GUNN EFFECT WIDE BAND CW WAVEGUIDE AMPLIFIER

A. Sene and F.J. Rosenbaum
Dept. of Electrical Engineering
Washington University
Saint Louis, Missouri

Abstract

The operation, design and performance of a CW Gunn effect wideband amplifier in an X-band waveguide circuit is described. An equivalent circuit for the amplifier is used to characterize the active device and to predict broadband performance. The results are in good agreement with experiments.

Wideband CW reflection type amplifiers using supercritically doped Gunn diodes in coaxial circuits have been reported recently by several workers.[1-4] Diodes which will oscillate in lightly loaded resonant circuits can exhibit stable amplification if they are circuit stabilized with a series resistive termination, R, which is greater than the magnitude of the effective negative resistance of the Gunn diode, e.g., $R > |-R_d|$. Wideband gain may be obtained by providing a broadband, nearly constant termination, and by suppressing circuit resonances in the frequency range over which the device exhibits negative resistance. Such circuit requirements can readily be satisfied in coaxial or microstrip geometries which are nearly dispersionless. This paper reports the operation and design of a wideband circuit stabilized amplifier in waveguide.

In order to achieve circuit stabilization the packaged Gunn diode ($nL \approx 10^{12}\,cm^{-2}$, $L \approx 11\mu m$) was imbedded in a reduced height waveguide circuit shown in Fig. 1a. The diode is shunt mounted in the reduced height section which is terminated by a sliding short circuit that may be tuned to suppress oscillation and to adjust the gain. A broadband five step transformer[5] was used to match the reduced height section to full height X-band waveguide (b=0.400"). In this way a 6:1 reduction of the load impedance was obtained.

A schematic diagram of the amplifier circuit is shown in Fig. 1b. The input impedance of the short circuit referenced to the plane of the diode is denoted by Z_s. The pill-prong diode package is represented by the shunt capacitor C_1=0.2pf and the lead inductance L_1=0.5nh[6]. The diode itself is modeled by a voltage dependent capacitance C_v in shunt with the effective negative resistance $-R_d$. The package parasitics, Z_s and C_v form a low pass filter which further reduces the load impedance shunting $-R_d$. The impedance of the external circuit (R+jX) viewed from the diode terminals was calculated using the equivalent circuit of Fig. 1b with the plane of the short circuit located at d=0.4825". The results are shown in Fig. 2. The circuit is series resonant at 10GHz. The effective series resistance loading the Gunn diode decreases from 40Ω to 2Ω across X-band. The device does not oscillate since $R > |-R_d|$ over the frequency range where the Gunn diode exhibits negative resistance.

An experimental small signal gain curve of the amplifier is shown in Fig. 3. Note that 10db gain was obtained over 1GHz bandwidth and that 4db gain was obtained at the upper and lower edges of X-band. In the measurement a directional coupler rather than a circulator was used to detect the reflected power.

Using these measured gain results, an independent measurement of the frequency dependence of the phase shift referenced to the input flange of the amplifier, and assuming the equivalent circuit of Fig. 1b, the effective series negative resistance and the series reactance of the amplifying diode were calculated. The results are shown in Fig. 4. The peak negative resistance is -13 ohms at 9.4GHz. The decrease in magnitude of the negative resistance experienced near the upper band edge proceeds faster than the decrease of circuit resistance as shown in Fig. 2, resulting in the experimentally observed gain roll-off. The effective reactance of the device varies considerably with frequency. A mean value of 0.4pf, the static parallel plate value, was taken as characteristic of the diode when operated as an amplifier although gain and phase variations with applied voltage indicate the presence of some space charge which gives rise to an effective reactance.

If a constant effective shunt negative resistance R_d=-30Ω and a constant capacitance C_v=0.4pf are assumed, then using the equivalent circuit of Fig. 1b, a theoretical frequency response can be obtained as shown in Fig. 5. This reasonable agreement between theory and experiment indicates that Gunn diode amplifiers can be designed with some confidence using even crude estimates of the device characteristics. Fig. 6 shows some predicted gain curves for various positions of the short circuit showing the tunable gain characteristics obtainable with this circuit.

Wideband performance has been shown in Fig.3. Narrow-band performance of a single stage amplifier has also been observed with 28db of gain over a 200 MHz BW (1db). The saturation characteristics of these amplifiers depend on the frequency, gain, circuit tuning and bias voltage. When saturated the output power is equal to the power obtainable from the device as an oscillator plus the input power. Linear gain was observed over a 94db dynamic range; 1db gain compression was observed at -13dbm of input power for an amplifier with a gain of 28db. Maximum saturated power was about 200 mw for the available diodes, with 3% efficiency. Noise performance will be described.

The demonstration of wideband amplification in waveguide circuits and the implied broadband impedance control suggests the feasibility of constructing solid-state waveguide amplifiers at elevated frequencies, perhaps even to millimeter wavelengths using Gunn diodes.

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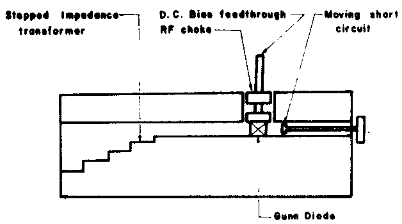

Figure 1a
Cross-sectional view of reduced height X-band waveguide amplifier circuit.

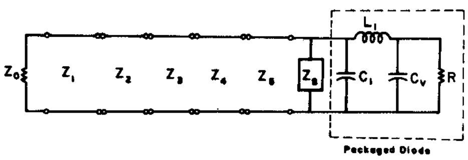

Figure 1b
Schematic diagram of amplifier.

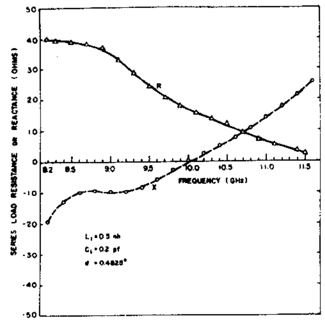

Figure 2
Theoretical series resistance and reactance of the circuit loading the Gunn diode.

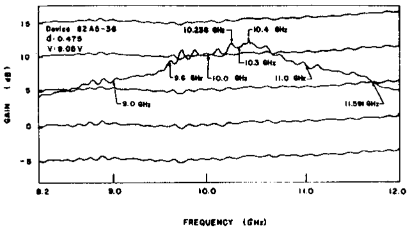

Figure 3
Broadband gain characteristics of wave-guide amplifier.

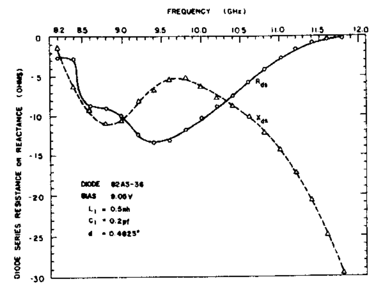

Figure 4
Experimental series negative resistance and reactance of amplifying diode.

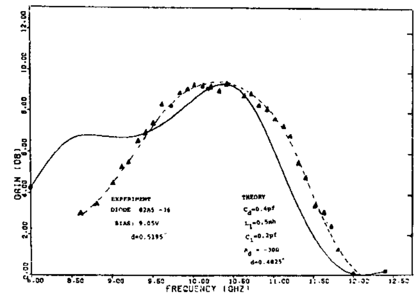

Figure 5
Comparison of theoretical and experimental gain.

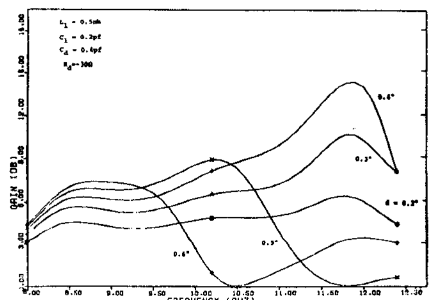

Figure 6
Gain variation for different short circuit positions.