Underwater LASER Systems

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TABLE OF CONTENTS

I. INTRODUCTION

This report describes the underwater LASER systems being developed at Harbor Branch Oceanographic Institution to improve the quality of sub-sea photographs and to aid in a variety of underwater tasks.* Originally configured to provide precise, non-contact range and direction measurements for underwater still cameras,[(1)] the LASER system has been adapted to yield at-a-distance size information for still and video cameras.[(2)] Photogrammetric and positioning applications are being investigated and variations, such as beam splitting and shaping, are under development.

The light source used in these systems is a compact and moderately priced helium-neon LASER, which emits a highly collimated beam of orange light at a rated output power of 2 milliWatts. The LASER is encased in pressure housing designed to operate to a depth of 3,000 feet (915 meters), and operates with an input voltage of 28 volts d.c.

II. CAUTION

The light intensity of the beam emitted is sufficiently intense to cause irreversible eye damage (approximately ten times more intense than the sun, on a clear day). Careless use or improper operation can result in a DANGEROUS situation. In particular, "sighting down the LASER bore", pointing a LASER at a reflective

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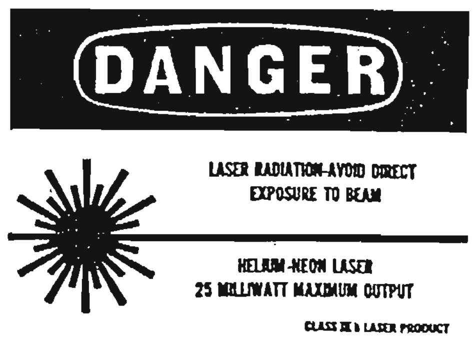
*This report supersedes Ocean Engineering Application Note No. 9.

surface (glass, smooth plastic, metal, an air-water interface, etc.) or in a direction in which a person may be, is UNSAFE. It is strongly recommended that technical and operations personnel be familiar with laser safety practices before using these systems.*

In accordance with the Code of Federal Regulations, Title 21, parts 1000, 1002 and 1040, the LASER housings are labeled with the following warning:



To prevent inadvertent operation, out of water, a pressure actuated safety switch is installed in the pressure housing. Submergence to a depth of 20 feet is required before power can be applied to the LASER.

III. SOME OPTICS FUNDAMENTALS

LASERs, as light sources, have some interesting and unique properties by comparison with more conventional illumination sources. The main characteristics are the highly collimated nature of the emitted light and the high power densities achievable in the

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*Refer also to Laser Safety Memo from Frank Caimi to Roger Cook, December 5, 1985 and to laser safety training films available through the Personnel Office.

propagating beam. In addition, the light output is highly monochromatic and is nearly an ideal plane-wave over its cross-section. Thus, unlike incandescent sources the beam can be projected over large distances with very little change in its characteristics (beam size, color, etc.). For the helium-neon units employed, the beam diameter, as it exits the LASER assembly, is approximately one millimeter, and expands approximately one millimeter for each meter of pathlength.

The term monochromatic (meaning one-color) is actually a misnomer since emission is within a very narrow band of wavelengths depending upon the physical properties of the laser medium and its surrounding optical cavity. For a helium-neon gas LASER, the most common emission wavelength is 632.8 nanometer (orange) within a bandwidth of less than 0.1 nanometer. Advances have recently been made, however, which allow helium-neon LASERs to produce many different emission lines, i.e., green, yellow, orange and red. A green LASER has been ordered for evaluation and the results will be reported in a subsequent report.

As a medium for optical transmission, water some undesirable properties. Transmission loss (or attenuation) is highly dependent on wavelenth.[3,4] In the clearest water, minimum loss is observed in the range of 470 to 500 nanometers (blue-green). Orange and red colored light is progressively more attenuated, and a beam of 633 nm light will attenuate exponentially with range, R as follows:

$$\text{Intensity} \; \alpha \; e^{-R/\ell},$$

where ℓ = characteristic attenuation length (approximately 3.5 meters for extremely clear water). For a total transmission pathlength of eight (8) meters, an orange light beam will be attenuated to approximately 10% of its initial value. Beam spreading will further decrease the intensity but not the energy in the beam.* The combination of attenuation and beam spreading limit the useful range of the present LASER systems to approximately five (5) meters for most photographic applications. With a low light-level camera or a dark-adapted observer the useful range is somewhat larger.**

IV. UNDERWATER LASER ASSEMBLY

Laser system specifications, characteristics, and operation is given the following subsections:

A. LASER Specifications

Manufacturer:	Aerotech, Inc., Pittsburgh, PA
Model No.	LLS-2R/28VDC
Size:	20" long by 2" diameter
Starting Voltage:	10 KV
Power Supply:	Integral DC to DC converter
Input Power:	28V d.c. (±20%) at 0.6 A
Output Power:	2 mW minimum
Wavelength:	632.8 nm (Orange)
Beam Diameter:	0.7 mm
Divergence:	1.2 m radian (full angle)

*Scattering of the light from particles in the water is neglected in the above, since the water is assumed to be clear. For a more complete discussion, refer to Reference 4.

**Note that the dark-adapted human eye is relatively insensitive to orange or red light. See Reference 5.

B. Mechanical Characteristics

Housing Size:	25" long by 3" diameter
Weight (in air):	5.5 lbs.
Weight (in water):	0.5 lbs.
Operating Depth:	3,000 ft.*
Housing Material:	6061-T6 aluminum with plastic hardware

C. Electrical Characteristics

Power Input:	23 to 33V d.c. at 0.6 A
Safety Interlock:	Pressure actuated switch enables input power at a depth great than 20 ft.
LASER Trigger Characteristics:	In the absence of a LASER trigger, the LASER is ON (providing input power is available and safety interlock enabled). Application of a trigger signal will turn the LASER off for 2 to 3 seconds, during which a camera trigger signal is generated.
LASER Trigger Requirement:	Isolated switch closure**
Camera Output Trigger:	Solid-State, Power-FET Switch closure with automatic transfer to LASER trigger, in the event of power failure.

D. Optical Characteristics

Beam Color:	Orange (633 nm)
Approximate Beam Diameter:	0.05 inch at window 0.10 inch at 5 feet 0.15 inch at 10 feet 0.20 inch at 15 feet
Brightness:	Visible in daylight or in presence of flood lamps.
Effective Range:	Up to 20 feet, depending on water clarity and observation system sensitivity.
Approximate Beam Alignment:	.02" and 2 mR with respect to housing.

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*Modifications for operation to a greater depth could be provided by increasing the housing wall thickness.

**Refer to Section E2 for details

E. Description

1. Mechanical

A mechanical assembly drawing of the basic Underwater LASER Unit is given in Figure 1. The LASER head is centered in the housing by the o-ring surrounding the lens holder (at the forward end) and by the o-ring and laser retaining ring (at the aft end). Axial loading is provided by a foam cushion and the printed circuit board. The two o-rings around the LASER head serve to approximately center it during assembly.

The output beam of the LASER passes through a lens holder and an anti-reflection-coated quartz window (or port).* The window is separated from the housing by a plastic back-up ring and sealing is provided by an o-ring in a conventional face-seal configuration. If a beam splitter is used, the window and port retainer are removed and replaced by a beam-splitter assembly.**

The removable end cap serves as a mounting base for the printed circuit board, the pressure switch, and the underwater electrical connectors. Sealing of the end cap is accomplished with a standard, single o-ring, piston seal and a threaded plastic retaining ring. A protective cage is

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*Beam-shaping lens options are discussed in Section V F1; the basic unit does not have a lens installed in the lens holder.

**A developmental beam splitter is discussed in Section V F2.

installed over the connectors to prevent damage during handling and especially during deployment and operation.

2. Electrical

A simplified block diagram of the LASER assembly is shown in Figure 2, and a detailed wiring diagram is provided as Figure 3 (drawing B-551-276). The FET POWER SWITCH is normally closed, so that INPUT POWER is applied to the LASER providing the PRESSURE SWITCH is actuated.* If a pair of LASER Assemblies are employed, the power input to the second LASER (slave unit) is connected in parallel with power input to the first LASER (master unit), so that both are gated off and on simultaneously.

For still-photographic applications it is often desired to briefly turn-off the LASERs so the photograph is not contaminated with the orange light spots. LASER turn-off-control is obtained by opening the POWER SWITCH for a duration of approximately two seconds after receipt of an input trigger signal. The triggering sequence is generated by a remote switch closure, between Pins 1 and 2 of J2,**

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*A provision for temporarily actuating the pressure switch is provided to facilitate initial optical alignment of the LASERs. This is accomplished by screwing a special plastic plunger into the pressure-switch port. It is important that this plunger be removed immediately following the alignment process; otherwise an important safety feature of the system will be negated!

**Note that one side of the remote trigger switch is connected to the 28V-Power Common Bus within the LASER Assembly; the remote switch must be isolated (neither switch terminal connected to any point in the power system).

which triggers the NON-RETRIGGERABLE ONE-SHOT.* The output of the ONE-SHOT is transmitted, via a pair of opto-transistor couplers, to the input of the POWER SWITCH and to the TRIGGER GENERATOR circuit. An input pulse to the POWER SWITCH results in the LASER power being interrupted for approximately two (2) seconds.

The TRIGGER GENERATOR circuit employs a moderate size FET switch, which provides the electrical equivalent of an isolated switch closure function at Pins 3 and 4 of J2, for triggering a camera/strobe system.

In general, the camera/strobe system obtains its power from a 28V source, which may or may not be the same power system as used to power the LASERs. With normal operation of the LASERs, the opto-electronic coupler ensures that the trigger lines are not connected into the power system. In case of loss of 28V power, at J1, a two-pole relay K1 transfers trigger control directly from the isolated switch closure to the camera/strobe systems (in this case the LASER(s) obviously remain off).

A few technical details about the connection of the LASER system(s) require emphasis:

(1) The polarity of input power is important; Pin B positive and Pin A negative at J1. Reverse power will

*Contact bounce, or inadvertent retriggering is ignored for a period of one second).

not cause damage due to the polarity protection diode, D1, but the system will not operate.

(2) The external trigger should be provided by an isolated switch closure (mechanical or electronic).

(3) The polarity of the camera/strobe trigger lines is important; Pin 4 of J2 must be positive with respect to Pin 3 of J2.

NOTE: Due to the high voltage of the LASER tube, and the adverse affect of condensation on the optics, humidity control must be maintained. One fresh Size-2 HUMI-CAP is recommended. Weekly operation of the system can prolong the operating life of the LASERs.

V. SYSTEM APPLICATIONS

A. Optical Sensor Aiming

A single LASER assembly is used as an aid to aiming a camera (or other sensor). In general, the axis of the LASER will not be the same as the axis of the sensor; in this case, the light spot is either allowed to be offset from the center of the sensor's field-of-view, or adjusted to cross the sensor axis at a pre-selected range.

B. Accurate Aiming and Ranging

As initially conceived, the underwater LASER system was configured to use two LASER assemblies to provide both direction and range information for photographing small, near-bottom dwelling organisms with a submersible. To obtain photographs in which the subject fills a large portion of the format, the camera is equipped with a 80 mm focal-length telephoto lens, which provides an angle-of-view of approximately ±9°. The corresponding depth-of-field is limited as shown in Figure 4. For example, with the camera range set for 6 feet (1.8 meters) and a lens opening of f-11, the in-focus distance is only 5.5 to 6.8 ft (1.68 to 2.07 meters). Because of the camera's narrow angle-of-view and limited depth-of-field, accurate aiming and ranging are <u>both</u> very important.

The camera/strobe/LASER arrangement shown in Figure 5 has proved to be effective. The LASERS are adjusted so that their beams cross at the midpoint of the camera's depth-of-field. The photographic system is aimed and the range to the subject adjusted (the camera is pre-focused for the optimum range) by maneuvering the entire system including the vehicle. When the two spots are coincident, and near the subject, the camera system is triggered. A reasonable amount of experience and some trial and error experimentation has been required to use the LASER aiming and ranging system. From the limited information provided by the pair of light spots, the operator is often unsure whether the range-to-subject is too great or too small. A solution to this problem is to make the two beams uniquely different (color, shape, size, etc.).

An alternate configuration, shown in Figure 6, is proposed to provide additional range information. With one orange LASER beam and the other beam a different color (i.e., green), the operator can easily determine whether the object is too close or too far.* For the arrangement shown in Figure 6, the object is too close when the red spot appears to the left of the green spot.

The highly collimated nature of LASER beams allows for simple shaping of the beam. A larger diameter beam can be obtained by using a beam-expander lens. Similarly, a fan shaped beam can be generated by a simple and inexpensive cylindrical lens, or a sequence of spots can be generated by a simple linear grating.** Holographic screens could be used to obtain more complex patterns.

One application for a fan-shaped beam is shown in Figure 7. The camera aided by the LASER assembly mounted directly above it, is aimed at the subject. The horizontal, fan-shaped beam, from the LASER assembly mounted on the strobe unit, is used to provide range information. In Figure 7, the distance-to-subject is known to be too great when the line of light is below the spot.

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*A variety of different color LASERs (there are several possible transition states in a Helium-Neon gas mixture) are becoming commercially available. A green one has been purchased and is being evaluated. A yellow HeNe LASER has recently been demonstrated and may well have operational advantages.

**Refer also to Section V F1 for additional information on the generation of special shaped beams.

C. Size Measuring Systems

Photographic surveys of benthic populations often require data on the absolute size of the marine animals. The underwater LASERs provide a simple and convenient means of non-contact sizing. A sketch of a basic "LASER Sizer" system, used with a video camera, is given in Figure 8. The two LASERs are mounted so that they project a pair of parallel and precisely spaced beams into the camera's field-of-view. A direct comparison between the subject size and the spacing of the two LASER spots provides an accurate measurement independent of camera lens setting, range, or distortion through the operator's viewport. For this application it is required that the LASERs be left on during the photographic recording, the internal trigger circuits are unused. Figure 9 is a photograph of a pair of LASERs mounted on a bracket designed for use with a high-resolution color video camera.

A slightly different configuration is used for a photographic survey of the ocean bottom where the area-of-coverage must be determined. One arrangement is shown in Figure 10. The two LASERs are spaced X cm above and below the camera axis. If the angle between the camera and the ocean bottom, θ, is known, the distance between the two light spots on the bottom, is 2X sin θ, independent of camera lens details, distance above the bottom, and a number of other parameters. Using the two dots, a square can be constructed, on the photograph, which represents an approximate trapezoidal region of the bottom, having an area of $\frac{4X^2}{\sin\theta}$.

The dual-beam LASER systems, described above, can be effected with a single LASER and a beam-splitter. A prototype beam-splitter which attaches to the end of the standard LASER housing will be described in Section VF2.

D. Size and Range Measurement System

A combination of the previous configurations can be used to aim a camera system, obtain size information, and verify range. This system uses three light beams, one of which must be easily distinguishable from the other two (color, shape, etc.), and is shown schematically in Figure 11. LASER A and LASER B provide size information with the parallel light beams which are spaced a distance S. The third LASER (LASER C) is mounted at an angle θ such that its beam crosses beam A at the minimum in-focus range and it crosses beam B at the maximum in-focus range. Thus, whenever the spot from LASER C is between those from A and B, the subject will be in focus.

E. Vehicle Positioning System

More complex systems may also be proposed to simultaneously measure the range and observational attitude of an underwater camera with respect to photographic subject, e.g., the ocean floor (Figure 12). The system utilizes two fan-shaped laser projections which are produced using the methods of Section F1. The beams are adjusted to cross at a distance R_p from the subject which the camera is positioned at range R_F. In operation, a small video camera (not shown) is placed near the still-camera, and is used to establish a reference frame (Range $R_F = R_o$ and parallel to the film plane). The observed light projections image locations in the video image are marked by either electronic or mechanical means. Vehicle positioning during subsequent photographic survey is adjusted to produce the best overall "fit" of the observed light projections to the video markers. By such a process, it can be shown that camera tilt and range errors can be minimized.[6] This approach has been successfully demonstrated with a ROV/camera survey system; improvements to this system are currently being developed.

F. Accessories

1. Beam Shapers

The Aerotech LASERs are equipped with a mechanical shutter assembly when they are received from the factory. This assembly, when modified, serves as a convenient lens holder for simple beam shapers. For example, a long-focal length lens could be used to increase the spot size. As briefly discussed above, a fan-shaped beam can be made using a small cylindrical lens.* This lens transforms the nearly circular beam of the LASER into an eliptical beam with an aspect ratio of approximately 20:1. At a range of 6 feet (2 meters), the "spot" will appear as a "line" approximately 3 inches (7 cm) long.

A somewhat similar beam shape can be obtained using an optical transmission grating in place of the lens. The resulting light pattern is a linear array of light beams which are divergent from the illuminated point on the grating. Thus, the separation of the beams increases linearly with range. The grating spatial frequency (lines/mm is directly proportional to the angular separation: It is usually chosen such that tens to hundreds of linear cycles are present within the diameter of the illuminating beam. The process governing the angular spread is called diffraction. The relative intensity and number of the diffracted orders are related to the type of waveform recorded on the grating (square-wave, rectangular wave, sine wave, etc.). By proper choice of the grating waveform, it is possible to tailor the projected beam pattern to a specific application.

Typically, most linear transmission gratings utilize a square-wave format, having equally wide opaque and

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*MELLES GRIOT, Rectangular negative cylindrical lens, focal length = 19 mm, size: 16 x 25 mm, Part No. 01 LCN 002.

transparent regions.* Therefore, half the light energy is lost in passing through a grating, while little is lost in propagation through a cylindrical lens.

2. Beam Splitter

A variety of techniques are available for generating two or more beams from a single LASER. The simple beam splitter shown in Figure 13 uses a small commercially available cube to split the incident LASER beam into two approximately equal beams.** The direct beam passes through the cube and exits through the axial window, with approximately half the incident power. The other half of the light beam exits the cube at 90° and passes through the side window.

To form a pair of spaced parallel beams, a 45° mirror would be provided in addition to the laser/beam splitter assembly. The mirror could be mounted in a different position to obtain a crossed-beam configuration. The beam splitter has yet to be used in a practical application. The precision with which the alignment must be maintained requires extremely precise mechanical design and assembly.

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*A convenient Linear Transmission grating is a PHYSITEC, Model 04-0173 which has 10 lines per mm and is mounted in a 25 mm diameter tube, 10 mm long.

**PHYSITEC Part Number 33-5510.

It may be that a suitable beam splitter is not cost effective. However, if beam-splitting techniques prove to be useful, more complex beam splitters or light-beam generating arrays could be developed. Moreover, if low-cost sources evolve in the near future, multiple beam projectors could be an economical alternative.

VI. FUTURE DEVELOPMENTS

The size and cost of helium-neon LASER tubes has been decreasing along with their power requirements. These advances make it feasible to build underwater laser units which are approximately a tenth the size of the present assemblies.(7) Reducing their size will increase the number of possible applications - especially with ROVs, where size and weight are critical.

Custom gratings, which provide higher intensity spots in the fan-shaped beam, are being investigated. Improvements in a number of the systems described above are being proposed or implemented.

VII. LIST OF FIGURES

VIII. REFERENCES

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2. Tusting, Robert F. Non-Conventional Techniques for Sampling and Collecting Marine Organisms, Proceedings of PACON 86, pp. MRM 1/12-18, March 24-28, 1986.

3. Smith, Raymond C. and Karen S. Baker. Optical properties of the clearest natural waters, Applied Optics, Vol. 20, No. 2, p. 177-184, 1981.

4. Mertens, Lawrence E. IN-WATER PHOTOGRAPHY. Theory and Practice, Section 2.4, Wiley Interscience, 1970.

5. RCA Electro-Optics Handbook, Technical Series EOH-11, Figure 5-8.

6. Caimi, F.M. and R.F. Tusting. Applications of Lasers to Ocean Research and Image Recording Systems, LASERs '86, Orlando, FL, Society for Optical and Quantum Electronics (In press).

7. Tusting, Robert F. A Miniature Underwater Laser System - Feasibility and Preliminary Design Study, HBF Technical Note No. 18, May 1986.

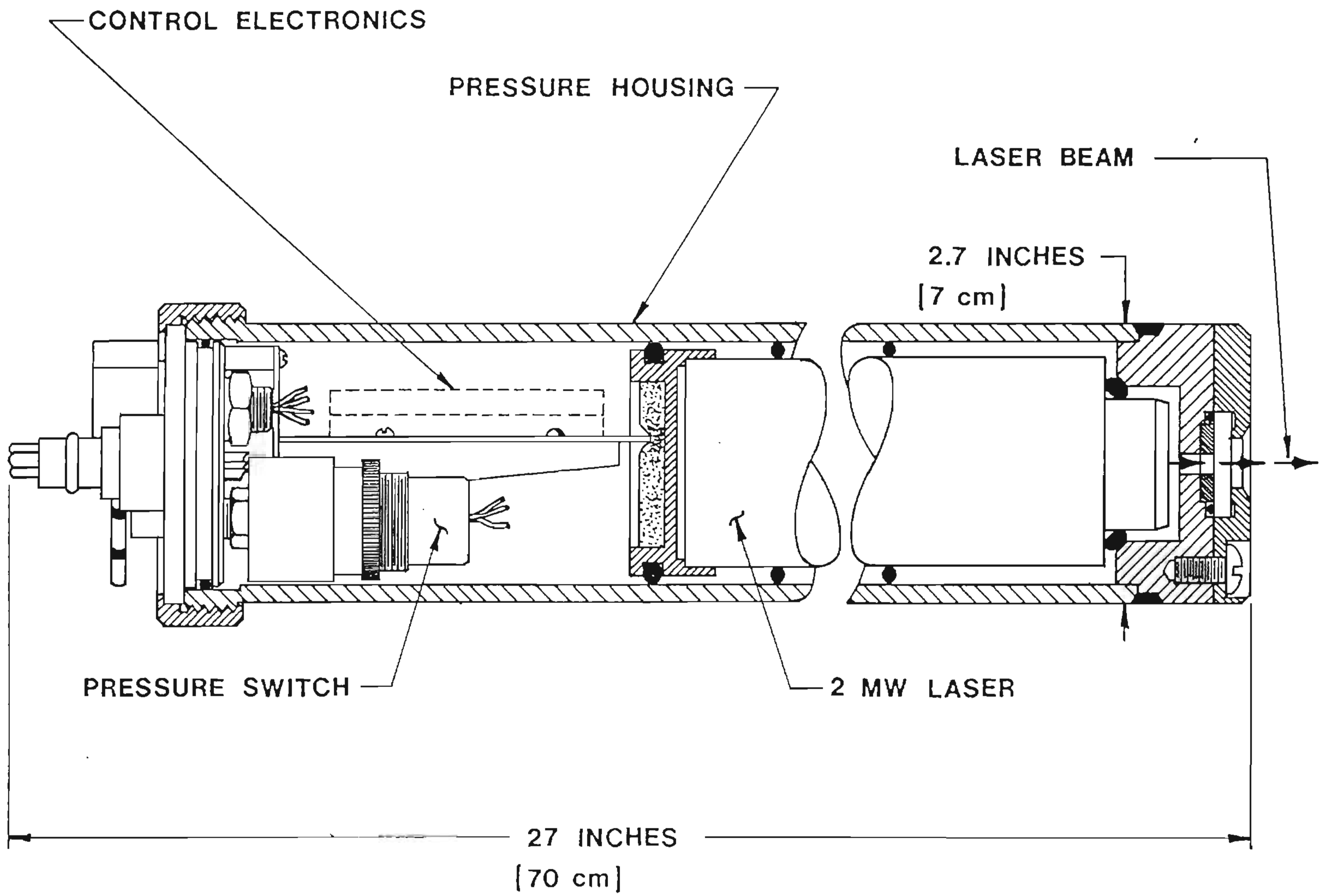


Figure 1. Mechanical Assembly, Underwater LASER Unit.

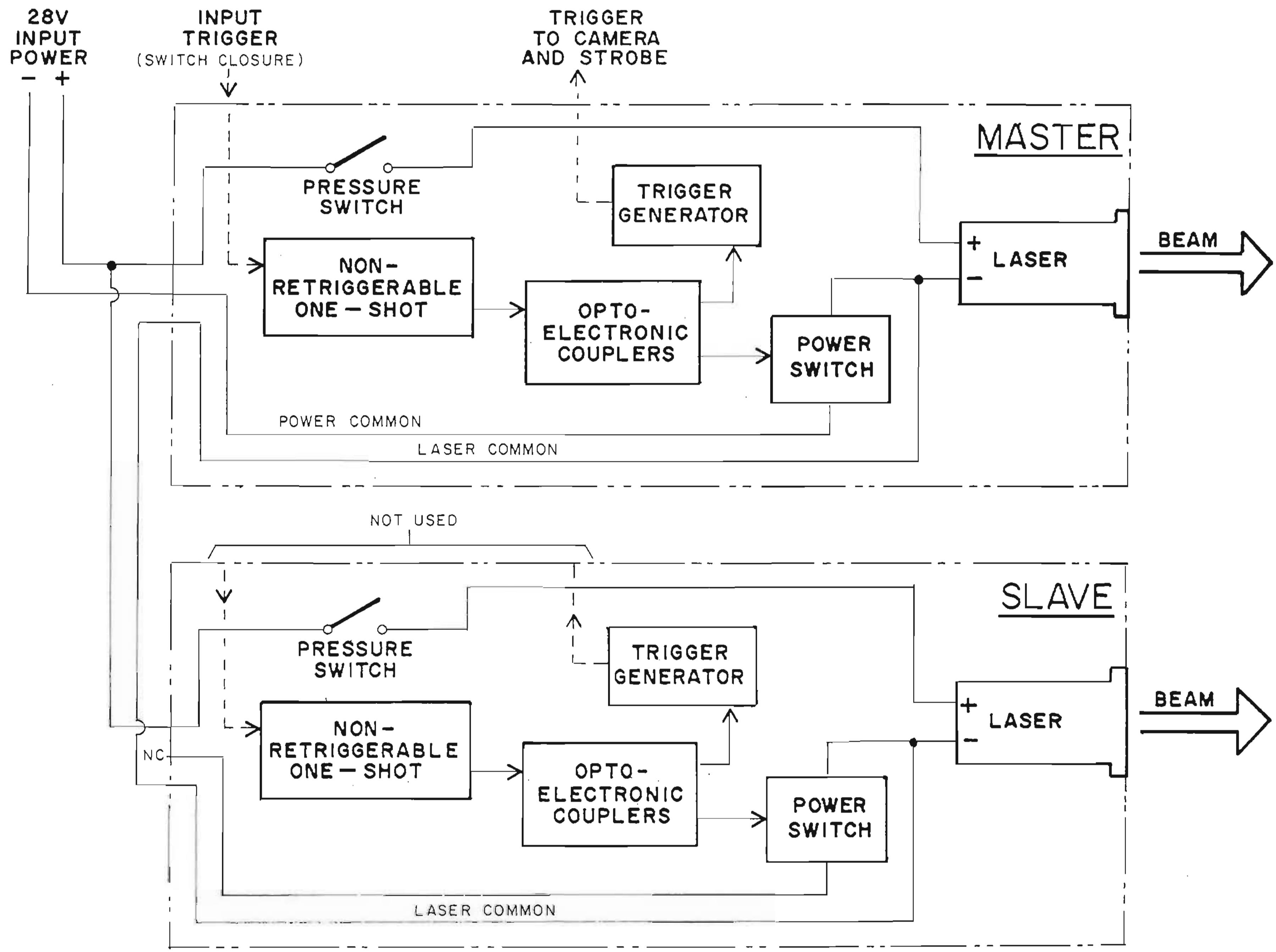


Figure 2. Triggered LASER System, Functional Block Diagram.

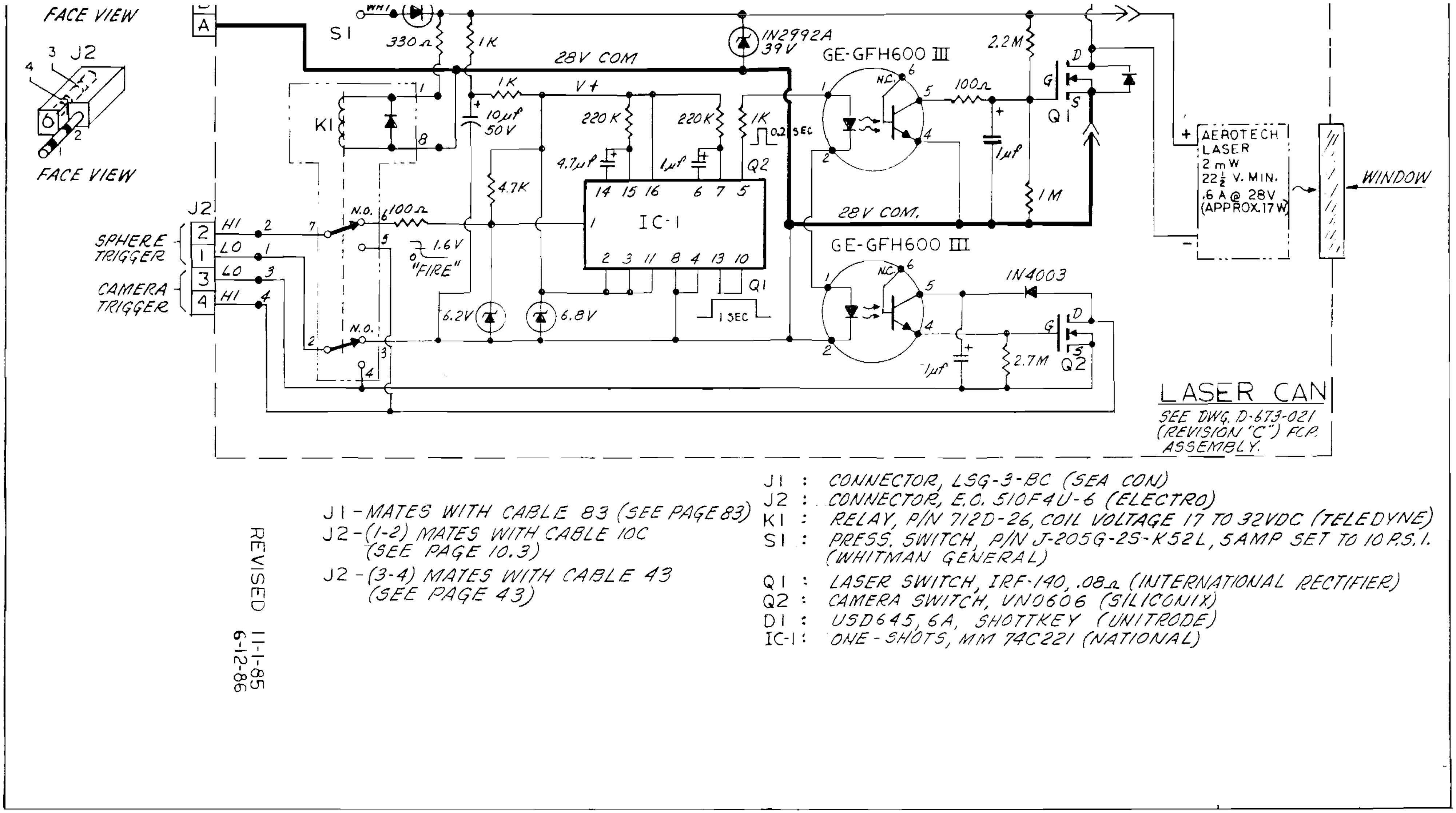


Figure 3. Triggered LASER Unit, Electrical Diagram.

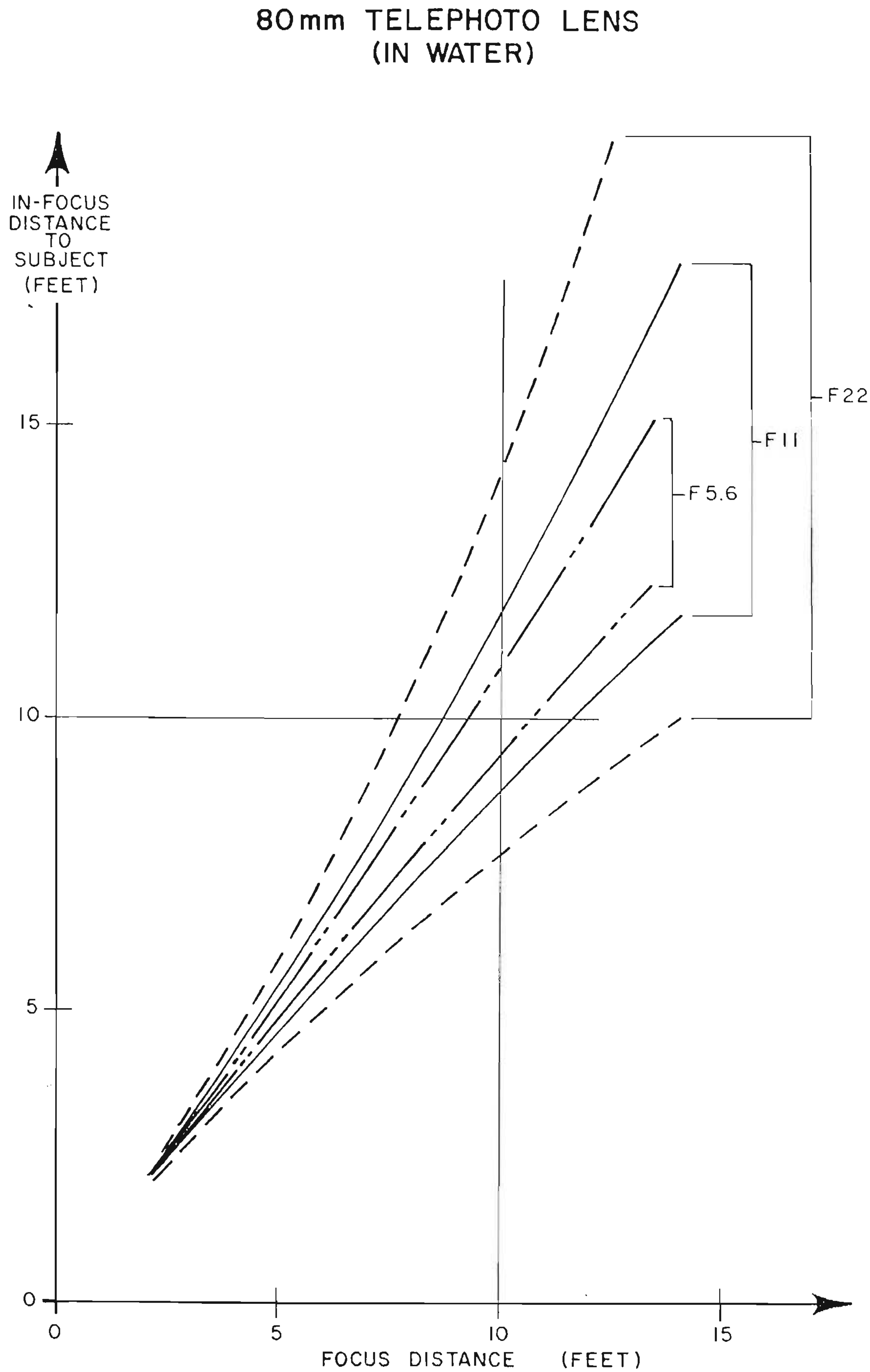


Figure 4. Depth-of-Field for a 35 mm Format Camera with an 80 mm focal-length lens.

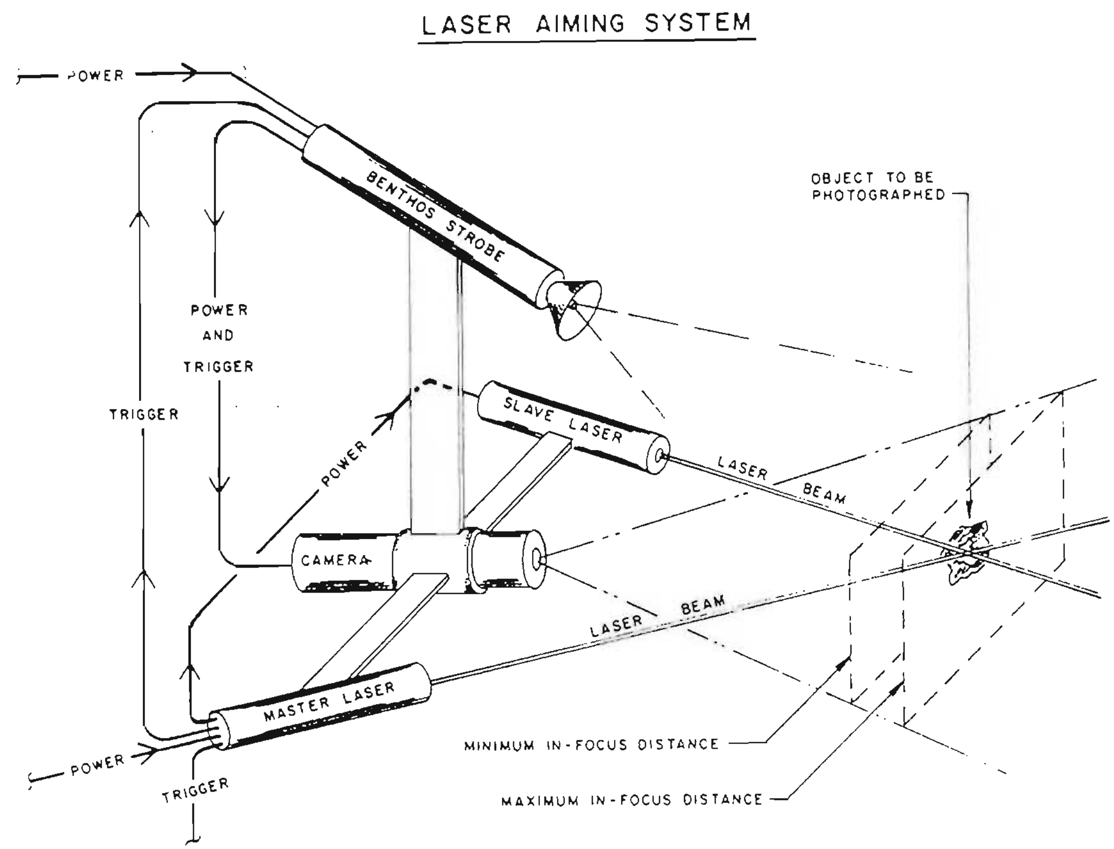


Figure 5. Camera and Strobe with Harbor Branch Oceanographic Institution LASER AIMING SYSTEM.

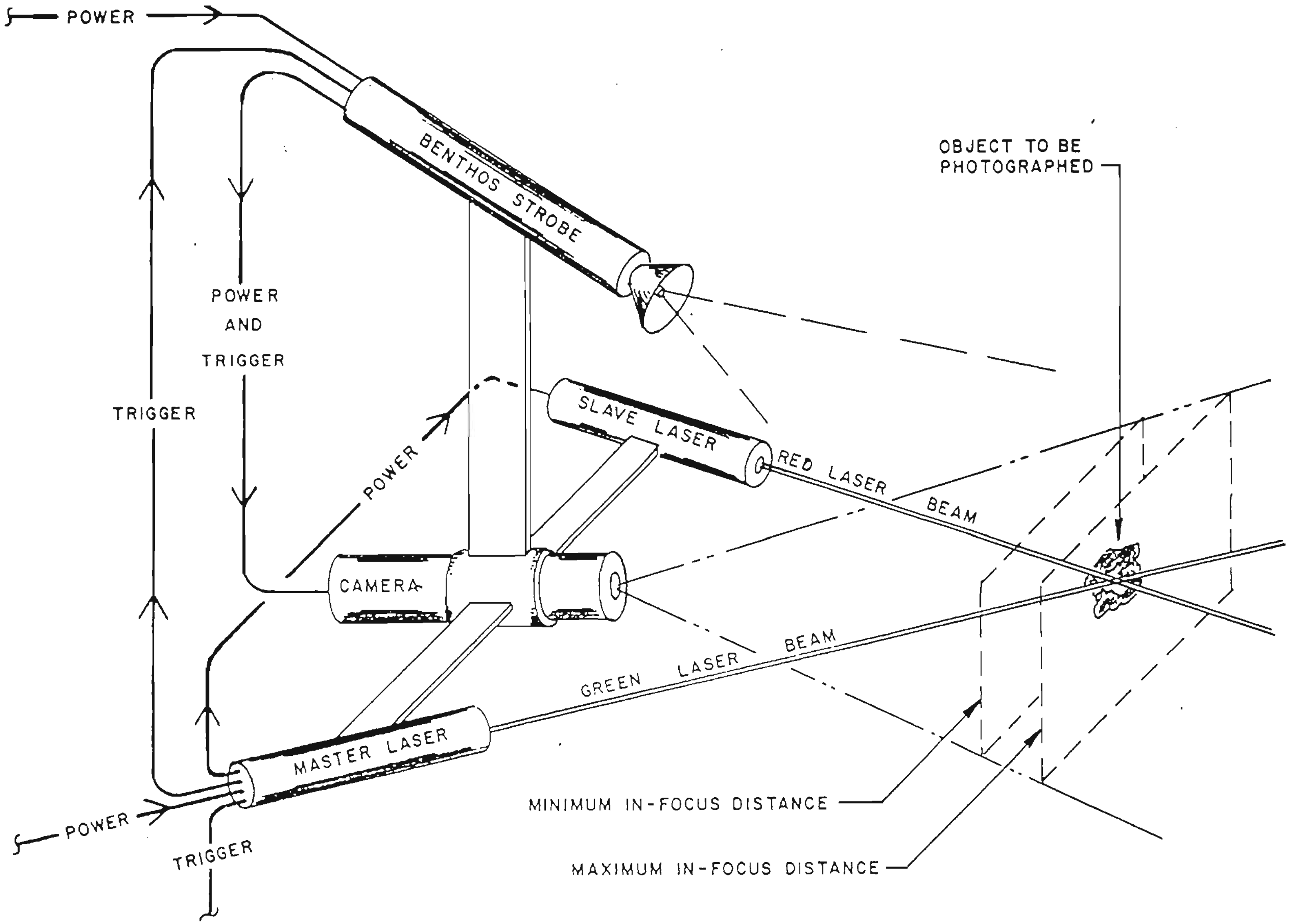


Figure 6. Red and Green LASER Beam Configuration.

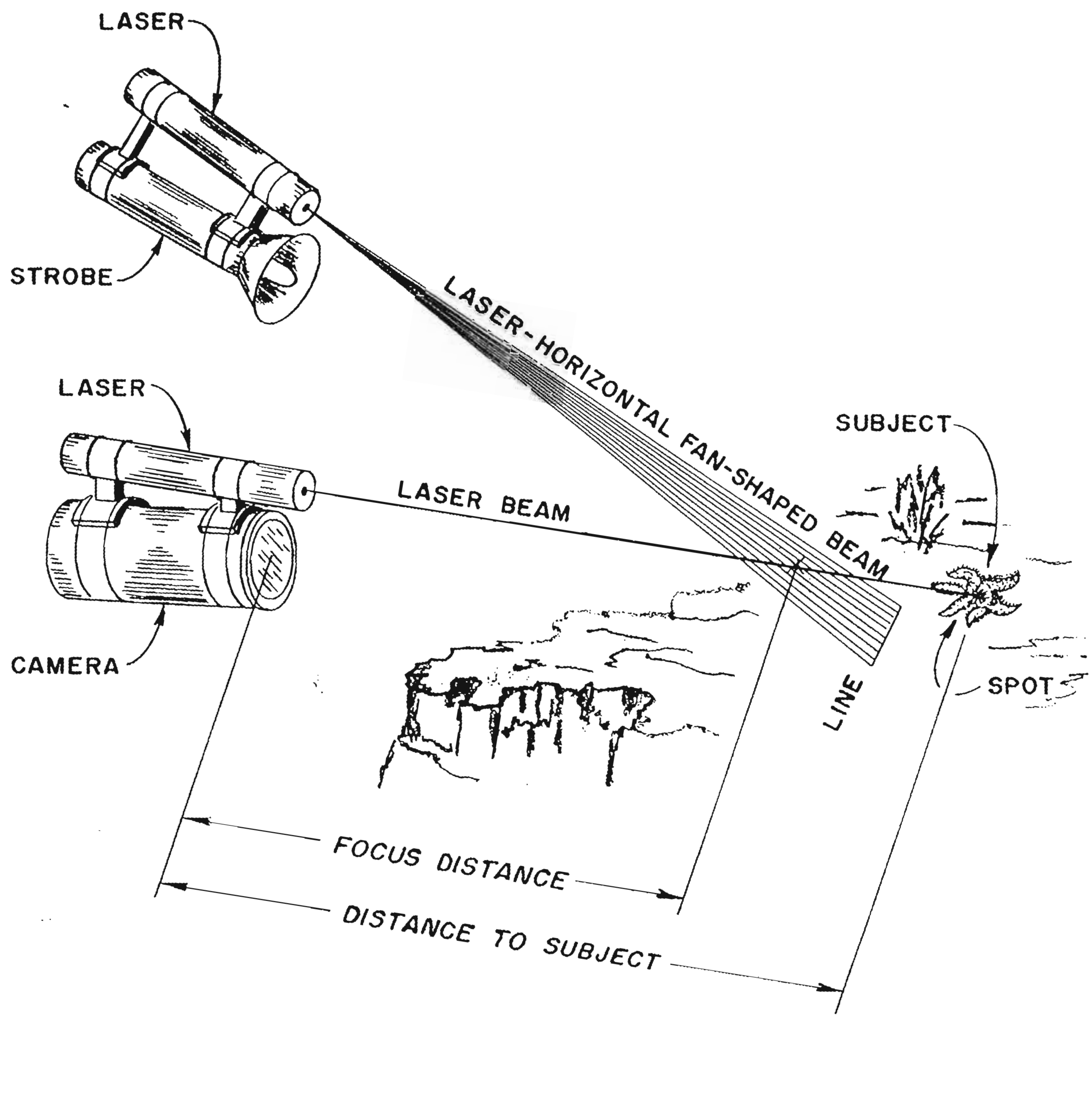


Figure 7. Use of a fan-shaped beam to provide additional range information.

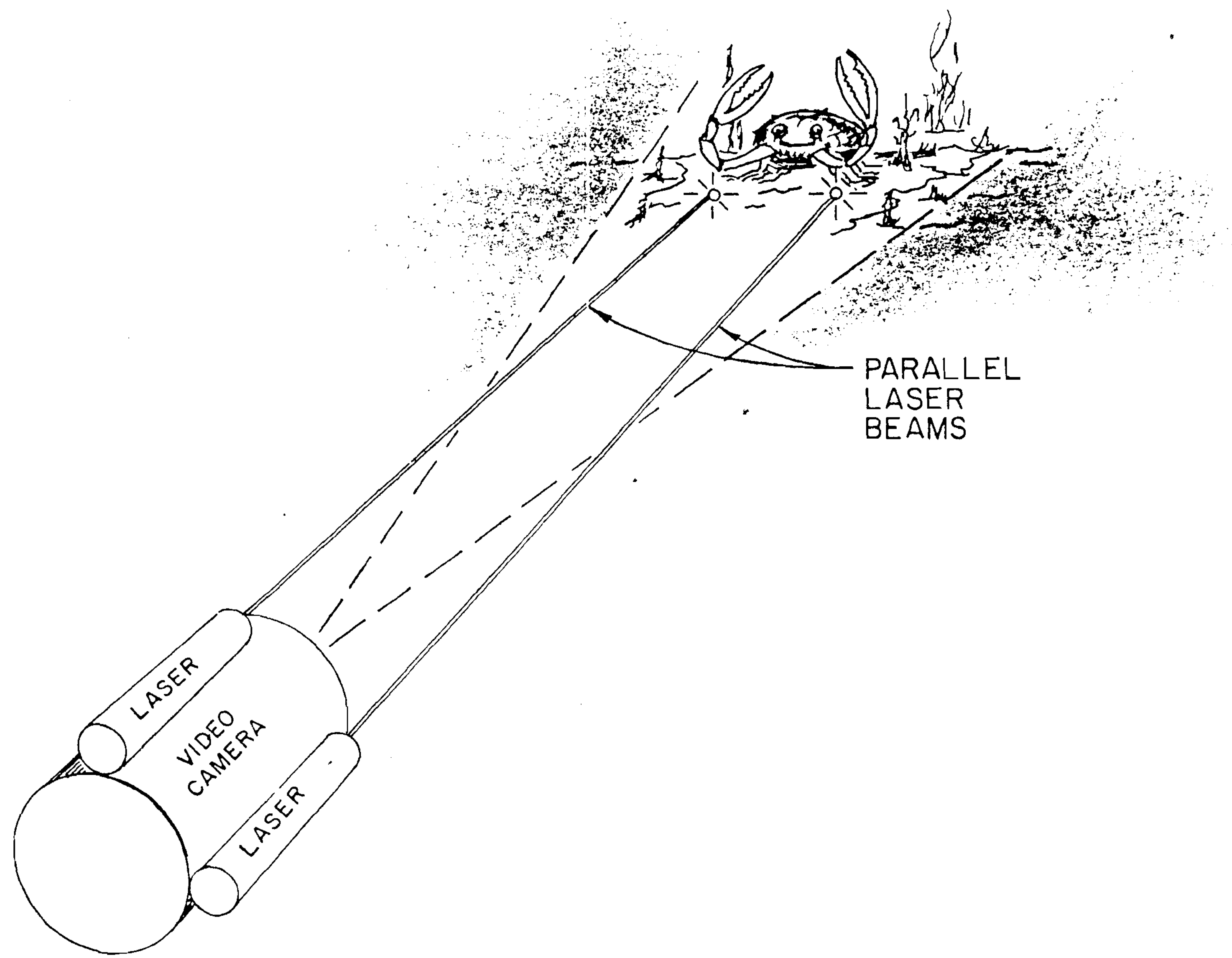


Figure 8. A System for Size Estimation of Benthic Animals (Artist's Conception).

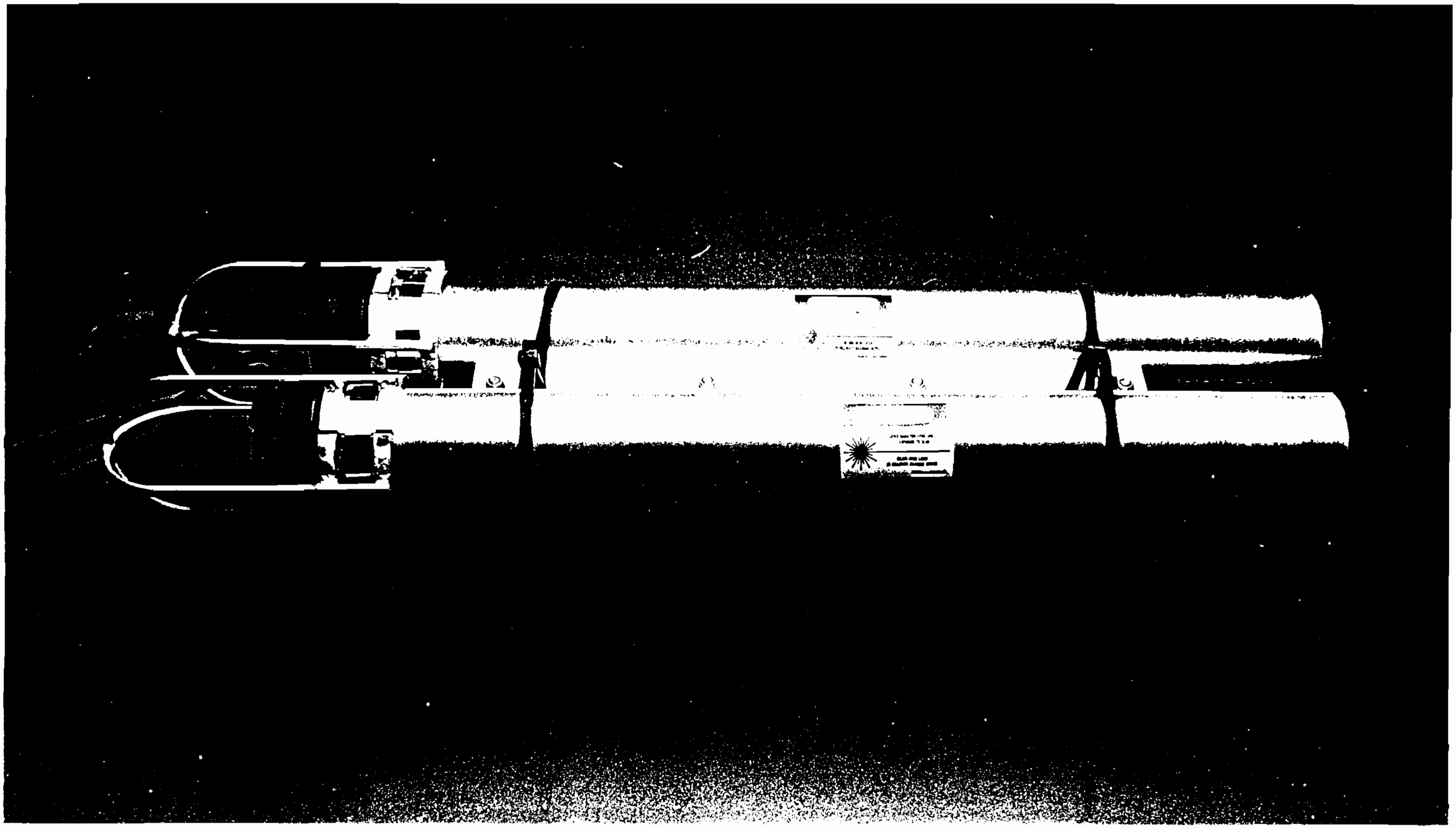


Figure 9. Photograph of a pair of LASER Units Mounted for Use with a High-Resolution, Color Video Camera.

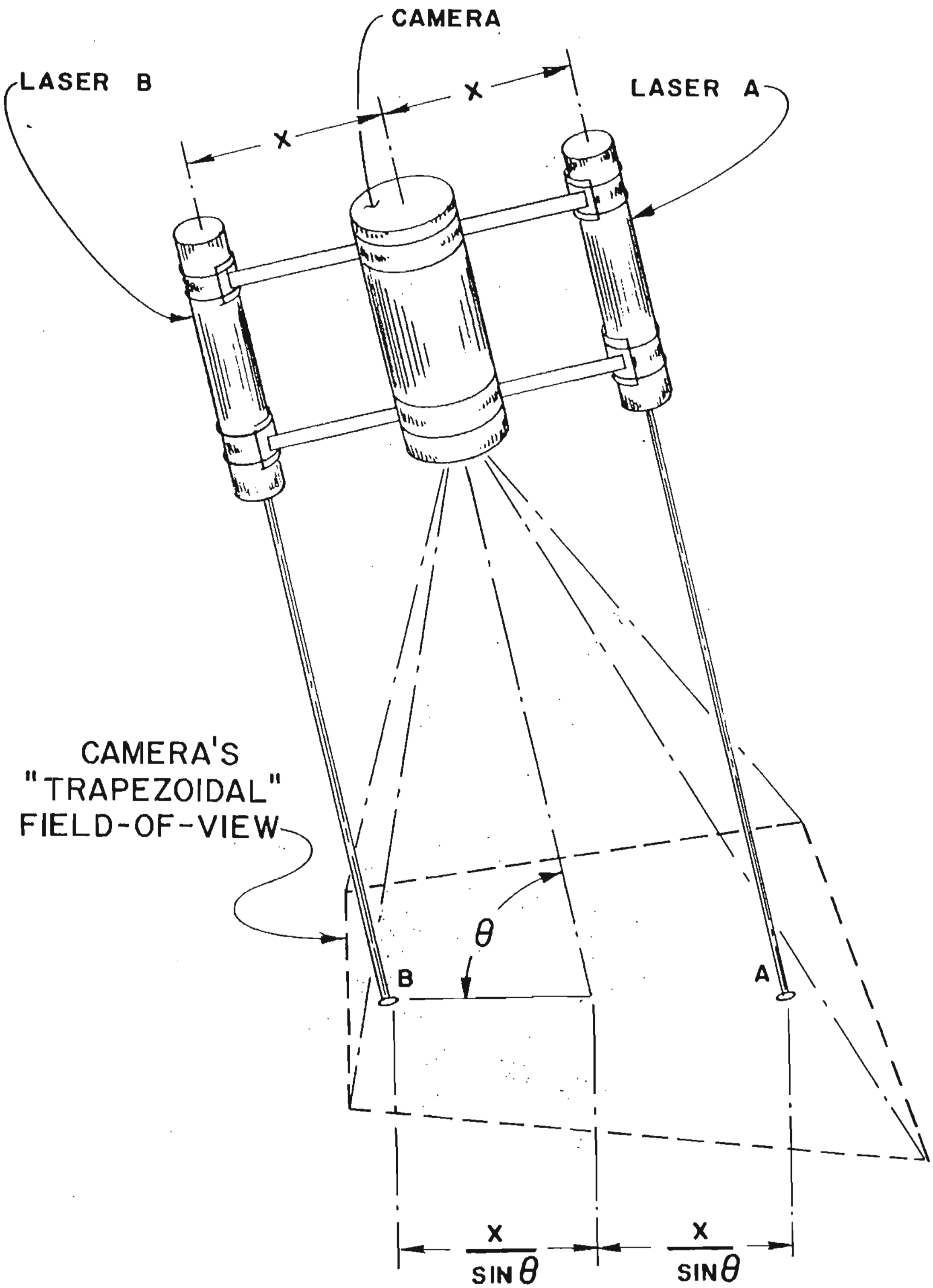
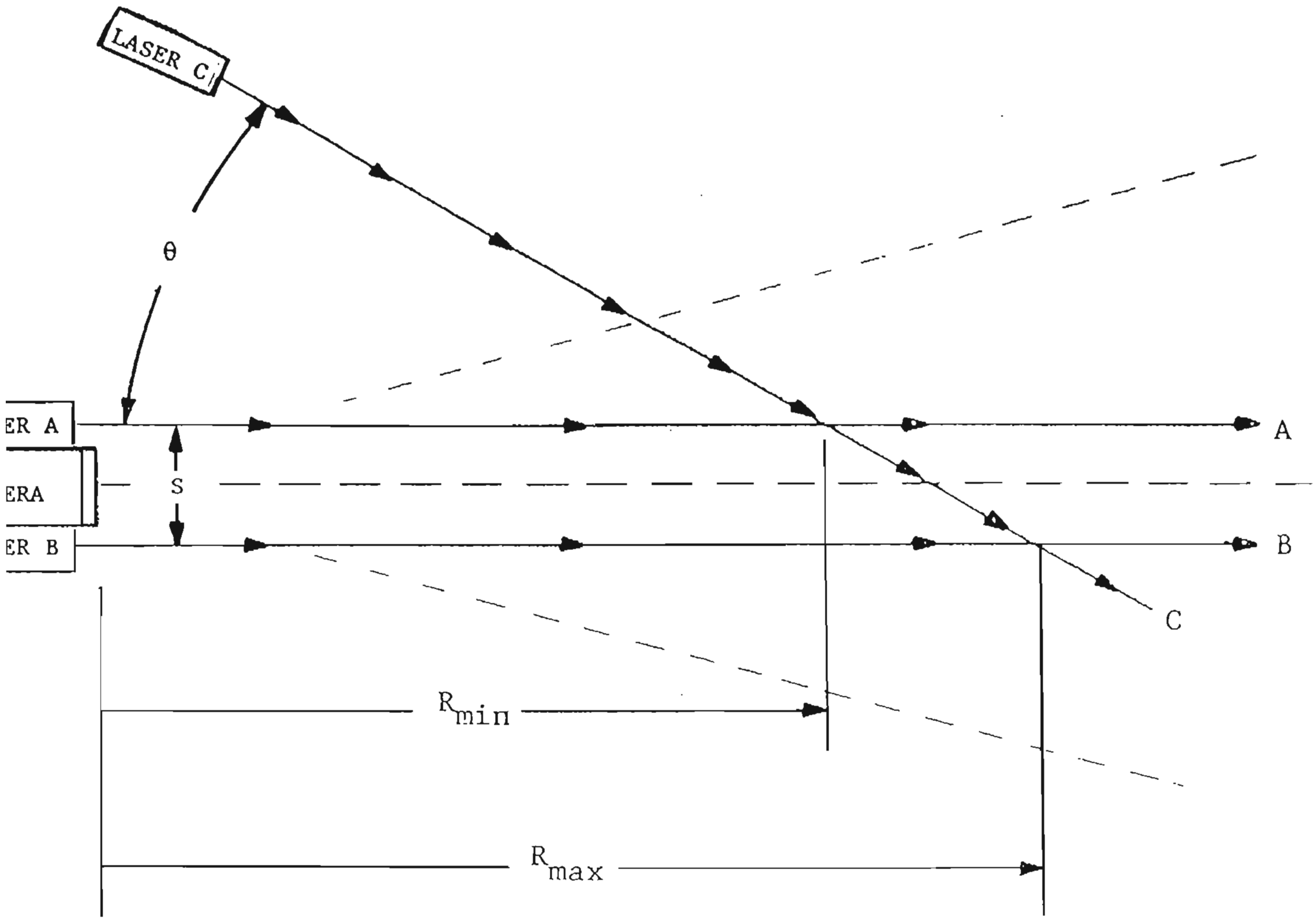


Figure 10. LASERs Configured to Provide Photographic Area-of-Coverage Information.



R_{min} = Minumum in-focus range

R_{max} = Maximum in-focus range

s = separation of parallel beams

θ = angle between parallel beams and third, unique beam

Figure 11. Combination Range and Size Measurement System.

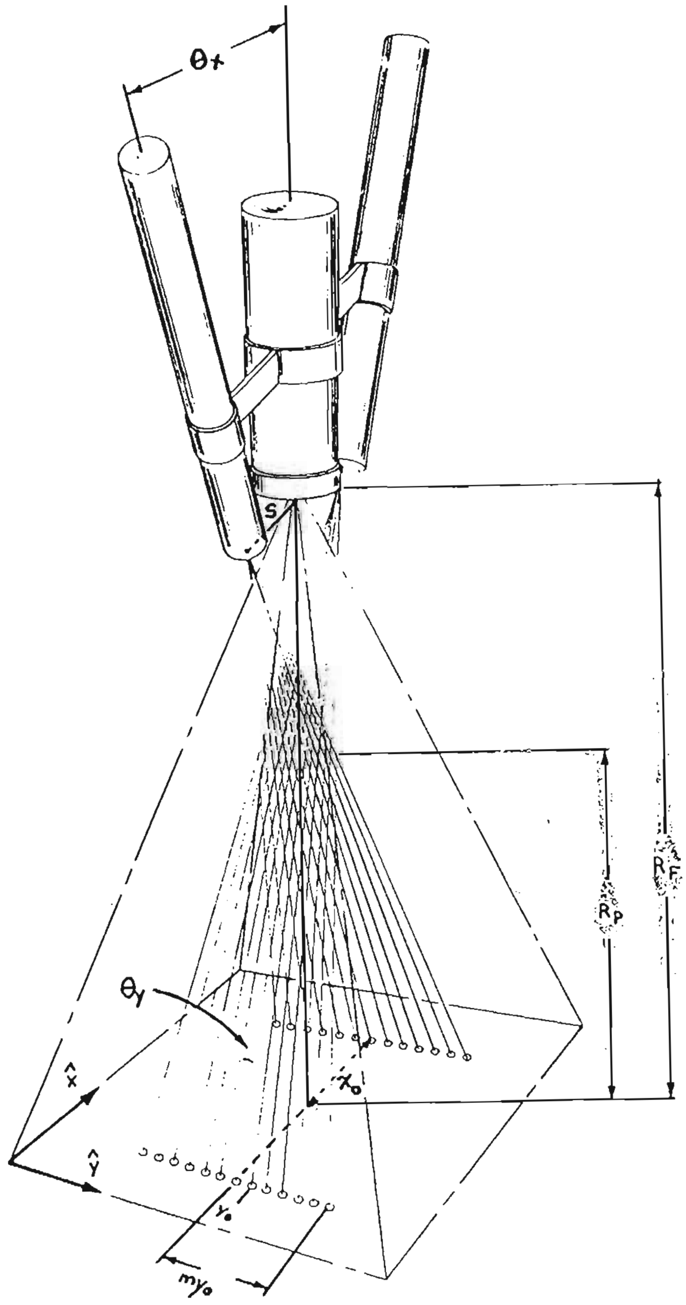


Figure 12. System for Measuring Range and Orientation of a Camera with Respect to a Surface.

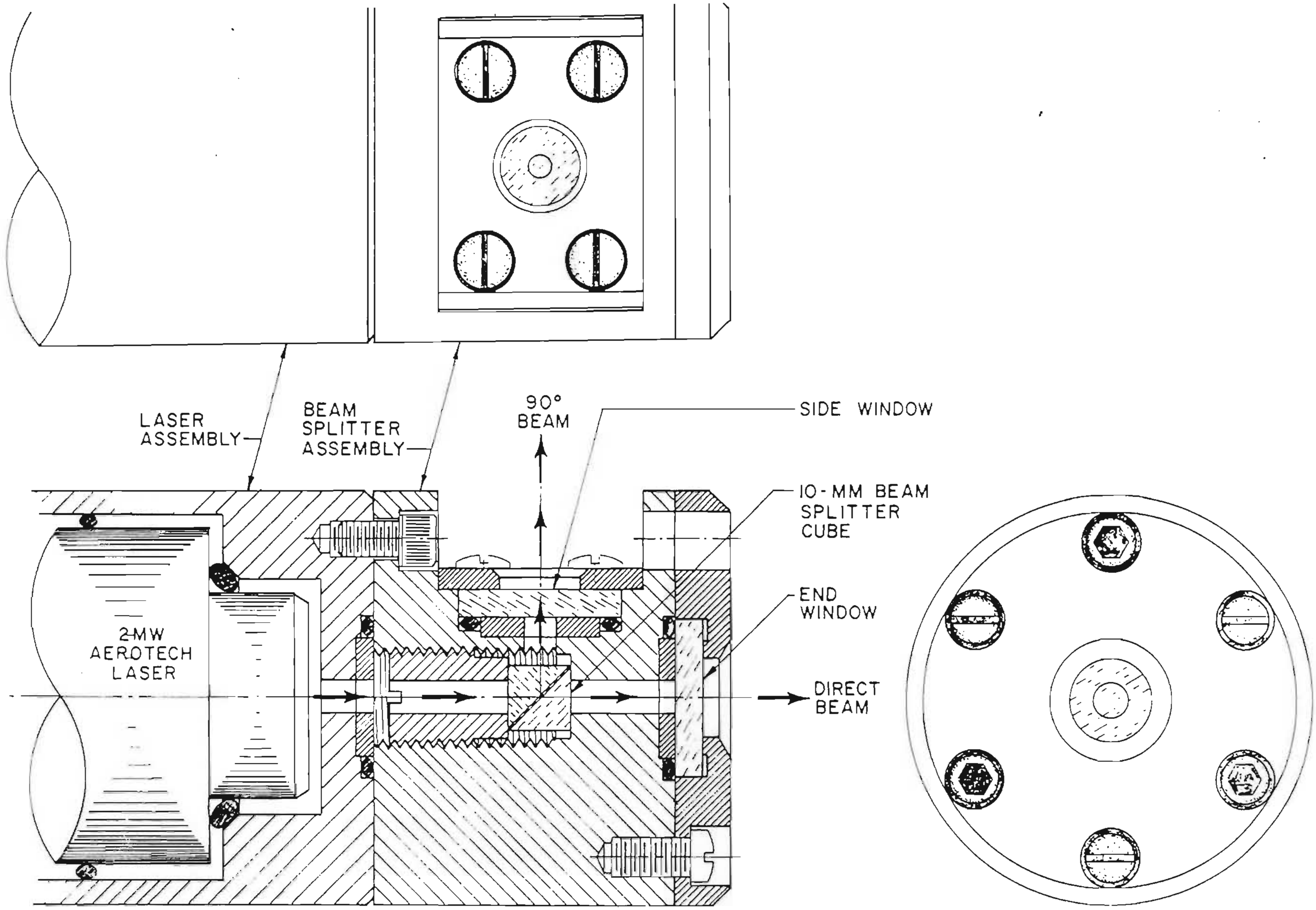


Figure 13. A Prototype LASER Beam-Splitter.