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A study of the Propagation Characteristics of a 13 Element Yagi-Uda Antenna

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***Abstract**: This paper reports the propagation characteristics of a 13- element 640MHz Yagi antenna.The Yagi-Uda antenna is a highly directional antenna and in the transmit mode propagates electromagnetic energy in the direction running from the dipole or driven element toward the director and is sensitive to incoming electromagnetic energy in the receive direction. In this study, NBS 688 technical notes and antenna design curves were used and the resulting antenna estimate was modeled. The simulation and optimization was carried out using 4NEC2 antenna design software. Verification of the optimal design was achieved using EZNEC v.6.0 antenna modeler. The simulation result showed Antenna characteristics such as input impedance, radiated power, efficiency and far-field radiation pattern.*

***Keywords**: Yagi antenna; radiation pattern; VSWR;* gain; *F/B ratio*

I. Introduction

Yagi antenna is made up of elements such as radiator, directors and a dipole which is the active component of the antenna. These elements make Yagi a high gain antenna suitable for VHF and UHF bands. It is a parasitic array antenna. This is because the active element is directly fed by the transmission line while the other elements receive their excitation by near field coupling. The shorter elements are the directors which help in the directional properties of the antenna while the longer element is the reflector that changes the radiation pattern through the feed. The antenna gain may be increased by stacking [1]

The stacking technique for improved gain and bandwidth is described in this paper. Here we have 5 reflector stacked in a 13 element antenna. The performance of this antenna after fabrication and testing showed improved gain on TV signal reception [2]. In this paper, its radiation properties are presented. Usually Yagi – Uda arrays have low input impedance and relatively narrow bandwidth [3]. It is a highly directional antenna and different studies have been undertaken to see ways of improving this very important property of directionality.

In the study carried out by (4), half wave dipole, one reflector and two directors were used. It was concluded experimentally for the dipole that its length has a small effect on forward gain but a large effect on backward gain. It was also concluded that the spacing and size of reflector have almost no effects on the forward gain but large effects on the backward gain (front-to back ratio) and input impedance which can be used to control or optimize antenna parameters without affecting the gain significantly. For the director, it was also observed that it has the shortest length in the design as it focuses radiation in one direction.

Fabrication and Testing of a 2.4GHz Yagi antenna was carried out in (5). The number of directors used was eight to increase the forward gain of the antenna. The antenna had good radiation patterns at higher frequencies. The results showed that increase in frequency beyond the centre feed point, reduces the amplitude of currents. It was also established that with increase in frequency beyond optimum level, the advantages of reduced beam width and few side lobes earlier gained became insignificant. They used Method of Moments in their analysis which required that only the array geometry and feed point be specified for determination of current distribution and radiation pattern.

In (6), a Yagi-Uda antenna was fabricated with two different shapes of antenna elements. They were able to show in their paper that the spherical shaped is the better choice as compared with square shaped element to achieve better potential antenna characteristics through Yagi-Uda antenna. They concluded that the square shaped antenna element increases the beam-width and makes the radiation pattern nearest to omni-directional one. In spite of that it also gives multi-frequency return loss characteristics to the Yagi-Uda Antenna.

Method of Moment based Numerical Electromagnetic Code, windows based NEC-2/NEC-4 antenna modeler was used in [7]. Their design was a 3-element Yagi-Uda antenna operating at the frequency of 200MHz.. The results obtained showed that the designed antenna suitable for Wind Profiling radar or Phased Array radar applications.

Most studies in this area have been on the conventional single element reflector Yagi antennas. This study goes a little further unlike others to verify the propagation characteristics of a multi-element reflector stacked together.

II. Methodology

In designing the antenna the following steps were taken [2]:

(i) Use of American National Bureau of Standard NBS 688 Technical notes and curves for antenna design to generate first antenna estimate.

Table 1: Antenna length and spacing estimate.

Elements	Multiplier (λ)	Length (cm)
R	0.55	26
R spacing	0.29	13.5
D	0.47	22
D_1	0.38	18
D_1 spacing	0.14	6.5
$D_2 - D_7$	0.34	16
$D_2 - D_7$ spacing	0.21	10
$V_1 - V_4$	0.51	24
$V_1 - V_4$ spacing	0.17	8

(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.

The procedures for obtaining the lengths and spacing of the antenna elements was realized by utilizing the design curves and data as enumerated in NBS 688 antenna design technical notes. This method was used to generate the first antenna estimate. The antenna bandwidth is 560MHz–730MHz. The geometric mean frequency was taken as the center frequency [8]. With the center frequency set at 640 MHz, the lengths and spacing were obtained using the wavelength (λ) of 0.4687m and tabulated in Table 1. It shows the spacing and lengths for the reflector (R), folded dipole (D), 7 directors (D_1-D_7) and 4 vertical reflector arrays (V_1-V_4).

The 4NEC2, a window based tool was used. It can be used to create, view and check antenna geometry structure and generate, display and compare near – and far field radiation patterns. Also standing wave ratio (SWR), input impedance, Front/Back (F/B) – ratio and smith chart can be displayed. An optimizer and sweeper was also used. With this optimizer it was possible to optimize antenna and other variables such as gain, resonance, SWR, efficiency, and Front/Back ratio.

The 4NEC2 main window was opened by clicking on 4NEC2 icon on the desktop, new file was selected, 'write symbol' was clicked on and the antenna geometry data entered. The geometry input data file is in Excel format with specified X, Y, Z coordinates. The X – coordinate was chosen to represent the antenna elements length, Y – coordinate as horizontal axis on which the antenna elements were fixed and spaced out and the Z – coordinate served as the vertical axis on which the reflector array was fixed. The source (voltage/current) was later added.

Frequency/environment symbol was clicked on and the design frequency specified, free space chosen as the environment. Finally 'view antenna' was clicked on, then the generate button. The options to be generated were finally selected. The resulting plot is shown in figure 1. It is a 3D radiation pattern of the first antenna estimate at 640MHz sliced to show structure.

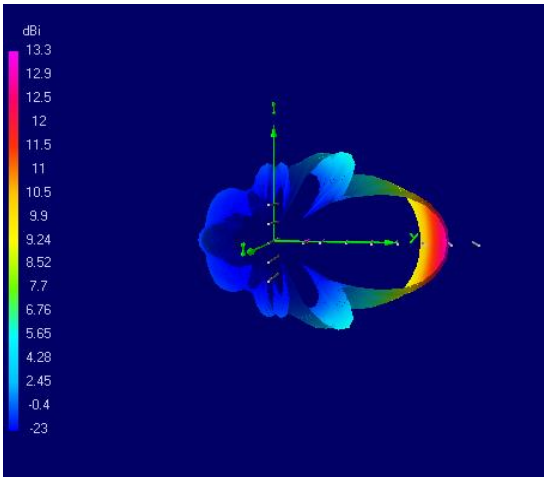

Figure 1: 3D pattern of antenna sliced to show structure.

The 4NEC2 software is equipped with optimization tool and it was applied to optimize the antenna after trimming. The optimization window was opened by clicking on the optimization icon and the antenna parameters to be optimized were selected. The variables were selected and set as shown in Table 2.

Table 2. Parameters for antenna optimization

Parameters	Values
SWR	2
Gain	10dB
input impedance,	75ohms
Reactance	10
Front–to–back ratio	15
Front–to–side ratio	10
Reflection coefficient	-20dB

The ‘start’ button was clicked to start optimization process. After 50sec the optimized output was displayed. The output conformed to the desired values and ‘update NEC file’ button was clicked to save the result. Optimization process modified the spacing and length of elements.

III. Simulation Results and Discussion

Values obtained after optimization are shown in Table 3

Table 3. Parameters after optimization

Parameters	Optimal Value
SWR	1.002
Gain	10.3dBi
Resistance,	70.8 ohms
Reactance	-10.1
Front – to – back ratio	24.22,
Front – to – rear ratio	16.4
Reflection coefficient	-58.3dB
bandwidth 27%,	27%,
Efficiency	98%.

The simulation results as shown in respective plots highlights the antenna performance metrics with frequency. Figures 3 and 4 show the antenna’s 3D and 2D radiation patterns at 640MHz respectively. The radiation pattern is a plot of radiated or received power as a function of angle at a far distance.

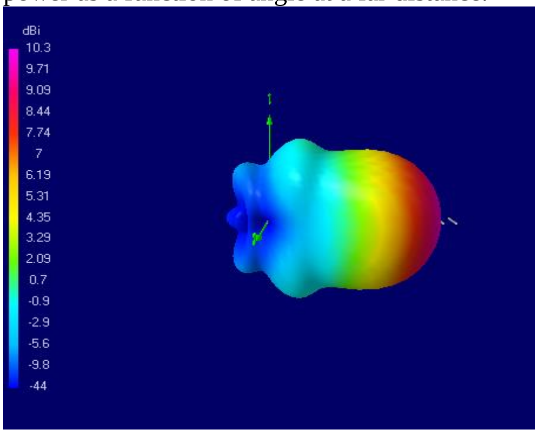

Figure 3. 3D radiation pattern of optimized antenna at 640MHz.

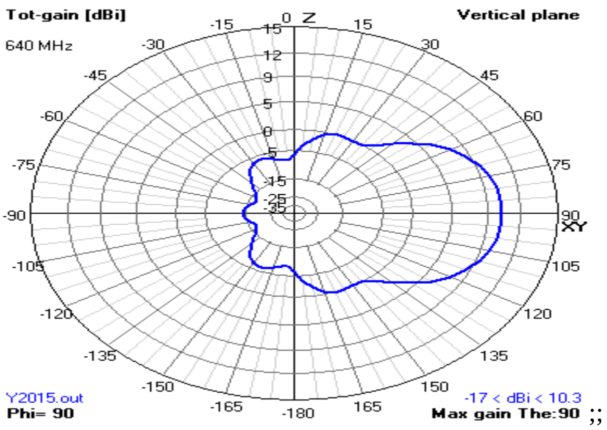

Figure 4. 2D radiation pattern of optimal antenna at 640MHz.

Figure 5 is a plot of SWR vs. Frequency. This plot displays the variation of voltage standing wave ratio with frequency.

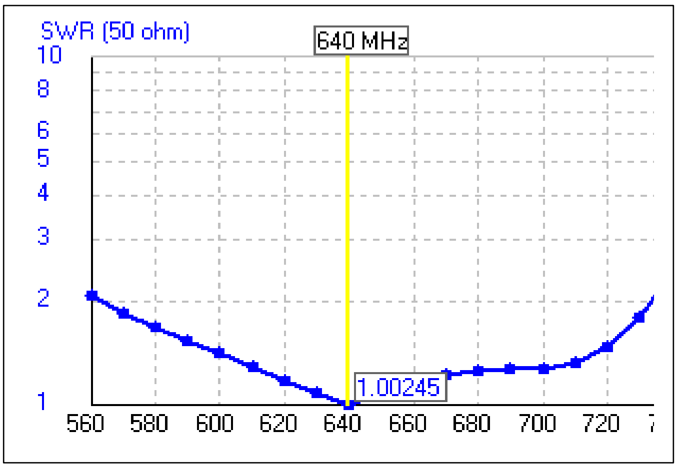

Figure 5. SWR vs. Frequency of optimal antenna at 640MHz.

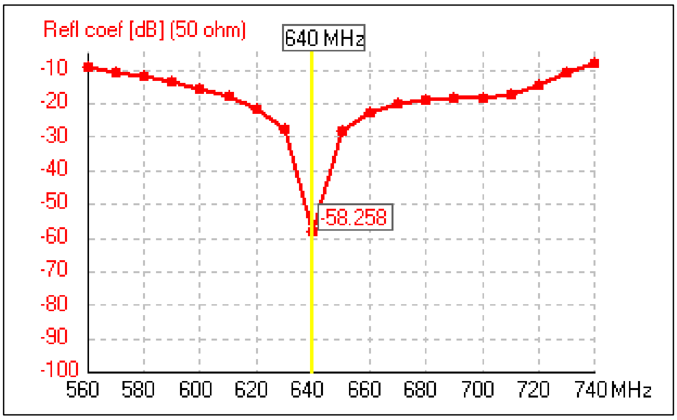

Figure 6. Plot of Reflection coefficient vs. Frequency

Figure 6 shows the variation of reflection coefficient with frequency. It shows the return loss at each frequency within the operating band. 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 the power instead of reflecting it back to the generator. The antenna bandwidth which is defined as the band or range of frequencies within which the return loss is sufficiently small (below –10dB) can also be estimated from this plot. Another antenna performance metric is its gain. Figure 7 shows a plot of Total Gain of the antenna against the frequency. Antenna gain is a measure of the strength of the signal received or transmitted compared to either an isotropic or to a dipole antenna. The optimal antenna has a total gain that increases slightly over the frequency band, from 9.5dBi to 13.5dBi.

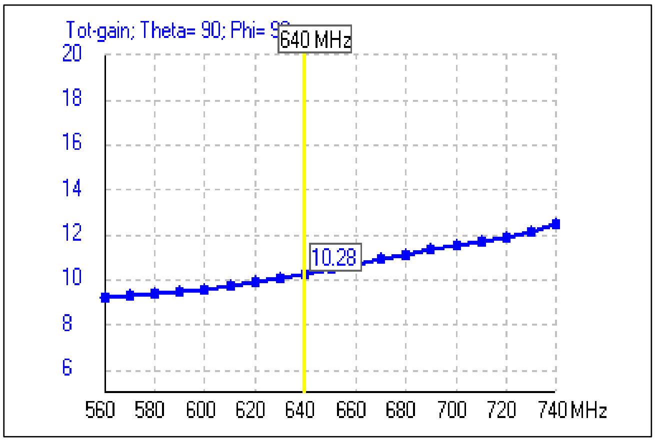

Figure 7. Plot of Total gain vs. Frequency

Figure 8 shows the smith chart at 640MHz, this displays information on impedance characteristics and the matching condition of the antenna at each frequency within the band. The magnitude of reflection coefficient or S_{11} , VSWR and Return loss can be seen as marked on the linear scale. The conjugate match for the antenna input impedance at each frequency can also be estimated from the Smith chart as well. The VSWR circle displayed in the Smith Chart is the locus of point (VSWR circle) which represents the input impedance of the antenna. The antenna has input impedance 73.08 + j1.949 ohms at resonance. Value of the respective parameters at resonance frequency is shown as marked on the figure.

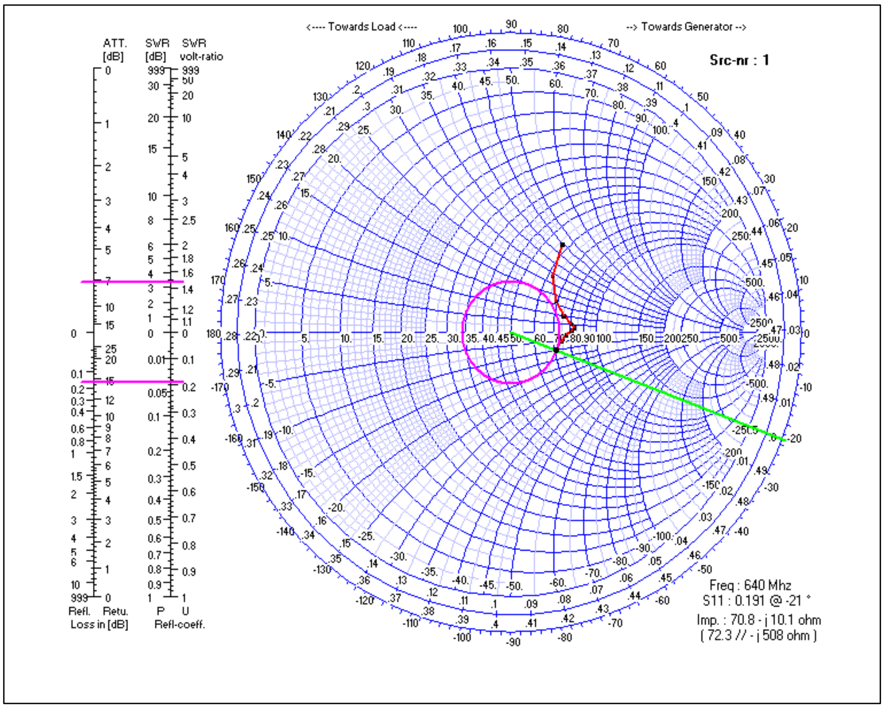

Figure 8. Smith chart of antenna.

The antenna was verified with EZNEC v6.0 which has alternative default reference impedance of 75 ohms. It can be seen in figure 9 that the antenna displayed return loss of -34.7dB at the resonance frequency with corresponding VSWR of 1.038. Return loss which is defined as the magnitude in dB that the reflected signal is below the incident signal.

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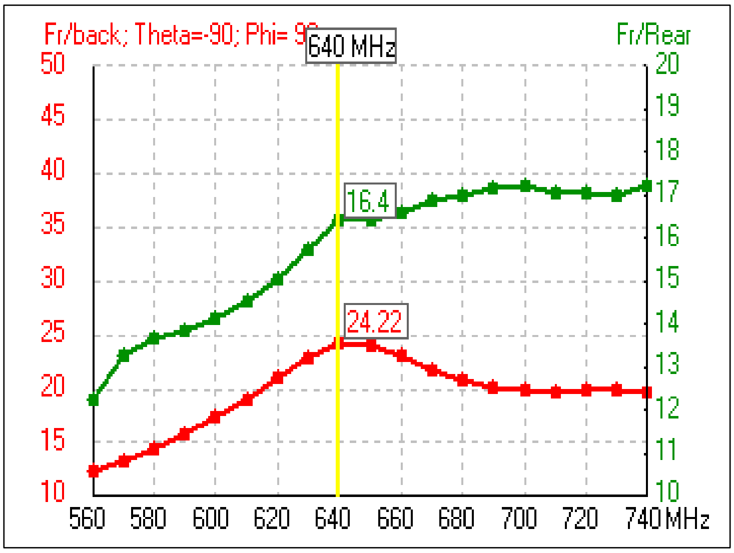

Figure 9 .Front-to-Back and Front-to-Rear ratios of optimal antenna.

F/B and F/R ratios are very important performance metrics for directional antennas. Figure 9 is a plot that displays the variation of these two metrics with Frequency. F/B is the ratio of maximum radiation intensity in the direction of maximum radiation of the antenna to radiation intensity of the back lobe in the opposite direction. On the other hand F/R ratio is the ratio of maximum intensity in the direction of maximum radiation to maximum radiation intensity of the side lobe. Consequently, energy waste in the back and side lobes are minimal and interference with other communication systems is also eliminated.

IV. Conclusion

The propagation characteristics of a 13-element Yagi antenna have been presented in a simple and concise manner. The figures obtained from the simulations are arranged for better understanding of the radiation properties of the antenna. The simulation result showed a uniform radiation pattern, high F/B ratio, an appreciable F/R ratio and high gain. The antenna displayed VSWR of 1.038 when modeled with EZNEC v6.0. A gain of 10.12 dBi, real impedance of 73.08 ohms, and return loss of - 34.8dB at resonance frequency of 640MHz were achieved. These results have been able to show the propagation characteristics of a Yagi antenna consisting of 4 reflector elements.

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