DEVELOPMENT OF A VARACTOR-CONTROLLED DUAL-FREQUENCY RECONFIGURABLE MICROSTRIP ANTENNA

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ABSTRACT: *A new design for a compact electronically reconfigurable single-feed dual-frequency dual-polarized operation of a square-microstrip antenna capable of achieving tunable frequency ratios in the range 1.1 to 1.37 is proposed and experimentally studied. Varactor diodes integrated with the arms of the hexagonal slot and embedded in the square patch are used to tune the operating frequencies by applying reverse-bias voltage. The design has the advantage of size reduction up to 73.21% and 49.86% for the two resonant frequencies, respectively, as compared to standard rectangular patches. The antenna offers good bandwidth of 5.74% and 5.36% for the two operating frequencies. A highly simplified tuning circuitry without any transmission lines adds to the compactness of the design.*
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Key words: *reconfigurable antenna; dual frequency; varactor diode; frequency tuning*

1. INTRODUCTION

Reconfigurable antennas have recently received significant attention due to their applications in communications, electronic surveillance, and electronic countermeasures, by adapting their properties to achieve selectivity in frequency, bandwidth, polarization, and gain. Compared to broadband antennas, reconfigurable antennas offer the advantages of compact size, similar radiation pattern for all designed frequency bands, efficient use of electromagnetic spectrum, and frequency selectivity, which is useful for reducing the adverse effects of co-site interference and jamming. Dual-frequency reconfigurable microstrip antennas can offer additional advantages of frequency reuse for doubling the system capability and polarization diversity in order to obtain good performance of reception and transmission or to integrate the receiving and trans-

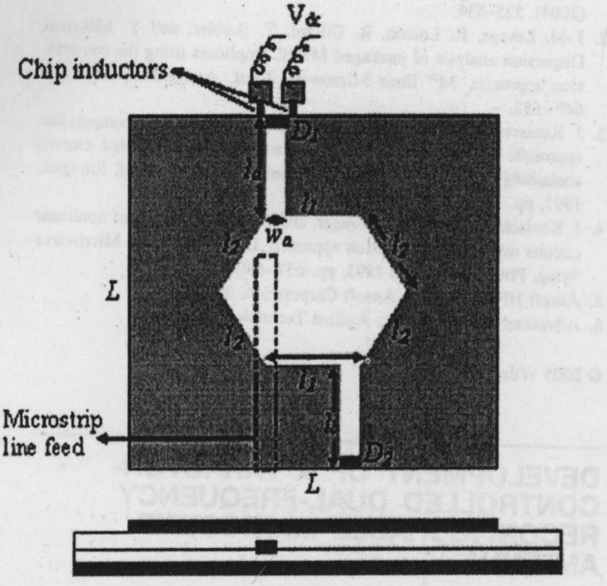

Figure 1 Reconfigurable dual-frequency microstrip antenna controlled by varactor diodes. (antenna parameters are given in Fig. 2)

mitting functions into one antenna for reducing the antenna size [1]. Electronic tuning of dual-frequency microstrip antennas to achieve desired frequency-ratio values has not been highly explored. The technique of electronically tuning a varactor-integrated dual-frequency coplanar strip dipole antenna was described in [2]. A pin-diode-controlled dual-frequency reconfigurable square-microstrip antenna with a hexagonal slot has recently been reported [3]. In this paper, we present novel designs of a compact single-feed reconfigurable dual-frequency square-microstrip antenna controlled by varactors, for achieving tunable-frequency ratios varying in the range 1.1 to 1.37. The proposed antenna can achieve a high tuning range of 24% for the first resonant frequency without significantly altering the second resonant frequency, with a single feed position. The design has the advantages of high area reductions of 73.21% and 49.86% for the two operating frequencies respectively, (as compared to standard rectangular patches) and high flexibility in frequency tuning. Another advantage of this design is that the antenna shows almost similar radiation patterns for the two operating frequencies in the entire tuning range, while hardly affecting the gain, which is highly desirable for frequency-reconfigurable antennas. A highly simplified biasing circuitry is designed, in which transmission lines in-between the nonlinear components and radiating element are avoided so that added noise and ohmic losses are suppressed and the resulting structure is more compact.

2. ANTENNA CONFIGURATION

The dual-slot arm-loaded reconfigurable antenna configuration is illustrated in Figure 1. A square-microstrip-patch antenna with side dimension L is fabricated on a substrate of thickness h and relative permittivity ε_r. A hexagonal slot of side parameters l_1 and l_2 with two slot arms of length l_a and l_b and width w_a, extending up to the edge of the square patch is placed at its center. Varactor diodes D_1 and D_2 are positioned at the extreme end of the slot arms in order to obtain maximum tuning range and better matching. The DC bias voltage is supplied from a battery, through two chip inductors across D_1. The antenna is electromagnetically coupled using a 50Ω microstrip line, as shown in Figure 1.

The fundamental resonant frequency of the conventional unslotted square patch is 1.885 GHz. By loading the hexagonal slot alone, the operating frequency can be lowered to 1.74 GHz, which results in greater area reduction. The upper and lower extended slot arms split the fundamental resonant frequency of the square microstrip patch with hexagonal slot alone, into two separate resonant modes, TM_{10} and TM_{01} with orthogonal polarization planes. Thus, the central hexagonal slot with the two slot arms considerably increases the effective lengths of the two excited resonant modes, TM_{10} and TM_{01}, and the excited patch surface-current densities are perturbed in such a way that these two modes can be excited for dual-frequency operation with a single feed. By varying the length of the upper and lower slot arms, the first resonant mode (TM_{10}) can be tuned without greatly affecting the second resonant mode, thus giving different frequency ratios. This concept can be used in the tuning of the first operating frequency by electronically varying the effective length of the two slot arms. Varactors embedded in the protruding slot arms provide various capacitive loadings across the slot arms in different reverse-bias conditions. The junction capacitance of the varactors varies against the reverse-bias voltage applied, and these different capacitive loadings correspond to different electrical lengths and thus different resonant frequencies.

3. EXPERIMENTAL RESULTS

Two different reconfigurable antenna configurations, one with a single upper-slot arm attached to the central hexagonal slot and the other with two slot arms are studied. It is found that the design with two slot arms can provide a much wider frequency-ratio tuning and higher area reduction, compared to the single-slot-arm design, without considerable reduction in gain.

The proposed reconfigurable antenna is tested using a HP 8510C Vector Network Analyzer. When the protruding slot arms are absent, the antenna shows a single resonant frequency at 1.74 GHz, which is much lower than the fundamental resonant frequency (1.884 GHz) of the unslotted square-patch antenna. When the reverse bias is off, the varactor loadings in the two slot arms correspond to high capacitance and thus lower resonant frequencies at 1.1875 and 1.6225 GHz with a frequency ratio 1.3663. The reconfigurable antenna was then electronically tuned with a re-

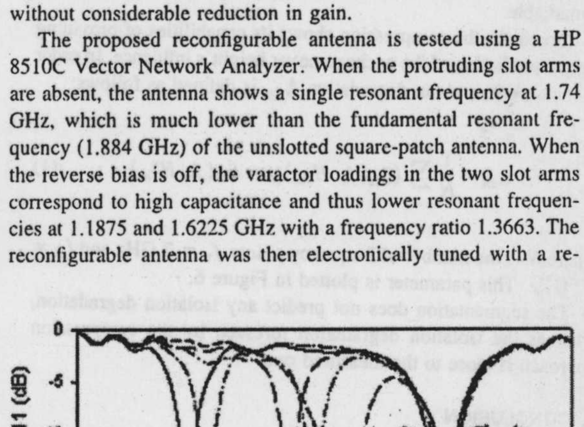

Figure 2 Measured reflection coefficient (S_{11}) of the antenna for different varactor reverse-bias voltages (L = 4 cm, $l_1 = l_2$ = 0.8 cm, $l_a = l_b$ = 1.1 cm, w_a = 0.1 cm, h = 0.16 cm, and ε_r = 3.98)

verse DC voltage applied across the diodes. When the bias voltage is varied from 0 to −29 V, the tuning range for the first resonant frequency is found to be 24% or 285 MHz upwards (from 1.1875 to 1.4725 GHz) and that of second resonant frequency is 0.9245% or 15 MHz upwards (from 1.6225 to 1.6375 GHz), as shown in Figure 2. At −29 V, the frequency ratio is found to be 1.1008. The variation of first and second resonant frequencies (f_1 and f_2) with the applied varactor reverse bias voltage is measured and plotted in Figure 3. On the other hand, the design with a single slot arm can provide only a tuning frequency range of 11.17% for the first resonant frequency and 1.6% for the second; therefore, the tunable-frequency ratio is 1.2663 to 1.3855.

The new design offers an area reduction of 73.21% for the first resonant frequency and 49.86% for the second, as compared to standard rectangular patches. The E- and H-plane radiation patterns are measured for different bias voltages. All the patterns show similar broadside-radiation characteristics with good cross-polarization levels, even when the operating frequencies are shifted greatly by applying reverse bias. Radiation patterns at 1.405 and 1.6375 GHz are shown in Figure 4.

Bandwidths up to 5.74% and 5.36% have been obtained for the two modes, respectively. The polarization planes of the two resonant frequencies are mutually orthogonal in the entire tuning range. The gain of the reconfigurable antenna is found to be 1.8- and 0.4-dB less for the first and second resonant frequencies, respectively, compared to a standard circular patch operating at the same frequencies.

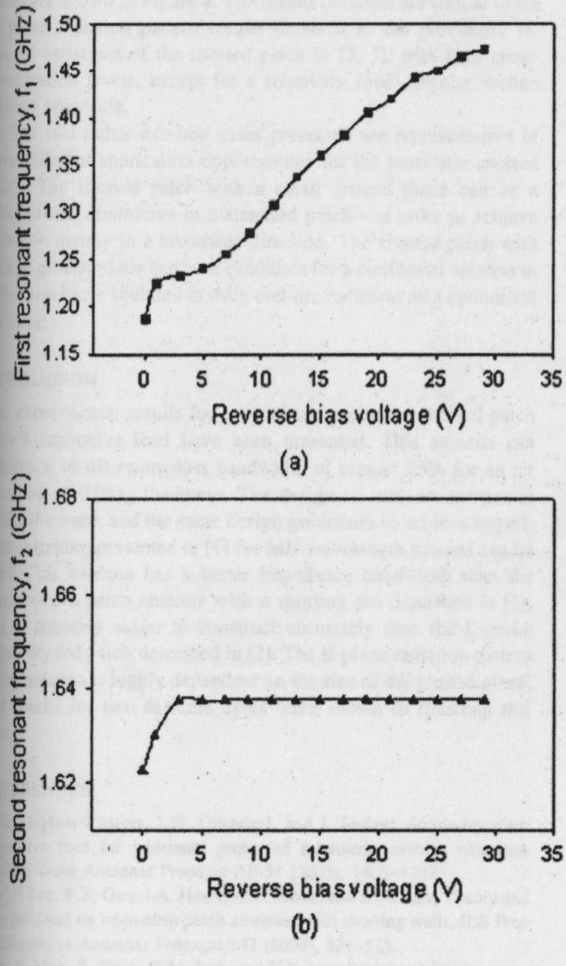

Figure 3 Variation of resonant frequencies with the varactors' reverse-bias voltage: (a) first resonant frequency f_1, (b) second resonant frequency f_2

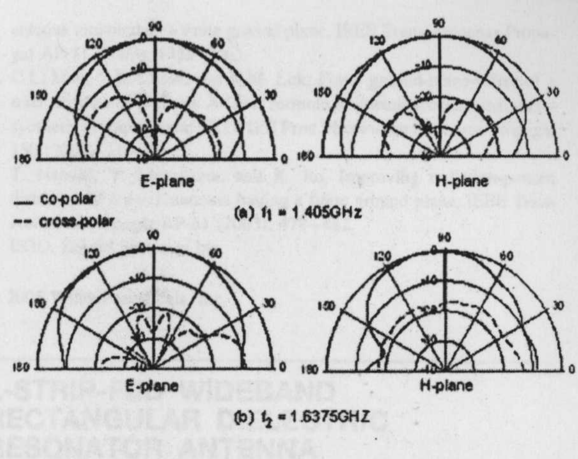

Figure 4 Measured E- and H-plane radiation patterns of the antenna at f_1 = 1.405 GHz and f_2 = 1.6375 GHz for V = −19 V

4. CONCLUSION

A compact, electronically reconfigurable, single-feed dual-frequency dual-polarized operation of a square-microstrip antenna controlled by varactor diodes has been reported. This design can achieve high tunable frequency ratios in the range 1.1 to 1.37. By controlling the reverse-bias voltage of varactor diodes integrated with the arms of the hexagonal slot, the operating frequencies can be tuned to the desired values without altering the radiation characteristics and gain. This design has the advantage of size reduction up to 73.21% and 49.86% for the two resonant frequencies, respectively, as compared to standard rectangular patches. The antenna offers good bandwidth of 5.74% and 5.36% for the two operating frequencies, respectively. A highly simplified tuning circuitry adds to the compactness of the design.

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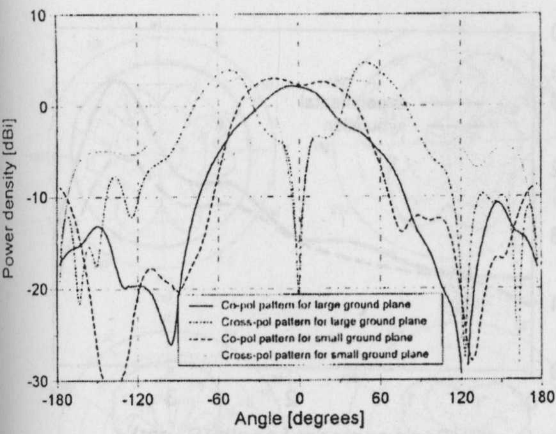

Figure 4 Measured H-plane radiation patterns

substantially lower—approximately 5-dB less than maximum gain.

The measured absolute H-plane radiation patterns for the two cases are shown in Figure 4. The results obtained are similar to the H-plane radiation pattern results obtained in the previously reported variations of the shorted patch in [2, 3], with high cross-polarization levels, except for a relatively small angular section around broadside.

The two rather extreme cases presented are representative of very different application opportunities for the particular shorted patch. The shorted patch with a small ground plane can be a reduced-size alternative to a standard patch—in order to achieve radiation mainly in a broadside direction. The shorted patch with a large ground plane can be a candidate for a conformal antenna in order to achieve squinted or even end-fire radiation on a cylindrical airframe.

CONCLUSION

The experimental results for a wideband probe-fed shorted patch with a capacitive feed have been presented. This antenna can achieve a 10-dB return-loss bandwidth of around 25% for an air substrate of $0.06\lambda_0$ thickness. The design of such an antenna is straightforward, and the same design guidelines to achieve impedance matching presented in [1] for half-wavelength patches can be used. This antenna has a better impedance bandwidth than the quarter-wave patch antenna with a shorting pin described in [3], and is arguably easier to construct accurately than the L-probe proximity fed patch described in [2]. The E-plane radiation pattern of the antenna is highly dependant on the size of the ground plane, and results for two extreme cases were shown to illustrate this effect.

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