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Optimal Design and Fabrication of a Wideband Antenna for Terrestrial DTV Reception

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Abstract

Optimal design and fabrication of a wideband antenna for terrestrial digital TV (DTV) reception is presented in this paper. Reception of poor digital TV (DTV) signal using Yagi antennas supplied by cable providers in some suburban and rural areas in Nigeria has been a major concern to subscribers. This problem could be solved by the use of high gain antennas such as the one presented in this paper. In developing this antenna, NBS 688 technical notes and antenna design curves were applied and the resulting antenna estimate was modeled, simulated and optimized with 4NEC2 antenna design software. Optimal design verification was achieved using EZNEC v.6.0 antenna modeler. On testing after fabrication, received signal strength was 60dB compared to 45dB obtained with the service provider's conventional Yagi antenna in position. A better picture clarity was observed owing to the 15dB increase in signal level.

Keywords: *Digital TV, antenna, bandwidth, Yagi*

1. Introduction

The principle objective in antenna design is to establish a specified pattern f(θ, φ) watts per square meter through a suitable arrangement of sources (elements). The specified pattern frequently embodies the intent to enhance the radiation in certain directions and suppress it in others [1]. This paper outlines a practical approach to improving antenna bandwidth and other radiation properties by stacking 5 reflectors in 13 element Yagi - Uda array.. Usually Yagi – Uda arrays have low input impedance and relatively narrow bandwidth [2]. Properly designed Yagi can achieve greater bandwidth up to 5% to more than 10% [3]. Notwithstanding, these bandwidths are still below the requirements of many wireless applications.

It is clearly defined by Federal Communication Commission (FCC), that an ultra – wideband (UWB) antenna must have fractional impedance bandwidth of at least 20% or absolute bandwidth of 500MHz [4]. In many practical applications, the radiation pattern of an array is required to satisfy some basic criteria including among others directivity and reduced side lobe level [2]. Antenna arrays are mainly used in military, commercial radio and TV transmission as well as wireless communication systems to improve signal quality, increase link coverage and capacity.

Antenna performance can be improved by geometry optimization i.e. intelligent selection of element height, spacing and excitation. This eliminates the damaging effects of mutual coupling which affects the far field radiation pattern of an array antenna. It also enhances the antenna beam width, front – to – back ratio, side lobe level and directivity [2].

1.1 Literature Review

Different methods and algorithms–both mathematical and artificial techniques for designing and optimization of antenna have been presented in several literatures. In [3], the aim was to achieve maximum gain and directivity of a Yagi–Uda antenna. Their method was based on computed and measured antenna currents and a graphical presentation was used to estimate optimum size of the antenna. There were no detailed numerical calculations.

Performance optimization of a Yagi antenna by varying the spacing between the directors of a 6–element Yagi antenna while holding the reflector-exciter spacing and elements length constant was presented in [4]. This spacing perturbation led to increase in gain. Optimum performance was achieved when the elements length were varied while keeping the optimum spacing constant.

In [5], genetic algorithm (GA) based automated antenna optimization technique that was applied on both fixed Yagi–Uda topology and a byte – encoded antenna showed an excellent gain with desirable impedance characteristics.

2. Materials and Methods

The materials used are:
(i) Aluminum boom because of its desirable property - light weight,
(ii) Copper tubing for the antenna elements-due its higher electrical conductivity, corrosion resistance, ease of soldering and availability.
(iii) Soldering iron and lead

In designing the antenna the following steps were taken:
(i) Use of American National Bureau of Standard NBS 688 Technical notes and curves for antenna design to generate first antenna estimate as shown in table 1.
(ii) Modeling of the first antenna estimate, then simulate and optimize using 4NEC2 antenna design software.
(iii) Verifying the optimal design using a professional antenna modeler, EZNEC v.6.0

2.1 Antenna Description

The antenna is a parasitic array comprising 13 elements – 7 directors, a folded dipole exciter and 5 reflectors stacked along vertical axis as shown in simulation structure window. The presence of the vertical array gave rise to broadband characteristics of the antenna, an antenna that has almost equal response in terms of VSWR (voltage standing wave ratio), gain, return loss, within the operating band.

In a receiving mode, incoming fields set up resonant currents on all dipoles. Consequently, all passive elements re–radiates signals. These re– radiated fields are then picked by the driven element. Therefore the total current induced in the driven element is a combination of direct field striking it and the re–radiated contributions from the directors and reflectors. This current creates an electric field which gives rise to a potential difference (voltage) between its terminals. This voltage constitute the received signal. The surface current distribution over the driven element's surface is the most critical antenna parameter [6].

2.2 First Antenna Estimate

The steps and procedures for generating Yagi antenna elements' lengths and spacing utilizing the design curves and data as enumerated in NBS 688 antenna design technical notes was used to generate the first antenna estimate as shown in Table 1. The antenna bandwidth is 560MHz–730MHz. The geometric mean frequency was taken as the center frequency [7].

The lengths and spacing were obtained at the center frequency of 640MHz (λ = 0.4687m). The Table shows the elements, spacings and lengths for the reflector (R), dipole (D), 7 directors (D_1-D_7) and 4 vertical arrays (V_1-V_4)

Table 1 Antenna lengths and spacing estimates

Element	***Multiplier***	***Length(cm)***
R	0.55	26
R spacing	0.29	13.5
D	0.47	22
D_1	0.38	18
D_1 spacing	0.17	6.5
D_2-D_7	0.34	14
D_2-D_7 spacing	0.21	10
V_1-V_4	0.51	24
V_1-V_4 spacing	0.17	8

2.2 Antenna Optimization

The 4NEC2 Modeler was used to create, view and check the antenna geometry, structure as well as display and compare near and far field radiation patterns. Also SWR, input impedance, F/B–ratio for range of frequency on a linear or logarithmic graph,smith chart was displayed.
EZNEC v 6.0, a more versatile and professional antenna modeler was also used as an advanced correction method for a more reasonable and accurate model. It is also a window based tool. The radiation

pattern of the antenna before optimization is shown in figure 1.

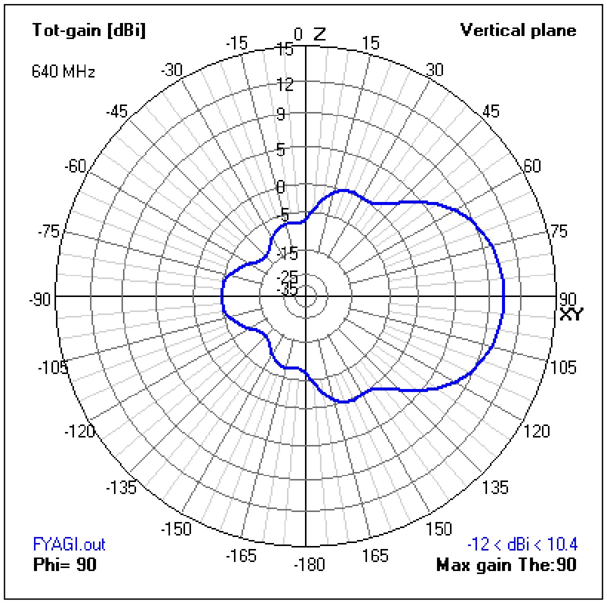

Fig. 1 Radiation pattern of the antenna

Resonance was observed at 590MHz which is 8% lower than the center frequency of 640MHz. To make the antenna resonate at the center frequency the length of the driven element was reduced by 0.92 and the length of the reflector increased by the same factor [8]. Optimization process modifies the spacing and length of elements. This was done using 4NEC2 software equipped with optimization tool. The aim was to ensure optimal performance of the antenna. Table 2 shows difference in elements length and spacing for the first estimate and the optimal design.

Table 2: Antenna Elements dimensions

Element	***Initial Length(cm)***	***Optimal Length (cm)***
R	26	28
R spacing	13.5	14
D	22	20.9
D_1	18	16.4
D_1 spacing	6.5	6.0
D_2-D_7	14	14
D_2-D_7 spacing	10	10
V_1-V_4	24	26
V_1-V_4 spacing	8	10

2.3 Antenna Fabrication

The following specifications were adhered to:

(i) $3cm \times 2cm$ Aluminum rectangular tube of appreciable thickness for the boom
(ii) 1cm diameter copper round tube for the dipoles.
(iii) $3cm \times 2.5cm$ Aluminum disc for provision folded dipole base
(iv) 75 ohms coaxial cable RG 6L
(v) Rubber caps for closing the ends of both boom and dipoles.
(vi) Wire solder.

The tools used were:
(i) Safety glasses
(ii) Measuring tape
(iii) Straight Edge Ruler
(iv) Electric impact drill
(v) Thread cutting die
(vi) Hacksaw
(vii) Tube cutting and bending set
(viii) Marking and punching tools
(ix) Soldering iron.

The 1cm diameter copper pipe was cut according to directors, exciter and reflector length of the optimal design. The driven element, (a folded dipole) was fabricated by folding two lengths of the size of the driven element into two different arms (using spacing s between the arms as $s = \frac{\lambda}{100}$) [9].The $3cm \times 2cm$ aluminum disc was drilled on both sides to make a 1cm diameter hole into which one end of each arm of the folded dipole was fitted. It also served as the support for the dipole, balun and coaxial cable. A BNC connector was attached underneath the base by means of a thread cut through the bottom. The U–section of the balun was formed with a length l by cutting a length of the coaxial cable. Here

$$l = \frac{\lambda \times velocity\ factor\ of\ the\ cable}{2} \quad ....(1)$$

The section was inserted into one arm of the folded dipole. One of its ends was soldered to the center conductor of the BNC connector and the other end soldered to the remaining end of the other arm of the folded dipole. This formed a 4:1 balun, an impedance matching network matching the 300ohms impedance of the folded dipole to that of 75ohms coaxial cable transmission line. Impedance matching is extremely important since the antenna is just like a load connected to a transmission line. Proper matching ensures extraction of maximum signal strength thus improving received signal quality.

The aluminum boom for both the vertical reflector array and the horizontal exciter/director array were marked based on the optimal element spacing and holes drilled with precision to ensure tight fitting of the dipoles to the booms. Finally, both the vertical and horizontal array were assembled and combined to form the antenna.

Folded dipole was used as the driven element of the antenna because of its salient features such as:

(i) radiation pattern that is the same as that of a straight dipole.

(ii) high input impedance about 300 ohms.

(iii) greater bandwidth, ease and low cost of fabrication with better impedance characteristics.

3. Results and Discussion

3.1 Simulation Result

The simulation results as shown in respective plots highlights the variation of the antenna performance metrics with frequency. Figure 2 shows radiation pattern of the antenna. The radiation pattern which can also be referred to as reception pattern is a plot of radiated or received power as a function of angle at a far distance. It describes the relative strength and orientation of radiated or received fields in space coordinate at a constant distance from the antenna.

It can be seen from figure 2, the optimal antenna has radiation pattern that is devoid of backlobe and sidelobes at the resonance frequency. This implies that the energy wasted in sidelobe and back lobe is eliminated with this antenna and the problem of interference with other communication systems is mitigated. This antenna also exhibits constant radiation pattern at all frequencies within the operating band.

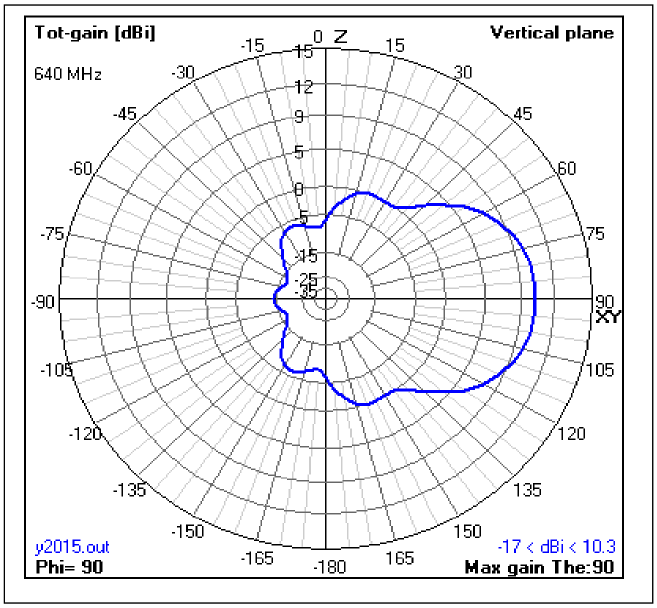

Fig 2 Radiation pattern of optimal antenna at 640MHz

Figure 3 shows the variation of Reflection coefficient in dB with Frequency. This shows the return loss of each frequency within the operating band. The antenna at 640MHz has its minimal return loss of -14.386dB. Return loss which is simply the magnitude of the reflection coefficient in dB is the most important parameter with respect to the load matching. It characterizes the antenna ability to radiate power instead of reflecting it back to the generator. The bandwidth can also be estimated from this plot.

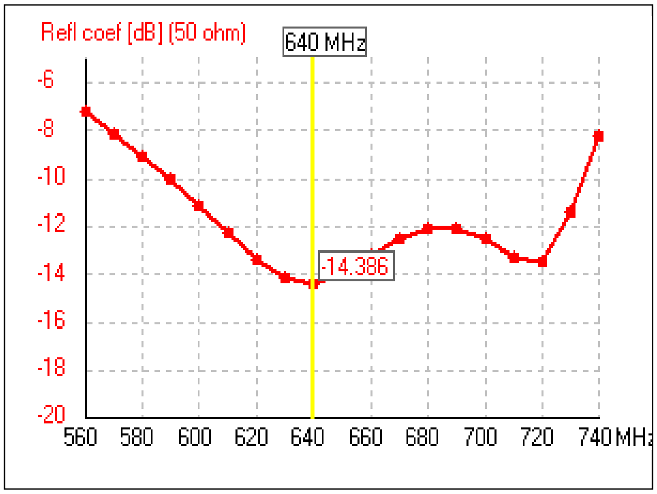

Fig 3. Reflection coefficient vs frequency

Another antenna performance metric is its gain. Figure 4 shows a plot of Total Gain of the antenna against the frequency. The optimal antenna has a total gain that increases slightly over the frequency band, from 9.5dBi to 13.5dBi. This confirms that the optimal antenna has radiation pattern that is almost uniform within the operating band, which is very important and a required characteristics for wideband antennas.

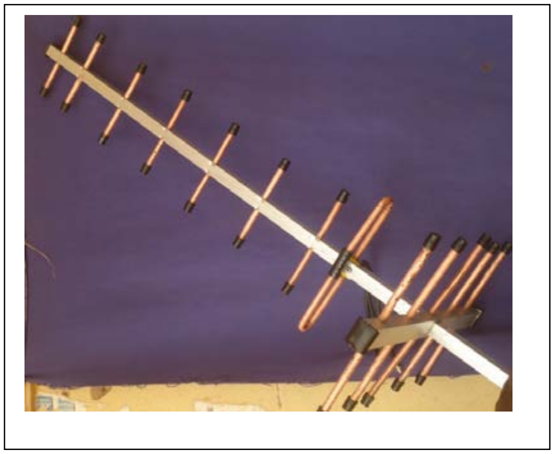

Fig 4. Total Gain vs. Freq.

Figure 5 shows the smith chart at 640MHz which displays information on impedance characteristics and the matching condition of the antenna at each frequency within the band. The magnitude of reflection coefficient or VSWR and Return loss can be seen as marked on the chart.

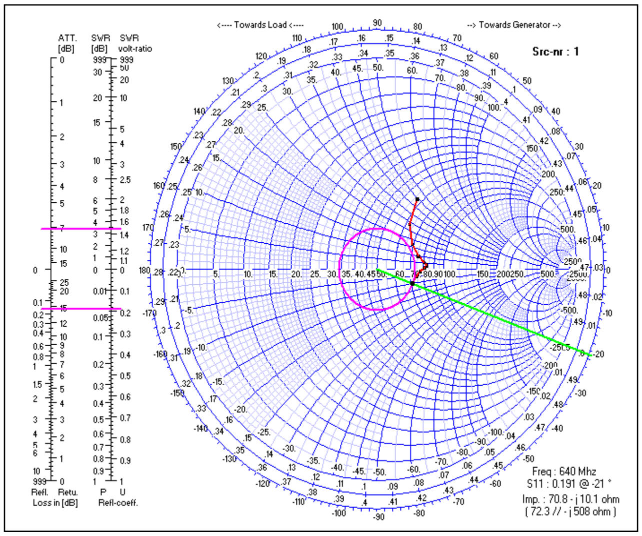

Fig 5. Smith chart of optimal antenna at 640MHZ

3.1 Antenna Testing

Figure 6 shows the complete fabricated optimal antenna. It has 7 directors, a folded dipole and 6 vertical reflectors.

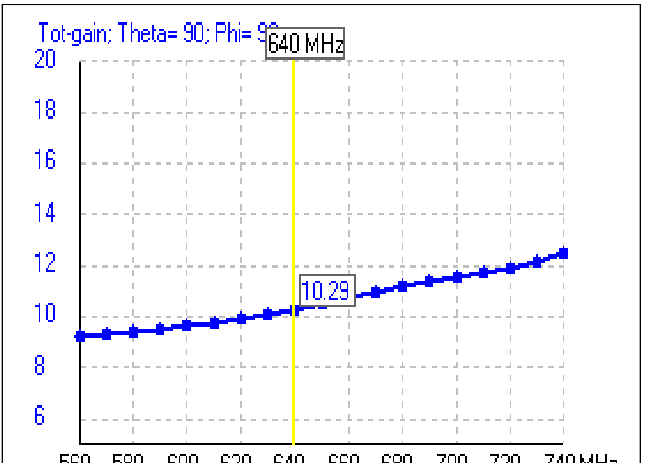

Fig 6. Fabricated antenna

The antenna was tested in a rural area using TV signal reception from a known Service provider's terrestrial digital TV decoder (STAR5000T2) as a case study. Before the test, the received TV signal using the STAR5000T2 antenna was monitored. The status of the received signal was observed as:

(i) signal strength of 45dB
(ii) signal quality 90%
(iii) BER of 1E-9.

The STAR5000T2 antenna was replaced with the antenna under test. The height and location unaltered. The received signal due to this antenna was monitored as follows:

(i) Signal strength 60dB
(ii) Signal quality 90%
(iii) BER of 1E-9.

The new antenna showed an increase in signal strength of 60dB. This is a 15dB gain over the STAR5000T2 antenna. With the improved signal strength of 60dB as compared to 45dB (STAR5000T2 antenna), there was a noticeable improvement in the picture and sound quality even at varied distances.

4. Conclusion:

The design and fabrication of a cost effective wideband Yagi antenna has been presented. It has a wide bandwidth, uniform radiation pattern, high F/B ratio. High gain was achieved by stacking the 5 reflectors in a vertical array with the middle having length that is slightly higher than the other 4 elements. It was fabricated with a folded dipole as the driven element and a 4:1 balun was used to match the impedance of the antenna to the 75ohms transmission line.

The antenna showed an improved gain of 15dB or 33.33% increase in signal strength above that of a conventional Yagi such as STAR5000T2 antenna used by a private DTV service provider.

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