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MULTIWAVELENGTH LASER PROPAGATION STUDY

Quarterly Progress Report No. 2

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for Study and Research  
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## SUMMARY

The major objective of this program is to experimentally investigate the wavelength-dependence of turbulence effects on optical propagation through the atmosphere, and to relate the results to certain meteorological parameters, theoretical models, and model-independent dimensional analyses. The experiments are conducted with the use of simultaneous, spatially-coincident laser beams at three wavelengths in the visible and infrared spectrum, with real-time processing for the various statistical results.

A particular motivation is to establish the validity of wavelength-scaling laws as applied to a growing body of experimental data at visible wavelengths, in order to predict and optimize the performance of systems operating at certain infrared wavelengths. Techniques are emerging which will place great practical value on reliable predictions of turbulence effects for a given site and conditions.

During the second period, the low noise, stable lasers were acquired, the three-wavelength transmitter and receiver optical systems were constructed, and the computer electronics were completed. A newly acquired, flat site was established with necessary power, cooling, communications, and protective arrangements. The above systems are currently being installed at the site. The resultant facility will be uniquely suited to atmospheric propagation work, in terms of multiwavelength capability, data processing versatility, meteorological instrumentation, and attention to experimental detail necessary to achieve reliable results in this difficult field of investigation.

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## I. INTRODUCTION

The motivation and approach for this multiwavelength laser propagation study was described in Quarterly Progress Report No. 1. During the second period, the transmitter optics, receiver optics and mechanical system, computer electronics, and general meteorological electronics were constructed. A new, flat, one-mile site was established, and the above systems are currently under installation. The resultant facility will permit simultaneous, congruent-path measurements at three widely-separated wavelengths, with versatile data-processing capabilities and considerable attention to experimental detail.

The resultant measurements should aid significantly in the evaluation of current theoretical models and model-independent dimensional reasonings. In particular, although the analytical understanding of propagation through a random medium is improving, especially for conditions of strong turbulence or "saturation,"<sup>1,2,3</sup> the fundamental assumption of local isotropy and an inertial subrange<sup>4</sup> is highly questionable under many conditions.<sup>5,6,7</sup> That is, the degree of theoretical understanding may be more limited by considerations of atmospheric physics than by perturbation mathematics. These points will be discussed in later reports.

## II. EXPERIMENTAL PROGRESS

During the second period, the systems described in Quarterly Progress Report No. 1 were constructed, evaluated, and calibrated. This work will be briefly described here.

## A. TRANSMITTER SYSTEM

The three-wavelength, combined-beam transmitting system has been completed and is shown in Figures 1 and 2. The three lasers were chosen for their stability and noise characteristics. Beams from the lasers are separately formed into f-32 cones and combined using dichroic optics. The focal planes of each beam coincide at the focus of a 6-inch Newtonian telescope, which is partially illuminated (off-axis) to avoid aperturing. The resultant beams leaving the transmitter are 1.5 inches in diameter, and are diffracted and/or defocused to result in a 1 meter spot at the receiver. Pointing is achieved by means of a gimballed mirror and fine steering of the entire telescope. The telescope mirrors are hard-aluminum-coated, with no overcoating which would interfere with performance at 10 microns. The entire system is mounted on a massive steel table.

The pertinent transmitter parameters are summarized in Table I.

Table I - - Transmitter Parameters

| <u>Wavelength</u> | <u>Laser Type</u>        | <u>Laser Power (TEM<sub>00</sub>)</u> | <u>Laser Noise (rms)</u> | <u>Optical Transmission (includes barium fluoride window)</u> |
|-------------------|--------------------------|---------------------------------------|--------------------------|---------------------------------------------------------------|
| 4880 A            | Argon                    | 0.9 Watts                             | 0.96%                    | 22%                                                           |
| 1.15 $\mu$        | He-Ne                    | 10 mW                                 | 0.53%                    | 17%                                                           |
| 10.6 $\mu$        | CO <sub>2</sub> (sealed) | 8 Watts                               | 0.1%                     | 68%                                                           |

The transmitted beams are chopped at 9 kHz using a precision chopping wheel which was developed for the purpose (Figure 3). The wheel is located at the focal plane of the telescopes and mechanical imperfections (such as wobble) are negligible.

## B. RECEIVER SYSTEM

As described in Quarterly Progress Report No. 1, the primary receiver consists of a variable-separation mirror drive for spatial correlation measurements, followed by a dichroic mirror and spike filter system to separate each wavelength into its appropriate detector. The system is shown in Figure 4. The rate of separation is variable down to a fraction of one cm/sec, and angular steering is negligible.

The detectors and associated electronics have been chosen and developed for maximum dynamic range, which is essential in log-amplitude data processing. At the visible and near-infrared wavelengths, appropriate photodiodes are mounted in modules with FET front-end and buffer amplifiers. At 10 microns, Ge:Hg dewars are connected directly to front-end modules. One set of detectors is shown in Figure 5.

The receiver characteristics, taking into account the use of 3 mm apertures with a 1 meter diameter beam, are summarized in Table II. The resulting SNR is based on quiet (non-scintillating) conditions. It is evident that sufficient signal will be present at 2 wavelengths to fully utilize the 80 dB dynamic range of the logarithmic electronics in the computer. At 1.15 microns, under conditions of strong scintillation, variances should be computed from the probability curves.

A special detector with a larger collecting aperture is utilized at 4880 Å to provide a reference of the chopping signal, for purposes of synchronous demodulation.

Table II -- Receiver Parameters

| <u>Wavelength</u> | <u>Detector Type</u>                  | <u>Receiver Optical Transmission</u> | <u>Received Optical Power at Detector</u> | <u>SNR (1 kHz bandwidth)</u> |
|-------------------|---------------------------------------|--------------------------------------|-------------------------------------------|------------------------------|
| 4880 A            | Silicon photodiode, ultra-low leakage | 32%                                  | $8 \times 10^{-7}$ W                      | > 80 dB                      |
| 1.15 $\mu$        | Infrared silicon photodiode           | 13%                                  | $10^{-8}$ W*                              | 35 dB                        |
| 10.6 $\mu$        | Ge:Hg                                 | 76%                                  | $5 \times 10^{-5}$ W                      | > 80 dB                      |

\*The radiation at 1.15 microns is defocused in one plane only, to decrease geometrical loss and conserve signal.

### C. COMPUTER ELECTRONICS

The special-purpose analog computer described in Quarterly Progress Report No. 1 has been completed. The basic elements are shown in Figure 6. There are six buffer - synchronous demodulator stages, one of which is shown on the left. These are followed by three log-correlation and probability-curve units, one of which is shown on the right. The rack-mounting control panel is shown in the center of Figure 6. The dynamic range is 80 dB, and averaging times of up to 100 seconds are provided.

The resultant data will be recorded on a four-track FM instrumentation tape recorder, Sony Type PFM-15. One track will be used for each wavelength, while the fourth track provides identification and a reference

such as mirror separation (cross correlations) or reference amplitude (probability density). These results will then be plotted on a chart or XY recorder and/or used for further (digital) processing.

It is worth noting that the small laser noise levels (less than 1% each) will not affect the dynamic range performance discussed above. The only effect of this noise will be to contribute to errors in very small variances or cross-correlations; these are not of particular practical importance.

#### D. METEOROLOGICAL INSTRUMENTATION

The system for the determination of the refractive index structure constant,  $C_N^8$ , is under construction as described in the previous report. Equipment has been assembled for the continuous recording of pressure, humidity, temperature, wind velocity, and wind direction.

#### E. SITES

Buildings have been installed on a new, flat propagation path of approximately one mile in length, at a field 14 miles from the Center. The shacks are insulated and heated, and provided with double locks and remote alarms against vandalism. The transmitter shack (Figure 7) has been provided with three-phase power for the argon laser, as well as an external heat exchanger and pump for recirculating laser cooling water. The receiver shack (Figure 8) is provided with a slit opening for spatial correlations and a large opening for aperture-averaging measurements. The two shacks and the Center are linked by radio.

### III. PLANS FOR THE NEXT PERIOD

The systems described above are now being installed at the new site. The logistics of establishing a new site, with zoning, power, and communications problems, combined with the late delivery of a number of major and

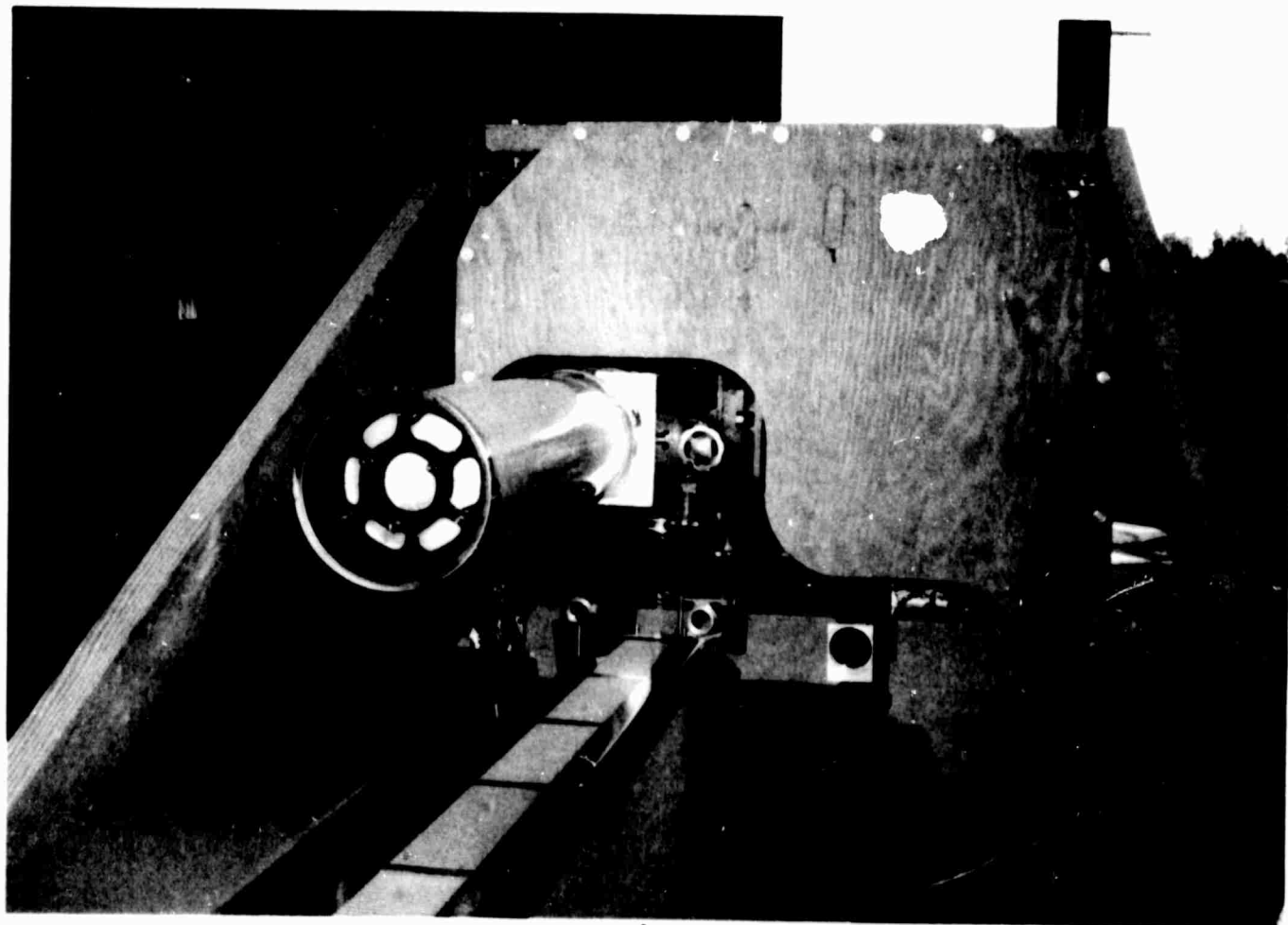
minor optical and electronic components, have resulted in our being delayed from our original schedule by several weeks. However, the versatile capability of the facility should justify this delay, and we expect to be taking three-wavelength data in the near future.

### References

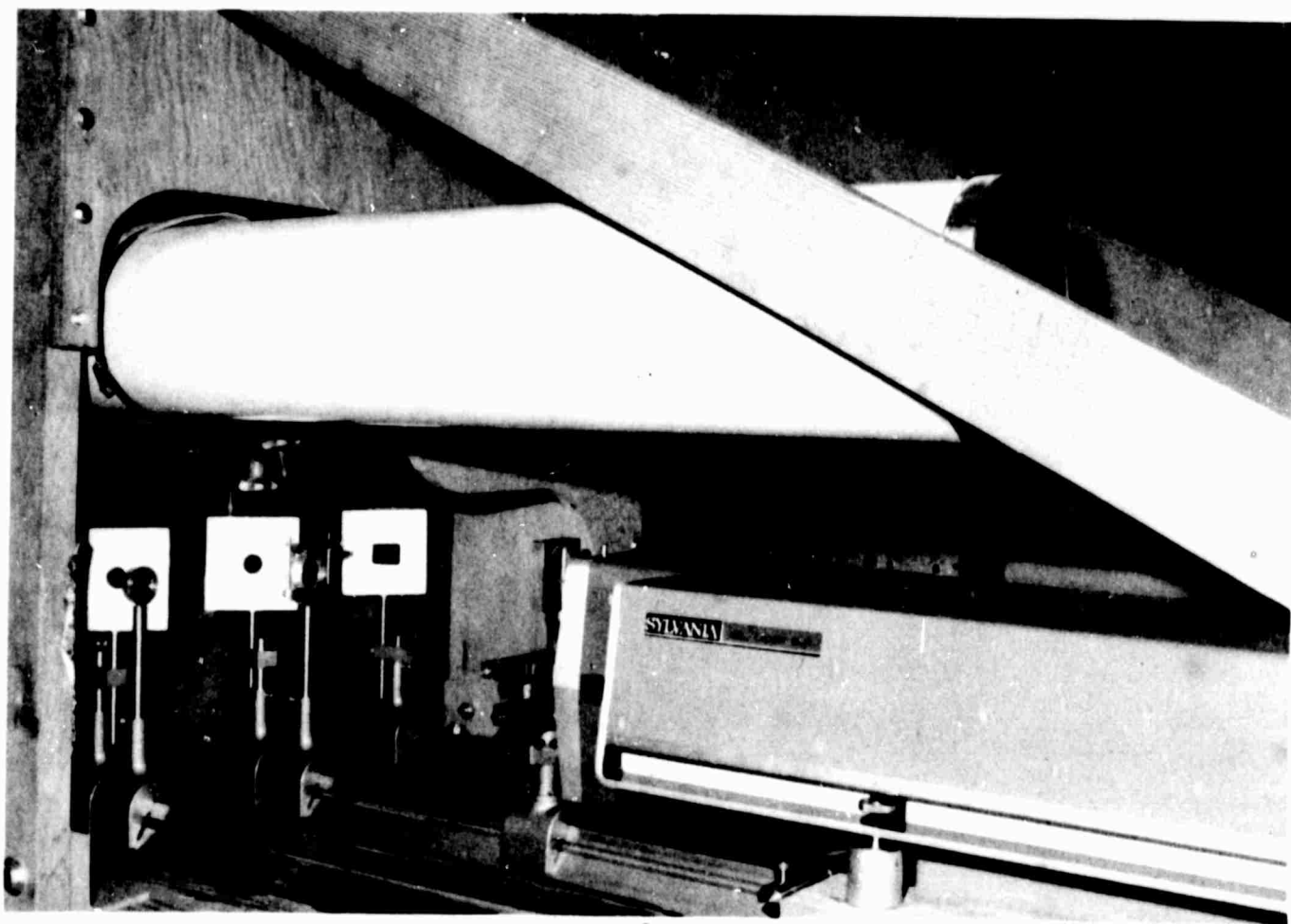
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## CAPTIONS TO FIGURES

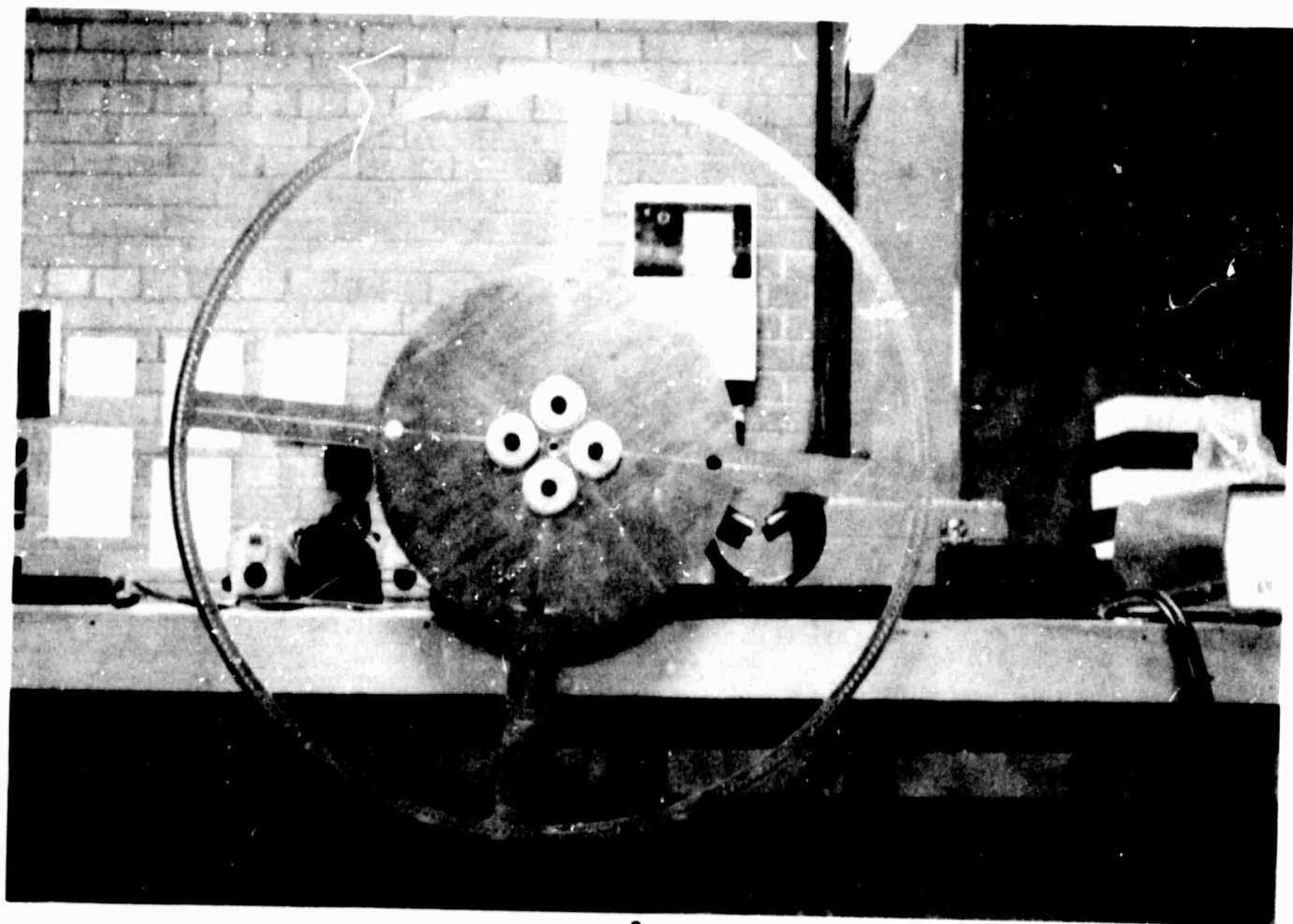
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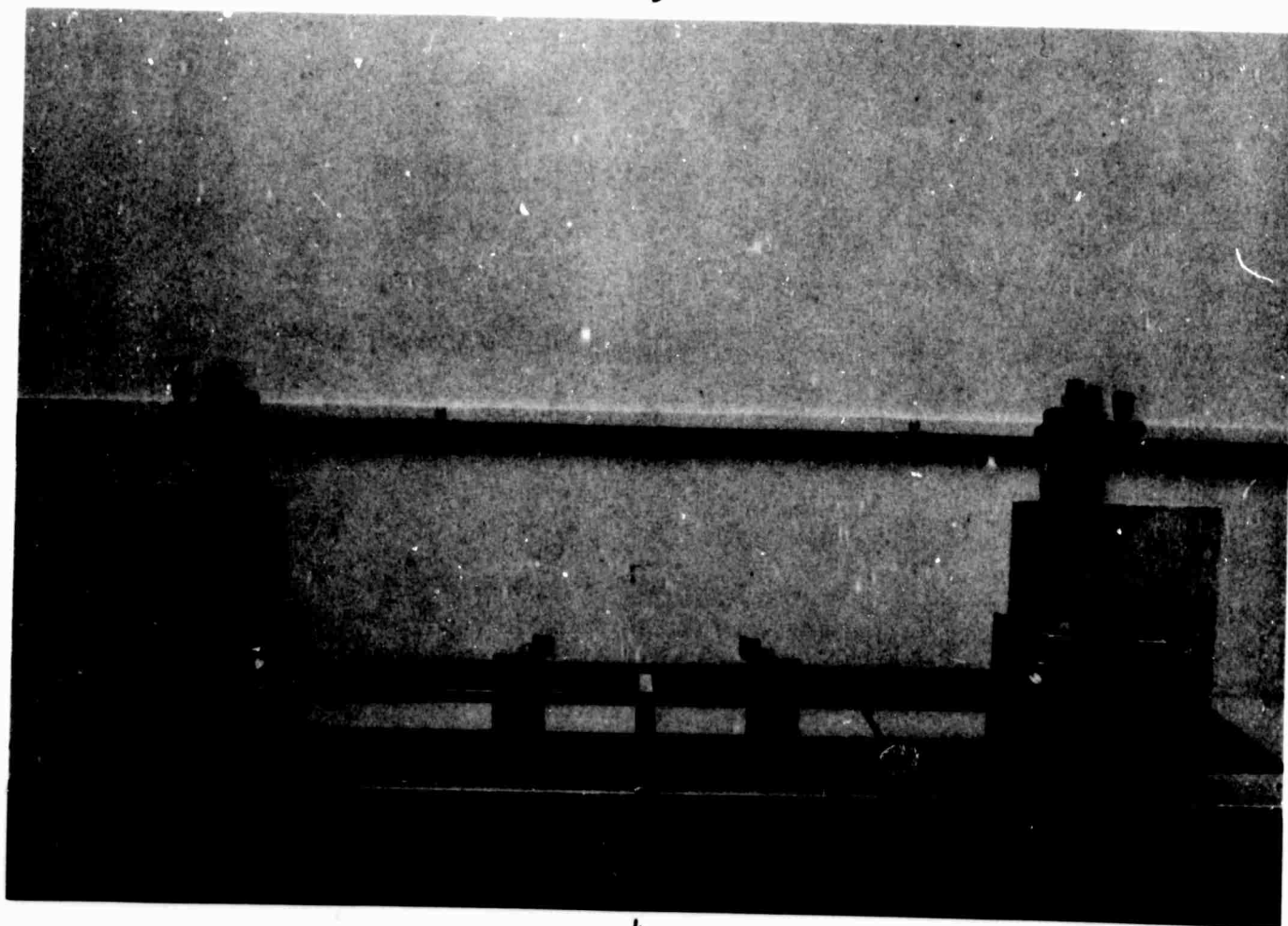
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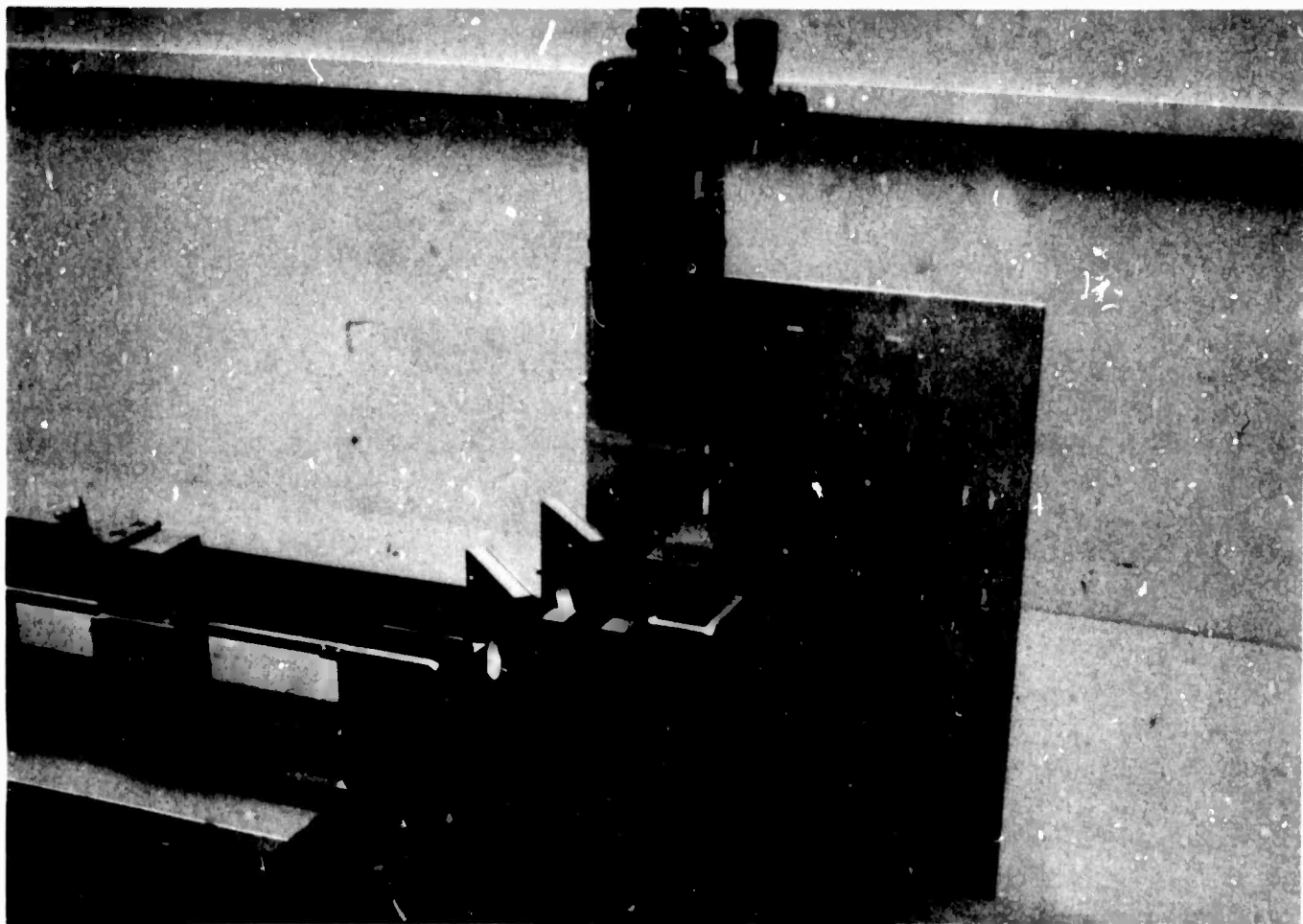
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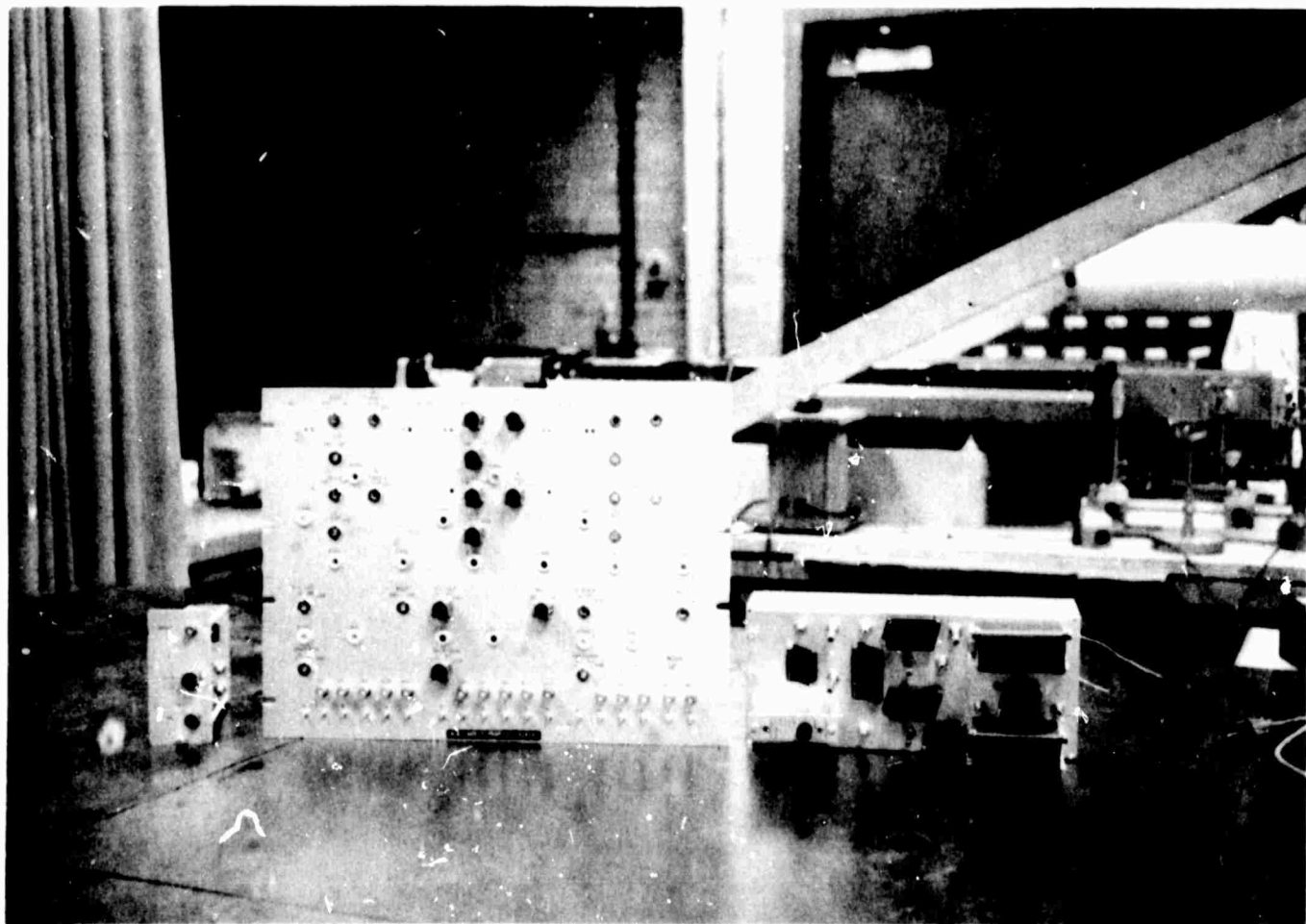
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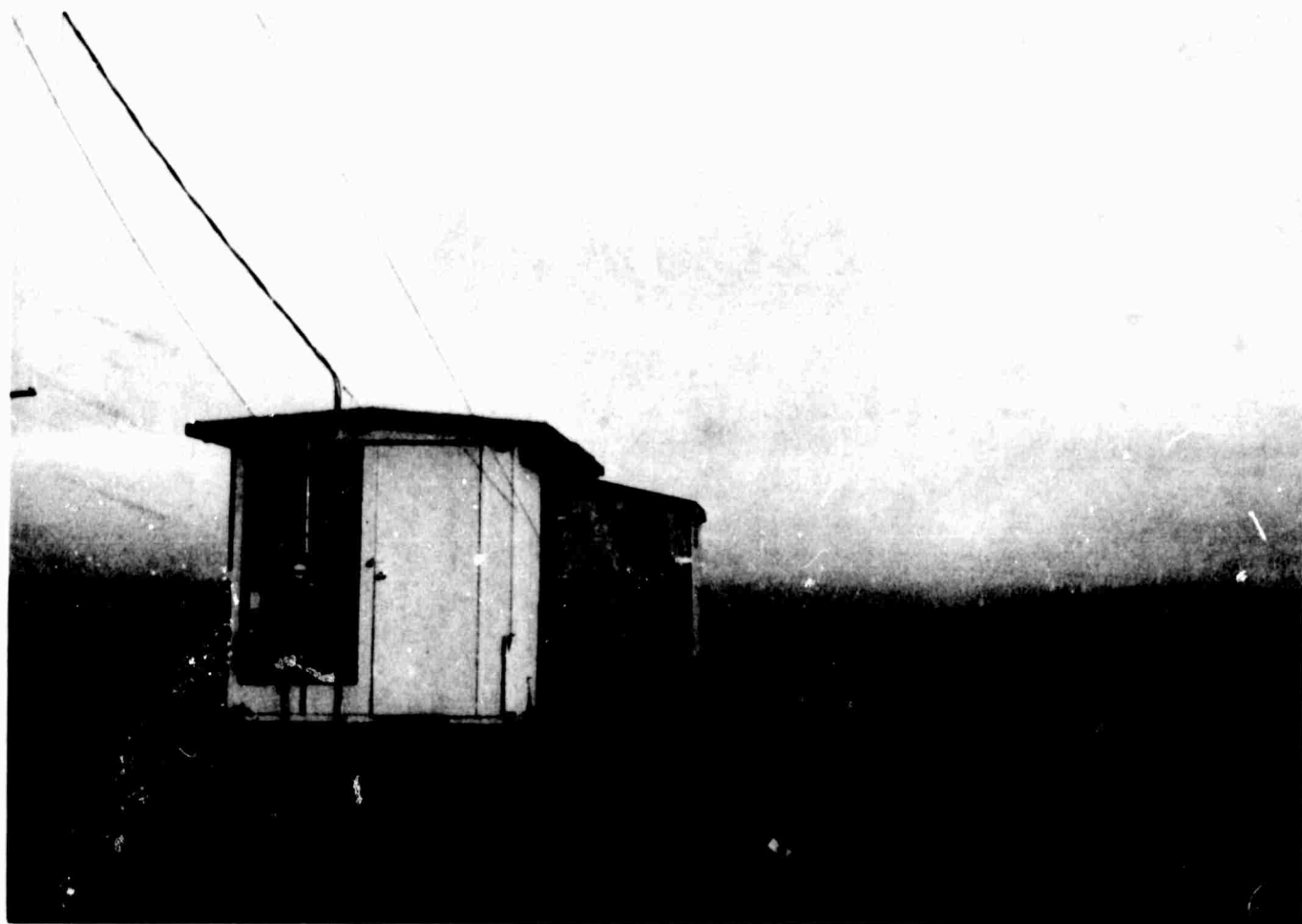
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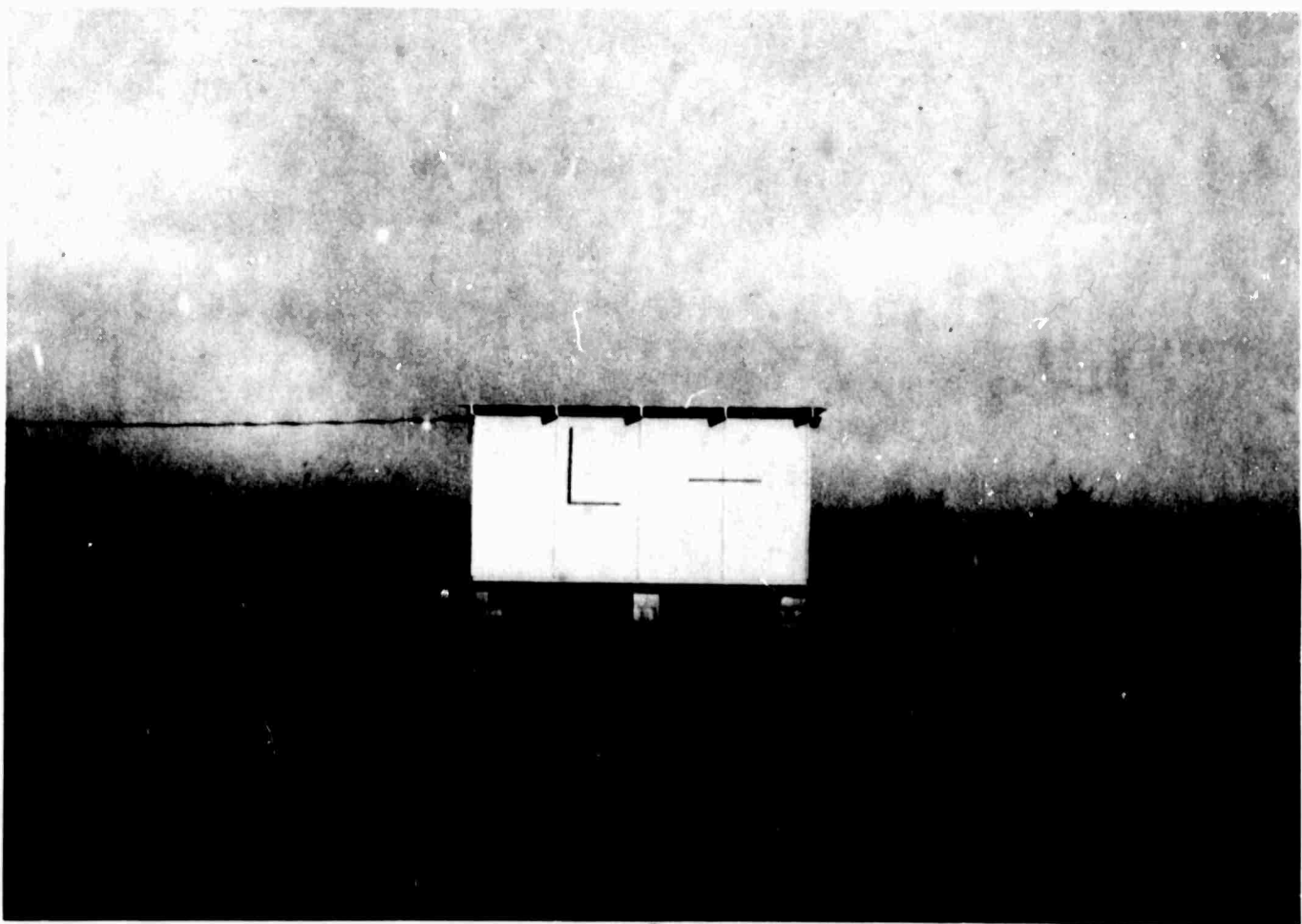
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| 13. ABSTRACT<br>The major objective of this program is to experimentally investigate the wavelength-dependence of turbulence effects on optical propagation through the atmosphere, and to relate the results to certain meteorological parameters, theoretical models, and model-independent dimensional analyses. The experiments are conducted with the use of simultaneous, spatially-coincident laser beams at three wavelengths in the visible and infrared spectrum, with real-time processing for the various statistical results.<br>A particular motivation is to establish the validity of wavelength-scaling laws as applied to a growing body of experimental data at visible wavelengths, in order to predict and optimize the performance of systems operating at certain infrared wavelengths. Techniques are emerging which will place great practical value on reliable predictions of turbulence effects for a given site and conditions.<br>During the second period, the low noise, stable lasers were acquired, the three-wavelength transmitter and receiver optical systems were constructed, and the computer electronics were completed. A newly acquired, flat site was established with necessary power, cooling, communications, and protective arrangements. The above systems are currently being installed at the site. The resultant facility will be uniquely suited to atmospheric propagation work, in terms of multiwavelength capability, data processing versatility, meteorological instrumentation, and attention to experimental detail necessary to achieve reliable results in this difficult field of investigation. |  |                                                                                                                                    |                      |

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| Visible atmospheric transmission<br>Infrared atmospheric transmission<br>Turbulence scattering<br>Atmospheric propagation |        |    |         |    |        |    |

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