the output waveguides accommodates one mode only. At the input, the waveguide structure is symmetric and, therefore, the fundamental mode of the structure at the input is symmetric and the other mode is anti-symmetric. At the output, one of the waveguides is wider than the other, and therefore has a higher effective refractive index. For the light originating from the star, if the interferometer is perfectly balanced, the input field in the focal plane of the focusing optic at the input of the device is symmetric, while for the light field originating from the planet (assuming the exact π phase shift) it is anti-symmetric. Thus, in the two-mode input waveguide the starlight excites the fundamental mode, while the planet light excites the second, anti-symmetric, mode.

This work was done by Alexander Ksendzov of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-47834

High-Speed Digital Interferometry

Optical decoding eliminates the need for high-speed detectors and digital signal processing.

NASA's Jet Propulsion Laboratory, Pasadena, California

Digitally enhanced heterodyne interferometry (DI) is a laser metrology technique employing pseudo-random noise (PRN) codes phase-modulated onto an optical carrier. Combined with heterodyne interferometry, the PRN code is used to select individual signals, returning the inherent interferometric sensitivity determined by the optical wavelength. The signal isolation arises from the autocorrelation properties of the PRN code, enabling both rejection of spurious signals (e.g., from scattered light) and multiplexing capability using a single metrology system. The minimum separation of optical components is determined by the wavelength of the PRN code.

A variation of DI has 100 times reduction in the minimum component separation, allowing measurements of optical components only a few centimeters apart. Instead of the usual electronic decoding, the DI signal is interfered with an appropriately delayed, identically PRN-encoded, local oscillator beam. Optical decoding allows the use of a low-bandwidth signal processing chain with GHz codes, negating the need for high-speed detectors and digital signal processing. This reduced bandwidth also reduces the power consumption of the entire system.

The heterodyne signal is created by off-set phase-locking two lasers with a digital phase-locked loop. The error-point is monitored on a dedicated phase-locking photoreceiver. PRN codes are phase-modulated by waveguide modulators onto each laser beam. These are subsequently interfered via a fiber beamsplitter, thus optically demodulating the laser signals, before being detected on a signal photoreceiver. One PRN code is digitally delayed with respect to the other in order to align the codes with respect to the reflected light from an optic under interrogation, thus optically demodulating the signal for that specific mirror. The delay is altered (controlled digitally) to pick out any one of the optics under interrogation.

At the time of this reporting, this is the first known time that DI has been employed to measure optics separated by less than meters, down to a few centimeters. This was achieved by implementing, for the first time, optical demodulation of the encoded laser beams (as opposed to the more traditional/common electronic demodulation). This technique is entirely implemented in software via hardware that would already exist onboard a spacecraft. This reduces complexity, power consumption, volume, and risk of failure.

There are many proposed missions that will employ lasers and require extremely high-resolution metrology. Digital interferometry can be implemented and achieve sub-10-pm resolution. With this new technique, the metrology can be performed on optical components separated by centimeters. This allows measurements of optics on a single optical bench within a single spacecraft, in addition to inter-spacecraft metrology measurements.

This work was done by Glenn De Vine, Daniel A. Shaddock, Brent Ware, Robert E. Spero, Danielle M. Wuchenich, William M. Klipstein, and Kirk McKenzie of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-47886

Ultra-Miniature Lidar Scanner for Launch Range Data Collection

New scanning technology promises at least a 10× performance improvement.

John F. Kennedy Space Center, Florida

The most critical component in lidar is its laser scanner, which delivers pulsed or CW laser to target with desirable field of view (FOV). Most existing lidars use a rotating or oscillating mirror for scanning, resulting in several drawbacks.

A lidar scanning technology was developed that could achieve very high scanning speed, with an ultra-miniature size and much lighter weight. This technology promises at least a 10× performance improvement in these areas over existing lidar scanners. Features of the proposed ultra-miniature lidar scanner include the ability to make the entire scanner <2 mm in diameter; very high scanning speed (e.g. 5–20 kHz, in contrast to several hundred Hz in existing scanners); structure design to meet stringent requirements on size, weight, power, and compactness for various applications; and the scanning speed and FOV can be altered for obtaining high image resolutions of targeted areas and for diversified uses.

This technology employs a single-mode optical fiber attached to the end of a mini tube made of piezoelectric material. The two-degrees-of-freedom (DOF) piezo tube is driven at the first mode of mechanical resonance frequency of the fixed-free cantilevered fiber. The gain of mechanical resonance allows a small vibration at the tip of the piezo tube to be amplified several hundred times to vibrate the tip of the optical fiber. The laser beam is delivered through the single-mode fiber and the vibrating fiber at high resonance frequency (e.g., 5–20 kHz), and generates scanning patterns with desirable FOV.

A laser beam is delivered via the single fiber core to the target surface. The direction of the light beam delivered by the single fiber is controlled by two piezoelectric drivers mounted orthogonally on the mounting base of the single fiber to generate a controllable motion of the cantilevered fiber with two degrees of freedom. With proper optics, the directed light beam produces a bright spot on the object surface. The reflected light energy from this spot is collected by multiple optical fibers embedded into the outer housing. These light collectors form a "fiber ring." The time duration between the beginning of the laser pulse and receiving pulse (in the case of pulse laser) or phase difference between emitted and received signals (in the case of CW laser) determines the target distance, based on time-of-flight principle.

The single-fiber core moves in an area-fill fashion to produce laser light spot sequentially over a target surface, and light collectors record the timing and brightness of these data points in a pixel-by-pixel fashion. The signal receiver, piezo controller, and the laser source are all connected to the distal end via flexible fiber/wire bundle with diameter less than one millimeter. A control computer is used to control the piezo driver motion, laser timing and intensity, returned signal processing, and 3D data construction and visualization.

This work was done by Jason Geng of Xigen LLC under the Small Business Innovation Research Program for Kennedy Space Center. Further information is contained in a TSP (see page 1). KSC-13570