Wideband Planar U-shaped Monopole Antenna with Meandering Technique for TV White Space Application

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Abstract. *A novel wideband planar U-shaped antenna with meandering technique is proposed for TV White Space operation in 470–798 MHz band. The antenna consists of a U-shaped antenna backed by a partial ground plane. The meandering technique is applied by inserting several slots at the bottom part of the U-shaped for bandwidth enhancement. An impedance bandwidth of 95.2 % is achieved when the planar U-shaped antenna is added with 21 slots. The radiation pattern confirms that good pattern stability is obtained. The antenna gain of 2.2 dBi up to 4.6 dBi is achieved for the operational frequency from 470 MHz to 798 MHz.*

Keywords

U-shaped antenna, meandering technique, UHF antenna, TV white space, microstrip antenna.

1. Introduction

Cognitive radio is useful to improve efficient spectrum utilization, whereby it can detect and allocate the unutilized spectrum, also known as white space, in an opportunistic manner while ensuring no interference [1]. In 2008, the FCC has adopted rules to allow unlicensed use of television (TV) white space (TVWS) [2]. This is an important development to promote innovation within the UHF band and to provide long distance broadband access to hard-to-reach population in typical rural area owing to favorable propagation characteristic in this band [3].

Due to the increasing interest in the TVWS application, recently, several antennas have been designed to be operated in UHF bands [4]-[6]. TVWS antenna required small size and high bandwidth, which is difficult to be implemented due to the respective large wavelength, is 400–640 mm [7].

In the past, planar U-shaped antennas have been intensively investigated due to the ability to provide wideband antenna [8]-[10] and multiple frequencies antennas [11]–[12]. These antennas are normally designed for ultrawideband (UWB) and wireless local area network (WLAN) applications, which is normally small due to the high frequency usage.

In this paper, we propose a novel planar U-shaped antenna with meandering technique for TVWS application at UHF band IV and V (470–798 MHz). Meandering antennas normally consist of a wire or microstrip antenna made from meander sections intended to reduce the resonant length of the antenna [13]. Several literatures have basically implement this technique in order to have a smaller or compact size of antennas [14]-[17], without concerning on the drawbacks such as increase in the antenna loss, reduction on the antenna gain and efficiency. Here, the proposed antenna with meandering technique is able to achieve higher impedance bandwidth with the increase of the resonant length, while the gain on the antenna at a specific frequency is remained constant.

The paper is organized as follows. Section 2 presents the proposed antenna design. Section 3 describes the characteristics of the proposed antenna with some deeper looks on the optimization and current distribution. The results are then discussed in Section 4. Finally, conclusion is drawn in Section 5.

2. Antenna Design

A printed planar U-shaped antenna is designed on FR-4 substrate (ε_r = 4 and thickness = 1.6 mm) to operate from 470–798 MHz using commercial CST^{TM} software. The U-shaped structure is first constructed by using elliptical structure with outer radius of 90 mm and inner radius of 75 mm. A portion of the shape is removed to perform the U-shaped structure. This structure is then backed by a 5 mm width of a partial ground plane as shown in Fig. 1(a). In order to meander the antenna, several slots are added at the bottom part of the U-shaped antenna as depicted in Fig. 1(b) and Fig. 1(c). Slots width of 1 mm and the gap between the slots of 2.0 mm is chosen in the area of 190 mm x 180 mm (Fig. 1(d)). The antenna is fed by 50 Ohm characteristic impedance and the effect of adding the numbers of slots are investigated.

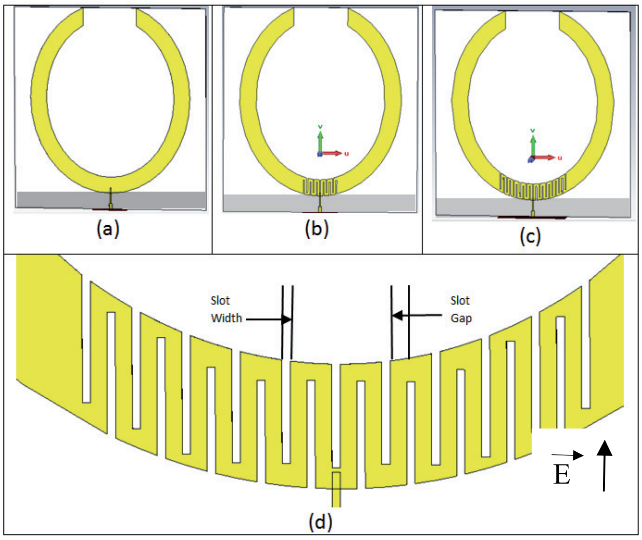


Fig. 1. (a) U-shaped antenna, (b) U-shaped antenna with 5 slots, (c) U-shaped antenna with 21 slots, (d) Enlarged view on the 21 slots.

3. Characteristics of Meandered U-shaped Antenna

Firstly, the impedance bandwidth of the U-shaped antenna is investigated. This is followed by the addition of a slot in the middle and each pair of slots on the bottom left and bottom right part of the U-shaped antenna. The effect on the reflection coefficient is shown in Fig. 2 and the analysis on the impedance bandwidth is shown in Tab. 1.

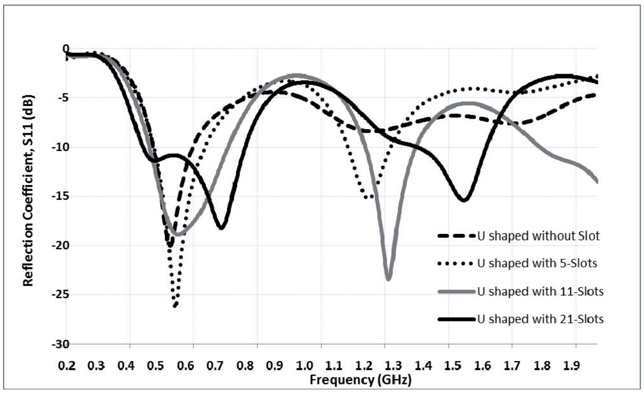


Fig. 2. Reflection coefficient for U-shaped antennas with different number of slots.

Fig. 2 shows that a small impedance bandwidth of 136 MHz is achieved for U-shaped antenna without meandering technique. However, when the number of slots is increased, the impedance bandwidth starts to increase. The slots act as a mechanism for matching purposes and at the same time it can enhance the impedance bandwidth of the overall antenna. From Fig. 2, we found that the optimum antenna for covering the 470–798 MHz band is achieved when 21 slots is used. The effects on the number of slots to the impedance bandwidth are summarized in Tab. 1. It is observed that when the number of slots is increased even further, the impedance bandwidth is still increasing but with an addition of a notch.

Number of slots	Frequency range (MHz)	Impedance bandwidth (MHz) (S_{11}<-10dB)
0	494-629	136
1	494-629	136
3	498-665	167
5	496-670	174
7	486-718	232
9	485-730	245
11	480-750	270
13	477-760	287
15	470-778	308
17	465-786	321
19	461-798 ***(Covering UHF band IV & V)***	337
21	459-808 ***(Covering UHF band IV & V)***	**349**
23	457-820 ***(Notch :530-593)***	363
25	451-821 ***(Notch:498-629)***	370

Tab. 1. Effects on the addition of the slots to the impedance bandwidth enhancement.

The effects of the slots addition on the antenna gain are investigated for four different antennas from 470 MHz until 798 MHz as shown in Fig. 3. From this figure, it shows that the antenna gain remains the same with and without slots within the frequency band of interest. This proves the advantages of introducing the meandering technique whereby it can provide high impedance bandwidth and at the same time, the antenna gain is kept unchanged when comparing to the antenna solution without the meandering technique. Overall, within the interested frequency, the antenna gain is quite high which are from 2.2 dB to 4.4 dB.

In order to have a good antenna performance, parametric studies on the width and gap of the slots are performed and the results are illustrated in Fig. 4 and Fig. 5. Fig. 4 shows that the effects on the slot width when the slots gap is fixed at 2.0 mm. From the figure, when the slot width is increased, the resonant frequency of the antenna is shifted to the higher frequency. At the same time, large impedance bandwidth is obtained for the cases of slots width equivalent to 1.0 mm and 1.5 mm. Further increase in the slots width will reduce the impedance bandwidth.

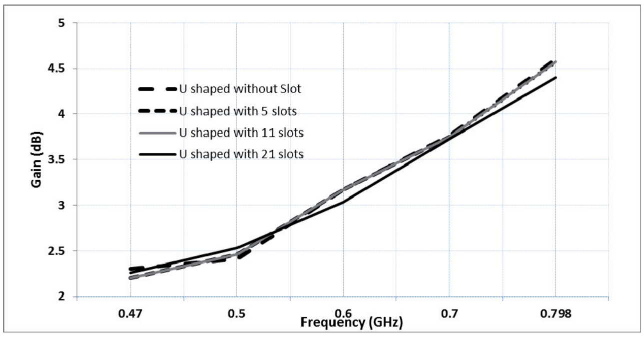


Fig. 3. Antenna gain for U-shaped antennas at different frequencies.

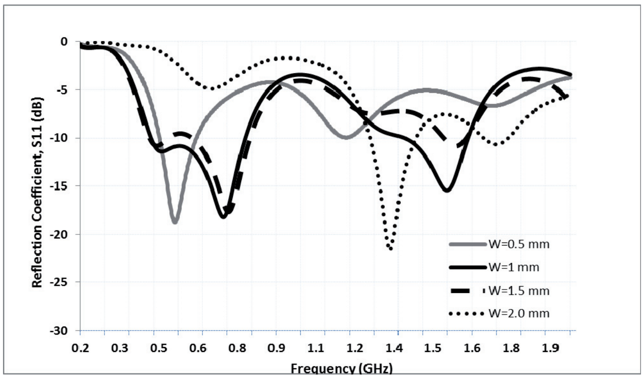


Fig. 4. Reflection coefficient for U-shaped antennas with different slot width.

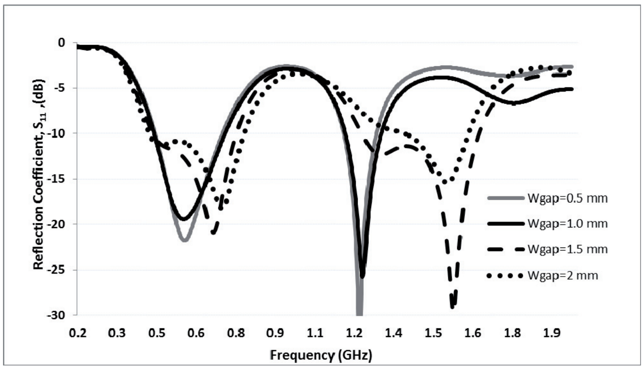


Fig. 5. Reflection coefficient for U-shaped antennas with different slot gap.

The parametric study on the different slots gap is shown in Fig. 5 when the slot width is fixed at 1.0 mm. From the figure, there is not much change on the reflection coefficient for the case when the slot gaps are equivalent to 0.5 mm and 1.0 mm, respectively. However, a large impedance bandwidth is achieved for the case of slot gap equivalent to 1.5 mm and 2.0 mm. Consequently, the slot width of 1.0 mm and gap of 2.0 mm are chosen to be implemented for fabrication. Overall, this design structure can give the highest numerical impedance bandwidth of 349 MHz or 57 %.

The current distribution of the selected structure is investigated at 470 MHz, 600 MHz and 798 MHz as shown in Fig. 6. This frequency selection is chosen since it covers within the TV White Space frequency of operation. We can see from this figure that most of the electric current is mainly distributed at the lower portion of the U-shaped and the two U-shaped arms for the cases of 470 and 600 MHz, respectively. Consequently, the antenna radiation pattern performance is dependent of these two configurations. On the other hand, at 798 MHz, more electrical currents are concentrated on the meandering slots only. As a result, the impedance matching at 798 MHz is sensitive to the meandering elements. Overall, these short analyses show that the meandering part responsible for the antenna operation at 470–798 MHz. Current concentration on meandering part making the antenna size is reduced from the standard half-wavelength antenna with additional advantage of a large impedance bandwidth.

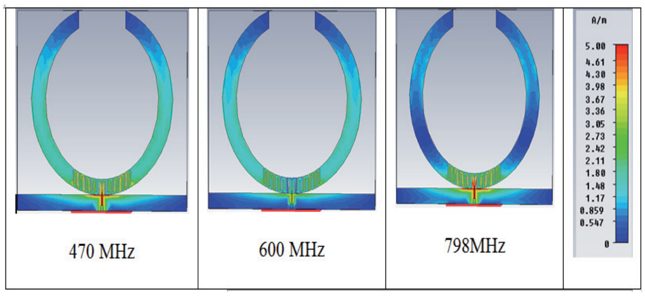


Fig. 6. Current distribution at 470 MHz, 600 MHz and 798 MHz.

4. Results and Discussions

In order to validate the design, the proposed antenna is constructed as shown in Fig. 7. Agilent Network Analyzer is used to measure the reflection coefficient. Fig. 8 shows the measured and simulated reflection coefficient for the fabricated antenna. From the figure, it can be seen that there is a good agreement between simulated and measurement results. A slight difference between simulation and measurement is due to fabrication errors. The measured reflection coefficient suggests that the fabricated antenna has a -10 dB impedance bandwidth from 325 MHz to 815 MHz, as high as 95.2 %, covering more than UHF band IV and V.

As depicted in Fig. 8, the reflection coefficient curve has several resonance frequencies that are combined together to perform wide impedance bandwidth.

In order to observe the radiation pattern of the antenna, two planes (E- and H-plane) are selected. Fig. 9 illustrates the simulated radiation pattern (both co-polar) at 500 MHz and 720 MHz, respectively. A good agreement is achieved for both frequencies when comparing the simula-

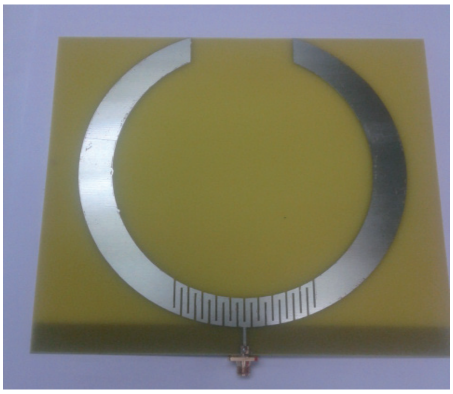


Fig. 7. Photograph of the fabricated antenna.

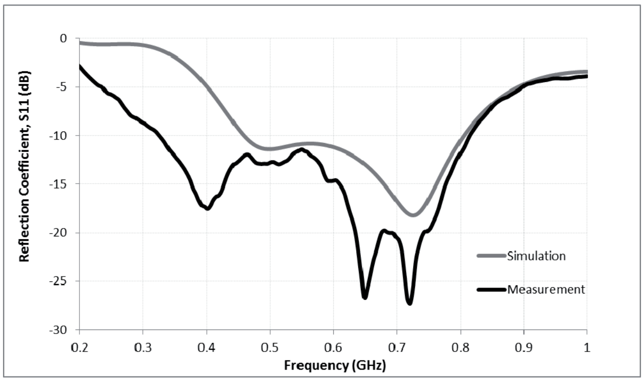
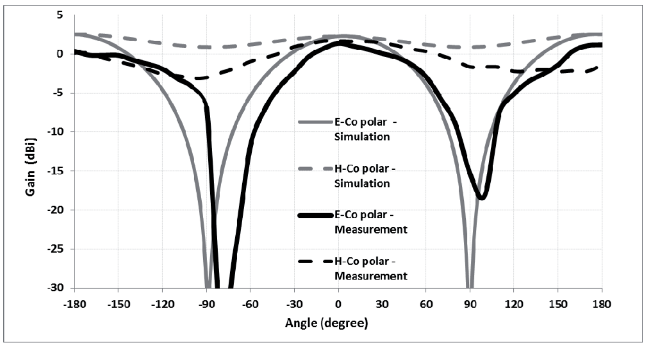
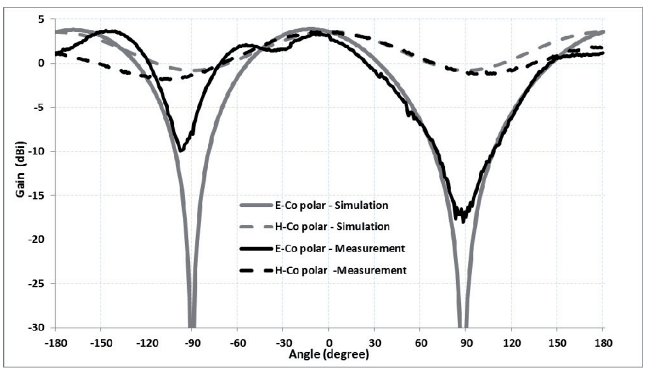


Fig. 8. Reflection coefficient comparisons between simulation and measurement.



(a)



(b)

Fig. 9. Simulated and measured radiation pattern comparison of U-shaped antenna with meandering line at (a) 500 MHz and (b) 720 MHz.

tion and measurement results. Measurement gain of 2.2 dBi and 3.7 dBi is obtained at 500 MHz and 798 MHz, respectively, which is 0.1 dB less that the predicted gain. It is proven that the antenna radiates over the interested frequency which is suitable for TVWS application. The radiation patterns in co-polar of E- and H-planes indicate that good pattern stability has been obtained.

5. Conclusion

A novel structure of U-shaped antenna has been proposed by implementing a meandering technique at the bottom part of the U-shaped structure. Here, the meandering elements provide matching mechanism which proven necessary for bandwidth enhancement and constant antenna gain. When the number of slots implemented on the U-shaped structure is increased, the impedance bandwidth is also increased. It has been verified that the proposed structure with 21 slots is able to achieve wideband characteristics covering frequency band from 325 MHz to 815 MHz as high as 95.2 % impedance bandwidth. The radiation patterns in E- and H-planes demonstrated good pattern stability on radiation characteristics. The gain achieved for this antenna is from 2.2 to 4.6 dBi. The ability to maintain the same gain with wider impedance bandwidth makes the antenna suitable for TVWS application.

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