International Journal of Multidisciplinary Research and Development 2015; 2(2): 296-301

International Journal of Multidisciplinary Research and Development

IJMRD 2015; 2(2): 296-301
www.allsubjectjournal.com
Received: 17-12-2014
Accepted: 26-01-2015
E-ISSN: 2349-4182
P-ISSN: 2349-5979
Impact factor: 3.762

Abdullah Alshahrani
School of Engineering, De Montfort University

Khloud Alshahrani
Business School, De Montfort University Leicester, LE1 9BH, United Kingdom.

Falah Alshahrany
School of Engineering and Design, Brunel University Uxbridge UB8 3PH, United Kingdom.

Correspondence:
Falah Alshahrany
School of Engineering and Design, Brunel University Uxbridge UB8 3PH, United Kingdom.

Designing and building a Yagi-Uda Antenna Array

Abdullah Alshahrani, Khloud Alshahrani, Falah Alshahrany

Abstract
Antennas are introduced in general then one type of the antenna is been focused on which is the Yagi-Uda in this paper. Also this paper outlines the process of designing a four element Yagi-Uda antenna that consists of one driven element, one reflector and two directors on software called CST to achieve specific requirements which are 2.4 GHz operation, minimum power reflected back to the source and maximum gain with minimum front-to-back ratio. The effects of changing the lengths of the elements in the antenna designed will be shown. The final antenna design with simulations of the S-parameters for both CST and PCB circuit (final design printed) are presented in this paper.

Keywords: Designing, Building, Yagi-Uda Antenna Array

1. Introduction

An antenna is a dielectric or a conducting structure that radiates and receives electromagnetic waves in the space which is the surrounding medium efficiently [2, 3]. The electric charges are the source of electromagnetic fields therefore the term radiation may be thought as the process of transmitting electric energy [2]. The antenna is needed to make the radiation efficient and to minimize reflection by matching wave impedances [2]. An antenna is used in devices such as mobile phones, televisions and wireless communication.

2. The Antenna Equivalent Circuit

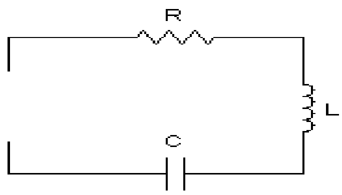

Fig 1: The antenna equivalent circuit [4].

Some energy is lost when the antenna starts the process of radiation and that energy lost could be thought as power dissipating from a component called the resistor. According to Fig 1 the antenna equivalent circuit is similar to an RLC circuit because when the frequency is low the dipole impedance is capacitive, at high frequencies the dipole impedance is inductive and at resonance the dipole impedance is resistive. The antenna uses the common-mode voltage to drive much current inside but it will be difficult to accomplish that if the input impedance is high therefore it is easier to send the current into the antenna at resonance when the impedance is low.

3. Yagi–Uda Antenn

The Yagi-Uda is a directional antenna that consist of a row of parallel straight cylindrical conductors of which only one (dipole) is driven by a source and all others are parasitic elements (director and reflector) [7]. The Yagi-Uda was invented in 1926 and named to who invented it (Shintaro Uda and Hidesugu Yagi) [5]. The Yagi-Uda antenna is used to either transmit electromagnetic radiation or to receive electromagnetic radiation with greater directivity or gain because it is a directional antenna meaning it concentrates a lot on one direction therefore Yagi-Uda antenna has found very important practical application such as applications in very high frequency (VHF) due to the simplicity and versatility of the Yagi-Uda antenna [7, 8].

The Yagi-Uda antenna is known for having a very high gain in one direction but limitations include that it works only in narrow bandwidth because it is usually in employment at frequencies between 30 MHz to 3 GHz or a wavelength range of 10 meters to 10 centimeters [5].

In the Yagi-Uda antenna there are three factors that determine the characteristics of the antenna [6]. The following are the factors:

- The number of parasitic elements.
- The lengths of the parasitic elements.
- The spacing of the parasitic elements with respect to the driven element.

4. Antenna Theory

A. *Antenna Equations*

- **Maxwell Equations**

The Maxwell equations are the set of four fundamental equations governing electromagnetism.

$$\nabla \cdot \mathbf{E} = \frac{\rho_v}{\varepsilon} \qquad \text{(Gauss' Law)}$$

$$\nabla \cdot \mathbf{H} = 0 \qquad \text{(Gauss' Law for Magnetism)}$$

$$\nabla \times \mathbf{E} = -\mu \frac{\partial \mathbf{H}}{\partial t} \qquad \text{(Faraday's Law)}$$

$$\nabla \times \mathbf{H} = \mathbf{J} + \varepsilon \frac{\partial \mathbf{E}}{\partial t} \qquad \text{(Ampere's Law)}$$

Fig 2: Maxwell equations [2].

- **Friis Transmission Equation**

The Friis transmission equation gives the ratio of received to transmitted power for given antenna gains, range and wavelength under ideal conditions. Also this equation is used as a basis for the calculations that designs the antenna.

$$\frac{P_r}{P_t} = G_t G_r \left(\frac{\lambda}{4\pi R}\right)$$

Fig 3: Friis transmission equation [1].

B. *Antenna Terms*

- **Radiation Pattern**

The radiation pattern is graphical plot of the power or field strength radiated by the antenna in different angular directions [3]. The most important property of the antenna is the radiation pattern because different antennas have different radiation pattern which means it radiates in different directions for example omnidirec-tional pattern it radiates in all directions meanwhile the pencil beam pattern radiates in one direction [3].

- **Gain**

The gain of the antenna is a measure of the concentration of the radiated power in a particular direction [2].

- **Directivity**

The directivity of the antenna is the ratio of the maximum radiation intensity to the average radiation intensity [2].

- **Nul**

The nul is the area or zone within the antenna where the radiation pattern of transmitted signal or received signal is at zero strength [2].

- **Lope**

The lobes are parts of the radiation pattern and they are classified into major, minor, side and back lobes [2]. The most important lobes are the major lobes because they contain the direction of the maximum radiation meanwhile the other lobes apart from the major contains the radiation of the undesired direction [2].

- **DBi**

It is the antennas gain which is a ratio expressed in decibels because they are relative to an isotropic antenna [1].

- **Resonance**

The resonance is a certain frequency that makes oscillation occurring at higher amplitude than normal in the system [1].

- **Resonance Frequency**

The resonance frequency of the dipole will happen at maximum gain by making the antennas length half of the wavelength [1].

- **Antenna Array**

An antenna array is a group of radiating elements arranged to produce a particular radiation characteristics [2]. The antenna array produces higher antenna gain by tuning the elements current of the array in the appropriate phases to improve the directional characteristics so that the antenna radiates the signal in one direction or in the direction of interest [2].

5. Antenna designing

A. *Antenna Design Specifications*

The following are the specifications for the antenna designed:

- One Driven (Dipole) Element.
- One Reflector Element.
- Two Directors Elements.
- Resonant frequency of 2.4GHz.
- Minimum Front-to-back Ratio.
- Maximum Gain.
- Minimum Power Reflected back to source.

B. Parameters for the Antenna Designed

The Friis equation is used to calculate the basis parameters of the antenna designed. The following are the calculations:

If $C = F \times \lambda$

C= the speed of light (3x10^8 m/s)
F= the resonant frequency (2.4GHz)
λ= the wavelength

Then $\lambda = C/F$

Wavelength = 0.125 meters
= 12.5 centimeters

The length of the driven element or dipole of the antenna is equal to the half of the wavelength calculated [6].

Dipole length= λ (wavelength) /2

= 12.5×0.5
= 6.25 centimeters

The length of the reflector element of the antenna is equal to the same length or about 5 percent longer (+5%) than the driven element or dipole [6].

Reflector length= λ (wavelength) ×0.55

= 12.5×0.55
= 6.875 centimeters

The reflector element is spaced a distance (shifted to the left side of dipole) of 0.1 to 0.25 times the resonant wavelength (lambda) from the driven element [6]. Therefore the chosen space value for the reflector away from the dipole is 0.25.
The length of the directors elements of the antenna are equal to approximately about 5 to 30 percent shorter (-5% to -30%) than the driven element or dipole [6].

Directors length= λ (wavelength) ×0.45

= 12.5×0.45
= 5.625 centimeters

The directors elements are spaced a distance (shifted to the right side of dipole) of 0.1 to 0.30 times the resonant wavelength (lambda) from the driven element [6]. Therefore the chosen space value for the first director away from the dipole is 0.13. Also the second director space value is equal to 2×space value of first director (0.13) therefore it equals 0.26.

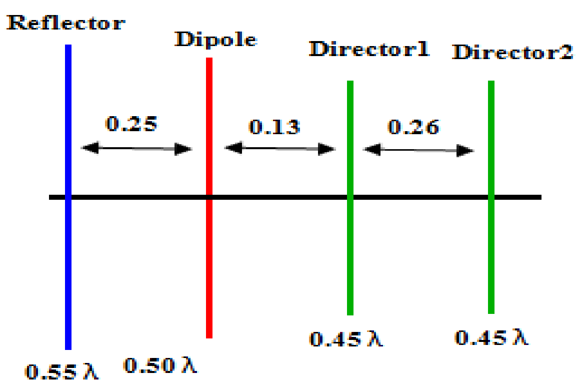

Fig 4: Basic antenna design using calculated parameters.

6. Designing the antenna on cst software

CST MICROWAVE STUDIO describes Maxwell's equations on a grid space and shows the electromagnetic simulation. Also CST is a collection of numerical modeling packages used widely in industry and it allows the user to create models of real systems. The following are the steps executed to design the antenna:

1. Opening the CST Studio.
2. Choosing the antenna and the workflow as planar in time domain from the microwave studio which opens a blank canvas window where the antenna can be constructed.
3. Creating the PCB substrate where the parasitic elements and the dipole are placed on.

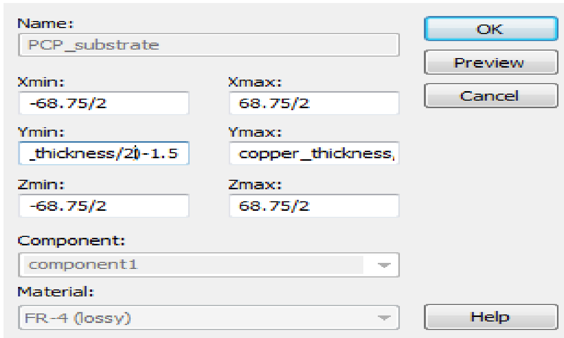

Fig 5: PCB substrate defining dialog box.

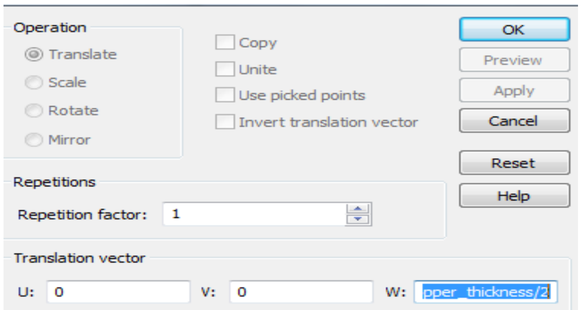

Fig 6: PCB substrate transforming dialog box.

4. Creating the dipole using copper annealed as the element type and mirror the dipole so it can be driven by a source from the ports created.

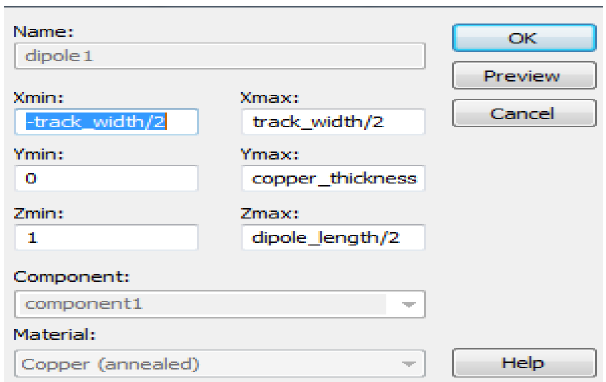

Fig 7: Dipole defining dialog box.

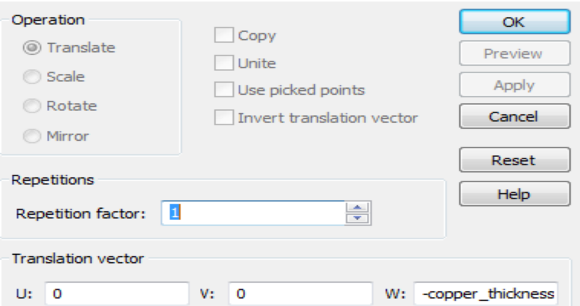

Fig 8: Dipole transforming dialog box.

5. Creating the reflector using copper annealed as the element type.

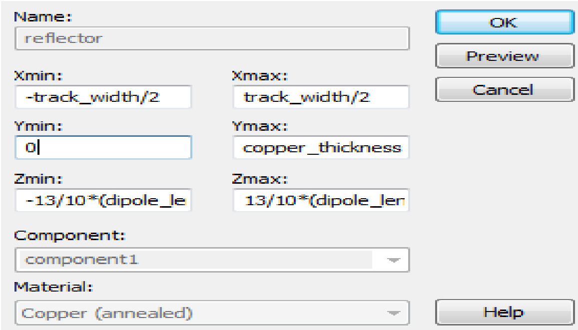

Fig 9: Reflector defining dialog box.

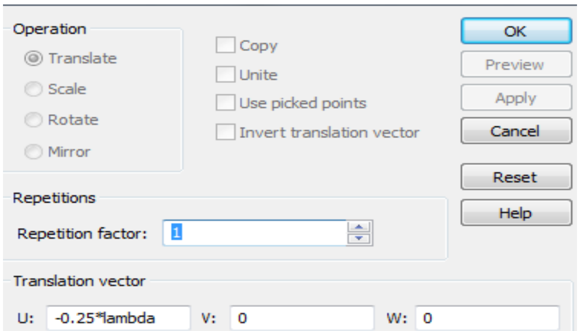

Fig 10: Reflector transforming dialog box.

6. Creating the directors using copper annealed as the element type.

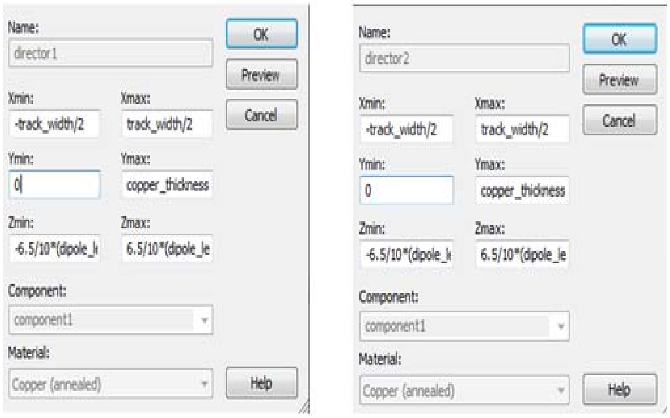

Fig 11: Directors defining dialog box.

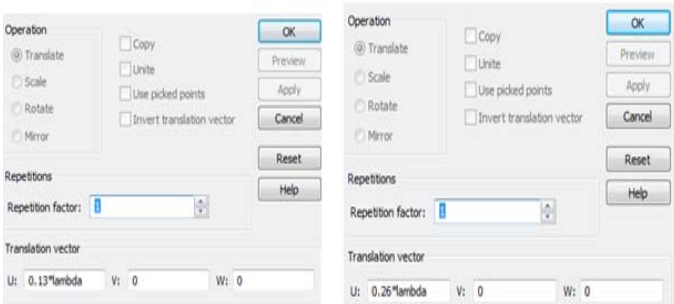

Fig. 12. Directors transforming dialog box.

7. Defining the parameters of the antenna. Also the calculated lengths of the elements are not used because they give results which are not near the desired results.

Name	Value	Description	Type
PCB_thickness	1.5		Undefined
PCB_width	68.75		Undefined
copper_thickness	0.035		Undefined
dipole_length	40		Undefined
dipole_scale	0.68		Undefined
director_length	33.75		Undefined
director_scaling_factor	1.185		Undefined
director_spacing	0.19 * lambda		Undefined
f0	2.4		Undefined
lambda	300 / f0		Undefined
reflector_length	47.2		Undefined
reflector_scaling_factor	1.18		Undefined
reflector_spacing	1.165 * lambda		Undefined
track_width	1		Undefined

Fig 13: Parameters of the antenna.

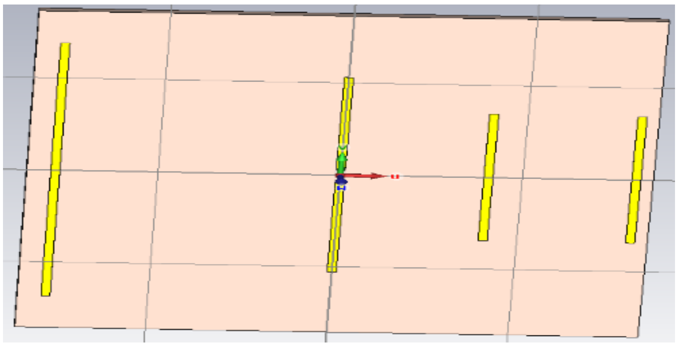

Fig 14: Antenna designed on CST.

8. Defining the frequency range from 2GHz to 3GHz and start the initial simulation to see where the dip of the wave is located on the frequency axis. The following is the S1, 1 wave (S-parameters):

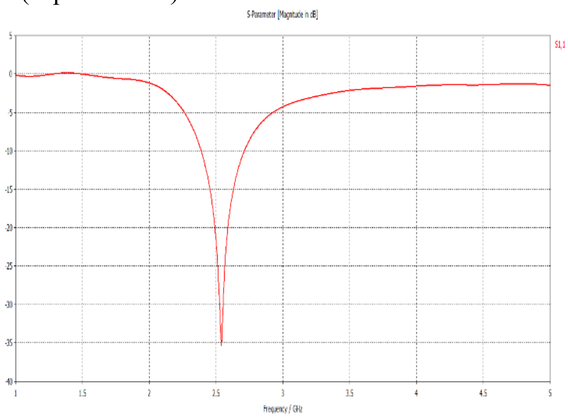

Fig 15: Initial simulation of S-parameters on CST.

From fig 15 it shows that the resonant frequency is slightly over 2.5GHz and with a resonant magnitude of -35 dB therefore the results of the antenna does not meet the specifications

7. Final Design

The length of the dipole, directors and reflector in the antenna designed are changed from what was on fig 13 to give a more accurate result (final design) that meets the requirements than the initial simulation on fig 15. Also the spacing of the reflector and the directors are kept the same because they are placed as much as further from the dipole without exceeding the PCB substrate created which helps in increasing the gain. The row with green highlighting shows the parameters of the final design of the antenna.

S1, 1 (S-parameters)						
Parameters				Results		
Dipole length in cm	Director1 length in cm	Director2 length in cm	Reflector length in cm	Frequency in GHz	Resonant magnitude in dB	Directivity in dBi
44	37.13	37.13	51.92	2.317	-35.59	5.198
42.5	35.86	35.86	50.15	2.393	-33.77	5.141
42.34	35.72	35.72	49.96	2.4	-33.55	5.124
41	34.6	34.6	48.38	2.473	-31.57	5. 09

Fig 16: Parasitic elements and dipoles effect on the antennas characteristics.

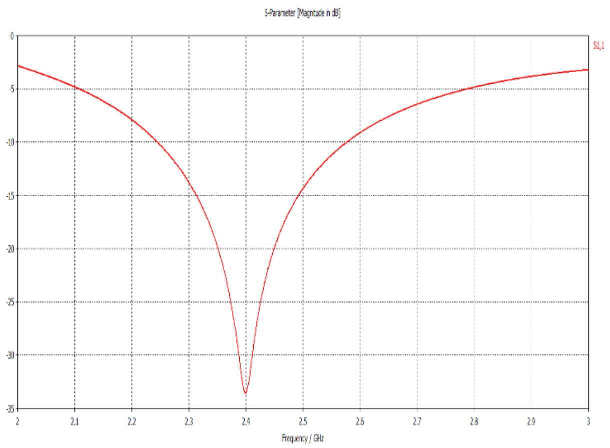

Fig 17: final simulation of S-parameters on CST.

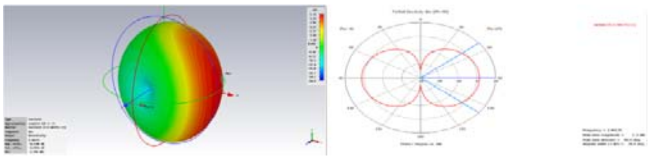

Fig 18: Radiation in the 3D and polar form of the antenna designed on CST.

8. Practical testing

The antenna designed is printed out as 2 PCB circuits, one for receiving and the other for sending.

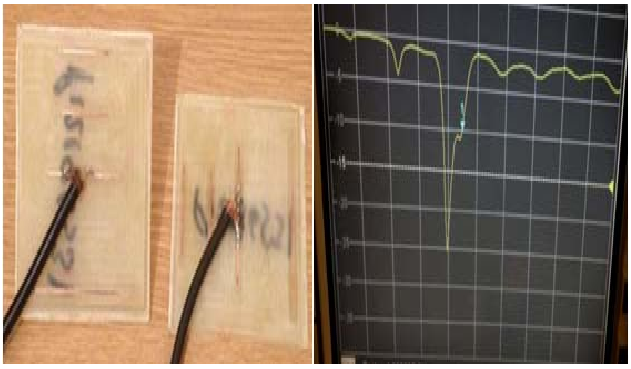

Fig 19: Practical testing and the antenna PCB.

The antenna circuits were distanced 25 cm (using Friis equation) apart from each other when tested to get the most accurate result. The results slightly matched the ones on the CST with 2.41GHz as the frequency and -28 as the resonant magnitude in dB. The cause of the small difference between the practical and the CST results is due to either human error (soldering the cables to the dipoles) or distortion from interference of signals.

9. Conclusion

The Yagi-Uda antenna radiates using the principle of the dipole antenna theory. In the design half wave dipole, one reflector and two directors are used. It has been concluded experimentally for the dipole that its length has a small effect on forward gain but a large effect on backward gain. Also it has been concluded experimentally for the reflector that it has the longest length in the design as it wants to reflect the signal when its inductive, also 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. Finally it has been concluded experimentally for the directors that it has the shortest length in the design as it focuses radiation in one direction when its capacitive, also the length and spacing of the directors have large effects on the forward gain, backward gain which makes the directors the most crucial element in the antenna design.

10. References

1. Robert E. Collin, Antennas and Radiowave Propagation, New York: McGraw-Hill, 1985
2. Matthew NO. Sadiku, Elements of Electromagnetics, International Fifth Ed. New York: Oxford University Press, 2011.
3. Connor FR. Antennas, Second ed. London: Edward Arnold, 1989.
4. Hardy, James K. Electronic communication technology, London: Englewood Cliffs, 1986.
5. Singh U, Kumar H, Kamal TS. Design of Yagi-Uda Antenna Using Biogeography Based Optimization, IEEE Transactions on Antennas and Propagation. 2010; 58(10):3375-3379.
6. Barbano N. Log Periodic Yagi-Uda Array, IEEE Transactions on Antennas and Propagation, AF-1966, 14(2):235-238.
7. Liang C-H, Cheng DK. Directivity Optimization for Yagi-Uda Arrays of Shaped Dipoles, IEEE Transactions on Antennas and Propagation, AP-31, 1983(3):522-525.
8. Varlamos PK, Papakanellos PJ, Panagiotou SC, Capsalis CN. Multi-objective Genetic Optimization of Yagi-Uda Arrays with Additional Parasitic Elements, IEEE
9. Antennas and Propagation. Magazine 2005; 47(4):92-97.