Design of a low cost Television White Space Z Antenna

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Abstract: The use of Television White Spaces (TVWS) for broadband communication has raised interest of late. In respect of rural areas, wireless is the only viable alternative for providing affordable telecommunications services. One limiting factor to the growth of wireless broadband penetration is the lack of available spectrum. White Spaces refer to regions of radio spectrum that are not used all the time in a specific geographical location. An assessment study on TV White Spaces availability in Malawi using affordable tools has been described and it was concluded that it is possible to assess the spectrum usage using low cost equipment. In this paper, the design aspects and the measured results of a low cost Television White Space Z antenna are described.

Keywords: Broadband, TVWS, UHF, Electric Gain, VSWR

1. Introduction

An Antenna is an important component of any wireless communication system. Properly designed antennas improve the overall performance of any radio or wireless system. Of great importance to note is that the rapid advancement in the wireless communication field in the past few decades has led to the development of more efficient antenna design to be deployed in various cutting edge applications. A good number of such applications require minimal weight, low cost, low profile antennas which have got the capability of delivering high performance over a wide range of frequency [1]. Now TVWS finds many applications in various areas such as e-health, education, security operations, and seismology to mention but a few [2].

TVWS is perceived to be a low cost solution for providing Internet hence a need to ensure that most components are affordable. Although the first paper on TVWS affordable tools was published in 2012 [3], it has taken considerable amount of time to publish another paper focusing on low cost TVWS components and tools. It should further be noted that several papers have been published on antennas [4 – 8], but very few papers provided an analysis of practical application aspects. In this paper, the authors have attempted to design a simple antenna useful for TVWS application.

The rest of the paper is organized as follows. Design aspects of a TVWS UHF antenna are presented in Section 4 while Section 5 presents realization and simulation results. Conclusions are finally drawn in Section 7.

2. Objectives

The main objective of this paper is to present an innovative TV White Space low cost antenna solution which has got a Z shape and simulation results as well as radiation patterns of the antenna.

The target audience of this paper is Engineers who are intending to venture into antenna manufacturing using low cost materials. These Engineers will learn antenna design techniques using simple locally found materials thereby facilitating mass production and availability of affordable equipment.

3. Methodology

The design of a low cost TVWS Z antenna is proposed to minimize the cost of TVWS infrastructure. This is a practical antenna which has been fabricated and tested for functionality at 554 MHz where the antenna has 50 Ohm impedance and matches with the TVWS communication central frequency (550 – 558 MHz).

The proposed antenna is designed using wires. In such a case, a wire can assume any shape depending on the bandwidth and gain requirements, apart from profile demands i.e. low or high. The authors were inspired with the design of a Z antenna that was used for dual band GSM applications (900 and 1900 MHz) and the body area network communication at 400 MHz [9]. The difference with the Z antenna proposed in this paper is that, the one in [9] was based on fractal geometry solved by methods of moments (MoMs) and also that the applications are different.

4. Technology description

Design of a TVWS UHF Z-Antenna

It is paramount to note that there is an incredible range of technology options that facilitate reuse of spectrum without disturbing the incumbent operator, including not only cognitive radios as well as tolerant coding, but also smart antennas that reduce interference. TV White Spaces offer essentially a family of new approaches to rural connectivity and for ongoing innovation along the lines of WiFi and other novel solutions.

Architectural antenna design is of great importance in modern wireless communication systems and hence its design optimization is an important aspect for improving the overall performance of a TVWS network. The antenna design aspects will focus on the Antenna geometry and specifications.

4.1 Antenna Geometry

The TVWS UHF Z-Antenna is primarily a wire-type dipole antenna whose geometry is as shown in figure 1 below.

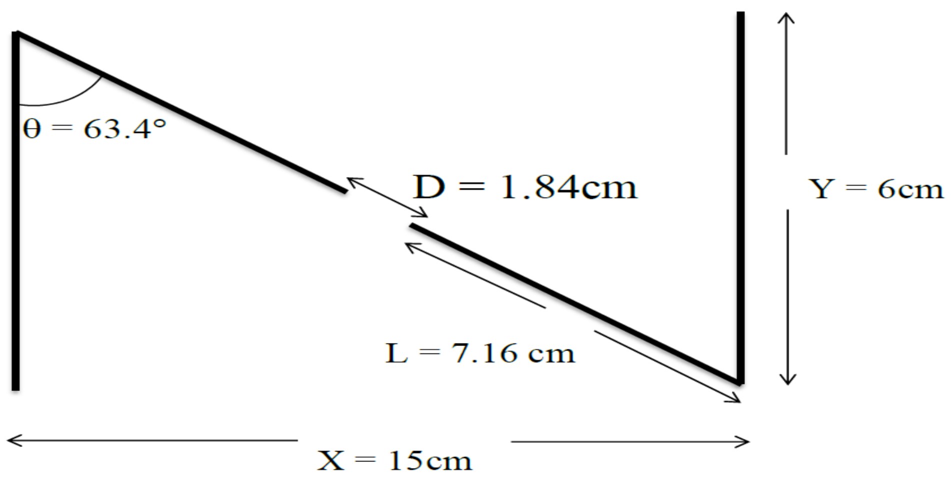

Figure 1: *Geometry of the Z-Antenna, where X and Y are orthogonal.*

From the geometric presentation in figure 1 above, the dimensions of the TVWS UHF Z-Antenna includes; dimension X = 15 cm and Y = 6cm. The feed gap which is represented by D = 1.84 cm as well as the diagonal which is computed as: 2L + D = 2(7.16 cm) + 1.84 cm = 16.16 cm.

4.2 Specifications

The TVWS UHF Z-Antenna is constituted of two un-insulated copper wires , each of which is 13.6 cm long (with a diameter of 2.08mm) and sharply bent at a length of 6 cm from one end at an angle of 63.4°, which are horizontally aligned in the *xy-plane* so as to give a Z shape; thus its name. The antenna has two connecting terminals at its feed point, one of which is the signal line while the other one is the ground, with a feed gap of 1.84 cm. The connecting wire at the feed point is the standard coax cable suitable for TV signals.

5. Results and Discussion

Analysis and optimization of the TVWS UHF Z-Antenna was facilitated by antenna design and simulation software called EMCoS Antenna VLab (Student version). The design and analyses parameters to be presented include the input scatter parameter, S11 (return loss); voltage standing wave ratio (VSWR); input impedance, electric gain and radiation pattern. The first three parameters relate to the bandwidth and input characteristics of the antenna useful for matching purposes to the radio equipment. The last two parameters relate to the radiation performance and directivity of the antenna with respect to over the air (OTA) communication.

5.1 Return loss dB [S11]

The optimized Z-Antenna has a minimum return loss of -25.2387 dB with a centre frequency (i.e. resonance frequency) of 555.0 MHz as shown by the graph in figure 2 below.

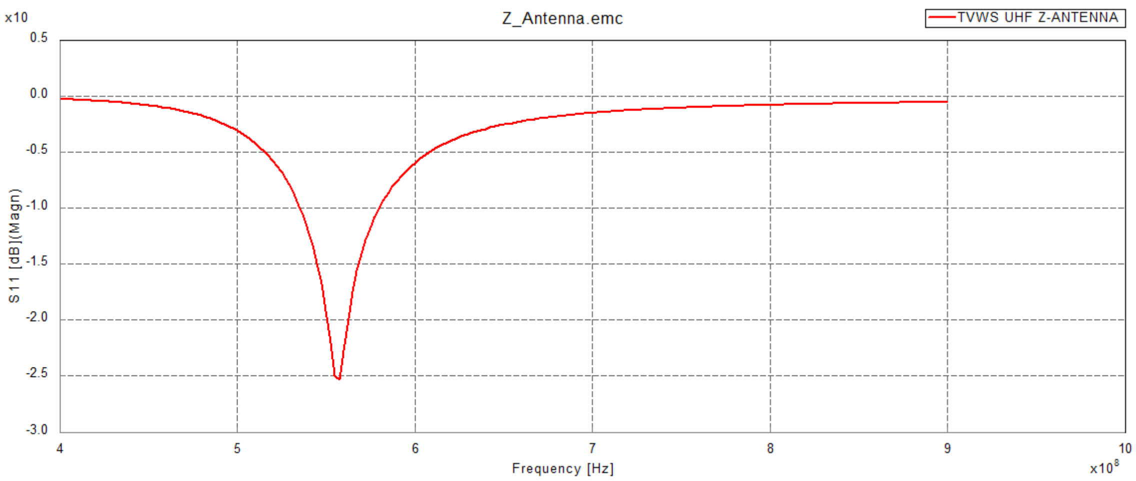

Figure 2: *Return loss plot of the TVWS Z-Antenna [S11 against frequency]*

From the graph in figure 2, the S11 simulation results (in dB) shows that the antenna covers a bandwidth of 13.7 MHz which ranges within the UHF band from a lower cut-off frequency of 549.8 MHz to a higher cut-off frequency of 563.5 MHz and is adequate for the single channel TVWS radio network deployed in Malawi for the pilot study.

5.2 Voltage Standing Wave Ratio (VSWR)

In general VSWR is a parameter that numerically measures how well is the antenna's impedance matched with either the electric circuit (i.e. the transmitter or receiver) or the transmission line to which it is connected to. Figure 3 shows the plot of VSWR as a function of frequency for the TVWS UHF Z-Antenna.

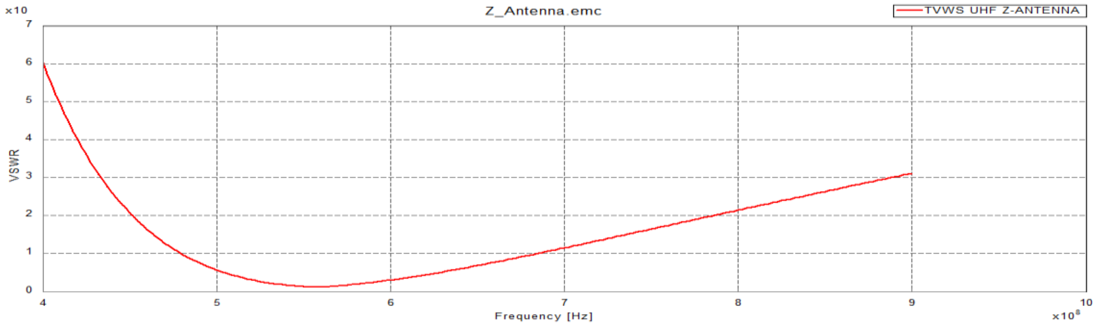

Figure 3: *Plot of VSWR against frequency*

The plot of VSWR against frequency, in figure 3 above shows that the TVWS UHF Z-Antenna has a VSWR value of 1.11 at a resonant frequency of 555.0 MHz which is tolerable in the designing of such antennas.

5.3 Input impedance

Another parameter of interest is the input impedance of the antenna. The plot of impedance against the frequency of operation for the TVWS UHF Z-Antenna is shown in figure 4 below.

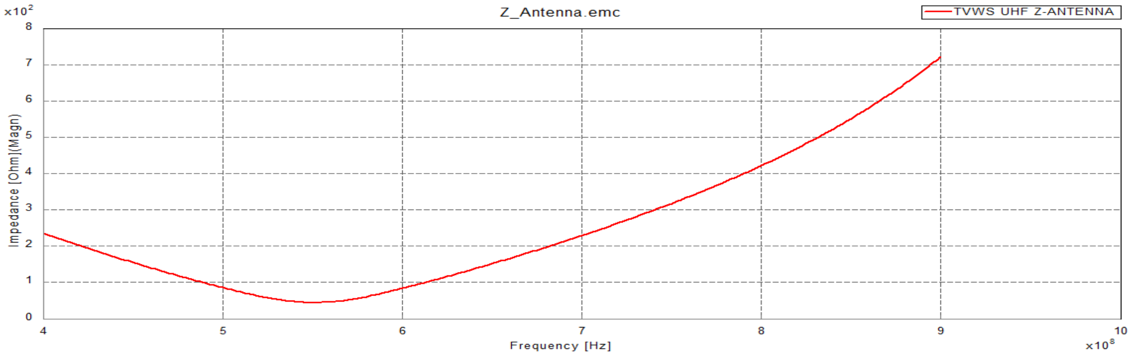

Figure 4: *Plot of impedance against frequency*

From the graph in figure 4 above, it has been shown that at the resonant frequency of 555.0 MHz the designed TVWS Z-Antenna has an impedance of 44.9 Ω which is ideally a better value for achieving impedance matching for typical microwave band radios and spectrum analyzers. In the case of television 75 Ω is the standard characteristic impedance. So, if strictly required, achieving 75 Ω impedance, given a 50 Ω antenna, some impedance transformation is required and it is easy to do even with lossless microstrip lines.

5.4 The Gain

The gain of an antenna describes how much power is transmitted in the direction of peak radiation to that of an isotropic source. This is to say that gain takes into account the actual power losses that occur on the antenna. Typically, the higher the gain, the more efficient the antenna's performance and the further the range (i.e. coverage distance) of the antenna. Thus for every 6 dBi in gain, you double the range of the antenna. The figure below shows the gain (in dB) of the Z-Antenna at different operating frequencies.

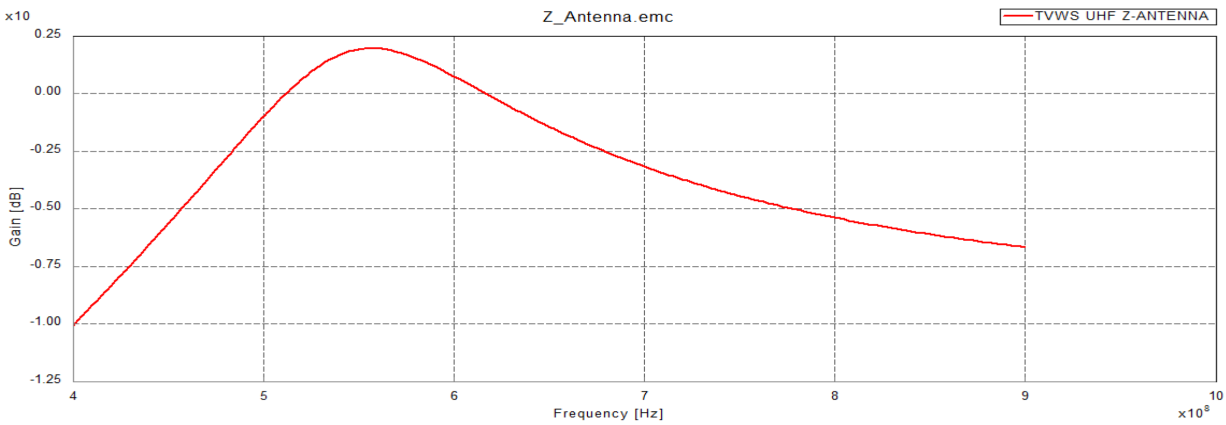

Figure 5: *Plot of gain (dB) against frequency*

As shown on the graph of gain against frequency in figure 5 above, the maximum gain of the TVWS UHF Z-Antenna was found to be 1.95 dB at an exact frequency of 555.0 MHz. From this observation, it can then be concluded that the Z-Antenna exhibit optimum performance at the stated frequency (i.e. at 555.0 MHz).

5.5 Radiation Patterns

In antenna theory, the radiation pattern basically refers to the graphical depiction of the relative field strength transmitted from or received by the antenna. It actually defines the variation of the power radiated by an antenna as a function of the direction away from the antenna. This power variation as a function of the arrival angle is observed in the antenna's far field. The figures below show the simulated results for the total field radiation patterns of the TVWS UHF Z-Antenna at an angle of 90° for three different frequencies (550, 555 and 560 MHz).

The radiation patterns displayed by figure 6 (a), (b) and (c) indicate that the total electric field gain for the designed TVWS UHF Z-Antenna at theta = *90°* is 1.8339 dB, 1.8753 dB and 1.8682 dB for the frequencies 550.0 MHz, 555.0 MHz and 560.0 MHz respectively. The simulation results, as seen from the radiation patterns below, clearly shows that the resonant frequency (i.e. 555.0 MHz) of the Z-Antenna has the maximum possible gain for the design.

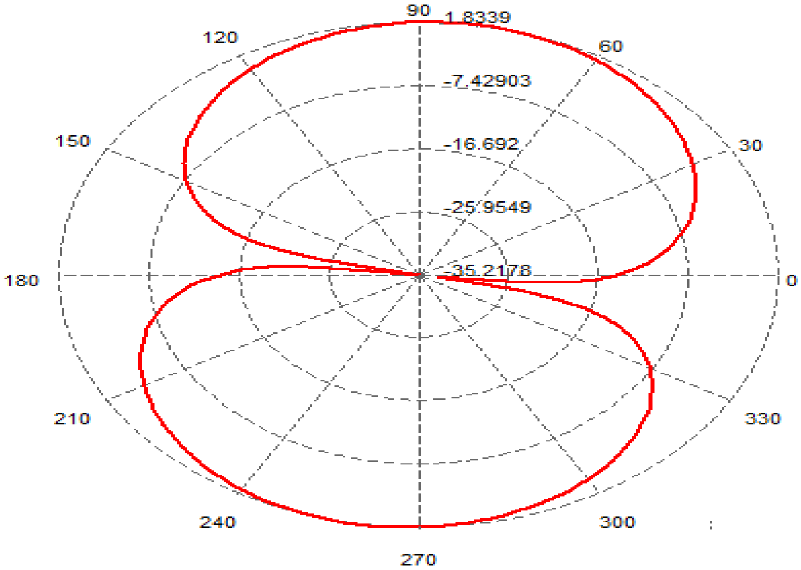

Figure 6 (a): *Total electric gain (in dB) vs. theta = 90° at 550.0 MHz*

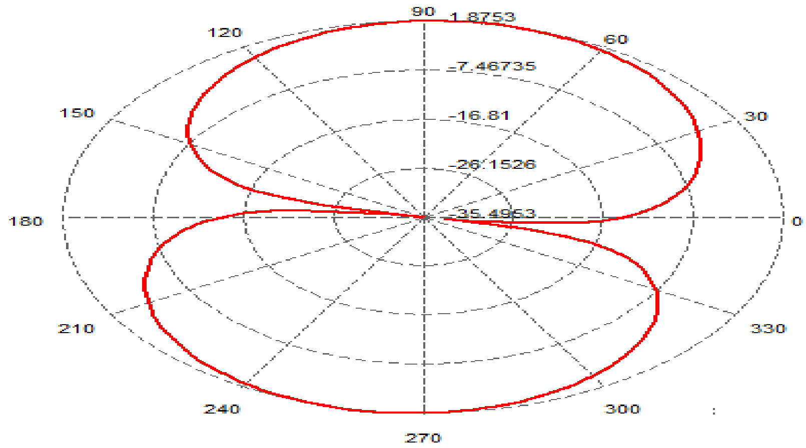

Figure 6 (b): *Total electric gain (in dB) vs. theta = 90° at 555.0 MHz*

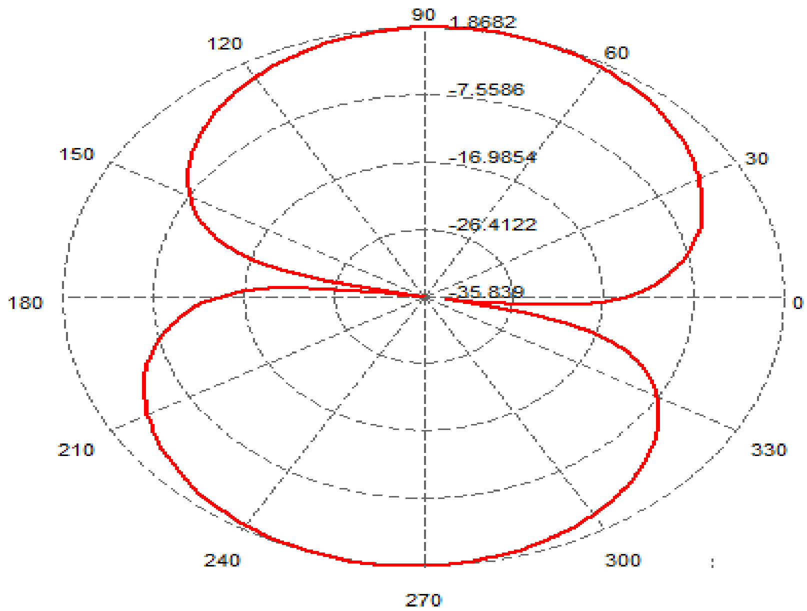

Figure 6 (c): *Total electric gain (in dB) vs. theta = 90° for a frequency of 560.0 MHz*

6. Business Motivation

In accordance with ITU statistics, household level Internet penetration is approximated at 77% in Europe as compared to Africa which is sitting at 7%. The key contributing factors for this digital divide are the limited distribution of basic Internet infrastructure and the high cost of access rendering unaffordability of services in continents like Africa, where the price of a computer-based broadband plan with 1 GB of data volume represents on average more than 50% of GNI per capita. In respect of comparative analysis, the figure is 2% in Europe [10].

Many countries in Africa like South Africa and Malawi have expressed early interest in TVWS technology hence trials have been conducted in areas such as Cape Town, Limpopo Province and Zomba district [11]. The business motivation for conducting this research work was centred on proliferation of TVWS trials in many African countries and the fact that the signals in the TV region of the spectrum have much longer ranges than those currently used for WiFi. This implies that there will be increased efficiency in the sense that fewer base stations will be required for the same coverage yielding better services at lower costs.

In addition, it is in rural areas of developing countries where the benefits of leveraging this technology is apt to cause the greater impact helping to alleviate the Digital Divide [12].

7. Conclusion

TV White spaces can help to improve Internet access across Africa and other developing regions. This can be achieved by reducing internet access costs whereby Internet service providers who are able to make innovative use of spectrum can assist to create more competition in markets for Internet access. The second aspect is providing more ubiquitous access whereby lower radio frequencies utilised by TVWS are able to reach long distances as opposed to high frequencies which are less cost-effective. The final aspect is providing reliable access whereby TVWS could be complemented by a WiFi connection.

The design and development of radio frequency (RF) equipment still remains one of the critical aspects of effective and efficient radio communication. This paper demonstrated the design of a low cost TVWS UHF Z-Antenna for the purposes of reception at client's side. The antenna is characterized by a Z shaped geometry, in the *xy-plane*, which is made out of copper wire with a diameter of about 2.08 mm. Various radiation properties such as S11, input impedance and VSWR were also considered and plotted on graphs as functions of frequency with the aid of EMCoS Antenna VLab (Student version). It has been clearly shown that the Z-Antenna has high efficiency of 99.6 % at a resonant frequency of 555 MHz with a gain of 1.875 dB and an optimum bandwidth of 13.7 MHz.

In future, the authors plan to increase the bandwidth by exploiting the fractal geometry or super-symmetry self-similar techniques of the antenna.

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