A Switchable Microstrip Patch Antenna for Dual Frequency Operation

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ABSTRACT—A novel design for equilateral-triangular microstrip antennas with switchable resonant frequency is proposed. For dual-frequency operation, the proposed design is achieved by loading a pair of slits in the triangular patch, and two PIN diodes are utilized to switch the slits on or off. By increasing the length of the slits, the lower resonant frequency can be varied in the range from 1.22 GHz to 1.72 GHz whereas the upper resonant frequency remains unchanged.

Keywords—Switchable frequency, microstrip antenna, dual frequency, T-shaped slit.

I. Introduction

In satellite and wireless mobile communication systems applications, microstrip antennas have attracted much interest due to their low profile, light weight, and easy fabrication with monolithic circuits [1], [2]. However, one difficulty in the development of microstrip antennas is their much narrower bandwidth compared to that of ordinary microwave antennas. For this reason, there has been a great deal of research on ways to overcome the bandwidth problem of microstrip antennas in recent years. In applications in which increased bandwidth is needed for operation at two or more separate sub-bands, a valid alternative to the broadening of total bandwidth is the use of dual- or multi-frequency microstrip antennas [3]. Operation in two or more discrete bands with an arbitrary separation of bands is desired in many applications, such as synthetic aperture radar (SAR), Global Positioning System (GPS), wireless local area networks (WLANs), and so on.

The range of application of microstrip antennas and their performance can be considerably improved by suitably loading shorts, stubs, and slot loadings. A simple dual-resonance printed antenna based on a spiral-like shorted patch configuration with an additional shorting pin to generate the second resonance was presented in [4]. Dual-frequency operation of the microstrip antenna with a stub embedded in the patch [5] or a slot in the ground plane [6] was also reported. Recently, the dual-frequency design of a single-feed triangular microstrip antenna with a pair of slits was reported [7]. Based on a similar concept, this paper presents a novel approach to realize a dual-band equilateral-triangular microstrip antenna using a pair of slits. Here, two slits are cut into the triangular patch and two PIN diodes are positioned at the ends of the slits to control their status.

II. Antenna Structure

The structure of the proposed switchable microstrip antenna is shown in Fig. 1. The antenna is built on a 1.6 mm thick FR4 dielectric ($\varepsilon_r = 4.4$ and $\tan \delta = 0.02$). The triangular microstrip antenna is fed by a 50 Ω coaxial probe. Because the probe feed point is located at the center line of the patch, linear polarization operation can be achieved. The distance from the bottom of the triangular patch to the feed point is denoted by s. Simulations were carried out using IE3D, a commercial electromagnetic simulator by Zeland Software, Inc., based on an integral equation method and the method of moment. Figure 1 shows the switchable microstrip antenna with T-shaped slits. The dimensions of the slits are $L_1 \times W_1$. The narrow gap of the slits is denoted by W_2.

When reverse bias is applied, the PIN diodes show open impedance and this has little effect on the shape of T-shaped slits. This can be considered the off-state of the microstrip patch antenna. When both diodes are off, the T-shaped slits of the proposed antenna increase the length of the electrical current for a given area. The longer path is much longer than the

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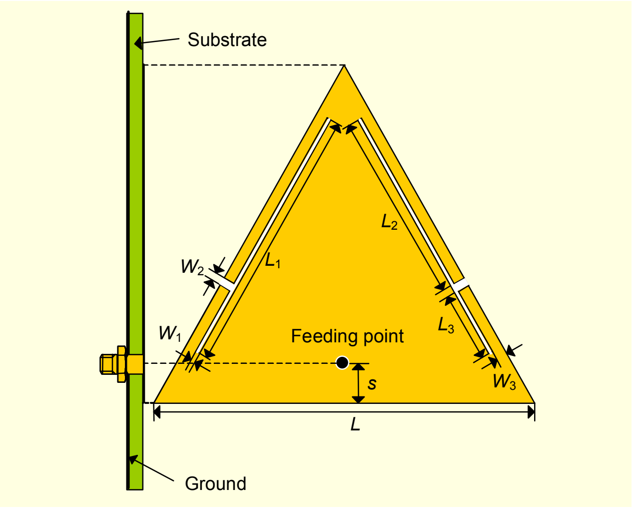

Fig. 1. Configuration of the switchable microstrip antenna with a pair of T-shaped slits (L_1=34.5 mm, W_1=1 mm, and W_2=1.5 mm).

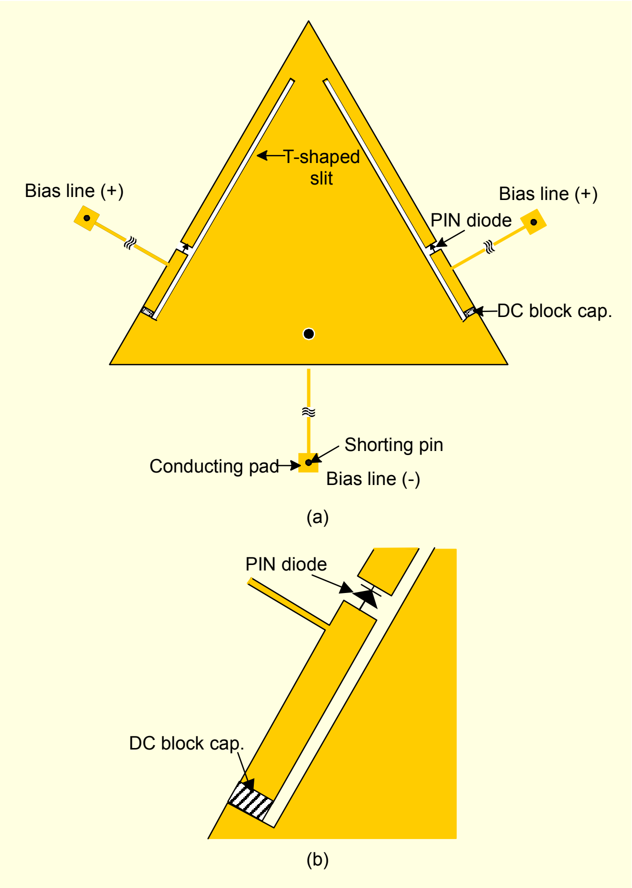

Fig. 2. (a) Proposed microstrip antenna with the bias line and (b) enlarged configuration of left side for switchable antenna.

equilateral-triangular patch, which greatly reduces the fundamental resonant frequency of the proposed antenna.

Once the diode is turned on, the resonant frequency shifts to 1.87 GHz. This can be considered the on-state of the microstrip patch antenna. When forward bias is applied, the PIN diodes show short impedance; therefore, the gaps in the front part are connected, and electric current flows through the diode. At this point, the T-shaped slits are transformed into I-shaped slits. Since the embedded I-shaped slits are oriented to be parallel to the patch edges and are expected to have very small effects on the performance of the TM_{10} mode, the upper resonant frequency remains unchanged. As previously mentioned, by varying the length of the slit, the lower resonant frequency of the proposed antenna is tunable in the range from about 1.2 GHz to 1.7 GHz. Therefore, various frequency ratios of the two resonant frequencies can be obtained.

Figure 2 shows the proposed switchable antenna with bias line. It is easy to implement a DC bias circuit because the slit gap is appropriate to insert a PIN diode, and the slits are located at the edge of the patch. The characteristics of the slits are changed depending on the on- or off-state of PIN diodes, and the triangular patch antenna has different characteristics in accordance with them. A bias current of 15 mA is supplied to the PIN diodes (HSMP-3894) using a constant-current circuit. For the RF-signal, the diode shows an ohmic resistance of 1.5 Ω in the forward state and a capacitance of 0.7 pF in the reverse-biased state. To isolate the DC bias circuit from RF signal, two 47 pF capacitors and high impedance lines are used as shown in Fig. 2. The width of the high impedance lines is 0.1 mm, which corresponds to 169 Ω. The length of the high impedance lines is set to a quarter wavelength at the lower resonant frequency.

III. Results and Discussion

Figure 3 shows the simulated and measured return loss for the two resonant frequencies of the proposed antenna, f_{off} and f_{on}. The side length d of the triangular patch is 50 mm, and the original resonant frequency of the antenna is 1.91 GHz. The proper position of the diode is confirmed by the simulation results. The dimensions of the slits are fixed to 34.5 mm × 1 mm. Other parameters of the proposed antenna are the following: L_2 = 24.5 mm, and L_3 = 9 mm. The gap W_2 is 1 mm, and distance s is 3 mm. When both diodes are off, the lower resonant frequency is 1.22 GHz. When the diodes are turned on, the resonant frequency shifts to 1.83 GHz. As can be seen from this graph, very good agreement between simulation and experiment is achieved, with an error in the predicted minimum return loss frequency of less than 2.0%. This small deviation is partially due to the diffracted field at the edge of the substrate, which is not considered in the simulation. A DC bias circuit is practically considered in the simulation as shown in Fig. 3. A short circuited $\lambda/4$ microstrip line is connected to

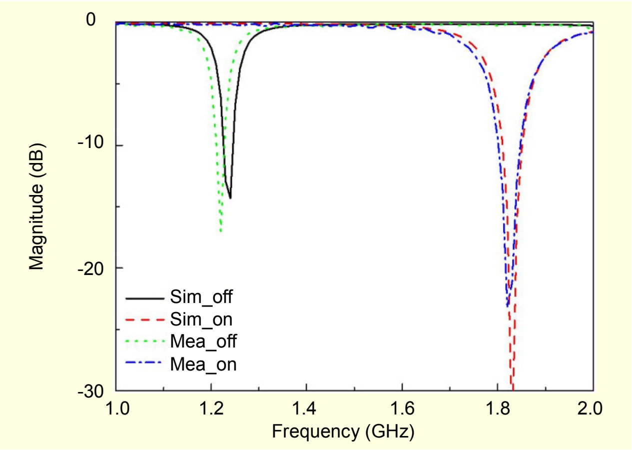

Fig. 3. Simulated and measured return loss of the proposed antenna.

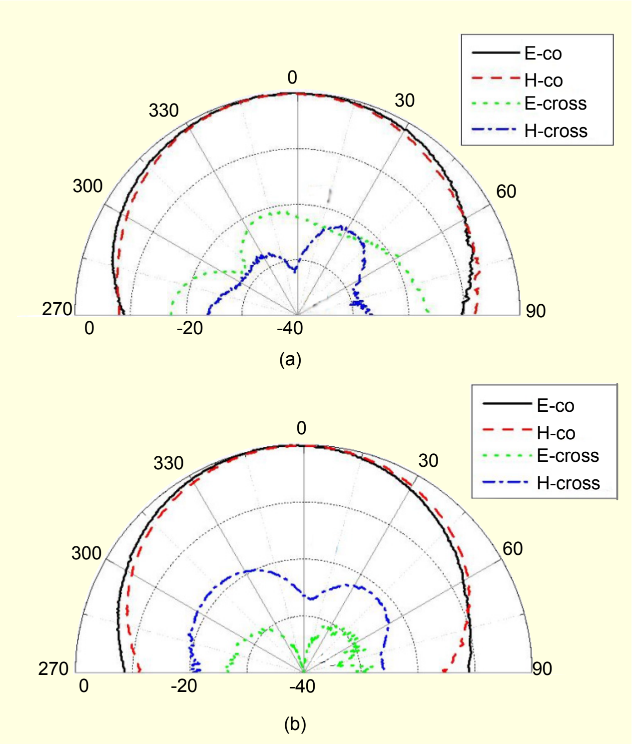

Fig. 4. Measured radiation patterns of the proposed antenna: (a) off-state (f=1.22 GHz) and (b) on-state (f=1.83 GHz).

the patch ground plane. With the use of T-shaped slits for the proposed antenna, the impedance bandwidths, which are determined from the 10 dB return loss, are about 1.6% and 2.2% for the two resonant frequencies. Many numerical simulations of the proposed antenna have been performed with T-shaped slits of various lengths. The feed point is insensitive to slit length variation. As previously mentioned, the lower resonant frequency is decreased when the slit length is increased; however, the higher resonant frequency remains unchanged. When the slit length is increased, the frequency ratio increases.

Measured radiation patterns at the resonant frequencies for four antennas are shown in Fig. 4. The electrical size of the ground plane is kept at about $1.2\lambda_0 \times 1.2\lambda_0$. The maximum gains of the proposed antenna are 1.3 dBi with the bias off and 3.4 dBi with the bias on. The measured results show that the proposed antenna has very similar stable co-polarized radiation pattern characteristics in both E- and H-planes. The cross-polarization levels in both E- and H-planes are better than 18 dB at the resonant frequencies. The radiation patterns are not affected by T-shaped slits for dual-frequency operation.

IV. Conclusion

A switchable microstrip triangular antenna has been demonstrated for dual-frequency applications. The resonant frequency of the microstrip antenna can be adjusted by setting the diodes on or off. The resonant frequencies of the proposed dual-frequency design are of the same polarization plane and have similar radiation characteristics. The frequency ratio of the proposed antenna can be tuned by varying the slit length. This design may be usefully applied to wireless communication.

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