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Compact Wideband Omnidirectional UHF Antenna for TV White Space Cognitive Radio Application

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This paper presents design and analysis of a compact wideband omnidirectional antenna for application in TV white space cognitive radio. The proposed antenna mainly consists of a monopole, a pair of parasitic elements, and a brief impedance matching network, all etched on an FR4 substrate. To obtain physical insight, an equivalent circuit is modelled and analysed to reveal the contribution of each part of the antenna to its bandwidth enhancement. Performance of the antenna is evaluated by simulations, and then further validated by experiments. Experimental results show that the antenna has an impedance bandwidth (voltage standing wave ratio less than 2) ranging from 460 MHz to 870 MHz, as well as omnidirectional radiation patterns in H-plane through the whole band.

Key words: TV white space, cognitive radio, wideband UHF antenna, omnidirectional radiation.

1. Introduction

With the ability of spectrum-sensing, cognitive radio is an attractive technology to make efficient use of radio spectrum [1]. Presently, analogue television broadcasts are being switched off and replaced by more spectrally efficient digital television transmissions in many countries [2]. The white spaces existing in the UHF TV band (470 MHz - 790 MHz in ITU Region 1) have good propagation and building penetration characteristics. Therefore, TV white spaces (TVWS) are competent to provide long distance broadband wireless access to population in rural area by virtue of the technology of cognitive radio [3]. For effective detection and allocation of TVWS, antennas with operating frequency from 470 MHz to 790 MHz and omnidirectional radiation patterns are required.

Several antennas with electrical performances suitable for the aforementioned application have been designed. A printed U-shaped monopole with meandering structure and a printed spline-shaped one with shorting stub are reported in [4] and [5], respectively, both with dimensions over 170 mm × 160 mm. Reconfigurable antennas [6, 7] can be more compact, whereas they are complex in retuning to cover the whole UHF TV band. The antennas reported in [8] and [9] are with lumped matching components, leading to enhanced impedance bandwidth while sacrificing the efficiency.

In this paper, we present a new design of a wideband omnidirectional antenna for TV white space cognitive radio application. The antenna is etched on an FR4 substrate with a compact strip profile. Explicit analysis with an equivalent circuit is performed for in-depth understanding of the wide band characteristic. Simulations and measurements are also carried out to evaluate and validate the electrical performance.

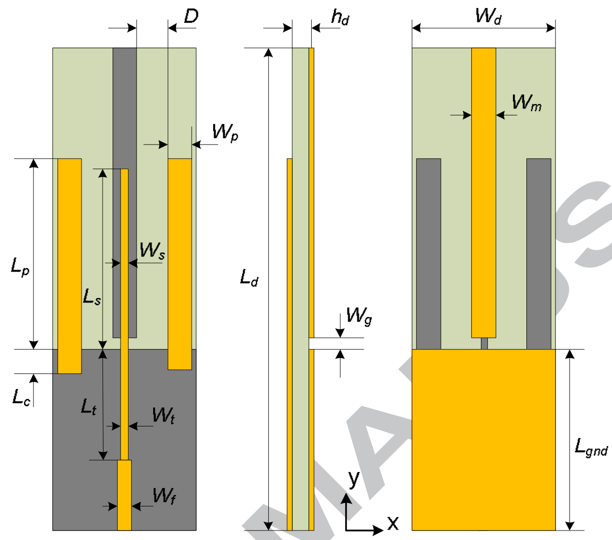
2. Antenna design

General configuration of the proposed antenna is described in Fig. 1. It is evolved from a printed monopole, to which a pair of parasitic elements and a brief matching network are added for bandwidth enhancement. All of the three parts are etched on an elongate FR4 substrate (ε_r=4.4, $tan\delta$=0.02) with a dimension of 261 mm × 30 mm × 0.8 mm. Excitation is realized by means of coupling energy from the microstrip line to the antenna through the gap W_g. Detailed dimensions of the antenna are listed in Table 1.

Fig. 2 shows the fabricated prototype of the antenna. An elaborate aluminium fixture is used to fasten a 50-Ohm SMA connector to the feed line of the antenna, and further to fix the entirety onto a turntable during the measurement process.

Table 1 Dimensions of the antenna (Unit: mm)

L_d	261	W_m	5	W_t	0.7
W_d	30	L_c	3	W_f	1.6
L_{gnd}	100	L_s	85	W_g	1
L_p	90	W_s	0.7	D	7
W_p	5	L_t	61	h_d	0.8



(a) (b) (c)

Figure 1. Configuration of the proposed antenna: (a) top view, (b) side view, and (c) bottom view.

(a) (b)

Figure 2. Prototype: (a) top view and (b) bottom view.

3. Equivalent circuit and analysis

The antenna being capable of working within a large bandwidth is attributed to the parasitic elements and the brief impedance matching network. To reveal the contribution of each part, the antenna is modelled as an equivalent circuit in Fig. 3, and then analysed by the aid of Smith Chart.

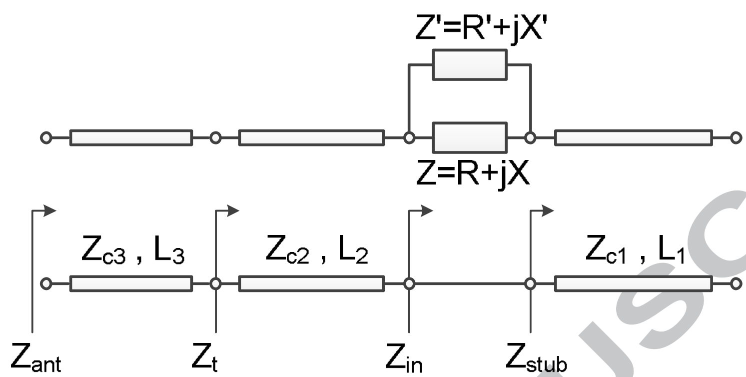
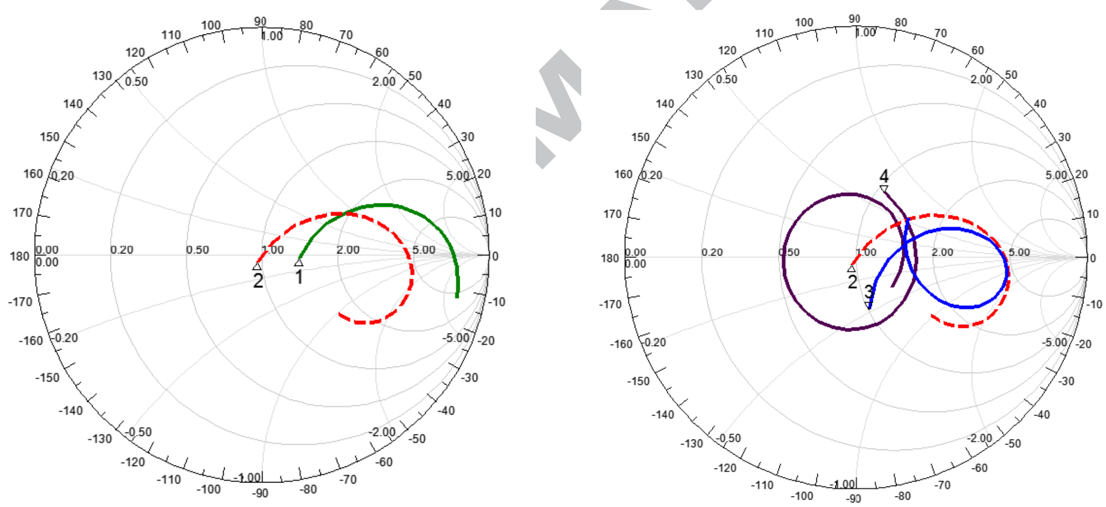


Figure 3. Equivalent circuit of the proposed antenna.

The monopole equates to a complex impedance with a value of Z = R + jX, so do the parasitic elements to one with Z' = R' + jX'. They are in parallel, since the parasitic elements are driven by energy coupled from the monopole. Line stub L_s is modelled as a segment of open-ended transmission line with electrical length L_1 and characteristic impedance Z_{c1}, while line Lt is modelled as one with electrical length L_2 and characteristic impedance Z_{c2}, respectively. Line W_f is the feed line with characteristic impedance Z_{c3} = 50 Ohm.

Firstly, take only the monopole into consideration by eliminating the parasitic elements and the transmission lines. We add an excitation voltage to the gap W_g and have the monopole calculated. The resulting input impedance Z = R + jX from 470 MHz to 790 MHz is plotted as curve 1 (solid green) in Fig. 4a. Note that the lower frequency end locates at the position of the figure notation. The curve on Smith Chart shows that values of Z versus frequency vary over a wide range, making it difficult to realize impedance matching through the whole band. Secondly, add the parasitic elements to the monopole. Curve 2 (dotted red) in Fig. 4a presents the calculated value of Z ∥ Z'. It can be observed that, as a result of the parallelization, the input impedance curve further curls inward and is closer to the matching point of Smith Chart. Both values of the resistance and the reactance decrease, and now each varies in a minified range. The bottom part L_c of each parasitic element overlaps with the ground plane, providing additional capacitance, and sequentially reducing the length of each parasitic element which ensures that they will not bring serious impact on radiation patterns in H-plane.

To further minify the reactance of curve 2, a line stub L_s, which is capacitive in the lower band and inductive in the higher, is added in series. The input impedance changes to $Z_{in} = Z \parallel Z' + Z_{stub}$, represented by curve 3 (solid blue) in Fig. 4b. Curve 3 retains the real part of curve 2 because Z_{stub} is purely reactive. In the next, the input impedance is transformed to Z_t by the microstrip line Lt. Curve 4 (solid purple) in Fig. 4b represents the input impedance Z_t, which already satisfies the requirement of voltage standing wave ratio (VSWR) less than 2 through the band from 470 MHz and 790 MHz.



(a) (b)

Figure 4. Impedance matching to 50 Ohm: (a) function of the parasitic elements and (b) function of the cascaded transmission lines.

4. Simulations and measurements

Based on the previously analysis, an antenna used for TV white space cognitive radio application is engineered and optimized, followed by fabrication. The top view and the bottom view of the prototype are shown in Fig. 2. Its performance is evaluated in an anechoic chamber with a vector network analyzer and a far-field antenna measurement system.

Comparisons between simulations and measurements are carried out to validate the performance. Fig. 5 plots simulated and measured VSWRs of the antenna. The measured result indicates that the antenna works well with VSWR less than 2 over 460 MHz to 870 MHz, whereas the simulated impedance bandwidth is from 465 MHz to 840 MHz. Though small discrepancies exist, which are probably caused by the aluminium fixture, these two results agree well with each other. Normalized radiation patterns at 500 MHz and 790 MHz are plotted in Fig. 6. It can be observed that the patterns are omnidirectional in H-plane (xoz) and have nulls in E-plane (yoz), similar to those of classic monopole antennas. Radiation gain in H-plane is also measured and plotted in Fig. 7 with the simulated one. Due to influence of the cable and the turntable, maximum radiation does not occur in H-plane at lower frequencies, as shown in Fig. 6b, resulting in the measured gain lower than the simulated one as presented in Fig. 7.

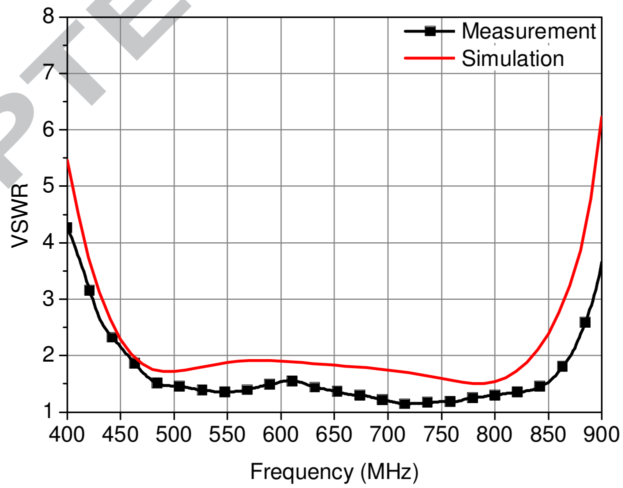


Figure 5. Voltage standing wave ratio (VSWR).

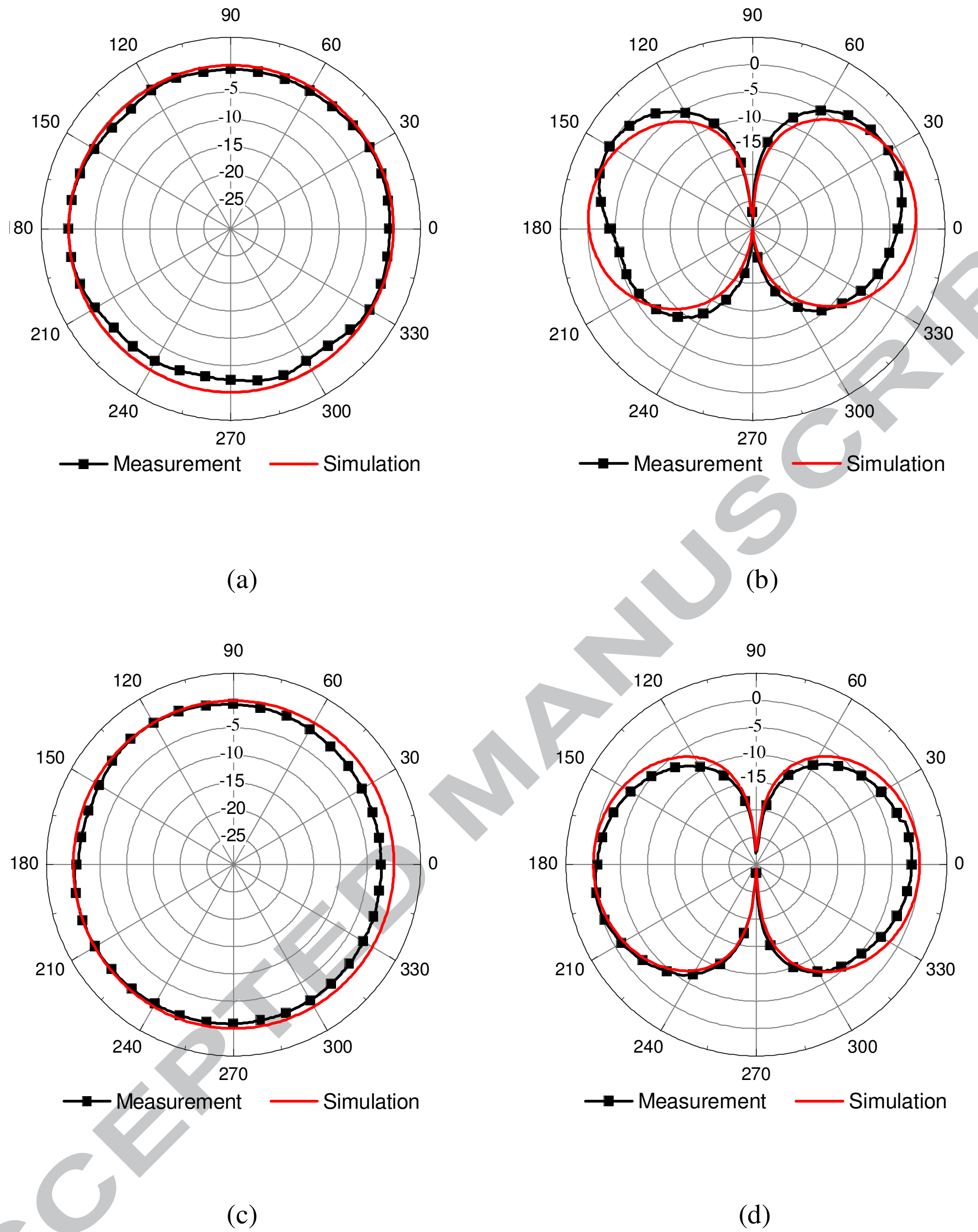


Figure 6. Normalized radiation patterns in dB: (a) H-plane at 500 MHz, (b) E-plane at 500 MHz, (c) H-plane at 790 MHz, and (d) E-plane at 790 MHz.

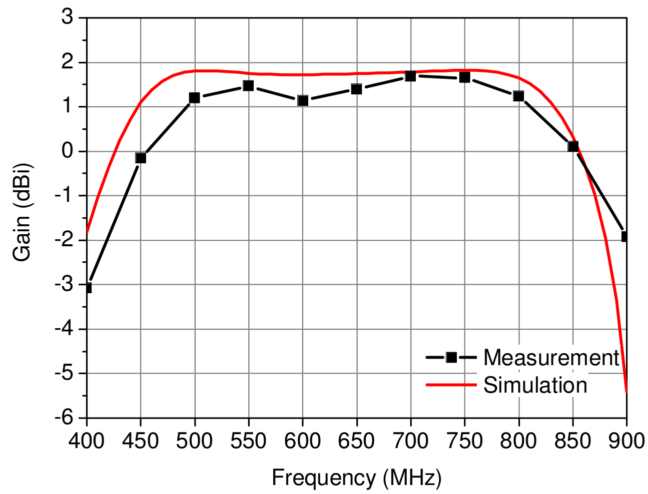


Figure 7. Radiation gain in H-plane.

5. Conclusion

A printed antenna working in the UHF TV band (470 MHz - 790 MHz) has been designed for the TV white space cognitive radio application. It is with a compact strip profile, good impedance matching, omnidirectional radiation patterns and stable gain through the frequency band of interest. The experimental results coincide with the simulated ones, having the excellent performance validated. All the features make the antenna a competent candidate for TV white space cognitive radio application. In addition, the bandwidth enhancement approach is revealed by modelling the antenna as an equivalent circuit and analysing the circuit by the aid of Smith Chart. This analysis will facilitate future designs of such antennas.

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References

[1] Ren X, Chen C. Spectrum sensing algorithm based on sample variance in multi-antenna cognitive radio systems. AEU-Int J Electron C 2016; 70(12): 1601-1609.

[2] Holland O, Ping S, Aijaz A, et al. To white space or not to white space: That is the trial within the Ofcom TV white spaces pilot. 2015 IEEE International Symposium on Dynamic Spectrum Access Networks; 2015 Sep 29 - Oct 2; Stockholm, Sweden.

[3] Qin Z, Gao Y, Plumbley M, et al. Wideband Spectrum Sensing on Real-time Signals at Sub-Nyquist Sampling Rates in Single and Cooperative Multiple Nodes. IEEE T Signal Proces 2015; 64(12):3106-3117.

[4] John M, Ammann MJ. A Compact Shorted Printed Monopole Antenna for TV White Space Trials. The 7th European Conference on Antennas and Propagation-EuCAP; 2013 Apr 8-14; Gothenburg, Sweden.

[5] Jamaluddin MH, Rahman TA, Mohamad H, et al. Wideband Planar U-shaped Monopole Antenna with Meandering Technique for TV White Space Application. Radioengineering 2013; 22(3): 708-713.

[6] Bao XL, Shynu SV, Ammann MJ. Design of a Tunable Compact Antenna for Digital Video Broadcasting Handheld Terminals. 2009 Loughborough Antennas & Propagation Conference; 2009 Nov 16-17; Loughborough, UK.

[7] Choi DH, Im YT, Cho YJ, et al. A Tunable Antenna for DVB-H Applications. IEEE Antenn Wirel Pr 2007; 6: 515-517.

[8] Liang X, Jin R, Zhao Y, et al. Compact DVB-T printed monopole antenna. 2010 International Workshop on Antenna Technology; 2010 Mar 1-3; Lisbon, Portugal.

[9] Bod M , Ahmadi-Boroujeni M, Mohammadpour-Aghdam K. Broadband loaded monopole antenna with a novel on-body matching network. AEU-Int J Electron C 2016; 70(11): 1551–1555.