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FREQUENCY NOTCHED WIDE BAND PLANAR MONOPOLE ANTENNAS

B. Rahmati and H. R. Hassani

Electrical & Electronic Engineering Department
Shahed University
Tehran, Iran

Abstract—The characteristics of an ultra-wideband (UWB) planar monopole antenna with multiple simple slots is presented. By placing a pair of symmetrical horizontal slots on the sides of the monopole antenna a tune-able notch characteristic can be obtained. The length, width and height of the slot can be used to tune the centre frequency, bandwidth and reflection coefficient of the notch. Placing two pairs of horizontal slots on the sides of the monopole antenna two tune-able notched characteristics can be obtained. Based on slot length and slot position an approximate formula for the notch centre frequency is given. The results of simulation and measurement are presented and discussed.

1. INTRODUCTION

The new UWB frequency range has interference to the existing communication systems frequency band. There are many communication systems that operate in two or more frequency bands, requiring dual or triple frequency band. To avoid the interference between the UWB system and the wireless local area network (WLAN) system with 5.15–5.35 GHz and HYPERLAN/2 with 5.725–5.825 GHz for IEEE802.11a frequency band, a band-notch filter in the UWB system is necessary. However, the use of a filter will increase the complexity of the UWB system. An UWB antenna having frequency band-notch characteristic is an alternative choice to overcome this problem [1–3].

With the advent of ultra-wideband technology, wideband planar monopole antennas have received increased attention [4–9]. These antennas exhibit good impedance matching, stable radiation patterns,

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Corresponding author: H. R. Hassani (hassani@shahed.ac.ir).

and high efficiency over bandwidths suitable for use with wideband systems.

Variety of techniques has been used to create multiband behavior. Cutting a slot inside the planar monopole antenna is one of the methods which have received great attention. In this method, the size and the position of the slot on the antenna plays an important role in the determination of the frequency center and the bandwidth of the notch. In [10] to create a narrow frequency band notch a V-shaped thin slot on a hexagonal radiating element is used.

The use of U-shaped slots placed in the centre of a wideband monopole antenna creating narrow frequency band notches are reported in [2, 3, 11, 12]. In [13] to design a wide band antenna a circular patch antenna is used and to create a frequency band notch behavior a slot in the shape of a crescent is place inside the patch surface.

In this paper, a study is presented on simple horizontal slots cut from the edges of the wideband monopole planar antenna. The antenna structure is able to achieve single and multiple tunable notch characteristics. The characteristics of a single horizontal slot, a single and a double pair of horizontal symmetrical slots placed on the edges of the planar monopole antenna for various size and positions of the slots are presented.

Simulation results based on software package HFSS along with experimental results are provided and discussed.

2. ANTENNA DESIGN

Figure 1 shows the proposed antenna structure. It consists of a planar wideband monopole antenna with multiple horizontal slots. The planar

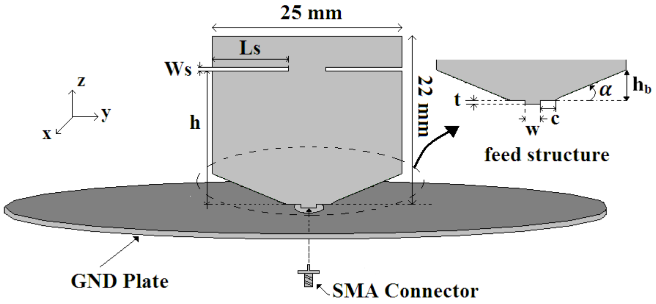

Figure 1. Geometry of the proposed multiple band-notched planar monopole antenna.

monopole antenna was proposed in [4] and further studied in [5, 6]. Such antennas exhibit good impedance matching and high efficiency. There are a number of parameters that influence the bandwidth; these include the size of planar monopole, the feeding gap, the beveling and the size of the ground plane. For the size of the ground plane, as is also used in [2, 3], a circular plate of radius 40 mm achieves the best result. A 50 SMA connector, centrally mounted from the back of the ground plane, was used to excite the antenna. A copper planar element of thickness, 0.2 mm, size 22 mm × 25 mm and beveling angle of 17° (or $h_b = 4\,\text{mm}$), is mounted 0.5 mm over the ground plane. To implement the notched characteristics, horizontal slots are inserted in the edges of the planar element. It will be shown that to create two band-notched characteristics, two symmetrically placed slots on the edges of the monopole antenna are required.

3. BAND-NOTCH CHARACTERISTICS

In this section, simulated and measured results of the horizontal slot loaded monopole antenna are presented. Initially a wideband beveled monopole antenna operating over 2.6–16 GHz is designed. Adding a slot to the edge of the planar monopole creates an additional resonance with a high impedance value that overlay the initial resonances of the monopole antenna. This can be viewed as a slot added in series to the initial planar monopole, creating a notch in the pass band of the antenna.

The configurations considered include the single horizontal slot, single and double pair of symmetrical horizontal slots on the monopole antenna.

3.1. Planar Antenna with Single Horizontal Slot

The effect that a single horizontal slot cut from one edge of a monopole antenna has on the antenna is shown in Figure 2. Also shown in this figure is the result of a planar monopole antenna without the slot loading, called the reference. The results show the reflection coefficient of the antenna for various position of the slot, h, as the length and the width of the slot are kept fixed. The simulated results show that when h was varied from 11 mm to 20 mm the notch bandwidth decreases from 20% to 4%, the reflection coefficient of the notch at centre frequency decreases and only a small shift in the notch centre frequency takes place. It is obvious that the reflection coefficient of the slot loading monopole at higher frequencies has improved as compared to the reference antenna.

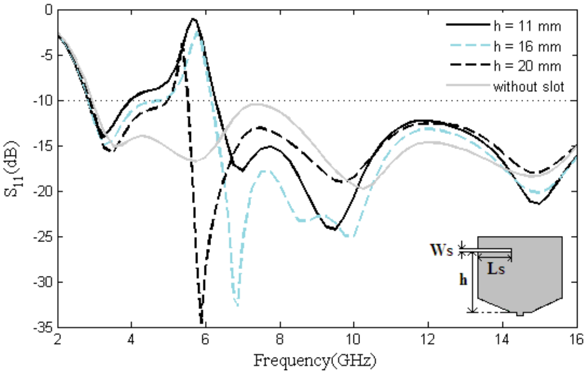

Figure 2. Simulated reflection coefficient of a single slot for various slot position, h ($L_s = 11\,\mathrm{mm}$, $W_s = 0.5\,\mathrm{mm}$).

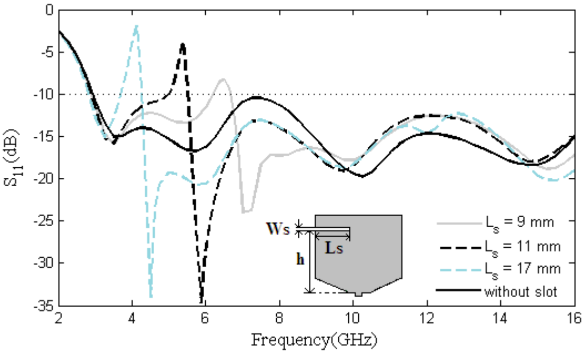

Figure 3. Simulated reflection coefficient of a single slot for various slot length, L_s ($h = 20\,\mathrm{mm}$, $W_s = 0.5\,\mathrm{mm}$).

Figure 3 shows the reflection coefficient of the slot loaded antenna as slot length, L_s, is varied. The simulated results show that with an increase in L_s, the notch centre frequency decreases with an improved notch behavior.

Figure 4 shows the effect of slot width, W_s, on the notch bandwidth. As W_s is increased, the notched bandwidth increases from 9% to 20% and only a small shift in notch centre frequency takes place.

From the above results, the centre frequency of the notch can be obtained through the following approximate formula:

$$f_{\text{notch}} \cong \frac{c}{4 \times L_s + 0.5 \times h} \tag{1}$$

where c is the speed of light. It can be seen that the notch frequency is controlled mostly by the slot length L_s.

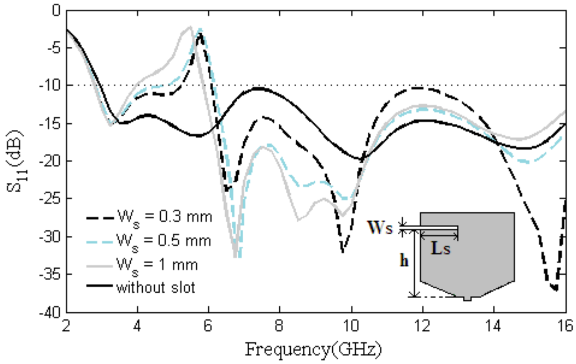

Figure 4. Simulated reflection coefficient of a single slot for various slot width W_s. ($h = 20\,\mathrm{mm}$, $L_s = 11\,\mathrm{mm}$).

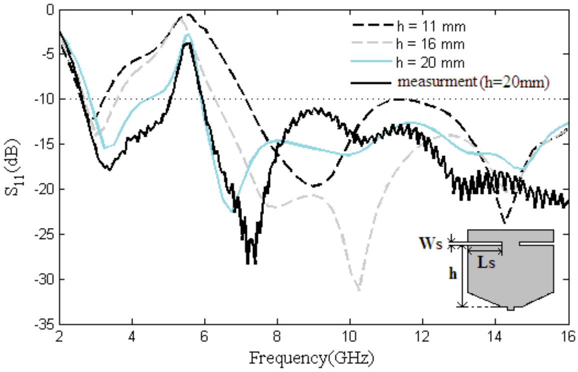

Figure 5. Simulated and measured reflection coefficient of a single pair of symmetric slots for various slot height, h. ($L_s = 11\,\mathrm{mm}$, $W_s = 0.5\,\mathrm{mm}$).

3.2. Planar Antenna with Single Pair of Symmetrical Slot

Figure 5 shows the reflection coefficient of the antenna loaded with a single pair of symmetrical slots cut from the sides of the antenna for various position of the slot, h. From this result it is seen that the pair of symmetrical slots results in a wider notch bandwidth as compared to that of single slot of previous section. When h is varied from 11 mm to 20 mm the notch bandwidth reduces from 55% to 12% and a very small shift in notch centre frequency takes place. The value of reflection coefficient is also higher at notch centre frequency than that of the single slot case. Also shown in this figure is the measured result for the slot height of 20 mm, which is very close to that of the simulated result. The single pair of symmetrical slots can be modeled as two resonances connected in series to the initial monopole antenna. Slots of equal length result in equal resonant frequency and higher notch bandwidth.

The effect of various slot length, L_s, on antenna reflection coefficient is shown in Figure 6. It is seen that the length of the slot determines the centre frequency of the notched band. As L_s is increased the notch centre frequency shifts toward the lower frequency with an increase in reflection coefficient level.

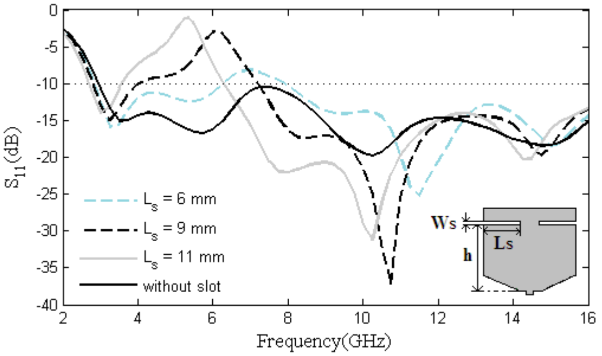

Figure 6. Simulated reflection coefficient of a single pair of symmetric slots for various slot length, L_s. ($h = 16$ mm, $W_s = 0.5$ mm).

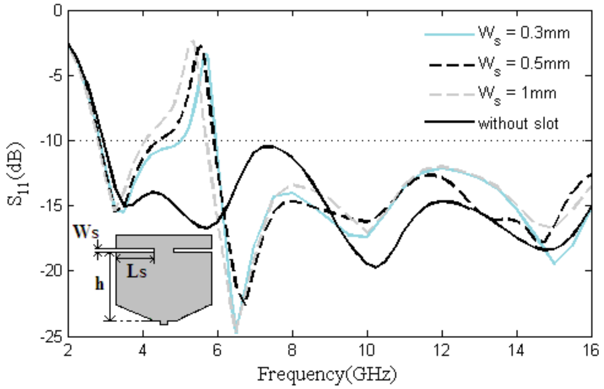

Figure 7. Simulated reflection coefficient of a single pair of symmetric slots for various slot width, W_s. ($h = 20$ mm, $L_s = 11$ mm).

Figure 7 shows the effect of slot width on the notch bandwidth. As W_s is varied from 0.3 mm to 1 mm, the notch bandwidth increases from 9% to 20% and only a small shift in notch centre frequency takes place.

From the results of Figures 5–7, it is seen that the centre frequency of the notch is more dependent on the length and position of the slot. The slot position also affects the bandwidth of the notch. From these results one can state that for slot position $h < 16\,\text{mm}$ the centre frequency of the notch can be obtained through the following approximate formula:

$$f_{\text{notch}} \cong \frac{c}{4 \times L_s + h} \tag{2}$$

while for $h > 16\,\text{mm}$, the effect of slot position becomes less, thus the formula in Equation (1) would be more suitable.

Figure 8 shows the normalized surface current distribution over the planar monopole antenna for the single and for a pair of slots at various frequencies. In Figures 8(a) and 8(c), where the antenna operates at pass band frequencies 3.5 and 13 GHz, there are more current distributions near the feeding point (i.e., slot does not resonate and has little effect). At notch frequency, 5.7 GHz, as shown in Figure 8(b), current is concentrated around the edge of the slot while there is almost no current at the feeding point. The high concentration of current around the slot can be represented as a short circuited stub. The edge loaded slot monopole antenna can then be modeled as a short circuited stub in series with the unloaded monopole

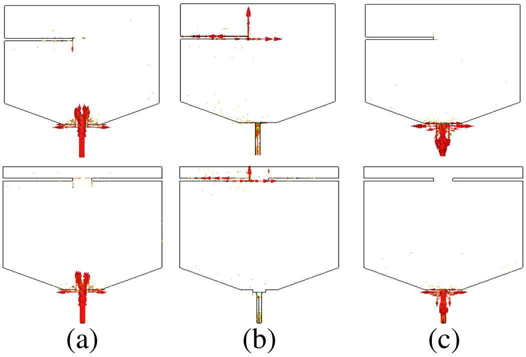

Figure 8. Surface current of antenna with one and two slots, at the (a) pass band 3.5 GHz, (b) notch frequency 5.7 GHz, (c) pass band 13 GHz.

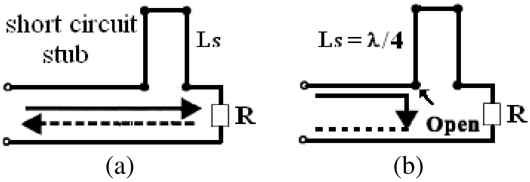

Figure 9. Equivalent-circuit model for slot loaded planar monopole antenna at (a), pass band frequency, (b) notch frequency.

radiation resistance, R, shown in Figure 9. For the case of single pair of symmetric slots, there would be two short circuited stubs connected in series with R. At notch frequency, the slot is almost $\lambda/4$ and thus transforms short circuit at the slot to open circuit at the antenna feeding point. This leads to the desired high attenuation and impedance mismatching around the notch frequency.

3.3. Planar Antenna with Two Pairs of Symmetrical Horizontal Slots

In this section the reflection coefficient results of the planar monopole antenna with two pairs of horizontal symmetrical slots is presented. The presence of the second pair of slots creates an extra resonance (notch), whose centre frequency is dependent on the parameters of this pair of slots. In all cases studied the dimensions of the upper pair of slots are kept fixed while those of the lower pair of slots are varied. Figure 10 shows the reflection coefficient results for various lengths of the lower pair of slots, L_{s2}. It is seen that increasing L_{s2} towards L_{s1} the centre frequency of the second resonance approaches that of the first, thus increasing the bandwidth of the notch.

Figure 11 shows the reflection coefficient for various heights of the lower pair of slots. From Figure 1, beveling height, h_b is 4 mm, thus, $h_2 = 3$ mm is for a slot which is placed in the beveling region of the monopole antenna. As the length of this slot in such a region is small, the upper centre frequency would be quite high. As the slot is moved up from this region (i.e., $h_2 > 4$ mm) there is not much change in upper centre frequency while its reflection coefficient level reduces.

Figure 12 shows the reflection coefficient for various widths of the lower pair of slots. As the width is increased the bandwidth of the upper resonance increases whiles its centre frequency changes slightly. Also shown in this figure, is the measured result for the width of 0.3 mm, which is very close to that of the simulated result.

From the results shown in Figure 10, it is seen that the upper pair of symmetrical slots does not have much effect on the lower pair of symmetrical slots, i.e., the mutual coupling between the two rows of slots is low. Figure 10 shows the notch centre frequencies when the size of the upper pair of horizontal slots is kept constant while the length of the lower pair of slots, L_{s2}, is varied. Since the mutual coupling is low, thus, one can use the same Equation (2) which was given for the single pair of horizontal slots to obtain the centre frequency of the

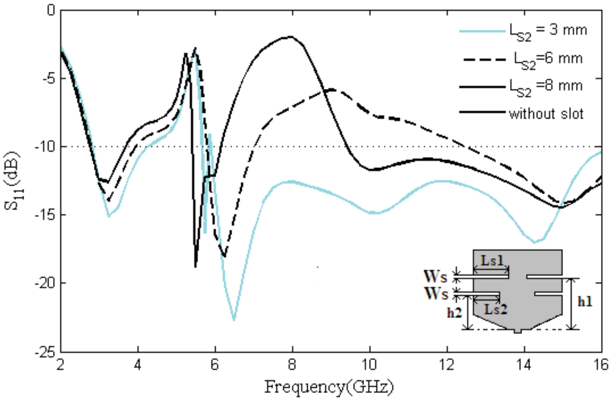

Figure 10. Simulated reflection coefficient of two pairs of symmetric slots for various lengths of lower pair of slots ($h_1 = 20\,\mathrm{mm}$, $L_{s1} = 11\,\mathrm{mm}$, $h_2 = 8\,\mathrm{mm}$, $W_s = 0.5\,\mathrm{mm}$).

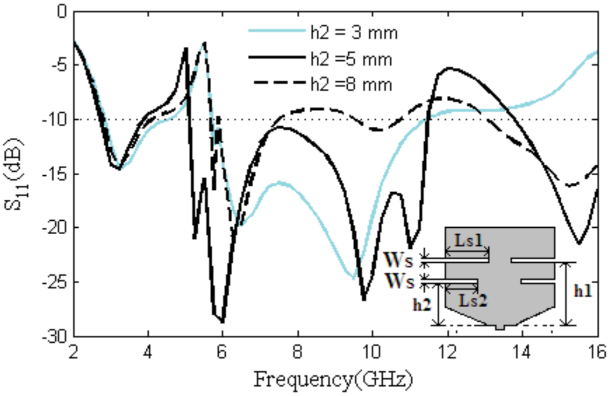

Figure 11. Simulated reflection coefficient of two pairs of symmetric slots for various heights of lower pair of slots ($h_1 = 20\,\mathrm{mm}$, $L_{s1} = 11\,\mathrm{mm}$, $L_{s2} = 5\,\mathrm{mm}$, $W_s = 0.5\,\mathrm{mm}$).

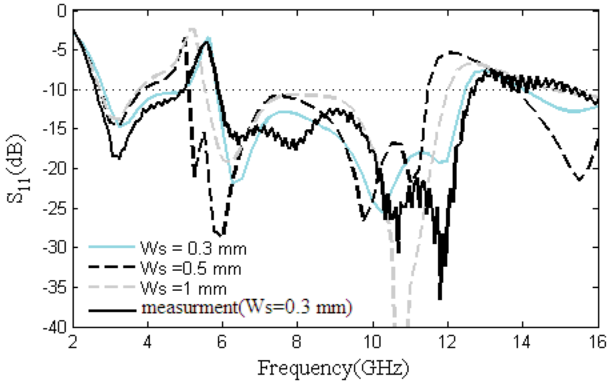

Figure 12. Simulated reflection coefficient of two pairs of symmetric slots for various slots widths ($h_1 = 20\,\text{mm}$, $L_{s1} = 11\,\text{mm}$, $h_2 = 5\,\text{mm}$, $L_{s2} = 5\,\text{mm}$).

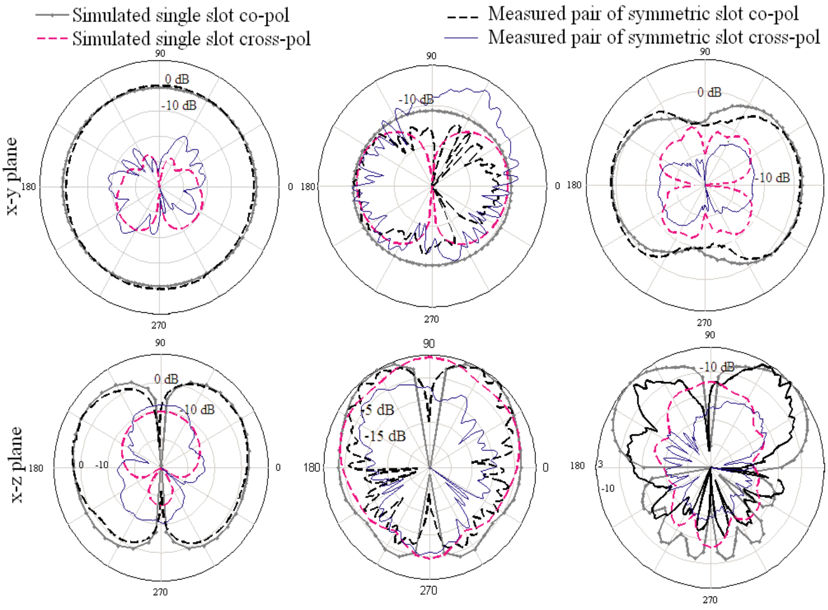

Figure 13. Simulated and measured radiation pattern of monopole antenna with single slot ($h = 15\,\text{mm}$, $L_s = 11\,\text{mm}$, $W_s = 0.5\,\text{mm}$), and with a pair of symmetric slots ($h = 20\,\text{mm}$, $L_s = 11\,\text{mm}$, $W_s = 0.5\,\text{mm}$), over y-z and x-y plane.

notches related to the bottom pair of horizontal slots.

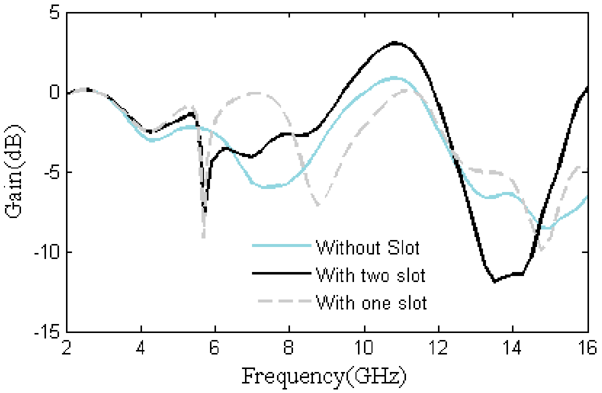

Figure 14. Simulated bore sight gain for an antenna without slot, with a single slot ($h = 15\,\text{mm}$, $L_s = 11\,\text{mm}$, $W_s = 0.5\,\text{mm}$), and with a pair of symmetrical slot ($h = 20\,\text{mm}$, $L_s = 11\,\text{mm}$, $W_s = 0.5\,\text{mm}$).

The same equivalent circuit shown in Figure 9 can be used to model the double pair of horizontal slots. Since we have two notches, two stubs in series should be considered in the equivalent circuit.

Figure 13 shows the simulated and measured radiation patterns of the single slot loaded antenna, and the antenna loaded with a pair of symmetrical slots, at three different frequencies, 3.5 and 13 GHz (pass band frequencies) and 5.7 GHz (the notch frequency). It can be seen that the cross polar level is well below the co-polar level at pass band.

The simulated broadside gain (at $\Phi = 0$ and $\Theta = 90$ degrees) of the reference antenna, antenna loaded with a single slot and antenna loaded with a pair of symmetric slots is shown in Figure 14. It is seen that the gain at notch frequency reduces compared to that of the reference antenna, as expected.

4. CONCLUSION

A parametric study on an UWB planar monopole antenna with simple slots cut from its edges, leading to multi band notch behavior has been given. As the slots are cut from the edges, the proposed antenna structure provides easy tuning of the notch centre frequency and bandwidth with good stop band rejection. The measured results are in agreement with the simulated results.

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