# An Active Inverted Patch Antenna with Wideband Varactor-Tuned Capability

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## ABSTRACT

A varactor-tuned inverted circular patch antenna has been developed with a power variation of ±1.0 dB over a 13 percent tuning bandwidth. A simple equivalent circuit has been used to model the active antenna, and the calculated results agree well with the experimental results. The circuit should have many commercial applications in wireless communications, radar, and sensors.

## I. INTRODUCTION

Active antennas have become promising candidates for low cost, compact transmitters in microwave and millimeter-wave radar, sensors and wireless communications applications. Recent research in active antennas has mainly concentrated on microstrip patch types [1, 2], i.e. where solid state devices (usually diodes or FETs) are integrated to the microstrip patches which make ideal planar, low-cost radiating elements. The microstrip patches serve as the resonant structures for devices to oscillate and a ground plane for efficient heat sinking. However, active microstrip patch antennas suffer from having narrow bias tuning ranges and wide output power variations. A good solution to the problems has been reported [3, 4] using varactors connected to the radiating elements. For a beam steering power combining array, varactor-tuned active antennas with wide tuning ranges are used to control the phase distribution in the array and to keep minimal power variation over the collective locking range of the active elements. Several other wideband varactor-tuned active antennas have also been developed using varactor tunable notch antennas and tunable power combiners [5] and quasi-optical grid VCOs [6]. To further extend the applications for active antennas, spatial power combining and beam steering, this paper reports a modification of the active inverted patch antenna in [7], using a varactor-tuned design to realize wideband frequency tuning.

The inverted microstrip patch is attractive for integrated antennas because it offers two distinct advantages. First, diode or probe insertion does not require drilling through the substrate as in microstrip. This characteristic allows non-destructive device testing and position optimization in inverted microstrip. Second, the inverted substrate can serve as a built-in radome for protection. By choosing the substrate and metal support carefully, quality hermetic seals can be achieved to protect solid-state devices and improve system reliability and durability. To fully utilize the advantages of the inverted microstrip structure, a new active enclosed (trapped) inverted microstrip circular patch antenna with varactor tuning is presented here. This active antenna exhibits an electronic tuning bandwidth from 6.73 to 7.67 GHz (i.e. 13% tuning range centered at 7.2 GHz) with a radiation power of 15.2 ± 1.0 dBm. The theoretical frequency tuning curve obtained from an equivalent circuit model agrees well with measured results.



## II. ANTENNA DESIGN AND SIMULATION

Although inverted microstrip has advantages mentioned above, this configuration is prone to exciting surface wave modes which cause considerable cross-talk in dense circuits and high mutual coupling in arrays. Surface modes reduce the antenna radiation efficiency and may distort the antenna pattern. To eliminate unexpected surface modes and reduce coupling, the trapped inverted microstrip (a modification of inverted microstrip with electric walls on either side of itself) can be used as follows Figure 1 shows the physical configuration of the varactor-tuned active inverted patch antenna. The antenna includes a circular enclosure which supports the patch insert, chokes out surface waves, and further increases the metal volume for heat dissipation. A screw-type Gunn diode is fastened to a base ground, and a varactor is placed near the Gunn and on top of a bypass capacitor which serves as a DC choke for varactor biasing. A circular patch etched on a circular dielectric insert is pressed into the enclosure over the diodes. The inverted patch serves as a resonant element for the Gunn diode. The optimum position of the diodes within the patch was found experimentally to obtain the maximum operation frequency tuning range with a minimal variation of output power. The diode biases are applied through filtering capacitors below the ground plane. The active antenna was designed at 7 GHz, chosen as the oscillating frequency only for convenient fabrication and test, with the following parameters: (1) substrate: $h_s = 1.524$ mm, $\varepsilon_r = 2.3$, (2) patch radius: $R_p = 12$ mm, (3) enclosure radius: $R_e = 31$ mm, (4) air spacing: $h_a = 3.2$ mm, (5) Gunn position: $R_G = 4.5$ mm. The Gunn and varactor diodes are M/A COM models MA49135 and MA46601F, respectively. The Gunn produces 16 dBm (40 mW) in an optimized waveguide circuit while the varactor features a maximum to minimum capacitance ratio of about 3.3 (1.0 to 0.3 pF) over a bias from 0 V to 20 V.

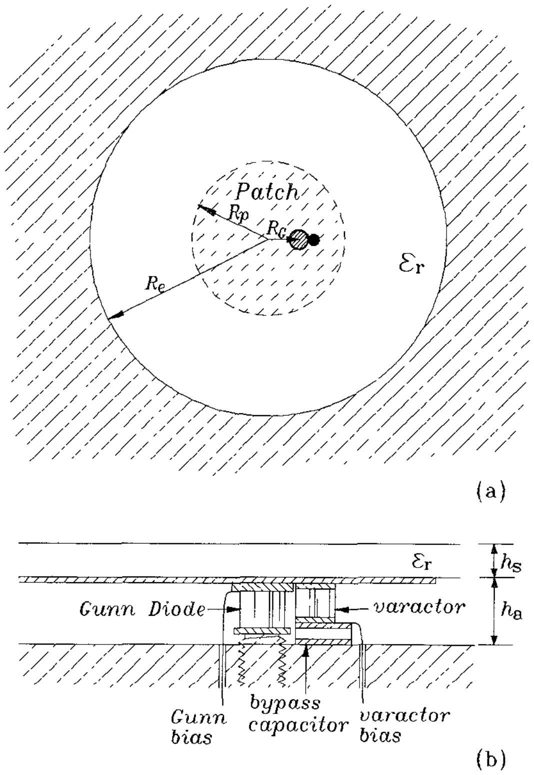



Fig. 1 Configuration of the varactor-tuned active inverted patch antenna. (a) Top view and (b) cross sectional view showing details under the patch.

A simple theoretical model was developed to analyze the design. The equivalent circuit can be represented as shown in Figure 2 The circular patch was approximately modeled by tandem-connected segments of piecewise uniform line of different widths. The edges of the patch are loaded with shunt radiation conductance and fringing capacitances given in [8]. The equivalent circuits of the Gunn and the varactor shown in Figure 2 were used for simulations. The diode parasitics for the Gunn and varactor are given by the vendor [5]. From circuit oscillating conditions, simulation of the circuit model was performed using Libra [9]. The circular patch was simulated by a cascade of 7 line segments of equal lengths but different characteristic impedances. The

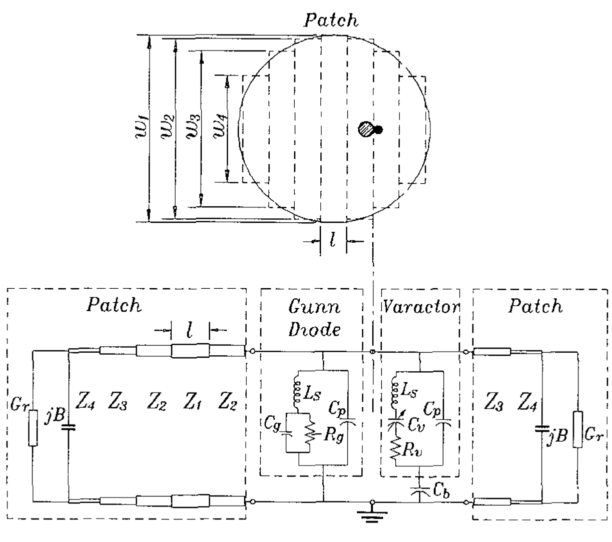



Fig. 2 Equivalent circuit model of the active antenna shown in Fig. 1. Gunn diode parameters: $R_g \approx -8\ \Omega$, $C_g \approx 1.05$ pF, $C_p \approx 0.25$ pF, $L_s \approx 0.3$ nH. Varactor parameters. $C_v \approx 0.3$ to $1.0$ pF, $C_p \approx 0.05$ pF, $R_v \approx 3\ \Omega$, $L_s \approx 0.3$ nH.

simulation indicated that when the varactor capacitance is varied from 1.0 to 0.3 pF, the frequency of the antenna should be tuned from 6.4 to 7.7 GHz as shown in Fig. 3.

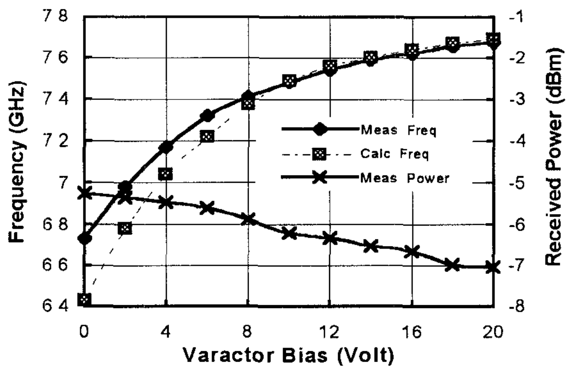
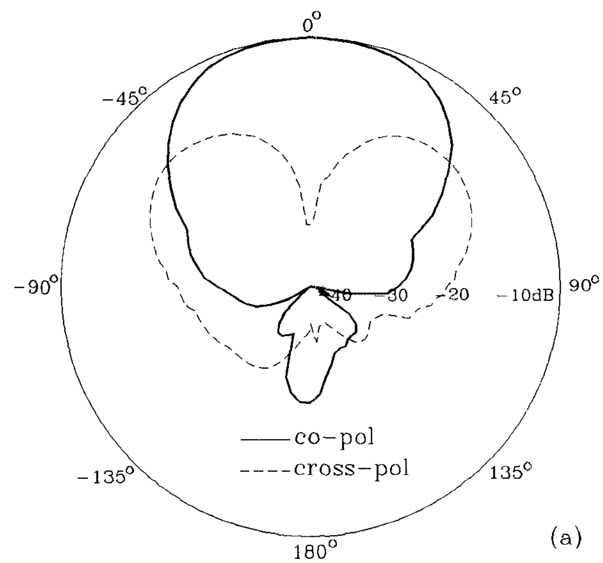



Figure 3. Measured and simulated frequency and received power vs. varactor bias. (Received power is obtained using a Narda 642 standard horn placed 1.1 meters away from the tested active antenna.)

## III. MEASURED RESULTS

The antenna performance was measured in a mini chamber specially made for active antenna testing. Figure 3 shows that the antenna achieved a tuning range of 6.73 to 7.67 GHz with a power variation of ± 1 dB. As shown in Figure 3, the calculated tuning curve is in good agreement with the measured results. The differences between the simulations and the measurements are due to the errors in device modeling parameters and the neglecting of the enclosure effects.

The H- and E-plane patterns of the antenna at a representative frequency in the tuning band are shown in Figure 4 The half-power beamwidths of the H- and E-plane are 62° and 41°, respectively. The radiation patterns are very smooth with cross-polarization levels of less than -10 dB. Figures 5 and 6 illustrate the H- and E-plane patterns of the antenna at varactor biases of 0, 10, and 20 V, respectively. These radiation patterns do not show significant variation within the tuning range. As shown in Figures 5 and 6, the radiation power decreases slightly when the varactor bias is increased. The reason for that is a mismatch which gradually increases in the antenna circuit. From the patterns, the active antenna has an equivalent isotropic radiated power (EIRP) of 27.3 dBm (537 mW) and a directivity of 12.1 dB, from which a radiated power of 15.2 dBm (33.1 mW) is estimated using the Friis transmission equation. The antenna's phase noise of -85 dBc/Hz at 100 kHz from the carrier was measured using an HP-8562A spectrum analyzer This specification is 6 to 9 dB worse than the same active antennas without varactors. A bias tuning bandwidth of 270 MHz centered at 6.85 GHz was observed by varying the Gunn bias from 10 to 15 V. This tuning range is much smaller compared to the varactor tuning range.



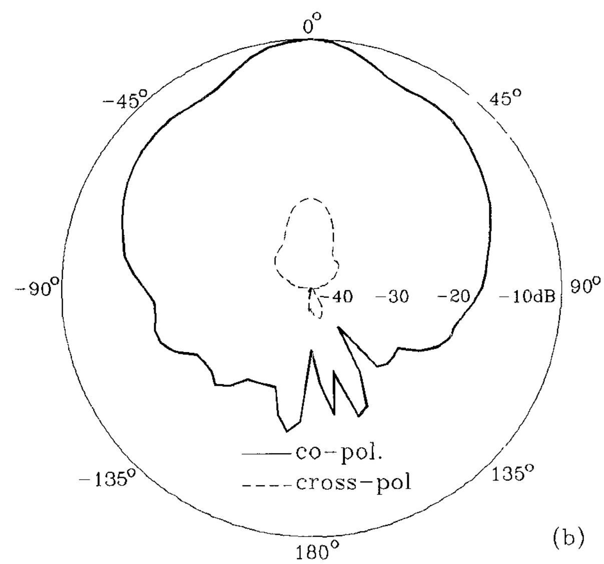




Figure 4. Typical radiation patterns of the varactor-tuned active antenna. (a) H-plane and (b) E-plane. (varactor bias = 0 V, $C_v$ = 1 pF, oscillating frequency = 6.8 GHz)

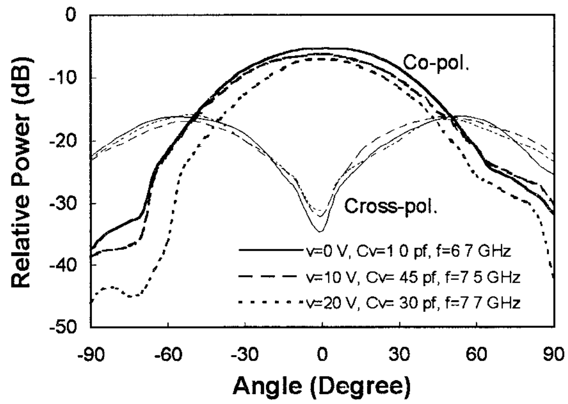



Figure 5. Measured H-plane patterns of the active antenna vs. varactor biases of 0 V, 10 V, and 20 V.

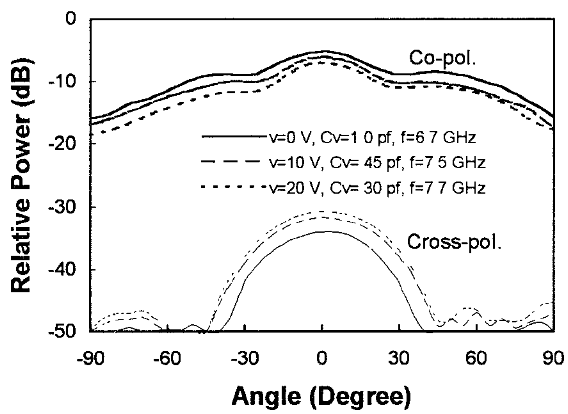



Figure 6. Measured E-plane patterns of the active antenna vs. varactor biases of 0 V, 10 V, and 20 V.

## IV. CONCLUSIONS

A 13% electronic tuning range was achieved with a fairly constant output power by using a varactor integrated in the active Gunn diode inverted patch antenna. The wide electronic tuning range is very useful for transmitter, power combining and active array beam steering applications. The inverted microstrip circuit offers a compact, simple, low-cost, reproducible, and hermetically sealed source. Because of its good circuit configuration and antenna performance, this tunable active antenna should also have many applications in frequency-modulated wireless communication links, radar, sensors, and electronic warfare at microwave and millimeter-wave bands.

## V. ACKNOWLEDGMENTS

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