A SELF-MIXING ACTIVE ANTENNA FOR COMMUNICATION AND VEHICLE IDENTIFICATION APPLICATIONS

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ABSTRACT

A cavity backed, Gunn diode driven, self-mixing active inverted stripline circular patch antenna has been developed. The active antenna provides good radiation patterns with cross-polarization levels 18 dB below co-polarization at boresight. The self-mixing performance shows that the circuit has a 2 dB conversion gain for IFs up to 450 MHz and a double sideband noise figure of 15 dB at 200 MHz. The antenna is suitable for use as a transceiver for short communications links or as a microwave identification transceiver.

I. INTRODUCTION

Recently, active antennas [1]-[2] and self-mixing oscillators have been offering savings in size, weight, and cost over conventional designs. These characteristics makes them desirable for possible application in microwave communication systems such as LAN, identification systems, short distance communication systems. Gunn diodes and FETs can operate as a self-mixing oscillator with conversion gains ranging from 4.1 dB to 13 dB and with single sideband noise figures from 11.5 to as low as 3.3 dB [3]-[5]. Although FET configurations usually deliver better circuit performance, the circuit design is far more complex. Gunn diodes are capable of delivering similar performance with a simpler bias circuit. In this paper a Gunn diode self-mixing oscillator was developed in the active inverted stripline antenna configuration. The circuit consists of an active transmitter antenna and a Gunn diode oscillator used as the transmitter, local oscillator, and self-mixer.

II. ACTIVE ANTENNA CONFIGURATION

The active antenna consists of an inverted stripline circular patch antenna press fitted onto a cylindrical cavity. Figure 1 shows the circuit configuration of the self-mixing active antenna. The substrate serves as a radome to seal the antenna and circuits. The Gunn diode is offset from the center of the patch by a distance (ρ) of 6 mm, which was determined empirically to provide the best radiation performance. The cavity's depth (B) is 3.0 mm and the patch diameter (D) is 30 mm. The cavity's diameter (C) is 62 mm and the substrate thickness (A) is 1.524 mm with dielectric constant of 2.3. These dimensions allow the patch to resonate at around 6.3 GHz for probe-fed antennas [6].

The active antenna operates at 6.25 GHz with a bias voltage of 9.4 volts and draws 250 mA. The Gunn diode used is a M/A COM, model MA 49135-11. The active antenna's tuning range is 240 MHz with radiation power of 14.8 ± 1 dBm for biases from 9-12 volts.

Figure 2 shows the radiation patterns of the self-mixing active antenna. The H-plane and E-plane patterns are smooth with cross-polarization levels of less than - 6 dB and -18 dB. The half-power beamwidths of the H-plane and E-plane are 57° and 51°, respectively.

III. SELF-MIXING PERFORMANCE

To measure the conversion loss (gain) of the self-mixing antenna, a procedure similar to that outlined in [7] was used. Refer to Figure 3 for the test set-up. The isotropic conversion loss, in ratio, is defined as:

$$L_{iso} = \frac{P_{iso}}{P_{IF}} \quad (1)$$

where P_{IF} is the power delivered at the intermediate frequency and P_{iso} is the power detected at the antenna aperture of the receiving antenna if it were isotropic. Since isotropic antennas are unrealizable, a standard 16 dBi gain horn was used to measure a reference power level (P_{ref}) instead. P_{ref} was measured directly to be -27.8 dBm. Therefore, we obtain a P_{iso} of - 43.83 dBm from $P_{iso} = P_{ref} - G_{std}$. The IF power of the self-mixing antenna measured using the test set-up in Fig. 3 (b) is -1.83 dBm. The isotropic conversion loss of -12 dB can be obtained from equation (1). The conversion loss of the self-mixing antenna is: $L_c = L_{iso} + G_{aa}$, where G_{aa} is the gain of the active antenna, which is estimated to be 10 dB. Thus, the conversion loss is -2 dB; i.e., a conversion gain of 2 dB was realized. This is consistent with the results reported in [3]-[5].

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The HP-8970B Noise Figure Meter was used for determining the double sideband noise figure of the self-mixing active antenna. Figure 4 shows the noise figure measurement set-up. It is important to note that the separation between the standard horn and the other antennas is very short because the noise power delivered by the HP-346C Noise Source is quite small.

Figure 5 shows the measured conversion gain and noise figure of the self-mixing active antenna after de-embedding reference data. As shown in Figure 5, the double sideband noise figure varies from 14.97 to 19.5 dB with a conversion gain greater than 2 dB over an IF bandwidth from 200 to 450 MHz. The conversion gain results obtained with this method are consistent with those from the test set-up shown in Fig. 3.

IV. APPLICATIONS

Several applications are possible with the developed self-mixing antenna, depending on whether the designer intends to use the self-mixing character of the device or not. The device can be used as a half-duplex transceiver for short communications links or as a microwave identification system.

A. Half-Duplex Communication System

The oscillation frequency of the active antenna can be modulated by applying a small A. C. signal to the bias voltage. This allows the oscillator to be frequency-modulated and be used as a transceiver. Figure 6 shows the communication system set up. It is important to note that, because the RF signal transmitted is also used as the LO reference, simultaneous transmission and reception cannot take place. This makes the self-mixing active antenna suitable for short distance TV transceivers or LAN gateways [8].

The minimum detectable signal can be computed from [9]:

$$\mathrm{MDS} = -111\,\mathrm{dBm} + 10\log \mathrm{BW} + \mathrm{F} \qquad (2)$$

where BW is the IF bandwidth in MHz and F (dB) is the noise figure of the transceiver. The double sideband noise figure of the transceiver was measured to be 14.97 dB for an IF of 200 MHz. For practical applications, the single sideband noise figure is 11.97 dB.

The MDS is computed to be -91.25 dBm for a typical video bandwidth of 6 MHz. This result, and the Friis transmission equation, can be used to compute the maximum length of a communications link using two of the circuits. For a carrier frequency f_o of 6.25 GHz, the wavelength in free space is 48 mm. The maximum length of the communications link, assuming polarization match and boresight alignment, is computed to be 7.6 km.

B. Microwave Identification System

Since the active antenna always transmits a signal, the device can also serve as a self-mixing interrogator for a microwave identification (MW-ID) system. In this case, the free-running oscillator frequency serves as an interrogator beacon and the self-mixing action would down-convert the reply signal which could be pulse code modulated (PCM) with an identification code. Such a system would be suitable for automated toll collection or personnel identification purposes.

An automated toll collection system can be implemented with the self-mixing active antenna presented here. The substrate of the active antenna is press fitted onto the Gunn diode mounting fixture. This assembly in turn can be embedded directly into the road surface in the center of the lane to interrogate oncoming vehicles. The antenna can be aimed toward zenith or tilted slightly toward oncoming traffic, as shown in Figure 7.

The free-running frequency interrogates the oncoming vehicle. The vehicle's low-power transmitter responds, with its antenna aimed at the ground, at a different frequency to produce an IF in the 200 MHz range. The vehicle's transmitter can be pulse code modulated (PCM) to send an account or vehicle identification number for billing purposes.

V. CONCLUSIONS

A self-mixing active antenna has been designed and demonstrated. The circuit radiates a clean spectrum and operates well in self-mixing mode with a conversion gain of 2 dB. Although the H-plane's cross-polarization levels need to be improved, the circuit has fairly good radiation patterns. The circuit is well suited for commercial and military applications as a transceiver for microwave ID applications or for short communication links.

VI. ACKNOWLEDGMENTS

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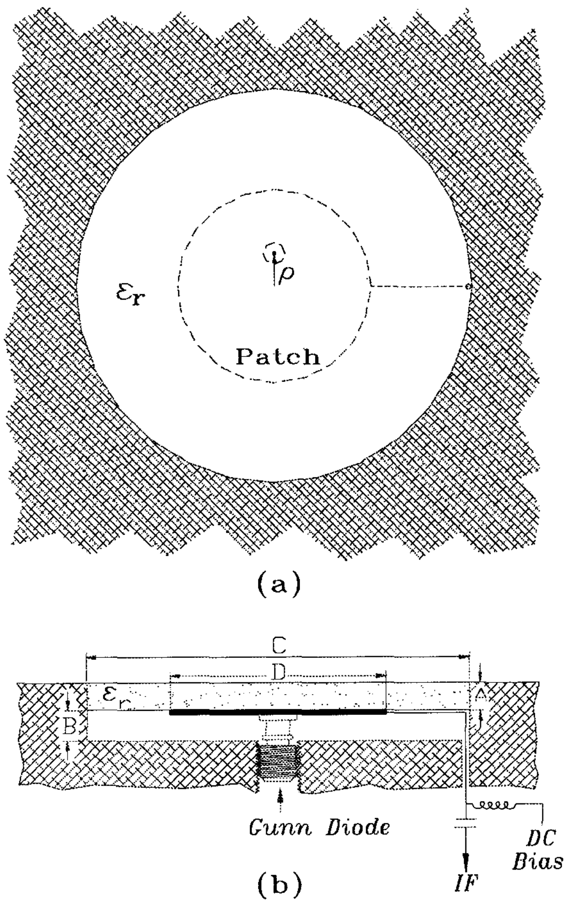

Figure 1. Configuration of a self-mixing active antenna. (a) Top view showing the Gunn diode placement and (b) side view showing the cavity depth, substrate thickness, DC bias, and IF output.

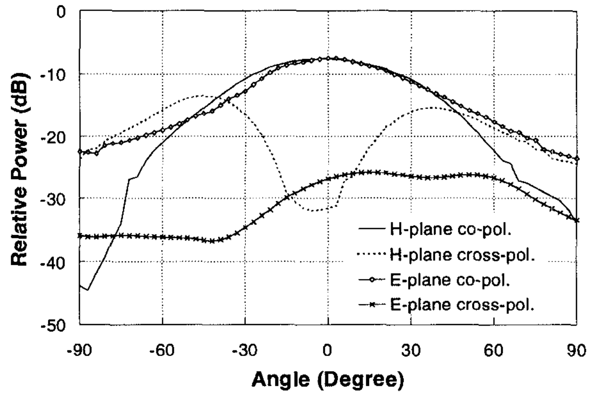

Figure 2. Radiation patterns of the self-mixing active antenna. H-plane pattern with HPBW of 57° and cross-polarization level of - 6 dB. E-plane pattern with HPBW of 51°and cross-polarization level of -18 dB.

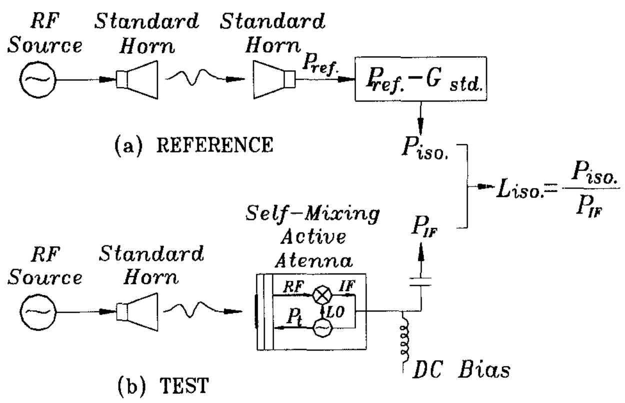

Figure 3. Test set-up for measuring the conversion gain of the self-mixing active antenna.

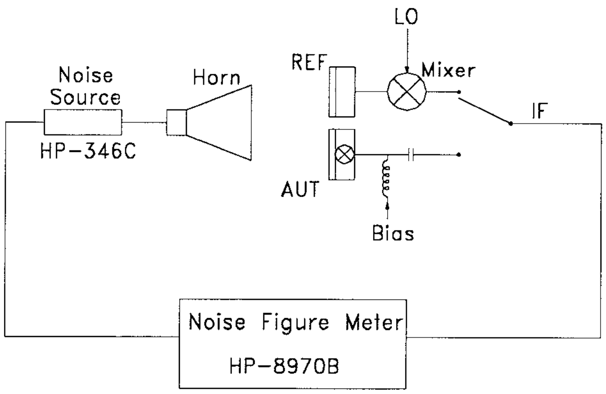

Figure 4. Noise figure measurement set-up using the HP-8970B Noise Figure Meter.

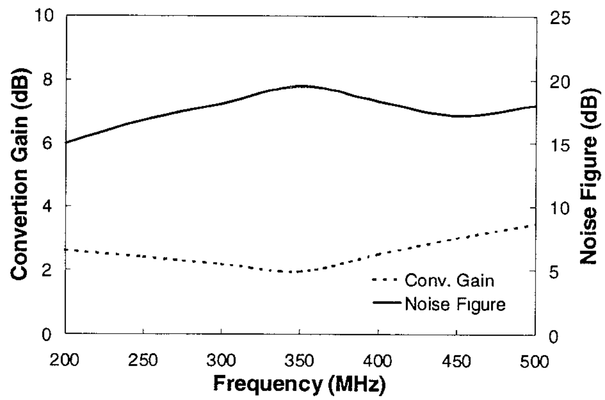

Figure 5. Conversion gain and noise figure characteristics of the self-mixing active antenna.

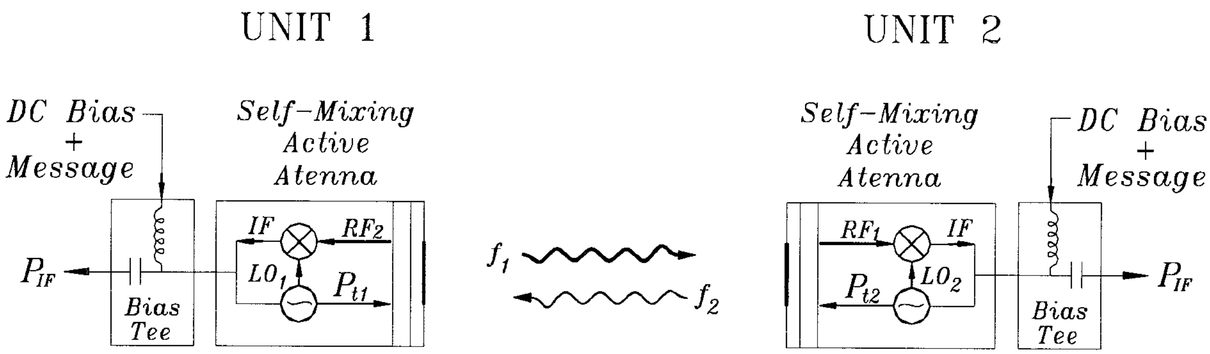

Figure 6. Communications link using two self-mixing active antennas.

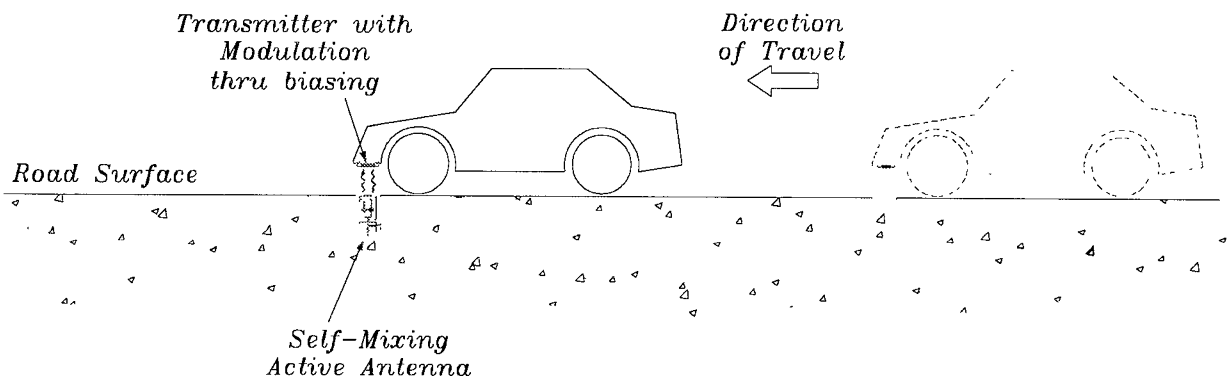

Figure 7. Conceptual drawing for automated toll collection applications.