Holographic Airborne Rotating Lidar Instrument Experiment (HARLIE)

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Introduction

Scanning holographic lidar receivers (Schwemmer, 1993) are currently in use in two operational lidar systems, PHASERS (Prototype Holographic Atmospheric Scanner for Environmental Remote Sensing) (Schwemmer and Wilkerson, 1994; Schwemmer et.al., 1996) and now HARLIE (Holographic Airborne Rotating Lidar Instrument Experiment). These systems are based on volume phase holograms made in dichromated gelatin (DCG) sandwiched between 2 layers of high quality float glass. They have demonstrated the practical application of this technology to compact scanning lidar systems at 532 and 1064 nm wavelengths, the ability to withstand moderately high laser power and energy loading, sufficient optical quality for most direct detection systems, overall efficiencies rivaling conventional receivers, and the stability to last several years under typical lidar system environments. Their size and weight are approximately half of similar performing scanning systems using reflective optics. The cost of holographic systems will eventually be lower than the reflective optical systems depending on their degree of commercialization.

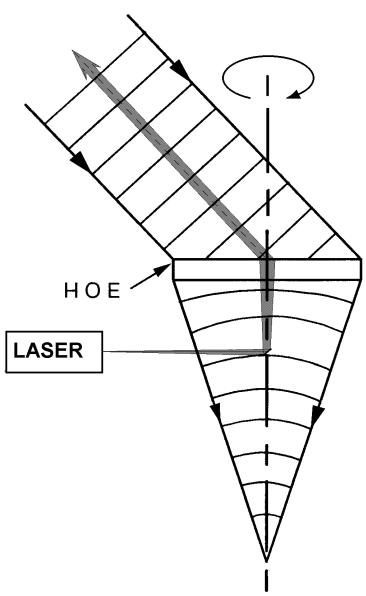

Figure 1. HARLIE transmission HOE geometry.

There are a number of applications that require or can greatly benefit from a scanning capability. Several of these are airborne systems, which either use focal plane scanning, as in the Laser Vegetation Imaging System (Blair and Coyle, 1996) or use primary aperture scanning, as in the Airborne Oceanographic Lidar (Krabill et. al., 1995) or the Large Aperture Scanning Airborne Lidar (Palm et. al., 1994). The latter class requires a large clear aperture opening or window in the aircraft. This type of system can greatly benefit from the use of scanning transmission holograms of the HARLIE type because the clear aperture required is only about 25% larger than the collecting aperture as opposed to 200-300% larger for scan angles of 45 degrees off nadir.

HARLIE

HARLIE is a technology demonstration to test the utility of using holographic scanning receivers in lidar systems at the 1064 nm Nd:YAG wavelength. Built as an atmospheric backscatter lidar system, it will also be used to test concepts for an airborne direct detection wind lidar that could one day be used for spaceborne applications. Referring to Figs. 1 and 2**,** it uses a 40 cm diameter by 1 cm thick Holographic Optical Element (HOE) as the receiver

Figure 2. HOE scanner assembly.

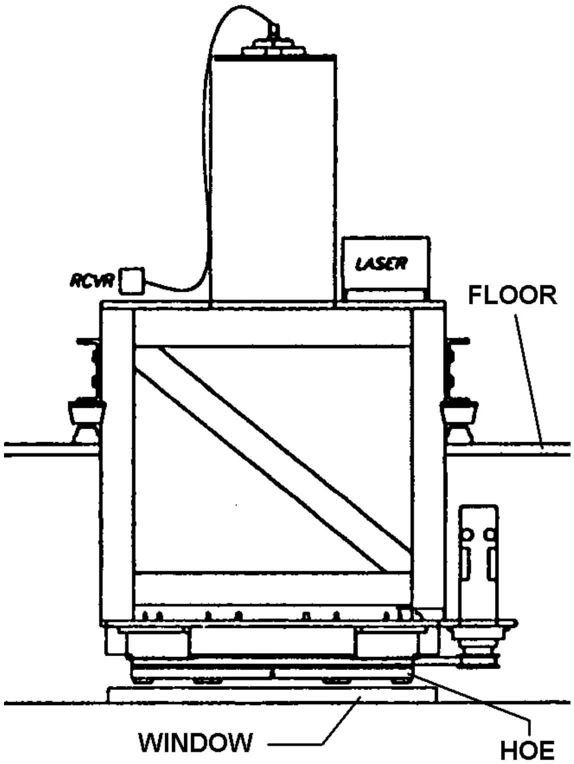

Figure 3. Position of HARLIE in an aircraft, suspended from the floor.

collecting and focusing aperture. It has a 45 degree diffraction angle and a 1 meter focus normal to its surface. It is continuously scanned up to 30 rpm, and can also operate in step and stare or static modes. Its 200µrad blur circle matches the 200 µm fiber optic field stop which delivers the light to the aft optics package. The aft optics contains a collimating lens, a 500 pm interference filter, focusing lens, a Geiger mode Avalanche Photo Diode, and measures 2.5 cm x 2.5 cm x 15 cm. The transmitter is a continuous diode pumped Q-switched Nd:YAG laser delivering 1 mJ pulses at a 5 KHz rep rate. The beam is expanded to 15 mm diameter before being transmitted through the center of the HOE, which also acts as the collimating lens of the beam expander, transmitting a 100µrad beam. The entire transmitter/receiver package can be placed within inches from an aircraft instrument window so that a 52 cm clear aperture window allows for an unobstructed view in all directions around the conical scan (Fig. 3).

Figure 4 is a photograph of the HARLIE transceiver assembly and electronics rack. Mounted on its transportation dolly, the lidar can operate on the ground in any of 8 elevation positions spaced 45° apart. In this figure the system is pointed up, so the HOE appears on top. It is mounted in a large ring ball bearing with a ring gear pressed into the inner race. It is belt driven by a DC servo motor with an overall gear ratio of 123:1. A 12 bit encoder on the motor shaft yields a 12.5 µrad resolution in the azimuth pointing position. The electronics rack contains the data system, the laser power supply and chiller, the scan motor controller and power supply, a GPS receiver, and an aircraft INS interface. The detector output is ping-ponged between a pair of 24 bit scalers to eliminate dead-time during the read-out cycle. A time history of backscatter profiles are displayed on the computer monitor in real-time as a false color image. Other salient technical specifications are listed in Table 1.

Figure 4. HARLIE system transceiver (left) and data system (right).

Table 1. HARLIE Preliminary Specifications

Transceiver Assembly
Weight: *118 kg.*
Overall dimensions (in cm, minus mounting rails): *56 w x 69 l x 102 h*
Transmitter: *diode pumped Nd:YAG, 1064nm wavelength, 1 mJ, 40 nsec pulse length, 5 kHz rep-rate, 100 mrad divergence*
Receiver: *40 cm diameter, f/2.5 volume phase HOE, 45° diffraction angle, effective collection area 1064 cm^2, 200 mrad FOV, 0.5 nm bandpass*
Detector: *Geiger mode or analog Silicon APD*
Electronics Rack
Weight: *125 kg*
Overall dimensions (cm): *56 w x 64 l x 127 h*
Power requirements: *1000 W max. @110 Vac., 19 amps peak (2.2 kVA peak)*

Table 1. *Cont.*

Scan Modes: *Point and stare, 8 position step-stare, Continuous scan (30rpm)*
Azimuth (scan) pointing resolution: *12.5 mrad*
Data System
Two ping-ponged *24 bit x 8192 bin scalers*
Range resolution: *30 m*
Integration time: *100 msec*

Figure 5 is a sample of night time data taken with HARLIE in the scanning mode. The top part of the figure represents 1 minute of data operating at a 30 rpm scan rate, and transmitting about 1.2 watts average laser power. The bottom part is an expanded view of the first 3 scans. Increased backscatter is rendered as increased brightness on these raw signal images. The integration time is 100 msec, yielding 18 degree resolution in azimuth, or 20 profiles per scan.

Doppler Wind Lidar

Another important lidar application that requires scanning or pointing is the measurement of atmospheric winds, particularly from space. The current holographic systems are smaller and simpler, but still contain a fair amount of glass, which is heavy compared to lightweight opaque materials such as beryllium or composites like graphite epoxy. In addition, the emphasis for direct detection Doppler wind lidars is on ultraviolet (UV) wavelengths in order to measure clear air winds by taking advantage of the large Rayleigh backscatter cross-sections at shorter wavelengths. Current UV hologram developments are following two paths: pushing the wavelength limit of the DCG volume phase technology; and second, developing surface holograms using photoresist and reactive ion etching technology. These techniques will enable the use of ultra-light weight materials.

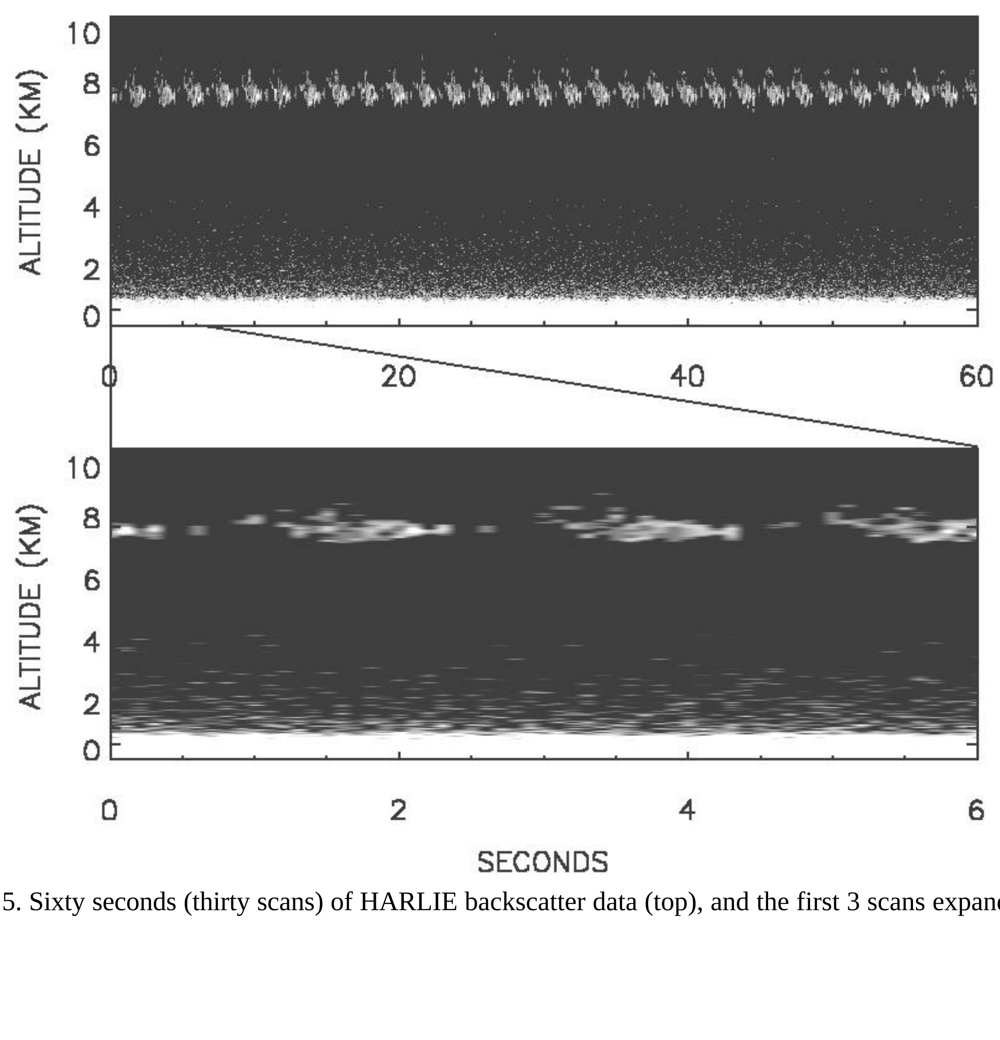

Figure 5. Sixty seconds (thirty scans) of HARLIE backscatter data (top), and the first 3 scans expanded (bottom).

Shared Aperture Multi-view Holographic Telescope

Additional reductions in mass and complexity may come from new concepts employing the use of angle-multiplexed HOES to build a multiple field of view (FOV) receiver with no moving parts. The measurement of atmospheric winds requires at least 2 pointing angles in order to derive the wind vector. More than 2 angles can be used to generate broader spatial coverage and better statistical sampling of the atmospheric air volume. For example, in a six FOV wind lidar receiver, six HOES are written into the same film or stacked on a common substrate, with equal diffraction angles separated in azimuth by 60 degrees. This is sufficiently far apart so that the backscatter from any one direction meets the Bragg condition for diffraction for only one hologram, so that almost all of the collected backscatter is diffracted into only one direction and cross-talk is minimized. However, the transmitted laser beam can not be directed through a common focus, for its energy would be divided among the various directions. Rather than transmitting a single laser beam through the receiver HOE, it can be directed through its own, smaller HOE that is rotated to each of the pointing angles in a sequential fashion. Alternatively, it may be more advantageous for a space borne system to use separately aligned static transmitting optics with six laser heads sharing a common power supply which is electrically switched between the various heads, fired in Gatling Gun fashion. This gives some redundancy to that part of the system with the shortest lifetime.

Rather than using a common field stop, separate stops for each of the FOVS can be arranged on a circle, with fiber optics carrying the backscatter signal to a single or separate miniature photon counting detectors. This configuration allows the collection of light from each FOV almost as efficiently as using a rotating HOE, and without the additional background from the other FOVS which a common focus would incur.

By removing the rotating optic requirement, the heaviest parts of the current holographic systems can be eliminated: the motor, the large ring bearing and gear or rotation stage, and the drive electronics. Also significant for spaceborne systems is the fact that these parts are more prone to failure then the benign optics replacing them.

Summary

The operational airborne lidar HARLIE has demonstrated that using a rotating HOE to perform the function of collimating, scanning, and collecting laser light in 1064 nm direct detection lidar systems is a practical and economical alternative to conventional reflective and refractive optical systems. Significant reductions in system size and weight are achieved without sacrificing performance. This technology will soon be available commercially, perhaps as an off-the-shelf option for manufactured lidars. Additional systems are currently under development and testing at Utah State University, Houston Advanced Research Center, and NASA Goddard Space Flight Center. Future systems will push the available wavelengths to the UV and may enable the development of compact multi-view systems without moving parts.

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