# Correspondence

## Oversize Bolometer Unit for Short Millimeter Wave Region

A bolometer unit has been developed with broad VSWR (less than 1.3) for frequencies to 100 GHz. This unit uses no matching elements, is easy to construct, and is highly efficient (90 percent).

Quasi-optional techniques and an oversize waveguide are used because the small cross sections of a standard size waveguide contribute more loss (estimated 2.7 dB). Larger cross sections cut this loss to about 0.7 dB. The transmission wave in the oversize waveguide is also considered nearly a plane wave with negligible spurious response.

The oversize waveguide is short circuited by a parabolic surface with a focal distance of 9 mm. The incident wave is concentrated at the focus and a resistor element absorbs the millimeter wave power which is compared with dc power. The optimum resistivity of the thin-film resistor element is 430 ohms/cm$^2$ and it is set parallel to the oversize waveguide axis at the center of the cross section.

A cross section of the bolometer unit is shown in Fig. 1. The dimensions of the oversize waveguide mount are 10.2 by 22.9 mm. The dimensions of the resistor element, which are determined by spot size, are 6 by 2 mm. Figure 2 shows the frequency characteristics of the bolometer unit.

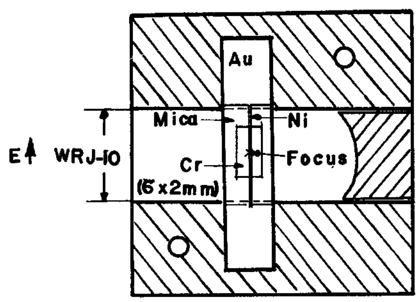


Fig. 1. Cross section of a bolometer mount.

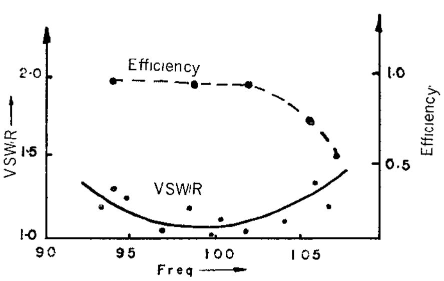


Fig. 2. Frequency characteristics of the oversized bolometer mount.

Hiroshi Kashiwagi
Electrotechnical Lab.
Nagata-Cho, Chiyoda-Ku
Tokyo, Japan

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## The Harmonics Produced by a PIN Diode in a Microwave Switching Application

The advantages of using semiconductor diodes to control power flow in microwave transmission lines, in such applications as phase shifting and array beam selecting, are well known. Less well known, however, is the extent to which the nonlinear characteristics of these devices cause the generation of harmonic signals.

This correspondence discusses the results of second- and third-harmonic measurements on a PIN diode mounted in a stripline configuration. The measurements were carried out at a fundamental frequency of 1610 MHz with a pulse width of 1.5 $\mu$s and a peak power up to 4.35 kW. Data were obtained for the diode biased in both forward and reverse directions.

Primary considerations for the design of the diode switch were that the diode be operated in a typical environment and that harmonics measured at the output port be directly related to the harmonics generated at the diode. A 50-ohm stripline configuration with a ground plane spacing of 0.25 inch, as shown in Fig. 1, was selected. The stripline was constructed of two dielectric sheets copper clad on one side, with a center conductor cut from copper foil tape. The diode is located at the end of the diode stub line. The remaining stub line (short circuited) provides a return path for bias current. The input and output connectors are modifications of the coaxial-to-stripline adapter described by Craven.[1] The main body of the diode mount is a Gremar 5760 BNC female connector with dc isolation achieved by two mica capacitors.

The diode impedances for forward and reverse bias were measured at the fundamental, and the Smith chart was used to ascertain the diode stub length (0.464 $\lambda$) to give desired isolation and insertion loss values. A final adjustment was made by moving the diode mount in a slot cut for this purpose.

The shorted stub was cut to be a quarter wavelength at the fundamental, and a final experimental adjustment was also found necessary because of the discontinuity in the ground plane at the end of the stub. The $T$-junction parameters[2] calculated at the second and third harmonics were found to be in close agreement with the fundamental frequency parameters, and therefore the shorted stub is one-half and three-fourths wavelength at the harmonics.

The low (high) impedance of the diode in a forward (reverse)-bias state is transformed to a low-(high)-shunt impedance at the diode stub line $T$-junction, yielding a high isolation (low insertion loss) value.

The distance between the shorted stub and the diode stub line was chosen to be three-fourths wavelength at the second harmonic in order to direct the generated second-harmonic power to the output port. This it does by transforming the effective short circuit of the shorted stub, at its $T$-junction, to a high impedance at the diode stub junction.

The shorted stub has no effect on the third harmonic and thus cannot give a directive coupling. If the diode impedance at the third harmonic is assumed to be 50 ohms the third-harmonic level at the output port is easily calculated to be 3.5 dB below that generated by the diode.

Tests made on the switch at the fundamental frequency showed that with the diode stub line removed and the output terminated in a 50-ohm load the input VSWR was less than 1.02. Isolation was measured to be greater than 28 dB at a peak power of 4 kW and a bias current of 150 mA. The insertion loss was less than 0.1 dB with peak power of 5 kW and bias voltage of 375 volts. As might be expected isolation decreased with increasing power and decreasing bias currents, and insertion loss increased with increasing power and decreasing bias voltage.

The calculated values for peak and average values capable of being switched by this configuration were 1.44 kW (with reverse bias of one-half breakdown and the assumption of a peak RF signal of bias voltage amplitude) and 95 watts, using an equivalent thermal resistance for the diode and mount of 25° C/W. Note that peak powers used in measurements exceeded the calculated peak power without damage to the diode.

A clean pulsed fundamental signal was applied to the switch for the harmonic measurements. At the switch output the fundamental was filtered out (as was the second harmonic when third-harmonic measurements were made) by a highpass filter. The remaining harmonic was compared to a reference CW signal of the same frequency by a spectrum analyzer.

The second and third harmonics of the applied signal were, respectively, 95 and 105 dB below the fundamental. The filters following the switch were waveguides below cutoff for the fundamental. Elimination of the fundamental was necessary to protect the spectrum analyzer mixer and to keep the fundamental from affecting mixer conversion efficiency. Ferrite isolators were used after it was determined that they produced no measurable harmonics. Since spectrum analyzer sensitivity is a function of pulse width of the applied signal, the loss of sensitivity was measured for the pulses used, as compared to a CW signal, and used as a correction to all measured values.

The measured second- and third-harmonic powers are shown graphically in Figs. 2 and 3 as functions of bias level and incident power level to the switch. The harmonics shown are measurements at the output port. For the second harmonic these are the same as produced

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[1] J. H. Craven, "Coaxial to strip transmission line adapter," *IRE Trans. on Microwave Theory and Techniques* (*Correspondence*), vol. MTT-9, pp. 200–201, March 1961.

[2] A. G. Franco and A. A. Oliner, "Symmetric strip transmission line tee junction," *IRE Trans. on Microwave Theory and Techniques*, vol. MTT-10, pp. 118–124, March 1962.

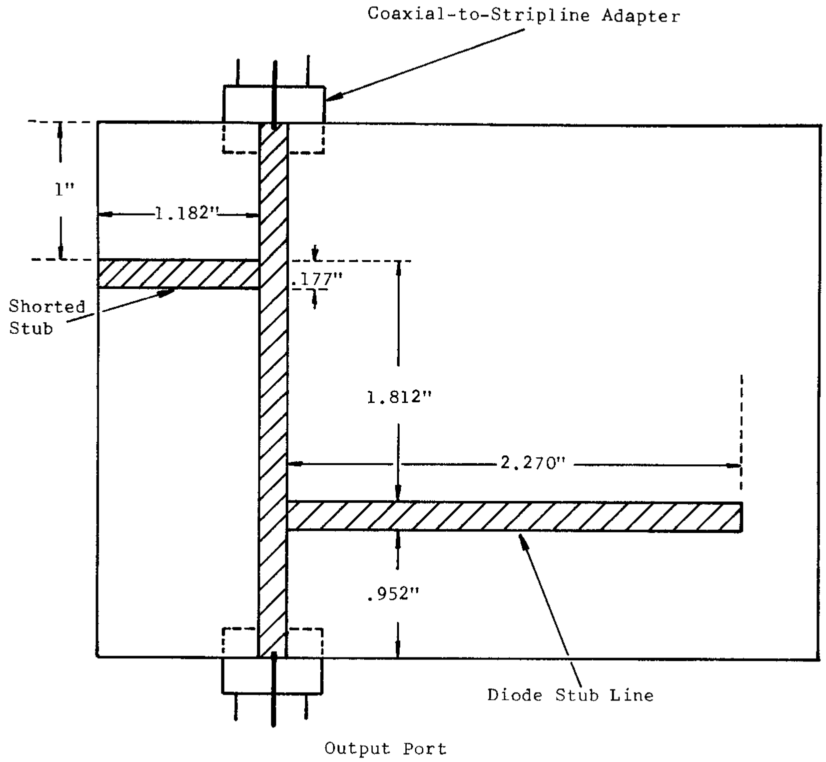


Fig. 1. Center conductor layout for the switch.

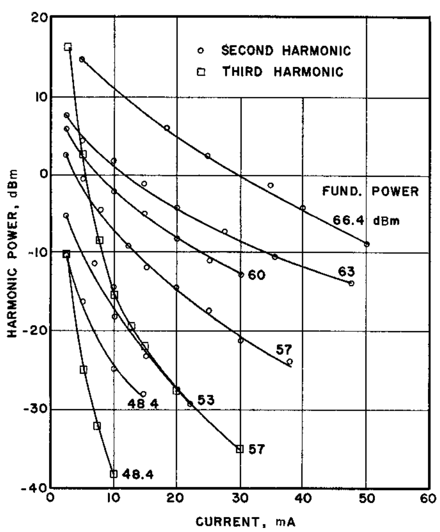


Fig. 2. Generated harmonic powers for forward bias.

by the diode, but for the third harmonic the diode-generated values exceed those shown by 3.5 dB, as discussed previously.

One of the more noteworthy features of these curves is the relatively high harmonics produced at low bias levels, for both forward and reverse bias. It is also apparent that for either bias state the harmonics increase with an increase in incident power at a faster rate than that of the incident power level. This agrees with the findings of Hunton and Ryals for a 12-diode stripline attenuator.[3]

[3] J. K. Hunton and A. G. Ryals, "Microwave variable attenuators and modulators using PIN diodes," *IRE Trans. on Microwave Theory and Techniques*, vol. MTT-10, pp. 262–273, July 1962.

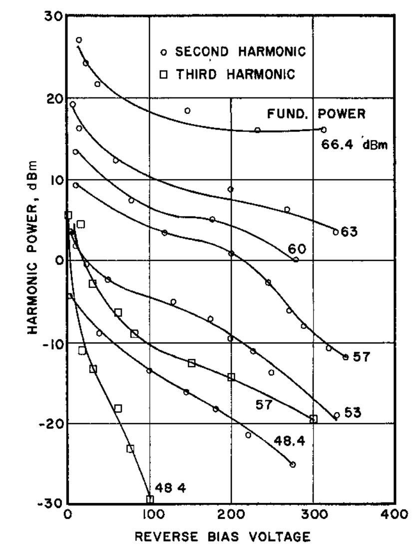


Fig. 3. Generated harmonic powers for reverse bias.

An increase in harmonic level with decrease in forward-bias current is to be expected, and this is apparent in Fig. 2. For very low bias currents insufficient charge is stored in the intrinsic region of the diode and this is depleted during the negative half cycle of the RF current, giving rise to a nonlinearity with high harmonics. With the assumption of a minority carrier lifetime of 0.2 $\mu s$ the point of charge depletion is determined to be about 10 mA for an incident power of 2.5 kW peak. Although there is no discontinuous increase in harmonics appearing near this bias in Fig. 2, it may be seen that the harmonic content is changing rapidly at that point.

One may also observe in Fig. 3 for reverse bias that harmonics are high for low bias voltages. In this range charge is injected into the intrinsic region on positive swings of the signal and nonlinearities are caused by recombination. With increasing bias voltages the harmonics are seen to decrease. At a bias voltage equal to the zero-peak RF voltage on the diode, charge injection no longer takes place. This point occurs for the second-harmonic curves marked 48.4 and 53 dBm of Fig. 3 at 84 and 141 volts bias, respectively.

As reverse-bias voltage increases the negative peaks of the RF signal drive the diode beyond its reverse bias (dc) breakdown value. This point occurs on the 66.4 dBm curve of Fig. 3 at a bias of 105 volts (with a breakdown voltage for this diode of 760 volts). One might expect an increase of harmonic content for a further increase of bias voltage. While the curves of Fig. 3 could not be extended sufficiently to ascertain this increase definitely it appears that the 66.4 dBm curve has leveled out and perhaps has started to rise for larger bias voltages.

Finally, we wish to note that no harmonics higher than the third were observed with the spectrum analyzer which had a sensitivity of about −60 dBm for the pulsed signal used.

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HAROLD MOTT
DAVID N. MCQUIDDY
University of Alabama
University, Ala.

## Phase Shifter in C-, X-, and Ku-Bands Using Segregated-Mode Resonance in Single Crystal YIG

Single crystal YIG has long been regarded as an ideal material for ferromagnetic resonance type devices. However, the performance of all such devices is far from ideal due to excitation of spin-waves at moderate power levels. The excitation of these spurious responses limits the device's power handling capability, as well as degrades its performance, such as insertion loss, noise figure, etc. In order to extend the usefulness of this material, it is necessary, either to suppress all spin-waves, or to segregate one resonant mode out of the manifold.

Single mode segregation has been achieved in a thin YIG disk coupled to a rutile resonator and in a YIG sphere of radius larger than the excitation wavelength (all the YIG samples being single crystal). We have reported and discussed our experimental data relating to such effects elsewhere.[1] Here, we

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[1] K. K. Chow and M. E. Hines, "Mode segregation effects in single-crystal YIG," *J. Appl. Phys.*, vol. 37, pp. 5000, December 1966.