

Airplane Ice Detector Based on a Microwave Transmission Line

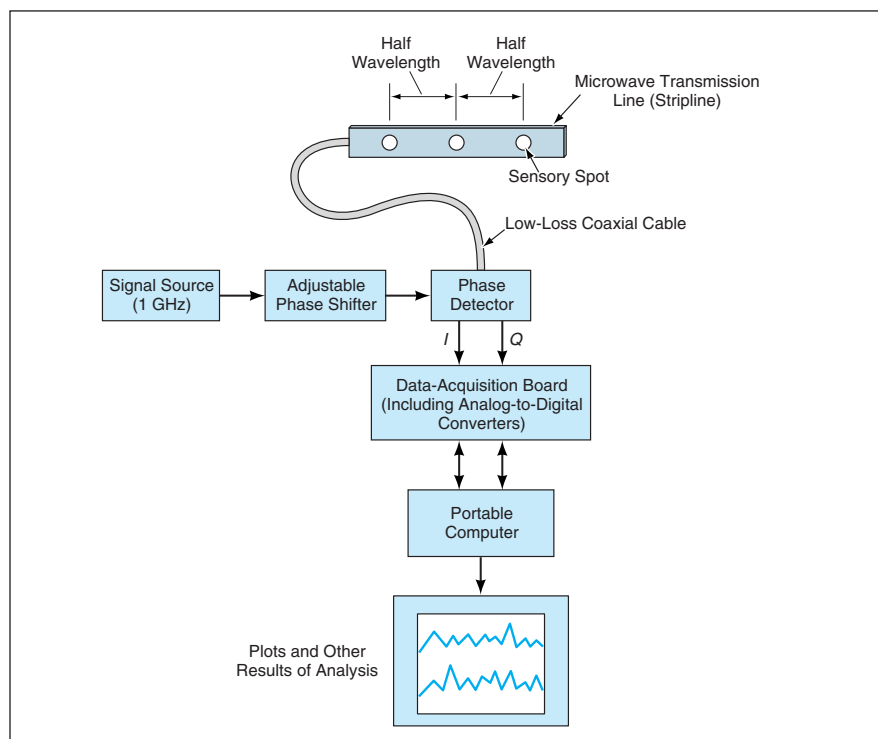
Electrical measurements are affected by thawing, freezing, and the presence or absence of water.

Lyndon B. Johnson Space Center, Houston, Texas

An electronic instrument that could detect the potentially dangerous buildup of ice on an airplane wing is undergoing development. The instrument is based on a microwave transmission line configured as a capacitance probe: at selected spots, the transmission-line conductors are partly exposed to allow any ice and/or liquid water present at those spots to act as predominantly capacitive electrical loads on the transmission line. These loads change the input impedance of the transmission line, as measured at a suitable excitation frequency. Thus, it should be possible to infer the presence of ice and/or liquid water from measurements of the input impedance and/or electrical parameters related to the input impedance.

The sensory transmission line is of the microstrip type and thus thin enough to be placed on an airplane wing without unduly disturbing airflow in flight. The sensory spots are small areas from which the upper layer of the microstrip has been removed to allow any liquid water or ice on the surface to reach the transmission line. The sensory spots are spaced at nominal open-circuit points, which are at intervals of a half wavelength (in the transmission line, not in air) at the excitation frequency. The excitation frequency used in the experiments has been 1 GHz, for which a half wavelength in the transmission line is ≈ 4 in. (≈ 10 cm).

The figure depicts a laboratory prototype of the instrument. The impedance-related quantities chosen for use in this version of the instrument are the magnitude and phase of the scattering parameter S_{11} as manifested in the in-phase (I) and quadrature (Q) outputs of the phase detector. By careful layout of the transmission line (including the half-wavelength sensor spacing), one can ensure that the amplitude and phase of the input to the phase detector keep shifting



The I and Q Outputs of the Phase Shifter are affected by the presence or absence of liquid water or ice on the sensory spots on the microwave transmission line.

in the same direction as ice forms on one or more of the sensor areas. Although only one transmission-line sensor strip is used in the laboratory version, in a practical application, it could be desirable to install multiple strips on different areas to detect localized icing. In that case, a multiplexer should be used to connect the various strips to the phase detector for sequential measurements.

Experiments have been performed with freezing and thawing of water and of water/glycol mixtures. The experiments have shown that, whether or not glycol is present, it is possible to distinguish between liquid water and ice via the I and Q outputs; in particular, the equipment can

be adjusted so that when water freezes, I decreases and Q increases. With respect to the operation of this instrument, the main effect of glycol is to increase the freezing or thawing time.

This work was done by G. Dickey Arndt and Phong Ngo of Johnson Space Center and James R. Carl of Lockheed Martin. For further information, contact G. Dickey Arndt at g.d.arndt@nasa.gov.

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-23118.

Microwave/Sonic Apparatus Measures Flow and Density in Pipe

The entire flow, rather than a small diverted sample flow, is probed.

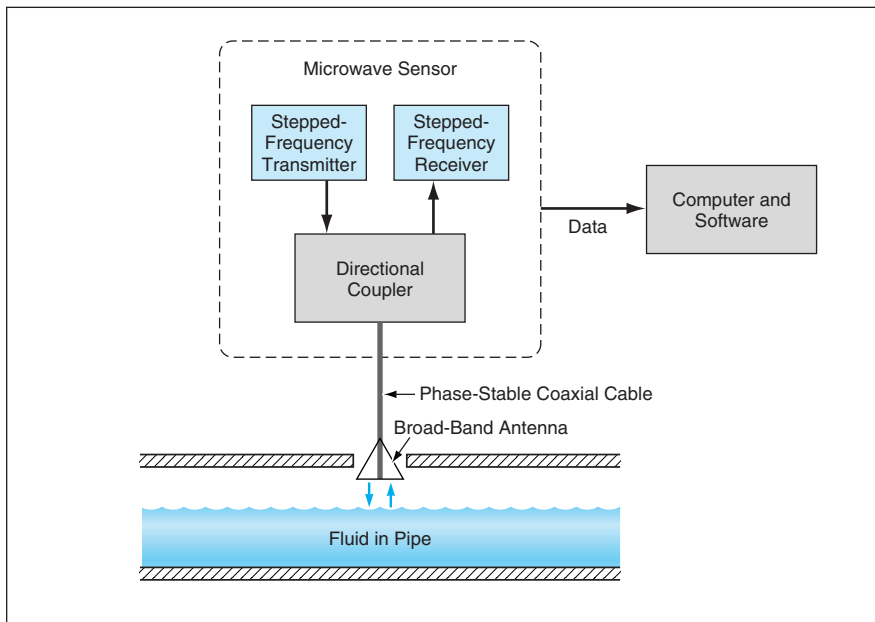
Lyndon B. Johnson Space Center, Houston, Texas

An apparatus for measuring the rate of flow and the mass density of a liquid or slurry includes a special section of pipe instrumented with microwave and sonic

sensors, and a computer that processes digitized readings taken by the sensors. The apparatus was conceived specifically for monitoring a flow of oil-well-drilling

mud, but the basic principles of its design and operation are also applicable to monitoring flows of other liquids and slurries.

In one configuration, a special section



The **Height of the Fluid** relative to the antenna is determined from differences between the phases of stepped-frequency microwave signals transmitted to, and reflected from, the top surface of the fluid.

of pipe is located immediately upstream of the point of discharge of the flow to be monitored. The special section of pipe must be large enough that the pipe can accommodate the entire flow of interest (in contradistinction to a small diverted sample flow), that the flow remains laminar at all times, and that the pipe is never entirely full, even at the maximum flow rate.

In another configuration, the apparatus does not measure the rate of flow or the density directly: Instead, it (a) measures the height of the fluid in the special section of pipe and computes the flow rate as a predetermined function of the height and (b) measures the speed of sound in the fluid and computes the density of the fluid as a predetermined function of the speed of sound in the fluid. To enable the apparatus to per-

form these computations, one must calibrate the apparatus, prior to operation, by measuring the flow rate as a function of height and the mass density as a function of the speed of sound for the drilling mud or other fluid of interest.

In the second configuration, the velocity of the fluid can be measured subsurface using a set of one transmitter and two receivers to measure differential phase shifts. This second configuration can be used within a filled or unfilled closed pipe to measure volume flow. The microwave portion of the apparatus (see figure) includes a broadband swept-frequency (more precisely, stepped-frequency) transmitter/receiver pair connected, via a directional coupler, to an antenna aimed downward at the liquid. Transmitted- and received-signal data are processed by an algorithm that uses a modified

Fourier transform to compute the round-trip propagation time of the signal reflected from top of the fluid. The height of the fluid is then computed from the round-trip travel time and the known height of the antenna. A sonic sensor that operates alongside the microwave sensor gives an approximate height reading that makes it possible to resolve the integer-multiple-of- 2π phase ambiguity of the microwave sensor, while the microwave sensor makes it possible to refine the height measurement to within 0.1 in. (≈ 2.5 mm).

Ultrasonic sensors on the walls near the bottom of the special section of pipe are used to measure the speed of sound needed to compute the density of the fluid. More specifically, what is measured is the difference between the phase of a signal of known frequency at a transmitting transducer and the phase of the same signal at a receiving transducer a known distance away. It may also be necessary to resolve an integer-multiple-of- 2π phase ambiguity. This can be done by using two sonic frequencies chosen according to a well-established technique. Alternatively, one could use a single sonic frequency low enough not to be subject to the phase ambiguity, albeit with some loss of density resolution. Simulations indicate that a density accuracy measurement of 0.25 percent (0.0025) can be attained with a single-tone system.

This work was done by G. D. Arndt and Phong Ngo of Johnson Space Center and J. R. Carl and Kent A. Byerly, independent consultants.

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-23311.

Reducing Errors by Use of Redundancy in Gravity Measurements

Mathematical identities are exploited to suppress noise or reduce numbers of measurements.

NASA's Jet Propulsion Laboratory, Pasadena, California

A methodology for improving gravity-gradient measurement data exploits the constraints imposed upon the components of the gravity-gradient tensor by the conditions of integrability needed for reconstruction of the gravitational potential. These constraints are derived

from the basic equation for the gravitational potential and from mathematical identities that apply to the gravitational potential and its partial derivatives with respect to spatial coordinates.

Consider the gravitational potential ϕ in a Cartesian coordinate system $\{x_1, x_2, x_3\}$.

The i th component of gravitational acceleration is given by

$$g_i = -\frac{\partial \phi}{\partial x_i}$$

(where $i = 1, 2, \text{ or } 3$) and the (α, β) com-