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OPTICAL DEVICES FOR PROXIMITY OPERATIONS STUDY AND TEST REPORT

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OPTICAL DEVICES FOR PROXIMITY OPERATIONS STUDY AND TEST REPORT

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1. SUMMARY

Future Earth orbit operations with manned space vehicles will be involved in specific activities which may require the use of a low-light-level viewing device, such as a Proximity Optical Device (POD), to insure continuity of activity under starlight and searchlight aided illumination conditions. An evaluation was made of the many operational and physical parameters involved in meeting the requirements for a useful spacecraft viewing device. A suitable prototype test unit was procured from a commercial vendor. This report describes the concept for use of the device, its constructional features, and a series of limited tests which were conducted to determine the potential effectiveness of the POD in spacecraft operations. As a result of this project, a POD type unit will be capable of performing specialized low-light-level viewing services and will enhance manned spacecraft operations.

2. INTRODUCTION

In the future, manned space vehicles in an Earth orbit will probably be used for the delivery, orbital storage, and assembly of large pieces of space hardware. While manually controlled manipulators will play a significant role in the berthing and assembly operations, it must be anticipated that the manned vehicles will also be a part of the space operation scenario. Scientific payloads might be free-flying in the vicinity of space stations where the control operations will be located. Small manned "tugs" for moving and assembling large elements along with other types of manned vehicles will be used for inspection and maintenance operations. These types of proximity activities will require instrumentation for pointing, object locating, line-of-sight navigating, stationkeeping, and docking. To insure continuity of activity under various illumination conditions, the use of a low-light-level viewing device, such as a Proximity Optical Device (POD), will be required.

This study has been undertaken to evaluate the many physical and operational parameters involved in meeting the requirements for a useful spacecraft viewing device. During the study's course, the following items were considered.

- Some conventional radar sensors are limited to minimum ranges of 100 feet and range rate accuracies of 1 foot per second. At least an order-of-magntiude improvement will be needed to achieve the required precision for space construction and assembly operations.
- The application of laser technology to rendezvous radar and automatic docking will result in a complex system which consumes relatively large amounts of power. Such a device which can fully demonstrate acceptable performance has yet to be designed and built.
- Even though a system might operate in an automatic mode, the experience from manned space flight operation activities shows that the flight crew has a distinct preference for manual control or at least a simple method of monitoring automatic system performance.

A preliminary analysis indicated that a window-mounted optical sight designed around conventional state-of-the-art optical technologies should provide pointing and range/rate information sufficiently accurate for the majority of proximity operations and can potentially be designed to satisfy all accuracy requirements for stationkeeping and docking. Such a window-mounted optical device would be extremely simple, inexpensive, and adaptable for all types of manual vehicles and operational situations.

2.1 TECHNICAL OBJECTIVE

A project has been established to develop, design, evaluate, and finally demonstrate the performance of a typical window-mounted optical sight for crew use in the pointing, navigating, stationkeeping, and docking of space vehicles. Its objective use is to support space station operations and the assembly of large structures in space. As a goal, the device should be functional at ranges from a few feet to possibly 20 nautical miles. At minimum ranges, an order-of-magnitude improvement over conventional radars in range/rate measurements is a major design goal. The device is to be simple, reliable, and extremely adaptable to a large variety of manned operational tasks associated with construction activities in space.

2.2 TECHNICAL APPROACH

The optical sight is designed around conventional and readily available optical technologies. It is developed for target acquisitions in sunlight, starlight, and proposed spotlight conditions. Image intensification techniques are investigated and evaluated for enhancing operation in nighttime or deep shadow situations. Range/rate measurement capabilities will probably be added and will include evaluation of laser as well as conventional stadimetric ranging. A hardware unit will be specified as a flight experiment for use in future Space Shuttle operations.

3. DESCRIPTION OF VISUAL PERCEPTION AND OPTICAL VIEWING DEVICES

3.1 HUMAN VISUAL PERCEPTION

The act of seeing and interpreting space-oriented target images is essentially the same as viewing during ordinary Earth-based operations. The primary differences lie in the light levels encountered and the background conditions seen. Target objects of viewing interest may have a wide dynamic range of brightness levels produced from the one extreme of sunlight levels to the other much lower condition produced by starlight only illumination. It is the latter condition which is of concern since the low-light-level performance of the eye is limited while bright sunlit objects can be normally seen with the aid of light attenuating devices if the target is too bright.

The formation and detection of images by the human eye depends upon the quantum emission nature of light. In human vision, the eye collects a definite level of photons per second which emit from an object in proportion to its radiance and area. An image is then detected by the reception of the photons by the eye retina. The number of photons received is absorbed by the retinal elements per integration time of the eye and varies with the image element brightness.

Under natural seeing conditions, the visual perception of details in low-light-levels depends on certain physical characteristics of the retinal image of the target image and its surrounding background as well as some physiological parameters of the eye. Physical characteristics of the eye image include the following.

a. Spectral irradiance of the retinal image by the detailed image

b. Spectral irradiance of the retinal image of the surrounding background

c. Area of the retinal image of the detailed image

Physiological parameters of the eye include:

a. Area of the entrance pupil

b. Spectral quantum efficiency

c. Area of an image sensor element

d. Integration time

e. Degree of dark adaption

In order to maintain and sustain visual perception, the naked eye automatically compensates for decreases in scene illumination by enlarging the area of the entrance pupil, enlarging the area of a sensor element, increasing the integration times, and increasing the sensitivity via dark adaptation time. With all of these operations working, it is obvious that due to statistical photon fluctuation and number, there will be a threshold of vision which results from the light level being so low that sufficient image information cannot be resolved.

3.2 BINOCULAR AIDED VISION

The introduction of a binocular optical viewing device between a low-light-level irradiated scene and the eye can sometimes extend the visibility threshold to details that would not otherwise be perceived by the eye alone. However, one must realize the increase in visual perception with optical magnification devices is solely due to the subjective magnification of the unit which produces an increase in retinal image area. It is not due to any increase in retinal image irradiance. Consequently, the value of binoculars depends on the spatial integration capability of the eye and is limited to scene details subtending small angles (2° to 3°) at the eye entrance pupil. The visual threshold may be extented but not without some penalty of field-of-view and loss of detail.

3.3 IMAGE INTENSIFIER VIEWING

If one uses an image intensifier system between a weakly irradiated scene and the eye, then in principle all of the physiological limitations on visual perception of detail are removed. The entrance pupil can be made larger in order to collect sufficient scene radiant flux, and if the intensifier photocathode diameter is increased in proportion at the same time, the desired field-of-view can be maintained. The image of the intensifier can be projected onto the retina at the optimum size by adjusting an eyepiece magnification parameter. By properly choosing the intensifier gain, the luminance of the output image can be optimized for maximum visual perception, and it is not necessary to wait for dark adaption to perceive detail in a low-light-level scene. Finally, seeing is enhanced by choosing photocathodes with a high quantum efficiency and a wider range of spectral response than the eye can provide.

No degree of technology can enable a person to see in total darkness. However, with the assistance of image intensifiers, the visual threshold can be extended far below human limits to a point near total darkness. In general, an image intensifier may be thought of as any device that produces an observable output image that is brighter than the input image. Image intensifiers are more adequately defined as electronic vacuum tubes equipped with a light sensitive electron emitter (photocathode) at one end and a phosphor viewing screen at the other. An electron lens or external magnetic field is used to focus and relay the image from one end to the other.

A logical breakdown of image intensifier devices is based on whether points within the image are operated upon simultaneously or sequentially. Television systems exemplify a sequentially scanned technique and for the purposes of this paper are not discussed.

Simple viewing devices use an intensifier that operates on all image points at the same time. The variety is not great, and they may generally be categorized on the basis of image inverting or noninverting, light or electron multiplying systems, focusing techniques, number of cascade stages, image format, and first generation or second generation.

3.3.1 BASIC OPERATION

A simplified version of a night vision telescope can be used to describe the main elements of an image intensifier (see fig. 3-1). An objective lens forms an optical image on the front surface of an image intensifier tube. This surface, usually a fiber optic face place, transmits the image photons to a

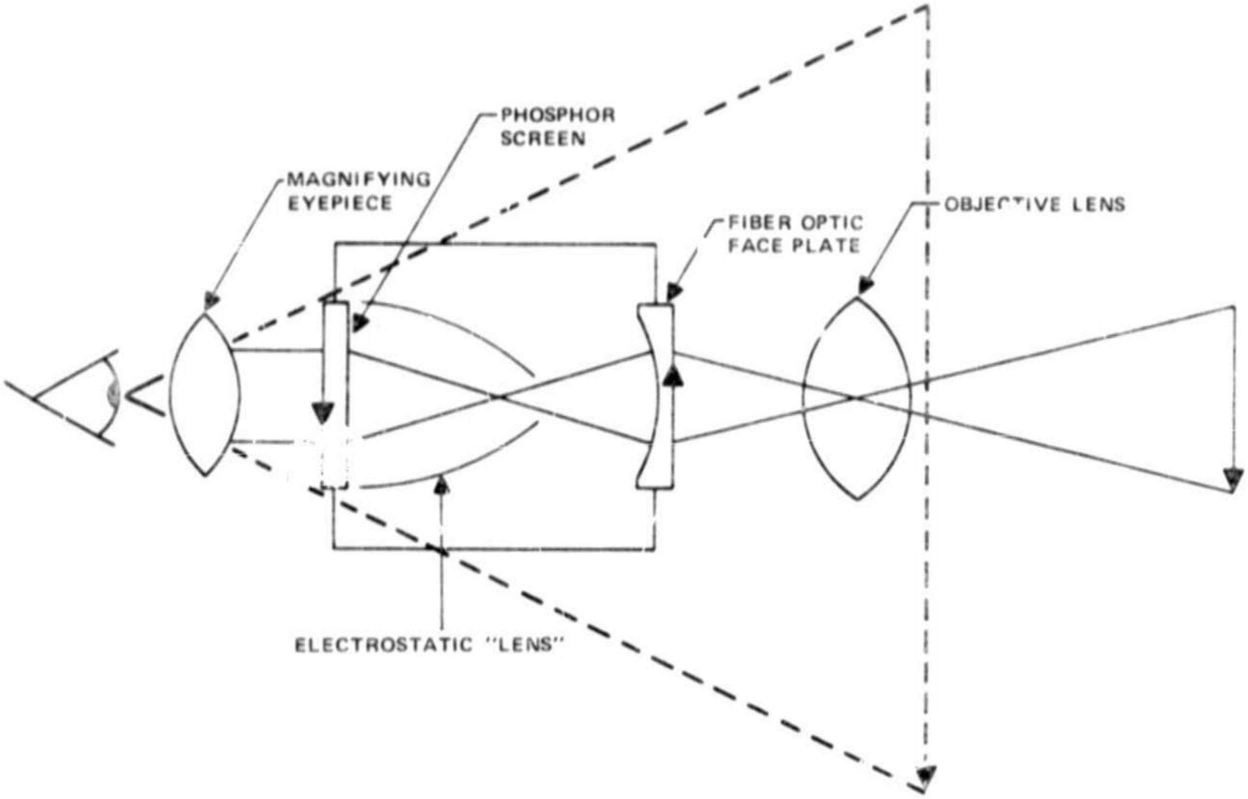


Figure 3-1.— Schematic of a simplified image intensifier viewing system (zero generation).

typical photocathode surface inside the tube. Photon/electron conversion takes place, and the emitted electrons are focused and accelerated by an electric field to strike with high energy velocities. These electrons impact against an output phosphor screen and are converted to visible light by the phosphor screen. The resulting image is viewed by the observer through a magnifying eyepiece.

This simple type of one stage intensifier is generally known as the zero generation intensifier. It has a light amplification of about 50 times and requires accelerating voltages of up to 15,000 volts.

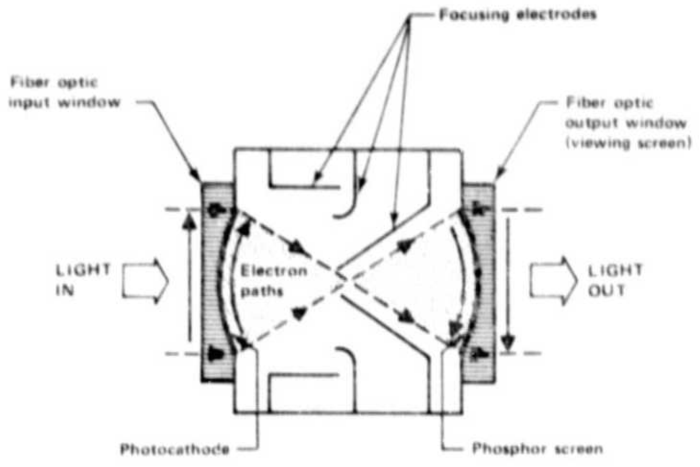
3.3.2 FIRST AND SECOND GENERATION SYSTEMS

A natural developmental sequence of events followed and include improved photocathodes and a cascading of the single stages to enhance amplification. This last improvement created a greater gain tube at the sacrifice of requiring even higher voltages. Gains of 30,000 or more were realized, and by cascading three stages, the first generation series of image intensifiers was born (see fig. 3-2).

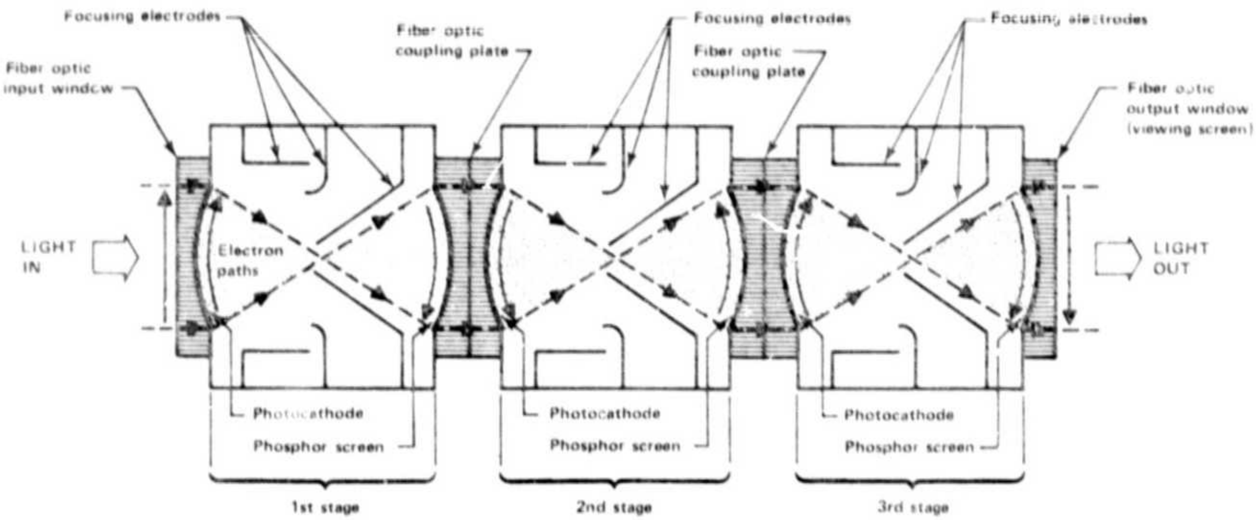
The first generation image intensifier is adequate for many uses; however, it also has operational disadvantages. It exhibits serious and objectionable image "bloom" and persistence that seriously limits its use in the presence of bright light sources in the field-of-view. It requires high voltages up to 40 or 50 kilovolts, and its substantial size and weight limit its portability.

The development of an image intensifier which eliminated most of the first generation faults was necessitated by military users who supported a substantial development program for an improved model. The development program paid off, and the second generation device was created, tested, and is currently a completely acceptable operating unit.

Of the various means of improving first generation intensifiers, the most successful was the incorporation of the microchannel plate (MCP) electron multiplier. This simple technique operates by increasing the quantities of



(a) Single-stage electrostatically focused image intensifier



(b) Three-stage (cascade) electrostatically focused image intensifier

Figure 3-2.— First generation image intensifiers.

electrons instead of increasing their energy to provide higher gain. The addition of the MCP alone defines the second generation device.

The MCP image intensifiers are much like first generation devices except that an MCP electron multiplier is placed between the phosphor and photocathode (see fig. 3-3). The MCP is a glass or quartz structure consisting of many holes or channels fused together. Each hole is in the order of 10 microns in diameter (approximately one eighth the diameter of a human hair). Each of these channels is coated with materials which emit several secondary electrons when struck by primary single electrons. The electron cloud is then accelerated down the channel by a voltage gradient across the plate. During the passage, each subsequent impact on the channel's inner coated surface produces additional quantities of secondary electrons. The multiplied electrons leaving the channel plate are "proximity" focused on the phosphor screen. To proximity focus, the screen is placed close to the MCP so the electrons leaving the tubes travel only a short distance before they strike the phosphor. This minimizes spreading for increased resolution and greatly reduces the physical size of the device.

The overall gain of the intensifier is easily controlled by varying the voltage gradient across the plate, and no electrostatic defocusing occurs. At extremely high light levels, the intensifier gain can be reduced to unity with no degradation of resolution.

In addition to gain control and the obvious reduction in size and weight, the second generation devices exhibit several other advantages. The first generation intensifiers require approximately 15 kilovolts per stage or 45 kilovolts across a three-stage model The second generation units use a maximum of 8 kilovolts which represents a significant reduction in power supply and reliability problems. The second generation intensifiers have a remarkable lack of persistence and image smear when compared to three-stage devices. When bright objects enter the field-of-view, the overload and bright image spot on the phosphor is localized while the remainder of the field stays

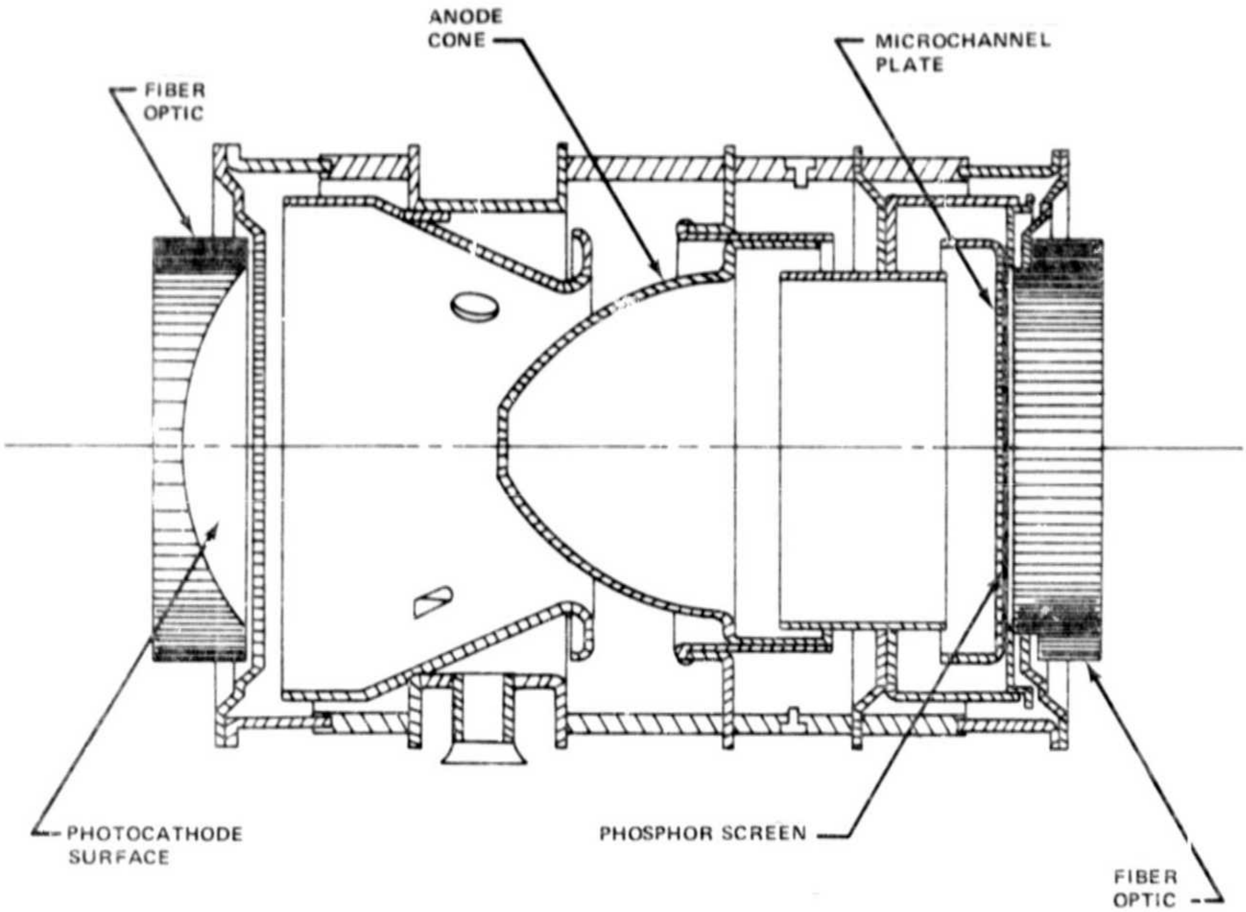


Figure 3-3.— Second generation microchannel image intensifier.

sensitive to low light levels. In three-stage intensifiers, an overload from a bright object results in a complete wipeout of the image with loss in resolution, focus, and a serious afterglow even after the bright target is gone.

3.4 TEST UNIT SELECTION

Selecting the correct system to meet the requirements of a useful spacecraft viewing device was made by evaluating the important parameters. The following list was generated by considering the operational needs as well as the physical constraints of the vehicle, its size, and its environment:

a. Size

b. Weight

c. Power requirements (voltage levels)

d. Susceptibility to overloads

e. Viewing screen "stickiness"

f. Restoration of image after image overloads

g. Optical gain

h. Image resolution

i. Temperature range

j. Shock susceptibility

After careful consideration of the many operational and physical parameters involved, it was decided that the ideal proximity optical device would be a second generation image intensifier with the fore-optic and the eyepiece specifications to be determined by test, demonstration, and solicitation of opinions from interested users with special attention to be paid to crew member inputs.

The selection of the second generation device was relatively simple because of the size, weight, and reliability advantages it has over first generation units. Probably the most significant feature which makes a first generation unit undesirable for spacecraft use is its need for extremely high voltage (not lethal) and its noncompatibility with bright objects in the field-of-view. Secondly, the first generation devices also are larger and heavier. In fact, the second generation device is better suited for spacecraft use than the first generation device except for optical gain levels and resolution. Tests described later verify the ability of the second generation devices to adequately meet these last two questionable characteristics.

During the preliminary planning for this program, the decision was made to design and fabricate a POD test prototype. Since the device only consists of an image intensifier tube with selected fore and aft optics, such a project would not be a major effort. After screening the commercial market, it was determined that several vendors had off-the-shelf units which would meet most of the requirements. A set of procurement specifications was written (see the appendix), and bids were solicited. The unit finally selected and purchased was NI-TEC Corporation model NVC-100 Zeniscope[1] Night Vision System.

The NVC-100 Zeniscope (see fig. 3-4) is comprised of three basic parts:

- The objective lens
- The second generation image intensifier with integrated power supply and supporting body
- The viewing eyepiece

The specifications for the body/intensifier module follow.

- Image format — 25 mm
- Gain — 25,000 times minimum
- Resolution — 25 lines/mm
- Photocathode — S-25
- Sensitivity — 175 μA/lumen

[1]Trade name of NI-TEC Corporation, Skokie, Illinois.

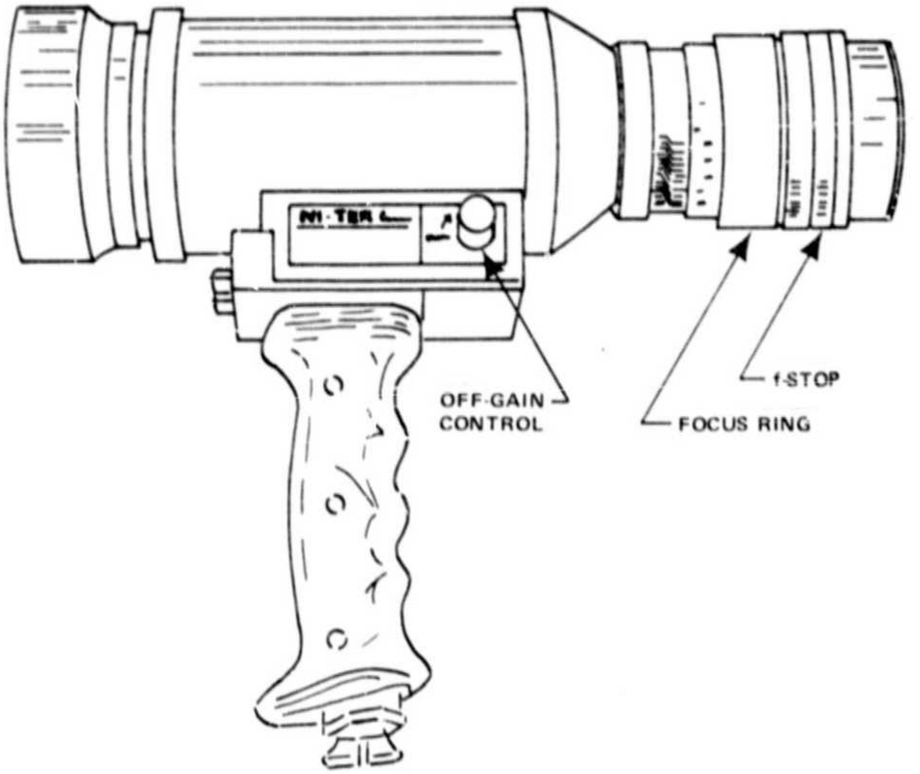


Figure 3-4.– Location of Zeniscope controls.

- Viewing phosphor — Modified P-20
- Magnification — 1.0
- Power source — 2.8 Vdc (battery)

The test device was supplied with a Nikon objective lens adapter which could accommodate several available lenses with focal lengths from 50 mm to 500 mm. These lenses provided an excellent test focal length range. Two eyepieces were received with the unit which permitted monocular or binocular viewing. A special relay lens for a 35 mm camera was also provided for photographing scenes or objects during testing.

4. TEST AND DEMONSTRATION PROGRAM

A test plan was written and approved. The plan as originally conceived was ambitious and reflected the types of tests which were thought to be useful in evaluation of the POD and within the available test resource capabilities. As the program progressed, some changes in technique were made and followed. The most significant fact which materialized from the program was that simulated demonstrations of the device played a more dominant role in the evaluation than technical testing. Although some empirical data and test results were achieved, the demonstrative usefulness of the device and its potential for spacecraft application preempted the test data value.

4.1 PRIMARY VIEWING DEVICE DESCRIPTION

A commercially available low-light-level viewing device Model NVC-100 Zeniscope was procured for the test program. The device has three basic parts which are described in the following sections.

4.1.1 OBJECTIVE LENS

Normally the NVC-100 Zeniscope can be purchased from the vendor with a choice of several objective lenses. However, a group of high quality photographic lenses were available at JSC, so the unit was obtained without any objective lens but fitted with a Nikon adapter to accommodate the lenses on hand. The following objective lenses were tested:

- 50 mm f/1.4 Nikkor
- 85-205 mm f/3.8 zoom Soligor
- 200-600 mm f/10 zoom Nikkor

This group offered a wide variety of focal lengths for testing and were of adequate aperture size to permit threshold sensitivity evaluation of the available target objects.

4.1.2 INTENSIFIER TUBE

The NVC-100 Zeniscope uses a second generation image intensifier tube. The power supply for the tube is encapsulated as an integral assembly with a permanent potting material. The primary power is 2 to 3 volts dc nominal and is supplied by two AA batteries in the base of the NVC-100 Zeniscope. A manual gain control with an on/off switch is mounted on the base and is used for optimization of image contrast by varying tube gain over a 5:1 ratio. The power supply also has automatic circuitry to prevent intensifier average screen brightness from exceeding 10 foot-lamberts (FL) with intensifier average input levels up to 1 lumen per square foot on the photocathode.

4.1.3 OPTICAL VIEWER/EYEPIECE

Two types of eyepieces were available for the tests. A binocular unit suitable for viewing the output intensifier screen with both eyes at a comfortable viewing distance of 6 to 10 inches was selected. It has a nominal magnification of 3.5X and produces a system magnification of 1.2X when used with an 85 mm objective lens. The second unit is a monocular eyepiece with a nominal focal length of 36 mm. This produces a system magnification of 2.4X when using an 85 mm objective lens or approximately 14X while using a 500 mm objective lens.

4.2 TEST EQUIPMENT

Several specialized items of test equipment were used to produce the necessary simulated star targets and background luminance inserted into the optical path of the POD being tested.

4.2.1 SIMULATED STAR TARGETS

An Optronics Laboratories, Inc., Model 300-3 low-light-level calibration source was used to provide simulated star targets. The device does not have outboard optics and is essentially a point source of radiation. Attenuation with neutral density filters, aperture size variations, and modification of distance to the source provide various levels of star visual magnitudes. The calibration points given were used to establish a zero magnitude base point, and subsequent star levels were then possible using the variable capabilities of the instrument. Targets of 0 to +9.1 magnitude were achieved.

4.2.2 BACKGROUND SIMULATION DEVICE

Insertion of background at measurable levels was accomplished by using an uncoated plate glass beam splitter placed at a 45° angle in front of the POD. Diffused light from a standard Spectra-Pritchard luminance source fell upon the plate glass at an angle normal to the image intensifier's optical axis. This technique was successfully used to fill the field-of-view of the POD with measured values of luminance while allowing the star image to be seen. A measured 13 percent loss of star image brightness was experienced from the glass plate.

4.2.3 PHOTOMETRIC MEASUREMENT EQUIPMENT

Throughout the test program, a calibrated Pritchard Model 1980 Photometer was used to measure all values of light required to provide accurate evaluation data.

4.2.4 CAMERA EQUIPMENT

A standard 35 mm single lens reflex (SLR) TOPCON camera was used to photograph any required targets for the test record. A relay lens with adaptors suitable for coupling it into the 35 mm SLR camera was available.

5. INDIVIDUAL TEST DESCRIPTIONS AND RESULTS

5.1 PHOTOGRAPHIC EXPOSURE TEST

5.1.1 OBJECTIVE

A photographic exposure series of tests was conducted to determine the correct camera and film exposure parameters required to obtain permanent film records of subsequent tests.

5.1.2 TEST METHOD

A controlled group of film exposures were made against various targets with different background light levels. The levels of illumination of the target and background brightness were measured with photometric measuring equipment.

5.1.3 TEST RESULTS

Although the original intent of the test was to prepare a useable reference table for subsequent photographic activities, it became distressingly apparent that useful photographs were obtainable only by using trial techniques. The built-in exposure meter on the camera was virtually useless, because in most cases where low-light-level targets were used, it did not offer meaningful readings. This led to cycling the camera shutter through a range of speeds and taking several photographs of the desired scene. Fortunately, the camera f-stop was fixed by the relay lens which eliminated one variable in the picture making process.

As a result of the test, it must be concluded that controlled picture taking using a table of exposure parameters is extremely difficult to achieve. After a final prototype design is defined and a particular camera selected, the POD operator could become skilled enough to take useful low-level-light photographs. The complete process of analyzing the scene characteristics, selecting film speed, selecting exposure speed, etc., becomes a subject of operator training which will need to be undertaken if successful photography in flight conditions is required.

5.2. STAR TARGET MAGNITUDE SENSITIVITY

5.2.1 OBJECTIVE

This test determined the minimum star target sensitivity which can be achieved with a zero field-of-view background level.

5.2.2 TEST METHOD

The POD was used to view simulated star targets of varying visual magnitude. The optical parameters of objective diameter and focal length were varied to determine optimum values and their effects on low-light-level viewing.

5.2.3 TEST RESULTS

The test equipment was configured to furnish a zero magnitude star target at a physical distance of 25.6 feet. This combination of the distance and the target was then modified by changing the target aperture until a simulated star target of +2.49 magnitude was presented. Various lens types with variable apertures were used. The star was viewed by an observer, and the POD viewing screen brightness was measured with the photometer. The data is presented in table 5-1. (The measured screen brightness is the target image area only.)

Using the test data, it can be shown that the ability of the POD to see a dim star is a function of effective aperture diameter. This value comes from the focal length/focal number relationship:

$$\text{Effective aperture} = \frac{\text{focal length}}{\text{focal number}}$$

Therefore, a lens suitable for dim star observation can be selected.

With the data given, it would seem possible to compute the minimum star magnitude sensitivity using the effective aperture and the screen brightness values. If this is done, the dim star values are impressive, but due to the nonlinear effect of screen brightness and photocathode sensitivity they are not completely accurate. For example, if the 50 mm lens at f/1.4 is taken, the data shows that a +2.49 visual magnitude (M_V) star target produces a

TABLE 5-1.– STAR TARGET SENSITIVITY
TEST RESULTS

(a) Star +2.49 M_V and lens 50 mm, f/1.4

f-stop no.	Measured screen brightness
1.4	6.6×10^{-3} FL
2	4.3×10^{-3} FL
2.8	2.2×10^{-3} FL
4	1.23×10^{-3} FL
5.6	9.1×10^{-4} FL
8	6.8×10^{-4} FL
11	5.3×10^{-4} FL
16	4.6×10^{-4} FL
Background	3.6×10^{-4} FL

(b) Star +2.49 M_V and lens 85 mm, f/3.8

f-stop no.	Measured screen brightness
3.8	3.1×10^{-3} FL
5.6	1.62×10^{-3} FL
8	1.25×10^{-3} FL
11	9.6×10^{-4} FL
16	7.6×10^{-4} FL
22	5.3×10^{-4} FL
Background	3.7×10^{-4} FL

TABLE 5-1.— Concluded.

(c) Star +2.49 M_v and lens 205 mm, f/3.8

f-stop no.	Measured screen brightness
3.8	3.1×10^{-3} FL
5.6	1.62×10^{-3} FL
8	1.25×10^{-3} FL
11	9.6×10^{-4} FL
16	7.6×10^{-4} FL
22	5.3×10^{-4} FL
Background	3.7×10^{-4} FL

(d) Star +2.49 M_v and lens 200 mm, f/9.5

f-stop no.	Measured screen brightness
9.5	6.3×10^{-3} FL

(e) Star +2.49 M_v and lens 600 mm, f/10.5

f-stop no.	Measured screen brightness
10.5	2.38×10^{-2} FL

screen brightness of 6.6×10^{-3} foot-lamberts. This is for an effective aperture diameter of 35.7 mm (table 5-2). Continuing this line of reasoning, the effective aperture at f/16 would reduce to a 3.12 mm diameter. The area change between f/1.4 and f/16 is therefore ≈ 130 times. Translating this into star magnitude ratios (2.5 log 130) shows a potential sensitivity of +5.29 M_V change. Since the test magnitude used was set at +2.49 M_V, then the predicted sensitivity would be +7.78 M_V.

Continuation of the test using observers to make the decision that threshold target values had been reached only increased the +7.78 M_V value by a small amount. Therefore, for practical considerations the stated method of determining minimum star sensitivity is useful for system concepts. Caution must be taken when comparing different lenses since each has different transmissions, reflective coatings, spectral responses, and other small variances. It can not be expected that a 50 mm f/1.4 lens will have the same exact sensitivity responses that might be obtained from (as an example only) a 339 mm f/9.5 unit.

In the observer tests, the minimum star magnitudes varied from +9.1 to +8.0 M_V depending upon the observer and the lens used. Parameters of lens size and description were not directly related to the observer's reaction, but the spread of only 1.1 magnitude indicated that the threshold values seem to generally follow the effective aperture size concept.

5.3 BACKGROUND LIMITING TESTS

5.3.1 OBJECTIVE

This test demonstrated and evaluated the effects of varying the background brightness superimposed on the threshold sensitivity of target stars and extended source targets. Limits of degraded observability were recorded and deleterious effects on observer visibility noted.

5.3.2 TEST METHOD

The procedures followed in test 5.2 were repeated with the addition of injecting varying levels of background luminance into the field-of-view. Special

TABLE 5-2.– LENS DATA

(a) 50 mm lens

f-stop no.	Effective aperture (mm)
1.4	35.7
2	25
3.5	14.28
4	12.5
5.6	8.92
8	6.25
11	4.54
16	3.12

(b) 85 mm lens

f-stop no.	Effective aperture (mm)
3.8	22.37
4	21.25
5.6	15.17
8	10.62
11	7.72
16	5.31

(c) 205 mm lens

f-stop no.	Effective aperture (mm)
3.8	53.947
4	51.250
5.6	36.607
8	25.625
11	18.636
16	12.813

TABLE 5-2.– Concluded.

(d) 200 mm lens

f-stop no.	Effective aperture (mm)
9.5	21.053

(e) 600 mm lens

f-stop no.	Effective aperture (mm)
10.5	57.143

attention was given to optical parameter changes; i.e., lens focal lengths, apertures, etc., which might affect the visibility contrast ratios and produce optimum seeing results.

5.3.3 TEST RESULTS

One of the most undesirable features of first generation image intensifier tubes is the tendency for the tube to overload and bloom with slight increases in background levels or target brightness. It is virtually impossible to perceive dimmer targets if a bright object appears at the edge of the field. A purpose of this test was to show the versatility and tolerance of the second generation tube towards bright background and objects in the field-of-view.

The POD was designed to have an automatic brightness control (ABC) which serves to protect the power supply and phosphor screen from damage when bright objects are seen. A test to determine the point where this ABC would begin was conducted. Table 5-3 outlines the data taken.

The data indicates that ABC saturation takes place when a background brightness level of $\approx 2.5 \times 10^{-2}$ foot-lamberts is achieved. Continued brightness levels produce no significant phosphor changes. The illumination of the photocathode was complete over the field-of-view. When bright point sources are observed, the photocathode illumination may exceed the 2.5×10^{-2} foot-lamberts object brightness level, but it was not considered prudent to test for this effect. Possible photocathode damage may result. Obviously, this level of target brightness should be avoided if the total image does not cover the full field-of-view.

The tests were then continued by observing a star target and increasing the background light until the star was no longer discernible. Star targets were discernible as long as the background light level did not equal the target brightness. With star targets, this point is difficult to define, and it was beyond the capabilities of the test setup to develop finite parameters.

TABLE 5-3.— AUTOMATIC BRIGHTNESS CONTROL
TEST RESULTS

Phosphor screen brightness (FL)	Background brightness (FL)
2.98	9.65×10^{-3}
3.58	1.21×10^{-2}
4.48	1.60×10^{-2}
5.84	2.03×10^{-2}
6.66	2.55×10^{-2}
6.69	3.15×10^{-2}
6.65	4.08×10^{-2}
6.63	5.5×10^{-2}
6.60	6.91×10^{-2}

A final test was performed with a simulated starlit model to monitor the background effect. A model of the orbiting space laboratory was placed at a distance from the POD which simulated an actual space distance of 1000 feet (see fig. 5-1). The model was illuminated with diffused light to an illumination level of 6×10^{-5} foot-candles and viewed by a trained observer. Background light was introduced into the total field-of-view until the object was barely discernible (operator's opinion). The level of background light measured was 2.1×10^{-5} foot-lamberts. A contrast ratio can be approximated by the expression:

$$C = \frac{B + T}{B}$$

where

C = contrast ratio

B = background brightness

T = target brightness

This computes to a contrast ratio of 1.7 which is a realistic value for operator viewing at nearly threshold conditions.

It can be concluded that the second generation POD can see objects or stars as long as the background brightness does not exceed that of the viewed target. No overall degradation of sensitivity for unit area, small or large, is affected by bright targets in other areas unless the ABC circuitry is activated.

5.4 OPERATIONAL TESTS

5.4.1 OBJECTIVE

In order to properly evaluate the POD's usefulness under actual operational conditions, a series of visual observer tests was conducted.

5.4.2 TEST METHOD

The POD was used with unique simulated target situations, and observer comments as to the image quality and operational usability were solicited. Both

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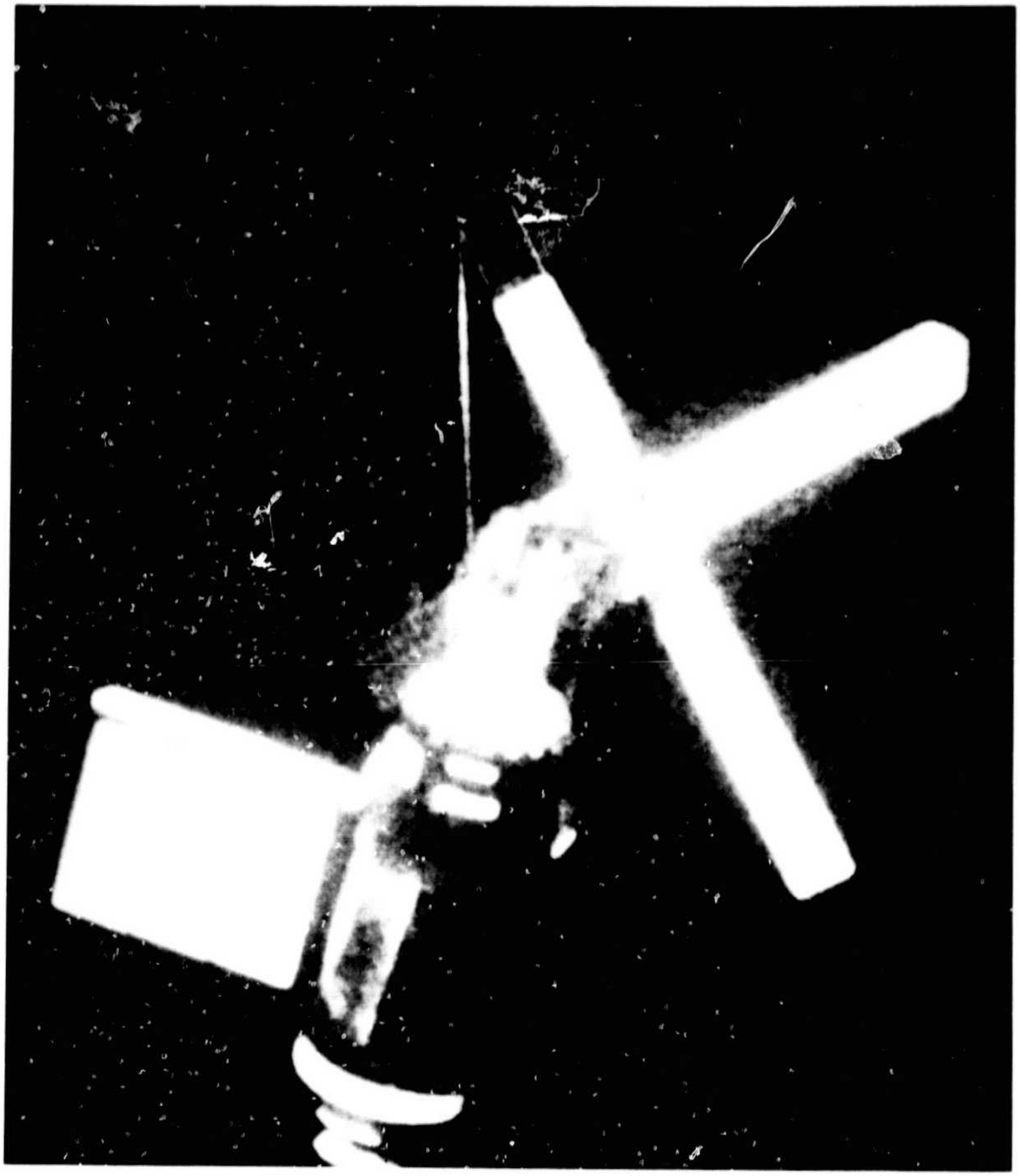

Figure 5-1.— Space laboratory model with simulated starlight illumination (1000-foot range).

monocular and binocular eyepieces were used as well as different focal length fixed and zoom objective fore-optics.

5.4.3 TEST RESULTS

A large variety of both trained and amateur observers were used to watch the targets. Primarily the orbiting space laboratory model was used to provide a realistic target. Starlight, moonlight, and searchlight illumination were simulated. Of these, starlight was the dimmest with searchlight and moonlight illumination levels increasing in that order. Illumination level values are shown in table 5-4.

Operators observed all levels of illumination, and each was impressed with the starlit level condition results. The group unanimously selected the binocular eyepiece as being more practical for spacecraft viewing since adequate eye relief was available and the image was bright enough to probably be seen under cockpit ambient lighting conditions (to still be fully verified).

TABLE 5-4.— ILLUMINATION LEVELS USED IN OPERATIONAL TESTS

Light source	Illumination
Moonlight (5500° K) CT	2.4×10^{-2} ft-c
Spotlight (2854° K) CT 500-ft range	1.34×10^{-2} ft-c
Spotlight (2854° K) CT 1000-ft range	3.6×10^{-3} ft-c
Starlight	6×10^{-5} ft-c

6. CONCLUSIONS

The original concept of testing a POD produced an ambitious test plan and program involving the intended purchase of optics and a separate image intensifier for fabrication into a prototype model to be tested. Originally, tube gain, resolution, and photocathode sensitivity were considered to be useful in evaluation of the device's application. However, a search of the commercial marketplace brought to light the fact that practical devices were readily available for a nominal cost.

These findings preempted the original idea of procuring components and fabricating a prototype POD. Tube performance technical data was available and believable, so a repetitive test series would have only been an academic exercise unless subsequent tube changes and development would be considered necessary to produce a final product. The size, weight, and power consumption characteristics of commercial devices were found to be adequate for consideration in spacecraft use. Selection of optical parameters for a final operational device would be easy since most all of the market devices use interchangeable objective and eyepiece components. Therefore, based on these facts and the tests performed on <u>one</u> device, the following conclusions can be made.

- The concept of using a POD for manned spacecraft specialized operations is considered feasible.
- A POD which could be used in manned spacecraft is available from commercial industry without need for an expensive and time-consuming research and development program.

The test results and operational demonstrations produced the following specialized conclusions.

- A binocular eyepiece is preferred over the monocular type.
- The size, weight, and power consumption parameters of the demonstration POD are within the scope desired for spacecraft operation.
- The sensitivity and resolution of the demonstration device were considered adequate when used against realistically simulated targets.

- The fore-optics to be used should be of the fixed focal length variety with some degree of lens interchangeability to be provided.
- Zoom lens fore-optics were not considered as an operational requirement.

7. RECOMMENDATIONS

In view of the test program results and the observation team's comments, it is recommended that:

- A POD be strongly considered for use in manned spacecraft specialized operations.
- Action be taken to procure a demonstration prototype for use in continued demonstrations and to serve as a model for a final flight unit.
- That the acceptable prototype be adequately tested to provide more factual data than was possible with this project.

PROXIMITY OPTICAL DEVICE (POD)

TEST UNIT PROCUREMENT SPECIFICATIONS

1. GENERAL

The breadboard test POD shall be composed of three basic parts.

1. Optical viewer or relay lens with camera attachments.
2. Image intensifier tube and associated power supply.
3. Objective lens

1.1 WEIGHT

The weight including an eyepiece, but without objective shall not exceed three (3) pounds.

1.2 SIZE

a. The length including an eyepiece, but without objective lens shall not exceed eight (8) inches.

b. The diameter of the supporting body including eyepiece, but not including battery compartment, mounting surfaces, or objective lens, shall not exceed three (3) inches.

1.3 VIEWING SCREEN

The viewing screen of the body shall accept either binocular or monocular vendor supplied eyepieces. A camera attachment and relay lens for a Nikon Camera mount shall be provided. Attachment of selected relay lens and eyepieces shall be made without the need for accessory tools.

1.4 IMAGE INTENSIFIER

The image intensifier tube shall be a second generation (GEN II) micro-channel plate (MCP) inverting type with photocathode format of not less then 25 millimeters. The photocathode surface material shall be S25 (extended red) and the phosphor screen shall have a P1/P39 misture with peak radiation at 5350A to 5400A. Input and output surfaces shall be fiberoptic with flatness deviation less than or equal to five micrometers. Luminous gain shall be greater than 40,000. Center resolution shall be no less than 32 lines/mm.

1.5 POWER SUPPLY

The power supply shall be encapsulated as an integral assembly with the image intensifer. Primary power shall be 2.0 - 3.0 volts DC nominal with maximum current drain not to exceed 40 milliamperes. Electrical insulation of all high voltage points shall withstand at least twice the nominal potential of the supply.

1.6 OBJECTIVE LENS

No vendor supplied objective lenses are required.

1.7 ACCESSORIES

a. Relay lens suitable for coupling into NIKON 35mm SLR camera shall be provided.

b. Objective lens adapters for NIKON and PENTAX lens types shall be provided.