Abstract

A compact coplanar waveguide (CPW) fed ultrawideband (UWB) printed circular monopole antenna (PMA) with triple frequency notched function is presented and validated here on a low cost FR4 Epoxy substrate. Here the antenna loaded with three single circular ring SRRs to create triple frequency notching in 3.5 GHz for WiMAX, 5.5 GHz for WLAN, and 7.9 GHz for X-band satellite communication systems, respectively. The SRR design equations are analyzed in detail here. Return loss and voltage standing wave ratio (VSWR) are used to show the effect of these rings. Measured result shows a close correlation to the theoretical results.

Keywords: ultrawideband (UWB); split ring resonator (SRR); monopole antenna; WLAN; WiMAX; X band.

1. Introduction

Ultra-wideband also known as UWB is a radio technology that can use a very low energy level for short-range, high-bandwidth communications over a large portion of the radio spectrum. Ultra-wideband is a technology for transmitting information spread over a large bandwidth ranging from 3.1GHz to 10.6GHz (>500 MHz) this should share spectrum with other system users. Ultra-wideband characteristics are well-suited to short-distance applications, such as peripherals of PC. Due to short duration of UWB pulses, it is easier to provide high data rates.
Ultra-wideband characteristics are well-suited to short-distance applications, due to its low emission levels permitted by regulatory agencies\(^1\). There also some existing narrow band systems such as WLAN, WiMAX, HIPERLAN which overlap with the other frequencies in the designated UWB spectrum. Due to the coexistence of the UWB system with frequency bands reserved for narrowband wireless technologies, there is a need in notching methods to provide filtering in order to avoid interference from, or causing interference to, narrowband devices. Hence, differentiating against signals from such narrowband sources is an important requirement for UWB systems. Using a stop-band filtering in the design, which will increase complexity of the UWB system, hence the method employed to extract the desired UWB bands that is to use an antenna with inherent band-notch properties. Till this time there are such antennas are implemented by making several variations in radiator or ground plane. There are many designs are available in open literature. Notch properties are accomplished by changing the shape of radiator with various types of slot or by parasitic strip loading\(^2-6\). Filtering achieved by using modified ground plane\(^7-9\). Other design configurations are dual-frequency notch and wideband notching by loading SRRs on the CPW-fed monopole antenna\(^10-12\).

This paper describes a novel and effective method to design a frequency notched UWB antenna by loading single circular ring multiple SRRs on the back side of a CPW fed printed circular monopole antenna on a low cost FR4 Epoxy material. Unlike other previous methods here it uses single circular ring SRR for each notched frequencies instead of using pair of rings with splits in the opposite side. The single ring SRRs are placed symmetrically on the opposite surface of the printed planar monopole antenna along the signal line which results in a notch frequency. Resulting notch frequency changes in accordance with the dimensions of single ring SRRs. Propagation of electromagnetic (EM) signals, with their magnetic fields along the axes of the SRR’s, interacts with the SRRs, and causes the SRRs to behave as magnetic dipoles. The propagating EM signal induces an electromotive force on the SRR, which in turn induces oscillating current within the single ring SRR\(^13\). At a particular frequency which corresponds to the dimensions of SRR yields a resonance and prohibits signal propagation at this resonance frequency. When the excitation is given the propagating signal is rejected and reflected back, which yields a weak radiation at the desired notch frequencies. Multiple notches can be achieved by loading multiple SRR with different geometrical dimensions.

In this letter simulated results are describe as four sections such as antenna with 3.5GHz WiMAX notch, antenna with 5.5GHz WLAN notch, antenna with 7.9GHz X band for satellite communication notch and by combining these three in a single printed circular monopole antenna yields triple frequency notch. Here we proposed frequency notching technique using single ring SRR, which yields a quasi-static resonance that is the notching at a single frequency\(^13\). In most of the previous methods described earlier, where most of the changes and inclusions are on the ground plane or radiator. The novelty of our design is that the antenna designed on a low cost FR4 Epoxy material and also here it uses single circular ring SRR for each frequency notching, which avoids the complexity of the system.

2. Antenna design

Schematic of the proposed antenna with triple frequency notch is shown in Fig.1. The proposed antenna is fabricated on FR4 Epoxy material having relative permittivity, \(\varepsilon_r=4.4\), thickness \(h=1.6\text{mm}\) and \(\tan\delta=0.02\). The circular uwb monopole having radius \(R\) is fed by a CPW consisting of ground planes having widths \(W_1\) and \(W_2\), length \(L_s\) and a signal line having length \(L_s+t\) and width \(S\). The slots between the signal line and ground planes have width \(S_g\). Antenna loaded with three circular shaped single ring split ring resonators, shown in Fig. 1(c), where \(r\) is the radius of the SRR, conductor width \(w\) and the split gap \(g\). Circular shaped single ring SRRs of three different dimensions are printed on the opposite surface of a CPW separated by the substrate height \(h\), as shown in Fig. 1(b). A single ring SRR is shown in Fig. 1(c) having dimensions \(r_i\), which is radius of SRR, conductor thickness \(d_i\), and split gaps \(w_i\), where \(i=1,2,3\) corresponding to the SRR 1,2, and 3 respectively. Table I shows the design parameters used for the prototypes. Single circular ring SRR’s radius \(r_1\), \(r_2\) and \(r_3\) corresponds to the notch frequencies 3.5GHz, 5.5GHz and 7.9GHz respectively.
Fig. 1. (a) Schematic of a printed circular monopole fed by CPW: Top view with SRR printed in the back side (b) Side view of the printed circular monopole antenna fed by CPW loaded with SRRs (c) Schematic of circular single ring SRR having dimensions $r_i$, $w_i$ and $g_i$, where $i=1, 2$ and 3 corresponding to SRR 1, 2 and 3.

Table 1. Design parameters for CPW fed printed planar monopole antenna having triple frequency notch

| Design parameters | Dimensions (mm) |
|-------------------|-----------------|
| $R$               | 12.5            |
| $L$               | 60              |
| $W$               | 50              |
| $W_1=W_2$         | 22              |
| $S$               | 5               |
| $S_g$             | 0.5             |
| $L_s$             | 29              |
| $t$               | 0.4             |
| $r_1$             | 7.6             |
| $w_1$             | 0.4             |
| $g_1$             | 1.5             |
| $r_2$             | 4.8             |
| $w_2$             | 0.4             |
| $g_2$             | 0.6             |
| $r_3$             | 3.1             |
| $w_3$             | 0.4             |
| $g_3$             | 0.7             |
3. Resonance frequency calculation of SRR

The single ring circular SRR used for achieving frequency notching is shown in fig.1(c). Here, theoretical expression for the resonant frequency of the single split single ring resonator is derived\(^{14}\). The parameters are, the radius of the ring, \(r\), the metallic ring width \(w\), the thickness \(d\), and the slit gap width, \(g\). Take a very small value for the thickness of the ring. SRR 1, 2, and 3 corresponds to the dimensions of frequencies 3.5GHz, 5.5GHz and 7.9GHz respectively.

The resonance frequency is,

\[
f_0 = \frac{1}{2\pi\sqrt{L_C}}
\]  
(1)

Capacitance \(C\) is given by,

\[
C = C_{pp} + C_S
\]  
(2)

\(C_{pp}\) and \(C_S\) are parallel plate capacitance and surface capacitance.

\[
C_S = \frac{2\varepsilon_0(d+w)}{\pi} \log \frac{4r}{g}
\]  
(3)

\(\varepsilon_0\) is the permittivity of free space, \(w\) is the width of the metallic split ring, \(t\) is the thickness of the metal used for split ring, \(r\) is the radius of the split ring, and \(g\) is the width of the split gap. The gap capacitance or parallel plate capacitance of the split is,

\[
C_{pp} = \frac{\varepsilon_0 \varepsilon_r A}{\pi}
\]  
(4)

\(\varepsilon_r\) is the relative permittivity and \(A\) is area of the plate of capacitor,

\[
A = t \times w
\]  
(5)

The inductance can be related by that of a closed ring \(^{14}\),

\[
L = \mu_0 Rm \left( \log \frac{2Rm}{g} + 0.9 + 0.2 \left( \frac{g}{2Rm} \right)^2 \right)
\]  
(6)

Where, \(L\) represents the inductance of SRR, \(g\) represents the width of the split, \(\mu_0\) is the free space permeability and \(Rm\) is the average or mean radius.

\[
Rm = \frac{r+w}{2}
\]  
(7)

Using equations (1) to (7) we can calculate the resonant frequencies of corresponding SRR structure.

4. Simulated and Measured Results

A CPW fed circular monopole uwb antenna without SRRs and with SRRs to obtain triple frequency notches is simulated on FR4 epoxy substrate having thickness \(h=1.6\text{mm}\) and dielectric constant \(\varepsilon_r=4.4\). The proposed triple frequency notch antenna is simulated as four steps - During the primary step 3.5GHz WiMAX frequency notching is achieved by loading a single SRR having radius \(r_1=7.6\text{mm}\), width \(w_1=0.4\text{mm}\) and split gap \(g_1=1\text{mm}\). In the second step, 5.5GHz WLAN frequency notching is achieved by loading another single ring SRR near the radiator having radius \(r_2=4.8\text{mm}\), width \(w_2=0.4\text{mm}\) and split gap \(g_2=0.6\text{mm}\). Third step is notching \(7.9\text{GHz}\) frequency which is used in X band for satellite communication, accomplished by loading single circular ring SRR having radius \(r_3=3.1\text{mm}\), width \(w_3=0.4\text{mm}\) and split gap \(g_3=0.7\text{mm}\). Last step is notching these three frequencies within this PMA structure by loading the three SRRs having different dimensions. The simulated and measured results show a close corresponds with the theoretical results obtained from the equations. The prototypes were designed and simulated on low cost FR4 Epoxy material using a commercial EM simulator that is HFSS.

4.1 Simulated return loss characteristics

UWB antenna operates in the frequency range 3.1 to 10.6GHz. The return loss (\(S_{11}\)) of the reference UWB antenna should be less than -10dB in order to get the stable radiation characteristics throughout the entire bandwidth. In the course of first step, 3.5GHz WiMAX band is notched by loading larger ring. The obtained return loss results shown in Fig.2 (a), there is a good agreement with the theoretical value and the return loss is above -10dB. During the second step, 5.5GHz WLAN band is notched by loading the second largest ring and the result is shown in Fig.2 (b).
Fig. 2 Simulated S11 plot with (a) 3.5GHz notch (b) 5.5GHz notch

Fig. 3 Simulated S11 plot with (a) 7.9GHz notch (b) triple frequency notch

Here also return loss is above -10dB, which offers better notching of WLAN frequency. In the third step, 7.9GHz X band used for satellite communication is notched by loading the smallest ring. Like the previous one, the return loss is above -10dB and is shown in Fig. 3 (a), which means the frequency gets rejected. Integrating all the three steps we can design a triple frequency notched UWB antenna by loading three single circular SRR on the back side of the reference antenna’s feed line. From the simulated results shown in Fig. 3 (b) it can be observe that three proposed frequencies such as 3.5GHz, 5.5GHz and 7.9GHz gets rejected.

4.2. Simulated VSWR characteristics

The voltage standing wave ratio (VSWR) of the reference UWB antenna without any band notching should have the VSWR value less than 2 in the entire UWB bandwidth for stable radiation characteristics. Fig. 4 (a) gives the simulated VSWR of single SRR loaded PMA results shows that VSWR is above 2 at the 3.5GHz WiMAX.
frequency. Fig. 4 (b) shows the simulated VSWR result of single SRR loaded PMA having VSWR above 2 at desired 5.5 GHz WLAN frequency, which confirm the notching at the specified frequency. The simulated VSWR plot of single circular SRR loaded PMA for 7.9GHz notch is shown in Fig. 5 (a), like the previous results this result also have VSWR above 2 which offer notching. By combining these three rings in reference UWB antenna we get the triple frequency notch as shown in Fig. 5 (b).

5. Measured Results

The proposed CPW fed planar UWB antenna with single circular ring SRR loaded to notch triple frequency has been designed and fabricated on FR4 Epoxy material. Fabricated prototypes are shown in Fig. 7 and the measured return loss result is shown in Fig. 8 which shows a close correlation with the theoretical and simulated results. Proposed antenna is fabricated on a lossy FR4 Epoxy material having permittivity 4.4, thus the antenna performance is also affected by the substrate’s lossy nature. Not only the permittivity of substrate but also the dimensions of SRR affect the notching frequency.
6. Conclusion

A CPW fed circular monopole UWB antenna loaded with circular single ring SRR with triple frequency notch characteristic on a low cost substrate has been proposed and presented in this work. The configuration works with precise positioning of the single circular ring SRRs on the opposite side of the CPW feed line. The electromagnetic coupling between the SRRs and the CPW feed line at its resonance frequency yields the desired frequency notch. The antenna dimensions and the SRR dimensions are independent of each other, SRR dimensions only depends on notching frequency. The notch frequency can be varied to the desired value by varying the SRRs dimensions. The good agreement between measured and simulated results will be useful for the UWB communication system without any electromagnetic interference from the three used frequencies.

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