

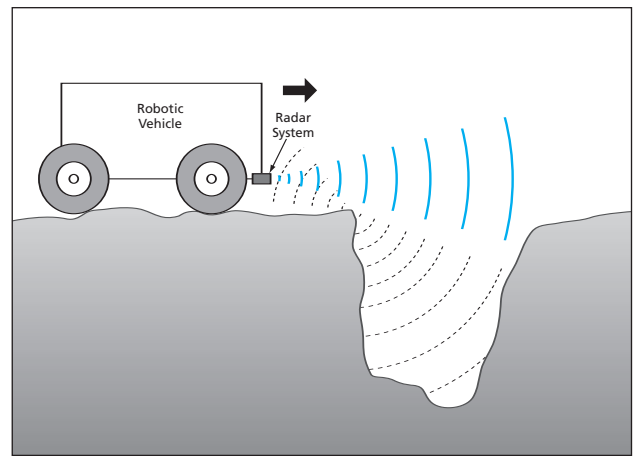
avorable lighting conditions, they cannot detect negative obstacles — at least in part because they cannot see around corners. Other obstacle-avoidance sensors that utilize thermal-infrared radiation from terrain features cannot detect obstacles when temperatures change too rapidly, as they often do at dusk and dawn. The proposed radar systems would not be subject to these limitations.

Radar systems partly similar to the proposed ones are already used in some cars and trucks to warn drivers during backing toward objects that cannot be seen from the drivers' positions. However, those systems are not designed to detect negative obstacles. A radar system according to the proposal would be of the frequency-modulation/continuous-wave (FM/CW) type. It would be installed on a vehicle, facing forward, possibly with a downward slant of the main lobe(s) of the radar beam(s) (see figure). It would utilize one or more wavelength(s) of the order of centimeters.

Because such wavelengths are comparable to the characteristic dimensions of terrain features associated with negative hazards, a significant amount of diffraction would occur at such features. In effect, the diffraction would afford a limited ability to see corners and to see around corners. Hence, the system might utilize diffraction

to detect corners associated with negative obstacles. At the time of reporting the information for this article, preliminary analyses of diffraction at simple negative obstacles had been performed, but an explicit description of how the system would utilize diffraction was not available.

Alternatively or in addition to using diffraction, the system might utilize the Doppler effect and/or the radiation pattern of the radar antenna for detecting negative obstacles. For example, if the forward speed of the vehicle were known, then the approximate direction from the radar apparatus to a reflecting object could be determined from the difference between the Doppler shift of the reflection and the Doppler expected of a reflection from an object straight ahead. For another example, if the main lobe of the radar beam were horizontal or nearly so, then the amount of power reflected from a nearby negative obstacle would be



A Robotic Vehicle Approaching a Ditch would carry a radar system that would detect the ditch by recognizing through differences between (1) the signals actually diffracted and reflected and (2) the signals that would be diffracted and reflected from level or nearly level ground.

less than that reflected from level ground at the same horizontal distance from the vehicle. Combining these two examples, it might be possible to detect approaching negative obstacles through changes in the reflected power and/or in the spectral distribution of the reflected power.

*This work was done by Anthony Mittskus and James Lux of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-40413*

## Cryogenic Pound Circuits for Cryogenic Sapphire Oscillators

Thermomechanical instabilities and associated frequency instabilities are reduced.

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Two modern cryogenic variants of the Pound circuit have been devised to increase the frequency stability of microwave oscillators that include cryogenic sapphire-filled cavity resonators. Invented in the 1940s and named after its inventor (R. V. Pound), the original Pound circuit is a microwave frequency discriminator that provides feedback to stabilize a voltage-controlled microwave oscillator with respect to an associated cavity resonator. Heretofore, Pound circuits used in conjunction with cryogenic resonators have included room-temperature electronic components coupled to the resonators via such interconnections as coaxial cables. The thermomechanical instabilities of these interconnections give rise to frequency instabilities. In a cryogenic Pound circuit of the present improved type, all of the active electronic components, the interconnections among them, and the interconnections between them and the resonator re-

side in the cryogenic environment along with the resonator and, hence, are thermomechanically stabilized to a large degree. Hence, further, frequency instabilities are correspondingly reduced.

The active microwave devices required in a Pound circuit are two amplitude detectors and a phase modulator. A Pound circuit generates a frequency-error signal by converting a phase modulation (PM) to an amplitude modulation (AM). The AM in question is generated when a microwave signal that is reflected from a resonator has a high value of the resonance quality factor ( $Q$ ) and the signal frequency differs from the resonance frequency. A pure PM signal is required because any AM at the input terminal of the resonator would generate a frequency error.

In the present cryogenic Pound circuits (see figure), the active microwave devices are implemented by use of state-of-the-art commercially available tunnel diodes that

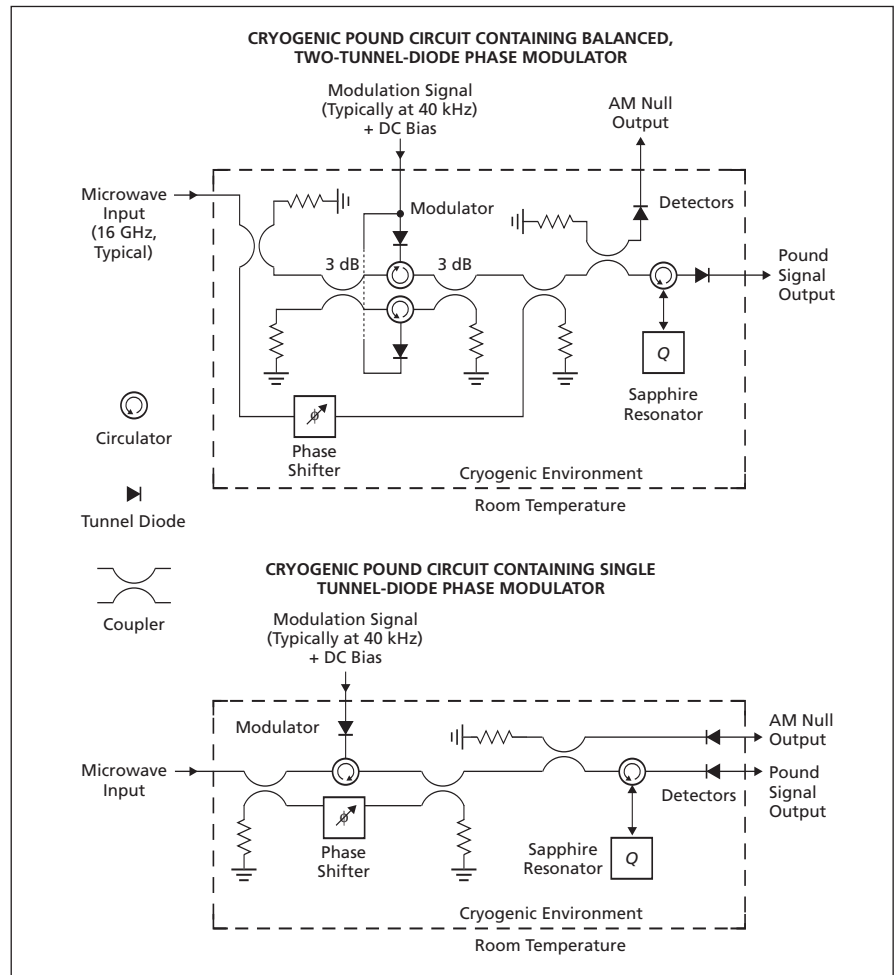
exhibit low flicker noise (required for high frequency stability) and function well at low temperatures and at frequencies up to several tens of gigahertz. While tunnel diodes are inherently operable as amplitude detectors and amplitude modulators, they cannot, by themselves, induce significant phase modulation. Therefore, each of the present cryogenic Pound circuits includes passive circuitry that transforms the AM into the required PM. Each circuit also contains an AM detector that is used to sample the microwave signal at the input terminal of the high- $Q$  resonator for the purpose of verifying the desired AM null at this point. Finally, each circuit contains a Pound signal detector that puts out a signal, at the modulation frequency, having an amplitude proportional to the frequency error in the input signal. High frequency stability is obtained by processing this output signal into feedback to a voltage-controlled os-

illator to continuously correct the frequency error in the input signal.

Each of these circuits first generates a carrier-suppressed AM signal and then transforms that signal into PM by use of a bypass from the radio-frequency input that injects a carrier with  $\approx 90^\circ$  phase shift from the carrier of the AM signal. (If AM carrier suppression is complete, this phase shift is exactly  $90^\circ$ ; if incomplete, a phase shift that deviates somewhat from  $90^\circ$  is required.) An approximation of pure PM is obtained via a coarse adjustment of the phase of this bypassed signal, this adjustment being made by use of a mechanical phase shifter. A fine adjustment to increase the accuracy of the approximation is made by varying the DC voltage applied to the modulation diode(s). Once the mechanical phase shifter is adjusted properly, the variation in DC voltage suffices to maintain pure PM.

The two circuits differ in how they generate the carrier-suppressed AM signal. In the first circuit, this involves combining the outputs from two tunnel diodes that are operated as amplitude modulators configured so that both amplitude modulations and carriers are oppositely phased. This functionality is implemented by mounting the diodes in an antisymmetric arrangement that affords the additional benefit of enabling the use of a single modulation signal, superimposed on a single DC bias, as input to both modulator diodes. If the diodes are perfectly matched, then the carrier can be suppressed completely.

The second circuit was developed after extensive tests and modeling of the behaviors of tunnel diodes showed that a nearly-suppressed-carrier AM signal



In these **Cryogenic Pound Circuits**, all of the components critical to maintaining frequency stability reside together in the cryogenic environment.

could be generated by use of only one tunnel diode. The obvious advantages of the second circuit, relative to the first one, are fewer components and, consequently, smaller dimensions.

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