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INCOHERENT AND COHERENT CW LASER SYSTEMS FOR REMOTE ATMOSPHERIC PROBING

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ABSTRACT

This report summarizes typical laser systems now available for atmospheric probing. Experiments comparing coherent and incoherent receiving techniques are described and typical performance data presented.

1. INTRODUCTION

A narrow CW laser beam could be used to remotely probe the refractive effects in the atmosphere. These refractive effects at optical wavelengths are produced by temperature differences and motion of the air over the transmission path between the laser beam source and the optical receiver. With an optical probe only average effects produced by the path may be discernible. Single and multiple probes can be employed. A description of theory, experiments, and references have been presented to the panel by other contributors.

Experimenters will have not only a choice of wavelength but a choice of receiver and transmitter configurations. Beamwidths, background noise radiation, transmitter apertures, and receiving apertures and pointing requirements are important considerations, as well as transmitter power and receiver sensitivity. In addition, the environment near the receiver and transmitter may require special design in order to minimize strong effects at the interface between the experiment and the atmosphere to be probed.

2. TRANSMITTERS

The transmitter would probably generate a simple spherical or plane wave over a predetermined aperture, and diffraction, as well as geometrical, optics effects must be considered. The transmitter beam may be either convergent, divergent or diffraction-limited plane parallel. Conical or cylindrical beam geometries are also an option to the experimenter. Wavelengths, such as 4880 Å, 5145 Å, 6328 Å, 3.39μ and 10.6μ, are now available in single mode, CW lasers. Optical modulators[1] are available and a variety of optical modulation techniques, including amplitude, phase, frequency, and polarization modulation, can be implemented. The modulation can be applied from dc up to several gigahertz.[2]

3. INCOHERENT RECEIVERS

At the receiver the experimenter can use either or both incoherent and coherent detection methods.[3,4] The incoherent detector, will measure the incident instantaneous optical power and produce current or voltage proportional to the optical power. If the aperture optics focuses the power received onto a simple detector, then the integral of the power over the aperture is measured. In addition, angle-of-arrival data may also be obtained by measuring focused signal motion in the optics focal plane. Narrow-band optical filters tuned to laser frequencies and field stops to minimize the receiver field of view will be required to keep scattered sunlight and other unwanted radiation from interfering with the measurements. Unwanted radiation can produce noise that will limit receiver sensitivity. The need for a restricted field of view introduces a pointing requirement in an incoherent receiver.

The minimum aperture size or system resolution realizable will be strongly influenced by the available power density, receiver sensitivity needed, experiment accuracy, and required receiver bandwidth. Thus, resolution of signal structure over the aperture may be limited. Both imaging and point detectors can be used. A scanning point detector, such as an image dissector in the visible, or mechanical scan device in the infrared, can be employed to dissect a large optical receiver aperture, reduced in size by the optics, into smaller elements. Television image tubes are also applicable in the visible. In any event, the detector integration time and scan period must be faster than expected time variations due to the transmission path.

4. COHERENT RECEIVERS

A coherent receiver may offer additional advantages not realized by incoherent receivers.[3,4] A coherent receiver uses a local phase reference that allows phase difference measurements to be made over the aperture. (This capability at an optical wavelength scale may allow a microprobe technique to be developed.) The received wave is added to the locally generated wave and then squared by the optical square law detector. The photocurrent or voltage represented by the cross product term is proportional to the scalar product of the local electromagnetic field and the received electromagnetic field. If the two fields are oscillating at different frequencies, then the resultant photocurrent or voltage beat is at the difference frequency. The coherent receiver is both amplitude and phase sensitive. Point-to-point phase differences across the incoming optical wave can be observed by simultaneously detecting the beat frequency relative to the local reference and comparing the phase of the two beat frequency signals. Alignment between the local and received signals is extremely critical.[5]

The wavefront over the receiver aperture is nonuniform as a result of propagating through the atmosphere. In communications receivers this represents noise;[6] in a remote probe this represents the measured quantity. When the signals of many phases and amplitudes are collected and heterodyned with the local reference, currents of many phases and amplitudes determined by the received optical wave are generated. If many portions of an aperture containing different phases and amplitudes are simultaneously imposed on a single detector, then the resultant beat frequency will be the vector sum of all the currents. Since there will probably be numerous phases, the resultant beat signal can be averaged out. The sensitivity of this receiver could thus be much less than a corresponding incoherent receiver. Angle-of-arrival fluctuations produced by the atmosphere near the receiver aperture will severely degrade the receiver performance. The commonly used antenna theorem[5] for a coherent aperture requires that the product of receiver field of view and aperture area should be equal to or less than the square of the wavelength if the receiver coherent efficiency is to be large. Consequently, at longer wavelengths receiver pointing accuracy and aperture atmosphere interfaces are less demanding and apertures can be larger than at shorter wavelengths.

When using large collecting apertures, the coherent receiver may demonstrate poor performance. However, when using apertures that are less than the coherence size of the received wave, a coherent system can be used to measure small angle fluctuations produced by the atmosphere with great sensitivity.

A major advantage of a coherent system over an incoherent system is that in the coherent system random noise from the detector and radiation background can be discriminated against.[3,4] When operating at the shorter wavelengths where the sun is a prime noise source, this approach may be invaluable. In addition, when operating at longer infrared wavelengths where detectors may be noisy, the coherent technique is necessary if a sensitive system is to be implemented.[3]

5. COMPARISON OF COHERENT AND INCOHERENT TECHNIQUES AT 6328 Å

Several experiments were performed at 6328 Å to obtain quantitative data due to atmospheric-induced scintillation on a coherent optical receiver system.[7] Parameters that were varied included transmitter aperture, receiver aperture, and transmitter beam divergence. The signal intensity variations, as well as the envelope of the heterodyne signal, were simultaneously recorded on magnetic tape for further computer processing. Of particular interest was the comparison of incoherent and coherent modes of detection. A comparison was also made for different weather conditions.

Three configurations demonstrating transmitter options were employed and are shown in Figure 1. In Experiment A all the energy was focused into the receiver aperture and the transmitter aperture was varied. In Experiment B a nearly plane wave was formed at the transmitter aperture and the receiver aperture was varied. In Experiment C a small transmitter aperture and a diverging beam were used and the receiver aperture was varied. Transmitter and receiver were separated by 1 kilometer. The beam traversed over a path consisting of buildings, parking lots, and trees. In all cases the beam was at least 5 meters above the underlying terrain and objects. In every case it was found that the coherent system signal fluctuations, due to atmospheric turbulence, was considerably greater than in the incoherent system. This result shows the greater sensitivity of the coherent system to the time-varying wavefront breakup produced by atmospheric turbulence.

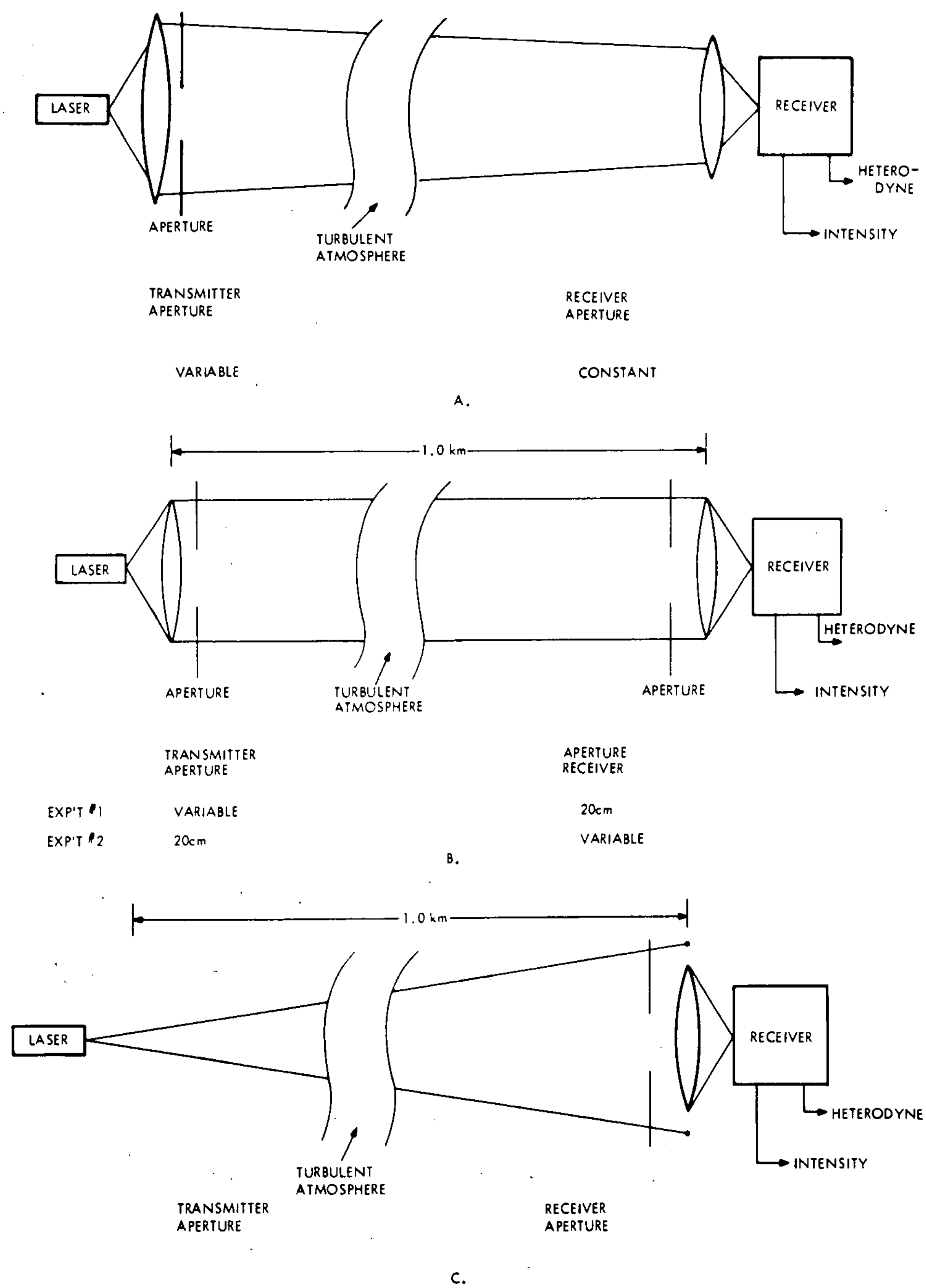

Figure 1. Signal fading experiment to compare coherent and noncoherent detection.

Figure 2 shows comparative cumulative probability data for the parallel beam case when the receiver was apertured. The data corresponds to a 1-minute sample taken near noontime on a sunny day. The rapid decrease in signal probability from unity toward zero is indicative of the larger effects in the coherent output as compared to the incoherent output. This is due to the additional phase sensitivity of the coherent system. Figure 3 compares performance on a clear sunny day to a light rainy day. The signal fluctuation spectra for the data of Figure 3 is shown in Figure 4. Note that the coherent system appears to have a greater number of higher frequency components. This may be due to the effect of the wind.

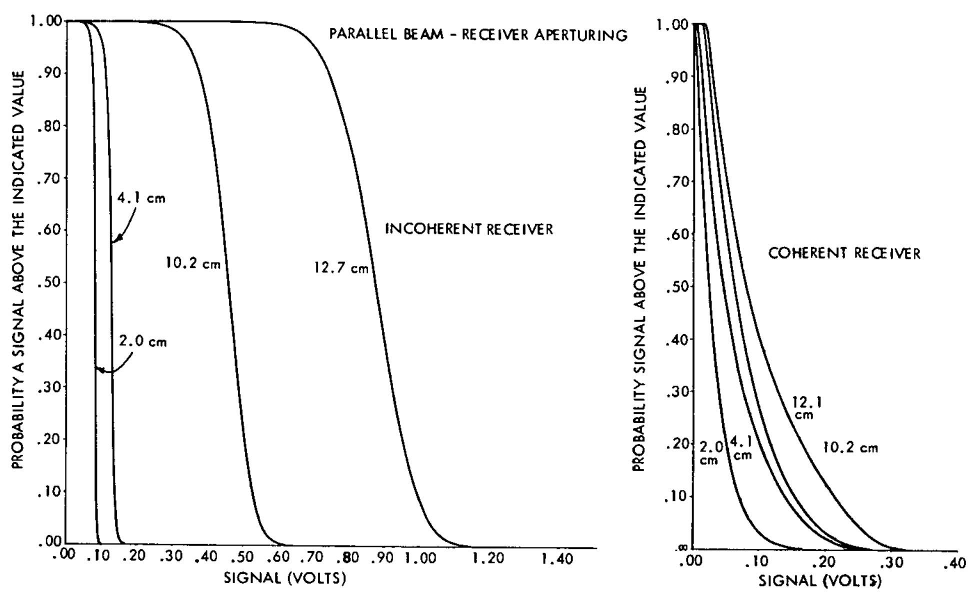

Figure 2. Comparison of incoherent and coherent signal probabilities.

6. COHERENT EXPERIMENT AT 10.6 MICROMETERS

An experiment to provide initial evaluation of atmospheric turbulence effects on coherent propagation at 10.6 micrometers was performed. The experiment utilized homodyne detection and was set up utilizing the 6328 Å optical superheterodyne receiver optics. A moving corner reflector, 1 kilometer from the equipment, was used to reflect the transmitted signal back to the receiver.

Signal fluctuations produced by the atmosphere were easily observed in the return signal. From visual estimates the approximate depth of many of these fluctuations was about 6 dB below the peak and occurred at rates from about 1 Hz to 20 Hz. It was significant to note that the measured peak mixing efficiency was as high as 38 percent. Typical mixing efficiencies measured at 6328 Å on a similar day have been found previously to be only

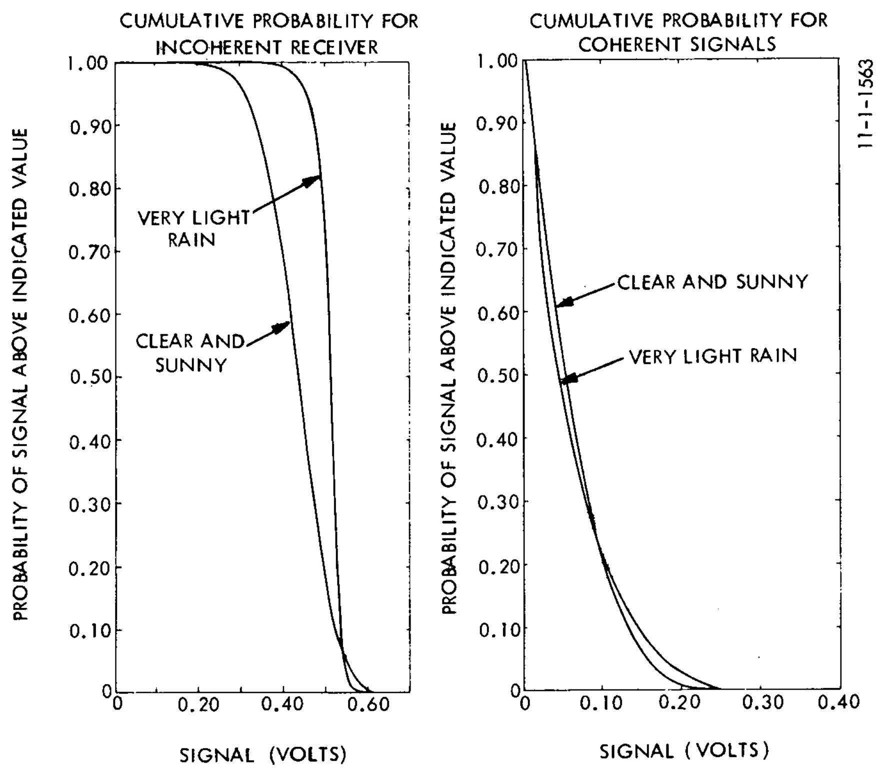

Figure 3. Effects of weather on signal probabilities.

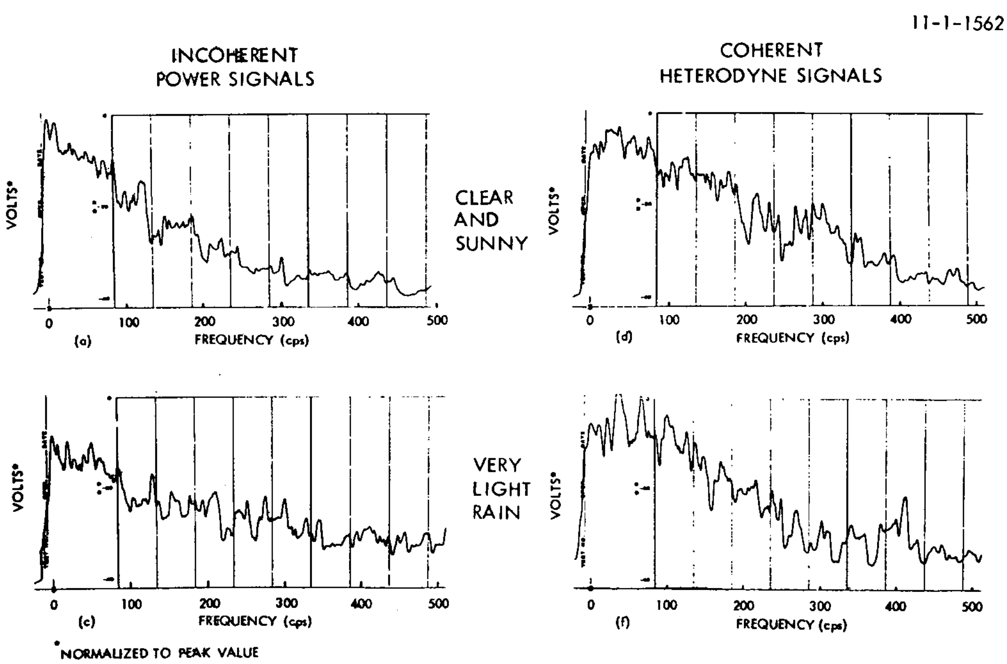

Figure 4. Comparison of signal fluctuation spectra.

a few percent.[7] This data, when compared with the performance of similar experiments at 6328 Å, shows the anticipated reduced angular sensitivity at the longer wavelength.

7. CONCLUSIONS

The technology to implement remote probing experiments using narrow laser beams as a tool is available. Plane or spherical, narrow frequency, optical beams can be formed to propagate through a turbulent atmosphere to a receiver. Detection techniques are available to measure the spatial and temporal amplitude, phase, direction, and polarization characteristics of the beam at the receiver. Use of a coherent system, that is extremely sensitive to phase and angle fluctuations, may offer atmospheric probing technique for microscale measurements.

8. RECOMMENDATIONS

A closely unified theoretical and experimental effort should be initiated to develop the techniques of atmospheric probing using narrow laser beams.

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