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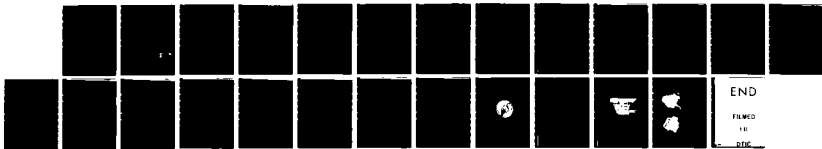
HOLOGRAPHIC ZOOM LENS: MODEL HZL-C-1000 DESIGN  
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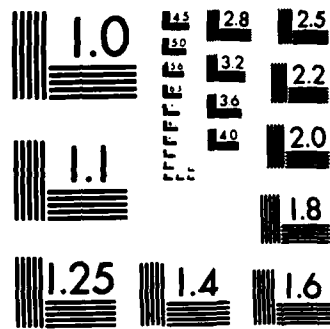
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HOLOGRAPHIC ZOOM LENS

Model HZL-C-1000

Design Description  
and  
Operations Manual

Prepared for:

Optics Group  
Research Directorate  
U. S. Army Missile Laboratory  
U. S. Army Missile Command  
Redstone Arsenal, AL 35898

Under Contract - DAAH01-81-C-B054

by

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## 1.0 Introduction

This prototype system, Holographic Zoom Lens HZL-C-1000, represents the first hardware version of a stepwise holographic zoom lens described by B. D. Guenther and C. D. Leonard in Technical Report, T-79-12 for the U. S. Army Missile Research and Development Command, 1978. As stated in that report ... "Optical components may be classified into the following three groups according to the mechanism by which they operate."

1) Refractive Components - This type of component uses the fact that the direction of a light ray will change according to Snell's Law when the ray encounters a change in index of refraction (i.e., a change in the speed of light). Conventional lenses and prisms are examples of this type of device. The operation of the device depends upon the curvature of the surface and the index of refraction of the material.

2) Reflective Components - This type of component uses the fact that light is reflected from a metal surface (or a surface where the index of refraction changes) at an angle equal to the angle of incidence. Astronomical telescopes and shaving mirrors are examples of this type of device. The operation of the device depends upon the shape of the surface and the optical properties of the surface material used.

3) Diffractive Components - This type of component uses the fact that light exhibits wave properties and, thus, interferes with itself. Gratings and holograms are examples of diffractive components.

Diffractive components, particularly holograms, differ from

other types of optical components in the following ways:

1) The index of refraction of the material is not an important factor in component design. Phase holograms produce the diffraction gratings by modulating the index of refraction but here only the change in the index (depth of modulation) is important.

2) The shape of the surface is not a first-order factor in component design. This allows conformal optics.

3) There is a large amount of dispersion - independent of component material which restricts simple designs to a narrow wavelength range.

4) Multiple functions can be combined in one element. For example, wavelength filtering and focusing elements can be produced in the same hologram.

5) Fabrication of a large number of copies is easier. In refractive or reflective components, replication techniques are restricted to only a few materials such as the plastics. Holographic elements can be replicated by contact printing or embossing which reduces their cost.

6) Computer generation of holographic elements is possible allowing the generation of components that cannot be constructed using reflective or refractive components."

We draw further from Guenther et al to answer the questions of, (1) Why use holographic optics for missile guidance systems and (2) What are some immediate applications?

1) "More and more missile guidance systems are using narrow wavelength band radiation in the visible and infrared (IR) region of the

spectrum. Holographic optical components operate best when limited to a narrow wavelength band and offer the following important advantages over conventional optical systems:

.Very complex optical systems can be reduced to one or two holographic lenses. This can provide a weight advantage as well as increased ruggedness.

.Computer-generated holograms can produce optical systems we do not know how to construct using conventional optics. Manufacturing and engineering costs can also be reduced through the use of computer-generated holograms.

.Holographic optical elements can be replicated easily and for a low cost. The manufacturing costs are reduced because the materials are inexpensive and the fabrication costs are low, but more importantly, the production personnel do not require extensive training.

.Either reflection or transmission optics can be constructed, reducing the dependence on available optical materials.

.The optical systems can be made to conform to the shape of the enclosure. For example, optical elements can be constructed on a sensor window which conforms to the shape of the missile.

2) Several immediate applications to current missile systems are apparent:

.A simple stepwise zoom lens can be configured to perform a beam-rider-type mission. With only two components, zoom ratios of almost any value can be constructed. Because the zoom lens can be constructed to work in reflection, the operational wavelength is uncoupled from the

holographic materials used.

.A set of wavelength filters that also perform optical functions can be constructed. The bandwidth of the filters can be controlled as can their center frequency. These filters would be of use in missile systems that used wavelength as a discriminant.

.In present laser designator systems, the aerodynamic performance of the missile is reduced to have a sensor window with minimum optical aberrations. It should be possible to construct a holographic corrector plate that would correct the optical aberrations of a sensor window that had good aerodynamic characteristics.

Following the concept further, a holographic element could be used to improve the optical performance of any optical train used in a missile guidance system. The use of a holographic corrector could reduce the total cost of an optical system by relaxing the tolerances on the conventional optical components."

## 2.0 Description of Holographic Optical Elements (HOE) as Simple Lenses<sup>1</sup>

Holographic optical elements (HOE) can be made to perform the same function as simple lenses and as such can be designed with existing lens design computer codes using an analogous lens mode. When the computer code performs a ray trace of such a lens model, it focuses light exactly the same as an HOE. This analogy works for both on and off axis rays and for all wavelengths.

Holographic optical elements act as Fresnel zone plates and/or diffraction gratings recorded in film emulsion or other sensitive medium just as any ordinary hologram, i.e., it is the result of the exposure of two interfering beams of monochromatic light onto a light sensitive medium.

Figure 1 shows two such monochromatic waves and their resultant interference.

The sensitive medium is greatly exposed where the waves are in phase (constructive interferences) as denoted by the points of intersection along the dotted lines. The region where the wavefront crests and valleys cancel (destructive interference) causes minimum exposure of the light sensitive medium. Exposure levels between the constructive and destructive interference varies sinusoidally. The interference process simply redistributes the total available energy in a sinusoidal fashion.

Figure 2 displays a sensitive medium as it was exposed to the two beams shown in Figure 1. Here the normal grating equation:

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This discussion follows that given by W. C. Sweat, "New Methods of Designing Holographic Optical Elements", SPIE, Vol. 126, 1977.

$$\alpha(\sin(\text{incident}) + \sin(\text{diffracted})) = \lambda$$

or for thick emulsion, the Bragg equation:

$$2d \sin \theta = \lambda$$

applies, where  $d$  is the separation between dotted lines of Figure 2. These "fringes" in the sensitive medium become the Bragg reflective planes upon development and act like partially silvered beam splitters. The light reflected off each one must be coherent with all of the other reflected beams or the reflections off of different planes will cancel each other out.

HOE are normally constructed with two interfering spherical waves as shown in Figure 3. In this figure, one of the wavefronts is diverging from  $Z_c$ , the other is converging toward  $Z'_c$ . The resulting interference record, after proper processing, will diffract light and focus it just like a lens, as shown in Figure 4. Further typical responses of either a thin lens or an HOE are shown in Figure 5.<sup>2</sup>

There are many types of recording materials: film with thin emulsions, thick emulsions sensitized with silver halide, ammonium dichromate, photoresist, and many types of photosensitive crystals. The physics of each recording material is different. As a result, the efficiencies vary, but the image quality does not. The angles through which a ray is diffracted are only a function of the fringe spacing as measured along the surface and hence a function of the constructing geometry, not the recording medium.

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<sup>2</sup> After Optics by Sears, Addison-Wesley 3rd edition, 1958.

### 3.0 Design Description of the Holographic Zoom Lens, Model HZL-C-1000

The two sets of hologram lens elements (HOE) used in the design of this prototype HOE stepwise zoom lens demonstrator were fabricated and furnished to TAI Corporation by the Optics Group, Research Directorate, U. S. Army Missile Laboratory, U. S. Army Missile Command, Redstone Arsenal, Al.

Figure 6 displays a schematic of a typical twelve element holographic lens array with 30 degrees separation between each element. Two such arrays were used in this prototype fabrication. Each circular element of the array is comprised by two holographic gratings, and constitute a lens of a specific focal length. The two arrays are matched as conjugate pairs with conjugate focal length. Each conjugate pair of HOE elements constitutes one step for the twelve position stepwise zoom lens. Each conjugate pair provides one specific image magnification factor and a specific image plane.

Each of the two twelve element HOE arrays is fabricated from two 4x5 inch hologram exposures with twelve circular exposures. These are then sandwiched together to form one twelve element HOE. One of these element arrays constitutes the input HOE lens while the other constitutes the output HOE elemental array. They are respectively called holographic lens 1 and 2 and holographic lens 3 and 4.

Each of these 4x5 holographic lens arrays are mounted in a hologram support and light baffle wheel. Figure 7 displays a schematic of this mounting wheel. Figure 8 displays a photograph of this unit, two of which are contained in the prototype HZL-C-1000 Holographic Zoom Lens device

Figure 9 provides a schematic of the Holographic Zoom Lens device in a longitudinal cross section. The above described lens arrays and hologram support and light baffle wheels are shown here as holographic lens 1 and 2 and holographic lens 3 and 4 respectively. These components are centered on the turret shaft which causes each conjugate pair of lens elements to be centered on the center line,  $C_L$ , which constitutes the optical axis of the system.

A 5mW HeNe laser and its associated power supply are shown mounted at the base of the system. Radiation is emitted from right to left. The raw laser beam is caused to turn through  $180^\circ$  via two, three axis adjustable turning mirrors to establish the optical axis,  $C_L$ . As the turret is rotated through its twelve positions, each conjugate pair of lens elements is caused to center about this optical axis or  $C_L$ . A microscope objective in this optical train provides the necessary spherical wave as a divergent beam for the input to the first lens element. This divergent wave is first passed through a reticle which serves as an object for the first lens element. The reticle is placed so as to be in the object plane of each conjugate pair of lens elements.

Upon passing through lens element 1 and 2, the wavefront is made incident on lens element 3 and 4 of the conjugate pair. Upon passage through lens element 3 and 4 the image undergoes the specific magnification required by the conjugate pair and so imaged at the specific image plane for that conjugate pair.

Figure 10 displays a photograph of the system without its barrel

cover and with the same perspective as that of the schematic of Figure 9.

Figure 11 displays a photograph of the final complete system.

#### 4.0 Operation of the HZL-C-1000 System

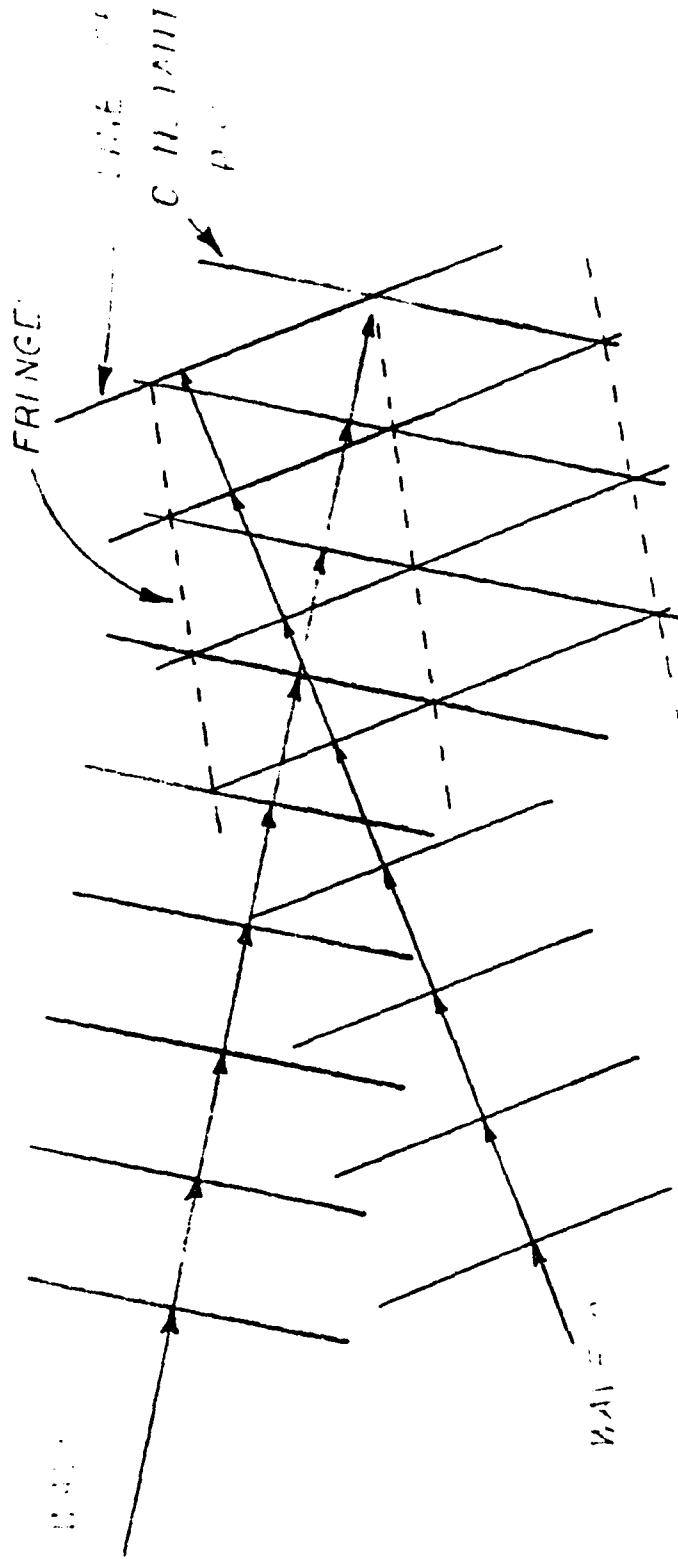
After removing the HZL from its carrying case and positioning it and its accompanying viewing screen on an appropriate surface, the power cord must be plugged into any standard 110v, single phase electrical outlet. This connection provides the on/off switch for the laser used in this model. Upon making this connection, a five second safety delay will be encountered before the laser fires and an image exits the HZL.

The object for the HOE is a transmission cross hair of width .005 inch. This object is rigidly fixed in a reticle positioned 10 mm behind the mating surfaces of holograms 1 and 2. Uniform illumination of the object is furthered by the placement of a diffuser immediately behind the cross hair.

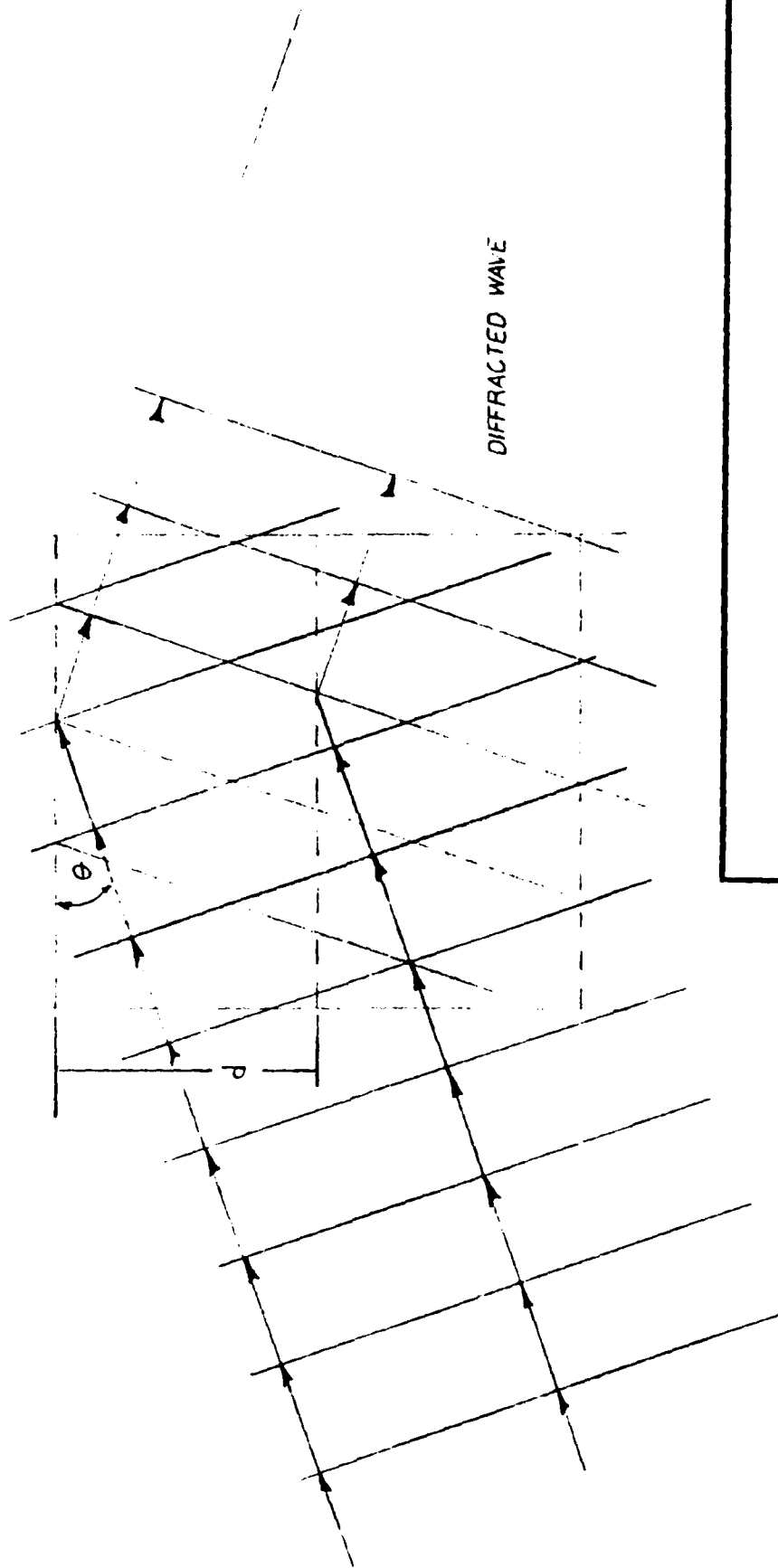
The white nylon bushing at the output end of the HZL has been engraved with the numbers one through twelve positioned in a relative fashion according to the lens element pair (conjugate pair) imaged on the screen. These elements correspond to those given by Guenther and Leonard. Desired lens element pairs may be examined by firmly grasping the knurled end of the turret shaft as shown in Figure 9, thus rotating the mounting wheel about its mechanical centerline which causes each successive pair of HOE to move into the optical path. The holding force applied by the detent pin may be varied by adjusting the set screw in the counterbore of the detent mechanism.

These twelve lens pairs yield an image at differing distances from the exit aperture of the HZL. Thus, the viewing screen must be repositioned with each  $30^{\circ}$  rotation of the turret shaft to accommodate the

changing image planes. Element pair #1 has the shortest image focal distance while element #12 is the most distant.



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WAVE INTERFERENCE				DRAWING NUMBER	
				FIG. 1	



DIFFRACTED WAVE

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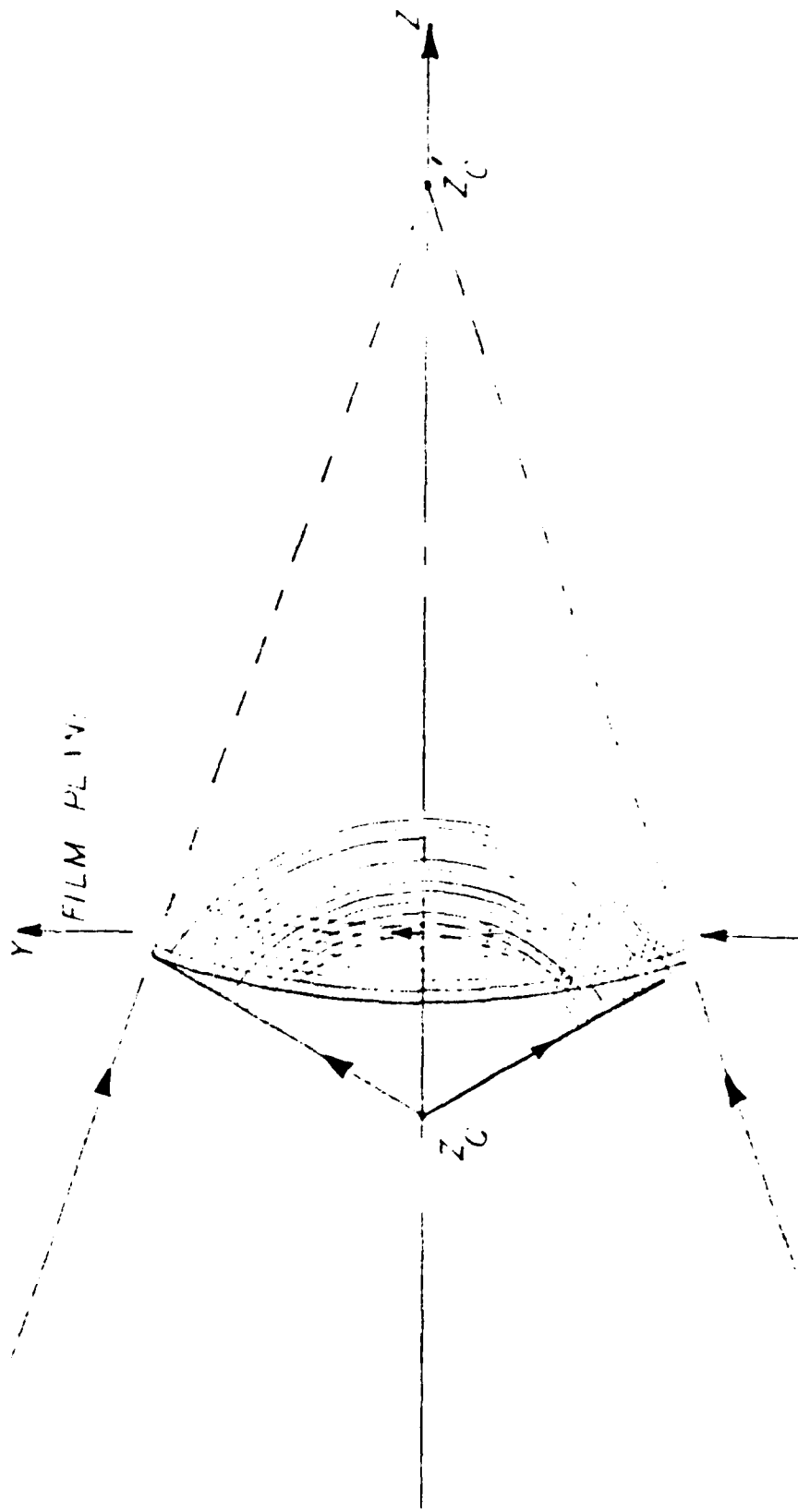
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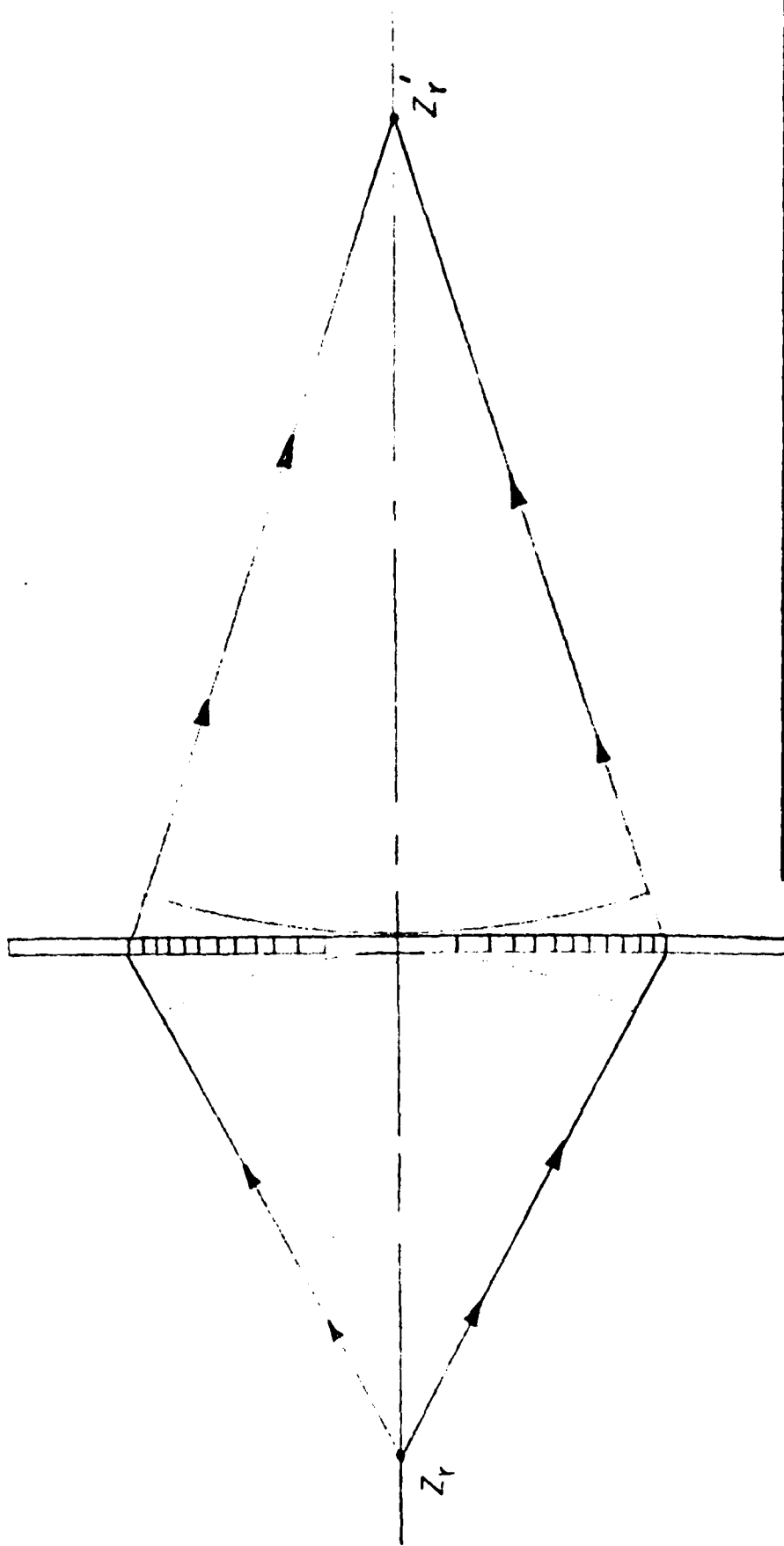
FIG 2



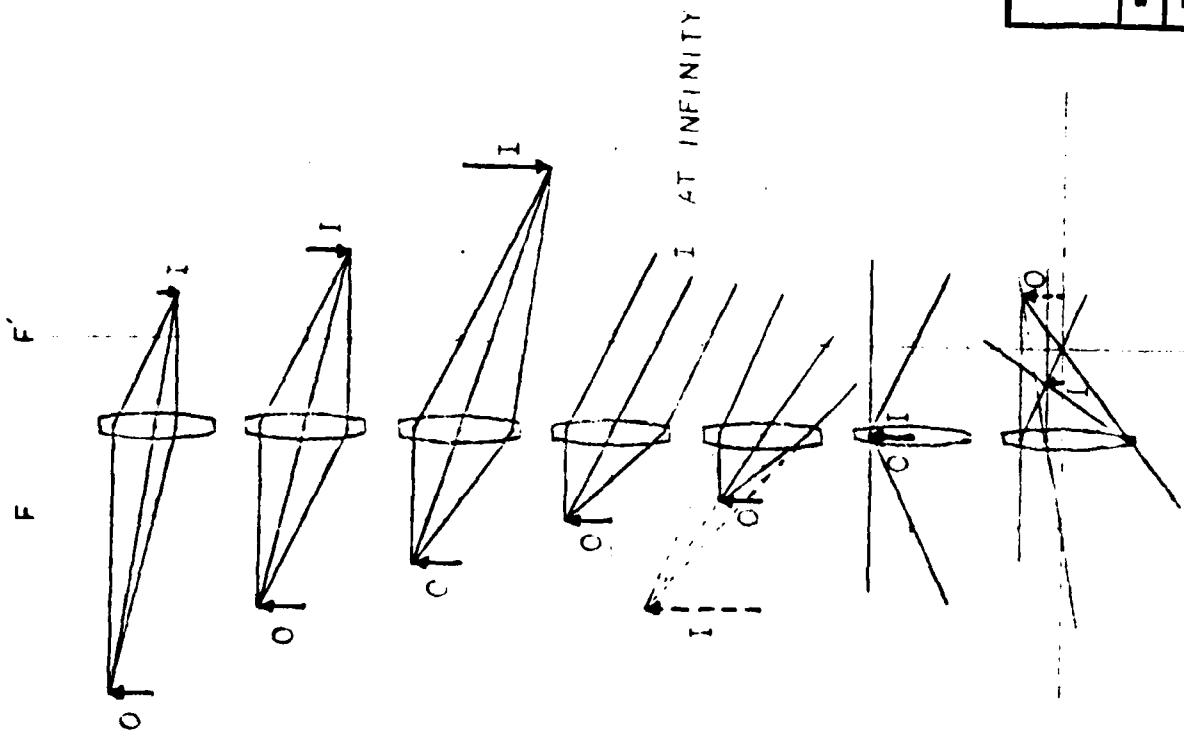
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**FIG. 3**

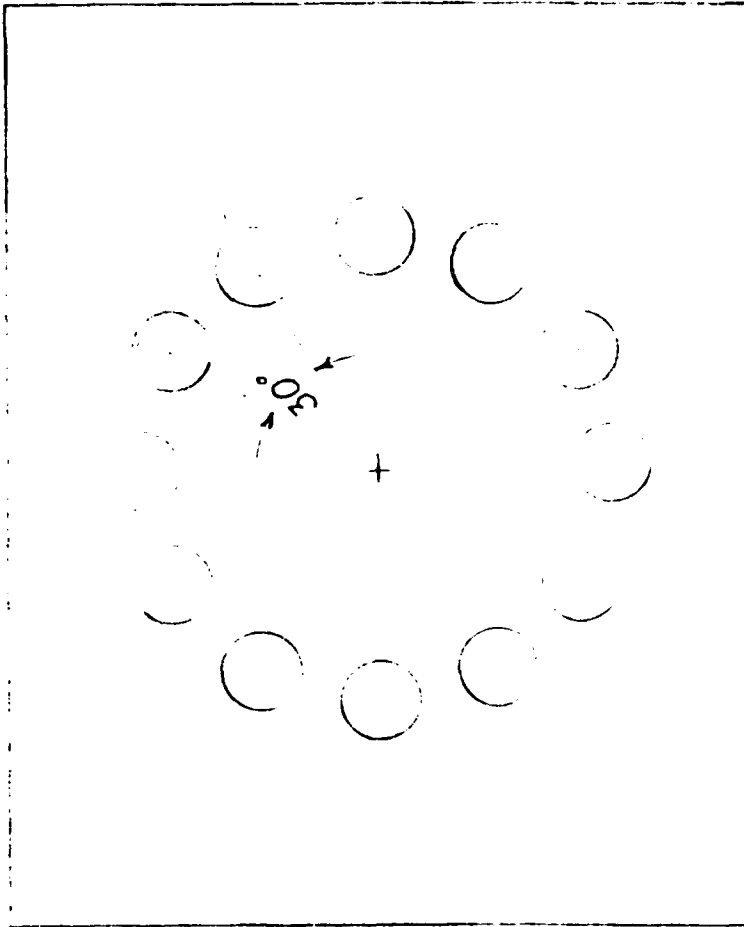
**SPHERICAL WAVE INTERFERENCE**



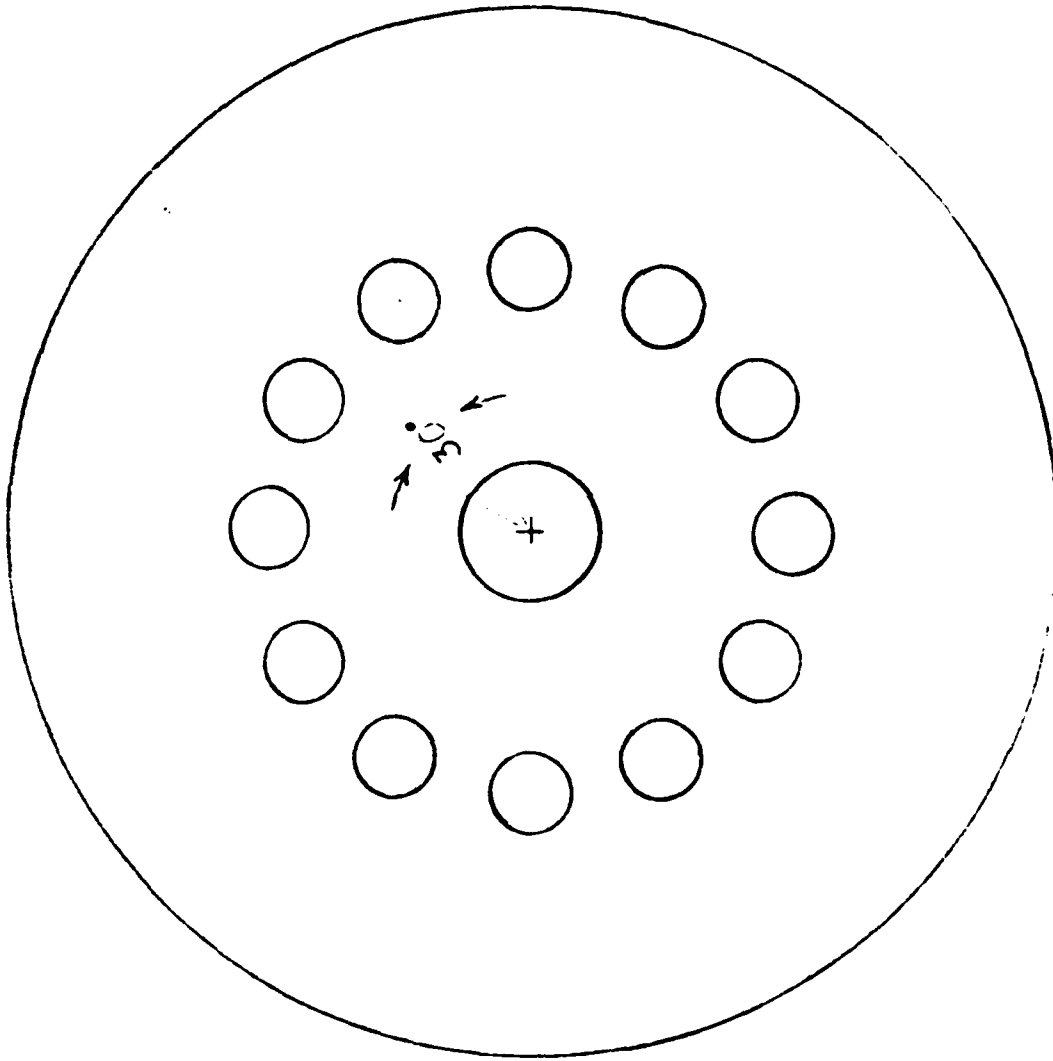
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SPHERICAL WAVE DIFFRACTION				DRAWING NUMBER	
				FIG. 4	



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TYPICAL LENS RESPONSE					
DRAWING NUMBER					



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TWELVE ELEMENT LENS ARRAY				DRAWING NUMBER	
				FIG. 6	



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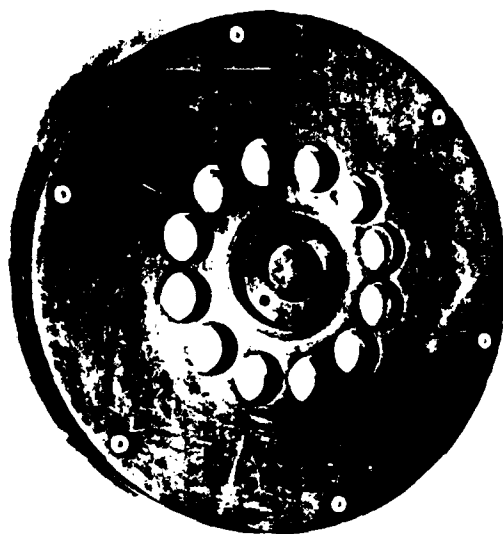
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MOUNTING WHEEL SCHEMATIC

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FIG 7



*FIG. 8: MOUNTING WHEEL*

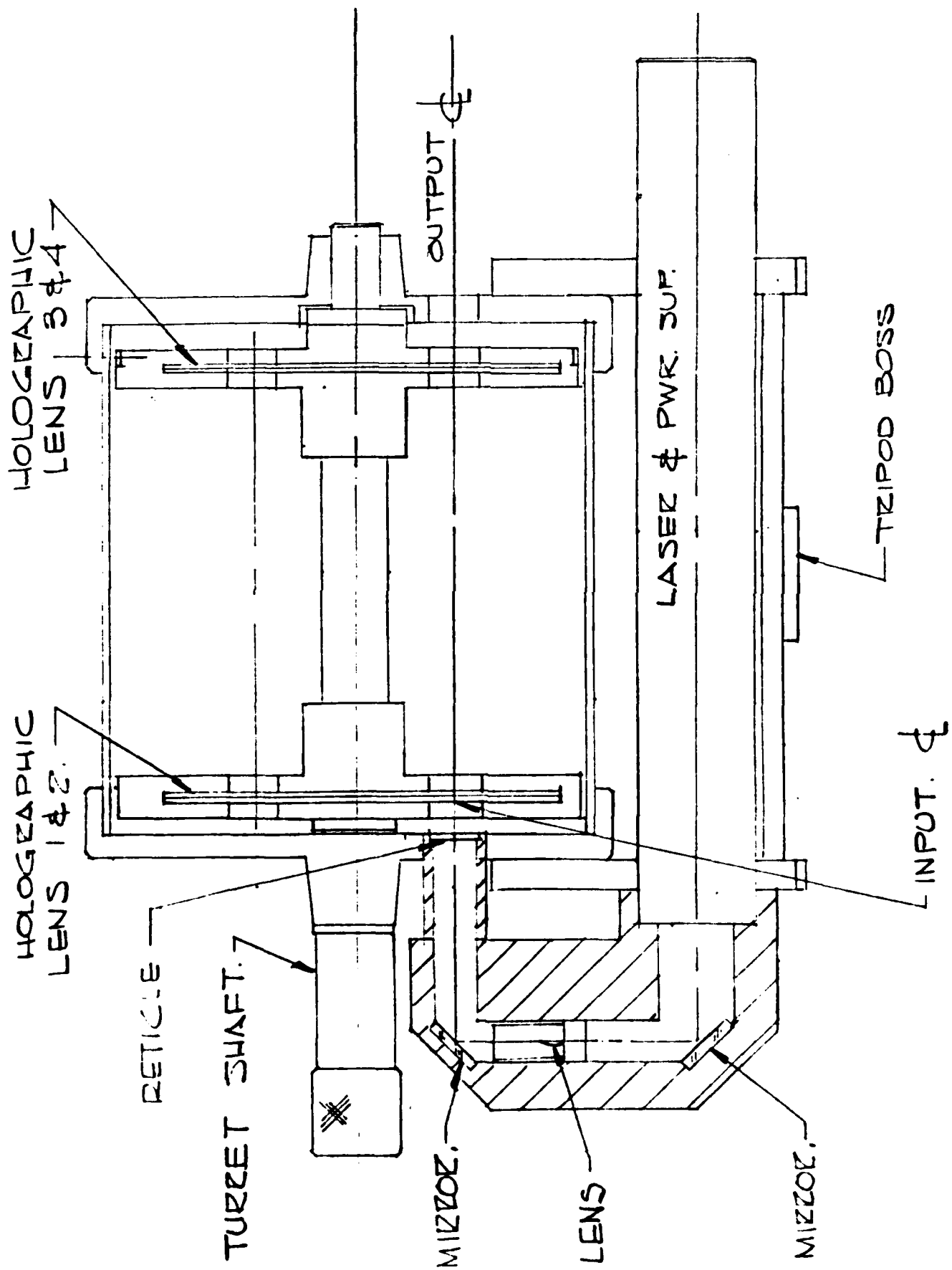
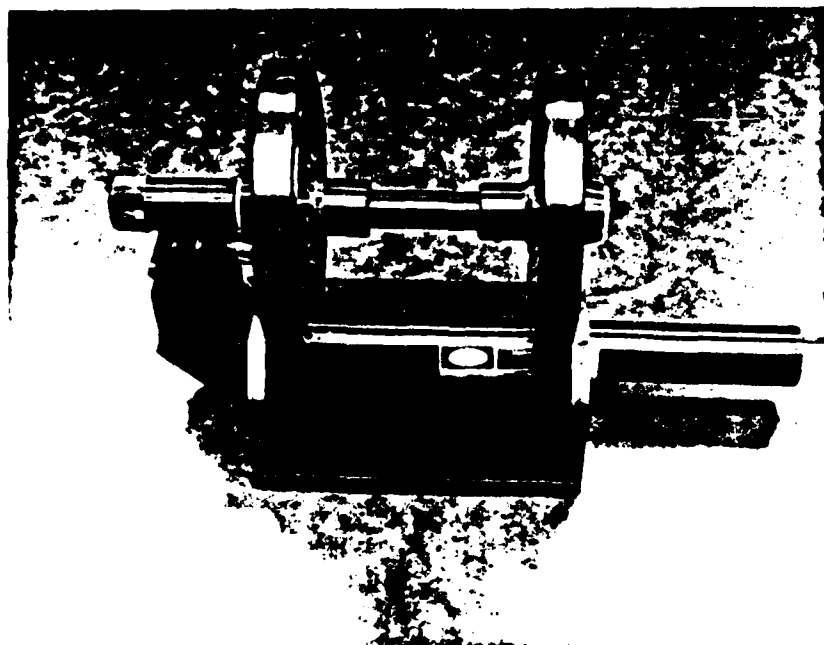


FIG. 9: HZL SCHEMATIC



*FIG. 10: HZL WITHOUT COVER*



FIG. 11 : COMPLETE HZL

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