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.

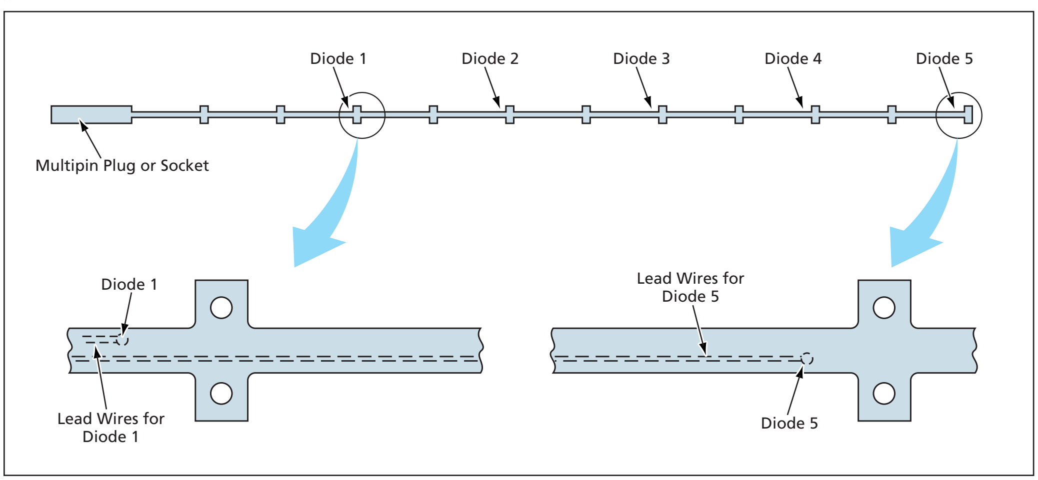
Stennis Space Center, Mississippi

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.

location along and across the polyimide strip.

In designing a probe for a specific application, one seeks a compromise between (1) minimizing the number of diodes in order to minimize the complexity of input/output connections and external electronic circuitry while (2) using enough diodes to obtain the required precision. Optionally, to minimize spurious heating of the cryogenic fluid, the external circuitry can be designed to apply power to the probe only during brief measurement intervals. Assuming that the external circuitry is maintained at a steady temperature, a power-on interval of only a few seconds is sufficient to obtain accurate data on temperatures and/or the height of the liquid/vapor interface.

This work was done by Mark Haberbusch of Sierra Lobo, Inc., for **Stennis Space Center**.

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:

Sierra Lobo, Inc.
11401 Hoover Road
Milan, Ohio 44846

Refer to SSC-00191, volume and number of this NASA Tech Briefs *issue, and the page number.*

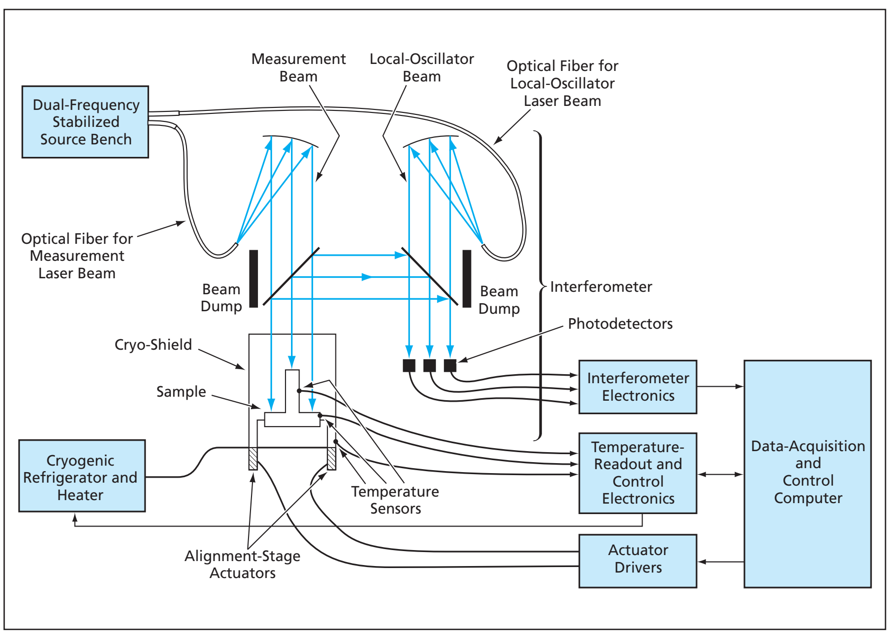
Precision Cryogenic Dilatometer

This instrument offers much greater precision than do other currently available dilatometers.

NASA's Jet Propulsion Laboratory, Pasadena, California

A dilatometer based on a laser interferometer is being developed to measure mechanical creep and coefficients of thermal expansion (CTEs) of materials at temperatures ranging from ambient down to 15 K. This cryogenic dilatometer has been designed to minimize systematic errors that limit the best previously available dilatometers. At its prototype stage of development, this cryogenic dilatometer yields a strain measurement error of 35 ppb or 1.7 ppb/K CTE measurement error for a 20-K thermal load, for low-expansion materials in the temperature range from 310 down to 30 K. Planned further design refinements that include a provision for stabilization of the laser and addition of a high-precision sample-holding jig are expected to reduce the measurement error to 5-ppb strain error or 0.3-ppb/K CTE error for a 20-K thermal load.

The dilatometer (see figure) includes a common-path, differential, heterodyne interferometer; a dual-frequency, stabilized source bench that serves as the light source for the interferometer; a cryogenic chamber in which one places the material sample to be studied; a cryogenic system for cooling the interior of the chamber to the measurement temperature; an ultra-stable alignment stage for positioning the chamber so that the sample is properly positioned with respect to the interferometer; and a data-acquisition and control system. The cryogenic chamber and the interferometer portion of the dilatometer are housed in a vacuum chamber on top of a vibration-isolating optical table in a cleanroom. The sample consists of two pieces — a pillar on a base — both made of the same material. Using reflections of the interferometer beams from the base and the top of the pillar, what is measured is the change in length of the pillar as the temperature in the chamber is changed.



The **Change in Height** of the sample pillar in the cryogenic chamber is measured interferometrically. Design features that are much too numerous to depict here ensure a high degree of optical and mechanical stability over wide temperature range, as needed for high-precision measurements of thermal expansion and creep in the sample.

In their fundamental optical and electronic principles of operation, the laser light source and the interferometer are similar to those described in "Common-Path Heterodyne Interferometers" (NPO-20786), *NASA Tech Briefs*, Vol. 25, No. 7 (July 2001), page 12a, and "Interferometer for Measuring Displacement to Within 20 pm" (NPO-21221), *NASA Tech Briefs*, Vol. 27, No. 7 (July 2003), page 8a. However, the present designs incorporate a number of special geometric, optical, and mechanical features to minimize optical and thermal-expansion effects that contribute to measurement errors. These features include the use of low-thermal-expansion materials for structural components, kinematic mounting and symmetrical placement of optical components, and several measures taken to minimize spurious reflections of laser beams.

This work was done by Matthew Dudik, Peter Halverson, Marie Levine-West, Martin Marcin, Robert D. Peters, and Stuart Shaklan of Caltech for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP (see page 1).*
NPO-40389