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Research Paper

A Circular Disc Microstrip Antenna with Dual Notch Band for GSM/Bluetooth and Extended UWB Applications

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Abstract

A microstrip antenna with a circular disc design and modified ground is proposed in this paper. Circular shapes of different size have been slotted out from the radiating patch for achieving extended ultra wideband (UWB) with GSM/Bluetooth bands with maximum bandwidth of 17.7 GHz (0.88-18.6 GHz). Further, characteristic of dual notch band is achieved, when a combination of T and L-shaped slots are etched into the circular disc and ground plane respectively. Change in length of slots is controlling the notch band characteristics. The proposed antenna has rejection bandwidth of 1.3-2.2 GHz (LTE band), 3.2-3.9 GHz (WiMAX band) and 5.2-6.1 GHz (WLAN band) respectively. It covers the frequency range of 0.88-18.5 GHz with the VSWR of less than 2. Also, an equivalent parallel resonant circuit has been demonstrated for band notched frequencies of the designed antenna. The gain achieved by the proposed antenna is 6.27 dBi. This antenna has been designed, investigated and fabricated for GSM, Bluetooth, UWB, X and Ku band applications. The stable gain including H & E-plane radiation pattern with good directivity and omnidirectional behavior is achieved by the proposed antenna. Measured bandwidths are 0.5 GHz, 0.8 GHz, 1.1 GHz and 11.7 GHz respectively.

Keywords: *Circular disc Antenna, Dual Notch Band, Integrated GSM band, extended UWB Antenna.*

1. Introduction

In recent years, modern telecommunication systems are required to function for different operating bands, for this reason a single microstrip antenna that works for various frequency band applications, such as GSM, Bluetooth and extended UWB with notch band to suppress the interfacing signals have come to good extent in designing. Benefits of microstrip antenna are their low silhouette, light heft, ease to manufacture with planar and non planar surface nature. So, it is most suitable contender for several types of communication system i.e. satellite communication system, GPS, radar technology, high data transfer rate, TV etc. all in one device [1-2]. There are various techniques to generate multiband behavior using microstrip antenna. By adding extra resonant element into the main radiating patch or modified ground plane with different shapes like U and T, are developed. Another technique is to create notch frequency band in UWB antenna for multiband operations [3-7]. Elliptical and circular microstrip antennas are common structure for UWB application. Various coplanar waveguide (CPW) and microstrip fed antennas are designed and small ground plane are used to augment the bandwidth of the antenna. Advantages of CPW fed antenna is wider bandwidth, less dispersion loss and lower radiation leakage as compare to microstrip and probe fed technique [8-10]. In studies, many methods have been developed to design multiband antenna by using slot loading technique and design of notch frequency band such as cutting slots into the ground plane or into the antenna radiators [11-15].

Recently, octagonal ring dual band antenna has been reported for integrated Bluetooth and UWB application. The notch band is created by using a strip slot entrenched at the center of the radiating patch [16]. A CPW fed fractal ring antenna with 2.5 GHz and 5.5 GHz dual notch band is reported [17]. In this antenna, desired notch band characteristics are achieved by using fractal ring shape structure. Above antennas have good characteristics but they do not cover GSM, Bluetooth, C, X, Ku band application. It is a tedious task to for the engineers to design such a simple antenna that is low cost, compact in size and efficient for simultaneous communication in multiple frequency bands.

In this paper, a CPW fed circular disc microstrip antenna with circularly shaped slotted structure into the radiating patch has been proposed. For the generation of first notch band, a T-shaped slot is etched into the radiating patch and for the second notch band a pair of L-shaped slots are etched into the ground plane. The notch band center frequencies are obtained at 3.5 GHz and 5.6 GHz with integrated notch band centered at 2.0 GHz. The resonant frequencies have been observed at 1.0 GHz, 2.4 GHz, 4.1 GHz and 9.6 GHz respectively with fractional bandwidths achieved of 42 % (0.88 ~ 1.3 GHz), 37.5 % (2.3 ~ 3.2 GHz), 31 % (3.9 ~ 5.2 GHz) and 127 % (19.3 ~ 6.1 GHz) respectively, while maintaining the multiband band characteristics. The proposed antenna has been designed and simulated results have been evaluated with the physically measured results of the fabricated prototype in the result section.

2. Antenna geometry

Initially circular monopole antenna structure is designed on FR-4 substrate with dielectric constant 4.4 and thickness of the substrate 1.59 mm. Size of substrate is 45 x 50 mm^2. Both left and right ground plane of antenna is 9.7 mm x 22.7 mm in size with optimized feed width of 3 mm and radius of circular monopole antenna 15.3 mm. TM_{110} is dominant mode for circular microstrip antenna. It is based on the cavity model formulation. The actual radius (a) of patch is equal to effective radius for first order approximation. The radius (a) of the circular patch has been determined using formula as given in equation (1) of [2], as shown here,

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

Where, $F = \frac{8.791\times10^{9}}{f_r\sqrt{\varepsilon_r}}$

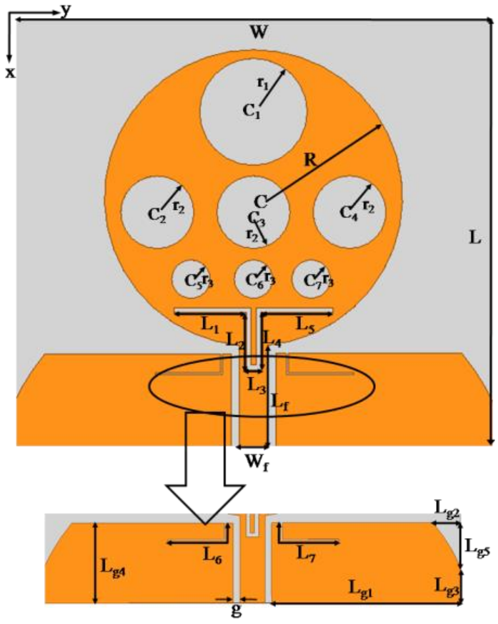
ε_r is effective dielectric constant and h is the height of dielectric substrate in cm. If f_L =2.5 GHz, the radius of the patch is calculated 15.0 mm for FR-4 substrate with ε_r =4.4, h =0.159 cm and loss tangent (tanδ) =0.02 which approximates the lower edge UWB frequency for VSWR less than 2. The EM-simulator Ansoft HFSS is used for further fine tuning of dimensions to attain the desired impedance bandwidth. The radius of the monopole element is then found to be 15.3 mm. Circular shape slots are introduced within the radiating patch with different radius. C is center of circular monopole antenna and C_1, C_2 up to C_7 are the center position of circular slots within patch shown in Figure 1(a). Coordinates of C is (19, 25) and coordinates of C_1, C_2, C_3 …..C_7 are (10, 25), (20.5, 15), (20.5, 25), (20.5, 35), (27.5, 18.5), (27.5, 25), and (27.5, 31) respectively. All dimensions are based on Cartesian co-ordinate system (x, y and z). Bottom surface of proposed antenna is oriented such that it lies on the x-y plane as shown in Fig. 1(a). Fig. 1(b) shows the prototype antenna. All dimension of proposed antenna is shown in Table 1. Detail of design steps are given in the next section.

3. Antenna geometry

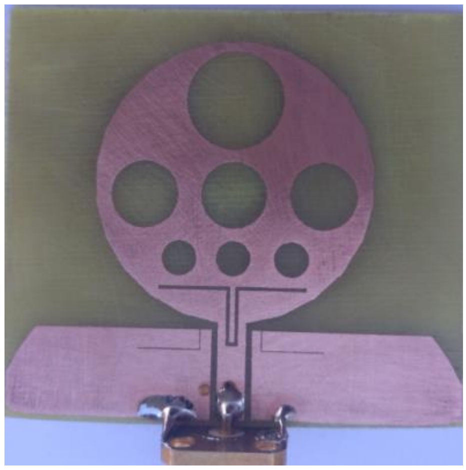
The proposed CPW fed monopole antenna with dual notch band has been simulated using listed dimensions given in Table 1. CPW fed slot antennas have advantages over other fed antennas like wide operating band of the antenna, less antenna mutual coupling and straightforward integration with other radio frequency (RF) devices. The critical design parameters are the gap between feed line and ground plane, gap between patch and ground plane, and length & width of ground plane. These parameters have strong influence on notch and GSM band characteristic of the antenna. Strong influence of these parameters can be justified based on the current distribution over the antenna structure.

Table 1: Dimension of proposed antenna.

Parameters	Unit (mm)	Parameters	Unit (mm)
L	45	W	50
W_f	3	L_f	10.5
R	15.3	r_1	5.6
r_2	3.8	r_3	2
L_{g1}	22.7	L_{g2}	3.31
L_{g3}	4.32	L_{g4}	9.7
L_{g5}	5.31	g	0.8
L_1	7	L_2	5
L_3	1.5	L_4	5
L_5	7	$L_6 = L_7$	7.8
g	0.8	Overall size	45 x 50 mm^2



(a)



(b)

Fig. 1: (a) Proposed antenna geometry (b) Fabricated antenna geometry.

3.1 Design of integrated GSM and UWB band antenna

Fig. 2 shows (from Ant.1 to Ant. 5) the design steps of integrated GSM with extended UWB antenna. The design process is started from the circular disc monopole antenna (Ant. 1) to integrated GSM antenna (Ant. 5) shown in Fig. 2. All designed and simulated antenna structures (from Ant.1 to Ant. 5) and its corresponding VSWR results have been shown in Fig. 3(b). The current distribution can be approximated by a sinusoidal root function in the resonance path of the patch antenna, this assumption leads the theoretical results observed in this design. Multiple radiating elements are the basis means of the patch antenna to evolve the Multi- frequency behavior which helps the antenna to deliver the strong current and radiation at resonance. Formation of rectangular, angular, circular and triangular slots in a patch radiator can be used to create the multi slot patch antenna which leads to the multi-frequency nature of the considered patch antenna. The corresponding result VSWR has been shown in Fig. 3(b) as Ant.1 of basic circular disc antenna without any slot support and multiple resonance modes. The fundamental mode generates the harmonics which finally leads to the higher order modes. The wavelength of the higher order modes is considered to satisfy the following relationship in equation (2), i.e.,

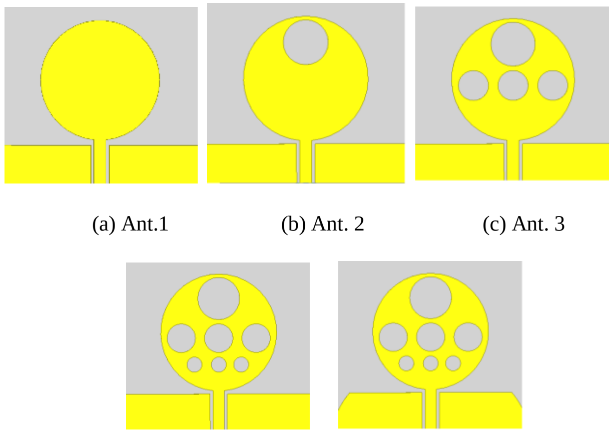
$$2R = \frac{m\lambda_m}{4} \tag{2}$$

Where, m is the mode number. The closely spaced higher order modes are considered to be generated in Fig. 3(a) as shown in [8]. Hence, the higher order modes overlapping leads to the UWB characteristics for the design shown in Fig. 3 (Ant.1) but some distortion occurred and there was impedance mismatching at 4.3-5.5 GHz, X and Ku band for the same design. Since the motive was to design an antenna which can cover UWB with GSM, Bluetooth, X and Ku frequency band in a single design without any addition of extra resonating elements, therefore the next step is to involve the matching of input impedance to the higher frequency range and to reduce the distortion received for the design shown in Fig 2(Ant1) especially in the frequency range 4.3-6 GHz, 8-10 GHz and 16-18 GHz band. For this purpose, circular slots have been introduced. Fig. 4 shows the current distribution of the basic circular disc antenna (without any slot). It shows that the current density of the basic circular patch antenna (without any slot), is mainly disseminated at the outer perimeter of the circular disc. As a result, the current density becomes very less at center and near the center area of the circular disc. Hereby, the current density will not be exaggerated if the center or near center area of the circular disc is slotted out. To obtain the extended UWB characteristics, the circular configuration added to increases the operating band in the high frequency ranges. It is obtained by adding resonance element with the self similarity property having different radius size. Here self similarity has been designed by using circular slots of radius r_1 with 5.6 mm dimension as shown in Ant. 2 of Fig. 2 and it is calculated using equation (3) given below

$$r_1 = \frac{\lambda}{8} \tag{3}$$

where, λ is wavelength and it is calculated at 5.6 GHz. The results are shown in Fig. 3 (Ant.2) which clearly shows that the VSWR in the frequency range 4.3-6 GHz is lower than 2. This is showing that there is impedance matching at these frequencies but still distortion is available in 9-10 GHz frequency range. If we add a number of circular slots, impedance matching at these frequency bands can be achieved. To add more number of circular slots, decrease in the radius size is required. Therefore, circular shape slots are etched with radius 'r_2' of 3.8 mm on the radiating circular patch which is shown in Fig. 2(Ant.3) and the corresponding result shows that the designed antenna captures the whole frequency band from 2.4 GHz to 12.0 GHz because of an additive effect of these small circular slots. The value of r_2 is calculated by using equation (3) at 9.5 GHz. It is presumed that a random shape can be considered to match the impedance and the slot shape is not as important as the size and position of the slots are for the design purpose, hence a circular slot has been considered here for the new proposition. Moreover, the circular slots were not widely used in the literature available and reviewed, for the parameters considered in the design process. The circular slots array has been primed to make the antenna design perform best at the X and Ku frequency band which makes it novel in such category of the Antenna. So, it is needed to add more circular slot for matching the impedance at frequency range 13.8-18 GHz, here circular slot is added with r_3 size using equation (3) at 13.8GHz as shown in Fig. 2 (Ant. 4) and corresponding result is shown in Fig. 3(Ant. 4).

Next step involves formation of notch band which requires the increase in VSWR value at frequency 2.1 GHz. The process involves etching of the arc shaped curves on the top side of the rectangular ground plane as shown in Fig. 2(Ant. 5). Various simulations for different possible structural changes have been tried to optimize up to the best possible level. The patch and feed-line junction matching characteristics is enhanced by modifying the ground plane, which results the antenna to exhibit impedance matching in GSM band (specially 800-1200 MHz) [18-20]. The VSWR result for Ant. 5 in Fig. 3(b) shows the GSM, Bluetooth, UWB, X and Ku band nature with very good improvement in VSWR when compared with circular monopole antenna without slotted circles in Fig. 5(b). Fig. 5(a) shows the fabricated antenna without any slots. Details of design to create dual notched band with center frequency of 3.5 and 5.6 GHz have been shown in next section.



(a) Ant.1 (b) Ant. 2 (c) Ant. 3

(d) Ant. 4 (e) Ant. 5

Fig. 2: Design steps of integrated GSM with UWB antenna.

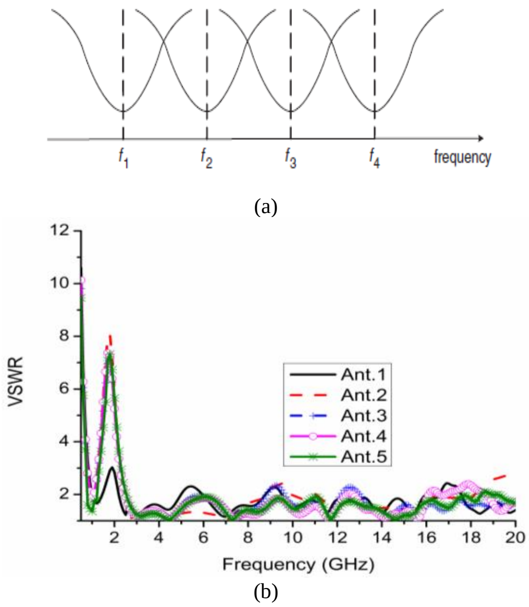


Fig. 3: (a) Multiple resonance modes to create UWB and (b) VSWR result of various antennas.

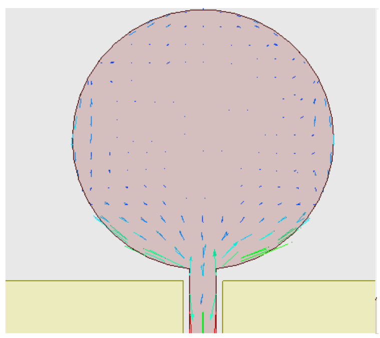
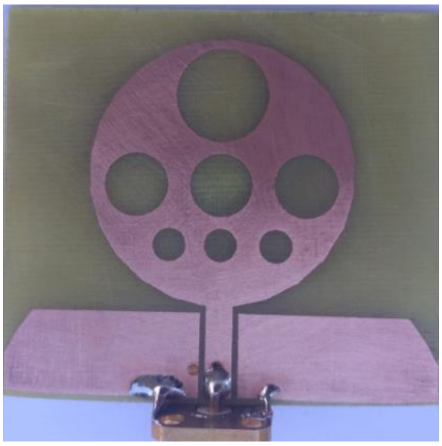
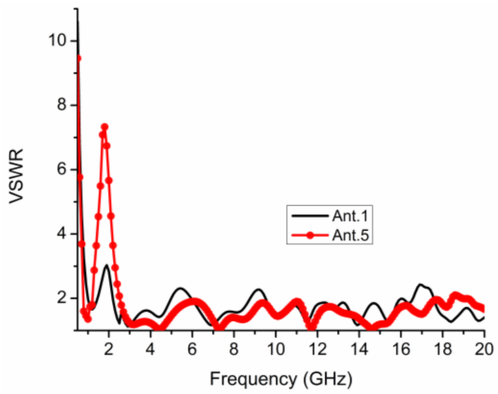


Fig. 4: Surface Current distribution of basic circular disc.



(a)

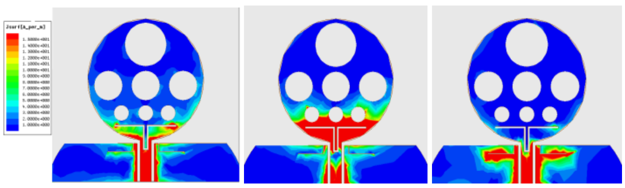


(b)

Fig. 5: (a) Fabricated Ant. 5 (b) A comparison VSWR results of Ant.1 and Ant. 5.

3.2 Design procedure of integrated GSM and UWB antenna with notch band characteristics

The process of the band notched features is possible to be achieved by studying the surface current distribution on the proposed antenna, which is shown in Fig. 6. The surface currents at 3.5 GHz (First notch) and 5.6 GHz (Second notch) are mainly distributed along the edges of T and L-shape slots respectively. Hence, the characteristics of these surface currents distribution show the near field radiation countered at these frequencies, this shows the generation of standing wave, as a result of the T and L shape slots effectively reflects back high energy signal at the input side of the port and the band notched behavior is achieved. Similarly, the distribution of current on the ground plane upper edges reveals that width of ground plane will also influence the impedance bandwidth of antenna. It can be easily observed that surface current distribution is on the lower side of ground plane. This helps to expose that gap (g) between circular disc and ground plane has a decisive role on the antenna's parameters.



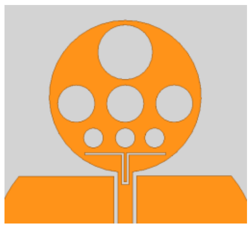
(a) (b) (c)

Fig. 6: Current distribution of the antenna at (a) 0.9 GHz (b) First notch at 3.5 GHz and (c) Second notch at 5.6 GHz

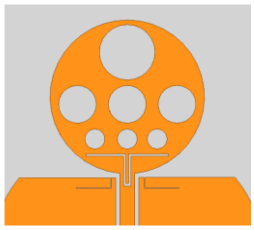
This section presents the creation of band notched characteristics in the UWB band with the help of T and L-shaped slots into the circular patch and ground plane respectively. This antenna is identical to the reference antenna presented in the section 3.1 and shown in Fig. 5 (Ant. 5), and 1st notch band at WiMAX (3.3-3.7 GHz) is achieved by using T-shape loaded into the radiating patch antenna as shown in Fig. 7 (Ant. 6) and corresponding result shows the first notch at WiMAX band which is shown in Fig. 7 (c). It is a known fact that the length of these slots should be λ/4 or λ/2 at the lower frequency to achieve the required notch band characteristics. To achieve the required notched band, the length of each folded loop strip should be quarter of the guided wavelength at the desired center frequency of the notched band [21]. Which has been utilized herewith this design too. The notch frequency band is decided by the length of the slot. The slot length is calculated by the formula shown in equation (4) as below,

$$L_{slot} = \frac{c}{f_r\sqrt{\varepsilon_r}} \quad (4)$$

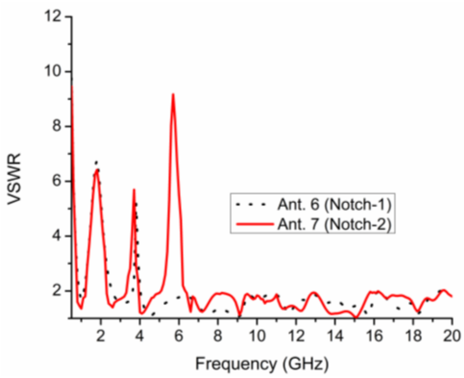
where, f_r is notch resonance frequency and ε_r is the dielectric constant of the substrate. Fig. 7 (Ant .7) shows the length of the L-shape slot which is kept same in both the ground plane and will deliver a single notch frequency. At last, various attempts using single slots have been tried to get the second notch band at WLAN band (5.15-5.825 GHz). Since it is known that the equivalent L-C component of slot gives rise to form band rejection characteristics, but the desired notch band is not achieved. At this stage, it has been chosen to etch symmetrical slot on both ground planes using the method shown in [22]. The length of these slots is close to $\lambda/4$ length of the notch band center frequency. The notch due to these symmetrical slots on both ground planes coupled together to generate a band stop characteristics, which finally generates single sharp notch at desired frequency band and VSWR result of second notch band is shown in Fig. 7(c). In this way, T and L-shape slots are used to generate dual different notches. The corresponding VSWR with dual notch including GSM band has been shown in Fig. 8. It shows that the VSWR result of proposed antenna and rejection band at 2.0, 3.5 and 5.6 GHz respectively, which shows the multiband characteristics.



(a) Ant. 6



(b) Ant. 7



(c)

Fig. 7: (a) Single notch band antenna (b) Dual notch band antenna (c) VSWR result of Ant.6 and Ant.7.

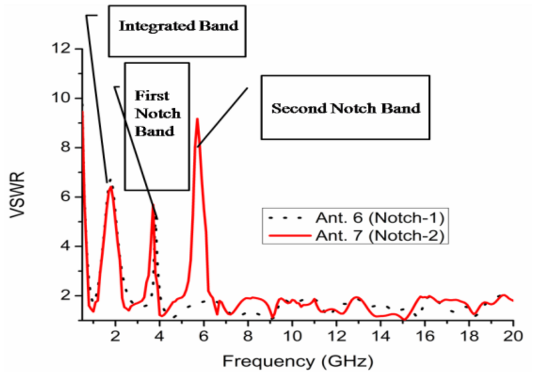


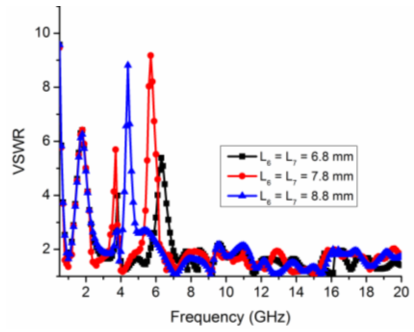
Fig. 8: VSWR results of different notch band.

The argument for optimization of dual notch bands is the conflict of ultra wide band (UWB) system with the narrow bands wireless communication system. Hence (Ant. 7) in Fig. 7 has been considered as proposed structure. To optimize for the better performance in the wireless communication system, the conflict is required to be minimized up to the maximum possible level. It has already been reported that the utilization of band stop filter needs additional area to integrate which conclusively raises the complexity and cost of the design. Notch band characteristics have been found as the solution to avoid the interferences between UWB system and narrow band wireless system [23].

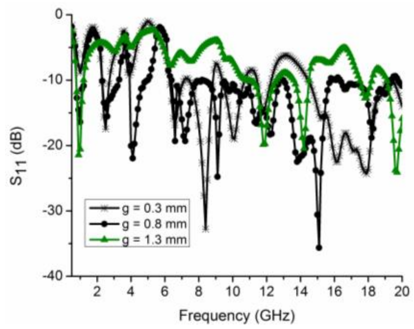
3.3 Effect of L slot on notch band and effect of gap between fed line and ground plane

The result of VSWR characteristics for different value of L_6 is shown in Fig. 9(a) and shows that the electrical length of the antenna can be increased by increasing the length L_6 and hence the notch band can be shifted remarkably towards its lower frequency side. When the length L_6 is increased from 6.8 mm to 8.8 mm, the center frequency of 2[nd] notch band is changed from 6.2 to 4.3 GHz. Also notch peak VSWR of 2[nd] notch band is changed from 5.79 to 9.12, so optimal length of L_6 slot is selected at 7.8 mm. The electromagnetic coupling among feed-line and ground plane leads to the capacitive and inductive effects which plays a major role in impedance matching. S_{11} values of the antenna for different gap (g) conditions have been shown in Fig. 9(b) as a function of frequency. The gap between the ground plane and feed line start from 0.3 mm to 1.3 mm with a step size of 0.5 mm while keeping all parameters fix. When there is a variation in gap (g) from 0.3 mm to 1.3 mm, all the notch modes are shifted across the spectrum. When the gap (g) is not optimal or it is very wide or narrow, the notch band degraded. When gap (g) =0.3 mm, results degraded due the mismatching the input impedance with 50 Ω line so there is week coupling of electric and magnetic field with patch. When the space between feed line and ground is increased, the impedance matching improves at lower as well as at higher frequency side. It means input impedance is approaching near to 50 Ω. The -10 dB S_{11} bandwidth of the proposed antenna improves. The optimum gap is achieved 0.8 mm for optimum impedance matching throughout the band. Further increasing the gap degrades the impedance matching and conclusively degrades the result. So, increase or decrease in the gap (g) enhances or deteriorates the electromagnetic coupling among the ground plane and the patch which leads to affect the impedance bandwidth. This is a key parameter in deciding the impedance bandwidth.

Another important parameter is ground plane width (L_{g4}). The simulated results showing the effect of variation of ground plane dimension (width) is shown in Fig. 9(c). Multiband with integrated bandwidth is achieved by making variation in the ground plane from 8.7 mm to 10.7 mm with step size 1 mm. When the ground plane dimension (width) is varied, the resonant frequencies are shifted in the operating band as evident in Fig. 9(c). When the ground plane dimension is very wide or narrow, the resonance frequencies degrade. As the ground plane width is decreased from 10.7 mm to 8.7 mm, the current density along the edge also decreases. There is downshift of resonance frequency bands towards the lower side when we decrease the dimension of the ground plane width but no changes are observed in the higher frequency ranges. It is clearly visible from this observation that the impedance matching has been found at the best possible optimized ground plane width L_{g4} = 9.7 mm. If the ground plane width is reduced, there is a distortion in higher frequency ranges but if it is increased, the distortion will be seen on higher and lower frequency ranges both.



(a)



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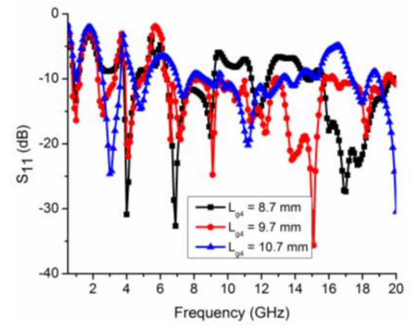


(c)

Fig. 9: (a) VSWR result for various values of L_6 and L_7 (b) S_{11} result for various values of g and (c) S_{11} result for various value of L_{g4}.

3.4 Circuit model analysis

The impedance's real and imaginary part for the proposed antenna has been shown in Fig. 11(b). The operating mechanism of the proposed antenna with its circuit model is explained ahead and an equivalent circuit model has been presented for notch bands in Fig. 11(a). In the first step, the equivalent circuit model has been designed for 2.0 GHz and the corresponding circuit model is shown in Fig. 10(a), in which a parallel RLC resonance circuit is connected with the complex input impedance of the Ant. 5 i.e. Zc. Fig. 10(b) shows the impedance characteristic with respect to frequency and impedance of notch band at 2.0 GHz, where the real part is very high while the imaginary part is comparatively small. The values of a capacitor, inductor and resistor of the parallel resonant circuit are calculated by use of circuit model methods for the resonance frequency, which is given in [1] and [24]. The admittance of the parallel resonance circuit has been determined using formula as given in equation (5), as shown here,

$$Y = G + B_L + B_C \quad (5)$$

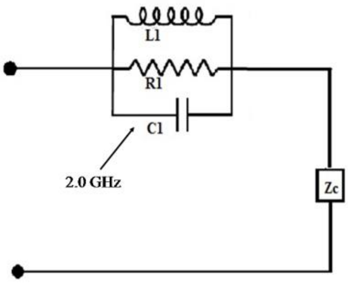
where, G is conductance, $B_L = \frac{1}{2\pi fL}$ is the inductive susceptance and $B_C = 2\pi fC$ is the capacitive susceptance, where L is the inductor, C is the capacitor, R is the resistor and f is the resonance frequency. The resonance frequency of the parallel resonator is obtained, when both the susceptance values are equal. The resonance frequency is

$$f = \frac{1}{2\pi\sqrt{LC}} \quad (6)$$

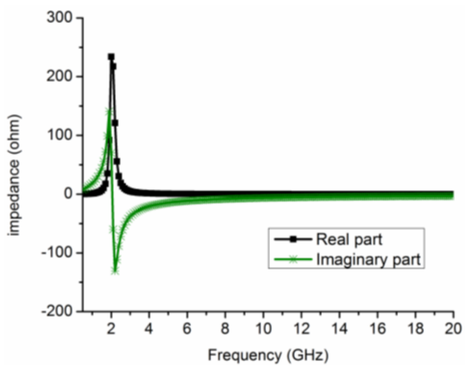
Also, impedance bandwidth is calculated by using equation (7), as given below

$$BW = \frac{1}{RC} \quad (7)$$

The parallel resonant circuit is behaving as an open circuit model at notch band. Due to this, the antenna impedance is very high at 2.0 GHz. Therefore, the antenna cannot radiate at notch band. But, the parallel resonant circuit with an input impedance of the antenna radiates for integrated GSM and extended UWB band as shown in Fig. 10(b) and this result show that antenna is radiating except notch band (2.0 GHz). The elements parameters of the equivalent circuit as shown in Fig. 10(a) are: R_1 = 146 Ω, L_1 = 0.86 nH and C_1 = 7.42 pF.



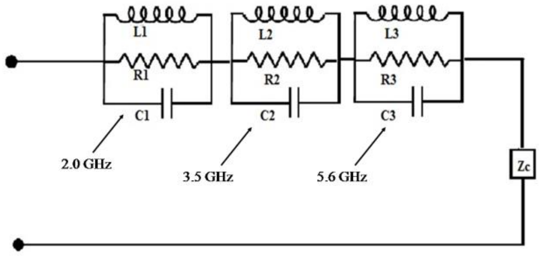
(a)



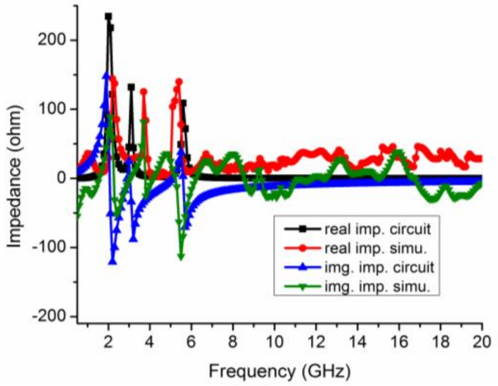
(b)

Fig. 10: (a) Equivalent circuit at 2.0 GHz (b) Real and imaginary impedance with respect to frequency.

In the next step, similarly, a parallel resonance circuit is added for second notch band. This parallel resonant circuit has been used to stop the resonance at 3.5 GHz and the value of resistance, capacitor and inductor at 3.5 GHz can be obtained as discussed above and optimized values are: R_2 = 128 Ω, L_2 = 0.288 nH and C_2 = 9.16 pF. Similarly, for 5.6 GHz; values are: R_3 = 112 Ω, L_3 = 0.119 nH and C_3 = 6.74 pF. The equivalent circuit model of the proposed antenna is shown in Fig. 11(a) and corresponding simulated and circuit model results are compared in Fig. 11(b). It shows that antenna is radiating except at notch bands. The simulated and circuit model results are similar, that validates the presented circuit model of the proposed antenna.



(a) Equivalent circuit of proposed antenna



(b) Real and imaginary part with respect to frequency

Fig. 11: (a) Equivalent circuit model (b) Impedance of proposed antenna.

3.5 Time domain analysis

To ensure stable transmission characteristics, fidelity factor of 1(approx.) and group delay with small variations are required. The correlation factor of transmitted and received pulses is able to be measure by τ fidelity factor and this factor is analysed using techniques given in [25] for the proposed antenna. The fidelity factor is defined in equation (8) as:

$$F = \max_{\tau}\left[\frac{\int_{-\infty}^{+\infty} s_t(t)\, s_r(t+\tau)\, dt}{\sqrt{\int_{-\infty}^{+\infty} s_t^2(t)\, dt \int_{-\infty}^{+\infty} s_r^2(t)\, dt}}\right] \quad (8)$$

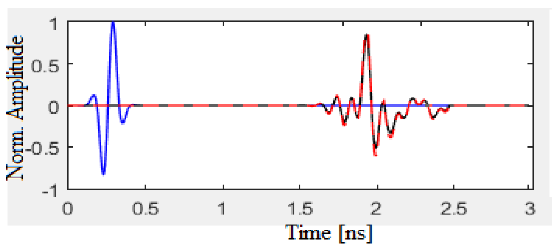
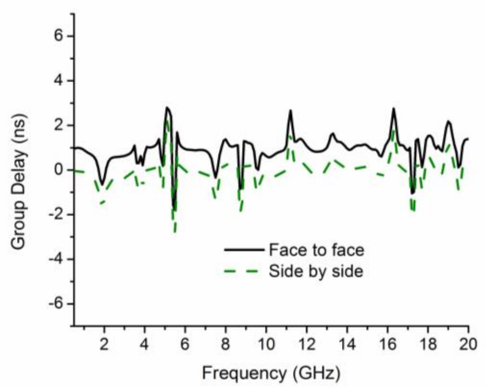
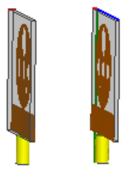


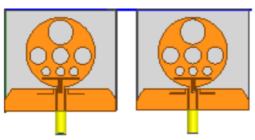
Fig. 12: Input and received pulse in face to face orientation of proposed antenna.

Where $s_t(t)$ and $s_r(t)$ are the input and output signals respectively. It determines the correlation between the excited input pulse signal $s_t(t)$ and the received output pulse signal $s_r(t)$. Fig. 12 shows the input and received signal. Face to face fidelity factor is 0.89. Group delay is another parameter in time domain analysis to measure the pulse distortion. The group delay response has been shown in Fig. 13(a) which shows a stable delay with average variation of 2 nanoseconds throughout the desired frequency band in both cases of Fig. 13(b-c) i.e. (I) face to face and (II) side by side. Conclusively, the phase linearity is exhibited by group delay characteristics of the proposed antenna at the desired frequency band which also delivers good pulse handling capacity.



(a)





(b) (c)

Fig. 13: (a) Group delay response of proposed similar antennas kept 40 cm apart (b) Face to face orientation and (c) Side by side orientation

4. Measured result and discussion

A new structure of circular disc microstrip antenna with circular shape slotted antenna has been designed and optimized. The optimized dimensions of antenna is fabricated on FR4 substrate and proposed antenna being tested on the network analyzer Anritsu MS2038C. The simulated and measure S_{11} of the proposed antenna is shown in Fig. 14. A good comparative similarity has been found between the measured result and the simulated results which leads to the conclusion that the bandwidth of 0.5 Ghz, 0.8 GHz, 1.1 GHz and 11.7 GHz have been found. The measured far field radiation pattern in *E* and *H* planes at 1.0 GHz, 2.4 GHz, 4.1 GHz, 8.5 GHz and 12 GHz have been presented in Fig. 15(a)-(b). Radiation patterns are nearly in eight shaped structure for *E*-plane at 1.0 GHz, 2.4 GHz, 4.1 GHz and 8.5 GHz but some distorted nature at 12 GHz. For *H*-plane the radiation patterns are nearly in omni direction. The gain and efficiency have also been measured and are plotted in Fig. 16. Gain measurement shows a peak gain of 6.37 dBi at 10.2 GHz and a peak efficiency of 96 % at 4.2 GHz has also been obtained. At the lower frequencies, gain is low due to smaller size of antenna (less surface area). The efficiency is low at higher frequency ranges due to dielectric losses. Distortion occurs in high frequency ranges due to FR-4 substrate which is made of fiber glass material with epoxy resin binder that offers low cost but offer losses at higher frequency ranges.

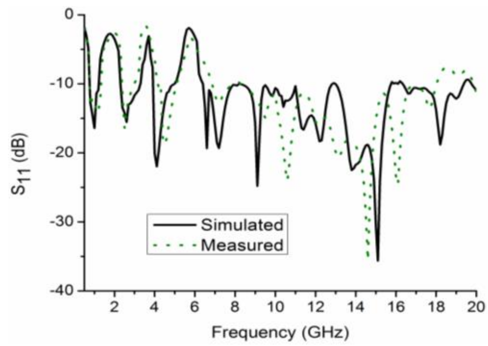
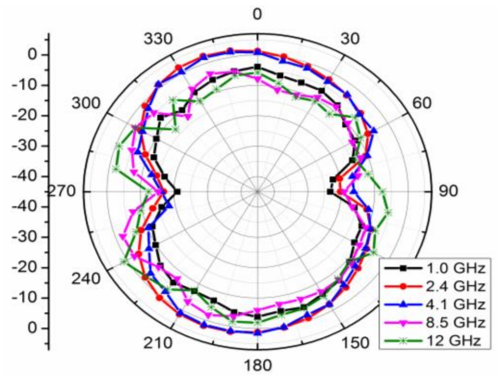
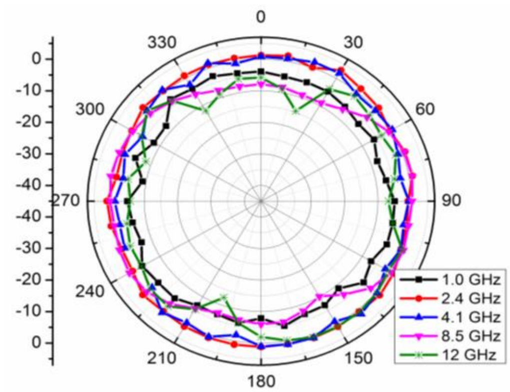


Fig. 14: Simulated and measured results of the proposed antenna.



(a) E-plane



(b) H-plane

Fig. 15: Measured radiation pattern of proposed antenna.

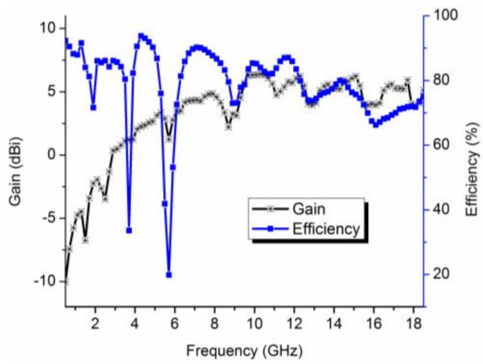


Fig. 16: Gain and efficiency of the proposed.

A good conformity between the simulated and the measured results are reasonably found as shown in respective figures. The little variations in the simulated and measured results are due to the soldering and tolerance levels of the SMA connector during the fabrication process of the proposed antenna. The proposed antenna has been observed with the advantage in size i.e. small in size and its simple structure covering multiband region i.e. GSM/Bluetooth/UWB/ X/Ku frequency band applications as compare to reported antenna structure in Table 2.

Table 2: Result analysis of proposed antenna with other reported antennas.

Parameters	Ref. [13]	Ref. [14]	Ref. [15]	Ref. [16]	Ref. [17]	Proposed
Operating bandwidth (GHz)	2.4-11.2	2.4-11.6	2.44-5.77	2.81-14.3	2.1-11	0.88-18.3
Notch band frequency (GHz)	5.5	3.5/ 5.5	3.55/5.79	3.5/5.5	2.5/5.5	2.0/3.5/5.6
Notches	01	02	01	02	02	03
Dielectric constant	4.4	4.4	2.2	4.4	4.4	4.4
Thickness of subtrate (mm)	0.8	0.8	2	1.59	1.6	1.59
Size (mm^2)	50 × 50	50 × 50	62 × 64	36 × 48	50 × 50	45 × 50

5. Conclusion

A study and analysis has been carried out to design a small, planar, low cost, multiband and easy to manufacture integrated GSM/Bluetooth/UWB bands with convent for other wireless applications due to its approach towards X & Ku band ranges. The gap between ground plane and radiating disc, gap between ground plane and feed, the length & width of ground plane have strong influence on the performance of the antenna. The antenna achieves dual notch band with integrated GSM characteristics and can be built on other type of substrate with some scaling in dimension of antenna. Overall dimension of proposed antenna is 45 × 50 × 1.59 mm^3. The radiation pattern is very stable across the operating band. The notch band frequencies are obtained at 2.0 GHz, 3.5 GHz and 5.6 GHz. The antenna has operating impedance bandwidths as 0.5 GHz (0.88 ~ 1.3 GHz), 0.9 GHz (2.3 ~ 3.2 GHz), 1.3 GHz (3.9 ~ 5.2 GHz) and 12.2 GHz (6.1 ~ 18.3 GHz) respectively for VSWR less than 2 and S_{11} less than - 10 dB over the operating frequency ranges. The UWB band is not affected by the GSM band resonance. The maximum measured gain of proposed antenna is obtained 6.37 dBi. At last it is concluded that this type of antenna configuration is useful in modern wireless communication systems for GSM (900 MHz), Bluetooth band (2.45 GHz), UWB (3.1–10.6 GHz), X-band (8–12 GHz) and Ku band (12-18 GHz) applications.

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References

[1] Anguera J et al. (2013), Advances in antenna technology for wireless handheld devices, *International Journal on Antenna and Propagation*, Article ID: 838364.

[2] Balanis CA, *Antenna theory - analysis and design*, A John Wiley & Son Inc. Publication, (2010), 3rd edition, pp: 843-852.

[3] Foudazi A, Hassani HR, & Nezhad SMA (2012), Small UWB planar monopole antenna with added GPS/GSM/WLAN bands. *IEEE Transactions on Antennas and Propagation* 60(9), 2987-2992.

[4] Mirzamohammadi F, Nourinia J, & Ghobadi C (2012), A novel dual wideband monopole like microstrip antenna with controllable frequency response. *IEEE Antennas and Wireless Propagation Letters* 11, 289-292.

[5] Chen IF & Peng CM (2003), Microstrip fed dual U shaped printed monopole antenna for dual band wireless communication applications. *Electronics Letters* 39(13), 955-956.

[6] Chen SB, Jiao YC, Wang W, & Zhang FS (2006), Modified T-shaped planar monopole antenna for multiband operation. *IEEE Transactions on Microwave Theory and Techniques* 54(8), 3267-3270.

[7] Deshmukh AA & Ray KP (2010), Multiband configuration of stub loaded slotted rectangular microstrip antenna. *IEEE Antennas and Propagation Magazine* 52(1), 89-103.

[8] Liang J, Chiau CC, Chen X, & Parini CG (2005), Study of CPW fed circular disc monopole antenna for ultra wideband applications. *IEE Proceeding- Microwaves, Antennas and Propagation* 152(6), 520-526.

[9] Srifi MN, Podilchak SK, Essaaidi M, & Antar YMM (2011), Compact disc monopole antenna for current and future UWB application. *IEEE Transactions on Antennas and Propagation* 59(12), 4470-4480.

[10] Dastranj A & Abiri H (2010), Bandwidth enhancement of printed E-shaped slot antennas fed by CPW and microstrip line. *IEEE Transactions on Antennas and Propagation* 58(4), 1402-1407.

[11] Sadeghi V, Ghobadi C, & Nourinia J (2009), Design of UWB semi circle like slot antenna with controllable band notch function. *Electronics Letters* 45(25), 1282-1283.

[12] Satyanarayana B & Mulgi S (2015), Design of planar band notched monopole antenna for 2.4 GHz WLAN and UWB applications. *Microwave Optical Technology and Letters* 57(11), 2496-2501.

[13] Lee DH, Yang HY, & Cho YK (2012), Tapered slot antenna with band notched function for UWB radios. *IEEE Antennas and Wireless Propagation Letters* 11, 682-685.

[14] Lee DH, Yang HY, & Cho YK (2014), UWB tapered slot antenna with dual band notched characteristics. *IET Microwaves, Antennas and Propagation* 8(1), 29-38.

[15] Peng L, Ruan CI, & Wu XH (2010), Design and operation of dual/triple band asymmetric M-shaped microstrip patch antennas. *IEEE Antennas and Wireless Propagation Letters* 9, 1069-1072.

[16] Mandal T & Das S (2015), Design of a CPW fed UWB printed antenna with dual notch band using mushroom structure. *International Journal of Microwaves and Wireless Technologies* 9(2), 327-334.

[17] Rahimi M, Heydari S, Mansouri Z, Gandji NP, & Zarrabi FB (2016), Investigation and design of an UWB fractal ring antenna for notch applications. *Microwave Optical Technology and Letters* 58(7), 1629-1634.

[18] Moghadasi MN, Sadeghzadeh RA, Sedghi T, Aribi T, & Virdee BS (2013), UWB CPW-Fed fractal patch antenna with dual notched function employing folded T-shaped element. *IEEE Antennas and Wireless Propagation Letters* 12, 504-507.

[19] Dehkhoda P & Tavakoli A (2004), A crown square microstrip fractal antenna. *IEEE Antennas and Propagation Society International Symposium*, USA.

[20] Ding M, Jin R, Geng J, & Wu Q (2007), Design of a CPW fed ulta wideband fractal antenna. *Microwave Optical Technology and Letters* 49 (1), 173-176.

[21] Zhai H, Ma Z, Han Y, & C. Liang C (2013), A compact printed antenna for triple band WLAN/WiMAX applications. *IEEE Antennas and Wireless Propagation Letters* 12, 65-68.

[22] Ghatak R, Biswas B, Karmakar A, & Poddar DR (2013), A circular fractal UWB antenna based on Descartes circle theorem with band rejection capability. *Progress in Electromagnetics Research C* 37, 235-248.

[23] Sharma M, Awasthi YK, Singh H, Kumar R, & Kumari S (2016), Design of compact flower shape dual notched band monopole antenna for extended UWB wireless applications. *De Gruyter* 70(11-12), 499-506.

[24] Anguera J, Puente C, & Borja C, “A procedure to design wide-band electromagnetically coupled stacked microstrip antennas based on a simple network model”, *IEEE Antennas and Propagation Society International Symposium*, (1999), pp: 944-947, Orlando, USA.

[25] Quintero G, Zurcher JF, & Skrivervik AK, System Fidelity Factor: A new method for comparing UWB antennas. *IEEE Transactions on Antennas and Propagation* 59(7), 2502-2512.