A 2.45 GHz microstrip antenna with harmonics suppression capability by using defected ground structure

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ABSTRACT

In this work, a microstrip patch antenna with an inset feed and defected ground structure (DGS) is designed at the resonant frequency of 2.45 GHz. The antenna is designed on a FR-4 substrate with a dielectric constant, εr of 4.5, loss tangent, tan δ of 0.019 and thickness, h of 1.6 mm. The technique of DGS is used to avoid the use of additional circuits in the antenna to suppress the harmonics. By introducing a single and additional slots DGS at both ends on the antenna ground plane, the proposed microstrip patch antenna is able to suppress the higher order harmonics. The reflection coefficient, S11 is -38.75 dB at 2.45 GHz. The proposed antenna have suppressed the higher order harmonics effectively from -38.04 dB to -2.61 dB at 4.54 GHz and from -13.08 dB to -1.38 dB at 5.76 GHz. The prototype of the antenna is fabricated for the verification of the design. The simulated and measured results are found to be in a good agreement.

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1. INTRODUCTION

The growth of wireless devices has been observed during the last decade. Energy that is delivered via free space does not required any physical transmission networks. However, the application of this system requires electrical signals to reach large distance from the antenna to radiate electromagnetic waves through free space. The best condition of transmitting antenna is when it produces power density that is detectable at great distance from the source [1]. However, the existence of electromagnetic interference that is caused by harmonic radiation is the main issue in microwave system. The procedure of the antenna arrangement is presupposed to be effective and the losses of energy should be reduced by suppressing the unwanted harmonics signal. The unwanted harmonics signal or noise radiated through antenna is generated by the power amplifier that produces higher order harmonics in the system [2]. Generally, the harmonic signals are inhibited by the circuit of harmonic filter which is connected to the antenna and the connection must be perfectly fitted so that the maximum power can be shifted between them, or otherwise another matching circuit need to be put between these circuits [3]. The introduction of an additional circuit to the system will increase the cost, size, complexity and weight of the system [4].

In order to suppress the unwanted signals of higher order harmonics in a microstrip antenna, a few techniques have been proposed such as stacking [5], frequency selective surface (FSS) [6], electromagnetic band gap (EBG) [7], photo band gap (PBG) [8] and metamaterial [9]. One of them is by using the defected ground structure (DGS) on the antenna itself due to its simple physical design [10]. A few structures of DGS have been proposed in the past such as the T-shaped DGS [11-12], H-shaped DGS [13], U-slot DGS [14-15], and circular slot DGS [16-19]. The DGS has attractive properties in terms of size miniaturization, suppression of surface waves and the ability to present distinctive stop bands [20]. In DGS, the modification is made on the under plane of the antenna to boost the performance by suppressing the higher order harmonics. The basic element of DGS is the resonant slot or gap that is placed on the ground plane [21]. They are placed directly under the transmission line and aligned for efficient line coupling [22].

2. RESEARCH METHODOLOGY

The antennas in this work are designed and simulated in CST Microwave Studio® software. In order to arrive at the final design of an antenna with DGS, an inset feed microstrip antenna without DGS is proposed. The design process of this antenna is based on the dimensions of the microstrip antenna from the calculation and optimization method. The DGS is then introduced on the ground plane of the optimized inset feed microstrip antenna to suppress the higher order harmonics. The linear characteristics of the antenna are then investigated in terms of reflection coefficient, radiation pattern, gain, efficiency and surface current distributions.

2.1. Inset feed microstrip antenna without defected ground structure (DGS)

Figure 1 shows the design and dimensions of the inset feed microstrip antenna in this work. The inset feed configuration is chosen in this work to improve the impedance matching of the antenna in order to get a better reflection coefficient [25]. Table 1 lists the dimension values of the antenna. Dimensions of the ground plane is the same as the dimensions of the substrate which is 57.3×57.3 mm^2.

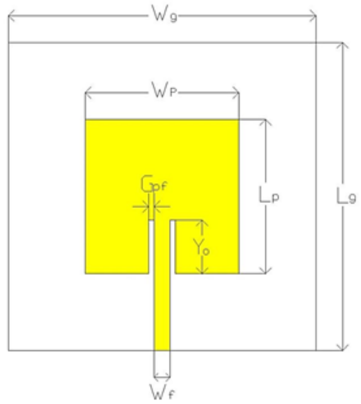


Figure 1. Inset feed microstrip antenna without DGS

Table 1. Dimensions of the inset feed optimized microstrip antenna

Parameter	Values (mm)
W_p	28.65
L_p	28.65
W_g	57.3
L_g	57.3
W_f	3
G_{pf}	1
Y_o	10
W_p	28.65

2.2. Inset feed microstrip antenna with defected ground structure (DGS)

In the next antenna design, a defected ground structure (DGS) is introduced into the ground plane to suppress the higher order harmonics produced between the frequency range of wireless communication from 1 to 6 GHz. In order to reach at the final design, a parametric study has been conducted to get the best result. Two antenna designs have been proposed which can be viewed in Figure 2. Figure 2(a) shows a single slot DGS which has been optimized. On the other hand, Figure 2(b) illustrates the additional dimensions at the right and left end of the initial slot. The additional dimensions are found to be able to further improve the harmonics suppression. The dimensions of the antennas are listed in Table 2. The position of the slot has been varied to find the best location to suppress the higher order harmonics. Figure 3 shows the variation of slot that is placed under the feed line. The reference point is at the edge of the feed line with x=0 mm. The position is then varied at 1.5 mm, 3.0 mm, 4.5 mm, 6.0 mm and 7.5 mm. It is found that the location of the slot at 6.0 mm gives the best result as it can suppress the higher order harmonics greatly. Table 2 lists the dimensions of both DGS on the ground plane of the antenna.

(a) (b)

Figure 2. Inset feed microstrip antenna with DGS, (a) A single slot DGS, (b) A single slot with additional slot DGS at both ends

Table 2. Dimensions of the DGS of the inset feed microstrip antenna in Figure 2

Parameter	Values (mm)
a	15
b_1	1.5
b_2	2.5
c	1
d	6

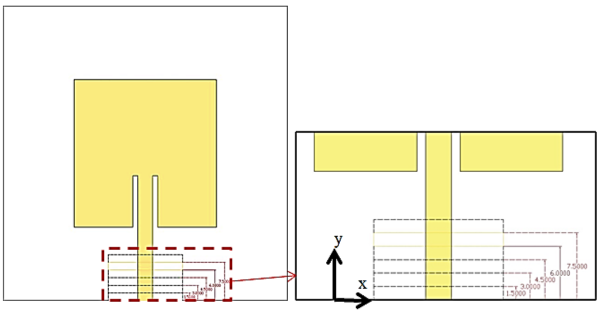


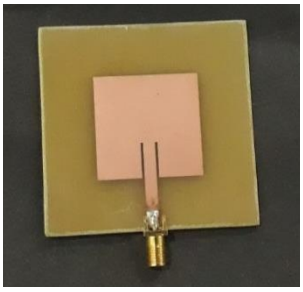
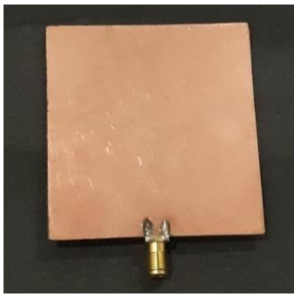
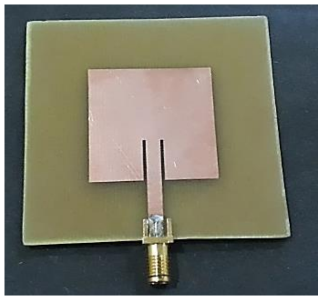
Figure 3. Position variations of a single slot DGS on the ground plane of the microstrip patch antenna

2.3. Antenna fabrication and measurement

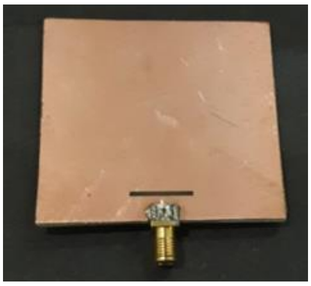
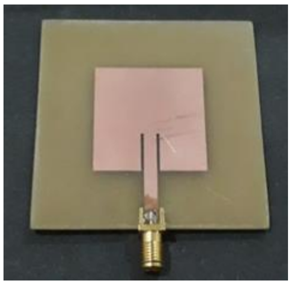
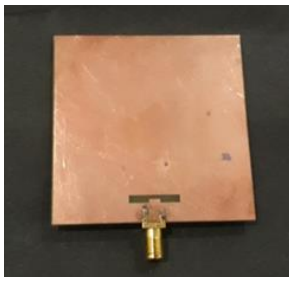
The antennas involved in this work are fabricated on a FR-4 substrate with a thickness, h of 1.6 mm, dielectric constant, ε_r of 4.5 and loss tangent, tan δ of 0.019 by using the printed circuit board (PCB) technology. The performance of these antennas are investigated by measuring the linear characteristics. The measurements are conducted by using the ZVB14 Rohde & Schwarz Vector Network Analyzer (VNA) and the results are analyzed. Figure 4 shows all the fabricated antennas in this work.

3. RESULTS AND ANALYSIS

In this section, the reflection coefficients of the fabricated microstrip antennas are measured and compared with the simulation results. In order to simplify the analysis, only the linear characteristics of the final antenna (the inset feed microstrip antenna with a single and additional slot DGS at both ends) are presented and analysed.

(a) (b) (c)

(d) (e) (f)

Figure 4. Fabricated inset feed microstrip antennas, (a) Without DGS (front view), (b) With DGS (back view), (c) With a single slot DGS (front view), (d) With a single slot DGS (back view), (e) With a single and additional slot DGS at both ends (front view), (f) With a single and additional slot DGS at both ends (back view)

3.1. Inset feed microstrip antenna without defected ground structure (DGS)

Figure 5 shows the comparison between the simulated and measured reflection coefficients of the inset feed microstrip antenna without DGS. From the figure, it can be seen that there is a slight shift in the measured resonant frequency of the fabricated antenna from 2.45 GHz to 2.51 GHz with S_{11} of -18.30 dB. This discrepancy can be attributed to the fabrication tolerances and cable losses during the measurement process. In addition, the higher order harmonics can be seen to be located at 4.54 GHz with S_{11} of -38.04 dB and 5.76 GHz with S_{11} of -13.08 dB.

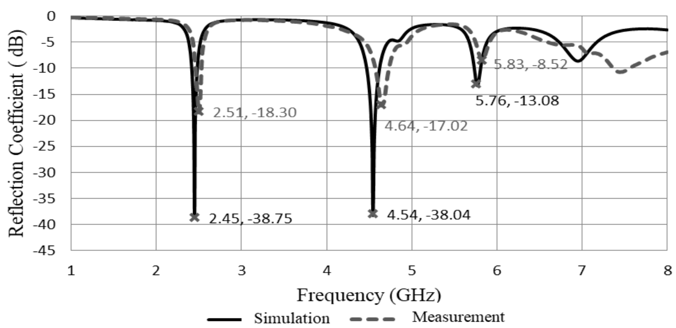


Figure 5. Comparison between the simulated and measured reflection coefficients of the microstrip patch antenna with an inset feed

3.2. Inset feed microstrip antenna with a single slot DGS

The fabricated inset feed microstrip antenna with a single slot DGS antenna is measured. Figure 6 shows the comparison between measured and simulated reflection coefficients of the antenna with a good agreement between the two. From the figure, the resonant frequency has been slightly shifted to 2.54 GHz with S_{11} of -21.72 dB. Furthermore, it can be seen that the S_{11} at 2.45 GHz is -24.19 dB and the S_{11} at higher order harmonics of 4.54 GHz and 5.76 GHz have been suppressed to -3.34 dB and -1.38 dB, respectively. Figure 7 compares the reflection coefficient of the microstrip patch antenna with and without the DGS.

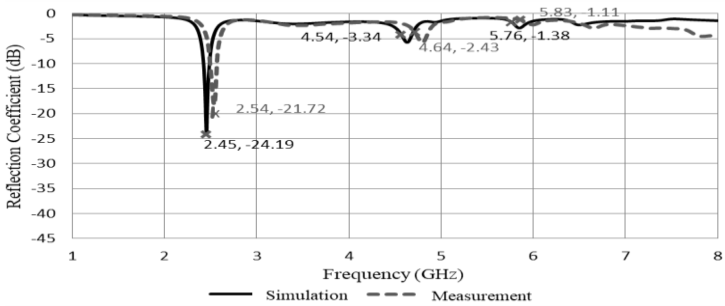


Figure 6. Comparison between the simulated and measured reflection coefficients of the microstrip patch antenna with a single slot DGS

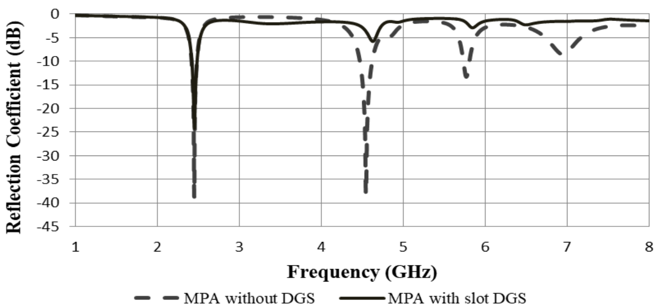


Figure 7. Reflection coefficient of the inset feed microstrip antenna with and without the single slot DGS

3.3. Inset feed microstrip antenna with a single and additional slot DGS at both ends

Figure 8 shows the comparison between the simulated and measured reflection coefficients of the inset feed microstrip patch antenna with a single and additional slot DGS at both ends. From the figure, the measured resonant frequency has been slightly shifted to 2.51 GHz with S_{11} of -21.72 dB. Moreover, it can be clearly seen that the existing suppressed harmonics have been further reduced to -2.61 dB at 4.54 GHz and remains at a relatively lower S_{11} of -1.38 dB at 5.76 GHz. The measured and simulated results are found to be in a good agreement.

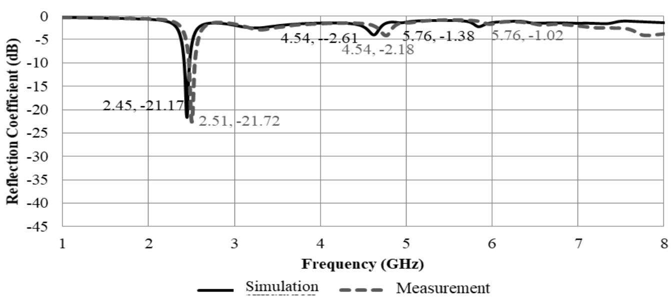
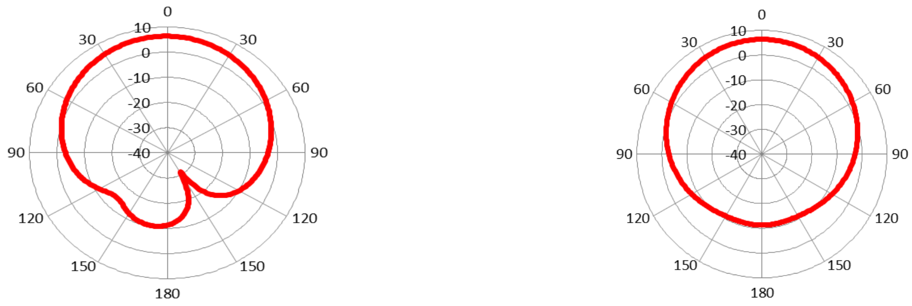


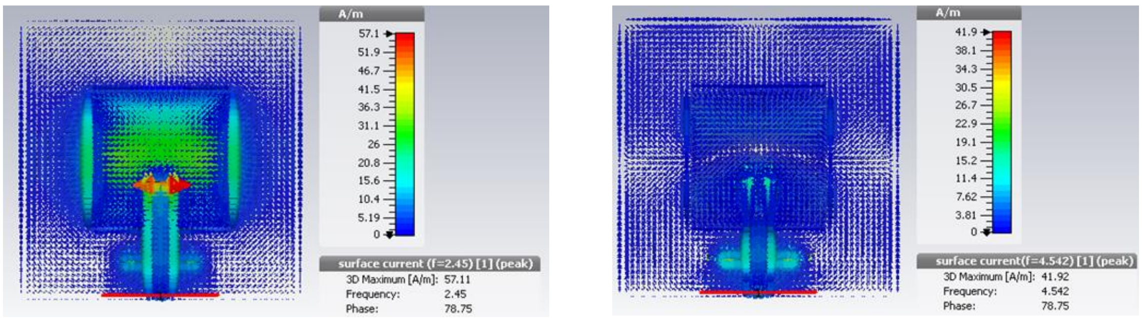
Figure 8. Comparison between the simulated and measured reflection coefficients of the microstrip antenna with a single slot and additional slot DGS at both ends

The radiation patterns of the antenna in the E-plane and H-plane can be viewed in Figure 9. The main lobe magnitudes for both planes are similar at 6.39 dBi. It can be seen from the figure that the radiation pattern in the E-plane is almost unidirectional and omnidirectional pattern is observed in the H-plane. The current distribution at resonant frequency and higher order harmonics of the antenna can be observed in Figure 10. From the figure, the maximum current is seen to be concentrated at the edge of the inset feed at the fundamental frequency of 2.45 GHz. No maximum current are seen on the surface of the antenna at higher order harmonics of 4.54 GHz and 5.76 GHz which imply that harmonics at those frequencies are suppressed.

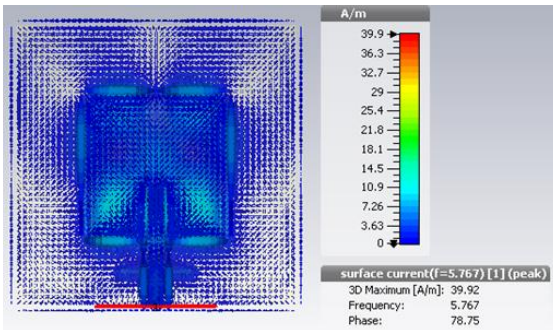


(a) (b)

Figure 9. Radiation pattern of the microstrip antenna with a single and additional slot DGS at both ends at the fundamental frequency of 2.45 GHz in the, (a) E-plane, (b) H-plane



(a) (b)



(c)

Figure 10. Simulated surface current of the microstrip antenna with a single and additional slot DGS at both ends at, (a) 2.45 GHz, (b) 4.54 GHz, (c) 5.76 GHz

4. CONCLUSION

In this work, the microstrip antenna with an inset feed and defected ground structure (DGS) has been designed, simulated and fabricated on a FR-4 substrate and measured by using the ZVB14 Rohde

& Schwarz VNA. The antenna operates at 2.45 GHz with a reflection coefficient of -38.75 dB and produces higher order harmonics at 4.54 GHz and 5.76 GHz. The geometry of the defected ground structure (DGS) has been optimized to get the best result in terms of harmonics suppression. The microstrip patch antenna integrated with a single slot and additional slot at both ends of DGS is found to have further suppressed the higher order harmonics as compared to a single slot DGS. The proposed antenna with DGS has suppressed the higher order harmonics effectively from -38.04 dB to -2.61 dB at 4.54 GHz and from -13.08 dB to -1.38 dB at 5.76 GHz.

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