# High-Performance Solid-State W-Band Power Amplifiers

Outputs ≥240 mW are available at frequencies from 71 to 106 GHz.

NASA's Jet Propulsion Laboratory, Pasadena, California

The figure shows one of four solid-state power amplifiers, each capable of generating an output power ≥240 mW over one of four overlapping frequency bands from 71 to 106 GHz. (The bands are 71 to 84, 80 to 92, 88 to 99, and 89 to 106 GHz.) The amplifiers are designed for optimum performance at a temperature of 130 K. These amplifiers were developed specifically for incorporation into frequency-multiplier chains in local oscillators in a low-noise, far-infrared receiving instrument to be launched into outer space to make astrophysical observations. The designs of these amplifiers may also be of interest to designers and manufacturers of terrestrial W-band communication and radar systems.

Each amplifier includes a set of six high-electron-mobility transistor (HEMT) GaAs monolithic microwave integrated-circuit (MMIC) chips, microstrip cavities, and other components packaged in a housing made from A-40 silicon-aluminum alloy. This alloy was chosen because, for the original intended spacecraft application, it offers an acceptable compromise among the partially competing requirements for high thermal conductivity, low mass, and low thermal expansion. Problems that were solved in designing the amplifiers included designing connectors and packages to fit the available space; designing microstrip signal-power splitters and combiners; matching of impedances across the frequency bands;
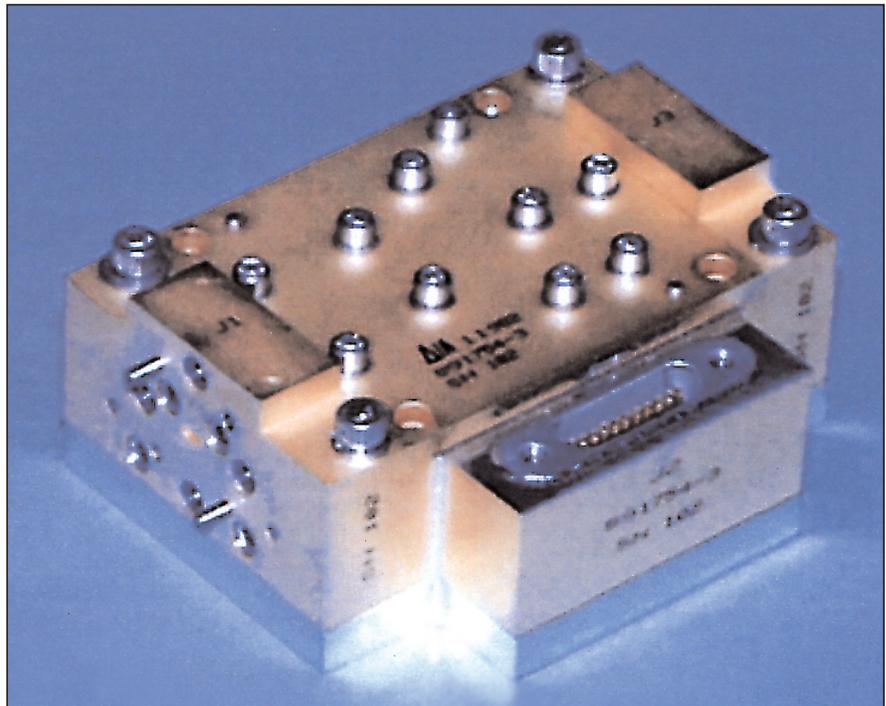
This **Photograph Shows One of the Amplifiers** described in the text. A WR-10 waveguide input port is on the left end. The output port is on the right end, facing away. DC input and sensing conductors enter the package via a 21-pin connector. (Module dimensions: 20 × 49 × 60 mm.)

matching of the electrical characteristics of those chips installed in parallel power-combining arms; control and levelling of output power across the bands; and designing the MMICs, microstrips, and microstrip cavities to suppress tendencies toward oscillation in several modes, both inside and outside the desired frequency bands.

Microbatteries for Combinatorial Studies of Conventional Lithium-Ion Batteries

Thousands of combinations of battery materials can be evaluated economically.

*NASA's Jet Propulsion Laboratory, Pasadena, California*

Integrated arrays of microscopic solid-state batteries have been demonstrated in a continuing effort to develop microscopic sources of power and of voltage reference circuits to be incorporated into low-power integrated circuits. Perhaps even more importantly, arrays of microscopic batteries can be fabricated and tested in combinatorial experiments

directed toward optimization and discovery of battery materials.

The value of the combinatorial approach to optimization and discovery has been proven in the optoelectronic, pharmaceutical, and bioengineering industries. Depending on the specific application, the combinatorial approach can involve the investigation of hundreds or

even thousands of different combinations; hence, it is time-consuming and expensive to attempt to implement the combinatorial approach by building and testing full-size, discrete cells and batteries. The conception of microbattery arrays makes it practical to bring the advantages of the combinatorial approach to the development of batteries.

Microbattery arrays (see figure) are fabricated on substrates by use of conventional integrated-circuit manufacturing techniques, including sputtering, photolithography, and plasma etching. The microbatteries incorporate the same cathode materials of interest for conventional lithium-ion batteries such as $LiCoO_2$ and $LiCo_xNi_{1-x}O_2$. If multiple deposition sources are used in the fabrication of a given array, then the chemical compositions of battery components of interest can be varied across the substrate, making it possible to examine what amounts to almost a continuum of compositions. For example, assuming
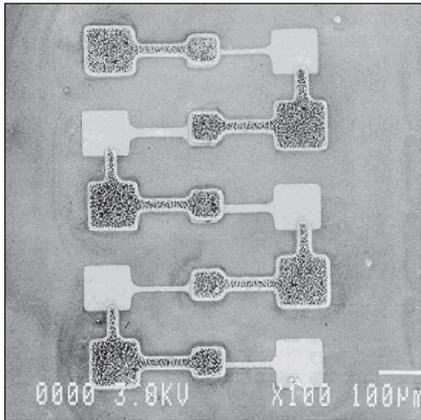
This is a **Scanning Electron Micrograph** of a microbattery array. The lightly shaded contact pads are cathode current collectors. The darker contact pads are anode current collectors. The cathodes and solid electrolyte of each cell are sandwiched between the anode and cathode contact pads and are not visible in this view.

that a 4-in. (10-cm) substrate is used, the test-device pitch is 50 μm, and the concentration gradient is 80 percent across the substrate, then the compositions of adjacent test cells can be expected to differ by only about 0.04 percent. Because thousands of test cells can be fabricated in a single batch, it becomes practical to test thousands of combinations of battery materials by use of microbattery arrays, as contrasted with only about 10 to 20 combinations by use of macroscopic cells.

The following is an example of a procedure for fabricating an array of $[LiCo_xNi_{1-x}O_2$ cathode/lithium phosphorus oxynitride solid electrolyte/nickel anode] cells like those shown in the figure, with a gradient in the cathode composition.

1. A Ti film is deposited on a 4-in. (≈10-cm) oxidized Si substrate. A Mo film is subsequently deposited on the Ti film.
2. The Mo-Ti bilayer is patterned by use of photolithography and wet etching to define the cathode current collectors.
3. The substrate is patterned with thick negative photoresist, with vias in the photoresist opened over selected areas of the current collectors.
4. A film of $LiCo_xNi_{1-x}O_2$ cathode material is deposited on the substrate with the desired gradient in x and selectively removed by use of a lift-off process, such that $LiCo_xNi_{1-x}O_2$ is present only on the cathode current collectors.

5. A film of the solid electrolyte lithium phosphorous oxynitride is deposited.
6. A film of Ni is deposited.
7. The Ni film is patterned to define the anode current collectors.
8. The Ni film is selectively removed by ion milling.
9. A protective coat (for example, vapor-deposited Parylene) is applied.

All depositions described above are performed by magnetron sputtering. The procedure can be readily modified to yield gradients in the cathode with other cations of interest: for example, $LiCo_xNi_{1-x}O_2$ could be replaced with $LiCo_xNi_yMn_{1-x-y}O_2$ with the desired gradients in x and y.

The cells can be tested by use of a commercial semiconductor-parameter analyzer connected to the test cells via tungsten probe needles. By applying a current of the order of 5 nA to a cell from the cathode to the anode, the cell can be charged by oxidizing the cathode and reducing the Li at the anode. The charged cell can be discharged by reversing the polarity of the current. The cells can be tested in the same manner as that used to test conventional lithium-ion cells to obtain information on such characteristics as cycle life and charge/discharge capacities, all as a function of compositions of the cathode.

This work was done by William West, Jay Whitacre, and Ratnakumar Bugga of Caltech for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP (see page 1).*
NPO-21216

Correcting for Beam Aberrations in a Beam-Waveguide Antenna
The transmitting feed is moved to compensate for movement of the target.

NASA's Jet Propulsion Laboratory, Pasadena, California

A method for correcting the aim of a beam-waveguide microwave antenna compensates for the beam aberration that occurs during radio tracking of a target that has a component of velocity transverse to the line of sight from the tracking station. The method was devised primarily for use in tracking of distant target spacecraft by large terrestrial beam-waveguide antennas of NASA's Deep Space Network (DSN). The method should also be adaptable to tracking, by other beam-waveguide antennas, of targets that move with large transverse velocities at large distances from the antennas.

The aberration effect arises whenever a spacecraft is not moving along

the line of sight as seen from an antenna on Earth. In such a case, the spacecraft has a cross-velocity component, which is normal to the line-of-sight direction. In order to obtain optimum two-way communication, the uplink and downlink beams must be pointed differently for simultaneous uplink and downlink communications. At any instant of time, the downlink (or receive, R_x) beam must be pointed at a position where the spacecraft was 1/2-round-trip light time (RTLT) ago, and the uplink (or transmit, T_x) beam must be pointed where the spacecraft will be in 1/2 RTLT (see figure). In the case of a high-

gain, narrow-beam antenna such as is used in the DSN, aiming the antenna in other than the correct transmitting or receiving direction, or aiming at a compromise direction between the correct transmitting and receiving directions, can give rise to several dB of pointing loss.

In the present method, the antenna is aimed directly at the apparent position of the target, so that no directional correction is necessary for reception of the signal from the target. Hence, the effort at correction is concentrated entirely on the transmitted beam. In physical terms, the correction is implemented by moving the transmitting feed along a small