International Journal of Advancements in Electronics and Electrical Engineering– IJAEEE
Volume 4 : Issue 1 [ISSN : 2319-7498]
Publication Date : 30 April, 2015

Optimisation and Design Analysis of Yagi Antennas for Digital Television Broadcasting Services

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***Abstract*—In this paper, an in-depth investigation on Yagi antennas are conducted. The antenna design is based on two distinct approaches: firstly, using the addition of further parasitic elements in the model and secondly, using different types of materials – Copper, Aluminum and Stainless steel. The Yagi models are simulated at frequencies near the 530 MHz. Six antennas are then fabricated based on the positive simulated results. The Yagi Antennas are physically tested on a DVB-T decoder at various locations using a Field Strength Meter. The maximum gain achievable is around 12.62 dBi with a MER value of around 25.0 dBi. Comparative analysis with existing antenna structures are made. A better performance of 3.72 dBi for non-commercialised antennas and of 1.12 dBi for comercialised antennas is obtained.**

***Keywords*—Dipole, Fabrication, Gain, Optimisation, Yagi structure.**

I. Introduction

A Yagi antenna is a very simple structured electromagnetic device and is widely being used in various applications as a result of its high gain. Parameters that affect this particularly antenna's performance and effectiveness are the reflector, the centre-fed dipole element, the diameter of the elements (directors), the number of elements and the separation between them on the boom [1]. If the length and spacing of the parasitic elements are accurate, then the radiation from the parasitic elements and the feed element add constructively in a specific direction, resulting in an increase directivity and gain [2]. The addition of more elements in front of the dipole rod immensely increases the gain of the antenna. In fact, for each additional director there is approximately a 1dBi increase in the gain. The Yagi antenna commonly operates at frequencies of approximately 30MHz to 3GHz [3].

Many work have been conducted over more than fifty years on design, optimization and usage of various Yagi structures to adapt to a particular services. In this paper, we will constraint our study on work done since ten years. Jue Li et al. designed a 3-element Yagi beam aerial for meteorological services at a frequency of 150 MHz [4]. The resultant maximum gain (front to back ratio) is at least 10 dBi.

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Some researchers have made an attempt to reduce the distance between two adjacent elements to still obtain good level of antenna gain [5,6]. Lim & Ling proposed a closely spaced, folded Yagi antenna structure for achieving high gain in a physically compact size [7]. The folding concept is used to make the antenna self-resonant at 50 Ω. After simulation using the NEC software, the antenna is then tested at 8 MHz over a lossy ground for potential applications in HF skywave transmission. It is shown that a three-element Yagi can achieve a realized gain of more than 6.7dBi, despite the fact that the spacing between the elements is 0.02 wavelength (λ) only. When compared with other conventional dipole antennas like the resonant horizontal loop antenna or the Shirley dipole antenna [8], it was found that gain was improved by 9dBi. Recently, Zhao et. al. presented a new design of the Yagi antenna with a super-directivity of 8.9dBi [9]. The Yagi antenna consists of only two folded elements - one is a fed element and the other is a parasitic element. In addition, the antenna shows quite good input impedance and return loss performance at a frequency of 300 MHz. The 10dBi fractional bandwidth is only about 1.3% and therefore restricts it to be used for narrow band application only.

The purpose of this paper is to investigate on the effect of gain when various materials with different number of elements are used. The antenna performance will be compared with some dipole antennas designed by the research community and with few commercialised antennas.

The rest of the paper is structured as follows: the experimental detail and optimisation technique are discussed in Section II; we discuss the results in Section III; we will give an insight of the fabrications of the antennas in Section IV. A comparative study with other existing models are conducted in Section V. We conclude in section VI with some future work.

II. Experimental Details and Design

We will design and adapt Yagi–Uda antennas operating at UHF range for digital television purposes while satisfying several sets of criteria. Optimization of the Yagi antennas is an extremely challenging design predicament since antenna's characteristics for instance gain, input impedance, voltage standing wave ratio, side lobes level are known to be particularly sensitive to the design variables that is element lengths, element size and the spacing in between. Several techniques like the Evolutionary algorithm [10], genetic algorithm [11], Taguchi algorithm [12], Colony optimisation algorithm [13] and Computational intelligence (CI)[14] are used for optimizing antennas. In this paper, the last mentioned is used.

The CI algorithm begins by initializing a set of solutions obtained through the method of moments-based numerical electromagnetic code (NEC-2). The NEC-2 is capable of computing current distributions on the antenna structure while taking into account physical phenomena such as mutual coupling between elements. It simulates the characteristics of antennas like the gain, radiation pattern and the standing wave ratio. The reflector distance from the dipole typically ranges from 0.15λ to 0.2λ and is around 0.5λ long. The directors are generally 0.4λ to 0.43λ long and are placed around 0.1λ apart to raise the gain whilst the resonant length of a dipole is made 0.46λ long. These elements are considered to be unbounded from the boom structure in NEC-2. Also, the main base station (Malherbes) [15] propagates TV signals at a frequency of 530 MHz to cover more than 70% of the land of Mauritius Island. Therefore, the antennas are simulated at frequencies near 530 MHz. From our study, a gain of at least 9 dBi is expected to be feasible for Mauritius.

Four antennas are designed as follows:

a) 6-element yagi antenna comprising of 1 folded dipole (Feed element), 1 reflector and 4 Directors.

b) 10-element yagi antenna comprising of 1 folded dipole, 1 reflector and 8 Directors.

III. Results and Discussion

After the optimization phase, a virtual simulation of the antennas on NEC-2 in free space is carried out. Data collected includes Radiation pattern, gain, impedance, front to back ratio and Voltage Standing Wave ratio (VSWR) of the antennas. Figures 1 and 2 shows the gain obtained for the two structures over a range of frequencies.

An improvement in gain of 17.0% is observed when four additional directors are added. Secondly, the values of frequencies obtained for which the antenna will work are quite positive. We obtain a gain of (9.00-11.00) dBi and (9.00-12.87) dBi for the frequency range of 530-550 MHz and 430-560 MHz for the 6-element and the 10-element Yagi antennas respectively. Finally, the impedance value obtained to match an impedance of 75Ω of the coaxial cable is equally important. Here, for both designs, a VSWR value of less than 1.5:1 for both designs is observed.

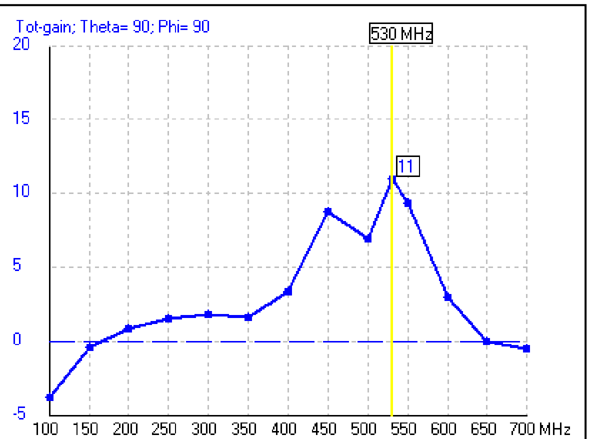

Figure 1: Gain vs Frequency for 6-element Yagi structure

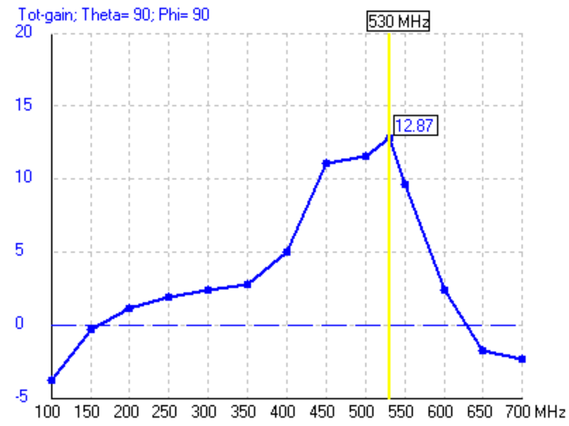

Figure 2: Gain vs Frequency for 10-element Yagi structure

IV. Fabrication and Testing

After simulation using NEC-2, a study on various materials are made before the fabrication of the practical antennas based the durability, conductivity, weight and cost of the materials. Aluminium, copper and stainless Steel materials are chosen. The antennas are then tested in a real environment in the central part of the island.

A. Fabrication

We construct six antennas – three for each structure as mentioned in sections II and III. Two examples are depicted in Figures 3 and 4.

Figure 3: 6-element Yagi structure (Copper)

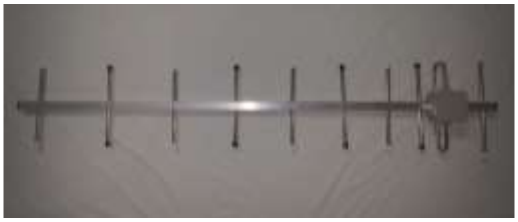

Figure 4: 10-element Yagi structure (Stainless Steel)

B. *Testing*

Field tests are conducted by raising the antenna and position to the direction of the main base station to achieve the maximum field strength. We measure the signal intensity and signal quality using a DVB-T decorder at 1 km, 7 km and 15 km from the base station (Tx-Rx Range). A digital Field Strength Meter (FSM) is used to analyze the received signal spectrum at center frequency 530 MHz and to measure the power received, the Modulation Error ratio (MER) and Noise Margin (NM). In this case, the transmitter for the main base station transmits a power of 250W. The gain of the antenna is calculated by measuring the power received in the same manner we did in one previous study [16].

The MER value can be expressed as the measurement of an average value over all OFDM subcarriers. And in practice, the MER values lies in the range of 0 to 20 dBi. For roof antennas, the MER values is around 20 to 30 dBi. Noise margin refers to the ratio by which the obtained signal exceeds the minimum adequate value.

The results, depicted in Table I, show that the antennas are quite adaptive in the UHF band at a range near the 530 MHz.

TABLE I. PERFORMANCE AT DIFFERENT DISTANCES

Tx-Rx Range, Km	Range, %	
	Signal Intensity	*Signal Quality*
1.0	69	97
7.0	65-70	61-96
10.0	55-67	70-94

As shown in the above table, the intensity and signal levels are adequate to produce an excellent picture and sound quality, which we observe when viewing on a TV screen. We also notice that there are no significant differences for the values of MER when using various materials. For example, for the case of the 6-element Yagi structure, all three materials give a positive NM value. The MER values for Aluminum, Stainless steel and Copper are all very close to 24.3dBi. For the 10-element Yagi, the MER value is slightly higher, that is, 24.7dBi. The measured gain for the 6-element structures are around 10.7 dBi and 12.62 dBi for the 10-element structures, that is, approximately in line with the values obtained during simulation.

V. Antenna Evaluation

The performance of the practical antennas are compared with three dipole antennas and two commercialised antennas (Log-periodic aerials) from Fracarro [17]. The maximum gain for our antenna (e.g. 10-element) is showing a better value than the Lim and Ling closely spaced folded Yagi [7], the Shirley dipole [8] and the Zhao et. al. Yagi antenna [9] by 6.25 dBi, by 18.99 dBi and by 3.72 dBi respectively. Moreover, for the same antenna, the maximum gain is higher than the LPV345HV and the LP45HV by 1.12 dBi and 2.62 dBi respectively.

VI. Conclusion

In this paper, we mounted six new Yagi antennas using three different materials (Copper, Aluminium and Stainless steel). The antennas are initially being optimised using the simulation software NEC-2. A directivity of 12.87 dBi is obtained for a 10-element structure. The measured value for the same antenna is 12.62 dBi. The antennas were tested in free space in the central regions of Mauritius. Finally, they were compared with other Yagi antennas. It was found that our antennas gave a better performance.

However, we believe that there are still improvements to be made. In this study, we have not focussed on the structure of the reflector. An investigation can be conducted on multi-rods reflector instead of single rod. The panel aerials design is another structure than needs to be revisited. In our future work, we will also work on the applications of Yagi antennas to design patch antennas and for RFID applications.

Acknowledgment

The authors would wish to express their warm appreciation to the engineers from the Mauritius Broadcasting Corporation for their unconditional help and support in terms of equipment and other resources. The authors would like to thank the Technical Director (A. Pather) of London Satellite Systems Ltd for technical advice.

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