K-Band Traveling-Wave Tube Amplifier

This amplifier can be used for high-data-rate transmission from communications satellites.

John H. Glenn Research Center, Cleveland, Ohio

A new space-qualified, high-power, high-efficiency, K-band traveling-wave tube amplifier (TWTA), shown in the figure, will provide high-rate, high-capacity, direct-to-Earth communications for science data and video gathered by the Lunar Reconnaissance Orbiter (LRO) during its mission. The TWTA is designed for 20 years of operational life, well in excess of the expected 7 years of mission life. It is a vacuum electronics device that is used to amplify microwave communications signals. TWTs are needed for high-frequency and high-power applications, such as communications from the Moon, because they have significantly higher power capability and efficiency than solid-state devices. Amplification in a TWT is by a factor of about 100,000. The RF power and data rate values for the LRO TWTA, when compared with other space based K-band transmitters, are an order of magnitude higher and represent a new state of the art.

Several technological advances were responsible for the successful demonstration of the K-band TWTA. A numerical model enabled manufacturing a wideband TWT with high power output and efficiency leading to a first-pass design success. A dual-anode isolated-focus electrode electron gun enabled excellent focusing, which kept the power loss due to beam interception minimal over a wide range of voltage and current values. A WR-34 waveguide was used for the input/output couplers and larger,

A **K-Band 40-W TWTA** is shown here for the Lunar Reconnaissance Orbiter Mission.

thicker RF quartz windows, allowing operation not only at LRO frequencies but also at future near-Earth mission frequencies. Furthermore, it is more robust against mechanical shock and vibrations, and lowers the total attenuation of the signal in the waveguide run between the TWT output and the antenna. An external filter was developed to suppress the unwanted conducted emissions from the EPC (electronic power conditioner) to the spacecraft bus by greater than 20 dB.

The TWTA has successfully completed a vigorous spaceflight qualification effort, including random vibration testing and cycling between temperature extremes

that the hardware is expected to experience during mission operation. Other possible applications include high-data-rate transmission from geosynchronous communications satellites to Earth.

This work was done by Dale A. Force, Rainee N. Simons, and Todd T. Peterson of Glenn Research Center, and Paul C. Spitsen of L-3 Communications Electron Technologies, Inc. Further information is contained in a TSP (see page 1).

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Innovative Partnerships Office, Attn: Steve Fedor, Mail Stop 4–8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-18443-1.

Simplified Load-Following Control for a Fuel Cell System

**A load-dependent voltage would be used to control a parasitic device.**

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A simplified load-following control scheme has been proposed for a fuel cell power system. The scheme could be used to control devices that are important parts of a fuel cell system but are sometimes characterized as parasitic because they consume some of the power

generated by the fuel cells.

The parasitic devices can include the following: a pump for circulating coolant to remove waste heat, pumps for circulating reactant gases and humidifying inlet gases, an electric heater for keeping the fuel cell stack

above a minimum operating temperature when the production of waste heat is insufficient for this purpose, and a centrifugal water separator. Operating these parasitic devices steadily at their full power levels would waste power, reducing the overall efficiency
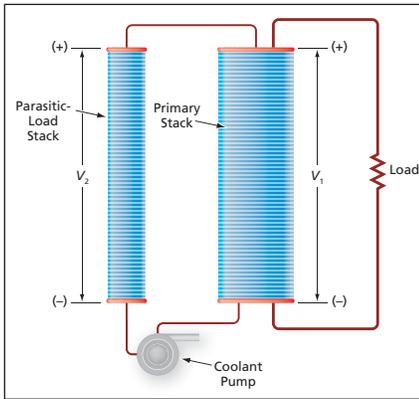
The **Voltage Applied to the Coolant Pump** ($V_2 - V_1$) would increase as V_1 decreased with increasing current through the load.

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.

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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-