able bandwidth, (2) relatively tight coupling with the microstrip connected to the coarse-tuning varactor, and (3) relatively loose coupling with the microstrip connected to the fine-tuning varactor.

Measurements of performance showed that the oscillator can be switched among any of the 26 channels and can be phase-locked to a nominal frequency in any channel. The degree of nonlinearity of tuning was found not to exceed 2.5 percent. The tuning sensitivity was found to be 6.15 MHz/V at a bias offset of –2 V on the phase-lock-loop varactor. The phase noise of the oscillator in free-running operation was found to be –107 dBc/Hz (where "dBc" signifies decibels relative to the carrier signal) at 100 kHz away from the carrier frequency.

This work was done by Narayan Mysoor, Matthew Dennis, and Brian Cook of Caltech for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP (see page 1).*
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Automatic Alignment of Displacement-Measuring Interferometer

Corrections are derived from fluctuations associated with circular dithering of a laser beam.

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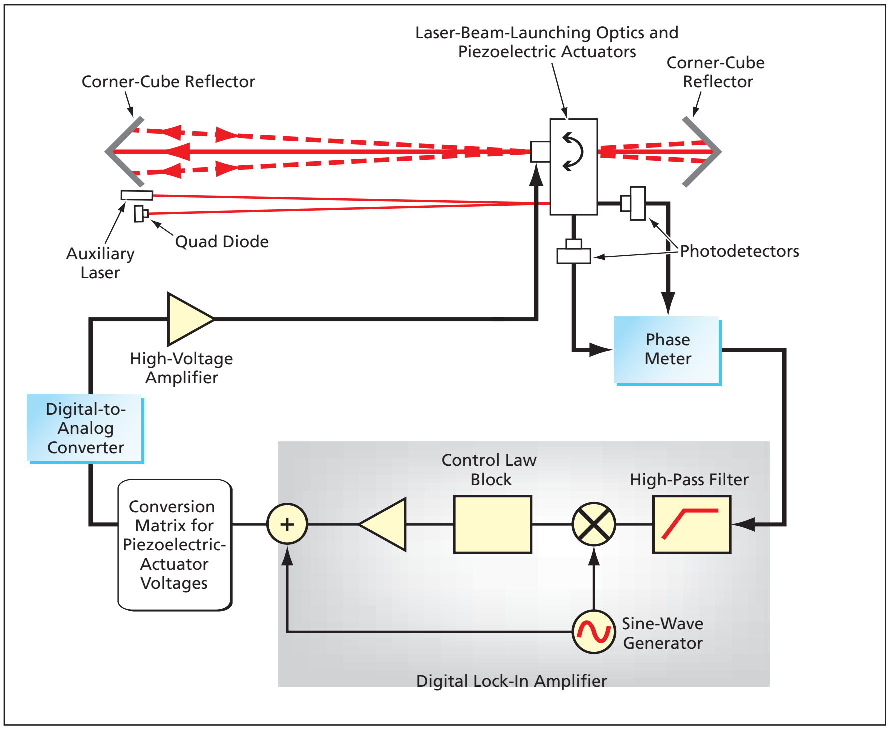
A control system strives to maintain the correct alignment of a laser beam in an interferometer dedicated to measuring the displacement or distance between two fiducial corner-cube reflectors. The correct alignment of the laser beam is parallel to the line between the corner points of the corner-cube reflectors: Any deviation from parallelism changes the length of the optical path between the reflectors, thereby introducing a displacement or distance measurement error.

On the basis of the geometrical optics of corner-cube reflectors, the length of the optical path can be shown to be $L = L_0 \cos\theta$, where L_0 is the distance between the corner points and θ is the misalignment angle. Therefore, the measurement error is given by $\Delta L = L_0(\cos\theta - 1)$. In the usual case in which the misalignment is small, this error can be approximated as $\Delta L \approx -L_0\theta^2/2$.

The control system (see figure) is implemented partly in hardware and partly in software. The control system includes three piezoelectric actuators for rapid, fine adjustment of the direction of the laser beam. The voltages applied to the piezoelectric actuators include components designed to scan the beam in a circular pattern so that the beam traces out a narrow cone (60 microradians wide in the initial application) about the direction in which it is nominally aimed. This scan is performed at a frequency (2.5 Hz in the initial application) well below the resonance frequency of any vibration of the interferometer.

The laser beam makes a round trip to both corner-cube reflectors and then interferes with the launched beam. The interference is detected on a photodiode. The length of the optical path is measured by a heterodyne technique: A 100-kHz frequency shift between the launched beam and a reference beam imposes, on the detected signal, an interferometric phase shift proportional to the length of the optical path. A phase meter comprising analog filters and specialized digital circuitry converts the phase shift to an indication of displacement, generating a digital signal proportional to the path length.



This **Simplified Schematic Diagram** of the control system illustrates the control of the tilt of the laser beam about one of two orthogonal tilt axes.

If the axis of the conical scan is correctly aligned, then the path-length signal is steady and the path-length error remains constant at about $-L_0\theta_0^2/2$, where, in this case, θ_0 is the half cone angle. If, however, the axis of the conical scan is slightly misaligned, then the misalignment angle consists of a steady component θ_0 plus a small fluctuating component $\Delta\theta$. In this case, the optical-path length fluctuates by approximately $-L_0\theta_0\Delta\theta$. In a lock-in amplifier, the digital path-length signal is high-pass-filtered to eliminate the steady component, then the remaining fluctuating component is synchronously demodulated to generate DC signals proportional to the two tilt angles that characterize the misalignment. These signals are superimposed upon the voltages applied to the piezoelectric actuators to counteract the misalignment.

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