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Technology Focus: Communications

High-Accuracy, High-Dynamic-Range Phase-Measurement System

Phase differences can be measured to within a microcycle.

NASA's Jet Propulsion Laboratory, Pasadena, California

A digital phase meter has been designed to satisfy stringent requirements for measuring differences between phases of radio-frequency (RF) subcarrier signals modulated onto laser beams involved in the operation of a planned space-borne gravitational-wave-detecting heterodyne laser interferometer. The capabilities of this system could also be used in diverse terrestrial applications that involve measurement of signal phases, including metrology, navigation, and communications. The capabilities of this system include:

- Accuracy to within a millionth of a cycle (greater than the accuracy of any prior phase meter);
- High dynamic range of phase (limited only by numerical capabilities of a supporting computer);
- Wide input frequency range (≈10 kHz to ≈20 MHz),
- Maintenance of accuracy even when the frequency of a signal slews by as much as 700 kHz/s within this range; and
- The ability to distinguish and measure multiple tones on the same carrier with undiminished accuracy.

In the operation of this system, two RF modulated laser beams interfere on a photodiode; their frequency difference results in a RF heterodyne signal. The RF signal output by the photodiode is digitized at 40 Mega-samples/s, then fed into a field-programmable gate array (FPGA). The digitized heterodyne signal is split and multiplied by two adjustable local oscillators (LOs), which separates the signal into in-phase (I) cosine and a quadrature phase (Q) sine components. During stable operation at a small phase difference between the RF and LO signals, the Q multiplier output includes a low-frequency component proportional to the phase difference. This phase-difference output is used to update the LO frequency (and, thereby, the LO phase) to keep the local oscillators locked to the incoming signal. The tracking loop updates the LO frequency every 0.1 ms.

While this makes for a stable digital phase-locked loop, to achieve the desired micro-cycle phase accuracy, the residual phase-tracking error is combined with the LO phase. The residual phase difference is computed as the arctangent of the ratio between the Q and I signals, filtered appropriately, and added to the phase used to update the local oscillators.

For transmission to ground, the phase measurements are decimated from 40 MHz to the frequency-and-phase-update rate of 10 kHz, then again to a final output rate of 100 Hz. To suppress aliasing of noise in the signal band from 1 mHz to 1 Hz in the decimation from 40 MHz to 10 kHz, an anti-aliasing filter is applied prior to decimation. After the reconstruction of phase at 10 kHz and prior to the final decimation to 100 Hz, another finite-impulse-response anti-aliasing decimation filter is applied. The characteristics of the antialiasing filters are tailored to the phase noise of the input signal.

This work was done by Daniel Shaddock, Brent Ware, Peter Halverson, and Robert Spero of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).

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Refer to NPO-41927, volume and number of this NASA Tech Briefs *issue, and the page number.*

Simple, Compact, Safe Impact Tester

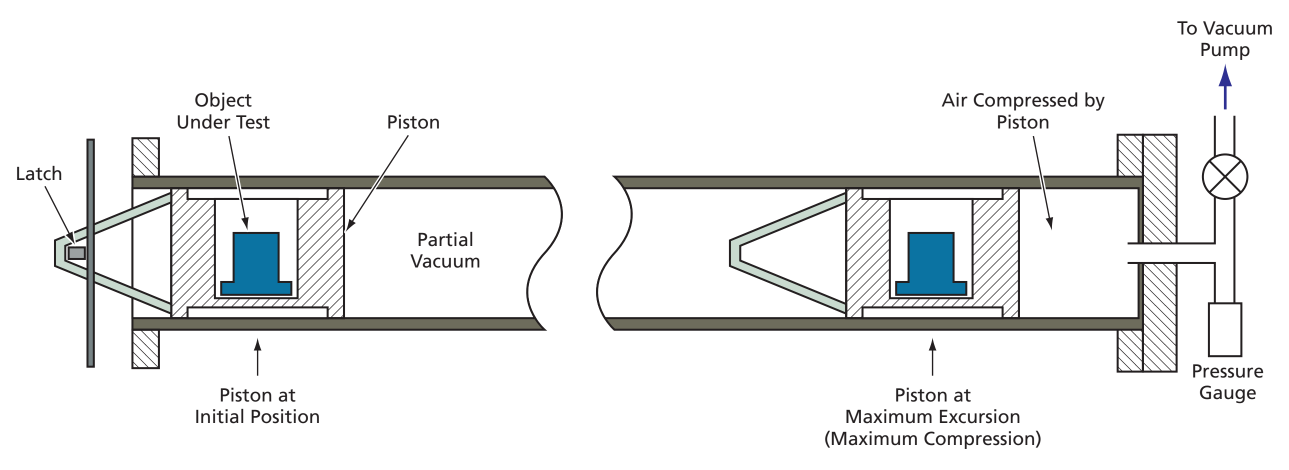
Cushioned impact decelerations up to hundreds of normal Earth gravitation are easily produced.

Ames Research Center, Moffett Field, California

An apparatus has been designed and built for testing the effects, on moderate-sized objects, of cushioned decelerations having magnitudes ranging up to several hundred g [where g = normal Earth gravitational acceleration (≈9.8 m/s^2)]. The apparatus was originally intended for use in assessing the ability of scientific instruments in spacecraft to withstand cushioned impacts of landings on remote planets. Although such landings can have impact velocities of 20 to 50 m/s, the decelerations must not exceed a few hundred g. This requires the deceleration to occur over a distance of as much as 50 cm in a time of tens of milliseconds. This combination of conditions is surprisingly difficult to simulate on the ground. The apparatus could also be used for general impact testing.

The apparatus is simple to build. Relative to drop-tower apparatuses that could produce equivalent impacts, this apparatus is very compact. This apparatus is also relatively safe to operate because its design inherently prevents the object under test or any debris from accidentally striking persons or equipment in the vicinity.

The apparatus (see figure) includes a steel pipe having an inside diameter of 20 cm and a length of 216 cm. A lightweight polyethylene piston carries the object under test. The piston is sealed to the inner wall of the pipe by means of a



Atmospheric Pressure Drives the Piston along the partially evacuated pipe toward the closed end. The piston is then decelerated strongly when it compresses the remaining air at the closed end of the pipe.

gasket. One end of the pipe is open; the opposite end of the pipe is closed and connected to a vacuum pump.

At the beginning of a test, the piston is held at the open end of the pipe by use of a latch while the vacuum pump is activated to introduce a partial vacuum [typically, characterized by an absolute pressure of 0.2 bar (20 kPa)] between the piston and the closed end. Once the desired partial vacuum has been reached, the latch is released so that differential pressure (atmospheric minus partial vacuum) accelerates the piston along the pipe toward the closed end. The piston reaches a maximum speed typically between 20 and 40 m/s, the exact value depending on the mass of the object under test and the starting pressure in the partly evacuated volume. As the piston approaches the closed end, it compresses the air ahead of it until, at a distance between 5 and 20 cm from the closed end, the pressure becomes high enough to stop the piston (and bounce it back toward its starting position). An accelerometer on the piston measures the impact deceleration.

The impact deceleration is a strong function of the amount of gas (and, hence, of the pressure) initially in the partially evacuated volume at the closed end of the pipe. Therefore, it is easy to adjust the peak deceleration by adjusting the pressure of the partial vacuum. The maximum speed is not a strong function of the mass of the object under test or of the starting partial-vacuum pressure but can be tailored over a wide range by using pipes of different length.

This work was done by Pat R. Roach and Jeffrey Feller of Ames Research Center. Further information is contained in a TSP (see page 1).
ARC-15085-1

Multi-Antenna Radar Systems for Doppler Rain Measurements

Use of multiple antennas would enable removal of platform Doppler contributions.

NASA's Jet Propulsion Laboratory, Pasadena, California

Use of multiple-antenna radar systems aboard moving high-altitude platforms has been proposed for measuring rainfall. The platforms contemplated in the proposal would be primarily spacecraft, but, in principle, the proposal could also apply to aircraft. The problem of measuring rainfall velocity from a moving platform is especially challenging because the velocity of the platform (especially in the case of a spacecraft) can be so large that it is difficult to distinguish between the rainfall and platform contributions to Doppler frequency shifts. Furthermore, nonuniform filling of radar beams can lead to biases in Doppler estimates. Although it might be possible to reduce these biases through improved data processing, a potential alternative is to use multiple antennas positioned at suitable along-track intervals.

The basic principle of the proposed systems is a variant of that of along-track interferometric synthetic-aperture radar systems used previously to measure ocean waves and currents. The simplest system according to the proposal would include two antennas that would perform cross-track scans as in a prior rainfall-measuring radar system. The antennas would be located at different along-track positions. The along-track distance between them would be chosen, in conjunction with the along-track velocity of the platform and the radar pulse-repetition frequency (PRF), such that this distance would equal the distance traveled by the platform between two successive pulses. (If necessary, the PRF could be adjusted to enforce this equality.) Thus, in effect, two sets of measurements would be performed at each platform position. Under this condition, extraction of the rainfall Doppler velocity without the platform contribution is substantially simplified and can be done with only minor modification of processing techniques traditionally used for ground-based Doppler radars.

This work was done by Stephen Durden, Simone Tanelli, and Paul Siqueira of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).
NPO-44018