Slotted Circular Microstrip Patch Antenna with Reduced Ground Plane for S, E, G, X and Ku-Band Applications

Apleen Kaur, Jaswinder Kaur

Abstract: ***This paper proposes a novel slotted circular microstrip patch antenna with reduced ground plane for covering a wide variety of applications such as S, E, G, X and Ku-band. The overall size of the suggested antenna is 30 X 30 mm^2. The main objective of this study is to utilize the reduced ground plane technique for obtaining a dual band behavior with wide bandwidth of the suggested antenna design. Further, a rectangular slot is cut in the circular patch to cover lower frequency bands (S, E and G) with appreciable return loss and increase of impedance bandwidth for the upper band (X and Ku). Excitation is provided to the antenna through a microstrip feed line. The antenna was simulated employing Computer Simulation Technology Microwave Studio Version 16.0 (CST MWS V16.0) software that is supported by a technique of finite integration. The design process, parametric study, simulation results along with measurements for the proposed microstrip patch antenna (MPA) operating over a number of frequency bands simultaneously are presented and discussed.***

Index Terms: Reduced Ground Plane, Microstrip Patch Antenna, Radiation Pattern, VSWR, VNA, S, E, G, X and Ku-Band Applications.

I. INTRODUCTION

The remarkable and speedy advancement in wireless and telecommunication sector has enormously exaggerated the requirement for the evolution of more novel designs of miniaturized antennas capable of operating at more than one frequency bands**.** The need for multi-band antennas to cover very wide bandwidth is of unending importance, particularly in the field of electronic warfare, satellite communication, wideband radar and measuring system. A microstrip antenna, commonly renowned as patch antenna or printed circuit antenna is appropriate for such applications. The microstrip patch antenna has certain advantages viz. light weight, low cost, planar profile, design flexibility, simple printed circuit fabrication and easy to install [1]. A thin dielectric sheet (substrate) having some particular value of dielectric constant, loss tangent and thickness is used on which the photoetching of the radiating elements (copper patch and feed line) is performed. The patch can be of any arbitrary shape (rectangular, square, elliptical, spiral or circular, etc.). Although microstrip patch antennas have extremely desirable features, they generally suffer from limited bandwidth. Narrow bandwidth is their most critical disadvantage. To overcome this problem without spoiling its principal advantages, a number of techniques and structures have been investigated till date.

Revised Manuscript Received on May 06, 2019

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Particularly for satellite applications, a light-weight low profile antenna with high reliablity is needed. Numerous techniques are presented by researchers for miniaturization of the size of antenna like introducing capacitive and inductive loading [2], use of substrates with high dielectric value [3], use of fractals [4], using metamaterials [5], use of slots on patch [6], and using the shorting pins and plates [7].

Table I. Frequency Bands [14]

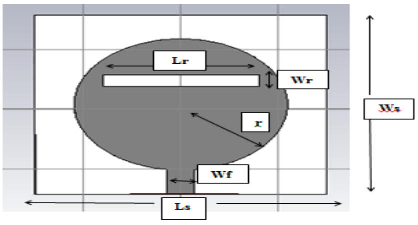
BAND	FREQUENCY RANGE (GHz)
R	1.70-2.60
D	2.20-3.30
S	2.60-3.95
E	3.30-4.90
G	3.95-5.85
X	8.2-12.4
Ku	12.4-18
K	15-26.5

Various antennas have been designed having distinct configurations of defects in the ground thus forming a unique/modified ground plane. In addition to exciting the additional resonant modes, modified ground plane also proves successful in reducing the size of antenna. A modified ground plane is realized by etching a certain shape in the ground of the patch antenna. As a modified ground plane, specifically known as defected ground structure (DGS) introduces additive lumped inductance, there is a reduction in phase velocity of the wave, due to which a slow wave effect is produced [8]. Slow wave effect is defined as the ratio of propagation constant β and free space wave number k. The slow wave effect causes the resonance frequency of antenna to decrease and effective electrical length of the antenna to increase that ultimately is responsible for antenna size reduction for the particular operating frequency [9]. A number of configurations of defected ground structure for example, partial ring [8], dumbbell shape [9], control of radiation and higher harmonics in microstrip antennas [10], proximity coupled stacked circular disc [11], spiral [12], annular ring [13] etc. have been suggested to ameliorate the performance features of antenna, such as to raise the radiation efficiency, to improve the impedance bandwidth, to trim down the overall size of patch, to scale down the mutual coupling, to inhibit higher harmonics and to curb the cross polarization of the antenna.

Different frequency bands along with their frequency ranges are given in the Table I as illustrated below.

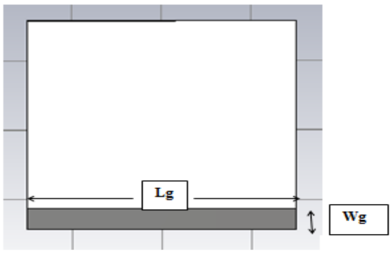
II. ANTENNA GEOMETRY

Fig.1. illustrates the geometry of the suggested antenna. Here circular patch is taken as the radiating element as circle shaped patch occupies a bit lesser region in comparison to the rectangular shaped patch. Furthermore, just varying or adjusting the radius of circular disc, different impedance values, radiation patterns and operating frequencies are produced. The proposed antenna is designed using Rogers RT5880 Duroid material for substrate and copper for patch and ground. Rogers RT5880 has relative permittivity ε_r =2.2 and loss tangent, tan δ= 0.0009 (at 10GHz). Thickness of the substrate is 1.57mm and that of both patch and ground is 0.02mm. Dimensions of the substrate are L_s X $W_s$mm^2. Circular patch is of radius r mm. DGS is used with dimensions L_g X W_g mm^2. A rectangular strip of dimensions L_r X W_r mm^2 is cut from the patch.



(a)

For proper impedance matching, a 50 ohm microstrip line was utilized for exciting the patch. The geometrical dimensions of the circular radiating element and ground plane are modified a number of times for the optimization of the antenna. The size of the rectangular slot in the patch is also adjusted many times in order to get desired radiation characteristics. The rectangular slot, circular shape of the patch and DGS considerably assist in the favorable excitation of the resonating frequency bands obtained.



(b)

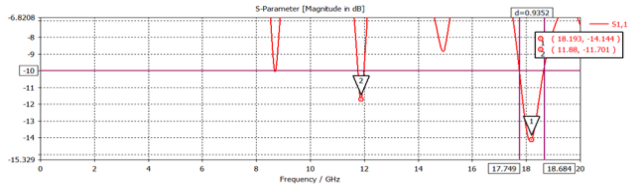
Fig.1. Geometry of the suggested antenna design (a) Front view (b) Rear view

III. SIMULATION RESULTS

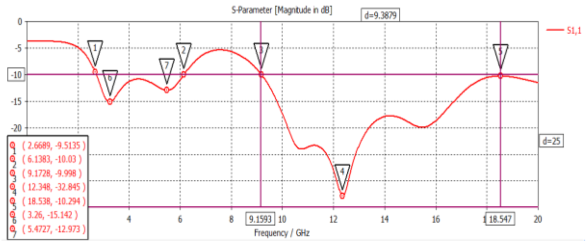
The results of the proposed design using DGS were obtained by using the commercially available simulation software, CST Microwave Studio software V14.0 [15]. Transient solver in the main menu has a parameter sweep option; with the help of it analytical parameters were regulated precisely after executing experimental repetitions number of times. Eventually, the best parameters for the designed configuration were obtained as follows: L_s=30mm, W_s=30mm, r=11 mm, W_f=2.8mm, L_r=16mm, W_r=2mm, L_g=30mm and W_g=3mm.

A. Return Loss

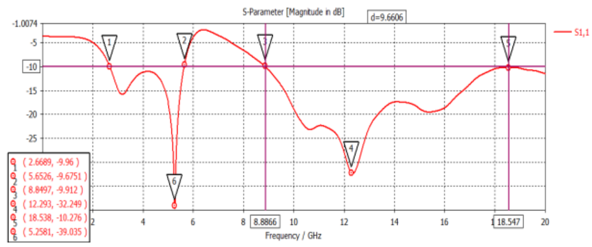
Return Loss, which is measured in decibels, is difference between forward and reflected power. At first, a circular MPA design is simulated and results are obtained. Two resonating frequencies at 11.88 and 18.193GHz are obtained as shown below. After number of trials for different dimensions of the ground, a 3mm wide DGS is used and simulated results are obtained for the same. Two wide bands with impedance bandwidths 3.5 GHz (2.6-6.1 GHz) and 9.33GHz (9.17 – 18.5 GHz) are obtained. As a rectangular slot gets embedded in the patch, we obtain reduced return loss results for the lower band and also an increase of 272MHz impedance bandwidth for the upper band is obtained. The resultant S-parameter plots are illustrated in Fig.2(a), (b) and (c) without rectangular slot and without DGS, with DGS but without any slot in patch and with DGS and rectangular slot in the patch respectively as shown below. After inclusion of both DGS and rectangular slot in the circular patch, we obtain dual wide-band microstrip antenna. A lower band covering S, E and G frequency bands is obtained from 2.67GHz to 5.65GHz with impedance bandwidth of 2.98GHz. The resonating frequency obtained for this band is at 5.25GHz with return loss of -39.035 db. The upper band covers both X and Ku-frequency bands from 8.85GHz to 18.538GHz with impedance bandwidth of 9.68GHz. The resonating frequency at 12.293GHz has a return loss of -32.249dB.



(a)



(b)



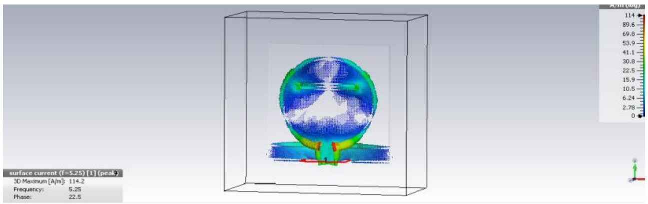
(c)

Fig.2. S_{11} versus frequency plots obtained for three different cases(a)Circular MPA

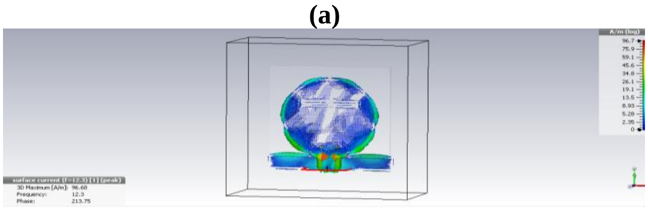
without rectangular slot and without DGS(b)Circular MPA with DGS but without any slot in patch(c) Circular MPA with DGS and Rectangular slot in the patch

B. Current Distribution

Return loss plots only help in obtaining the behavior of the antenna as a lumped load towards the end point of feeding line. The analysis of current distributions at the top and bottom part of the patch is used to obtain the elaborated electromagnetic conduct of the suggested antenna prototype. To clarify more about excited resonant modes of the designed antenna, the simulated results of current distributions at two resonant frequencies of 5.25GHz and 12.3GHz are shown in Fig.3(a) and (b) from which it is clear that the defected DGS was the cause of resonance at 12.3GHz and the rectangular slot in the circular patch was cause of resonance at 5.25GHz. As it is clear from the surface current distributions, circular shape of patch and DGS are responsible for resonating frequency at 12.3GHz. As seen in Fig.3(a), the rectangular slot in addition is strongly responsible for the resonating frequency at 5.25GHz. The slot also decreases the return loss at this frequency.



(a)



(b)

Fig.3. Surface Current distribution results for the suggested antenna
(a) At resonating frequency 5.25GHz
(b) At resonating frequency 12.3GHz

C. Voltage Standing Wave Ratio and Gain

Voltage Standing Wave Ratio **(**VSWR) is defined as the ratio of maximum to minimum voltage. Transmission line imperfections are measured through VSWR. Due to mismatches in impedance within the connector, some of the signal power is reflected. The standing wave's amplitude is higher if impedance mismatching is large. For no voltage standing wave impedance matching needs to be perfect means VSWR equals to 1. This ratio when measured in decibels (dB) is called return loss. Fig.4 demonstrates the VSWR for the proposed design. We obtain 1.0312 VSWR value at 5.25 GHz frequency and 1.0499 VSWR value at 12.3 GHz frequency.

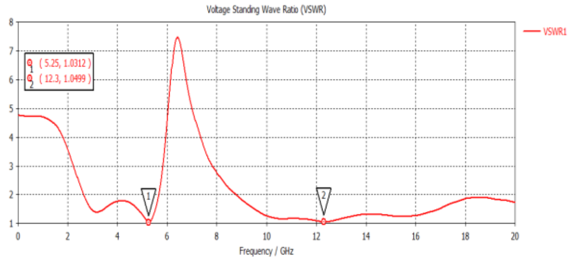


Fig.4. VSWR plot for the proposed design

D. Gain

Gain versus frequency plot for the design is illustrated in the Fig.5 given below.

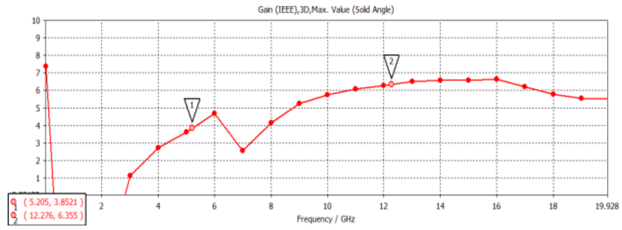
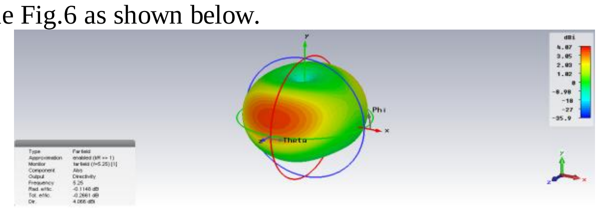


Fig.5. Gain versus frequency plot

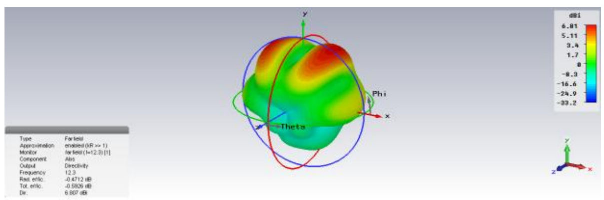
As clear from the plot, gain at resonating frequency 5.205GHZ is 3.8521 dB and that at 12.276GHz is 6.355dB approximately.

E. Directivity

As we know, directivity is defined as the radiation intensity in a given direction from the antenna divided by the radiation intensity averaged over every direction. In this proposed design, directivity of 4.05dB is obtained at frequency of 5.25 GHz and 6.5dB at 12.3 GHz. Directivity plots are shown in the Fig.6 as shown below.



(a)



(b)

Fig.6. Directivity plot at (a) 5.25 GHz and (b) 12.3GHz.

IV. FABRICATION AND MEASUREMENT RESULTS

Photographs of the fabricated antenna prototype are illustrated in Fig.7 showing its front view and rear view.

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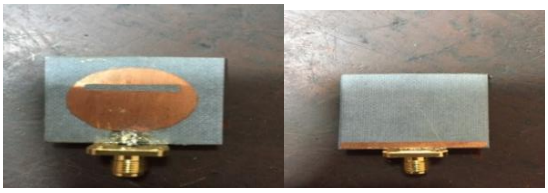
Keysight E5063A (100kHz-18GHz) ENA series network analyzer is used for testing the fabricated antenna. Fig.8 depicts the comparison between software generated and experimental S_{11} results of the suggested antenna. We obtain the lower band ranging from 3.28GHz to 5.12GHz with impedance bandwidth of 1.84GHz. The upper band is obtained with bandwidth of 6.14GHz ranging from 9.36GHz to 15.5GHz. A small band from 15.8 to 16.1GHz is also obtained. The measurement results differ to a little extent to simulated results due to number of factors like connector losses, fabrication errors etc. The bandwidth of the fabricated antenna is reduced over the whole frequency band as compared to the bandwidth that was obtained during simulation. Due to various errors and losses, we obtained an additional band from 6.38 to 7.36GHz.



(a) **(b)**

Fig.7. Fabricated antenna prototype (a) Front view (b) Rear view

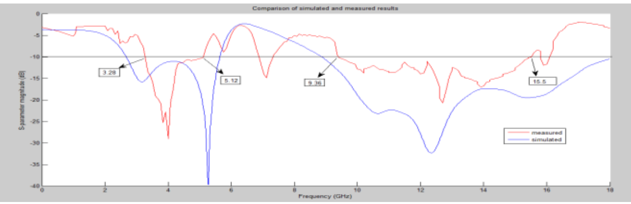


Fig.8. Comparison of simulated and measured results of the suggested antenna

V. CONCLUSION

A compact slotted circular patch antenna with reduced ground plane is designed and fabricated to cover S, E, G, X and Ku-band. Therefore, this design could be used in applications such as WiMAX, WLAN and satellite applications as well. DGS and the rectangular slot in patch played an important role for obtaining such a wide band performance of antenna. Although, due to errors and various losses, the measured bandwidth is lesser than the simulated bandwidth, but still we obtained an appreciable value of bandwidth and gain. The measured impedance bandwidths are about 1.84 GHz (3.28 to 5.12 GHz) and 6.14 GHz (9.36 to 15.5 GHz), that correspond to an impedance bandwidth of 43.8% and 49.4% respectively. The reduction in the bandwidth obtained in measurement from the simulated result is may be attributed to factors such as fabrication losses, connector losses, cable losses, etc. The upcoming scope of this work can be to achieve the impedance bandwidths for S, G and Ku band completely covering the whole frequency spectrum as discussed earlier in Table I.

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