Design of A Compact CPW-FED UWB Antenna with WiMAX and WLAN Band-Notched Characteristic Evaluated in AHP Framework

Y. Zehforoosh*(C.A.) and M. Sefidi**

Abstract: In this article, we present a new design of a coplanar waveguide fed (CPW-fed) ultra-wideband (UWB) antenna with dual band-notched characteristics. Two notched frequency bands are achieved by using two inverted U-shaped stepped impedance resonators. The proposed antenna can operate from 2.82 to 11 GHz (118%), defined by VSWR< 2, except two notched bands around 3.5 GHz (WiMAX) and 5.5 GHz (WLAN). The size of the antenna is 20×20×1.6 mm3. The experimental and simulated results of the prototyped antenna, including voltage standing wave ratio (VSWR), radiation pattern, and gain characteristics are presented and discussed. In addition, Analytical Hierarchy Process (AHP) method used for comparison the proposed antenna with previous designed structures.

Keywords: Ultra-wideband Antenna, Dual Band-notched Characteristics, Inverted U-shaped Stepped Impedance Resonators, AHP Framework.

1 Introduction

ULTRA-WIDE band (UWB) communication systems have been drawing considerable attention among researchers and the industrial community due to the advantages provided by them such as, high data rate, compact system size, and low power consumption [1-11]. However, Mitigating interference between ultra-wideband (UWB) antennas and other narrow band systems have spurred growth in designing UWB antennas with notch characteristics [2-12-13]. Several design configurations have been proposed in the open literature using planar monopole antennas with modified radiator and/or ground plane to achieve this characteristic [2]. There are various methods to achieve the band-notched characteristics. The conventional methods are cutting different shaped slots in the radiating element [3-4-14], adding two slits within the radiation element [5], alternate way is putting parasitic strip [6], adding parasitic patch [7], adding capacitively-loaded loop (CLL) resonators [8], inserting stepped impedance resonators (SIRs) [9-10]. In this article, the proposed CPW-fed ultra-wideband antenna has been described with two band-notched frequencies. These two notched frequency bands are obtained by using two inverted U-shaped stepped impedance resonators (SIRs). The upper SIR (longer in length) controls the WiMAX band (3.3-3.6 GHz) and the lower SIR (shorter in length) controls the WLAN band (5.15-5.85 GHz). The details and simulated and measured results of the proposed antenna are presented. The simulated results are carried out using the Ansoft simulation software high frequency structure simulator (HFSS) [15].

Also In section 4 the proposed antenna in this paper evaluated and compared with four previously presented monopole structures employing Analytical Hierarchy Process (AHP) method. AHP is one of the Multi Attribute Decision Making (MADM) techniques used to make complex problems dealing with more than one effective factor easy. The nominees are four antennas with equal size, similar substrate materials and identical operating frequency band with same number of notch functions [9, 10, 13, and 14].

2 Antenna Design

Fig. 1 shows the antenna design procedure. The antennas are fabricated on the 1.6 mm- FR4 substrate with permittivity of 4.4. The 50Ω CPW feed structure consist of a CPW-fed transmission line with width of 3 mm and a gap between the transmission line and the CPW ground plane with width g=0.5 mm. Fig. 2 presents the VSWR plot for antennas illustrated in Fig. 1. It is obvious that only proposed antenna meets the two frequencies notched band standard. The proposed microstrip antenna with two band notch functions is shown in Fig.3.

Fig. 4 shows the simulated VSWR curves with different values for gap between the ground plane and

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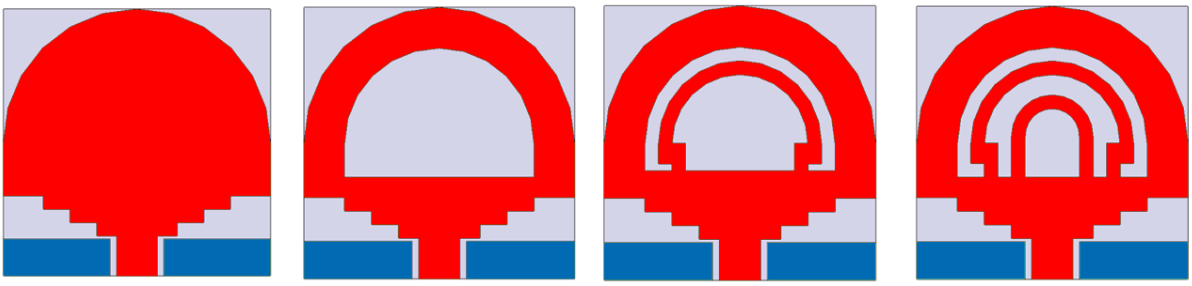


Fig. 1 (a) Basic structure antenna, (b) ordinary slot antenna, (c) antenna with upper stepped impedance resonator, (d) the proposed antenna.

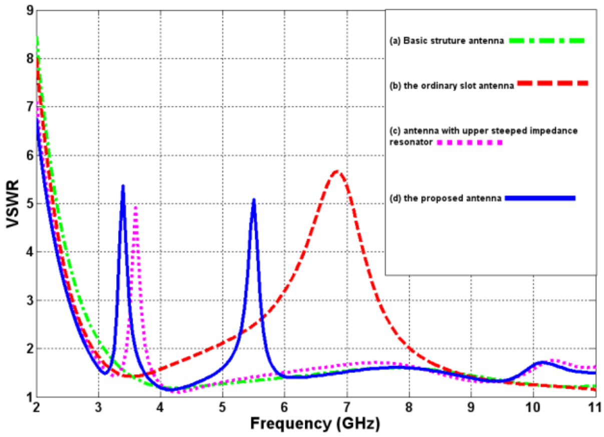


Fig. 2 Simulated VSWR of characteristics for the various antennas shown in Fig. 1.

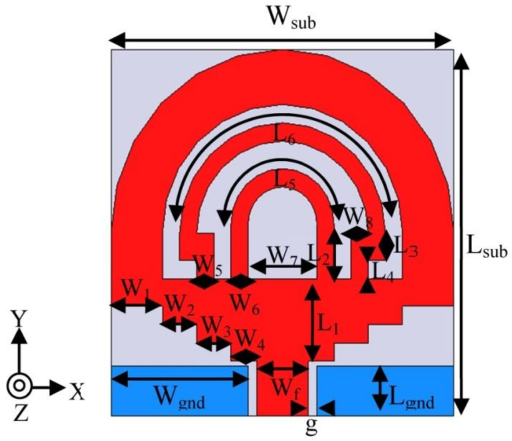


Fig. 3 Geometry of proposed antenna.

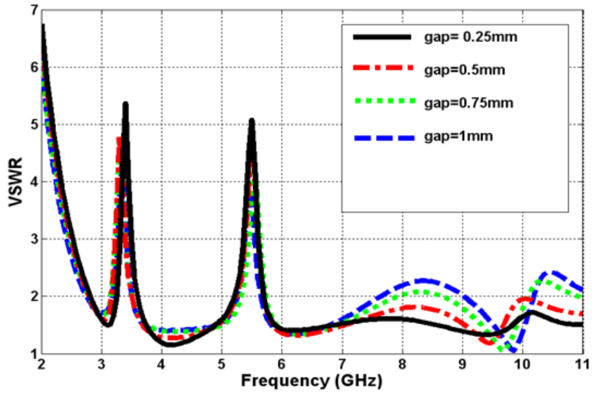


Fig. 4 Simulated VSWR of the proposed antenna with different value of gap (g).

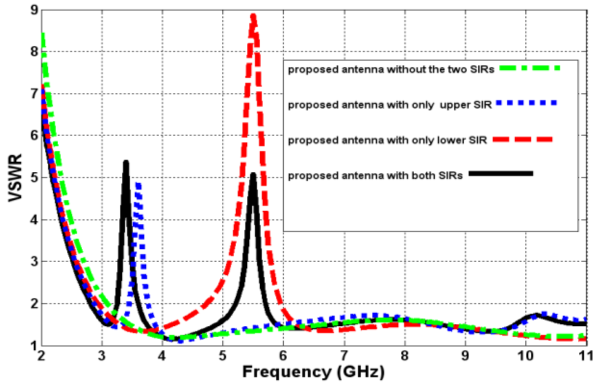


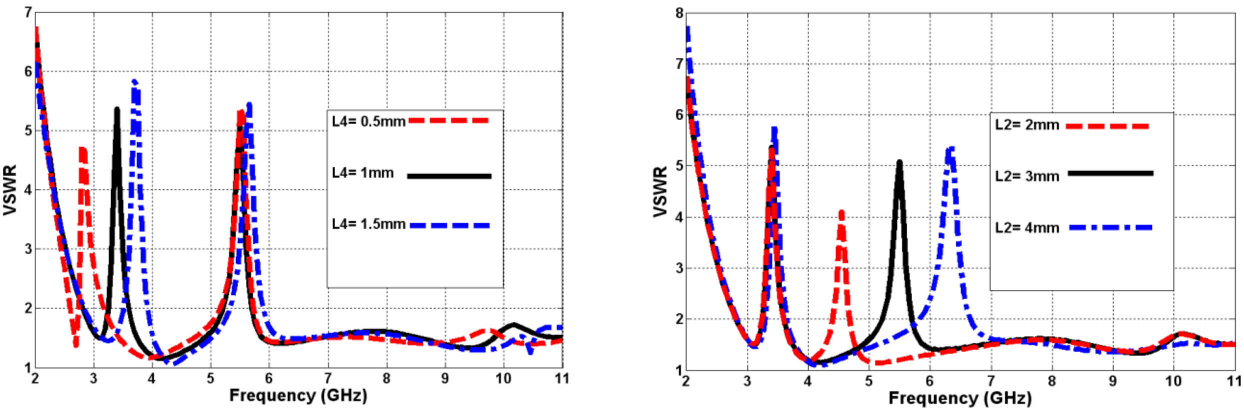
Fig. 5 Simulated VSWR of the proposed antenna with and without SIRs and with only upper and lower SIR.

patch. For the impedance matching, the distance between the radiator patch and ground plane is optimized at 0.25 mm.

The optimized dimensions of proposed antenna are as follows: W_{sub}=20 mm, L_{sub}=20 mm, W_{gnd}=8 mm, L_{gnd}=2.75 mm, g=0.5 mm, W_1=3 mm, W_2=2 mm, W_3=2 mm, W_4=1.5 mm, W_5=1 mm, W_6=1 mm, W_7=4 mm, W_8=1 mm, W_f=3 mm, L_1=4.5 mm, L_2=3 mm, L_3=1.5 mm, L_4=1 mm, L_5=9.42 mm, L_6=18.84 mm . Fig. 5 shows the simulate VSWR for proposed antenna, without the SIRs, with only upper SIR, with only lower SIR, with both SIRs, it can be clearly seen from Fig. 5 that the two notched band are obtained by using upper SIR and lower SIR.

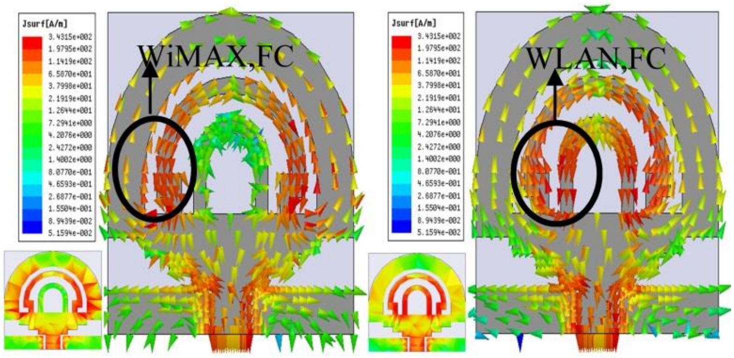
The antenna without two SIRs is an UWB antenna which cover UWB band ranging from 2.82 to 11 GHz for VSWR less than two. Fig. 6(a) illustrate the VSWR with varying L4, It is obviously shown that center frequency of the lower notched band which is near 3.5 GHz moves to low frequency with the increase of L4 and moves to high frequency with the decrease of L4. Fig. 6(b) shows the simulation VSWR curves with different length L2 of the lower SIR. The center frequency of higher notched band which is near 5.5 GHz moves to low frequency with the increase of L2 and moves to high frequency with the decrease of L2.

Fig. 7 shows the current distribution at first and second notch frequencies, it is obviously from Fig. 7(a) that surface current contrarily directed between upper SIR and inner edges of radiation patch at 3.5



(a) (b)

Fig. 6 (a) Simulated VSWR of the proposed antenna with different value of L_4 (b) Simulated VSWR of the proposed antenna with different value of L_2.



(a) (b)

Fig. 7 Simulated current distribution at different notch frequencies (a) 3.5 GHz and (b) 5.5 GHz.

GHz. Thus, the total radiation at this band very low and thus first notch band is achieved. Fig. 7(b) shows that surface current oppositely between upper SIR and lower SIR at 5.5 GHz. Thus, the radiation at this band is very weak and second notch band is obtained.

For the dominant TM_{010} mode, the resonant frequency of the microstrip antenna is a function of its length. Usually it is computed by formula from [16], So the length of each SIRs can be calculated by the formula from [16]:

$$(f_r)_{010} = \frac{1}{2L\sqrt{\varepsilon_r}\sqrt{\mu_0\varepsilon_0}} = \frac{c}{2L\sqrt{\varepsilon_r}} \tag{1}$$

$$L_{UpperSIR} = \left(L_6 + 2\times\left(L_3 + L_{4+}W_8\right)\right) = 25.84$$

$$\simeq \frac{\lambda_{WiMAX}}{2} = \frac{C}{2f_{notch}\sqrt{\varepsilon_{eff}}} \tag{2}$$

$$L_{LowerSIR} = \left(L_5 + 2\times L_2\right) = 15.42$$

$$\simeq \frac{\lambda_{WLAN}}{2} = \frac{C}{2f_{notch}\sqrt{\varepsilon_{eff}}} \tag{3}$$

$$\varepsilon_{eff} \simeq \frac{1+\varepsilon_r}{2} \tag{4}$$

where c is the speed of light, L is the length of the SIR and ε_{eff} is effective dielectric constant.

3 Simulation and Measurement Results

The prototype of fabricated antenna is shown in Fig. 8.

The simulated and measured results of VSWRs are illustrated in Fig. 9 and good agreement between them can be seen in Fig. 9. It is clearly seen that impedance bandwidth of proposed antenna for VSWR<2 in which notched bands from 3.25 to 3.65 GHz, 5.14 to 5.86 GHz, covering WiMAX and WLAN successfully.

Fig. 10 shows the maximum antenna gain from 3 to 11 GHz for the proposed antenna with and without two notched bands. The Fig. 10 shows that proposed antenna has suitable gain levelness except two notched band. As shown in Fig. 10, gain decrease intensely at the notched bands.

Fig. 8 Prototype of the fabricated antenna.

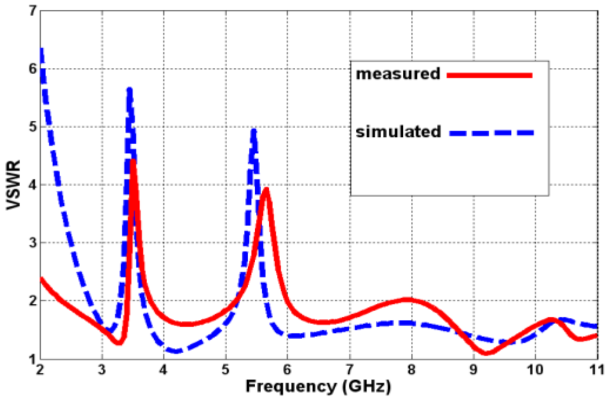


Fig. 9 Measured and simulated VSWR of the proposed antenna.

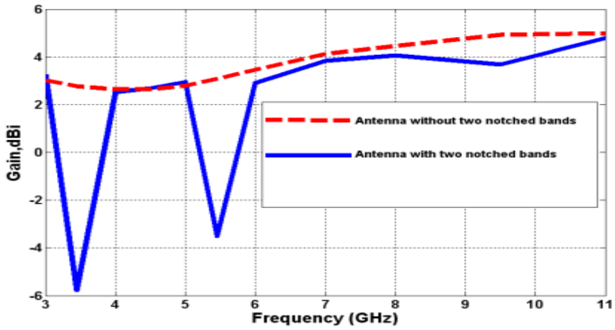


Fig. 10 Peak gain of the proposed antenna with and without two notched bands.

Fig. 11 shows radiation pattern in frequencies 3, 6, 8 GHz in x-z and y-z planes. It can be seen that proposed antenna has omnidirectional radiation characteristics in the H-plane and bidirectional radiation characteristics in the E-plane. The group delay indicates the quality of pulse Distortion and far field phase linearity. The simulated Group delay variation is less than 1ns in the operating band except in notched bands as shown in Fig. 12. In notched bands the group delay variation are nearly 3.2 and 7.3 ns. The radiation efficiency of proposed antenna are shown at Fig. 13, according to Fig. 13 the radiation efficiency is upper %90 except in notched bands that are lower %35.

4 Comparing the proposed antenna with previous designs using Analytical Hierarchy Process (AHP) based methodology

The selection between the enormous numbers of monopole antennas (alternatives) introduced in recent years is definitely not an easy task because of the many different selection criteria. These criteria include: the band width of the presented antennas, construction cost, physical properties such as weight and design complexity, number of filtering frequency bands, and the technical characteristics of the antenna such as gain and radiation pattern. Using multi-criteria decision analysis (MCDA) can help to reduce the struggle of decision makers for a long time. A decision support

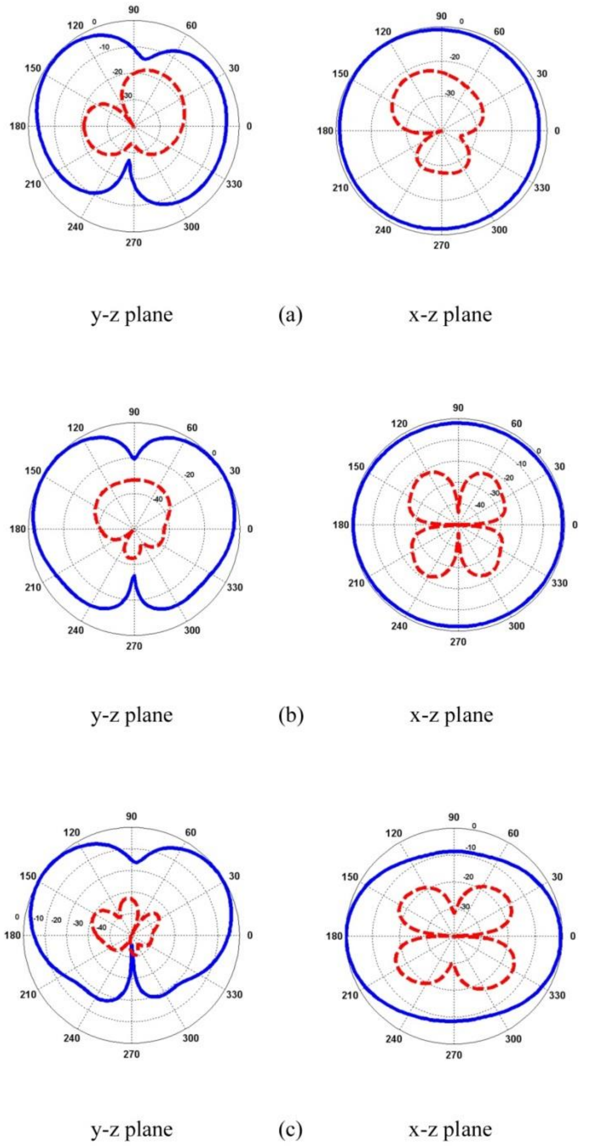


Fig. 11 Radiation pattern of the proposed antenna (a) 3 GHz, (b) 6 GHz, (c) 8 GHz.

model utilizing the Analytical Hierarchy Process (AHP) is used. The intention is to choose the best monopole antenna regarding the alternatives mentioned above.

AHP is a commonly used multi-criteria decision-making (MCDM) tool designed to solve MCDM problems. In its simplest form, AHP involves a goal, attributes and alternative level. Goal is the purpose of the comparison in the investigated problem. Attributes are the most important parameters that affect the decision making process, and the alternatives are the compared nominees [19]. Fig. 14 shows the hierarchy schematic for the best monopole antenna selection problem. In this paper, "Selecting the best monopole antenna structure" is the absolute goal , also antennas presented in [9,10,13,14] and surveyed monopole antenna in this paper are the considered alternatives that are compared considering bandwidth,

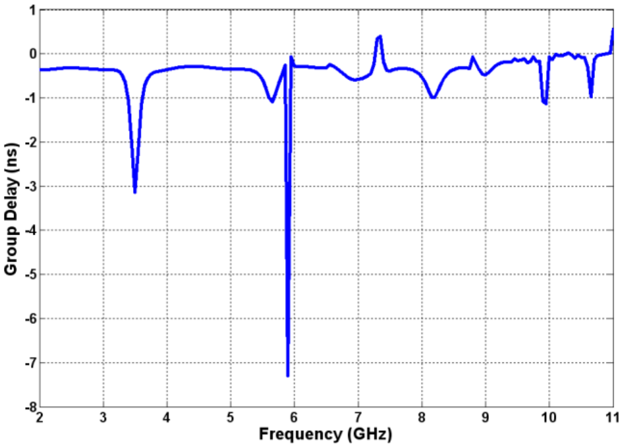


Fig. 12 Group delay of proposed antenna.

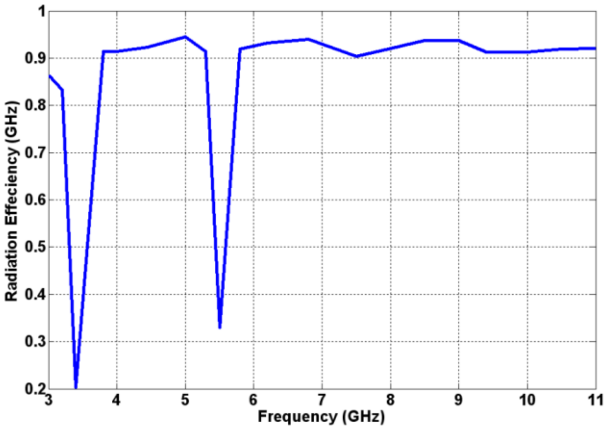


Fig. 13 Radiation efficiency of proposed antenna.

size, structure complexity, manufacturing cost, number of notches and gain variation. As an example, wider bandwidth, small size, low manufacturing cost, structure simplicity, more filtering notches and low gain variations are recognized as desirable properties for monopole antennas. For doing reliable comparison between presented monopole antenna in this paper with monopole antennas proposed in [9,10,13,14], also ease of computations the antennas selected for comparison have same size, same substrate materials and same number of notch functions. In this way the comparisons would be fairer and more reliable. Characteristics of all antennas selected for comparison are summarized in Table 1. To make use of AHP method, a comprehensive utility function is defined based on Simple Additive Weighted (SAW) method. In this way, a utility value is assigned for each of the attributes namely $U_{Bandwidth}$, $U_{structure\ complexity}$, and $U_{Gain\text{-}variation}$ for all of the considered alternatives, also a normalizing system is utilized for utility value assignment.

Regarding this issue, antenna having the lowest structure complexity gets the most value of unity and the antenna with the highest structure complexity has the minimum share of unity. The proposed utility function for assessing the aforementioned antennas is introduced:

$$\begin{aligned} U_{Antenna}(i) = & W_{Structure} U_{Structure}(\text{Antenna}(i)) \\ & + W_{Bandwidth} U_{Bandwidth}(\text{Antenna}(i)) \\ & + W_{Gainvariations} U_{Gainvariations}(\text{Antenna}(i)) \end{aligned} \quad (5)$$

where $W_{Bandwidth}$, $W_{Gain\text{-}variation}$, and $W_{complexity}$ are the weight values given to the bandwidth, gain variation and structure complexity of the antenna, respectively. Weight allocation is done based on the importance degree of each attribute keeping their summation equal to one. The Expert Choice software [20] is used to implement the AHP technique encompassing four different scenarios as shown in Table 2. The obtained utility values for the investigated antennas in each of the foregoing states are reported in Table 3.

Fig. 15 shows the acquired utility values in various states, which can help comparison between nominees in different states. It can be observed that in all states presented in Table 2 the introduced antenna in this paper shows a higher utility value based on Equation (1). In addition, priority of each monopole antenna can be obtained from Fig. 15, for instance, the antenna [9] is the nearest competitor for the antenna proposed in this work.

5 Conclusion

In this paper, a novel CPW-fed antenna with dual band-notched characteristics is designed, fabricated and measured for UWB application. The dual notched bands are achieved by using two inverted U-shaped stepped impedance resonators. The first band-notched for WiMAX (3.3-3.6 GHz) is obtained by using upper SIR and second band-notched for WLAN (5.15-5.85 GHz) is obtained by using lower SIR. This antenna covers the frequency band between 2.82 and 11 GHz (118%), defined by VSWR< 2. AHP method base evaluation endorsed the acceptable performance of the proposed monopole antenna regarding simple structure, wide bandwidth and suitable gain versus antennas of the same size and same substrate materials.

Table 1 Characteristics of the proposed antenna and antennas presented in [9, 10, 13&14].

	Size (mm3)	Bandwidth (%)	Gain variation (dB)	Substrate	Number of notches	Structure complexity (Grade between 1-10)
Proposed antenna	640	118	2	FR4	2	5
[9]	640	118	2	FR4	2	7
[10]	640	113	4	FR4	2	6
[13]	640	116	6	FR4	2	9
[14]	640	139	3	FR4	2	8

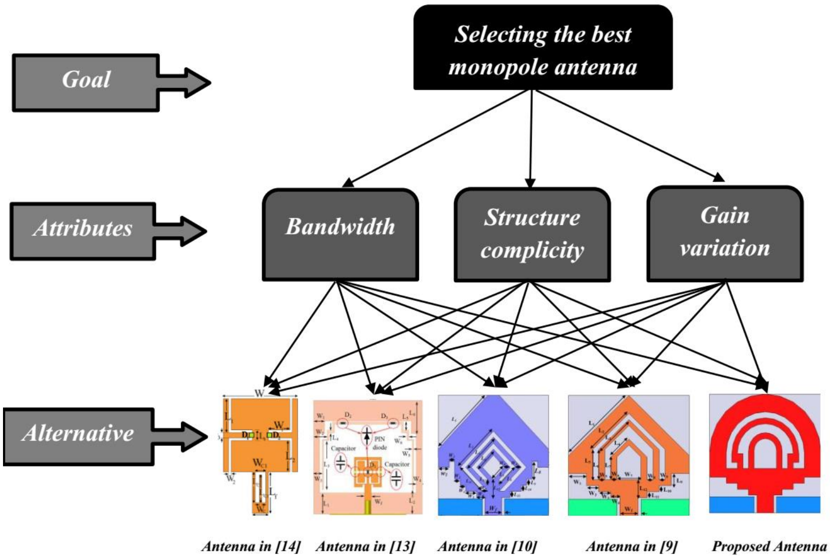


Fig. 14 Analytical hierarchy process schematic for the selecting best monopole antenna.

Table 2 Weight assignments for the different attributes in different states.

	State I	State II	State III	State IV
$W_{\text{Bandwidth}}$	0.33	0.5	0.25	0.25
$W_{\text{Gain variation}}$	0.33	0.25	0.5	0.25
$W_{\text{Structure complexity}}$	0.33	0.25	0.25	0.5

Table 3 Utility values for the investigated antennas in different states.

	State I	State II	State III	State IV
Proposed antenna	0.26	0.247	0.267	0.275
[9]	0.217	0.215	0.235	0.21
[10]	0.171	0.175	0.165	0.18
[13]	0.155	0.175	0.142	0.152
[14]	0.178	0.182	0.182	0.175

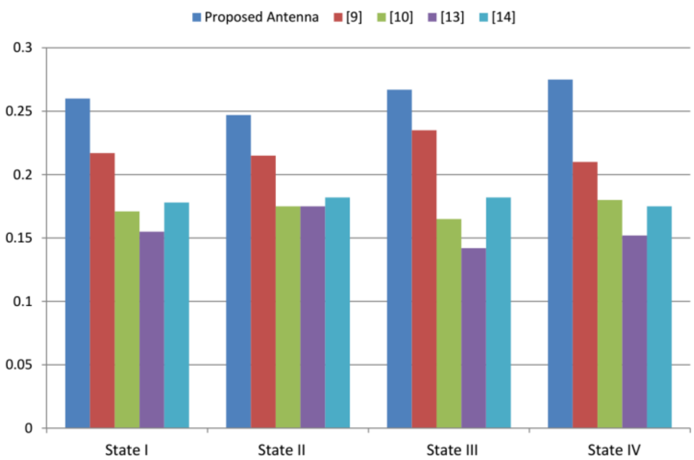


Fig. 15 Utility function values for the proposed antenna and antennas in [9,10,13,14] in four states.

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