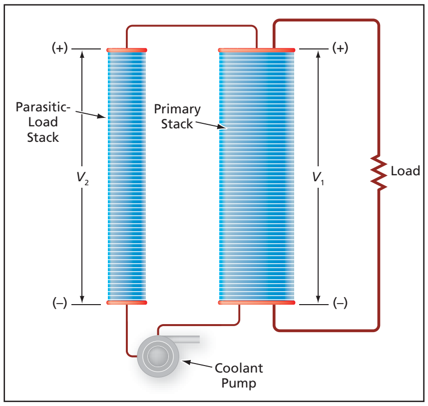

The **Voltage Applied to the Coolant Pump** ($V_2 - V_1$) would increase as V_1 decreased with increasing current through the load.

of the fuel cell power system. In general, the power demands for optimal operation of the parasitic devices vary with the load (e.g., the optimum coolant-circulation power increases with the load). The power levels of the parasitic devices in fuel cell power systems can be regulated at optimal levels by electronic feedback control systems that include sensors (e.g., current, voltage, temperature, or motor-speed sensors) and power-conditioning subsystems. However, such control systems can sometimes be so complex as to detract from the overall reliability of the affected fuel cell power systems.

In the proposed scheme, a single approximate control signal, generated by relatively simple means, would be used for controlling one or more parasitic devices. The scheme is based on the fact that the terminal voltage of a fuel cell stack decreases with increasing current (in other words, voltage decreases with increasing load) even more strongly than does the voltage of a typical battery having a nominally equivalent current and voltage rating. The figure depicts a simple fuel cell system in which the scheme would be applied to control of a coolant pump. The system would include a primary fuel cell stack and a lower-power secondary fuel cell stack denoted the parasitic-load stack. The two fuel cell stacks would be electrically connected at their positive ends. The coolant pump would be connected between the negative ends of the two stacks.

An increase in the power demand of the load would cause a decrease in the voltage of the primary stack, thereby causing an increase in $V_2 - V_1$, the difference between the voltages of the parasitic-load and primary stacks. This, in turn, would cause an increase in the power supplied to the coolant pump. In a design process, that would entail careful selection of the stack cell areas, the numbers of cells in the two stacks, the electrical resistance of the coolant pump, and other design parameters; it should be possible to make the power supplied to the coolant pump, as a function of the load level, closely approximate the amount required for dissipation of waste heat at that level.

This work was done by Arturo Vasquez of Johnson Space Center. 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, Johnson Space Center, (281) 483-0837. Refer to MSC-24169-1.

Modified Phasemeter for a Heterodyne Laser Interferometer

An FPGA-based design could be exported to other heterodyne laser interferometers.

NASA's Jet Propulsion Laboratory, Pasadena, California

Modifications have been made in the design of instruments of the type described in "Digital Averaging Phasemeter for Heterodyne Interferometry" (NPO-30866), *NASA Tech Briefs*, Vol. 28, No. 9 (September 2004), page 6a. To recapitulate: A phasemeter of this type measures 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 displacements with accuracy of the order of 100 pm. This 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.

At the time of writing the cited prior article, the phasemeter design lacked immunity to drift of the heterodyne frequency, was bandwidth-limited by computer bus architectures then in use, and was resolution-limited by the nature of field-programmable gate arrays (FPGAs) then available. The modifications have overcome these limitations and have afforded additional improvements in accuracy, speed, and modularity.

The modifications are summarized as follows:

- Taking advantage of improvements made in FPGAs since the original design effort, major phasemeter functions are implemented in a commercial, off-the-shelf FPGA card. It is necessary to add supplementary interface electronic circuitry to support legacy peripheral equipment, but even so, it is significantly easier to implement the phasemeter in the modified design than in the original high-speed-digital-board design.
- In the previous design, a reference clock signal having a frequency of 128 MHz was generated outside the FPGA and delivered to the FPGA board via a coaxial cable. Since many commercial FPGAs contain built-in phase-locked-loop frequency multipliers, it has become feasible to utilize these multipliers to internally generate a reference clock signal in response to a precise externally generated reference signal having a frequency between 10 and 20 MHz. In addition, the internally generated reference clock signal has a higher frequency — 200 MHz — and, hence, affords higher resolution.
- Modularity is enhanced by incorporation of a microprocessor-type periph-

eral component interface (PCI) block, making the phasemeter design exportable to a variety of computer architectures. The PCI interface can transfer an entire block of phasemeter registers at a rate of 10 kHz.

- A few hardware components were added to enable measurement of the heterodyne-signal period, to count reference clock cycles during an averaging cycle, and to utilize the resulting data in such a way as to make the phasemeter immune to drift of the heterodyne frequency. These additions also eliminate the necessity of incorporating, into the phasemeter software, a different reference-clock-cycle parameter for every different heterodyne frequency that might be used.

This work was done by Frank M. Loya of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-45484

Loosely Coupled GPS-Aided Inertial Navigation System for Range Safety

Goddard Space Flight Center, Greenbelt, Maryland

The Autonomous Flight Safety System (AFSS) aims to replace the human element of range safety operations, as well as reduce reliance on expensive, downrange assets for launches of expendable launch vehicles (ELVs). The system consists of multiple navigation sensors and flight computers that provide a highly reliable platform. It is designed to ensure that single-event failures in a flight computer or sensor will not bring down the whole system. The flight computer uses a rules-based structure derived from range safety requirements to make decisions whether or not to destroy the rocket.

By combining the inertial navigation system (INS) with Global Positioning System (GPS), the GPS signal can be used to check error growth of the INS and, due to the small, short-term errors of the INS, the system is more accurate than the sensor alone. The fused system helps to solve the common cause failures, and also provides the benefit of graceful degradation of system performance should a failure occur.

This innovation has algorithms developed specifically with range safety applications in mind. The INS and Kalman filter algorithms, including the linearized error model, for integrating the two systems were developed and simulated to determine their performance. The system calculates the errors in the IMU and provides information on the quality of the data it outputs to aid the AFSS system in determining what level of trust to give the data.

The filter is designed in such a way that there is always position and velocity output. Loss of GPS will not cause the INS to go unstable, or to cease information output. Also, covariance estimates and the error states are available to the user for further use in determining data quality.

This work was done by Scott Heatwole and Raymond J. Lanzi for Goddard Space Flight Center. For further information, contact the Goddard Innovative Partnerships Office at (301) 286-5810. GSC-15549-1

Sideband-Separating, Millimeter-Wave Heterodyne Receiver

NASA's Jet Propulsion Laboratory, Pasadena, California

Researchers have demonstrated a submillimeter-wave spectrometer that combines extremely broad bandwidth with extremely high sensitivity and spectral resolution to enable future spacecraft to measure the composition of the Earth's troposphere in three dimensions many times per day at spatial resolutions as high as a few kilometers. Microwave limb sounding is a proven remote-sensing technique that measures thermal emission spectra from molecular gases along limb views of the Earth's atmosphere against a cold space background.

The new receiver will down-convert thermal emission spectra in the 180–300 GHz band using superconductor-insulator-superconductor (SIS) heterodyne mixers. A technique called sideband separation is used to provide 24 GHz of instantaneous bandwidth from a single receiver, enabling many chemical species to be measured simultaneously by a single receiver with accurate calibration. The high sensitivity provided by SIS mixers will enable accurate measurements of chemicals at low concentrations with very short integration times. A novel scanning telescope, also under development at the Jet Propulsion Laboratory, will take advantage of these short integration times to measure three-dimensional maps of the concentration of a large number of key chemical species in the troposphere over nearly the entire planet five to nine times per day. These frequent measurements will enable researchers to both monitor air quality and to understand how pollution is transported by the atmosphere.

This work was done by John S. Ward, Bruce Bumble, Karen A. Lee, Jonathan H. Kawamura, Goutam Chattopadhyay, Paul Stek, and Frank Rice of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-46205