Laser System for Precise, Unambiguous Range Measurements

Simultaneous, overlapping, coarse-resolution measurements would resolve ambiguities in fine-resolution measurements.

NASA's Jet Propulsion Laboratory, Pasadena, California

The **M**odulation **S**ideband **T**echnology for **A**bsolute **R**ange (MSTAR) architecture is the basis of design of a proposed laser-based heterodyne interferometer that could measure a range (distance) as great as 100 km with a precision and resolution of the order of 1 nm. Simple optical interferometers can measure changes in range with nanometer resolution, but cannot measure range itself because interference is subject to the well-known integer-multiple-of-2π-radians phase ambiguity, which amounts to a range ambiguity of the order of 1 μm at typical laser wavelengths. Existing rangefinders have a resolution of the order of 10 μm and are therefore unable to resolve the ambiguity. The proposed MSTAR architecture bridges the gap, enabling nanometer resolution with an ambiguity range that can be extended to arbitrarily large distances.

The MSTAR architecture combines the principle of the heterodyne interferometer with the principle of extending the ambiguity range of an interferometer by using light of two wavelengths. The use of two wavelengths for this purpose is well established in optical metrology, radar, and sonar. However, unlike in traditional two-color laser interferometry, light of two wavelengths would not be generated by two lasers. Instead, multiple wavelengths would be generated as sidebands of phase modulation of the light from a single frequency-stabilized laser. The phase modulation would be effected by applying sinusoidal signals of suitable frequencies (typically tens of gigahertz) to high-speed electro-optical phase modulators. Intensity modulation can also be used.

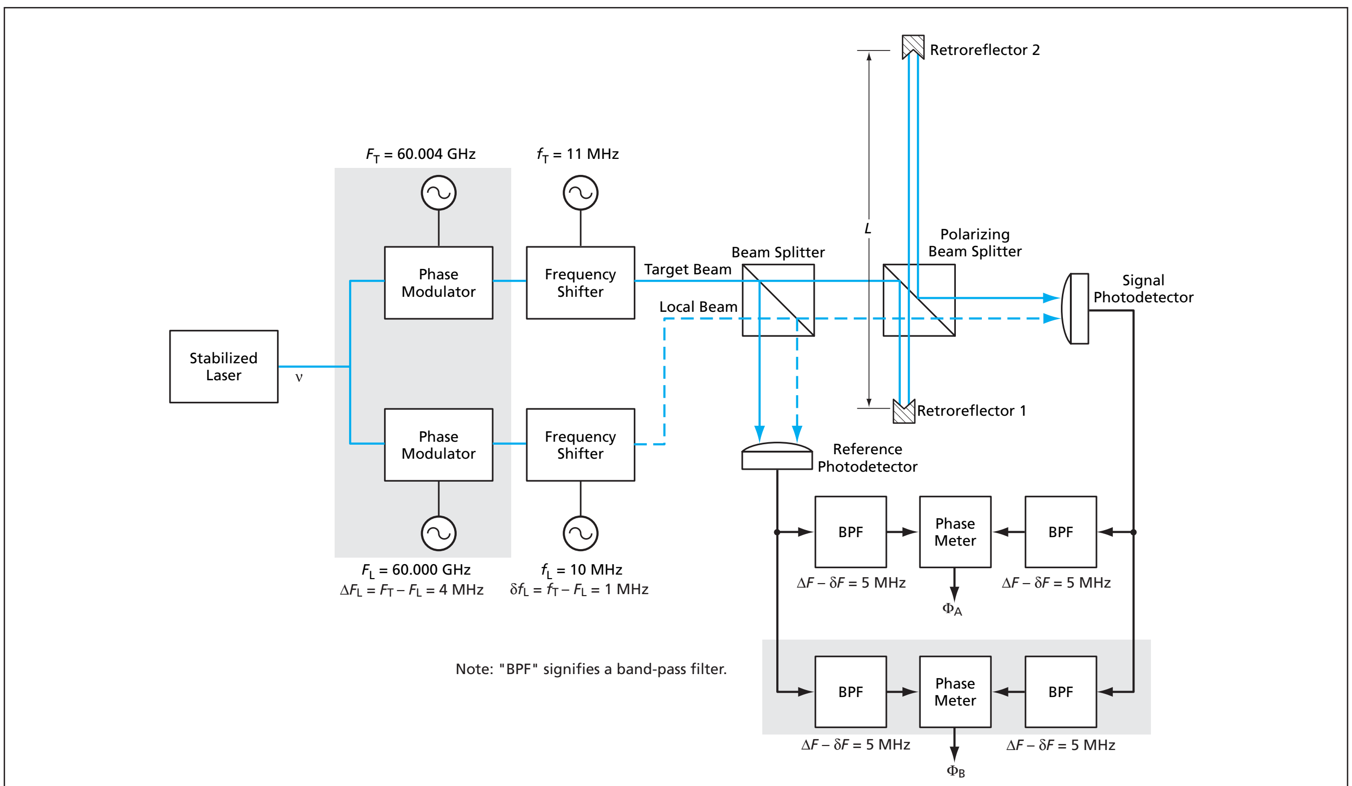
An MSTAR system (see figure) would include a conventional laser heterodyne interferometer as a subsystem, plus two high-speed phase modulators and a second phase meter. The light from the laser of carrier frequency ν would first be split into a target beam and a local beam. The target beam would be phase-modulated by a sinusoid of frequency F_T, producing sidebands displaced from the laser (carrier) frequency at positive and negative integer multiples of F_T. The carrier and all the sidebands would then be shifted in frequency by f_T. The local beam would be processed similarly, except that it would be phase-modulated at a frequency F_L and shifted in frequency by f_L. The corresponding frequencies are chosen to differ from each other by convenient small amounts:

$$\Delta F = F_T - F_L$$

and

$$\delta f = f_T - f_L.$$

The primary innovation of the MSTAR architecture is the selection of



An **MSTAR System** would include a conventional heterodyne laser interferometer plus the additional components depicted in the shaded areas. This system would provide phase measurements ϕ_A and ϕ_B that, taken together with a coarse range measurement by a pulsed ranging sensor, would yield an unambiguous measure of length L to high resolution.

phase-modulation and shift frequencies such that every sideband order m forms a heterodyne pair with a distinct heterodyne frequency,

$$m\Delta F - \delta f.$$

The signal from each heterodyne pair can be isolated by appropriate filtering. In the case illustrated in the figure, one would choose the first upper sideband pair ($m = +1$) and the first lower sideband pair ($m = -1$). Filters would isolate heterodyne frequencies

$$f_A = \Delta F + \delta f$$

and

$$f_B = \Delta F - \delta f.$$

The phase-meter outputs would be

$$\phi_A = 2\pi(\nu + f_T + F_T)2L/c$$

and

$$\phi_B = 2\pi(\nu + f_T - F_T)2L/c,$$

where L is the distance that one seeks to measure and c is the speed of light. Each of these outputs would be characterized by the same range resolution and ambiguity range as those of a conventional heterodyne interferometer, and, as such, would constitute the fine incremental range outputs. The difference between these outputs,

$$\phi_A - \phi_B = 8\pi F_T L/c$$

would constitute the gap-bridging coarse incremental range output, characterized by an ambiguity range of $c/4F_T$. One could lower the modulation frequency, F_T, to extend the ambiguity range as needed.

This work was done by Serge Dubovitsky and Oliver Lay of Caltech for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP (see page 1).*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, NASA Management Office–JPL (818) 354-7770. Refer to NPO-30304.

Flexible Cryogenic Temperature and Liquid-Level Probes

These probes can be readily customized.

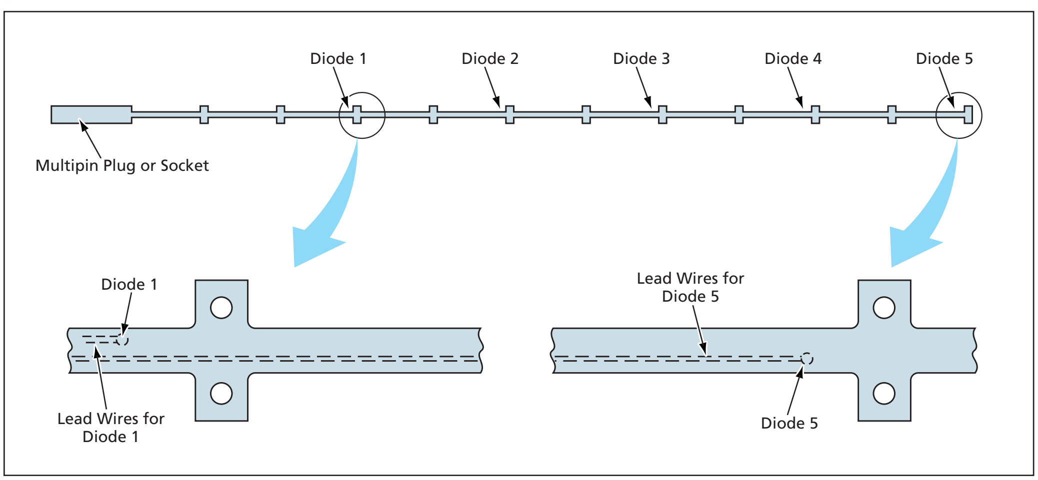
Stennis Space Center, Mississippi

Lightweight, flexible probes have been developed for measuring temperatures at multiple locations in tanks that contain possibly pressurized cryogenic fluids. If the fluid in a given tank is subcritical (that is, if it consists of a liquid and its vapor), then in one of two modes of operation, the temperature measurements made by a probe of this type can be used to deduce the approximate level of the liquid.

The temperature sensors are silicon diodes located at intervals along a probe. If the probe is to be used to measure a temperature gradient along a given axis in the tank, then the probe must be mounted along that axis. In the temperature-measurement mode, a constant small electric current is applied to each diode and the voltage across the diode — a known function of the current and temperature — is measured as an indication of its temperature. For the purpose of this measurement, "small electric current" signifies a current that is not large enough to cause a significant increase in the measured temperature. More specifically, the probe design calls for a current of 10 μA, which, in the cryogenic temperature range of interest, generates heat at a rate of only about 0.01 mW per diode.

In the liquid-level-sensing mode, one applies a larger current (30 mA) to each diode so as to heat each diode appreciably (with a power of about 36 mW in the temperature range of interest). Because the liquid cools the diode faster than does the vapor, the temperature of the diode is less when the diode is immersed in the liquid than when it is above the surface of the liquid. Thus, the temperature (voltage) reading from each diode can be used to determine whether the liquid level is above or below the diode, and one can deduce that the liquid level lies between two adjacent diodes, the lower one of which reads a significantly lower temperature.

The aforementioned techniques for measuring temperature and deducing liquid level are not new. What is new here are the designs of the probes and of associated external electronic circuitry. In each probe, the diodes and the lead wires are embedded in a strong, lightweight, flexible polyimide strip. Each probe is constructed as an integral unit that includes a multipin input/output plug or socket for solderless connection of the lead wires to the external circuitry. The polyimide strip includes mounting tabs with holes that can accommodate rivets, screws, or other fasteners. Alternatively, a probe can be mounted by use of an epoxy. A probe can be manufactured to almost any length or width, and the diodes can be embedded at almost any desired



Diodes and Their Lead Wires are embedded in a polyimide strip at locations from which temperature measurements are desired.