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Design and Fabricate the UWB Tapered Fed Printed Log-Periodic Dipole Antenna with Dual Notched Band Using Double Side SRR

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ABSTRACT

In this paper, proposed a notch filter using the parallel microstrip line with a pair of rectangular C-shaped split ring resonator (CSRR) that is placed on the top and bottom side of the substrate. The CSRR has a width (*w*), length (*L*), and the gap region (*g*) in the CSRR is parallel and far from the microstrip line. It can be stored and absorbed all of the passing fields in the microstrip line at its resonance frequency and thus generated a notch frequency or a band filtering. This study focuses on creating a notch-bands for the UWB dipole antenna with frequency selectivity. By embedding two double side CSRRs near the microstrip feed-line, filter characteristic with cutoff band for WiMAX and WLAN are generated for a printed log-periodic dipole antenna (PLPDA) consists of 12 dipole elements fed by a tapered microstrip line. The final proposed structure of PLPDA is fabricated on Rogers Ro4003 substrate with dielectric constant 3.55, loss tangent 0.0027, and thickness of 0.8 mm. Also, the radiation patterns of the structure for three selected frequencies are presented that indicate stability directional beams in the operational band. The simulation and measurement results are in good agreement with each other and the proposed antenna can be used for UWB applications without affecting WiMAX and WLAN bands.

1. Introduction

A log-periodic dipole antenna (LPDA) consists of some dipole antennas which are placed along a specific feed line. The dimensions and spacing between the antennas are chosen as a constant factor from each other so that the length of each element, and the distance from the centreline increases periodically. LPA is a frequency-independent antenna that has moderate gain and linear polarization. The expression of frequency-independent means that antenna characteristics such as input impedance change very negligibly with frequency changes. [1-8]. Ultra-Wide Band (UWB) communication systems have a high data rate with low power spectral density. For the first time, the Federal Communications Commission introduced and approved a frequency band from 3.1 to 10.6 GHz [2, 9]. The UWB antennas can be designed for the progress of the parameters such as the wide impedance matching, radiation pattern and compact size.

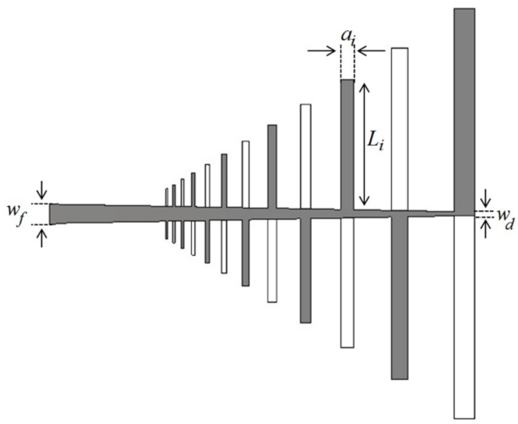

Fig. 1. Geometry of the PLPDA with details

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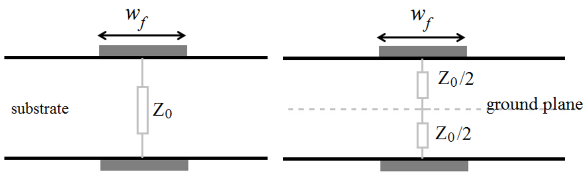
The 3.3 ~ 3.8 GHz and 5.15 ~ 5.85 GHz bands for Worldwide Interoperability for Microwave Access (WiMAX) and Wireless Local Area Network (WLAN) are two-narrowband communication systems, respectively.



(a) (b)

Fig. 2. Cross section of the microstrip feed line

To reduce electromagnetic interference (EMI) we need to design a UWB antenna has notch-bands. Recently UWB antenna with single notch band [10-12], dual notch-bands [13-15] and triple notch-bands [17-23] are reported. The most-reported UWB antennas with notched frequency bands are printed monopole antenna [10, 12-13, 16-23]. Another type of UWB antenna is achieved by the CPW-fed planar structures [3, 4, 23]. These antennas are generally embedded with a half-wavelength slot such as an L and T-shaped slot [15], a U-shaped slot [6, 7, 23], H-shaped resonator [5, 19], or volumetric resonant [13] on the radiator or feed line. By adding the capacitively-loaded loop resonators [17], step impedance resonators (SIRs) [20], and split ring resonators (SRRs) [10, 16, 23] close to the feed line or near the radiator, the desired frequency bands can be rejected in the operational band. In the following of the UWB antenna can be referenced the printed dipole antenna with single notch band using short circuited coplanar strip line resonator [10]. The notch-bands for the UWB dipole antenna and frequency selectivity are the main objective of this paper. The log-periodic dipole antenna is proposed and a split-ring resonator is introduced originally to obtain a band-stop filter. The design of the proposed PLPDA with the notch band is organized as follows. Section one presents the simple PLPDA with a microstrip feed line. The feed line is tapered with various slopes to improve the impedance bandwidth. In section two, a pair of the rectangular C-shaped SRR coupled to the microstrip line and placed on both sides (top and bottom) of the substrate is proposed.
The proposed SRR has a stop-band response that is can be used for creating a notched band in the dipole antennas such as a log-periodic antenna. In section three, a rectangular C-shaped SRR is placed near the parallel microstrip feed line for creating a single notch band. Notch frequency can be increased by decreasing the total length of the rectangular C-shaped SRR.
Band-rejected filtering around the WiMAX and WLAN bands are generated by embedding the two rectangular C-shaped SRRs with different lengths in which are placed right and left side of the microstrip feed line. PLPDA with dual notch bands is fed by tapered microstrip line and fabricated on Rogers Ro4003. The comparison between simulated and measured results shows that the proposed antenna can be used for ultra-width band applications.

2. LP Dipole Antenna Design

The geometry of the proposed LPDA, as illustrates in Fig. 1, has 12 dipole elements that are printed on Rogers Ro4003 substrate with loss tangent 0.0027 and thickness equal to 0.8 mm.

Table I. The dimensions of the PLPDA (unit:mm)

i	s_i	L_i	a_i	i	s_i	L_i	a_i
1	-	2.00	0.2000	7	2.44	7.63	0.763
2	0.80	2.50	0.2500	8	3.05	9.54	0.954
3	1.00	3.125	0.3125	9	3.81	11.92	1.192
4	1.25	3.91	0.3906	10	4.77	14.90	1.49
5	1.56	4.88	0.4883	11	5.96	18.63	1.863
6	1.95	6.10	0.6104	12	7.45	23.28	2.33

The length and width of each dipole are named L_i and a_i, respectively. The length of the longest dipole L_N should be computed for longest wave length.

$$L_N = \frac{\max(\lambda_{eff})}{4} \tag{1}$$

$$\max(\lambda_{eff}) = \frac{c}{\min(f)\sqrt{\varepsilon_{eff}}} \tag{2}$$

where c, ε_{reff} and λ_{eff} are the speed of light in vacuum, effective wavelength and effective dielectric constant, respectively.

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(1+12\frac{h}{w}\right)^{-\frac{1}{2}} \tag{3}$$

where h, w, and ε_r are thickness, width and permittivity, respectively. Using (1)-(3) L_N=23.28 for minimum frequency equals to 2 GHz and other dimension of each dipole (L_i and a_i,) and space between (s_i) can be computed by,

$$\tau = \frac{L_i}{L_{i+1}} = \frac{a_i}{a_{i+1}} \qquad i = 1,2,\ldots,N \tag{4}$$

$$s_{i+1} = 4\sigma L_i \qquad i = 1,2, \ldots, N-1 \tag{5}$$

the scale factor is τ=0.8, the space factor is σ=0.1 and the number of the dipole element is N=12. The size of all dipoles is computed and given in Table I. This antenna is fed by two parallel microstrip lines. Fig 2(a) shows the cross-section of the feed line. Input impedance or characteristic impedance (Z_0=50 ohms) of two parallel microstrip lines can be modelled by two microstrip lines with a ground plane as shown in Fig. 2. The width of feed line microstrip (w_f) for $Z_0/2$=25 ohms can be obtained by (3) and (6):

$$\frac{Z_0}{2} = \frac{120\pi}{\sqrt{\varepsilon_{eff}}\left(\frac{w_f}{\frac{h}{2}}+1.393+\frac{2}{3}\ln\left(\frac{w_f}{\frac{h}{2}}+1.444\right)\right)} \tag{6}$$

The microstrip tapered feedline width is narrow to w_d in the antenna axis to improve the impedance bandwidth. Fig. 3 illustrated the voltage standing wave ratio (VSWR) for various w_d. The proposed PLPDA has an impedance bandwidth of 2.5 to 11 GHz with a VSWR less than 2 for w_f =4.7 mm and w_d =0.8 mm.

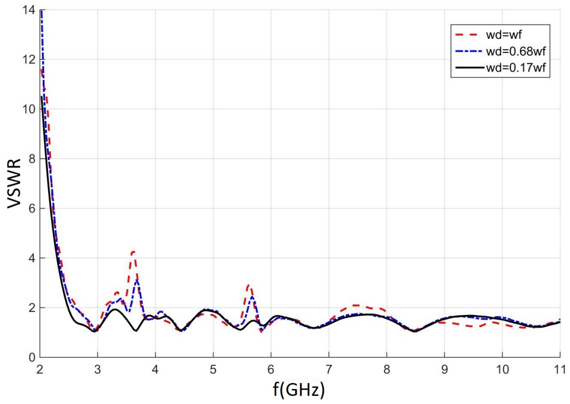
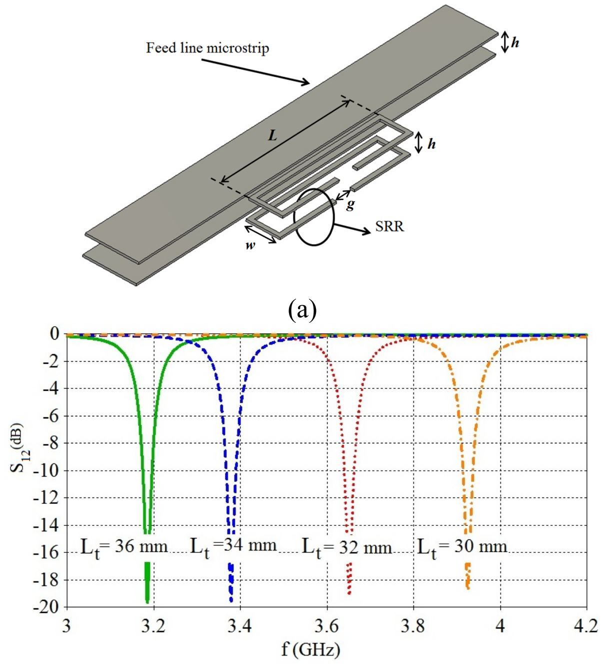


Fig. 3. VSWR of proposed antenna for various size of w_d.



(a)

(b)

Fig. 4. (a) Microstrip feed line with single SRR, (b) Transmission coefficient simulated by CST Studio for different values of L_t.

3. Design of the stopband for parallel microstrip line

Fig. 4 (a) shows the parallel microstrip line with a pair of rectangular C-shaped SRR that is placed on both sides of the substrate and the same plane with a microstrip line. The SRR has a width (*w*), length (*L*), and the gap region (*g*) in the SRR is parallel and far from the microstrip line. This resonator can be coupled to the microstrip line when it is placed close to it. It can be stored and absorbed all of the passing fields in the microstrip line at its resonance frequency and thus generated a notch frequency or a band filtering. Microstrip line with a single SRR is simulated by full-wave simulation software CST Studio and transmission coefficient (S_{12}) is shown for various total lengths (L_t=2L+2w-g) of the SRR element. Fig. 4(b) indicates the S_{12} parameter for different sizes of L_t. Fig. 5 shows a microstrip line with two SRR (SRR_1 and SRR_2). The total length of SRR_1 is larger than SRR_2. In Fig. 5, the proposed SRR has a stop-band response that is can be used for creating a notched band in the dipole antennas such as a log-periodic antenna.

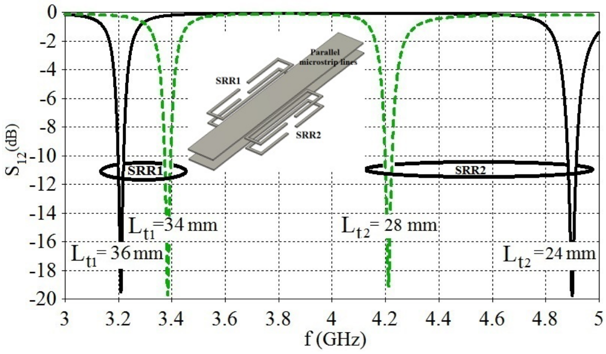
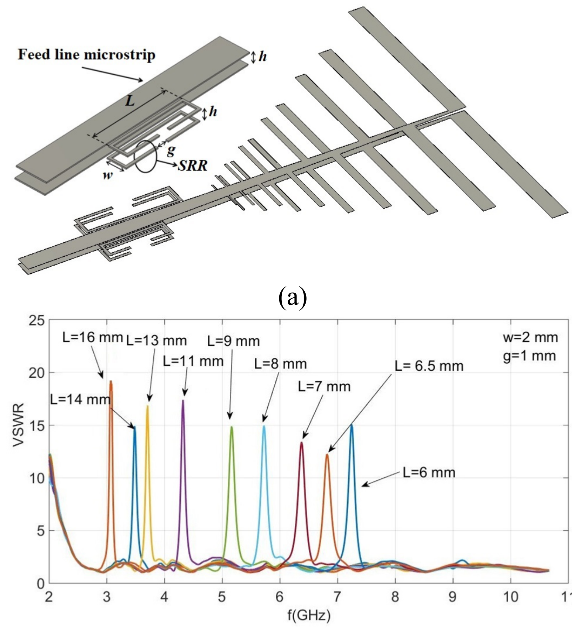


Fig. 5. Microstrip feed line with two SRRs and Transmission coefficient simulated by CST Studio.



(a)

(b)

Fig. 6. (a) Schematic of proposed PLPDA with double SRR (b) VSWR for various *L* sizes as a function of frequency

4. Design of a notch-band for LPDA

4.1. Parametric study

To create the notch-bands for the UWB dipole antenna with frequency selectivity, a pair of SRR was introduced originally to obtain a single band-stop filter. The SRR is placed on both sides of the substrate and parallel with the feedline of the PLPDA as a parasitic element.

The distance between the SRR and the 50 Ω microstrip feed line is fixed and equals 0.2 mm. VSWR for different sizes of the lengths (*L*), widths (*w*), and gaps (*g*) are simulated and shown in Figs. 6 and 7. These parameters (*L*, *w,* and *g*) play the key roles to change the notch frequency. These results illustrated that when *w* and *L* are decreased and *g* is increased, the notched frequency is shifted to the larger values. The peak of VSWR at notch frequency is larger than 12 and smaller than 20 for *L* between 6 mm to 16 mm. For different sizes of *w* and *g*, the peak of VSWR has sharp changes. These results approved that the proposed structure captures and reserves all of the input energy at its resonance frequency and thus makes a single notch band frequency filter.

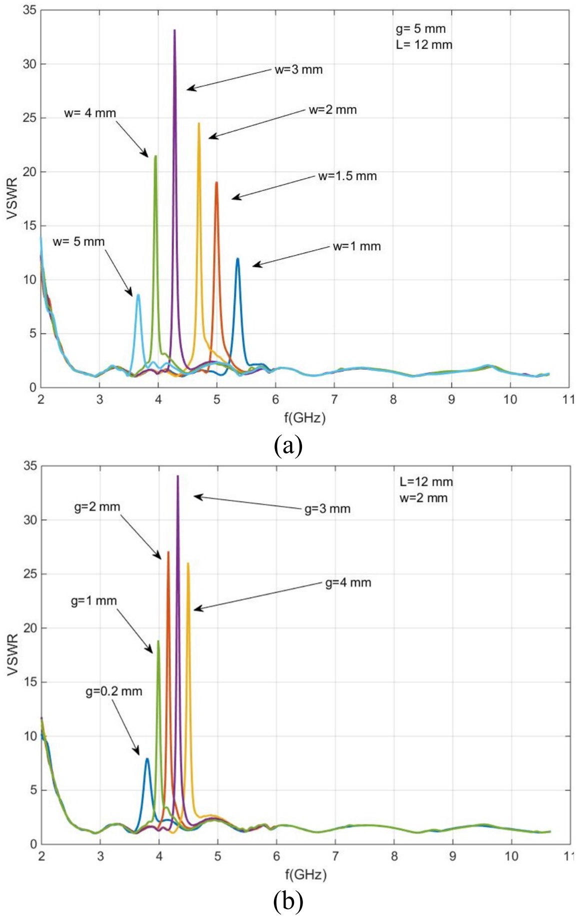


Fig. 7. VSWR for various (a) *w* and (b) *g* sizes as a function of frequency

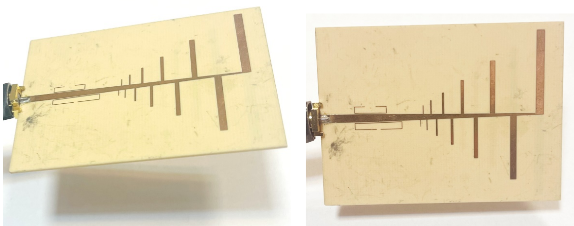


Fig. 8. Photograph of the fabricated PLPDA

4.2. Simulation and Experimental results:

The schematic of the final proposed PLPDA with two SRRs is shown in Fig. 6(a). Table I shows the dimension of a 12 dipole-elements of the PLPDA on the Rogers RO4003 with relative dielectric permittivity 3.55. The design parameters of the SRRs are as follows: for SRR1: *L*=13.7 mm, *w*= 2.5 mm, and *g*= 1 mm and for SRR2: *L*=9.3 mm, *w*= 2.5 mm, and *g*= 3 mm. Fabricated photo of the PLPDA with two SRR is shown in Fig 8. A comparison between the simulated and measured VSWR results of the proposed PLPDA with concerning frequency is demonstrated in Fig 9.

The impedance bandwidth of the fabricated PLPDA is 2.6-11.0 GHz with two notch-bands in the frequency ranges of 3.49–3.70 GHz and 5.33–5.71 GHz. These notch bands correspond to WiMAX and WLAN communication frequency, respectively.

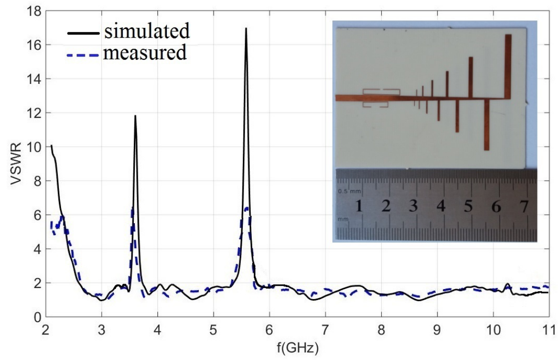


Fig. 9. Simulated (—) and measured (– –) VSWR for the proposed PLPDA

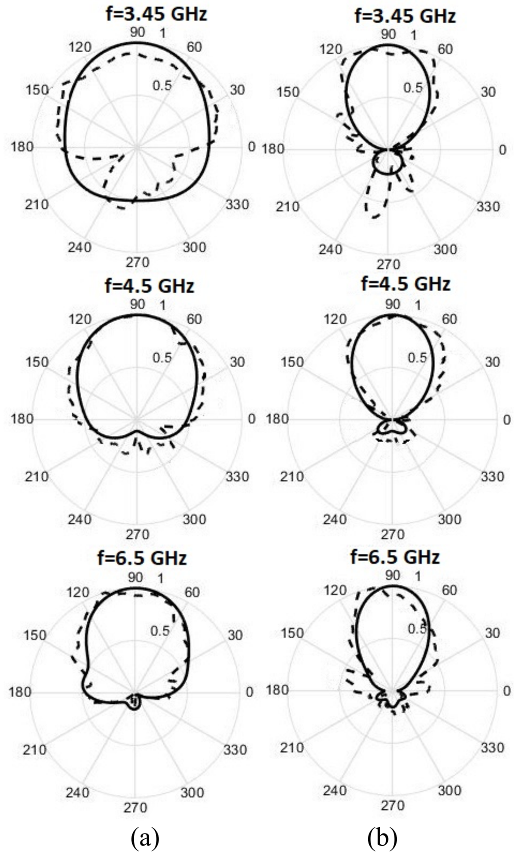


Fig. 10. Radiation pattern, (a) H-plane and (b) E-plane simulated (—) and measured (– –) for f=3.45, 4.5 and 6.5 GHz

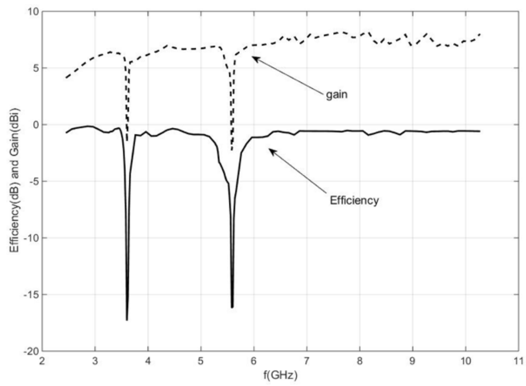


Fig. 11. Gain and efficiency for the proposed PLPDA

Table II. Performance comparison this work and other published papers

Ref.	NE*	NNB**	Size (mm^2)	Antenna type	Notch structure	BW(GHz)	Gain(dB)
[3]	19	-	141.9×73.44	CPW	-	1.7–19.8	1.8-3.6
[4]	11	-	117.19×39	CPW	-	3.0-6.0	5-7
[5]	18	1	47.8×42	Strip line	H-shaped slot	3.1-10.6	5
[6]	10	4	91×57	HMSIW	U-shaped slot	3.1-10.6	5
[7]	9	2	60×57	Modified ground	U-Shaped Loaded Slots Pair	3.1-10.6	4-6
[8]	16	2	96.5×41.5	Double side	Sub-Sectional Taper	3.1-10.6	3-9
This work	12	2	65×47.5	Double side	SRR	2.6-11.0	5-8

* Number of Elements, ** Number of the Notch Band

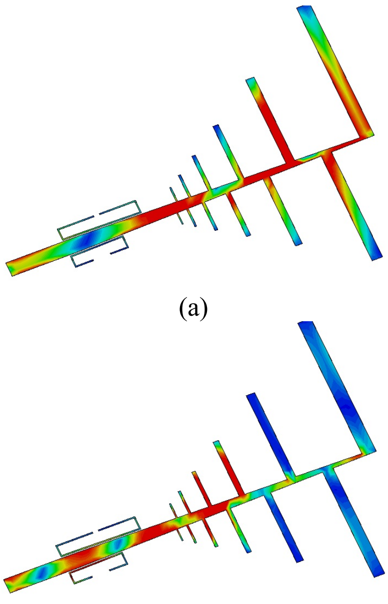


Fig. 12. Surface Current distribution on the PLPDA at, a) 3 GHz and b) 7 GHz passing frequency.

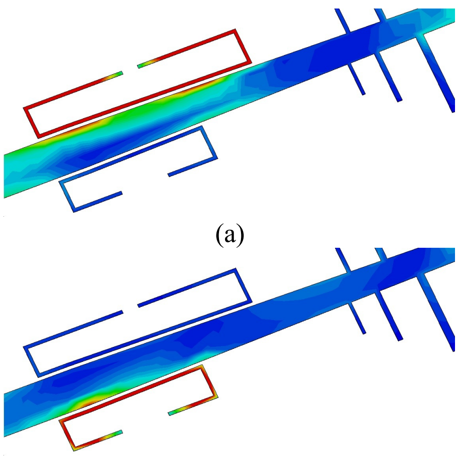


Fig. 13. Surface Current distribution on the PLPDA at notch frequency, a) 3.7 GHz and b) 5.5 GHz

Fig. 10 shows the simulated and measured radiation patterns at three selected frequencies of 3.45, 4.5, and 6.5 GHz in the operational band in the H and E-plane. The gain and efficiency values versus frequency are shown in Fig. 11. The result of VSWR in Fig. 9 can be corresponded to the gain and efficiency in Fig. 11 in other words gain and efficiency fall down in both notch-bands.

The surface current distributions of the proposed PLPDA with dual notched bands are shown in Fig. 12 and 13 for working and notch frequencies, respectively. Fig. 12 shows that the current is concentrated on the modified rectangular C-shaped SRRs at the notched frequencies of 3.7 GHz and 5.5 GHz while the currents on the dipole elements are very small.

5. Conclusion

All the performance of this work and comparison with other published paper are shown in Table II. [3, 4] reported LPDA fed by CPW without notch band but [3] has good BW. [5] using strip line to fed LPDA and H-shape slot created one notch band. [6] using HNSIW to design LPDA and U-shape slot created four notch bands with average gain in passband about 5 dB is reported. The size of antenna and multi notch band are the advantages of the [6]. In [7] two notch band are obtained by U-shaped loaded slots pair with modified ground. [8] used sub-sectional taper to create the two notch bands. The main motivation of this paper is to propose a new structure to reject frequency bands in the UWB dipole antennas. First, in this paper design a printed LPDA and improved bandwidth using tapered microstrip feedline. The proposed printed LPDA has impedance bandwidth from 2.6 to 11.0 GHz. The proposed SRRs have a stopband response, and they can be used as basic elements in the design of the notch bands for dipole antenna such as PLPDA without changing the sizes of the dipole antenna. Notch bands around the WiMAX and WLAN in a PLPDA are created by using modify C-shaped SRRs that are placed on both sides of the substrate and near the parallel microstrip feedline. VSWR and gain values have a good peak at the centre frequency of the rejected bands.

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