CHAPTER 1

INTRODUCTION

1.1 Background of Study

Radio wave transmission over the Earth's surface is one of the most difficult and significant propagation problems. In big city such as Kuala Lumpur or New York City with buildings meant for office spaces and other purposes, has been one of the obstacles for radiowaves to propagate since those objects will reflect the waves. Reflection from buildings and surfaces can permit a radio service to exist where shadowing would otherwise greatly attenuate the signal. Reflection may also cause interference where shadowing itself would provide adequate attenuation of an unwanted signal.

In addition to those obstacles, propagation of UHF and VHF in the jungle will eventually faded within quite a short range of distance. Tree trunks and branches also cause a significant scattering of VHF radio waves [1].

One of the methods used is by using Split-Step Parabolic Equation Method. However, for the purpose of this project, Ray Tracing Method is used and to be developed into a MATLAB code to analyze the wave propagation. The most difficult part in propagation simulation is to predict the ray path between a transmitter and receiver. The chosen method of Ray-Tracing Method is used to find a computationally fast way to specify the most dominant ray paths that signify the field-strength prediction [2].

1.2 Problem Statement

As the scope of research has been narrowed down to more specific problem, this research project will emphasize on propagation in the jungle. The canopy tiers of the foliage are one of the problems for communication in the jungle.

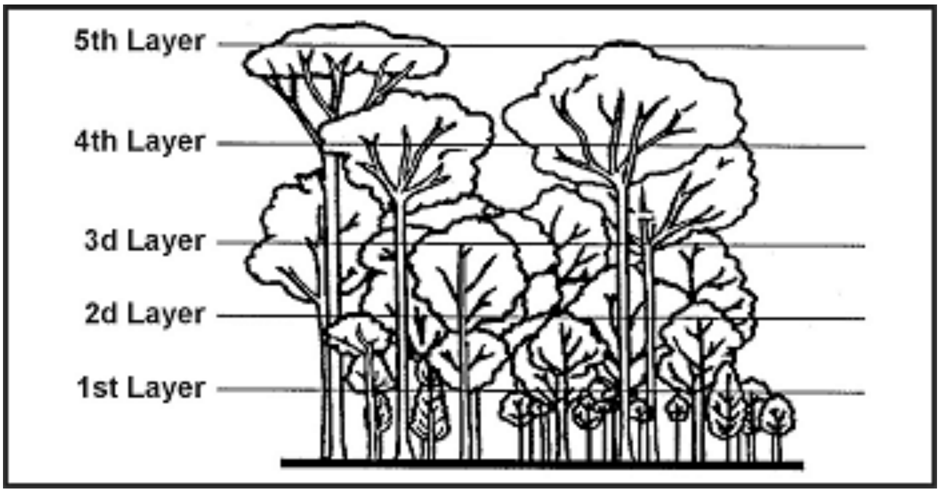

Figure 1 Forest Layers

This project will be focusing on a journal written by Wilbur R. Vincent, entitled **"Comments on the Performance of VHF Vehicular Radio Sets in Tropical Forest"**. The paper written have some property values fixed and those values are to be used in calculations throughout this report.

Table 1 Fixed Value

Frequency	**Height**
50 MHz	1.37 m

Based on the journal, for a three-slab forest layer, the properties of each layer can be summarized as follow:

Table 2 Electrical Properties of Forest

Medium	Air	Forest	Ground
Permittivity (F/m)	1	1.05	11
Conductivity ($S.m^{-1}$)	-	0.00018	0.013

The journal also shows the result of vertically aligned and horizontally aligned antenna. However for the purpose of this project, the analysis is done for vertically aligned antenna hence uses a parallel polarization calculation.

Ray-tracing method will be used with the aid of MATLAB-based calculation to analyze the situation and make comparison to the actual result in [1].

1.3 Objectives And Scope of Study

The main objective of this research is:

- To develop MATLAB code using Ray Tracing Analysis for Wireless Propagation that can help calculate ray tracing given different values with the help of appropriate visualization.

The scope of work for this project is to develop MATLAB code using one of the methods of Wireless Propagation, which is the Ray Tracing.

CHAPTER 2

LITERATURE REVIEW

2.1 Wireless Communication

Wireless communication is a type of communication using the unguided media that transport electromagnetic (EM) waves without using a physical conductor. As explained by Albert Einstein (1879-1955) when asked to describe a radio:

> *"You see, wire telegraph is a kind of a very, very long cat. You pull his tail in New York and his head is meowing in Los Angeles. Do you understand this? And radio operates exactly the same way: you send signals here, they receive them there. The only difference is there is no cat."*

The distances involved in wireless communication may be short such as in television remote control or Bluetooth technology or long as in radio communications or communication satellite.

The history of wireless communication dated back in 1864 when James Clerk Maxwell whom formulated the *Maxwell's equation* predicted the existence of wireless communication. However, it is not until 23 years later that Heinrich Hertz managed to demonstrate the physical existence of radio waves.

Over the years, wireless communication technology has been rapidly developed. From wireless telegraphy, amplitude modulation (AM) radio, microwave relay system, SCORE (Signal Communication by Orbital Relay Equipment) satellite to GSM (Global System for Mobile) communications. The development of wireless communication is still on going to ensure that the newest technology delivers faster, and precise information than later technology.

2.2 Wireless Propagation

Electromagnetic waves are broadcast through free space and are available to receivers. This type of unguided signal travels in several ways, which includes through ground propagation, sky propagation, and line-of-sight (LOS) propagation [6].

2.2.1. Ground Propagation

Ground wave propagation follows the contour of the earth and can propagate in considerable distances, well over the visual horizon. This effect found in frequency up to 2 MHz. Several factors account for the tendency of electromagnetic wave in this frequency band to follow the earth's curvature.

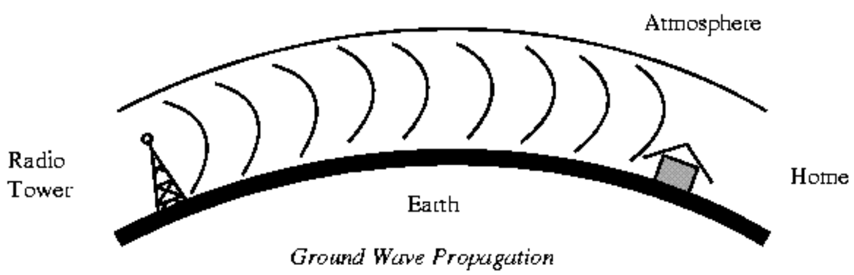

Figure 2 Ground Propagation

One factor is that the EM wave induce a current in the earth's surface, the result of which is to slow the wavefront near the earth, causing the wavefront to tilt downward and hence follow the earth's curvature. Another factor is diffraction, which is a phenomenon having to do with the behavior of the EM waves in the presence of obstacles. EM waves in this frequency range are scattered by the atmosphere in such a way that they do not penetrate the upper atmosphere. The best example for ground wave propagation is AM radio.

2.2.2. Sky Propagation

Sky propagation bounces off the Earth's ionospheric layer in the upper atmosphere. It appears as if the wave is reflected by a hard reflecting surface. However, the effect is in fact caused by refraction.

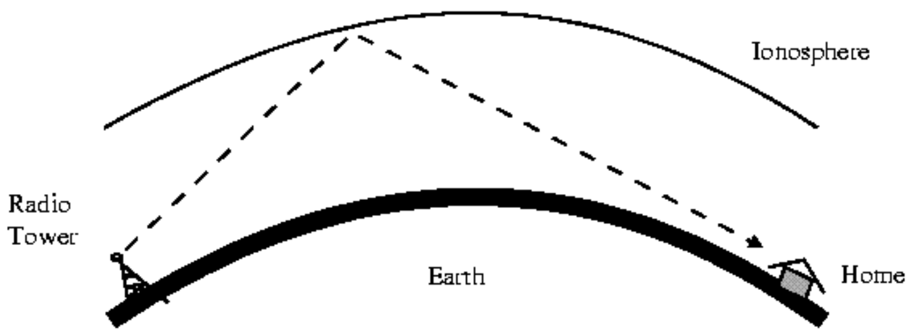

Figure 3 Sky Propagation

Sky propagation is sometimes called double hop propagation. It operates in the frequency range of 30 – 85 MHz. Because it depends on the Earth's ionosphere, it changes with the weather and time of day.

2.2.3. Line-of-sight (LOS) Propagation

Above 30 MHz, neither ground wave nor sky wave propagation modes operate, and communication must be by line of sight. For satellite communication, a signal above 30 MHz is not reflected by the ionosphere and therefore signal can be transmitted between an earth station and a satellite overhead that is not beyond the horizon. For a ground-based communication, the transmitting and the receiving antennas must be within an effective line of sight of each other.

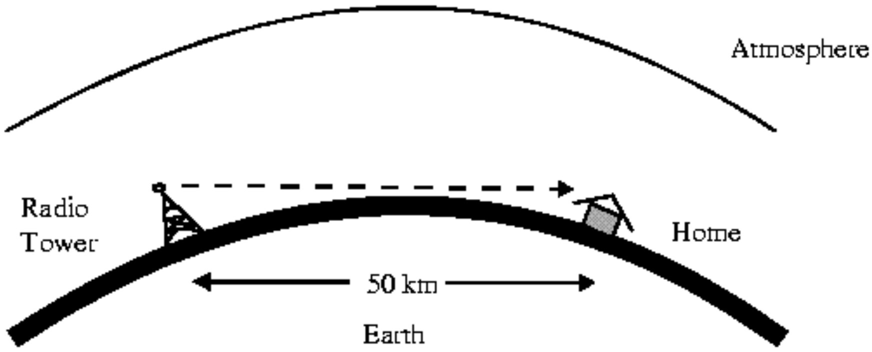

Figure 4 Line-of-sight (LOS) Propagation

Effective line of sight between transmitter and receiver signify that microwaves are refracted or bent by the atmosphere. The amount or the direction depends upon conditions, but generally microwaves are bent with the curvature of the earth and will hence propagate farther than the line of sight.

2.3 Wireless Propagation In Jungle

Wireless propagation through rough terrain will cover how refractivity and reflectivity play important roles of the transmission. In practice, reflection on rough surfaces such as ground and buildings will not be as smooth as on flat terrain. The directional distribution of the scattered of diffuse scattering will depend on the angle of incidence, the nature and roughness of the terrain [5]. Evaporation ducts on the other hand, is present most of the time over the ocean that indeed influence the communication system [3].

Propagation in the jungle as per rough terrain is not perfect. The existence of the trees and the foliages will scatter the radio waves of VHF. The trunks are the most significant scatterers in jungle. Apart from that, communication in jungle using VHF in practice covers only small range of distance between transmitter and receiver due to minimum power supplied. Study [1] also shows that vertical orientation of the tees is a significant factor, causing more scattering of vertically rather than horizontally polarized signals.

2.4 Ray Tracing Analysis

The most common approximations use ray-tracing technique. This technique approximates the propagation of electromagnetic waves by representing the wavefronts as simple particles. Ray tracing calculates the path of waves through a system with regions of varying propagation velocity, absorption characteristics, and reflecting surfaces. Under these circumstances, ray may bend, change direction, or reflect off surfaces, hence complicating analysis.

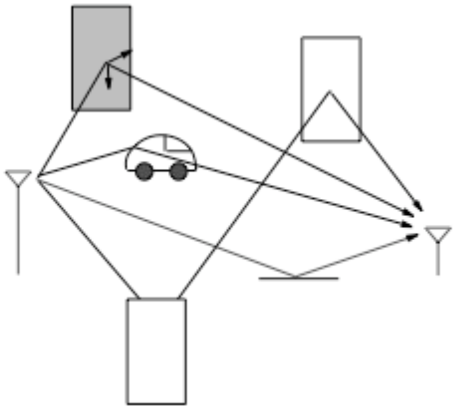

Figure 5 Reflected, Diffracted, and Scattered Wave Components

Figure below shows ray tracing of a beam of light passing through a medium with changing refractive index. The ray is advanced by a small amount, and then the direction is recalculated.

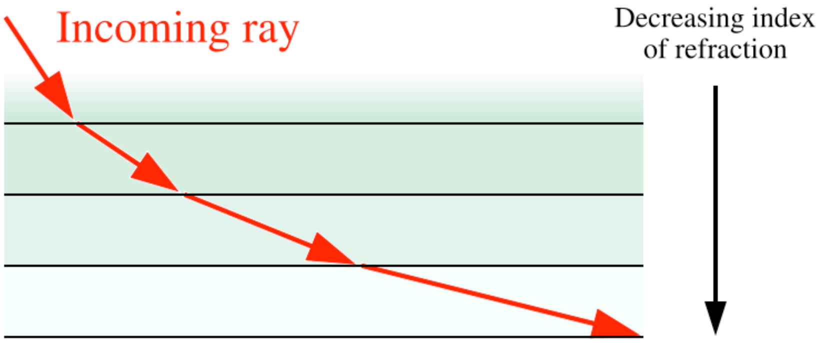

Figure 6 Beam of light depicted in a ray-tracing method

Ray tracing solves the problem by repeatedly advancing idealized narrow beams called rays through the medium by discrete amounts or particles. Simple problems can be analyzed by propagating a few rays using simple mathematics. However, by using a developed coding on computer to propagate many rays can perform more detailed analyses efficiently.

CHAPTER 3

METHODOLOGY

3.1 Procedure Identification

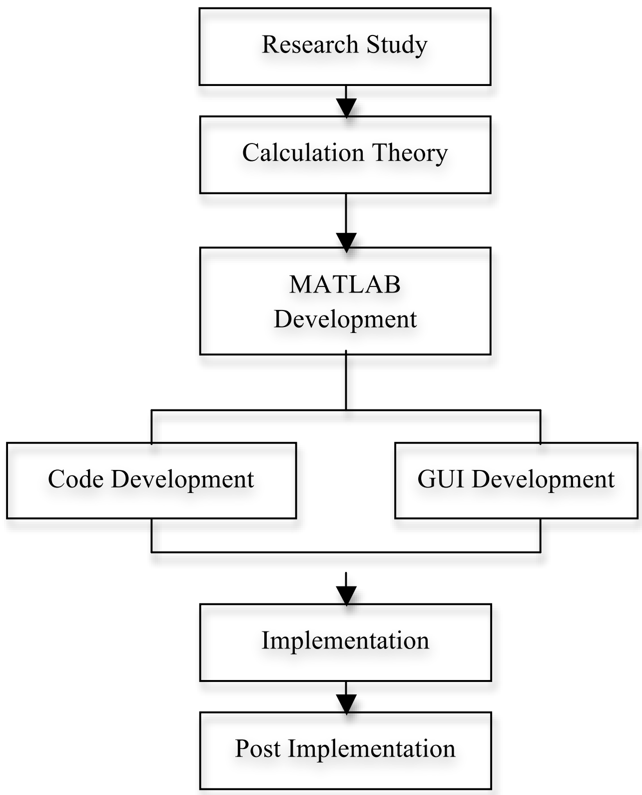

Figure 7 Flow Chart of Project

3.2 Tools Required

Tool required for the purpose of this project is:

1. MATLAB
2. GetData Graph Digitizer

CHAPTER 4

RESULT AND DISCUSSION

4.1 Matlab Code Development

4.1.1 Incident Angle

The first stage of the MATLAB code has been developed. Which is to calculate the angles of the reflected wave and the ray path.

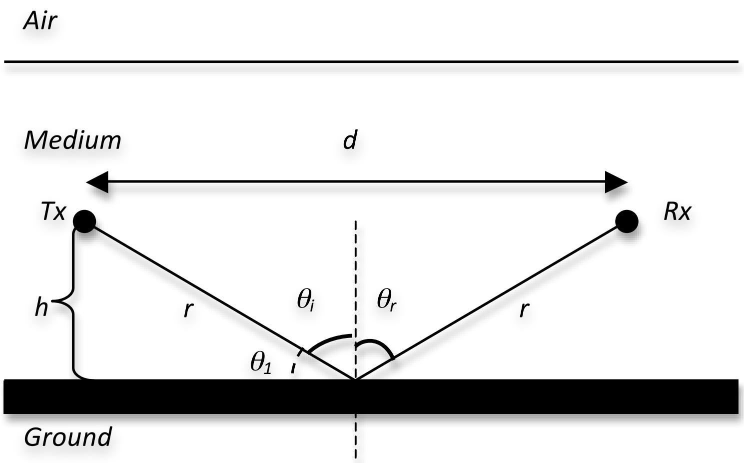

Figure 8 Reflected Angle

The MATLAB code was developed by the basic theory of reflected wave. The transmitter and receiver are at *h* distance from the ground with angle of reflection, θ_1. The distance between receiver and transmitter are *d*. Value of θ_1 can be calculated as:

$$\theta_1 = \tan^{-1}\left(\frac{2h}{d}\right)$$

The above equation is for simple reflection at which reflection of wave happened one time. For the case of multiple reflections as shown in the figure below, the following equation can be used:

$$\theta_n = \tan^{-1}\left(\frac{2h}{dn}\right)$$

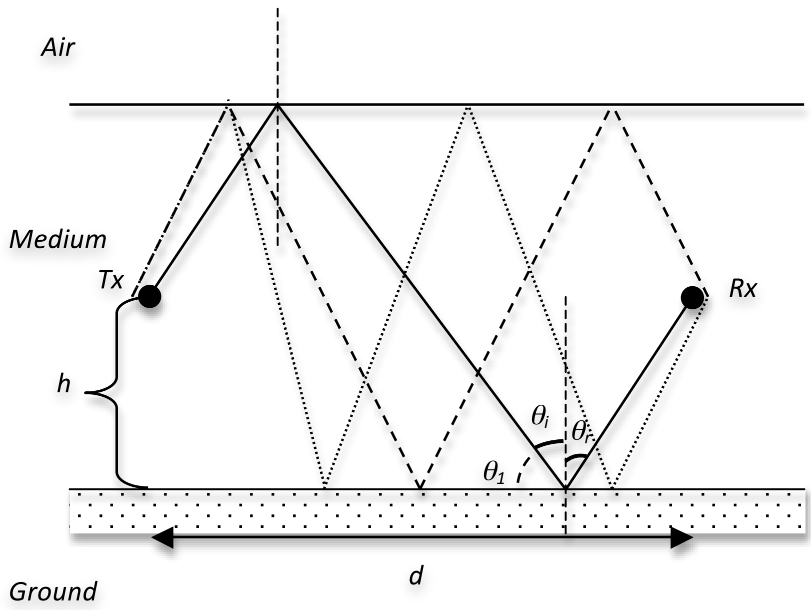

Figure 9 Multiple Angle Reflection

Where *h* is the height of transmitter and receiver from the ground, *d* is the distance between transmitter and receiver and *n* is the number of wave reflected.

The reflection angle or also known as the reflection coefficient is the needed value for the calculation. It can be calculated by subtracting θ_n from 90º.

$$\theta_i = 90 - \theta_n$$

Table 3: Value of θ_i As ***n*** Increases At ***h*** = 1.37, ***d*** = 100

n	**Reflection Coefficient, θ_i**
1	88.4305°
2	89.2151°
3	89.4767°
4	89.6075°
5	89.686°

In Table 1, we can see that as n increases, the value of θ increases. However, if we look at n as a constant (say n = 10) and vary the distance of transmitter and receiver, the value of θ_i will be closer to 90° .

Table 4: Value Of θ_i As ***d*** Increases With Constant Value Of ***n***

Distance, *d*	**Reflection Coefficient, θ_i**
100	89.843
200	89.9215
300	89.9477
400	89.9608
500	89.9686

4.1.2 Path Length

The path length of the ray can be calculated using simple trigonometric equation. The transmitter and receiver are at h distance from the ground and the distance between receiver and transmitter are d as depicted in Figure 10 below.

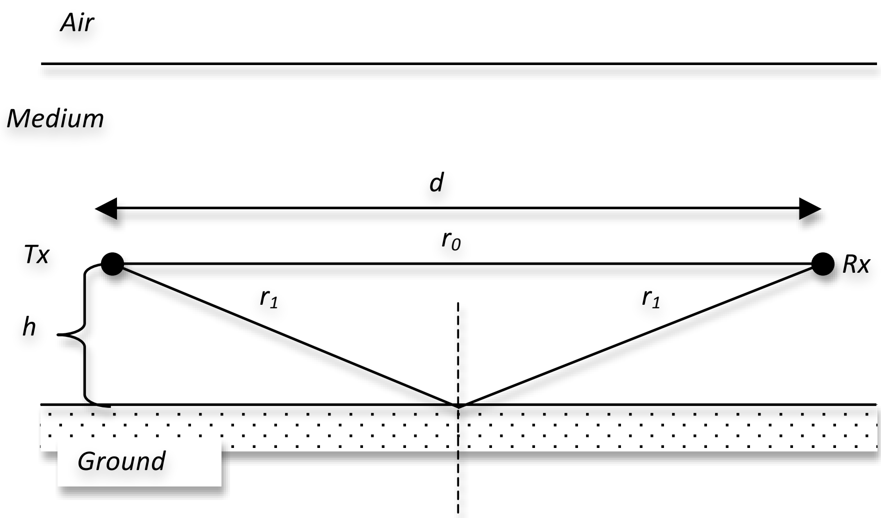

Figure 10 Path Length Indicated By r_0 And r_1

Value of r can be calculated as:

$$r = \sqrt{\left(\frac{d}{2}\right)^2 + h^2}$$

Hence, the total path length (PL) for a single reflection (at n=1) is the sum of each ray that travels from transmitter to the receiver:

$$PL = 2r$$

The above equation is the path length for single reflection. For the case of multiple reflections as in Figure 6 below, the following equation can be used:

$$r_n = \sqrt{\left(\frac{d}{2n}\right)^2 + h^2}$$

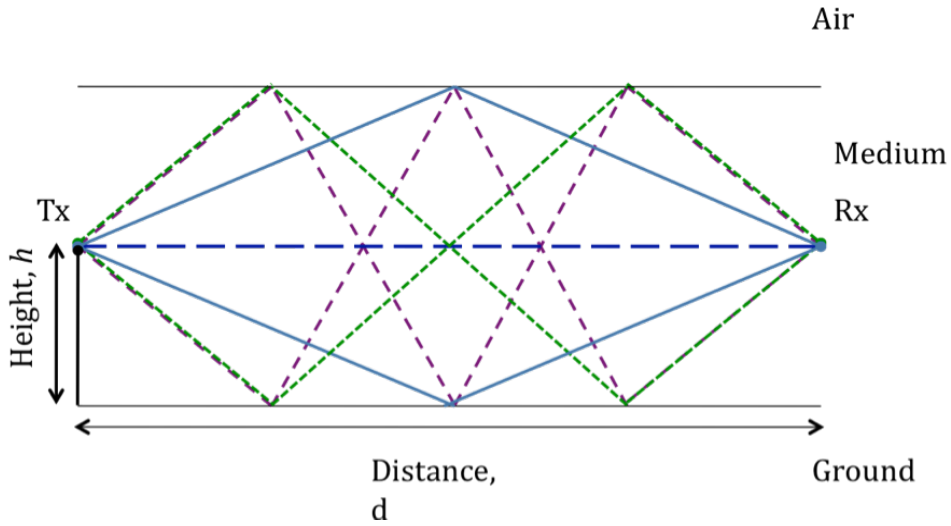

Figure 11 Ray Path For Multiple Reflections

The total path length for multiple reflections will be as follow:

$$PL = 2nr$$

Table 5: Total Path Length For Multiple Reflections At ***h*** = 1.37, ***d*** = 100

n	**Path Length**	**Total Path Length**
1	50.0188	100.038
2	25.0375	100.15
3	16.7229	100.337
4	12.5749	100.599
5	10.0934	100.943

In Table 2, we can see that as *n* increases, the value of total path length also increases.

4.1.3 Parallel Polarization

A wave is parallel polarized when its **E** lies in the plane of incidence. Figure below shows the parallel polarization of a wave.

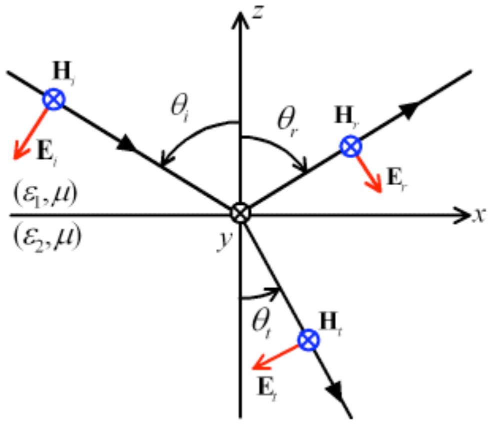

Figure 12 Parallel Polarization

The polarization helps in determining the orientation of an antenna. The parallel polarization is used in a vertically oriented antenna as what is used in the journal as reference.

According to Fresnel formula, the angles θ_i of the incident wave, θ_r of the reflected wave and θ_t of the refracted wave are given by the equation:

$$\theta_i = \theta_r$$

$$n_1 \sin \theta_i = n_2 \sin \theta_t$$

The intensity reflection coefficients $R_{\|}$ and transmission coefficients $T_{\|}$ are described by the equations:

$$\Gamma_B = R_{\|} = \frac{E_{\|}^r}{E_{\|}^i} = \frac{n_t \cos\theta_i - n_i \cos\theta_t}{n_i \cos\theta_t + n_t \cos\theta_i} \qquad \tau_B = T_{\|} = \frac{E_{\|}^t}{E_{\|}^i} = \frac{2 n_i \cos\theta_i}{n_i \cos\theta_t + n_t \cos\theta_i}$$

For parallel polarization, Fresnel reflection and transmission coefficient can be related by:

$$\tau_1 = (1 + \Gamma_{||})\frac{\cos\theta_i}{\cos\theta_r}$$

For a nonmagnetic materials, the expression for $\Gamma_{||}$ can be written as:

$$\Gamma = \frac{-(\varepsilon_2/\varepsilon_1)\cos\theta_i + \sqrt{(\varepsilon_2/\varepsilon_1) - \sin^2\theta_i}}{(\varepsilon_2/\varepsilon_1)\cos\theta_i + \sqrt{(\varepsilon_2/\varepsilon_1) - \sin^2\theta_i}}$$

Where ε_1 is the permittivity where the ray coming from while ε_2 is the permittivity where the ray is coming to. In simplification, the polarization can be divided into two hence, leading us towards the following formulas (for the purpose of this calculation, the permittivity values as shown in Table 2 are used):

i) Polarization at the air layer, Γ_{air}

$$\Gamma = \frac{-0.9523\cos\theta_i + \sqrt{0.9523 - \sin^2\theta_i}}{0.9523\cos\theta_i + \sqrt{0.9523 - \sin^2\theta_i}}$$

ii) Polarization at the ground layer, Γ_{gnd}

$$\Gamma = \frac{-10.476\cos\theta_i + \sqrt{10.476 - \sin^2\theta_i}}{10.476\cos\theta_i + \sqrt{10.476 - \sin^2\theta_i}}$$

Table 6: Value for Polarizations as ***d*** increases (*n* = 10)

Distance, *d*	**Polarization of Air, Γ_{air}**	**Polarization of Ground, Γ_{gnd}**
100	0.999714	0.981523
200	0.999928	0.990719
300	0.999968	0.993803
400	0.999982	0.995348
500	0.999989	0.996277

4.1.4 Attenuation Factor

For waves traveling through non-magnetic materials, the permeability can be regards as the permeability of a vacuum, $\mu = \mu_o$, hence giving the wave number to be:

$$k = \omega\sqrt{\mu_o \varepsilon_o \varepsilon^*} = \omega\sqrt{\mu_o \varepsilon_o \left(\varepsilon_r - j\frac{\sigma}{\omega \varepsilon_o}\right)}$$

$$k = \alpha + j\beta$$

Where α is the attenuation constant while β is the phase constant. This factor contributes to the decaying of the amplitude of the electrical fields.

$$k = 2\pi \bullet 50M\sqrt{4\pi \times 10^{-7} \bullet 8.854 \times 10^{-12}\left(11 - j\frac{0.00018}{2\pi \bullet 50M \bullet 8.854 \times 10^{-12}}\right)}$$

$$k = 1.074 - j0.0331$$

Hence, the attenuation factor of $k = 1.074 - j0.0331$ will be a constant value throughout the entire calculation of this project.

4.1.5 Total Field

The electric field, which corresponds to the ray, can be shown by the general equation below:

$$E_n = \Gamma_{air}^{p} \Gamma_{gnd}^{m} \frac{e^{-j2nkr}}{2nr}$$

Where $p + m = n$.

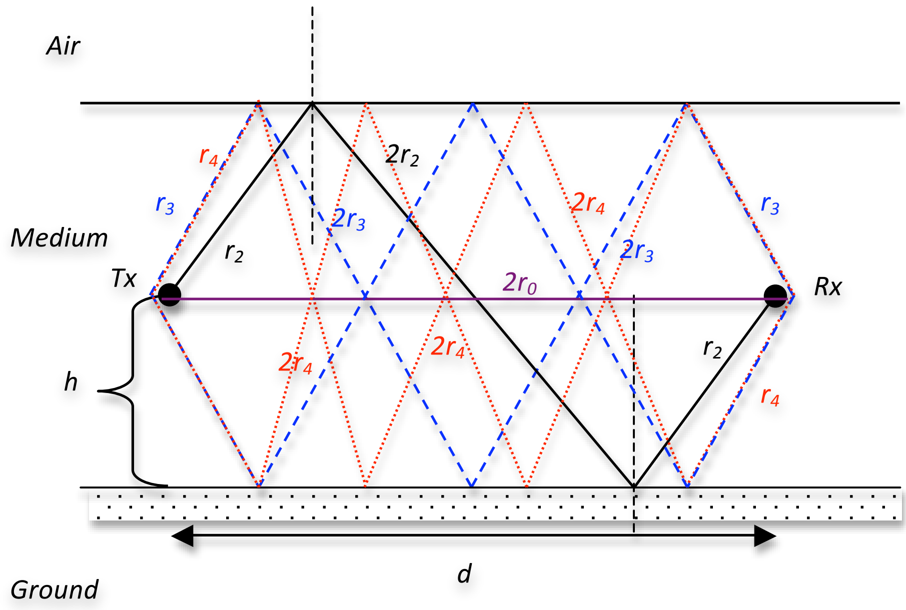

Figure 13 Multiple Ray Path

As we can see in the figure above, there are many rays represented in various colours. The single line in the middle is the direct propagation from transmitter to receiver. The orange-coloured lines are the propagation at a single-reflected ray, black-coloured lines are the two-reflected rays, blue-coloured lines are the three reflected rays and the red-colored lines are the four-reflected rays.

To calculate for example the total electrical field at *n* = 3, all reflecting rays must be taken into calculation.

$$E_n = \underbrace{\frac{e^{-jkr}}{r}}_{E_0} + \underbrace{\frac{e^{-jk2r}}{2r}\Gamma_{air} + \frac{e^{-jk2r}}{2r}\Gamma_{gnd}}_{E_1} + \underbrace{\frac{e^{-jk4r}}{4r}\Gamma_{air}\Gamma_{gnd} + \frac{e^{-jk4r}}{4r}\Gamma_{air}\Gamma_{gnd}}_{E_2} + \underbrace{\frac{e^{-jk6r}}{6r}\Gamma_{air}{}^{2}\Gamma_{gnd} + \frac{e^{-jk6r}}{6r}\Gamma_{air}\Gamma_{gnd}{}^{2}}_{E_3}$$

At which the terms E_1, E_2 and E_3 were added together. This gives the following formula:

$$E_n = E_0 + E_1 + E_2 + E_3 + ... + E_n$$

Where E_0 is the direct transmission (at *n* = 0). Below is the calculated value for ***d*** = 100 until 500 at ***n*** = 10.

Table 7: Total Electrical Field For Varied Distance

Distance, *d*	**Electrical Field (Direct Transmission)**	**Total Electrical Field**
100	-68.7271	-180.823
150	-86.6124	-225.641
200	-103.475	-262.848
250	-119.776	-295.388
300	-135.724	-324.819
350	-151.426	-352.039
400	-166.95	-377.612
450	-182.336	-401.908
500	-197.615	-425.189

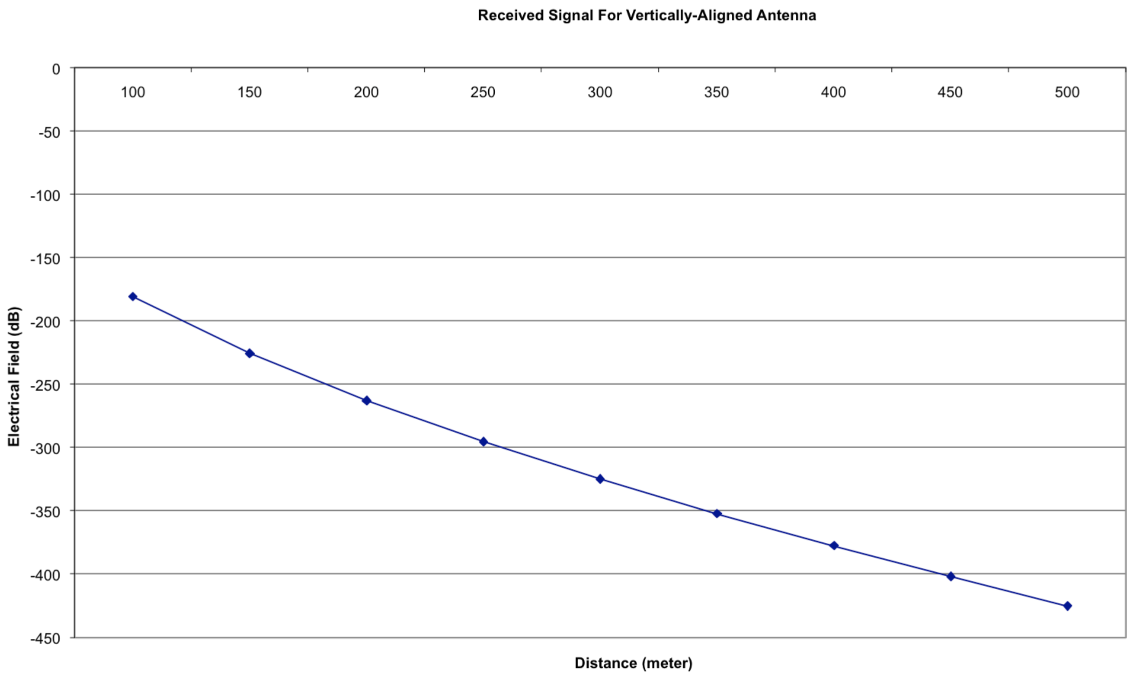

Figure 14 Total Electrical Field vs. Distance

If it were to be calculated for a large number of wave propagations, the total field of the ray will be decreasing and consequently becomes so small. This suggests that the total electrical field of the ray can be ignored for a large number of wave propagations.

4.2 Matlab GUI Development

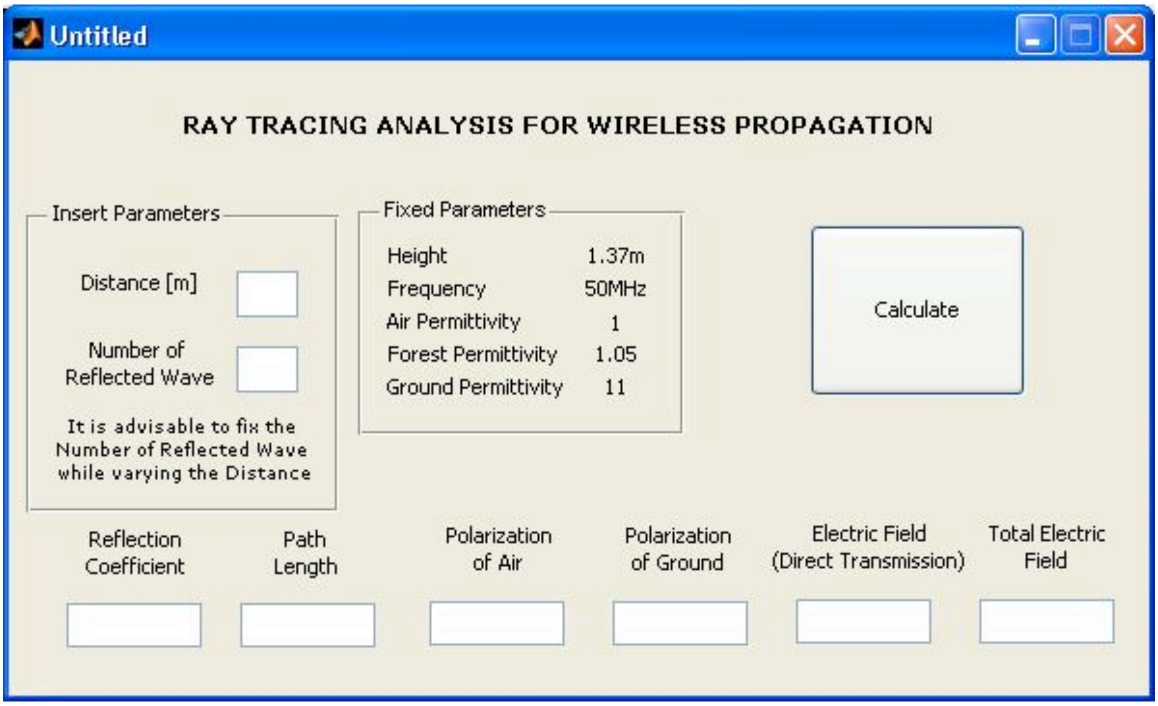

Figure 15 Electrical Field Calculation Interface

The above is the interface of the MATLAB calculation. The interface is built to ease user in inserting own value of distance between receiver and transmitter and number of wave reflected in the 'Insert Parameters' box. It is advisable to make constant either one value and vary another value. This is to ensure that the total electric field obtained is consistent.

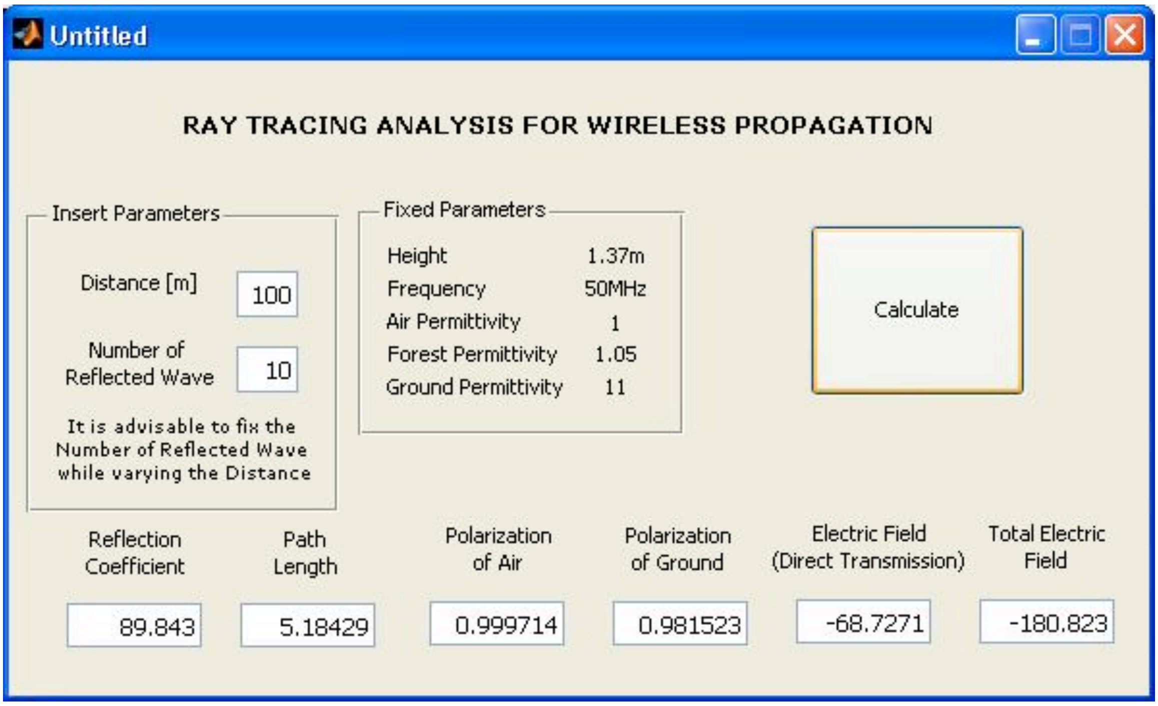

Figure 16 Example of Inserted Values

Figure above shows the example of value when certain parameters are inserted into the interface. This interface helps us to calculate Electrical Field much faster.

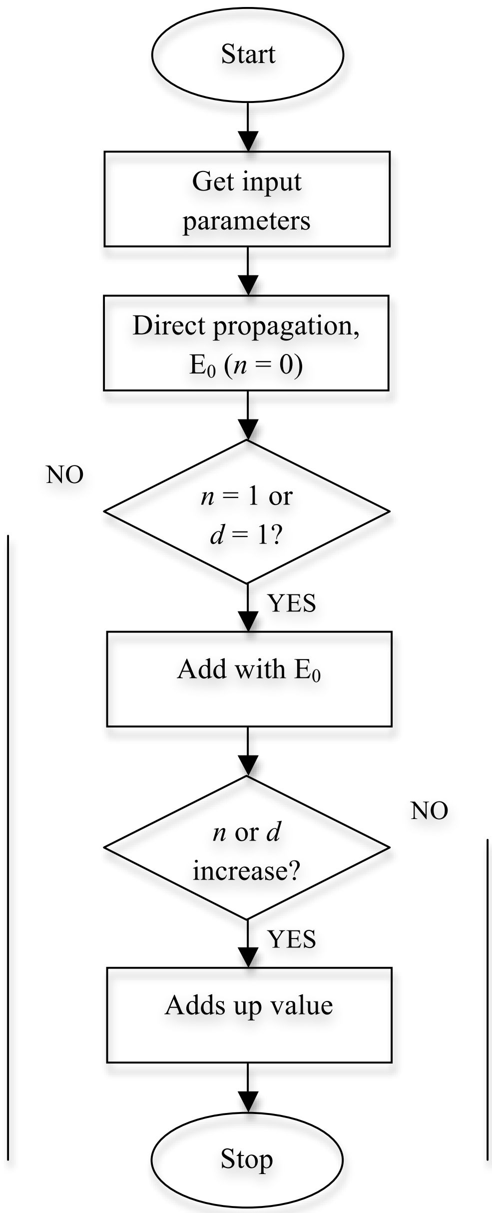

Figure 17 Flow Chart of Ray Tracing Method

The figure above shows the flow chart of the Ray Tracing Method in MATLAB as a routine. The method takes the user-supplied input parameters (distance between transmitter and receiver, *d* and number of wave reflected, *n*) and MATLAB will start calculating. The method will automatically calculate for direct transmission and will move on to first increment, $n = 1$ or $d = 1$. The calculations will continue until maximum distance or number of wave reflected. The routine will ends when the values are added up together.

4.3 Original Data

The original data was captured using GetData Graph Digitizer software in order to make a comparison to the theoretical calculation.

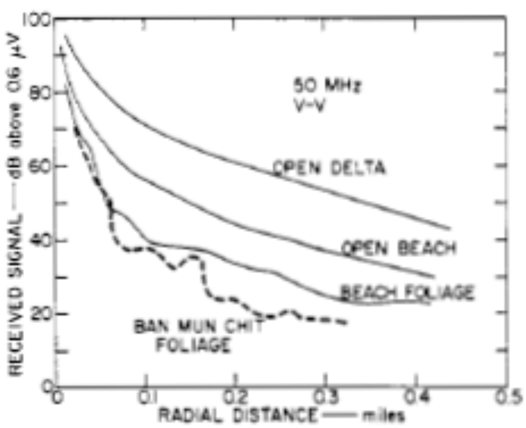

Figure 18 Original data from [1]

Below is the data captured using GetData Graph Digitizer:

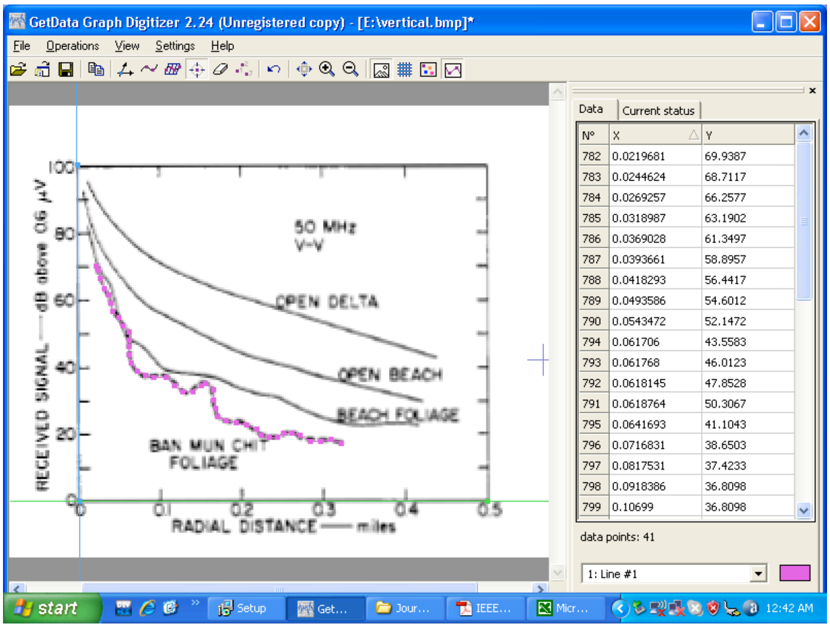

Figure 19 GetData-Graph-Digitizer data

The graph was dotted in pink to trace the value of that particular line for Ban Mun Chit foliage that is similar to ray tracing analysis for wireless propagation in a jungle. The data was then captured in excel format.

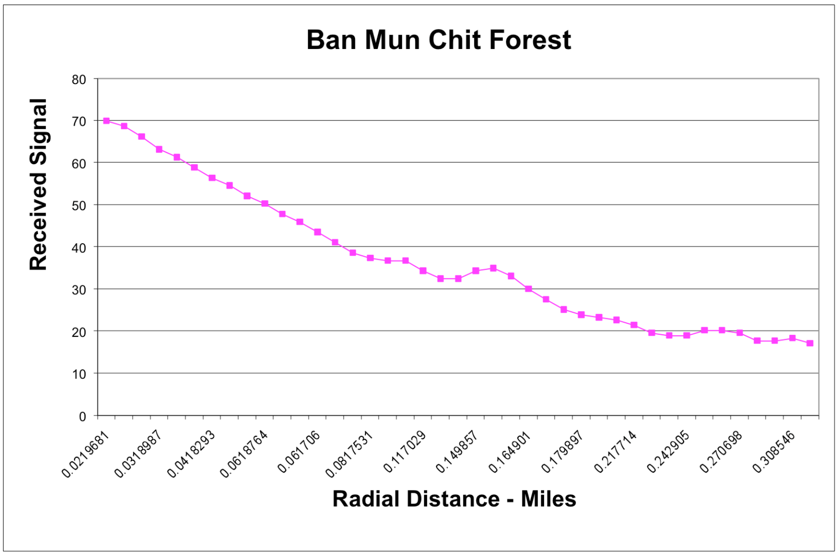

Figure 20 Ban Mun Chit Forest's Data Extracted To Excel

CHAPTER 5

CONCLUSION & RECOMMENDATION

5.1 Conclusion

Ray Tracing Method is one of the ways to investigate wireless propagation problems. With the aid of MATLAB package, the analysis of wireless propagation problems can be done effectively.

Ray Tracing Method can also be used in analyzing – computationally – the characteristic of the ray by each stroke made. It is rather simple and less complicated in order to determine its characteristics.

The results show that both graphs (Figure 14 and Figure 18) depicted same characteristic, which is a decreasing value. This project also shows that it is very difficult to get the accurate same result. In reality there could be many rays distributed from the transmitter while theoretical calculations could not determine the exact rays that were transmitted. However, it is certain that at some point, the electrical field will converges to zero where signal can no longer be received.

5.2 Recommendation

A development of a GUI will help users in inserting some important variables such as the height of transmitter and receiver, distance between transmitter and receivers, and also frequency used. The insertion of these variables will help to see the pattern of ray propagation by using MATLAB. Apart from that, parallel computing, will also help to determine the wireless ray paths that is transmitted faster. It would be much helpful to see comparable figures as in graph for example to analyze any differences in parameters.

Another recommendation made by brilliant minds after presenting this project is to carry out an experiment with a clean transmitter and receiver in a confined space. A miniature or mock bushes that represents jungle can also be used to analyze and compare the theoretical data with original data for advanced experiment purposes.

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[7] Simon Haykin and Michael Moher, “Introduction” in *Modern Wireless Communications*, New Jersey: Pearson Education Inc. 1st Edition, pp 1 – 2, 2005.

APPENDICES

APPENDIX A

MATLAB CODING

```
d = str2num(get(handles.distance,'String'));
n = str2num(get(handles.waveNumber,'String'));

% -- defining parameters

f=50*10^6;              %frequency 50MHz
height=1.37;            %height of antenna in meter
u0=4*pi*10^(-7);        %permeability of free space
e0=8.854*10^(-12);      %permittivity of free space
e1=1;                   %permittivity of air
e2=1.05;                %permittivity of forest at 50MHz
e3=11;                  %permittivity of ground at 50MHz
s2=0.00018;             %conductivity of forest at 50MHz
s3=0.013;               %conductivity of ground at 50MHz

w=2*pi*f;
p=sqrt(u0*e0);
q=sqrt(e2-(s2/(w*e0)*i));
k=w*p*q;                %attenuation factor

% -- calculation starts here

x=0;
y=0;

for m=1:1:n

    RefCoeff = 90-atand (2*height/(d*n));
    R (m) = RefCoeff;
    set(handles.RefCoeff, 'String', RefCoeff);
    PathLength = sqrt((d/(2*n))^2+height^2);
    L (m) = PathLength;
    set(handles.PathLength, 'String', PathLength);
    PolarAir = (-(e1/e2)*cosd (RefCoeff)+ sqrt((e1/e2)-(sind
(RefCoeff))^2))/((e1/e2)*cosd (RefCoeff)+ sqrt((e1/e2)-(sind
(RefCoeff))^2));
    A (m) = PolarAir;
    set(handles.PolarAir, 'String', PolarAir);
```

```
    PolarGnd = (-(e3/e2)*cosd (RefCoeff)+ sqrt((e3/e2)-(sind
(RefCoeff))^2))/((e3/e2)*cosd (RefCoeff)+ sqrt((e3/e2)-(sind
(RefCoeff))^2));
    G (m) = PolarGnd;
    set(handles.PolarGnd, 'String', PolarGnd);

    if x>y;
        y=y+1;
        z = (PolarAir^x)*(PolarGnd^y)+(PolarAir^y)*(PolarGnd^x);
        w (m) = z;
    else

        x=x+1;
        z = (PolarAir^x)*(PolarGnd^y)+(PolarAir^y)*(PolarGnd^x);
        w (m) = z;
    end

    En (m) = 20*log10(abs(z*exp(
(2*k*n*PathLength)*j)/(2*n*PathLength)));

end

E0=exp(-sqrt(-1)*k*d)/d;  %EM field contributed by ray at n=0
Eo=20*log10(abs(E0))      %EM field in dB
set(handles.En0, 'String', Eo);

En(1) = 20*log10(abs(z*exp(-(2*k*1*PathLength)*j)/(2*1*PathLength)));

for N = 2:n

    En(N) = En(N-1) + 20*log10(abs(z*exp(-
(2*k*1*PathLength)*j)/(2*1*PathLength)));

end

box = E0 + En;

disp(['Values of N___Electrical Field'])
disp([1:N; box])

set(handles.box, 'String', box(N));
```

The code above is the vital information on the calculation part. Functions are set prior to the calculation.

APPENDIX B

COMPUTATIONAL VALUE WHEN *d* IS VARIED

*The value of the parameters are set to:

h = 1.37 m
n = 10
f = 50 MHz

Distance [meter]	Reflection Coefficient, θ_i	Path Length	Polarization of Air, Γ_{air}	Polarization of Ground, Γ_{ground}	Direct Transmission	Total Electrical Field, dB
100	89.843	5.18429	0.999714	0.981523	-68.7271	-180.823
110	89.8573	5.66806	0.999764	0.983188	-72.4276	-190.615
120	89.8692	6.15442	0.999801	0.984579	-76.0561	-199.947
130	89.8792	6.64281	0.999831	0.985756	-79.6241	-208.866
140	89.8879	7.1328	0.999854	0.986767	-83.1405	-217.418
150	89.8953	7.6241	0.999873	0.987644	-86.6124	-225.641
160	89.9019	8.11646	0.999888	0.988412	-90.0457	-233.568
170	89.9077	8.6097	0.999901	0.98909	-93.445	-241.228
180	89.9128	9.10368	0.999912	0.989693	-96.8142	-248.647
190	89.9174	9.59828	0.999921	0.990232	-100.157	-255.848
200	89.9215	10.0934	0.999928	0.990719	-103.475	-262.848
210	89.9252	10.589	0.999935	0.991159	-106.771	-269.666
220	89.9286	11.085	0.999941	0.991559	-110.048	-276.316
230	89.9317	11.5813	0.999946	0.991924	-113.307	-282.813
240	89.9346	12.078	0.99995	0.992259	-116.549	-289.166
250	89.9372	12.5749	0.999954	0.992568	-119.776	-295.388
260	89.9396	13.072	0.999958	0.992853	-122.99	-301.487
270	89.9419	13.5693	0.999961	0.993117	-126.19	-307.473
280	89.9439	14.0669	0.999964	0.993362	-129.379	-313.352
290	89.9459	14.5646	0.999966	0.99359	-132.556	-319.132
300	89.9477	15.0624	0.999968	0.993803	-135.724	-324.819
310	89.9494	15.5604	0.99997	0.994002	-138.881	-330.418
320	89.9509	16.0585	0.999972	0.994189	-142.03	-335.935
330	89.9524	16.5568	0.999974	0.994365	-145.17	-341.375
340	89.9538	17.0551	0.999975	0.99453	-148.302	-346.742

350	89.9551	17.5535	0.999977	0.994686	-151.426	-352.039
360	89.9564	18.0521	0.999978	0.994833	-154.544	-357.272
370	89.9576	18.5507	0.999979	0.994972	-157.654	-362.442
380	89.9587	19.0493	0.99998	0.995104	-160.759	-367.554
390	89.9597	19.5481	0.999981	0.995229	-163.857	-372.609
400	89.9608	20.0469	0.999982	0.995348	-166.95	-377.612
410	89.9617	20.5457	0.999983	0.995462	-170.037	-382.563
420	89.9626	21.0446	0.999984	0.995569	-173.119	-387.467
430	89.9635	21.5436	0.999985	0.995672	-176.196	-392.324
440	89.9643	22.0426	0.999985	0.99577	-179.268	-397.137
450	89.9651	22.5417	0.999986	0.995864	-182.336	-401.908
460	89.9659	23.0408	0.999986	0.995954	-185.4	-406.639
470	89.9666	23.5399	0.999987	0.99604	-188.459	-411.331
480	89.9673	24.0391	0.999988	0.996122	-191.515	-415.985
490	89.968	24.5383	0.999988	0.996201	-194.567	-420.604
500	89.9686	25.0375	0.999989	0.996277	-197.615	-425.189

APPENDIX C

JOURNAL:

COMMENTS ON THE PERFORMANCE OF VHF VEHICULAR RADIO SETS IN TROPICAL FOREST BY WILBUR R. VINCENT