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Design of Multiple Band, Meandered Strips Connected Patch Antenna

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Abstract—In this paper, a compact printed monopole antenna for multiband communication application is designed and investigated. The multiband functionality is achieved by the combination of a rectangular radiating element with a pair of symmetrical meandered strip resonators. The proposed antenna works efficiently ($> 86\%$) with an optimally matching ($S_{11} < -10\,\text{dB}$) and adequate gain in the desired frequency bands centered at 4.27 GHz, 4.85 GHz and 6.45 GHz. The prototype of the antenna is fabricated to validate effectiveness of the proposed design. A good agreement between simulated and measured results is observed.

1. INTRODUCTION

Currently, the explosive growth of wireless communications has led to a prominent demand of multiband antennas to fulfill the requirements of multi-services systems. Worth noting in this respect that monopole designs are actually receiving considerable attention for such communication systems, since they are extremely simple in design, are conformable, have an appreciable radiation pattern as well as low loss factor [1]. The monopole geometry was used either to downsize the antenna or to generate multiband functionality. Thus, in the open literature, an appreciable interest is pointed toward multi-band monopole antennas design. In this regard, various methodologies are used to obtain the multiband functions. Multiple band antennas are designed in [2, 3] using lumped switches. In [4], an octagonal monopole antenna incorporating a dual L-slits and U slot for Spacecraft, WLAN, Wi-Fi, and Bluetooth applications is proposed. In [5], a triangular monopole with an etched rectangular slot and a pair of symmetrical L-shaped parasitic elements for WLAN and WIMAX applications is proposed. In [6], a monopole antenna with an etched Ω-shaped slot and a parasitic ring resonator for WLAN and WIMAX application is presented.

In [7], the multiband functionality is obtained by etching inverted multiple U-shapes. A C-shaped monopole antenna operating at 2.4 and 5.8 GHz bands is designed in [8]. Other useful shapes are also used for designing multiband antennas: In [9], an E-shaped monopole antenna for WLAN (2.4 and 5.2 GHz) application is proposed. An F-shaped antenna for RFID and WLAN applications is presented in [10]. A flower shaped patch and Split ring resonator (SRR) are used for achieving multiple bands in [11]. Multiple Split Ring Resonators (SRR) are used in [12] for dual band performance. Multiple resonance frequency antenna using Swastika metamaterial antenna is reported in [13].

In this paper, a printed triple-band monopole antenna is designed and experimentally validated. By the combination of the rectangular radiating element and a pair of meandered strip resonators,

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the newly proposed monopole antenna can operate in three frequency bands (4.25 GHz, 4.85 GHz, and 6.45 GHz). For good antenna optimization, the influence of some critical parameters on the reflection coefficient associated to the new design are realized and discussed. The designed antenna achieves good radiation characteristics in terms of gain and efficiency.

2. ANTENNA DESIGN METHODOLOGY

Figure 1 shows the configuration of the proposed triple band monopole antenna. The radiating element is printed on a 1.6-mm thicker FR-4 substrate with a relative permittivity of 4.5 and a loss tangent of 0.019. The designed antenna consists of a pair of meandered strips each linked to the rectangular radiating element. To feed the antenna, a 50 Ω microstrip line is used. The detail dimensions of the antenna's associated parameters are presented in Table 1.

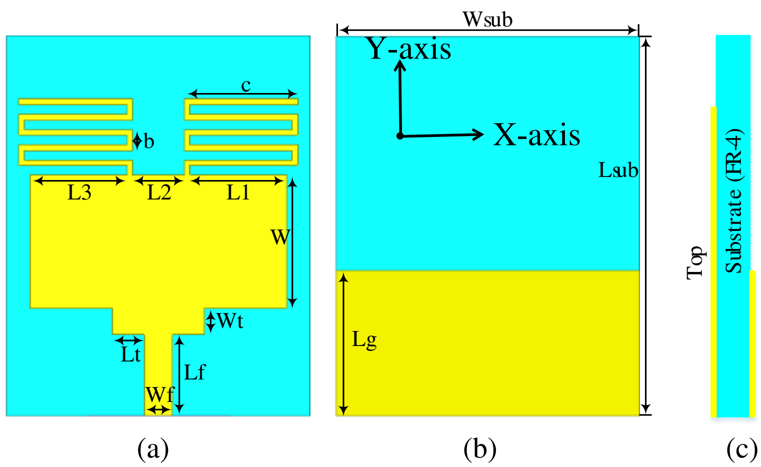

Figure 1. Figure of the Proposed monopole antenna. (a) Top view. (b) Bottom view. (c) Side view.

Table 1. Different parameters and values of the antenna.

Parameter	Value (mm)	Parameter	Value (mm)
$Wsub$	32	Wf	3
$Lsub$	40	Lf	8.5
Lg	15.27	Lt	2.35
$L1$	10.2	Wt	2.81
$L2$	5.4	W	14
$L3$	10.2	b	2.2
C	12		

The design procedure of the triple band antenna as depicted in Fig. 2 includes three steps. Firstly, a monopole antenna with a rectangular radiating element associated to a microstrip feed line is designed to operate at a single band at approximately 4.8 GHz with an S_{11} lower than −10 dB.

Secondly, two meandered radiating arms each linked to the rectangular radiating element are introduced. Consequently, as appears in Fig. 3 a second resonance at about 7 GHz appears while the resonant frequency of the lower band is shifted towards the lower frequencies. Finally, by increasing the number of the meandering strips, a third resonance at about 6.45 GHz is induced. Then, the antenna's structures need careful optimization to resonate at targeted frequencies with good performances. In this respect, the antenna's associated parameters were adjusted in order to get the desired resonance at the target frequencies (4.27 GHz, 4.85 GHz and, 6.45 GHz) and to fulfill the design goals.

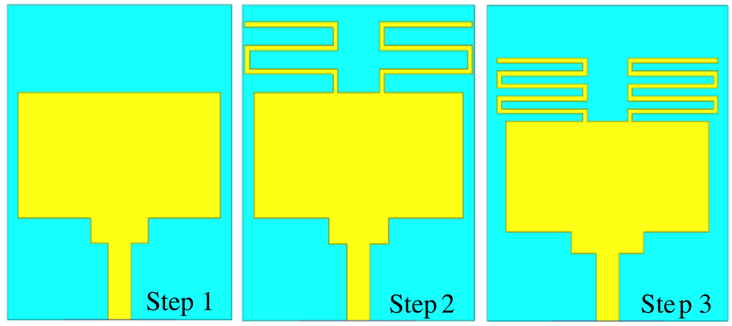

Figure 2. Designing steps for the proposed antenna.

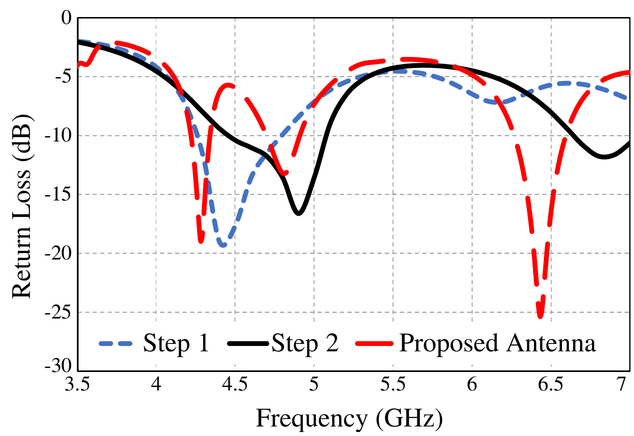

Figure 3. Return loss for the designing steps against frequency.

Prior to fabrication and measurement of the antenna model, precisely designed and optimized antenna simulations should be initially realized. The antenna simulations were performed using ANSYS High Frequency Structural Simulator (HFSS) software [14].

The resonant frequencies and bandwidths of the proposed design depend on the physical dimensions of its associated parameters. Therefore, the influences of these parameters are investigated in the Fig. 4.

To study the effect of "wt", some arbitrary values may be considered. Fig. 4(a) shows the reflection coefficient curves for different values of "wt" ($wt = 2.31, 2.81, 3.31, 3.84$ mm). It can be seen that varying "wt" induces a noticeable change in the antenna's bandwidths. Increasing "wt" from 2.31 mm to 3.81 mm enhances the higher band as well the matching effectively at this band. Moreover, the increase in "wt" dimension decreases the middle bandwidth and deteriorates the matching at this band. In addition by increasing "wt", the lower band showed little effect on its center frequency and no change in its bandwidth.

The study of "lt" variation is presented in Fig. 4(b). As highlighted in the figure, with increasing "lt" from 2.31 mm to 3.81 mm, the center frequency belonging to each band is slightly decreased. At the same time, the matching is deteriorated at the higher band. The variation of S_{11} with different "c" values is plotted in Fig. 4(c). It is clear from the figure that any variation in the "c" parameter affects simultaneously all bands of interest. In addition, this variation highly influences the matching of the middle band. Fig. 4(d) shows the reflection coefficient curves for the four values of "b" length ($b = 0.5, 1, 1.5$ and 2 mm). It can be seen that varying "b" values influence the matching at the lower, middle and higher band. Yet, with increasing "b" length from 0.5 mm to 2 mm, the bandwidth at the lower band becomes narrower. Also with increasing "b" length, the middle band is very slightly affected except with $b = 2$ mm where the center frequency is shifted downward and the bandwidth is enhanced.

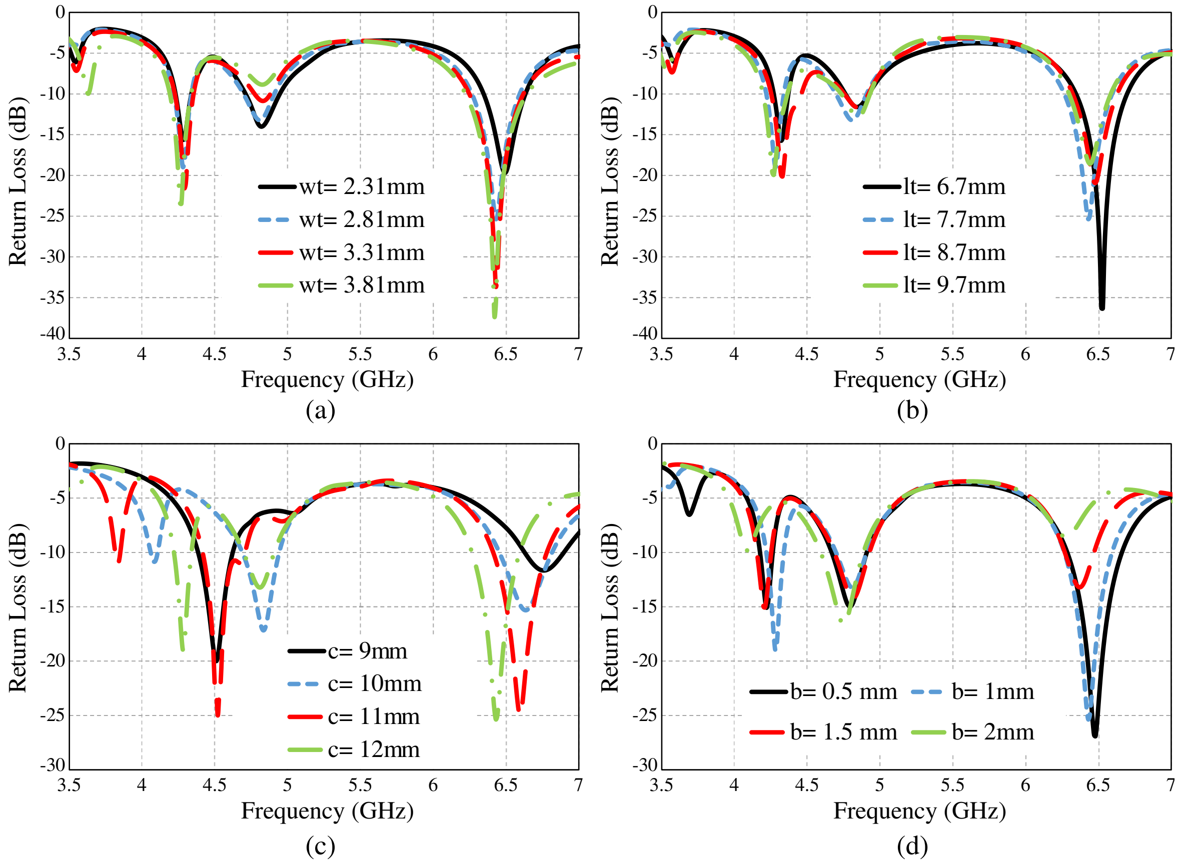

Figure 4. Return loss against frequencies for varied parameter. (a) "*wt*". (b) "*lt*". (c) "*c*". (d) "*b*".

3. RESULTS AND DISCUSSIONS

In this section, simulated and experimental results are presented to evaluate the effectiveness of the proposed design. The reflection coefficient of the antenna was measured using Vector Network Analyzer (VNA) and the radiation patterns were tested in the Anechoic chamber.

Figure 6 shows the measured and simulated return losses for the fabricated prototype antenna (Fig. 5). A reasonable agreement is shown between the simulated results and measured ones. The small

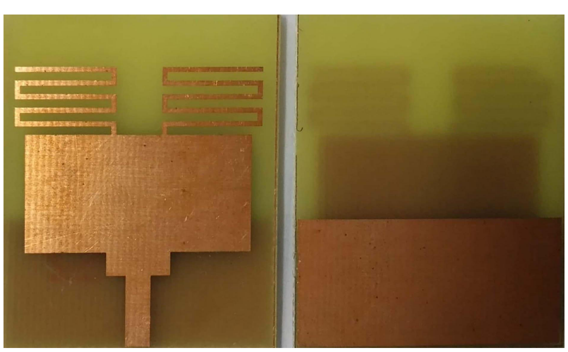

Figure 5. Fabricated antenna according to the parameters defined in Table 1.

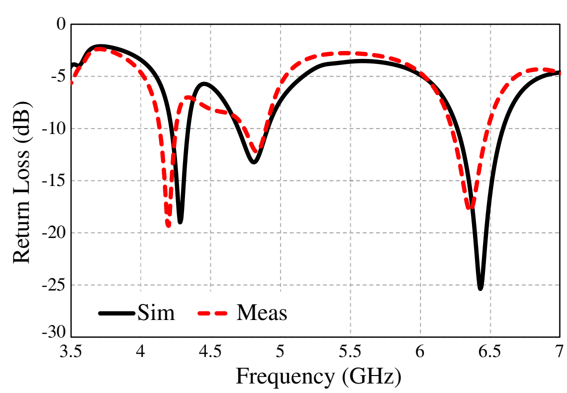

Figure 6. Simulated and measured return loss comparison.

discrepancy is due to the fabrication tolerance. The measured bandwidths are 120 MHz, spanning the entire range from 4.15 to 4.27 GHz for the lower band; 160 MHz, which covers the frequency range from 4.74 to 4.9 GHz for the middle band; and 250 MHz, covering the frequency range from 6.23 to 6.48 GHz for the higher band.

The performance mechanism of the proposed triple band antenna can be understood through the analysis of its surface current distribution at the targeted frequencies. The current distributions at 4.27 GHz, 4.85 GHz and 6.45 GHz are shown in Fig. 7. At 4.27 GHz, the current distribution as shown in Fig. 7 is maximum through the entire feed line as well as the rectangular radiating element. Concerning the 4.85 GHz, the lower side of the symmetrical meandered resonators linked to the rectangular radiating element has more current concentration. As appears in Fig. 7 the surface current becomes more concentrated on all parts of the symmetrical meandered resonators for frequency of 6.45 GHz.

Figure 8 illustrates the gain and efficiency of the proposed design at the three bands of interest. The simulated peak gain is 1.76 dB, 2.3 dB and 1.45 dB at 4.27 GHz, 4.85 GHz and 6.45 GHz respectively. As shown in the figure, the antenna radiates highly efficiently in the three frequency bands with a simulated radiation efficiency $> 86\%$.

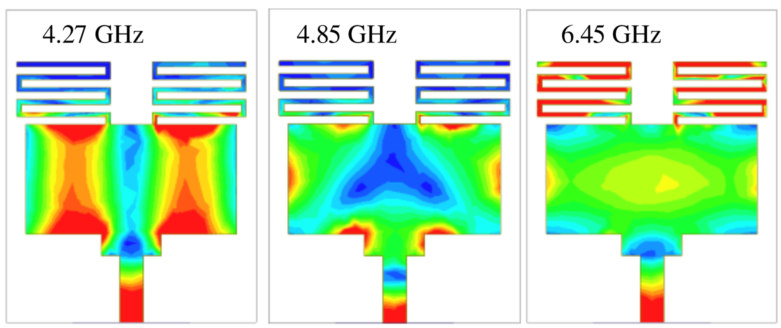

Figure 7. Surface Current Density (Jsurf) for resonant frequencies at 4.27, 4.85 and 6.45 GHz.

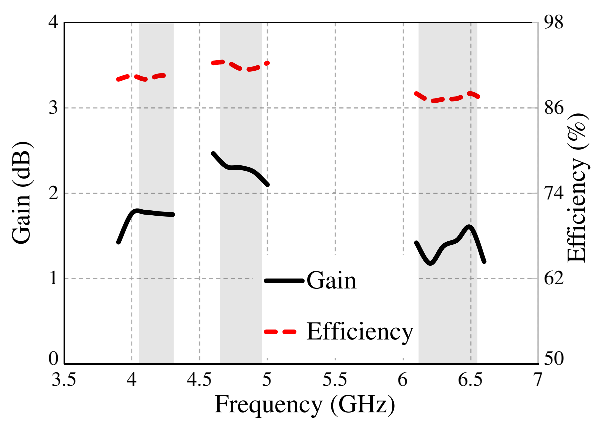

Figure 8. Gain and efficiency of the proposed antenna against frequencies.

Further study in terms of radiation characteristics of the proposed antenna has also been highlighted. Fig. 9, Fig. 10 and Fig. 11 exhibit the simulated and measured far-field radiation patterns in both planes Phi = 0° and Phi = 90° for 4.27 GHz, 4.85 GHz and 6.45 GHz respectively. As depicted in Fig. 9, the main lobe is directed towards 0° at 4.27 GHz in elevation plane while it is directed towards 30° in the azimuth plane. At 4.85 GHz the radiation patterns as depicted in Fig. 10 in both planes (elevation and azimuth planes) are almost omnidirectional. Concerning the 6.45 GHz, the antenna as depicted in Fig. 11 presents four lobs at 0°, 90°, 180° and 270° in azimuth plane while, it radiates predominantly as a distorted 'figure of eight' in the vertical or E plane.

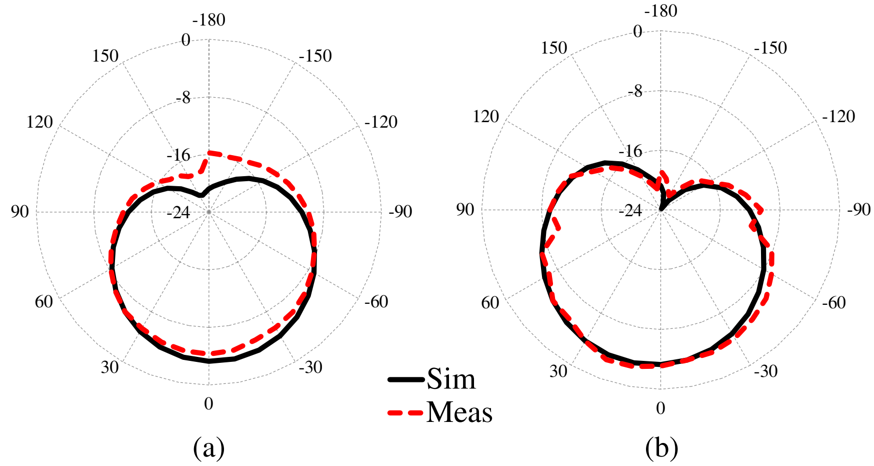

Figure 9. Radiation pattern at 4.27 GHz for (a) Phi = 0°, (b) Phi = 90°.

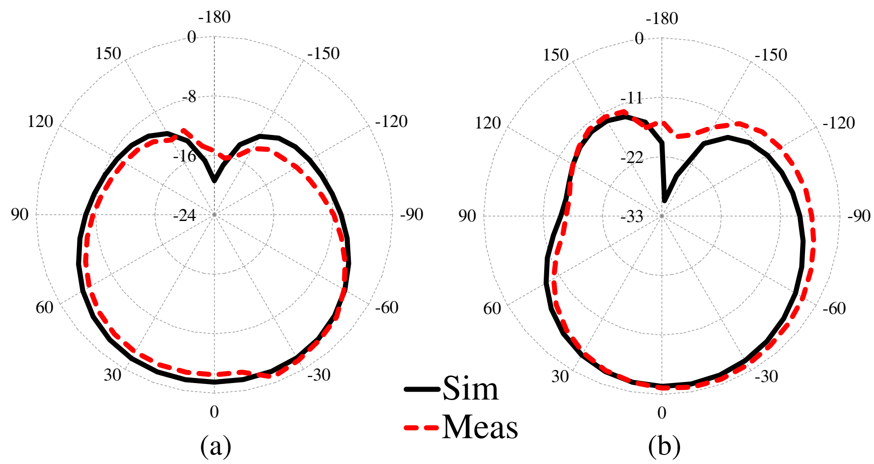

Figure 10. Radiation pattern at 4.85 GHz for (a) Phi = 0°, (b) Phi = 90°.

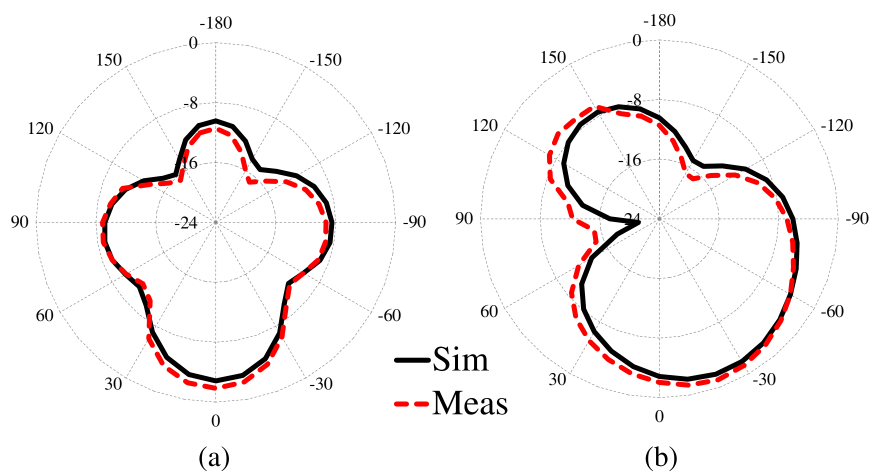

Figure 11. Radiation pattern at 6.45 GHz for (a) Phi = 0°, (b) Phi = 90°.

4. CONCLUSION

A compact printed monopole antenna for triple band operation has been proposed and studied. The proposed antenna resonates at 4.27 GHz, 4.85 GHz and 6.45 GHz. The triple band operation has been realized by the combination of a rectangular radiating element with a pair of meandered strip resonators. The proposed antenna presents good radiation characteristics at all resonant frequencies with peak gain around 1.76 dB at 4.27 GHz, 2.3 dB at 4.85 GHz and, 1.45 dB at 6.45 GHz. A prototype of the proposed multiband antenna has been successfully designed, fabricated, and measured. Measured results show good agreement with the simulated ones.

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