Compact slotted multiband patch antenna with defected ground structure for wireless communication

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Abstract. A novel compact Slotted Microstrip patch antenna with Defected Ground structure (DGS) operating for Wireless and satellite communication applications is proposed and investigated. This proposed antenna generates six different resonances operate at 3.3 GHz (WLAN), 5.1 GHz (WiMAX), 5.9 GHz (Satellite Application), 7.12 GHz (Earth Exploitation Satellite), 10.4 GHz (Mobile & fixed Radio location) and 13.1 GHz (Satellite Application) while maintaining overall compact size of 32x32x1.6 mm³ using a FR-4 substrate commonly available with a permittivity of εr = 4.4. The proposed microstrip Patch Antenna (MSPA) consists of a square radiator in which a Log Periodic slot is etched out along with square defects on ground surface and a Microstrip feedline. The slotted patch with DGS modifies the total current path there by making the antenna to operate at six useful bands. The structure shows the impedance bandwidth of 3%, 3.3%, 5.2%, 14.7%, 5.6% and 9% with gains 3dB, 3.8dB, 2dB, 1.8dB, 3.1dB and 4.82dB respectively. The antenna performance is analyzed using various s parametric optimization studies, field distributions and currents. Excellent agreement is obtained between measured and simulated results.

1. INTRODUCTION

In view of the increasing demand for high data rate, the need for wide band antenna in the communication systems also increased simultaneously. This facilitates the transmission of large volumes of data with a short time. The design of antennas that can operate over a wide range of frequencies requires the integration of several structures on the same substrate. The design of microstrip patch antenna has become a challenge for designers in mobile wireless communication systems with enhanced features. Much research is underway to develop structures that can meet the desired needs [1]. Microstrip patch antenna is designed by different feeding techniques such as microstrip line, aperture coupling, coaxial probe and proximity coupling. The frequently used feeding technique is the microstrip line because of ease of fabrication and integration. The most important part of MSPA is the ground plane. Due to the fringing effect between the ground and patch the radiation is emerged in MSPA. A few fix reception apparatuses are planned with various shapes on the fix or emanating components, for example, round, square, ring, triangle, polygonal, hexagonal, octagonal [5]. The introduction of slot / slots on the radiating surface can resonate with multiple bands. In addition, to enhance the impedance bandwidth of the patch antenna, different shapes of defects are introduced at the surface of the ground, described by various authors [3]. Subsequent introduction of various slot / slots on the patch as well as defects on the ground surface can also improve bandwidth and gain. The performance of various multi-band antennas is reported by several authors with impedance bandwidth and gain characteristics with various structures utilizing Defected ground structure.
In the present work, which is different from the existing literature, a new compact log periodic slit patch antenna is proposed with a defect on the ground surface resonates at 3.3 GHz, 5.1 GHz, 5.9 GHz, 7.12 GHz, 10.4 GHz and 13.10 GHz, which is suitable for various wireless and satellite with good gain and impedance bandwidth.

2. PROPOSED ANTENNA DESIGN

Geometry of the proposed slotted patch antenna with and without DGS is shown in Figure 1. The length and width of the proposed antenna is 32mm X 32mm. For this design, the ground plane and radiating patch are etched on either side of most commonly available FR4 substrate material having dielectric constant \( \varepsilon_r=4.4 \), loss tangent of 0.02 and substrate thickness of 1.6mm. The simulation is carried out using licensed electromagnetic solver High frequency structure simulator HFSS software. The periodic process of designing the proposed antenna is carried out by changing iteration 1 to iteration 3 to obtain high impedance bandwidth is shown in Figure 2. Various dimensions of proposed patch antenna are indicated in Table 1.

The width and the length of the square patch antenna shown in Iteration 1 can be calculated by the following design equations

\[
Width(w) = \frac{C}{2f_r \sqrt{\varepsilon_r + 1}}
\]

(1)

where \( C \) is Velocity of Light, \( f_r \) is operating frequency and \( \varepsilon_r \) is relative permittivity

\[
L = \frac{c}{2f_r \sqrt{\varepsilon_r}} - 2\Delta L
\]

(2)

Where \( \varepsilon_e \) is Effective relative permittivity and \( \Delta L \) is effective length

\[
\varepsilon_e = \frac{(\varepsilon_r + 1)}{2} + \frac{(\varepsilon_r - 1)}{2} \left[ 1 + \frac{12h}{W} \right]^{-1/2}
\]

(3)

where \( h \) is height of substrate

\[
\Delta L = \frac{0.412h(\varepsilon_r + 0.3)(W/h + 0.264)}{(\varepsilon_r - 0.258)(W/h + 0.8)}
\]

(4)

Based on these above equations the lengths and widths of basic patch antenna are calculated operating at 4GHz and further modification on patch and removing some portions on ground additional resonant frequency will be obtained.
Figure 1. Schematic configuration of (a) Antenna without DGS (b) Antenna with DGS.

Table 1. Notations of various parameters of proposed antenna.

| Parameter                  | Notation | Dimension (mm) |
|----------------------------|----------|----------------|
| Length of the Substrate    | Ls       | 32             |
| Width of the Substrate     | Ws       | 32             |
| Ground Length              | Lg       | 32             |
| Ground Width               | Wg       | 32             |
| Length of Patch            | Lp       | 16             |
| Width of Patch             | Wp       | 18             |
| Length of Strip            | Lf       | 10             |
| Width of Strip             | Wf       | 2              |
| Length of Slit             | L4       | 6              |
| Spacing between Slits      | L1       | 0.5            |
| Width of Slit              | L2       | 1              |
| Width of Slit              | L3       | 0.5            |
| Length of each DGS slot    | L5       | 8              |
| Width of each DGS slot     | W5       | 8              |

3. ANTENNA RESULTS AND DISCUSSIONS

3.1. Parametric Analysis
The parametric study is used to analyze the proposed antenna with improved impedance bandwidth and gain. The variability of the L5 and W5 of square DGS, the Wf Strip feed width, Varying Slit widths L2, Various DGS shapes and the use of various substrates is used to assess the presentation of the proposed antenna for different parametric qualities. All the Parametric analysis results are indicated in Table 2.

3.1.1 Return loss Variation with design iterations
Parametric analysis was carried out for different iterations as shown in Figure 2. Comparative variations of return loss for design iterations (1), (2) and (3) are illustrated in Figure 3. In Iteration 1 a square patch antenna was designed based on design equations operating at 4 GHz. In Iteration 2 slots are introduced on patch results in more operating Frequency. In Iteration 3 four square slots are etched results furthermore operating bands. A significant increase in the multi band has been observed from one iteration to the next. The frequency bands covered by the Iteration (3) are 3.3 GHz, 5.1 GHz, 5.9 GHz, 7.12 GHz, 10.4 GHz and 13.1 GHz.
3.1.2 Return loss curves with and without DGS

Parametric analysis was performed with and without DGS, as shown in Figure 4. An increase in operating bands, impedance bandwidth was observed due to the introduction of DGS into the proposed antenna. Simulated results are shown in Figure 5.
3.1.3 Return loss curves due to Variation in slot width $L_3$.

The parametric variation is made by varying the Gap $L_3$ between the slots is shown in Figure 6. Optimized results were observed for $L_3 = 0.5$ mm.

3.1.4 Return loss curve for Various Substrates

The parametric variations of proposed structure with various substrates are simulated namely with FR4 ($\varepsilon_r=4.4$), RT Duroid ($\varepsilon_r=2.2$) and Teflon ($\varepsilon_r=2.1$) shown in Figure 7. FR4 substrate has exhibited comparatively better performance when compared with RT Duroid and Teflon. Using RT Duroid operates at only 4 bands whereas Teflon substrate also 4 bands.
3.1.5 Return loss curve Variation for Various DGS
The parametric analysis is performed by changing various DGS as shown in Figure 8 and the return loss curves for Various DGS is shown in Figure 9.

Figure 8. Different DGS (a) Half Square, (b) triangular DGS, (c) circular DGS and (d) square DGS

Figure 9. Simulated return loss curves for various substrates

3.1.6 Return loss curve Variation for strip feed width $W_f$
The parametric analysis is performed by varying the width of feed strip $W_f$ for different widths, namely 1mm, 2 mm and 3 mm is illustrated in Figure 10. Optimized results were observed for a width of 1 mm strip feed $W_f = 2$ mm.

Figure 10. Simulated return loss curves for various values of $W_f$
3.1.7 Return loss curve Variation of DGS Square Cut Length(L5) and width(W5)

The parametric analysis is performed by varying L5, W5 of Square cut Dgs with different lengths with 6mm, 7 mm, 8 mm and 9 mm and simulated results are shown in Figure 11. The optimised results are obtained for L5, W5 equal to 8 mm.

![Figure 11. Simulated return loss curves for various values of Wf](image)

Table 2. Parametric Performance analysis of various parameters variation.

| Parameter Variation                  | Frequency bands (GHz) | Impedance Bandwidth (%) | Gain in dB |
|--------------------------------------|-----------------------|--------------------------|------------|
| Iteration                            |                       |                          |            |
| 1                                    | 4                     | 2.2                      | 2.1        |
| 2                                    | 6.25, 7.93, 8.43, 8.99, 14.5 | 2.8, 4.2, 3.6, 5.6, 6.3 | 2.1, 1.8, 2.4, 3.1, 1.4 |
| 3                                    | 3.3, 5.10, 5.88, 7.12, 10.39, 13.10 | 3, 3.3, 5.2, 14.7, 5.6, 9 | 3.3, 8.2, 1.8, 3.7, 4.82 |
| Slot Width L5 (mm)                   | 0.5                   | 3.3, 5.10, 5.88, 7.12, 10.39, 13.10 | 3, 3.3, 5.2, 14.7, 5.6, 9 | 3.3, 8.2, 1.8, 3.7, 4.82 |
|                                      | 1                     | 3.14, 5.07, 7.19, 10.36, 13.0 | 0.03, 3.5, 16.9, 4.5, 7.9 | 2.85, 3.91, 2.7, 2.7, 4.8 |
|                                      | 1.5                   | 3.08, 5.04, 7.12, 10.39, 13.13 | 1.6, 3.5, 17.1, 5.1, 6.8 | 2.81, 3.97, 1.8, 3.1, 4.8 |
| Slot Width L5 (mm)                   |                       |                          |            |
| 1                                    | 3.3, 5.04, 5.72, 6.94, 10.33 | 1.8, 2.9, 3.8, 12.5, 3 | 3.3, 9.7, 1.2, 2.3 |
| 2                                    | 3.3, 5.10, 5.88, 7.12, 10.39, 13.10 | 3, 3.3, 5.2, 14.7, 5.6, 9 | 3.3, 8.2, 1.8, 3.7, 4.82 |
| 3                                    | 3.3, 5.2, 7.31, 10.7, 13.6 | 1.2, 2.8, 13.3, 14.4, 7.5 | 3.3, 1.1, 1.1, 3.2, 4.46 |
| Width of Strip feed Wf (mm)          |                       |                          |            |
| 1                                    | 3.3, 5.04, 5.72, 6.94, 10.33 | 1.8, 2.9, 3.8, 12.5, 3 | 3.3, 9.7, 1.2, 2.3 |
| 2                                    | 3.3, 5.10, 5.88, 7.12, 10.39, 13.10 | 3, 3.3, 5.2, 14.7, 5.6, 9 | 3.3, 8.2, 1.8, 3.7, 4.82 |
| 3                                    | 3.3, 5.2, 7.31, 10.7, 13.6 | 1.2, 2.8, 13.3, 14.4, 7.5 | 3.3, 1.1, 1.1, 3.2, 4.46 |
| Length(L5) and Width(W5) of Square Cut DGS |                       |                          |            |
| 6mm                                  | 7.8, 11.9             | 1.1, 2, 1.9, 1.9         | 0.8, 1.2, 3.1 |
| 7mm                                  | 3.3, 5.6, 1.11        | 2.1, 3, 1.2, 2.2         | 2.1, 1.5, 2.7, 2.1 |
| 8mm                                  | 3.3, 5.10, 5.88, 7.12, 10.39, 13.10 | 3, 3.3, 5.2, 14.7, 5.6, 9 | 3.3, 8.2, 1.8, 3.7, 4.82 |
| 9mm                                  | 3.3, 4.8, 13          | 1.2, 2, 6, 1.7           | 1.5, 2.1, 2.2 |
| Teflon εr=2.1                        | 4.48, 7.03, 8.62, 11.01 | 1.3, 4.8, 19.4, 11.02    | 2.14, 0.2, -10.39, -12.2 |
| RT Duroid εr=2.2                     | 4.42, 6.88, 8.24, 10.86 | 1.3, 4.06, 20.3, 9.2     | 1.75, -1.86, -9.16, -7.7 |
| FR 4 εr=4.4                         | 3.3, 5.10, 5.88, 7.12, 10.39, 13.10 | 3, 3.3, 5.2, 14.7, 5.6, 9 | 3.3, 8.2, 1.8, 3.7, 4.82 |
| Without DGS                          | 6.25, 7.93, 8.43, 8.99, 14.5 | 2.8, 4.2, 3.6, 5.6, 6.3  | -1.05, -7.47, -9.26, -9.5, 0.56 |
| With DGS                             | 3.3, 5.10, 5.88, 7.12, 10.39, 13.10 | 3, 3.3, 5.2, 14.7, 5.6, 9 | 3.3, 8.2, 1.8, 3.7, 4.82 |
3.2 VSWR
The mismatch power among reception apparatus and feed line has been characterized by VSWR of any antenna. The VSWR plot of simulated proposed antenna is shown in Figure 12.

![Figure 12. Simulated VSWR](image)

3.3 Gain
The measured and simulated gain in dB for proposed antenna design is shown in Figure 13. The measured results and simulated gain results are good in agreement.

![Figure 13. Measured and Simulated Gain Vs Frequency](image)

3.4 Surface Current and Field Analysis
The simulated surface current analysis of proposed antenna is shown in Figure 14. The E field and H field distribution of proposed antenna is shown in Figure 15. It is seen that the flow is essentially focuses on the edges of occasional transmitting Patch which expands the electrical way length and ultra-multiband recurrence range execution is accomplished.
Figure 14. Simulated Surface current distribution of Proposed Antenna

Figure 15. Simulated (a) E- Field and (b) H-Field distribution of Proposed Antenna

4. MEASURED RESULTS AND DISCUSSIONS

The top and bottom view of fabricated antenna is shown in Figure 16. The fabricated antenna is tested using Anritsu MS2037C Vector network Analyzer is shown in Figure 17, the simulated and measured results of proposed antenna are shown in Figure 18.
The Prototype results are on par with simulated results with small deviations. This deviation is due to limitations in measurement setup and fabrication.

To obtain Far field radiation plots fabricated antenna is tested in anechoic chamber. The far field radiation pattern of proposed antenna is bidirectional obtained from anechoic chamber and shown in Figure 19. The measured plots E and H fields of proposed antenna taken at 3.3 GHz/5.1 GHz/5.9 GHz/7.12 GHz/10.33 GHz/13.1GHz, respectively.
Comparison of performed results of proposed Antenna with the existing referred papers in the published literature is tabulated in Table 3.

![Figure 19. Simulated Radiation patterns of proposed antenna at 3.3 GHz, 5.1 GHz, 5.9 GHz, 7.12 GHz, 10.33 GHz and 13.1GHz.](image)

| Ref. | Size (mm²) | No. of Bands | Freq. Of Operation (GHz) | % B.W | Applications |
|------|------------|--------------|--------------------------|-------|--------------|
| [7]  | 35 × 35    | 3            | 2.16/3.37/5.54           | 3.25,2.06,4.1/8 | IMAT/WiMAX, |
| [8]  | 96 × 96    | 3            | 0.68/1.88/2.5            | 89,19,45,36.2/5 | GSM, DCS, WLAN |
| [9]  | 70 × 60    | 4            | 1.8/3.6/4.53/5.73        | 1.2,2.1,2.4,1   | GSM1800/WiMAX/ WiFi |
| [10] | 50 × 50    | 3            | 4.3/6.9/8.8              | 4.2,5.3,4.8    | WiMAX/C-band/X-band |
| [11] | 27 × 29    | 4            | 1.5/2.4/3.5/5.2          | 6.06/8.33/5.5/5.94 | GPS/WiMAX/ WLAN |
| Proposed | 32 × 32 | 5            | 3.3/5.1/5.9/7.1/10.4/13.1 | 2.3/3.78/6.05/2.21/3.22 | Multimedia/WiMAX / WLAN/ Satellite Application/Mobile/ Earth exploitation satellite |

Table 3. Performance comparison of proposed antenna with previously reported antennas in literature.
5. CONCLUSION

In this paper a slotted patch antenna with Defected Ground structure (DGS) is proposed and investigated operating at six bands. To obtain a good impedance matching and gain, the optimized dimensions of the proposed antenna were realized, fabricated and tested. The design antenna operates at 3.3 GHz (WLAN), 5.1 GHz (WiMAX), 5.9 GHz (Satellite Application), 7.12 GHz (Earth Exploitation Satellite), 10.4 GHz (Mobile & fixed Radio location) and 13.1 GHz (Satellite Application), suitable for Wireless and satellite communication applications and having impedance bandwidth impedance of 3%, 3.3% , 5.2%, 14.7% , 5.6% and 9% with gains 3dB, 3.8dB, 2dB, 1.8dB, 3.1dB and 4.82dB respectively. The simulated and measured results of the antenna designed yielded. In addition, a comparison was made between the impedance bandwidth and the size of the antenna designed with respect to antennas previously reported in the literature.

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