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A Compact Triple Band Metamaterial Inspired Antenna using SRR and Hexagonal Stub for UMTS, WLAN, and WiMAX Applications in S/C Bands

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Abstract

A compact triple band metamaterial (MTM) inspired antenna using split ring resonator (SRR) and hexagonal stub acting as a virtual ground for UMTS, extended UMTS, WLAN, and WiMAX applications in S/C Bands is presented here. The physical dimension of the projected antenna is 28 × 20 × 1.6 mm^3. Due to MTM loading, compactness (ka = 0.79 < 1) is achieved resulting the electrical dimension as 0.14 λ_0 × 0.20 λ_0 × 0.011 λ_0 ,where λ_0 is calculated at 2.20 GHz. The antenna gives triple band from (2.12–2.31 GHz), (2.54–2.94 GHz), and (5.27–5.71 GHz) with -10 dB impedance bandwidths of 8.68%, 14.50%, and 8.01% respectively. The simulated gain of 2.41 dBi, 2.37 dBi, and 5.50 dBi are obtained at the center frequency of 2.20 GHz, 2.76 GHz, and 5.49 GHz respectively. The designed triple band MTM antenna has the advantages of easy fabrication, miniaturization, and low profile, which is suitable for various wireless mobile communication protocol like 2.2 GHz UMTS, extended UMTS, 5.8 GHz WLAN, and 5.5 GHz WiMAX applications in S/C bands.

1. Introduction

In the modern age of wireless communication, compact, low profile, economic and multi-band antennas are very essential to be used in laptops and mobile phones. For traditional microstrip antennas, the minimum resonant length required for radiation is around half the guided wavelength. This leads to the increased size of the antenna. On the other hand, loading MTM structures to microstrip antenna, compact and multiband antennas can be realized. MTMs are artificial electromagnetic periodic structures having negative ε and μ concurrently and it shows unusual property like Zeroth order resonance (ZOR), which is not possible for existing right-handed materials [1]. SRR is excited with proper magnetic field orientation, resulting in negative μ region. By merging different resonating modes of the antenna, multiband can be achieved. Different resonating elements like closed ring resonator (CRR), SRR, complimentary split ring resonator (CSRR), and complimentary closed ring resonator (CCRR) are used for obtaining extra mode in the antenna structure. An ENG-TL based MTM antenna [2,3], triple band MTM loaded antenna [4], complementary capacitive loaded loops [5], wideband MTM antenna [6], MTM antenna with EBG and ELC loading [7], and ultrawideband antenna with triple band-notched characteristics [8], and ENG-TL loaded multiband antenna [9] are explained in literature.

In this work, a compact triple band MTM inspired antenna using SRR and hexagonal stub which acting as a virtual ground for UMTS, extended UMTS, WLAN, and WiMAX applications in S/C bands is presented. The suggested antenna mainly incorporate an L-shaped partial ground plane for the improvement of input reflection coefficient and a rectangular shaped SRR with a small gap at one end. All the simulations and analysis are performed in CST microwave studio and HFSS and a comparative study of different parameters of the intended antenna are made with respect to previously published triple band MTM antennas found in the literature.

2. Antenna Geometry and Design

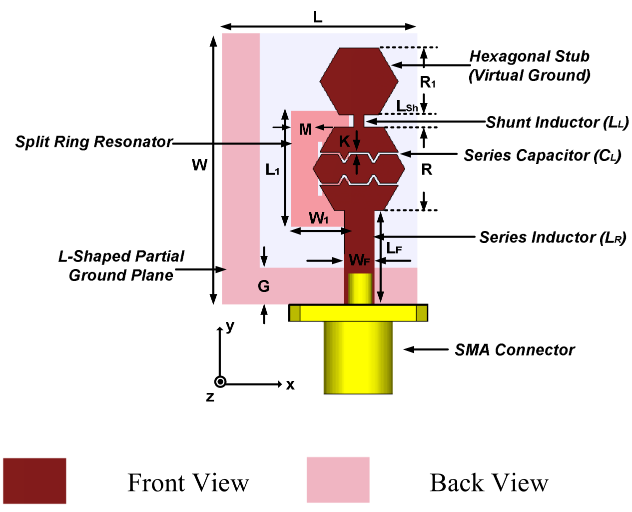


Figure 1. Simplified view of the designed MTM inspired antenna using SRR, partial ground and hexagonal stub.

The designed triple band MTM antenna is shown in Figure 1. The whole structure is designed on a low-cost FR-4 substrate with height h = 1.6 mm, dielectric constant ε_r = 4.4, and loss tangent $tan\ \delta$ = 0.02. The length and width of the substrate are L = 20 mm and W = 28 mm respectively. On the top of the substrate, a microstrip line feed of width

W_f = 3 mm and length L_f = 10 mm is used for 50 Ω impedance matching. Then to realize MTM loading of composite right/left-handed transmission line (CRLH-TL) approach, a hexagonal shaped patch of length R = 8.66 mm is used. On this patch, two saw-tooth shaped slots are realized. The gap between the two slots is k = 0.3 mm. To the other end of the hexagonal patch, a metallic stub of length L_{sh} = 1.21 mm is used, which is further connected to a hexagonal shaped stub of length R_1 = 6.92 mm. This stub acts as a virtual ground on the top patch of the proposed antenna. On the other side of the substrate, an L-shaped partial ground of width G = 3.8 mm is used for the improvement of the input reflection coefficient. A rectangular shaped SRR of length L_1 = 12 mm, width W_1 = 6 mm and the concentric gap of M = 3.2 mm is designed.

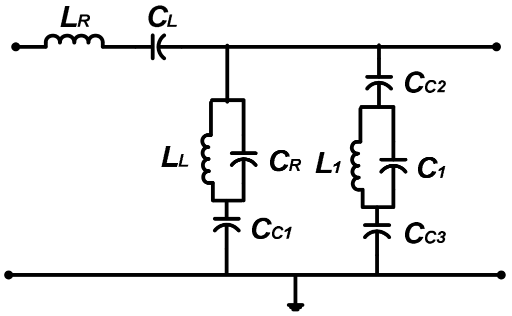


Figure 2. Equivalent circuit diagram of the presented MTM antenna

The equivalent circuit representation of the designed MTM antenna is depicted in Figure 2. The microstrip feed line acts as a series inductor represented by L_R. The two saw-tooth slots on the hexagonal patch act as two capacitors connected in series and the net series capacitance is denoted as C_L. The metallic patch which is connected to the other end of the hexagonal patch represents shunt inductor (L_L) and the coupling between top and bottom patch gives shunt capacitance (C_R). C_{C1} shows the coupling between the hexagonal stub and L-shape ground plane. The SRR is represented by L_1 and C_1. To the SRR, two capacitors C_{C2} and C_{C3} are connected, which represents the coupling between SRR and L-shaped ground and coupling between hexagonal patch, L-shaped ground and SRR respectively.

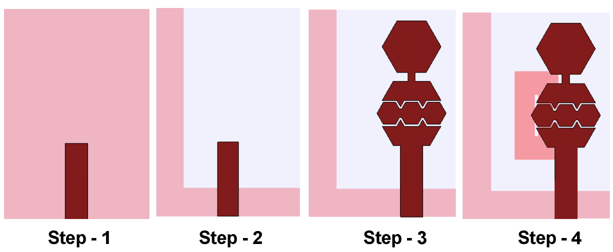


Figure 3. Design steps for the generation of triple band MTM antenna.

Figure 3 shows the four steps involved in constructing the presented antenna. Step-1 shows only a microstrip patch having a full ground plane on the back side of the substrate. Step-2 shows the microstrip patch having an L-shaped partial ground plane. The MTM concept using CRLH-TL is loaded in step-3. Step-4 is our proposed antenna, which incorporates a rectangular SRR and an L-shaped ground. Figure 4 depicts the input reflection coefficient of these four steps.

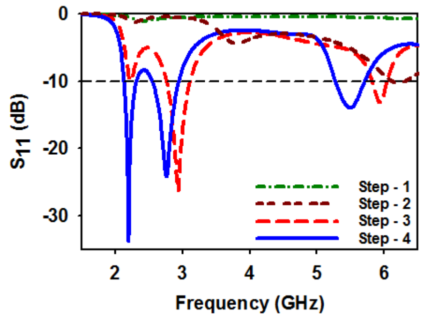
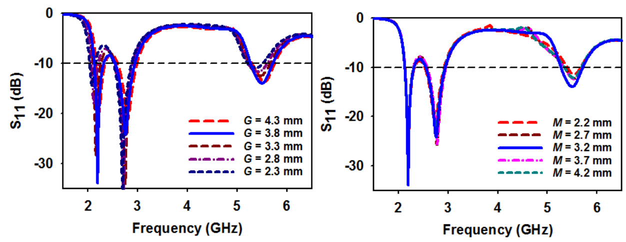


Figure 4. Simulated return loss (S_{11}) of the designed MTM antenna at various design steps.



(a) (b)

Figure 5. Simulated $S_{11}$of the intended tri-band MTM antenna by varying (a) the width *(G)* of the L-shaped partial ground plane, and (b) the width *(M)* of the SRR.

3. Results and Discussions

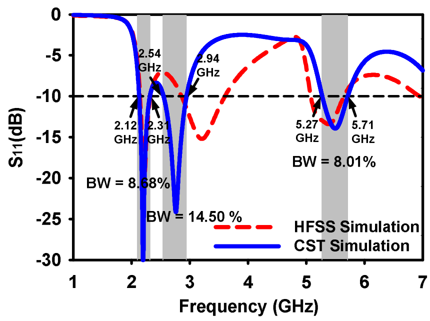


Figure 6. Simulated return loss (S_{11}) of the presented MTM triple band antenna using HFSS and CST.

Figure 5(a) exhibits the variation of the width G of ground plane from 4.3 mm to 2.3 mm and the optimized result is obtained at G = 3.8 mm. Figure 5(b) exhibits the variation of S_{11} with respect to the variation of the gap (M) of the SRR and the optimized value is M = 3.2 mm. Figure 6 shows the input reflection coefficient (S_{11}) of the antenna simulated in CST and HFSS. A slight shift in the second resonance when simulated in HFSS. It shows that three bands are obtained from (2.1–2.31 GHz), (2.54–2.94 GHz) and (5.27–5.71 GHz) at 2.20 GHz, 2.76 GHz and 5.49 GHz as center frequency resulting -10 dB impedance bandwidth of 8.68%, 14.50%, and 8.01% respectively.

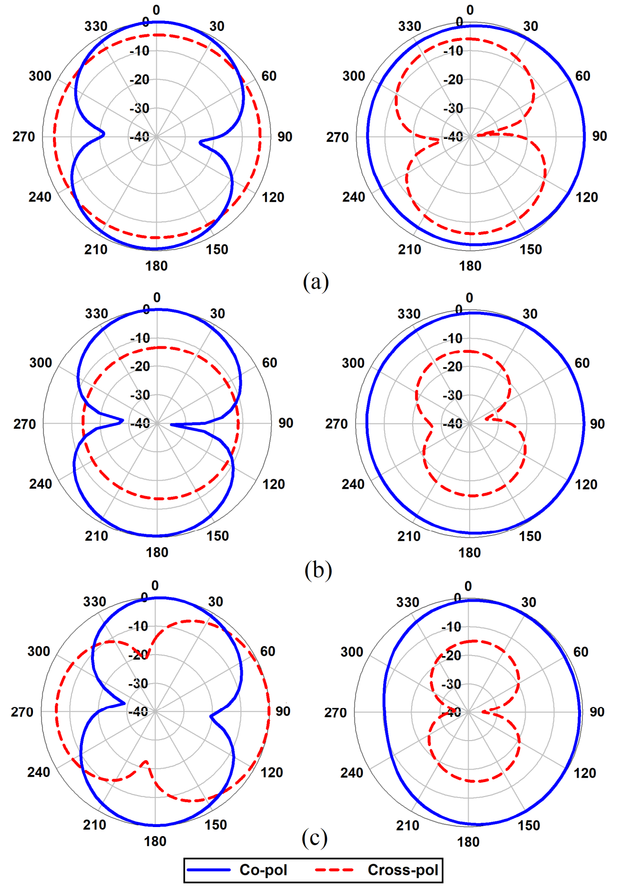


Figure 7. Simulated radiation pattern of the intended MTM antenna in CST microwave studio at (a) 2.2 GHz, (b) 2.76 GHz, and (c) 5.49 GHz respectively.

Figure 7 shows the normalized two-dimensional radiation pattern of the proposed antenna at 2.2 GHz, 2.76 GHz, and 5.49 GHz in *xz*–plane and *yz*–plane respectively. For *xz*–plane bidirectional radiation pattern and in *yz*–plane nearly omnidirectional radiation pattern are observed. The cross-polarization level is lower than the respective co-polarization in the direction of maximum radiation so that the antenna is suited for different wireless communication applications. The gain and radiation efficiency of the intended antenna is shown in Figure 8. It depicts a fair gain of (1.03–2.55 dBi), (2.33–2.43 dBi) and (4.70–5.65 dBi) with an average gain of 2.41dBi, 2.37dBi, and 5.50dBi at the frequency of 2.2 GHz, 2.76 GHz, and 5.49 GHz respectively. An efficiency of 90.50%, 93.46%, and 90.43% are observed for the first, second and third bands respectively. A comparative analysis of different parameters of the designed antenna is made with respect to previously published triple band MTM antennas found in literature and is depicted in Table. 1.

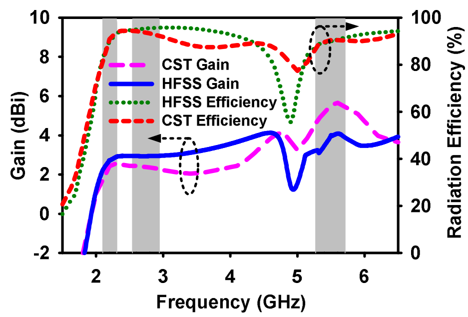


Figure 8. Simulated gain and radiation efficiency of the designed MTM antenna using CST and HFSS.

Table 1. Comparative analysis of presented MTM antenna with previously published triple band MTM antennas.

Ref. No.	Freq. (GHz)	Antenna Size (mm)	Electrical size (λ_0)	*Ka* value	Impedance BW (%)	Gain (dBi)	Type	Applications
[4]	2.45	20 × 23.5 × 1.59	0.16 × 0.19 × 0.013	0.77	3.6	1.14	CPW	WiFi, WiMAX
	3.50				17.71	1.15		
	5.5				32.72	1.78		
[5]	2.50	70 × 78.5 × 0.8	0.58 × 0.64 × 0.006	2.7	22	1.4	Microstrip	WLAN, WiMAX
	3.50				17	3.85		
	5.50				17	4.55		
[6]	3.05	30 × 30 × 1.6	0.3 × 0.3 × 0.016	1.35	5.90	1.6	Microstrip	WLAN
	4.90				45.91	3.4		
	8.25				30.30	4.1		
[7]	2.50	35 × 35 × 1	0.29 × 0.29 × 0.008	1.29	2.4	NA	Microstrip	WLAN, WiMAX
	3.50				19.42			
	5.50				18.36			
[8]	3.50	50 × 50 × 1.52	0.58 × 0.58 × 0.017	2.59	NA	NA	CPW	WLAN, WiMAX
	5.80							
	7.50							
Prop. Ant.	2.20	20 × 28 × 1.6	0.14 × 0.20 × 0.011	0.79	8.68	2.41	Microstrip	UMTS, WLAN, WiMAX
	2.76				14.50	2.37		
	5.49				8.01	5.50		

Note: The electrical size of some antenna configurations in the above table is determined on the basis of their corresponding wavelength. In some papers, electrical size, *ka* value, and overall antenna size are not given directly and these are calculated according to the proposed antenna design.

4. Conclusion

A compact, low profile triple band MTM inspired antenna using L- shaped partial ground plane, hexagonal stub and SRR is designed and different antenna parameters are analyzed. The antenna provides triple band with impedance bandwidths of 8.68%, 14.50%, and 8.01% respectively. The gain of the designed antenna is 2.41 dBi, 2.37 dBi, and 5.50 dBi and the radiation efficiency is 90.50%, 93.46%, and 90.43% at the center frequency of 2.2 GHz, 2.76 GHz, and 5.49 GHz respectively. The antenna achieves compactness (ka = 0.79 <1) due to MTM loading and the electrical size of the antenna is 0.14 $\lambda_0 \times 0.20\ \lambda_0 \times 0.011\ \lambda_0$, where λ_0 is calculated at 2.20 GHz. Due to this compact size, it can be easily integrated with the mobile handset and can be used for different wireless applications like 2.2 GHz UMTS, extended UMTS, 5.8 GHz WLAN, and 5.5GHz WiMAX.

5. Acknowledgements

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