ANALYSIS OF NON UNIFORM SURFACE CURRENT DISTRIBUTION ON THICK AND THIN WIRE ANTENNA

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ABSTRACT

When wires are closely parallel, the surface current distribution becomes non uniform. Normal mode helical antenna is choosing in particular in order to study the effect of surface current distribution along its segmentation from the excitation segments towards the end of the antenna length. Antenna of different wire geometries such as wire thickness, and number of turn is designed to analyze anticipated results. The frequency operating in UHF band frequency spectrum is choose as a contribution towards widely application nowadays. The surface current distribution of thin wire antenna is not uniform as well for thick wire antennas. The difference is that thicker wire antennas results higher amount of current comparing to thin wire antennas. Higher amount of current of the surface wire antenna produce better gain and higher magnetic field strength value.

ABSTRAK

Apabila wayar antenna diletakkan selari, arus pada permukaan menjadi tidak seragam. Mod biasa antena helik dipilih khususnya untuk mengkaji kesan pengagihan permukaan semasa bersama-sama segmentasi dari segmen pengujaan penghujung panjang antena. Antena dengan geometri yang berbeza seperti ketebalan wayar, dan beberapa geometri lain pula direka untuk menganalisis keputusan yang dijangkakan. Frekuensi didalam julat spektrum UHF digunakan diatas faktor sumbangan kepada keperluan masa kini. Pengaliran arus pada permukaan antena wayar nipis adalah tidak seragam begitu juga untuk antena menggunakan wayar yang lebih tebal. Dari segi kuasa penerimaan dan pancaran, perbezaan adalah ketara bahawa antena wayar tebal menghasilkan nisbah kuasa penghantaran yang lebih tinggi jika dibandingkan dengan antena wayar yang lebih nipis. Jumlah yang lebih tinggi semasa antena wayar permukaan menghasilkan keuntungan yang lebih baik dan medan magnet kekuatan nilai yang lebih tinggi. Antena yang mempunyai arus pada permukaan yang lebih tinggi menghasilkan nisbah kuasa penghantaran serta kuasa medan magnet yang lebih tinggi.

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LIST OF SYMBOLS AND ABBREVIATION

D	-	Directivity
E	-	Electric Field Intensity
G	-	Gain
λ	-	Wavelength
C	-	Circumference of a Helix
R_L	-	Loss Resistance
R_r	-	Radiation Resistance
Γ	-	Reflection coefficient
P_a	-	Radiated Power
E_z	-	Electric Field in z domain
V_g	-	Feed Gap
ρ	-	Wire Radius
I_z	-	Current Distribution
C_n	-	Current expansion coefficient
S	-	Spacing between turns
D	-	Diameter of base support
Q-factor	-	Qualitative Behaviour of an Antenna
E-theta	-	Electromagnetic Field Azimuth Angle
E-phi	-	Electromagnetic Field Elevation Angle
NEC	-	Numerical Electromagnetics Code
NMHA	-	Normal Mode Helical Antenna

CHAPTER 1

INTRODUCTION

An antenna is defined as a “transmitting or receiving system that is designed to radiate or receive electromagnetic waves” [1]. An antenna can be any shape or size. A list of some common types of antennas is wire, aperture, microstrip, reflector, and arrays. Each antenna configuration has a radiation pattern and design parameters, in addition to their benefits and drawbacks. Common antenna types such as wire antenna, microstrip antenna, aperture antenna and others have their own benefits and drawbacks. When we design antennas, it is vital to be able to estimate the current distribution on its surface. From the current distribution, we can calculate the input impedance, gain and the far-field pattern for the antenna.

1.0 Antenna parameters

An antenna or aerial is an electrical device design to transmit or receive radio waves or more generally any electromagnetic waves. Antenna is used in system such as radio and television broadcasting, point to point radio communication, radar, space exploration. Physically an antenna is an arrangement of conductors that generate a radiating electromagnetic field in response to an applied alternating voltage and associated alternating electric current or can be placed in an electromagnetic field so that field will induce an alternating current in the antenna voltage between its terminals.

The input impedance of an antenna is the ratio of the voltage to current at the terminals connecting the transmission line and transmitter or receiver to the antenna.

The impedance can be real for an antenna tuned at one frequency but generally would have a reactive part at another frequency.

The electric field is in a plane orthogonal to the axis of a magnetic dipole. This dependence of the plane of the radiated electromagnetic wave on the orientation and types of antenna in terms polarization. A receiving antenna requires the same polarization as the wave that it is to intercept. By combining field from electric and magnetic dipoles that have common centre, the radiated field can be elliptically polarized.

The operating bandwidth of an antenna may be limited by pattern shape, polarization characteristic and its impedance performance. There are two fundamental types of antenna which with reference to a specific three dimensional usually horizontal or vertical plane are either omni-directions antenna or directional antenna. The omni-directional antenna radiated equally in all directions while directional antenna radiates more in one direction than in the one.

1.1 Radiation Efficiency

Radiation efficiency is the "ratio of total power radiate by an antenna to the net power accepted by the antenna from the connected transmitter. Only 50% of the power supplied through the transmitter network is used to transmit. In the best case scenario, the maximum power accepted by the transmitting antenna is 50% of the total power supplied and occurs when the generator impedance and the antenna are matched, usually to 50Ω. The efficiency of an antenna is given by Equation 1.1

$$E = \frac{Pradiated}{P} = \frac{RrI^2}{(Rr + R\mathrm{L})I^2} = \frac{Rr}{(Rr + RL)} = \frac{1}{1 + \frac{RL}{Rr}} \qquad (1.1)$$

R_L is your loss resistance which corresponds to the loss of your antenna and R_r is the radiation resistance.

1.1.2 Directivity and Gain

Directivity is defined as “the ratio of radiation intensity, in a given direction, to the radiation intensity that would be obtained if the power accepted by the antenna where radiating isotropic ally [5]. In other words it’s the ratio of the radiation intensity of an antenna to one that radiates equally in all direction. This is similar to that of antenna gain but antenna gain takes into account the efficiency of the antenna while directivity is the losses gain of an antenna. Directivity can be calculated using the Poynting Vector, P, which tells you the average real power per unit area radiated by an antenna in free space [6]. The equation for the directivity of an antenna is given by Equation 2.

$$D = \frac{P}{P_0}, \qquad D|_{dB} = 10log_{10}\frac{P}{P_0}, \quad P_0 = \frac{P_a}{4\pi r^2} \tag{1.2}$$

Pa is the total power radiated by the antenna and r is the distance between the two antennas. The antenna gain takes into account loss so the gain of an antenna will always be less than the directivity. Knowing the directivity of the antenna, the total power radiated by the antenna, and the received power which takes into account loss, the antenna gain can be calculated using Equation 1.3.

$$G = D\frac{P_a}{P_{accepted\ by\ the\ antenna}} \leq D \tag{1.3}$$

1.1.3 Antenna Bandwidth

Antenna bandwidth is the range of frequencies within which the performance of the antenna, with respect to some characteristic, conforms to a specified standard [5]. The bandwidth can be viewed as the frequencies left and right of the center frequency in which the antenna performance meets the specified values. The impedance bandwidth of an antenna is commonly agreed upon as the power delivered to the antenna greater than or equal to 90% of the available power [6]. Another way to interpret the antenna bandwidth is in terms of the reflection coefficient Γ. Γ is usually plotted in as the power reflection coefficient by using Equation 1.4.

$$|\Gamma|_{dB} = 20log_{10}|\Gamma| = 10log|\Gamma|^2 \qquad (1.4)$$

Figure 1 displays an example of a power reflection coefficient graphed in terms of frequency.

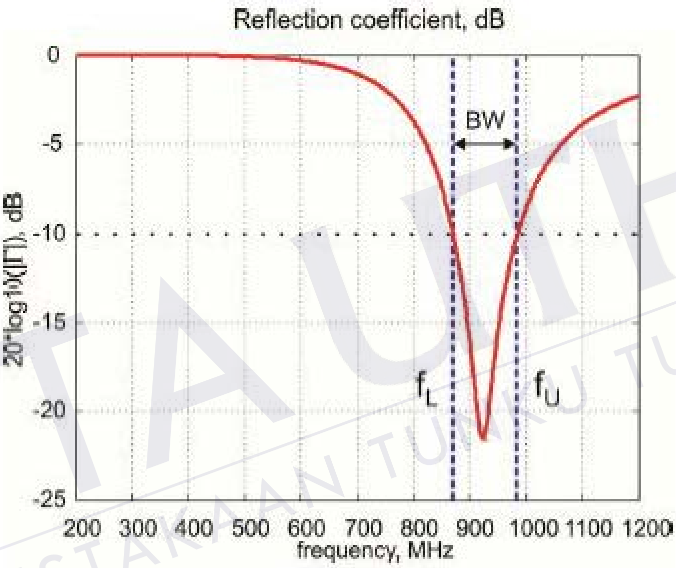

Figure 1.0: Power Reflection Coefficients

f_L represents the lowest frequency that satisfies the 90% power, and f U represents the highest frequency that follows the criteria. The average of f_L and f_c will give you the center frequency fc and the bandwidth or commonly referred to as fractional bandwidth.

1.2 Surface Current Distribution

When wires are closely parallel, the surface current distribution become non-uniform. This effect has been investigated previously subject to certain approximations. Smith and Olaefe assumed that the average current flowing in a set of parallel wires was equal, which means that the cross sectional distribution of surface current remain constant along the wires [3]. These earlier studies were restricted to simple geometries. Tuluyathan used a more general treatment but still neglected the possibility of a circumferential component in the surface current [5]. It is intuitively obvious that such component must be present when there is significant displacement current flow in the inter wire capacitance.

Most of the methods used for analysis of wire antenna of arbitrary shape including the possibility of closely parallel wire assume a uniform surface current distribution across the cross section [8]. Hence, surface resistive losses and reactive effects that may be augmented by the non-uniform surface current will not be correctly predicted.

1.3 Background of Study

The analysis of radiation and scattering from the straight thin wire antenna is one of the most important problems in antenna theory. The excitation of the straight thin wire can be regarded as a standard canonical problem. Furthermore, this configuration itself is one the practical interest in the design of the antenna arrays same as in wire grid modeling. In a numerical sense, this relatively simple geometry is very convenient for testing newly developed numerical techniques.

1.4 Statement of Problem

This problem is particularly significant for resonant coiled electrically smaal antennas, such as normal mode helical antenna, spiral antennas and other closely space antennas, in which the surface current distribution has a critical effect on the efficiency, Q-factor and resonant frequency. A new moment of method is developed which solves this problem.

1.5 Objective of the Study

The principle objectives of the research are depicted as follows.

1.5.1 To design a helix antenna using NEC Software Simulation with matching feeding network in the UHF-Band frequency spectrum.

1.5.2 Analyze the different of thin and thick wire antennas to its surface current distribution.

1.5.3 To optimize the performance of the helix antenna in term of surface current distribution between antennas of different antenna thin and thick dimensions.

1.6 Scope Of The Study

The study will focus on wires that are closely parallel to each other, in particular the normal-mode helical antenna and spiral antenna. The investigation will consider the surface current distribution which has a vital part in contribution to the efficiency, Q-factor and resonant frequency of an antenna.

1.7 Significant of Study

The analysis of non-uniform surface current distribution on wire antennas may improve the understanding of complex coupling processes between surface resistive losses and reactive effects. The design and analysis developed by the end of the research is hoped to determine the surface current distribution for different antenna wire geometries. Results of study might be of interests to related field of study and industry.

CHAPTER 2

LITERATURE REVIEW

2.0 Chapter Overview

In this chapter, several topics on core theories behind the research will be discussed. Section 2.1 provides information on mathematical foundation on method of moments in antenna fundamental design which has been used in the research. Later, a Pocklington Iintegral Equation is discussed in section 2.2 in more details. In section 2.3, researches that have been done previously by others which closely related to this research are revealed and discussed.

2.1 Mathematical Foundations

Moment's technic, as applied to problems in electromagnetic theory, was introduced by Roger F. Harrington (Harrington 1967). Throughout the history of physical science, natural behaviors have been represented in terms of integral-differential equations. In many instances, behaviors are described in terms of simple differential equations.

$$\frac{dy}{dt} = v \tag{2.1}$$

where the function *x(t)* is defined over the domain or *t*. The differential operator then yields the function *x(t)* which also defined over the domain of *t*. In other instances, where the function *v(t)* is known over the domain of *(t)*, specific values of x may be derived from representatives expressions given by:

$$\int_0^{t_1} v(t)dt \tag{2.2}$$

For example, if v(t) = k, then x = kt1. A special case arises when the function v(t) is unknown and values of x are known at only discrete values of t. this type of problem is generally referred to as an integral equation problem where the task is to determine the function v(t) with boundary conditions described by values of x at specific values of t. the task of determining the current distribution on a wire antenna resulting from an arbitrary excitation may be readily stated in terms of an integral equation problem. The formulation begins with the development of an integral expression which defines the electric field resulting from an arbitrary current distribution on the wire. This integral expression will employ a function which relates the electric field at an arbitrary observation point to the current at an arbitrary source point. The integral equation problem then employs the integral expression to relate known electric field boundary conditions to an unknown current distribution on the wire.

The method of moments applies orthogonal expansions to translate the integral equation statement into a system of circuit like simultaneous linear equations. Basic functions are used to expand the current distribution. Testing functions are used to invoke the electric field boundary conditions. Matrix methods are then used to solve for the expansions coefficients associated with the basic functions. The current distribution solution is the constructed from the expansion coefficients. The antenna’s radiation characteristics and feed point impedance are then derived from the calculated current distribution [10].

2.2 Pocklington integral Equation

A well-known formulation for simple wire antennas is Pocklington Integral Equation. The Pocklington integral equation use time domain processing model. Figure 2, depicts a representatives geometry from which Pocklington equation can be derived. A simple wire antenna is positioned along the z axis in a Cartesian coordinate system. The current is restricted to the centerline of the wire and directed along the z axis. Elemental current segments are located at coordinate z’. Field observation pointsb are located at coordinate’s z. A feed gap is positioned at z=0. The electric field along the surface of the wire and in the feed gap, which establishes the boundary conditions for the problem, is defined as follows:

$$E_z = 0 \tag{2.3}$$

On the surface of the wire.

$$E_z = \frac{V_g}{\Delta z} \tag{2.4}$$

At the feed gap, V_g, the antenna excitation, is normally set to 1.0V for input impedance calculations. Δz is commonly set equal to the diameter of the wire. However, it is possible to study the impact of the feed gap dimensions on antenna input impedance by varying the value of Δz.

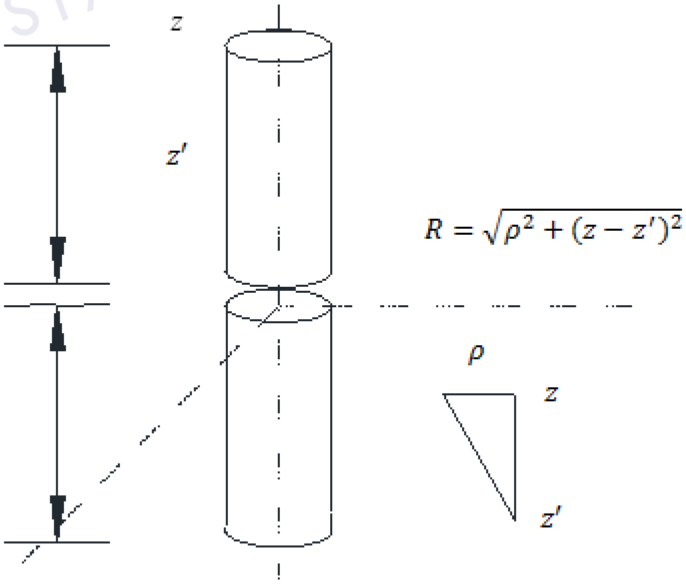

Figure 2.0: Integral Equation Formulation

With the conditions presented in Figure 1, Pocklington’s equation may be written as:

$$\int_{-l/2}^{l/2} I_z(z') \left[\frac{\partial^2}{\partial z^2} + k^2\right] \frac{\varrho^{-jkR}}{4\pi R} dz' = j\omega\varepsilon E_z(z) \qquad (2.5)$$

Where,

$$R = \sqrt{\rho^2 + (z - z')^2} \qquad (2.6)$$

The variable R represents the distance between the current source and field observation points. The variable ρ specifies the radius of the wire. The current distribution $I_z(z')$ is defined along the length of the wire from $z = \frac{l}{2}$ to $z = \frac{-l}{2}$. The kernel $\frac{\partial^2}{\partial z^2} + k^2$ denotes the wave equation differential operator on the free space function. The constant k specifies the free space wave number. $E_z(z)$ represents the electric field generated by the current on the wire. With the specific excitation applied, as modeled through the appropriate boundary conditions, radiation characteristics and feed point impedances are determined from knowledge of the antenna’s current distribution$I_z(z')$. Of the many techniques available to solve such integral equations problems, the method of moments is one of the related filed popular approaches.

2.3 The Method of Moments

The fundamental concept behind the methods of moments employs orthogonal expansions and linear algebra to reduce the integral equation problem to a system of simultaneous linear equations. This is accomplished by defining the unknown current distribution $I_z(z')$ in terms of an orthogonal set of basic functions and invoking the boundary conditions; the values of the electric field on the surface of the wire, and in the feed gap. Moving the currents expansions coefficients to the outside of the integral differential operator permits the evaluation of known functions, yielding values which are loosely defined as impedances. The current expansions coefficients, the orthogonal projections of the electric field boundary conditions, and these impedances are gathered into a system of simultaneous linear equations. This system of equations is solved to yield the current expansion coefficients. The original current distribution is then determined by the introducing these coefficients back into the basic function expansion.

The solution procedure begins by defining the unknown current distribution $I_z(z')$ in terms of an orthogonal set of basic functions. Two categories of basic functions exist. Sub domain basic functions, significantly more popular in industry, subdivide the wire into small segments and model the current distribution on each segment by a simple geometrical construct, such as a rectangle, triangle or sinusoidal arc. The amplitudes of these construct represent the expansion function coefficients. These simple constructs, illustrated in Figure 2.1, often overlap to maintain continuity of the current distribution along the wire.

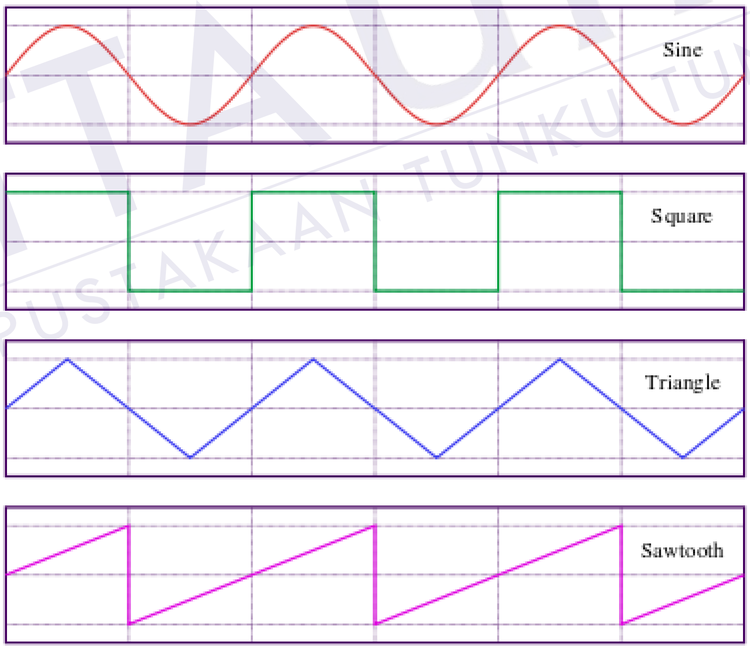

Figure 2.1: Basic Function of Current distribution Construction (en.wikipedia.org)

Entire domain basic functions employ a more formal orthogonal expansion, such as a Fourier Series to represent the current distribution along the entire wire. Entire domain basic functions tend to yield more complicated calculations for the impedances, therefore impractical. The introduction of the redefined current distribution reduces the integral equation to the form:

$$\sum_{n=1}^{N} C_n G_n(z) = E_z(z) \qquad 2.6$$

Where

$$G_n(z) = \frac{1}{j4\pi\omega\varepsilon} \int_{-l/2}^{l/2} F_n(z') \left[\frac{\partial^2}{\partial z^2} + k^2\right] \frac{e^{-jkR}}{R} dz' \qquad 2.7$$

C_n = current’s expansion coefficient
$F_n(z')$ = basic function

The boundary conditions are now enforced through the use of an inner product operator with a set of orthogonal testing function. Each testing function is applied to both sides of the integral equation, the inner product then enforces the boundary condition at the location described by the testing function. This operation may be thought of as simply enforcing the boundary condition at a single point on the wire. After each testing function operation, the integral equation will be stated as:

$$\sum_{n=1}^{N} C_n \langle H_m(z), G_n(z)\rangle = \langle H_m(z), E_z(z)\rangle \qquad 2.8$$

where the fractional equation represent the inner product operator,

$$\langle H_m(z), G_z(z)\rangle = \int_{-l/2}^{l/2} H_m(z) G_n(z) dz \qquad 2.9$$

Where $H_m(z)$ is a testing function which has a non-zero value for only a small segment of wire located at z = Z_m. There are two common approaches to

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