Patch loaded slot antenna for super wideband applications with dual-band notch characteristic

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Patch loaded slot antenna for super wideband applications with dual-band notch characteristic

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Abstract This paper presents a patch loaded slot antenna for super wideband (SWB) application. To obtain SWB characteristic, the proposed antenna geometry combined a rectangular slot and an overlying patch excited by a trident shaped microstrip feed. It is observed that the hybrid nature of the proposed antenna effectively enhances the impedance bandwidth up to 120%, by combining the resonance of both patch and slot. Besides, it is investigated that after converting the conventional tapered feed into the trident shape feed, the impedance bandwidth is increased further from 120% to 167% ranging between 1.25 to 15 GHz. Moreover, one U-shaped slot and two L-shaped stubs are inserted into the antenna design to introduce the dual-band rejection property from 1.8 to 2.4 GHz (GSM 1800, Wi-Fi 2.1 and 2.4) and 3.1 to 4.2 GHz (WiMAX and C-band). Further, to validate the simulation results a prototype is fabricated and tested. The measured result shows that the proposed antenna offered an impedance bandwidth of 170.3% from 1.2 GHz to 15 GHz.

Keywords Super wideband antenna · Antenna gain · Band rejection · Impedance bandwidth

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1 Introduction

Rapid evolution in wireless communication builds a huge demand for the super wideband (SWB) antenna to support a very high data transmission rate. The term that differentiates the SWB antenna from the other existing wideband and ultra-wideband (UWB) antenna is the ratio of upper and lower edge of frequency response. Practically, antenna offering f_h/f_l ratio more than 10:1 is considered as SWB antenna [1]. Unlike UWB, no specific frequency band is allotted for SWB technology. It has an extremely wide bandwidth, which can completely cover many frequency bands like GSM-900, 1800, Wi-Fi, and entire UWB simultaneously.

However, some narrow frequency bands co-located within UWB and SWB range like WiMAX (3.3-3.6 GHz), downlink of C-band (3.7-4.2), Wi-Fi 2.1 and 2.4 GHz may degrade the performance of SWB antenna by causing undesired electromagnetic interference from these coexisting bands. One way to reduce their interference is to connect several band stop filters with SWB antennas; however, it will increase the system complexity and size tremendously. Another method is to design the SWB antenna with band notch characteristics without affecting the size and complexity. In literature, different types of SWB antennas, including fractal, printed monopole has been proposed [2]-[6]. However, none of them neither covering important frequency bands like GSM-900, 1800, Wi-Fi 2.1 and 2.4 GHz nor offering band rejection property. In order to cover lower frequency applications with broadband behavior, several SWB antenna has been proposed in the recent past [7]-[13]. Although, the reported works covered most of the lower frequency band, but not ensured band notch characteristics.

Very few of SWB antennas offered single [14]-[17] dual [18]-[19], and triple [20] band notch characteristics. However, none of the design focused on band rejection outside the UWB range. For instant, a monopole SWB antenna with a single-band notch is reported in [15]. Although the proposed antenna is compact and operated under low frequency region 0.9 to 100 GHz, nonetheless the suppressed band is only one which falls outside the UWB band. Similarly, a SWB monopole antenna with tri-band notch characteristic is reported in [20], but all the rejection bands belong to UWB range. Moreover, the antenna do not support the lower frequency region. In this study, a hybrid SWB antenna operating between 1.2 to 15 GHz with dual-band notch property is proposed. In order to achieve broad impedance bandwidth, a trident shape feed line is used to excite the antenna. It shifts the upper edge of frequency response from 5.1 to 15 GHz and enhance the bandwidth from 120% to 167%. Further, to obtain the dual-band rejection inside (entire WiMAX frequency band and downlink frequency of C-band) and (GSM-1800, Wi-Fi 2.1, 2.4 GHz) outside of the UWB range, one U-shape slot and two L-shape stubs are introduced in patch and slot, respectively. A comprehensive investigation is done in the subsequent section to achieve the broad impedance bandwidth with strong band rejection characteristics.

2 Antenna Design and Parametric study

Step 1

Step 2

Step 3

Fig. 2 Geometrical evolution of the proposed antenna

Fig. 3 (a) Simulated S_{11} against different design steps and (b) simulated gain against different design steps

shaped microstrip line comprising three arms of different sizes. The central arm is the linearly tapered 50Ω transmission line connected to two inverted L-shaped stubs at either side, which comprises the second and third arm of the feed.

The proposed antenna is primarily designed for broad impedance bandwidth afterward, a rectangular U-shaped slot and two L-shaped stubs are introduced in patch and star shaped slot to achieve dual-band rejection property. In the proposed antenna, the broadband characteristic is achieved in two simple steps. First, the conventional slot antenna is converted into the hybrid antenna by embedding a rectangular patch of size $P_l \times P_w$ at the top layer of the substrate, as shown in step 2 of Fig. 2. The added rectangular patch introduced a new resonance that gets merged with the slot resonance after optimizing the dimension and position of both slot and patch. Subsequently, two inverted L shaped stubs defined by $f_h \times f_l$ are attached with feed line near to the bottom edge of the patch. This yields a strategic perturbation of magnetic current distribution in both slot and patch, which enormously enhances the impedance bandwidth. The optimized values of the proposed antenna are depicted in Table 1.

Fig. 3(a) shows the simulated $|S_{11}|$ against the different design stages of the proposed antenna shown in Fig. 2. It can be noticed that the antenna radiates in high frequency region and offers very low impedance bandwidth when it consists of a rectangular slot excited by the microstrip feed. However, after introducing a rectangular patch at the other side of the substrate, it achieved an impedance bandwidth of 120%, which is approximately 12 times larger than the slot antenna but radiates mainly in the low frequency region. Afterward, the conventional feed is converted into a trident shaped feed, which results in further improvement in impedance bandwidth from 120% to 167% by shifting the upper edge of resonance from 5.1 GHz to 15 GHz.

The gain comparison corresponds to different design steps is illustrated in Fig. 3(b). It can be seen after embedding the patch to the slot and converting the conventional feed to trident shaped feed, the antenna gain is drastically

Table 1 Dimension of the proposed antenna

Antenna design parameters	P_l	P_w	U_l	U_w	U_h	f_l	f_w	S_{w1}	S_{w2}	S_h	h
Value (in mm)	18	14	9	9	0.5	2.5	9	16.5	8	5	4

Fig. 4 Simulated VSWR for different value of stub (a) length f_l and (b) width f_w

improved in lower and upper frequency regions, which was contradictory otherwise in steps 1 & 2. The maximum gain variation is observed at 2 GHz, where the antenna gain is increased from -10 dBi to 4.16 dBi i.e., total 141% improvement.

Fig. 5 Simulated VSWR for different value of stub offset position

Though the additional stubs at feed line end contribute to the bandwidth enhancement from 5.1 to 15 GHz, therefore variation of their dimensions strongly affects the impedance matching in this frequency range. Fig. 4(a)& 4(b) demonstrate the simulated VSWR for different values of stubs length (f_l) and width (f_w), respectively. As seen in Fig. 4(a), varying the f_l from 2.5

Fig. 6 Simulated VSWR for different value of slot (a) length u_l and (b) width u_w

mm to either 1.5 mm or 3.5 mm, the impedance matching of the antenna is affected. A similar effect can be observed when the stub width (f_w) is reduced from 5.5 mm to 3.5 mm. By lowering the f_w , the impedance matching gets

Fig. 7 Simulated VSWR for different value of slot offset position u_h

worse, especially between 8 GHz to 11 GHz. As seen in Fig.4(b), adjusting the stub width, the band notch characteristic of the antenna can be controlled.

Fig. 5 illustrates the simulated VSWR against the different offset value between the bottom edge of ground slot and patch. It can be seen that a small shift in offset value made a drastic change in antenna performance. The optimum impedance bandwidth is achieved for an offset value of $h=4$ mm. It could also be observed that by connecting or disconnecting the patch (or using switch between feed and patch), the matching of either lower region or upper region could be controlled. This way a bandwidth reconfigurability can be achieved in the proposed circuit.

Fig. 8 Simulated VSWR for different value of stub (a) horizontal length S_{w1} and (b) vertical length S_{w2}

Besides, broad bandwidth, our aim is to generate dual-band notch characteristics in the proposed SWB antenna. For this one U-shaped slot and two L-shaped stubs are introduced in the patch and slot, respectively. The addition of slot and stub to the proposed antenna changes the impedance bandwidth slightly by downshifts the lower edge frequency from 1.3 to 1.25 GHz. The optimized dimension and position of U-shaped slot and L-shaped stubs produce the strong current distribution in the opposite direction of the patch and slot, respectively, which results in sharp band rejection from 1.8 to 2.4 GHz and 3.1 to 4.2 GHz.

To obtain the band rejection at WiMAX and lower frequency region of C-band, a U-shape slot is etched at the lower portion of the patch, as shown in Fig.1. As seen that there are two major parameters slot length u_l and slot width u_w , which can directly control the attenuation level strength and position of the rejection band. The rejection band frequency can be calculated by using the equation.1.

$$f_{notch} = \frac{c}{2L_{total}\sqrt{\epsilon_{eff}}} \quad (1)$$

Where, c is speed of light and $L_{total} = u_w + 2u_l$ and $\epsilon_{eff} = (\epsilon_r + 1)/2$. The simulated VSWR corresponds to different values of u_l and u_w are depicted in Fig. 6(a) & 6(b), respectively. As seen, increasing either slot length or width, the center frequency of the rejection band is shifted downwards which validates the equation 1. Moreover, increasing the slot width, the rejection band gets wider and stronger. It can be noticed that the lower edge of the rejection band is greatly influenced by slot width u_w , whereas u_l curbs the movement of the entire rejection band. Apart from slot width and length, the offset position of slot may also contribute to the rejection band moderation. Fig. 7 illustrates the simulated VSWR against the different slot offset positions. As seen, the upper edge of the notch band is shifted towards the higher frequency by varying the offset value (u_h) from 0.5 mm to 2 mm. The optimum value of U-shaped slot length, width and position, where the proposed antenna obtains the appropriate band rejection are $u_l = 9$, $u_w = 9$ mm and $u_h = 0.5$ mm.

Fig. 9 Simulated VSWR for different value of stub offset position s_h

Fig. 10 Current distribution at different frequencies

In order to suppress GSM-1800, Wi-Fi 2.1 and 2.4 GHz, two L-shaped stubs are attached at either side of the rectangular slot, as shown in Fig. 1. Equation 2 shows the relationship between the notch frequency and the stub length. Here, it can be noticed that increasing either s_{w1} or s_{w2} , the notch

Fig. 11 Simulated and measured VSWR.

frequency will reduce which can be confirm from Fig. 8(a) & 8(b).

$$f_{notch} = \frac{c}{2(s_{w1} + s_{w2})\sqrt{\epsilon_{eff}}} \quad (2)$$

As seen, increasing the stub length in both X and Y direction, the center frequency of the rejection band is shifted downwards. Moreover, increasing the stub length the rejection band becomes broader and stronger. Here, the upper edge of the rejection band is almost unaffected, whereas lower shifted downwards. Fig.9, illustrates the effect of offset (S_h) value on antenna performance. It can be seen that the small movement of stub in upward or downward direction does not much affect the antenna performance.

To support the above results, electric current distribution at the center frequency of both rejection bands is shown in Fig. 10. As seen, the maximum current is distributed along the inverted L-shaped stubs at 2.1 GHz (center frequency of the first rejection band). As seen in supporting figure, the electric current changes its direction at the connecting point of the stub and becomes completely opposite to the direction of ground plane current. As a consequence, this stub cancels out the antenna radiation in rejection band. Here, stubs act as a resonator and their effective length is nearly equals to quarter wavelength calculated at 1.8 GHz. At 3.6 GHz and 4.1 GHz, the current is mainly concentrated at the periphery of the U-shaped slot. As seen, the current is in upward direction at the interior edge of the U-slot whereas, at the exterior edge, it is in the downward direction. Therefore, destructive interferences occur in the above frequency range and result in no radiation. Fig. 11 shows the simulated and measured VSWR of the proposed antenna. As seen, both the results are in well agreement and notches are perfectly coming at desired frequency bands. Further, at higher frequencies small ripples can be observed that may be due to cable and connector losses.

Fig. 12 Simulated and measured radiation pattern for different operating frequencies

The simulated and measured radiation pattern of the proposed antenna at five different frequencies is illustrated in Fig. 12. As seen, in E-plane antenna ensures almost monopole like pattern, whereas in H-plane it exhibits Omnidirectional radiation pattern in the entire frequency range. Above 10 GHz,

Fig. 13 (a) Antenna gain with and without band rejection and (b) Simulated antenna efficiency with and without band rejection

the antenna shows Omni-directional pattern in both planes. From the above results, we can conclude that the proposed antenna offers approximately stable radiation pattern throughout the operating band.

Fig. 12(a) & 12(b), shows the simulated gain and radiation efficiency with and without the band rejection. From Fig. 12(a), it can be seen that the antenna attains almost stable gain throughout the frequency range. It is varying between 3.3 to 5.5 dBi (except at the rejection band) and exhibits a maximum gain of 7.15 dBi at 6.4 GHz. Though, the antenna operating over a large frequency range, therefore, this gain variation could be acceptable. Further, at both notch frequencies, gain and efficiency are reduced considerably. At first notch frequency, the gain is reduced from 4.1 to -2.3 dBi, whereas at the second notch, it drops from 5.4 to -6.4 dBi. In addition, by activating/deactivating (through switch) two stubs in the slot and U-slot in the patch reconfigurable band rejection capability could also be realized in the same circuit. The performance comparison of the proposed antenna with other similar reported works is shown in Table 2. It can be observed that compared to earlier reported SWB antennas, the proposed antenna offers the wide impedance bandwidth with lower frequency convergence and dual band notch property.

3 Conclusion

A patch loaded slot antenna is proposed for SWB application. The proposed antenna covers the impedance bandwidth from 1.2 to 15 GHz. The result shows that using a trident shaped feed line, impedance bandwidth is increased from 120% to 167%. A dual-band notch rejection property from 1.8 to 2.4 GHz (GSM-1800, Wi-Fi 2.1 and 2.4 GHz) and 3.1 to 4.1 GHz (WiMAX and lower band of C-band) is introduced by using a U-slot and inverted L-shaped stubs in patch and ground plane, respectively. Besides, the proposed structure has the capability to reconfigure its bandwidth and notch bands electronically.

Table 2 Comparison of the proposed antenna with recently published SWB antennas.

Ref.	Antenna type	Impedance bandwidth (GHz)	No. of rejection band	Dimension ($w \times l$) λ_c^2	λ_l (mm) calculated at lower frequency	Lower freq. applications covered
[2]	SWB	4.6-52	None	0.3×0.29	65.2	No
[4]	SWB	10-50	None	2×2	30	No
[5]	SWB	3.4-37.4	None	0.32×0.34	88.2	No
[6]	Wideband	4.9-25	None	0.23×0.31	61.2	No
[7]	SWB	0.96-13.98	None	0.16×0.13	312.5	Yes
[8]	SWB	0.96-13.8	None	0.17×0.13	315.7	Yes
[9]	SWB	0.96-10.9	None	0.17×0.13	315.7	Yes
[10]	SWB	1-19.4	None	0.45×0.45	300	Yes
[12]	SWB	0.92-22.35	None	0.12×0.07	326	Yes
[13]	SWB	0.64-16	None	0.32×0.32	468.7	Yes
[14]	SWB	3-50	One (4.85-5.83)GHz	0.3×0.3	100	No
[15]	SWB	0.9-100	One (4.7-6)GHz	0.09×0.12	333	Yes
[20]	SWB	2.3-23	Three (3.1-4.45)GHz (5.1-6.3GHz), (8.45-9.05)GHz	0.35×0.3	115.3	No
Proposed	SWB	1.2-15	Two (1.8-2.4)GHz (3.1-4.1) GHz	0.4×0.32	250	Yes

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Figures

Figure 1

Geometry of the proposed SWB antenna (a) Cross sectional view and (b) photograph.

Figure 2

Geometrical evolution of the proposed antenna

Figure 3

(a) Simulated S11 against different design steps and (b) simulated gain against different design steps

Figure 4

Simulated VSWR for different value of stub (a) length l and (b) width w

Figure 5

Simulated VSWR for different value of stub offset position

Figure 6

Simulated VSWR for different value of slot (a) length u_l and (b) width u_w

Figure 7

Simulated VSWR for different value of slot offset position u_h

Figure 8

Simulated VSWR for different value of stub (a) horizontal length S_{w1} and (b) vertical length S_{w2}

Figure 9

Simulated VSWR for different value of stub offset position s_h

Figure 10

Current distribution at different frequencies

Figure 11

Simulated and measured VSWR.

Figure 12

Simulated and measured radiation pattern for different operating frequencies

Figure 13

(a) Antenna gain with and without band rejection and (b) Simulated antenna efficiency with and without band rejection