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Application of Coherent 10 Micron Imaging Lidar

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9th Conference on Coherent Laser Radar
Linkoping, Sweden
June 23-27, 1997

* Managed by Lockheed Martin Energy Research Corp. for the U.S. Department of Energy under contract DE-AC05-96OR22464

DISCLAIMER

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Submitted: 9th Conference on Coherent Laser Radar, Linköping, Sweden, June 23-27, 1997.

Abstract

With the continuing progress in mid-IR array detector technology and high bandwidth fan-outs, i.f. electronics, high speed digitizers, and processing capability, true coherent imaging lidar is becoming a reality. In this paper experimental results are described using a 10 micron coherent imaging lidar.

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Submitted: 9th Conference on Coherent Laser Radar, Linköping, Sweden, June 23-27, 1997.

Introduction

With the continuing progress in mid-IR array detector technology and high bandwidth fan-outs, i.f. electronics, high speed digitizers, and processing capability, true coherent imaging lidar is becoming a reality. In this paper experimental results are described using a coherent imaging lidar configuration to perform Doppler measurements on the blades of a rotating squirrel cage fan in the laboratory and passive heterodyne detection on a smoke stack in the atmosphere. Data is also presented using the coherent imaging array to reduce speckle noise by spatially averaging over the detector array.

Summary

Several recent technology developments are now paving the way for imaging coherent 10 μm lidar systems that use 2-D focal plane arrays. HgCdTe detectors have historically been difficult to mass manufacture due to material instabilities. Consequently, process yields have been low and HgCdTe detectors have been expensive. As a result of advances in the materials and processes utilized in fabrication of HgCdTe devices and advances in device configurations, 2-D staring arrays of HgCdTe detectors as large as 640 x 480 are now becoming available.[1] In addition, new GaAs/Al_xGa_{1-x}As quantum well infrared photodetector (QWIP) technology is providing high-yield 2-D infrared staring arrays with the added promise of very wide bandwidth heterodyne detection.[2] Progress is likewise being made in the miniaturization and mass manufacturing of high bandwidth integrated circuits which can operate at liquid nitrogen temperatures. These electronics are fabricated using GaAs-based monolithic microwave integrated circuit (MMIC) technology. MMIC technology is a special case of standard integrated circuits (ICs), optimized for linear and rf applications above 1 GHz. Typical commercially-available processes allow applications up to about 20 GHz and some experimental GaAs processes have reported frequencies above 100 GHz.[3,4]

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Previously, we reported on a heterodyne imaging system design that provided collection optics with resolution capabilities consistent with both the grid dimensions and the coherence properties of an observed source[5]. A single-detector heterodyne receiver is generally illuminated by a Gaussian- profile local oscillator beam. The reverse projection of this beam, referred to as the antenna beam or as the back propagating local oscillator (BPLO) specifies the field-of-view of the receiver system. A receiver array requires an array of such local oscillator beams, and the resulting antenna beam array must behave so as to efficiently sample the image field. For example, an object in the image plane should be sampled by non-overlapping antenna beams, as should all objects beyond this plane. Furthermore, these non-overlapping beams should be spaced with the same geometry as the detector array for all points on the object plane and beyond. The local oscillator power on the focal plane array was generated by illuminating a grid mask and imaging the resulting pattern of individual Gaussian beamlets onto the detector array (Figure 1). The size of the apertures and the f-number of the optics spatially filters the high orders of diffraction producing nearly Gaussian mutually coherent local oscillator beams.

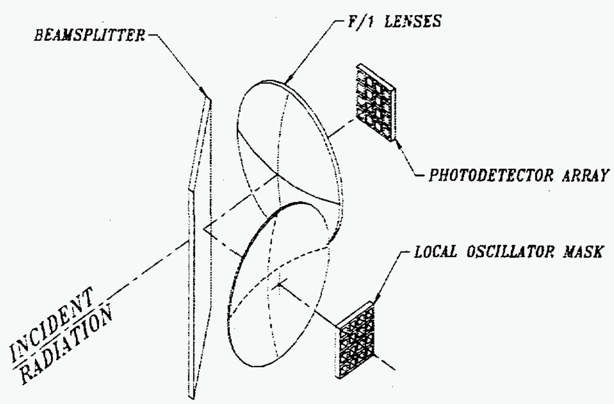

Figure 1 Optical configuration for coherent imaging lidar

In order to test the performance of the receiver design illustrated in Figure 1, a 30x30 element 2D detector array was synthesized by scanning a single 100 micron diameter HgCdTe detector over an image plane illuminated with a LO beam array as described above. The step-size was adjusted so that the detector position coincided with an available LO beamlet prior to taking data. The detector utilized had a modulation bandwidth in excess of 10^9 Hertz, which is wide enough to allow the acquisition of thermal signals with high signal-to-noise ratio over reasonably small integration times. The measurement of thermal signals is referred to as passive operation as opposed to the active mode where the scene is illuminated by a laser source whose frequency is within a detector modulation bandwidth of the LO frequency. In Figure 3 below, the results of a passive measurement of a power facility smoke stack is shown at a range of about 300 m. In this measurement, the output of the detector was integrated for a time period of several minutes and the resulting image shows the thermal signature of the stack as well as the emission plume.

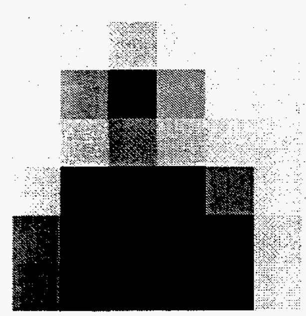
Figure 2 Passive Heterodyne Image of a Smoke Stack at 300 m

In another experiment, active mode images were recorded by illuminating the scene with a portion of the LO radiation which had been shifted in frequency by 40 MHz using an acousto-optic modulator. Figure 3 shows an active image of a vertical squirrel cage fan where each pixel is rendered to represent the peak Doppler shift measured with the detector at the corresponding location in the image plane. The moving target scatters incoherently and thus speckle effects do not degrade the image. The measured Doppler shifts are consistent with the known rotational velocity of the target.

Speckle effects associated with coherent sources can be reduced by signal averaging.[6] Averaging over many transmitter pulses can reduce speckle but also reduces temporal resolution. The alternative considered here is to sacrifice spatial resolution by averaging over an array of detectors all of which record the signal returned from a single transmitter pulse. Detectors separated by a coherence area diameter will record signals that approach statistical independence, and in this case speckle effects can be reduced by an amount approaching the square-root of the number of detectors in the subarray.

We performed laboratory experiments demonstrating speckle reduction by spatial averaging with a fixed focal plane array. The detectors used in this experiment consisted a 3 x 3 2-D array of HgCdTe detectors manufactured by Rockwell International. The 50-micron diameter detectors were arranged in a square pattern 100 microns center to center. Custom electronics multiplexed the output of each detector for subsequent processing. Lidar illumination was produced by frequency shifting a portion of the local oscillator beam by 40 MHz with an acousto-optic modulator prior to illuminating the object field. Polarization of the illumination beam was parallel to the LO prior to scattering from the target. The measured receiver bandwidth, limited mostly by the dewar design, was about 100 MHz which permitted the acquisition of the 40 MHz heterodyne signal. Collection optics consisted of a 38 mm f/2 asphere which produced a 2 mm diameter pixel image at a 3 m object distance.

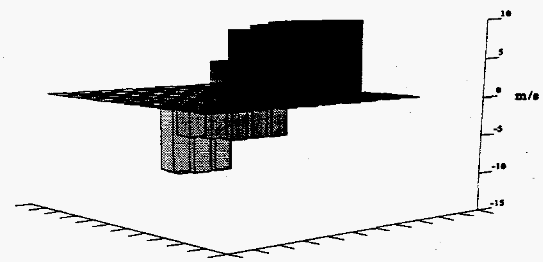

Figure 3 Doppler image of squirrel cage fan

The target for these experiments consisted of a 30 cm diameter disk coated with an aluminum powder. The particle size of this powder ranged from 1 to 100 microns determined by electron microscopy. The disk was attached to a stepper motor which was incremented between frames to provide statistically independent speckle fields. Figure 4 below shows the distribution of measurements taken with a single pixel superimposed on the distribution taken by averaging over the focal plane array. A reduction in speckle noise by a factor of the square root of the number of averaged pixels was obtained as predicted.

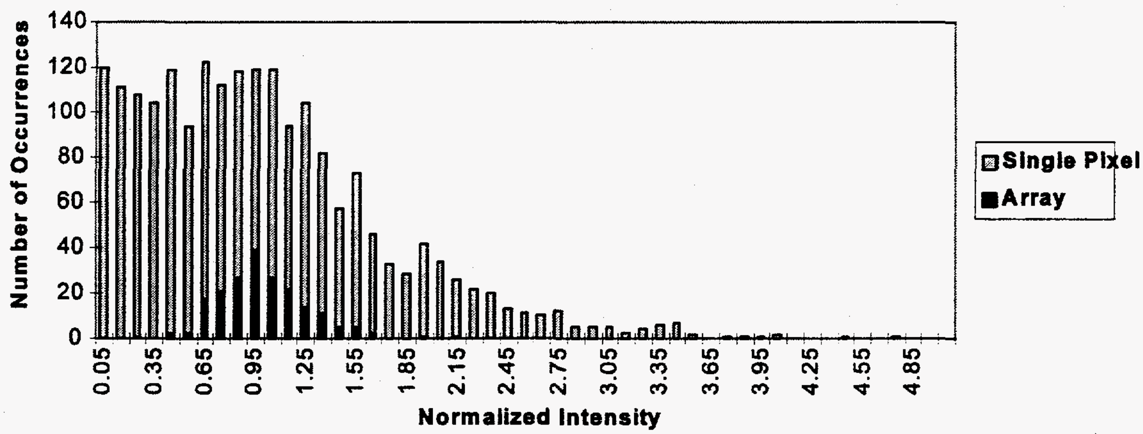

Figure 4 Speckle reduction using spatial averaging over a coherent array

Conclusion

The combination of optical heterodyne detection, imaging, and wide-band IR focal plane arrays offer significant new capabilities to the next generation in remote sensing. We have described laboratory experiments demonstrating the use of coherent imaging lidar in thermal detection, passive heterodyne detection and characterization of plumes, production of Doppler images of rotating hard bodies, and reduction of speckle for DIAL measurements by spatial averaging.

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