APPLICATION OF THE POWER LINE SYSTEM FOR TRANSMISSION OF RF AND MICROWAVE SIGNALS

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By

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FINAL PROJECT REPORT

Submitted to the Electrical & Electronics Engineering Programme
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CERTIFICATION OF APPROVAL

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Approved:

Professor. Ellis Grant Andrew

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK

June 2009

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Mojdeh Rastgo Dastjerdi

ABSTRACT

The Power Line System has been used for purposes other than the transmission of Electrical power, such as low data rate transmission and even AM broadcast transmission. The broad band over power line (BPL) communication (also known as the power line communication or PLC) has become the topic of considerable interest during the last decades. This technology has been proposed for high data transmission and for a variety of applications including customer Internet access, emergency communications, and utility grid control. The objective of this project is to evaluate the use of the power line system in a typical commercial building for high frequency RF signals (e.g. 100 MHz to 3 GHz) and to develop simple models of the transmission line to evaluate the effects of the attenuation such as line loss and radiation in the power line distribution system and also to analyze the electric and ,magnetic fields around the lines .In order to achieve the objectives of the project, the simple model of the transmission line would be developed to corroborate the model measurements to the result obtained and to evaluate the effect of the attenuation such as line loss and radiation on the transmission line. This will help to evaluate the communication potential of the system. By the end of the project the objectives mentioned above has been achieved the electric field around the line has been analyzed and formulated, the transmission model has been developed and measurements have been obtained and analyzed. It is found that there is high attenuation in the BPL system which is frequency dependent as well as background noises. This significant problems over higher frequencies almost make it impossible to use this system for communication purposes.

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LIST OF ABBREVIATIONS

BPL	: Broad Band over Power Line
ADS	: Advanced Design System

CHAPTER 1
INTRODUCTION

1.1 Background of Study

Power line communication or Broadband over power line (BPL) stands for the use of power supply for communication purposes. Power line network has very extensive infrastructure in nearly each buildings. Because of this fact the use of this network for transmission of data in addition to power supply has gained a lot of attention. Electrical power is transmitted over high voltage transmission lines, distributed over medium voltage, and used inside buildings at lower voltages. Power line communications can be applied at each stage. All power line communications systems operate by impressing a modulated carrier signal on the wiring system. Different types of power line communications use different frequency bands, depending on the signal transmission characteristics of the power wiring used. The frequency spectrum for data communication usually vary depending on the particular system; with the typical operating range being within 3-30 MHz. Higher frequency systems operating in the GHz range have also been proposed [1].

In the BPL system, a signal injector is used to launch a signal on a pair of overhead wires, and this signal propagates on the transmission line that is formed by the pair of wires above the earth. The two wires that form the transmission line are typically two of the three wires that form the three-phase power system. Further down the system the signal is extracted from the power lines and separated from the low frequency power (which is typically at 50 or 60 Hz).

1.2 Problem Statement

During the last decades, power line communication and its variety of application has become the topic of significant interest. Many valuable jobs have been done in this field; however until now there have not been any mathematical model available to describe the transmission of the RF signals in power line system.

The data frequency for using in power line communication usually varies with the typical operating range within 3-30MHz. In this project we are interested to transfer the RF signals, basically in the range of 300MHz to 1.3 GHz.

Analyzing the nature of the field in the vicinity of the power line as well as the nature of the signal on the line versus the distance from the source are considered as other aspects of this project. The nature of the field in vicinity of the power line may provide some interface with other users and the attenuation of the signal along the power line may affect the system in the way of line losses and radiations [1]. .

1.3 Objectives and Scope of Study

The main objective of this project is to evaluate the use of the power line system for communicating the high frequency RF signals in a typical commercial building. Evaluating the effects of the attenuations such as line loss and radiation for the power distribution system are considered as other aspects of this project. The other objectives would be to develop the simple model of the transmission line in order to get the model measurements to evaluate the communication potential of the system.

CHAPTER 2
LITERATURE REVIEW

2.1 Broad Band over Power Line

Broad Band over Power lines is a new type of carrier current technology [2]. In the BPL transmission system carriers will be digitally modulated in the frequency range of 2-80MHz. The BPL topology consist of : PC, Modem, Transition from the residential/commercial low voltage power lines to one of the three phase supplying the residential or commercial establishment , Injector, extractors, repeaters and transition from the power line phase to the fiber optic link (Figure 2.1). The injectors are the interface between the internet and Medium Voltage power lines. The MV power line consists of the three phase wiring which one or more phase could be used to serve the customers [3].

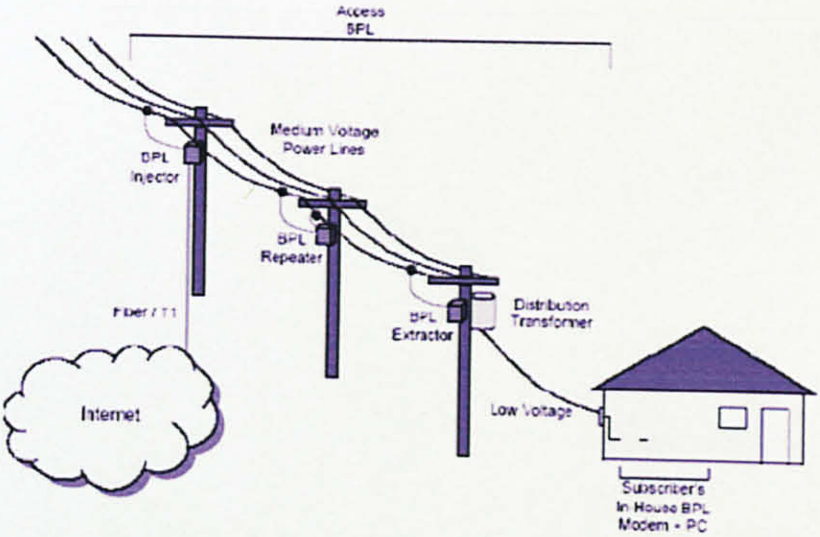


Figure 2.1 Basic BPL System

2.2 Transmission Line

The transmission line's family may cover all structures and media that serve to transfer energy or information between two points. Basically a transmission line is a two port network (sending and receiving end), with each port consisting of two terminals as shown in Figure 2. The source (generator circuit) is known as any kind of circuit with the output voltage connected to the sending port while the circuit connected to the receiving end of the transmission line is called load [4]. Our interest of transmission line is more specific in transmission of guided electromagnetic signal or Transverse Electromagnetic (TEM) transmission lines. The waves propagating along these lines are characterized by electric and magnetic field that are entirely transverse to the direction of propagation [5]. Figure 3 shows the equivalent circuit of a two conductor transmission line.

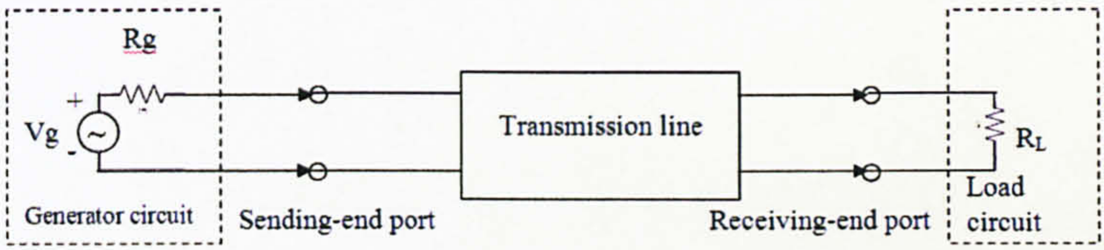


Figure 2.2 Transmission Line

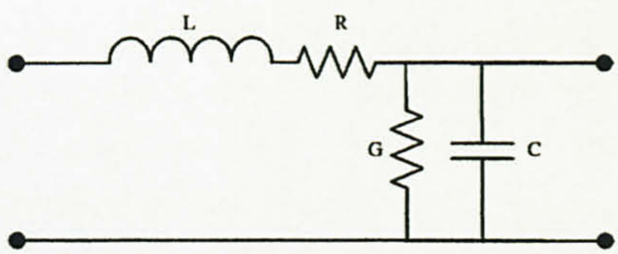


Figure 2.3 The equivalent circuit of a two conductor transmission line

The transmission line consider for this project consists of a pair of wires , one vertically displaced from the other one, suspended over the earth as shown is Figure 4.

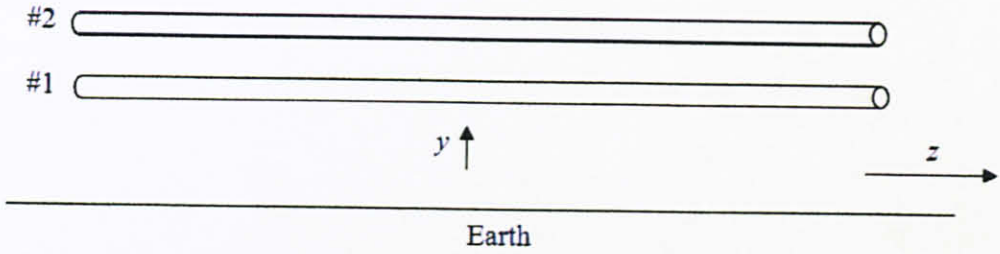


Figure 2.4 The BPL system, consisting of the two vertically displaced wires suspended over the earth

2.3 The Electric Field around the Transmission Line

A straight forward approach for findings the electric field and magnetic fields as a point Q (r ,θ, φ) in space (Figure 5), due to the radiation by a current source is through the retarded vector potential A. The phasor retarded vector potential $\tilde{A}(R)$ at distance vector r' (equation 2), from volume v' containing a phasor current distribution $\tilde{J}$ is given by

$$\tilde{A}(R) = \frac{\mu_0}{4\pi}\int_{v'} \frac{\tilde{J}e^{-jkR}}{R} dv' , \tag{1}$$

Where μ_0 is the magnetic permeability of free space and k= $2\pi/\lambda=\omega/c$ is the wave number, since the direction of the propagation is in the z direction the current density is simply $J = \hat{z}(I_0/s)$ where (s) is the cross sectional of the cable. The limits of the integration also are varies from $-l/2$ to $l/2$. Based on what mentioned the vector potential is given by:

$$r' = \sqrt{r^2 + z'^2 - 2rz'\cos\theta} , \tag{2}$$

$$\tilde{A} = \frac{\mu_0 I_0}{4\pi}\int_{-l/2}^{l/2} \frac{e^{-jkr'}}{r'}\hat{z}dz' , \tag{3}$$

Where θ is the angle between the z and y axes or the angle between the z axes, and the x-y plane.

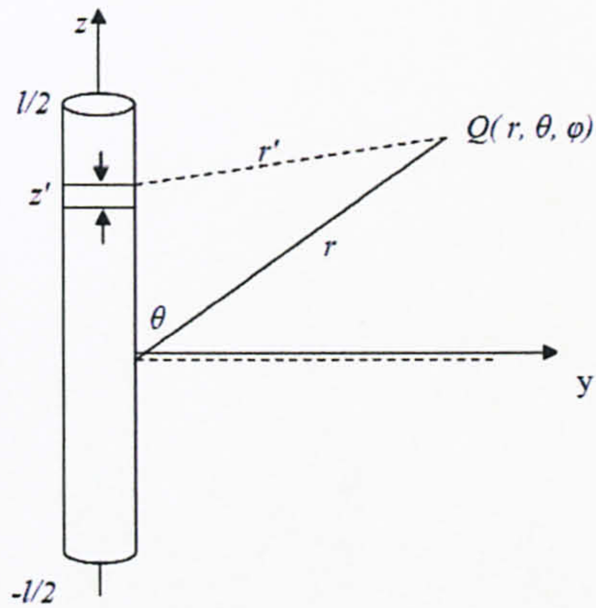


Figure 2.5 Distance r' from the line

Using the above equations and the free space relationships, will result in the electric and magnetic field:

$$\tilde{H} = \frac{1}{\mu_0} \nabla \times \tilde{A} , \tag{4}$$

$$\tilde{E} = \frac{1}{j\omega\varepsilon_0} \nabla \times \tilde{H} , \tag{5}$$

$$H_\phi = \frac{I_0 k^2}{4\pi} [j \int_{-l/2}^{l/2} \frac{e^{-jkr'}}{kr'} dz' + \int_{-l/2}^{l/2} \frac{e^{-jkr'}}{(kr')^2} dz'] \sin\theta , \tag{6}$$

$$E_R = \frac{2 I_0 k^2}{4\pi} \eta_0 [\int_{-l/2}^{l/2} \frac{e^{-jkr'}}{(kr')^2} dz' - j \int_{-l/2}^{l/2} \frac{e^{-jkr'}}{(kr')^3} dz'] \cos\theta , \tag{7}$$

$$E_\theta = \frac{I_0 k^2}{4\pi} \eta_0 [j \int_{-l/2}^{l/2} \frac{e^{-jkr'}}{kr'} dz' + \int_{-l/2}^{l/2} \frac{e^{-jkr'}}{(kr')^2} dz' - j \int_{-l/2}^{l/2} \frac{e^{-jkr'}}{(kr')^3} dz'] \sin\theta , \tag{8}$$

In the above equations $\eta_0 \cong 120\pi\,(\Omega)$, is the intrinsic impedance of free space. The remaining components E_ϕ, H_R, H_θ have the value of zero [5].

2.4 Filon's Sine and Cosine Formula [6]

The Filon method is applied to have the more accurate integration. These formulas can be applied to integrals of the form:

$$\int_a^b f(x)\cos(kx)dx \quad \text{and} \quad \int_a^b f(x)\sin(kx)dx\ , \tag{9}$$

$$\int_0^{2\pi} f(x)\cos(kx)dx = h[A\{f(x_n)\sin kx_n - f(x_0)\sin kx_0\} + BC_e + DC_o], \tag{10}$$

$$\int_0^{2\pi} f(x)\sin(kx)dx = h[A\{f(x_0)\cos kx_0 - f(x_n)\cos kx_n\} + BS_e + DS_o], \tag{11}$$

Where $h= (a-b)/n$, $q=kh$ and

$$A = (q^2 + q\sin 2q/q - 2\sin^2 q)/q^3, \tag{12}$$

$$B = 2\{q(1+\cos^2 q) - 2\sin q\}/q^3, \tag{13}$$

$$D = 4(\sin q - q\cos q)/q^3, \tag{14}$$

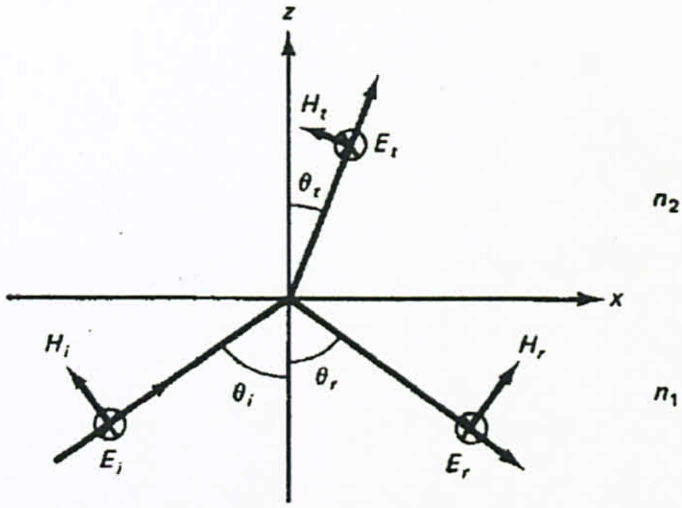
$$C_O = \sum_{i=1,3,5,\ldots}^{n-1} f(x_i)\cos kx_i\ , \tag{15}$$

$$C_e = \frac{1}{2}\{f(x_0)\cos kx_0 + f(x_n)\cos kx_n\} \sum_{i=2,4,6,\ldots}^{n-2} f(x_i)\cos kx_i\ , \tag{16}$$

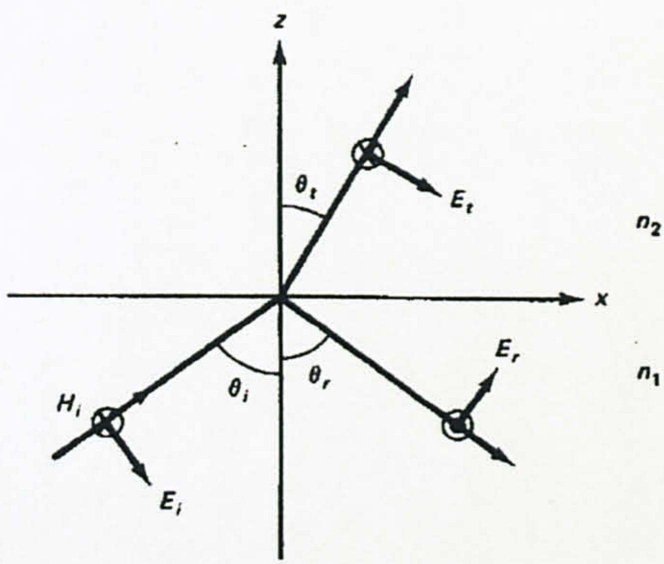
It can be seen that C_o and C_e are the odd and even sums of the cosine terms. S_o and S_e are similarly defined with respect to sine terms. The MATLAB codes used for the Filon method are shown in Appendix A.

2.5 Plane-wave Incidence on Plane-wave Boundary [7]

By considering the reflection of a plane wave incident on a single boundary separating two media with the dielectric constant ε_1 and ε_2 and permeability μ_1 and μ_2 , respectively (Figure 2.6). The plane of incident has been defined as the plane including the direction of the wave propagation and the normal to the boundary. The x-z plane considered to be the plane of incidence. The angle of incidence θ_i is defined as the angle between the direction of propagation and the normal to the boundary (Figure 2.6).



(a)



(b)

Figure 2.6 The reflection on a plane wave incident on a single boundary separating the two media (a) Perpendicular and (b) Parallel Polarization

The relative indexes n_1 and n_2 are given by $n_1 = [(\varepsilon_1\mu_1)/(\varepsilon_0\mu_0)]^{1/2}$, (17) and $n_2 = [(\varepsilon_2\mu_2)/(\varepsilon_0\mu_0)]^{1/2}$, (18) and the characteristic impedance of the medium is $\eta_1 = (\mu_1/\varepsilon_1)^{1/2}$, and $\eta_2 = (\mu_2/\varepsilon_2)^{1/2}$, respectively.

The two cases shown in Figure 6 consists (a) perpendicular polarization (electric field perpendicular to the plane of incidence) and (b) parallel polarization (electric field parallel to the plane of incidence). Case (a) is also called *s polarization* on the TE wave (electric wave is transverse to the direction of wave propagation). Case (b) is then called the *p polarization* (parallel) or the TM wave (magnetic field is transverse to the direction of the wave propagation). These two waves are independent in fact for the two dimensional problems where the dielectric constant and permeability are functions of x and z only, the electromagnetic field can be separated into two independent waves: TE and TM.

In the first case we consider the perpendicular polarization to prove the law of reflection and Snell's law.

Based on $i = \hat{x}\sin\theta_i + \hat{z}\cos\theta_i$, (19) the incident field E_{yi} with magnitude E_0 will define as ;

$$E_{yi} = E_0 \exp(-jq_i z - j\beta_i x) \ , \tag{20}$$

Where $q_i = k_1\cos\theta_i , \beta_i = k_1\sin\theta_i$, $k_1 = \omega(\mu_1\varepsilon_1)^{1/2} = k_0 n_1$, is the wave number in medium I and $k_0 = \omega(\mu_0\varepsilon_0)^{1/2}$ is the free space wave number. The reflection field also satisfies the wave equation, and there for

$$E_{yr} = R_s E_0 \exp(+jq_r z - j\beta_r x), \tag{21}$$

Where R_s is the reflection coefficient for perpendicular polarization, (s-polarization), $q_r = k_1\cos\theta_r$, $\beta_r = k_1\sin\theta_r$, and the θ_r is the angle of the reflection . Similarly for the transmitted filed

$$E_{yt} = T_s E_0 \exp(-jq_t z - j\beta_t x), \tag{22}$$

Where T_s is the Transmission coefficient for perpendicular polarization, (s-polarization), $q_t = k_2\cos\theta_t$, $\beta_t = k_2\sin\theta_t$, $k_2 = k_0 n_2$ and the θ_t is the angle of the transmission. By applying the boundary conditions at $z=0$: the continuity of the tangential electric field E_y, and the magnetic field H_z. Continuity of the tangential electric field:

$$E_{yi} + E_{yr} = E_{yt} \text{ at } z = 0, \tag{23}$$

This yields the following:

$$\exp(-j\beta_i x) + R_s \exp(-j\beta_r x) = T_s \exp(-j\beta_t x), \tag{24}$$

For this to hold at all x, all exponents must be the same, thus we get the phase-matching condition:

$$\beta_i = \beta_r = \beta_t \ , \tag{25}$$

This yields to the law of reflection $\theta_i = \theta_r$, (26)

and Snell's law, $n_1 \sin\theta_i = n_2 \sin\theta_t$, (27)

We now consider the parallel polarization, by considering E_0 the magnitude of the incident electric filed. The x component of the incident electric filed is given by

$$E_{xi} = E_0 \cos\theta_i \exp(-jq_i z - j\beta_i x)\,, \tag{28}$$

Based on the laws of reflection and Snell's law, the reflected and transmitted waves are

$$E_{xr} = R_p E_0 \cos\theta_i \exp(+jq_i z - j\beta_i x)\,, \tag{29}$$

$$E_{xt} = T_p E_0 \cos\theta_t \exp(-jq_t z - j\beta_i x)\,, \tag{30}$$

The magnetic filed H_y is related to E_x by

$$E_x = -\frac{1}{j\omega\varepsilon}\frac{\partial}{\partial z}H_y \ , \tag{31}$$

This yields to:

$$H_{yi} = \frac{E_0}{Z_1}\cos\theta_i \exp(-jq_i z - j\beta_i x), \tag{32}$$

$$H_{yr} = \frac{-R_p E_0}{Z_1}\cos\theta_i \exp(+jq_i z - j\beta_i x)\,, \tag{33}$$

$$H_{yt} = \frac{T_p E_0}{Z_2}\cos\theta_t \exp(-jq_t z - j\beta_i x)\,, \tag{34}$$

Where wave impedances Z_1 and Z_2 are given by

$$Z_1 = \frac{q_i}{\omega\varepsilon_1} \tag{35}$$

$$Z_2 = \frac{q_t}{\omega\varepsilon_2}, \tag{36}$$

Applying the boundary conditions :

$$E_{xi} + E_{xr} = E_{xt} \tag{37}$$

$$H_{yi} + H_{yr} = H_{yt}, \tag{38}$$

Yields the following:

$$1+R_P=T_P\frac{\cos\theta_t}{\cos\theta_i} \tag{39}$$

$$\frac{1-R_P}{Z_1}=\frac{T_P}{Z_2}\frac{\cos\theta_t}{\cos\theta_i}, \tag{40}$$

Equation (39) and (40) the *frensel formula* will obtain:

$$R_p=\frac{Z_2-Z_1}{Z_2+Z_1}, \tag{41}$$

$$T_p=\frac{2Z_2}{Z_2+Z_1}\frac{\cos\theta_i}{\cos\theta_t}, \tag{42}$$

The wave impedances Z_1 and Z_2 are shown in equation (35) and (36).

If $\mu_1=\mu_2=\mu_0$, equation (34) is reduced to more familiar form:

$$R_p=\frac{(1/n_2)\cos\theta_t-(1/n_1)\cos\theta_i}{(1/n_2)\cos\theta_t+(1/n_1)\cos\theta_i}, \tag{43}$$

And $$T_p=\frac{(2/n_2)\cos\theta_i}{(1/n_2)\cos\theta_t+(1/n_1)\cos\theta_i}, \tag{44}$$

Where $$\cos\theta_t=[1-(n_1/n_2)^2\sin^2\theta_i]^{1/2}, \tag{45}$$

2.6 NEC (Numerical Electromagnetic Code) -WIN Professional Software [8]

The Numerical Electromagnetic Code (NEC) is an outgrowth of a program developed by Nittany Scientific in the 1970s, called the Antenna Modeling Program (AMP). NEC in all its forms is a computer code for the analysis of the electromagnetic response of antennas and other metal structures that use method-of-moments techniques for the numerical solution to integral equations for the currents induced on an antenna structure by sources or incident fields. The approach has no theoretical limit and may be used for very large arrays or for the very fine subdivision of smaller arrays.

NEC-WIN Professional is an initiative program that helps antenna designers quickly and efficiently design and analyze antennas. Novice and advanced designers alike will appreciate the power and ease-of-use of this program. NEC-WIN Pro uses the powerful Numerical Electromagnetic Code (NEC) as a core for antenna analysis.

The Numerical Electromagnetic Codes is a user oriented computer code for analysis of the electromagnetic response of antennas and other metal structures. It is built around the numerical solution of integral equations for the current induced on the structure by sources or incident fields. This approach avoids many of simplifying assumptions required by other solution methods and provides a highly accurate and versatile tool for electromagnetic analysis. The code combine an integral equation for smooth surfaces with one specialized to wires to provide for convenient and accurate modeling of a wide range structures. A model may include non radiating networks and transmission lines connecting parts of the structure, perfect or imperfect conductors, and lumped element loading .A structure may also be modeled over a ground plane that may be either a perfect or imperfect conductor. The excitation may be either voltage sources on the structure on an incident plane wave of linear or elliptic polarization. The output may include induced current and charges, near electric or magnetic fields, and radiated fields. Hence, the program is suited to either antenna analysis or scattering and EMP studies.

CHAPTER 3
METHODOLOGY

In order to accomplish the objectives of this project the following procedures were conducted;

Planning-This phase is the fundamental process of understanding why this research should be conducted and it determines how the project is going to be approached.

Analyzing-This phase answers the questions of who will use the results of this research, what the results will do and where it will be used.

Identifying the alternatives-This phase is where all the alternative solutions to the problem are identified and analyzed.

Testing and simulating - This phase is where a conclusion is finally reached based on a set of tests conducted and obtained result of models simulated.

The flow chart for the methodology of this project is shown in Figure 3.1.

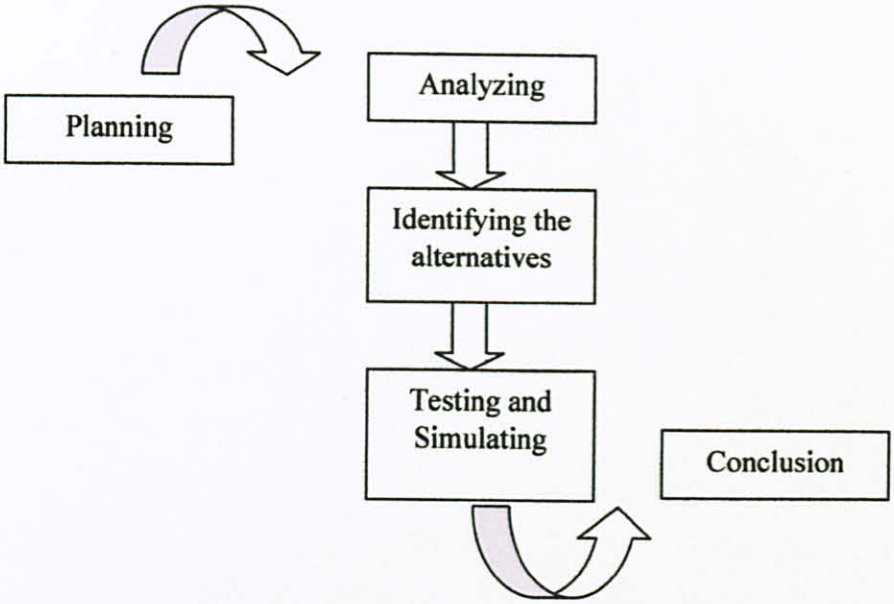


Figure 3.1 Flow Chart of the project Methodology

Below more details are given on each stage of the methodology.

3.1 Planning

In order to understand the need for this research a solid literature review had to be conducted. Sufficient information has been gathered on the problems concerning application of the power line system for transmission of communication signals, and broad band over power line as seen in the literature review in section 2. Based on the information gathered, it is obvious that broad band over power line system is a new technology which is being applied in the range of low frequency mostly. It could also be concluded that broad band over power line can be used in different aspects where the communication signals are required. So the need for this research has been identified.

To carry out this project software such as, MATLAB, NEC WIN Professional, Advanced Design System (ADS) and equipment such as circuit analyzer are going to be used. MATLAB software has evolved into a very common and standard tool for rapidly prototyping and testing algorithms in the academic and scientific communities. NEC WIN Professional is an initiative program that helps antenna designers quickly and efficiently design and analyze antennas. Advanced Design

System (ADS) is a powerful electronic design automation software system. It supports developing RF designs, from simple to most complex. With a complete set of simulation technologies ranging from frequency-, time-, numeric and physical domain simulation to electromagnetic field simulation, ADS allow us to characterize and optimize designs.

3.2 Analyzing

The research intends to identify the best algorithm available for calculating and analyzing the electric field around the lines. The electric field is calculating to analyze the potential of the system to support the broad band over the system. Based on the literature review and background of study it is clear that there is not any mathematical model to describe the transmission of the RF signals in power line system. In order to find the nature and characteristics of the electric and magnetic field above the transmission line to fulfill the required information to design the model, the basic theories mentioned in chapter 2 has been used.

3.3 Identifying the alternatives

In order to evaluate the system potential, calculating the electric and magnetic fields, analyzing the effects of the power line on both fields and comparing the results two approaches have been used by using two different softwares. First the codes were implemented by using the MATLAB software. By considering the ground effect the electric field was analyzed around the transmission line while the current considered constant. Second the codes were implemented by using NEC WIN Professional software. The same assumptions and conditions as MATLAB were made in this session as well, with the difference of existing standing wave on the lines (variable current on the lines). After obtaining the results they were compared to each other to certify the conditions of the fields around the lines.

3.4 Testing and Simulating

After creating an M-file in MATLAB for finding the electric field, and considering the feasible situation of the transmission line, the electric field were calculated in two conditions, existence of the ground, by considering the plane wave incidence and without existence of the ground.

The same situations were applied for the codes implemented in NEC WIN professional software, to analyze the field behaviors in existence or not existence of the ground.

After analyzing the fields, a transmission model was constructed to obtained the transmission and reflection coefficient of the lines. The reflection and transmission coefficients were measured by network analyzer. The obtained result were simulated by ADS (Advanced Design System), to evaluate the transmission line response to higher frequencies and also to find the main requirements of the BPL system.

The result obtained from each part is shown in chapter 4. Figure 3.2 shows the steps followed in the analyzing, identifying alternatives as well as testing and simulating stage in more detail.

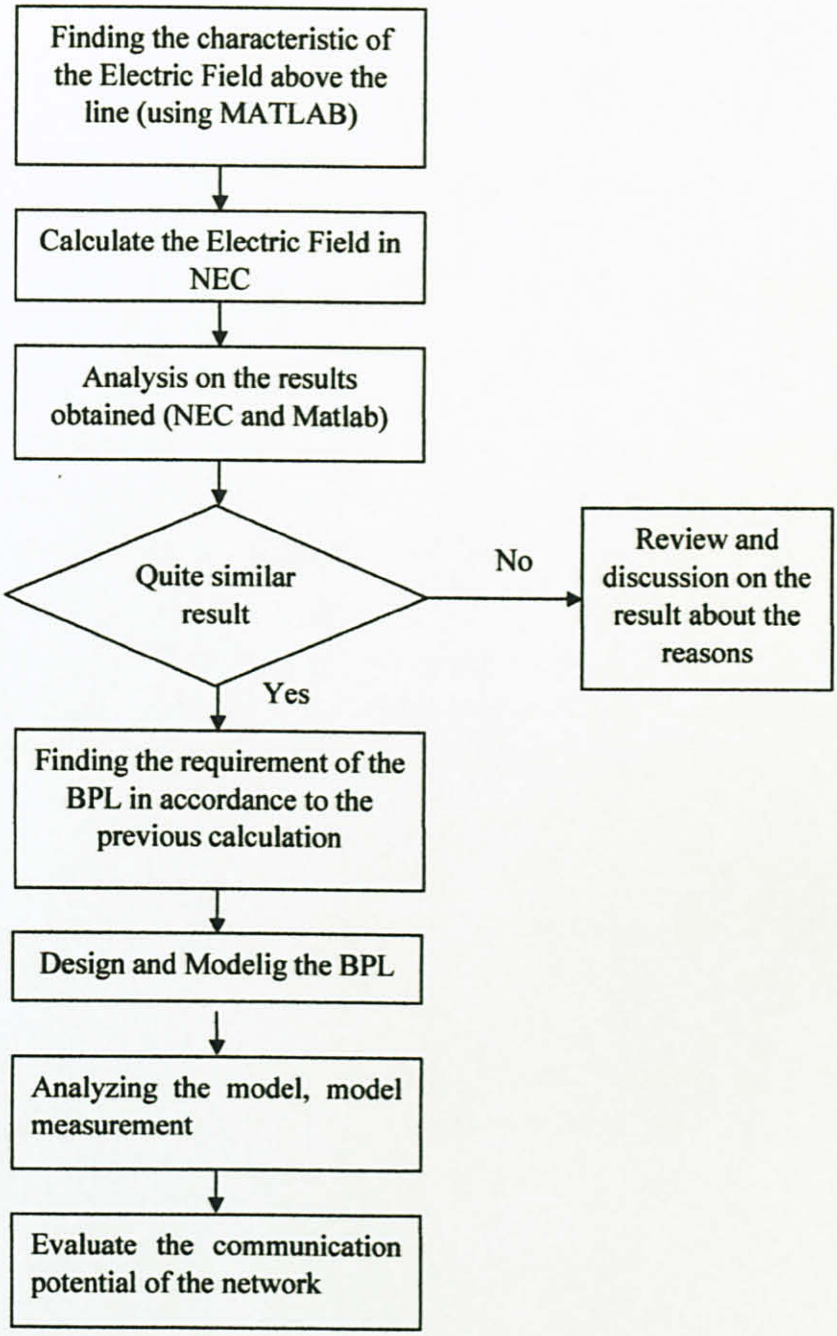


Figure 3.2 The flow chart of the project in more detail

CHAPTER 4

RESULT AND DISSCUSSION

In this chapter we will go through the work and result obtained during analyzing the application of the power line system for transmission of RF and microwave signals.

During the first stage of the project, the major attention paid to analyze and calculate the nature of the electric field about the line. The results were compared with the previous references in this field, basically with the result mentioned in IEEE paper ("*Investigation of Fields and Currents for Broadband over Power Line BPL Communication* "), done by D.R Jackson [1- Figure3].

To certify the accuracy of the reference result in compare to the obtained result from MATLAB , NEC WIN Professional software were used to calculate the near electric field around the wires. Different conditions were considered to calculate the fields were the major conditions changed by considering the existence of the ground and applying the plane wave incidence. The results obtained from both softwares are shown in the next section.

In order to calculate the electric field about the lines, we considered the BPL model (Figure 2.4) [1] contains of the two parallel wires in the z direction at 30 MHz frequency. The features of the wires and the model are tabulated in Table 4.1.

Table 4.1 Features of the BPL System

Height of the first wire	8 meter from the ground
Height of the second wire	11 meter from the ground
Earth relative permittivity	$n = \sqrt{8.0}$
Earth conductivity	σ=0.1 S/m
Zenith angle , (angle between the lines and x-y plane)	θ =90° (Figure 4.1)

Azimuth angle (angle from the x and y axis to the point)	$\Phi = 45°$ (Figure 4.1)
Length of the wires	1000 m
Nominal current	1.25 mA
Radius of the wire	0.0113 m
Wire conductivity	$\sigma = 3.77\times10^7$ S/m
Voltage source used in NEC WIN Pro	0.9V
Terminated Resistances used in NEC WIN Pro	R= 13 Ohm

4.1 MATLAB Result

The positions of the wires are in accordance to the features mentioned in the previous part are shown in Figure 4.1. In the first condition, free space, the total electric field is obtained from the subtraction of the fields on each wire. As it is shown in the figure 4.1 the electric filed is calculated along the distance of the line in the x-y plane and based on the same assumptions, the $\theta = 90°$, the E_R component of the Electric field will be eliminated.

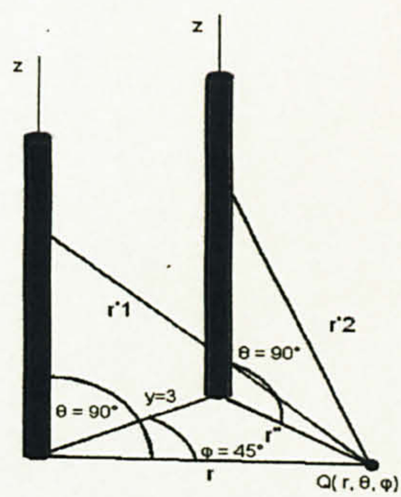


Figure 4.1 The position of the wires in Spherical coordinates

In the second condition, existence of the ground and plane wave incidence, the total electric field is obtained by considering four fields, electric field and reflection on each wire. The position of the wires and reflection distance for each wire is shown in figure 4.2. These distances were calculated to find the reflection coefficient for the applied situation.

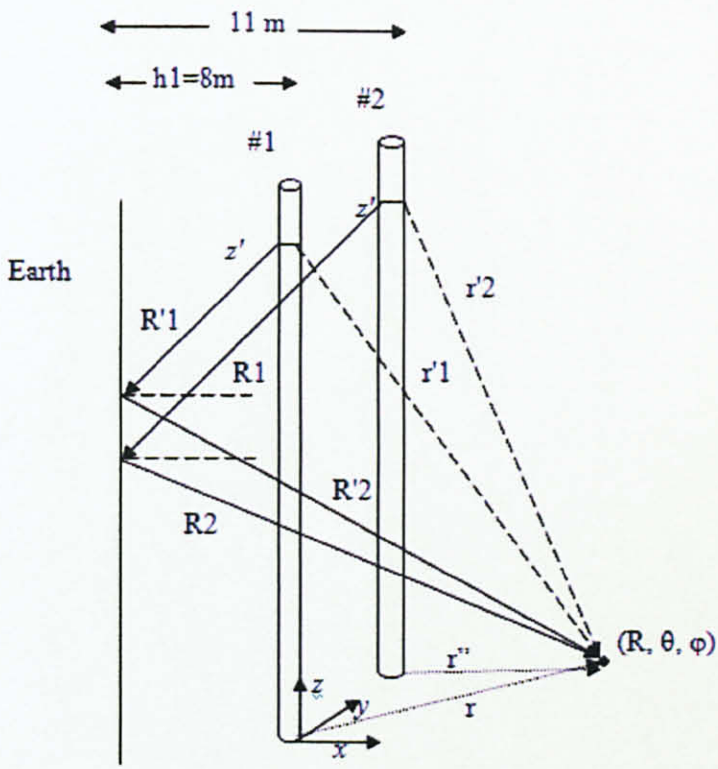


Figure 4.2 The reflected distance for the two wires

The electric fields on each wire in accordance to the information mentioned in chapter 2 will be in the following form:

$$E1_{\theta} = \frac{I_0 k^2}{4\pi}\eta_0 [j \int_{-l/2}^{l/2} \frac{e^{-jkr_1'}}{kr_1'} dz' + \int_{-l/2}^{l/2} \frac{e^{-jkr_1'}}{(kr_1')^2} dz' - j \int_{-l/2}^{l/2} \frac{e^{-jkr_1'}}{(kr_1')^3} dz'] \sin\theta$$

(46)

$$E2_\theta = \frac{I_0 k^2}{4\pi}\eta_0 [j\int_{-l/2}^{l/2} \frac{e^{-jkr_2'}}{kr_2'}dz' + \int_{-l/2}^{l/2} \frac{e^{-jkr_2'}}{(kr_2')^2}dz' - j\int_{-l/2}^{l/2} \frac{e^{-jkr_2'}}{(kr_2')^3}dz'] \sin\theta$$
(47)

Parameters r'_1 and r'_2 are the distance from the (z) position on the wires to the desired point in x-y plane. These distances are shown clearly in Figure 4.3. The relative calculations are shown as well.

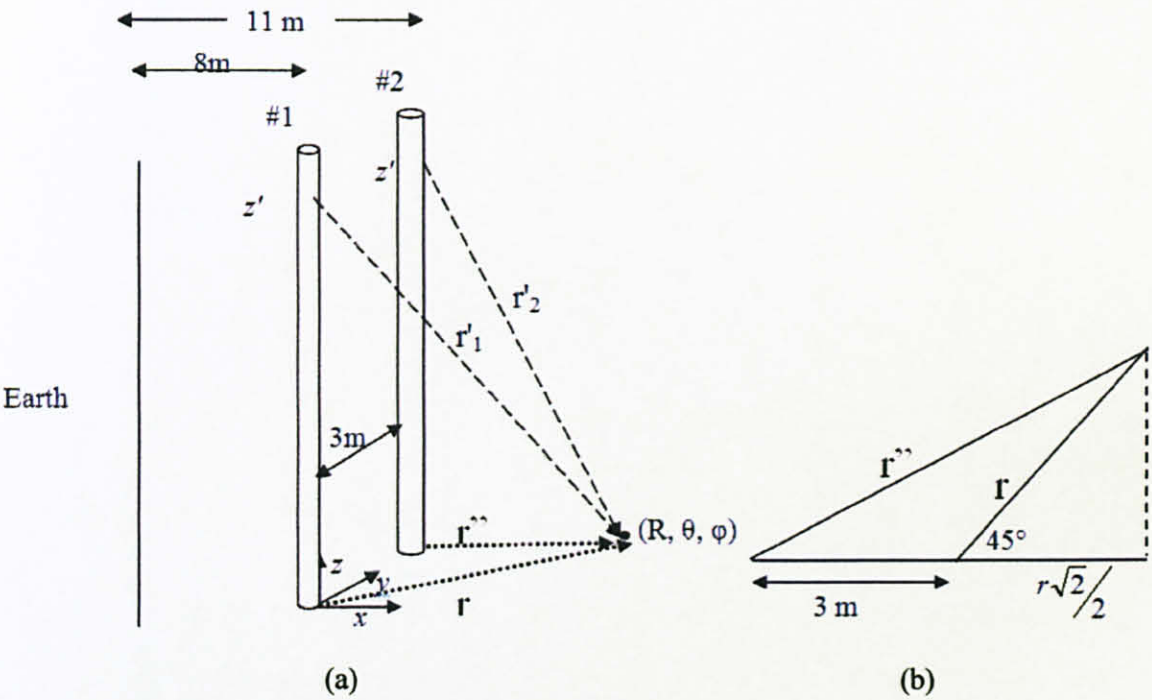


Figure 4.3 (a) The distances from the wires to the desired point, (b) Reflection with the distance

$$r'' = \sqrt{r^2 + 9 - (3r\sqrt{2})}\,, \tag{48}$$

$$r_1' = \sqrt{r^2 + z'^2}\,, \tag{49}$$

$$r_2' = \sqrt{r''^2 + z'^2}\,, \tag{50}$$

In order to have more accurate integration for the length of the wires , and since the assumptions were made on the wires with long length, the Filon integration method has been used. In accordance to the information mentioned in chapter 2, the Filon method is applicable to the functions in the form of sine and cosine functions. Consequently the electric fields have been calculated in the following form:

$$E1_\theta = \frac{I_0 k^2}{4\pi}\eta_0[j\int_{-l/2}^{l/2}\frac{\cos(kr_1') - j\sin(kr_1')}{kr_1'}dz' + \int_{-l/2}^{l/2}\frac{\cos(kr_1') - j\sin(kr_1')}{(kr_1')^2}dz'$$
$$-j\int_{-l/2}^{l/2}\frac{\cos(kr_1') - j\sin(kr_1')}{(kr_1')^3}dz']\sin\theta \tag{51}$$

$$E2_\theta = \frac{I_0 k^2}{4\pi}\eta_0[j\int_{-l/2}^{l/2}\frac{\cos(kr_2') - j\sin(kr_2')}{kr_2'}dz' + \int_{-l/2}^{l/2}\frac{\cos(kr_2') - j\sin(kr_2')}{(kr_2')^2}dz'$$
$$-j\int_{-l/2}^{l/2}\frac{\cos(kr_2') - j\sin(kr_2')}{(kr_2')^3}dz']\sin\theta \tag{52}$$

In this case we have six different functions in form of sine and cosine. Electric field is obtained from adding all of them after each is integrated based on Filon method for the wires with 1000 meters long.

In the following we will go through the calculations for the reflection distances for the second wire, and the first wire respectively, In the next page Figure 4.4 , shows the distances in accordance to the second wire.

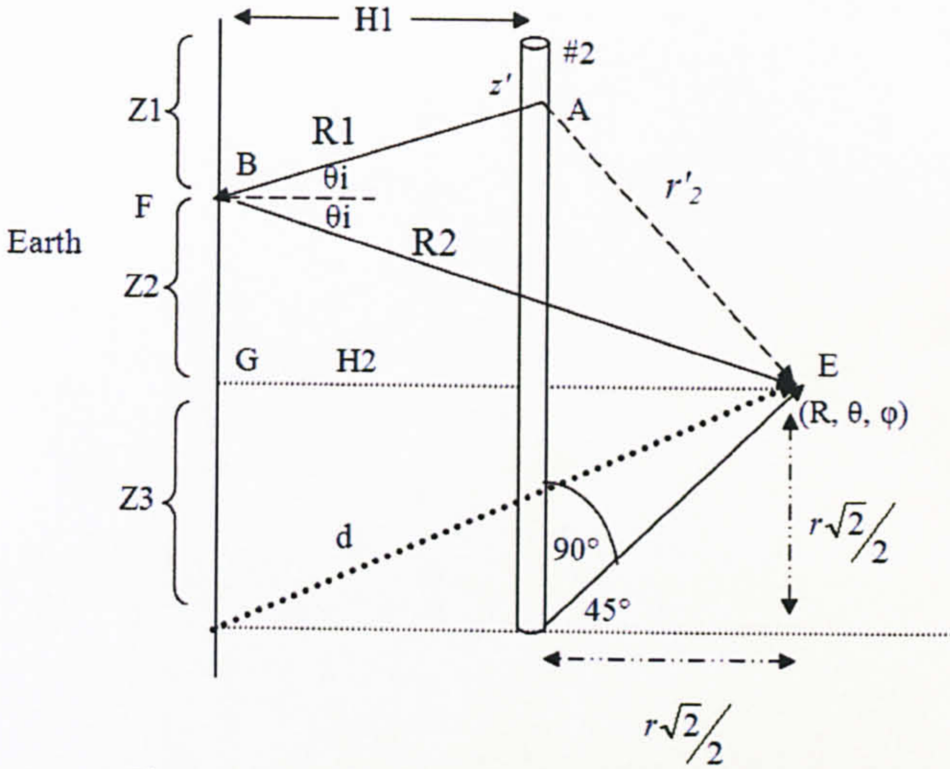


Figure 4.4 The reflection distances for Wire number 2

$$
\left.\begin{array}{l}
H_1 = 11m \\
d = (11^2 + r^2 - 11r\sqrt{2})^{1/2}, \\
H2 = H1 + \dfrac{r\sqrt{2}}{2}, \\
Z3 = (H2^2 - d^2)^{1/2}, \\
Z = Z1 + Z2 + Z3 \\
Z^2 + r^2 = r_1^2 \Rightarrow z^2 = r_1^2 - r^2 \\
H2 = H1 + {}^{r\sqrt{2}}\!/_{2} \\
\Delta ABF \cong \Delta FEG \Rightarrow \dfrac{H1}{Z1} = \dfrac{H1 + {}^{r\sqrt{2}}\!/_{2} + 3m}{Z2} \\
Z2 = Z - Z1 - Z3
\end{array}\right\} \Longrightarrow
\begin{array}{l}
\dfrac{H1}{Z1} = \dfrac{H1 + {}^{r\sqrt{2}}\!/_{2} + 3}{Z - Z1 - Z3} \\
\dfrac{H1}{Z1} = \dfrac{H1 + {}^{r\sqrt{2}}\!/_{2} + 3m}{Z - Z1 - (H2^2 - d^2)^{1/2}}
\end{array}
$$

$$\Longrightarrow \begin{cases} Z1 = \dfrac{2ZH1 - 2H1(H2^2 - d^2)^{1/2}}{19 + {}^{r\sqrt{2}}\!/_2} & (53) \\ Z2 = Z - Z1 - (H2^2 - d^2)^{1/2} & (54) \end{cases}$$

$$\Longrightarrow \begin{cases} R1^2 = Z1^2 + H1^2 & (55) \\ R2^2 = Z2^2 + (H1 + {}^{r\sqrt{2}}\!/_2 + 3)^2, & (56) \end{cases}$$

With the same method and based on Figure 4.5 the distances of the first wire calculated

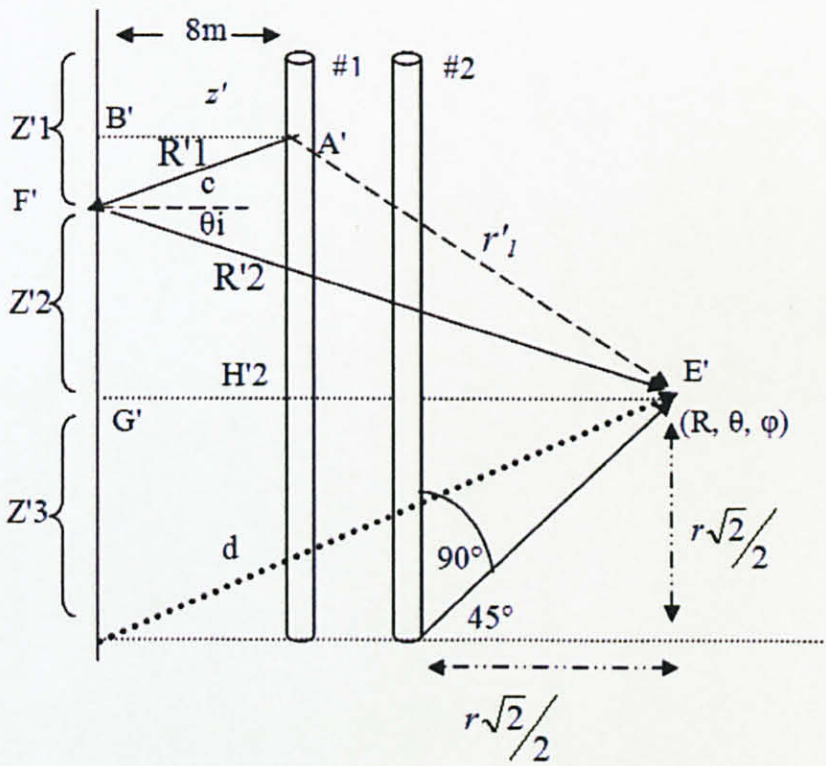


Figure 4.5 The reflection distances for the first wire

$H'1 = 8m$

$H'2 = H'1 + 3m + \frac{r\sqrt{2}}{2}$

$$\Longrightarrow \begin{cases} Z'1 = \dfrac{2ZH'1 - 2H'1(H'2^2 - d^2)^{1/2}}{38 + r\sqrt{2}/2}, & (57) \\ Z'2 = Z - Z'1 - (H'2^2 - d^2)^{1/2} & (58) \end{cases}$$

$$\Longrightarrow \begin{cases} R'1^2 = Z'1^2 + H'1^2 & (59) \\ R'2^2 = Z'2^2 + (H'1 + r\sqrt{2}/2)^2 & (60) \end{cases}$$

Based on the above information

$$R1 \sin\theta_i = Z1, \qquad R1 \cos\theta_i = H1,$$
$$Z1 / R1 = \sin\theta_i \quad , \quad H1 / R1 = \cos\theta_i$$

$$\cos\theta_t = \left[1 - (\frac{n1}{n2})^2 \sin^2\theta_i\right]^{1/2}, \quad \cos\theta_t = \left[1 - (\frac{1}{8})\sin^2\theta_i\right]^{1/2}, \tag{61}$$

$$R_p = \frac{(1/n2)\cos\theta_t - (1/n1)\cos\theta_i}{(1/n2)\cos\theta_t + (1/n1)\cos\theta_i}, \tag{62}$$

$n_1 = 1 \quad n_2 = \sqrt{8.0}$

$$R_p = \frac{(1/\sqrt{8})\cos\theta_t - \cos\theta_i}{(1/\sqrt{8})\cos\theta_t + \cos\theta_i}, \tag{63}$$

Based on the following information, the reflected field will be:

$$RE\,1_\theta = \frac{I_0 k^2 R_p}{4\pi}\eta_0[j\int_{-l/2}^{l/2}\frac{e^{-jk(R_1+R_2)}}{k(R_1+R_2)}dz' +$$
$$\int_{-l/2}^{l/2}\frac{e^{-jk(R_1+R_2)}}{(k(R_1+R_2))^2}dz' - \quad , \tag{64}$$
$$j\int_{-l/2}^{l/2}\frac{e^{-jk(R_1+R_2)}}{(k(R_1+R_2))^3}dz']\sin\theta$$

$$RE\,2_\theta = \frac{I_0 k^2 R_p}{4\pi}\eta_0[j\int_{-l/2}^{l/2}\frac{e^{-jk(R_1'+R_2')}}{k(R_1'+R_2')}dz' +$$
$$\int_{-l/2}^{l/2}\frac{e^{-jk(R_1'+R_2')}}{(k(R_1'+R_2'))^2}dz' - \quad , \tag{65}$$
$$j\int_{-l/2}^{l/2}\frac{e^{-jk(R_1'+R_2')}}{(k(R_1'+R_2'))^3}dz']\sin\theta$$

The integration parts in the reflection field were also calculated based on the Filon method, rewriting the above formulas in term of the sine and cosine will yields to:

$$RE\,1_\theta = \frac{I_0 k^2 R_p}{4\pi}\eta_0[j\int_{-l/2}^{l/2}\frac{\cos k(R_1+R_2) - j\sin k(R_1+R_2)}{k(R_1+R_2)}dz' +$$
$$\int_{-l/2}^{l/2}\frac{\cos k(R_1+R_2) - j\sin k(R_1+R_2)}{(k(R_1+R_2))^2}dz' -$$
$$j\int_{-l/2}^{l/2}\frac{\cos k(R_1+R_2) - j\sin k(R_1+R_2)}{(k(R_1+R_2))^3}dz']\sin\theta$$
$$\tag{66}$$

$$RE\,2_\theta = \frac{I_0 k^2 R_p}{4\pi}\eta_0[j\int_{-l/2}^{l/2}\frac{\cos k(R_1'+R_2') - j\sin k(R_1'+R_2')}{k(R_1'+R_2')}dz' +$$
$$\int_{-l/2}^{l/2}\frac{\cos k(R_1'+R_2') - j\sin k(R_1'+R_2')}{(k(R_1'+R_2'))^2}dz' -$$
$$j\int_{-l/2}^{l/2}\frac{\cos k(R_1'+R_2') - j\sin k(R_1'+R_2')}{(k(R_1'+R_2'))^3}dz']\sin\theta \tag{67}$$

The last codes used to calculate the electric fields in MATLAB are attached in Appendix A .

The obtained graph from MATLAB codes are shown bellow , the first graph represents the electric field in free space , and the second one represents the field by considering the plane wave incidence, or in other word existence of the ground.

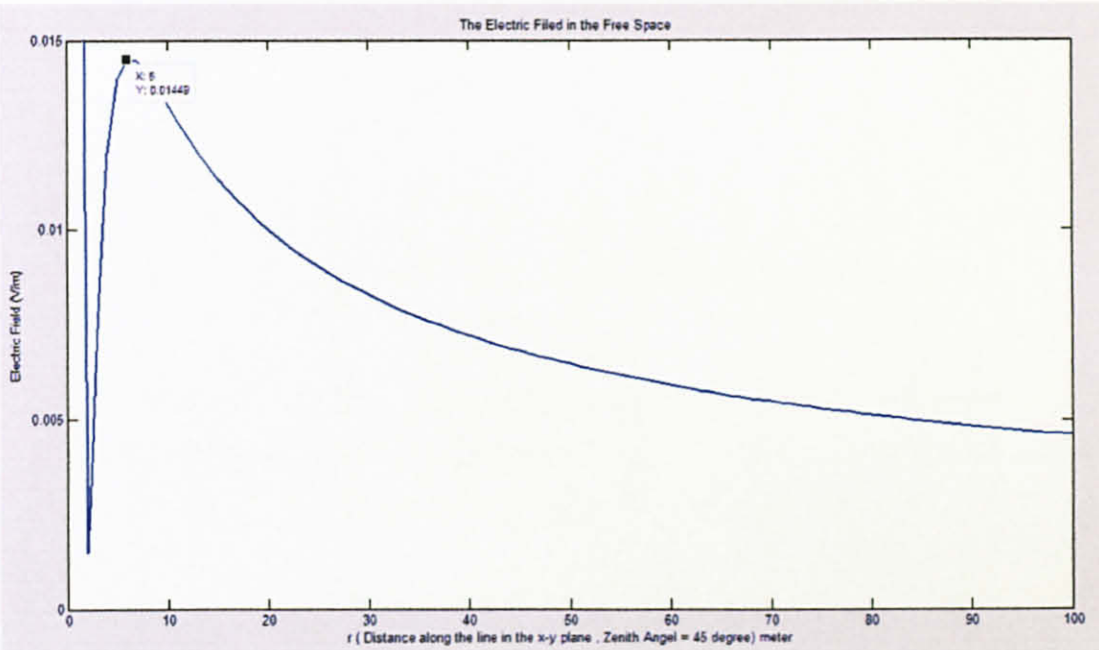


Figure 4.6 The electric field in free space obtained from codes implemented in MATLAB

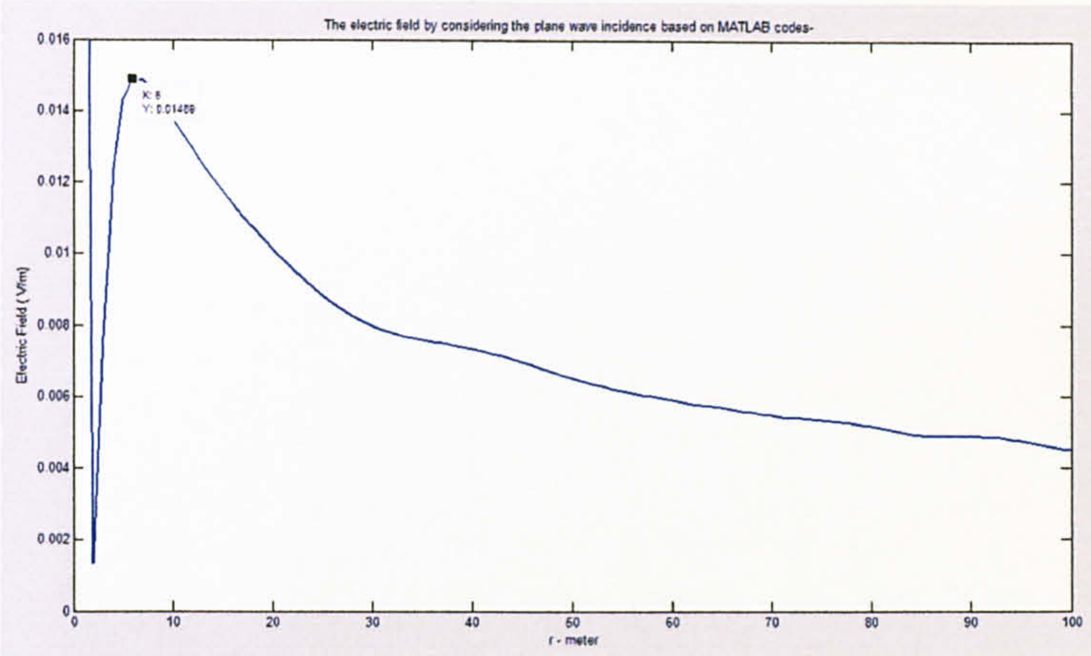


Figure 4.7 The electric field in present of the ground in MATLAB.

Based on the above graphs the difference between the two conditions in the near field is almost around 0.4 mV/m. This could be based on the assumptions made in the first place, earth conductivity, 0.1 S/m and permittivity, 8.0.

4.2 NEC WIN Professional Result

The result obtained from the NEC WIN Professional in the both conditions is shown bellow in Figure 4.8 and 4.9. In the first design of the model the result obtained from the NEC WIN professional shows standing wave on the wires. Figure 4.10 shows the current obtained in the first design.

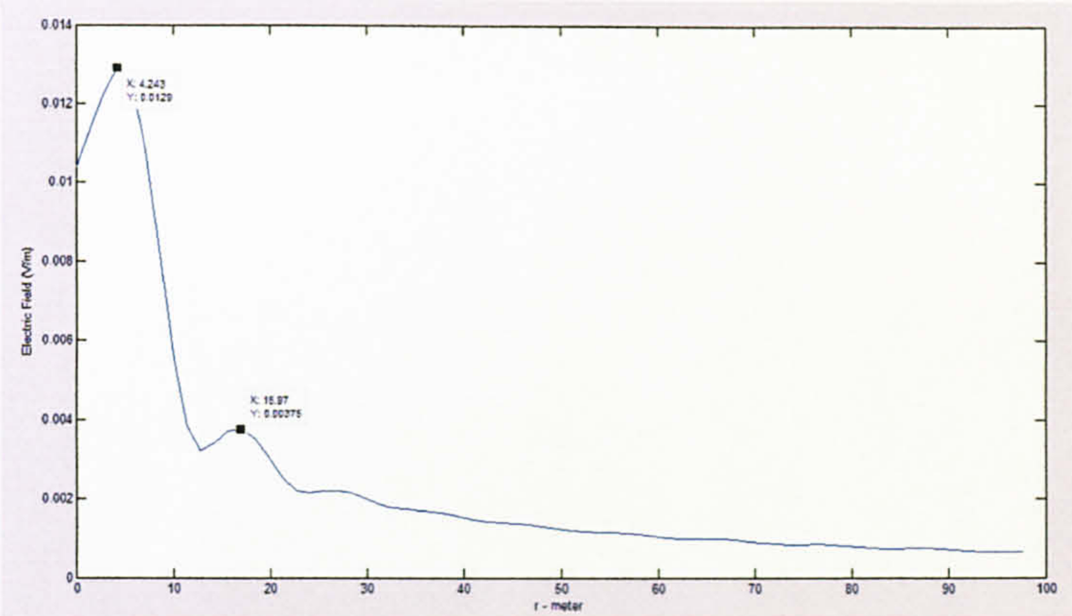


Figure 4.8 The electric field in free space obtained in NEC WIN Professional software

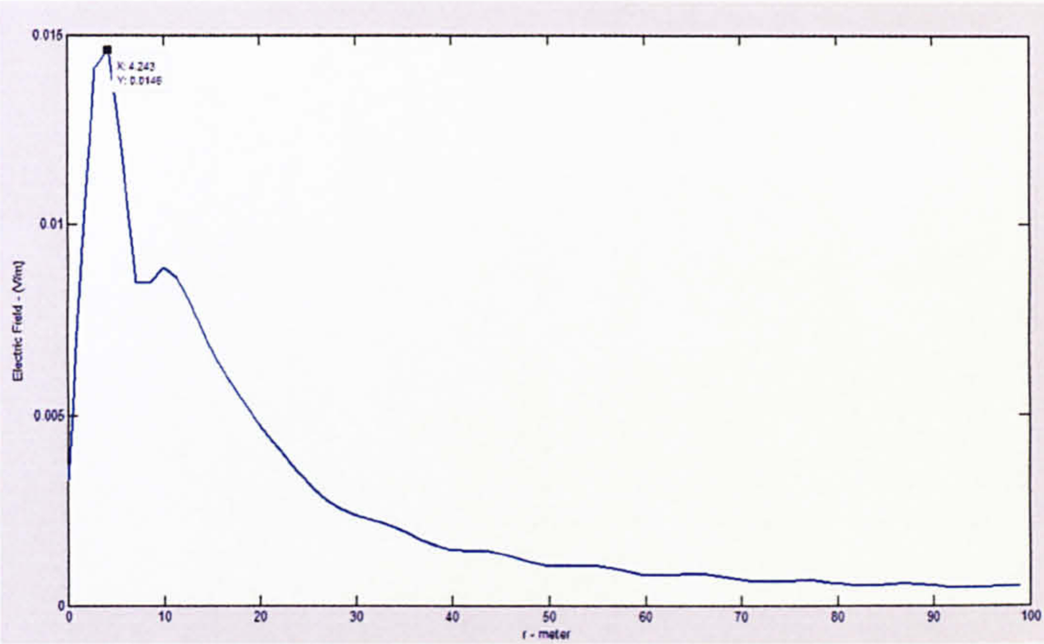


Figure 4.9 The electric field in present of the ground in NEC WIN Professional

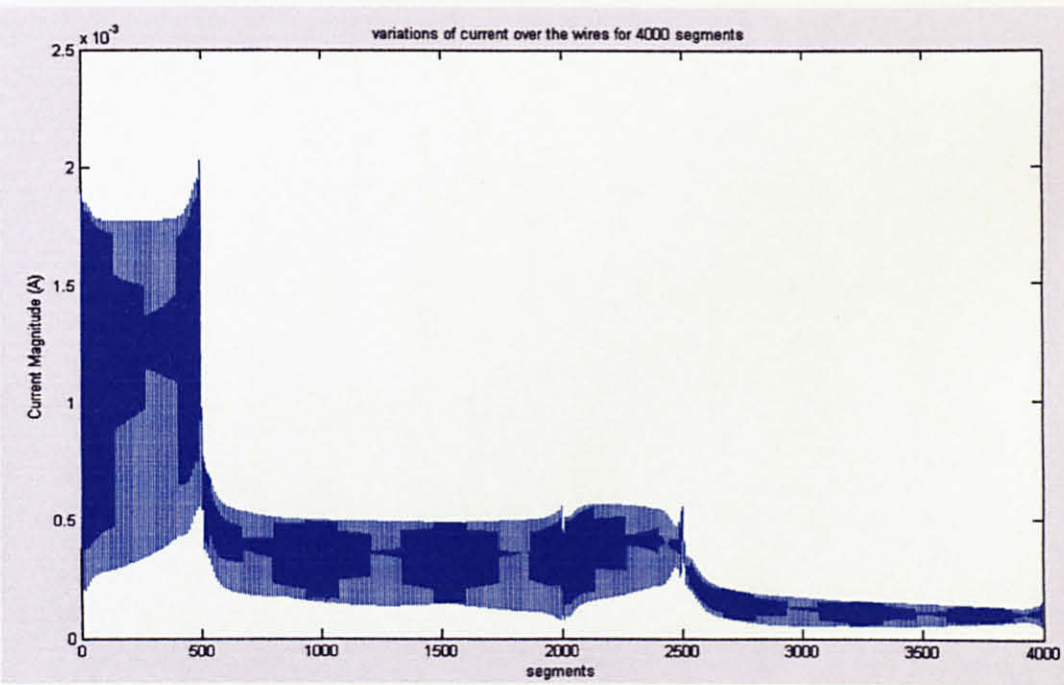


Figure 4.10 The standing wave on the wires before terminating the model by 13 Ohm resistance

In order to eliminate the standing waves, the model has been terminated by 13 Ohm resistance, after termination the circuit the currents on the wires changed to the range of 0.95 mA to 1.35 mA, this current is more near to the constant current used in MATLAB.

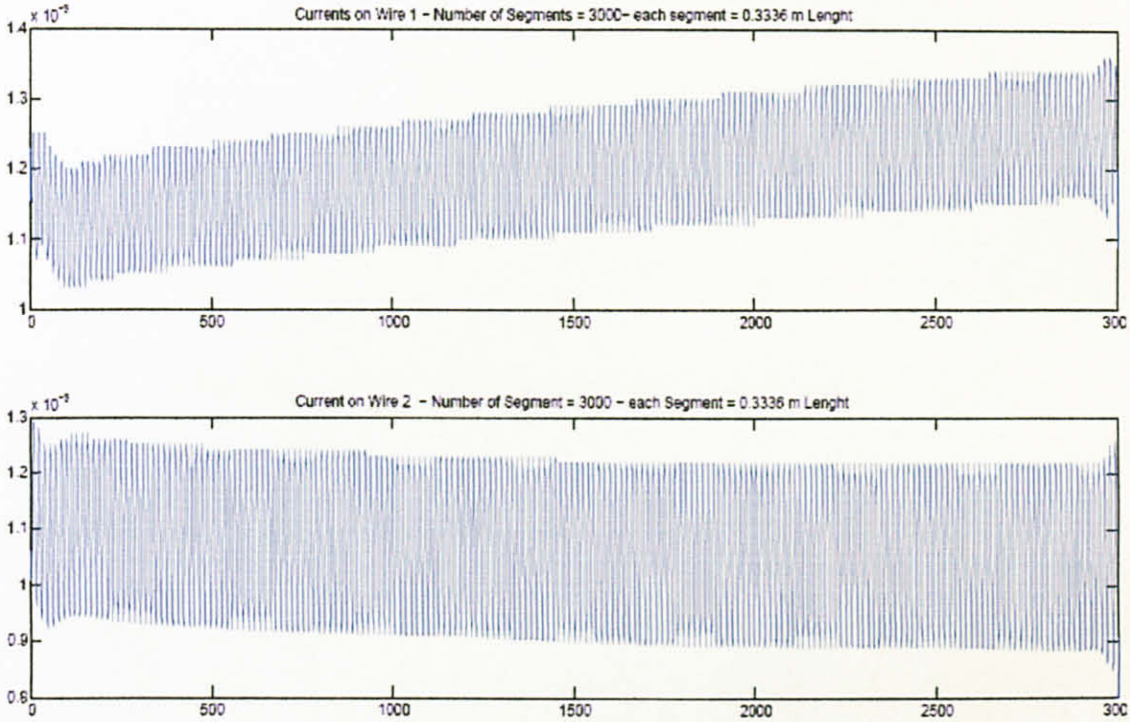


Figure 4.11 the current on the both wires after eliminating the standing waves

The NEC codes are shown in appendix B.

4.3 Comparison between the electric field results obtained

The obtained graph from the MATLAB and NEC is shown in the Figure 4.12. Based on the results achieved the NEC results almost confirms the codes used in MATLAB, although there is an offset between the results. This offset could be according to the mismatches between the NEC and MATLAB which could be probably eliminated by more work.

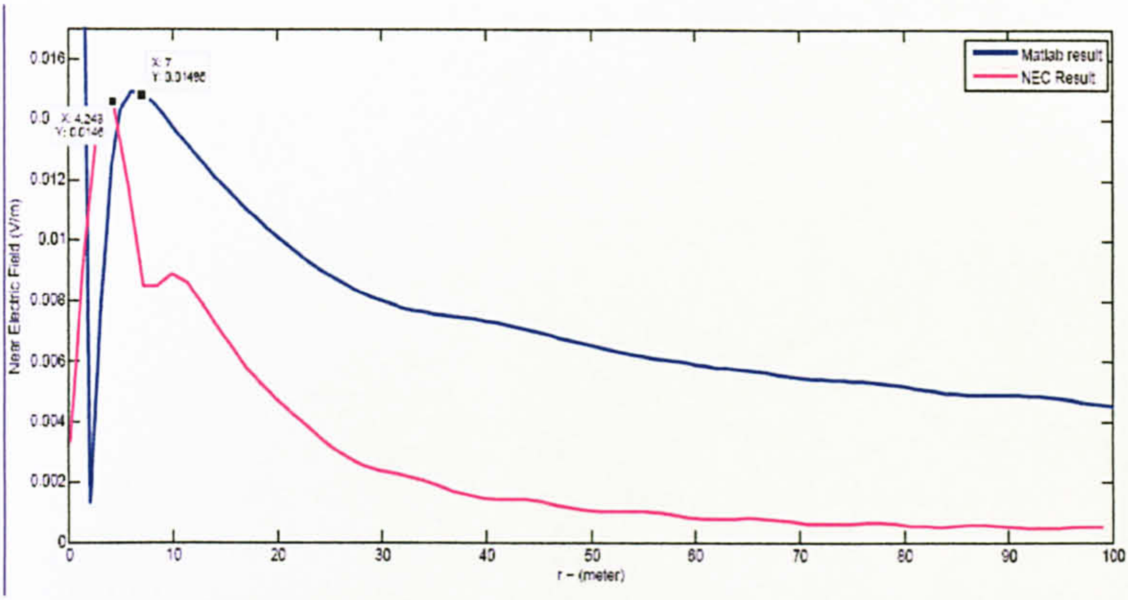


Figure 4.12 The obtained result - Electric field –transmission length from 0 to 1000 meter

4.4 Simulation of the simple model in network analyzer

The simple transmission line model has been constructed by using the two set of 4mm PVC power line cables. The cables are placed closed to each other in 4.9 meter length. The transmission and reflection of the model were measured by using the network analyzer in three positions. In the first positions the cables just placed in the table near the circuit analyzer as it is shown in Figure 4.13. The magnitude and phase of the reflection and transmission coefficients of the model are shown in Figure 4.14.

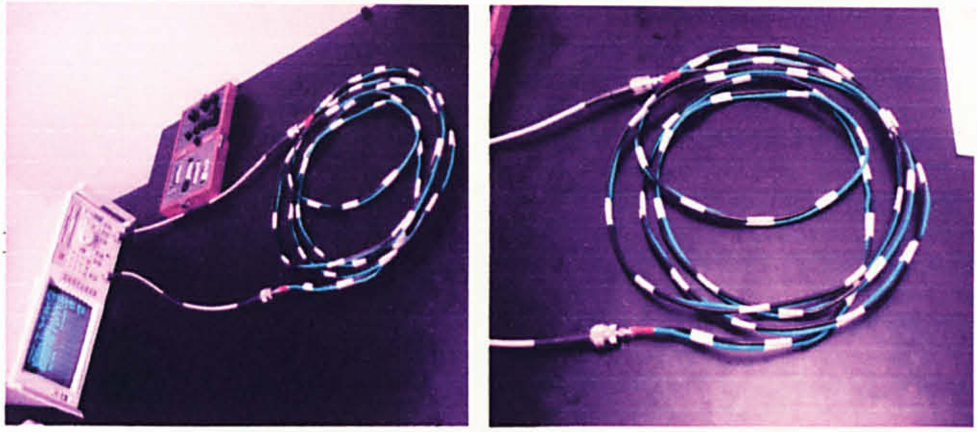


Figure 4.13 The transmission line model in the first conditions

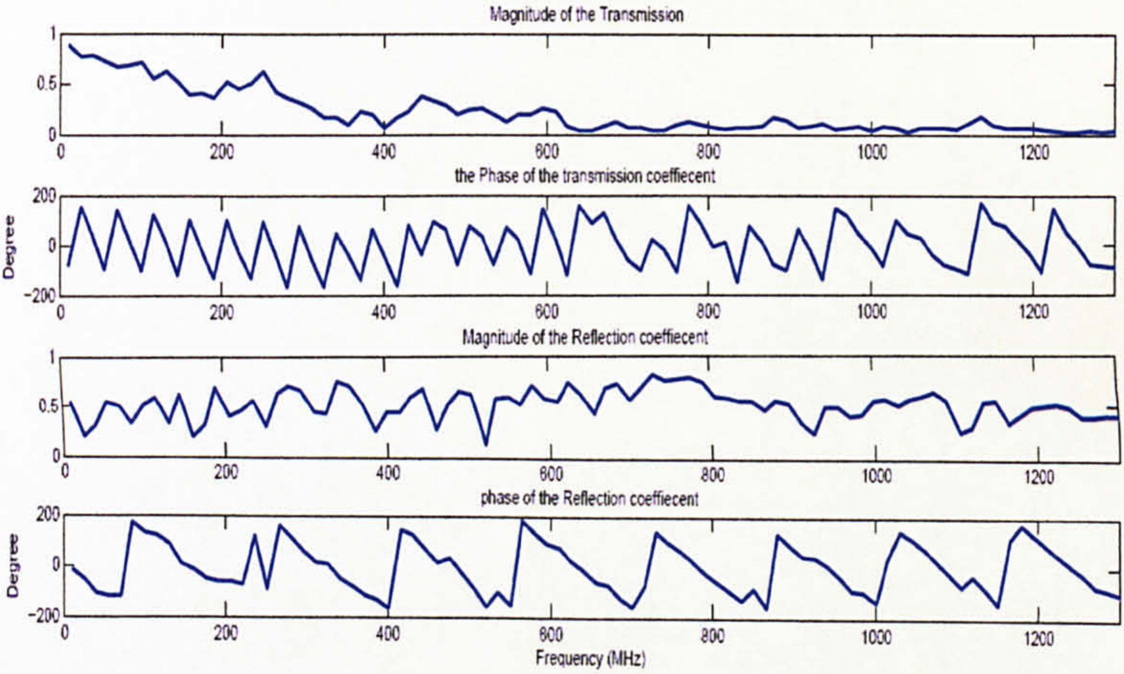


Figure 4.14 The Transmission and Reflection magnitude and phase of the transmission line, obtained from the circuit analyzer

In the second position the wires were placed in the big circle around the room as it is shown in Figure 4.15. The magnitude and phase of the reflection and transmission line coefficients are also shown in figure 4.16.

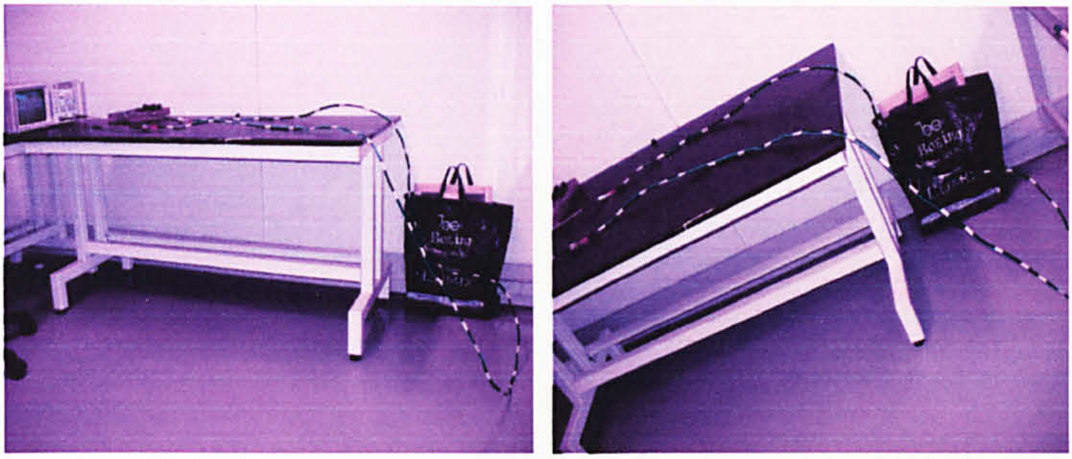


Figure 4.15 The transmission line model in the second condition

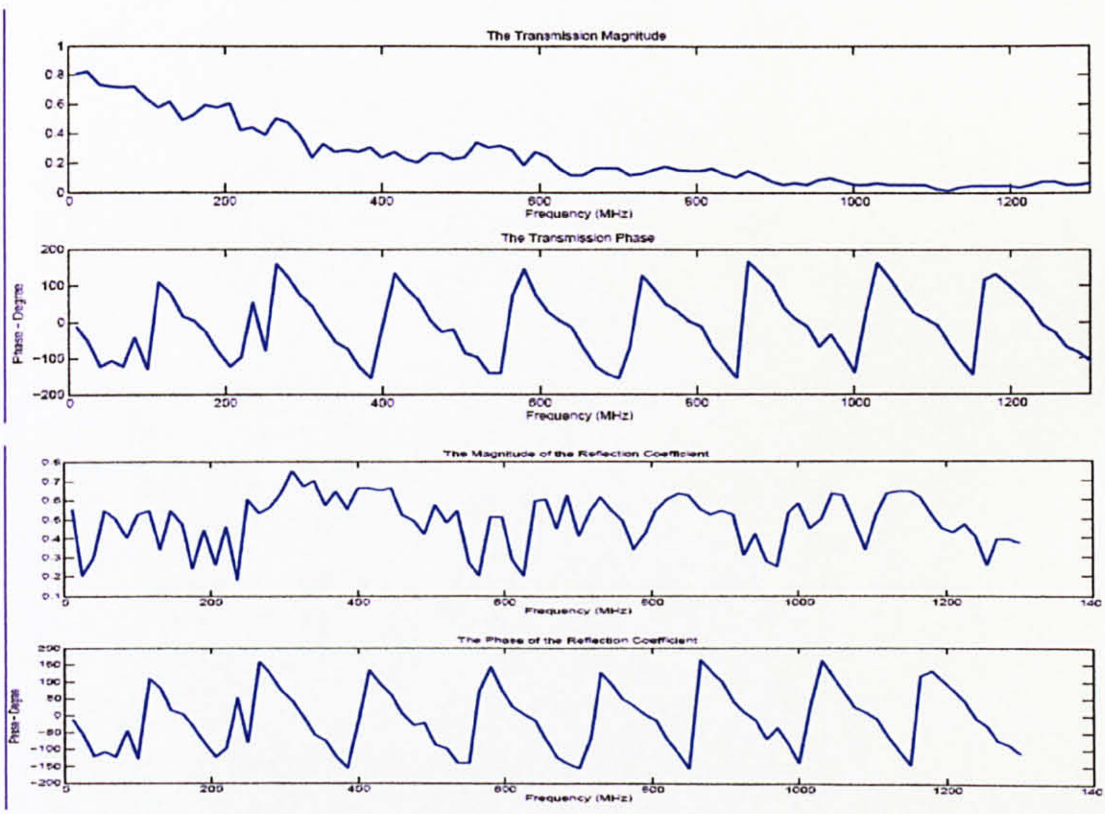


Figure 4.16 The Transmission and Reflection magnitude and phase of the transmission line, obtained from the circuit analyzer

Based on the Figure 4.16 and 4.14 the magnitude of the reflection coefficient is quite high for the normal transmission line. This could be due to the fact of existing of the radiation on the wires. In order to eliminate the radiation the wires were coiled and wrapped in the foil to short circuit the radiations. The position of the wire is shown in Figure 4.17. The results obtained from the network analyzer were simulated by ADS to evaluate the system potential, and BPL system criteria. The ADS results is shown in Figure 4.19 based on this figure the conductor of the system is increasing by increasing the frequency and in the higher frequency it's not based on what we expected.

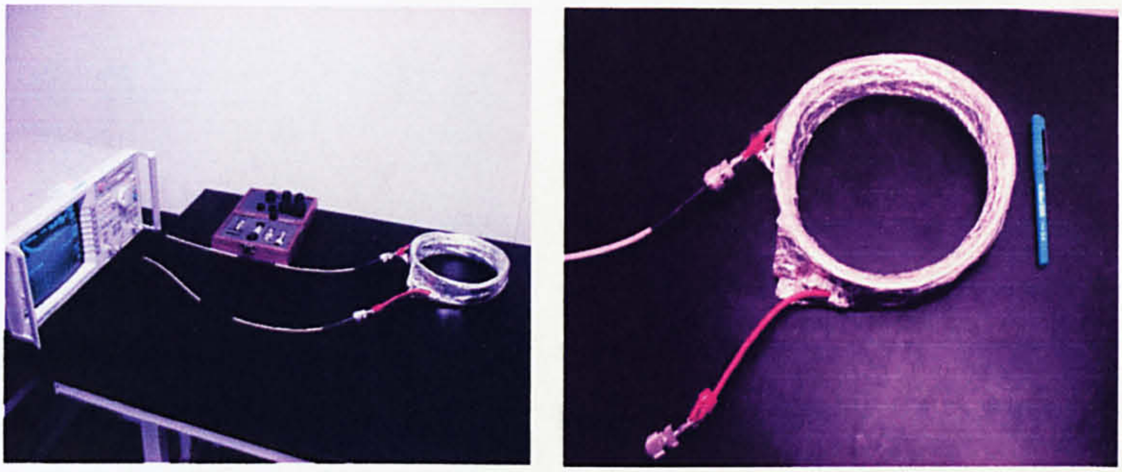


Figure 4.17 The wires in the third position

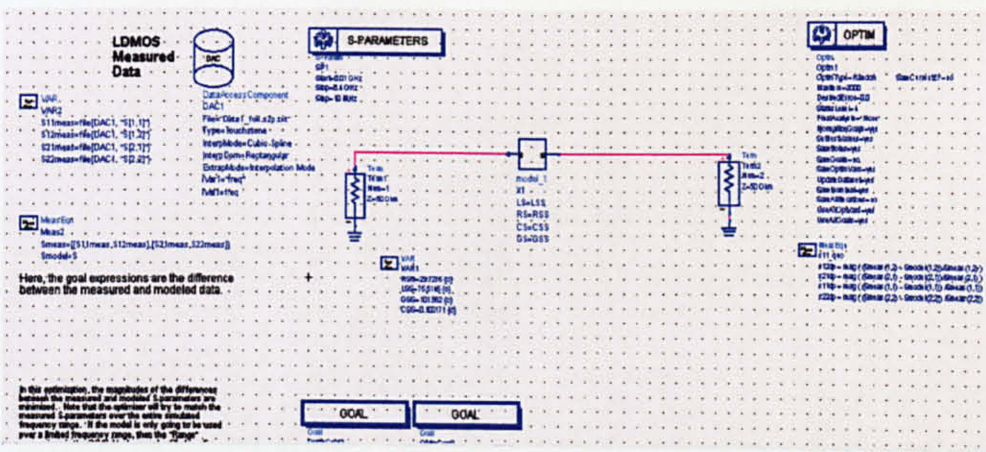


Figure 4.18 The ADS circuit based on the network analyzer measurements

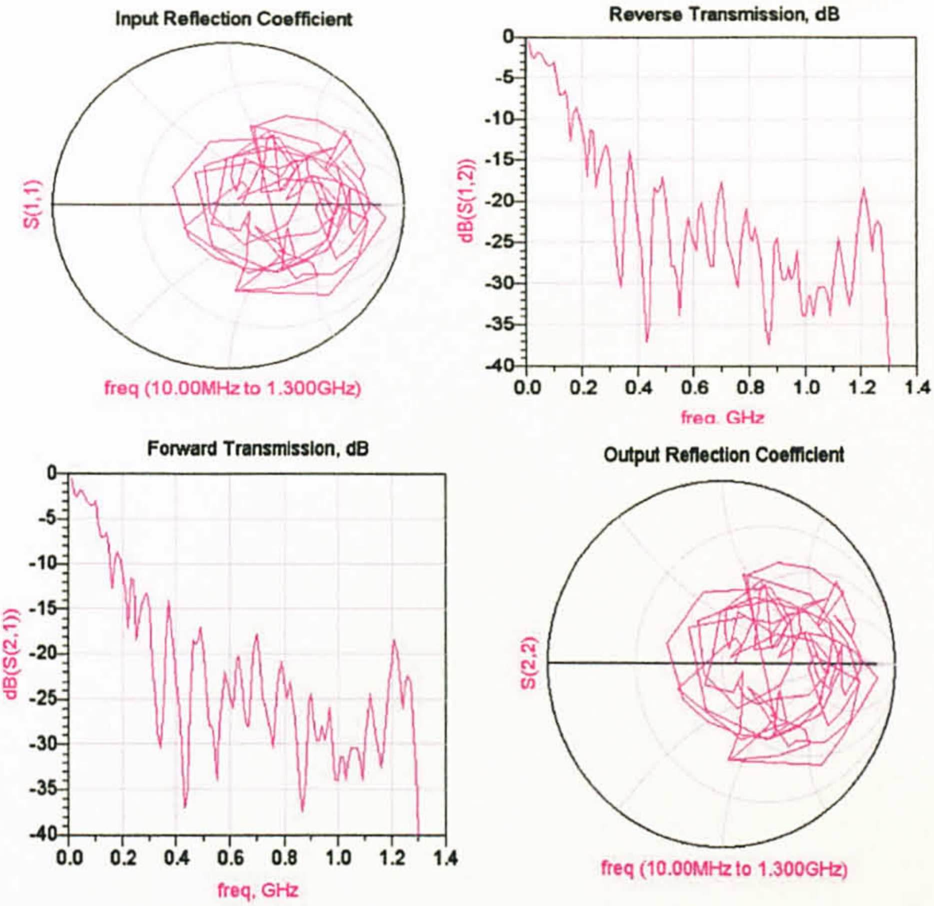


Figure 4.19 The result obtained from the ADS circuits

The result obtained from the network analyzer as mentioned before is shown in figure 4.19, this result has been compared to the ideal condition by using ADS software to see the behavior of radiation and attenuation and their effects on the system in higher frequencies. The ideal case achieved by optimizing the previous circuit by using ADS software. The result obtained is shown in figure 4.20 this result has been shown in the range of 10MHz to 400 MHz to see the respond of the system in the lower frequencies.

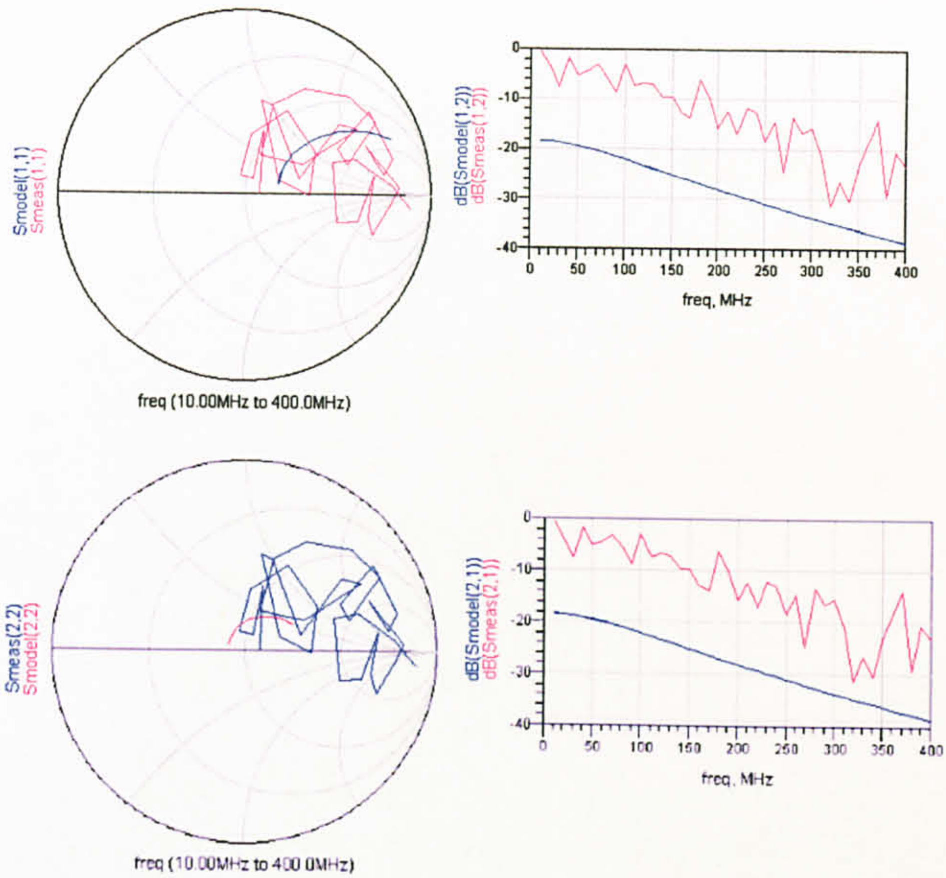


Figure 4.20 Optimizing the result in ADS software and comparison with the ideal case

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Power line communication or Broadband over power line (BPL) has been developed during the last decades. It has been used for low frequencies. The used of the BPL systems in higher frequency is what is interested in this project. In order to evaluate the potential of the system the electric fields around the line were calculated in two softwares to certify the results. After calculating the electric field, the simple model of transmission line has been constructed and the model measurements were measured by network analyzer to evaluate the potential of the system as well as BPL requirements.

In overall from the results obtained, it could be concluded that the inductor of the model will increase with increasing the frequency, especially at higher frequency the model instructed did not responds to the expected values, however it is not possible to evaluate the communication potential of the systems until now, since the model still can be modified to have better results. And the input impedance of the system over the frequency range of 10 MHz to 1.3 GHz can be analyzed in MATLAB and NEC.

In general the most significant advantage of broadband over power line communication unlike xDSL and cable modem is that they do not require an entirely new infrastructure, however they are several technical challenges in using BPL system, the first serious problem which we faced also in our design is attenuation, attenuation can be due to junctions such as taps, connected elements such as transformers and lake of matched impedances. Second problem will be due to background noise, usually due to induced radio broadcast signals and the third problem is due to the legal limits on electromagnetic emissions from these unlicensed systems. Attenuation and signal noise are very frequency dependent. In this case we saw how attenuation as well as background noises increased in higher frequency.

By completing this thesis, the valuable knowledge has been gained on the broad band over power line system and electromagnetic fields as well as plane wave incidence and Filon integration. During this project also I became familiar with NEC WIN Professional software and most importantly how to do the research project.

5.2 Recommendation

During this project two alternatives for calculating the electric field have been used and the transmission line model measured in three different positions , however the model could be measured in other positions where the radiation is eliminated and the input impedance of the BPL system could modeled in MATLAB and NEC software. Due to the lake of time these parts couldn't be included in the project.

Based on the researches have been done during this project. There is a high attenuation in higher frequency. This attenuation can be decreased, based on the researches done previously [9], which requires a financial investment that is incompatible with the requirement that the system be profitable.

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[9] R.G.Olsen, "Technical Considerations for Broadband Powerline (BPL) Communication," School of EECS, Washington State University

APPENDIX A

IMPLEMENTED CODES IN MATLAB

1. **filon function – filon1 , for the first wire**

```
function int =filon1(func,P,k,l,u,r,n)
if (n/2)~=floor(n/2)
   disp('n must be even');
else
    h=(u-l)/n;
    q=k*h;q2=q*q;q3=q*q2;
    if q<0.1
         a=2*q2*(q/45-q3/315+q2*q3/4725);
         b=2*(1/3+q2/15+2*q2*q2/105+q3*q3/567);
         d=4/3-2*q2/15+q2*q2/210-q3*q3/11340;
    else
         a=(q2+q*sin(2*q)/2-2*(sin(q))^2)/q3;
         b=2*(q*(1+(cos(q))^2)-sin(2*q))/q3;
         d=4*(sin(q)-q*cos(q))/q3;
    end

    z=[l:h:u];
    g=sqrt(r.^2+z.^2);

    y=feval(func,g);
    yodd=y(2:2:n);yeven=y(3:2:n-1);

    if P==1
         c=cos(k*g);
         codd=c(2:2:n); co=codd*yodd';
         ceven=c(3:2:n-1);
         ce=(y(1)*c(1)+y(n+1)*c(n+1))/2;
         ce=ce+ceven*yeven';
         int=h*(a*(y(n+1)*sin(k*u)-y(1)*sin(k*l))+b*ce+d*co);
    else
         s=sin(k*g);
         sodd=s(2:2:n); so=sodd*yodd';
         seven=s(3:2:n-1);
         se=(y(1)*s(1)+y(n+1)*s(n+1))/2;   se=se+seven*yeven';
         int=h*(-a*(y(n+1)*cos(k*u)-y(1)*cos(k*l))+b*se+d*so);
    end
end
```

2. **filon function – filon2, for the second wire**

```
function int =filon2(func,P,k,l,u,r,n)
if (n/2)~=floor(n/2)
   disp('n must be even');
else
    h=(u-l)/n;
    q=k*h;q2=q*q;q3=q*q2;
    if q<0.1
         a=2*q2*(q/45-q3/315+q2*q3/4725);
         b=2*(1/3+q2/15+2*q2*q2/105+q3*q3/567);
         d=4/3-2*q2/15+q2*q2/210-q3*q3/11340;
    else
         a=(q2+q*sin(2*q)/2-2*(sin(q))^2)/q3;
         b=2*(q*(1+(cos(q))^2)-sin(2*q))/q3;
         d=4*(sin(q)-q*cos(q))/q3;
```

```
    end

    z=[l:h:u];
    x= sqrt(r.^2+9-(3*r.*sqrt(2)));
    g=sqrt(x.^2+z.^2);
    y=feval(func,g);
    yodd=y(2:2:n);yeven=y(3:2:n-1);
    if P==1
        c=cos(k*g);
        codd=c(2:2:n); co=codd*yodd';
        ceven=c(3:2:n-1);
        ce=(y(1)*c(1)+y(n+1)*c(n+1))/2;
        ce=ce+ceven*yeven';
        int=h*(a*(y(n+1)*sin(k*u)-y(1)*sin(k*l))+b*ce+d*co);
    else
        s=sin(k*g);
        sodd=s(2:2:n); so=sodd*yodd';
        seven=s(3:2:n-1);
        se=(y(1)*s(1)+y(n+1)*s(n+1))/2;  se=se+seven*yeven';
        int=h*(-a*(y(n+1)*cos(k*u)-y(1)*cos(k*l))+b*se+d*so);
    end
end
```

3. filon function – filon3, for the reflected field of the 1st wire

```
function int =filon3(func,P,k,l,u,r,n)
if (n/2)~=floor(n/2)
   disp('n must be even');
else
    h=(u-l)/n;
    q=k*h;q2=q*q;q3=q*q2;
    if q<0.1
        a=2*q2*(q/45-q3/315+q2*q3/4725);
        b=2*(1/3+q2/15+2*q2*q2/105+q3*q3/567);
        d=4/3-2*q2/15+q2*q2/210-q3*q3/11340;
    else
        a=(q2+q*sin(2*q)/2-2*(sin(q))^2)/q3;
        b=2*(q*(1+(cos(q))^2)-sin(2*q))/q3;
        d=4*(sin(q)-q*cos(q))/q3;
    end

     z=[l:h:u];

     h1=11;
     h2=r.*((sqrt(2))/2)+11;
     r3= sqrt(r.^2+121-(11*r.*sqrt(2)));
     Z3=sqrt((h2.^2)-(r3.^2));
     Z1=(((z.*22)- Z3.*22)/(44+r.*sqrt(2)));
     Z2=z-Z1-Z3;

      D1=sqrt(h1^2+Z1.^2);
      D2=sqrt(h2.^2+Z2.^2);
      g=D1+D2;
      sininc=Z1./D1;
      cosinc= h1./D1;
      Er=8;
      v=sqrt(1-((sininc.^2).*(1/Er)));
```

```
        gama=((v./sqrt(Er))-
(cosinc./sqrt(Er)))./((v./sqrt(Er))+(cosinc./sqrt(Er)));


     F=feval(func , g);
     y=F.*gama;
     yodd=y(2:2:n);yeven=y(3:2:n-1);

     if P==1
          c=cos(k*g);
          codd=c(2:2:n); co=codd*yodd';
          ceven=c(3:2:n-1);
          ce=(y(1)*c(1)+y(n+1)*c(n+1))/2;
          ce=ce+ceven*yeven';
          int=h*(a*(y(n+1)*sin(k*u)-y(1)*sin(k*l))+b*ce+d*co);
     else
          s=sin(k*g);
          sodd=s(2:2:n); so=sodd*yodd';
          seven=s(3:2:n-1);
          se=(y(1)*s(1)+y(n+1)*s(n+1))/2;   se=se+seven*yeven';
          int=h*(-a*(y(n+1)*cos(k*u)-y(1)*cos(k*l))+b*se+d*so);
     end
end
```

4. filon function – filon4, for the reflected field of the 2nd wire

```
function int =filon4(func,P,k,l,u,r,n)
if (n/2)~=floor(n/2)
   disp('n must be even');
else
     h=(u-l)/n;
     q=k*h;q2=q*q;q3=q*q2;
     if q<0.1
          a=2*q2*(q/45-q3/315+q2*q3/4725);
          b=2*(1/3+q2/15+2*q2*q2/105+q3*q3/567);
          d=4/3-2*q2/15+q2*q2/210-q3*q3/11340;
     else
          a=(q2+q*sin(2*q)/2-2*(sin(q))^2)/q3;
          b=2*(q*(1+(cos(q))^2)-sin(2*q))/q3;
          d=4*(sin(q)-q*cos(q))/q3;
     end

      z=[l:h:u];
      x= sqrt(r.^2+9-(3*r.*sqrt(2)));

      h1=8;
      h2=r.*((sqrt(2))/2)+11;
      r3= sqrt(r.^2+121-(11*r.*sqrt(2)));
      Z3=sqrt((h2.^2)-(r3.^2));
      Z1=(((z.*16)- Z3.*16)/(38+r.*sqrt(2)));
      Z2=z-Z1-Z3;
      R1=sqrt(h1^2+Z1.^2);
      R2=sqrt(h2.^2+Z2.^2);
      g=R1+R2;
      sininc=Z1./R1;
      cosinc=8./R1;
      Er=8;
      v=sqrt(1-((sininc.^2).*(1/Er)));
```

```
     gama=((v./sqrt(Er))-
(cosinc./sqrt(Er)))./((v./sqrt(Er))+(cosinc./sqrt(Er)));


      F=feval(func , g);
      y=F.*gama;
      yodd=y(2:2:n);yeven=y(3:2:n-1);

    if P==1
        c=cos(k*g);
        codd=c(2:2:n); co=codd*yodd';
        ceven=c(3:2:n-1);
        ce=(y(1)*c(1)+y(n+1)*c(n+1))/2;
        ce=ce+ceven*yeven';
        int=h*(a*(y(n+1)*sin(k*u)-y(1)*sin(k*l))+b*ce+d*co);
    else
        s=sin(k*g);
        sodd=s(2:2:n); so=sodd*yodd';
        seven=s(3:2:n-1);
        se=(y(1)*s(1)+y(n+1)*s(n+1))/2;  se=se+seven*yeven';
        int=h*(-a*(y(n+1)*cos(k*u)-y(1)*cos(k*l))+b*se+d*so);
    end
end
```

5. function definitions for Filon's codes

```
function y=f408(g);
k=0.2*pi;
y=ones(size(g))./((g.*k).^3);


function y=f407(g);
k=0.2*pi;
y=ones(size(g))./((g.*k).^2);



function y=f406(g);
k=0.2*pi;
y=ones(size(g))./(g.*k);
```

6. Calculating the electric field on the first wire

```
 function EF1=EE1(r)

n= [512, 2048,4096,8192,16384,32768];
for k = 1:size(n,2)
A(k)=filon1('f406',1,(0.2*pi),0,1000,r,n(k));
end;

for k = 1:size(n,2)
B(k)=filon1('f406',2,(0.2*pi),0,1000,r,n(k));
end;
```

```
for k = 1:size(n,2)
C(k)=filon1('f407',1,(0.2*pi),0,1000,r,n(k));
end;

for k = 1:size(n,2)
D(k)=filon1('f407',2,(0.2*pi),0,1000,r,n(k));
end;

for k = 1:size(n,2)
O(k)=filon1('f408',1,(0.2*pi),0,1000,r,n(k));
end;

for k = 1:size(n,2)
F(k)=filon1('f408',2,(0.2*pi),0,1000,r,n(k));
end;

m=(((1.25*10^-3)*((0.2*pi)^2)*120*pi)/(4*pi));
EF1=[];
for k = 1:size(n,2)
E1(k)=m.*[(B(k)+C(k)-F(k))+((A(k)-D(k)-O(k)).*sqrt(-1))];

temp1=E1(k);
EF1=[EF1 temp1];
end;
```

7. Calculating the electric field on the second wire

```
function EF2=EE2(r)

n= [512, 2048,4096,8192,16384,32768];
for k = 1:size(n,2)
A(k)=filon2('f406',1,(0.2*pi),0,1000,r,n(k));
end;

for k = 1:size(n,2)
B(k)=filon2('f406',2,(0.2*pi),0,1000,r,n(k));
end;

for k = 1:size(n,2)
C(k)=filon2('f407',1,(0.2*pi),0,1000,r,n(k));
end;

for k = 1:size(n,2)
D(k)=filon2('f407',2,(0.2*pi),0,1000,r,n(k));
end;

for k = 1:size(n,2)
O(k)=filon2('f408',1,(0.2*pi),0,1000,r,n(k));
end;

for k = 1:size(n,2)
F(k)=filon2('f408',2,(0.2*pi),0,1000,r,n(k));
end;

m=(((1.25*10^-3)*((0.2*pi)^2)*120*pi)/(4*pi));
```

```
EF2=[];
for k = 1:size(n,2)
E2(k)=m.*[(B(k)+C(k)-F(k))+((A(k)-D(k)-O(k)).*sqrt(-1))];
temp2=E2(k);
EF2=[EF2 temp2];
end;
```

8. Calculating the electric field for the reflected field of the 1st wire

```
function EF3=EE3(r)

n= [512, 2048,4096,8192,16384,32768];
for k = 1:size(n,2)
A(k)=filon3('f406',1,(0.2*pi),0,1000,r,n(k));
end;

for k = 1:size(n,2)
B(k)=filon3('f406',2,(0.2*pi),0,1000,r,n(k));
end;

for k = 1:size(n,2)
C(k)=filon3('f407',1,(0.2*pi),0,1000,r,n(k));
end;

for k = 1:size(n,2)
D(k)=filon3('f407',2,(0.2*pi),0,1000,r,n(k));
end;

for k = 1:size(n,2)
O(k)=filon3('f408',1,(0.2*pi),0,1000,r,n(k));
end;

for k = 1:size(n,2)
F(k)=filon3('f408',2,(0.2*pi),0,1000,r,n(k));
end;
m=(((1.25*10^-3)*((0.2*pi)^2)*120*pi)/(4*pi));
EF3=[];
for k = 1:size(n,2)
E3(k)=m.*[(B(k)+C(k)-F(k))+(A(k)-D(k)-O(k)).*sqrt(-1)];
temp3=E3(k);
EF3=[EF3 temp3];
end;
```

9. Calculating the electric field for the reflected field of the 2nd wire

```
function EF4=EE4(r)

n= [512, 2048,4096,8192,16384,32768];
for k = 1:size(n,2)
A(k)=filon4('f406',1,(0.2*pi),-1000,1000,r,n(k));
end;

for k = 1:size(n,2)
B(k)=filon4('f406',2,(0.2*pi),-1000,1000,r,n(k));
end;
```

```
for k = 1:size(n,2)
C(k)=filon4('f407',1,(0.2*pi),-1000,1000,r,n(k));
end;

for k = 1:size(n,2)
D(k)=filon4('f407',2,(0.2*pi),-1000,1000,r,n(k));
end;

for k = 1:size(n,2)
O(k)=filon4('f408',1,(0.2*pi),-1000,1000,r,n(k));
end;

for k = 1:size(n,2)
F(k)=filon4('f408',2,(0.2*pi),-1000,1000,r,n(k));
end;

 m=(((1.25*10^-3)*((0.2*pi)^2)*120*pi)/(4*pi));
EF4=[];
for k = 1:size(n,2)
E4(k)=m.*[(B(k)+C(k)-F(k))+(A(k)-D(k)-O(k)).*sqrt(-1)];

temp4=E4(k);
EF4=[EF4 temp4];

end;
```

10. Calculating the total electric field from the wires on distance r

```
r=1:01:100;

Efield=[];

for i=1:size(r,2)

    temp=(EE1(r(i))+EE3(r(i)))-(EE2(r(i))+EE4(r(i)));

    temp1=abs(temp);
    Efield=[Efield temp1'];


end
```

APPENDIX B

IMPLEMENTED CODES IN NEC. PROFESSIONAL SOFTWARE

1. Calculating the near Electric Field and the currents on the lines

```
CM with R
CE
GW 1 5000 0 0 8 0 1000 8 0.0113
GW 2 5000 0 0 11 0 1000 11 0.0113
GW 3 50 0 0 8 0 0 11 0.0113
GW 4 50 0 1000 8 0 1000 11 0.0113
GS 0 0 1.000000
GE 1
GN 0 0 0 0 8 0.1
FR 0 1 0 0 30.00 1
EX 0 3 25 00 0.900 0.00000
LD 0 3 30 45 13 0 0
LD 0 4 5 45 13 0 0
NE 0 30 1 30 0 0 0 3 1 3
EN
```