

Tunable Reduced Size Planar Folded Slot Antenna Utilizing Varactor Diodes

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Abstract — A tunable folded slot antenna that utilizes varactor diodes is presented. The antenna is fabricated on Rogers 6006 Duriod with a dielectric constant and thickness of 6.15 and 635 μm , respectively. A copper cladding layer of 17 μm defines the antenna on the top side (no ground on backside). The antenna is fed with a CPW 50 Ω feed line, has a center frequency of 3 GHz, and incorporates Micrometrics microwave hyper-abrupt 500MHV varactors to tune the resonant frequency. The varactors have a capacitance range of 2.52 pF at 0 V to 0.4 pF at 20 V; they are placed across the radiating slot of the antenna. The tunable 10 dB bandwidth of the 3 GHz antenna is 150 MHz. The varactors also reduce the size of the antenna by 30% by capacitively loading the resonating slot line. At the center frequency, 3 GHz, the antenna has a measured return loss of 44 dB and a gain of 1.6 dBi. Full-wave electromagnetic simulations using HFSS are presented that validate the measured data.

Index Terms — capacitive loading, Duriod, folded slot antenna, varactor.

I. INTRODUCTION

Wireless systems, such as mobile communications, RFID and wireless sensors, are becoming more complex and require components that are smaller and have the ability to operate at multiple frequencies. Electrically small antennas that are tunable allow the antenna to increase the operational bandwidth and, therefore, cover multiple applications while fitting within a small package.

Tuning planar antennas with varactors has been previously demonstrated. A band-notched ultra wideband (UWB) planar monopole has been reported [1] with a usable bandwidth of 3.1 to 10.6 GHz and varactor diodes to tune the notch band of antenna, which has a 10 dB bandwidth of 5.2 to 5.6 GHz and a tunability of 400 MHz, or 7.4%. The antenna requires $\lambda/4$ stubs, inductors and vias to connect to a resonator on the bottom-side of the substrate. Tunable coplanar and microstrip patch antennas have been reported [2]. The microstrip patch has a tuning range of 240 MHz over the frequency band of 1.796 – 2.036 GHz for a 6.2% tunability and the coplanar patch has a tuning range of 875 MHz over the frequency band of 1.395 – 2.27 GHz for a 47% tunability. Both antennas use varactors to achieve the tuning ability and are

fabricated on a dielectric substrate with a dielectric constant of 2.94 and a thickness of 20 mils. A U-slot microstrip antenna with a varactor has demonstrated a tuning range of 750 MHz over a range from 2.6 to 3.35 GHz [3], or 25% tuning.

Other methods used to tune antennas are MEMS and liquid crystal (LC). A tunable patch using RF MEMS technology has been described [4]. The antenna can be tuned 300 MHz over the frequency range of 15.75 to 16.5 GHz. However MEMS technology suffers from high fabrication costs and reliability issues. A tunable patch that utilizes LC substrates for tuning capability has been reported [5]. The antenna has a tuning range of 230 MHz over a frequency range of 5.43 to 5.66 GHz. A DC bias is applied between the patch and ground across the LC substrate to achieve maximum tuning range.

A compact tunable PIFA that illustrates a size reduction has been demonstrated with 10 dB bandwidth tuning capabilities from approximately 1.6 to 2.4 GHz [6]. DC blocks are used to connect a supplemental patch, which is intended to reduce the overall volume of the antenna. A patch was also reported with reduced size and tuning capability [7] with a 63% change in resonate frequency.

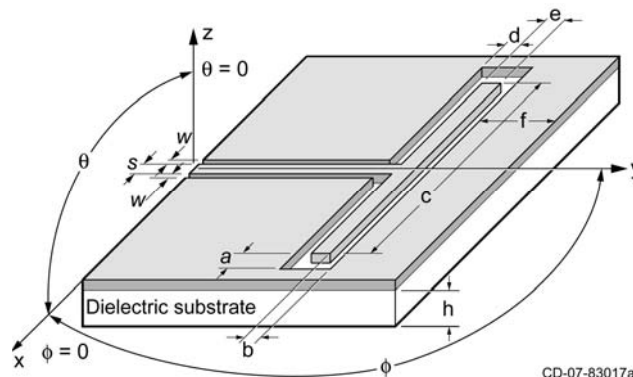


Figure 1: Conventional coplanar waveguide fed folded slot antenna.

A conventional, CPW fed, folded slot antenna (FSA) is shown in Fig. 1. The antenna is comprised of a pair of slotline resonators that are folded such that they

meet along the center line of the CPW. Because the CPW mode on the feed line has a virtual magnetic wall along the longitudinal axis (y -axis) and the antenna is symmetric, a virtual open circuit exists on the antenna where the slots meet at the y -axis. The folded slots are designed with a $\lambda_0/2$ mean path length, ignoring the parasitic reactance due to the 90° bends and T-junction.

To decrease the physical size of the antenna, lumped capacitors can be added to the mid-point of the folded slots as shown in Fig. 2 [8]. By optimizing the capacitance value and antenna dimensions, the physical size of the antenna may be reduced while maintaining the same impedance match frequency. A 30% reduction in mean path length has been demonstrated while maintaining a resonant frequency of 3 GHz.

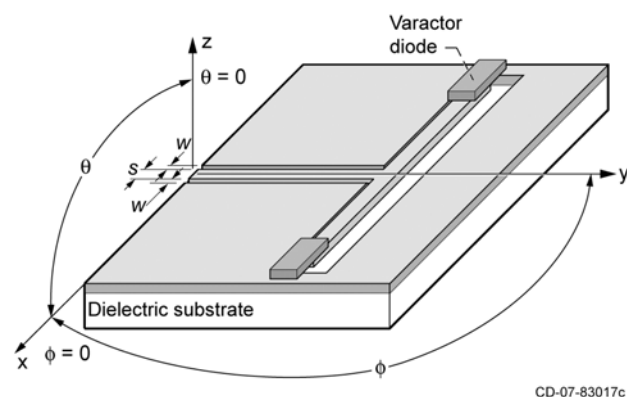


Figure 2: Folded slot antenna with capacitor or varactor loading.

This paper extends the development of the reduced size FSA by replacing the chip capacitors with varactors, allowing the tuning of the resonant frequency. In Section II, the antenna design is described. Measured return loss and radiation patterns are presented to demonstrate the tunability and overall performance of the FSA. HFSS simulations are presented to confirm the measured data [9].

II. ANTENNA DESIGN

In the 3 GHz antenna presented here, the mean path length is 50 mm. From Fig. 1, the antenna dimensions are $e = 2$ mm and $a = b = d = 0.1$ mm [8]. These were optimized with HFSS when fabricated on Rogers RT Duriod TM 6006 with a dielectric constant of 6.15, substrate thickness of 0.635 mm and a $17 \mu\text{m}$ -thick (0.5 oz.) copper laminate on its top-side (no ground plane). The antenna is fed by a CPW line with an $S = 2.3$ mm and $W = 0.3$ mm, which results in a characteristic impedance (Z_0) of approximately 50Ω .

To provide tuning, Micrometrics 500MHV-19-1 microwave hyper-abrupt varactors are placed across the

radiating slots, as shown in Fig. 2. Ablebond Silver Base epoxy is used for chip attachment. The full metal surface is not shown, but it extends 15 mm from the edge of the slot in all directions. Lastly a SMA to microstrip launcher adapted for CPW was soldered to the Duriod board to facilitate measurements.

III. EXPERIMENTAL RESULTS

To determine the capacitance values of the varactor at each specific bias voltage, a 2-port CPW test board with RF probe pads was fabricated and the diodes were mounted across a gap in the CPW center conductor. A thru-reflect-line calibration was performed on an Agilent E8361C Precision Network Analyzer (PNA) to place the reference planes at the varactor edge. The measured S-parameters were used to determine the component values of the varactor equivalent circuit model shown in Fig. 3 with Agilent's Advanced Design System (ADS) software package.

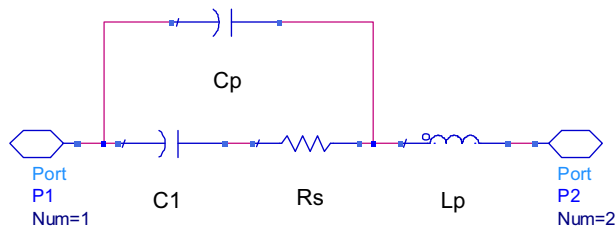


Figure 3: Varactor equivalent circuit model.

The model consists of the junction capacitance, $C1$, and the series resistance, R_s , of the varactor. Parasitic capacitance, C_p , and inductance, L_p , are included to account for the plastic package. The parasitic components, C_p and L_p , are specified by the manufacturer to be 0.04 pF and 0.8 nH, respectively. Table 1 lists the manufacturer's provided model values and those from the measurements for $C1$ and R_s . It is noted that the measured values of $C1$ are derived from S-parameters measured over the frequency range of 0.1 to 5 GHz while the manufacturer's data is from a 1.8 GHz measurement. The R_s -fit data is from a numerical fitting of the antenna measured gain data that will be discussed below. It is seen that the measured and data sheet values agree well.

Table 1: Varactor equivalent circuit component values.

| Bias (V) | 1.89 | 2.58 | 2.99 | 3.44 | 4.89 |
|--------------------------|------|------|------|------|------|
| C1-meas (pF) | 1.34 | 1.16 | 1.08 | 1.00 | 0.80 |
| C1-data (pF) | 1.34 | 1.18 | 1.11 | 1.05 | 0.86 |
| R_s -fit (Ω) | 9.75 | 8.75 | 8.45 | 7.90 | 6.55 |
| R_s -data (Ω) | 9.14 | 8.51 | 8.16 | 7.82 | 6.60 |

The return loss is measured on the Agilent E8361C PNA. A coaxial short-open-load calibration was performed, which places the reference plane at the coaxial launcher. To bias the varactors, an HP 11612A bias tee was placed in series between the PNA and FSA.

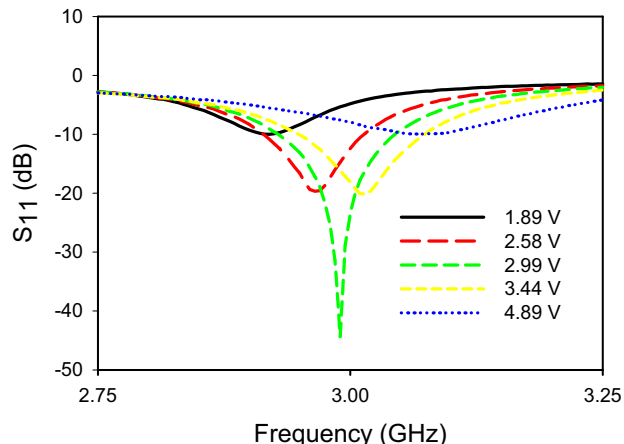


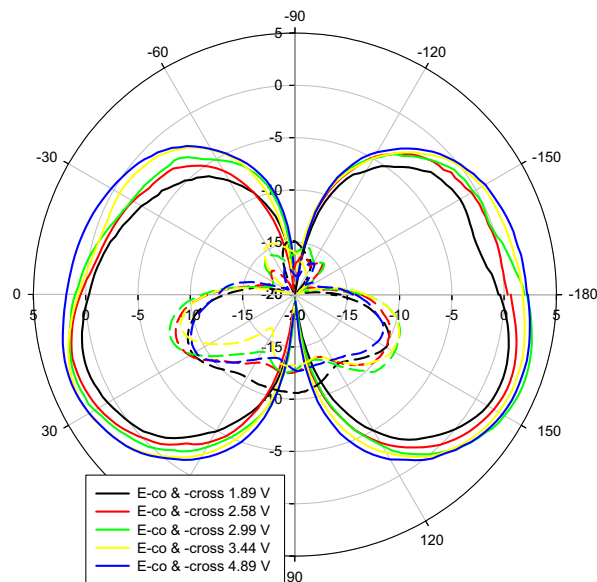
Figure 4: Measured return loss of the folded slot antenna as a function of varactor bias.

Figure 4 shows the measured return loss of the FSA as a function of the varactor bias voltage. Although the tuning of the resonant frequency varies over a greater frequency range as the bias voltage is increased further, the impedance match degrades. Therefore, the bias voltage range is limited to 1.89 V to 4.89 V, which results in a measured 10 dB return loss bandwidth from 2.92 to 3.07 GHz. Thus, the tuning range is 150 MHz, or a 5%. At the center frequency, the return loss is 44 dB. These results are summarized in Table 2.

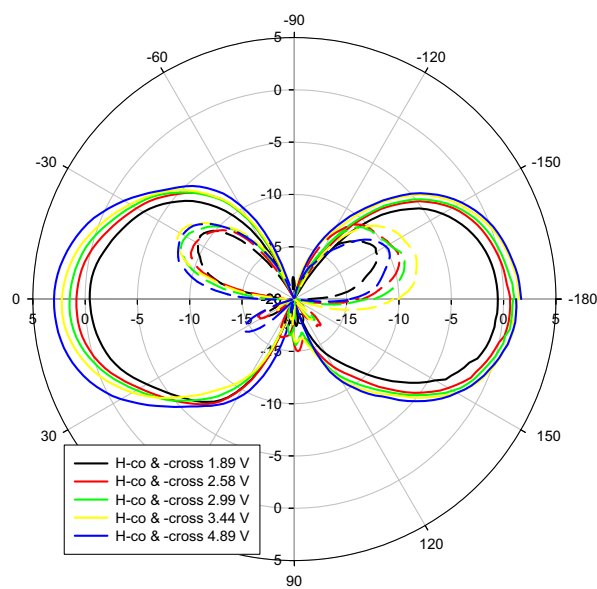
Table 2: Measured return loss as a function of varactor bias.

| Freq (GHz) | 2.92 | 2.96 | 2.99 | 3.01 | 3.07 |
|---------------|------|------|------|------|------|
| S_{11} (dB) | -10 | -20 | -45 | -20 | -10 |
| Bias (V) | 1.89 | 2.58 | 2.99 | 3.44 | 4.89 |

The radiation patterns were measured in an anechoic chamber. The far-field radiation pattern was recorded with the E8361C PNA and the gain was calculated using the substitution method. A 2 to 18 GHz wideband gain horn was used as the transmit antenna. The E- and H-co and -cross pol patterns are shown in Figs. 5a and 5b.



(a)



(b)

Figure 5: Measured (a) Eco- and E-cross and (b) Hco- and H-cross radiation patterns as a function of the varactor bias.

The measured radiation patterns show an increase in gain as a function of varactor bias and frequency, which is summarized in Table 3. Over the voltage range, the gain increases from -0.44 dB at 1.89 V to 2.97 dB at 4.89 V. This may be due to the 28% decrease in varactor series resistance (according to manufacturer data sheet) and because the antenna is electrically larger as the frequency is increased. The lumped varactor model was added to the

FSA and simulated with HFSS electromagnetic simulator while tuning the series resistance to match the measured antenna gain. These values are shown in Table 1 where it is seen that they agree with the manufacturer's values. Because the tuning range is small and the electrical size of the antenna does not vary much over 150 MHz, the series resistance is the major contributor to the variation in FSA gain, which agrees with observations in [10]. The E- and H-cross pol patterns are more than 10 dB down from the co pol maximums at all bias conditions and the shape of the radiation patterns is independent of the bias. Thus, the frequency tuning of the FSA only affects the antenna gain.

Table 3: Measured antenna gain.

| | | | | | |
|------------|-------|------|------|------|------|
| Freq (GHz) | 2.92 | 2.96 | 2.99 | 3.01 | 3.07 |
| Bias (V) | 1.89 | 2.58 | 2.99 | 3.44 | 4.89 |
| Gain (dBi) | -0.44 | 0.82 | 1.48 | 2.22 | 2.97 |

IV. CONCLUSION

A reduced size planar folded slot antenna with tuning capability has been presented. Varactor diodes are positioned across the radiating slots of the antenna to capacitively load the FSA, which results in a 30% reduction in size. The varactors are reverse biased over 1.89 to 4.89 V resulting in a tunability of over 150 MHz. The gain of the antenna improves from -0.44 to 2.97 as the reverse bias voltage increases from 1.89 to 4.89 V. It is shown that the variation in the varactor series resistance is the main reason for variations in the antenna gain as a function of bias and frequency. The antenna presented clearly operates very well and would be very useful if implemented in communication systems such as cellular, RFID and wireless sensor applications.

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