Review Paper on Design of Integrated Multi-Band UWB Antenna for Wireless Applications

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Abstract - *In this review paper, a survey conducted on different techniques to introduce multi-band capability in printed microstrip patch Ultra-wideband (UWB) antennas is presented. UWB is a promising technology for future wireless communication systems. However other lower frequency bands about UWB such as WLAN, Bluetooth, WCDMA, GSM, and GPS, etc. are important for many wireless communication systems so that the need of integrated lower frequency multi-band –UWB antenna design is essential. In this paper, we studied the different techniques proposed in the literature for design multi-band UWB antenna. Every paper from literature is described in the different subsection for better understanding of design techniques. Parametric effects are given in respective section for the particular antenna with the particular antenna structure diagram and* S_{11} *plot. After studying these techniques comparison and guideline to choose the best method for the particular design is given.*

***Key Words*: CLLR`s, Quarter wavelength, Slit, GPS, UWB.**

1. INTRODUCTION

In satellite communication, in air and space crafts or in missile applications where mass, heaviness, volume, budget, performance, etc. are the main requirements of antennas. Such demands are fulfilled by the Microstrip Antennas (MSA). These antennas are subjected to stringent specifications such as small size, light weight, robustness and conformability [1].

In February 2002, Federal Communications Commission (FCC) of the United States assigned a 3.1-10.6 GHz unlicensed frequency band of UWB applications [2]. UWB system has features such as cost efficient, quiet intricacy and very high data rate for short range communication and approves short distance radio communication technology that performs high-speed communication with the speeds of more than 100 Mbps. The ultra-wideband (UWB) communication systems have received great attention from both the academic and the industrial sectors. There are two types of UWB system as follows: UWB (DS-UWB) and multi-band orthogonal frequency division multiplexing (MB-OFDM). The DS-UWB proposal foresees two different carrier frequencies lower frequency band at 4.104 (3.1–5.15 GHz) and higher frequency band 8.208 GHz (5.825–10.6 GHz), while the MB-OFDM format in IEEE 802.15.3 a has an interval between 3.1 and 10.6 GHz and is divided into 14 subintervals. Each subinterval covers 528 MHz of bandwidth [3], [4]. UWB antenna is an integral part of UWB systems whereas new communication systems need a single antenna to cover multiple frequency bands Gradually, need a compact single antenna operating on multiple radiation bands including UWB range is extensively growing due to its large channel capacity, small size and stress-free integration with other wireless standards.

There are two techniques reported in the literature to create multiband printed monopole antennas. In the first, a patch antenna is designed to cover the desired wide bandwidth, and then the unwanted bands are notched using one of the band notching technique. Due to the lower frequency in antenna design size of the structure increases. To create the multi-band behavior, notches are introduced into the antenna [4], [5]. In the second technique, a small-size antenna can be designed to cover the highest frequency band, and for creating lower frequency bands, resonating strips are used [6], [7].

TABLE -1: wireless standards and frequency bands.

Sr. no	Wireless Technology	frequency band (GHz)	Lower Frequency(MHz)	Upper Frequency(MHz)
1	WLAN	2.4	2400	2483.5
2	Bluetooth	2.4	2400	2500
3	GSM	1.8	1710.2	1784.8
4	WCDMA	2.1	1920	2170
5	GPS	1.2	1260	1300

Frequency bands used in literature and their band of spectrum is given in Table 1.

From few years, Bluetooth (IEEE 802.15.1) has been widely used in the portable devices such as mobile phones, PDA's, notebooks, etc. earning an advantage of license-free frequency operation covering the 2.40–2.48GHz band. To integrate with Bluetooth wireless technology, the Bluetooth Special Interest Group selected MB-OFDM UWB in 2006 [8]. WLAN (Wireless Local Area Network) is based on IEEE802.11 standards, including WLAN 2.4 GHz and WLAN 5.8 GHz bands. WLAN can be applied in the family and enterprise to access the internet.

In recent years, GSM (Global System For Mobile Communication) system has found large applications in mobile and portable wireless communications because of its stability and greater network capability. GSM system contains GSM 850, GSM 900, GSM 1800 and GSM 1900. Among all, GSM 900 and GSM 1900 are mostly used. WCDMA (Wideband Code Division Multiple Access) is selected as the third generation (3G) of wireless communication technique. WCDMA can provide the higher data rate of voice, image, data, and video communication for the mobile terminal device. The GPS (Global Positioning System) provides users with positioning, navigation, and timing (PNT) services. The Global Positioning System carriers are in the L band, centered at 1176.45 MHz (L5), 1227.60 MHz (L2), 1381.05 MHz (L3), and 1575.42 MHz (L1) frequencies [9].

In this review paper, we arrange the details from different literature in the different section for better understanding. Integrated Bluetooth, GSM, and GPS UWB antenna is described in section 1.A. Integrated GSM and Bluetooth with UWB is presented in section 1.B. Integrated GSM, WCDMA, WLAN UWB antenna is described in section 1.C. Integrated GPS, GSM, and WLAN UWB antenna is described in section 1.D. Comparison is given in section 3, which shows the result obtained so far in literature, techniques used and limitation of design. Conclusion is given in Section 4.

2. ANTENNA DESIGN

2.1 Integrated GPS, GSM and WLAN UWB Antenna [10]

In [10] multi-band antenna is presented. The basic structure of the proposed antenna is a diamond-shaped patch (DSP) that covers the ultra-wideband (UWB) frequency range. To create a multi-band antenna, the second method is used. The center part of the DSP antenna is removed without distorting the UWB behavior, quarter-wavelength strips can be added to the notched region to achieve multi-band antenna. The given antenna covers frequency bands of 2.4,1.3,1.8, and 3.1–10.6 GHz which includes WLAN, GPS, GSM, and UWB respectively.

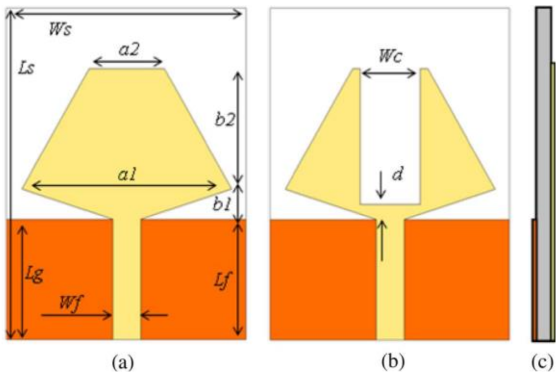


Fig -1: (a) DSP UWB antenna, (b) DSP antenna with inserting notched region in the middle part, (c) side view of the proposed base antenna.

There are four parameters a1, a2, b1 and b2 that could affect the performance of the UWB antenna. (The dimension in fig.1 as follows: Ws=16, Ls=22, a1=14, a2=5, b1=2, b2=8, Lf=8, d=1, Lg=8 mm.) To obtain UWB antenna beveled along lower edges for improving the reflection coefficient characteristic over the desired band. For the constant value of b1, b2 control the lower cut-off frequency of the DSP antenna also the a1 provide impedance matching at the higher frequency and provide impedance matching over the UWB range. a2 do not have any effect on performance, but it should be large enough to provide space for resonating strips.

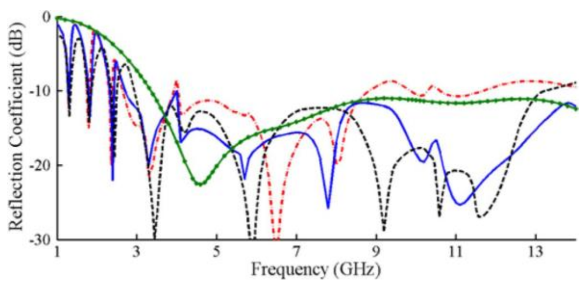
To obtain multi-band behavior, additional resonant strips are placed in the notched region. These strips are efficiently excited, if set along the direction of the current flow and near the main micro strip feed line, i.e. at position lf+d. For a desired resonant frequency, the wavelength is given by equation 1.

$$\lambda_g = \frac{\lambda}{\sqrt{\epsilon_{r(eff)}}} \qquad (1)$$

Where λ is the free space wavelength and $\epsilon_{r(eff)}$ is given by the approximate formula of

$$\epsilon_{r(eff)} = \frac{\epsilon_r + 1}{2} \qquad (2)$$

The total required resonant strip length, which is a multiple of quarter-wavelength, can be calculated approximately by [11] is as follows:



$$L_{total} = n\,\frac{\lambda_g}{4} \qquad (3)$$

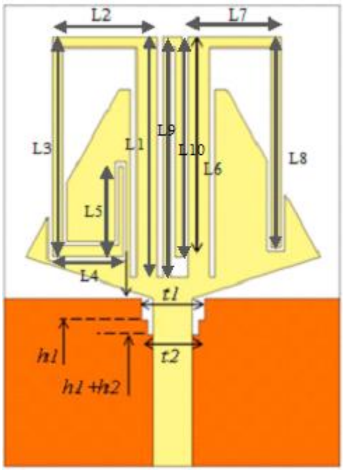


Fig-2: shows the diamond-shaped structure of the antenna. The dimensions used as follows: Wc=4, L1=L6=L9=12.6, L2=L7=5, L3=L8=10.5, L4=3.5, L5=4.4, L6=4.4, L7=10, L10=10mm.

To create a quad-band antenna, apart from the base UWB antenna, three additional strips should be added to the structure to create the other three bands below the UWB frequency. The quad-band structure is shown in Fig. 2 To create the four bands; three strips are placed in between the etched region of the base antenna. Strip 1 (L1 to L5) corresponds to the 1.3GHz band, strip 1 (L6 to L8) corresponds to the 1.8GHz band, and Strip 3 (L10, L11) correspond to the 2.4GHz frequency band.

Strip 1 and 3 can be interchanged without affecting antenna parameters. To keep the size of third strip compact within the given substrate size, the third strip is brought back towards the base patch. If this is done either towards the left or right-hand side of the existing strips, the resonance of the previous strips would be lost. Therefore, the third strip is brought back towards itself on a path along the axis of the patch. Due to the limitation of the length of this center strip, it can only be used for resonances just below the UWB range, e.g., WLAN band at 2.4 GHz. The three strips added to the base antenna structure would generate higher frequency harmonics that would affect the reflection coefficient as well as the impedance matching of the UWB antennas. The performance of the antenna can be improved by placing steps in the ground plane around the feed line as shown in Fig. 2.

Fig- 3: Simulated and measured reflection coefficient of the quad-band antenna (—•— simulated simple DSP antenna, ━•━simulated Quad-band without step,
── simulated Quad-band with two steps, ---- measured Quad band with two steps).

Fig. 3 shows the simulated reflection coefficient of the quad-band antenna with and without the steps as well as the measured reflection coefficient of the proposed quad-band antenna with two steps. As seen, four practical frequency bands, GPS (1.26–1.3), GSM (1.71–1.88), WLAN (2.4–2.48), and the UWB (3.1–10.6) GHz with a good filtering effect between the bands is achieved in given paper. The results shown in Fig. 3, it is noticed that the two steps in ground plane result in a better impedance matching over the UWB range.

2.2Integrated GSM and Bluetooth Antenna[12]

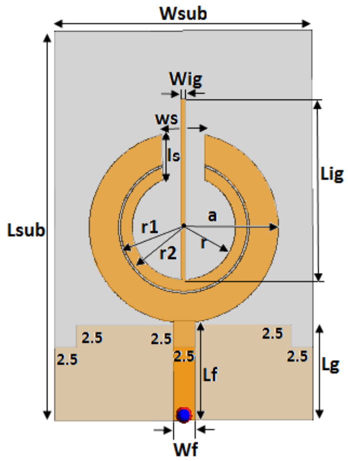


Fig- 4: Geometry of the designed antenna [L_{sub}=38, W_{sub}=30, a=11, r=6, r_1=6.95, r_2=6.70, l_s=7, W_s=5, L_f=11.5, W_f=3, L_g=11, L_{ig}=21]

In the [12] UWB frequency band operation is achieved by modifying a circular radiating patch and ground plane. Further, a circular arc of half wavelength is etched just below the circular slot on the patch to resonate over the Bluetooth band and then just above it a rectangular quarter wavelength strip is inserted to resonate over GSM band. The radius *(a)* of the circular patch is calculated by –

$$a = \frac{F}{\left\{1+\frac{2h}{\pi\varepsilon_r F}\left[\ln\left(\frac{\pi F}{2h}\right)\right]+1.7726\right\}} \quad (4)$$

Where $$F = \frac{8.791\times10^9}{f_r\sqrt{\varepsilon_r}} \quad (5)$$

h should be considered in 'cm.'

The basic circular patch provides an impedance bandwidth from 3.0 - 6.2 GHz. The dimensions of a circular slot followed with the rectangular slot on the radiating patch and ground plane beveling have been optimized, to get an impedance bandwidth over an entire UWB range.

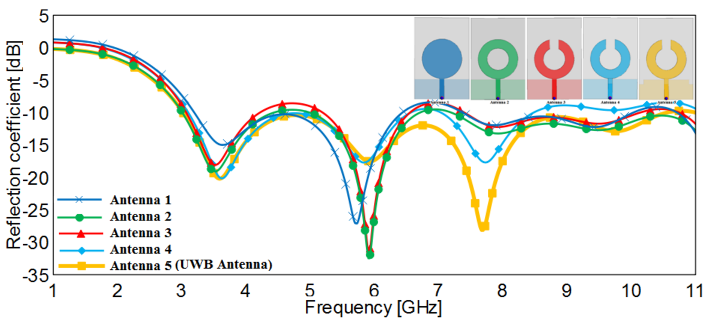


Fig- 5: The evolution of UWB.

Antenna 1 shows reflection coefficient (S11) of the primary circular monopole antenna providing an impedance bandwidth from 3.0 - 6.2 GHz. A circular slot is inserted as there is no current in the central part of the antenna to enrich the impedance bandwidth of an antenna 1. The antenna 2 shows good impedance bandwidth, but at some frequencies, S11 slightly goes beyond -10 dB. A rectangular slot is then inserted into antenna 3 which also does not cover an entire UWB frequency range. In antenna 4, a slot is added on the behind the feed of dimensions 2.5×2.5mm^2 which provides impedance bandwidth from 3-8.4 GHz. Still a frequency mismatched is observed. The ground plane corners are beveled both 2.5×2.5mm^2 which provide an entire UWB (3.1-10.8GHz). The gap between the radiating patch and slots on the ground plane are optimized to impedance bandwidth of UWB antenna [13].

A circular arc of half wavelength etched on to the radiating patch to resonate over the Bluetooth band (2.40-2.48 GHz). For Bluetooth band: center frequency (f_{ib}) = 2.44 GHz and $\lambda_g/2$ = 37.41 mm. Where λg is given by equation 1. The length of the circular arc is calculated from the circumference of the circular arc. $\text{Circumference of the circle} = 2\pi \times r_1$. So for finding r_1, $2\pi \times r_1 = 37.41$ and r_1=5.95 mm. The radius r_1 of the greater circular arc is considered to be 6.9 radii (r_2) is given to be 6.70 mm. GSM frequency band operating from 1.78-1.82 GHz is an unlicensed band. Rectangular quarter wavelength strip resonating at F_{ig}=1.8 GHz is inserted just above the circular arc and at the center of the radiating patch. L_{ig} and W_{ig} are the length and width of the rectangular quarter wavelength the strip is calculated using equation 3. Where n is 1. If the length of the circular arc increases, the Bluetooth band shifts to the lower edge frequency with the different peak. The width (Wig) of the strip affects the bandwidth of GSM band, while length (L_{ig}) effects on the position of the GSM band. By increasing the length of the monopole strip, the GSM band shifts to the lower edge frequency with the varying peak.

2.3 Integrated WLAN, GSM and WCDMA UWB Antenna [14]

In [14], a compact printed antenna design operating on ultra-wideband (UWB) and three extra wireless communication bands is given. An ellipse-shaped monopole antenna is used to resonate over UWB range. The modified ground helps to get impedance match over the entire UWB. To achieve relatively lower frequency bands three folded Capacitive Loaded Line Resonators (CLLRs) used. Lower frequency bands such as GSM (Global System for Mobile Communications), WLAN (Wireless Local Area Networks) and WCDMA (Wideband Code Division Multiple Access) are utilized.

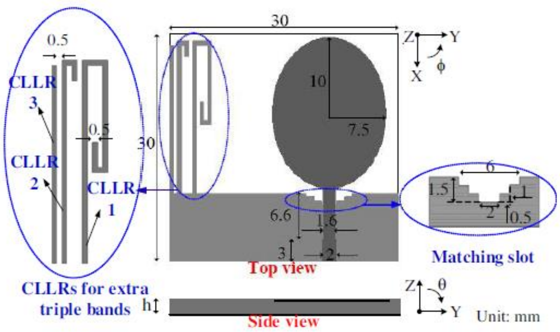


Fig- 6: Geometries of the antenna.

Fig. 6 shows the geometries of the UWB antenna based on an ellipse monopole. Three CLLRs deposited at the ground plane create lower frequency bands. The CLLRs have the widths and gaps of 0.5 mm. The lengths are 20 + + 1.5 + 2 = 23.5mm for WCDMA band 20 + 2.5 + 11 + 1.5 + 3 = 38mm for GSM band, 19.5mm for WLAN band. The lengths are approximately $\lambda_g/4$ for the corresponding resonance. λ_g can be determined using equation 1.

First CLLR is designed a little longer than, $\lambda_g/4$ for GSM band to reduce the coupling between monopole and CLLRs. This design adds extra bands without increasing the overall size. Moreover, by etching a matching slot with steps of equal width 1mm and height 0.5mm in the ground, ultra-impedance wideband characteristic covering 3.1GHz to 13GHz is achieved. A 50-Ohm feed line is connected to an impedance transformer, which can improve the matching property furthermore.

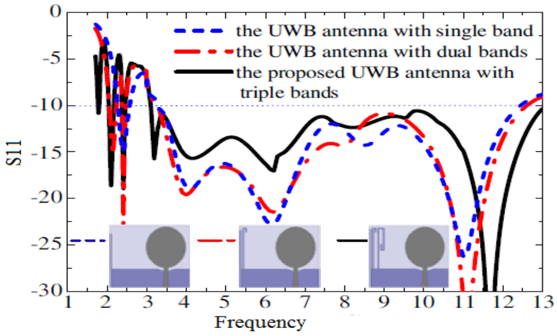


Fig- 7: Simulated *S*11 curves for the integrated single, double, triple UWB antenna.

Fig. 7 shows the freq vs. s_{11} curve for different added CLLR`s. As seen in fig as each added CLL add new resonating frequency corresponding to the length of CLL. As the length of CLLR 1 increases, the corresponding resonant frequency for GSM shifts lower but this will not affect the other added bands resonance frequency because the other added resonance bands are almost unchanged. The effect of CLLR 2 can be observed that the as the length increases, the resonant frequency of WCDMA decreases. Besides, as the CLLR 2's length increases, the resonances of WLAN and GSM also shift toward lower frequencies due to coupling and interaction between the adjacent CLLR structures. The design of length of CLLR 3 is critical because has a significant effect on the added resonant frequency of WCDMA and GSM bands. Individual CLLR`s can control the corresponding wireless bands so to design of a new lower frequency band is easy by adjusting the length of the single CLLR. Therefore, their dimensions can be changed easily for the desired applications without the need to redesign the whole antenna.

2.4 *Integrated GPS, GSM, and Bluetooth UWB Antenna [15]*

In [15] A novel compact multi-band UWB printed slot antenna with three extra bands is presented. The antenna consists of an octagonal-shaped slot fed by a beveled and stepped rectangular patch for covering the UWB band. The three inverted U-shaped strips are added to the upper part of the slot in the ground, to achieve additional triple linear polarized bands covering GPS (1520–1590 MHz), part of GSM (1770–1840 MHz), and Bluetooth (2385–2490 MHz). The design of the UWB printed slot antenna is illustrated in Fig. 8. The base antenna consists of an octagonal- shaped slot structure fed by a beveled rectangular patch. This structure covers the whole UWB micro strip transmission line. The antenna has compact dimensions of 25x28 mm. Over the frequency range of excitation, current is present on the ground plane so thatBy attaching resonant strips to the ground plane additional resonances created to the UWB antenna. The position of the strip attachment to the ground plane provides the impedance matching. The width of three narrow strips is 0.4 mm which are connected to the backside of the antenna for creating additional resonance. To create resonance frequency of the GPS band, the length of strip 1 should be L_{t1}=9.2+4.7+11.2+.35=28.6mm for GSM band, the length of strip 2 should be L_{t2}=9.1+4+10.4+0.7=24.2 mm for Bluetooth, the strip length 3 is set at L_{t3}=8.9+3.3+5.7=17.9 mm.

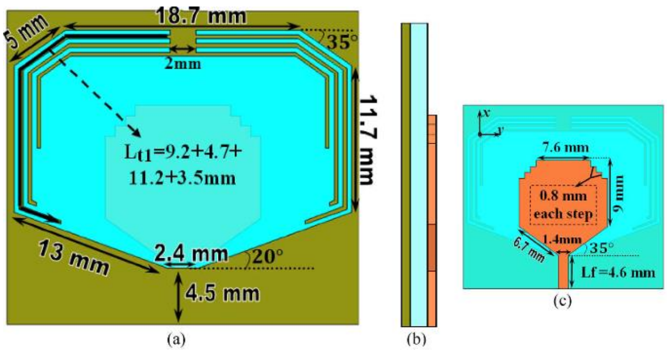


Fig- 8 The antenna I: The multiband printed UWB slot antenna with three inverted U-shaped strips. (a) Bottom layer. (b) Side view. (c) Top layer.

TABLE-2: Comparison of Different Techniques

Sr. no	Ref. No	UWB technique	UWB bandwidth achieved (GHz)	Lower bands			Limitation
				Protocol	Technique used	Bandwidth Achieved (GHz)	
1	[10]	Diamond shaped patch with two steps in ground plane	3.1-10.6	GPS	Quarter wavelength resonating strip	1.26-1.3	Due to large slot created within main patch group delay properties of UWB antenna distorted at 7 GHz, but it can be for UWB effectively if only 2-lower bands are used.
				GSM	Quarter wavelength resonating strip	1.71-1.88	
				WLAN	Quarter wavelength resonating strip	2.4-2.48	
2	[12]	Modified circular radiating patch with destructive ground plane	3.1-10.8	Bluetooth	A circular arc of half wavelength is etched on radiating patch	2.38-2.48	Radiation pattern is not stable over an entire UWB region.
				GSM	Quarter wavelength resonating strip at center of patch	1.78-1.82	
3	[14]	Elliptical shape monopole antenna	3.1-13	GSM	Quarter wavelength CLLR at ground plane	1.77-1.83	Less radiation at lower frequency bands due to lower coupling current into CLLR`s and group delay is distorted at lower UWB frequencies.
				WCDMA	Quarter wavelength CLLR at ground plane	2.08-2.19	
				WLAN	Quarter wavelength CLLR at ground plane	2.34-2.47	
4	[15]	Octagonal shape slot fed by beveled and stepped rectangular patch	3.1-10.6	GSM	Quarter wavelength inverted U shaped strip	1.77-1.84	Only part of the bandwidth of GSM band is achieved.
				GPS	Quarter wavelength inverted U shaped strip	1.52-1.59	
				Bluetooth	Quarter wavelength inverted U shaped strip	2.385-2.49	

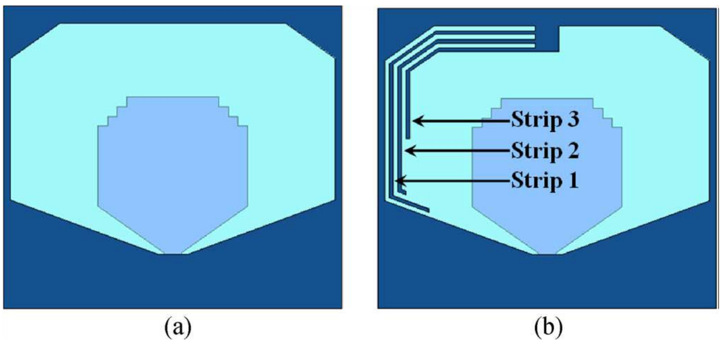


Fig- 9: The printed UWB antenna. (a) Antenna II: UWB antenna. (b) Antenna III: UWB antenna with added strips on one side.

The strip length is obtained from equation 3 where n is 1. The presence of the strips makes the surface of the octagonal slot smaller, the UWB starting frequency changes. The reflection coefficient of the antenna is shown in Fig. 10. The added strips on one side create impedance mismatch, so the strips are added on both sides for better impedance match. As seen from Fig. 10 of frequency vs. s_{11}, the antenna covers the whole of the UWB band as well as the three extra other linear polarized bands. The measured reflection coefficients of the proposed UWB printed slot antenna with the three inverted U-shaped strips are also compared in Fig. 10. From the fig. 10, it can be seen that the first band covers 2385–2490 MHz, the second band covers 1770–1840 MHz, and the third band covers 1520–1590 MHz.

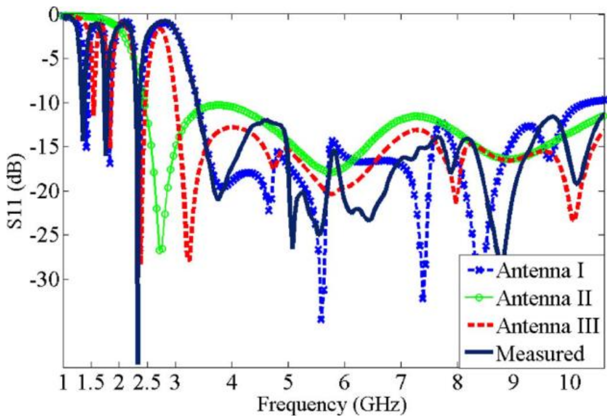


Fig. 10: The simulated reflection coefficient of (UWB with three inverted U-shaped strips, (UWB, (UWB with added strips on one side. The measured reflection coefficient of Antenna I.

Thus, the proposed antenna in literature can cover the covers part of the GSM band (1710–1880 MHz), a whole of the GPS and the Bluetooth bands. The effect of changing the length of each strip, the related extra frequency changes with the small effect on the design of the lower frequency bands. Therefore, one can simply add the desired extra frequencies to the UWB band by simply choosing the desired strips length through equation 3. Other parameters of the inverted U-shaped strips like the gap between each strip and width of strips have little effect on antenna performance.

3. COMPARISON

In this section we compare the different antenna design based on technique used for obtaining UWB and to obtain lower frequency bands, given in table 2. Table 2 also shows the result obtained in respective literature and Limitations for given antennas.

4. CONCLUSION

In this paper, we have surveyed the past research works which mainly focuses on integrating different lower frequency band in UWB antenna design. UWB antenna can be designed using different structures as given in [16]. Circular, Elliptical, diamond shape and octagonal shapes can be used effectively to create integrated UWB. To create relatively lower frequency bands second technique is used i.e. first create UWB antenna and then using tanning or resonating stub lower frequency bands are formed. In given literature the quarter wavelength strips are used to design integrated lower frequency band.

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