tic mine or other dielectric object, then some microwave energy would penetrate the object, would undergo one or more internal reflections, and would then be scattered or reflected back toward the antenna. The magnitude and phase of each of these reflections would depend on frequency and would contribute to the spectral signature of the object and the surrounding material. The spectral signature would manifest itself as the frequency dependence of the input impedance of the antenna. This impedance would be measured by the computer.

The impedance-vs.-frequency data must be processed to extract useful information on the location and nature of the sought object. One algorithm that could be used for this purpose can be summarized as follows:

1. Proceeding across the frequency band, calculate a running average of the magnitude of input impedance vs. frequency.
2. Compute the difference between the magnitude of impedance and the running average at each frequency.
3. Uniformly digitally amplify the difference data for all frequencies over the band.
4. Compute the Fourier transform of the difference-vs.-frequency data to obtain a plot that is intuitively easy to interpret because its abscissa is proportional to time and is thus related to signal-propagation distance and permittivity.

Figure 2 presents such a plot calculated theoretically for an apparatus operating in the frequency band of 1 to 10 GHz with its antenna aimed toward soil in which a plastic mine 3 in. (7.6 cm) in diameter and 1-1/2 in. (3.8 cm) thick is buried. The first spectral peak is caused by reflection of the microwave signal from the antenna input terminal and is located at d_1, which is proportional to the length of a coaxial cable from the network analyzer to the antenna. The second peak, located at d_2, is associated with the reflection of the microwave signal at the surface of the ground. The largest next two peaks, located at d_3 and d_4, are attributable to reflection from the top and bottom surfaces of the mine; thus, d_3 and d_4 are measures of the depth of burial of the mine.

This work was done by G. Arndt and P. Ngo of **Johnson Space Center***, J. R. Carl of Lockheed Martin, and K. Byerly and L. Stolarcyzk.*

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, Johnson Space Center, (281) 483-0837. Refer to MSC-22839.

Digital Averaging Phasemeter for Heterodyne Interferometry

One instrument performs functions for which separate instruments were previously needed.

NASA's Jet Propulsion Laboratory, Pasadena, California

A digital averaging phasemeter has been built for measuring the difference between the phases of the unknown and reference heterodyne signals in a heterodyne laser interferometer. This phasemeter performs well enough to enable interferometric measurements of distance with accuracy of the order of 100 pm and with the ability to track distance as it changes at a speed of as much as 50 cm/s. This phasemeter is unique in that it is a single, integral system capable of performing three major functions that, heretofore, have been performed by separate systems: (1) measurement of the fractional-cycle phase difference, (2) counting of multiple cycles of phase change, and (3) averaging of phase measurements over multiple cycles for improved resolution. This phasemeter also offers the advantage of making repeated measurements at a high rate: the phase is measured on every heterodyne cycle. Thus, for example, in measuring the relative phase of two signals having a heterodyne frequency of 10 kHz, the phasemeter would accumulate 10,000 measurements per second. At this high measurement rate, an accurate average phase determination can be made more quickly than is possible at a lower rate.

Figure 1 schematically depicts a typical heterodyne laser interferometer in which the phasemeter is used. The goal is to measure the change in the length of the optical path between two corner cube retroreflectors. Light from a stabilized laser is split into two fiber-optic outputs, denoted P and S, respectively, that are mutually orthogonally polarized and separated by a well-defined heterodyne frequency. The two fiber-optic outputs are fed to a beam launcher that, along with the corner-cube retroreflectors, is part of the interferometer optics. In addition to launching the beams, the beam launcher immediately diverts and mixes about 10 percent of the power from the fiber-optic feeds to obtain a reference heterodyne signal. This signal is detected, amplified, and squared to obtain a reference square-wave heterodyne sig-

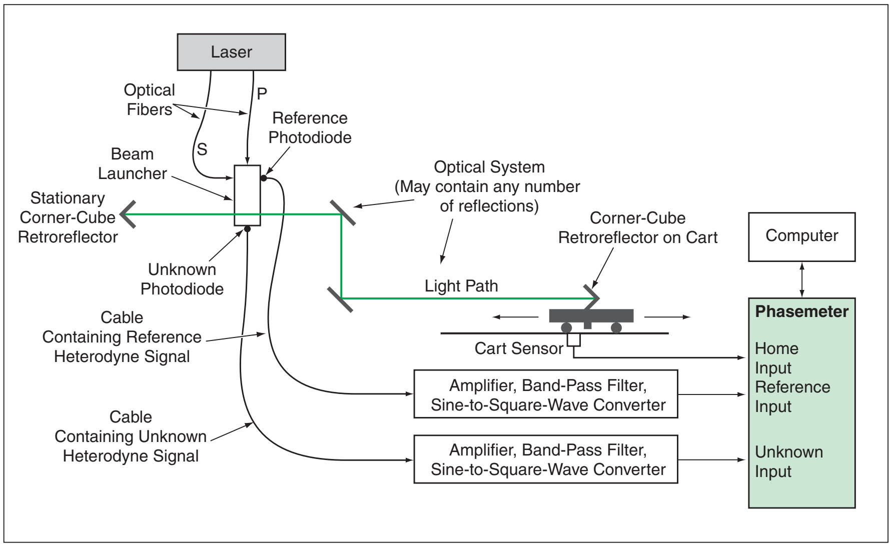

Figure 1. A **Heterodyne Laser Interferometer** is used to measure changes in the length of the optical path between the corner-cube retroreflectors. These changes are proportional to changes in the phase difference between the reference and unknown signals, which are measured by the phasemeter.

nal, which is fed to the reference input terminal of the phasemeter.

The remaining 90 percent of the power from the fiber-optic feeds of the light from the two inputs is treated as follows: The P beam is launched toward one corner-cube retroreflector, while the S beam travels to the unknown photodiode. The S beam returns to the beam launcher, passes through it, and continues to the other retroreflector. The S beam then returns to the beam launcher where it mixes with the P beam, producing the "unknown" heterodyne signal, which is then detected, amplified, and squared in the same manner as that of the reference signal. The resulting square-wave is fed to the unknown input terminal of the phasemeter.

The frequency of the unknown heterodyne signal is close to that of the reference signal: If the optics are motionless, the unknown frequency is exactly the reference frequency. Motion of the optics gives rise to a Doppler shift in the unknown frequency relative to the reference frequency. By tracking the relative phases of the unknown and reference signals, one tracks the change in the length of the optical path between the retroreflectors.

The phasemeter (see Figure 2) tracks the integer number of cycles and the fractional-cycle portions of the phase difference separately. The integer part of the phase difference is taken to equal the number of positive- or negative-going square-wave level transitions at the reference input minus the number of such transitions at the unknown input. The fractional part of the phase difference is taken to be proportional to the number of ticks of a clock of 128-MHz frequency during the time interval from the most recent reference transition to the next unknown transition.

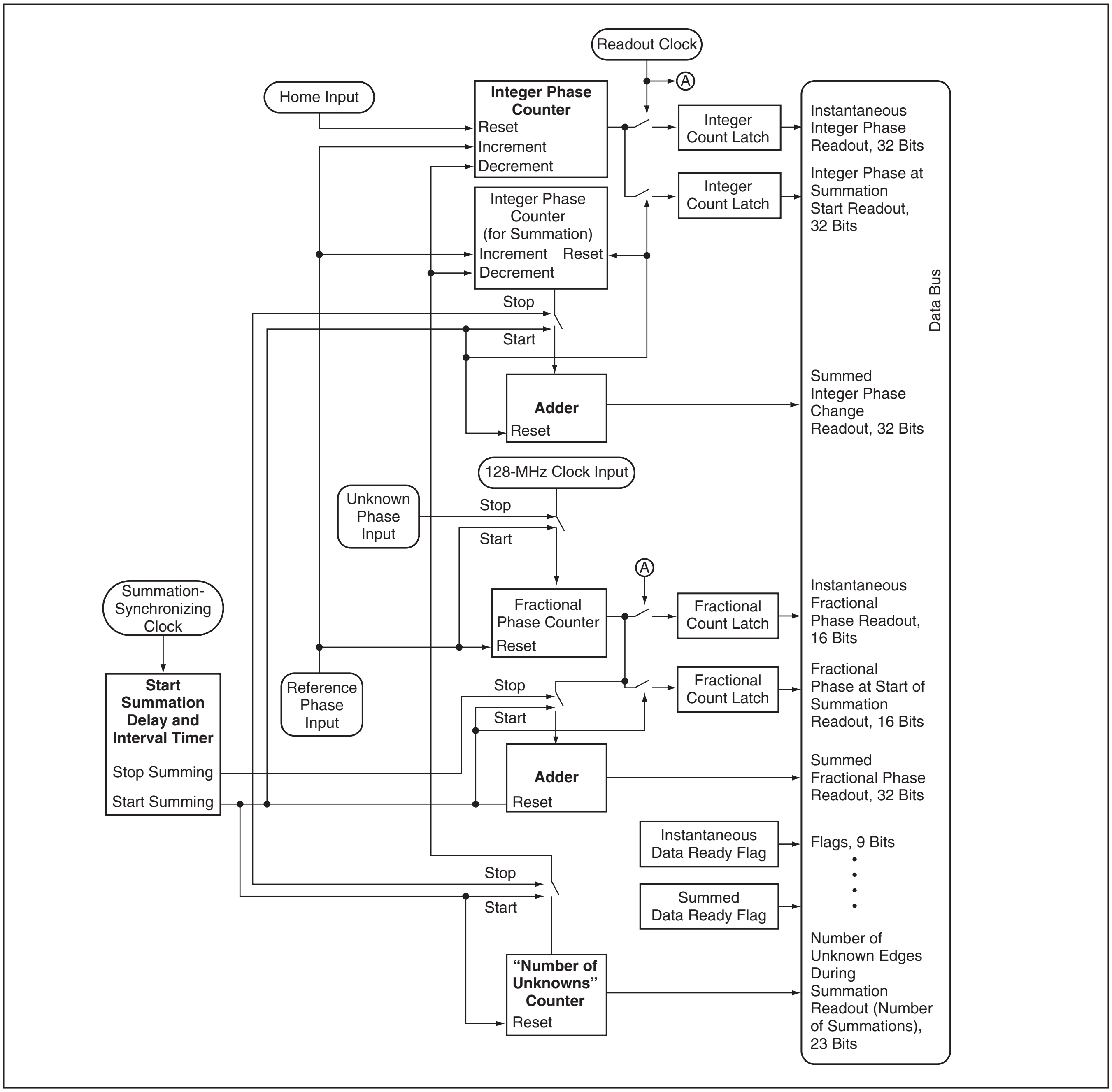

Figure 2. In the **Phasemeter**, the integer-cycle and fractional-cycle parts of the phase difference are measured separately. For greater accuracy, the phasemeter can average its measurements over many cycles of the heterodyne signals.

The integer and fractional phase-counter outputs are also fed to accumulators to compute the sum of many phase measurements over a programmed interval. The sum is then used to compute an average. The summing interval can be made to repeat at a fixed frequency, typically in the range between 1 Hz and 1 kHz, that is defined by a signal from a summation-synchronizing clock. The averaging interval can be programmed to start any time after the summation-synchronizing clock signal and can continue for any time up to the next such signal. During the summation, each negative-going transition of the unknown signal causes a phase measurement to be summed into the integer and fractional phase accumulators. As a result, the number of readings in an average equals the duration of the summation interval multiplied by the unknown heterodyne frequency; for example, if the heterodyne frequency is 10 kHz and the summation interval is 0.1 second, then 1,000 measurements are accumulated.

This work was done by Donald Johnson, Robert Spero, Stuart Shaklan, Peter Halverson, and Andreas Kuhnert of Caltech for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP (see page 1).*
NPO-30866

Optoelectronic Instrument Monitors pH in a Culture Medium

This instrument is noninvasive and is not significantly affected by biofilm.

Lyndon B. Johnson Space Center, Houston, Texas

An optoelectronic instrument monitors the pH of an aqueous cell-culture medium in a perfused rotating-wall-vessel bioreactor. The instrument is designed to satisfy the following requirements:

- It should be able to measure the pH of the medium continuously with an accuracy of ±0.1 in the range from 6.5 to 7.5.
- It should be noninvasive.
- Any material in contact with the culture medium should be sterilizable as well as nontoxic to the cells to be grown in the medium.
- The biofilm that inevitably grows on any surface in contact with the medium should not affect the accuracy of the pH measurement.
- It should be possible to obtain accurate measurements after only one calibration performed prior to a bioreactor cell run.
- The instrument should be small and lightweight.

The instrument includes a quartz cuvette through which the culture medium flows as it is circulated through the bioreactor. The cuvette is sandwiched between light source on one side and a photodetector on the other side. The light source comprises a red and a green light-emitting diode (LED) that are repeatedly flashed in alternation with a cycle time of 5 s. The responses of the photodiode to the green and red LEDs are processed electronically to obtain a quantity proportional to the ratio between the amounts of green and red light transmitted through the medium.

The medium contains some phenol red, which is an organic pH-indicator dye. Phenol red dissociates to a degree that is a known function of pH and temperature, and its optical absorbance at the wavelength of the green LED (but not at the wavelength of the red LED) varies accordingly. Hence, the pH of the medium can be calculated from the quantity obtained from the photodetector responses, provided that calibration data are available.

During the calibration procedure, the dyed culture medium to be used in the bioreactor is circulated through the cuvette and the photodetector responses are processed and recorded while small amounts of hydrochloric acid are added to the medium from time to time to make the pH decrease in small increments through the pH range from 7.5 to 6.5. For each set of measurements, the pH is determined by conventional means. Then the resulting data are fitted with a second-order polynomial, the coefficients of which are thereafter used to compute the pH as a function of the aforementioned quantity proportional to the ratio between the amounts of green and red light transmitted.

The cuvette is the only part of the instrument in contact with the culture medium. The cuvette can readily be sterilized, either separately from or as incorporated into the bioreactor system, by use of an autoclave or by use of ethylene oxide. Tests have shown that the error in the pH measurement by this instrument does not range beyond ±0.1 pH unit, even when a biofilm is present. As required, the instrument is lightweight (total mass, including electronic circuitry, only 150 g) and compact [overall dimensions of 1.0 by 1.5 by 2.5 in. (approximately 2.5 by 3.8 by 6.4 cm)].

This work was done by Melody M. Anderson and Neal Pellis of **Johnson Space Center** *and Anthony S. Jeevarajan and Thomas D. Taylor of Wyle Laboratories. For further information, contact the Johnson Commercial Technology Office at (281) 483-3809.*
MSC-23107

Imaging of γ-Irradiated Regions of a Crystal

Electron-trapping and photorefractive effects are exploited.

NASA's Jet Propulsion Laboratory, Pasadena, California

A holographic technique has been devised for generating a visible display of the effect of exposure of a photorefractive crystal to γ rays. The technique exploits the space charge that results from trapping of electrons in defects induced by γ rays.

The technique involves a three-stage process. In the first stage, one writes a holographic pattern in the crystal by use of the apparatus shown in Figure 1. A laser beam of 532-nm wavelength is collimated and split into signal and reference beams by use of a polarizing beam splitter. On its way to the crystal, the ref-