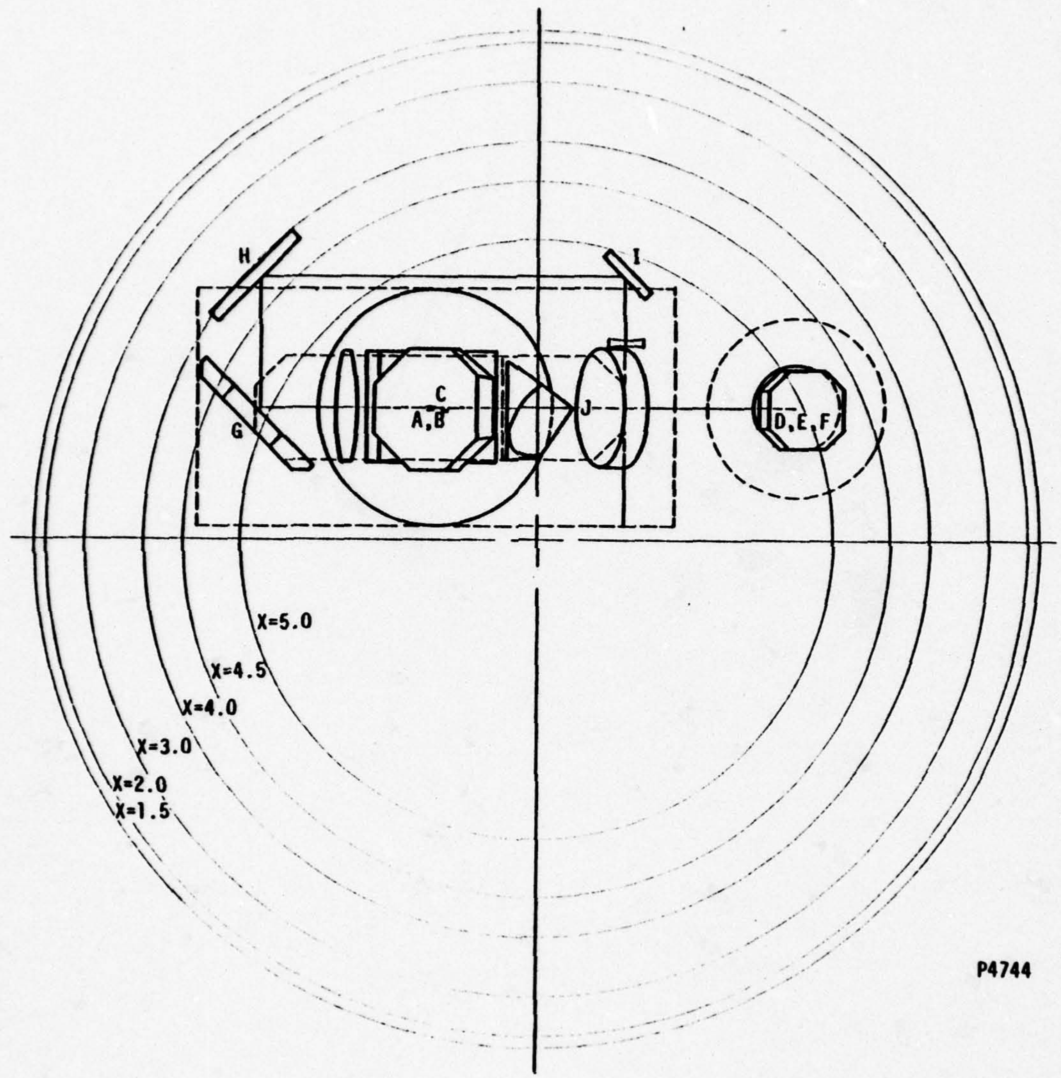


Figure 15. First Design (Top View)

TABLE 7. FIRST DESIGN COMPONENT COORDINATES

	X	Y	Z	R	R*
A	4.5	1.5	-1.2	1.107	2.1
B	-2.0	1.5	-1.2	3.227	3.86
C	-5.0	1.5	-1.126	0.660	1.46
D	-4.0	1.5	3.0	0.780	1.16
E	-3.0	1.5	3.0	1.500	1.86
F	3.0	1.5	3.0	1.500	1.86
G	-2.0	1.5	-3.2	1.939	2.1
H	-2.0	3.0	-3.2	1.179	1.24
I	-2.0	3.0	1.0	2.258	2.5
J	-2.156	1.5	0.4	3.343	4.2
O	1.5	1.5	-1.2	3.563	3.86
O*	1.5	1.5	-3.98	1.490	1.5
O**	1.5	1.5	1.58	3.355	2.05

R - Clearance to 12" diameter sphere
R*- Approximate clearance in X, Z plane to 12" diameter sphere.

TABLE 8. FIRST DESIGN LENS DATA

LENS	EFL	C.A.
L1	8.77	2.600
L2	-3.92	1.120
L3	10.48	1.246
L4	5.34	1.318
L5	9.66	1.120
L6	-2.16	0.300

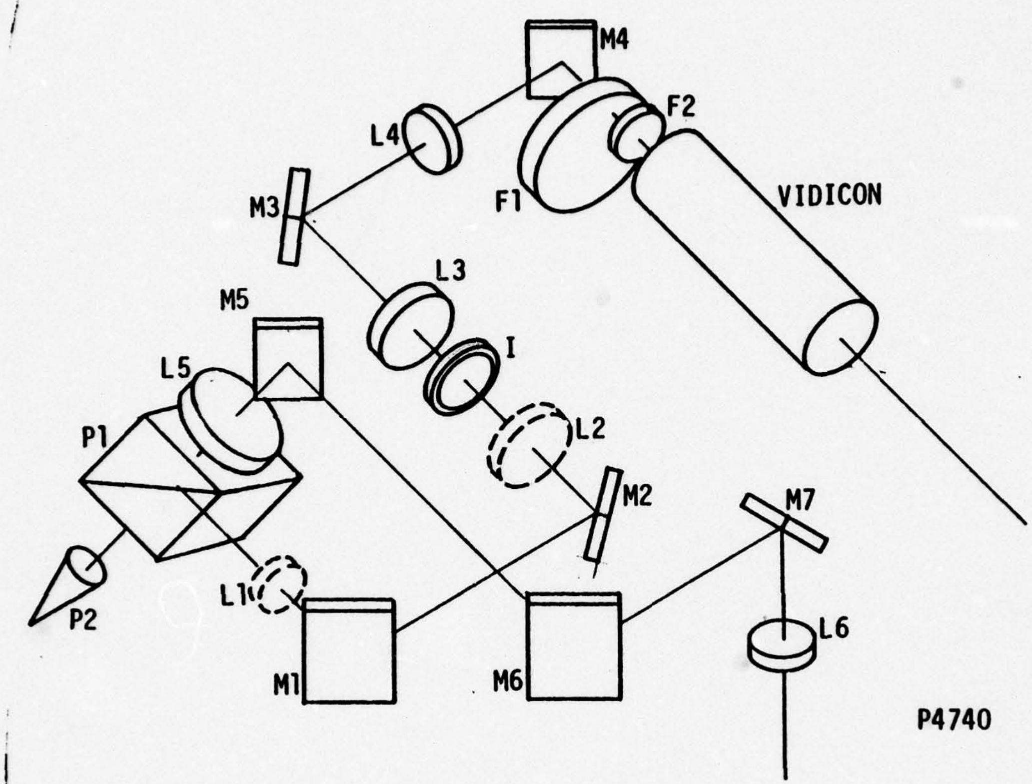


Figure 16. Second Design (Scheme B-1)

This system does maintain a constant laser beam divergence for the two fields of view. However, it results in the need for large optics, relatively poor boresight integrity, and the need for a complex light control mechanism. The field of view change mechanism does not impact boresight integrity of the NFOV (this being considered of primary importance) but it does affect boresight integrity of the WFOV. In addition, if boresight correction is effected by lateral displacement of the reticle, the angular shift in object space would be 5 times as large for the wide field as for the narrow field resulting in a 4 milliradian error in the wide field when a 1 milliradian correction is made for the narrow field. This 5:1 boresight effect could be eliminated by effecting boresight correction in the laser train but only at the expense of added complexity and some reduction in beam-expander magnification and hence some reduction in performance. The large aperture required in collimated space behind the power change assembly precludes the use of a simple light control mechanism such as that used in Scheme A to obtain the required 36 dB attenuation because of space limitations. An iris diaphragm having an open aperture of 2.5 inches is used to obtain 12 dB attenuation (f/4 to f/16). Variable density light control filter wheel F1 is used in conjunction with a fixed variable density filter F2 to provide the residual 24 dB attenuation, these filters being tilted to prevent ghost images from multiple reflections. The open transmission of this assembly is about 70 percent. The iris diaphragm could be eliminated by increasing the gradient of the variable wedges. This would minimize the diffraction effect on MTF but would limit depth of field to that from an f/4 lens and would reduce the open transmission of this assembly to about 59 percent.

Narcissus problems of this system are minimal due to lack of common optics, permitting use of a beam-splitter prism in lieu of a beam-splitter plate.

b. Optical Packaging

This scheme has more large elements and was difficult to contain within the half-sphere. Figure 17 is a plan view of this configuration. Table 9 tabulates the X, Y and Z coordinates of the various points shown in Figures 17 and 18 and clearances from these points to a 12 inch diameter sphere. R is the radius to the closest point on the sphere and R* is the approximate clearance in the X, Z plane to the surface of the sphere. A contour line is shown in Figure 17 for a height Y=1.4.

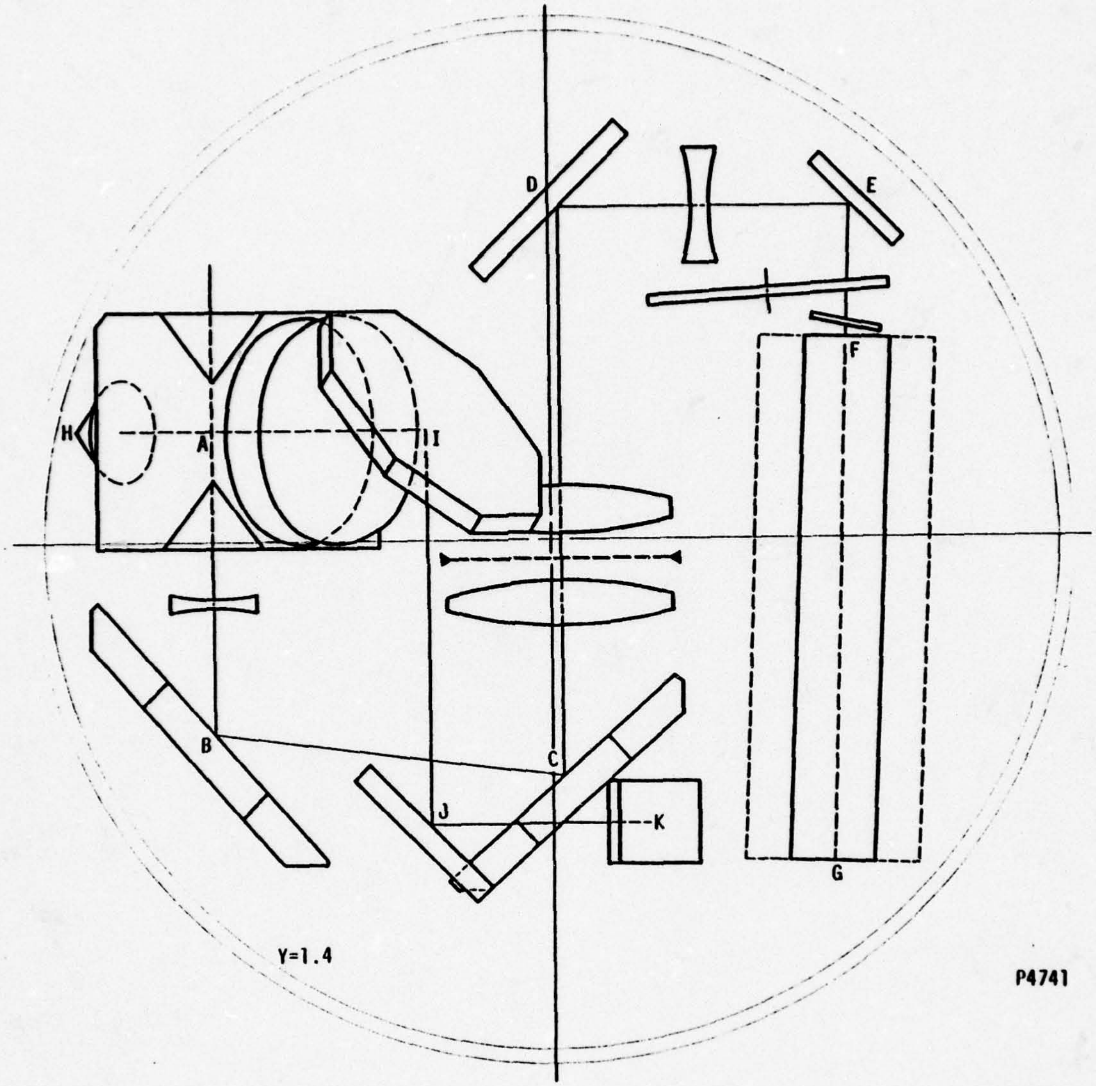


Figure 17. Second Design (Side View)

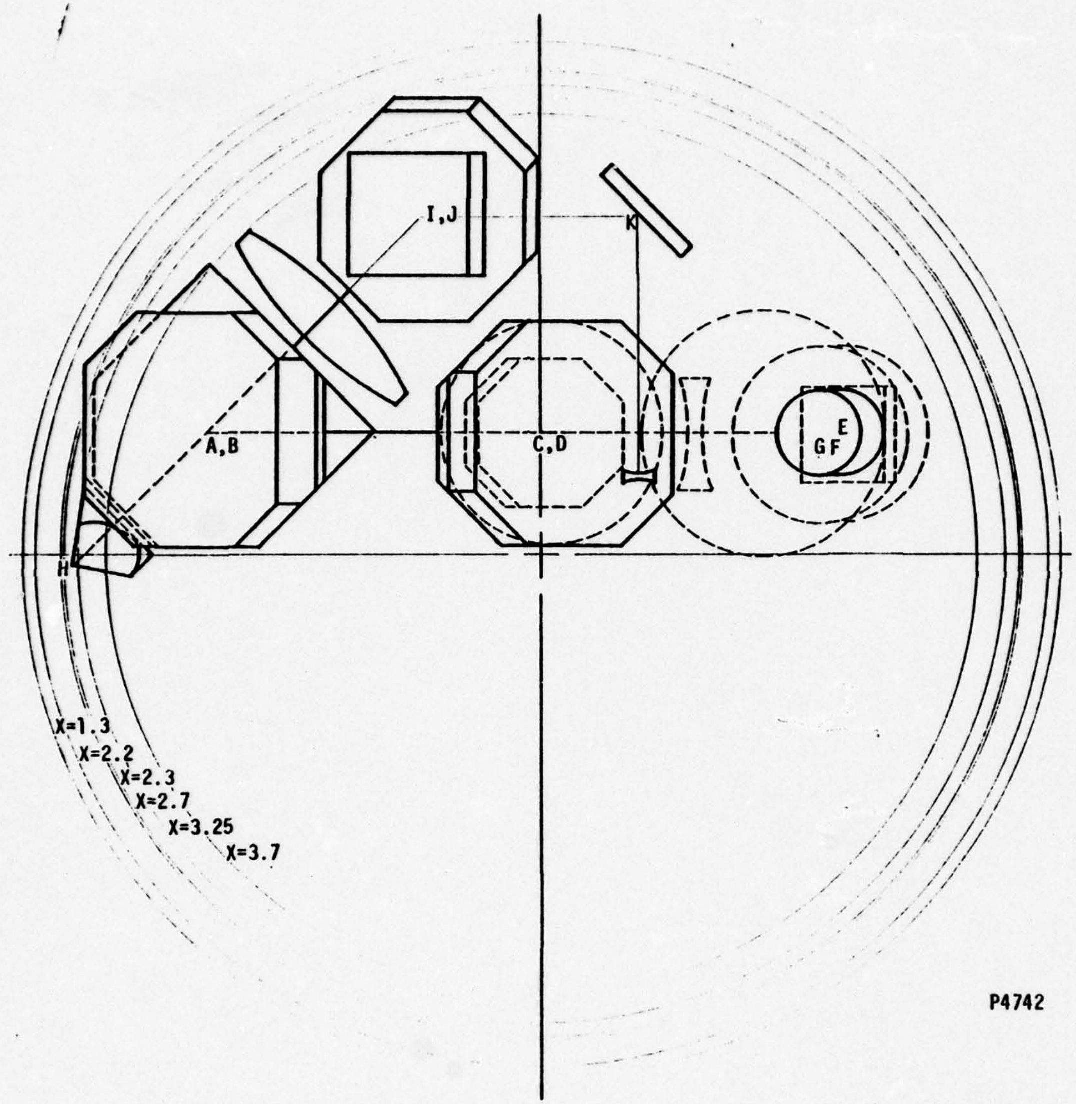


Figure 18. Second Design (Top View)

TABLE 9. SECOND DESIGN COMPONENT COORDINATES

	X	Y	Z	R	R*
A	1.3	1.4	-3.9	1.7	1.657
B	-2.2	1.4	-3.9	1.44	1.309
C	-2.7	1.4	0.1	4.0	2.957
D	3.8	1.4	0.1	3.2	1.949
E	3.8	1.4	3.5	0.9	0.647
F	2.295	1.4	3.440	1.85	1.634
G	-3.7	1.4	3.2	1.24	0.912
H	1.3	-0.17	-5.47	0.40	0.375
I	1.3	3.875	-1.425	1.75	1.671
J	-3.25	3.875	-1.425	0.95	0.746
K	-3.25	3.875	1.1	1.03	0.824

R - Clearance to 12" diameter sphere
R*- Approximate clearance in X, Z plane to 12" diameter sphere

TABLE 10. SECOND DESIGN LENS DATA

LENS	EFL	C.A.
L1	-1.65	0.900
L2	8.23	2.530
L3	7.84	2.530
L4	-12.71	1.170
L5	12.98	2.500
L6	-1.30	0.300

Figure 18 is a rear elevation view of Scheme B-1. Contour lines are shown for X=1.3, 2.2, 2.3, 2.7, 3.25, 3.7 and 3.8. The approximate focal lengths and clear apertures of the lenses are shown in Table 10.

Moderate interferences are evident from this drawing. A next iteration would be to reduce the space between the beam-splitter prism Pl and folding mirror Ml and to reduce the height of the optical axes. It is believed that the present interference could be elimimated with moderate changes.

4. Modified Flip-in Design

This scheme (See Figure 19) is a modification of Scheme B-1 to reduce the size required of some of the optical components to permit the use of a simpler light control mechanism and improve boresight integrity of the overall system. Light for the NFTV enters the system through a common, fixed, afocal objective assembly (L1 and L2) which has a magnification of $\sqrt{5}$x. The light is then transmitted through a beam-splitter plate (BS), reflected from folding mirrors M1 and M2, transmitted through a Wedge Filter/Iris Assembly (F-I) and is focussed at the vidicon by Petzval objective L5 and L6 after being reflected from folding mirrors M3 and M4. Wide field is introduced in the same manner as Scheme B-1 by introducing lenses L3 and L4 into the optical train and reducing the system focal length by a factor of 5 to 1.

The laser energy is transmitted through lens L8, reflected from folding mirrors M6 and M5, collimated by lens L7, reflected from beam-splitter plate (BS), and transmitted through the common afocal objective lens assembly L2 and L1 to object space.

A simple, reliable boresight check system is provided in the same manner as for Scheme A by placing a corner cube prism P1 in line with the laser axis.

This system, as Scheme B-1, maintains a constant laser beam divergence for both fields of view. The boresight integrity of this system is improved due to the use of a common afocal objective assembly which reduces boresight errors by a factor of $\sqrt{5}$ in object space and the reduced size of components which results in a more compact configuration. In addition, a simple light control mechanism identical to that of Scheme A is used reducing complexity and improving the open light transmission of the system. The boresight integrity of this system is poor, however, when compared to

Scheme A due to the increased number of components in separate paths which could contribute to boresight errors, the susceptibility of the wide field boresight to error in positioning of power change mechanism, and the 5:1 reticle shift of line of sight. Also the size, weight and complexity of this scheme falls short when compared to Scheme A.

Potential narcissus problems again pose a challenge to design but are considered manageable with reasonable lens configurations. Again a beam-splitter plate is used in lieu of a beam-splitter prism to facilitate correction.

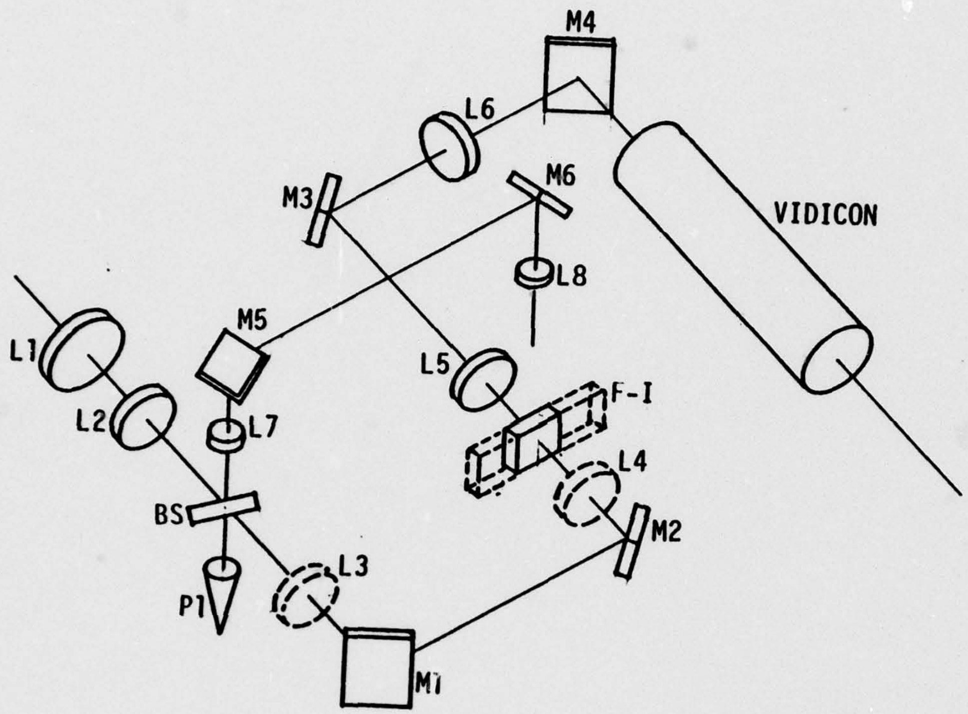


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Figure 19. Modification of Second Design (Scheme B-2)

III. AUTO-BORESIGHT TECHNIQUE STUDIES

A. ANALYSIS OF THE PROBLEM

The ability to determine, during flight, the exact laser aiming point in the TV field would have many benefits. One of the most important of these benefits is the reassurance of the operator that he is doing what he is supposed to do. The structure required to assure good boresight retention might also be reduced, as might the required ground support equipment. The LR/D is the "raison d'etre" for the RPV system, and an aiming error of even as little as a milliradian can easily result in mission failure.

Many approaches are possible. At one extreme, the system can be designed very ruggedly and assumed to stay operational: ignored, as it were. Even if the sensor is tested prior to launch, there is no guarantee that it will stay aligned when subjected to the rigors of launch and flight. At the other extreme, a reticle and laser flash could be presented on the TV screen continuously. This would present an additional challenge to the auto-tracker, but could be made to work.

If boresight is checked, measurement accuracy may be a problem. A beam 200-μrad or less in diameter should ideally be aimed to within about ± 20% of its diameter, or ± 40-μrad. This is just about the NFOV scan line spacing with a 2:1 underscan. Aiming should certainly be possible to within ± 2 scan lines (full scan) or roughly ±150-μrad, which is almost the full beamwidth.

The image seen on the monitor must be capable of being centered to the desired accuracy. This places demands not only on the scan resolution, but also on the pattern being centered. A well-focussed cross-hair projected reticle should present no problem, for example, but excessive linewidth or poor focus could render adequate boresight impossible. Problems associated with use of the laser beam itself are (1) the unpredictability of the laser pattern, (2) the "worm pattern" sensitivity profile of silicon vidicons to 1.06 μ radiation, (3) a strong tendency to "bloom", (4) interaction with the TV attenuator, and (5) the small spot which is difficult to see when dim and can burn the vidicon if too intense. On the other hand, direct viewing of the laser beam both avoids doubt as to laser/reticle alignment and proves laser operation.

B. TECHNIQUE LIST

There are too many choices to permit a clean list of possibilities, but some of the choices and components can be identified. Major choices are:

- Boresight device internal or external to sensor
- Reticle, laser, or modified laser beam source
- Uniform or real-world background
- Electronic or mechanical activation
- Continuous or "on-call" indication of boresight
- Retro-reflective prism, lens, or combination

Some of these will be addressed in the following paragraphs, along with some of the more viable of the following components:

- External transparent retro
- Laser-mounted reticle projector
- Servoed quad detector/reticle assembly
- Frequency doublers (CDA, KDP, Niobate)
- UV-excited phosphor screens
- Narrow-bandpass filter in TV channel
- Incandescent targets (gas or metal)
- Detector array (such as CCD)

C. BREADBOARD DESIGN

All the approaches currently conceived were discussed with Scidmore. The one chosen unanimously as most promising was a variation of the reticle projector used on the ALLD program. This projector was therefore included in the breadboard system. It consists of a back-lit dark-field reticle, which is built into the laser and projected coaxially with the 1/4-inch laser beam. A lens and corner reflector built into the dichroic splitter assembly (where TV and laser are separated) re-image this reticle on the TV. A ramp voltage applied to the lamp filament will permit whatever brightness is required for the production of an acceptable TV image under all conditions. The physical layout is shown in Section II B, Figure 10.

Such a projector can be mounted inside the laser and shine out through the RG-830 visible blocking filter. The spectrum between 0.83 and 0.95 micron will be available, will go through the dichroic nicely, and will not be visible to the naked eye.

The device performed completely as expected. Even with the very small lamp, there was never any problem seeing the reticle, usually with only a few volts on the lamp. A small condenser lens added near the end of the tests caused even further improvements in brightness and uniformity. The dual-circle reticle became an easily-centered dot, about three lines wide, with an easily-seen circle around it. A KG-3 filter was needed to stop the 1.064 μ radiation so that the reticle could be seen clearly.

The lens + corner cube is acceptable as a retro, but is not optimum. It would be better if the splitting occurred in collimated space because of the color correction and focussing problems. Also, the reflection from the retro must pass through splitter C (see Figure 10) twice on its way to TV lens B, since the reflection is off surface 5. The second pass introduces uncorrected axial astigmatism which is unavoidable as designed, but would not be present if the split were in collimated space. As long as the retro aperture is kept small — around f/10 — this aberration is visible but not objectionable.

It is instructive to calculate the amount by which the direct laser beam, if it were used for auto-boresight purposes, needs to be attenuated. Starting with the equations and data in Section II D, the laser-produced spot must obviously exceed the 0.27 nw/mm^2 given in Table 6. A 200-μrad laser beam at 250-mm focal length subtends about 0.05-mm, so the spot area is 2×10^{-3} mm^2. The TV integration time, needed to convert watts to joules, is 1/30-sec. This gives a value for the laser energy at the vidicon face-plate of $(0.27)\ (2 \times 10^{-3})\ (1/30) = 18 \times 10^{-6}$ nanojoules or 18 "femto joules". A 100-mJ laser must be attenuated by $(100 \times 10^{-3})/(18 \times 10^{-15}) = 5.6 \times 10^{12}{:}1$ or 127-dB. This was for the minimum perceptible spot on the screen. Maximum would be to provide the 800-na signal, which is 26-dB over the 2-na minimum. Thus, if it is to be visible, the laser attenuation must be somewhere between the absolute limits of 101 and 127-dB. Somewhere below these numbers is a damage threshold which has been exceeded on at least one ILS camera.

D. NV&EOL BORESIGHT SUGGESTION

A novel boresight approach was suggested by Robert Dockery of NV&EOL. The design is based on the configuration shown in Figure 2, and includes a boresight mechanism in the fourth leg of the beamsplitter. As can be seen in Figure 20, an incandescent lamp projector is employed in a manner similar to that being built for the breadboard. Thus, a ramp filament voltage can still be used to overcome the TV iris.

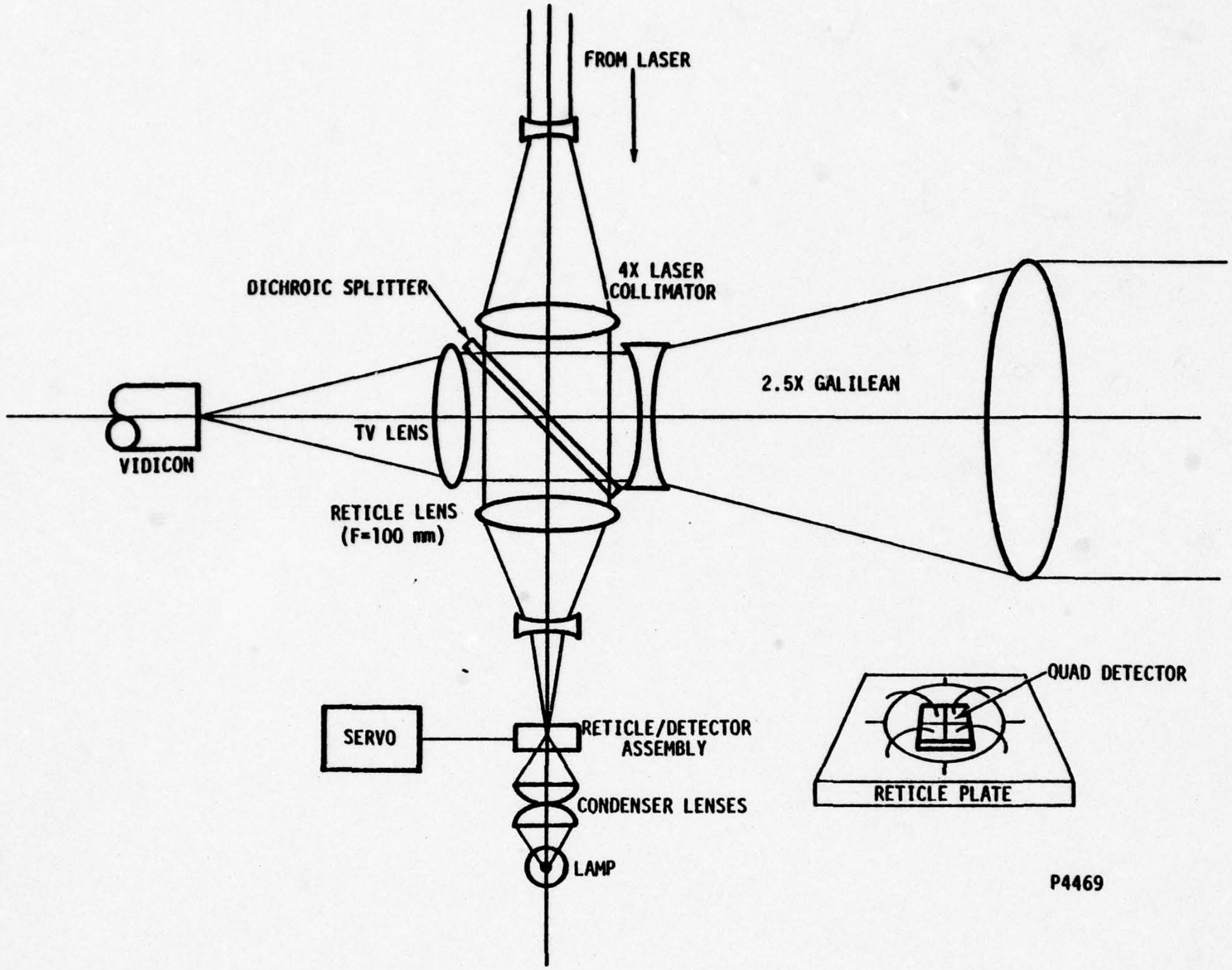


Figure 20. NV&EOL Auto-Boresight Concept

The unique feature of this design is the reticle. It is a dark field pattern somewhat like that proposed by ILS, but it (1) has a quad detector mounted in its center, and (2) is servo-driven to maintain the centering of the projected pattern. The reticle/detector assembly is simply driven until a balanced quad detector output is obtained. Alternatively, wedges or a mirror in the laser path could be servoed to perform the centering.

The TV resolution at the splitter is about 200 μrad. For good aiming, the reticle pattern should be no more than 20X this size, and preferably 10X. Thus, the reticle should subtend no more than 4 mrad. If we assume a telephoto projector lens of 100 mm focal length, as shown, this angle corresponds to 0.4 mm (0.016") on the reticle. The 0.5 mrad (or so) laser would have a spot size of 0.05 mm (0.002") at the detector. The reticle, then, would contain a 0.016" circle around a quad of detectors which are (at most) 0.005" square. This may be hard to obtain; a vendor search should be done. An alternative might be to ignore the reticle, use a large quad detector, and use front lighting to make the detector separation lines show up on the TV. The quad itself might even be back-lit, since it starts transmitting (like a window) at about one micron. A third alternative would be the use of a splitter cube to separate reticle and detector. This would also simplify the achromatization.

Adjustment of the reticle must be possible to well within the 200 μrad TV resolution. If 50 μrad is used as the minimum servo resolution, the 100 mm lens demands positioning to a tolerance of 0.005 mm (0.0002 inch!). This is possible, but will require very fancy machinery. A pair of piezoelectric or magnetostrictive drivers would probably be necessary, along with zero backlash and zero play in the slide bearings. Wedges would be easier, but still difficult, to control.

The servo electronics must be able to deal with data rates of less than 10 pps and a rather erratic source. Laser beam patterns are, to say the least, not noted for their uniformity. Even if the spot were held perfectly centered, the quad output would wander significantly from pulse to pulse. Defocussing doesn't help much: the near and far fields are both erratic in detail, while being quite stable in aggregate. Because of this, a significant amount of smoothing will be required, and the servo response time will, therefore, be several seconds.

Care would have to be taken that the laser did not burn the detectors. Under some conditions, the laser energy reflected from the detectors will be visible in the TV; in fact, it could conceivably be strong enough to burn the vidicon. Some sort of protective filter would, therefore, be required. The projector lens will also have to be achromatized for both laser and projector.

In summary, the design could work if: (1) the detector/reticle can be made, (2) the servo drive can be made with no backlash or play and 0.005 mm resolution, and (3) the servo electronics can be made adequately simple, small, and light.

E. OTHER POSSIBILITIES

1. Auto-Boresight via Doublers

There are three crystals which are commonly used as doublers for 1.064 μ: Lithium niobate, KD*P, and CD*A. The latter two require luquid cells, but all are capable of supplying enough green light to excite a television camera.

A system layout would be identical to that of the breadboard (Figure 2) with three changes: (1) An output window, outside the objective lens of RG-650 glass would be required; (2) the reticle projector would be eliminated; and (3) a doubler cell would be added between the laser and the laser's negative lens. Also, the RG-830 laser window would have to be on the laser side of the doubler.

Only a thin piece (~ 1-2 mm thick) of any of the materials would be needed. Some experimentation would be required to determine an optimum material and tuning technique, but some general statements can be made. CD*A is very termperature-sensitive and would need to be in a small oven. This could be used to control the green output: only a few degrees should be required to go from zero to full output. This is, however, a very difficult material to obtain and work with.

Lithium niobate and KD*P are less sensitive to temperature than CD*A, but may still require an oven (really just a wrap-around heater). The best tuning technique with these materials is mechanical rotation (or possibly tilt). A simple solenoid/dashpot assembly could be used as a driver to slowly provide a ramp-type green output.

While a little more complex than the original reticle projector, this type of technique has the dual advantages of (1) showing the laser beam directly and (2) working at any iris setting except fully closed.

2. NBP Filter

The use of a narrow bandpass filter directly in front of the TV lens was suggested previously and ought to be kept in mind. It permits, after the full opening of the auto-iris, direct viewing of the laser beam without distraction or obscuration by scene details. No projector would be required, unless a continuous display were desired. A retro-reflector would be needed: either an internal one like the breadboard or an external transparent type. Disadvantages are: the loss of video and therefore autotrack, and possible scan distortion due to the change in beam current.

3. Remote Device

Another possibility is a remote boresight device, mounted on either the gimbal or airframe. This was suggested verbally some time ago and ought to be recorded, even though there are arguments against the idea. The idea is adaptable to both gimballed-sensor and gimballed-mirror designs. The boresight device would end up looking to the sensor like a retro-reflector, since it is in collimated light, leading to the choice between prism and lens retro configurations. For example, the transparent retro might be mounted so the laser looked at it in the "stow" position. An absorber and filter would also be required, plus a splitter arrangement if the receiver uses a separate aperture. Such an arrangement might also satisfy the ground test requirement if the laser was permitted to fire while stowed.

Alternatively, a small lens could be used, along with a KG3 or KG1 filter and an appropriate (possibly aluminum) target. The laser beam would be attenuated by the filter and then focussed by the lens onto the target. The resultant flare of vaporized target material would be easily visible in the TV. Two disadvantages of this approach are: the need for occasional target replacement, and the coating of optics by the vaporized target material.

One way around this might be to make a "fire bottle": a sealed glass container of an appropriate high pressure gas. When placed at the lens focus, the gas would flash and replenish with no residue/replacement problems. The bottle could be quite small — an inch or so across — with a good optical window on one side and an absorber on the other.

4. Boresight Adjustment

Suppose the boresight is checked, after launch, and found to be in error. Then what? There is something to be said for "making do" on a manual basis and not trying to fix anything in flight. Any adjustment can be misadjusted and will therefore increase the frequency with which adjustments are needed. If adjustments must be made in flight, electronic methods are far to be preferred over mechanical. The raster or reticle can be moved quite easily with little effect on system reliability.

If mechanical adjustments are made, almost any element in the system can be used except those which are common to both laser and TV. Candidates include the dichroic splitter, laser channel elements, and TV channel elements. The retro in the breadboard design is common and therefore unusable.

It should be noted at this point that tilting of the negative lens of a Galilean telescope is strictly forbidden. The laser negative lens is especially sensitive: one or two minutes tilt can cause unacceptable beam deformation. The effect of this restriction is to eliminate many otherwise attractive adjustment elements. Most reflectors are out, for example, including the main beamsplitter (dichroic #1 in Figure 9), because when a mirror is tilted all elements beyond that mirror are optically tilted including, in this case, the laser negative lens.

A process of elimination leaves only three apparent possibilities (there may be others): (1) translate, without tilting, either of the negative lenses; (2) rotate a pair of wedge (Risley) prisms on the collimated side of either negative lens; or (3) tilt the entire TV camera & lens assembly. Of these, translation of the TV negative lens appears to be the most viable if the boresight adjustment must be done mechanically. This is based on ILS experience with all of the techniques.

IV. IRIS STUDIES

A. ANALYSIS OF THE PROBLEM

A major problem is the requirement for a 40 dB dynamic range. There are many "standard" ways to achieve such a range, but all have problems which prevent their application to the RPV system. ILS has developed versions of two existing techniques which, at some expense, should meet all the RPV requirements.

There are three general ways to eliminate unwanted light: reflection, absorption and diffusion. The ordinary camera iris uses all three via the insertion of blackened metal plates into the lens aperture. Other systems utilize beamsplitters (pure reflection) or so-called "neutral density" (ND) filters (absorption or reflection depending on type). Neutral density filters are available in wedge format for applications where continuous control is desirable.

The problem with a 40-dB iris-only arrangement is that the aperture varies in size by 100:1. Diffraction effects at the small apertures will not permit the resolution required by RPV. The Cosmicar-type black spot iris would be only slightly better than a simpler type. Light control is easier but resolution will in all probability still fall below acceptable limits, because of diffraction effects. ND filters can be snapped in and out of the path, but the signal transient will drive a video auto-tracker nuts. Wedge ND filters introduce an illumination taper across the field, and also rarely start at zero density.

Two solutions to this problem have been investigated. One involves the use of two specially-shaped opposing ND wedges. This would make the field much more uniform while still permitting continuous adjustment. The other involves the (relatively) slow insertion of discrete ND filters, with the iris tracking the filter insertion to eliminate the switching transient. Both approaches look good. Implementation details and boresight interaction will be discussed in the following pages.

B. TECHNIQUE LIST

The designers imagination is the only real limit to the number of possible attenuator techniques. Some of those considered in more or less detail are:

- Classical iris
- Metalized filters
- Absorption filters
- Crossed polarizers
- Attenuator wedges - single and crossed
- Attenuator/iris combinations:
  - The ILS crossed wedges (Sec. IV D)
  - The Cosmicar "black spot"
- Electronic control (AGC)
- Tilted multi-layer spectral filters
- Spectral absorption filters
- Electronic control (target strobing)
- Electro-optic cells

C. STEP FILTER ANALYSIS

Based on the diffraction discussion, the iris opening is limited to the range of f/4 to f/16. This provides 12 dB out of the required 40 dB intensity range. AGC can provide at least 4 dB, leaving 24 dB to be handled by other methods. This and the next two sections discuss three possible ways to obtain the 24 dB.

One method is the insertion of discrete neutral density (ND) filters to supplement the iris. Past attempts to do this have given problems to the video auto-tracker because of signal transients. The approach to be presented contains provisions which eliminate such transients.

The filter size must be less than the iris range (12 dB) or coverage will not be continuous. Even if they matched (12 dB filters), problems would occur when the light levels varied around a transition value. Since 2 X 12 = 24, the next integral number of filters would be 3, each of which provided 8 dB attenuation. This would leave 4 dB excess iris travel and minimize flip-flopping. The edge of the filter which enters the beam should have no frame, to permit a smooth, transient-free transition.

Assuming an automatic iris control, all that is required is slow filter insertion. The iris should be able to follow well enough if insertion takes a second or so. The momentary illumination taper will not be objectionable, and the slow speed will eliminate mechanical transients as well. The only problem with this approach is that it requires two motors.

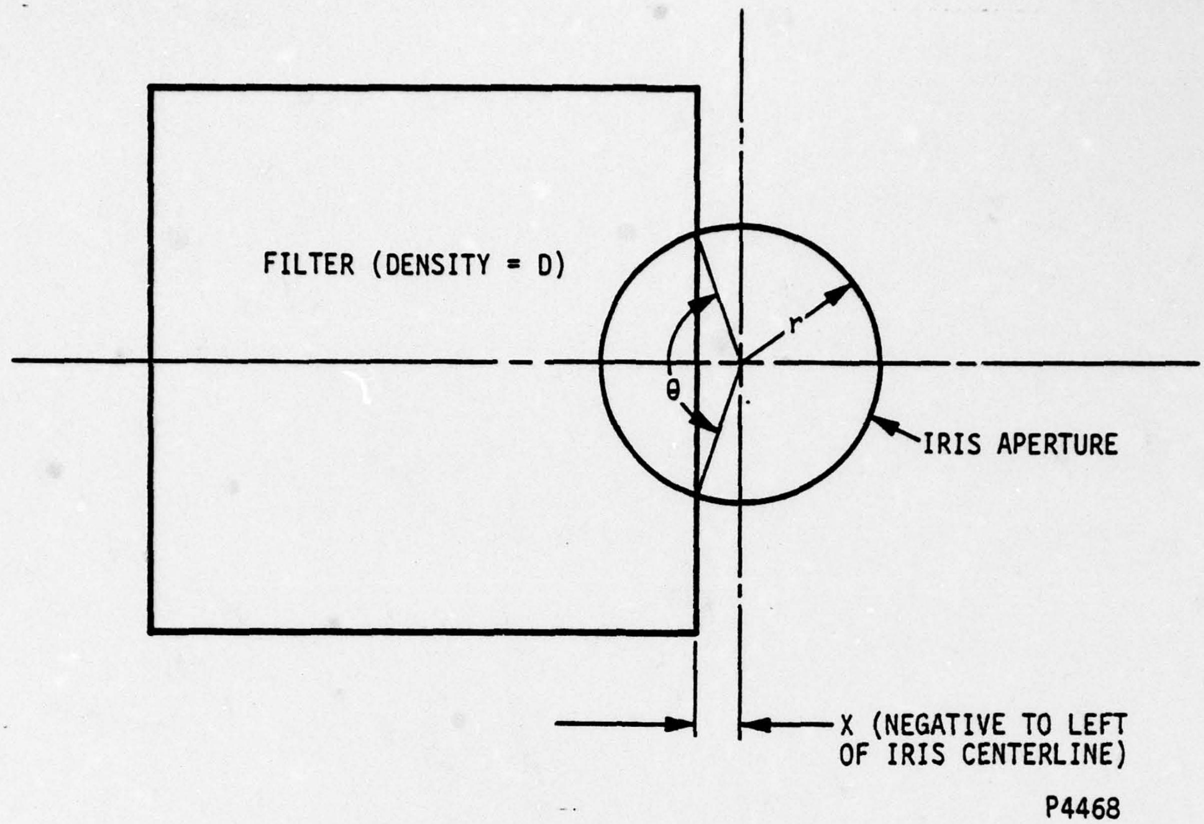
It is instructive to examine the relative filter and iris motion required to maintain constant axial image brightness. If one assumes the configuration shown in Figure 21, with a square filter moving across a round iris, plots can be made of iris diameter as a function of filter position for constant total transmission. Plots for an 8 dB filter are shown in Figure 22. The values of X (filter position) and r (iris radius) are normalized to the (smallest) iris radius with no filter intrusion.

Superimposed on the above curves is a straight-line approximation to the curves. As can be seen, this approximation leads to errors of not over 7% at any position; this small an error can be ignored in all normal applications. Thus a linear gear mechanism could be employed between iris and filter, driven by a single motor. When not switching filters, the motor would operate the automatic iris. The complete cycle is shown in Figure 23. Note that the iris starts at 25 mm diameter and drops to 10 mm when removing the filter, but goes from 6.3 to 15.6 mm during insertion. In spite of these different values, the line slopes are identical, meaning that only one gear ratio is necessary.

The mechanical linkage between motor and lens would have four sections: (1) a mechanism to select and move the three filters in sequence; (2) gearing to synchronize the iris with the filters; (3) the automatic-iris drive; and (4) mechanisms for switching between sections. The net result will have a lot of parts but should be less complicated (more reliable) than, for example, an expensive camera shutter. It is even conceivable that a single cam could be used instead of mechanisms (2), (3) and (4).

D. WEDGE PAIR ANALYSIS

It is quite possible to make filters which have a tapered density profile, while retaining a flat physical shape to avoid beam deviation. Sliding such a filter across an aperture will vary the transmission of light through the aperture. Problems are physical size and, when inserted, an illumination taper across the field. Both problems can be solved.



Define: (1) $U=\Theta - \mathrm{SIN}\,\Theta$ where (1A) $\Theta=2\cos^{-1}(-X/r)$

(2) $K=10^{-D}$

(3) $Q=(1-K)/2\pi$

Then (4) $T=r^2(1-QU)$ = relative transmission

solving parametrically in Θ gives

(5) $r=\sqrt{T/(1-QU)}$ from (4)

and (6) $x=-r\cos(\Theta/2)$ from (1A)

Figure 21. Filter Insertion Geometry

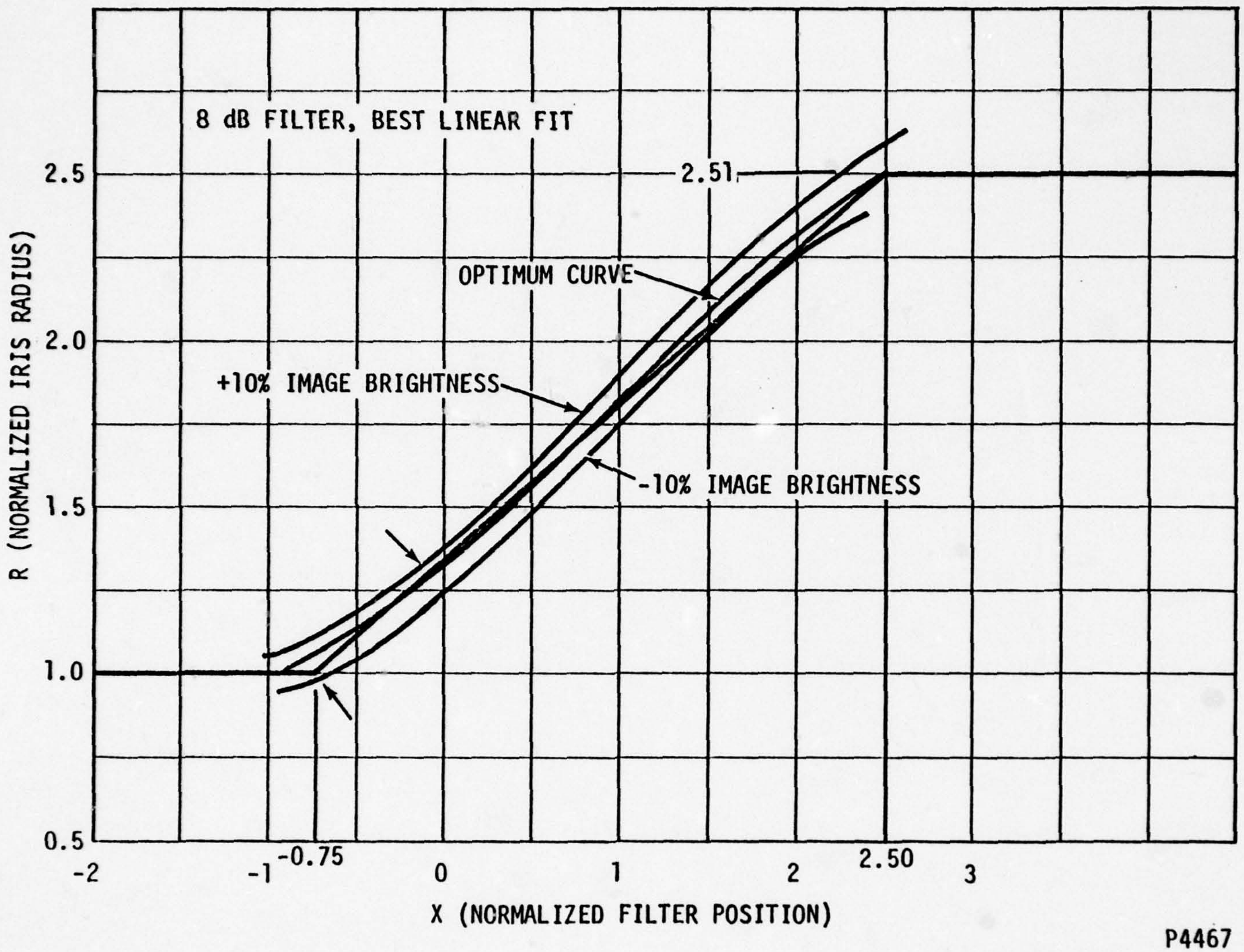


Figure 22. Normalized Filter Motion Curves

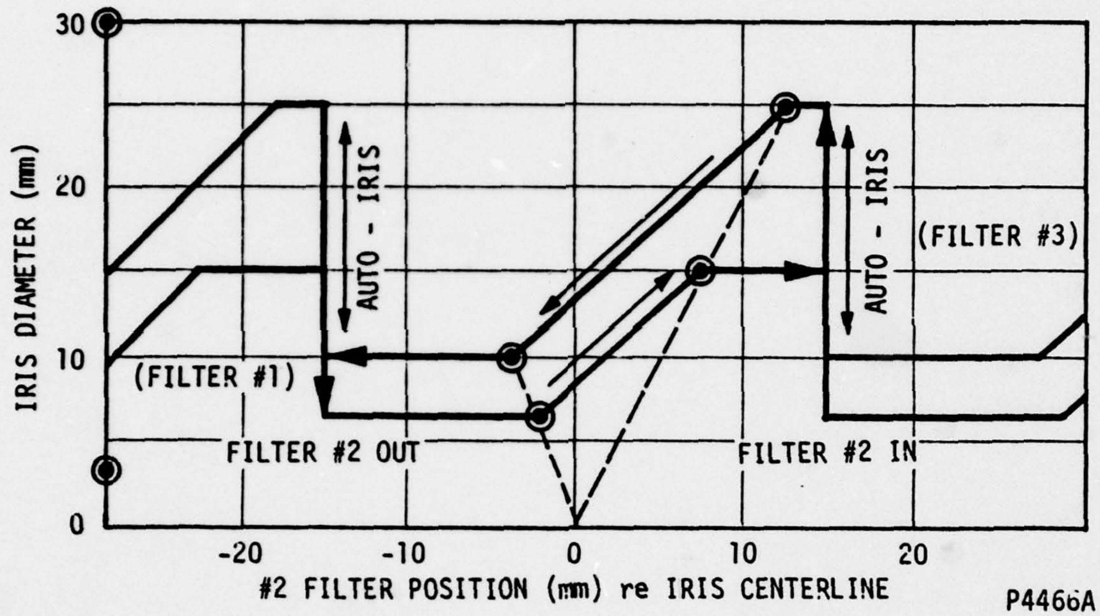


Figure 23. Filter/Iris Motion Cycle

The use of two opposing wedges solves the illumination taper problem but introduces others. If both filters move, the assembly becomes very bulky. If one is fixed in front of the aperture, zero dB can never be realized. If both are moved starting from outside the aperture, a V-shaped profile is obtained during the transition. The effect of this profile is not serious, however, and it only occurs at one specific attenuation.

A combination of iris-like aperture reduction and opposed tapered filters would appear to do the job quite nicely, dealing with both taper and size problems. One of many possible implementations is shown in Figure 24.

The attenuator shown functions as a combination iris and tapered filter. As the attenuators move toward each other across the lens aperture, the first thing that happens is that the top and bottom of the aperture are blocked by the iris blades. When the filters just meet, the top and bottom 8 mm bands are totally blocked, leaving only the (filtered) central 9 mm. As the filters overlap their attenuations begin to add. Shortly thereafter the outside edge of the iris begins to restrict the horizontal aperture. 36 dB attenuation can be obtained in this manner while still having an aperture large enough to avoid diffraction effects. The iris motion can then, of course, continue until the lens aperture is blocked completely. This is very useful for vidicon protection purposes.

The filter density will taper, as shown in Figures 24 and 25, from zero to 15 dB. This will be accomplished without optical wedging via the technique shown in Figure 25. Schott's NG-4 filters have an almost flat attenuation versus wavelength curve. BK-7 glass has almost exactly the same refractive index and dispersion as NG-4. The combination may have a very slight residual physical wedge in order to completely eliminate any optical wedge.

E. COSMICAR LENS

The Cosmicar lens was obtained and has been examined. There appears to be no way to attach a manual actuator to the lens, so the electrical remote actuation must be employed. This proved impossible to stabilize, so no measurements could be made on this lens.

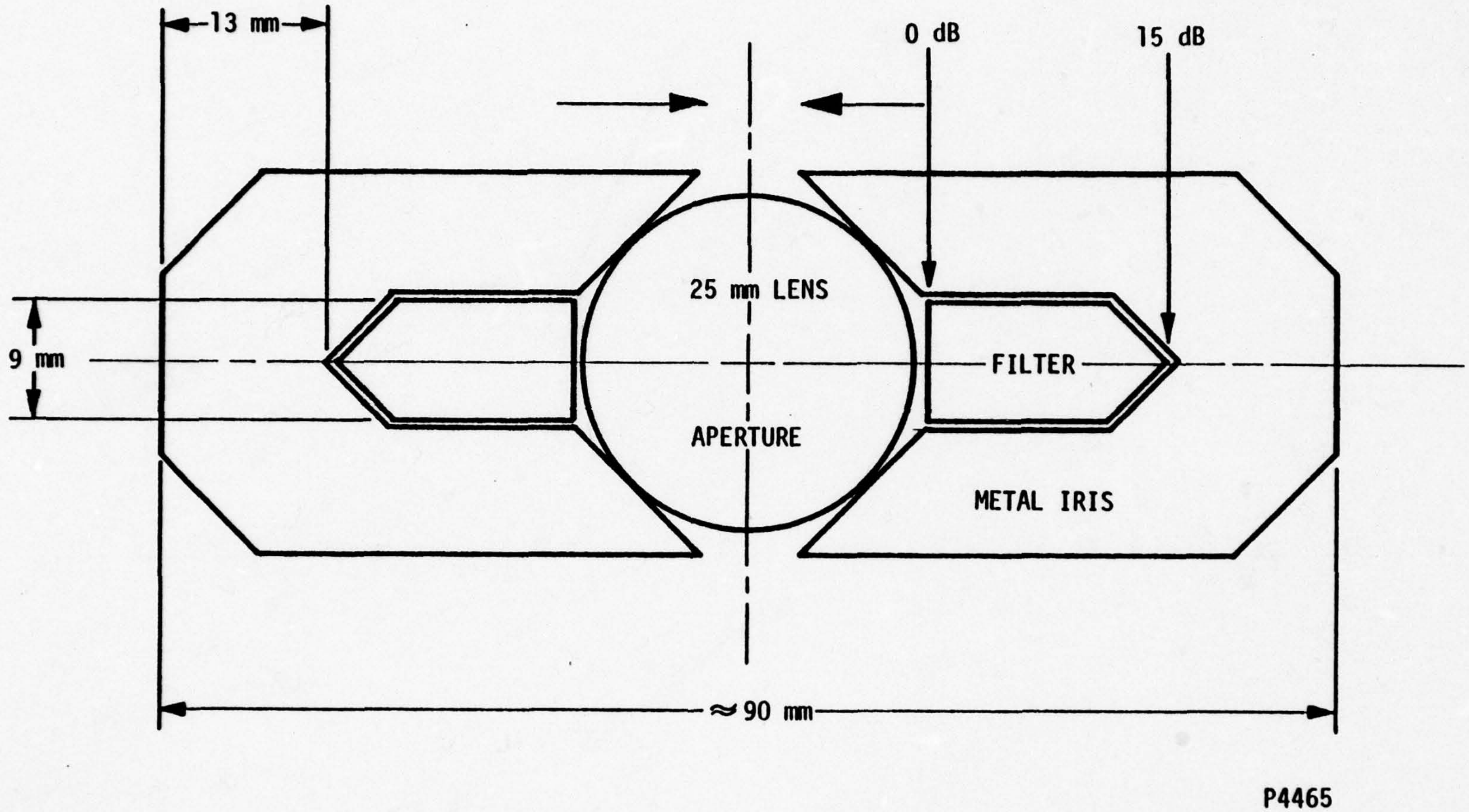


Figure 24. Wedge Filter Iris

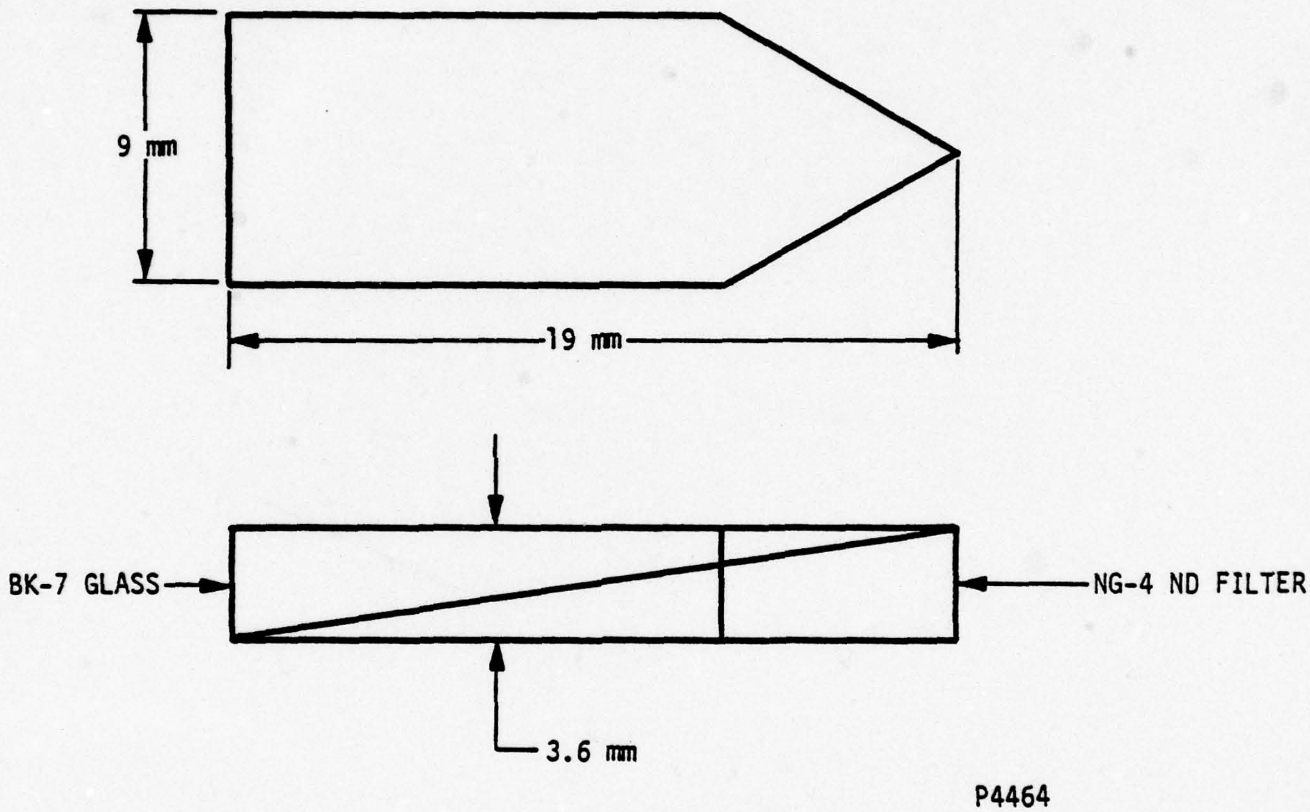


Figure 25. Wedge Filter Construction

The Cosmicar "black spot" approach should work, but there are several potential disadvantages. In the first place, it will be expensive to produce in quantity. In addition to the cost of the spot plate itself, the iris is of much higher precision than most other irises.

Secondly, the black spot blocks most of the light in the "sweet spot" at the center of the lens. This will have the effect of exaggerating abberations when the lens is wide open. Finally, there may be diffraction problems caused by the spot pattern.

V. TEST RESULTS

A. INITIAL TESTS

Initial tests were conducted to determine some of the problems associated with mating a television camera to a laser transmitter using a common optical system. A GLLD laser and optical housing assembly, containing a coaxial sighting telescope, was modified by removing the sighting telescope erecting prism assembly and by replacing it with a machined, light-tight, transition section containing an iris diaphragm and filter holder. An RCA, Model TC1160, television camera with a silicon charge coupled detector was attached to the rear end of the transition section.

In the original GLLD system, the sighting telescope objective lens was designed to be used for both the visible spectrum and for the 1.06 micron output radiation of the laser and was optically corrected and anti-reflection coated for both wavelength bands. The laser beam collimating telescope uses the same objective as the sighting telescope and the laser beam is folded into the sighting telescope optical axis using a penta-mirror system with one mirror used as a beamsplitter. The television camera was positioned at the focal point of the objective.

The necessity of conducting the initial tests in a small laboratory created special problems. Since the laser collimating telescope must always be focussed for infinity to maintain beam divergence, and the television camera must focus on a real target, a 62-inch achromatic lens was positioned in front of the objective lens of the system. While it focussed the target on the vidicon, this same lens however also focussed the laser radiation in the focal plane which caused burning and generation of a plasma plume with a broad spectral output that caused flaring in the camera. This problem was eliminated by inserting an angled dielectric coated mirror, with maximum reflectivity (99.7%) at 1.06 microns wavelength, ahead of the target, to reflect the laser radiation up into the air and prevent the formation of a plasma except when a dust particle passed through the focal plane.

The problems to be anticipated in using a coaxial camera system with a laser transmitter would be caused by reflections of the laser output from the optical surfaces and a broadband flare caused by the flashlamp. Flashlamp flare was limited to wavelengths greater than 0.78 microns by using a Schott RG-780 filter as a window between the laser and the optical system. Additionally, flashlamp flare was limited in this particular laser by shielding the electrodes of the lamp in opaque sleeves, thus limiting the light output to that which was emitted from the ends of the laser rod.

The laser was set up with an output of 100 millijoules, Q-switched, but the laser output was blocked in the oscillator for the first tests. The electronics for the laser were contained in the original housing and were connected to the laser transmitter with a four foot unshielded cable containing signal leads, the 1,100 volt flashlamp leads and trigger transformer leads.

The first test revealed that the laser electronics created nothing more than slight noise in the video presentation which was later determined to be caused by the television monitor. The next test checked the effect of flashlamp flare on the camera while the laser output was inhibited. Some flashing on the TV camera from the flashlamp was observed when the iris was in the full open position. All filters were removed and the room lights were turned off to create maximum gain in video. A 6 dB neutral density filter eliminated all flashlamp flicker under maximum gain conditions. When the room lights were on, and the camera was adjusted for good picture quality, the flashlamp only caused a slight flicker in the video presentation of the target.

The next test was conducted with the laser output on and the camera operating with no filter, open iris and room lights on. Considerable flare from the laser was observed under these conditions. A 99.75% reflective dielectric mirror at 1.06 microns wavelength, in the filter holder ahead of the camera caused the laser flare to disappear and only a slight flicker was observed in the video. Testing was repeated with room lights turned off to maximize the video gain. The same dielectric filter used with a 6 dB neutral density filter completely eliminated all the laser flare and flashlamp flicker from the video.

A final test was run to determine the effect of the laser beam on the camera caused by target reflectivity. A highly reflective diffuse target was positioned in the laser beam at different positions from directly in front of the output lens to just ahead of the focal point of the 62 inch lens. No laser flare or flicker was noted in the video presentation.

B. BREADBOARD TESTS

1. Laser Tests

The GLLD laser was set up on the side plate and was run at a 10-pps rate and with an 85-millijoule output. The raw beam divergence was measured with a 62-inch focal length lens and an EG&G Model 580 radiometer. A variable diameter iris was inserted at the focal point of the 62-inch lens and the iris was adjusted until 90% of the energy was indicated by the radiometer. The iris diameter was 0.089 inches. The calculated beam divergence was 1.43 milliradians.

The breadboard laser collimator lenses were installed in an in-line configuration ahead of the laser beam by using a gas laser. The in-line configuration was used to eliminate any degrading effects that could be caused by non-flat mirrors.

A 10-meter focal length lens was placed in front of the collimator objective and the GLLD laser was turned on. The collimator was focussed and the beam divergence was measured in the same manner as with the 62-inch lens. Iris diameter at 90% energy was 0.058 inches and the beam divergence was 0.15 milliradians.

Since the laser collimator was designed to decrease beam divergence by a factor of 10, it is assumed that the optical design of the lenses was correct since the calculated reduction is 9.53X. The discrepancy can be accounted for by focussing errors between the 62-inch and 10-meter focal length lenses and a ±5% energy reading error in the radiometer, without even considering any lens aberrations.

2. Television Camera Tests

An RCA 1005/SD1 closed circuit television camera, equipped with a 1-inch diameter RCA 4532 silicon target vidicon, and equipped with a Schneider, Tele Xenar 100-mm focal length lens was used in the following tests.

A square wave test chart for measurement of center and corner resolution, made by the Sierra Scientific Corporation, was set up in the laboratory and was illuminated with a quartz halogen studio lamp. The lamp was run at a constant voltage to maintain the color temperature, and the light intensity into the camera lens was controlled by the lens iris and by using neutral density filters.

The target light intensity was monitored with a reflective type light meter. The camera lens was equipped with a Schott RG-630 filter to simulate the bandpass characteristics of the wedge beam-splitter.

The resolution characteristics of the lens and camera was measured at three iris settings and at three light levels at each iris setting. Optimum lighting was established by determing the point where the maximum resolution could be achieved at the center of the screen on the television monitor. The optimum level yielded a peak raw video level of 0.6 volts. Too dim and too bright light levels were established by selecting a minimum of 200 lines resolution on the bottom right pattern and recording the video levels. Too dim was established at 0.4 volts peak and too bright was established at 0.9 volts peak video output. Too dim corresponded to the ND filter combination to achieve maximum resolution plus a 1.0 density ND filter. Too bright was achieved with the optimum filter minus a 0.6 density filter. This last criterion was also used to evaluate the resolution of the 50 mm focal length lens. The dynamic range is therefore a little more than 16 dB, or 40:1.

The maximum horizontal and vertical resolution of the 100-mm focal length lens under optimum lighting was 300 lines at center and dropped to 250 lines in the corners at iris settings of f/2.8, f/4, and f/16.

Maximum resolution under the too bright and too dim conditions was approximately 250 lines in center and 200 to 225 lines in the corners at the same iris settings.

Focussing tests indicated that some of the 50 lines resolution drop from center to corners could be attributed to a curved focal plane caused by the 100-mm focal length lens which could be improved with the use of a field flattener.

3. Boresight Projector

The reticle projector, consisting of a doublet objective, a lens tube, a dark-field reticle and a GE328, 6 volt, unfocussed bulb was tested by itself without the remainder of the optical system designed for it. It was focussed for infinity, in visible light, in front of a collimator and the lamp filament was aligned on the optical axis.

Then a Schott RG 830 filter was installed in front of the projector objective lens to limit the spectral bandwidth to the designed limits of the optical system. The projector was then set up about 60 cm in front of the television lens and camera and pointed toward the center part of the wide open lens which was focussed for infinity. With the room completely dark, the projector lamp voltage was raised until a glow was visible on the television monitor and the reticle projector was focussed until the best image was achieved. The voltage on the projector lamp was then adjusted under the following conditions.

- Dark Laboratory (no ND filters)

Reticle barely visible	- 0.39 VDC on lamp
Good clear image	- 0.47 VDC on lamp
Too bright (blooming)	- 0.66 VDC on lamp

- Dark Laboratory (1.75 density ND filter)

Reticle barely visible	- 0.58 VDC on lamp
Good clear image	- 0.91 VDC on lamp
Too bright	- 1.48 VDC on lamp

- Normal Room Illumination (no ND filters)

Reticle barely visible	- 0.41 VDC on lamp
Good clear image	- 0.62 VDC on lamp
Too bright	- 0.90 VDC on lamp

The results of the above test indicated that the reticle projector design was suitable since the lamp voltages were much below the 6 volt rating and the circle images were reasonably clear.

Subsequent tests were made on the reticle projector when it was mounted on the breadboard common optical system and aligned to the laser optical axis. The first step was to align the reticle projector axis with the laser optical axis until they were coincident in the focal plane of a 10 meter focal length lens placed in front of the objective lens. There were no unusual problems in accomplishing the alignment since it only requires tilting and rotating of one combining mirror which aligns the laser beam to the reticle axis. An alternate method requires that the reticle projector be tipped in two planes to line it up with the laser axis.

The retro lens and prism were then set up on the test bed and adjusted until the reticle imagine could be clearly seen on the television monitor. With the laboratory darkened and the camera lens set at f/4, the reticle lamp voltages were recorded as follows.

- Image too dim — 1.5 VDC on lamp filament
- Image right — 2.5 VDC on lamp filament
- Image too bright — 3.0 VDC on lamp filament

Again the lamp voltages were well below 6 volts.

Additional tests to determine the visibility of the reticle pattern under all ambient lighting conditions were conducted in the laboratory and outside. At an ambient light level of 120,000 lux in the laboratory, the reticle voltage rose to 8 volts before the reticle could be seen clearly against the bright background. At this point the reticle projector was modified to include a small condenser lens that imaged the lamp filament near the reticle plane and increased the reticle brightness. The reticle bulb voltage never exceeded 6 volts under the brightest ambient conditions after this modification was added.

4. Irises

Tests were conducted to determine the taper effect in the focal plane of the television lens caused by introducing straight edged filters in the edge of the lens aperture. These tests could then be evaluated to determine the probable effects of incorporating the variable wedge filters described by Figure 24, Section IV, of this report. However, it was first necessary to determine the illumination taper and vignetting characteristics of the 100 mm focal length objective lens and the television camera when used behind the 2.5X Galilean telescope. This was accomplished by illuminating a target that was covered by a mask with a hole in the center and a hole in each corner of the field and recording the video level of each exposed spot at aperture settings of f/4, f/8, and f/16. The video level data was represented in the following format.

Left Top		Right Top
	Center	
Left Bottom		Right Bottom

The first test varied the aperture by using the iris on the 100 mm lens.

f/4 aperture

0.50		0.42
	1.02	
0.60		0.48

f/8 aperture

0.60		0.50
	0.80	
0.70		0.55

f/16 aperture

0.80		0.68
	1.00	
0.85		0.70

The second test was a repeat of the first test except that the lens iris was opened to f/2.8 and a separate iris was inserted in the parallel space between the 100 mm lens and the 2.5X Galilean telescope.

0.30		0.30
	0.70	
0.30		0.30

f/4 aperture

0.6		0.55
	0.80	
0.6		0.55

f/8 aperture

0.70		0.70
	1.00	
0.70		0.70

f/16 aperture

The third test used the external iris between the camera lens and the 2.5X Galilean telescope. A 0.8 ND filter was inserted half-way across the indicated iris openings on each test and then the iris was opened until the previous video reading at the center of the target was regained.

0.40		0.32
	0.70	
0.40		0.32

f/4 aperture

0.60		0.55
	0.80	
0.60		0.52

f/8 aperture

0.60		0.60
	0.90	
0.70		0.70

f/16 aperture

The results of the last test were at best indeterminate except possibly at an f/4 aperture opening where a right and left side difference of 20% was noted. The 0.8 ND filter was inserted in a manner that would split the aperture across the wide horizontal field with the dividing line in a vertical plane. This effect is less noticable at f/8 and does not appear at f/16 where the difference is in the vertical plane. The variation in energy from top to bottom at f/16 was probably caused by two large chips in one of the objective lenses of the 2.5X Galilean telescope in the bottom edge of the lens. This particular lens was replaced with a new lens on the day after this test but the tests were not re-run.

The fourth test was conducted with the variable wedge filter mounted in the parallel space with the external iris. The variable wedge filter was designed to move each jaw bilaterally across the aperture and was installed to split the aperture in the vertical plane across the narrow vertical field. Each aperture reading was established by setting the variable wedge wide open (1 inch diameter, f/4, clear opening) and then setting the iris to the desired f number and reading the video output at the center of the screen. Then the iris is returned to a full open position and the variable wedge was adjusted to yield the same video signal at the center of the screen. Then the measurements for all five screen positions were recorded.

0.55		0.48
	0.80	
0.60		0.50

f/4 aperture

0.64		0.60
	0.80	
0.78		0.70

f/8 aperture

0.70		0.60
	1.00	
0.90		0.84

f/16 aperture

The data indicated that no large differences in field intensity taper or vignetting was caused by using this variable wedge filter. There was no observable evidence of variable shading of the field of view as the filter was moved. However, it is the opinion of the writer that the resolution at the edges of the field would be improved over what can be achieved with a regular iris control used at f/8 to f/16 and higher openings. Outdoor tests indicated that the image contrast in the transition zone from a ground scene to a sky background was much improved with the variable wedge filter. This is caused by the fact that the wedges ride over each other in different planes and they have a finite thickness. This spacial relationship, plus the fact that the absorbing glass filters are actually wedges, as far as absorption is concerned, gives the filters a variable absorption as a function of angle in one plane. A proper relationship of the wedges creates a higher attenuation of the bright sky background versus a lower attenuation of the ground scene which is helpful to the vidicon response and the associated electronic circuits.

Manual control of the variable wedge filter was very easy and motorization should present few problems.

5. Common Optics

The complete breadboard common optical system, as shown in Figure 9, was assembled and subjected to various tests to determine its characteristics. The first system to be tested was the 2.5X Galilean system with the television camera equipped with the 100 mm focal length lens. This test was conducted to determine the resolution and the vignetting of the compound optical system and to verify the computer design of the 2.5X Galilean system.

The optimum lighting portion of the resolution tests outlined in paragraph B.2 of this section, Television Camera Tests, was repeated at aperture settings of f/4, f/8, and f/16. The light level was controlled by the iris located in the parallel space between the 100 mm lens and the Galilean system. The wedge beamsplitter was also included in the Galilean system optical path.

The data from this test is presented in Table 11 with the horizontal and vertical resolution given at each portion of the field.

TABLE 11. HORIZONTAL AND VERTICAL RESOLUTION

f/4

Location	Horizontal Resolution	Vertical Resolution
Left Top	300	275
Left Bottom	250	275
Center	325	300
Right Top	225	275
Right Bottom	250	275

f/8

Location	Horizontal Resolution	Vertical Resolution
Left Top	325	275
Left Bottom	275	325
Center	350	350
Right Top	250	275
Right Bottom	275	300

f/16

Location	Horizontal Resolution	Vertical Resolution
Left Top	325	300
Left Bottom	275	325
Center	350	350
Right Top	250	275
Right Bottom	275	300

The results of this test were surprising since they were better than the tests of the camera with the 100 mm lens alone. The maximum resolution at the center of the field increased to 350 lines in horizontal and vertical.

The next step performed was to assemble the folding mirrors to insert the laser beam into the Galilean telescope and to align it with the projected reticle axis which was imaged in the far field with a ten meter focal length lens. The only control used was tipping and rotating the beam-splitter between the laser and the reticle projector until the laser spot coincided with the center of the reticle. Then the retro lens and retro prism assembly behind the wedge beam-splitter was aligned and focussed until the reticle pattern was imaged on the vidicon face. The retro assembly was then blocked with an optical shield to prevent any feedback of laser energy passing through the 1.06 micron high reflectivity coating of the wedge beam-splitter.

The laboratory was then darkened and the laser was activated at 10 hertz and the camera iris was opened to f/4. Flare originating from reflections from the surfaces of the objective lens was suppressed by closing the iris to f/32 or by inserting a 1.9 density ND filter in the optical path in the parallel space.

Next, the objective lens was blocked with a dark cloth and the retro lens was unblocked and the laser energy transmitted through the wedge beam-splitter was observed on the vidicon. The flare in this instance was very bad and required a 4.7 density ND filter inserted in the parallel space to suppress it.

It was obvious that further tests would require some combination of filters to suppress the laser radiation without too much reduction in the scene radiation between 0.63 and 0.95 microns. A 99.75%, 1.06 micron dielectric mirror, with plane parallel polished sides, was inserted in the parallel space to suppress the laser flare from the objective lens surfaces since it added only a small loss to the optical passband for the background scene. It was also apparent that the laser energy passing through the wedged beam-splitter required more attenuation (47 dB) and that an absorption type filter was required rather than a reflection type filter that would send the laser energy back toward the television camera. The final choice was a 1 mm thick Schott KG-3 filter, placed on the entrance aperture of the retro lens and prism assembly, which fully absorbed the 1.06 radiation and allowed most of the reticle projector light to pass through it.

Additional tests were conducted to verify the narcissus analysis that only one surface of one of the Galilean objective lenses could contribute sufficient energy feedback density to cause flare in the vidicon. The retro lens and prism assembly was blocked off while these tests were conducted. This test assumed that if the external objective lens was removed from the system and the 1.06 micron dielectric mirror was also removed, that the laser flare would disappear from the video presentation. The first test removal of the lens failed since the flare pattern was slightly different but required approximately 10 dB of attenuation to fully suppress it. The second objective lens was then removed but the flare remained.

The complete system was then carefully examined to determine the source of the laser radiation causing the flare. It was finally traced to the wedge beam-splitter and was caused by laser radiation passing through the splitter through areas covered by the mask or support during the dielectric coating process. These areas were windows rather than mirrors since they had not been coated and the splitter support frame was reflecting the energy toward the camera. A few pieces of black masking tape applied to cover these bare edges on the laser side of the beam-splitter completely removed the flare. Then the objective lenses were replaced and the suspected lens was then the only contributor to flare. The flare intensity was low enough that it was only visible in the scene when the laboratory was completely darkened and the vidicon had maximum gain.

At these low light levels, another source of energy could just be seen. It was determined that it was caused by flashlamp leakage in the laser rod and could be completely removed by using a Schott RG-830 filter on the output of the laser.

Outdoor tests in bright sunlight indicated that the common optical system could match the resolution of any ordinary system with no unusual effects to be expected.

6. Boresight Tests

The primary optical system, containing the projected reticle, was checked to verify that movement of any optical component common to both the laser and the reticle projector would shift the optical axes of both systems equally. The mirror and dichroic beamsplitter were moved without changing the relative positions of the laser spot to the reticle projection when viewed on the television monitor. Alignment of the reticle projector axis and the laser axis could only be achieved by moving the combining beamsplitter at the output of the laser. The images of the reticle and the laser spot were focussed in the far field with a 10 meter focal length lens since both systems are afocal. (focussed at infinity). Some of the 1.06 micron attenuation was removed from the television camera lens to allow some of the laser radiation passing through the dichroic beamsplitter to be imaged on the vidicon face along with the reticle projection.

A secondary method for checking the laser firing axis was to interpose a transparent corner cube into the output beam, external to the objective lens, and reflect some of the laser energy back to the television camera. This corner cube was constructed from three plane parallel plates of uncoated glass that were cemented together at 90° angles plus a few minutes of arc. The uncoated glass surfaces reduced the reflected energy by a factor of 10^{-5} and required that the 1.06 micron filter be removed from the system to increase the energy transmitted through the system to the camera. The expected results would consist of a six spot pattern centered around the laser axis.

The test results were not as expected since the actual number of spots varied from twelve to forty eight when the transparent retro was held in various positions in the output laser beam. The pattern was not symmetrical and this was caused by differences in angles between the three glass plates relative to each other. There were two patterns offset from each other and this was caused by the fact that the two surfaces of each plate were not parallel and was different in each plate. This increased the probable number of spots to forty eight. Finally the variation in the number of spots could be controlled by rotating the retro around the axis of the laser beam and by tilting it in the beam. This last effect was caused by the fact that the laser beam was strongly polarized and that as the angle of the glass plates of the retro approached Brewsters angle, their effective reflectivities were dependent on the tilt and rotation of the retro assembly. If the first plate to intercept the laser beam was at the right angle, it transmitted all of the laser energy and reflected none of it to the other plates. If none of the plates exactly coincided with the plane of polarization, a maximum number of spots was recorded but the intensity of the spots varied around the axis of the beam as the retro assembly was rotated by a small angle.

The results of these tests indicated that this system was feasible but would require a considerable engineering effort to properly implement it.

Another method of checking boresight was suggested as a result of the tests with the transparent retro. This test used a normal corner cube prism in front of the objective lens of the breadboard system. The retro prism was equipped with an aperture limiter and with a holder to hold neutral density filters in front of it. The 1.06 micron wavelength attenuator was reinstalled in the breadboard system to prevent damage to the vidicon target. The laser was activated and the corner cube reflected a controlled intensity laser beam that was imaged as a spot on the vidicon face by the television lens. A single spot was recorded since the corner cube was well corrected, but a six spot pattern could be achieved by using a prism with the faces polished at angles greater than 90 degrees.

One additional test was conducted to determine the practicality of firing the laser through a lens to an aluminum target in the focal plane. The high energy density of the laser spot vaporizes the aluminum surface and creates a plume with a broad spectral output in the visible range and which can be easily seen by the television camera. A 62 inch focal length lens was used to focus the energy of the laser on the target and neutral density filters were required to attenuate the intensity of the resultant plume to prevent flaring of the vidicon. The final result was that the camera was able to easily record the laser spot on the target when it was barely visible to the naked eye. This was caused by the camera's ability to record the near infrared radiation emitted from the target which easily passed through the dichroic beamsplitter in the Galilean system. This test was run for thousands of shots without any appreciable degradation of the target.

C. CONCLUSIONS

The projected reticle, with the light intensity controlled by varying the bulb voltage, has been shown to be feasible under all ambient conditions that are likely to be encountered. The projected reticle gives a continuous visible presentation of the laser boresight and is superior to the presentation of the intermittent laser pulse itself since it provides a continuous reference of the laser axis versus the target. The laser pulse is only available for reference at various periods depending on the repetition rate and is an unsatisfactory reference to determine the boresight axis. It is only useful to check against the continuous reference to determine if the reticle axis has shifted relative to the laser axis.

The common optics system is practical and has been demonstrated to work under the background conditions stipulated for the RPV system. The actual breadboard optical system has a demonstrated performance very close to the calculated performance relative to target resolution and dynamic range requirements and represents a good starting point for the design of an advanced common optics RPV system.

APPENDIX

RPV SENSOR BREADBOARD TEST PLAN

RPV SENSOR BREADBOARD TEST PLAN

The tests are divided into eight logical groups, starting with the measurement of the performance of individual components and ending with follow-up to the common optic and boresight tests. Since this is a study, the tests are listed below in a semi-formal manner and were modified as necessary to best meet the study goals. The eight groups are: laser, TV, optics, assembly, irises, common-optic tests, boresight tests and follow-up.

1. LASER

1A. Raw Laser Beam

For both the Aquila and GLLD lasers, running at 10 pps, measure pulse energy, energy stability, and (90% energy) beam divergence. Note the pump voltage used in each case. Also make note of the GLLD comp-scope position.

1B. Collimated Laser Beam

Set up the 10X breadboard collimator in an in-line configuration, so that no mirrors are involved. Line up the assembly using the reticle projector as an alignment source. Then set up one of the two lasers (preferably the Aquila) to fire through the collimator.

Next adjust the lens positions, lens tilts, and laser aiming to produce the minimum possible divergence out of the 2.5-inch collimator lens. Then measure energy and divergence out of the collimator and compare with raw beam data.

2. TELEVISION CAMERA

2A. Resolution

Set up the camera with the 100-mm lens. Attach probes, if possible, to measure AGC voltage and raw video level. Attach the RG-630 filter to the lens. Adjust the camera so that the test chart exactly fills the scan.

NOTE: Under-scan the monitor so that all of the scan lines are visible, keeping the H/W ratio 3/4.

Set the camera iris at f/16. Adjust the test chart illumination for "best" viewing and focus the lens (a Variac on a lamp might help). Measure the chart brightness. Measure the resolution — both directions and all five locations. Record AGC voltage.

Repeat the above test for three lens speeds (f/16, f/4, and wide open) and three illumination levels ("barely visible", "best", "too bright").

2B. Other Lenses

Repeat the previous test, at f/4 and f/16 with "best" illumination level, for all the other lenses except the Cosmicar.

2C. Cosmicar Lens

Repeat 2B with the Cosmicar lens. Then increase the illumination level as high as possible; adjust the iris for the best results, and repeat. Then use the early afternoon sun as a source, and repeat the resolution measurement. (Set up for maximum possible chart brightness.)

2D. Sensitivity

Set up the camera as in Test 2A, with the iris at f/8 or so. Use a photographic flood lamp to illuminate the test chart. Keeping the iris between f/4 and f/16, adjust for best picture by moving and masking the light.

NOTE: Do NOT use a Variac on the lamp!

Do not use indirect lighting. Monitor video (raw and processed) and AGC level. Also estimate the ratio of peak video to peak noise. Record the target brightness.

Next reduce the light level until the peak signal is about equal to the peak noise and record the same data.

Then use the sun as the illumination source and repeat the above steps.

3. OPTICAL ELEMENTS

3A. Galilean Telescope

Set up the camera as in test 2A. Then set up the 2.5X Galilean Telescope lenses in front of the camera (the stripped breadboard rail may be a good bed for this test). Set the camera lens focus for infinity and the speed at f/4. Move the test chart 2-1/2 times as far away as it was in 2A.

Adjust the light level for a good, clear picture. Then adjust the telescope optics (especially the negative doublet) for the best picture. Record all usual data.

Repeat the test at f/8 and f/16, adjusting the light level appropriately for each test.

3B. Wedge Splitter

Starting with the 3A setup at f/4, install the 30° dichroic splitter and shift the negative Galilean lens appropriately. Then repeat the f/4 part of test 3A.

3C. Reticle Projector

Set up the reticle projector about 30-60 cm in front of the TV camera (which has been set up as in 2A except with the lens wide open). Temporarily attach a small piece of RG-830 filter glass to the output end of the projector, completely covering the lens. Aim the projector directly at the center of the camera lens.

With the room completely dark, turn up the projector lamp voltage slowly until a glow is visible on the monitor. Focus the projector for the sharpest possible image (it may be a little fuzzy even at this point — don't worry about it). Determine the lamp voltages at which the reticle is (1) barely visible, (2) a good, clean image, and (3) too bright for the camera.

Insert an ND filter of density between 1.2 and 2.0 in front of the projector and repeat the previous paragraph.

Remove the filter, increase room illumination until a good, clear image of the lab is obtained on the monitor, and repeat.

Insert lenses between projector and camera as shown in Figure 1 and repeat.

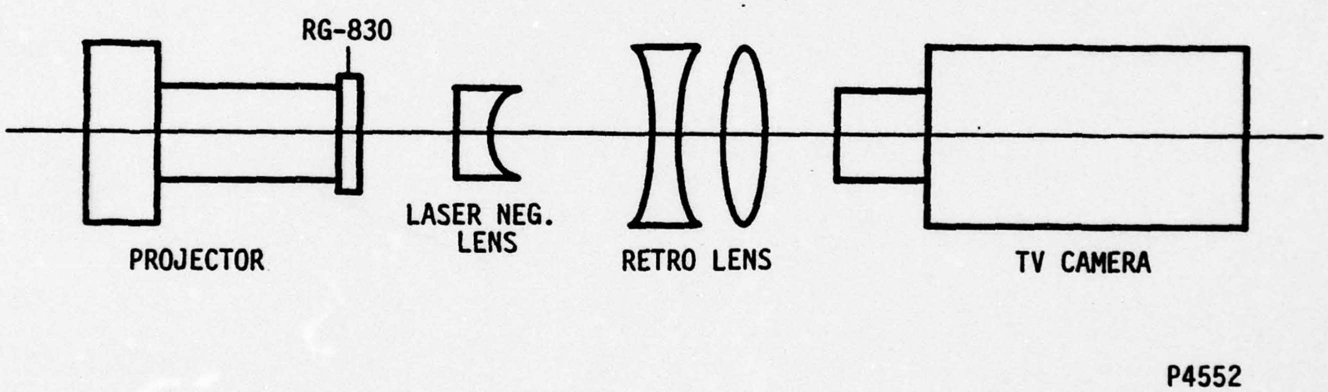


Figure 1. Projector Test

AD-A066 379 INTERNATIONAL LASER SYSTEMS INC ORLANDO FLA F/G 17/8
RPV ACTIVE BORESIGHT INVESTIGATION.(U)
DEC 78 J A POTVIN, D A ROBERTS, W SCIDMORE DAAK70-78-C-0014

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4. BREADBOARD ASSEMBLY

4A. Television

Assemble the 50-mm and 100-mm lenses to the lens slide, and the slide to the channel. Assemble the camera to the channel. With the lens focused at infinity and a distant target, focus the camera.

Assemble the 2.5X Galilean telescope and the wedge dichroic beamsplitter to the channel. Align and focus the negative lens of the telescope to obtain the clearest possible image. (Refer to Figure 2.)

4B. Laser

Assemble the laser folding mirror, negative lens, and small dichroic mirror to the channel. Then mount the laser. Place a piece of cardboard between the TV negative lens and the wedge splitter.

Align the laser path as well as possible with a HeNe laser. Then turn on the YAG laser and complete alignment of the 10X collimator.

4C. Projector

Mount the projector on the channel. Align and focus it so that, at the focus of a 5-meter mirror (or 10-m lens), the reticle circles are centered on the laser beam.

4D. Retroreflector

Mount the retro lens and prism to the rail. Remove the cardboard TV protector and adjust the retro lens until the reticle can be seen clearly on the monitor.

With the lab darkened and the camera lens at f/4, determine lamp voltages for the three cases listed in 3C.

NOTE: The retro lens/prism assembly should now be completely blocked and kept blocked until Test 7B.

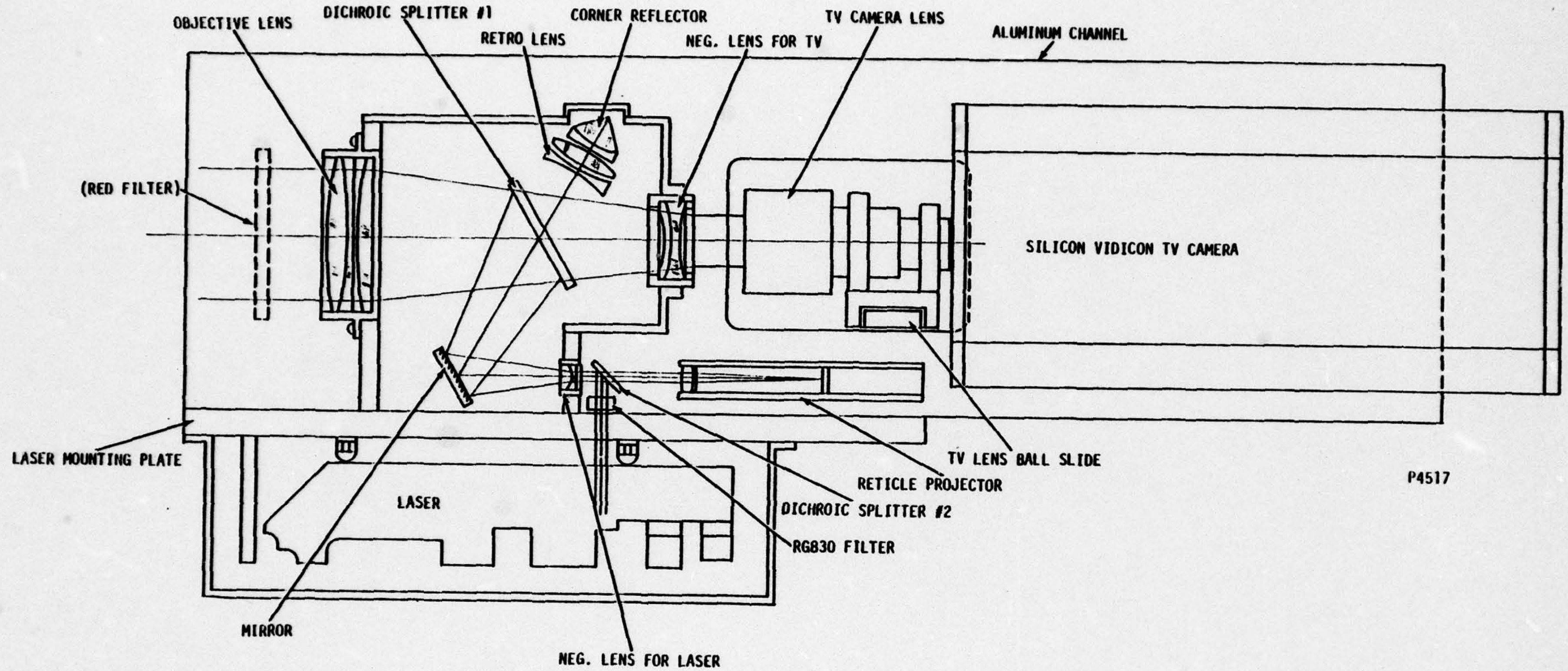

Figure 2. RPV Sensor Test Layout

5. IRISES

5A. Traditional

Set the breadboard up with the 100-mm camera lens, set at f/4. Examine corner-to-center intensity taper and vignetting, using an oscilloscope and an aperture mask.

Repeat at f/8 and f/16.

Open camera lens to full aperture and place a 30-mm iris just behind the negative TV lens (on the TV side). Repeat the above test for apertures of 25, 12.5, and 6.25-mm.

5B. Discrete Filters

Set up the breadboard so that the camera can see a good picture of something with the 30-mm iris (see 5A) at 6.25-mm. Insert an ND-0.8 filter (ND-0.6 to 0.9 will work) just behind the iris so that it blocks exactly half the aperture. Open the iris until the center of the picture regains its original brightness. Examine corner-to-center and edge-to-edge intensity tapers, vignetting, and any strange effects caused by introduction of the filter.

Set the iris at 25-mm, adjust the scene brightness appropriately, and examine above effects (NOTE: This test maintains iris aperture and adjusts brightness, just the opposite of the preceding test).

5C. Wedge Filters

Remove the 30-mm iris and install the wedge filter assembly. Experiment with at least four settings from full open to 36-dB. Examine the same type of parameters as in 5A and 5B, recording whatever seems appropriate.

6. COMMON OPTICS

6A. Initial Tests

Completely block the retro assembly. Place a temporary piece of cardboard in front of the negative TV lens (on the splitter side). Open the camera iris to f/4. Darken the lab. Start the video recorder.

Turn on the laser at 10 pps and observe the effect on the TV monitor. Slowly remove the cardboard and observe any effects (stop and re-insert cardboard if image suddenly gets very bright).

Reduce the iris aperture until all effects disappear. Record this iris setting.

Open the iris to f/4 and insert ND filters until all effects disappear.

6B. Lab Tests

Experiment with the common optics under as many sets of conditions as possible. Use low and high ambient light levels. Work in a small lab and a long tunnel. Focus the lens on the wall and at infinity (let the image blur). Use a 5-meter mirror or other device to simulate distant targets. Look for conditions where the laser spot is made visible on the monitor in addition to the undesired effects.

6C. Outdoor Tests

Repeat 6B in an environment where wall/floor/ceiling effects are reduced or eliminated. Try system at sunrise and sunset to determine vidicon limits. Experiment with irises in bright daylight. Also look for laser/TV interaction after dark. Choose a moonless night to eliminate all background and local scatter.

7. BORESIGHT TECHNIQUES

7A. Reticle Projector

With the retro still blocked, set up a 62-inch lens in front of the breadboard with a target at its focus. Mark a cross on the target located such that it appears focused and centered on the monitor. Set the camera lens at f/4.

Turn out the lab lights and turn up the projector lamp until the image of the reticle is visible in the TV. Center the cross on the reticle circles. Fire the laser and note the location of the laser burn with respect to reticle and cross. It should be centered (See Test 4C).

If not, readjust the reticle on the projector until its image is centered on the laser burn.

7B. Laser Self-boresight

Remove the block from the retro lens and replace it with a 30-mm iris which has been closed to its smallest aperture (~1 mm). Turn the reticle projector off. Remove the 62-inch lens and put an absorber in front of the output lens to minimize laser scatter back into the camera. Set the camera lens at f/4. Put a piece of cardboard in front of the retro iris. Turn off the room lights.

Turn on TV and laser. Slowly remove the cardboard and watch monitor for an image of the laser beam. If nothing is visible, slowly open the iris until the spot just appears. Record this iris diameter. Increase the opening until a good, clean spot is produced. Record diameter.

Attempt to refocus retro by sliding retro lens assembly until the smallest laser spot is obtained on the monitor. Then turn on reticle projector and observe its image quality.

Turn off laser. Remove retro iris and insert appropriate ND filter. Then repeat previous paragraph (focusing).

Remove the absorber and place a blank white paper on the wall in front of the breadboard. Increase the illumination on this paper until the laser spot disappears from the video presentation. Measure wall brightness.

Move ND filter from retro lens to TV lens and determine the maximum permitted brightness.

Return to the setup in 7A except with the retro unblocked. Turn up projector until the retro provides a clear image of the reticle. Fire the laser and note the retro/laser boresight. Apply slight misadjustments to critical components to demonstrate laser/reticle tracking. (This would include all common elements, such as the wedge splitter, the objective lens, the retro lens and prism, the laser neg lens, and the laser mirror).

7C. Transparent Retro

Return to the setup of Paragraph 1 of Test 7B. Support the transparent retro by its edges in front of the laser output. Turn off the room lights, run the laser, and see if anything happens on the screen. If it does, measure and video-tape it.

7D. Others

Within time and money limits, test other auto-boresight approaches. The list in the July report (POS-9) is a good place to start.

8. FOLLOW-UP

8A. Summary

After completion of the seven groups of tests, write a brief but complete summary of all the data obtained. Where possible include any analysis related to the data, but keep it brief. Add notes of unexpected or anomalous results, plus any tests which, when looked at in retrospect, were either missed or only partially performed.

8B. Retests

Within time and money constraints, run those tests necessary to fill in gaps exposed by the summary.

8C. Future

Make recommendations as to future studies or experiments which would be of value to the RPV effort.