Experimental and Simulation Study of Effects in Etched Patch Antenna with Multi Slots

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Abstract: - This paper aims for the design and development of a multi slotted novel patch antenna with multi-band characteristics. The work focused on designing a patch, feedline with novel multi-slots on the same patch which can be commonly used in wireless applications. In addition, the analysis shows the effects of the improved antenna properties obtained by etching such novel slots on epoxy dielectric substrate using photolithography process. The paper concentrated on the design aspects of the patch antenna with slot dimensions as a function of operating wavelength (λ) to get better results. The antennas are implemented with the help of software package V15.4 - Integral Three-Dimension Equation (IE3D) EM simulator. The experimental and simulation findings show the overall required bandwidth of 1120MHz with a return loss of -43dB achieving a gain of 8.39dB with better radiation characteristics.

Key-Words: - Simulation, Integral, Miniature, Multiband, Slotted, Axial, Bandwidth.

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1 Introduction

Microstrip antenna (MSAs), is one of special category of antenna in RF, microwave signal communication which plays a significant role in the wireless communication application, because of its numerous advantages of microstrip antennas over the normal antenna. Over decades the designing of the low profile antenna for the communication applications was a fundamental area of research. The multi strip antenna is one such[1]. The literature shows the variety of designs of multi-band MSA characteristics with better bandwidth and more than one functional wireless terminal based on ortho-polarized concepts [2-10] recently. Single radiators with Multi-band antennas are desirable in most applications [6]. some of them are Bow tie antenna with meandered slot, U-type slot patch antenna for improved percentage bandwidth (BW), slotted microstrip antenna with miniaturized size and circularly polarized nature, E and U slotted patch etched dielectric material, circular shape asymmetric slotted MSA, slots of ring on patch having dissimilar designs[11–24]. Some of the common demerits of MSAs are small BW ranging between 1- 2 %, minimal gain, least power handling capacity. From the Multiple methods of design the novel slot etched patch with direct strip feeding was found to be rare in survey papers and this method proves to enhance various antenna[25-29] parameters. Improving bandwidth, gain and radiation pattern [30-35] of MSA has been important research challenge in the strip line antenna field. A compact, circularly polarized wideband (CP) squared slot antenna for universal ultra-high-frequency (UHF) handheld reader (RFID) applications is proposed [36]. The antenna is a coplanar waveguide (CPW) fed by a feeding line inverted Z-shaped. Through installing four stubs inside the square slot in diagonal directions and two inverted T-shaped wires, broadband CP service, large axial ratio bandwidth and good impedance matching is achieved. The impedance bandwidth estimated < −10 dB ranges from 706 MHz to 1007 MHz (301 MHz, 35.1 per cent). The 3-dB axial ratio (AR) calculated is 427MHz (745–1172 MHz, 44.5 per cent). The proposed antenna has a
maximum gain estimated at 4.8 dBi. In [37] suggested a novel concept to minimize mutual coupling in circular patch antennas. A circular MIMO antenna with parasitic portion in the dumbell form is placed between the two circular patch antennas thus minimizing the mutual coupling. The proposed design has been observed to achieve multi-band characteristics at 3.1 GHz, 6.2 GHz and 7.7GHz. Impedance bandwidths (IBWs) at the tri-band frequencies are around 90 MHz, 320 MHz, and 540 MHz. A low-profile, dual-band, unidirectional, tag antenna for ultra-high frequency band (UHF) radio frequency (RFID) applications [38]. The antenna consists of a lightweight printed dipole, a 4 x 4 periodic metallic plates surface, and a metallic reflector. The dipole antenna is fed by a modified T-matching network to match the impedance in conjugation matching with UCODE GSM chip. Simulated $S_{11} < -10$ dB bandwidth are of 840–855 MHz and 916–932 MHz and unidirectional radiation with a range of 7.0 dB and 5.8 dB at 925 MHz and 845 MHz respectively. The final design with an overall size of 190mm x 190mm x 15.8mm (0.532λ x 0.532λ x 0.044λ at 840 MHz) yields a simulated $|S_{11}| < -10$ dB bandwidth of 840–855 MHz and 916–932 MHz. A novel dual-band co-aperture planar array antenna is proposed [39]. The radiating elements operating at a higher frequency band are grouped and reused for the lower frequency band by adopting the concept of segmented patches. A total of $4 \times 4$ “H"-shaped patches, fed by two independent microstrip-feeding networks through rectangular slots, are taken as the radiating elements for a $4 \times 4$ higher-band array antenna, and simultaneously as the radiating elements for a $2 \times 2$ lower-band array antenna. A Ku-band, compact, polarization-reconfigurable, multilayered, wideband antenna is proposed in [40]. Two orthogonal linear polarizations can be realized by switching the ON-OFF state of four p-i-n diodes that are embedded into the polarization-reconfigurable coupling slots. A prototype of the proposed reconfigurable antenna has been fabricated and tested. The measured fractional impedance bandwidth is larger than 22.4% with the reference of $|S_{11}| \leq -10$ dB. The measured gain versus frequency is stable and higher than 4 dBi within the operating frequency band. This paper is organized into introduction, design considerations of antenna, results and discussion, conclusion, acknowledgment and references.

1.1 Article Highlights

- The novel slots are etched on the patch plane to improve the performance parameters for the proposed antennas by the method of photolithography process. The initial design is carried out using AutoCAD software and later these designs are simulated using IE3D Electromagnetic simulation software for verification.

- The proposed antennas achieved a maximum bandwidth of 1200MHz with a return loss of -43 dB (with a gain if 8.39dB) having better radiation broadsided radiation properties.

- The proposed antennas are suitable for wideband wireless application such as RADAR, X band application, Fixed satellite based services

2 Design consideration of Novel Multi-Slotted Patch Antennas

The designed CAD sketch of the Microstrip antenna (MSA) is represented in Fig.1. The equivalent circuit of MSA has inductance ($L_1$), resistance ($R_1$) and Capacitance ($C_1$) connected in parallel with each other and terminated to the ground. Photolithography process is the technique used to fabricate/etch the patch according to the optimized design of CAD sketch. A 50 Ω SMA connector is connected to the microstrip feed line for excitation of the patch. The geometry of conventional-rectangular microstrip antenna (Conventional MSA: C-MSA) is shown in Fig.1. The back side of the patch is copper layer acting as a ground plane connected to the base of the SMA connector. The dimensions of the length and width of patch and slots are the order of multiples of wavelengths ($\lambda$) and fraction of wavelength ($\lambda$). In the next step, the C-MSA is etched with novel eight multi-slotted patch having octagonal slot, square slot, circular slot on patch and named as Eight Multi-Slotted Patch having Octagonal slot, Square slot, Circular slot on Patch (EMSPOSC) backed with ground plane ($L_w \times W_f = 40 \times 40$ mm). The dimensions of various novel slots on the patch surface are factor of wavelength and the octagonal slot dimensions in outside length ($S$) and its inside side length ($T$) are 4.30mm and 2.30mm, wide square slot dimensions are $S_1, S_2 = 3.48mm$ and narrow square slot are $S_{11}, S_{12} = 1.28mm$. The original patch dimensions of ($L \times W_f$), ($L_w \times W_f$) and ($L_d \times W_f$) are same as C-MSA. Similarly, in fig.3 a novel Multi Slotted Patch antenna having Hexagonal slots, Rhombus slots, Square slots on patch (MSPAHRSP) and its dimensions of horizontal and vertical rhombus slot lengths ($L_1$ and $L_2$) are 9.6 mm and 13.8 mm, side length $SL_{ij}$ is 6.61 mm and hexagon slide length $SL_2 = 5.2$ mm respectively. Broad shape slots are etched on MSPAHRSP when compared to narrow shape.
slots since broader slots are more efficient improving the BW, gain of antenna when compared to narrow slots [25]. The effects and the enhanced properties of patch antenna by etching such novel slots are studied in next section.

1. **Results & discussion: Experimental & IE3D EM Simulation**

2. **3.1 Conventional - rectangular microstrip antenna (C-MSA) characteristics**

The frequency response characteristics of designed C-MSA, EMSPOSSCP, MSPAHRSRSP are experimentally studied on Agilent Technology E8363 model PNA working for 0.10MHz – 40 GHz frequency range. The C-MSA as in fig.1 is theoretically designed for 3 GHz frequency. The -10dBRL frequency response characteristics is studied and measured for 2-4 GHz frequency band as in Fig.4. The simulation study is also carried out using licensed Mentor Graphics IE3D V.15.4 EM simulation software. Fig.4 shows the experimental and simulation -10 dB frequency response curve of C-MSA where it has BW of 2 % (20MHz) with minimum RL of -20dB at 3GHz resonance which validates the theoretical design. It also shows the simulated response where C-MSA resonated for 3.2 GHz with BW = 2.8% (31MHz) with RL = -18dB. The slight variation in the simulated and experimental frequency resonance is due to the dependent temperature variation of dielectric permittivity material, also due to the effect of 50 ohm SMA connector and coaxial feed [32]. The variations in the bandwidth can also be seen because the simulated study is done by declaring the parameters in ideal conditions in IE3D EM software and hence experimental bandwidth varies marginally with simulated result. From the radiation pattern plot as shown in fig.5, it is clear that the pattern is linearly polarized with broadsided nature at 3 GHz resonance. The broadside is because of the patch acting as the full resonant element at 3GHz frequency fed by a microwave fed power connected to SMA (sub miniature A type) connector.

![Fig 1. Structural geometry of Conventional MSA (C-MSA)](image1)

![Fig 2. Structural geometry EMSPOSSCP](image2)

![Fig 3. Structural geometry of MSPAHRSRSP](image3)

![Fig 4. Variation of RL Vs frequency of C-MSA (3GHz)](image4)
This patterns makes the antenna to have its coverage range to be broader with less cross polar level and intereference for desired user based communication applications. The measured half power beam width of C-MSA is 43°. The practical gain of C-MSA if found to be 2.1 dB. Such antenna (C-MSA) can be useful for indoor communication applications.

3.2 Eight Multi-Slotted Patch having Octagonal slot, Square slot, Circular Slot on Patch (EMSPOSCP)

The Eight Multi-Slotted Patch having Octagonal slot, Square slot, Circular Slot on Patch (EMSPOSCP) as shown in fig.2 is tested practically and simulated. The IE3D simulated and experimental frequency response graph of EMSPOSCP is shown in Fig.6 and is measured for 2-12GHz frequency band. The experimentally resonance for EMSPOSCP are 2.8GHz (RL=-18 dB), 6.2 GHz (RL=-17 dB) and 9.8 GHz (RL=-43 dB) respectively. Measured bandwidths (BW of EMSPOSCP 1 are found to be 11%, 48.51% (1200 MHz) and 29% with wide bandwidth i.e. for 2.0 GHz - 12 GHz band. The simulated resonance of EMSPOSCP are 2.8GHz (RL=-20 dB), 6.1GHz(RL=-33 dB) and 9.6GHz (RL=-36 dB). EMSPOSCP has achieved practical gain of 8.39 dB.Compared to C-MSA, EMSPOSCP has shown improvement in BW which is due to new type of slots etched on the patch which provides elongated surface patch current excited on the patch width and length making antenna to resonate over wide bandwidth [32] with better RL. Fig. 7 shows that EMSPOSCP exhibited linearly polarized broadside pattern with 57° half power beamwidth. The gain is improved to 8.31 dB due to the current path excitation resulting into decrease of q-factor of antenna [33]. This antenna has its applications in communication band.

3.3 Multi-Slot Patch Antenna with Hexagonal slot, Rhombus slot, Square slot on patch (MSPAHRSP)

The experimentally measured and IE3D simulated result of -10 dB RL characteristics of MSPAHRSP for 2-12GHz is as shown in Fig. 8. As per fig.8, MSPAHRSP resonated for triple band of frequencies i.e., \( f_1, f_2 \) and \( f_3 \) having different impedance bandwidth \( BW_1, BW_2 \) and \( BW_3 \) respectively. The calculated bandwidth at each operating band are found to be \( BW_1= 12.51\% (310 MHz),BW_2= 16.51\% (480 MHz)\) and \( BW_3= 20.21\% (531 MHz) \) respectively with better RL. The minimum RL at \( BW_1\) is − 29.51 dB which appears at \( f_1 = 1.8 \) GHz, RL at \( BW_2\) is − 43 dB at \( f_2 = 6.3 \) GHz and RL at \( BW_3\) is − 45 dB at \( f_3 = 9.4 \) GHz. The simulated resonant frequencies of MSPAHRSP are \( f_1= 2.4 \) GHz (\( BW_1= 10.51\% , RL = -11.06 \) dB), \( f_2= 5.7 \) GHz (\( BW_2= 19.51\% , RL = -26 \) dB) and \( f_3= 9.4 \) GHz (\( BW_3= 25.21\% , RL = -34 \) dB). Hence by adding slots (wider in size) on patch, not only multi bands are achieved but also...
enhancement up to 531 MHz of bandwidth at BW1 is achieved when compared to the bandwidth of BW1 of C-MSA.

Table 1. Measured antenna characteristics

| Proposed Antenna | f1 | Minimum return loss (RL) in dB | BW1 (MHz) | BW2 (MHz) | GPH (dB) | VSWR | Nature of Bandwidth | Frequency Bandwidth |
|------------------|----|--------------------------------|-----------|-----------|----------|------|--------------------|---------------------|
| C-MSA            | 2.0 GHz | -30 dB | 45 (MHz) | 55 (MHz) | 2.18 dB  | 1.4  | Bandpass          | 1 GHz               |
| EMSPOSCP         | 2.5 GHz | -16 dB | 45.51 MHz(128 MHz) | 11.71 MHz(113 MHz) | 7.85 dB  | 1.2  | Bandwidth         | L.C.Band application|
| MSPAHRSP         | 1.8 GHz | -15 dB | 46.5 MHz(128 MHz) | 11.71 MHz(113 MHz) | 7.85 dB  | 1.2  | Bandwidth         | L.C.Band application|

The maximum gain of MSPAHRSP measured in BW1, BW2, and BW3 are found to be 5.64 dB, 7.21 dB, and 7.81 dB. This kind of antenna suits for wireless communication application in C, X band frequency range. Among all the proposed antennas EMSPOSCP remains as the best option for wireless applications as given in table 1. The table 2 show the study of few comparisons made with the research findings related to survey paper.

Table 2. Comparative study with few literature survey papers

| Sl No | Literature survey | Literature survey Results | Present results obtained |
|-------|-------------------|---------------------------|--------------------------|
| 1     | In Survey paper 37 (2019) | A maximum bandwidth of 540 MHz is obtained. | Our study has shown a 1100 MHz bandwidth. |
| 2     | In Survey paper 38 (2019) | A bandwidth of 440-450 MHz and 914-923 MHz and transversal isolation with an average of 7 dB and 5.8 dB at 912 MHz and 443 MHz respectively. | A gain of 3.31 dB is obtained. |
| 3     | In Survey paper 39 (2019) | A validation model is simulated and measured on a 4-bit data converter is a working bandwidth of 4% from 5 to 9.5 GHz and another working bandwidth of 7.5% from 13.2 to 14.1 GHz. | A bandwidth of 48.5 MHz is obtained with modified data technique on GaAs plate. |
| 4     | In Survey paper 40 (2019) | The measured fractional impedance bandwidth larger than 22.4% with the reference of S11 ≤ –30 dB. The measured gain versus frequency is stable and higher than 4 dB within the operating frequency band. | A bandwidth of 48.3 MHz with 3.3 dB gain is achieved in this proposed study. |

Fig. 9 shows the 2D Radiation characteristics of MSPAHRSP measured at only one resonant frequency. From this figure, it is clear that MSPAHRSP has broadsided radiation with linear polarization characteristics. Measured half power beam width of MSPAHRSP is found to be 47°, 40°.
Conclusion

This paper presented the results in the form of experimental and IE3D simulation study of novel multislots on the patch surface which has shown a signifying improvement in the antenna characteristics. Proposed antenna has multi-bands for the communication based application in wireless domain (RADAR, X band application, fixed satellite based services). EMSPOS SCP has attained bandwidth of 1200MHz with return loss of -43dB. The measured gain was also found to be 8.39dB. The improved antenna characteristics with multiband nature are achieved through the process of optimizing the dimension of patch length, width as well as slot dimensions keeping a dependent. The improvements in bandwidth and gain are due to the addition new type of multislots on patch surface.

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Conflict Of Interest

The declaration is made to thereof that the author’s donot have any conflict of interest.

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