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Research paper

A Novel Wineglass Shaped Wide Band Antenna for TV White Space Communication

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Abstract

This paper presents a novel patch antenna for TV white spaces applications. The shape of the proposed antenna is based on the shape of a wineglass. The dimension of the proposed antenna is 170 mm x 120 mm x 1.6 mm. After simulation, the proposed antenna resonates at 703 MHz with a return loss of -21.97 dB and covering a bandwidth from 495 MHz to 1540 MHz. Overall bandwidth coverage is 1045 MHz. So the proposed antenna is a wide band antenna covering almost the entire TV Ultra High Frequency (UHF) range. Simulated VSWR obtained at 703 MHz is 1.38 dB and simulated gain is 2.32 dB. The proposed antenna is fabricated using FR4 substrate and tested on Vector Network Analyzer (VNA). The measured return loss of fabricated antenna is -20.20 dB at 596 MHz. Proposed antenna shows the simulated radiation efficiency of 95%. Simulated and measured results showed good match between them. Proposed design is compared with few designs available in literature to validate its novelty and advantages.

Keywords: *FR4, TV White Space, Vector Network Analyzer (VNA), Wineglass.*

1. Introduction

The TV white space opens new possibilities and dimension to the world of wireless transmission and communications[1]. The TV broadcast services are operated in analog as well as the digital mode in VHF and UHF bands. The digital transmission replaced analog transmission worldwide as it was not spectrum efficient. The switching from analog transmission to digital transmission is defined as digital switchover (DSO) or digital dividend. The digital switchover (DSO) releases spectrum which is known as vacant spectrum. This vacant spectrum is being used by various International Mobile Telecommunication (IMT) services and another standard as per regulatory guidelines[3].

In terrestrial TV networks, there are channels which are not used in a particular location and therefore, in order to avoid interference caused due to adjacent channels, these channels are left vacant[6]. These vacant channels are known as TV White Spaces (TVWS) with respect to that particular location[2-4]. From the coverage point of view, the TV band is the most precious band and is allocated for TV broadcasting[9]. Various countries have developed a regulatory framework in TV white space for unlicensed applications[5]. IEEE 802.11 is a set of standards for implementing Wireless Local Area Network in 2.4 GHz, 3.6 GHz, and 5GHz frequency bands. The most commonly used Wi-Fi protocols are 'b', 'g', and 'n'. The main drawbacks of using these protocols are the ranges of it. IEEE 802.11af; define about the TV White Space spectrum sharing[6]. The main advantages of the TV white space frequencies are well signal traveling and its coverage. White Space frequencies can be used for broadband and Super Wi-Fi mainly because it operates between 50 MHz and 1 GHz.

In Section 2, the antenna structure and its dimensions are presented. Section 3, present the simulated results of proposed antenna such as return loss, VSWR, gain, and radiation pattern. The paper is concluded in Section 4. Section 5 represents the future scope..

2. Structure of Proposed Antenna

Various types of techniques and antenna designs have been used so far for TVWS systems such as printed antennas for UHF, UWB & EWB bands. The popular antenna types are printed monopoles, patch, PIFA, meander-shaped etc [6-12]. Several bandwidth enhancement techniques can be used for antenna design. The antenna can be of U-shaped [13] [15], V- shaped[16] and elliptical [17] etc. Microstrip patch antenna is used for the designing of proposed antenna. Initially, the basic patch antenna is designed. In this design the TVWS frequency, required bandwidth, gain, and radiation efficiency is not achieved. Then microstrip patch antenna with defected ground plane is designed. In this design also the desired frequency range and radiation efficiency have not achieved for TV white space. Finally to overcome these problems a new wineglass shaped antenna is designed.

2.1. Design of Basic Rectangular Microstrip Patch Antenna with DGS

In this design, the front view is shown in Figure 1 and the modified back view is shown in Figure 2 respectively. The ground plane of the antenna is modified to be defected ground structure (DGS). Introducing DGS, performance parameters of the antenna such as VSWR, bandwidth etc. are improved.

Table 1:. Design specifications of basic patch antenna

Parameter	Value
Substrate Type	FR4
Dielectric Constant (ε_r)	4.4
Loss Tangent (δ)	0.018
Substrate Thickness	1.6 mm

2.1.1 Patch Dimension:

Dimensions of the patch can be calculated by following formulas. These equations are widely used for initial approximation of dimensions of rectangular patch antennas. Then the dimensions and shape of the patch can be modified and optimized as per desired performance parameters.

$$w = \frac{v_0}{2f_c}\sqrt{\frac{2}{\epsilon_{rel}+1}} \quad (1)$$

$$\epsilon_{rel(eff)} = \frac{\epsilon_{rel}+1}{2} + \frac{\epsilon_{rel}-1}{2}\left[1+12\frac{h}{w}\right]-\frac{1}{2} \quad (2)$$

$$\frac{\Delta l}{h} = 0.412\frac{(\epsilon_{rel(eff)}+0.3)\{\frac{w}{h}+0.264\}}{(\epsilon_{rel(eff)}+0.258)\{\frac{w}{h}+0.8\}} \quad (3)$$

$$l = \frac{v_0}{2f_c\sqrt{\epsilon_{rel(eff)}}}-2\Delta l \quad (4)$$

So the dimensions are: Length (L_p) = 105 mm and Width (W_p) = 90 mm. Fig. 1 shows dimensions of a basic patch antenna with a rectangular patch fed by a microstrip line.

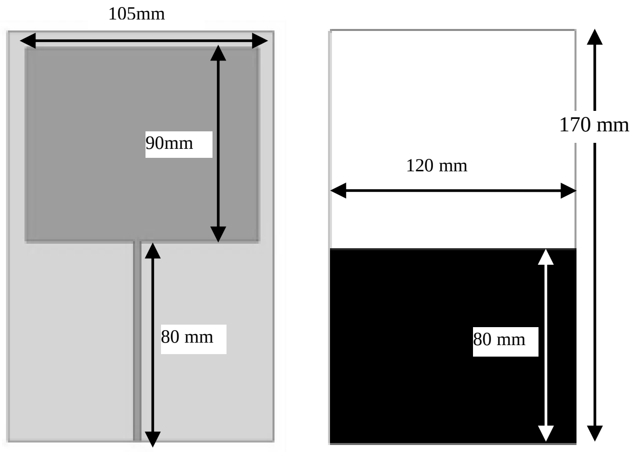

Fig. 1:. Basic Patch Antenna with DGS (a) Front View (b) Back View

2.1.2 Design of a Wineglass shaped Patch Antenna with DGS for TVWS applications

To achieve desired frequency range, radiation efficiency, the high gain of the antenna, again the designed antenna is modified. Figure 2 shows the front view and side view of the proposed wineglass shaped patch antenna with DGS respectively.

Use of DGS is to enhance gain and bandwidth of the antenna within UHF range. This structure shows significant improvement in bandwidth, gain and radiation efficiency of the antenna. Further, the VSWR value is also improved.

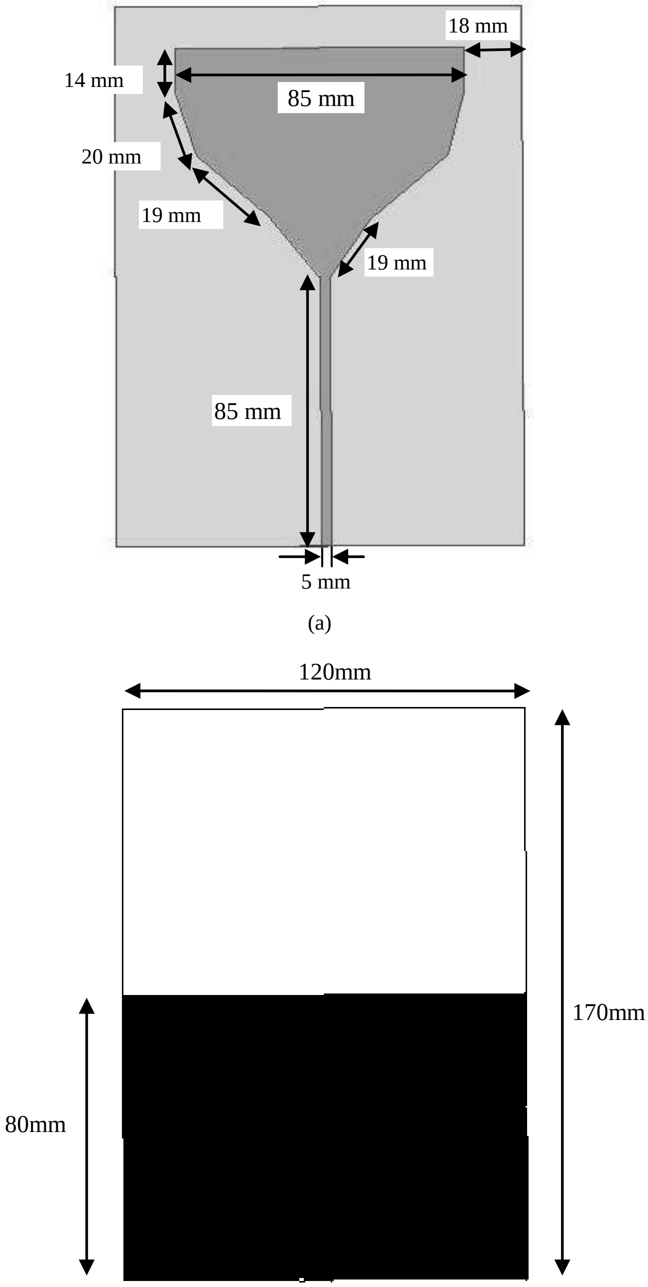

Fig. 2:. Proposed Wineglass Shaped Antenna (a) Front View (b) Back View

Figure 3 shows the fabricated TVWS antenna on ground plane side and wineglass shaped top patch structure to increase the bandwidth. In this design, the material used for fabrication of antenna is of thickness 0.035 mm with 1.6 mm (FR4 Substrate). The overall dimension of the antenna including the ground plane is 170 mm × 120 mm × 1.6 mm. A patch antenna for TVWS band has been designed using HFSS and antenna has been tested using VNA from Anritsu, model no: MS46322A.

(a) (b)

Fig. 3:. Fabricated Antenna (a) Front View (b) Back View

Compared to conventional patch antennas, the proposed antenna has ground plane on the half portion of the substrate leaving the rest of the substrate vacant for other device components.

3. Simulation Results of Proposed Antenna

High Frequency Structure Simulator (HFSS) is used to design the proposed antenna and simulate it. The design parameters include scattering parameter, Voltage Standing Wave Ratio (VSWR), gain and the radiation pattern. The efficiency of the proposed antenna obtained after the simulation is 95%.

3.1 Simulation Results of Basic Rectangular Microstrip Patch Antenna with DGS

3.1.1 Return Loss:

Figure 4 shows S_{11} parameter (return loss) for the basic patch antenna with DGS. The antenna resonates at 860 MHz having a value of -11.10 dB. Due to the use of DGS, the overall bandwidth of the basic patch antenna is 630 MHz This gives wideband operation to cover desired frequency band for TVWS applications. But return loss is not good and needs improvement

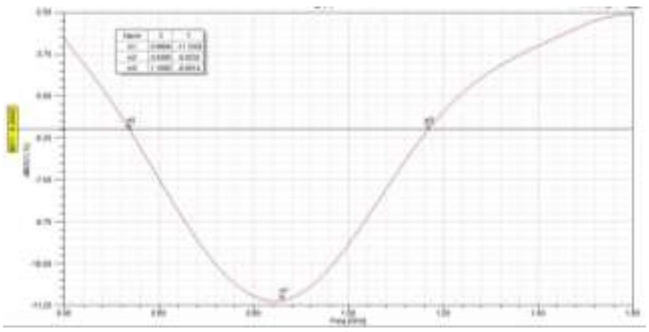

Fig. 4:. Simulated Return Loss S_{11} of Basic Patch Antenna with DGS

3.1.2 Voltage Standing Wave Ratio (VSWR):

Figure 5 indicates the VSWR of the basic patch antenna with DGS. It shows 4.96 dB VSWR at the resonant frequency. So it can be observed that VSWR is not within acceptable limits i.e. < 3 dB.

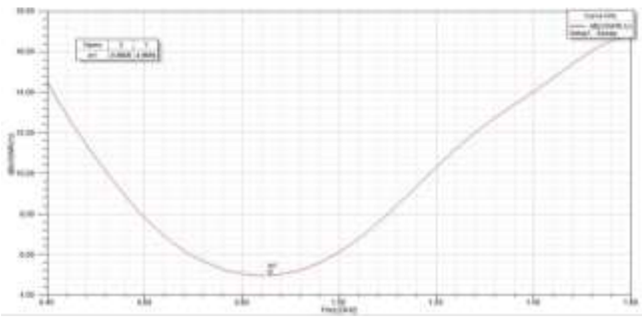

Fig. 5:. Simulated VSWR Plot of Basic Patch Antenna with DGS

3.1.3 Gain Plot:

From the Figure 6 the peak gain is 1.21 dB. In a particular direction, the gain of the antenna is more as compared to isotropic antenna radiating in all directions. Gain is enhanced as compared to basic patch antenna with the full ground plane.

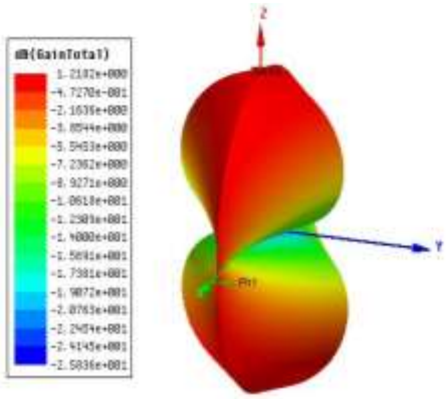

Fig. 6:. Simulated Peak Gain of Basic Patch Antenna with DGS

3.1.4 Radiation Pattern:

Fig. 7 shows the polar plot view of the radiation pattern. It can be seen that the radiation pattern obtained is Omni directional at the resonant frequency.

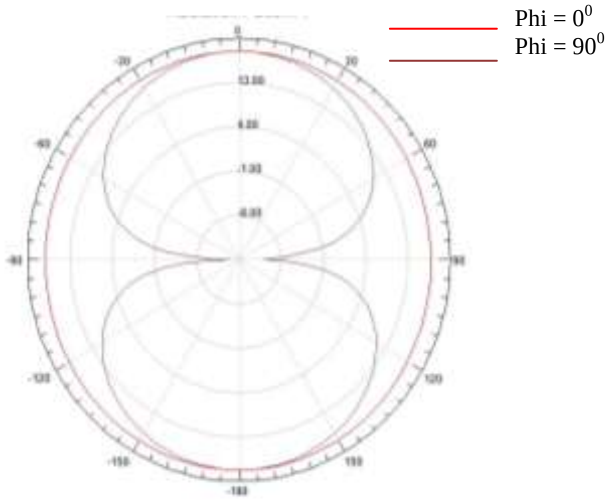

Fig. 7:: Simulated Radiation Pattern of Basic Patch Antenna with DGS (2D view)

3.2 Simulation Results of Wineglass shaped Patch Antenna with DGS for TVWS applications

3.2.1 Return Loss:

Fig. 8 shows S_{11} parameter (return loss) plot for the proposed antenna. Using lumped port configuration, S_{11} plot is obtained taking the level as -6 dB which is considered good for frequencies in UHF range. The proposed antenna resonates at 703 MHz with a return loss of -21.97 dB and covering frequencies from 495 MHz to

1540 MHz. Overall bandwidth coverage is 1045 MHz which is considered as wideband coverage.

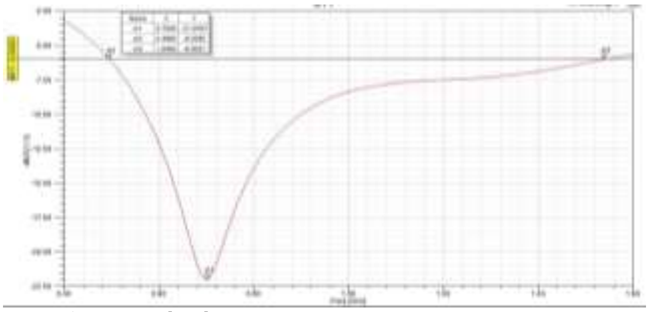

Fig. 8:. Simulated Return Loss S_{11} of Proposed Antenna [10]

3.2.2 Voltage Standing Wave Ratio:

Fig. 9 shows the voltage standing wave ratio (VSWR) of the proposed TVWS antenna. The VSWR ideally should be 1 dB and it should not exceed 3 dB. But practically VSWR is between 1 dB to 3 dB for most of the antenna types used in wireless devices. The VSWR obtained at 703 MHz is 1.38 dB.

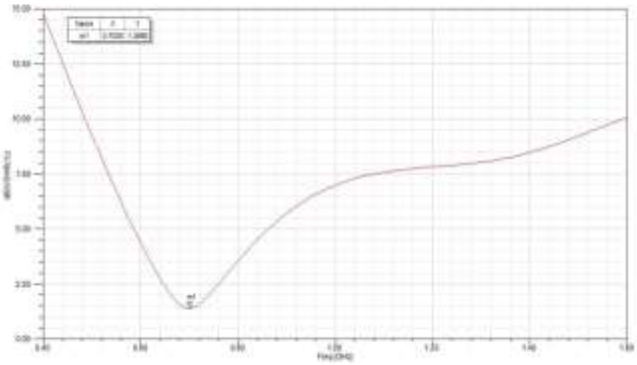

Fig. 9: Simulated VSWR Plot of the Proposed Antenna [11]

3.2.3 Gain Plot:

The proposed antenna shows peak gain of 2.32 dB which is considered excellent in terms of a compact antenna design for UHF range of frequencies. Figure 10 shows the 3D gain plot of the proposed wineglass shaped antenna.

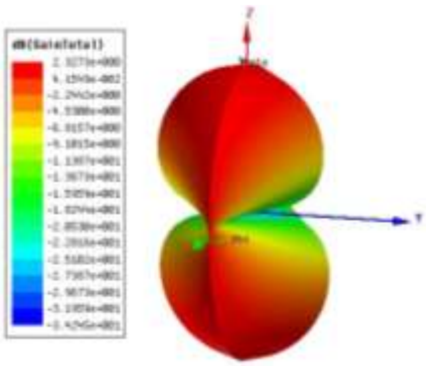

Fig. 10:: Peak Gain of the Proposed Antenna (3D view) [11]

3.3 Measured Results of Wineglass shaped Patch Antenna with DGS

Figure 11 and Figure 12 show the measured return loss and VSWR of the fabricated antenna respectively. A measured return loss of -20.20 dB is obtained at 596 MHz. It was found that the results have some variations and it covers TV UHF range with the overall bandwidth of 551 MHz.

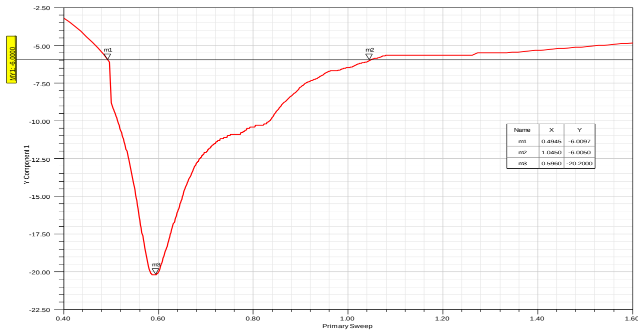

Fig. 11:. Measured Return Loss of the Fabricated Antenna

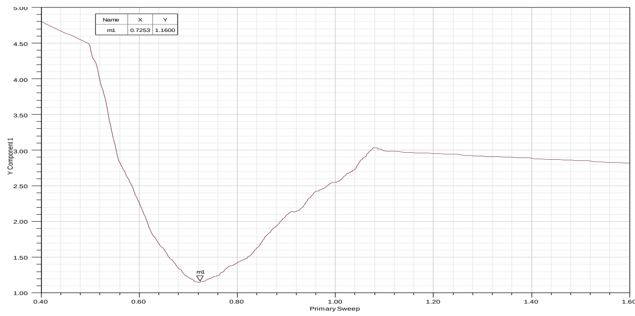

Fig. 12:. Measured VSWR Plot of the Fabricated Antenna

Comparison between simulated and measured results is given below as for proposed TVWS antenna.

Table 2:. Comparison between simulated results and measured results

Parameters	Simulated Results	Measured Results
Resonant Frequencies	703 MHz	596 MHz
Return Loss	-21.97 dB	-20.20 dB
Overall Impedance Bandwidth	1045 MHz	551 MHz

Fig. 13 shows the comparison between simulated and measured return loss. In the given Figure there occur some shifts between the results of simulated and fabricated antenna and these results are due to fabrication process.

Table 3:. Comparison of proposed antenna with antennas available for TVWS applications.

Parameters	Proposed Design	Design in [12]	Design in [9]	Design in [14]
Overall Size	120 mm x 170 mm	188 mm x 157 mm	160 mm x 170 mm	150 mm x 60 mm
Resonant Frequency	703 MHz	706 MHz & 940 MHz	510 MHz & 830 MHz	555 MHz
Return Loss	-21.97 dB	-13.5 dB & -12 dB	-19 dB & - 17.6 dB	-25.23 dB
Bandwidth (-6 dB level)	495 to 1540 MHz (1045 MHz)	63 MHz & 51.8 MHz	470 MHz to 1050 MHz (580 MHz)	535 MHz to 575 MHz (40 MHz)
Gain	2.32 dB	2.95 dB & -0.12 dB	2 to 4 dBi	1.95 dB
Radiation Efficiency	95 %	84 % & 74 %	Not clear	99.6 %

3.4 Result Validation:

Comparing proposed wineglass shaped antenna with antenna in [12], return loss and bandwidth are many times enhanced as well as efficiency. As compared with antenna from [9, 14], the proposed antenna shows larger bandwidth and gain. Antenna in [14] show highest efficiency, good return loss but the gain is low as compared to the proposed antenna also the bandwidth covered is very narrow. From the comparison of proposed antenna with [14], it is clear that if efficiency increases then the gain decreases. From the data given in table 3, it is clear that there is enhancement in bandwidth coverage, gain and efficiency of the proposed antenna. The proposed antenna is compact as compared to other antennas.

4. Conclusion

In this paper, a compact patch antenna for UHF TV range with enhanced bandwidth is designed and analyzed. The overall size of the proposed antenna is 170 mm x 120 mm x 1.6 mm. The simulated return loss plot in the result section shows resonance at 703 MHz having value of -21.97 dB. Simulated results show that the proposed antenna covers a bandwidth of 1045 MHz in UHF frequency range and beyond. There is a reduction in the size, improvement in the bandwidth, and gain of the proposed patch antenna with wineglass shaped patch and defected ground plane. Hence this antenna can be used for the TVWS applications. The physical parameters examined in this research include feed line and ground plane coupling. The antenna parameters like operating frequency, VSWR, bandwidth, return loss and gain are determined for the antenna configuration. Peak gain is 2.32 dB which is considered to be good for UHF TV applications. The antenna is fabricated on FR4 substrate and tested using Anritsu VNA. The measured result shows that the return loss is -20.20 dB obtained at resonant frequency 596 MHz. The overall bandwidth coverage is 551 MHz of the fabricated antenna. This is different from simulated values due to losses incurred by connector, soldering and other fabrication processes.

Future Scope

Various techniques can also be used in future to design antenna which are as follows:

- **Size reduction techniques**: Some methods can be employed to reduce the antenna size further using FSS or metamaterial structures.
- **Other feeding techniques:** the other feeding techniques of Microstrip patch antenna like probe feeding, aperture coupling and CPW can also be used in future to design Microstrip patch antenna.

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