A Low-Profile Quadruple Band Rejected UWB Circular Monopole Antenna using EBG Structures

V.Saritha, C. Chandra Sekhar, B. Teertha Priyanka

Abstract*: This work presents analysis and design of a low-profile quadruple band rejection UWB circular monopole. The band reject features can be obtained by using EBG structures as well as etching an inverted C shape slot in the radiating patch. The band rejection characteristics of an antenna operating in UWB are necessary to avoid interference with narrow bands having frequencies such as (2.43 – 2.65) GHz – Bluetooth, (3.2 – 4.1) GHz – WiMAX, (5.1 – 5.9) – WLAN, (6.6 – 7.4, 7.4 – 8.2) GHz – WPAN and X-Band satellite communication (both Uplink & Downlink). The proposed antenna comprises to have compact dimensions of about 46 x 26 x 1.6 mm^3 with a volume of 1913.6 mm^3. The simulations are carried out by using HFSS. The designed antenna is fabricated and the corresponding results are Measured and validated. It is found that both the results are significantly matched.

Keywords: quadruple band, EBG structures, slots.

I. INTRODUCTION

Ultrawide band spectrum which has a frequency ranging from 3.1 GHz to 10.6 GHz acts as an unlicensed spectrum. As such this UWB region has been extensively used for a wide number of applications. Due to various advantages like low cost, higher bandwidth, high data rates and lower power consumption, UWB antennas are being widely in use. In the recent years, many antennas have been designed and analyzed with different band rejection techniques to eliminate the interference caused by the widely used narrow band wireless technologies such as S-Band, INSAT frequencies, WPAN, C-Band, WLAN, WiMAX and X-Band uplink and X-Band downlink that are within the same bandwidth range of UWB technology. Mahendra M. Sharma, etal. Proposed a planar UWB antenna in which the quad band notch characteristics are achieved by using a nested C-shaped slot and a U-shape slot in the radiator and at the center of microstrip feed line respectively. The corresponding band notch center frequencies obtained are at 2.5, 3.7, 5.8 and 8.2 GHz [1]. D.O. Kim, et.al. employed the Complementary Split Ring Resonance (CSRR) method has been to attain band reject characteristics. Here to achieve the WLAN/WiMAX 5GHz band rejection, CSRRs have been embedded in the antenna feeding location and to obtain band rejection performance

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***** Correspondence Author

V.Saritha*, Research scholar, Department of ECE, JNTUA, Anantapur, India.

Dr.C.Chandrasekhar, Department of ECE, SV Engineering College, Tirupati, India.

B. Teertha Priyanka, Department of ECE, V R Siddhartha Engineering College, Vijayawada, India.

the ITU 8 GHz, a CSRR having a split gap at the base part of the radiation patch is considered. The center frequency of the outer and inner ring corresponds totally to the rejection bands of 3.5 GHz WiMAX and 2.4-2.6 GHz WiMAX /WLAN /SDMB correspondingly. An optimized quadruple band reject co-planar waveguide (CPW) ultrawide band (UWB) antenna has been presented [3]. The band rejection features of downlink C-band (3.70 - 4.20) GHz and S-band (2.70 - 3.10) GHz are obtained by including an extended stub and L-shape slot on the back plane of the antenna and cutting horizontal slot and meander-line in the radiating surface. Here rejection in WLAN (4.90 - 5.75) GHz, and WPAN (6.60 - 7.40) GHz is also obtained. Xiaoyin Li etal., proposed a miniaturized printed quadruple band rejection UWB antenna where a C-shaped strip of parasitic element has been used to obtain a notched band at (8- 8.5) GHz which is the ITU band, an inverted U-shaped slot and two C-shaped slots etched in the radiating surface are designed to obtain triple notched bands at (5.7- 5.8) GHz, (5.1 - 5.3) GHz, and (7.2 - 7.7) GHz for filtering the X-band satellite and WLAN signals [4]. In [5], by etching 4 U-shape slots in the radiating surface, quadruple band rejected characteristics in the WiMAX, INSAT lower WLAN and higher WLAN are achieved. Raed Abdulkareem A, etal., have proposed a quadruple band rejection ultra-wideband antenna to function on the scientific, medical and industry bands where a band is notched at 3 GHz for WiMAX and a band that is resonant at 2.45 GHz for ISM are obtained by employing a meander line strip. An inverted diamond-shaped slot and a 2 F-shape slots on the patch were used to notch the WLAN and a couple of J-shape slots are etched on the bottom plane to reject downlink X-Band [6]. In [7], a CPW fed printed planar circular patch antenna has been proposed where by inserting 2 C-shaped slots, band notch is obtained at 3.9 GHz & 5.4 GHz for WiMAX and WLAN respectively and to attain a third notch band at 8.2 GHz a U-shaped slot is engraved in the feed line and the fourth notch at 7.27 GHz is obtained by placing a CSRR in the ground. G Shrikanth Reddy, etal. proposed a Compact Bluetooth and UWB Dual-Band Antenna where the proposed antenna design is implemented by using a rectangular spiral structure for quadruple notched bands i.e., WiMAX, WLAN, and ITU [8]. In [9], by implementing complementary split ring resonators on the semi-circular surface, the notching of various bands within the UWB band such as the INSAT, WiMAX and upper and lower WLAN have been obtained.

The above papers provided quad band notch characteristics and used different techniques to obtain these band notch frequencies.

This paper proposes a very low-profile circular monopole antenna with notches at (2.43 – 2.65) GHz – Bluetooth, (3.2 – 4.1) GHz – WiMAX, (5.1 – 5.9) –

WLAN, (6.6 – 7.4, 7.4 – 8.2) GHz – WPAN and X-Band satellite communication frequencies correspondingly.

II. ANTENNA CONFIGURATION

The designed Quadruple - notched strip fed circular monopole antenna's dimensional details and structural configuration are shown in Figure 1. This antenna is printed on FR -4 substrate with ε_r of 4.4 and δ = 0.024.

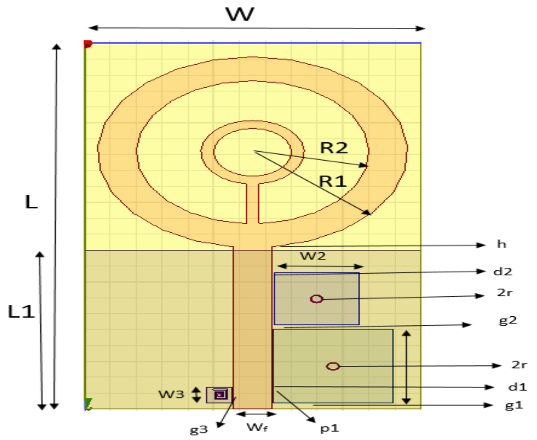

Fig 1: Dimensions of antenna along with structural configuration

The antenna comprises a circular radiating surface which is fed by a microstrip line which is shown in Fig 1.
Since the designed patch is considerably a circular loop, the actual radius of the patch is given by the following formula

$$a = \frac{F}{\left\{1 + \frac{2h}{\pi \varepsilon_r F}\left[\ln\left(\frac{\pi F}{2h}\right) + 1.7726\right]\right\}^{1/2}}$$

$$F = \frac{8.791\ x\ 10^9}{f_r\sqrt{\varepsilon_r}}$$

The effective radius of circular patch is given by the formula

$$a_e = a\left\{1 + \frac{2h}{\pi \varepsilon_r a}\left[\ln\left(\frac{\pi a}{2h}\right) 1.7726\right]\right\}^{1/2}$$

The resonant frequency is given by the formula

$$(f_r)_{110} = \frac{1.8412 v_0}{2\pi a_e \sqrt{\varepsilon_r}}$$

Three Mushroom shaped EBG structures which are frequency selective surfaces, of different sizes corresponding to their notched frequencies are placed nearer to the feed line for providing notched bands at different frequencies as mentioned above. The equivalent circuit of EBG structures is an *LC* filter where *C* is due to a gap between the EBG structure and feed or gap between the adjacent EBG structures and *L* accounts for current flow through the via that is connecting EBG structure and ground plane. The relation of electrical parameters to the physical parameters for mushroom EBG structure is formulated in equations. The corresponding sizes of the EBG structures at the different notched frequencies are calculated using these equations

$$L = 0.2h\left[\ln\left(\frac{2h}{r}\right) - 0.75\right]$$

$$C = \varepsilon_0 \varepsilon_r \frac{w^2}{h}$$

$$\omega_0 = \frac{1}{\sqrt{LC}}$$

where *L* indicates the inductance and *C* indicates the capacitance associated with mushroom EBG structure.

The designed antenna has defected ground structure for proper rejection, to suppress out of band harmonics and its dimensions are found by using the following equations.

$$L(g) = 6h + L$$

$$W(g) = 6h + w$$

Here *w* represents the width of mushroom EBG structure, *h* the height of antenna, *r* represents the radius of via for the mushroom shaped EBG structures, ε_0 represents the free space permittivity, ε_r is the relative permittivity of the material and ω_0 is the resonant frequency of antenna structure.

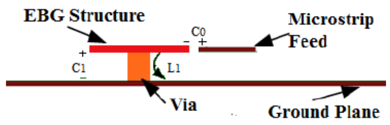

Fig 2: Mushroom EBG structure

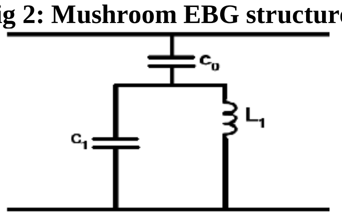

Fig 3: Mushroom EBG equivalent circuit

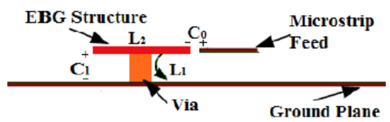

Fig 4: A compact spiral slotted EBG structure (CSS-EBG)

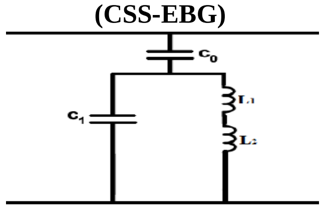

Fig 5: Equivalent circuit of CSS-EBG

In the mushroom EBG structures and CSS-EBG structure inductor L_1 results current flow from thin connecting plates of the EBG cell to the ground plane through the via and capacitance C_0 results from the gap between the EBG structure and feed, capacitance C_1 results from the gap between EBG structure and ground plane. In CSS-EBG structure, L_2 represents the inductance in series with L_1 due to the spiral slotted structure placed in the top plane of CSS-EBG cell as depicted in figure 5.
The optimized dimensions of the antenna structure are calculated and are provided in the table 1 shown below.

Table 1: Dimensions of the antenna.

Antenna Parameters Value (mm)	Value(mm)
Circular disc radius (R1)	12
Radius of inner circular disc (R2)	8
Length of ground plane (L_1)	20
Width of substrate (W)	26

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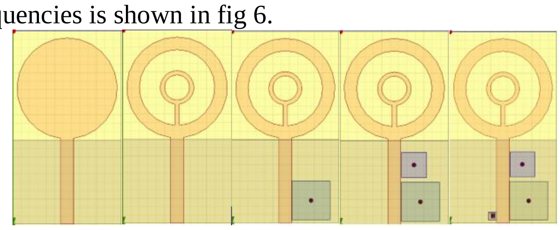
Length of substrate (L)	46
Feed line width (W_f)	3.0
Separation between circular patch & ground (h)	0.30
Radius of the vias of EBG 1 and 2 (r)	0.50
Radius of via of CSS-EBG 3 structure (r_1)	0.25
Separation between feed line and EBG 1 (g_1)	0.750
Separation between EBG 1 and EBG 2 (g_2)	1.15
Separation between feed and CSS-EBG structure(g_3)	0.750
Separation between feed line & EBG 1 (d_1)	0.10
Separation between microstrip feed line & Mushroom EBG 2 (d_2)	0.20
Separation between feed line and EBG 3 (d_3)	0.05
Side of EBG 1 (W_1)	9.25
Side of EBG 2 (W_2)	6.0
Side of CSS-EBG (W_3)	2

III. EVOLUTION AND RESULTS OF ANTENNA

Design of the antenna includes different stages. This evolution of antenna for obtaining notches at desired frequencies is shown in fig 6.



Stage 1 Stage 2 Stage 3 Stage 4 Stage 5

Fig 6: Evolution of the proposed antenna

Stage 1 consists of only a circular patch antenna fed by a microstrip line and a defected ground in order to improve stop band and pass band characteristics. Stage 1 is designed so that the antenna operates in entire UWB.

In addition to Stage 1, Stage 2 is etched with an inverted C shape slot in the circular patch to get a band notch at 2.5 GHz with a bandwidth of 0.25 GHz.

In addition to Stage 2, Stage 3 is designed with mushroom EBG 1. This EBG structure is designed to provide a band notch at 3.4 GHz with a bandwidth of 0.8 GHz other than the obtained Bluetooth band.

In addition to Stage 3, Stage 4 is designed with mushroom EBG 2. This EBG 2 is intended to provide a band notch at 5.4 GHz with a band width of 0.9 GHz other than the obtained Bluetooth and WiMAX bands.

In addition to Stage 4, Stage 5 consists of DG compact spiral slotted EBG 3. EBG cell 3 is designed to develop a band notch at 7.4 GHz. Finally Stage 5 provides quadruple band notches at 2.5, 3.4, 5.4 and 7.4 GHz with a bandwidth of 1.6 GHz.

The simulated results at different stages of the antenna are shown in fig 7.

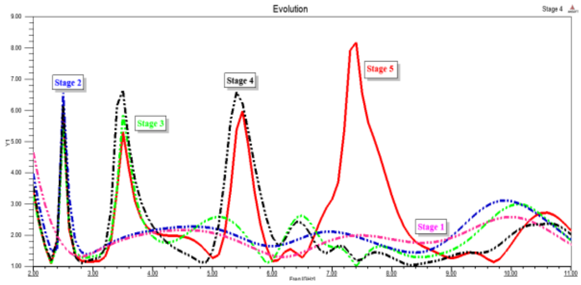


Fig 7: Evolution of the proposed antenna structure.

The inner radius of the inverted C – shape slot on the circular patch is varied to attain the desired band notch. It is detected that by decreasing the radius of the inner circle of the inverted C – shaped slot the rejection values at that band are widely varied. It is observed that due to the mutual coupling between the inverted C – shape slot etched on the patch and EBG cell 2 structures there is frequency band variation observed at 5.4 GHz WLAN band. By performing the above analysis an optimized value of the radius is selected. The performed Optimetrics is depicted in fig 8.

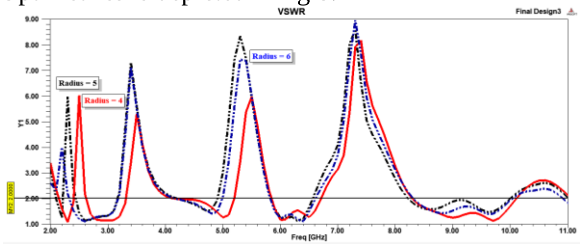


Fig 8: Optimetrics for the parameter d1

The VSWR and return loss (S11) plots are shown in fig 9 and fig 10 respectively.

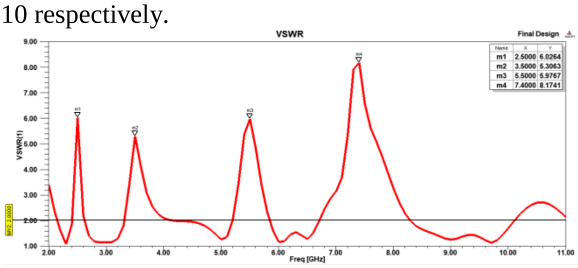


Fig 9: VSWR plot

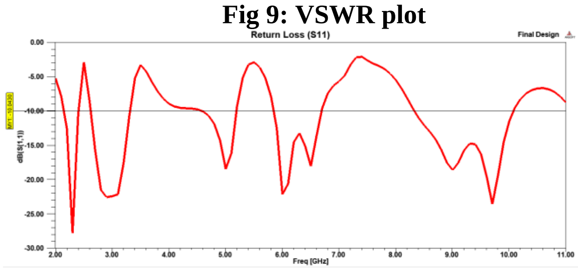


Fig 10: S_{11} plot

There is an interference with various narrow bands i.e. due to Bluetooth, C – Band, INSAT frequencies, WLAN, WiMAX, X-band satellite communications etc. in the UWB operating range. Hence in order for the antenna to operate in the entire UWB range it need to overcome interference with these specific bands. In order to achieve notched bands at these different frequencies, an inverted C shaped slot is etched and three EBG cells of different sizes corresponding to their notched frequencies are placed nearer to the feed line.

EBG 1 and EBG 2 are mushroom type EBG structures which are conducting patches with shorting vias that connects this conducting patch to the ground plane. EBG 3 is a compact spiral slotted EBG structure. The spiral shaped slots present in the CEBG structure increases the total series inductance between the EBG and ground plane making the structure more compact.

The band notch at WiMAX and WLAN are obtained due to EBG 1 and EBG 2 respectively. At these bands, the EBG 1 and EBG 2 having equivalent circuit as LC network as shown in fig 3 acts as a high impedance surface, making an electric filter that eliminates the surface waves propagation. The current distribution is shown in the figures 12 and 13.

The band notch at X-Band is obtained due to EBG cell 3. At this band, the EBG cell 3 having equivalent circuit as LC network that is shown in fig 5 acts as a high impedance

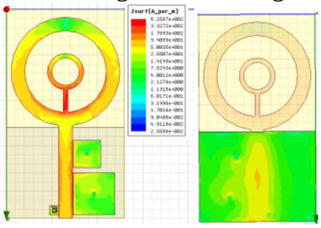


Fig 11: Current distribution in the radiating plane and ground plane at 2.5 GHz

surface, forms an electric filter that eliminates the propagation of surface waves.

It can be observed from fig 11 that at 2.5 GHz the etched slot resonates relative to EBG structures with a maximum current density of 4.52 x 10^2 A/m.

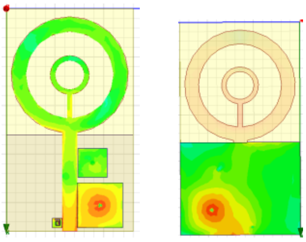


Fig 12: Current distribution in the radiating plane and ground plane at 3.4 GHz

At 3.4 GHz it can be detected from fig 12 that EBG cell 1 resonates with a maximum current density of 5.13 x 10^2 A/m.

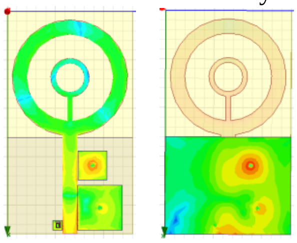


Fig 13: Current distribution in the radiating plane and ground plane at 5.4 GHz

At 5.4 GHz it can be detected from fig 13 that EBG cell 2 resonates with a maximum current density of 1.07 x 10^3 A/m.

Fig 14: Current distribution in the radiating plane and ground plane at 7.4 GHz

At 7.4 GHz it can be detected from fig 14 that EBG cell 3 resonates with a maximum current density of 9.224 x 10^3 A/m.

The gain plot of the proposed antenna is shown in fig 15.

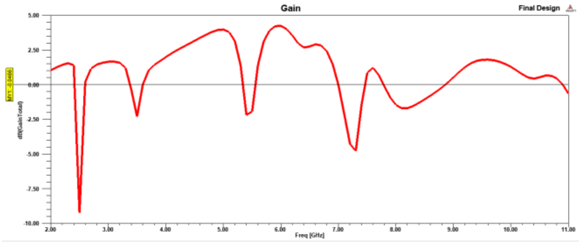


Fig 15: Gain plot of the proposed antenna

It can be noticed from the gain plot that at notched frequencies the antenna has a negative gain and at operating frequencies the antenna has a positive average gain of 3.

The E – plane patterns i.e. elevation plane patterns and H – plane patterns i.e. azimuthal plane patterns at notched frequencies are shown in the figures 16,17,18 and 19.

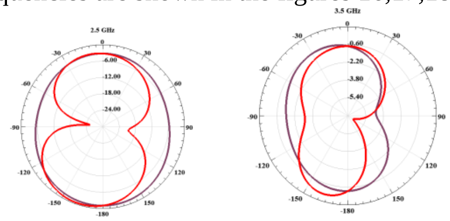


Fig 16,17: E-plane & H-plane radiation pattern at 2.5 GHz and at 3.5 GHz

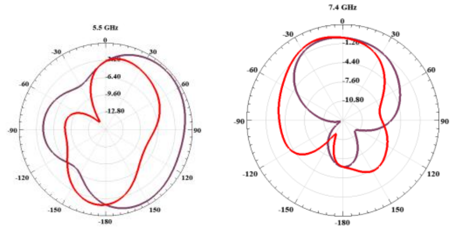


Fig 18,19: E-plane and H-plane radiation pattern at 5.5 GHz and at 7.4 GHz

Table II: Comparison of size of antenna cited in the references

Reference number	Bands Rejected	Size of Antenna
1	(2.44 - 2.77) GHz, (3.42 - 3.97) GHz, (5.45 - 5.98) GHz, (8 - 8.68) GHz	40 x 34 x 1.6 = 2176 mm^3
2	(2.37 - 2.9) GHz, (3.27 - 3.76) GHz, (5.2 - 5.89) GHz, (8.06 - 8.8) GHz	40 x 40 x 0.812 = 1299.2 mm^3
3	(2.7-3.1) GHz, (3.7-4.2) GHz, (4.9-5.75) GHz, (6.6-7.4) GHz	28 x 30 x 1.524 = 1330.56 mm^3
4	(5.15 - 5.35) GHz, (5.75- 5.85) GHz, (7.25 - 7.75) GHz, (8.01 - 8.55) GHz	26 × 28 × 0.4 = 291.2 mm^3
5	(3.3 - 3.6) GHz, (4.5 - 4.8) GHz, (5.15 - 5.35) GHz, (5.725-5.825) GHz	30 x 31 x 1 = 930 mm^3
6	(2.7 - 3.4) GHz, (3.4 - 4.5 GHz, (5.4 - 6.1) GHz, (6.8 - 9.9) GHz.	43× 28× 1.6 = 1926.4 mm^3

7	(3.7- 4.2) GHz, (5.15 - 5.35) GHz, (5.72 - 5.85) GHz, (7.25 - 7.75) GHz	30 x 30 x 1.6 = 1440 mm^3
8	(3.3 - 3.6) GHz, (5.15 - 5.35) GHz, (5.725 - 5.825) GHz, (8.025 - 8.4) GHz.	24 x 17 x 0.787 = 321.096 mm^3
9	(3.30 - 3.36) GHz, (4.50 - 4.70) GHz, (5.15 - 5.35) GHz, (5.70 - 5.825) GHz	28 x 30 x 1 = 840 mm^3
Designed Antenna	(2.43 – 2.65) GHz, (3.2 – 4.1) GHz, (5.1 - 5.9) GHz, (6.6 – 8.2) GHz	42 x 26 x 1.6 = 1913.6 mm^3

The designed antenna is found to more be compact in size when compared to the reference antennas that are cited above.
The three-dimensional polar plots at the notched frequencies are shown in figures 20,21,22 and 23.

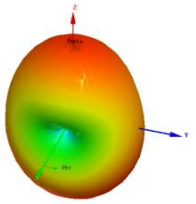
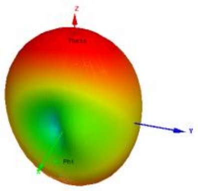



Fig 20: 3-D polar plot Fig 21: 3-D polar at 2.5 GHz plot at 3.5 GHz

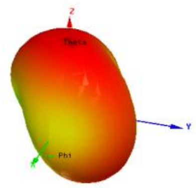
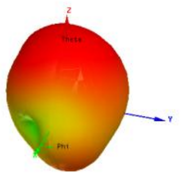



Fig 22: 3-D polar plot Fig 23: 3-D polar at 5.5 GHz plot at 7.4 GHz

Fig 24,25 show the front and back view of the fabricated prototype

Fig 24: Front view of the fabricated prototype

Fig 25: Back view of the fabricated prototype

Fig 26 shows the comparison of measured and simulated VSWR values and it can be observed that measured VSWR values agree with the simulated VSWR values.

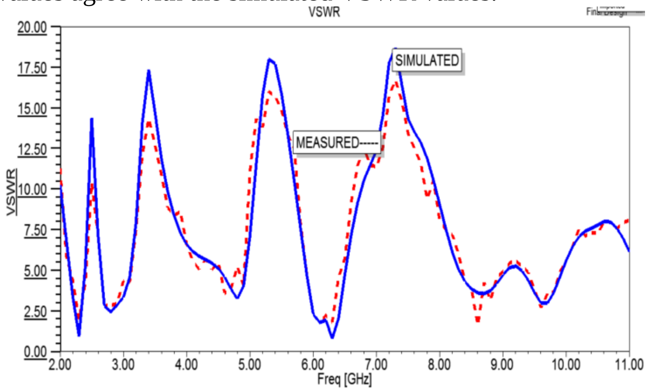


Fig 26: Comparison of measured and simulated VSWR for the designed antenna.

The blue colour curve indicates the simulated graph of VSWR using HFSS and the red colour curve indicates the measured graph of VSWR using vector network analyzer.

IV. CONCLUSION

A circular monopole ultrawide band antenna with quadruple notched bands at Bluetooth, WiMAX, WLAN, WPAN and X-band satellite communication bands is analyzed and presented. Benefits of using EBG structures are explored. It is shown that each EBG unit cell and an inverted C-shape slot that is cut in the patch are accountable for a notch in its band gap. The fabricated antenna shows close agreement with the simulated results which is exclusively suitable for UWB applications. The procedure presented for obtaining notches for the designed antenna using the mentioned equations is independent of the antenna structure which can be easily applied to any other antenna structures without negotiating the performance of the antenna.

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AUTHORS PROFILE

First Author V. Saritha, presently pursuing Ph.D. from JNTU college of Engineering, Anantapur. She is working as an Assistant Professor in VR Siddhartha Engineering College, Vijayawada. She graduated in E.C.E from Adams Engineering College in 2002 and MTech in Digital Electronics and communication systems from JNTU college of Engineering College, Anantapur in 2011. She has 16 years of teaching experience and 2 years of research experience. She has 10 international journals in the area of ULTRAWIDEBAND ANTENNAS.

Second Author Dr.C. Chandrasekhar is working as a professor and Head in Electronics and Communication Engineering, Sri Venkateswara Engineering College Tirupati, India. He has twenty-two years of teaching and industrial experience. He completed his B.Tech. Degree in Instrumentation Technology from Govt. BDT College of Engg. Davanagere, Karnataka.. He completed his MTech. Degree in Digital Electronics from BVB College of Engg. Hubli, Karnataka. He completed his Ph.D. on Image Processing from Sri Venkateswara University College of Engineering, Tirupati, AP, India. His areas of interest are Signal Processing, Embedded systems, RF communication and VLSI. He has published nearly 50 papers in national and international, conferences and international journals. He is a life member of ISTE and FIE

Third Author B. Teertha Priyanka, B. Tech, ECE, V R Siddhartha Engineering College, Vijayawada, India. Her areas of interest are Multiband operating and Multiple band notch Antennas using EBG Structures.