

log downconversion to baseband, the signals would be digitized, and all subsequent processing would be digital.

In the digital process, residual carriers would be removed and each signal would be correlated with a locally generated model pseudorandom-noise code, all following normal GPS procedure. As part of this procedure, accumulated values would be added in software and the resulting signals would be phase-shifted in software by the amounts necessary to synthesize the desired antenna directional gain pattern of peaks and nulls.

The principal advantage of this technique over the conventional radio-frequency-combining technique is that the parallel digital baseband processing of the signals from the various antenna elements would be a relatively inexpensive and flexible means for exploiting the inherent multiple-peak/multiple-null aiming capability of a phased-array antenna. In the original intended GPS application, the peaks and nulls could be directed independently for each GPS signal being tracked by the GPS receiver. The technique could also be applied to other

code-division multiple-access communication systems.

*This work was done by Charles E. Dunn and Lawrence E. Young of Caltech for NASA's Jet Propulsion Laboratory. 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, NASA Management Office-JPL, (818) 354-7770. Refer to NPO-20031.*

## Modern Design of Resonant Edge-Slot Array Antennas

**Better antennas can be designed at lower cost.**

*Goddard Flight Space Center, Greenbelt, Maryland*

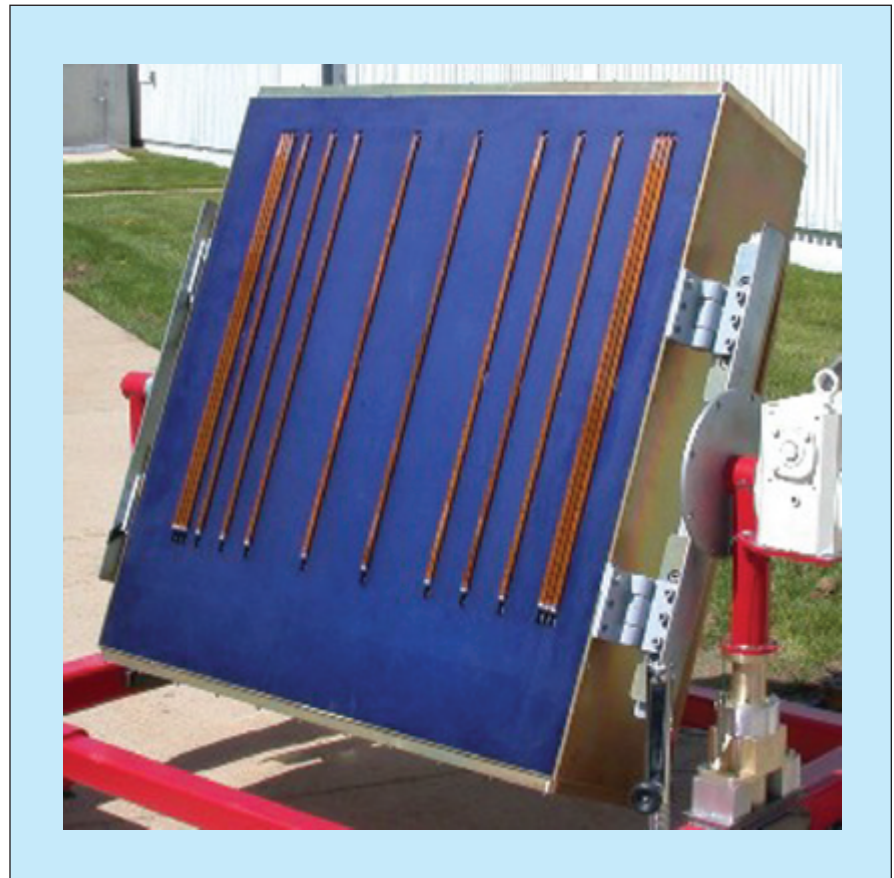
Resonant edge-slot (slotted-waveguide) array antennas can now be designed very accurately following a modern computational approach like that followed for some other microwave components. This modern approach makes it possible to design superior antennas at lower cost than was previously possible.

Heretofore, the physical and engineering knowledge of resonant edge-slot array antennas had remained immature since they were introduced during World War II. This is because despite their mechanical simplicity, high reliability, and potential for operation with high efficiency, the electromagnetic behavior of resonant edge-slot antennas is very complex. Because engineering design formulas and curves for such antennas are not available in the open literature, designers have been forced to implement iterative processes of fabricating and testing multiple prototypes to derive design databases, each unique for a specific combination of operating frequency and set of waveguide tube dimensions. The expensive, time-consuming nature of these processes has inhibited the use of resonant edge-slot antennas. The present modern approach reduces costs by making it unnecessary to build and test multiple prototypes. As an additional benefit, this approach affords a capability to design an array of slots having different dimensions to taper the antenna illumination to reduce the amplitudes of unwanted side lobes.

The heart of the modern approach is the use of the latest commercially available microwave-design software, which implements finite-element models of electromagnetic fields in and around waveguides, antenna elements, and sim-

ilar components. Instead of building and testing prototypes, one builds a database and constructs design curves from the results of computational simulations for sets of design parameters.

The figure shows a resonant edge-



This **Resonant Edge-Slot Antenna** with tapered illumination was designed on the basis of computational simulations, instead of following the traditional approach of iterative fabrication and testing of prototypes.

slot antenna designed following this approach. Intended for use as part of a radiometer operating at a frequency of 10.7 GHz, this antenna was fabricated from dimensions defined exclu-

sively by results of computational simulations. The final design was found to be well optimized and to yield performance exceeding that initially re-

*This work was done by R. B. Gosselin of Goddard Space Flight Center. Further information is contained in a TSP (see page 1). GSC-14747-1*

## Carbon-Nanotube Schottky Diodes

These devices can outperform conventional Schottky diodes at submillimeter wavelengths.

NASA's Jet Propulsion Laboratory, Pasadena, California

Schottky diodes based on semiconducting single-walled carbon nanotubes are being developed as essential components of the next generation of submillimeter-wave sensors and sources. Initial performance predictions have shown that the performance characteristics of these devices can exceed those of the state-of-the-art solid-state Schottky diodes that have been the components of choice for room-temperature submillimeter-wave sensors for more than 50 years.

For state-of-the-art Schottky diodes used as detectors at frequencies above a few hundred gigahertz, the inherent parasitic capacitances associated with their semiconductor junction areas and the resistances associated with low electron mobilities limit achievable sensitivity. The performance of such a detector falls off approximately exponentially with frequency above 500 GHz. Moreover, when used as frequency multipliers for generating signals, state-of-the-art solid-state Schottky diodes exhibit extremely low efficiencies, generally putting out only microwatts of power at fre-

quencies up to 1.5 THz.

The shortcomings of the state-of-the-art solid-state Schottky diodes can be overcome by exploiting the unique electronic properties of semiconducting carbon nanotubes. A single-walled carbon nanotube can be metallic or semiconducting, depending on its chirality, and exhibits high electron mobility (recently reported to be  $\approx 2 \times 10^5 \text{ cm}^2/\text{V}\cdot\text{s}$ ) and low parasitic capacitance. Because of the narrowness of nanotubes, Schottky diodes based on carbon nanotubes have ultra-small junction areas (of the order of a few square nanometers) and consequent junction capacitances of the order of  $10^{-18} \text{ F}$ , which translates to cut-off frequency  $>5 \text{ THz}$ . Because the turn-on power levels of these devices are very low (of the order of nanowatts), the input power levels needed for pumping local oscillators containing these devices should be lower than those needed for local oscillators containing state-of-the-art solid-state Schottky diodes.

In terms that are necessarily simplified for the sake of brevity, a carbon-nanotube-based Schottky diode is fabricated

in a process that features evaporative deposition of dissimilar metal contacts onto opposite ends of a semiconducting single-walled carbon nanotube. One of the metals (platinum in initial experiments) is chosen to have a work function greater than that of the carbon nanotube, so as to form an ohmic contact. The other metal (titanium in initial experiments) is chosen to have a work function less than that of the carbon nanotube, so as to form a Schottky contact. These metals are then covered with outer layers of gold. The figure shows the rectifying behavior of four experimental devices fabricated in such a process.

To reduce the effective series resistance, it is preferable to fabricate such a device in the form of a set of multiple parallel single-wall carbon nanotubes, grown on the same substrate, bridging the gap between the higher- and the lower-work-function metal contact. Usually, in such a case, some of the carbon nanotubes turn out to be metallic and, hence, must be removed to obtain the desired rectifying behavior. Removal can be effected by a previously published procedure in which the semiconducting nanotubes are gated off and the metallic ones are selectively burned out.

*This work was done by Harish Manohara, Eric Wong, Erich Schlecht, Brian Hunt, and Peter Siegel of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).*

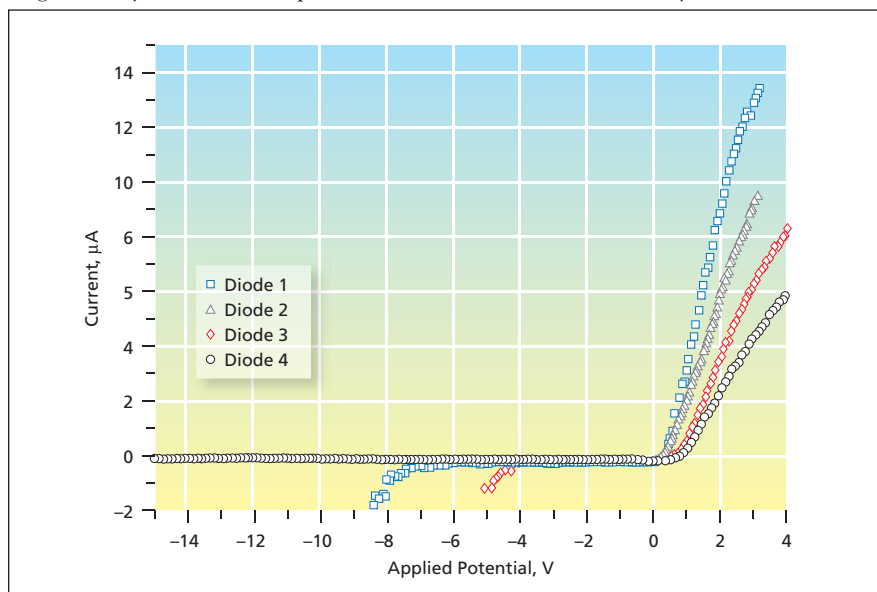
*In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to:*

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Rectifying Behavior is apparent in the DC current-versus-voltage characteristics of four experimental carbon-nanotube-based Schottky diodes that were fabricated on the same substrate.