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Miniaturized Microstrip Patch Antenna with Spiral Defected Microstrip Structure

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Abstract—Use of discontinuities in microstrip lines is currently employed to improve the performance of different passive circuits, including size reduction of amplifiers, enhancement of filter characteristics and applications to suppress harmonics in patch antennas. This paper presents an improved method of size reduction of a microstrip antenna using Defected Microstrip Structure (DMS) that it is used to perform serious LC resonance property in certain frequency. The DMS is integrated in antenna structure, and therefore this method keeps the antenna size unchanged and makes a resonance frequency. This resonance is due to the abrupt change of current path of antenna that resonates at 5.8 GHz which is shifted to 2.69 GHz thanks to spiral DMS. A prototype of the antenna was fabricated with an FR4 substrate and tested.

1. INTRODUCTION

In recent years there is a need for more compact antennas due to rapid decrease in size of personal communication devices. As communication devices become smaller due to greater integration of electronics, antenna becomes a significantly larger part of the overall package volume. This results in a demand for similar reductions in antenna size. In addition to this, low profile antenna designs are also important for fixed wireless application. Therefore, the microstrip antennas are used in a wide range of applications from communication systems to satellite and biomedical applications [1].

A Microstrip Patch Antenna is a low profile antenna that has a number of advantages over other antennas. It is lightweight, inexpensive, and easy to integrate with accompanying electronics [2].

With the rapid development in wireless communications, much effort has been devoted to reduce the size of microstrip antennas. In this way, several methods have been proposed recently [3], such as using a dielectric substrate of high permittivity [4], Defected Microstrip Structure (DMS) [5], Defected Ground Structure (DGS) at the ground plane [6, 8] or a combination of them.

DMS is more easily integrated with other microwave circuits and has an effectively reduced circuit size, compared with DGS. Simultaneously, DMS exhibits the properties of slow-wave, rejecting microwaves at certain frequencies and has an increasing electric length in certain circuits, which are similar to the well known DGS, but without affecting any of the ground plane [7]. Moreover, DMS has been widely used in the development of miniaturized antennas.

Mainly, DMS is made by etching slots in the microstrip line, so the enclosure problems need not be considered because there is no leakage through the ground plane. DMS are used to enhance the behavior of different planar passive circuit and perform a serious LC resonance property in certain frequency and suppress the spurious signals [7]. Accordingly, DMS increases the electric length of microstrip line and disturbs it current distribution, and the effective capacitance and inductance of a microstrip line increase [8].

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In other words, introducing DMS in a microstrip antenna can result in an increase of the effective capacitance and inductance [9], which influences the input impedance and current flow of the antenna [10, 11] and thus, reducing it size with respect to a given resonance frequency.

In this paper we use DMS to design a miniaturized microstrip antenna, as compared with a conventional one, resonating at 2.69 GHz. Initially, the proposed antenna resonates at 5.8 GHz, and then DMS is employed to shift the resonance frequency to 2.69 GHz. Finally, a comparison between our DMS microstrip antenna and the conventional one, at 2.69 GHz, is carried out.

2. MICROSTRIP PATCH ANTENNA RESONATING AT 5.8 GHz

The proposed microstrip patch antenna is shown in Figure 1. For improved adaptation, we use the quarter-wave impedance transformer. In this design the substrate FR4 is used due to its low cost and easy fabrication. The substrate height is 1.6 mm, the dielectric constant is 4.4 and the loss tangent is 0.021. The dimensions of our antenna are optimized by using CST Microwave Studio tool.

The simulated return loss obtained for this antenna is shown in Figure 2. We can see that the adaptation is better than 10 dB in a frequency band of about 100 MHz, and the resonance frequency is around 5.8 GHz.

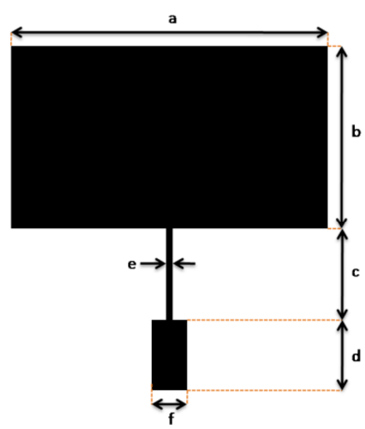

Figure 1. Top view of our patch antenna resonating at 5.8 GHz, ($a = 14$ mm, $b = 9.3$ mm, $c = 7$ mm, $d = 5.3$ mm, $e = 0.4$ mm, $f = 3$ mm).

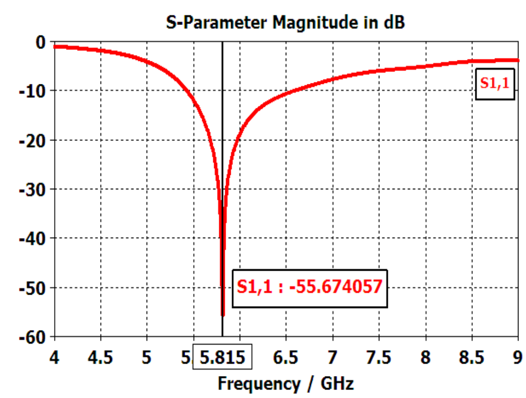

Figure 2. Simulated return loss of the patch antenna resonating at 5.8 GHz.

3. DEFECTED MICROSTRIP STRUCTURE

Many techniques have been used to reduce the size of antenna, such as using dielectric substrates with high permittivity [12], applying resistive or reactive loading [13], utilizing strategically positioned notches on the patch antenna [14], or increasing the electrical length of antenna by optimizing its shape [15], namely, electromagnetic bandgap (EBG) structures [16, 17], DGS and DMS [18, 19], because of their interesting properties of miniature size, suppression of surface waves and arbitrary stopbands.

DGS disturbs current distribution on ground plane. This turbulence creates some resonators which will be added to main structure [18]. DGS can be used for size reduction which is studied in [8], harmonic suppression and etc. [19, 20]. But the radiation from the ground plane is the major constraint to design a DGS based circuit. However, DMS provides the same slow wave characteristics, keeping ground plane intact [21]. Thus, DMS is a defect process which adds defects to planar strips and it has no unwanted radiation from its ground in comparison to DGS.

Therefore, the DMS increases the electrical length of the microstrip line and disturbs the current distribution across the patch. Then, the effective capacitance and inductance of the microstrip line increase, and accordingly, a microstrip patch antenna with DMS has slow wave characteristics which lead to reduction of antenna size [22].

The Slow Wave Factor (SWF) is the relationship between the wave number in free space, k_0, and the propagation constant, β, of the transmission line. For loss less microstrip line, the SWF is determined by (1):

$$\mathrm{SWF} = \sqrt{\varepsilon_e} \tag{1}$$

with,

$$\varepsilon_e = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{w}\right]^{-1/2} \tag{2}$$

where ε_e is the effective dielectric constant of the microstrip antenna, ε_r the dielectric constant, h the thickness of substrate, and w the width of rectangular patch.

And the propagation constant is determined by (3):

$$\beta = \sqrt{\varepsilon_e} \cdot k_0 \tag{3}$$

where k_0 is the wave number in free space.

The SWF of a microstrip line is raised when a discontinuity is introduced in the path of the electromagnetic wave, increasing the impedance of the line.

Thus (4),

$$\mathrm{SWF} = \frac{\beta}{k_0} \tag{4}$$

The use of DMS allows an increase in the slow wave factor (SWF) in transmission line in which they are introduced. This phenomenon can be used to reduce the size of passive planar circuits like microstrip line lengths, coupling lines and microstrip antennas [23].

The defect in microstrip line creates resonance characteristics in the frequency response. Therefore, similarly to DGS, each DMS can be modeled by LC resonator [24, 25] as shown in Figure 3. The theory was studied in detail in [8].

As shown in Figure 4, the spiral structure is introduced in the ground plane of the transmission line. Therefore, we simulated the transmission line with our structure of spiral DMS but as defected Ground Structure due to it size compared with the width of the transmission line.

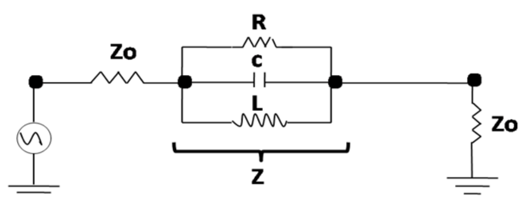

Figure 3. Equivalent circuit of Defected Microstrip Structure.

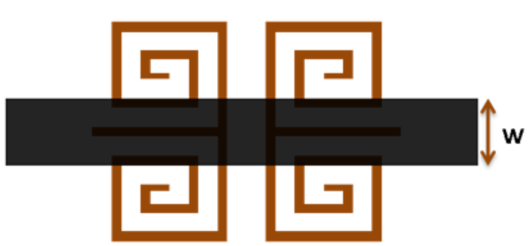

Figure 4. Transmission line with spiral structure ($w = 3$ mm).

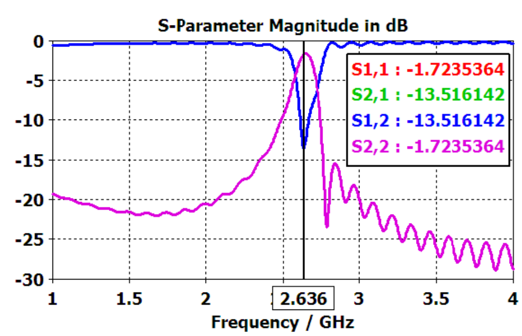

Figure 5. *S*-parameter magnitude of the spiral structure resonating at 2.63 GHz.

The s-parameter obtained for our structure is shown in Figure 5. We can see that the resonant frequency of the spiral is 2.63 GHz, and the cutoff frequency is 2.56 GHz.

In order to compute the equivalent circuit parameters (R, L, and C), we use the following Expressions (5), (6) and (7) [8]:

$$C = \frac{\omega_c}{2Z_0\left(\omega_0^2 - \omega_c^2\right)} \tag{5}$$

$$L = \frac{2Z_0\left(\omega_0^2 - \omega_c^2\right)}{\omega_c \omega_0^2} \tag{6}$$

$$R = \frac{2Z_0\left(1 - S_{21|\omega=\omega_0}\right)}{S_{21|\omega=\omega_0}} \tag{7}$$

where ω_c is the cutoff angular frequency, ω_0 is the resonance angular frequency of the spiral DMS and Z_0 is the characteristic impedance of the line.

In Table 1 we have the value of the DMS equivalent circuit parameters.

Table 1. Values of the DMS equivalent circuit parameters.

Parameters	Values of parameters
R (Ω)	100.4
L (nH)	0.324
C (pF)	0.113

4. MICROSTRIP PATCH ANTENNA WITH DMS

Now, as shown in Figure 6, we introduce the spiral structure as DMS in order to shift the resonance frequency of the microstrip antenna previously presented in Figure 1. We introduce DMS geometry and study its effect on the antenna properties, specially the resonance frequency. The simulations have been carried out by CST Microwave Studio.

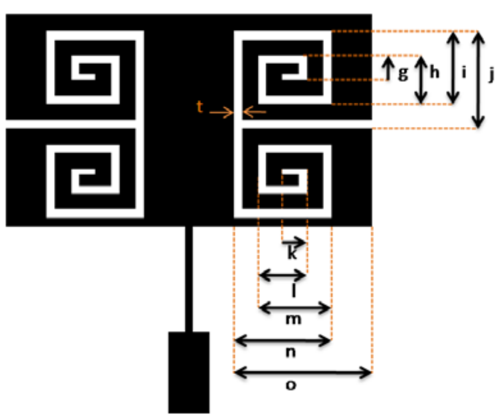

Figure 6. Microstrip patch antenna with Defected Microstrip Structure ($g = 1.1$ mm, $h = 2$ mm, $i = 2.9$ mm, $j = 3.8$ mm, $k = 1$ mm, $l = 1.7$ mm, $m = 3.2$ mm, $n = 4.7$ mm, $o = 53$ mm and $t = 0.2$ mm).

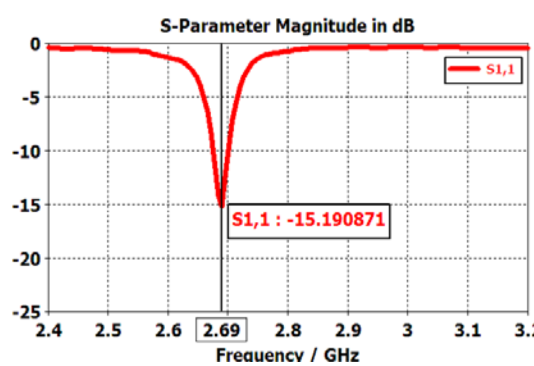

Figure 7. Simulated return loss of the patch antenna with DMS resonating approximately at 2.69 GHz.

In absence of DMS, we have seen in Section 2 that the resonance frequency of our microstrip patch antenna is at 5.8 GHz. Now with our spiral DMS introduced, the simulation result obtained for the return loss is shown in Figure 7. It is observed that the resonant frequency is shifted from 5.8 GHz to 2.69 GHz.

Spiral DMS presents a greater slow wave effect, since it has more discontinuities, providing a longer trajectory to the electromagnetic wave. In this way, we can say that we have obtained very acceptable result with simulation. Namely, we have designed a microstrip patch antenna with DMS resonating at 2.69 GHz. Next we present our antenna fabrication and compare simulation with measurement results.

5. FABRICATION AND MEASUREMENT

The designed antenna structure is fabricated and tested in the lab, and the practical results are found to be well consistent with the simulated ones. Shown in Figure 8 is the size of the fabricated DMS microstrip antenna that operates at 2.69 GHz. In order to measure the scattering parameters of the proposed antenna, we have employing a Rohde and Schwarz ZVB 20 vector network analyzer, whose frequency range is limited to 20 GHz.

Thus, the S_{11} parameter was measured and compared to the simulated results. Figure 9 shows the comparison between measurement and simulation results of the microstrip patch antenna with DMS. As can be seen, the measured results agree well with the simulated ones, but some discrepancies have occurred, due to the fabrication inaccuracy and conditions of measurement.

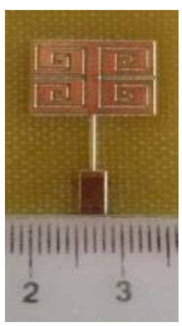

Figure 8. Prototype of DMS microstrip antenna, (a) top view.

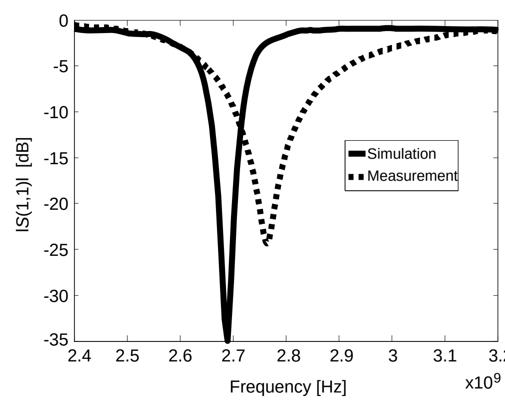

Figure 9. Measurement and simulation results for the antenna with DMS (resonating at 2.69 GHz).

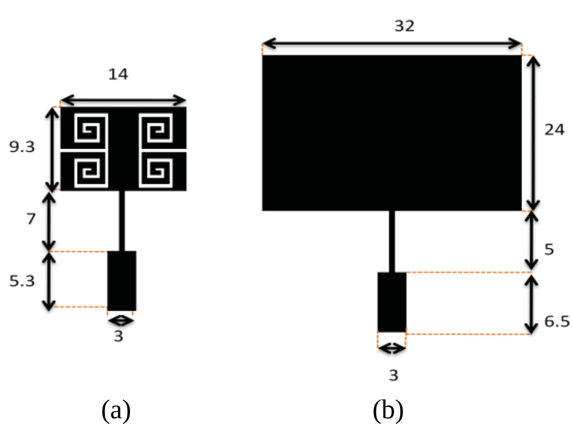

Figure 10. Top view dimensions (mm) for the 2.69 GHz antennas, (a) antenna with DMS, (b) conventional antenna.

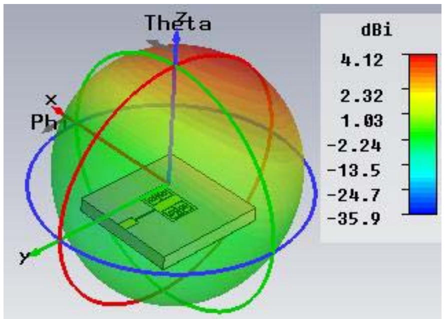

Figure 11. Radiation pattern for the DMS antenna.

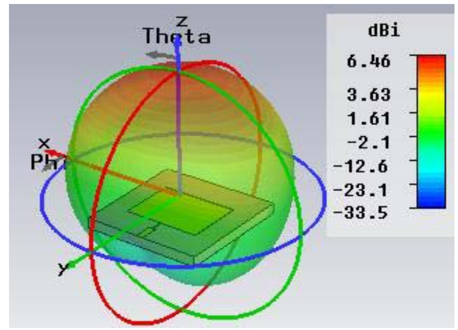

Figure 12. Radiation pattern for the conventional antenna.

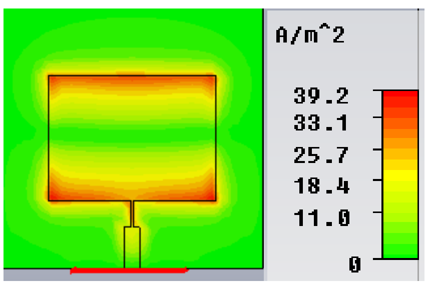

Figure 13. The current distribution of conventional antenna at 2.69 GHz.

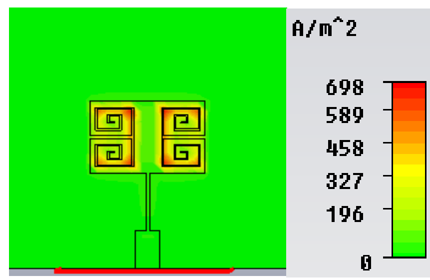

Figure 14. The current distribution of DMS patch antenna at 2.69 GHz.

6. COMPARISON BETWEEN CONVENTIONAL ANTENNA AND ANTENNA WITH DMS AT 2.69 GHz

6.1. Size Comparison

Figure 10 shows a size comparison between a conventional microstrip antenna and the antenna that we have previously designed using DMS, and both resonating at 2.69 GHz. We can see that the patch size, as compared with the conventional one, is reduced by 78%.

6.2. Radiation Pattern

From Figures 11 and 12 we can see that the simulated gain for the conventional antenna is 6.46 dBi, and for the DMS antenna the simulated gain is 4.12 dBi, which is a very important gain compared with the conventional antenna. In fact, one of the problems in microstrip antenna applications is to reduce the size while keeping good performance.

6.3. Current Distribution

Figures 13 and 14 show the current distribution of patch antenna without and with DMS respectively at 2.69 GHz. It can be seen that in conventional antenna, a large surface current was observed over the coins of the patch and along the microstrip line (Figure 13). However, the current was more concentrated along the DMS (Figure 14) of the patch antenna. The DMS disturbs the current distribution of the patch antenna, resulting in a controlled excitation and propagation of the electromagnetic waves and changes the resonance peak to a lower one.

7. CONCLUSION

By inserting our spiral DMS on the antenna, surface current path is meandered, and hence the electrical length of antenna is increased. So by increasing the electrical length of the antenna, the resonance frequency is decreased. This means that for an antenna with the same resonance frequency, the overall surface is decreased to a great amount. In our case, a reduction about 78% is achieved in antenna size. Thus, this antenna can be used in applications where the overall volume of the structure is an important factor, such as mobile terminals, etc.

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