Design of Frequency-Agile Microstrip Antennas with Conical-Beam Radiation

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1. Introduction

Microstrip antennas are attractive to wireless communication systems because they have the features of low profile and easy integration with microwave circuits. To provide more communication channels, wideband operation has become a basic requirement of the microstrip antennas. From the system point of view, the wideband microstrip antenna represents a resonant structure with a low quality factor (Q), and consequently numerous unwanted signals can enter receiver circuits along with the desired signal, leading to a worse signal-to-noise ratio. Frequency reconfigurable antenna is a possible candidate to improve the problem. In addition, the frequency reconfigurable antenna has other advantages over the wideband antenna, such as smaller size and more stable radiation pattern. Therefore, a great number of designs related to the reconfigurable microstrip antenna have been proposed in recent years [1]-[5]. For these designs, the frequency agility is achieved by introducing perturbation segments on the radiating patch to alter the resonant current path or by adding a loading into the feed structure to vary antenna input impedance. On the other hand, the radiation pattern of the reconfigurable microstrip antennas is related to the operating mode. Planar inverted-F mode [1], fundamental half-wavelength mode [2, 3], and monopolar patch mode [5] have been employed in the past designs, in which only the design described in [5] can generate uniform conical radiation that is required to the wireless mobile communication. However, the antenna in [5] operates at a monopolar patch mode and therefore it needs a sufficient substrate thickness; besides, a complex dc bias network is also required to separately control the state of each diode.

In this paper, a design method to frequency reconfigurable microstrip antenna is proposed. The frequency agility is realized by placing a tunable capacitor at the feed structure of the microstrip antenna operating at the TM_{01} mode. With the increasing of capacitance, the resonant frequency is decreased, and successive operating frequencies can be obtained. Details of the design concept are described and the obtained experimental results are also presented.

2. Antenna structure and analysis

Fig. 1 shows the geometry of the proposed antenna. A circular radiating patch with radius 18 mm is etched on a FR4 substrate of thickness 1.6 mm, relative permittivity 4.4, and loss tangent 0.02. The antenna is fed through a probe of radius 0.65 mm, and the feed point is located at the centre of the circular patch to excite the TM_{01} mode well. The probe is connected to one end of a transmission line, which is fabricated on anther FR4 substrate of thickness 0.8 mm, via a tunable capacitor or a varactor *C*. As a result, the capacitor can be regarded as a loading connected to the antenna in series. Provided that the microstrip antenna operating at the TM_{01} mode is equivalent to a series resonant circuit, the impedance at the point P can be expresses as

$$Z_P = R_P + jX_P = R_A + jX_A + \frac{1}{j\omega C} \qquad (1)$$

where R_A and X_A are the input resistance and reactance of the probe-fed microstrip antenna, respectively.For demonstrating the effect of the capacitor on Z_P, the input impedance of the probe-fed circular microstrip antenna without the capacitor was first simulated with the HFSS software. The results are exhibited in Fig. 2, and they clearly indicate that the antenna is resonant at 5 GHz, defined as the frequency with $X_A = 0$, and the corresponding R_A is about 6 Ω. In addition, it is also observed that while the frequency is varied from 5 to 6.2 GHz, X_A belongs to inductive reactance and its magnitude is increased linearly, but R_A nearly remains constant.

As the capacitor C is added, the inductive reactance at a specific frequency would be cancelled out, causing the resonant frequency to be changed. Fig. 2 presents the results when a capacitor of 1 pF is connected to the microstrip antenna as shown in Fig. 1. Obviously, the resonant frequency is moved to 5.4 GHz where the resonant resistance is about 5.6 Ω. It can be expected that the resonant frequency will be further increased when a lower capacitance is used. To match the resonant resistance to 50 Ω, an impedance transformer with the characteristic impedance of 17 Ω is required and the related dimensions are revealed in Fig. 1. The simulated impedance results including the impedance transformer, looking at point Q, is also given in Fig. 2. The resonant frequency is slightly moved to 5.3 GHz.

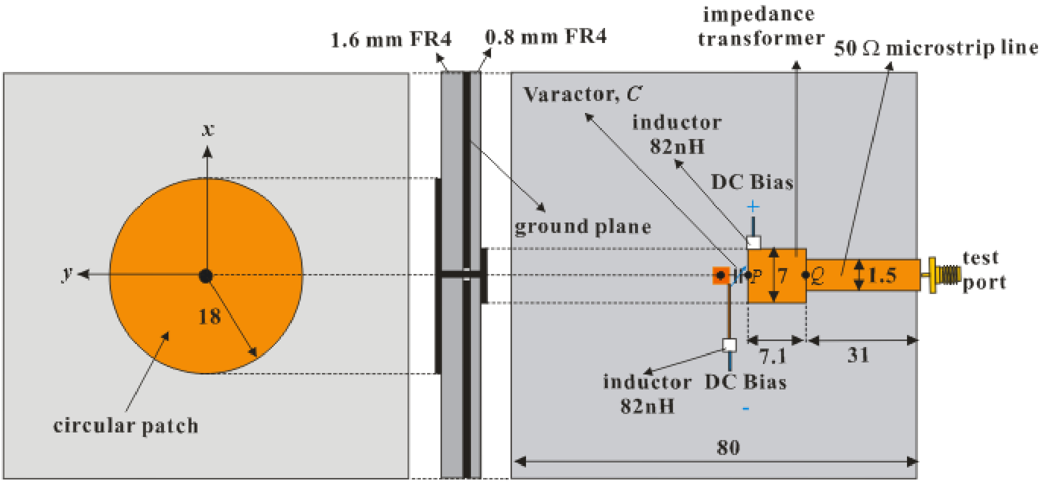


Figure 1: Geometry of the proposed microstrip antenna.

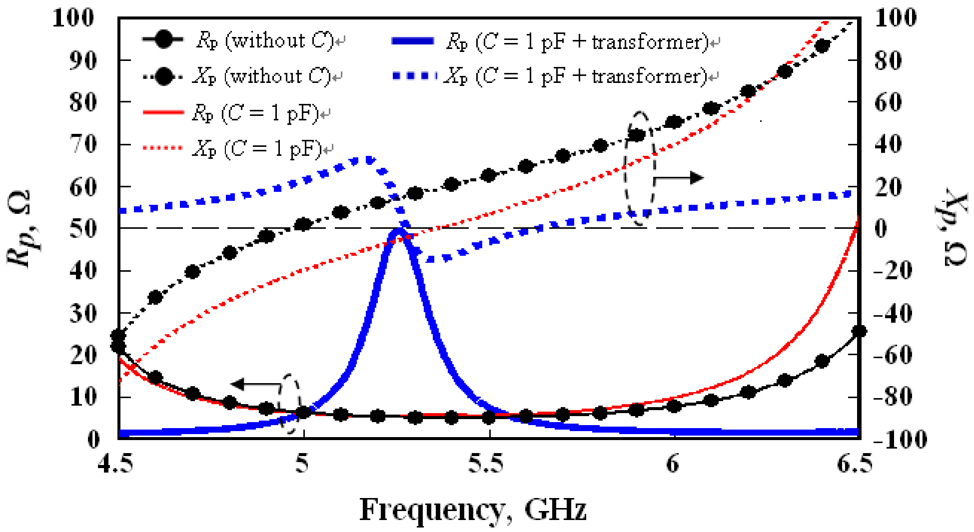


Figure 2: Simulated input impedance Z_P of the probe-fed microstrip antenna.

3. Experimental results

According the antenna dimensions in Fig. 1, at first several prototypes with different capacitance values C were fabricated and tested, then varactor was loaded and measured. Fig. 3 presents the variations of the measured resonant frequency and peak gain when C is increased from 0.25 to 5 pF. Note that these resonant frequencies are defined as the frequency with minimum return loss. From Fig. 3, it can be seen that with the increasing of capacitance value, both the resonant frequency and gain are apparently decreased, and they are respectively steady around 5 GHz and 1 dBi when C is larger than 2 pF. The frequency responses of return loss for the cases of C = 5, 1, 0.5, 0.25 pF are also shown in Fig. 4. Due to the limitation of the varactor diode(SKYWORKS SMV1231-079) values(0.466 pF to 2.35 pF), only 10.6 % tunable range could be obtained, and the measured return loss are shown in Fig. 5. All of them have good impedance matching with less than 10 dB return loss. In addition, the radiation patterns of each prototype were measured at their respective resonant frequency, and it is found that they have similar results. The results of the C = 5, 1, 0.25 pF cases are plotted in Fig. 6. Conical-beam radiation with θ-polarized is observed, and the corresponding peak gain of 0.5, 1.4, 2.5 dBi occurs at θ = 38°, 37°, 43°. The gain would be further increased if microwave laminates with a lower loss tangent are employed.

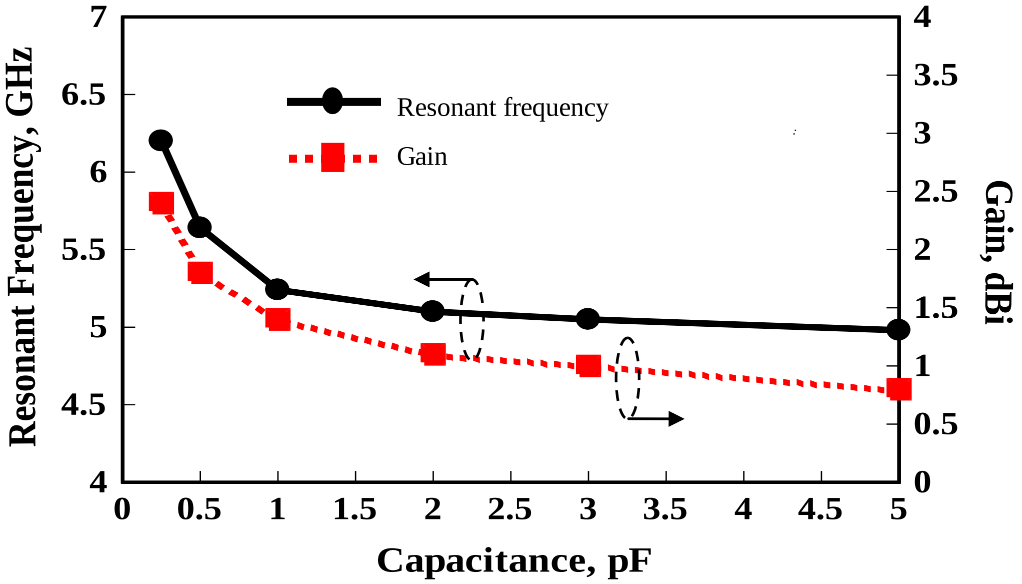


Figure 3: Variations of measured resonant frequency and gain against different capacitances.

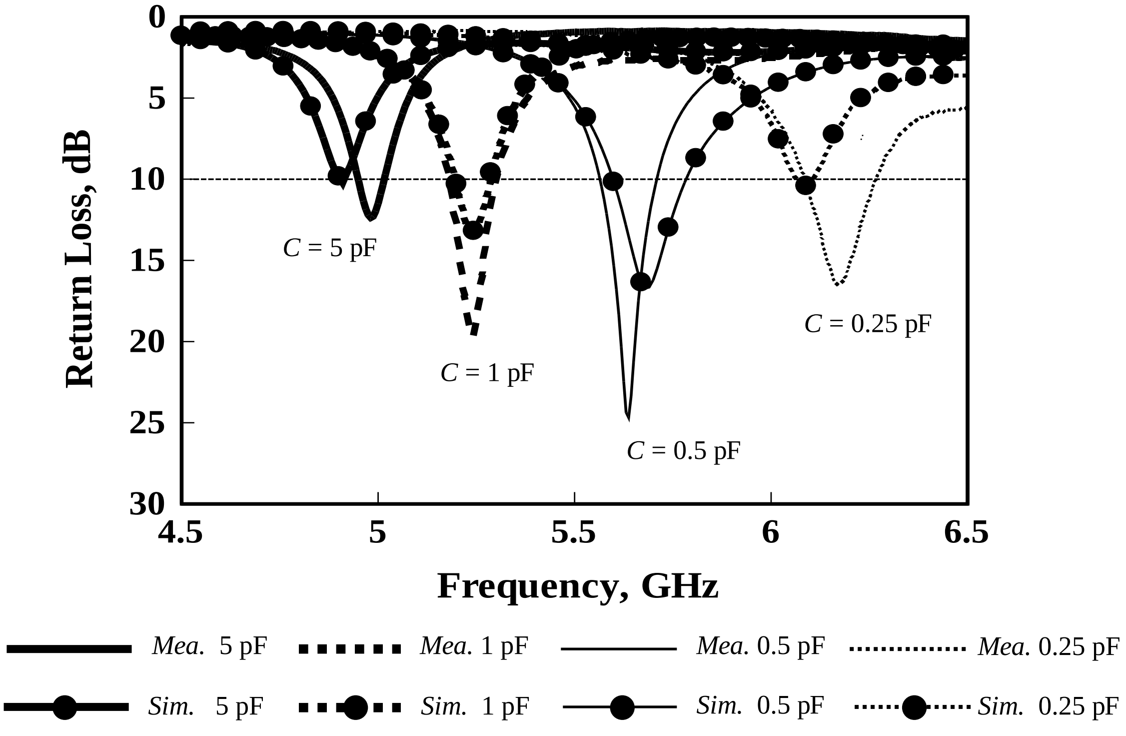


Figure 4: Measured and simulated return loss for the cases of C = 5, 1, 0.5, 0.25 pF.

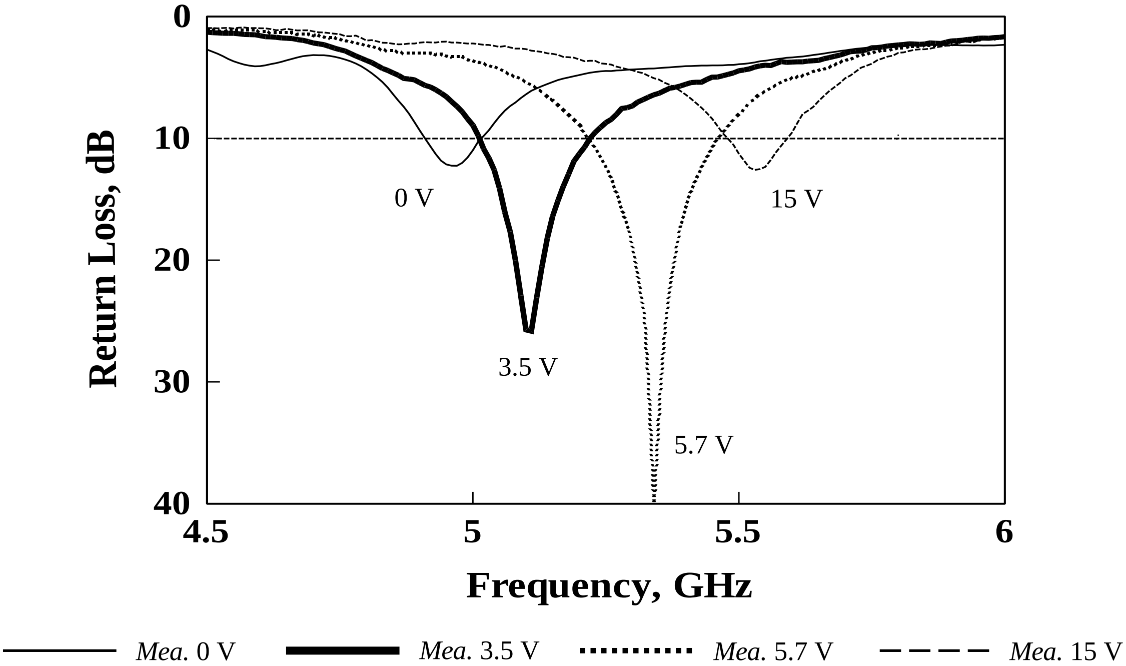
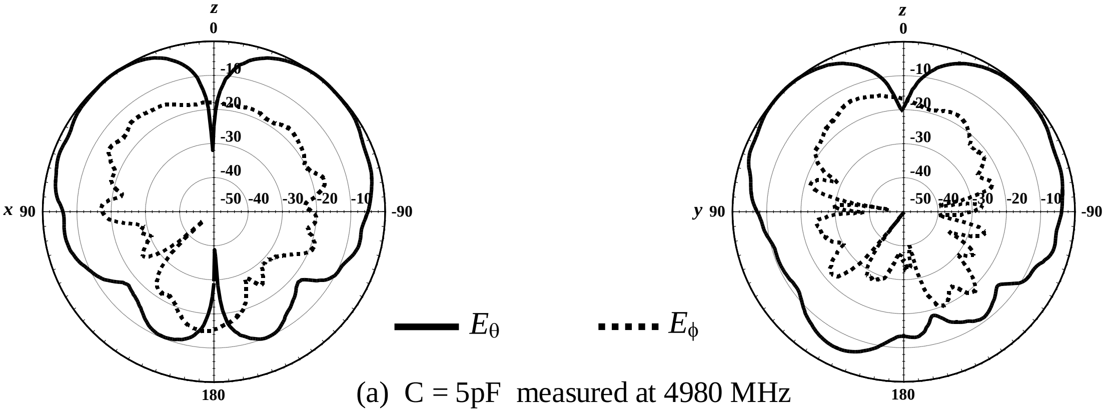
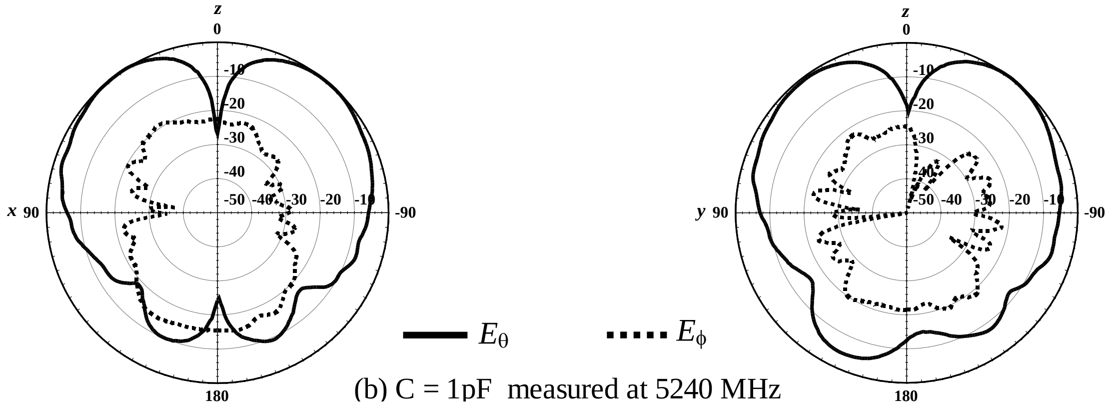


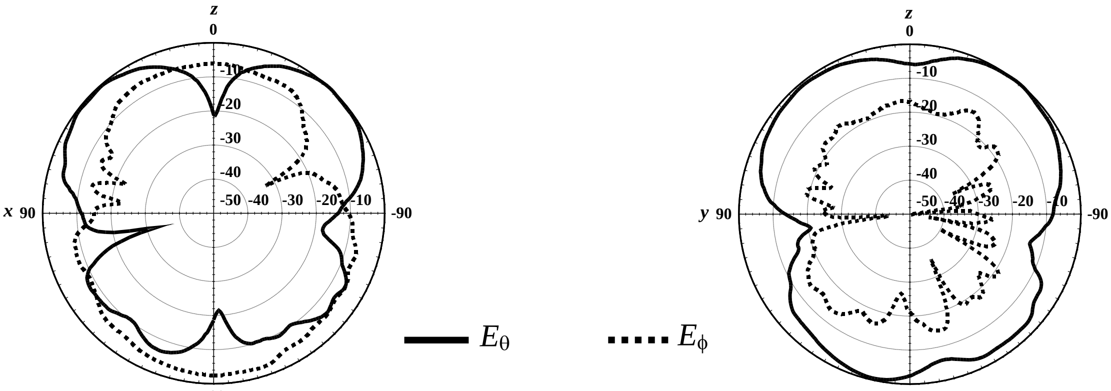
Figure 5: Measured return loss for varactor diode with bias from 0V(2.35 pF) to 15V(0.466 pF).



(a) C = 5pF measured at 4980 MHz



(b) C = 1pF measured at 5240 MHz



(c) C = 0.25pF measured at 6170 MHz

Figure 6: Radiation patterns of the C = 5pF、1 pF、0.25pF cases
(a) C=5pF (b) 1pF (C)C=0.25pF

4. Conclusions

A design method to a frequency tunable microstrip patch antenna has been presented, and a tunable range of 21 % is obtained experimentally. The frequency agility is achieved by introducing a loading capacitor into the feed structure of the microstrip antenna. The design can be applied to the frequency reconfigurable antenna if the varactor diode values is wide enough, and the required dc bias network will be rather simple. Moreover, the features of low profile and omnidirectional radiation make the antenna suitable for some applications of mobile communications.

References

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