Free-Space RF Triggering of an Active Antenna with Series-Connected Tunneling Diodes

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***Abstract*—Connecting several tunneling diodes—resonant tunneling diodes (RTD's) or tunnel diodes—in series has been shown to be a feasible method for increasing the output power and stability of oscillator circuits using these devices. However, such oscillators require special means of triggering due to biasing difficulties associated with their dc instability. RF triggering was proven to be an effective method of initiating such an oscillation in one-port circuits. An experimental demonstration of free-space RF triggering of an active antenna with a series connection is described here. Active antenna circuits offer excellent isolation between the triggering and oscillation signals and a favorable configuration for spatial power-combining arrays.**

I. Introduction

THE RESONANT tunneling diode (RTD) remains a device of interest because of its potential as a high-frequency solid-state source [1], [2]. Several efforts have been undertaken to increase the power of RTD oscillators [3]–[5]. Connecting several tunneling diodes (RTD's or tunnel diodes) in series has been shown to be a feasible method for increasing the output power and stability of oscillator circuits using these devices [6]–[8]. However, series-connection tunneling diode oscillators require a special means of triggering due to biasing difficulties associated with their dc instability [6]–[8]. In a previously demonstrated one-port oscillator configuration, oscillation was successfully triggered by an external RF signal applied through a circulator [9], [10]. Recent experimental findings have shown that there is no lower limit on the triggering frequency, as long as the triggering power can be sufficiently increased [11]. The experimental demonstration of RF triggering of an active antenna with two tunnel diodes in series at 2.5 GHz is described here. In this configuration, the RF triggering signal is applied from free space, eliminating the need for a circulator. Active antenna circuits also offer excellent isolation between the triggering and oscillation signals and a favorable configuration for spatial power-combining arrays.

II. Active Antenna Design

Two active antennas, each with a two-diode oscillator, were designed to operate at 2.52 GHz. Tunnel diodes (M1X1168 manufactured by Metelics Co.) were used in these circuits

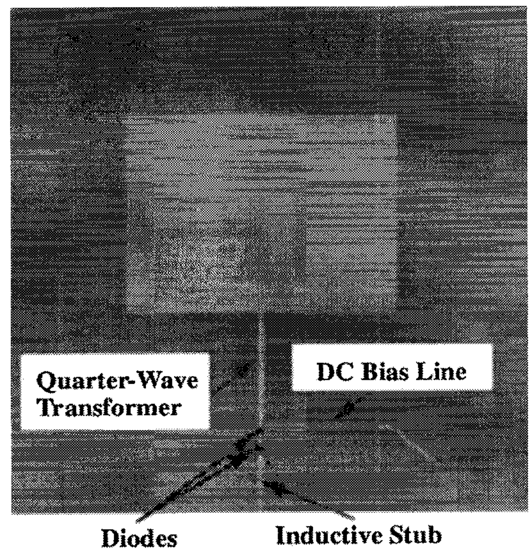

Fig. 1. Active antenna configuration (Circuit 1). A microstrip patch antenna was connected to the diodes through a quarter-wave impedance transformer, and an inductive stub was used to cancel the capacitive part of the device impedance.

to demonstrate the principle of operation. Similar circuits could employ RTD's, which are less readily available. The series-connection diode impedance was calculated using the procedure described in [9]. A microstrip patch antenna was connected to the diodes through a quarter wave impedance transformer, and an inductive stub was used to cancel the capacitive part of the device impedance (Fig. 1). Circuit 1 was designed for an oscillation amplitude of 0.154 V on each diode, which corresponds to -16.5 dBm of total output power, and Circuit 2 for an oscillation amplitude of 0.176 V (-23.6 dBm) [10]. The patch antenna is the same in both circuits, whereas the impedance of the quarter-wave transformer varies. The patch dimensions are 50.8 mm by 38.1 mm, and the dielectric substrate is Rogers RT-Duroid, 0.75 mm thick with a dielectric constant of 2.33. The resonant frequency and input impedance of the patch were measured using an HP8510 network analyzer, and they were found to be 2.52 GHz and 190 Ω, respectively.

III. Experimental Results

Initially, a dc bias voltage sufficient to bias both diodes in the middle of the negative differential resistance (NDR) region of the I–V curve was applied to each circuit. Because of the dc instability of the series connection [6]–[8], both diodes

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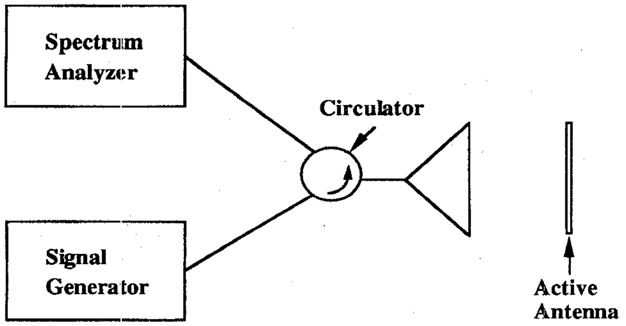
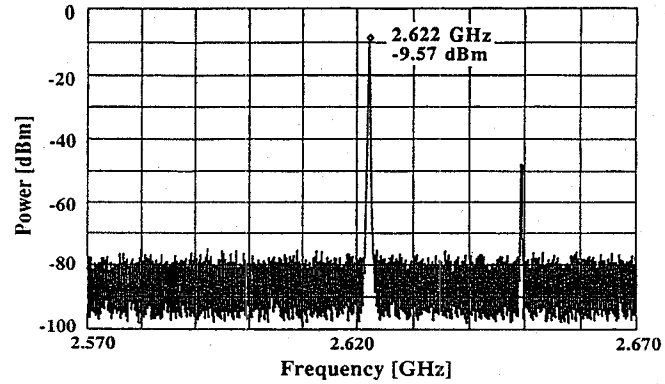


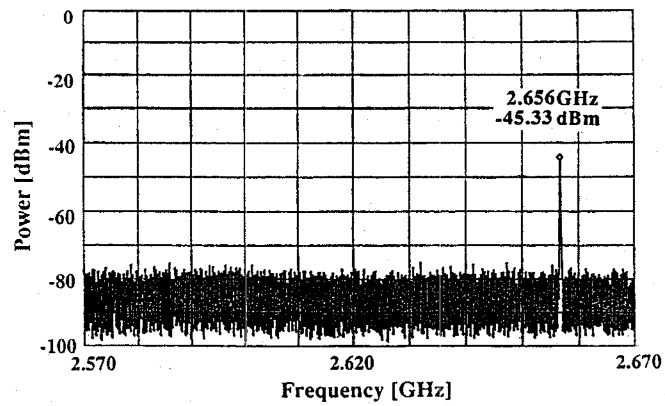
Fig. 2. Experimental setup. A circulator was not required for circuit operation, since the RF source can be physically disconnected from the horn antenna and a spectrum analyzer connected in its place without disturbing the oscillation.

became biased in the positive differential resistance (PDR) region, and oscillation did not occur. The circuits were then illuminated with an RF signal of frequency close to the predicted oscillation frequency (fundamental triggering) through a pyramidal horn antenna (AEL H-1498), from a distance of approximately 2 m. The external RF signal switched the diode bias points from the PDR to the NDR region and initiated the oscillation [9], [10]. An HP 8350B sweep oscillator with an HP 83592C plug-in was used as an external RF source. The oscillator signal was detected with the same horn antenna and an HP 8562A spectrum analyzer. A circulator was used so that the excitation signal and generated signal could be observed simultaneously (Fig. 2), however it was not required for circuit operation. Alternatively, the RF source could be physically disconnected from the horn antenna and a spectrum analyzer connected in its place without disturbing the oscillation. Free-space RF triggering can be very useful at millimeter-wave frequencies, for which circulators are not available.

Once oscillation was initiated, the triggering signal was turned off without disturbing the oscillation signal. Circuit 1 oscillated at 2.55 GHz, with an effective isotropic radiated power (EIRP) of -15 dBm radiated from the patch, and Circuit 2 at 2.65 GHz with the EIRP of -20 dBm. Assuming a patch gain of 2.5 dB, the diodes produced -17.5 dBm of power in Circuit 1 and -22.5 dBm in Circuit 2, which was within 1 dB of predicted values. Circuit 1 could be triggered with about -22 dBm at the patch in a frequency band of 10 MHz centered around the oscillation frequency, and Circuit 2 with -14 dBm in a 60-MHz band. The amount of power required for triggering depends on the oscillation amplitude, which is different for the two circuits. The larger voltage oscillation (lower power, Circuit 2) requires more triggering power than the smaller voltage oscillation (higher power, Circuit 1) [10]. Successive triggering [6], [10] conditions were observed in Circuit 2. The overall behavior of both circuits was consistent with previous observations for one-port oscillators [10]. Fig. 3 shows the spectrum of Circuit 2 during (a) and after (b) triggering, in this case with the RF source 0.5 m away from the patch to allow the triggering signal to be seen on the same scale as the oscillation signal. The intensity of the triggering signal may be misleading, since it shows what is received by a spectrum analyzer through a circulator and not what is received by the patch. Initially, the triggering signal pulled the oscillation signal, and hence the oscillation frequency and power changed slightly after the triggering signal was turned off.



(a)



(b)

Fig. 3. Spectrum of Circuit 2 during (a) and after (b) triggering, with the pyramidal horn 0.5 m away from the patch. The intensity of the triggering signal may be misleading, since it shows what is received by a spectrum analyzer through a circulator, and not what is received by the patch.

Subharmonic [10] and low-frequency [11] triggering could not be tested, since the patch antenna was designed for the first resonance and therefore could not receive lower frequencies. Had the antenna been designed for the second resonance, triggering with one third of the fundamental frequency could have been tested. However, it may be more practical to use a slot antenna at the back side of the circuit to test subharmonic triggering, since slot antennas have a broader bandwidth and are resonant at all multiples of a half wavelength. Energy received by a slot antenna would couple to the microstrip line connected to the diodes, and thus initiate the oscillation.

IV. Conclusion

The free-space RF triggering of active antennas with series-connected tunneling diodes was demonstrated experimentally at 2.5 GHz. The overall behavior of the active-antenna circuits was consistent with previous observations for one-port oscillators [10]. These circuits may be improved by adding a slot antenna to the back of the substrate to facilitate subharmonic triggering [10]. At millimeter-wave frequencies, the active antenna configuration can provide a distinct advantage since circulators are not available, and it would also be favorable for spatial power-combining arrays.

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