wide-angle optics. Examples include a panoramic annular lens (PAL), a convex mirror, a fish-eye lens, scanning optics, or a panoramic refracting optic (PRO), which is described in the next paragraph. If necessary, the transfer optics can include one or more mirror(s) to flip the image. Downstream from the panoramic imaging optic and transfer optics, the image is further conditioned by the camera lens, then detected by the CCD in the camera. The camera output is digitized, processed by the computer, and displayed and/or stored as needed.

A PRO is a recently developed optic that operates partly like a PAL, partly like a fish-eye lens, and partly like a convex mirror. In comparison with a PAL, a PRO provides a wider field of view, yet is simpler and can be fabricated at lower cost. As shown in Figure 2, light from a scene enters the optic at location 1 (where it is refracted), travels through the optic, is totally internally reflected at location 2, leaves the optic at location 3 (where it undergoes a small amount of refraction), then goes through the transfer optics and camera lens into the camera. The net effect of refraction and reflection from surfaces of the optic is to define the wide, approximately cylindrical field of view. The limits of the field of view are deter-
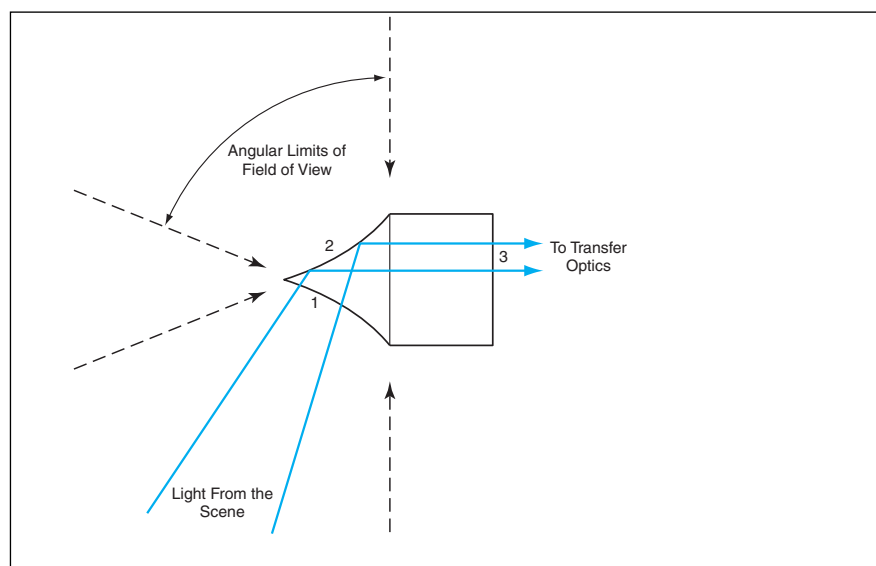

Figure 2. **A Panoramic Refractive Optic** utilizes both refraction and total internal reflection to enable projection from a wide, approximately cylindrical field of view onto a wide annulus in a focal plane.

mined primarily by the index of refraction of the optic and the curvature of its refracting/reflecting surface. A significant issue that remains to be addressed in subsequent development efforts is that the resolution of the image is approximately inversely proportional to the angular width of the field of view.

This work was done by Jeffrey L. Lindner of Marshall Space Flight Center and John Gilbert of Optechnology, Inc. For

further information, contact Jim Dowdy, MSFC Commercialization Assistance Lead, at jim.dowdy@nasa.gov.

This invention has been patented by NASA (U.S. Patent No. 6,580,567). Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to Sammy Nabors, MSFC Commercialization Assistance Lead, at sammy.a.nabors@nasa.gov. Refer to MFS-31432/75.

Interface Electronic Circuitry for an Electronic Tongue

Compact, low-noise interface circuits are mounted in proximity to the tongue.

NASA's Jet Propulsion Laboratory, Pasadena, California

Electronic circuitry has been developed to serve as an interface between an electronic tongue and digital input/output boards in a laptop computer that is used to control the tongue and process its readings. Electronic tongues were described in two prior *NASA Tech Briefs* articles: "Electronic Tongue for Quantitation of Contaminants in Water" (NPO-30601), Vol. 28, No. 2 (February 2004), page 31; and "Electronic Tongue Containing Redox and Conductivity Sensors" (NPO-30862), Vol. 31, No. 8 (August 2007), page 58. Electronic tongues can be used for a variety of purposes, including evaluating water quality, analyzing biochemicals, analyzing biofilms, and measuring electrical conductivities of soils.

The present electronic tongue and interface circuitry are updated versions of those described in the latter-mentioned

prior article. The instrument was designed for use in characterizing biofilms by Prof. D. Newman and Dr. D. Lies at Caltech. To recapitulate: An electronic tongue is a rugged, compact sensor unit that can include a heater, a temperature sensor, a conductivity sensor, and an array of three-electrode electrochemical cells, all on one planar surface of a ceramic substrate. The cells of an electronic tongue are connected to electronic excitation and readout circuits. Among the tasks identified by Prof. D. Newman and Dr. D. Lies that must be performed to characterize biofilms are stimulation of the microbial environment through generation of oxygen and hydrogen, detection of their metabolic products, and visual observation of biofilms. An electronic tongue can provide the needed stimulation while serving as a

means of electrochemical detection of metabolic products of a biofilm.

A prototype apparatus for characterizing a biofilm includes an electronic tongue mounted in a flow-through, see-into chamber. The chamber is mounted on a platform under a microscope that is used to observe the biofilm growing on the electronic tongue. The flow-through, see-into chamber is made of polycarbonate structural components plus a cover glass. A watertight compartment containing the electrodes is formed by O-ring seals between the upper and lower surfaces of the electronic tongue and the facing surfaces of the chamber. On the top side of the electronic tongue, a spacer establishes the thickness of the flow-through cell as a gap between the electrodes and the cover glass.

In the present version, the electronic tongue contains 12 analog cells: nine oxidation/reduction (redox) electrochemical cells, an electrical-conductivity cell, and the aforementioned heater and temperature sensor. The interface circuitry (see figure) consists mainly of 12 digital-to-analog converters (DACs) for excitation of the cells, and four analog-to-digital converters (ADCs) for readout from the cells connected to 12 analog cells. Each analog cell is made of two instrument amplifiers, two operational amplifiers and analog filters for reducing signal-to-noise ratios, and control and switching circuits.

The interface circuitry resides on a board mounted immediately below the ceramic substrate and, as in the prior version, is connected to the analog cells via miniature edge connectors on the ceramic substrate. By thus placing the ADCs and DACs near the analog cells, the design helps to minimize pickup of noise and reduce cross-talk on the analog signal lines.

As in the prior version, the control circuitry can be programmed to make the DACs generate the specified excitation waveforms and to make the ADCs acquire the specified response waveform data, and each electrochemical cell can be addressed individually. Depending on the specific application, a given electrochemical cell can be operated in a potentiostatic mode (voltage forced, current measured) or a galvanostatic mode (current forced, voltage measured), or can be made to alternate between the two modes. In one typical application, the main sequence of excitations and responses in a potentiostatic mode is chosen to implement anodic stripping voltammetry or cyclic voltammetry. In another typical application, a working electrode of a cell is operated in a galvanostatic mode at a positive bias for generating oxygen or a negative bias for generating hydrogen.

This work was done by Didier Keymeulen and Martin Buehler of Caltech for NASA's Jet Propulsion Laboratory.
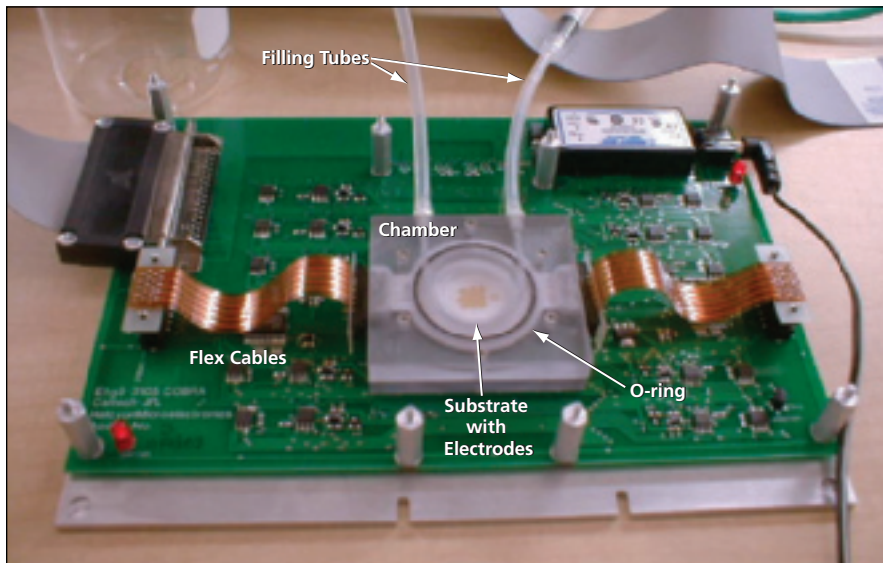
The **Interface Circuitry** is laid out compactly on a board that, when installed, lies immediately below the electronic tongue.

Inexpensive Clock for Displaying Planetary or Sidereal Time

An external oscillator is substituted for an internal quartz clock oscillator.

NASA's Jet Propulsion Laboratory, Pasadena, California

An inexpensive wall clock has been devised for displaying solar time or sidereal time as it would be perceived on a planet other than the Earth, or for displaying sidereal time on the Earth. The concept of a wall clock synchronized to a period other than the terrestrial mean solar day is not new in itself. What is new here is that the clock is realized through a relatively simple electronic modification of a common battery-powered, quartz-crystal-oscillator-driven wall clock (which, as unmodified, displays terrestrial mean solar time).

The essence of the modification is to shut off the internal oscillator of the clock and replace the internal-oscillator output signal with a signal of the required frequency generated by an external oscillator. The unmodified clock electronic circuitry includes a quartz crystal connected to an integrated circuit (IC) that includes, among other parts, a buffer amplifier that conditions the oscillator output. The modification is effected by removing the quartz crystal and connecting the output terminal of the external oscillator, via a capacitor, to the input terminal of the buffer amplifier (see figure).

The frequency and amplitude of the external-oscillator signal must be chosen in accordance with the IC design as well as the desired clock speed. Typically, the required amplitude is 0.5 V peak-to-peak and the frequency required for two complete revolutions of the hour hand (two 12-hour cycles) spanning a terrestrial mean solar day is 2^{15} = 32,768 Hz. Examples of other clock cycles and frequencies based on this typical design include the following:

- For one complete revolution of the hour hand (one 24-hour cycle) during a terrestrial mean solar day, the required frequency is 2^{14} = 16,384 Hz.
- For two complete revolutions of the hour hand (two 12-"hour" cycles) during a terrestrial sidereal day, the required frequency is 32,859.27577 Hz.
- For one complete revolution of the hour hand (one 24-"hour" cycle) during a terrestrial sidereal day, the required frequency is 16,429.63788 Hz.
- For two complete revolutions of the hour hand (two 12-"hour" cycles) during a Martian mean solar day, the required frequency is 31,947.1361 Hz.
- For one complete revolution of the