Journal of Information Engineering and Applications
ISSN 2224-5782 (print) ISSN 2225-0506 (online)
Vol.4, No.12, 2014
www.iiste.org

Yagi-Uda Antenna Gain Improvement for Enhanced Reception of DVB-T2 Signals

Lusekelo Kibona Anael Sam
School of Computational and Communication Sciences and Engineering (CoCSE),Nelson Mandela African Institution of Science and Technology (NM- AIST).,P.O BOX 447,Arusha, Tanzania
kibonal@nm-aist.ac.tz; anael.sam@nm-aist.ac.tz

Abstract

Yagi-Uda Antenna is a widely used roof top DVB-T2 receiver antenna due to its high forward gain capability, low cost and ease in construction. In Tanzania, there have been some complaints which were logged to Tanzania Communications Regulatory Authority (TCRA) by the customers on the poor reception of DVB-T2 signals which may be caused by signal degradation. In this paper we propose enhancement of the gain of the Yagi antenna so as to improve the reception signals of the DVB-T2. This will help solve those complaints. It is well known that the increase in radiation pattern causes the increase in directivity and hence gain which will have an impact on good quality of reception for DVB-T2 signals coming from the transmitter. After carefully design and simulation in FEKO simulating software by adding the number of director elements and making some adjustments on the length and spacing between the elements, we managed to increase the gain of the antenna by 4.7dB. This is significant improvement of the quality of received signals.

Keywords: DVB-T2, Yagi Uda antenna, Set Top Box (STB), antenna gain, Directivity, Wavelength, Electric field strength, Signal reception, Radiation pattern.

1. INTRODUCTION

An Antenna is a device which is used to transmit and receive the electromagnetic waves, converting them into electric currents and vice versa. The radiation capabilities of an antenna are characterized by the characteristics of an antenna such as the radiation pattern (including amplitude and phase patterns), polarization and gain. All these quantities are measured on the surface of a sphere with a constant radius. The radiation pattern is nothing but a graph which shows the variation of actual field strength of electromagnetic field at all the points equidistant from the antenna.

As a receiving antenna, antenna gain describes how well the antenna converts radio waves arriving from a specified direction into electrical power[1]. Although the gain of an antenna is directly related to its directivity, antenna gain is a measure that also takes into account the efficiency of the antenna, that is, the fraction of the input power dissipated in losses such as resistance. In contrast, directivity is defined as a measure that takes into account only the directional properties of the antenna and therefore it is only influenced by the antenna pattern. However, if we assumed an ideal antenna without losses then antenna gain will equal directivity as the antenna efficiency factor equals 1 (100% efficiency). Therefore, for real antennas, the gain of an antenna is always less than its directivity[2].

A directional antenna or beam antenna is an antenna, which radiates greater power in one, or more directions allowing for increased performance on transmit and receive and reduced interference from unwanted sources. Directional antennas like Yagi-Uda antennas provide increased performance over dipole antennas when a greater concentration of radiation in a certain direction is desired.

DVB-T2 is the second generation of the digital terrestrial television broadcasting system which transmits composite (compressed digital audio and video) signal and other data in an MPEG-4 transport stream, using coded orthogonal frequency-division multiplexing (COFDM or OFDM) modulation. DVB-T2 uses multiple MPEG-4 transport streams and have enhanced FEC and higher QAM (256-QAM) constellations. Tanzania switched from analogue to Digital Video Broadcasting Terrestrial second generation (DVB-T2) in 2013, since the official switching there has been complaints from the DVB-T2 users on the coverage and quality of service provided. In this paper we evaluated the DVB-T2 performance and make the recommendations on the ways to optimize the performance. Through measurements it has been observed that, the quality of coverage in some areas (locations) is poor, so to improve the received signal strength coverage and quality we recommend the use of enhanced Yagi-Uda antenna gain [3].

DVB-T2 uses Yagi antenna as the receiving antenna in most of the areas in the country (Tanzania), but in some places it suffers as the signal reception becomes poor and this may be due to low gain of the antenna or the poor coverage in the areas. So the aim of this paper is to enhance the gain of the antenna so as to improve the reception signal and hence have good quality of reception.

A Yagi-Uda array, commonly known simply as a Yagi antenna, is a directional receiving antenna consisting of a driven element (typically a dipole or folded dipole) and additional parasitic elements (usually a so-called *reflector* and one or more *directors*) and it is mostly used in DVB-T2 broadcasting network. The reflector element is slightly longer (typically 5% longer) than the driven dipole, whereas the so-called directors are a little shorter. This design achieves a very substantial increase in the antenna's directionality and gain compared to a simple dipole[4].

DVB-T2 transmitting antenna used in Tanzania by different multiplexers have the following specifications:

a) Frequency range 470-697MHz
b) VSWR <1.12
c) Gain (reference to λ/2) 11dB at mid-band
d) Impedance 50ohms
e) Maximum transmit power 3kW
f) Polarization Vertical polarization but in some areas horizontal polarization is also used for example, Star Media Limited they have set horizontal polarization in Arusha and Moshi with maximum transmit power in those regions being 0.8kW

Note: Vertical polarization covers the large area compared with the horizontal polarization that's why for small coverage region the horizontal polarization is better than vertical polarization. So with these specifications of the transmitting antenna, the good reception antenna having high receiving gain will have the very good quality of reception.

Special configuration (long reflector and short directors) has made the Yagi–Uda antenna radiate as an end-fire antenna. The simplest three-element Yagi–Uda antenna (just one director) already shows an acceptable end-fire antenna pattern. The radiation towards the back seems to be blocked/reflected by the longer element, but not just by the reflector; the reflector and director produce push-and-pull effects on the radiation. Induced currents are generated on the parasitic elements and form a traveling wave structure at the desired frequency. The performance is determined by the current distribution in each element and the phase velocity of the traveling wave[5].

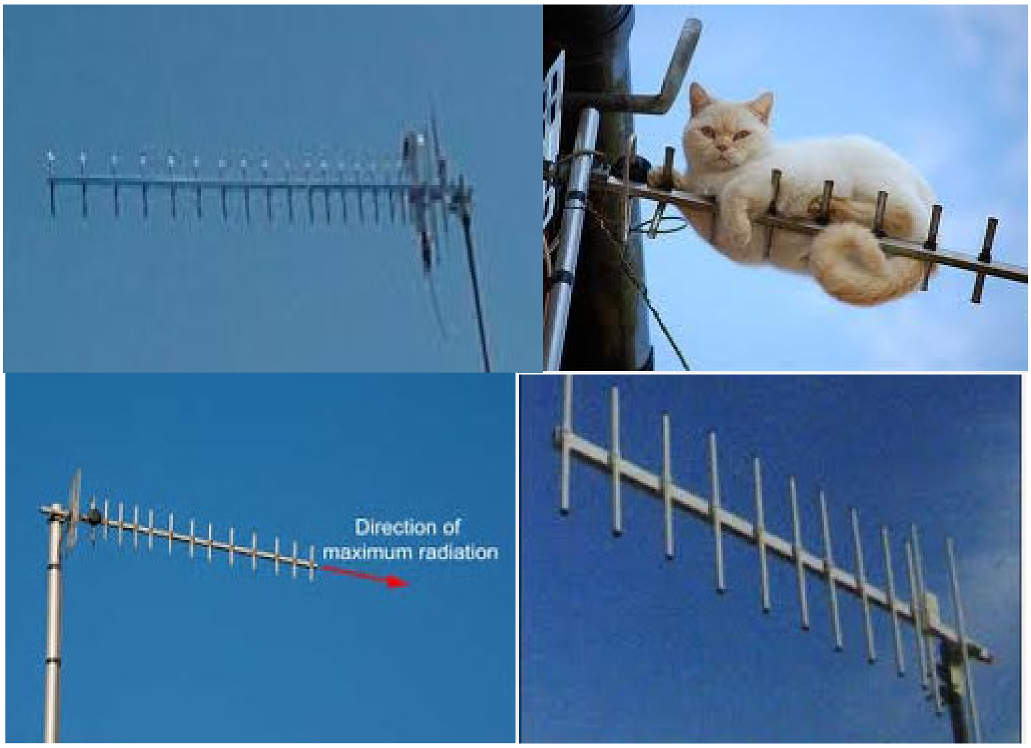


Figure 1: Different diagrams of Yagi-Uda antennas which can be placed on the roof.

2. BACKGROUND AND LITERATURE SURVEY

The bandwidth of a Yagi-Uda antenna refers to the frequency range over which its directional gain and impedance match are preserved to within a stated criterion. The Yagi-Uda array in its basic form is very narrowband, with its performance already compromised at frequencies just a few percent above or below its design frequency. However, using larger diameter conductors, among other techniques, the bandwidth can be substantially extended[6].

There are no simple formulas for designing Yagi-Uda Antenna due to the non-linear relationships between physical parameter such as element length, diameter and position and electrical characteristics such as input impedance and gain, but performance can be estimated by computer simulation[7, 8].

To achieve a good Yagi- Uda antenna design, several population based optimization techniques are extensively used to optimize its sensitive physical dimensions resulting in desirable current distributions. Genetic algorithm (GA) is firstly adopted for the optimal design of Yagi-Uda antennas[9]. In another attempt, Venkatarayalu and Ray solved the Yagi-Uda antenna optimization problems using computational intelligence (CI) method[10].

Other evolutionary algorithms such as the comprehensive learning particle swarm optimization (CLPSO) and biogeography based optimization (BBO) method are also introduced for the optimal design of Yagi-Uda antennas[11, 12].

As discussed by [13];A modified two-element Yagi-Uda antenna with tuneable beams in the H-plane (including four significant beams: forward, backward, omni-directional, and bi-directional beams) is presented. These tuneable beams are achieved by simply adjusting the short-circuit position of the transmission line connected to the parasitic element.

According to [14]; An analytical method is developed for the maximization of the directivity of a Yagi-Uda array by adjusting the lengths of the dipole elements. The effects of a finite dipole radius and the mutual coupling between the elements are taken into consideration. Currents in the array elements are approximated by three-term expansions with complex coefficients that convert the governing integral equations into matrix equations. Array directivity is maximized by a perturbation procedure that adjusts the lengths of all array elements simultaneously and that converges very rapidly.

3. CONCEPTS AND THEORY

Main feature of this type of antenna is that, it consists of three different elements: the driven element, reflector and director, as shown in figure 1 below. Some people consider the Yagi–Uda antenna an array, since it has more than one element. However, it has just one active element and feed port; all the other elements (the reflector and directors) are parasitic. Thus, some people consider it an element antenna rather than an antenna array[5].

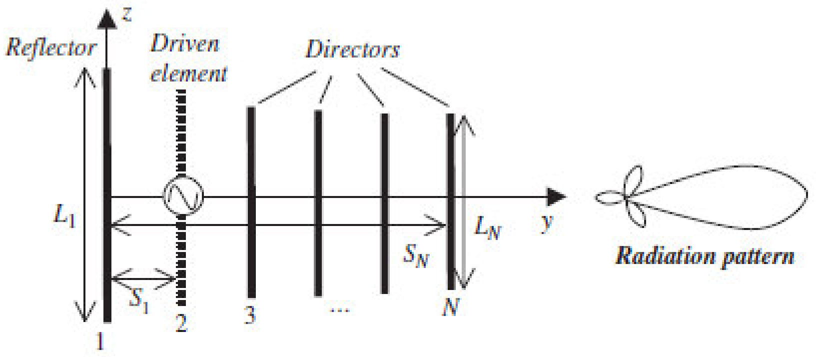


Figure 2: A diagram of a Yagi- Uda Antenna as the courtesy of [5]

Active element of a Yagi-Uda antenna consists of a dipole whose length is λ/2 where λ is the operating wavelength. The parasitic elements consist of one reflector and few directors. Length of the reflector is greater than λ/2 and is located behind the active element. The length of each director is less than λ/2 and they are placed in front of the active element. Spacing between the each element is not identical and it can be considered as a non-linear array. The number of directors in the antenna depends on the gain requirements[15].

The following are the common features of Yagi antennas[16]:

- Yagi-Uda antenna consists of a driven element, a reflector and one or more directors.
- The active element is a folded dipole which has a length of λ/2 and it is at resonance.
- Length of director is less than λ/2 and length of reflector is greater than λ/2.
- Its radiation pattern is almost uni-directional.
- Reflector resonates at a lower frequency and director resonates at a higher frequency compared to that of a driven element.
- More directors can be added to increase the gain. In this case, directors can be of equal length or decreasing slightly away from the driven element.
- The mutual impedance of the antenna depends on the spacing and the length of the elements.
- Highest gain is obtained when the reflector is slightly greater than λ/2 in length and space at λ/4 from the driven element and when the length of director is about 10% less than λ/2 with an optimal spacing of λ/3.

- The reflector spacing and size have negligible effects on the forward gain and large effects on backward gain and input impedance.
- The maximum gain of a Yagi-Uda is limited to an amount given approximately by the gain of a dipole times the total number of elements.

Several critical parameters affecting the antenna's performance are directivity, gain, electric field intensity, resonant frequency, impedance, gain, aperture or radiation pattern, polarization, efficiency and bandwidth.

The current distribution on the driven element is determined by its length, frequency and interaction/coupling with nearby elements (mainly the reflector and first director), while the current distribution in parasitic elements is governed by the boundary condition: the total tangential electric field must be zero on the conducting surface. This results in induced currents and they may be viewed as the second sources of the radiation[5]. Antenna characteristics are controlled by the currents distributed on the driven element as well as those induced on the parasitic elements through electromagnetic coupling[17].

The following are the relations representing the radiation pattern, directivity, and gain for the Yagi antenna.

Radiation pattern for n-elements is given by:

$$E(\theta)_n = j\eta \frac{I_n e^{j\beta r}}{2\pi r}\left(\frac{\cos(\beta l_n \cos\theta)-\cos(\beta l_n)}{\sin\theta}\right) \qquad ---------(1)$$

Where $I_n = Maximum\ current\ flowing$

$l_n = half\ the\ length\ of\ the\ nth\ dipole$

Thus the total radiation electric field intensity pattern of the Yagi antenna is the field superposition from all elements and is given by:

$$E(\theta) = j\eta \frac{e^{j\beta r}}{2\pi r}\sum_{n=1}^{N} I_n \left(\frac{\cos(\beta l_n \cos\theta)-\cos(\beta l_n)}{\sin\theta}\right) e^{(j\beta S_{n-1}\cos\theta)} \qquad -------(2)$$

The directivity of the Yagi is given by:

$$D = \frac{4\pi U(\theta,\emptyset)}{\int_0^{2\pi}\int_0^{\pi} U\sin\theta \, d\theta \, d\emptyset} = \frac{4\pi U(\theta,\emptyset)}{\oiint U d\Omega} \qquad -----------(3)$$

$$Gain\ G = \frac{4\pi U(\theta,\emptyset)}{P_{in}} = \frac{P_t}{P_{in}} \times D = n_e \times D$$

Where U= radiation intensity found on equation (4) above.

$$n_e = radiation\ efficiency\ factor\ of\ the\ antenna = \frac{P_t}{P_{in}}$$

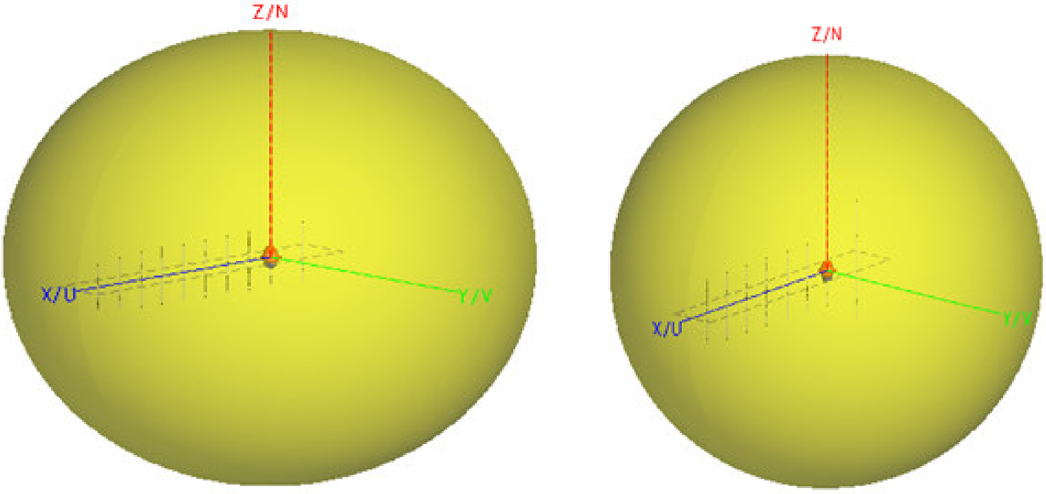
Pt=Total radiated power by antenna
Pin=Total input power accepted by antenna

But the maximum directivity of the Yagi antenna is limited to:

$$D = 3.28 * N$$

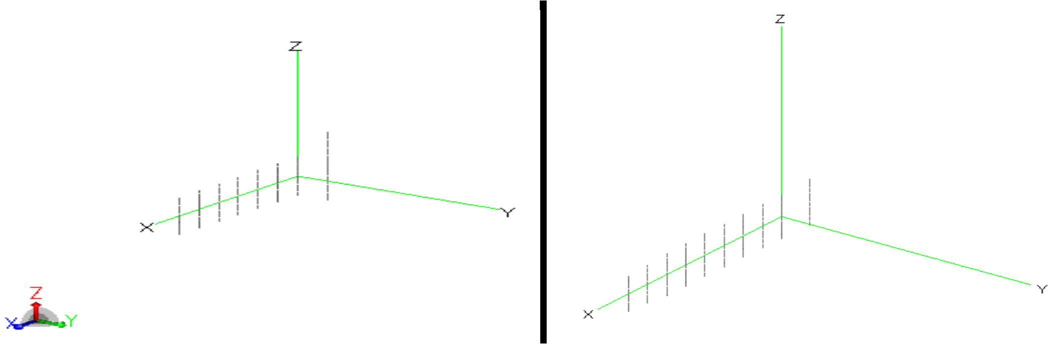
4. METHODOLOGIES

A Yagi antenna having 10 elements (8 director elements, 1 reflector element and 1 driver element or active element) were constructed in Antenna Magus and simulated in a FEKO simulating software in which the reflector length of the Yagi used was 0.2375 λ, and the driven element length was taken as 0.2265 λ and the director elements lengths were 0.2230 λ, 0.2230 λ, 0.221 λ,0.221 λ, 0.221 λ, 0.215 λ, 0.2 λ and 0.18 λ respectively for 8 directors and the spacing between the reflector and the active element (driven element) was 0.3 λ and that of active element and the first director was 0.2 λ while the spacing between the directors for the optimized Yagi was taken to be 0.2 λ The center frequency used was 574MHz. These elements are usually parallel in one plane, supported on a single crossbar known as a boom.



(a) (b)

Figure 3: (a) A diagram showing the 10 elements (8 directors) and (b) A diagram showing 8 elements (6 directors) elements of the Yagi antenna after being meshed in a FEKO software.



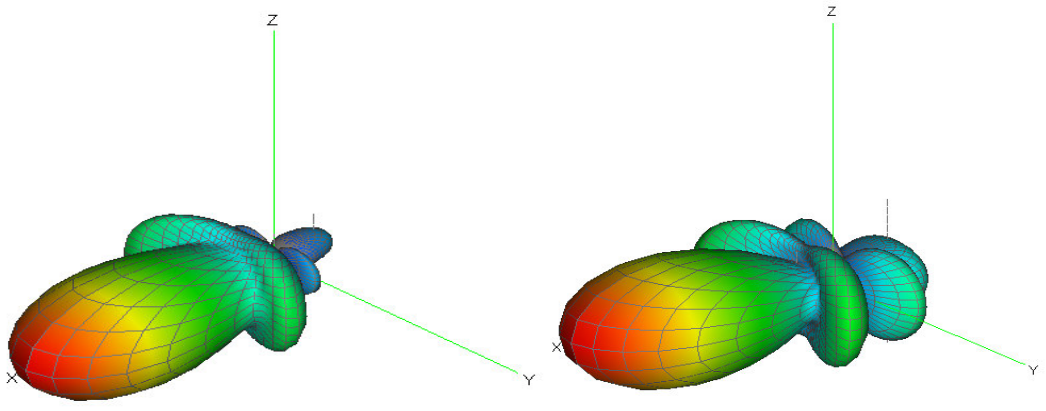
(a) (b)

Figure 4 :(a) a 3-D full plot of the Yagi Uda Antenna with 8 elements directors (b) a 3-D full plot for 10 element Yagi antenna as seen in Postfeko

The parameters of the Yagi Uda antenna 8 elements are the ones which are currently used by different multiplexers in Tanzania including Star Media whose frequency range for their receiving antenna lies between 562MHz to 730MHz. The length of the reflector element is 0.4 λ, the length of the active element is 0.2265 λ which is the same as that used in the optimized Yagi with 10 elements. In figure 4 (b) above the length of the reflector element is shorter compared to the length of the reflector element of diagram in figure 4 (a) which brings some effects on the radiation pattern of the antenna as discussed below.

5. RESULTS AND DISCUSSION

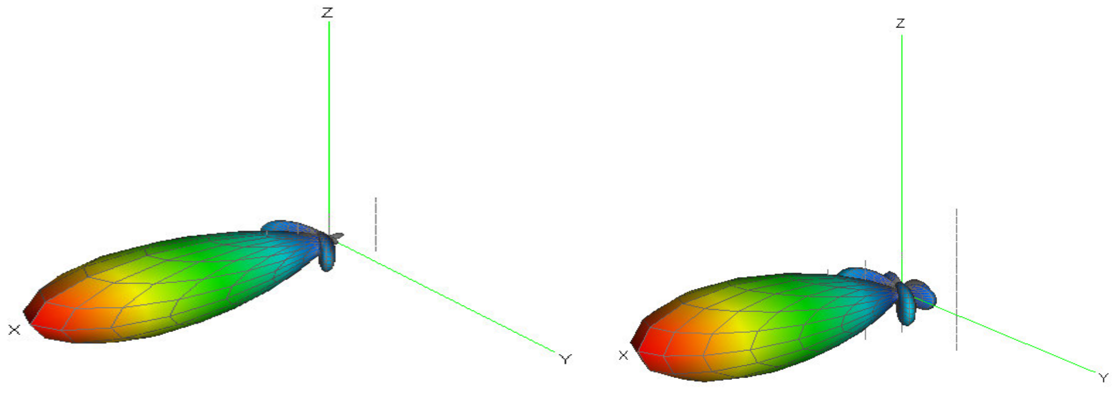
The following are the results after careful simulation in a FEKO simulating software in which the length of the director elements and the spacing between them were carefully defined.



(a) (b)

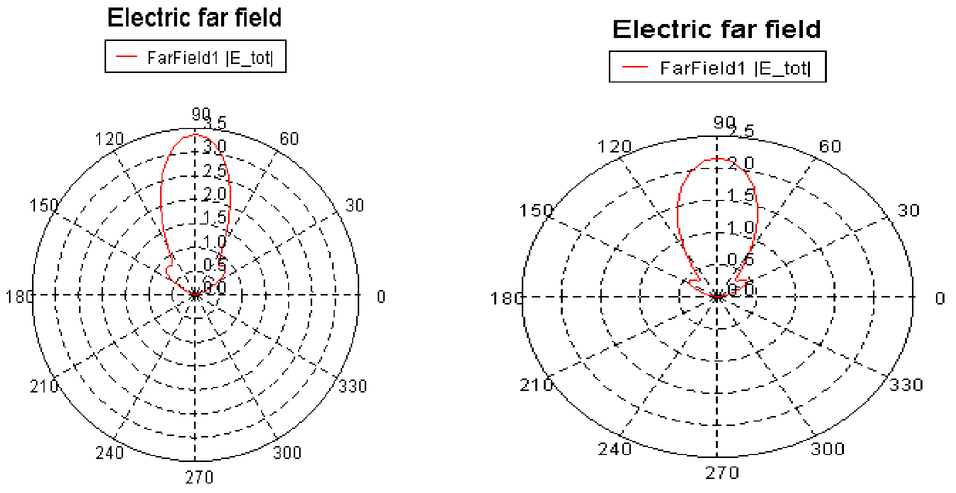
Figure 5 :(a) a 3-D radiation pattern plot of the Yagi Uda Antenna with 10 elements (b) with 8 elements.

As it can be seen in the figure above the radiation pattern of the antenna with 8 elements has been affected by the back side lobe leakage of the pattern while that with 10 elements and carefully defined reflector length has small effects of the radiation pattern as most the pattern are directed towards the main lobe which will have impact on the directivity and hence gain.



(a) (b)

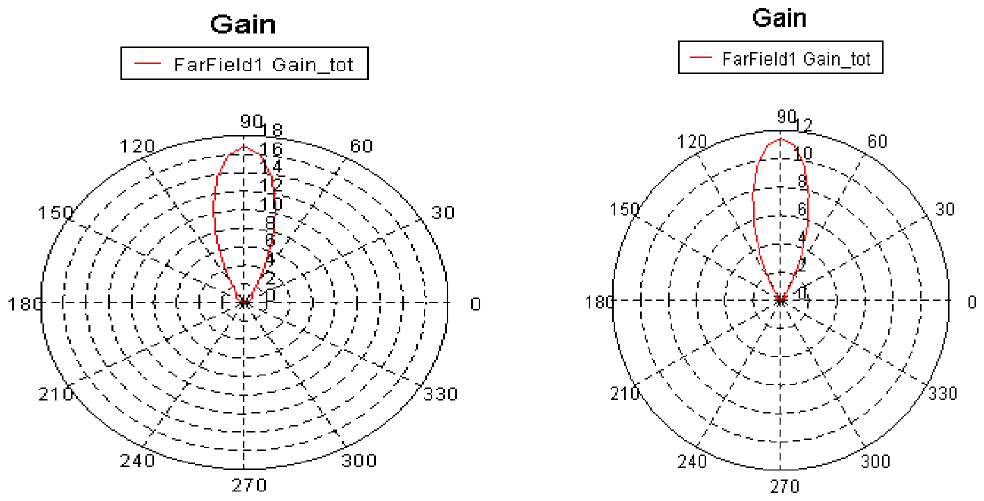
Figure 6: (a) 3-D directivity for 10 elements (b) 8 elements Yagi antenna.



(a) (b)

Figure 7: (a) Electric far field polar plots for 10 elements (b) 8 elements Yagi antenna.

Form figure 7(a), it can be realized that the signal strength or electric field strength has increased significantly after the increase of the director elements which eventually increases the directivity of the Yagi antenna and hence the gain of the antenna.



(a) (b)

Figure 8: (a) Gain polar plots for 10 elements (b) 8 elements Yagi antenna.

From figure 8 above, it can be easily realized that the gain of the antenna has been increased after increasing the number of elements with carefully measured length and spacing between the reflector and active element and then the spacing between the directors, which means that increasing the number of director elements have got direct impact on the gain of the Yagi-Uda antenna as shown in the polar plot of figure 8(a). So for the Yagi Uda antenna the Gain is somehow proportional to the number of elements present when the distance from one element to the other has been carefully considered and the length of the dipole (elements) themselves have been taken into considerations.

So the gain $G \propto N$ and $G = kN$

Where G= Gain of the Yagi and N is the number of elements in the Yagi and k is the constant of proportionality which is approximately to 1.66 in some special cases.

6. CONCLUSION

From the above discussion it can be concluded that the gain of the Yagi antenna have been improved from the value of 11.8dB as shown in figure 8 (b) above to 16.5dB as in figure 8 (a) above. So the improvement of this gain was largely contributed by the increase in the number of directors from the previous six to eight while taking into consideration the length of these directors together with the length of the reflector element. In the case of 10 element Yagi antenna, the length of the reflector element was reduced compared to the length of reflector in the 8 element Yagi which is currently used by DVB-T2 customers as the receiving antenna. Hence, the use of 10 element Yagi antenna with carefully design as done above will improve the quality of coverage due to the increased directivity and hence gain in the reception side and for digital television. This will lead to enhanced quality of received DVB-T2 signals.

7. RECOMMENDATION AND FUTURE WORK

In the future, we would like to recommend the use of 10 element Yagi Uda antenna (1 reflector, 1 active or driven element and 8 directors) as the new receiving antenna of the DVB-T2 signals in the new phase of rollout in the remaining regions due to its high reception gain as narrated above. Another antenna which may be used in the place of Yagi antenna is Quadrifillar helical antenna (QHA), because it has also good and super reception gain.

ACKNOWLEDGMENTS

The authors wishes to acknowledge the Nelson Mandela African Institution of Science and Technology (NM-AIST) for their support during the preparation of this study.

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