odyne Interferometers” (NPO-20786), Vol. 25, No. 7 (July 2001), page 12a. and “Interferometer for Measuring Displacement to Within 20 pm” (NPO-21221), Vol. 27, No. 7 (July 2003), page 8a. Wavefront splitting is one of those innovations. To recapitulate from the second-mentioned article: Heretofore, the most popular method of displacement-measuring interferometry has involved two beams, the polarizations of which are meant to be kept orthogonal upstream of the final interference location, where the difference between the phases of the two beams is measured. Polarization leakage (deviations from the desired perfect orthogonality) contaminates the phase measurement with cyclic nonlinear errors. The advantage afforded by wavefront splitting arises from the fact that one does not utilize polarization in the separation and combination of the interfering beams; the cyclic nonlinear errors are much smaller because the polarization-leakage contribution is eliminated.

One example of a sub-aperture interferometer, denoted a sub-aperture vertex-to-vertex interferometer, is one of several prototype common-path heterodyne interferometers designed and built at NASA’s Jet Propulsion Laboratory. This interferometer (see figure) makes use of two collimated laser beams — one at a frequency of f_0, the other at the slightly different frequency of $f_0 + \Delta f$. The f_0 beam is denoted the measurement beam. It passes through beam splitter 1 on its way toward two targets. The retroreflector on the first target is truncated; it is a flat mirror that reflects a portion of the measurement beam and contains two holes through which portions of the measurement beam continue toward the second target and through which they return after reflection from the retroreflector on the second target. A mask establishes guard bands between the measurement sub-beams to reduce diffraction.

The measurement sub-beams returning from the targets are reflected from beam splitter 1 to beam splitter 2, where the $f_0 + \Delta f$ beam becomes superimposed upon them. Then by use of mirrors (one of which is truncated) and lenses, the f_0 sub-beam from target 1 and part of the $f_0 + \Delta f$ beam are sent to photodiode 1 while the f_0 sub-beam from target 2 and another part of the $f_0 + \Delta f$ beam are sent to photodiode 2. The lowest-frequency components of the heterodyne outputs of the two photodetectors are signals of frequency Δf. The difference between the phases of these heterodyne signals is proportional to the difference between the lengths of the optical paths to the two target retroreflectors. Any displacement of either target along the optical path results in a proportional change in this phase difference. Hence, measurement of the phase difference and of any change in the phase difference yields information on the displacement.

This work was done by Feng Zhao of Caltech for NASA’s Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov. NPO-30779

Terahertz Mapping of Microstructure and Thickness Variations

Previously, it was not possible to separate microstructural and thickness effects using electromagnetic methods.

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A noncontact method has been devised for mapping or imaging spatial variations in the thickness and microstructure of a layer of a dielectric material. The method involves (1) placement of the dielectric material on a metal substrate, (2) through-the-thickness pulse-echo measurements by use of electromagnetic waves in the terahertz frequency range with a raster scan in a plane parallel to the substrate surface that do not require coupling of any kind, and (3) appropriate processing of the digitized measurement data.

More specifically, the method provides for mapping, in a coordinate system defined by the raster scan, of spatial variations of the thickness normal to the substrate surface and spatial variations of the through-the-thickness velocity of the terahertz mapping signal. (In general, variations in the velocity of this or any signal through a material are associated with variations in density and/or other characteristics associated with local microstructure of the material.) The method has been demonstrated on nominally flat metal-backed specimens of two dielectric materials: a silicon nitride ceramic and a spray-on foam of the type used on the external tanks of a space shuttle. The method should also be applicable to other dielectric materials, and it may be feasible to extend the method to cylindrical, beveled, and other non-planar shapes.

In a prior method of terahertz mapping or imaging of this type as applied to space-shuttle external-tank foam bonded to the metal tank surface, one maps variations in the time of flight of the terahertz signal through the thickness of the foam, the time of flight being typically defined as the time between the echo from the substrate surface and the front foam surface. That approach yields information on the combined effects of thickness and through-the-thickness velocity; it does not enable separate determination of variations in thickness and variations in velocity.

In contrast, the present method provides for generation of velocity-variation images free of thickness-variation effects and thickness-variation images free of velocity-variation effects. In this method, terahertz pulse-echo measurements with a raster scan are made as in the prior method. The raster-scan plane is chosen so that there is a suitable air gap between the terahertz transceiver and the front surface of the dielectric material. One difference between the present and prior methods is that two sets of data are acquired: For one set, the sample is absent and the times of the echoes from the substrate alone are measured. For the other set, the dielectric sample is placed on the metal substrate and echoes from both the substrate and front surface of the dielectric are measured as in the prior method.

Another difference between the present and prior methods lies in processing of the two sets of measurement data. The processing is effected by special-purpose software that performs signal-enhancement and data-fusion functions to obtain enhanced values of the times of front-surface and substrate echoes in the presence of the dielectric sample and of the substrate echo in the absence of the sample. Then by use of equations that are readily derived from the basic signal time-of-flight equations, the thickness of the sample and the through-the-thickness velocity in the sample are computed from the various echo times.

This work was done by Donald J. Roth, Jeffrey P. Seebo, and William P. Winfree of Glenn Research Center. Further information is contained in a TSP (see page 1).

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Innovative Partnerships Office, Attn: Steve Fedor, Mail Stop 4–8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-18254-1.

Multiparallel Three-Dimensional Optical Microscopy

Lyndon B. Johnson Space Center, Houston, Texas

Multiparallel three-dimensional optical microscopy is a method of forming an approximate three-dimensional image of a microscope sample as a collection of images from different depths through the sample. The imaging apparatus includes a single microscope plus an assembly of beam splitters and mirrors that divide the output of the microscope into multiple channels. An imaging array of photodetectors in each channel is located at a different distance along the optical path from the microscope, corresponding to a focal plane at a different depth within the sample. The optical path leading to each photodetector array also includes lenses to compensate for the variation of magnification with distance so that the images ultimately formed on all the photodetector arrays are of the same magnification.

The use of optical components common to multiple channels in a simple geometry makes it possible to obtain high light-transmission efficiency with an optically and mechanically simple assembly. In addition, because images can be read out simultaneously from all the photodetector arrays, the apparatus can support three-dimensional imaging at a high scanning rate.

This work was done by Lam K. Nguyen, Jeffrey H. Price, Albert L. Kellner, and Miguel Bravo-Zanoquera of the University of California for Johnson Space Center. For further information, contact the JSC Innovation Partnerships Office at (281) 483-3809.

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to:

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Stabilization of Phase of a Sinusoidal Signal Transmitted Over Optical Fiber

Two-way transmissions allow for rapid correction of common reference tones.

NASA's Jet Propulsion Laboratory, Pasadena, California

In the process of connecting widely distributed antennas into a coherent array, it is necessary to synchronize the timing of signals at the various locations. This can be accomplished by distributing a common reference signal from a central source, usually over optical fiber. A high-frequency (RF or microwave) tone is a good choice for the reference. One difficulty is that the effective length of the optical fiber changes with temperature and mechanical stress, leading to phase instability in the received tone. This innovation provides a new way to stabilize the phase of the received tone, in spite of variations in the electrical length of the fiber.

Stabilization is accomplished by two-way transmission in which part of the received signal is returned to the transmitting end over an identical fiber. The returned signal is detected and used to close an electrical servo loop whose effect is to keep constant the phase of the tone at the receiving end.

The technique is useful in large arrays of Earth-based antennas used for space communication or radio astronomy. It is also useful in any situation where precise timing information must be transferred over distances for which optical fiber transmission is appropriate (~10 m to 30 km). It has been used in a demonstration uplink array as part of a technology development for the Deep Space Network.

In the past, other techniques have been used for a similar purpose, but they involve either manipulation of the optical fibers, or they measure and record the phase variation rather than correcting it immediately via a closed-loop servo. The optical methods are generally slow, so they cannot correct rapid variations. The open-loop methods are less accurate, and they are not useful in situations where real-time correction is needed. The method described here is fast, accurate, and inexpensive to implement. A method similar in principle to this one has been reported earlier, but the new configuration is different and permits variable transmitted frequency and higher correction speed. Related round-trip stabilization methods have been used for signal transmission in coaxial cable and in waveguide

The new method is illustrated by the block diagram in Figure 1. The signal to be transmitted is at frequency f_0. It is generated by mixing an input at $f_0 + f_1$ (from the first master synthesizer) with a voltage-controlled crystal oscillator (VCXO) at nominal frequency f_1 (77.76 MHz in this implementation). It