MATLAB Implementation of Yagi-Uda Antenna using circuit theory approach

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Abstract - **In this paper, the radiation pattern of yagi-uda antenna is simulated in MATLAB using circuit theory approach. Our basic approach was to simulate the radiation pattern for a symmetrically shaped antenna and then maximizing the output parameters by using various techniques such as using reflector surfaces wherever the loss in antenna was due to side lobes. We have designed this antenna using circuit theory and adopting Pocklington's integral equation to calculate the performance given a set of parameters and adjust them to optimize the gain. and have made improvements in the previous designs to have better electric field intensity and directivity.**
Keywords – Yagi-Uda, Pocklington Integral equation, MATLAB

I. Introduction

Yagi-Uda antennas are directional along the axis perpendicular to the dipole in the plane of the elements, from the reflector toward the driven element and the director(s). Typical spacing's between elements vary from about 1/10 to 1/4 of a wavelength, depending on the specific design. The lengths of the directors are smaller than that of the driven element, which is smaller than that of the reflector(s). These elements are usually parallel in one plane, supported on a single crossbar known as a *boom*.

II. Design

Kirchhoff's laws establish relations between current and voltage in electric networks where electrical parameters are considered concentrated in certain points in meshes. They lead to Circuit Theory, which is an engineering area that models electric networks accurately enough while the mesh dimensions are less than wavelength. However, as the dimensions become greater than or equal to the wavelength, the more electrical parameters are distributed through the network. In this way, Circuit Theory should be modified in order to model accurately distributed phenomena and current-voltage relations.

2.1 Finite Difference Time Domain (FDTD) method

The Finite Difference Time Domain (FDTD) method is a general method to solve Maxwell's partial differential equations numerically in the time domain. It has been used extensively to model all kinds of electromagnetic problems, such as radiation, scattering, and circuit problems. However, due to the limitation of computer resources, it is difficult to apply the FDTD method in the modeling of electrically large objects. At the same time, the implementation of the FDTD method requires absorbing boundary conditions to terminate the spatial grid, which adds an additional burden on computational resources. Moreover, the recursive nature of the classic Yee algorithm for the FDTD method implies that all the cells contained in a given volume must be computed. Therefore, when applied to model scattering problems, the computation of free space nodes between scatterers is required even though this is actually unnecessary. As a result, the FDTD method is characteristically time consuming and memory demanding.

2.2 Circuit Theory Approach

Circuit Theory's exactness is established upon network's dimensions regarding the wavelength. If it is large enough, current and voltage in any network branch could be assumed changeless along it. As the network dimensions are equal or higher than wavelength, electric parameters cannot be considered concentrated in certain points but distributed along the network. Therefore, for finding out current and voltage distributions, Maxwell equations must be solved for certain boundary conditions, which lead to an integral equation for the current. As a special case, this integral equation corresponds to Pocklington's one for thin wires, used frequently in antennas.
Since with an N element Yagi-Uda antenna, there are 2N-1 parameters to adjust (the element lengths and relative spacing's), this design adopted here seems to be the more relevant approach.
The theory is based on Pocklington's integral equation for total field generated by an electric current source radiating in an unbounded space as

$$\int_{-1/2}^{1/2} I(z')\left(\frac{\partial^2}{\partial z^2}+ k^2\right)\frac{e^{-jkR}}{R}dz' = j4\pi\omega\varepsilon o Ez.^{t} \qquad (1)$$

The reduced form of the Pocklington's integral equation is

$$\int_{-1/2}^{1/2} I(z')\left(\frac{e^{-jkR}}{R}\right)dz' + k^2 \int_{-\frac{1}{2}}^{\frac{1}{2}} I(z')\frac{e^{-jkR}}{R}dz' = j4\pi\omega\varepsilon o E^{t}z \qquad (2)$$

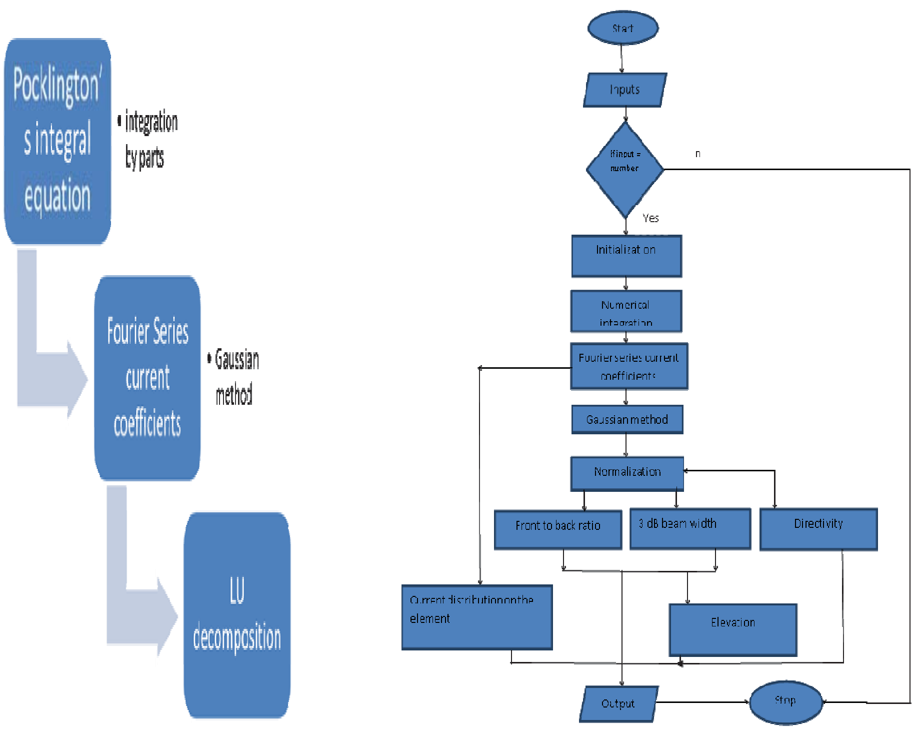


Figure 1. (a) Design steps (b) Flow chart showing the design and measurements

A weighted method - Gaussian method which states "In numerical analysis, a quadrature rule is an approximation of the definite integral of a function, usually stated as a weighted sum of function values at specified points within the domain of integration" is used for integration.

III. RESULTS OF SIMULATION

Table -1 Program Input for the Yagi-Uda Array

PARAMETERS	CASE 1	CASE 2	CASE 3
3-dB BEAMWIDTH IN THE E-PLANE PATTERN	60.01 DEGREES	61.77 DEGREES	32.30 DEGREES
3-dB BEAMWIDTH IN THE H-PLANE PATTERN	78.05 DEGREES	82.26 DEGREES	34.16 DEGREES
FRONT-TO-BACK RATIO IN THE E-PLANE	13.8937 dB	15.4882 dB	8.1523 dB
FRONT-TO-BACK RATIO IN THE H-PLANE	13.8876 dB	15.4827 dB	8.1366 dB
DIRECTIVITY	8.994 dB	8.599 dB	12.782 dB

Table -2 Program output for the Yagi-Uda Array

PARAMETERS	CASE 1	CASE 2	CASE 3	
NUMBER OF MODES PER ELEMENT	2	3	2	
NUMBER OF ELEMENTS	3	3	10	
LENGTH OF DIRECTOR	0.43900 WAVELENGTHS	0.43900 WAVELENGTHS	# 1	0.36000 λ
			# 2	0.34500 λ
			# 3	0.33000 λ
			# 4	0.31500 λ
			# 5	0.30000 λ
			# 6	0.28500 λ
			# 7	0.27000 λ
			# 8	0.37500 λ
LENGTH OF REFLECTOR	0.50200 WAVELENGTHS	0.50200 WAVELENGTHS	0.56250 WAVELENGTHS	
LENGTH OF DRIVEN ELEMENT	0.45200 WAVELENGTHS	0.45200 WAVELENGTHS	0.41250 WAVELENGTHS	
SEPARATION BETWEEN DRIVEN ELEMENT & 1ST DIRECTOR	0.23800 WAVELENGTHS	0.23800 WAVELENGTHS	0.24000 WAVELENGTHS	
SEPARATION BETWEEN REFLECTOR & DRIVEN ELEMENT	0.13800 WAVELENGTHS	0.13800 WAVELENGTHS	0.24000 WAVELENGTHS= SEPARATION BETWEEN DIRECTORS	
RADIUS FOR ALL ELEMENTS USED	2.00000e-003 WAVELENGTHS	1.00000e-003 WAVELENGTHS	3.75000e-002 WAVELENGTHS	

Consequently, these antennas are often empirical designs using an element of trial and error, often starting with an existing design modified according to one's hunch. The result might be checked by direct measurement or by computer simulation. A well-known reference employed in the latter approach is a report published by the National Bureau of Standards (NBS) (now the National Institute of Standards and Technology (NIST)) that provides six basic designs derived from measurements conducted at 400 MHz and procedures for adapting these designs to other frequencies. These designs, and those derived from them, are sometimes referred to as "NBS yagis." There are so many ways to optimize the directivity and other antenna parameters such as the most primitive trial and error method and the simple genetic algorithm method.

Table -3 Program output plots for the Yagi-Uda Array

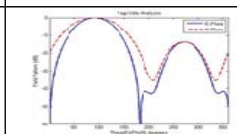
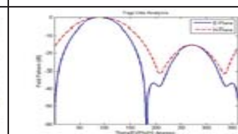
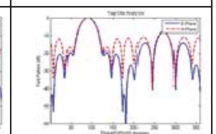
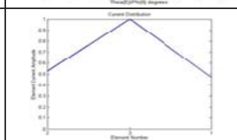
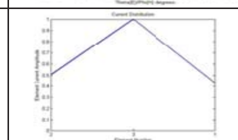
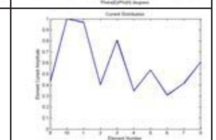
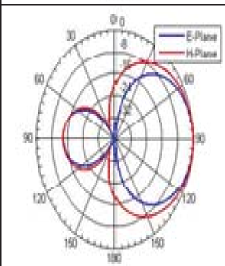
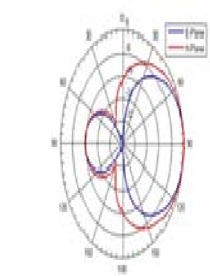
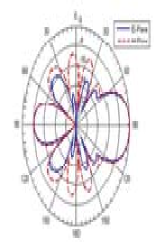
PARAMETERS	**CASE 1**	**CASE 2**	**CASE 3**
Linear plot			
Current distribution			
Polar plot			

Table -4 Program output plots for the Yagi-Uda Array

Number of elements	Approx. anticipated gain(dB over dipole)
2	5
3	7.5
4	8.5
5	9.5

IV.CONCLUSION

The gain of a Yagi antenna is governed mainly by the number of elements in the particular RF antenna. However the spacing between the elements also has an effect. As the overall performance of the RF antenna has so many interrelated variables, many early designs were not able to realize their full performance. Today computer programs are used to optimize RF antenna designs before they are even manufactured and as a result the performance of antennas has been improved.

V. FUTURE ENHANCEMENTS

The front to back ratio is important in circumstances where interference or coverage in the reverse direction needs to be minimized. Unfortunately the conditions within the antenna mean that optimization has to be undertaken for either Front to back ratio, or maximum forward gain. Conditions for both features do not coincide, but the front to back ratio can normally be maximized for a small degradation of the forward gain. For Yagi-uda antenna, the results of Matlab implementation and theoretically calculated results are within the reasonable error limits. Here also, the final radiation possesses minimum radiation intensity in the back lobe (at angle of 180 degrees) and a maximum of lobe power is concentrated in the main lobe along the axis of the antenna. The directivity of the antenna first increases with frequency and then decreases. The simulations, that of Matlab, proved the above mentioned result. These MATLAB implementations can also be expanded for other types of antennas and results are obtained. Calculating the parameters of an antenna required for the work becomes cumbersome and prone to error if done manually or in any other method so this MATLAB procedure finds its application.

VI. ACKNOWLEDGMENT

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