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REGULAR ARTICLE

Hybrid Shaped Miniaturized Ultra-Wideband Microstrip Patch Antenna for Various 5G and Remote Sensing Application

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In this paper, shaped printed Microstrip Patch Antenna (MPA) for a remote sensing application that operates in the ultra-wide band (UWB) spectrum is reported. By converting the upper side of a traditional rectangular patch into a semi-circular shape and the lower side into a shape like a staircase, the suggested radiating patch is created. Physical and electrical volume of the presented antenna is 33 × 24 × 1.6 mm^3 and $0.253\,\lambda_0 \times 0.184\lambda_0 \times 0.012\lambda_0$ respectively. The proposed antenna is developed, optimized, and simulated with Computer Simulation Technology's (CST) Microwave Studio Suite software. The antenna is developed on a 1.6 mm-thick FR4 dielectric substrate, featuring a loss tangent of 0.09, relative permittivity of 4.4 and measured using standard microwave test bench. Measured outcome of the suggested antenna confirms a wide impedance bandwidth of 13.7 GHz (2.3-16 GHz) with a fractional bandwidth of 149.7 % and Bandwidth Dimension Ratio (BDR) of 3215. Within this frequency range, the proposed antenna exhibits a peak gain of 3.9 dBi. Additionally, adequate co-polarization and cross-polarization separation are attained in all directions for the proposed antenna. The designed antenna is compact and lightweight, exhibits consistent gain, and is compatible with wireless system equipment. The UWB antenna may be used with Surface Penetrating Radar to detect explosive and dangerous things underground.

Keywords: BDR, Hybrid, Microstrip patch antenna, Ultra-wideband.

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1. INTRODUCTION

In contemporary and upcoming wireless communication systems, ultra-wideband (UWB) antennas are becoming more and more popular for two main reasons. First of all, since the Federal Communications Commission (FCC) formally published the regulations for UWB technology in 2002, there has been a significant increase in the demand for wireless transmission rates and UWB characteristics like high data rates, low power consumption, and low costs. This has greatly aided industry and academic research and development of UWB antennas. Second, in order to perform a variety of wireless transmission functions, Antennas for wireless portable devices must function at many frequencies. As a result, there are an increasing number of operating bands and functions, which can lead to antenna design challenges like interference from multiple antennas, antenna space limitations, and more. Multiple narrow-band antennas may be replaced with single UWB or broadband MPA, potentially lowering the total number of antennas. Under these conditions, broadband, wideband, super wideband or ultra-wideband (UWB) technology seems like a promising solution that can handle large channel capacity. The most recent state-of-the-art study on the many types of antennas and performance improvement techniques for contemporary communication technology is described by S. Kumar et al. [1]. Following a thorough explanation of the requirements and classification of the antennas, they contrasted several antenna designs for modern communication systems. A summary of the many methods for microstrip patch antenna miniaturisation that have been proposed in the published literature has been presented by S. Chourasia et al. [2]. Using a substrate with a higher dielectric permittivity, using a magneto dielectric material, modifying the radiating patch and ground plane by loading slots, slits and notches at the ideal positions, incorporating meander line structure in the patch and ground, integrating a metal plate inside a patch antenna, designing a planar inverted F antenna, designing a monopole antenna and using metamaterial substrate are some examples of miniaturisation techniques for planar antennas. Not only miniaturization, Researchers are simultaneously looking on a variety of strategies to significantly increase

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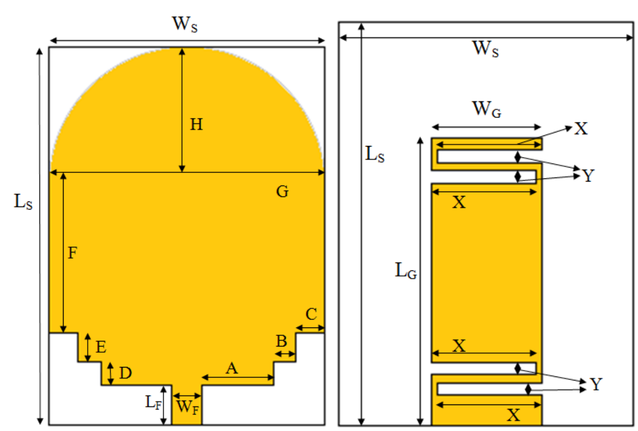
bandwidth. A thorough analysis of several multiband, broadband patch antennas with unconventional hybrid radiating patch configurations was provided by B. Mishra et al. [3]. In [4] T-Q. Fan et al. modified traditional U-slot patch antenna by introducing another 'U' shaped slot to enhance the antenna bandwidth. A novel hybrid form broadband (2.469 to 14.203 GHz) monopole antenna for wireless communication was proposed by H.T. Sediq et al. in [5]. A reference elliptical form and several circular shapes are combined to create the "inverted comma"-like radiating patch of the proposed monopole antenna. To increase the operating bandwidth, M.A. Banu et al. suggested an aperture-coupled Y-shaped microstrip line fed microstrip patch antenna in [6] with four strips separated by three thin slots. T. Tewary et al. developed a hybrid form microstrip patch broadband (2.27-5.55 GHz) antenna for wireless communication applications in [7]. In [8], S. Maity et al. suggested a "HEART"-shaped microstrip patch antenna for broadband (2.5-7.5 GHz). A traditional circular patch was effectively transformed into a "HEART" shape. Again S. Maity et al. In [9], a tree-shaped broadband (2-15.4 GHz) hybrid MPA with a radiating patch made up of four parallelograms and a circle that overlapped one another was presented. A second hybrid-shaped super broadband (2-95 GHz) microstrip patch antenna was also suggested in [10]. A reference rectangle patch with two ellipses and two notches has been overlapped to create the radiating patch for the proposed antenna. A.B. Devarapalli et al. in [11] presented hybrid shaped elliptical tree structure monopole multiband antenna (2.56-3.91 GHz, 8-10.1 GHz). T. Tewary et al. in [12] proposed broadband antenna by modifying reference antenna by loading slots in patch and ground and improving impedance matching by modifying feedline. Similarly in [13-19] many hybrid shape patch configuration like "sunflower", "corona virus", "tri-shul", "leaf" etc. was proposed in recent times for broadband operations.



(a) (b)

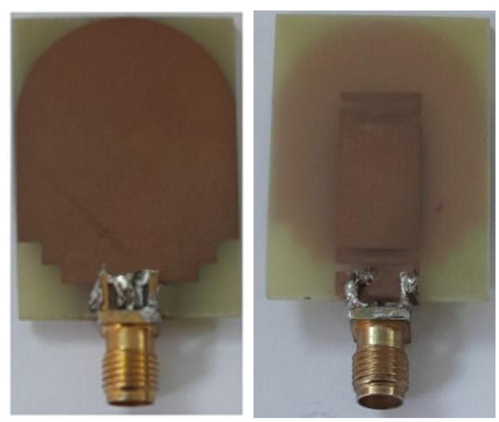
Fig. 1 – Proposed antenna: (a) Radiating plane (b) View of ground plane

This article discusses a hybrid shaped printed radiator with slot loaded finite ground plane fed by a microstrip line. Suggested antenna is both miniaturized and broadband (2.3-16 GHz) with high BDR of 3215 and 149.7 % bandwidth. Due to broadband characteristics, acceptable gain, and stable spatial distribution of radiation, the presented antenna can be utilized for remote sensing applications.

2. PROPOSED ANTENNA

Figure 1 shows radiating patch and ground plane geometry of the presented antenna.

A rectangular patch is combined with semi circular arc and staircase shaped slots in upper portion and lower portion of the rectangular patch respectively. To get the necessary features of the proposed antenna, the ground plane is lowered throughout its length and width, and four rectangular slots are positioned appropriately. The values of every parameter for the suggested antenna are compiled in Table I. The manufactured prototype of the suggested antenna is shown in Fig. 2.



(a) (b)

Fig. 2 – Printed antenna: (a) Radiating plane (b) View of ground plane

Table 1 – Design Parameters with optimal measurements in mm

Parameter	Dimension	Parameter	Dimension
W_S	24	C	2.5
L_S	33	D	2
L_G	23.5	E	2.5
W_G	9	F	19
W_F	2.7	G	24
L_F	3.5	H	6
A	6.15	X	8.5
B	2	Y	1

3. DESIGN STEPS

The suggested broadband antenna's development phases are depicted in Fig. 3 from step 1 (the original antenna) to step 5. Fig. 4 illustrates reflection coefficient for all design steps.

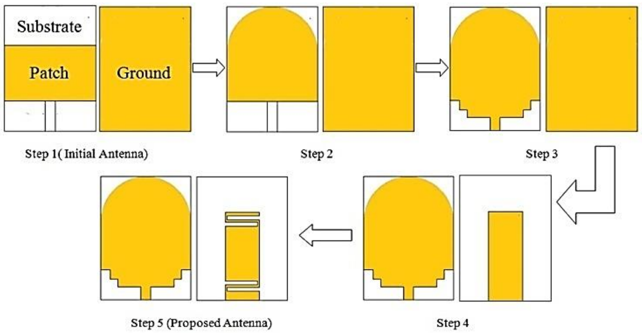


Fig. 3 – Design Steps of the prescribed antenna

Step 1: Initially a rectangular patch of length 18 mm and width 24 mm is considered on a FR4 substrate of length 33 mm and width 18 mm. Height (h) of the substrate is taken as 1.6 mm. Length and width of the microstrip feedline for the antenna is taken as 8 mm and 2.7 mm to match the characteristics impedance of the antenna as 50 Ω. For reference antenna finite ground plane having same dimension as substrate layer is taken. According to conventional equation [20] resonant frequency of a rectangular patch antenna having the above said patch dimension should resonate as 3.8 GHz for infinite ground plane. Using the standard equation [20] (1), where c represents the velocity of light, the width and length of the patch (W_P) at a resonant frequency (f_r) of 3.8 GHz can be determined using the Equation (1-5)

$$W_P = \frac{c*\sqrt{2}}{2*f_r*\sqrt{1+\varepsilon_r}} \quad (1)$$

Equation (2) is used to get the patch's effective dielectric constant.

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2} * [1 + 12 * \frac{h}{W_P}]^{-\frac{1}{2}} \quad (2)$$

Equation (3) determines the patch's extended incremental length, ΔL.

$$\Delta L = 0.412 * h * \frac{(\varepsilon_{reff}+0.3)*(\frac{W_P}{h}+0.264)}{(\varepsilon_{reff}-0.258)*(\frac{W_P}{h}+0.8)} \quad (3)$$

Equation (4) determines the patch's actual length.

$$L = \frac{c}{2*f_r*\sqrt{\varepsilon_{reff}}} - 2\Delta L \quad (4)$$

And the effective length is given by (5)

$$L_{eff} = L + 2\Delta L \quad (5)$$

But due to finite ground plane dimension impedance matching does not occur at fundamental frequency. Rather it resonates at higher harmonics of fundamental frequency as 5.5 GHz and other higher frequencies as can be seen from Figure 4.

Step 2-3: Upper portion and lower portion of the reference patch of the step 1 is combined with a semi circular shaped patch and staircase shaped patch for miniaturization of the proposed antenna. This disturbs the current distribution and elongates the current line path which results in miniaturization of the proposed antenna.

Step 4: For better impedance matching ground plane length and width is reduced to an optimum dimension. Step 5: Four slots of dimension (8.5 mm × 1 mm) are removed from the reduced ground plane which improves the impedance matching and proposed antenna characteristics is achieved.

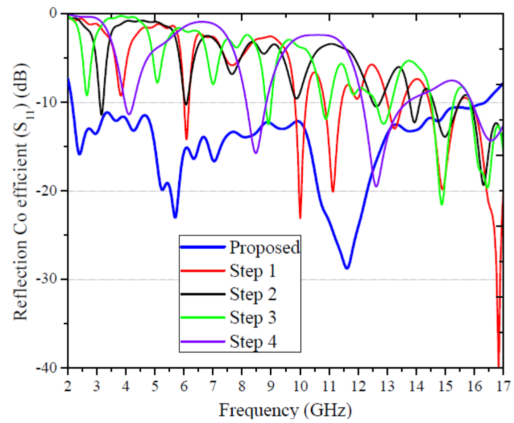


Fig. 4 – Reflection coefficient (S_{11}) of all design steps

4. ANTENA RESULTS AND DISCUSSIONS

Fig. 5 displays the suggested antenna's computed and measured reflection coefficient, S_{11}. An expansive impedance bandwidth of 13.7 GHz (ranging from 2.3 to 16 GHz), 149.7 % fractional bandwidth and BDR of 3215 are features of the antenna that is being showcased.

Fractional bandwidth has been calculated from the obtained result.

$$\%\ \text{Bandwidth} = \left(\frac{(F_H - F_L)}{F_C} \times 100\right)\%$$

Where the symbols (F_H, F_L, and F_C) signify their usual meanings.

$$\text{BDR} = \frac{\%\ \text{Bandwidth}}{\lambda_{\text{antennalength}} \times \lambda_{\text{antennawidth}}} = 3215$$

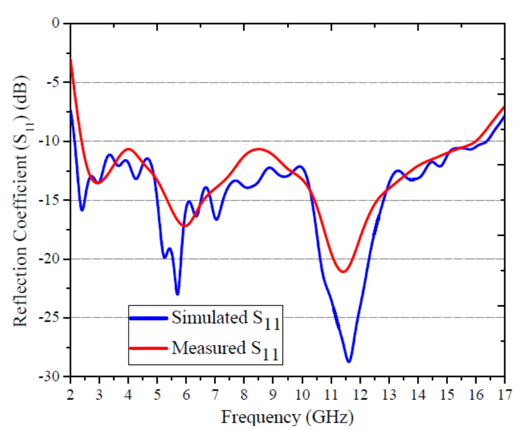


Fig. 5 – S_{11} parameter in dB for the prescribed antenna

Fig. 6 illustrates simulated and measured peak gain (dBi) of the recommended radiator. The antenna's normalized simulated and measured radiation pattern is displayed in Figures 7-8 for the *E* and *H* planes at 5.5 and 11.5 GHz resonant frequencies, respectively. Both simulated and measured results are very close to each other.

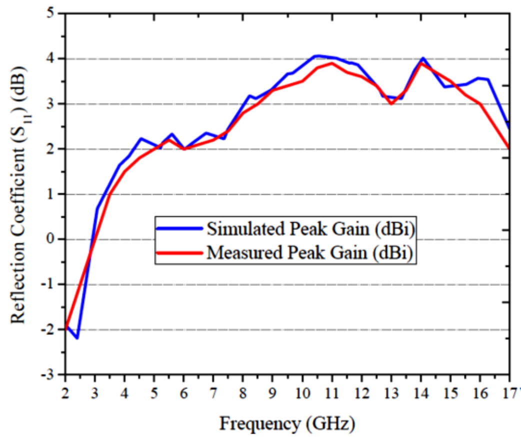
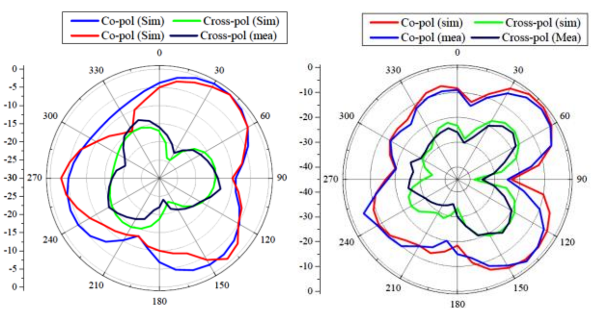
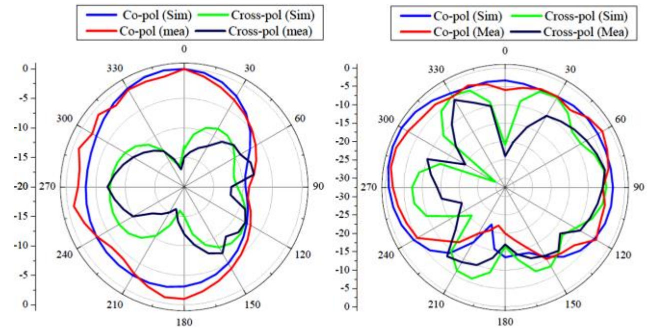


Fig. 6 – Peak gain of the proposed antenna



(a) (b)

Fig. 7 – Radiation patterns (*E*-plane) at (a) 5.5 and (b) 11.5 GHz



(a) (b)

Fig. 8 – Radiation patterns (*H*-plane) at (a) 5.5 and (b) 11.5 GHz

5. CONCLUSION

For wireless communication applications, a low-profile, broadband rectangular MPA with a reduced finite length ground plane and slot-loaded radiating patch is presented in this paper. The suggested antenna exhibits broadband characteristics (2.3-16 GHz) with 149.7 % percentage bandwidth and high BDR of 3215. Throughout the entire operating band, it exhibits consistent gain, high efficiency, and stable spatial distribution of radiationwith enough co-pol and cross-pol component separation. The proposed antenna is an appropriate choice for N78 (3.3-3.8 GHz), N77 (3.3-4.2 GHz), 3.5 GHz and N79 (4.7 GHz) (4.4-5 GHz) 5G communication applications, WiMAX band, WLAN band, C band, Wi-Fi band, remote sensing application in UWB, X band, Ku band wireless application due to its low profile structure, and acceptable radiation pattern.

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Гібридна мініатюрна надширокосмугова мікросмужкова антена для 5G застосувань та дистанційного зондування

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У роботі описується друкована мікросмужкова патч-антена (MPA) для дистанційного зондування, яка працює в надширокосмуговому (UWB) спектрі. Шляхом перетворення верхньої сторони традиційної прямокутної патч-антени на напівкруглу форму, а нижньої сторони – на форму сходів, створюється запропонована випромінювальна патч-антена. Фізичний та електричний об'єм представленої антени становить 33 × 24 × 1,6 мм^3 та $0.253\lambda_0 \times 0.184\lambda_0 \times 0.012\lambda_0$ відповідно. Запропонована антена розроблена, оптимізована та змодельована за допомогою програмного забезпечення Computer Simulation Technology (CST) Microwave Studio Suite. Антена розроблена на діелектричній підкладці FR4 товщиною 1,6 мм, має тангенс кута втрат 0,09, відносну діелектричну проникність 4,4 та виміряна за допомогою стандартного випробувального стенду для мікрохвильових хвиль. Параметри запропонованої антени підтверджують широку смугу пропускання імпедансу 13,7 ГГц (2,3-16 ГГц) з частковою смугою пропускання 149,7 % та коефіцієнтом розмірності смуги пропускання (BDR) 3215. У цьому діапазоні частот запропонована антена демонструє піковий коефіцієнт посилення 3,9 дБ. Крім того, для запропонованої антени досягається адекватне розділення кополяризації та крос-поляризації у всіх напрямках. Розроблена антена є компактною та легкою, демонструє стабільне посилення та сумісна з обладнанням бездротових систем. Антену надширокого діапазону (UWB) можна використовувати з поверхневим радіолокатором для виявлення вибухонебезпечних та небезпечних об'єктів під землею.

Ключові слова: BDR, Гібрид, Патч-антена, Надширокосмугова.