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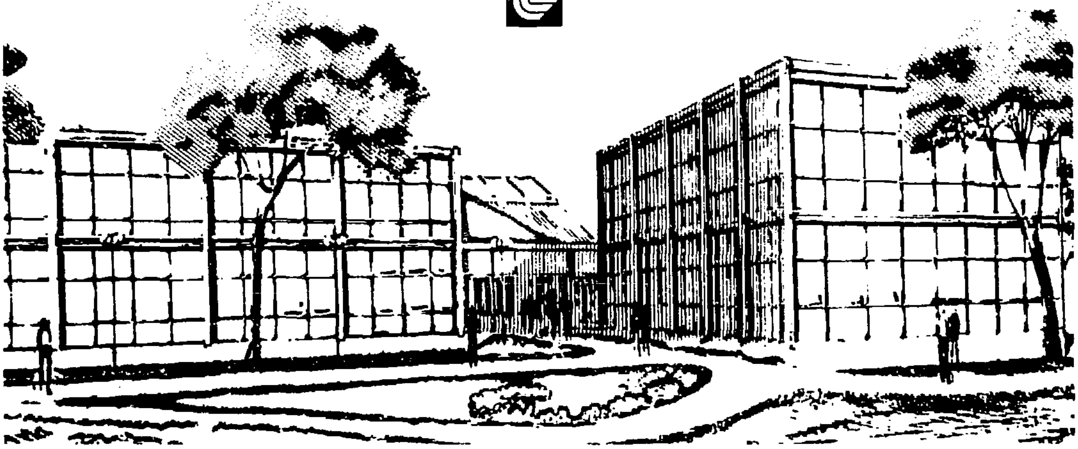

THE SHIVA TARGET ALIGNMENT AND VIEWING INSTRUMENT*

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Abstract

To view and align Shiva laser targets, two new telemicroscopic instruments integral with TV camera and HeNe laser illuminator have been designed. The common requirement of both instruments is the capability of imaging two objects of different sizes on a TV screen: the large surrogate target (5 mm diameter) and the laser fusion target (0.250 mm diameter) with the same resolution (better than 7 μm). Both instruments have an optical relay which images the targets on a fixed reference reticle; the object is to center each target on the reticle. One of the instruments reimages the reticle plane onto the TV detector using a zoom arrangement. This instrument translates the TV camera-zoom assembly in three axes and is thereby capable of exploring an object-space volume of 1 cm^3.

In the other instrument, the reticle plane is reimaged by a zoom lens and this enlarged image is relayed to the TV detector by a cluster of five lenses. Four lateral lenses image the periphery of the surrogate target and the reticle for coincidence. The central objective images the center of the reticle and the fusion target when it is centered.

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THE SHIVA TARGET ALIGNMENT AND VIEWING INSTRUMENT

Introduction

The automated target alignment system(1) of the 10 kJ output twenty beam Shiva laser requires that each beam be focused on a reflecting sphere of approximately 5 mm in diameter. Located at the nominal center of the target chamber(2) this "surrogate target's" center is the zero reference for the positioning of the laser fusion target and the pointing and focusing of each individual Shiva beam.

The position of the surrogate target is established and recorded by coincidence with at least two fixed reference reticles. Once this is done, the surrogate target must be removed and the fusion target located in coincidence with this center (using the reticles as centering references) with an accuracy of ± 5 µm. This operation is done remotely and requires an opto-electronic imaging instrument capable of imaging on the same screen size two objects of greatly differing dimensions; namely the large 5 mm surrogate target and the small fusion target whose characteristic dimensions are 200 to 500 µm.

When two objects of such different sizes must be aligned for axial coincidence with respect to a fixed reference, the accuracy depends upon the characteristic dimension of the smaller object. This dimension, then, becomes the governing parameter in determining the magnification to be used and the resolution that may be achieved by the optical system. Since the positional accuracies of the two objects are to be identical, the corresponding magnifications and resolutions of the two objects should also agree. Under such circumstances, one finds that the larger object will overfill the available image field, if the size ratio between the two objects is about 5:1 or greater.

In the Shiva Target Alignment and Viewing Instrument (TAVI) this problem has been solved in two different ways, each one fulfilling specific additional requirements. One system is designated "Single Translating Field Instrument" and the other is the "Multiple Field Instrument". The relative position of these instruments on the target chamber is shown in Figure 1. The general appearance of both instruments is shown in Figures 2 and 3.

1) Characteristics common to both instruments

1a) They are integrated illumination-imaging systems. The targets are front and back illuminated by a HeNe laser beam injected through the optical axis of the objective/relay optics. After passing by the target, the laser beam is retroreflected by a replicated array of 1 mm aperture triangular corner cubes placed 400 mm behind the target. The interference pattern caused by the coherence of the laser light is averaged by interposing an optical wedge(3) in the expanded HeNe laser beam and rotating it at approximately 4000 RPM.

1b) An objective/relay lens system transports (with M≅1) the image of the target outside of the target chamber and projects it on the reference reticle (central cross and concentric circles with the major circle 5 mm in diameter). This reticle is mounted on an x-y stage for initial alignment after which it is locked in place.

2) Optical Characteristics of the Objective-Relay Lens System (Figure 2)

This M≅1 lens system, besides being used in the alignment instruments here described, is the main optical component of the "Sentry System"(4) (not discussed here). The Sentry System is designed to monitor the position of the target up to the time of the laser pulse arrival using two reticon arrays. It is interrogated at 20 μsec intervals, and if the target moves, the shot can be aborted. Consequently unlike the alignment optics, Sentry cannot be protected by closing a mechanical shutter before the laser pulse arrives and therefore is exposed to the radiation reflected and emitted by the fusion target. In addition to this, the objective lens and the first relay lens in all the systems are subject to the vacuum of the target chamber. The lens system must be located as far away as practical from the target, be evacuable and tolerate high optical fluences. The Cooke triplet design was chosen for all the three lenses because it fulfilled these basic requirements, plus it is a design which permits correction of all the primary aberrations.(5) The characteristics of each lens are shown on Figure 2 and all of them are standard items. The second and third lenses are identical. They are mounted facing each other in order to minimize aberrations.

As can be seen in Figure 2, the vacuum barrier is incorporated between the first and second relay lens where the light rays are quasi parallel. This minimizes spherical aberration which would later be magnified by the optical system. Another characteristic of the vacuum barrier is that it is mounted at an angle of 3° with respect to the optical axis. As a result, that part of the light from the illumination beam which is back reflected by the vacuum barrier (even if it is AR coated) misses the aperture of the zoom lens and is eliminated from the image field. The image contrast is enhanced by using a field stop in the object plane of the first relay lens and a pupil stop placed just in front of the vacuum barrier; this corresponds to the plane of the exit pupil of the objective and first relay lens combination.

Between the vacuum barrier and the second relay lens is located a 50% beamsplitter pellicle 8 μm thick which directs the illumination beam along the optical axis toward the target. The use of a pellicle beamsplitter in transmission for the imaging light minimizes spherical aberration and eliminates ghost images. Standard pellicles are made with a wavefront distortion better than 1/10 λ in transmission; therefore, they can be safely used in this mode even before magnification.

Since the image of the target transmitted by this part of the instrument has to be between 5 μm to 10 μm smaller than the 5 mm diameter circle on the reference reticle, it is of crucial importance that the objective relay lens system have the proper magnification. Magnification adjustment is done by sliding the first relay lens along the optical axis. This adjustment is made on the optical bench before the instrument is installed on the target chamber, and allows for the use of different surrogate target diameters, on the condition that the magnification of the relay optical system is adjusted to produce an image of the proper size (always 5 μm to 10 μm smaller than the reticle diameter disregarding the real size of the surrogate target). For the surrogate targets in use at the present time, the required magnification turns out to be $M_R=1.05$.

3) <u>Characteristics of the Single Translating Field Instrument</u> (Figure 2)

After the target is relayed ($M \cong 1$) outside of the target chamber, a zoom lens integral with the TV camera magnifies the target and reticle image approximately twelve times ($M \cong 12$) and focuses the image directly on the vidicon face. Under these conditions only one edge of the surrogate target can be seen (see Figures 4 and 5). Therefore to monitor the centering of the reticle it is necessary to translate the zoom lens-TV camera unit and survey the image plane. The TV camera-zoom lens unit is mounted on a three axis remotely controlled translation stage. The range of motions for each axis is ± 5 mm, thereby enabling the system to explore a volume of 1 cm^3 in the object space when the relay system is working with M=1X. In addition to these translations, the "Z" stage can be displaced a full 50 mm along the optical axis. This is done in order to change the available range of magnifications provided by the zoom lens.

The zoom lens is an f/1.3 lens remotely controlled in focusing and zooming with a focal length range between 15 mm and 30 mm which, combined with the 50 mm translation of the "Z" stage, provides for a range of magnifications between M=3.9 to M=12. Since the power of the objective-relay system is $M_R=1.05$, the magnification range of the entire optical train at the image plane defined by the vidicon face will be: $M_{TO}=3.05$ to $M_{TO}=12.6$. The resolution of the vidicon is the width of a double line ($R_d = 2W = 36\ \mu m$), so the effective resolution on the object is

$$R_o = \frac{Rd}{M_T}\ . \tag{1}$$

This gives a resolution range between

$$R_{omax} = 2.9\ \mu m \text{ for } M_{TO} = 12.6 \tag{2}$$

and

$$R_{omin} = 10.3\ \mu m \text{ for } M_{TO} = 3.05. \tag{3}$$

The optical resolution of the system determined experimentally is

$$R_o = 5\ \mu m \text{ to } 6\ \mu m. \tag{4}$$

Therefore at maximum power the resolution is limited by the optics while at minimum power the resolution is limited by the TV detector. For a 14" TV monitor the magnification ratio screen/detector is 25.5 so the range of magnifications on the TV screen are

$$M_{TV} = 320 \text{ to } M_{TV} = 78. \tag{5}$$

Figures 4 and 5 show two steps in the process of centering the surrogate target by translating the field of view to four orthogonal points of the target-reticle image and equalizing the reticle-target gap at these locations. After this condition is achieved, the fusion target is centered on the reticle as shown in Figure 6.

4) Characteristics of the Multiple Field Instrument (Figures 3 and 7)

The target image and the reticle are magnified 7.6 times by a zoom lens after they are relayed outside the target chamber. A cluster of five lenses (four lateral lenses 90° apart on a circle plus a central lens) view this magnified image and relay it to the surface of the vidicon. The four lateral lenses look at the silhouette of the surrogate target at four different points. The central objective looks at the center of the reticle (see Figure 7a). As can be seen in Figure 7, the rays from the four lateral lenses are folded by four specially designed prisms so that the image is in focus and within the available field provided by the effective area of the TV detector. The design is such that the four images appear on the four corners of the TV screen, leaving the central area free for viewing the laser fusion target and reticle centering crosshair (see Figure 7b). By these means it is possible to center two objects of very different sizes (5 mm and 200 μm) with the desired magnification and accuracy on the same reticle without using any moving parts in the imaging system. In both systems the reticle is securely locked in place after it has been centered, thereby defining a permanent zero reference for all future surrogate target and fusion target alignments.

The relevant characteristics of the optical components used in the magnifying optics of the multiple field instrument are: zoom lens f#/1.5 with a focal length range between 20 mm and 32 m mounted on a rack and pinion focusing mechanism which permits fine focusing adjustments as well as changes in power. The aerial image projected by the zoom lens on the object plane of the lens cluster has to be of a definite size in order for the lateral lenses to transmit the image onto the TV detector. The variable power of the zoom provides the necessary flexibility for achieving this goal independent of the real object and reticle dimensions. The system can therefore be used with different surrogate target diameters as well as different reticle circles, on the condition that the image size projected by the zoom lens be of the required dimensions (39 ± 2 mm).

As can be seen in Figure 8, the lens cluster is made of a central lens, which is a microscope objective of F_ℓ=40 mm working at M=1.55 and the four lateral lenses which are microscope objectives of F_ℓ=46.8 mm working at M=1.1X. Since the total optical magnification is the project of the partial magnifications, we have

$$M_{TO} = M_R \cdot M_Z \cdot M_{CL} \cdot M_{TV} \qquad (6)$$

where

power of the objective-relays system $= M_R = 1.05$
power of the zoom lens $= M_Z = 7.6$
power of the central lens $= M_C = 1.55$
power of the lateral lens $= M_L = 1.10$.

So the optical power of the central system

$$M_{TC} = 12.37, \qquad (7)$$

and for the lateral system

$$M_{TL} = 8.78X. \qquad (8)$$

Using a 14" TV monitor the magnification ratio screen/detector is 25.5, so the magnifications on the TV screen are

$$M_{TVC} = 315, \text{ and} \qquad (9)$$

$$M_{TVL} = 225. \qquad (10)$$

The respective resolutions for a double line turn out to be

$$R_C \cong 3\ \mu m, \text{ and} \qquad (11)$$

$$R_L = 4\ \mu m. \qquad (12)$$

Experimentally, the optical resolution was found to be the same as that of the single field instrument, namely R_O = 5 μm to 6 μm. We conclude that our system resolutions are limited by the resolving power of the optical relay systems.

5) Practical Results

Figures 4, 5 and 6 are actual polaroid pictures taken during the test conducted at the experimental setup for the single field translating instrument. The irregularities in the silhouette of the surrogate target are specs of dust.

Figures 9, 10 and 11 apply to the multiple field system. Figure 9 shows the fields as they appear on the television screen when the surrogate target is centered. There is an image inversion introduced by the lenses in the cluster, and a glint is returned by the center of the reflective surrogate target. The image of the glint appears on the TV screen when the surrogate target silhouette is centered on the 5 mm circle within approximately ± 100 μm and converges toward the reticles center as the alignment error goes to zero, thereby providing an additional aid for alignment.(6)

In Figures 10 and 11 the surrogate is being replaced by the fusion target. Here the central objective images the fusion target and the reticle on the TV detector, and the fusion target can then be aligned with the reticle. These conditions are shown schematically in Figures 7a and 7b. This series of pictures show that the transition zone for the full range of the gray scale is approximately 3 μm wide. Considering that the reticle line thickness is 7 μm, we observe a centering accuracy of both systems of approximately ± 5 μm. Four of these units, two multiple field instruments, one translating field instrument and one Sentry System are presently used for target alignment in the Shiva target irradiation facility.

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4) Don Campbell, etal, "The Electronics of the Sentry System", UCRL Technical memo in preparation.

5) Warren J. Smith, Modern Optical Engineering, McGraw Hill Book Co., Chapter 12.

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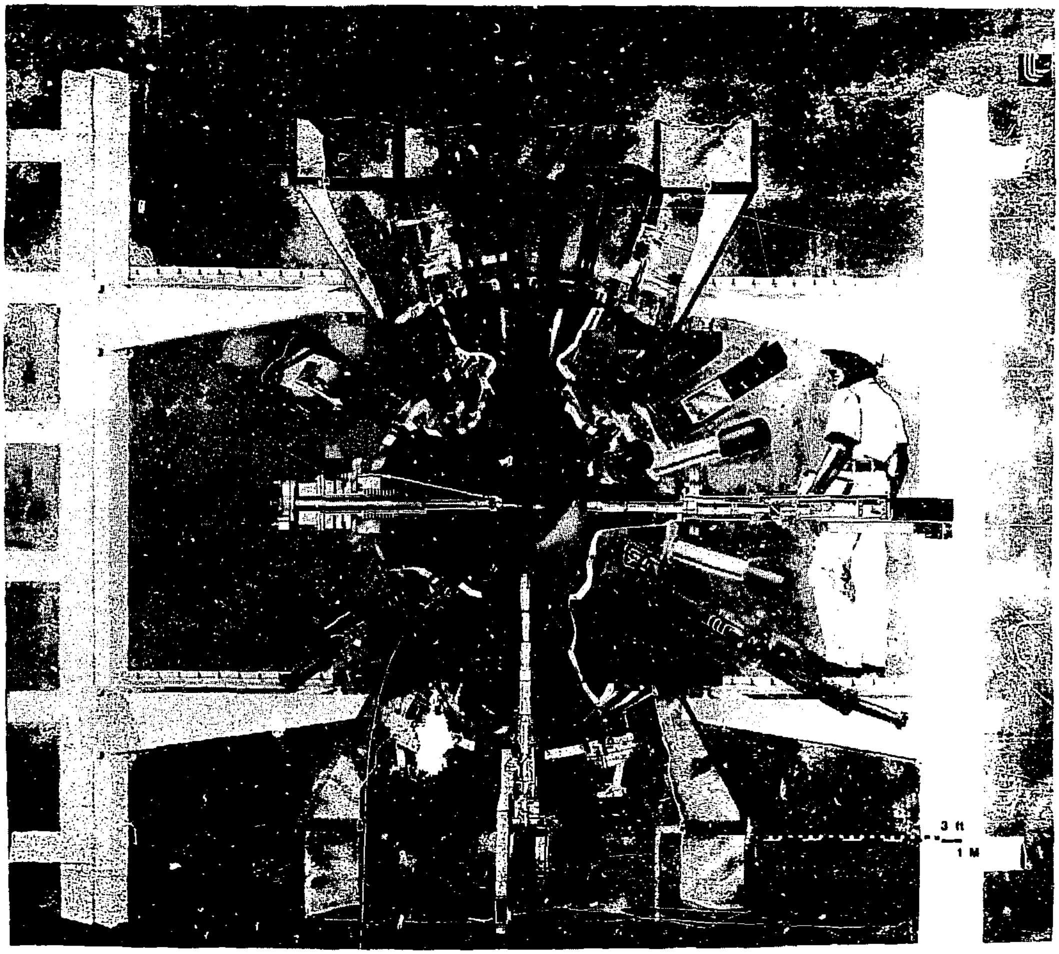


Figure 1.

Shiva Target Chamber Assembly. The multiple field instrument is mounted on the equatorial plane on the right hand side. The single field instrument is mounted on the lower pole along the center line of the ten laser beam lower cluster.

Fig. 2 SHIVA-T.A.V.I. SINGLE TRANSLATING FIELD INSTRUMENT

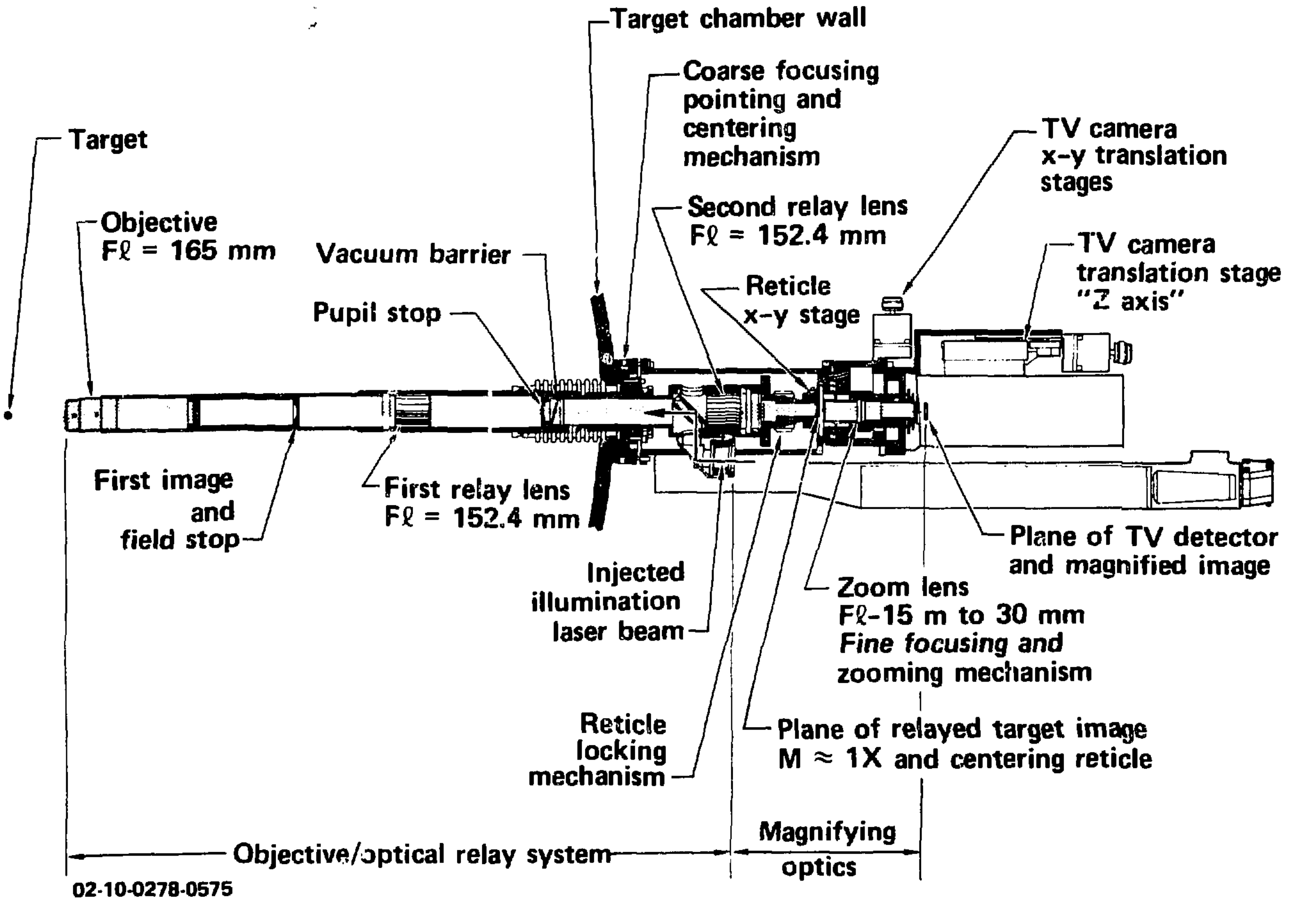


Figure 2.

T.A.V.I. Single Field Instrument. This figure shows the main optical and mechanical components. The instrument can be pointed by tilting it about the hollow spherical joint located on the mounting flange.

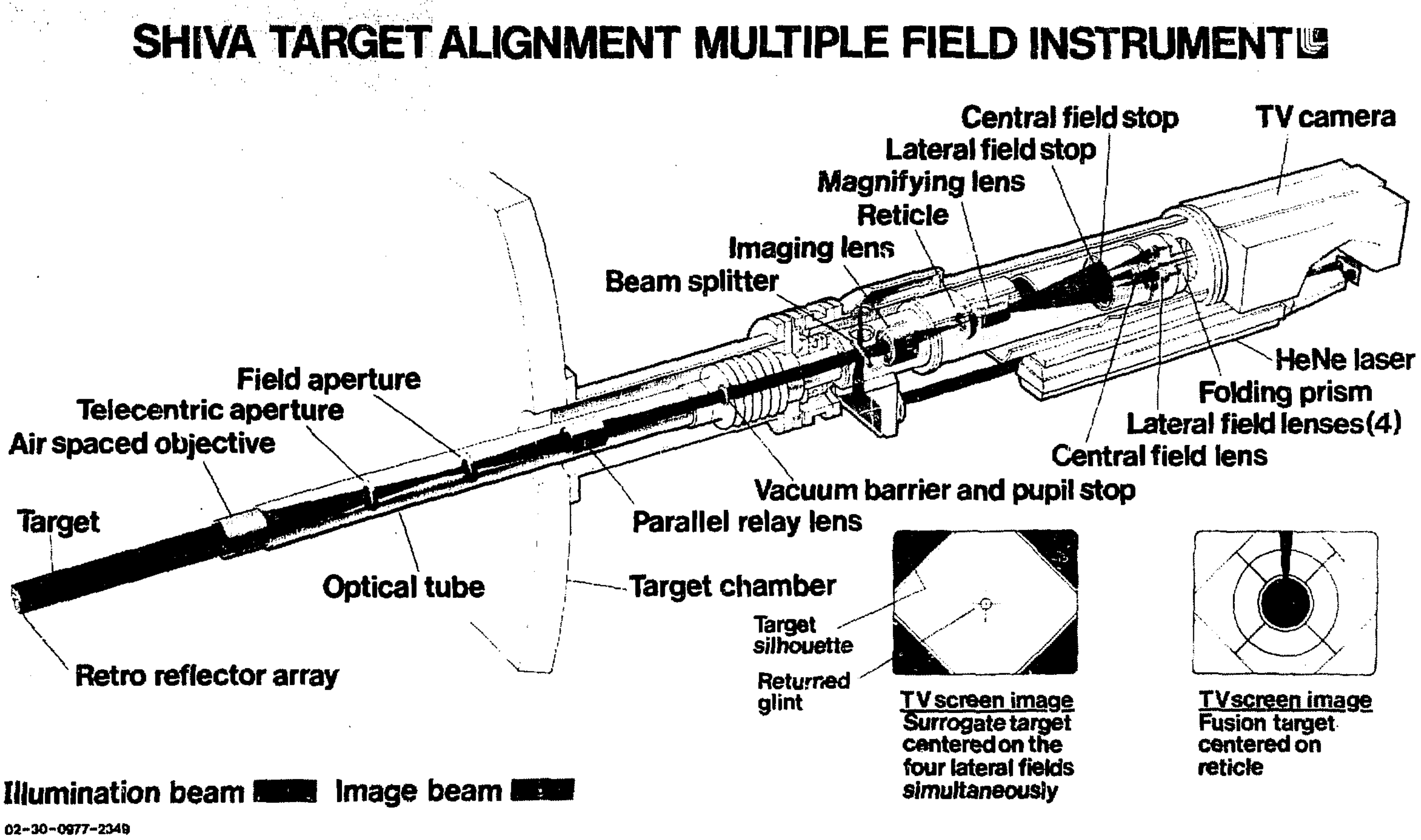


Figure 3.

T.A.V.I. Multiple Field Instrument. This figure shows the colinear illuminating and image forming beam, as well as the corner cube retro reflector used to back illuminate the target.

Figure 4. Surrogate target and reticle's 5 mm diameter circle as seen during first step of the centering operation using the single field instrument.

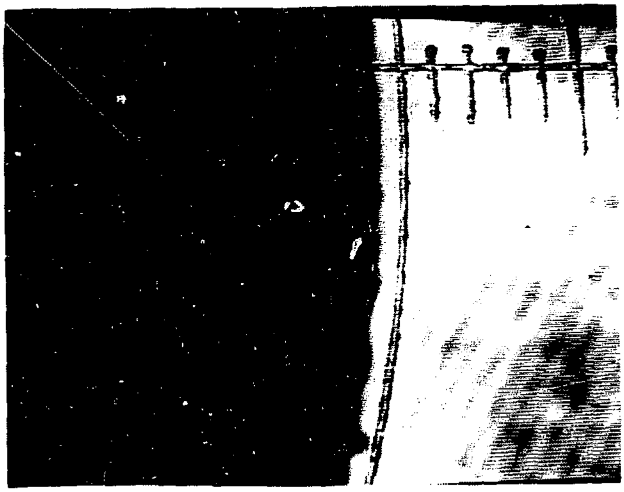


Figure 5. Same as Figure 4 but the opposite side of the surrogate target. When the surrogate target-reticle spacing is made equal at both sides of the target, it is centered along the vertical axis. The operation is repeated at 90° for centering along the horizontal axis.

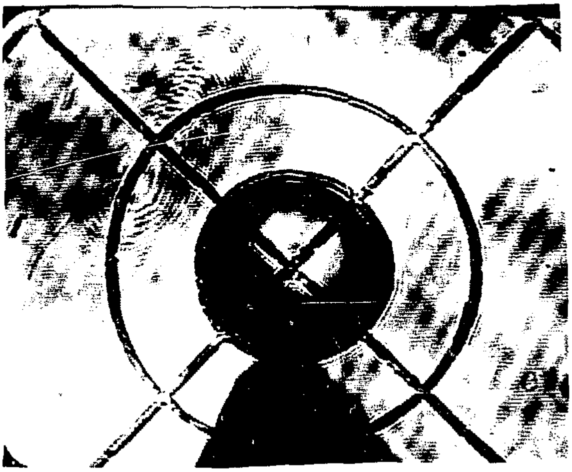


Figure 6. 250 μm diameter laser fusion target centered on the reticle.

Fig. 7 SHIVA–T.A.V.I. MULTIPLE FIELD MAGNIFYING OPTICS

Fig. 7A Object field covered by "5 lens cluster"

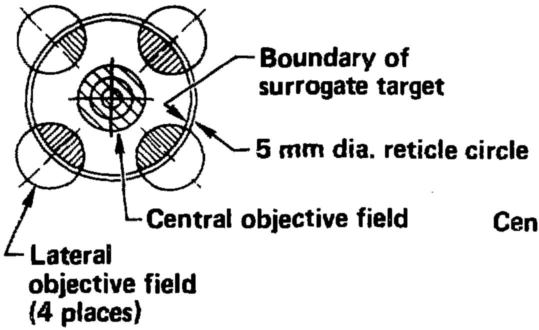
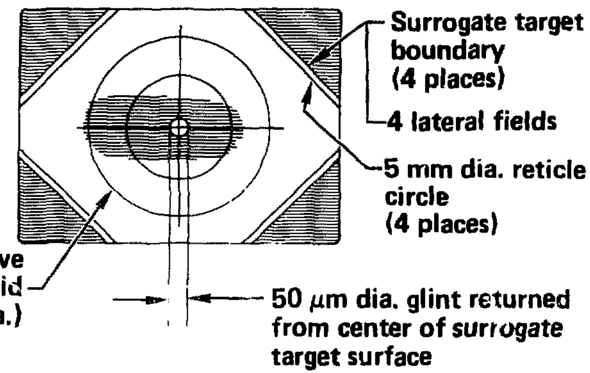
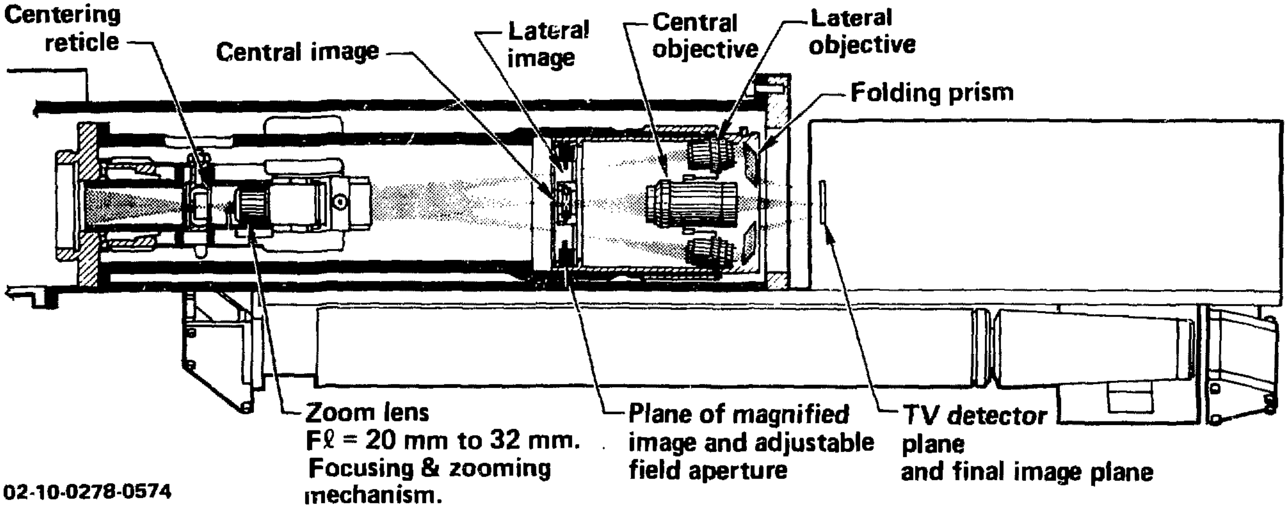


Fig. 7B Multiple image field on TV screen





<u>Figure 7.</u> Magnifying Optics of the Multiple Field Instrument. This figure shows a longitudinal cross section on a plane 45° with respect to the vertical such that two of the four lateral lenses can be seen.

<u>Figure 7a.</u> This figure shows the field of view covered by each one of the cluster's five lenses on the object plane.

<u>Figure 7b.</u> This figure shows the cluster's five lenses image field as it is focused on the vidicon face. Note that the silhouette of the surrogate target shows on the outside of the central reticle (toward the corners of the TV screen). This provides an unobstructed image field for the central lens.

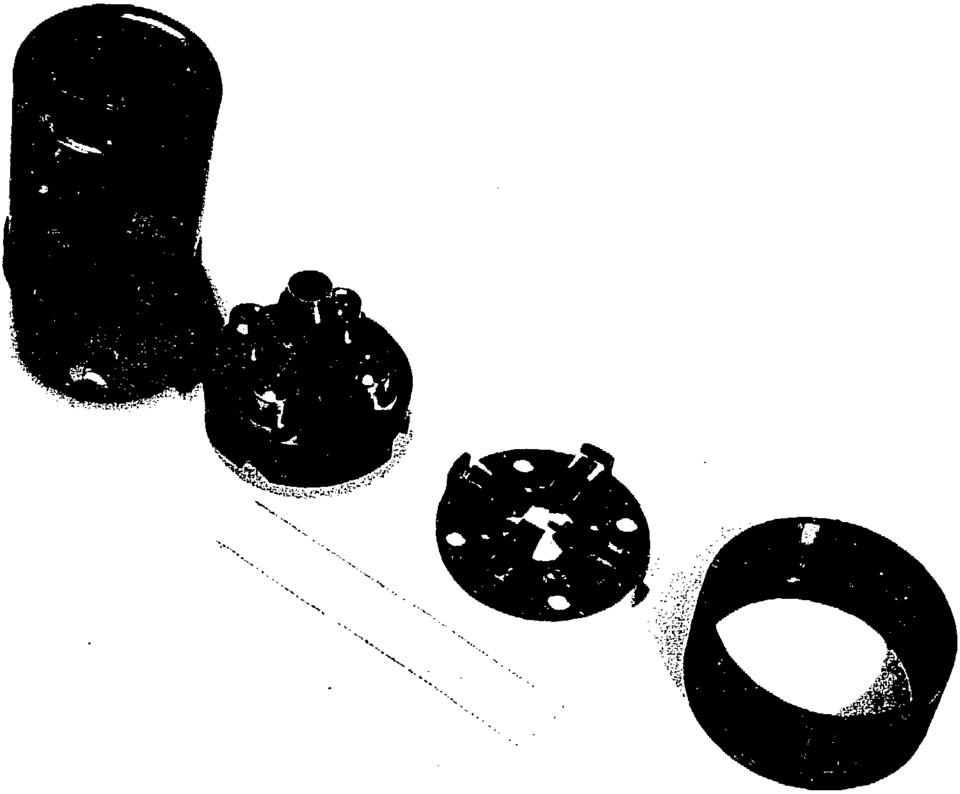
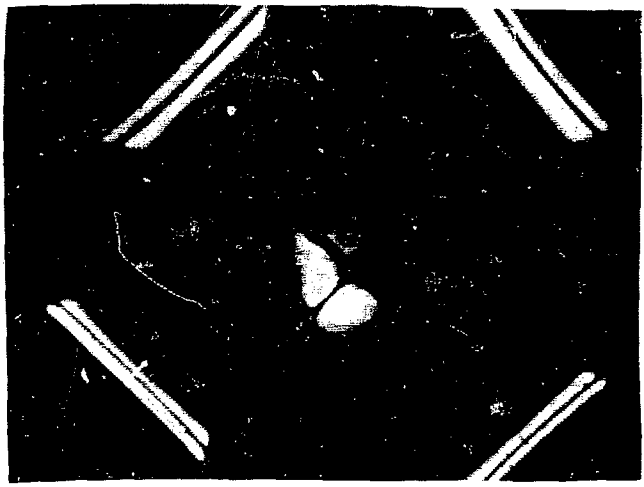


Figure 8.

Five Lens Cluster and Four Folding Prisms. The folding prism on its circular base is mounted directly behind the lens cluster onto a common mounting tube.

Figure 9. Surrogate Target being Centered. The target silhouette is the external shadow toward each corner of the TV screen. The 5 mm diameter reticle circle is seen in the illuminated areas. The center of the field is illuminated by the glint returned from the surface of the target.



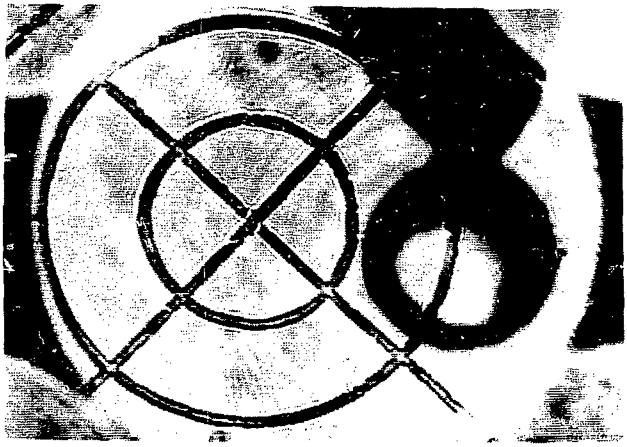


Figure 10. Laser Fusion Target (spherical glass shell) being Centered. This image is transmitted by the central lens. The reticle line thickness is 7 μm and the smallest circle is 250 μm in diameter.

Figure 11. Laser Fusion Target (spherical glass shell) on Center ± 5 μm. Same conditions as Figure 10 but with the target rotated 90° about the vertical axis.