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# EXPERIMENTAL TESTS OF THE EFFECT OF BACKSCATTER SUPPRESSION ON THE PERFORMANCE OF A THEODOLITE MISSILE AZIMUTH CONTROL

SIO Ref. 65-15

Bureau of Ships Contract NObs-72092, Amendment 38
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Visibility Laboratory

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# FOREWORD AND SUMMARY

This is the final report on work performed under Contract NObs-72092, Amendment 38, between the Bureau of Ships, Department of the Navy, and the Visibility Laboratory of the University of California. Funds for this work were transferred from the U.S. Army Missile Command, Redstone Arsenal, Alabama to the Bureau of Ships by MIPR 1591-03-60. The purpose of the amendment was to study the problems associated with the optical alignment of missiles under restricted visibility conditions, such as those caused by fog. Existing work on methods of dispersing or penetrating natural fogs and fog condensates resulting from fueling with liquid oxygen immediately prior to launch were reviewed in the hope of finding some means to decrease the number of occasions on which the optical alignment in azimuth of missile systems is inhibited by fog. No panacea was discovered. Experimental tests were made of polarization techniques for suppressing unwanted back-scattered light in one existing photo-theodolite azimuth servo system, and these tests are the principal subject of this report. No statistically significant improvement in the performance of the photo-theodolite system during foggy conditions was achieved.

# 1.0 INTRODUCTION

## 1.1 Background

Conversations between the Visibility Laboratory and a representative of the Army Ballistic Missile Agency indicated the need for a fundamental exploration of optical means of positioning a missile in azimuth on its launching pad prior to firing during conditions when natural fog or fogs produced by condensation of moist air with liquid oxygen during the fueling procedure obscures the view of the photoelectric autocollimating theodolites presently used. It was suggested that a study be undertaken in an effort to find a means of either dispersing the fog in the line of sight or of penetrating the fog in such a manner as to allow the maintenance of the positioning of the missile to the required accuracy in azimuth. During this first meeting various methods of azimuth alignment were discussed, some of which were non-optical; in fact, at that time a method using microwave interferometry was suggested, and members of the staff of the U.S. Navy Electronics Laboratory were contacted in regard to its possible application to this problem. It was the opinion of the NEL specialists that this method could be developed to perform the alignment within the required tolerance. Nevertheless, this Laboratory was requested to study possible solutions to the optical problem.

The Visibility Laboratory, in discussing the general problem which was to become the subject of this contract amendment[1], made

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[1] Ltr. S. Q. Duntley to ABMA, Redstone, dtd 9 August 1960.

it clear that it knew of no way to achieve the desired goal and that it considered a negative final result of the work to be quite possible. Because of the importance of the problem, however, the Laboratory agreed to undertake a study with the hope that some unforeseen development might result in an improvement in all-weather optical positioning of missiles in azimuth.

Representatives of the Visibility Laboratory visited the George C. Marshall Space Flight Center for an initial conference on the project. During this visit they had the opportunity to observe a fueling of a Jupiter missile and to examine the optical equipment used for azimuth positioning and control. Certain responsibilities were still being divided between NASA and ABMA at that time, and it was not clear which group would have the responsibility for this project; consequently, representatives of both agencies were present for the discussions. Certain understandings were reached concerning the scope of the project in addition to those mentioned above. These were 1) that the study was to be general, i.e., non-specific to any missile system, 2) that the Visibility Laboratory was not required to provide, develop, construct, or devise system components, and 3) that the Visibility Laboratory was not to be required to explore microwave techniques, far infrared techniques foreign to the Laboratory's normal sphere of interest and activity.

## 1.2 Statement of the Problem

It became obvious from discussions with personnel at the Marshall Space Flight Center and from observations of the fueling procedures that the problems of the "short range" type of optical alignment theodolite systems were not those of primary concern. For the short optical paths therein involved, a means of mechanically sweeping the fog from the path was deemed entirely feasible. Such means might consist simply of a tube surrounding the optical path which could be purged free of fog by a dry atmosphere (e.g., nitrogen) injected at a low velocity to minimize turbulence. It was understood that proposals of this nature had been made and were felt to offer a reasonable operational solution to the problem. No further consideration, therefore, was given to the short-range systems.

In the case of the "long-range" theodolite systems, a reference or "monitoring" line of sight in azimuth is maintained by directly autocollimating to a reflecting surface located on the guidance module in the nose of the missile. Because the length of the optical path in such systems may be from 100 to 400 feet, the strictly mechanical approach suggested above for the short-range systems was not operationally feasible. The study was limited, therefore, to investigating systems for either removing or "seeing through" fogs in situations similar to those encountered in the operational use of long-range automatic autocollimating theodolites. As the Jupiter missile system was typical of an operational system wherein problems of the type which were to be the subject of the study were encountered,

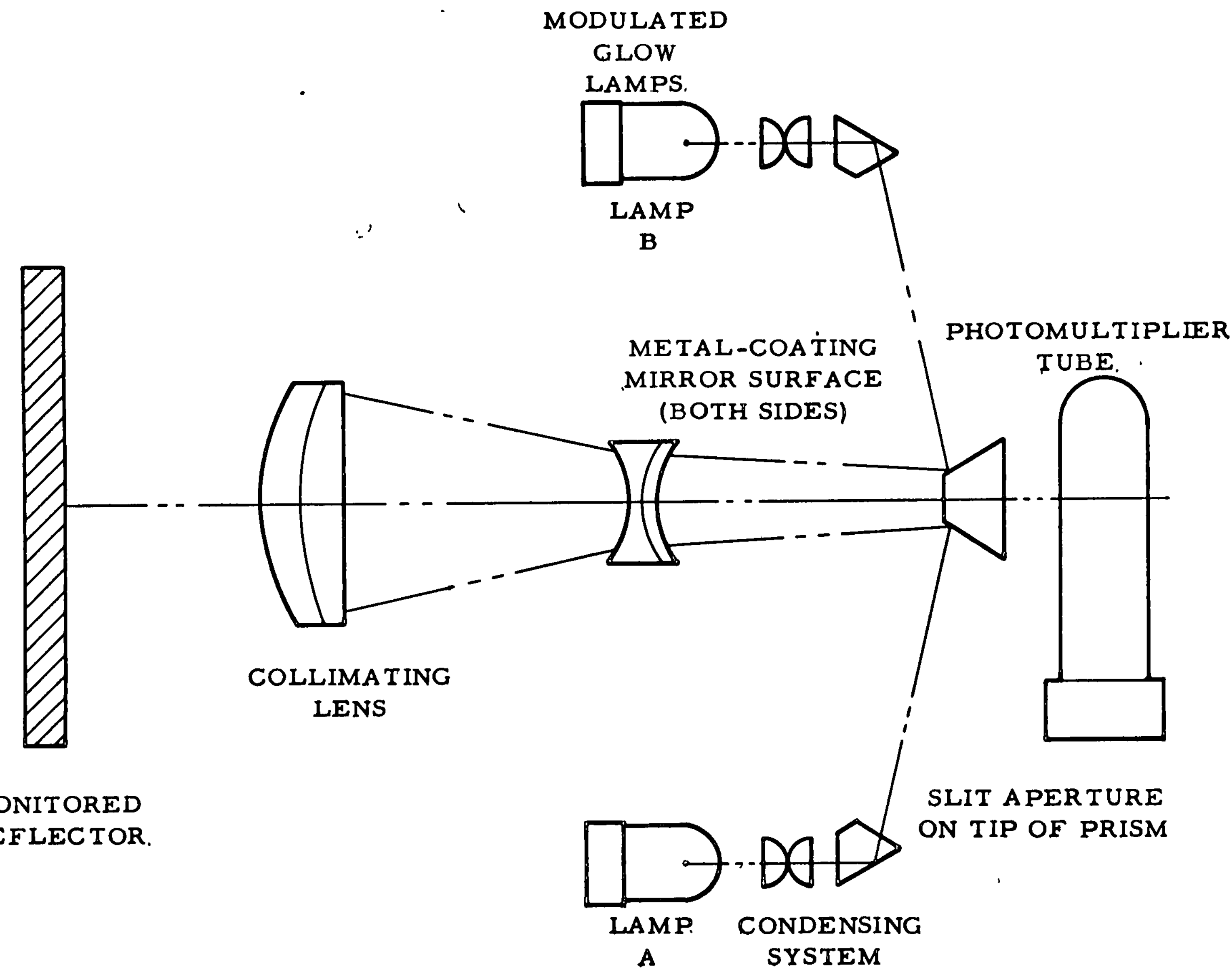


Figure 1. Simplified schematic diagram of the theodolite.

long-range theodolite equipment used with this system was used during the course of the study.

No specific study was undertaken which involved fogs artificially induced by liquid oxygen as might accompany the fueling procedure. The reasons for this were twofold. First, results obtained in the course of investigations of natural fogs would, in general, be expected to apply to the LOX-induced fogs. Secondly, there seemed to be the real possibility that since these were locally generated, a mechanical means could be installed for their removal from the vicinity of the path of sight. For example, LOX overflow on fueling and the normal boil-off vapors could be removed from filler and vent holes by appropriate ducting connected to a fan which would draw the cold gas away to a harmless location. The ducting could be removed from the missile at the same time the umbilical separation occurs.

## 1.3 Fundamental Principles of the Theodolite Operation

Figure 1 shows a simplified schematic diagram of a theodolite.[2] The two glow tubes are modulated at a 400-cycle frequency and with $180^{\circ}$ phase shift relative to each other. The two light beams thus generated pass through the collimating lens and are transmitted to the reflecting optics on the missile and are then reflected back to the theodolite. If the monitored reflector is perpendicular to the line of sight then the two beams return at positions equally distant from the central axis of the optical system, and very little flux is passed through the slit aperture on the tip of the prism. If the

[2] Perkin-Elmer Corporation Data Sheet, "High-Precision Azimuth Alignment Theodolites," 1960

reflecting surface is not perpendicular to the transmitted beams then one of the return beams will move into the slit and the flux received by the multiplier phototube serves as an error signal. Sensing the phase of the 400-cycle error signal allows determination of which beam is within the slit and hence determination of the direction of the error.

The performance of the theodolite is determined by the signal-to-noise ratio associated with the error signal. The signal is dependent on the flux output of the glow modulator tubes modified by the total transmission of the two-way path from the lamp to the missile and back. There are two primary noise sources associated with the system. Since a multiplier phototube is used, the amplifier noise should be negligible, but there will be a component of dark current noise from the multiplier phototube. Dark current noise is generated by the random thermal emission of electrons from the photocathode. The other source of noise is the photon-shot noise associated with the steady-state flux incident on the photocathode.

### 1.4 Fog and its Relationship to Theodolite Performance

Fog constitutes a transmission medium having prominent scattering properties. The scattering process reduces the signal-to-noise ratio of the error signal and therefore the theodolite performance in four ways. First, the high degree of scattering dramatically reduces the beam transmittance of the path of propagation of the glow modulator beams and therefore directly reduces the error signal by an amount proportional to the transmittance. Second, the fog results in a backscattering of the glow modulator beams so that flux from the beams is scattered back through the optical system of the theodolite, passing through the slit and falling on the photocathode of the multiplier phototube. Under normal conditions it would be reasonable to assume that there would be very nearly equal components from the two beams and, since they are in phase opposition, the result would be a steady-state flux level at the photocathode. This flux level will result in photon-shot noise as indicated in the preceding section. The third effect of the fog will be to scatter ambient light into the path which will also result in photon-shot noise. Finally, rapid temporal fluctuations in the consistency of the fog result in time varying flux incident on the multiplier phototube, which is a form of noise.

## 2.0 APPROACH TO THE PROBLEM

### 2.1 Alternatives

The experimental work was preceded by a literature survey* and a trip by Visibility Laboratory staff members to the east coast to visit various organizations having pertinent input to the problem. This activity served to highlight a number of possible alternative approaches to the problem which were then weighed from the standpoint of the funding, personnel, and facilities available for the project.

It follows from the preceding section that in order to achieve improved performance from the theodolite system it is necessary either to increase the signal flux at the detector or to decrease the system noise. With respect to increasing the signal flux at the

*See bibliography

detector, the most obvious solution is to increase the flux at the source. Under conditions where the system noise is dominated by the photon-shot noise from backscattering of the transmitted beam, an increase in transmitted signal will result in a similar increase in backscattered flux which in turn will result in a square-root increase in the photon-shot noise. Nevertheless, if it were possible to increase the source power by a number of orders of magnitude, substantial performance increases would result. This approach should be reviewed if and when suitable modulatable laser sources become available.

The other alternative to obtaining increased signal strength is to improve the transmission properties of the path of sight. Various ideas have been proposed for supplying an artificial transmission path by means of evacuated tubes, helium-filled balloons, etc., each of which is probably fraught with many practical objections. Fog dissipation by heating, chemically treating, electrical coagulation, etc., have been studied by a number of investigators primarily associated with attempting to obtain useful solutions to the problems of aircraft operations at foggy airports.

Pulsed light source systems are a possible partial solution to the problem. A pulsed system offers the opportunity to eliminate the backscatter from the source since the signal information is delayed in time from the arrival of the backscatter. To be effective, the pulse length of such a system must be short compared to the transit time of the round trip from theodolite to missile. This means pulse lengths on the order of 20 nanoseconds. Performing the servoing operations with a pulsed system requires techniques quite different from those used in conventional autocollimating theodolites. Another technique which has been suggested is the use of polarization techniques to reduce the backscatter from the transmitted light beams. This technique is based on the idea that the polarization of incident light is preserved in the process of backscatter from fog. By polarizing the transmitted light beams and cross-polarizing the flux at the detector backscatter would be eliminated or, at least, severely attenuated. This technique requires that the reflector in the missile is made to inject a change of polarization on reflection in order that the desired signal is not eliminated by the cross-polarization process.

### 2.2 Selected Approach

It was decided that the use of polarization techniques to accomplish back-scatter reduction was the most likely avenue to pursue in an endeavor to achieve a potential improvement. The investigation centered upon an experimental determination of the effect of polarization techniques applied to an existing autocollimating theodolite system, specifically the Perkin-Elmer Model 523-0005 Long-Range Theodolite, without any extensive modification of the existing equipment. The only electronic design and construction to be performed by the Visibility Laboratory would be a transmissometer to be used to document the environmental conditions under which the experiments were conducted. The Perkin-Elmer theodolite was furnished to the Visibility Laboratory by the Army Ballistic Missile Agency, Redstone Arsenal.

## 3.0 EXPERIMENTAL SETUP

### 3.1 Transmissometer

A transmissometer for the measurement of beam transmittance was designed and constructed. It consists of a light source and projection optics which transmits a narrow beam of light over a 100-foot path to a photoelectric receiver. The light source and projection optics are shown schematically in Fig. 2. The light source was modulated at a 25 cps rate. The receiver utilized a telephotometer previously designed and built by this Laboratory and known as the Telephotometer Mark IV. A sketch of this instrument is shown in Fig. 3. In initial testing the transmissometer readings were read from an A.C. voltmeter. On the basis of operating experience it was later found that the rapid fluctuations in transmission which were encountered made the meter reading technique unsatisfactory,and a demodulator-amplifier was designed and constructed. This circuit, which is shown in Fig. 4, allowed continuous chart recording of the transmission measurement.

### 3.2 Autocollimating Theodolite

The Perkin-Elmer Model 523-0005 Long-Range Theodolite was set up along a path parallel to and displaced 15 inches from the 100-foot transmissometer path. A Porro prism to simulate the reflecting optics in the missile was mounted at the far end of the path alongside the transmissometer receiver. The mounting for the Porro prism was designed such that it could be hand-

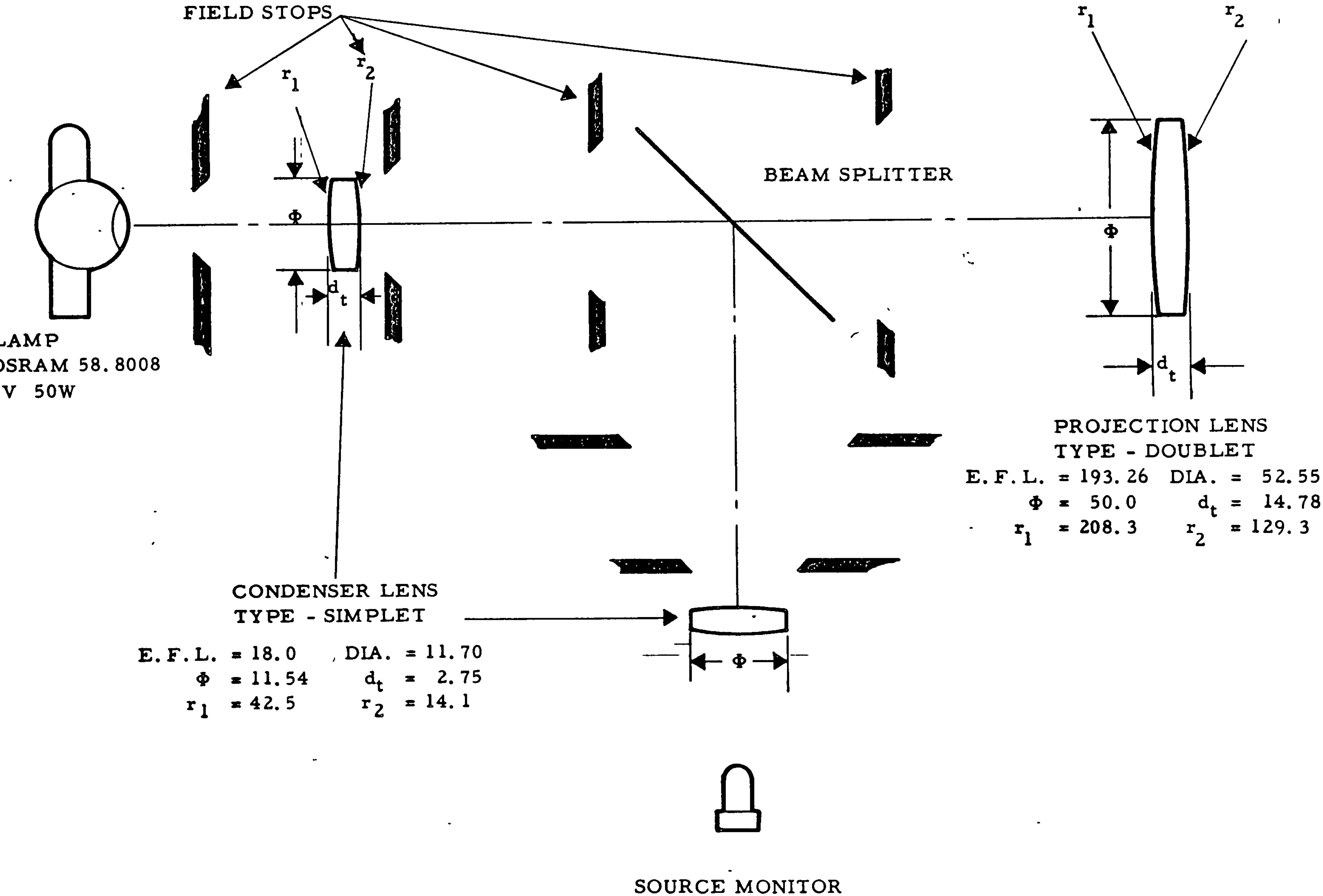


Figure 2. Sketch of Transmissometer Projector

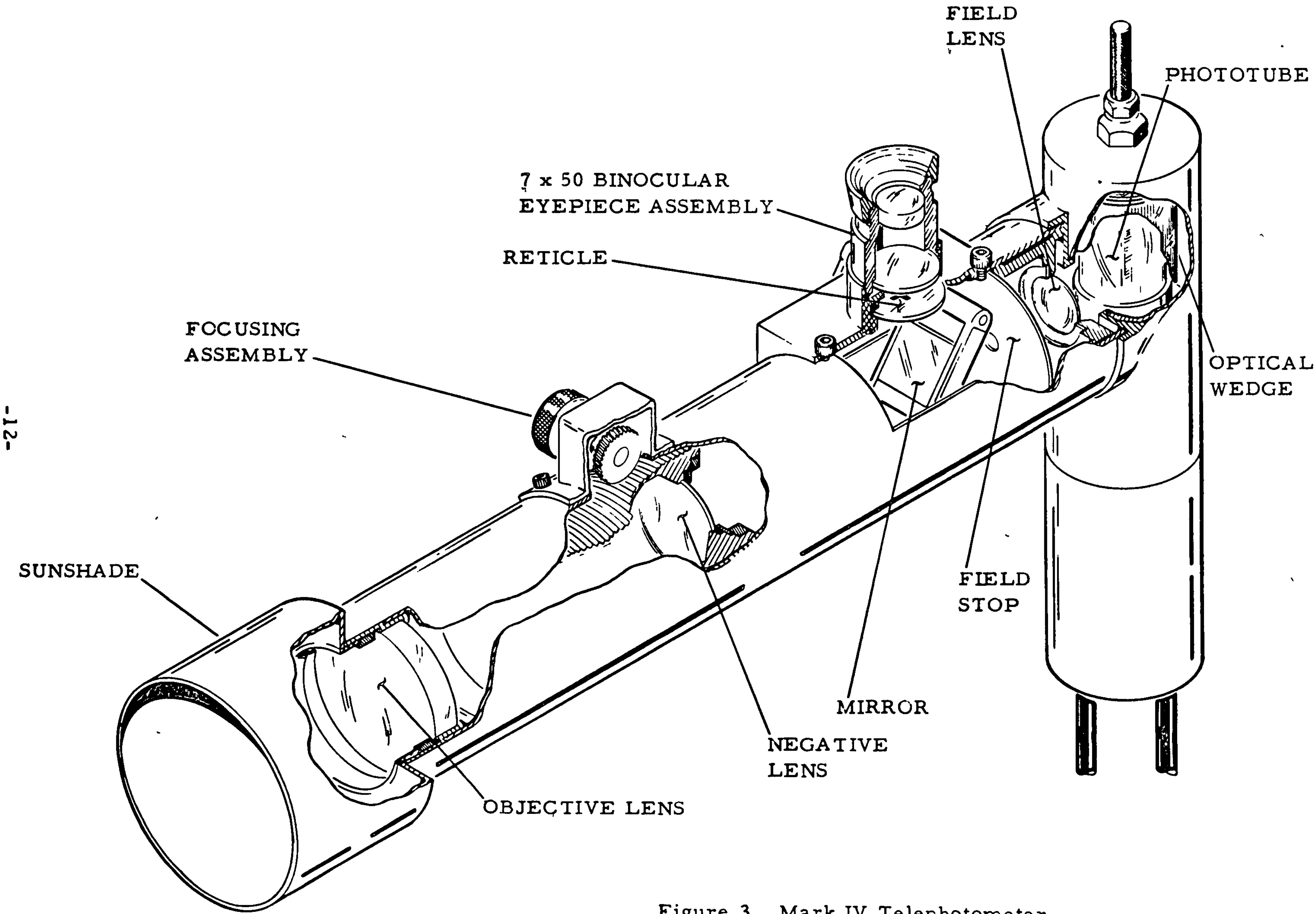


Figure 3. Mark IV Telephotometer

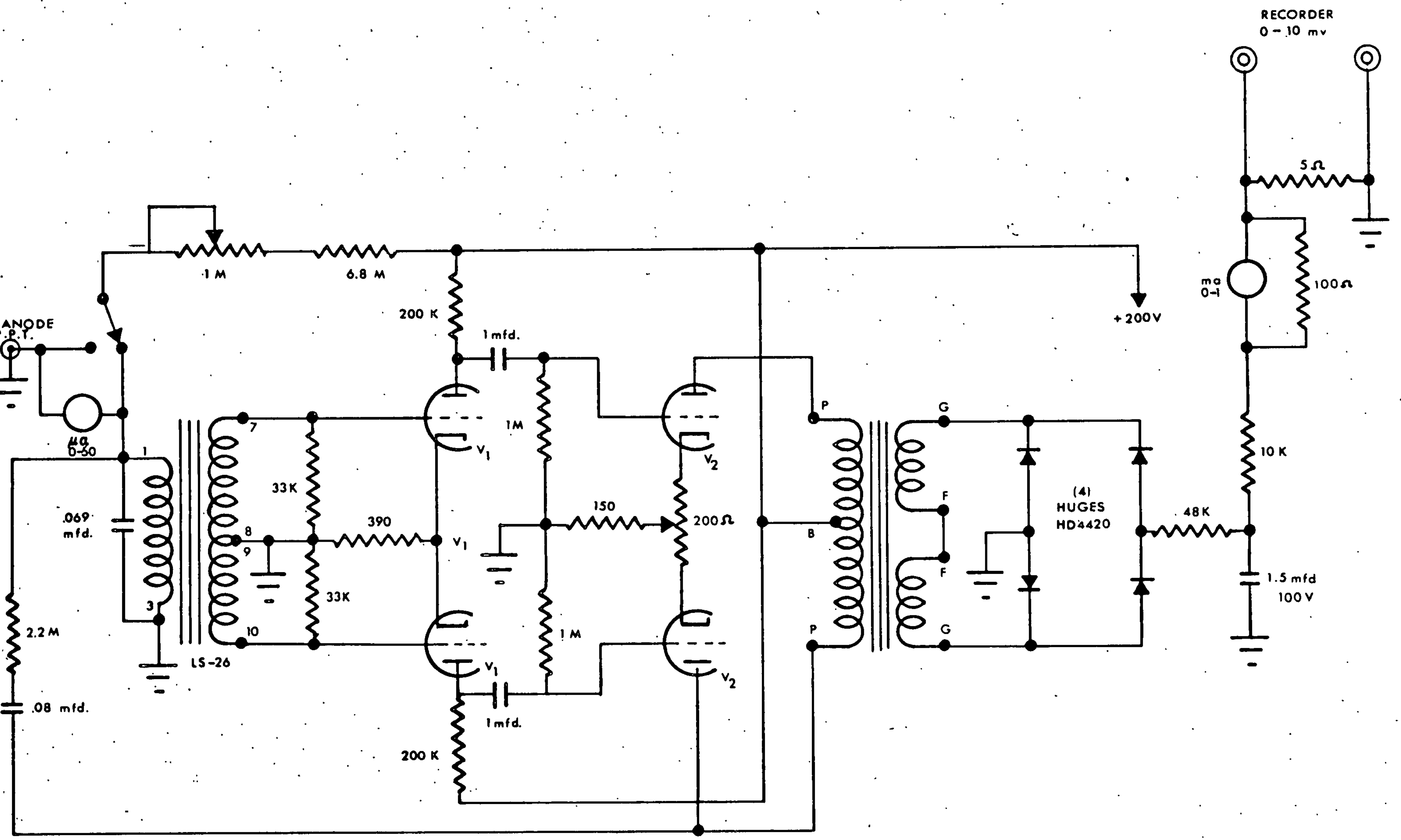


Figure 4. Fog Transmissometer Amplifier-Demodulator Circuit

positioned with a micrometer or motor-driven at a linear rate through an angle of $\pm 4$ minutes of arc. The latter arrangement made it possible to obtain a systematic recording of the error signal as a function of the error angle. This data recording, coupled with the simultaneous recording of the beam transmittance from the transmissometer, constitutes the primary experimental evidence which was collected.

## 4.0 POLARIZATION EXPERIMENTS - NATURAL FOGS

### 4.1 Polarization Techniques

Initial experimentation was conducted using both circular and linear polarization techniques. In the first of these techniques a Polaroid Corporation type HNCP37 (a linear polarizer laminated to a quarter-wave plate with axis at 45$^{\circ}$) was inserted at Position C (see Fig. 5). In this way the modulated light beams from the two sources were circularly polarized. According to Perrin's treatment (1942) radiation scattered directly backwards should be circularly polarized also but in the opposite sense. The back-scattered light in passing through the quarter-wave plate will become plane polarized again but now at right angles to the acceptance plane of the polarizer portion of the laminate and will therefore be absorbed. The signal, on the other hand, is twice reflected at 45$^{\circ}$ incidence by the metallized Porro prism and returns as circularly polarized light of proper sense to be transmitted by the circular polarizer to the detector. The insertion loss associated with the incorporation of these components in the system was

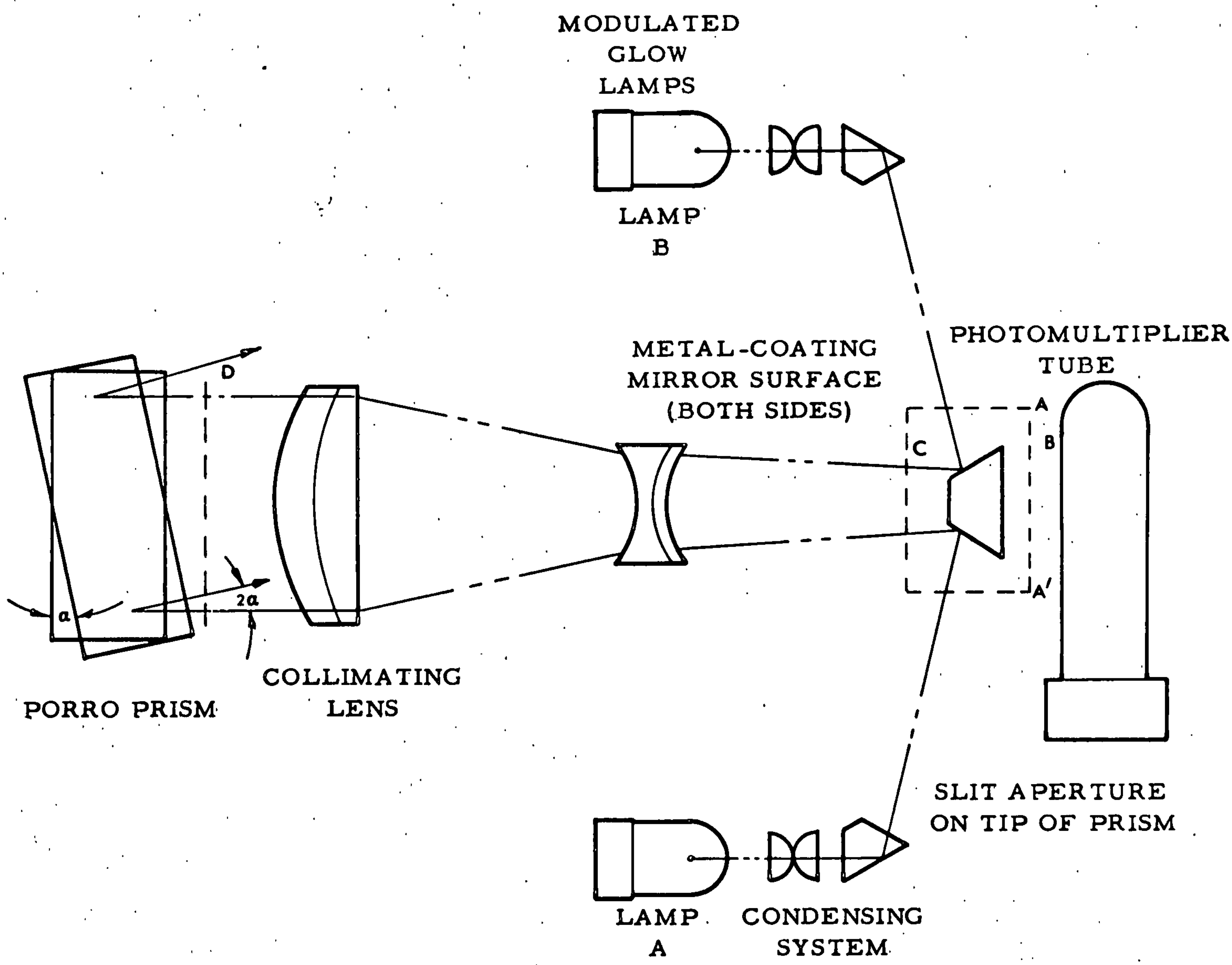


Figure 5. Schematic of the theodolite showing position of filters described in the text

calculated to be 6.3 db.

In the linear polarization technique selected specimens of HN22 or HN38 linear polarizers were placed at position A and A' as shown in Fig. 5, and a polarizer at right angles placed at B. According to the theory, the back-scattered flux will retain its polarization and therefore be absorbed by the polarizer at B. A quarter-wave plate was inserted at D in front of the Porro prism in order that the modulated beam in passing twice through the plate will undergo a 90° shift in the axis of polarization and therefore be passed by the polarizer at B. The insertion loss associated with the incorporation into the system of the polarizers and quarter-wave plate was calculated to be 12.4 db for the HN22 and 7.6 db for the HN38.

In connection with both of the polarization techniques described above, it should be noted that a quarter-wave plate can only be quarter-wave at one wavelength. To achieve any kind of significant backscatter reduction without signal attenuation, it is necessary to spectrally filter the flux at the detector since the glow modulator produces light of broad spectrum. This spectral filtering severely curtails the available signal flux at the detector. A system employing monochromatic CW laser sources would not suffer from this rather drastic limitation.

## 4.2 Experimental Results

A great deal of time was dissipated in waiting for the natural fogs which supposedly occur so frequently in the San Diego area. When natural fogs did occasionally occur they were light, as evidenced by transmissometer readings of 0.6 to 0.9 per 100 feet. In the presence of these light fogs excellent error signals were recorded, as might be expected for these relatively high transmittance values. Performance of the theodolite was good either with or without the polarization techniques. In a three-month period only one dense fog occurred. During the three-hour period of the presence of the fog, the transmission of the 100-foot path varied from 0.1 to 0.7. During this period the theodolite without polarizers functioned satisfactorily at a transmission of 0.16 but appeared to degenerate rapidly below this value. With the linear polarization technique the theodolite was operated satisfactorily during a brief period when the transmissometer was reading 0.12. This was the lowest transmission value which occurred during the time the polarizers were in position.

### 4.3 Conclusions from Natural Fog Operations

The brief period of operation described in the preceding paragraph showed promise for the polarization technique but was inconclusive because the short duration of the fog prevented the demonstration of repeatibility. The greatest single conclusion, in fact, was that the supposition that adequate testing could be achieved in natural fogs was incorrect. The great time delays associated with waiting for the occurrence of natural fogs and the rapid variability during their occurrence made further experimentation on this basis impractical.

This conclusion presented great difficulties for the project. The time delays already encountered in the project had created a situation in which the staff members needed for the project work were also needed on other research activities to which the Laboratory had prior commitments. In addition to these manpower problems, the logical next step, the generation of artificial fogs, was not a part of the planning either in terms of manpower or funding at the time that the proposal was written. Nevertheless, it was concluded that if any meaningful tests were to be performed, an artificial fog generation system must be designed and constructed.

## 5.0 EXPERIMENTS IN THE FOG TUNNEL

### 5.1 Description of the Fog Tunnel

A 2" x 2" framework was constructed along the exterior of an available building and covered with 0.06" polyethylene sheeting. The dimensions of the enclosure were 4 x 6 x 100 feet. Tents for the test equipment were placed at the ends of the tunnel. Figure 6 shows a sketch of the tunnel with the transmissometer and theodolite in position. A photograph of the completed tunnel as viewed from the top is shown in Fig. 7. An inside view looking down the tunnel toward the theodolite and transmissometer source is shown in Fig. 8. A closeup view of the theodolite and transmissometer source is shown in Fig. 9. The fog-forming nozzles were pneumatic atomizing nozzles, Spraying Systems Company type 1/4 J with fluid nozzle 60100 and air nozzle 1401110. A photograph of one such nozzle is shown in Fig. 10. Their use was suggested by Professor Marsh of the University of Pennsylvania.

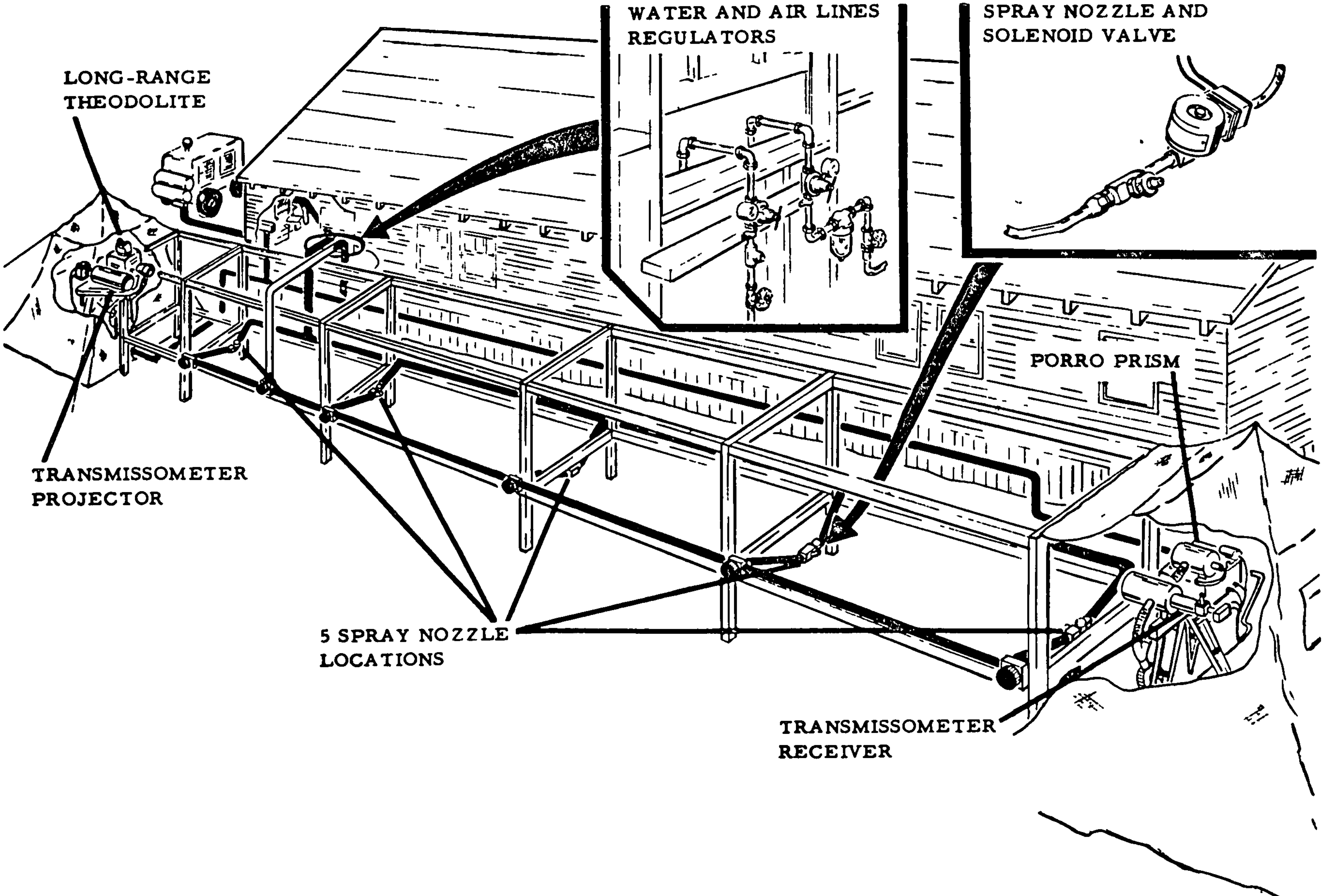


Figure 6. Sketch of the fog tunnel showing the position of spray nozzles, transmissometer, and theodolite

Figure 7. Photograph of the fog tunnel as viewed from above.

Figure 8. Photograph of the inside of the fog tunnel looking toward the autocollimating theodolite.

An alternative scheme, using ultrasonic fog-forming nozzles, was rejected because of higher initial cost and lack of evidence that performance would be superior without excessive developmental effort. Five nozzles were used, situated as shown in Fig. 6. Best performance was obtained in controlling the transmittance of the fog at levels below 20% by careful elimination of air leaks in the upper portion of the tunnel, and by mounting the nozzles at the bottom of the tunnel. Air at pressures up to 90 psig was obtained from a portable compressor and surge tank, and was distributed to the nozzles through a single solenoid valve and individual solenoid-operated valves. Water was supplied through a single solenoid valve and individual manual gate valves. After a particular arrangement had been set up manually the generation and control of artificial fog could be conducted from within the control room by means of the control panel shown in Fig. 11. The complete control station is shown in Fig. 12.

As recommended by Prof. Marsh (1957, 1962), the water flow was maintained at a constant level and the amount of fog was controlled by throttling the air supply. Droplet size distribution is a function of the air-to-water ratio, nominally 100 for air at 88 psig and water at 30 psig. Larger droplets fall more rapidly, and advantage was taken of this by waiting after preparation of a heavy fog when small drop-sizes were desired. Water pressure was a critical factor. Starting pressure had to be 45 psig or more, then had to be reduced to 32 - 35 psig to avoid overly large droplets and extreme fog density. Under favorable conditions the transmittance could be maintained at a desired level plus or minus about 0.02 over the range $0.05 \leqslant T \leqslant 1.00$ by pulsing the air supply to the nozzles.

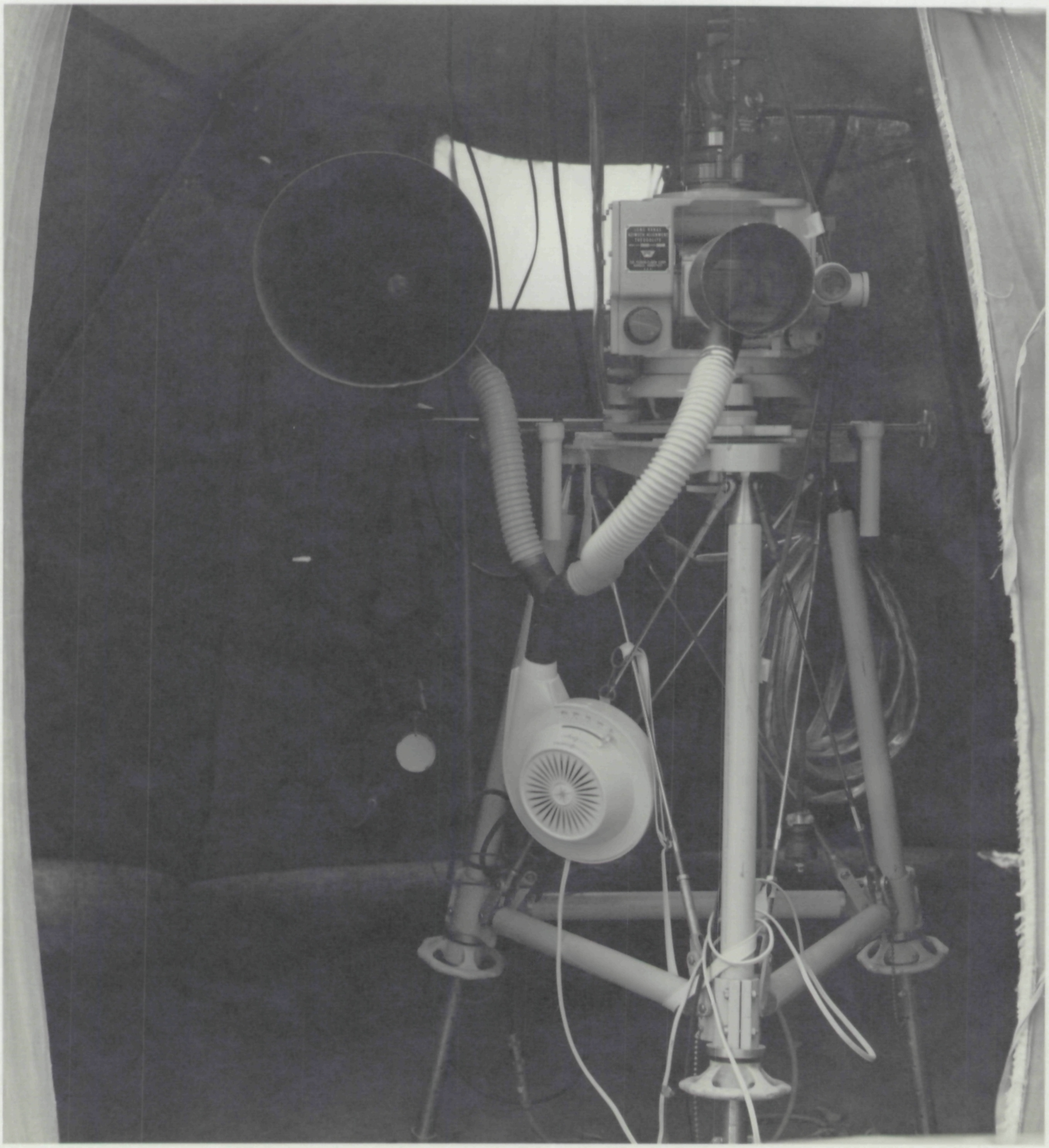

Figure 9. Closeup view of the tent-enclosed transmissometer source and theodolite.

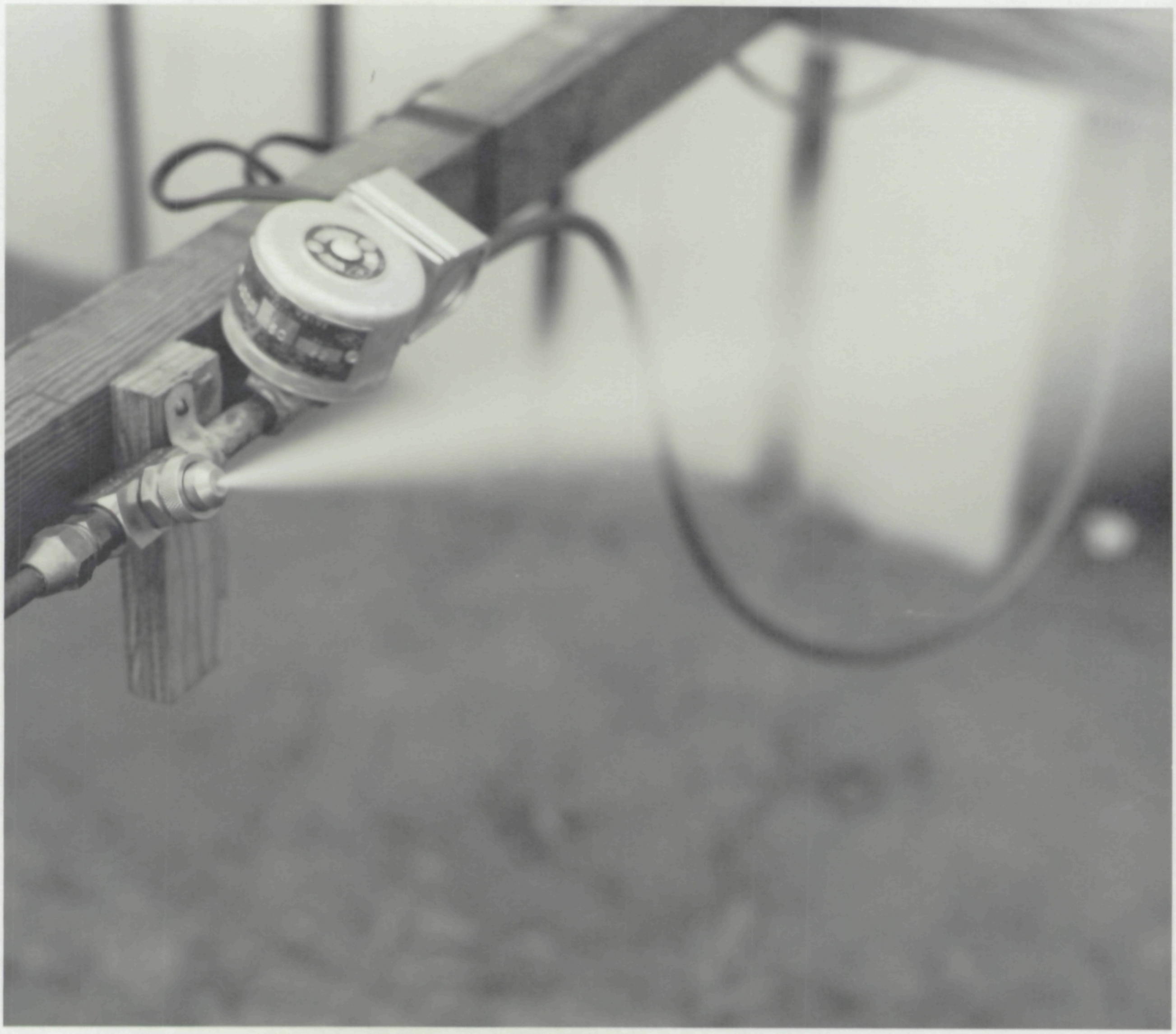

Figure 10. Photograph of one of the spray nozzles and valves.

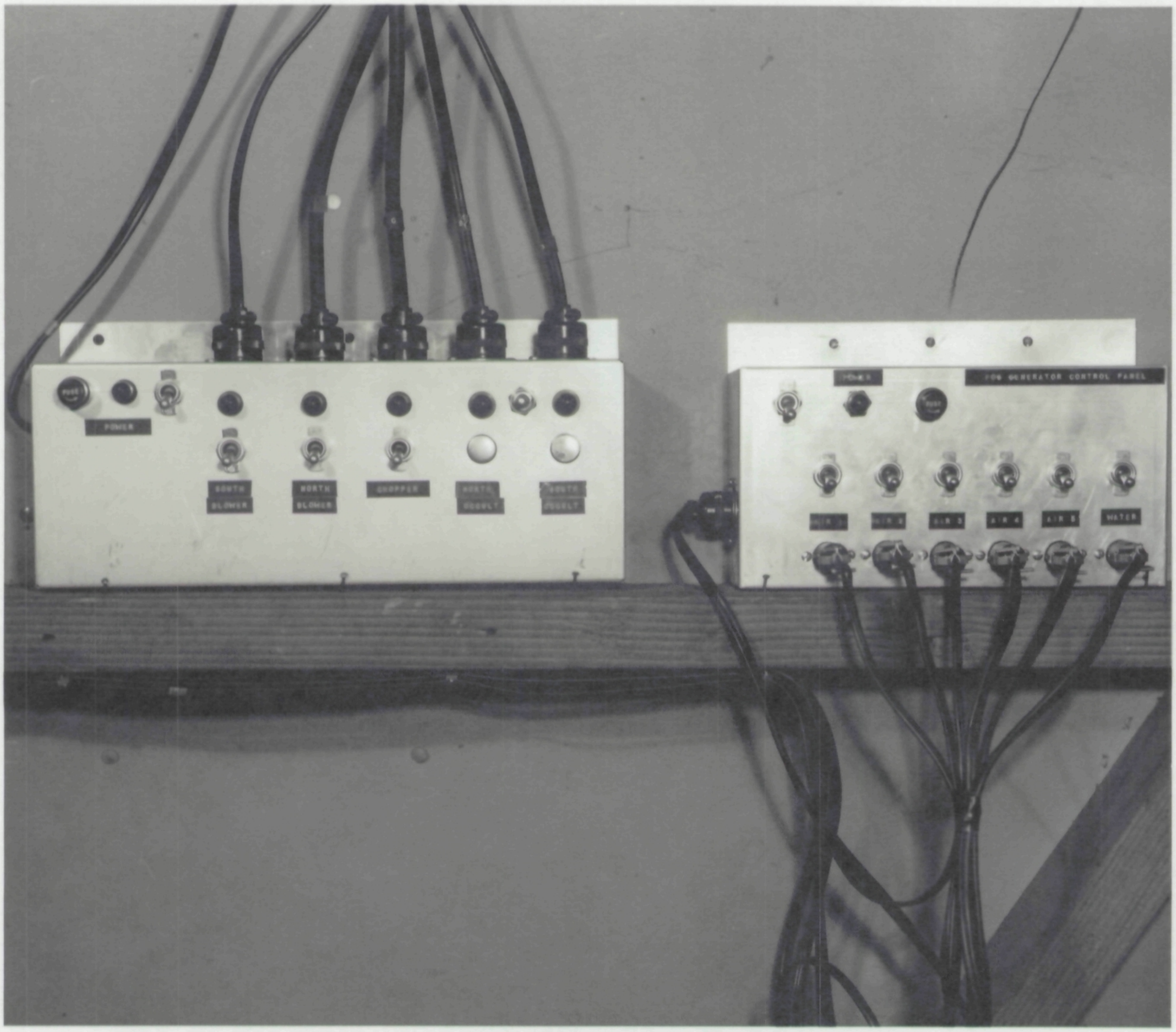


Figure 11. Photograph of the fog generating control panel

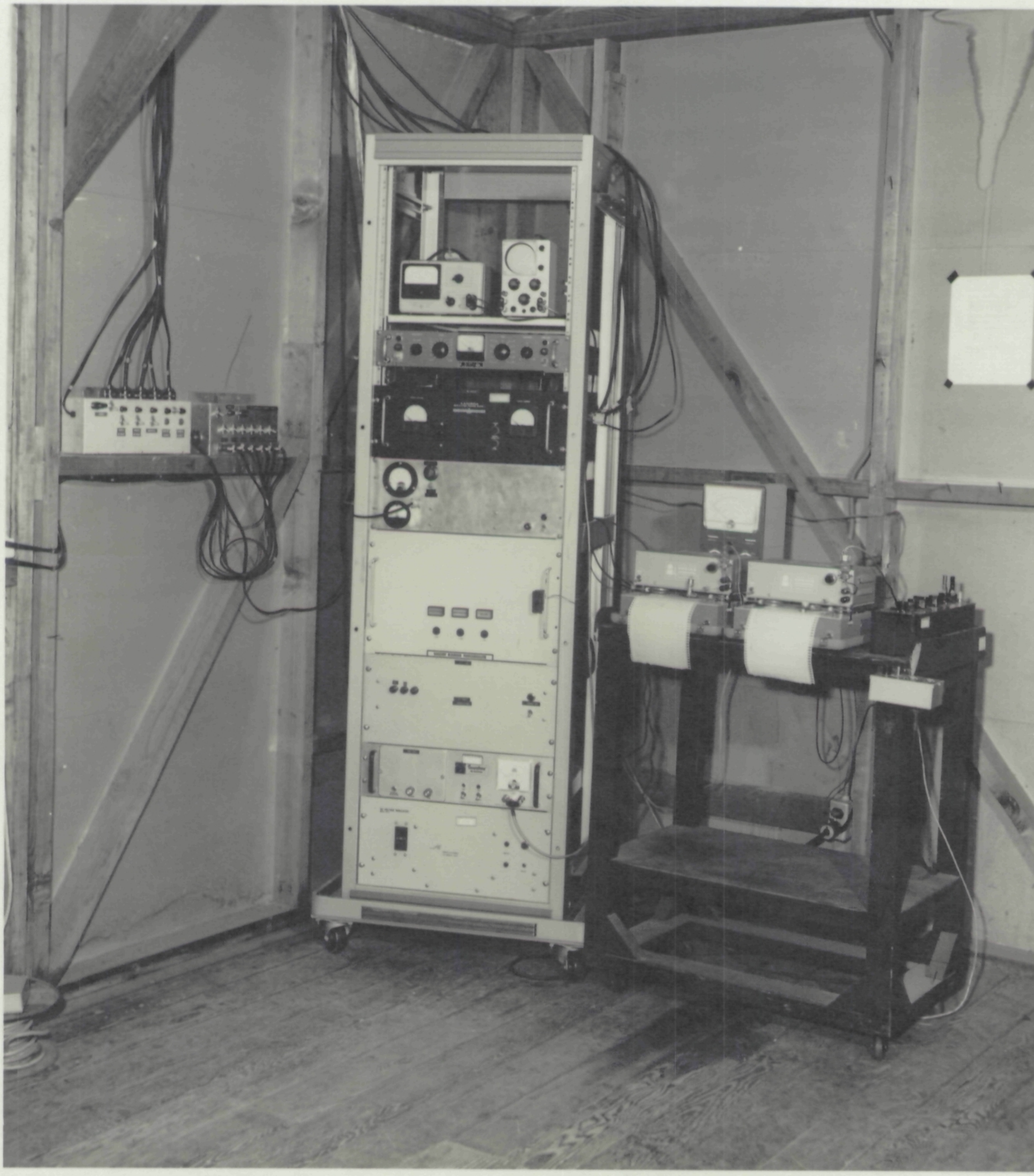

Figure 12. Photograph of the complete control station.

## 5.2 Experimental Results

A great many hours of experimentation was performed with error signals documented for normal unfiltered operation, operation with a Wratten No. 21 filter over the photocell, operation with the circular polarization technique, operation with the linear polarization technique for both types of linear polarizers and combinations thereof. These experiments can be summarized by stating that as the transmission of the path was reduced to the order of 0.1 the data points became wildly scattered regardless of which mode of operation was being utilized. At no time did any clean, repeatable experiment indicate performance improvement with the use of polarization techniques.

The quantitative results of this program of research are best documented in one particular set of experiments. In this particular set of experiments the 800-cycle acquisition signal (the sum of the returns from both glow modulator tubes) was recorded as a function of transmittance of the 100-foot path. Recordings were taken under three conditions, (1) normal operation of the equipment, (2) an occulting disk lined with black Norzon was placed in front of the entrance pupil of the optical system, and (3) an occulting disk was placed in front of the Porro prism. The purpose of the occulting was to establish the relative values associated with the signal and scattering components. With occulting over the entrance pupil of the theodolite the measurement of the acquisition signal should indicate the system noise level (plus any internal scattering and/or scattering from the occulting device.) With occulting at the Porro prism the return signal is eliminated and the reading should indicate system noise plus internal reflections plus backscatter from the light beams plus noise produced by scattering of ambient light into the system. With no occulting, the reading should be due to the factors above plus the signal from the return light beam plus any forward scattering associated with the return light beam. This entire set of measurements was repeated with a Wratten No. 21 red filter inserted in front of the photocathode of the multiplier phototube, and again with the quarter-wave plate and linear polarizers inserted in the system. The results of these experiments are shown in Table I.

A number of inconsistencies in the data are apparent. The readings at 100% transmittance show a higher value for occulting at the entrance pupil that for occulting at the Porro prism. It would seem likely that this is due to an appreciable reflection from the occulting paddle. It is difficult to rationalize the decrease in the readings for occulting at the entrance pupil which takes place as the transmittance is reduced. The values drop as the transmittance is reduced from 100% to 40-50% and then seem to be uncorrelated with beam transmittance. For the unfiltered case with occulting at the Porro prism the reading is once again highest for the case of 100% transmission.

In spite of the inconsistencies in the data the experiment serves to emphasize one extremely important fact. Polarization techniques can be expected to improve performance <u>if and only if</u> the normal system operation is limited by backscattering of the modulated light beam. The data tabulated under conditions of

| Transmittance | Occulting at Entrance Pupil | Occulting at Porro Prism | No Occulting |
|---|---|---|---|
| | **Unfiltered** | | |
| 100 | 140 | 70 | 2500 |
| 40-50 | 62 | 54 | 800 |
| 15-20 | 50 | 55 | 150 |
| 15 | 50 | 56 | 150 |
| 10-15 | 64 | 49 | 100 |
| | 50 | 55 | 100 |
| 10-20 | 49 | 62 | 82 |
| 8-10 | 50 | 54 | 80 |
| | 50 | 50 | 65 |
| | **Wratten No. 21 Filter** | | |
| 100 | 40 | 24 | 750 |
| 30-40 | 28 | 71 | 85 |
| 30 | 20 | 48 | 100 |
| 20-30 | 25 | 57 | 62 |
| 15-20 | 26 | 60 | 52 |
| 15-20 | 25 | 65 | 100 |
| | 20 | 64 | 80 |
| 10-20 | 26 | 65 | 72 |
| 10-20 | 22 | 54 | 60 |
| 10-20 | 25 | 60 | 64 |
| 10 | 20 | 62 | 64 |
| | **Quarter-wave Plate and Linear Polarizers** | | |
| 100 | 39 | 39 | 620 |
| 30-45 | 23 | 51 | 170 |
| 25-30 | 24 | 40 | 100 |
| 20 | 25 | 55 | 100 |
| 15-20 | 23 | 33 | 39 |
| 15-20 | 26 | 54 | (68) |
| 10-20 | 28 | 62 | 58 |
| 10-15 | 24 | 33 | 32 |
| | 23 | 32 | 34 |
| 10-15 | 26 | 60 | 62 |
| 5-10 | 25 | 48 | 50 |
| 5-10 | 26 | 60 | 61 |
| 10 | 27 | 58 | 61 |
| 0-5 | 25 | 44 | 48 |

Table I

occulting at the Porro prism indicate that the system is not limited by backscatter from the modulated beam. The alignment signal is plotted as a function of transmittance readings for the three filtering conditions in Figs. 13, 14, and 15. The data plots show considerable scatter but, more importantly, fail to show the strong relationship between beam transmittance and signal reading which would occur if backscatter from the modulated light source was limiting the system operation. The graphs tend to indicate that the readings are to a first approximation uncorrelated with beam transmittance. It is therefore concluded that for this particular theodolite used under the conditions outlined, backscatter from the modulated light source does not limit the operation of the system and polarization techniques could not be expected to improve performance.

## 6.0 CONCLUSIONS

It is concluded that the performance of the Perkin-Elmer Model 523-0005 Long-Range Theodolite in the configuration used in this study is not limited in performance by the backscattering from the modulated light beam and therefore its performance will not be improved by the incorporation of backscatter-reduction polarization techniques. This conclusion might not apply to a theodolite system specifically designed for use of polarization techniques and employing high intensity light sources of narrow spectral bandwidth. Consideration of the design of new equipment was specifically stated to be beyond the scope of this study. A fundamental determination of the relative magnitudes of the various flux components received by the photoelectric sensor to determine the relative significance of backscatter should be made before polarization techniques can warrant further exploration for use in autocollimating theodolite applications.

The alternative approaches to this problem such as high intensity pulsed sources, operations in regions of the spectrum other than the visible portion, fog elimination and dissipation techniques, etc., were beyond the scope of this study and this report does not therefore draw conclusions as to the feasibility of these techniques.

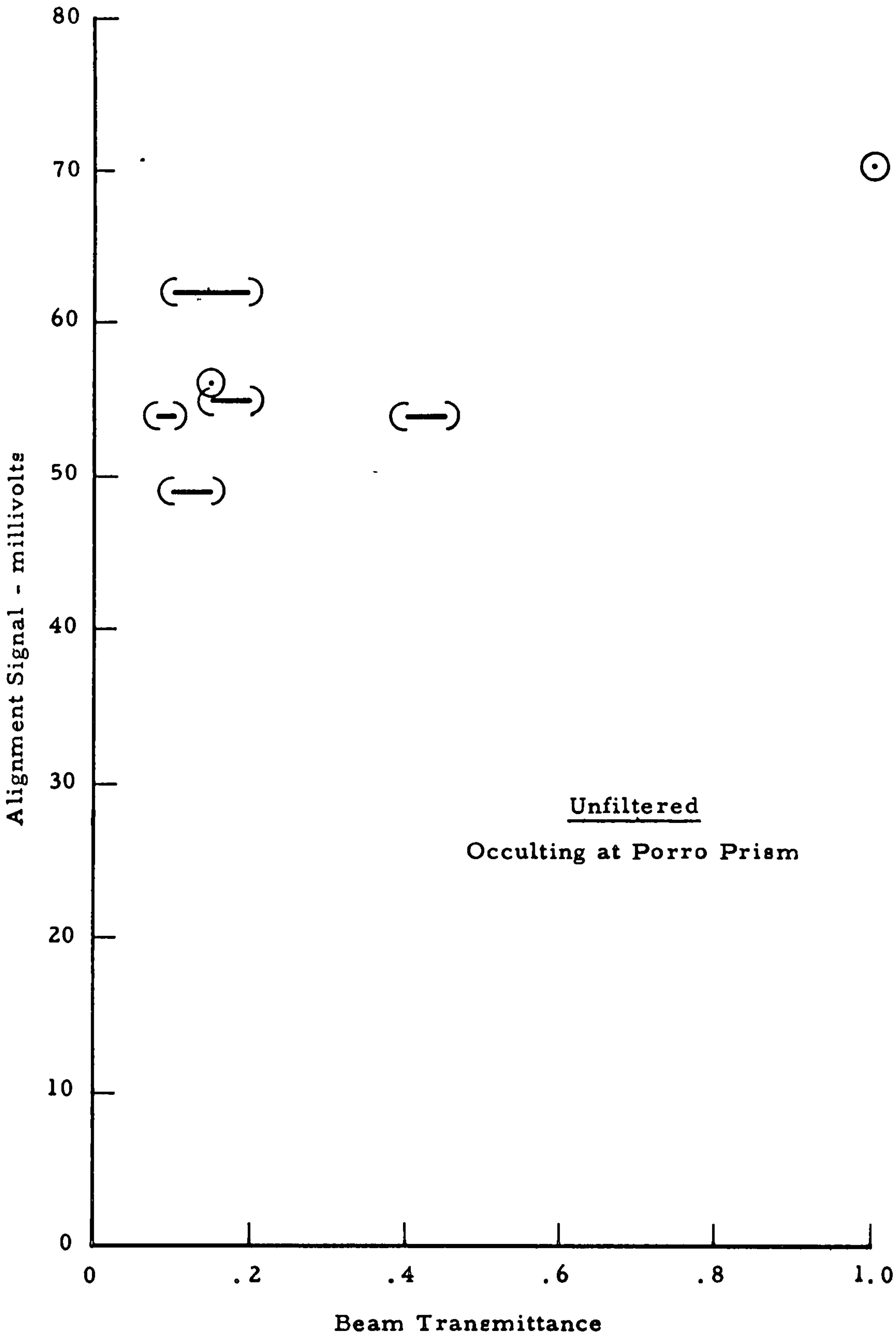
80
70
60
50
40
30
20
10
0
Alignment Signal - millivolts
Unfiltered
Occulting at Porro Prism
0
.2
.4
.6
.8
1.0
Beam Transmittance

Figure 13

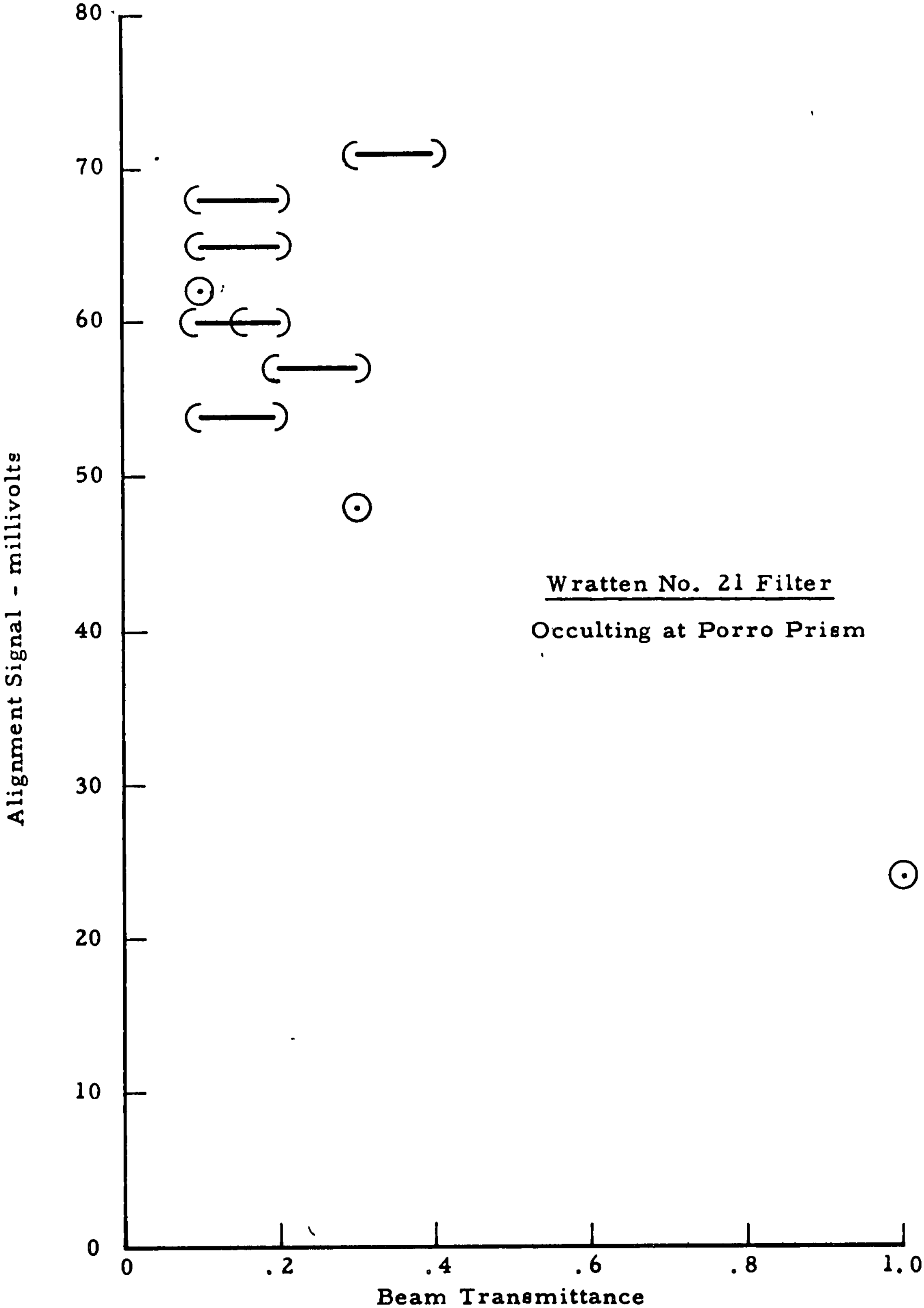
80
70
60
50
40
30
20
10
0
Alignment Signal - millivolts
Wratten No. 21 Filter
Occulting at Porro Prism
0
.2
.4
.6
.8
1.0
Beam Transmittance

Figure 14

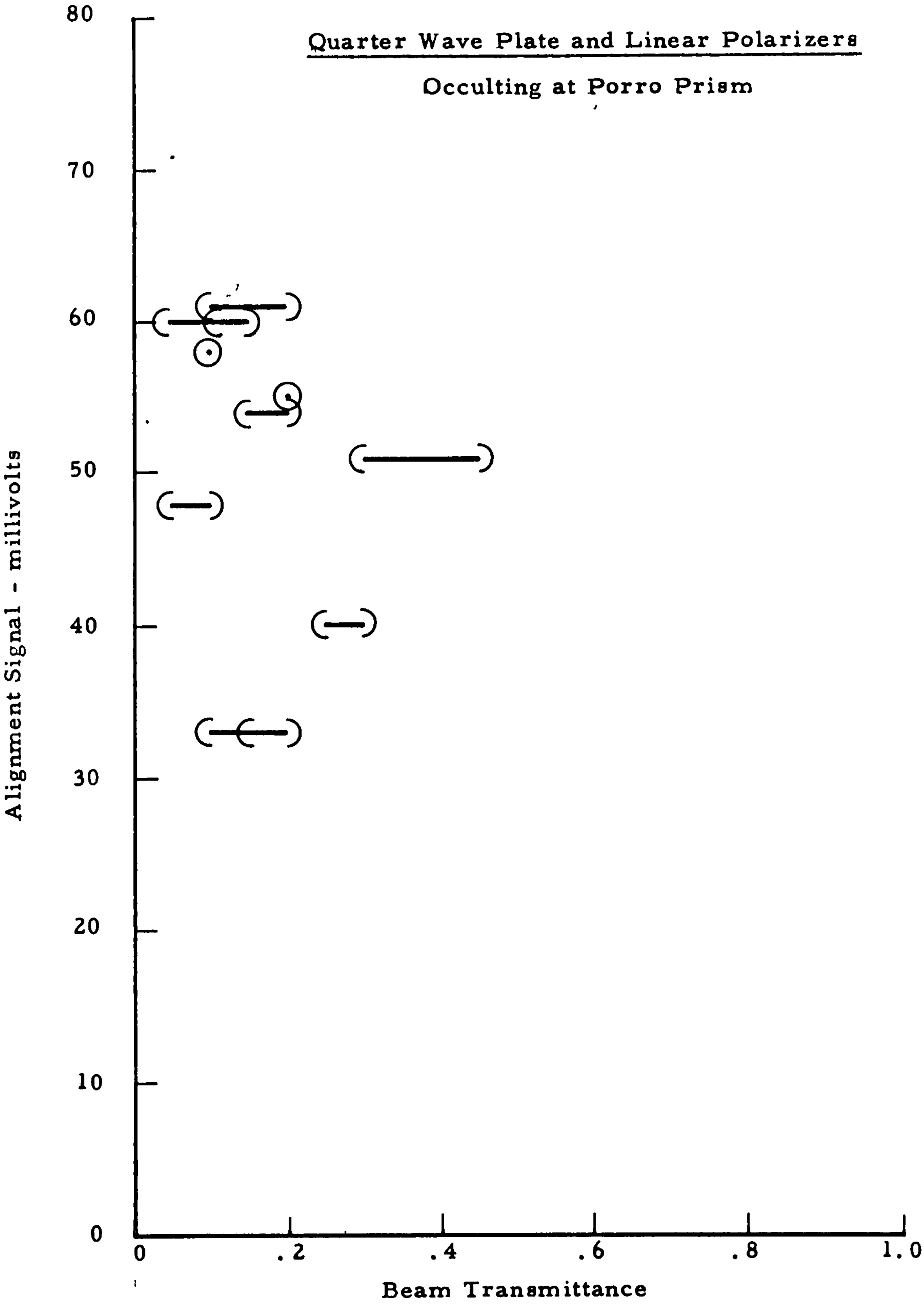
Quarter Wave Plate and Linear Polarizers
Occulting at Porro Prism
80
70
60
50
40
30
20
10
0
Alignment Signal - millivolts
0
.2
.4
.6
.8
1.0
Beam Transmittance

Figure 15

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