

Measurement	Input Stage	Driver Stage	Final Stage
Input Voltage Standing-Wave Ratio	1.0023:1	1.9:1	33:1
Gain, dB	13.3	8.8	9.6
DC-to-RF Efficiency, Percent	54.2	42.6	58.6
Power-Added Efficiency, Percent	51.7	36.9	52.2

Several Measurements were made on each amplifier stage to characterize its performance.

amplifiers are less likely to go into oscillation.

In order to design this amplifier, it was necessary to derive mathematical models of microwave power transistors for incorporation into a larger mathe-

tical model for computational simulation of the operation of a class-D microwave amplifier. The design incorporates state-of-the-art switching techniques applicable only in the microwave frequency range. Another major novel

feature is a transmission-line power splitter/combiner designed with the help of phasing techniques to enable an approximation of a square-wave signal (which is inherently a wideband signal) to propagate through what would, if designed in a more traditional manner, behave as a more severely band-limited device (see figure).

The amplifier includes an input, a driver, and a final stage. Each stage contains a pair of GaAs-based field-effect transistors biased in class D. The input signal can range from -10 to +10 dBm into a 50-ohm load. The table summarizes the performances of the three stages.

*This work was done by William H. Sims of Marshall Space Flight Center.*

*This invention has been patented by NASA (U.S. Patent No. 6,388,512). Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to Sammy Nabors, MSFC Commercialization Assistance Lead, at (256) 544-5226 or sammy.a.nabors@nasa.gov. Refer to MFS-31455.*

## Improvements of ModalMax High-Fidelity Piezoelectric Audio Device

Langley Research Center, Hampton, Virginia

ModalMax audio speakers have been enhanced by innovative means of tailoring the vibration response of thin piezoelectric plates to produce a high-fidelity audio response. The ModalMax audio speakers are 1 mm in thickness. The device completely supplants the need to have a separate driver and speaker cone. ModalMax speakers can perform the same applications of cone speakers, but unlike cone speakers, ModalMax speakers can function in harsh environ-

ments such as high humidity or extreme wetness. New design features allow the speakers to be completely submerged in salt water, making them well suited for maritime applications. The sound produced from the ModalMax audio speakers has sound spatial resolution that is readily discernable for headset users. [The ModalMax product line was described in "High-Fidelity Piezoelectric Audio Device" (LAR-15959), *NASA Tech Briefs*, Vol. 27, No. 8 (August

2003), page 36.] Other improvements of the ModalMax audio speakers include methods to reduce size, reduce power demand, and increase audio fidelity by increasing vibrational responses at the low and high ends of the audio frequency range.

*This work was done by Stanley E. Woodard of Langley Research Center. Further information is contained in a TSP (see page 1). LAR-16321-1*

## Alumina or Semiconductor Ribbon Waveguides at 30 to 1,000 GHz

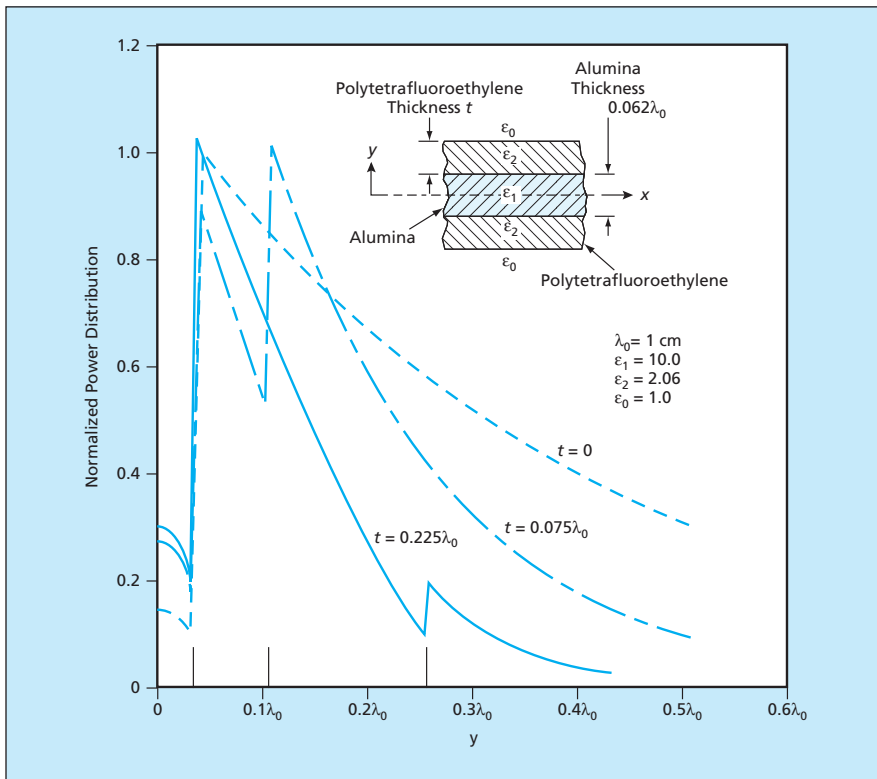
The waveguides would be configured to exploit low-loss electromagnetic modes.

NASA's Jet Propulsion Laboratory, Pasadena, California

Ribbon waveguides made of alumina or of semiconductors (Si, InP, or GaAs) have been proposed as low-loss transmission lines for coupling electronic components and circuits that operate at frequencies from 30 to 1,000 GHz. In addition to low losses (and a concomi-

tant ability to withstand power levels higher than would otherwise be possible), the proposed ribbon waveguides would offer the advantage of compatibility with the materials and structures now commonly incorporated into integrated circuits.

Heretofore, low-loss transmission lines for this frequency range have been unknown, making it necessary to resort to designs that, variously, place circuits and components to be coupled in proximity of each other and/or provide for coupling via free space through bulky



**Normalized Power Densities** were computed for a dominant  ${}_{e}HE_{11}$  mode on a ribbon waveguide made of alumina (having assumed relative permittivity of 10), both uncoated and coated with various thicknesses polytetrafluoroethylene (having assumed relative permittivity of 2.06). The unit of thickness used in the computations was the free-space wavelength,  $\lambda_0$ .

and often lossy optical elements. Even chip-to-chip interconnections have been problematic in this frequency range. Metal wave-guiding structures (e.g., microstriplines and traditional waveguides) are not suitable for this frequency range because the skin depths of electromagnetic waves in this frequency range are so small as to give rise to high losses. Conventional rod-type dielectric waveguide structures are also not suitable for this frequency range because dielectric materials, including ones that exhibit ultralow losses at lower frequencies, exhibit significant losses in this frequency range.

Unlike microstripline structures or metallic waveguides, the proposed ribbon waveguides would be free of metal and would therefore not be subject to skin-depth losses. Moreover, although they would be made of materials that are moderately lossy in the frequency range of interest, the proposed ribbon waveguides would cause the propagating electromagnetic waves to configure themselves in a manner that minimizes losses.

The basic principle for minimizing losses was described in "Ceramic Ribbons as Waveguides at Millimeter Wavelengths" (NPO-21001), *NASA Tech Briefs*, Vol. 25, No. 4 (April 2001), page 49. To

recapitulate: The cross-sectional geometry of a waveguide ribbon would be chosen in consideration of the permittivity of the ribbon material to support an electromagnetic mode in which most of the energy would propagate, parallel to the ribbon, through the adjacent free space and only a small fraction would propagate within the ribbon. As a result, the interaction of the propagating wave with the dielectric core (and thus the attenuation) would be minimal.

For straight runs, the ribbon waveguides would be uncoated. However, since most of the guided power would be carried in the nearly lossless air just outside the ribbon, a significant portion of the guided power could be expected to be radiated (and thus lost) where the guiding ribbon was sharply curved (for example, to bend it around a corner). In such a case, the short length of the ribbon containing the curve could be coated with a layer of a polymer having a suitable permittivity intermediate between that of air and that of the ribbon, so that most of the power would not be radiated but would remain confined within the polymer layer (see figure) while propagating around the corner.

*This work was done by Cavour Yeh, Daniel Rascoe, Fred Shimabukuro, Michael Tope, and Peter Siegel of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).*

*In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to:*

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## HEMT Frequency Doubler With Output at 300 GHz

**This is the highest-frequency HEMT doubler reported to date.**

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

An active frequency doubler in the form of an InP-based monolithic microwave integrated circuit (MMIC) containing a high-electron-mobility transistor (HEMT) has been demonstrated in operation at output frequencies in the vicinity of 300 GHz. This is the highest-

frequency HEMT doubler reported to date, the next-highest-frequency active HEMT doubler having been previously reported to operate at 180 GHz. While the output power of this frequency doubler is less than that of a typical Schottky diode, this frequency doubler is consid-

ered an intermediate product of a continuing effort to realize the potential of active HEMT frequency doublers to operate with conversion efficiencies greater than those of passive diode frequency doublers. An additional incentive for developing active HEMT frequency dou-