10^3 at a frequency of 100 GHz and to even lower values at higher frequencies. In contrast, the maximum Q attainable in a resonator based on an optoelectronic delay line is of the order of 10^6 at a frequency of 10 GHz and increases with frequency.

The proposed method is partly similar to two older patented methods that involve the use of fiber-optic delay lines as RF-phase-noise discriminators. However, unlike those methods, the proposed method does not call for the generation of a low-frequency signal applied to a control port of the oscillator to be stabilized. Instead, the delayed RF signal would simply be returned to the oscillator, as described below.

The lower part of the figure shows an example of the same oscillator as before, but this time stabilized by use of optoelectronic feedback according to the proposed method. The RF signal from the oscillator would be fed through a circulator to an electro-optical modulator, which would modulate the RF signal onto a laser beam. After traveling the length of an optical fiber or other optical delay line, a photodetector would demodulate the signal. The RF output of the photodetector would be returned via the circulator to the oscillator.

The return of the delayed RF signal would enforce a steady phase in an otherwise noisy free-running oscillator, thereby suppressing phase noise in the oscillations. This stabilizing effect is expected as a consequence of the frequency-pulling effect or self-injection locking observed previously in oscillators equipped with high-Q external resonant cavities.

The original tunability of the free-running oscillator would be substantially preserved in the presence of optoelectronic stabilization, except as described next: Upon tuning of the oscillator, the frequency of the oscillator would not change continuously but would jump between successive resonances of the optoelectronic feedback loop. Typical frequency jumps would likely range from a few tens of kilohertz for a kilometer-long fiber-optic delay line up to a few gigahertz for an optical microresonator.

Small X-Band Oscillator Antennas

In some applications, these compact units could be powered by solar cells.

John H. Glenn Research Center, Cleveland, Ohio

A small, segmented microstrip patch antenna integrated with an X-band feedback oscillator on a high-permittivity substrate has been built and tested (see Figure 1). The oscillator antenna is powered by commercial solar photovoltaic cells mounted nearby or on the same substrate. This oscillator antenna is a prototype for demonstrating the feasibility of such devices as compact, low-power-consumption building blocks of advanced, lightweight, phased antenna arrays that would generate steerable beams for communication and remote-sensing applications.

The solar-powered oscillator antenna includes a commercially available super-low-noise, high-frequency field-effect transistor integrated into the center of the segmented microstrip-patch antenna. Along with bias lines, a feedback loop, and other conductors that are parts of the oscillator antenna circuitry, the patch antenna was formed by etching the corresponding pattern out of a surface metal layer on the substrate, which is a commercial microwave laminate having a relative permittivity of 10.2 and a thickness of 0.635 mm. The oscillator antenna occupies an area of 5 by 6 mm on the substrate. The oscillator feedback path ex-
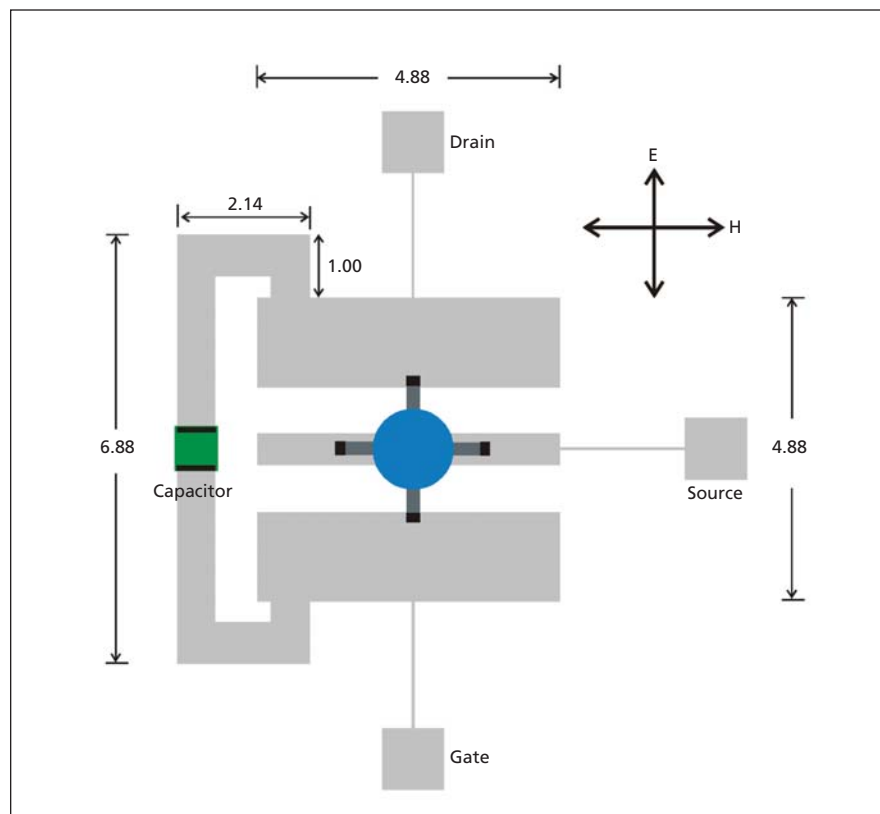

Figure 1. A **Schematic of Oscillator Antenna** is shown with feedback loop. The dimensions are in millimeters.
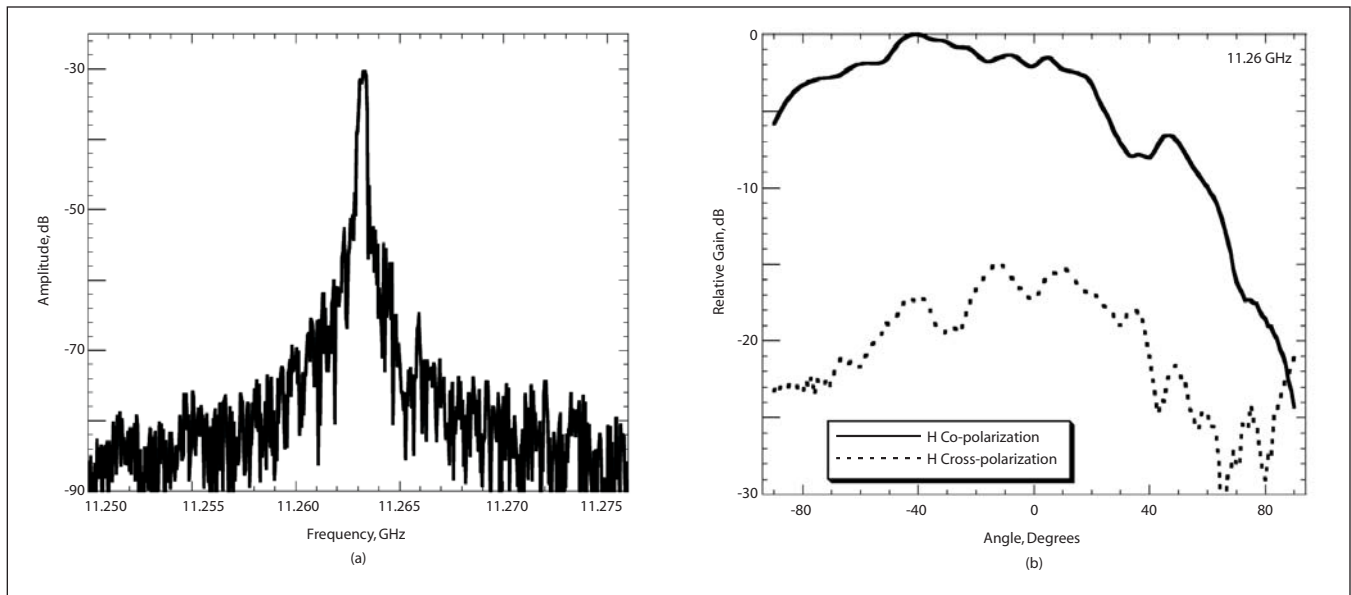
Figure 2. **Performance Characteristics**: (a) RF power emitted from solar powered radiating oscillator (the resolution bandwidth is 270 kHz) and (b) far field radiation pattern of solar powered radiating oscillator antenna.

tends between the drain and gate terminals of the transistor and includes a 1.2-pF capacitor that passes the oscillation signal while providing DC isolation between the drain and the gate.

A comparison between simulated and experimental performance data confirmed that the oscillation frequency is controlled mainly by the length of the feedback path. The RF signal radiated at the fundamental frequency from the solar powered antenna is shown in Figure 2(a). The magnetic field radiation pattern of the solar powered antenna is shown in Figure 2(b). The solar-powered oscillator antenna radiates a power of 1.8 mW at a frequency of about 11.2 GHz with a directivity of 5.25 relative to an isotropic radiation pattern. The power in the second harmonic at 22.4 GHz is 20 dB below the fundamental signal level. It has been found that a current of about 120 mA is needed to initiate oscillation, but thereafter the device

can continue to oscillate at a current <20 mA. One of the drawbacks of using commercial solar cells is its large size due to low efficiency. Ways to minimize solar-cell area could include: (1) powering the oscillator antenna from a rechargeable battery that would be recharged by a single, smaller solar cell, (2) the use of more-efficient solar cells, and/or (3) the use of a capacitor to supply the high current needed to start oscillation.

One notable advantage of using high-permittivity substrates is the inherent reduction in the sizes of resonant antenna elements. In addition to compactness, the designs of this oscillator antenna feature simple geometry, and the radiated power levels and radiation efficiency are comparable to those typical of oscillator antennas on lower-permittivity, thicker substrates.

Another motivation for the use of high-permittivity substrates is the prospect of developing solar oscillator array antenna

as fully integrated circuits. Some essential components of such a development have already been accomplished: High-mobility transistor structures are readily available on insulating substrates having dielectric properties similar to those of the microwave laminate material mentioned above. Dielectric substrate materials including gallium arsenide and sapphire that support high-frequency active electronic devices have relative permittivities between 10 and 14.

This work was done by Richard Q. Lee, Félix A. Miranda, Eric B. Clark, and David M. Wilt of Glenn Research Center and Carl H. Mueller, Carol L. Kory, and Kevin M. Lambert of Analex Corp. 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-18114-1.

Free-Space Optical Interconnect Employing VCSEL Diodes
These optical interconnects are applicable for large-capacity interconnection between information-processing equipment.

John H. Glenn Research Center, Cleveland, Ohio

Sensor signal processing is widely used on aircraft and spacecraft. The scheme employs multiple input/output nodes for data acquisition and CPU (central processing unit) nodes for data processing. To connect 110 nodes and CPU

nodes, scalable interconnections such as backplanes are desired because the number of nodes depends on requirements of each mission. An optical backplane consisting of vertical-cavity surface-emitting lasers (VCSELs), VCSEL

drivers, photodetectors, and transimpedance amplifiers is the preferred approach since it can handle several hundred megabits per second data throughput. Conventional electrical interconnects severely limit the perform-