Progress In Electromagnetics Research, PIER 60, 197–205, 2006

DESIGN OF COMPACT RECONFIGURABLE DUAL FREQUENCY MICROSTRIP ANTENNAS USING VARACTOR DIODES

S. V. Shynu, G. Augustin, C. K. Aanandan, P. Mohanan, and K. Vasudevan

Centre for Research in Electromagnetics and Antennas
Department of Electronics
Cochin University of Science and Technology
Kochi, 682 022, India

Abstract—The design of a compact, single feed, dual frequency dual polarized and electronically reconfigurable microstrip antenna is presented in this paper. A square patch loaded with a hexagonal slot having extended slot arms constitutes the fundamental structure of the antenna. The tuning of the two resonant frequencies is realized by varying the effective electrical length of the slot arms by embedding varactor diodes across the slots. A high tuning range of 34.43% (1.037–1.394 GHz) and 9.27% (1.359–1.485 GHz) is achieved for the two operating frequencies respectively, when the bias voltage is varied from 0 to −30 V. The salient feature of this design is that it uses no matching networks even though the resonant frequencies are tuned in a wide range with good matching below −10 dB. The antenna has an added advantage of size reduction up to 80.11% and 65.69% for the two operating frequencies compared to conventional rectangular patches.

1. INTRODUCTION

Reconfigurable antennas have recently received much attention for their applications in wireless communications, electronic surveillance and countermeasures, by adapting their properties to achieve selectivity in frequency, bandwidth, polarization and gain. Compared to broad band 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 useful for reducing the adverse effects of co-site interference and jamming [1]. Dual frequency reconfigurable microstrip antennas can offer additional advantages of frequency reuse for doubling the system capability and polarization diversity for good performance of reception and transmission or to integrate the receiving and transmitting functions into one antenna for reducing the antenna size [2]. Preliminary studies in reconfigurable microstrip antennas reported recently received great attention. A linearly polarized square spiral microstrip antenna capable of pattern and frequency reconfigurability is recently been introduced [3]. A reconfigurable microstrip patch antenna using switchable slots for right hand and left hand circular polarization diversity is also studied [4]. An interesting approach of electronic tuning of a varactor integrated dual frequency coplanar strip dipole antenna was studied, which provides an attractive feature of electronic control [5]. However, electronic tuning of microstrip patch antennas having dual frequency operation is not much explored. Design of matching networks and the placement of switches are crucial in these types of antennas. A pin diode controlled switching technique for reconfigurable dual frequency operation is recently been reported [6].

This paper presents novel compact designs of single feed, reconfigurable dual frequency square microstrip antennas capable of achieving high tuning ranges without using any matching networks. Hexagonal slot with extended arms embedded in a square patch are used to generate dual resonant frequencies. Varactor diodes integrated across the slot arms can tune the resonant frequencies considerably, when reverse bias is applied. The antenna offers 34.43% (1.037–1.394 GHz) tuning for first resonant frequency and 9.27% (1.359–1.485 GHz) for second, with good impedance match in the entire tuning range. The important aspect of this design is that it provides a high size reduction of 80.11% and 65.69% for the two operating frequencies respectively, compared to conventional rectangular patches. A greatly simplified biasing circuitry is designed, in which transmission lines are avoided in between the nonlinear components and radiating element, so that, added noise and ohmic losses are suppressed and the resulting structure is more compact. The radiation pattern, gain and polarization are essentially unaffected by the frequency tuning, which is highly desirable for frequency reconfigurable microstrip antennas.

2. ANTENNA CONFIGURATION

As the aim is to devise a reconfigurable dual-frequency microstrip antenna having high tuning ranges, with single feed, the original passive antenna design is vital. The design must ensure good matching below −10 dB for both resonant modes, even when the frequencies are shifted a great extend by applying the reverse DC voltage. The basic antenna configuration consists of a square microstrip patch with side dimension L, fabricated on a substrate of thickness h and relative permittivity ε_r. A hexagonal slot of side parameters l_1 and l_2 placed at its centre reduces the fundamental resonant frequency of the patch from 1.885 GHz to 1.74 GHz, giving enhanced size reduction. Dual frequency operation is realized by embedding a protruding slot arm of length la and width w_a, which splits the fundamental resonant frequency into two distinct 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 electrical length of the extended slot arm, the first resonant mode, TM_{10} can be tuned without much affecting the second resonant mode.

A standard 50Ω microstrip feed line is used to excite the two resonant modes, with good matching. In this passive antenna design, the 50Ω line is well matched for both the frequencies when it is essentially away from the protruding slot arm. This implies that the antenna input impedance is not very sensitive to small changes in the length of the extended slot arm. This remarkable property greatly simplifies the design of the reconfigurable antenna and its feeding network. This is also the reason that the proposed antenna never needs a matching network in the entire tuning range.

The second resonant mode TM_{01}, orthogonal to TM_{10}, is less affected by the length alteration in the vertical slot arm. Thus the electrical length variation of a horizontal slot arm of length l_b and width w_a introduced in the patch can effectively tune the second operating frequency. Figure 1 describes the reconfigurable microstrip antenna configuration with two extended slot arms. To implement electronic reconfigurability, varactor diodes are directly integrated across the slot arms and DC bias is applied through two chip inductors as shown in Figure 1. 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. The positions of the varactors are so selected to achieve maximum frequency tuning while less perturbing the antenna matching.

The concept described above is extended to a design with four

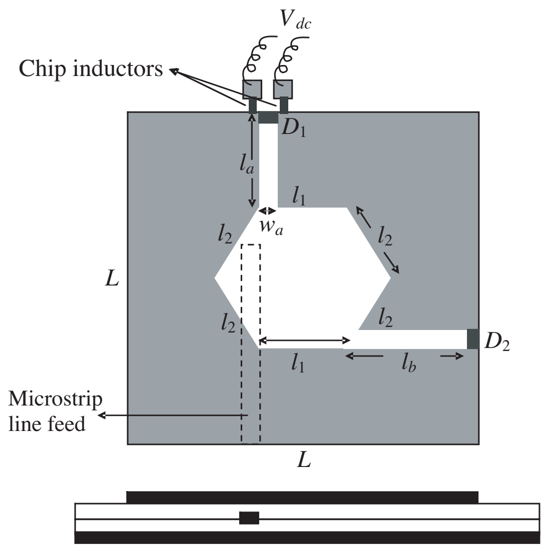

Figure 1. Reconfigurable dual frequency microstrip antenna configuration with two slot arms. ($L = 4\,\text{cm}$, $l_1 = l_2 = 0.8\,\text{cm}$, $l_a = 1.1\,\text{cm}$, $l_b = 1.5\,\text{cm}$, $w_a = 0.1\,\text{cm}$, $h = 0.16\,\text{cm}$ and $\varepsilon_r = 3.98$).

slot arms loaded with varactors (Figure 2). Experimental results reveal that, this new design provides improved frequency tuning range and size reduction compared to two slot arm design, without much reduction in gain.

3. EXPERIMENTAL RESULTS

The proposed reconfigurable antenna designs are 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, much lower than the fundamental resonant frequency (1.884 GHz) of the unslotted square patch antenna. In the case of the proposed design with four protruding slot arms (Figure 2), when the reverse bias is OFF, the varactor loadings in all the slot arms correspond to high capacitance and thus lower resonant frequencies at 1.037 GHz and 1.359 GHz with a frequency ratio 1.3105. The reconfigurable antenna was then electronically tuned with a reverse DC voltage applied across the diodes as demonstrated in Figure 2. When the bias voltage is varied from 0 to −30 V, the tuning range for the first resonant frequency is found to be 34.43% or 357 MHz upwards

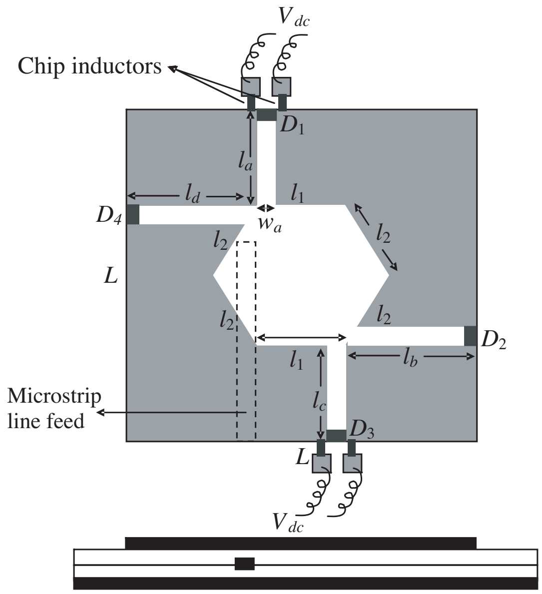

Figure 2. Four slot arm loaded reconfigurable dual frequency microstrip antenna controlled by varactor diodes. Antenna parameters are $L = 4$ cm, $l_1 = l_2 = 0.8$ cm, $l_a = l_c = 1.1$ cm, $l_b = l_d = 1.5$ cm, $w_a = 0.1$ cm, $h = 0.16$ cm and $\varepsilon_r = 3.98$.

(from 1.037 to 1.394 GHz) and that of second resonant frequency is 9.2715% or 126 MHz upwards (from 1.359 to 1.485 GHz) as shown in Figure 3. At −30 V the frequency ratio is found to be 1.0653. 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 4. Since the first resonant frequency is produced by perturbing the original patch current density of the TM_{01} mode, with a protruding slot arm, a change in length of the slot arms considerably affects the first resonant frequency (TM_{01}) than the second resonant frequency (TM_{10}). The second resonant frequency mainly depends on the original patch current density which is unperturbed by the inclusion of the vertical slots. The new design offers a maximum area reduction of 80.1053% for the first resonant frequency and 65.6912% for the second, compared to standard rectangular patches.

On the other hand, the design with two slot arms can provide only a tuning frequency range of 21.46% for the first resonant frequency and 4.49% for the second. The size reduction for this design is also less compared to four slot arm design; 73.8832% for the first

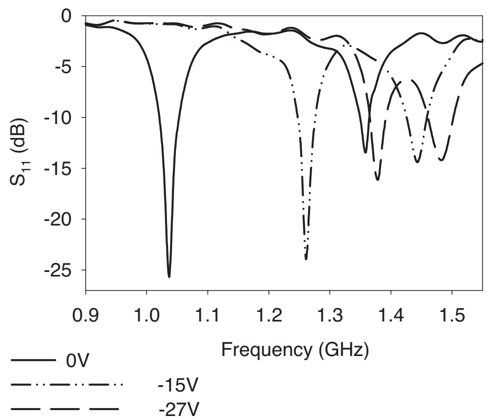

Figure 3. Measured return loss, (S_{11}) of the four slot arm antenna configuration for different varactor reverse bias voltages.

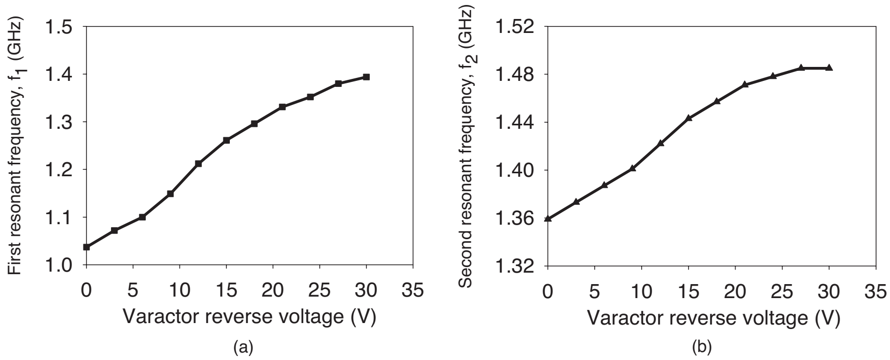

Figure 4. Variation of resonant frequencies for the four slot arm reconfigurable antenna design with varactors reverse voltage. (a) First resonant frequency, f_1 (b) Second resonant frequency, f_2.

resonant frequency and 57.0843% for the second, compared to standard rectangular patches. A comparison between the two and four slot arm antenna configurations is given in Table 1.

The E and H-plane radiation patterns for the two reconfigurable antenna configurations 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. Typical radiation patterns for the resonant frequencies of two and four slot arm design are given in

Table 1. Comparison between two and four slot arm reconfigurable antenna configurations.

No. of slot arms	Operating band, f_1 (GHz)	Operating band, f_2 (GHz)	% Tuning range for f_1	% Tuning range for f_2	% Area reduction for f_1	% Area reduction for f_2
Two	1.1745-1.4265	1.5030-1.5705	21.46	4.49	73.88	57.08
Four	1.0370-1.3940	1.3590-1.4850	34.43	9.27	80.11	65.69

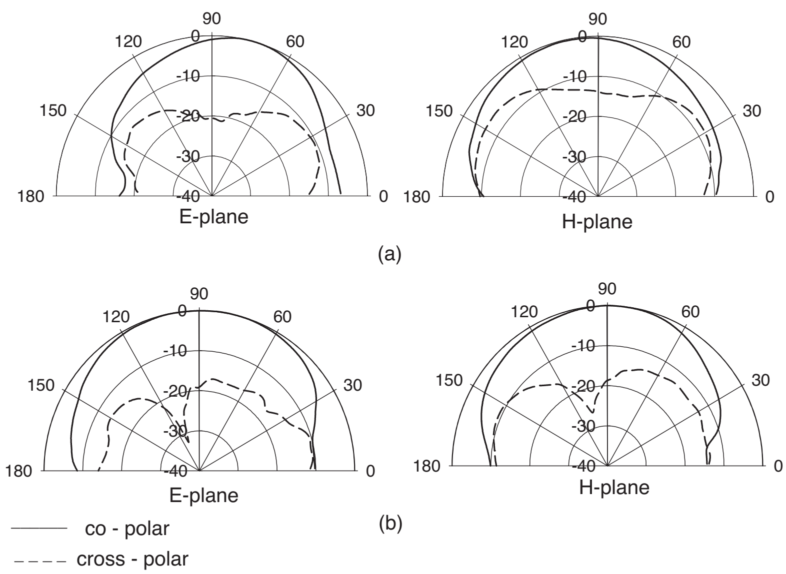

Figure 5. Measured E and H-plane radiation patterns of the proposed antenna designs. (a) Four slot arm ($f_1 = 1.331$ GHz at $V = -21$ volt). (b) Two slot arm ($f_2 = 1.35345$ GHz at $V = -12$ volt).

Figure 5.

Bandwidths up to 3.65% and 2.92% respectively, have been obtained in the two modes. The polarization planes of the two resonant frequencies are mutually orthogonal in the entire tuning range. The gain of the reconfigurable antenna with four slot arms is found to be nearly 2.1 dB and 1.2 dB less for the first and second resonant frequencies respectively, compared to standard square patch operating at the same frequencies.

4. CONCLUSION

A novel, single feed design of compact, electronically reconfigurable dual frequency microstrip antennas is proposed in this paper. The concept is based on the electronic tuning of embedded slots in the patch antenna using varactor diodes. A high tuning range of 34.43% (1.037–1.394 GHz) and 9.27% (1.359–1.485 GHz) is achieved for the two operating frequencies respectively, when the bias voltage is varied from 0 to -30 V. The salient feature of this design is that it uses no matching networks even though the resonant frequencies are tuned in a wide range with good matching below -10 dB. The antenna has an added advantage of size reduction up to 80.11% and 65.69% for the two operating frequencies compared to conventional rectangular patches. Another feature of this antenna is that the radiation characteristic is remaining essentially unaffected by the frequency tuning.

ACKNOWLEDGMENT

S. V. Shynu acknowledges support of this work by Kerala State Council for Science Technology and Environment, Government of Kerala, India, through STEC-JRF scheme.

REFERENCES

1. Peroulis, D., K. Sarabandi, and P. B. K. Katehi, "Design of reconfigurable slot antennas," *IEEE Transactions on Antennas and Propagation*, Vol. 53, 645–654, 2005.
2. Shynu, S. V., G. Augustin, C. K. Aanandan, P. Mohanan, and K. Vasudevan, "A reconfigurable dual frequency slot loaded microstrip antenna controlled by pin-diodes," *Microwave and Optical Technology Letters*, Vol. 44, 374–376, 2005.
3. Huff, G. H., F. S. Zhang, and J. T. Bernhard, "A novel radiation pattern and frequency reconfigurable single turn square spiral microstrip antenna," *IEEE Microwave and Wireless Components Letters*, Vol. 13, 57–59, 1998.
4. Yang, F. and Y. Rahmat-Samii, "A reconfigurable patch antenna using switchable slots for circular polarization diversity," *IEEE Microwave and Wireless Components Letters*, Vol. 12, 96–98, 2002.
5. Kolsrud, A. T., M. Y. Li, and K. Chang, "Dual-frequency electronically tunable CPW-fed CPS dipole antenna," *Electronics Letters*, Vol. 34, 609–611, 1998.

6. Shynu, S. V., G. Augustin, C. K. Aanandan, P. Mohanan, and K. Vasudevan, "A compact electronically reconfigurable dual frequency microstrip antenna for L-band applications," *International Journal on Wireless and Optical Communications*, Vol. 2, No. 2, 181–187, 2004.