Design of Miniaturized Multiband Microstrip Patch Antenna using Defected Ground Structure

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Abstract—The recent developments in communication and antenna engineering demands compact and multiband antennas. Microstrip antenna is one of the most useful antennas for wireless communication because of its inherent features like low profile, light weight and easy fabrication. This design is aimed at miniaturized Microstrip Patch Antenna (MSA), without deteriorating its other parameters, such as gain, bandwidth, directivity and return loss. A significant amount of 89% miniaturization has been made possible by careful and meticulous investigation of slots insertion in patch and ground of MSA antenna. Dielectric substrate used in this design is polyester which has shown better result. As the focus of this design is to miniaturize the MSA, the technique used here is Defected Ground Structure (DGS), along with Defected Patch Structure (DPS) which actually shifted the resonant frequencies to the lower range without increasing its physical dimensions. Besides this shorting pin is also introduced between patch and ground, which also contributed in the enhancement of parameters like gain and return loss. The position of pin played an important role in the acquirement of better performance and radiation at desirable frequency band. Different shapes have been designed on Ground and Patch to obtain enhanced results. With the use of DGS, the designed antenna started radiation at multiple frequency bands. The frequency bands generated by this designed antenna are in the range of L band and S band of IEEE standard which made it apposite to use in variety of applications.

Keywords—Miniaturization; multiband; defected ground structure (DGS); defected patch structure (DPS); directivity; gain

I. INTRODUCTION

In contemporary world, where the space technology is booming with very high pace, require the hardware which is of small size and high efficiency. The antenna is the integral part of the wireless communication and it also required to be low profile with high efficiency and improved parameters. Low profile antennas are regularly used in various commercial and public applications such as radio, mobile and wireless communication wherein size of the antenna is matter of concern [1]. For this purpose Microstrip Antenna (MSA) is unvaryingly used. MSA is well-matched with MMIC design.

The microstrip patch antenna is majorly consist of patch, substrate and ground mounted one above other in a layer making three slices, along with this there is feeding part also connected on the suitable place [2]. The dimension of patch and ground of MSA can be exploited to get more affirmative variation in different parameters like resonant frequency,

radiation pattern, gain, efficiency and directivity. Moreover when certain load is inserted, such as pins and varactor diode, between the patch and ground, results in variation of parameters values [3].

Major drawbacks in operation of MSA are low power gain, low efficiency, spurious feed radiation and narrow bandwidth [4]. However, in certain application like security systems narrow frequency bandwidth is considered advantageous. Also there are certain techniques to enhance the bandwidth and efficiency i.e. increasing the substrate's height. However, at the same time as the height increase it extracts more power for direct radiation because of introducing of surface wave which is again undesirable. These surface waves in return radiate at discontinuity or bands and result in the degradation of polarization characteristic and antenna pattern. Defected Ground Structure (DGS) is useful in suppressing cross polarization [5]. By introducing cavity or any shape the surface wave can be removed while bandwidth remains as improved. Stack configuration is also use to enhance the bandwidth. DGS technique is used to achieve size reduction and also further bandwidth as well as gain enhancement. Artificial magnetic conductor has been used for the antenna's miniaturization and reduction of antenna size has achieve but at the cost of lower gain [6]. Introduction of Koch fractal shape on the patch also reduce the size of antenna up to 21% but the gain starts decreasing after few iteration [7]. One more technique of short circuiting the patch to ground of MSA is introduced for miniaturization but again the problem happened with the gain [8]. The main drawback of smaller physical dimensioned antenna is that it has narrow impedance bandwidth. Multiband response is introduced in MSA antenna but yet again the gain is remained problem [9]. Miniaturization has been accomplished by using complementary split ring resonators, wherein the size reduced up to 10% [10]. For the reduction of size of antenna Meta material is used for ground plane along with high permittivity substrate which results in considerable antenna reduction but at the cost of poor efficiency and narrow impedance bandwidth of antenna [11]. This task can also be performed by substrate of pure magnetic property but finding pure magnetic material is demanding to obtain [12]. Defected ground structure is already investigation in microstrip patch antenna for miniaturization purpose and till then the reduction of antenna achieved was 34% [13]. Arrangement of L-Shape and U-Shape slits on the Ground plane are also used for miniaturization of antenna wherein impedance bandwidth is in range of 3.1%-25% [14]. Patch and the ground plane are

shorted through a shorting pin and ground plane are disturbed for miniaturization and has acceptable gain for all band which is in the range of 3.5dBi to 6.6dBi [15]. When MSP antennas are used in low frequency band the size of antenna get increased.

A particular inset-fed MSA has generated resonant frequency of 3.6 GHz wherein defected ground structure makes the frequency band shifted towards a lower frequency, in doing so miniaturization of the MSA antenna is justified [16]. Defected ground structure is incorporated with defected patch antenna to improve its performances and achieve miniaturization but miniaturization up to 50% was achieved, comparing with conventional microstrip antenna [17]. Electromagnetic band gap (EBG) structure is used like defect ground structure to miniaturize and attain multiband resonant frequencies. Two cells of spiral-shaped defected ground structure (DGS) with each cell composed of spiral with four arms are used in the design. Simulations outcome showed that 50% reduction in size was accomplished [18], [19]. Without defected ground structure and other slots the antenna resonates at 3.22 GHz but after the DGS and slots introduced in MSA the frequency shift from 3.22 GHz to 1.07 GHz [20]. DGS technique is also used for array microstrip patch antenna size reduction wherein the miniaturization achieved is 37% [21].

II. ANTENNA CONFIGURATION

In designing microstrip patch antenna the first and foremost task is to measure the dimension of antenna for specific frequency and substrate. For dimension, the parameters required are length of patch (P_L), width of patch (P_W), length of ground (G_L), width of ground (G_W), height of substrate (S_H). It is also a matter of concern to find the proper feed location on antenna as it ensures the better impedance matching. Feeding point is point on antenna where antenna is made excited by input energy. The suitable feeding point on antenna is where the input impedance matches the antenna impedance.

Before finding other parameters of antenna for its dimension, it's important to set following three parameter on the basis of which other parameters have to derive.

A. Operating Frequency

To find out the length, height and width of antenna, it's imperative to choose a desired frequency for which antenna has to be design. For this specific MSA design the frequency that has been chosen is 4.1 GHz.

B. Dielectric Substrate

Dielectric substrate plays an important role in defining MSA antenna design. Here, in this design the substrate used is "Polyester". This dielectric substrate has very low relative permittivity of about 1.39.

C. Substrate Height (H_S)

Since the miniaturization of an antenna is the major objective of this design, so the thickness of dielectric substrate is kept such that the goal is achieved without disregarding other parameters such as bandwidth, gain, and efficiency. As the bandwidth is related to thickness of substrate, trade-off has

been made between miniaturization and other parameters i.e. bandwidth. Height of substrate in this particular design is kept 2mm.

Thus, this design is based on following parameters

Frequency= 4.1 GHz

Dielectric substrate permeability, $\varepsilon_r = 1.39$

H_S= 2mm

III. CALCULATING DESIGN PARAMETERS

On the basis of these above mentioned factors other designed parameters of planned antenna have to be calculated. These designed parameters include length of patch (P_L), width of patch (P_W), length of ground (G_L), width of ground (G_W), Effective Dielectric Constant (ε_{reff}), Effective Length (L_{eff}), Length Extension (ΔL) and Feed Location (X_F, Y_F). Moreover, shorting pin is also used in this design at different location endeavoring for better results.

A. Width of Patch (P_W) Width of Ground (G_W)

The width of patch of design MSA is computed by the expression 1 given below:

$$P_W = \frac{c}{2f_0\sqrt{\frac{\varepsilon_r+1}{2}}} \qquad (1)$$

Whereas, ε_r =1.3, speed of light, c =3×10^8 m/s and Frequency f_0 = 4.1 GHz and by putting the values of variables in right side of expression, the width of patch is calculated as; P_W =33 mm

The width of ground is greater than width of patch (P_W) by simply addition of length equal to six time thickness of substrate (6h) and is given as

$$G_W = 6h + P_W \qquad (2)$$

By inserting the values of unknowns in right side of equation we get the width of ground as G_W = 47 mm

B. Effective Dielectric Constant (ε_{reff})

The effective dielectric constant ε_{eff} is given by expression:

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}[1 + 12\frac{h}{P_W}]^{-\frac{1}{2}} \qquad (3)$$

Putting the values of variables as ε_r= 1.39, P_W = 33 mm and h= 2 mm, the resulting effective dielectric constant will be as under: ε_{eff}= 1.344

C. Length of Patch (L_P) and Length of Ground (G_L)

Equation for the effective length of patch is given as:

$$L_{Peff} = L_P + 2\Delta L_P \qquad (4)$$

$$L_P = L_{Peff} - 2\Delta L_P \qquad (5)$$

By inserting the values of L_{Peff} = 31.95 mm and ΔL = 1.2096mm, consequential Length of Patch is derived as: L_P = 29.53 mm
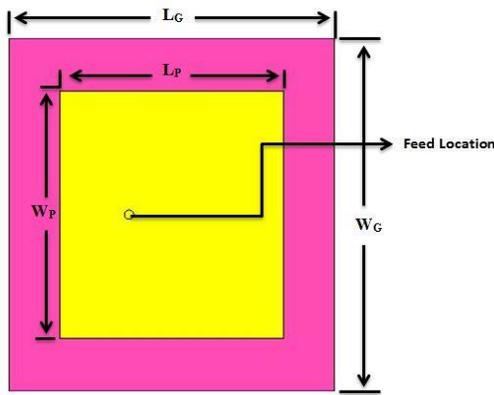
Fig. 1. Front view of conventional MSA.

Likewise the length of ground, the length of ground is also greater than width of patch (P_L) by simply addition of length equal to six time thickness of substrate (6h) and is given as

$$G_L = 6h + P_L \qquad (6)$$

By inserting the values of unknowns in right side of equation we get the width of ground as $G_L = 42$ mm.

D. Feed Scheme and Feed Point (F_X, F_Y)

In this design the feeding technique used is coaxial probe feeding. The coaxial probe feeding method is frequently used in microstrip patch antenna. The outer conductor of coaxial probe is connected to the ground plane while inner conductor is drilled into the dielectric substrate and extended outside soldered to radiation patch. The inner and out conductor of coaxial cable are insulated.

The feeding location also plays an important role in impedance matching of antenna. The feed location (F_X, F_Y) are calculated by using following expression:

$$F_X = \frac{P_L}{\sqrt{\varepsilon_{eff}}} \qquad (7)$$

$$F_Y = \frac{P_W}{2} \qquad (8)$$

Using above expression the feed location calculated are FX = 12.73 mm and FY = 16.94 mm. Because of the slots insertion the feeding point will slightly change from the calculated location and new proper location found is $F_X = 8$ mm and $F_Y = 16.5$ mm. According to these calculated parameters first conventional antenna for 4.1GHz is designed shown in Fig. 1. Then slots are inserted on patch and ground structure of that antenna.

E. Defected Patch

Fig. 2 presents the deformed patch shape of Design MSA wherein inverted double L shape slots are introduced along with stack configuration. The length of long arm of each L is 19mm and width is 1mm, while the length of short arm of each L is 8mm and width is of 1mm. Each L is inverted and facing toward each other. Besides inverted double L slits, a stack configuration is also introduced. Stack configuration represents

cutting at each side of the patch. Opposite sides of the patch are equally slotted, the slits parallel to long arms of L are large i.e. its length is 16.4mm and width is 2.5mm while the slit parallel to short arm is small whose length is 8.22mm and width is 2.5mm.
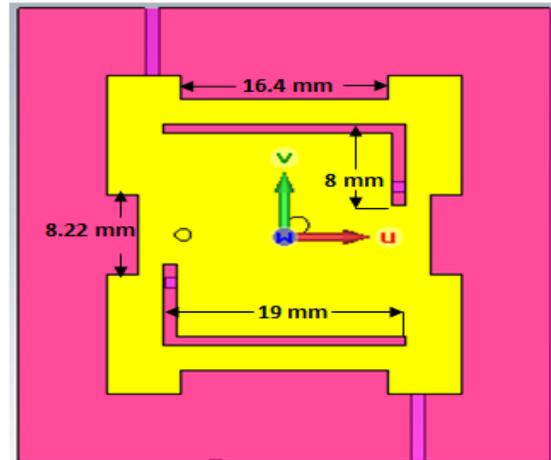
Fig. 2. Defected patch of design MSA.

F. Defected Ground

Fig. 3 presents the defected shape of ground of Design 2 MSA. Likewise the radiation patch of Design 2 the ground is also deform by introducing inverted double L but this time both L are not facing each other but lying in same line facing in opposite direction. The long arm of each L of length 20mm and of width 1mm each while the short arm of each L is of length 19mm and width 1mm each.
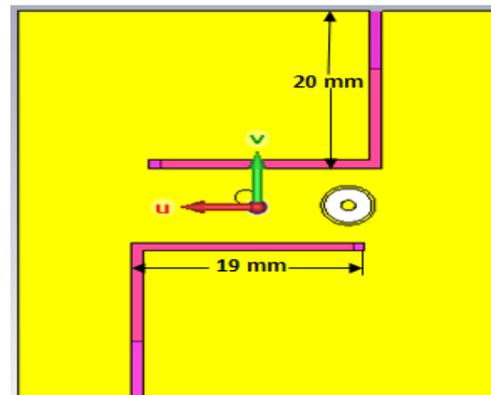
Fig. 3. Defected patch of design MSA.

G. Shorting Pin

Fig. 4 displayed the bottom view of Design MSA wherein the feeding through coaxial probe is vividly noticeable along with that on the right side of which the shorting pin is visible. Shorting pin short the ground plane with patch for providing low resistive path to current which play an important role in setting parameters of antenna at different frequency band. In side design the best location of shorting pin found is pinU=1 and pinV=1 (mean 1mm in x direction and 1mm in y direction of local working coordinate system).
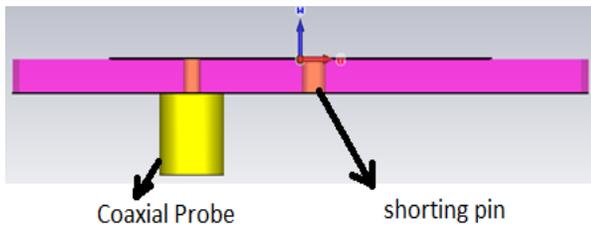
Fig. 4. Shorting pin in design MSA.

IV. RESULTS AND DISCUSSION

Fig. 5 shows the s-parameter of conventional antenna wherein the antenna is explicitly resonating for only 4.1 GHz.
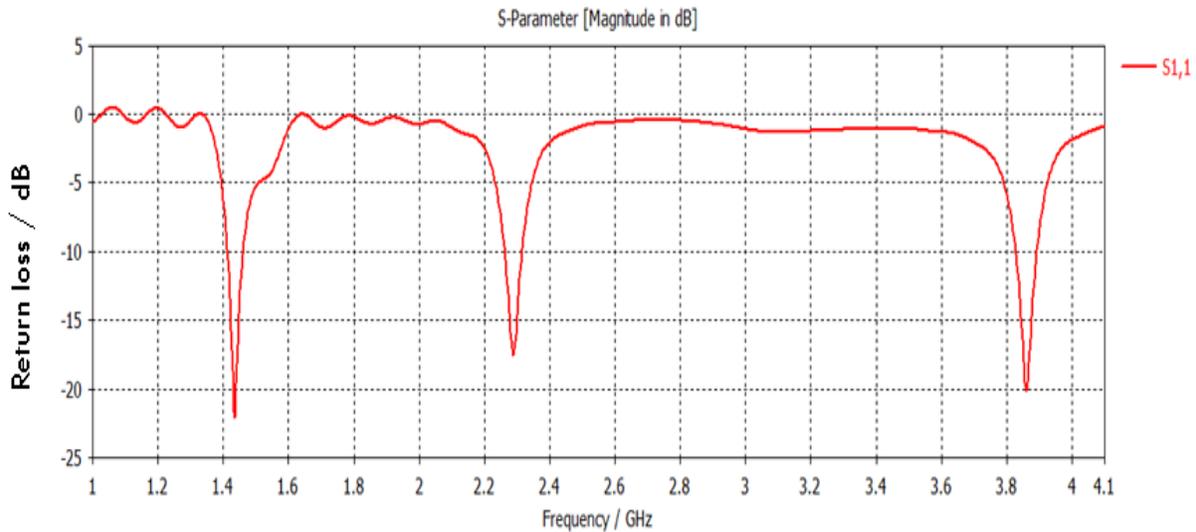
The designed antenna, which is the modification of same antenna that resonated at 4.1 GHz, by introducing different shapes on Patch and Ground, is now operating in three different frequency bands shown in Fig. 6.

The S-parameter (S1,1) of the Design MSA depict the multiband resonating nature of MSA wherein three different frequency bands show good return losses This designed antenna operates at 1.4GHz, 2.2GHz and 3.88GHz. Return loss of 1.48GHz is about -23dB and that of 2.24GHz is almost -18dB while that of 3.84GHz is around -21dB. Gain, directivity and Bandwidth at three different frequency bands are given in Table I.

Fig. 5. Return loss in dB of conventional MSA.

Fig. 6. Return loss in dB of conventional MSA

TABLE I.   PARAMETERS' VALUE OF DESIGN MSA

Design 2 MSA Parameters	Simulation Results (1st frequency band)	Simulation Results (2nd frequency band)	Simulation Results (3rd frequency band)
Resonant Frequency	1.48GHz	2.24GHz	3.84GHz
Return Loss	-23dB	-18dB	-21dB
Gain	4.11dB	4.88dB	6.47dB
Directivity	4.2dBi	4.95dBi	6.69dBi
Bandwidth	114.3MHz	117.8MHz	135MHz

Polar pattern of Radiation Gain of Design MSA in the farfield region at resonant frequency 1.48GHz is show in Fig. 7(a). The Main Lobe magnitude shows maximum gain of 4.11dB at 1.48GHz. Polar pattern of Radiation Gain at resonant frequency 2.24 GHz is show in Fig. 7(b). The Main Lobe magnitude shows maximum gain of 4.54 dB at 2.24 GHz in direction of 89^0. Polar pattern of Radiation Gain at resonant frequency 3.84 GHz is show in Fig. 7(c). The Main Lobe magnitude shows maximum gain of 6.43 dB at 3.84 GHz.

Unlike conventional antenna, design antenna radiates at three different useful frequency bands i.e. 1.4 GHz, 2.24 GHz and 3.84 GHz. Since, 1.4 GHz lies in IEEE L band and used for a number of applications. Mobile, military, maritime, land mobile telemetry, fixed telemetry, digital multichannel system, satellite (downlink) and aeronautical are the applications of frequency band 1.4 GHz. Moreover, the same final design antenna operates at 2.24 GHz frequency band, which lies in IEEE S band. This frequency band is also used in some communications satellites. The Design 2 MSA antenna also works at 3.84 GHz which too is present in S band of IEEE standard.

The Design MSA antenna start operating at lower frequencies simply by defecting ground and patch of antenna rather than increasing its size. This design MSA antenna is miniaturized for 1.4 GHz frequency band up to 89%. For conventional MSA antenna, working at 1.4 GHz frequency, the required dimension would be 98.01 x 89.10 = 8732.691mm^2 while the dimension of Design MSA antenna is 33.47 x 29.14 = 975.315 mm^2. By calculation it is found that Designed antenna is approximately 89% smaller in size than conventional antenna.
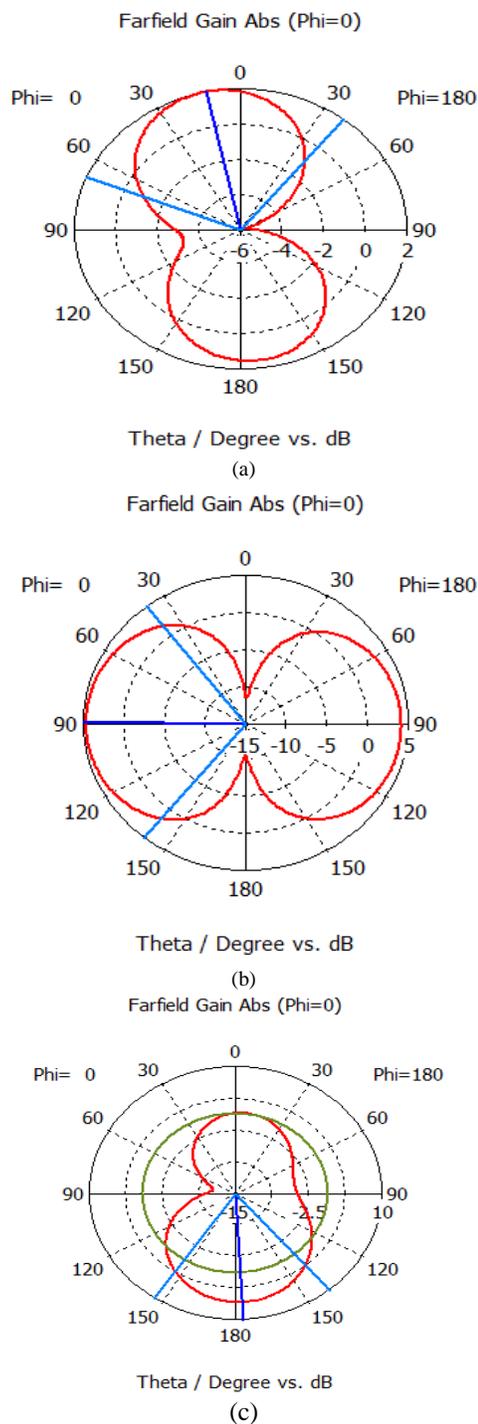
Fig. 7. Polar Pattern of Radiation Gain of Design 2 MSA (a) at 1.48GHz (b) at 2.24GHz (c) at 3.84GHz.

V. CONCLUSION

A significant amount of 89% miniaturization has been made possible by careful and meticulous investigation of slot insertion in patch and ground of MSA antenna. After scrutinizing for different designs of cuts on patch and ground plane of MSA, it is made possible to resonate at several frequency bands and produce multiband response. By inserting shorting pin at a proper position between ground and patch, its parameters like gain, directivity and efficiency are improved. The frequency bands generated by this designed antenna are in range of L band and S band of IEEE standard. This antenna design is very apposite for application like Mobile, military, maritime, land mobile telemetry, fixed telemetry, digital multichannel system, satellite (downlink) and aeronautical.

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