INFLUENCE OF WIND AND RAIN ON A FOLIAGE RADIO-WAVE PROPAGATION CHANNEL

BY

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M.Sc/ENG/48534/05-06

A Thesis Submitted to the School of Postgraduate Studies, Ahmadu Bello University Zaria, in Partial Fulfillment of The Requirements for the Award of Master of Science (M.Sc.) Degree in Electrical Engineering.

DECLARATION

I, NUHU Sufiyanu hereby declare that this thesis titled **"Influence of Wind and Rain on a Foliage Radio-wave Propagation Channel"** presented to the Department of Electrical and Computer Engineering, Ahmadu Bello University, Zaria, is the result of my own work and it has not been presented in any form, anywhere for the award of a degree.

All sources herein referenced and cited have been duly acknowledged. All shortcomings are entirely my responsibility.

…….. ……

NUHU Sufiyanu **Date**

CERTIFICATION

This thesis titled **"Influence of Wind and Rain on a Foliage Radio-wave Propagation Channel"** satisfies one of the requirements for the award of Master of Science (M.Sc) degree in Electrical Engineering and has been approved by the Department of Electrical and Computer Engineering, Ahmadu Bello University, Zaria.

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DEDICATION

I dedicate this work to my children: Saifullahi, Ibrahim, Umar, Nabila, Mustapha, Bashir, Hassan and Hussain; and the entire members of Malam Nuhu family.

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First and foremost I thank Almighty God for making this thesis a reality and for granting me the courage to continue the work when I was about to give up.

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(HUKPDEE)
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LIST OF SYMBOLS

x – Normalized random variable (normalized received signal in the foliage channel).

f(x) – The probability density function of x.

μ - Mean (location of the peak value).

 – Standard deviation.

Φ(x) – Standard normal distribution.

e – Exponent.

$I_o(z)$ – Modified Bessel function of the first kind.

 – Euler-Mascheroni constant.

Ψ – Horn's confluent hypergeometric function.

F_m – maximum probability density function.

μ_k – Raw moment in the Rayleigh distribution.

X_x – Characteristic function of the Rician distribution.

V – wind speed.

 - Gamma function.

 $_1$ – skewness of the Rician distribution

 $_2$ – Excess Kurtosis of the Rician distribution.

M(t) – Moment generating function.

erf(z) – Error function.

Φ(t) – Characteristic function of the Rayleigh distribution.

H – Information entropy.

 – mean square value of the random variable.

Q1 – First quartile.

Q3 – third quartile.

γ – Specific attenuation.

D – Diameter of a rain drop.

S_o – Scattering function of rain drops.

P(o) – Power flux in.

P(r) – Power flux out

r – Range of radio channel in rainfall

a – Reciprocal of r.

R – Rain intensity.

b – Rain attenuation constant.

LIST OF ABBREVIATIONS

dB – Decibel

EM – Electromagnetic

EU – European Union

GHz – Gigahertz

ITU-R – International Telecommunication Union relating to Radio Communication

KHz – Kilohertz

NRMED – National Resources Management and Environmental Department

Pdf – Probability Density Function

RAM – Random Access Memory

RET – Radiative Energy Transfer Theory

RI – Rain Intensity

RSS – Received Signal Strength

UMYA – Umaru Musa Yar'adua Airport

VBA – Visual Basic Application

WS – Wind Speed

x □ R – x is a real number

ABSTRACT

In this thesis, electromagnetic (EM) wave measurements at microwave frequency (10.7 GHz) were conducted in a foliage environment under the influence of artificially created wind and rain in order to investigate their combined effects on a short-range foliage radio-wave propagation channel. The obtained data was normalized to its mean to extract the temporal fading components due to the created weather-induced variations. A well-developed software program (by Mathwave Technologies) called "EasyFit 5.5 professional" was then used to characterize and model these variations through the commonly known probability distribution functions associated with radio wave propagation channels. After successful modeling and characterization, the temporal fading components were found to be Rician distributed, and the Rician K-factor decreases as the strength of wind or rain increases. This reduction in the K-factor indicates an increase in the variability of the channel when wind speed or rain intensity increases.

CHAPTER ONE

INTRODUCTION

1.1 Background Information

A foliage radio-wave propagation channel refers to the space between transmitter and receiver embedded with trees or shrubs which may or may not attenuate the propagating waves, depending on many factors such as water content and size of tree leaves, tree trunks diameters, frequency of the waves etc. While microwave propagation refers to the technology of transmitting information or power by the use of radio waves whose wavelengths are conveniently measured in small numbers of centimeters. This part of radio spectrum ranges across frequency of roughly 1.0 GHz to 30 GHz. This corresponds to 30.0cm to 1.0cm (Natasha, 2011).

Near-ground foliage radio-wave propagations are of interest for the emerging military applications, such as battle field sensor networks and for wireless communication between dismounted soldiers. In order to guarantee link availability and provide targeted quality-of-service to all the soldiers concerned, a thorough understanding of the temporal variations in the wireless channel is essential. Besides that, knowledge concerning channel time characteristics is also required to design effective fade mitigation schemes (Joshi, *et al,* 2005).

Wind/rain-induced tree movement is one of the main factors which contribute to temporal variations in foliated fixed wireless links (Chua, *et al,* 2010). The influence of this factor on the

variability of a short-range, short-height foliage radio-wave propagation channel (in the Savanna region of Northern Nigeria) is investigated and presented in the following chapters of this thesis.

1.2 Aim and Objectives of the Thesis Work

The aim of this thesis work is to determine the additional power attenuations, statistically model and characterize the temporal variations caused by wind and rain on a short-range, short-height foliage radio-wave propagation channel.

The objectives of this investigation are as follows:

-To create the required rain (artificially).

-To determine the relationship between rain intensity and rotations of the stop cock of water sprinkler (i.e. to calibrate the valve or faucet which controls the rate of water flow and hence the rain intensity).

-To create the required wind (artificially).

-To determine the relationship between wind speeds and currents into the fan (i.e. to calibrate the current transformer which controls the current flow into the fan and hence the wind speed).

-To group each weather condition into three and combine them to form nine combinations so that the resulting weather model represents that of Katsina metropolis where the investigation was conducted.

-To apply the created weather conditions (at different ranges of rain intensities and wind speeds) on the short-height foliage environment in which the microwave transmitter and receiver are situated.

-To carry out EM wave measurements in the foliage channel under the influence of these applied weather conditions.

-Finally, to carry out statistical analysis of the results.

1.3 Scope of the Study

It is viable to make theoretical computations of temporal changes imposed on the channel due to the effects of rain and wind. Unfortunately, there is still no mathematical model (in the open literature) that represents signal loss in vegetation under the combined influence of wind and rain (Meng *et al*, 2007). The closest is a Radiative Energy Transfer Theory (RET) model which represents just the power loss in vegetations without the combined influence of rain and wind.

This investigation is concerned with the experimental determination of the dynamic effects caused by artificially created wind and rain on the foliage radio-wave propagation channel and the statistical analysis of the signal variations by comparing the experimental results with the four theoretical models which are usually used for modeling radio-wave propagation channels. Namely, Gaussian, Rician, Rayleigh and Nakagami distribution models (Meng *et al*, 2007).

1.4 Motivation and Significance of the Study

The significance of the study cannot be over emphasized because near ground communication is extensively used both for scientific and military applications. These two applications require a detailed understanding of the foliage propagation channel in order to establish a good communication link through a well-defined link budget and a good design of the fade margin

(Jim, *et al,* 1998). Signal variations caused by the influence of wind and rain on a foliage channel, if not taken into consideration during design process, can affect the reliability of modern communication systems when implemented for use within such environments

1.5 Methodology

In this work, the methods used to carry out the investigation are experimental. Three different sets of experiments were conducted in order to obtain the required data. They are:

1) Determination of the relationship between wind speed in m/s and current into the fan in amperes. This is achieved using an electric fan, an anemometer (air velocity meter), and an analogue ammeter for current measurement.

2) Determination of the relationship between angles of rotation (in degrees) of stopcock (i.e. valve for controlling water flow) and rain intensity in mm/h, using a water pumping machine, high pressure hose pipes, water sprinkler with stopcock, a rain gauge and a digital electronic timer.

3) EM wave measurements in the foliage channel under the influence of the created wind and/or rain at different wind speeds and/or rain intensities. This was achieved using a microwave transmitter (10.7GHz), a microwave receiver (10.7GHz), a digital voltmeter with data-hold facility and a digital storage oscilloscope (DSO).

After collecting the required data, Microsoft Excel was used for data normalization. Finally, a well-authored software program by Mathwave Technologies named EasyFit 5.5 professional was then used for statistical analysis of the results.

1.6 Thesis Outline

The thesis report is organized into five chapters. Chapter one is the introduction which paves the way for the entire contents of the report. Chapter two is the literature review and theoretical background of the study. Chapter three is methodology which gives the full details of the measurements set-up together with pictorial and schematic illustrations. The obtained raw data under each weather phenomenon as well as the plotted waveforms are also presented in this chapter. Chapter four is results analysis which includes determination of the imposed attenuations on the channel, data normalization, modeling and characterization. It also introduces the four probability distribution functions associated with radio-wave propagation channels and the software used for the analysis. Finally, chapter five gives concise summary, conclusion and recommendations for further work.

CHAPTER TWO

LITERATURE REVIEW AND THEORETICAL BACKGROUND

2.1 Introduction

In this chapter available documents (both published and unpublished) on the topic, which contains information, ideas, data and evidence written from particular point of view are selected. The chapter expresses certain views on the nature of the topic and how it was investigated. It also presents an effective evaluation of the literatures in relation to the thesis.

The chapter also explains the theory of EM wave attenuation and scattering by vegetation and by rain drops. In addition to these, it explains briefly the reasons why rain drops scatter EM waves and the essential features of rain scatter.

2.2 Literature Review

1) Meng, Y.S., *et al,* (2007): investigated the effect of tropical weather on foliage radio wave propagation channel at UHF and VHF frequencies.

2) James S.T., (1998): carried out a research work and wrote a paper titled "RF Propagation and system design technique for broadband wireless application from 5 to 40 GHz".

3) Perras S., *et al* (2002) investigated the various temporal characteristics of radio channels for a broad range of frequencies (from 2 to 60 GHz), in various foliage environments and weather conditions.

4) Joshi G.G. *et al* (2005) investigated the effect of rain on near-ground propagation at 1900 MHz in a forest environment.

5) Chua T.H., *et al* (2010) investigated the combined effects of wind and wind direction on received signal strength (RSS) in foliated broad band fixed wireless links.

6) Mike W. (2011), investigated extensively, the impact of clutter (including vegetation under the influence of wind) on radio wave propagation channels.

2.3 Comparison of the literature in Relation to the Thesis Work

The idea of this thesis was derived from the IEEE journal paper by Meng Y. S. In that research work, the experimental site was a large-tree plantation investigated using VHF and UHF (240 MHz) and (700 MHz) frequencies at a foliage depth of 400 meters. While in this thesis work, young eucalyptus tree plantation was investigated using microwave frequency at a foliage depth of just three (3) meters due to the limit of the transmitter range and the length of the water sprinkler. This mean that there is a well pronounced difference in tree- trunk diameters, the wave lengths of the propagated signals and the length of the foliage depths.

In the referred paper, natural rainfall and wind were used while in this thesis work, artificially created wind and rainfall were used. This implies that there is an advantage in this thesis work, because parameters of the artificially created weather conditions (wind speed and rain intensity) can be controlled at will, by controlling the independent variable (i.e. current into the fan and angle of rotation of the stopcock of the sprinkler respectively).

Although created weather conditions (wind and rain) were used, the result is believed to be reliable because such created conditions are widely used for commercial and scientific applications with high degree of success. Popular examples include:- 1) Space explorations,

where astronauts are subjected to artificially created weightlessness conditions similar to that of free space in order to acclimatize before embarking on space travels. 2) The second popular example is artificial avian egg incubation practice in which eggs are subjected to artificially created temperature and humidity conditions similar to that provided by the mother-birds. 3) In film making industries artificially created wind and rain are used in place of natural ones.

2.4 Theory of Attenuation due to Vegetation (foliage environment)

Vegetation and shrubs are forms of clutter. "Clutter" means things spoiling the view that are not part of the terrain which also get in the way of radio path. Clutter causes loss as it is usually made of “lossy” materials (Mike, 2007). Buildings are often thought to be completely opaque; but this is incorrect, because signals do penetrate buildings especially if there are many windows in an open plan design or if the walls are made of wood. Tree branches and leaves cause loss and they also scatter EM waves passing through them, resulting in a strong multipath component which varies with movement of the leaves and branches in the wind. Trees often have more foliage in the summer than the winter and this leads to seasonal variability in their effect on radio waves (Mike, 2007).

There is no such thing as a typical tree (or typical shrub) but below are some examples of the loss in dB/m experienced while moving into woodland:

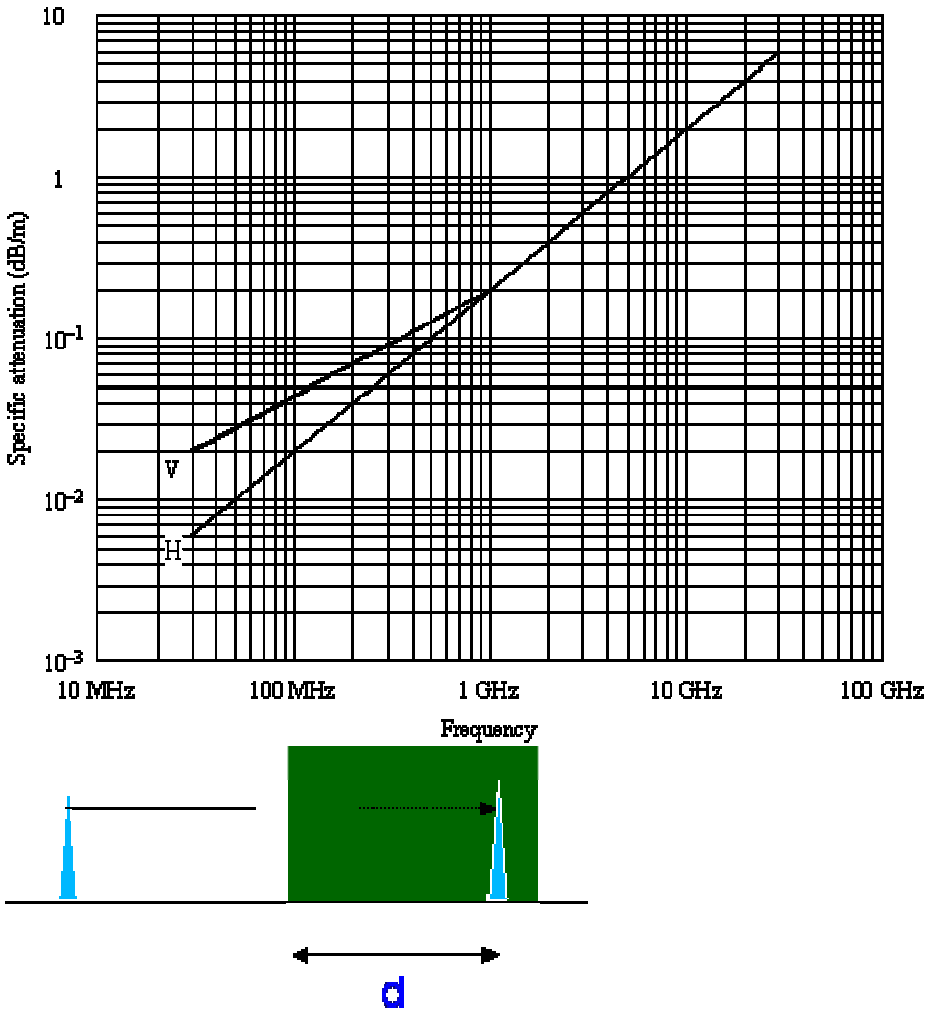


Figure 2.1: Specific attenuation (dB/m) VS frequency (Mike, 2011)

This is a little misleading as it depends very much on the particular foliage environment in question. Looking at it more analytically, higher frequency waves propagate little into the vegetation, but diffract around it both horizontally and vertically. They also reflect from the ground.

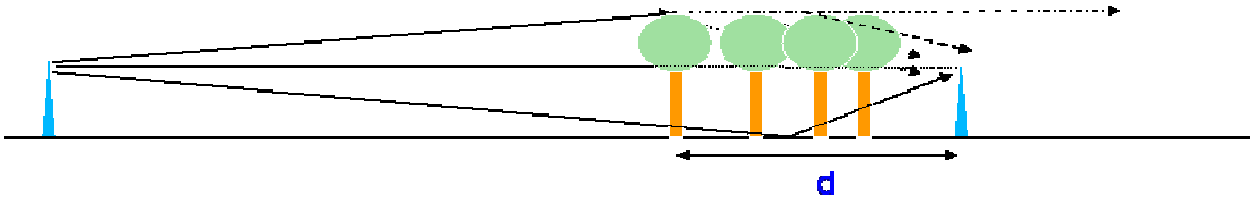


Figure 2.2: Multi-path components in a foliaged channel (Mike, 2007).

A traveling wave propagates over the top of the vegetation by Radiative transfer. This is a forward scattering mode through the canopy, a bit like rain scatter. The scattering function depends strongly on the number of leaves, the leaf shape, how much water each leaf contains and the antenna height.

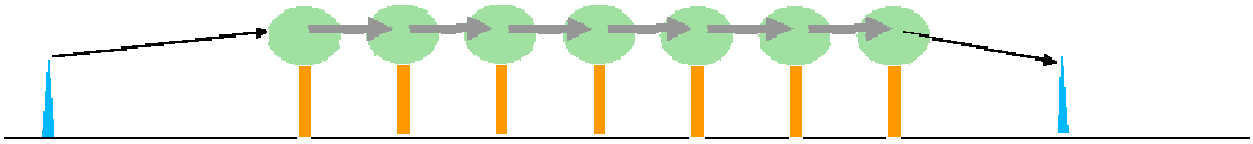


Figure 2.3: Wave Propagation by Radiative Transfer (Mike, 2007).

The result is an initial rapid signal drop with loss that starts to tail off as one goes further into the forest. Beyond a certain depth in the foliage environment, the loss does not increase much. This is illustrated in figure 2.4.

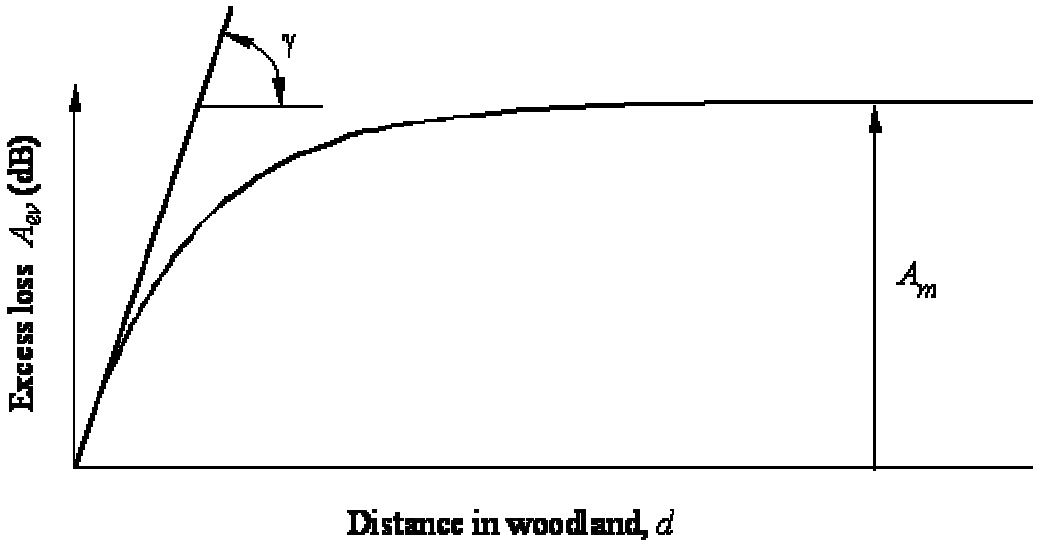


Figure 2.4: Channel depth (M) VS Excess Loss (dB) (Mike, 2007)

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2.5 Dynamic effects

As trees move in the wind, the signal received through them which contains many multipath components varies rapidly with time, due to the continuous variations in the absorbed and reflected energy. This is illustrated in Figure 2.5.

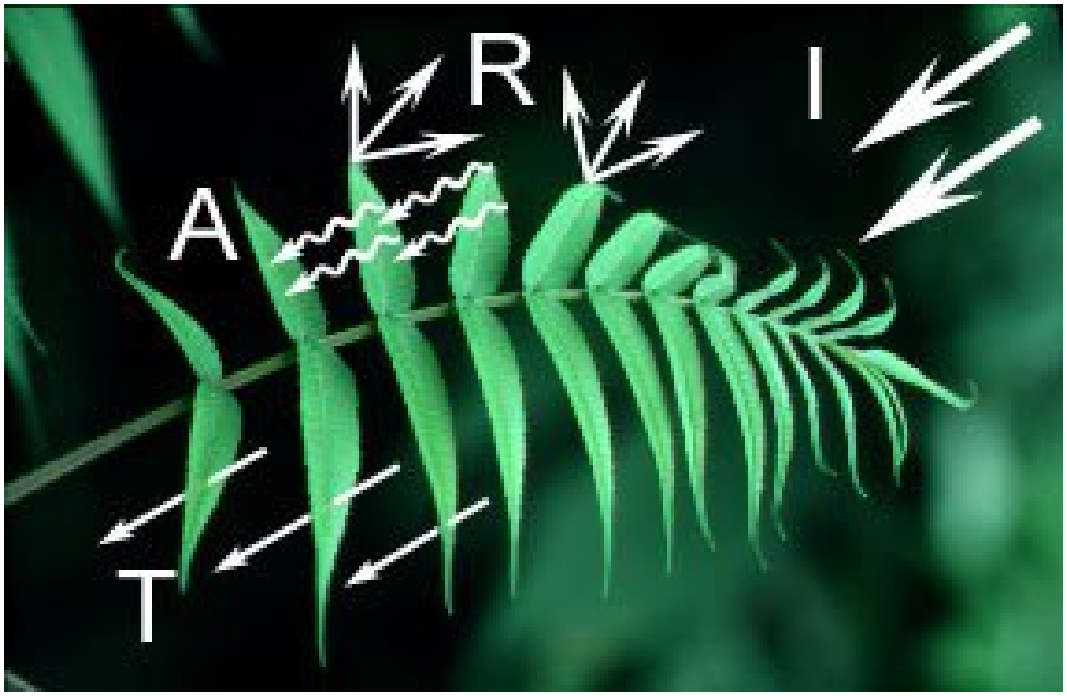


Figure 2.5: Incident (I), Transmission (T), Absorption (A) and Reflection (R) of EM waves by tree leaves (Electromagnetic spectrum, 2011)

An example of a measured standard deviation of signal level (in vegetation) against wind speed at 38GHz was measured as part of the EU 5th Framework Embrace project and are now incorporated in ITU-R recommendation P.1410 (Mike 2007).

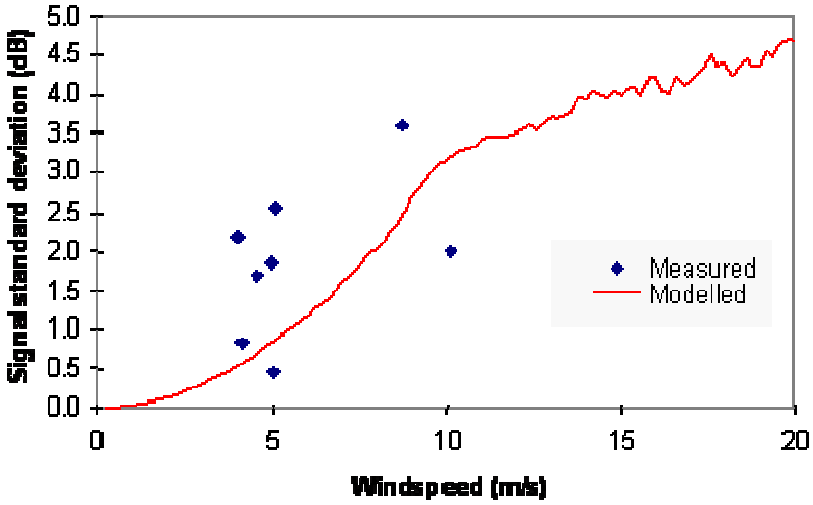


Figure 2.6: Wind speed (m/s) Vs Standard deviation (dB) (Mike, 2007)

Table 2.1: Effect of wind and tree-diameter on power loss in foliage environment (Mike, W. 2007)

Tree type		Dog-rose bush Diameter of 2 m	Apple tree Diameter of 2.8 m	Pine Diameter of 1.5 m
No wind	Mean loss (dB)	8.6	17.4	7.7
	Std (dB)	2.0	2.8	2.2
Strong wind	Mean loss (dB)	11.7	17.8	12.1
	Std (dB)	4.4	4.2	4.3

Note how the mean loss and standard deviation increase, for different tree diameters, in the presence of strong wind. This shows that wind increases power attenuations as well as variability of foliage radio channels.

2.6 Attenuations due to rain

Rain is a form of hydrometeors. "Hydrometeors" simply mean there is water in the atmosphere. Other forms include Snow, Hail, Fog, Mist, and Clouds (Ice crystals). As far as the radio wave is concerned, they are bits of lossy dielectric suspended in air. Just like troposcatter there will be scattering but there will also be dielectric losses. Cross polar isolation is also reduced which means less channel capacity.

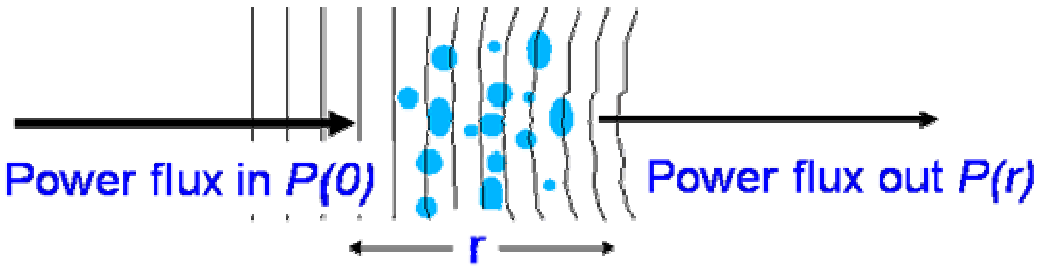


Figure 2.7: Radio-waves power attenuation by rainfall (Mike, 2007)

The attenuation due to rain can be calculated from the ratio of the power flux in to the power flux out which can be written as $P(r) = P(0)\, e^{-\alpha r}$, where α is the reciprocal of the range where P drops by 1/e. Writing this in dB form gives us:

$$\text{Loss} = 10 \log\left[\frac{P(0)}{P(r)}\right] = 4.434\,\alpha r \quad \text{dB} \qquad 2.2$$

The value 4.343α is called the specific attenuation, γ which is usually expressed in dB/km. It can be calculated from EM theory if the drop size and shape distributions are known, but it is easier to take the standard model based on the rainfall rate:

$\gamma = aR^b$ dB/km

Where a and b are constants provided in tables like the one below.

Table 2.2: Effect of frequency on attenuation due to rain (Mike, 2007)

f (GHz)	*a*	*b*
1	0.0000387	0.912
10	0.0101	1.276
20	0.0751	1.099
30	0.187	1.021
40	0.350	0.939

Note how' a' increases with frequency while 'b' varies less, rain attenuation is much higher at high frequencies.

2.6.1 Rain scatter

Another effect that is particularly important above 3GHz is rain scatter - or more strictly Hydrometeor scatter. Rain scatter, in the absence of vegetation, can extend the propagation of microwave signals to well beyond line of sight (Mike, 2007). With scattering from rain at 2-4km above the ground, the range extension can be by several hundred km.

2.6.2 Why Rain Scatters Radio waves

The forward scatter by Hydrometeors at microwaves is via a mechanism called Rayleigh scattering. Rayleigh wrote a paper about it in 1871, hence the name. Rayleigh type scattering occurs when the particle is electrically small and phase shift across the particle is small, that is the particle is much smaller than the wavelength. Rayleigh scattering scatters energy with a radiation pattern like that of a dipole, the amount of scattered energy is proportional to D^3/λ. If the particle is of the order of the size of the wavelength, Mie scattering occurs. With Mie scattering, there is more forward scattering and a forward radiation lobe.

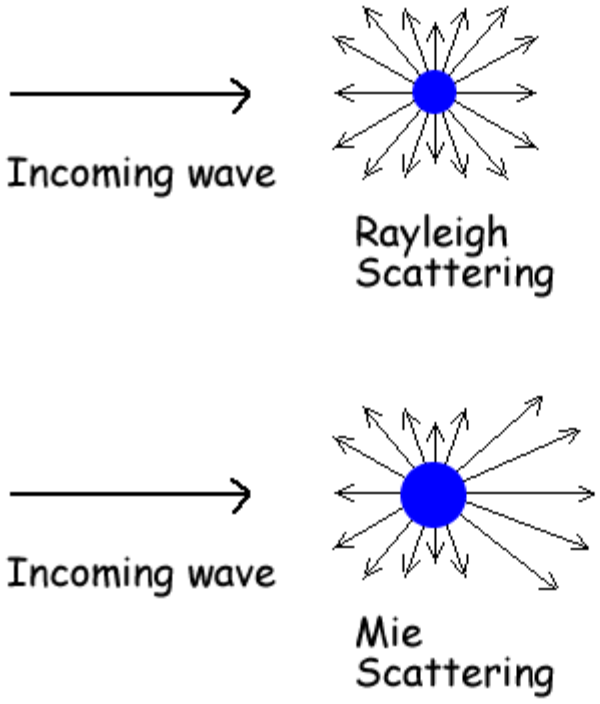


Figure 2.8: Radio waves scattering by a rain drop (Mike, 2007)

The Rayleigh and Mie are not different mechanisms; they are simply models approximating the scattering mechanism applicable at different wavelengths.

2.6.3 Essential Features of Rain Scatter

Naturally being weather dependent, values vary considerably with time and space - so actually calculating the rain scatter from first principles requires complex integration, assuming the structure of the rain is known or can be modeled and will generally require a numerical integration using a computer program. However the important features are that the received signal strength is proportional to**:**

- transmitted power (obviously)
- the common volume (this is the antenna beam intersection),
- the particle density (for example how hard it is raining)
- the scattering function So^2 (how well the particles scatter - for example how large they are, D^6)

and is inversely proportional to:

- the forth power of range
- the forth power of the wavelength.

Of course, the rain also attenuates the energy in the radio wave, so the scattered power at the receiver will be reduced.

CHAPTER THREE

METHODOLOGY

3.1 Introduction

This chapter explains, in details, how various equipments were used to create the artificial rain and wind and how the relationships between these two dependent variables and the independent ones were established. It also explains the experimental set up for EM wave measurements in the foliage channel under the influence of the applied parameters (rain intensity and wind speed). The procedures for data recording as well as the recoded data are also presented in this chapter.

3.2 Experiment site

The experiment site is a naturally grown vegetation of young eucalyptus trees of heights ranging from 1.5m to 4m, located directly opposite Hassan Usman Katsina Polytechnic, Katsina; and adjacent to Federal College of Education, Katsina. It is an irregular- shaped site with approximate area of 5000m^2. The experiment was conducted in the dry season as such the tree-leaves were scanty and their water contents considered being very low. The young trees are nearly equally spaced at a distance of about 0.3m apart. The average tree trunk diameter at antenna height is about 3cm and the leaves of the trees measure approximately 2cm by 6cm.

3.3 Creation of the artificial rain

The maximum amount of rainfall recorded in a single day in Katsina city was 71.50mm on 24th April, 2010 from 16.32 GMT to 17.48 GMT (UMYA, 2010). That is the duration of the rainfall was 1 hour and 16 minutes (or 1.267 hours).

Rain intensity (RI) = ( ) (3.1)

RI = = 56.3mm/h

The aim of this experiment is to produce a condition which will look as if it is actually raining on the foliage channel. That is to create rainfall artificially whose intensity can be varied from 0mm/h to a maximum of 56.3mm/h as recorded in Katsina metropolis on the above-mentioned date; and to find, experimentally, the relationship between rain intensities (RI) in mm/h and angle of rotation of water sprinkler stop cock (θ) in degrees.

This was achieved using the following equipment:-

- WP20X, 3.2kW, 3600rpm high pressure water pump with a volume reducer.
- Flexible high pressure hose pipes.
- Improvised water sprinkler (in the form of perforated PVC pipes joined to form a T-shaped water sprinkler).
- Nokia digital stop watch.
- Rain gauge with a measuring cylinder having 0.2mm graduations.

Traditionally, rainfall is measured by placing a rain gauge in an open field and recording the amount of water collected in a given period of time. Rain intensity (RI) is then obtained by dividing this collected amount of water by the period of time (NRMED, 2010).

In this case, the average maximum rain intensity is 56.3mm/h. This corresponds to 56.3/60 =0.94mm/minute. This can be approximated to 1.0mm/minute. That is 56.3mm/h corresponds to 1.0mm/minute.

To find the angular rotation θ of the stop cock that produces 1.0mm/minute of rainfall (i.e. 56.3mm/h), the valve (faucet) was opened fully at 5.5 rotations or 1980^0. The sprinkler was raised to about 3.5m (the average height of the trees). The rain was allowed to continue falling in

the rain gauge for 1 minute and the collected water in the gauge was found to be 1.2mm approximately.

The procedure was repeated using different rotations of the control valve θ and the corresponding rain intensities RI (in mm/minute) were recorded in Table 3.1. Using Microsoft Excel, a graph of θ^o vs RI was plotted (Figure 3.1).

Table 3.1: Angular valve rotation θ in degrees Vs Rain intensity RI in mm/minute

Valve rotation θ (degrees)	0	180	540	900	1260	1620	1980
Rain intensity RI (mm/minute)	0	0.2	0.3	0.6	0.7	0.9	1.2

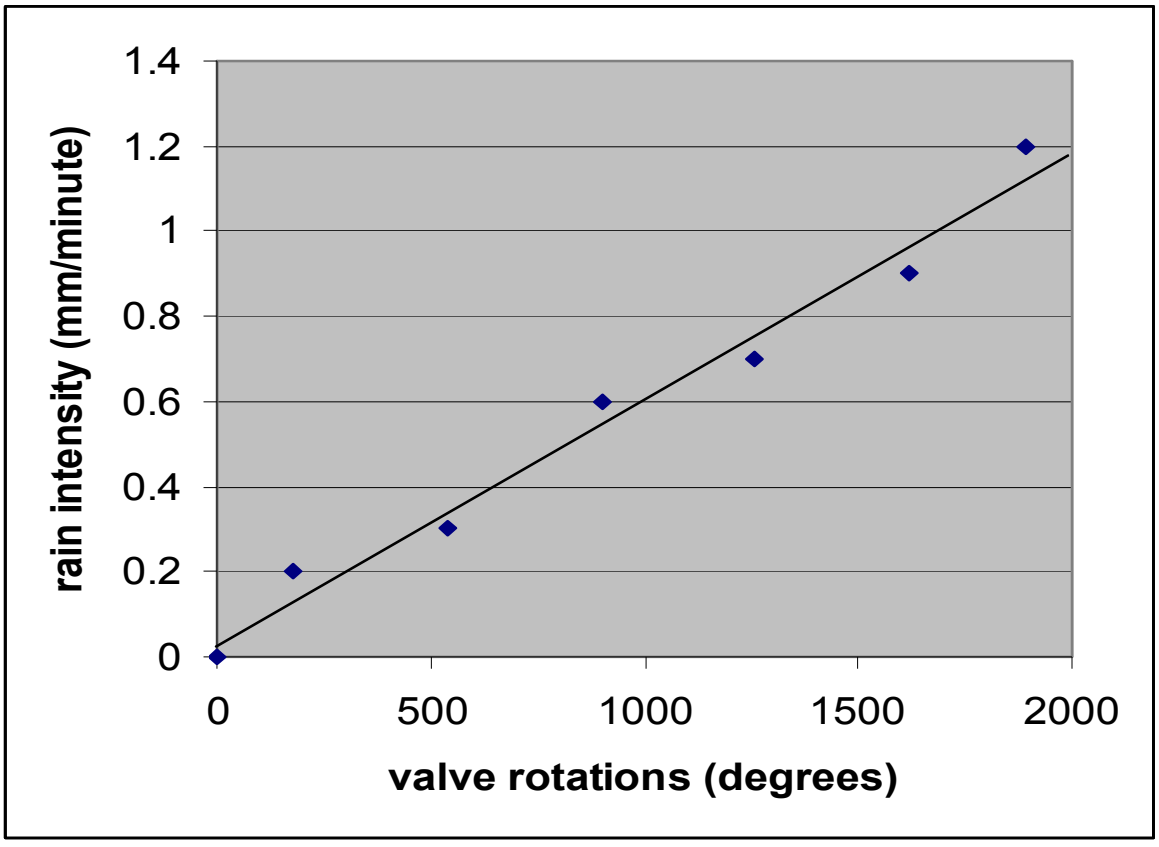


Figure 3.1: Graph of water valve rotation Vs rain intensity

From the graph, it was found that the angle that produces RI of 1mm/minute (i.e. 56.3mm/h) is approximately 1800^0 (or 5 rotations). Half of this angle is 900^0 and the corresponding rain intensity is 0.6mm/minute (i.e. 28mm/h). Rain intensities in mm/h which is the unit usually used in practice, are recorded in Table 3.2

Table 3.2: Angular rotation of valve controller (in degrees) VS rain intensity in mm/h

Angular rotation θ^0	0	900	1800
Approx. Rain intensities (mm/h)	0.00	28.0	56.0

From table 3.2, rain intensities are classified into three:

1) No rain (RI = 0.0mm/h).

2) Light rain (0mm/h ≤ RI ≤ 28mm/h).

3) Heavy rain (28mm/h ≤ RI ≤ 56mm/h).

This means that at any given moment of the year, in Katsina metropolis, rain intensity will be between 0mm/h and 28mm/h or between 28mm/h and 56mm/h. This is because the maximum rain intensity ever recorded in the town was 56mm/h (UMYA, 2010).

3.4 Creation of the artificial wind

Wind is a moving air especially a natural and perceptible movement of air parallel to or along the ground, OR a movement of air generated artificially such as by bellows or a fan (Farlex, 2011). In this experiment, the aim was to generate the required wind with controllable wind speed to be imposed (or applied) on the propagating channel and to find experimentally, the relationship between the speed of the generated wind and the current flowing in the fan that generates it.

The equipments used for this purpose are:

- 240V ac power supply.
- Analogue ammeter.
- High power electric standing fan.
- Anemometer (wind speed meter).

The circuit diagram for measuring the current through the fan is shown in Figure 3.1 and the pictorial diagram of the whole set up is in Figure 3.2.

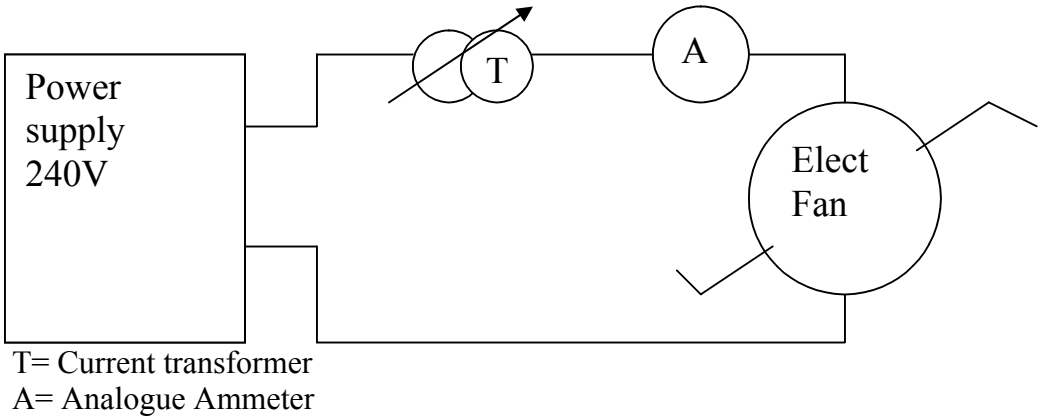


Figure 3.2: Current measurement at different wind speed



Figure 3.3: Wind speed measurement

The maximum wind speed recorded in Katsina town was 40 knot (at 10-m height) on the 24th of April, 2010 (UMYA, 2010)

40 knot = 40 x 0.5138 m/s

= 20.556 m/s

This means that at any moment of the year in Katsina metropolis, wind speed is between 0.0m/s and 20.56m/s.

Wind speed at any given height is given by the following equation (Nasiru, 2010):

$$= \quad - \qquad (3.2)$$

Where: V_1 = Wind speed at 10-metre height.

V_2= Wind speed at extrapolated height.

h_1 = reference height.

h_2 = height of interest.

n = exponent determining wind change.

For the Katsina terrain which is flat in nature, n = 0.214 (Nasiru, 2010).

In this investigation, h_2 =2m

From UMY airport data, V_1 =20.56m/s; h_1 = 10m.

Then at h_2 = 2m,

$$V_2 = 20.56\ (2/10)^{0.214}\ \text{m/s}$$

$$V_2 = 17.73\text{m/s}$$

To obtain this wind speed artificially, the fan was put on with the current transformer at its maximum current position. This produces a maximum current of 1.9A. The distance of the anemometer from the fans was adjusted gradually. At about 0.6m the wind speed was found to be 18.0m/s. this is approximately equal to the interested wind velocity (i.e. 17.73m/s).

Keeping the anemometer distance constant, current into the fans was changed to 1.2A by varying the current transformer position producing a wind speed of 11m/s. These values are tabulated below.

Table 3.3: Currents into the fan and corresponding produced wind speeds.

Current (A)	0.00	1.20	1.90
Wind speed (m/s)	0.00	11.0	18.00

From table 2.3, wind speeds (W) are classified as follows

1) No wind (WS = 0.0m/s).

2) Slight wind (0.0m/s ≤ WS ≤ 8.8m/s).

3) Strong wind (8.8m/s ≤ WS 18.0m/s).

3.5 Representation of the weather conditions (rain and wind) of Katsina metropolis

In order to get full representation of the weather conditions (rain intensity and/ wind speed) of Katsina town throughout the year, the two parameters classified into three each were combined with one another to give $3^2 = 9$ combinations as follows:

1) No rain and no wind (RI = 0mm/h; WS = 0m/s).

2) No rain and slight wind (RI = 0mm/h; 0m/s ≤ WS ≤ 11m/s).

3) No rain and strong wind (RI =0mm/h; 11m/s ≤ WS ≤ 18.0m/s).

4) Light rain and no wind (0mm/h ≤ RI ≤ 18mm/h; WS = 0m/s).

5) Light rain and slight wind (0mm/h ≤ 28mm/h; 0m/s ≤ WS ≤ 8.8m/s).

6) Light rain and strong wind (0mm/h ≤ RI ≤ 28mm/h; 0m/s ≤ WS ≤ 18m/s).

7) Heavy rain and no wind (28mm/h ≤ RI ≤ 56mm/h; WS = 0m/s).

8) Heavy rain and slight wind (28mm/h ≤ RI ≤ 56mm/h; WS = 0m/s).

9) Heavy rain and strong wind (28mm/h ≤ RI ≤ 56mm/h; 11m/s ≤ WS ≤ 18m/s).

This means that at any given moment of the year, the weather condition in Katsina metropolis must fall within one of the above nine (9) combinations, bearing in mind that other weather parameters (such as temperature, hamattan dust, etc) are not taken into considerations.

3.6 EM wave measurements in the foliaged channel under the influence of rain and wind

After successfully modeling the weather conditions into 9 combinations, each of these combinations was applied on the propagating channel and the signal strength at the receiver was measured at 10 seconds interval in order to study the level of attenuations and the variations caused by the random imposition of these two variable parameters.

Equipment used are:

- PA2140-040 microwave (10.7GHz) transmitter with both continuous wave and integral modulation transmission; including audio (voice) transmission.
- PA2140-030 RX2AS microwave (10.7GHz) receiver with integral audio amplifier and an analogue signal strength meter.
- Horn antenna for both transmission and reception.
- VC-300 digital multi-meter with data holds facility.
- An oscilloscope with digital storage facility.

3.6.1 EM wave measurement under 'no rain and no wind' condition

The foliage channel under investigation was kept in its stable condition i.e. no rain and no wind. Both the receiver and the transmitter were kept stationary 3-metres apart at 1-metre height from the ground. The received signal passed through the horn antenna into the receiver and then into an analogue signal strength meter.

After every 10 seconds, the data was recorded by holding the instantaneous reading of the VC-300 digital voltmeter connected at the output of the receiver. At the same time, a visual display of the received signal was observed using oscilloscope. Table 3.4 presents the recorded data.

Table 3.4: Data recorded under no rain, no wind condition
Rain intensity: 0mm/s, Wind speed: 0m/s.

Time (s)	Received signal (mV)	Time (s)	Received signal (mV)	Time (s)	Received signal (mV)
10	64.0	210	64.4	410	65.0
20	65.5	220	64.4	420	65.5
30	64.0	230	65.0	430	66.0
40	64.0	240	65.0	440	64.5
50	64.0	250	64.5	450	64.0
60	66.0	260	64.5	460	64.8
70	64.5	270	65.0	470	63.0
80	64.5	280	63.0	480	64.9
90	64.5	290	64.5	490	64.1
100	65.0	300	65.0	500	65.6
110	64.0	310	63.5	510	64.0
120	64.0	320	65.0	520	64.4
130	64.5	330	64.5	530	64.5
140	64.5	340	65.0	540	63.8
150	65.2	350	65.5	550	65.2
160	65.0	360	64.5	560	65.7
170	64.0	370	64.4	570	63.0
180	64.5	380	66.1	580	64.6
190	64.5	390	64.5	590	64.0
200	64.1	400	65.3	600	64.8

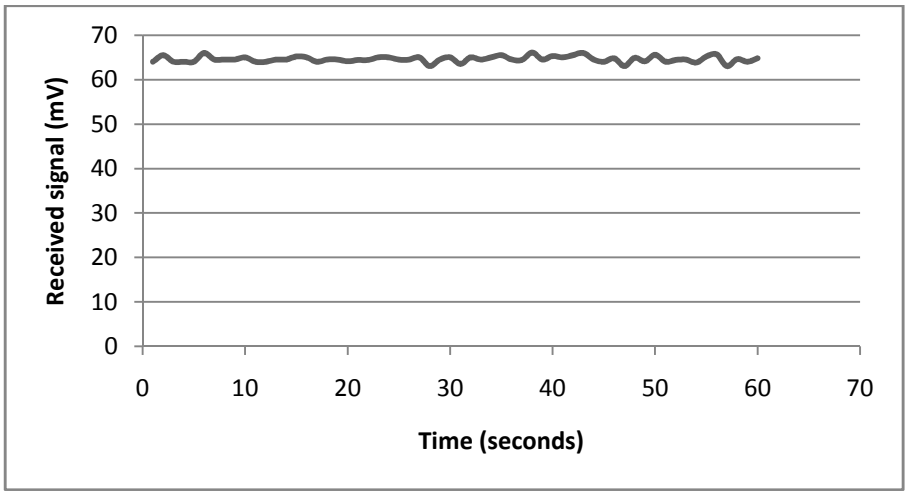


Figure 3.4: No rain, no wind waveform

3.6.2 EM wave measurement under 'no rain and slight wind' condition

In this measurement, water supply to the sprinkler was cut off by positioning the stop cock (the valve or faucet that controls the water flow) at $\theta = 0^0$ (i.e. no rain condition; RI=0mm/h). The fan was put on to produce the required windy condition. The wind speed was varied between 0m/s to 11m/s. This was achieved by varying supply current to the fan from 0.0A to 1.2A. Variation of current into the fans was continuously performed and in a random manner. Consequently the variation in the produced wind speed was also random.

Due to the turbulence caused by the produced wind in the channel, the received signal strength was observed to vary randomly by the fluctuation of the analogue meter pointer and the voltage variations of the digital voltmeter.

Data was obtained using the VC-300 by holding and recording the voltages at 10 seconds intervals for a period of 600 seconds (or 10 minutes). The recorded data under this condition is as shown in Table 3.5.

Table 3.5: Data recorded under no rain, slight wind condition.
Rain intensity: 0mm/h, Wind speed: 0m/s to 11m/s.

Time (s)	Received signal (mV)	Time (s)	Received signal (mV)	Time (s)	Received signal (mV)
10	50.8	210	49.5	410	41.6
20	50.0	220	50.8	420	43.0
30	49.5	230	52.1	430	35.5
40	50.8	240	54.9	440	35.0
50	50.2	250	53.4	450	39.2
60	53.4	260	53.4	460	40.5
70	55.9	270	50.8	470	46.9
80	57.2	280	45.7	480	52.2
90	53.4	290	43.1	490	54.7
100	54.7	300	49.5	500	50.3
110	51.5	310	50.8	510	55.9
120	53.4	320	49.5	520	57.2
130	55.9	330	46.9	530	56.7
140	58.6	340	41.8	540	50.8
150	53.4	350	44.2	550	52.1
160	50.9	360	46.9	560	50.0
170	48.5	370	49.1	570	54.7
180	50.6	380	47.0	580	42.1
190	57.9	390	50.0	590	41.4
200	53.5	400	46.9	600	44.2

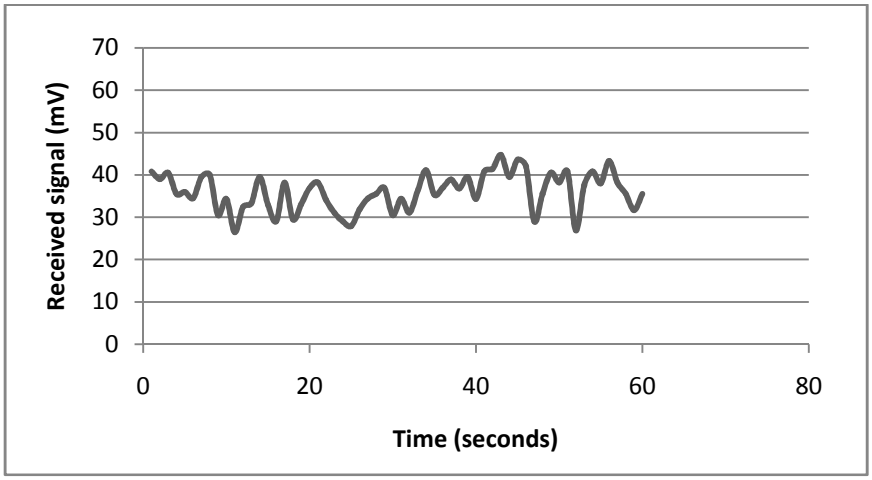


Figure 3.5: No rain, slight wind waveform

3.6.3 EM wave measurement under 'no rain and strong wind' condition

Here, rain intensity was kept at zero by cutting off water supply to the sprinkler (as in 3.5.2), but wind speed was varied randomly between 11m/s and 18m/s. This was achieved by varying the current supply between 1.2A and 1.9A.

In this case also data was recorded by holding and jotting down the values of the received signal at 10 seconds interval. Table 3.6 shows the recorded data.

Table 3.6: Data recorded under no rain, strong wind condition.
Rain intensity: 0mm/h, Wind speed: 11m/s to 18m/s.

Time (s)	Received signal (mV)	Time (s)	Received signal (mV)	Time (s)	Received signal (mV)
10	46.9	210	36.6	410	46.9
20	36.6	220	36.6	420	50.5
30	46.8	230	43.7	430	36.5
40	51.5	240	37.9	440	39.9
50	53.4	250	36.6	450	48.2
60	45.5	260	41.8	460	52.0
70	50.8	270	35.5	470	47.0
80	41.8	280	37.9	480	39.0
90	39.9	290	36.6	490	48.5
100	44.3	300	41.8	500	43.0
110	48.2	310	37.9	510	49.5
120	45.6	320	28.9	520	46.0
130	36.8	330	36.8	530	45.0
140	38.0	340	41.7	540	52.1
150	35.4	350	43.1	550	45.7
160	26.3	360	37.8	560	58.5
170	36.5	370	32.5	570	50.1
180	43.0	380	40.5	580	46.9
190	23.8	390	25.0	590	36.6
200	32.5	400	35.4	600	46.8

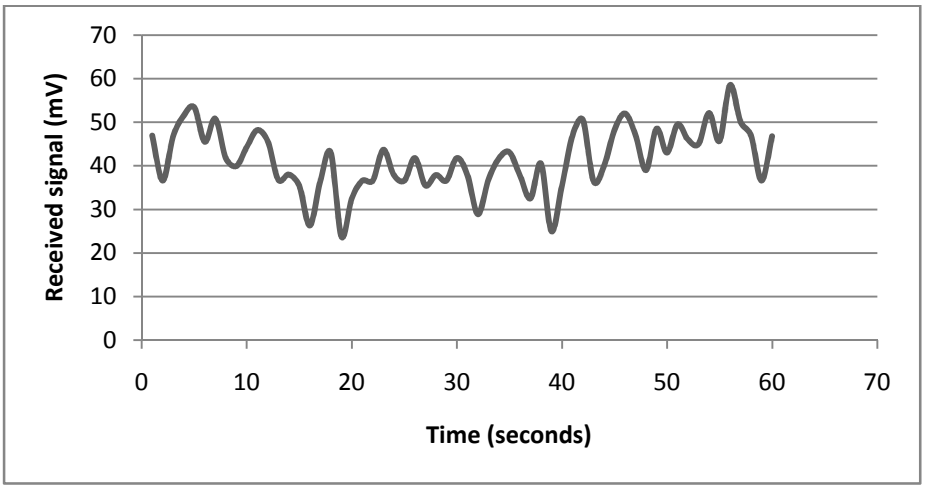


Figure 3.6: No rain, strong wind waveform

3.6.4 EM wave measurement under 'light rain and no wind' condition

In this experiment, the water sprinkler was raised to about 2.5 metres (i.e. just above the height of the foliaged channel). The water pumping machine was put on, and the water valve controller was rotated to-and-fro between 0^0 and 540^0 in a random manner so that the intensity of the sprinkled water spray (i.e. intensity of the artificial rain) was varied between 0mm/h and 18mm/h in the same manner. In this case, the fans were switched off to satisfy the second condition (i.e. no wind).

The fluctuating received signal in the wet foliage channel was recorded as before using the VC-300 digital multi-meter. The readings are in Table 3.7

Table 3.7: Data recorded under light rain, no wind condition.
Rain intensity: 0mm/h to 28mm/h, Wind speed: 0m/s.

Time (s)	Received signal (mV)	Time (s)	Received signal (mV)	Time (s)	Received signal (mV)
10	52.0	210	56.6	410	50.8
20	53.4	220	55.3	420	54.5
30	56.0	230	56.0	430	55.3
40	57.2	240	53.5	440	52.2
50	56.6	250	48.5	450	47.0
60	59.0	260	52.7	460	52.0
70	57.2	270	52.0	470	47.5
80	54.7	280	49.0	480	50.8
90	56.0	290	56.0	490	53.0
100	53.5	300	56.2	500	54.1
110	56.0	310	52.0	510	57.0
120	57.0	320	49.0	520	55.5
130	53.5	330	57.0	530	56.0
140	57.0	340	54.1	540	58.5
150	59.0	350	50.5	550	59.2
160	56.0	360	52.0	560	54.7
170	58.5	370	52.8	570	58.0
180	56.0	380	48.0	580	61.0
190	57.2	390	52.0	590	56.1
200	56.0	400	56.1	600	52.0

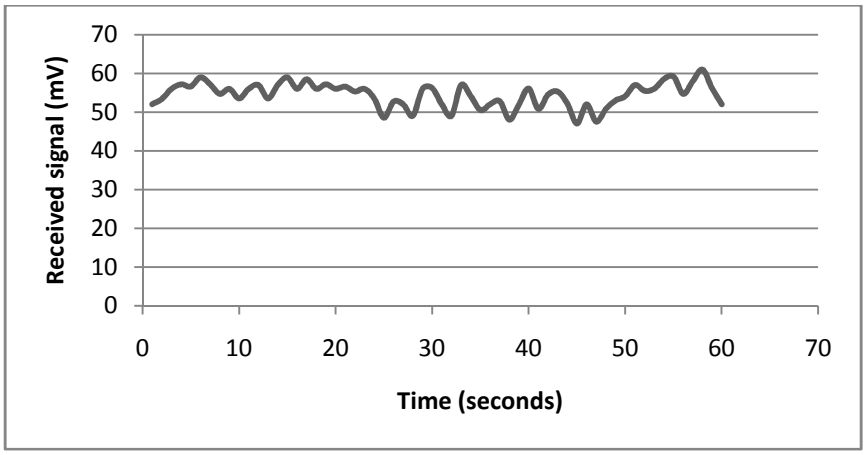


Figure 3.7: Light rain, no wind waveform

3.6.5 EM wave measurement under 'light rain and slight wind' condition

Here also the stop cock was rotated to-and-fro between 0^0 and 540^0. Consequently the rain intensity (RI) falling on the channel also varied between 0mm/h and 18mm/h. at the same time the speed of the artificial wind applied on the channel was varied to-and-fro continuously between 0m/s and 11m/s. The combined influence of these two varying parameters on the propagating channel was recorded in Table 3.8 using the same 10 seconds interval.

Table 3.8: Data recorded under light rain, slight wind condition.
Rain intensity: 0mm/h to28mm/h, Wind speed: 0m/s to11m/s.

Time (s)	Received signal (mV)	Time (s)	Received signal (mV)	Time (s)	Received signal (mV)
10	39.5	210	49.5	410	43.6
20	44.0	220	53.8	420	48.1
30	51.0	230	49.4	430	53.8
40	42.3	240	53.5	440	50.9
50	38.0	250	52.4	450	43.9
60	55.0	260	40.0	460	38.1
70	38.0	270	49.0	470	44.7
80	38.5	280	56.6	480	48.0
90	42.0	290	58.0	490	42.5

100	38.8	300	52.5	500	43.5
110	48.0	310	52.0	510	53.9
120	43.5	320	46.5	520	46.5
130	52.4	330	49.5	530	52.0
140	46.5	340	48.0	540	46.8
150	53.8	350	50.9	550	39.0
160	49.4	360	45.0	560	56.6
170	43.7	370	49.5	570	40.5
180	39.0	380	42.2	580	52.1
190	45.1	390	36.5	590	43.5
200	40.9	400	43.8	600	43.5

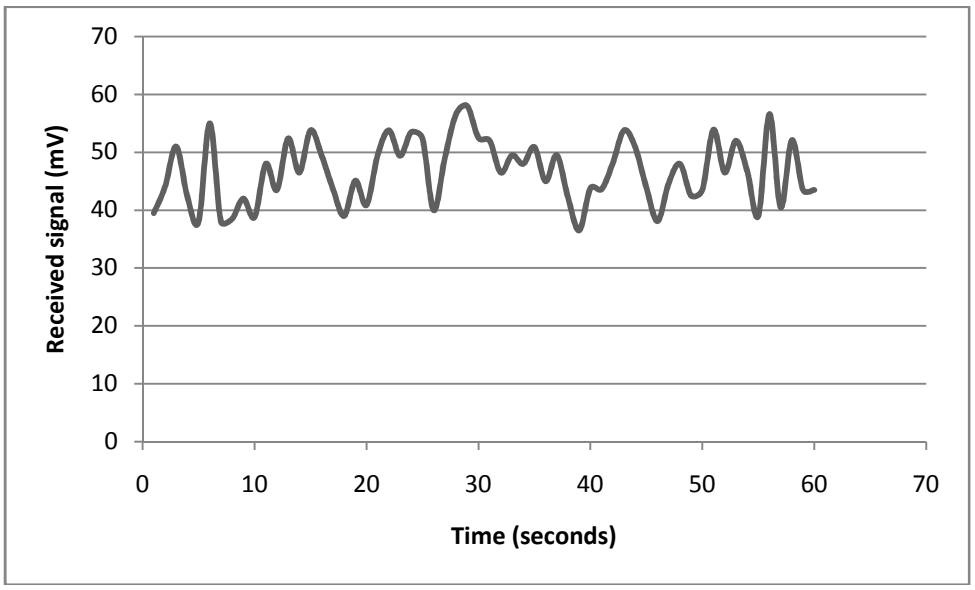


Figure 3.8: Light rain, slight wind waveform

3.6.6 EM wave measurement under 'light rain and strong wind condition'

In this case the intensity of the sprinkled water (or artificial rain) on the channel continued to be varied between 0mm/h and 28mm/h using the water valve control handle, while the varying wind speed on the channel was varied between 11m/s and 18m/s by controlling fans' current supply between 1.2A and 1.9A.

The received signal in the wet and windy foliage channel was recorded in a similar manner as in the previous EM wave measurements (Table 3.9)

Table 3.9: Data recorded under light rain, strong wind condition
rain intensity:0mm/h to 28mm/h, wind speed 11mm/h to18m/s

Time (s)	Received signal (mV)	Time (s)	Received signal (mV)	Time (s)	Received signal (mV)
10	35.5	210	22.2	410	36.5
20	34.0	220	29.0	420	32.7
30	22.9	230	35.3	430	27.6
40	14.0	240	25.0	440	21.0
50	10.2	250	23.8	450	27.5
60	14.8	260	16.0	460	36.0
70	30.0	270	22.9	470	36.5
80	29.0	280	16.0	480	25.0
90	30.1	290	02.9	490	30.2
100	21.9	300	17.3	500	35.4
110	27.5	310	21.2	510	34.0
120	35.0	320	26.5	520	28.9
130	32.8	330	14.7	530	27.5
140	29.0	340	04.5	540	35.5
150	28.5	350	18.6	550	31.5
160	32.5	360	16.0	560	26.3
170	32.0	370	25.5	570	32.0
180	27.7	380	17.3	580	21.5
190	36.0	390	31.5	590	26.1
200	30.5	400	30.2	600	32.7

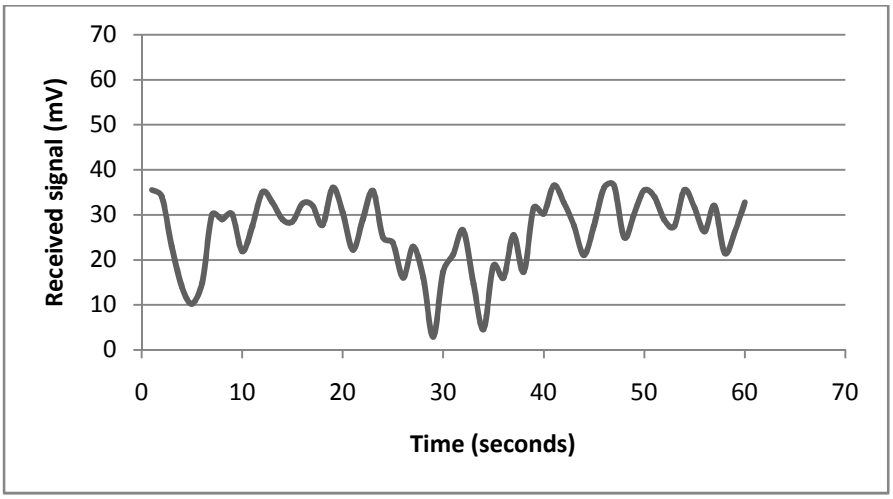


Figure 3.9: Light rain, strong wind waveform

3.6.7 EM wave measurement under 'heavy rain and no wind' condition

Here, the artificially created rain from the sprinkler was controlled in such a way that the rain intensity (RI) on the propagating channel was made to vary continuously between 18mm/h and 33mm/h, while the wind speed (WS) was made equal to zero (WS=0) by switching the fan off. Under this condition, the propagating signal in the wet channel was received, measured and recorded in Table 3.10.

Table 3.10: Data recorded under heavy rain, no wind.
Rain intensity: 28mm/h to 56.3mm/h, Wind speed: 0m/s.

Time (s)	Received signal (mV)	Time (s)	Received signal (mV)	Time (s)	Received signal (mV)
10	40.8	210	38.2	410	40.8
20	39.0	220	34.0	420	41.4
30	40.5	230	31.0	430	44.7
40	35.5	240	29.0	440	39.5
50	36.0	250	27.9	450	43.6
60	34.5	260	31.8	460	42.1
70	39.5	270	34.4	470	29.0
80	40.0	280	35.5	480	35.5
90	30.5	290	36.9	490	40.5
100	34.3	300	30.5	500	38.2
110	26.5	310	34.4	510	40.8

120	32.4	320	31.1	520	26.9
130	33.3	330	36.3	530	37.5
140	39.5	340	41.1	540	40.8
150	33.0	350	35.3	550	38.0
160	29.1	360	37.0	560	43.3
170	38.2	370	38.9	570	38.2
180	29.5	380	36.8	580	35.5
190	33.1	390	39.5	590	31.7
200	36.9	400	34.3	600	35.5

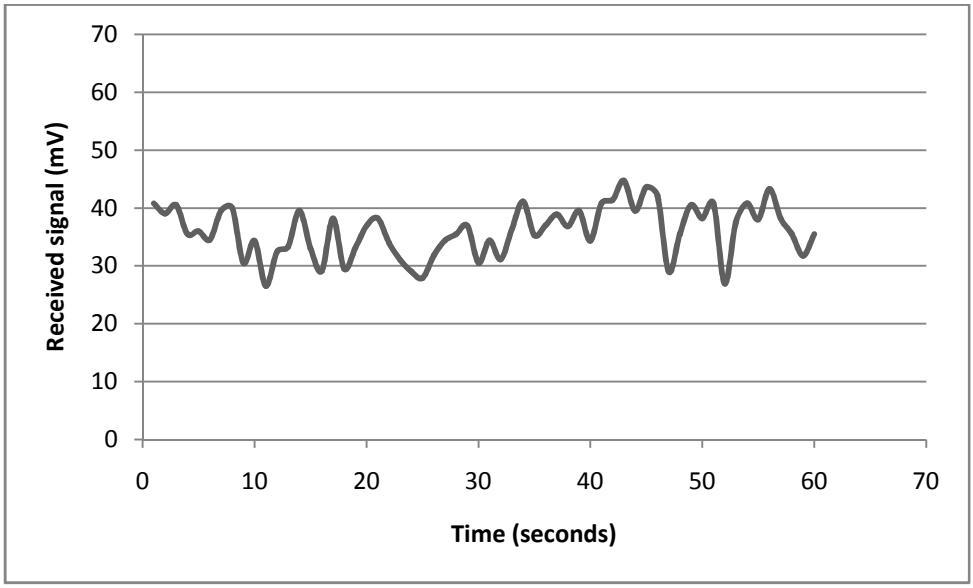


Figure 3.10: Heavy rain, no wind waveform

3.6.8 EM wave measurement under 'heavy rain and slight wind' condition

In this measurement, the created artificial rain was made to continue falling heavily and variably in a random manner between 18mm/h and 33mm/h by continuous and random angular variations of the stop between 450^0 and 1080^0.

At the same time the artificial wind produced by the fan and applied on the foliage channel was varied to-and-fro between 0m/s and 11m/s. The received signal strength (influenced by these two varying parameters) was recorded at 10 seconds interval as shown in Table 3.11.

Table 3.11: Data recorded under heavy rain, slight wind condition. Rain intensity: 28mm/h to 56.3mm/h, Wind speed: 0m/s to 11m/s.

Time (s)	Received signal (mV)	Time (s)	Received signal (mV)	Time (s)	Received signal (mV)
10	25.3	210	29.2	410	34.4
20	31.7	220	39.5	420	34.0
30	34.5	230	29.1	430	36.8
40	31.5	240	29.8	440	32.7
50	34.4	250	34.7	450	29.0
60	32.4	260	21.5	460	38.2
70	34.3	270	28.0	470	38.0
80	30.5	280	33.7	480	34.5
90	36.9	290	37.6	490	33.1
100	41.4	300	36.2	500	31.0
110	38.2	310	31.6	510	30.5
120	45.3	320	35.7	520	33.0
130	39.5	330	38.2	530	37.0
140	42.0	340	35.6	540	40.8
150	44.6	350	36.2	550	42.1
160	40.8	360	34.4	560	41.4
170	31.0	370	29.3	570	39.5
180	27.8	380	21.5	580	32.4
190	34.4	390	38.2	590	38.2
200	32.2	400	36.9	600	34.5

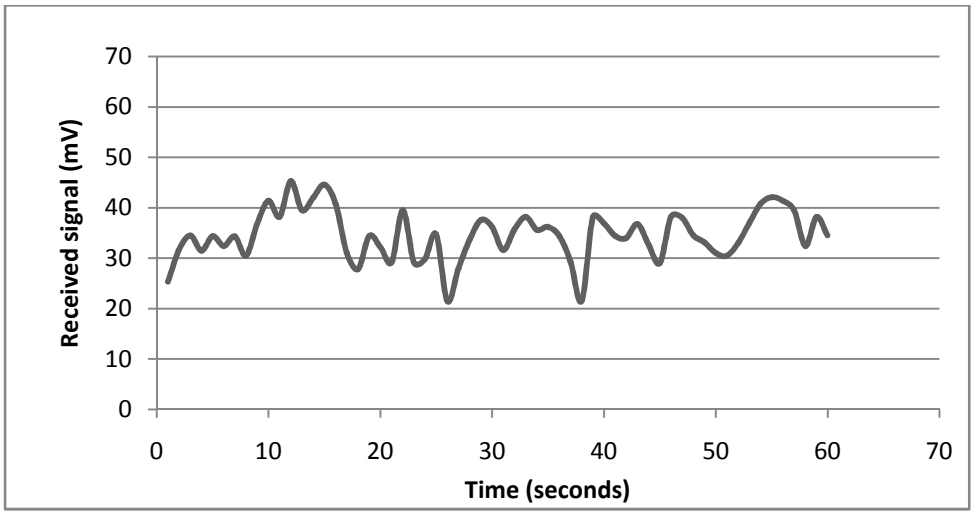


Figure 3.11: Heavy rain, slight wind waveform

3.6.9 EM wave measurement under 'heavy rain and strong wind' condition

The last measurement of the received EM wave signal in the foliage channel under investigation is the one in which the artificial weather conditions (wind and rain) were at their maximum level (rain intensity between 18mm/h and 33mm/h, while wind speed from 11m/s and 18m/s). Variation of these two parameters was achieved in a similar way as in the previous experiments The data was recorded as in Table 3.12.

Table 3.12: Data recorded under heavy rain, strong wind condition Rain intensity: 28mm/h to 56.3mm/h, Wind speed: 11m/s to 18m/s.

Time (s)	Received signal (mV)	Time (s)	Received signal (mV)	Time (s)	Received signal (mV)
10	38.8	210	38.2	410	36.2
20	35.9	220	45.0	420	24.5
30	19.5	230	24.7	430	31.8
40	40.8	240	29.5	440	38.2
50	26.9	250	34.3	450	47.2
60	30.0	260	33.0	460	38.2
70	10.2	270	27.8	470	27.9
80	25.0	280	07.5	480	32.0

90	34.3	290	12.4	490	33.3
100	41.0	300	0.00	500	29.0
110	44.3	310	21.4	510	20.2
120	30.5	320	14.3	520	36.5
130	38.2	330	42.7	530	24.0
140	44.6	340	38.1	540	42.1
150	39.5	350	18.8	550	16.3
160	35.0	360	31.1	560	29.2
170	38.2	370	02.5	570	07.7
180	35.3	380	07.3	580	27.9
190	43.4	390	15.5	590	36.8
200	38.5	400	40.8	600	09.5

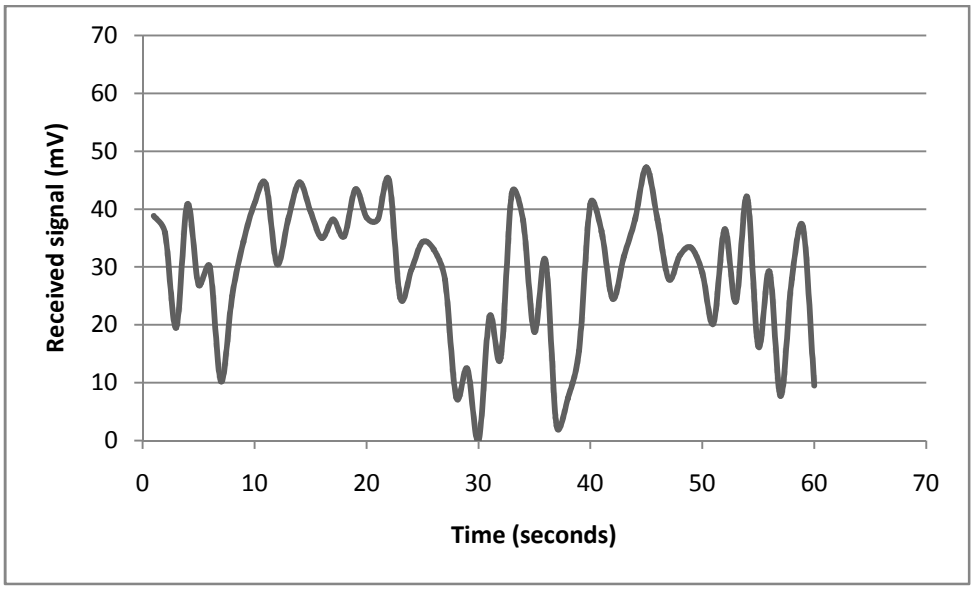


Figure 3.12: Heavy rain, strong wind waveform

The recorded experimental results and their plotted wave forms have been presented in this chapter. The following chapter presents analysis of the results.

CHAPTER FOUR

RESULTS ANALYSIS

4.1 Introduction

In this chapter, the additional power attenuation imposed by each weather phenomenon is determined from the results. The same experimentally obtained data or result (i.e. the set of values of the received signal in the foliage channel under the influence of wind and/or rain) is then normalized to its mean (using Microsoft Excel) to extract the temporal variations (Meng, *et al*, 2007). These temporal variations are characterized through the statistical modeling of the signal envelop (amplitude) using the commonly known probability distributions usually associated with radio-wave propagation channels. Before the data analysis, the four distribution functions and the software program used for the analysis are briefly discussed in the following sections.

4.2 Normal distribution

In probability theory, the normal (or Gaussian) distribution, is a continuous probability distribution that is often used as a first approximation to describe real-valued random variables that tend to cluster around a single mean value. The graph of the associated probability density function is "bell"-shaped, and is known as the Gaussian function or bell curve (NIST, *et al,* 2012).

$$f(x;\,\mu,\sigma^2) = \frac{1}{\sqrt{2\pi\sigma^2}}\,e^{-(x-\mu)^2/(2\sigma^2)} = \frac{1}{\sigma}\,\phi\left(\frac{x-\mu}{\sigma}\right), \qquad x \in \mathbb{R}. \tag{4.1}$$

where parameter μ is the mean (location of the peak) and σ^2 is the variance (the measure of the width of the distribution). The distribution with μ = 0 and $\sigma^2 = 1$ is called the standard normal. The normal distribution is considered the most prominent probability distribution in statistics (Mathworks, 2012. Bryc, 1995).

The simplest case of a normal distribution is known as the standard normal distribution, described by the probability density function

$$\phi(x) = \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}x^2}. \tag{4.2}$$

The factor $1/\sqrt{2\pi}$ in this expression ensures that the total area under the curve ϕ(x) is equal to one, and 1/2 in the exponent makes the "width" of the curve (measured as half the distance between the inflection points) also equal to one (Mathworks, 2012)

The parameter μ is at the same time the mean, the median and the mode of the normal distribution. The parameter σ^2 is called the variance; as for any random variable, it describes how concentrated the distribution is around its mean. The square root of σ^2 is called the standard deviation and is the width of the density function (Normal Distribution, 2011).

The occurrence of normal distribution in practical problems can be loosely classified into three categories:

1. Exactly normal distributions;
2. Approximately normal laws, for example when such approximation is justified by the central limit theorem; and

3. Distributions modeled as normal — the normal distribution being the distribution with maximum entropy for a given mean and variance (Normal Distribution, 2011)

4.3 Rician distribution

In probability theory, the Rician distribution or Rice distribution is the probability distribution of an absolute value of a circular bivariate normal random variable with potentially non-zero mean. It was named after Stephen O. Rice (Mathworks, 2012).

The probability density function is

$$f(x|\nu,\sigma) = \frac{x}{\sigma^2}\exp\left(\frac{-(x^2+\nu^2)}{2\sigma^2}\right) I_0\left(\frac{x\nu}{\sigma^2}\right), \tag{4.3}$$

where $I_0(z)$ is the modified Bessel function of the first kind with order zero. When v = 0, the distribution reduces to a Rayleigh distribution (Jean-Poul, 2009; Rician, 2011).

The characteristic function is:

$$\chi_X(t|\nu,\sigma) = \exp\left(-\frac{\nu^2}{2\sigma^2}\right)\left[\Psi_2\left(1;1,\frac{1}{2};\frac{\nu^2}{2\sigma^2},-\frac{1}{2}\sigma^2t^2\right)\right.$$
$$\left. + i\sqrt{2}\sigma t\Psi_2\left(\frac{3}{2};1,\frac{3}{2};\frac{\nu^2}{2\sigma^2},-\frac{1}{2}\sigma^2t^2\right)\right], \tag{4.4}$$

where $\Psi_2(\alpha;\gamma,\gamma';x,y)$ is one of Horn's confluent hypergeometric functions with two variables and convergent for all finite values of x and y. It is given by:

$$\Psi_2(\alpha;\gamma,\gamma';x,y) = \sum_{n=0}^{\infty}\sum_{m=0}^{\infty}\frac{(\alpha)_{m+n}}{(\gamma)_m(\gamma')_n}\frac{x^m y^n}{m!n!}, \tag{4.5}$$

where

$$(x)_n = x(x+1)\cdots(x+n-1) = \frac{\Gamma(x+n)}{\Gamma(x)} \tag{4.6}$$

is the rising factorial (Srivastava, 1985)

4.4 Rayleigh Distribution

In probability theory and statistics, the Rayleigh distribution (pronounced /reili/) is a continuous probability distribution. A Rayleigh distribution is often observed when the overall magnitude of a vector is related to its directional components. One example where the Rayleigh distribution naturally arises is when wind speed is analyzed into its orthogonal 2-dimensional vector components. Assuming that the magnitude of each component is uncorrelated and normally distributed with equal variance, and then the overall wind speed (vector magnitude) will be characterized by a Rayleigh distribution. A second example of the distribution arises in the case of random complex numbers whose real and imaginary components are independently and identically distributed (i.i.d.) Gaussian. In that case, the absolute value of the complex number is Rayleigh-distributed. The distribution is named after Lord Rayleigh (Sijbers, *et al,* 1998).

The Rayleigh probability density function

$$f(x;\sigma) = \frac{x}{\sigma^2} e^{-x^2/2\sigma^2}, \quad x \geq 0, \tag{4.7}$$

for parameter $\sigma > 0$, and cumulative distribution function

$$F(x) = 1 - e^{-x^2/2\sigma^2} \tag{4.8}$$

for $x \in [0, \infty)$.

4.5 Nakagami Distribution

The Nakagami distribution or the Nakagami-m distribution is a probability distribution related to the gamma distribution. It has two parameters: a shape parameter μ and a second parameter controlling spread, ω (Laurenson, 1994).

Its probability density function (pdf) is

$$f(x;\, \mu, \omega) = \frac{2\mu^{\mu}}{\Gamma(\mu)\omega^{\mu}} x^{2\mu-1} \exp\left(-\frac{\mu}{\omega}x^2\right). \tag{4.9}$$

Its cumulative distribution function is

$$F(x;\, \mu, \omega) = P\left(\mu, \frac{\mu}{\omega}x^2\right) \tag{4.10}$$

where P is the incomplete gamma function (regularized).

The parameters μ and ω are obtained by

$$\mu = \frac{\mathrm{E}^2\left[X^2\right]}{\mathrm{Var}\left[X^2\right]} \tag{4.11}$$

and

$$\omega = \mathrm{E}\left[X^2\right]. \tag{4.12}$$

The Nakagami distribution is relatively new, being first proposed in 1960. It has been used to model attenuation of wireless signals traversing multiple paths (Laurenson, 1994).

4.6 Introduction to "EasyFit 5.5"

EasyFit 5.5 is a data analysis and simulation application allowing the user to fit probability distributions to sample data, select the best model, and apply the analysis results to make better decisions. EasyFit can be used as a stand-alone Windows application or with Microsoft Excel and other third party Excel-based simulation tools, leaving the complex technical details behind the scenes and enabling the user to focus on his/her business goals (Mathwave, 2011).

4.6.1 Key Features.

EasyFit 5.5 combines the classical statistical analysis methods and innovative data analysis techniques, making it a tool of choice for anyone dealing with probability data. Product features include:

i) Support for more than 50 continuous and discrete distributions;

ii) Powerful automated fitting mode combined with flexible manual fitting capability;

iii) Interactive graphs;

iv) Goodness of fit tests;

v) Random number generation;

vi) Easy-to-use interface;

vii) Comprehensive Help system.

viii) Excel Integration.

Excel users can apply the power of EasyFit without the need to leave their favorite spreadsheet application. EasyFit seamlessly integrates into the main menu of Excel, allowing the user to perform data analysis and simulation right in Excel (Mathwave, 2011). This invaluable software

program provides more than 650 additional Excel worksheet and VBA functions which can be used to carry out advanced probability calculations such as Monte Carlo simulation (Mathwave, 2011).

With EasyFit, one can:

a) analyze large data sets (up to 250,000 data points);

b) improve the validity of models by applying the advanced distributions;

c) calculate descriptive statistics;

d) enter and manipulate data using an Excel-like spreadsheet;

e) organize data and analysis results into Project Files;

f) view distribution graphs and explore their properties without entering the data;

g) export analysis results.

System Requirements

Windows 7/Vista/XP/2000 or Windows Server 2008/2003;

20 MB available hard disk space;

128 MB available RAM .

EasyFit is compatible with Microsoft Excel 2010, 2007, 2003, 2002, and 2000 (Mathwave, 2011) and its latest version can be obtained from http://www.mathwave.com/downloads.html.

4.7 Additional Power Attenuation Imposed by Different Weather Phenomenon

To find the level of additional power attenuation in decibel (dB) imposed by different weather conditions on the foliage channel, the average (or mean) received signal for each condition was determined using the software program. This was achieved using the following procedure:-

Copying and pasting the raw data (for each weather condition) into the software. Left-clicking "analyze" on the tool bar, selecting "descriptive statistics" and then "ok".

Using "No wind, no rain" as the reference condition, the average power attenuation for each weather condition was calculated using equation (4.13) and tabulated in Table 4.1.

$$\text{Power Loss (in dB)} = 20\log \quad — \qquad (4.13)$$

Where: v_1 is the average RSS under no rain, no wind condition (i.e. reference condition)

v is the average RSS under the condition of interest.

Table 4.1: Additional power attenuation for different weather phenomenon

Weather phenomenon	**Average RSS (mV)**	**Power loss (dB)**
No rain, no wind	64.588	0.000
No rain, slight wind	49.673	− 2.281
No rain, strong wind	41.615	− 3.829
Light rain, no wind	54.412	− 1.489
Light rain, slight wind	46.658	− 2.825
Light rain, strong wind	31.868	− 6.136
Heavy rain, no wind	35.992	− 5.079
Heavy rain, slight wind	34.612	− 5.418
Heavy rain, strong wind	29.388	− 6.840

From Table 4.1 it can be seen that as rain intensity increases, power attenuation increases. Similarly when wind speed increases, power attenuation also increases.

4.8 Modeling the temporal variations

To achieve this, the whole data set was normalized to its mean and the result was used as an input parameter to the EasyFit 5.5 software program. [Normalization refers to the division of multiple set of data by a common variable in order to negate that variable's effect on the data, thus allowing underlying characteristics of the data set to be compared; this allows data on different scale to be compared, by bringing them to a common scale (Scott, 2010)].

The mean was determined by highlighting the data column (using Microsoft Excel 7) and was found to be 42.57889)

The following formula was then used in a separate column.

$$= a1/42.57889 \qquad (4.14)$$

Normalization of the whole data set was finally achieved by left clicking under the cell of equation (4.14) and rolling down the data length (540 entries). The results of this operation (see appendix A) was copied and pasted in the EasyFit 5.5 software program as an input parameter.

Modeling, using the four probability distribution functions, was automatically achieved by clicking the "fit distribution" on the tool bar. Distributions of interest were selected one- by- one while holding down the CTRL key. The result is as shown in Figure 4.1.

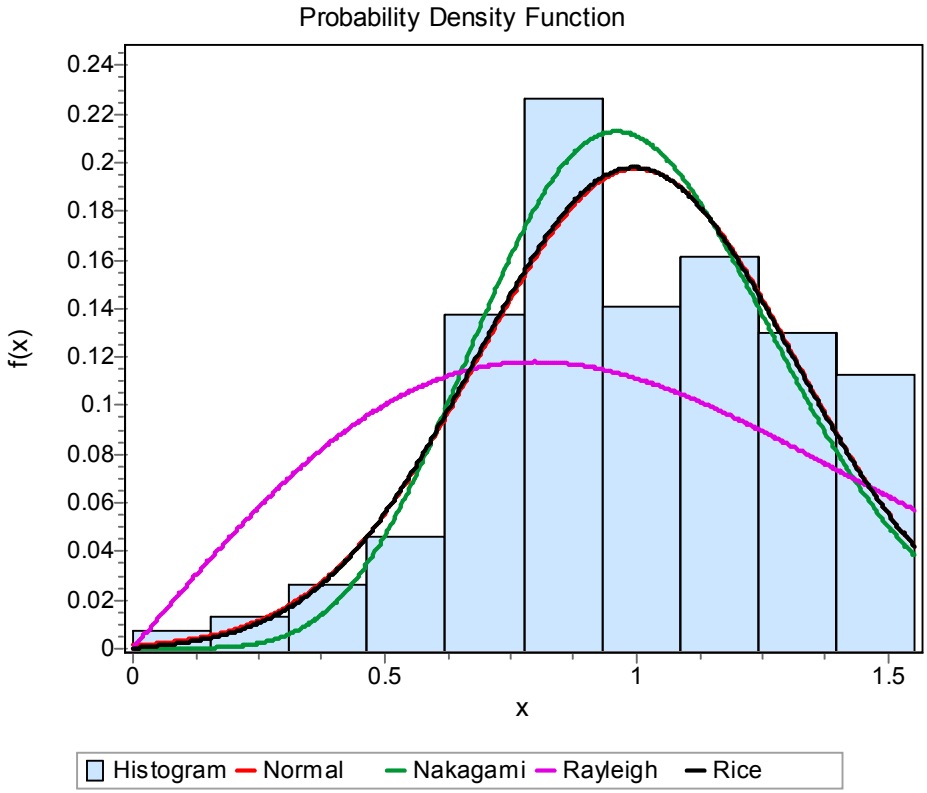


Figure 4.1: The pdf derived from the normalized data fitted with different distributions.

The descriptive statistics of the temporal variations (Table 4.2) was obtained by clicking the "analyze" on the tool bar of the EasyFit, selecting the "descriptive statistics" and clicking "ok".

From Figure 4.1, the Rician and Gaussian distributions (red and black curves in the figure) are found to be the two models with good fit for the description of these weather-induced temporal variations on the channel. Since the Rician function is a generally good approximation for this type of variations , and the standard error (in Table 4.2) obtained using the Rician model is just 0.0135 (or 1.35 %), it (the Rician function) will be used for the analysis of the individual experimental results obtained under different weather phenomena.

Table 4.2: Descriptive Statistics of the Data set

Statistic	Value
Sample Size	540
Range	1.5524
Mean	1.0
Variance	0.09839
Std. Deviation	0.31367
Coef. of Variation	0.31367
Std. Error	0.0135
Skewness	-0.22294
Excess Kurtosis	-0.15186

Percentile	Value
Min	0
5%	0.49344
10%	0.63318
25% (Q1)	0.80556
50% (Median)	0.97466
75% (Q3)	1.2307
90%	1.5031
95%	1.5148
Max	1.5524

.

4.9 Results analysis of different weather phenomena

The data obtained under each weather phenomena (appendix I) was normalized to the fair weather condition (i.e. no rain, no wind condition) using equation 4.15 in Microsoft Excel and then using the same operation as before.

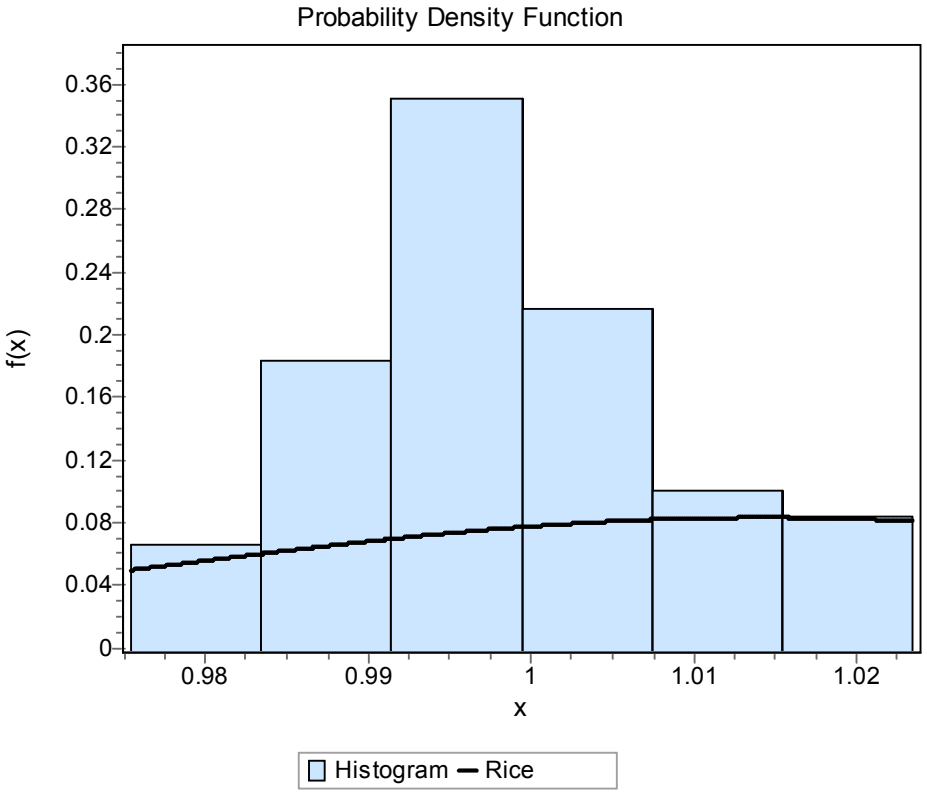
$$= a1/64.588 \qquad (4.15)$$

Note that the data range in each weather phenomenon is 1 to 60 and 64.588 is the average (mean) value of the received signal under the fair weather condition. The normalized data of each weather condition is used as input to the "EasyFit 5.5" software program as explained previously. The results of the analysis were obtained by clicking the "fit distribution" on the software toolbar followed by "summary" and then "ok". The later operation produces, among other parameters, the amplitude of steady components "v" and the standard deviations "σ" which

are used for Rician K- factor calculations. All the results for the nine different weather phenomena are as presented in the following pages:

Table 4.3: Normalized data under "no rain, no wind" condition.

1.006379	1.015669	0.990896	0.975413	0.997089	1.021862	1.009475
1.01412	0.990896	1.003282	0.998638	1.02341	0.998638	1.006379
1.021862	0.997089	0.997089	1.006379	0.998638	0.998638	0.990896
0.998638	0.998638	0.997089	0.983155	1.011024	0.998638	0.998638
0.990896	0.9878	1.006379	1.006379	0.990896	1.006379	0.998638
1.003282	1.009475	1.006379	0.998638	1.01412	0.990896	0.992444
0.975413	1.017217	0.998638	1.006379	0.990896	0.990896	
1.004831	0.975413	0.998638	1.01412	0.990896	0.998638	
0.992444	1.000186	1.006379	0.998638	0.990896	0.998638	

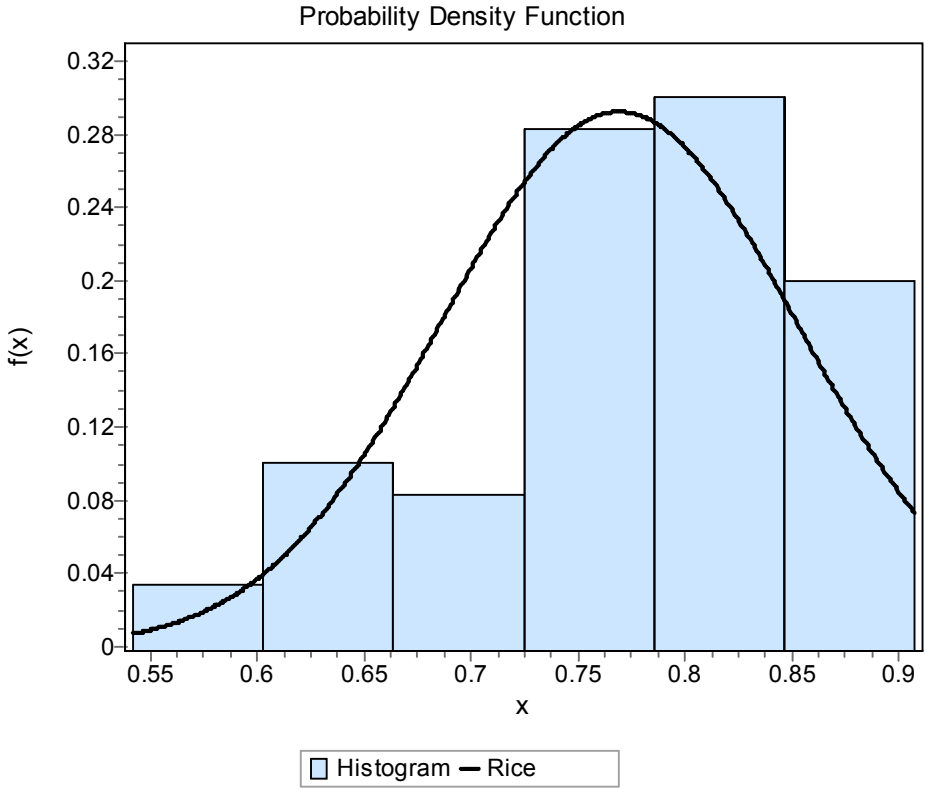


v =1.0135, ϭ = 0.03828

Figure 4.2: Histogram and pdf under no rain, no wind condition

Table 4.4: Normalized data under "no rain, slight wind" condition

0.786524	0.846907	0.896451	0.707562	0.760203	0.627051	0.806651
0.774138	0.797362	0.828327	0.667307	0.727689	0.726141	0.774138
0.766396	0.826779	0.766396	0.766396	0.774138	0.8082	0.846907
0.786524	0.865486	0.786524	0.786524	0.726141	0.846907	0.651824
0.777234	0.907289	0.806651	0.766396	0.644082	0.778782	0.640986
0.826779	0.826779	0.850003	0.726141	0.665758	0.865486	0.684338
0.865486	0.788072	0.826779	0.647179	0.549638	0.885613	
0.885613	0.750913	0.826779	0.684338	0.541896	0.877872	
0.826779	0.783427	0.786524	0.726141	0.606924	0.786524	

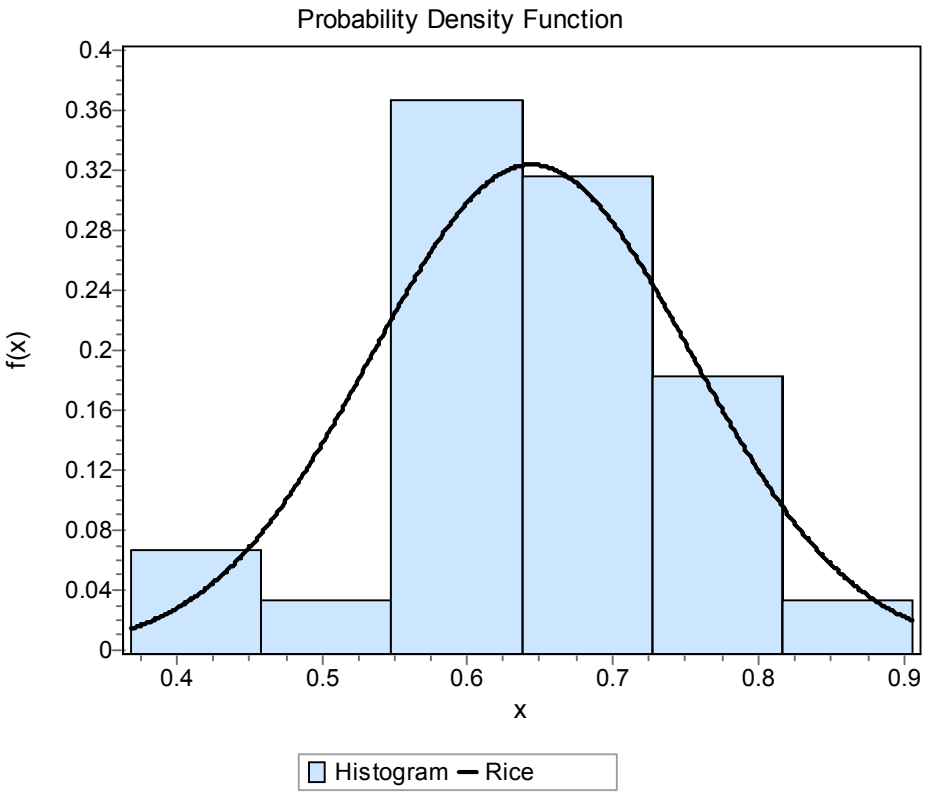


$v = 0.7645$, $\sigma = 0.0833$

Figure 4.3: Histogram and pdf under no rain, slight wind condition

Table 4.5: Normalized data under "no rain, strong wind" condition

0.726141	0.685886	0.36849	0.586796	0.503189	0.805103	0.707562
0.566669	0.746269	0.503189	0.566669	0.627051	0.727689	0.905741
0.724593	0.706014	0.566669	0.647179	0.387069	0.603827	0.775686
0.797362	0.569765	0.566669	0.586796	0.548089	0.750913	0.726141
0.826779	0.588345	0.676596	0.447452	0.726141	0.665758	0.566669
0.704465	0.548089	0.586796	0.569765	0.781879	0.766396	0.724593
0.786524	0.407196	0.566669	0.645631	0.56512	0.712207	
0.647179	0.56512	0.647179	0.667307	0.617762	0.696724	
0.617762	0.665758	0.549638	0.585248	0.746269	0.806651	

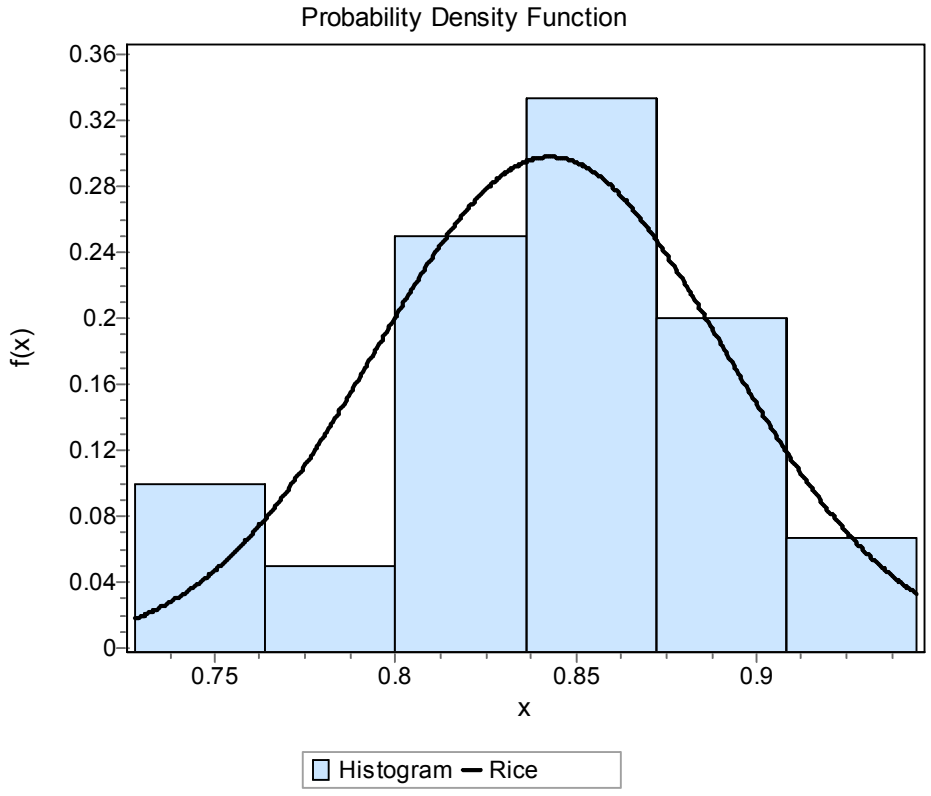


v = 0.63454, ϭ = 0.11103

Figure 4.4: Histogram and pdf under no rain, strong wind condition

Table 4.6: Normalized data under "light rain, no wind" condition

0.805103	0.828327	0.885613	0.758655	0.817489	0.805103	0.916579
0.826779	0.867034	0.867034	0.867034	0.743172	0.735431	0.846907
0.867034	0.882517	0.876324	0.870131	0.805103	0.786524	0.898
0.885613	0.828327	0.856196	0.805103	0.868582	0.820586	0.944448
0.876324	0.882517	0.867034	0.758655	0.786524	0.837617	0.868582
0.913482	0.913482	0.828327	0.882517	0.84381	0.882517	0.805103
0.885613	0.867034	0.750913	0.837617	0.856196	0.859293	
0.846907	0.905741	0.815941	0.781879	0.8082	0.867034	
0.867034	0.867034	0.805103	0.805103	0.727689	0.905741	

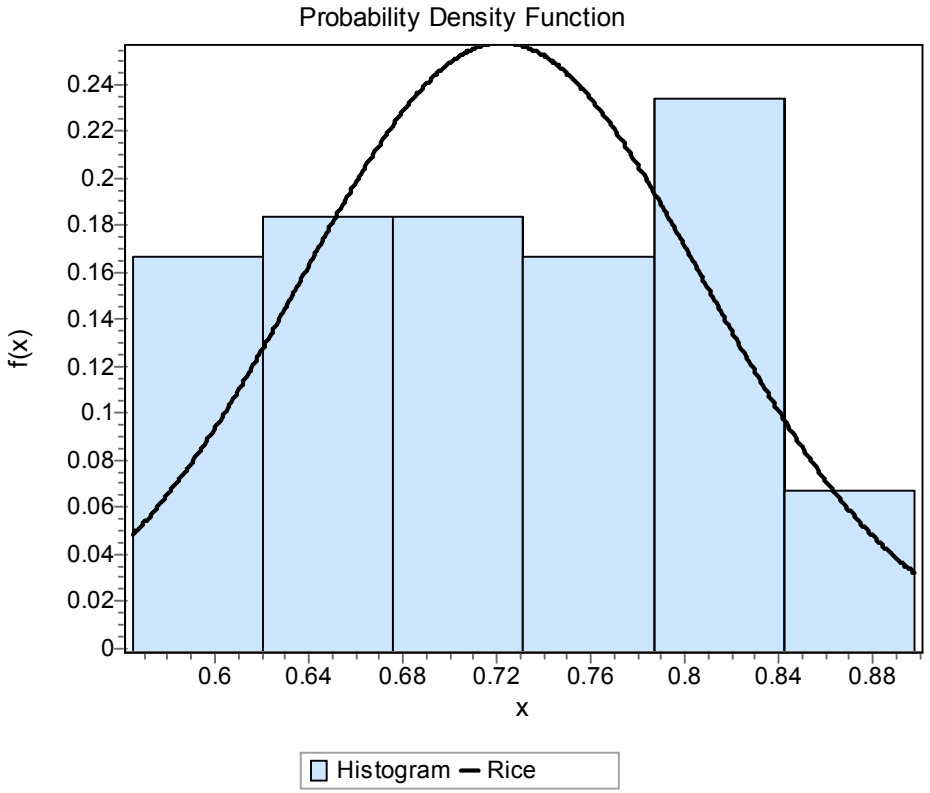


v= 0.84147, ϭ = 0.04837

Figure 4.5: Histogram and pdf under light rain, no wind condition

Table 4.7 Normalized data under "light rain, slight wind" condition

0.611569	0.600731	0.698272	0.876324	0.766396	0.589893	0.603827
0.681241	0.743172	0.633245	0.898	0.653372	0.692079	0.876324
0.78962	0.6735	0.766396	0.812844	0.56512	0.743172	0.627051
0.65492	0.811296	0.832972	0.805103	0.678145	0.658017	0.806651
0.588345	0.719948	0.764848	0.719948	0.675048	0.6735	0.6735
0.851551	0.832972	0.828327	0.766396	0.74472	0.83452	0.6735
0.588345	0.764848	0.811296	0.743172	0.832972	0.719948	
0.596086	0.676596	0.61931	0.788072	0.788072	0.805103	
0.650276	0.603827	0.758655	0.696724	0.679693	0.724593	

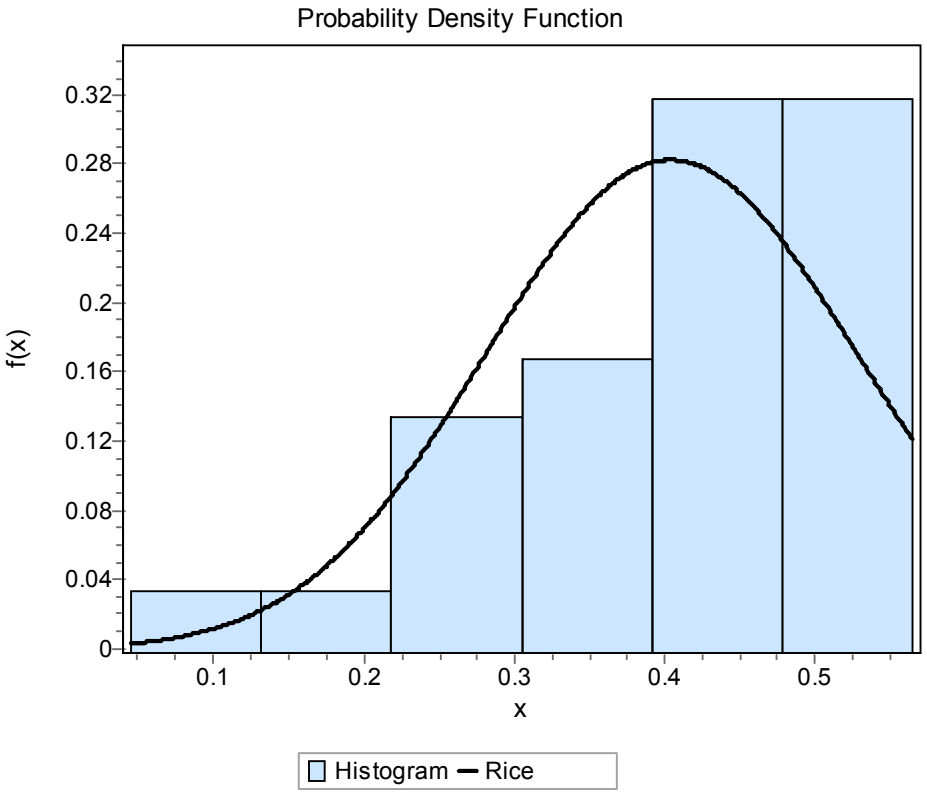


v = 0.7172, ϭ = 0.08626

Figure 4.6: Histogram and pdf under light rain, slight wind condition

Table 4.8: Normalized data under "light rain, strong wind" condition

0.456391	0.339072	0.557379	0.247724	0.39481	0.557379	0.487707
0.526414	0.425776	0.472224	0.0449	0.267852	0.56512	0.407196
0.354555	0.541896	0.343717	0.267852	0.487707	0.387069	0.495448
0.216759	0.507834	0.449	0.328234	0.467579	0.467579	0.332879
0.157924	0.449	0.546541	0.410293	0.56512	0.548089	0.4041
0.229145	0.441258	0.387069	0.227596	0.506286	0.526414	0.506286
0.464483	0.503189	0.36849	0.069672	0.427324	0.447452	
0.449	0.495448	0.247724	0.287979	0.325138	0.425776	
0.466031	0.428872	0.354555	0.247724	0.425776	0.549638	

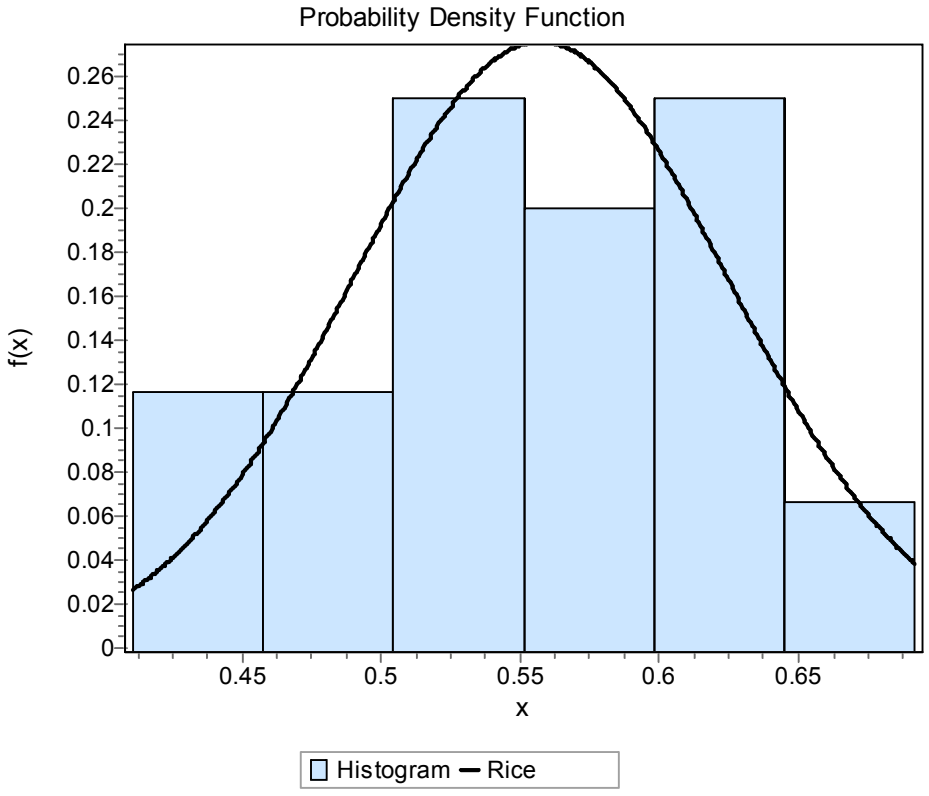


v = 0.38502, ϭ = 0.12587

Figure 4.7: Histogram and pdf under light rain, strong wind condition

Table 4.9: Normalized data under "heavy rain, no wind" condition.

0.631696	0.531058	0.512479	0.549638	0.602279	0.651824	0.588345
0.603827	0.410293	0.571314	0.571314	0.569765	0.449	0.670403
0.627051	0.501641	0.591441	0.472224	0.611569	0.549638	0.591441
0.549638	0.515576	0.526414	0.532607	0.531058	0.627051	0.549638
0.557379	0.611569	0.479965	0.481514	0.631696	0.591441	0.490803
0.534155	0.510931	0.449	0.562024	0.640986	0.631696	0.549638
0.611569	0.450548	0.431969	0.636341	0.692079	0.416486	
0.61931	0.591441	0.492352	0.546541	0.611569	0.580603	
0.472224	0.456741	0.532607	0.572862	0.675048	0.631696	

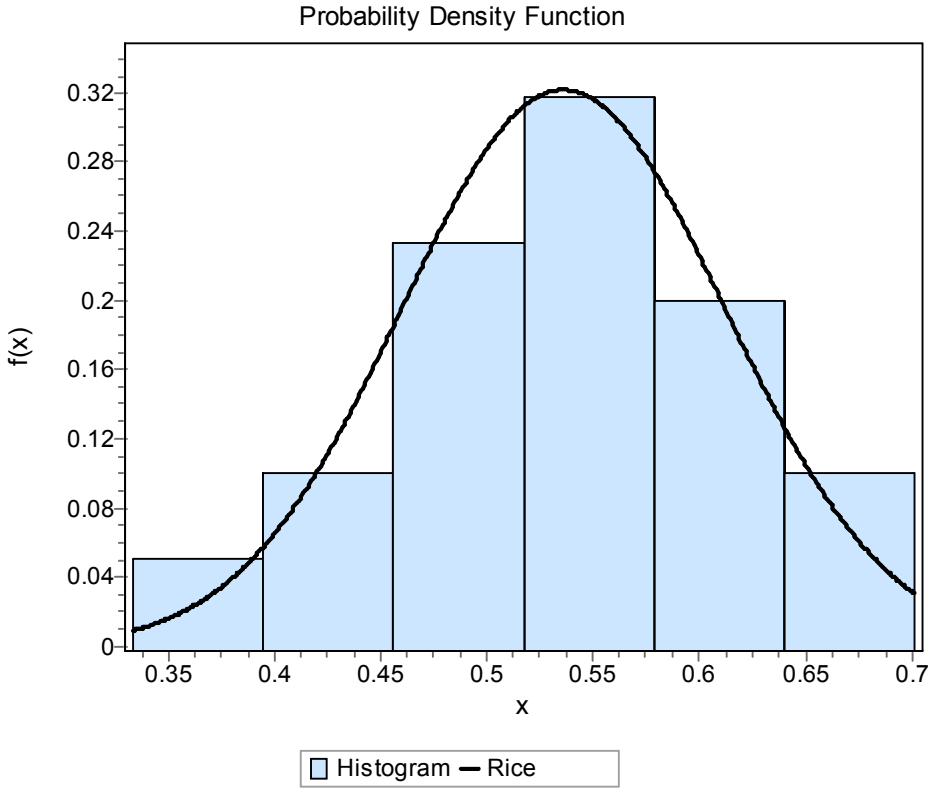


v = 0.55304, ϭ = 0.0681

Figure 4.8: Histogram and pdf under heavy rain, no wind condition

Table 4.10: Normalized data under "heavy rain, slight wind" condition.

0.391714	0.640986	0.532607	0.521769	0.453645	0.591441	0.651824
0.490803	0.591441	0.498545	0.582151	0.332879	0.588345	0.640986
0.534155	0.701369	0.452096	0.560476	0.591441	0.534155	0.611569
0.487707	0.611569	0.611569	0.489255	0.571314	0.512479	0.501641
0.532607	0.650276	0.450548	0.552734	0.532607	0.479965	0.591441
0.501641	0.690531	0.461386	0.591441	0.526414	0.472224	0.534155
0.531058	0.631696	0.537252	0.551186	0.569765	0.510931	
0.472224	0.479965	0.332879	0.560476	0.506286	0.572862	
0.571314	0.430421	0.433517	0.532607	0.449	0.631696	

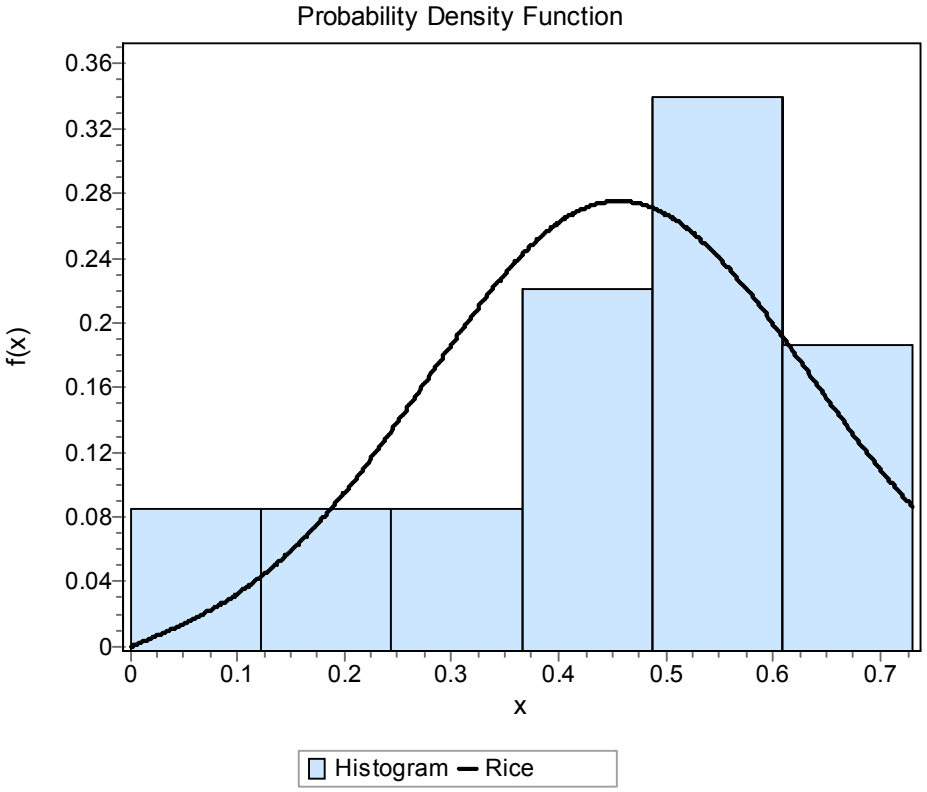


$v = 0.53031$, $\sigma = 0.07663$

Figure 4.9: Histogram and pdf under heavy rain, slight wind condition

Table 4.11: Normalized data under 'heavy rain, strong wind" condition

0.600731	0.634793	0.671951	0.116121	0.038707	0.591441	0.252369
0.555831	0.685886	0.596086	0.191986	0.113024	0.431969	0.452096
0.301914	0.472224	0.591441	0	0.239983	0.495448	0.119217
0.631696	0.591441	0.696724	0.331331	0.631696	0.515576	0.431969
0.416486	0.690531	0.382424	0.221403	0.560476	0.449	0.569765
0.464483	0.611569	0.456741	0.661114	0.379327	0.312752	0.147086
0.157924	0.541896	0.531058	0.589893	0.492352	0.56512	
0.387069	0.591441	0.510931	0.291076	0.591441	0.371586	
0.531058	0.546541	0.430421	0.481514	0.730786	0.651824	



v = 0.42067, ϭ = 0.18493

Figure 4.10: Histogram and pdf under heavy rain, strong wind condition

4.10 Characterization of the Temporal Variations

The Rician distribution function is described and characterized in terms of a fading parameter K which is commonly known as the Rician K-factor (Meng,*et al*, 2007).

$$K \text{ (in decibel)} = 10\log_{10}\frac{v^2}{2\sigma^2} \quad (4.16)$$

Where: v is the amplitude of the steady components

σ^2 is the variance of the random components

The physical interpretation of the Rician K-factor depends on the type of multipath channel. For a fixed channel where both transmitter and receiver are stationary, as in this case, the Rician K-factor is the ratio of the mean power to the variance of the received components (Meng, *et al*, 2007). This is used to characterize the temporal variability of the propagation channel, which is sensitive to the movements of scattering objects within the propagation channel.

Using equation 4.18 and results of the statistical analysis (the values of "v" and "σ", the K-factor for each weather condition was calculated and tabulated (Table 4.2).

Example: For the fair weather condition (no rain, no wind),

$v = 1.0135$, $\sigma = 0.03828$

$K = 10\log \frac{(\quad .\quad\quad)}{(\quad .\quad\quad)} = 25.4466$ dB.

Table 4.12: K-factors for different weather conditions.

WEATHER	**No wind**	**Slight wind**	**Strong wind**
No rain	25.4466 dB	16.2448 dB	12.1301 dB
Light rain	21.7989 dB	15.3863 dB	6.7009 dB
Heavy rain	16.2818 dB	13.7923 dB	4.1284 dB

From Table 4.12, it can be seen that, the Rician K-factor decreases as the strength of either wind or rain increases. This is due to the movement of the physical element (leaves and branches) caused by the wind and rain within the foliage channel (Meng, *et al*, 2007). As the strength of wind and rain increases the movement of the branches and leaves also increases, thereby increasing the variability of the propagation channel. It can also be observed (in the second column of Table 4.12) that even without the effect of wind; the falling created rain can also increase the variability of the channel and hence decrease the temporal Rician K-factor. This is because the long leaves of the young eucalyptus trees are easily moved by the created rain drops.

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

In chapter one it was stated that the study of combined effects of wind and rain on foliage radio channels has not been fully developed, because there is still no mathematical model for calculating power loss in forest environments under the influence of the above mentioned weather conditions. This is so despite the importance of the area and the considerable amount of development in telecommunication engineering. It was this situation that prompted this study, the aim of which was to find, experimentally, the additional power attenuations imposed on the channel, characterize the variations and determine a statistical model which compares very well with the experimental results. This could serve as a step towards solving the above mentioned problem.

5.2 Summary

Foliage radio propagation channels, under the influence of wind and rain are very difficult to investigate in the above mentioned region or Katsina metropolis in particular where rainfall is seasonal, which means that long term measurements are required in order to get meaningful results. Furthermore, there is no radar system to provide the required full set of volumetric reflectivity and velocity data of weather information during the measurements (Meng, *et al,* 2007) around the city, periodically.

Notwithstanding these problems, this work has produced some useful results and ideas that will go a long way in contributing to the study of foliage channels under the influence of wind and rain. The achievements could be summarized as follows:

a) Wind and rain have been systematically created using the combination of both standard and improvised equipment so that the required weather information (wind speed and rain intensity) is easily derived.

b) Using the maximum wind speed and maximum average rain intensity of Katsina metropolis (UMYA, 2010), a weather model with nine combinations was developed to represent the actual weather conditions of the city.

c) EM wave measurements in the channel under the influence of the artificially created weather conditions were successfully carried out and the raw data/corresponding graphical representations have been presented.

d) Additional power attenuations imposed by the different weather phenomena have been determined and compared.

e) After normalization of data about its mean, the temporal variations have been statistically modeled and found to be Rician distributed.

f) Based on the Rician model, the variations have also been characterized by calculating the K-factor for each weather phenomenon. It was found that the K-factor decreases as the weather conditions become stronger. This indicates that variability of the propagation channel increases when the strength of wind or rain intensity increases.

5.3 Conclusion

The effects of artificially created weather conditions (wind and rain) on a short-range foliated microwave channel have been studied in this thesis. The experimental results show that wind and rain, even though created, can impose additional attenuation on propagating signals in foliage environments. The imposed attenuation, as well as variability, increases when wind speed or rain intensity increases.

In the final conclusion, it is the humble view of the author that the aim and objectives of the thesis have been achieved. The work can be useful for design of a fade margin for microwave communication systems to be used in foliage environments having a weather condition similar to that of Katsina city which is located in the Savanna region of Northern Nigeria.

5.4 Limitations

There are limitations in the accuracy of the results in this thesis due to the following reasons:

a) The applied weather conditions were artificially created; as such the coverage area is limited.

b) The pipe-borne water used for creation of the rain contains dissolved compounds for water purification. This could affect the attenuation and scattering effects of the rain drops and hence the accuracy of the data.

c) The microwave transmitter used was of low power, as such there was a limit to the range of the propagation channel.

5.5 Recommendations for further work

The following suggestions are hereby given for further work.

a) Development of a mathematical model for power loss in foliage environments taking into account the effects of wind and rain. This can be achieved through long term measurements in different forest environments using standard and sophisticated measuring instruments.

b) Investigation of foliage channels to find attenuations and variability in relation to the size and water contents of the leaves, tree-trunk diameter, height of the trees, and their average separation distance, under the influence of weather conditions.

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APPENDIX A: Normalized RSS in the Foliage radio-wave Channel under Different Weather Conditions

1.503093	1.359830	0.763290	1.390361	0.770335	0.807913	0.777381
1.538322	1.256492	0.951176	1.284675	0.681089	0.730409	0.728061
1.503093	1.162549	0.587146	1.362178	0.669346	0.852536	0.716318
1.503093	1.193080	0.831398	1.432636	0.763290	0.965268	0.775032
1.503093	1.223612	1.101486	1.317555	0.751547	0.82905	0.868976
1.550065	1.289372	1.186035	1.221263	0.650558	0.868976	0.958222
1.514836	1.254143	0.857233	0.92769	0.845490	0.913599	0.988754
1.514836	1.254143	0.937085	1.033377	0.716318	0.864279	0.972313
1.514836	1.193080	1.132017	1.197777	0.521385	0.92769	0.92769
1.526579	1.073303	1.221263	0.993451	0.681089	0.805564	0.760941
1.503093	1.012239	1.103834	0.892462	0.829050	0.958222	0.897159
1.503093	1.162549	0.915947	1.291721	0.587146	0.972313	0.810261
1.514836	1.19308	1.139063	0.892462	0.558963	1.049817	0.91125
1.514836	1.162549	1.009891	0.904205	0.375773	0.92769	0.843141
1.531276	1.101486	1.162549	0.986405	0.537826	1.023982	0.457974
1.526579	0.981708	1.080348	0.911250	0.375773	0.988754	0.958222
1.503093	1.038074	1.056862	1.127320	0.068109	0.681089	0.631769
1.514836	1.101486	1.223612	1.021634	0.406305	0.833747	0.704575
1.514836	1.153154	1.073303	1.230658	0.4979	0.951176	0.239555
1.505442	1.103834	1.373921	1.092091	0.622375	0.897159	0.587146
1.512488	1.174292	1.176640	1.263538	0.345242	0.958222	0.805564
1.512488	1.101486	1.101486	1.160200	0.105686	0.631769	0.962919
1.526579	0.977011	0.859581	1.026331	0.436836	0.880719	1.040422
1.526579	1.009891	1.099137	0.915947	0.375773	0.958222	0.716318
1.514836	0.833747	1.221263	1.059211	0.598889	0.892462	0.897159
1.514836	0.822004	1.254143	0.960571	0.406305	1.016937	1.047468
1.526579	0.920645	1.315207	1.162549	0.739804	0.897159	0.92769

1.479607	0.951176	1.343390	1.263538	0.709272	0.833747	0.822004
1.514836	1.101486	1.329298	1.1602	0.857233	0.744501	0.897159
1.526579	1.22596	1.385664	1.256492	0.767987	0.833747	0.82905
1.49135	1.284675	1.343390	1.230658	0.648209	0.594192	1.019285
1.526579	1.181337	1.284675	0.939433	0.493202	0.744501	0.904205
1.514836	1.312858	1.315207	1.150806	0.64586	0.810261	0.897159
1.526579	1.34339	1.256492	1.329298	0.84549	0.739804	1.056862
1.538322	1.331647	1.315207	1.362178	0.857233	0.807913	0.5801
1.514836	1.19308	1.338692	1.233006	0.587146	0.760941	0.692832
1.512488	1.223612	1.256492	1.221263	0.709272	0.805564	0.805564
1.552414	1.174292	1.338692	1.092091	0.831398	0.716318	0.775032
1.514836	1.284675	1.385664	1.162549	0.798518	0.866627	0.652906
1.533625	0.988754	1.315207	1.12732	0.678741	0.972313	0.176144
1.526579	0.972313	1.373921	1.195429	0.64586	0.897159	0.291224
1.538322	1.038074	1.315207	1.056862	0.833747	1.063908	0.000000
1.550065	1.101486	1.343390	1.162549	0.739804	0.92769	0.502597
1.514836	0.859581	1.315207	0.991102	0.617677	0.986405	0.335847
1.503093	1.099137	1.329298	0.857233	0.751547	1.047468	1.002845
1.521882	1.20952	1.298767	1.028679	0.504945	0.958222	0.89481
1.479607	1.254143	1.315207	1.023982	0.61298	0.728061	0.441534
1.524231	1.068605	1.256492	1.129669	0.767987	0.652906	0.730409
1.505442	1.19308	1.139063	1.263538	0.958222	0.807913	0.058715
1.540671	0.981708	1.237703	1.195429	0.915947	0.756244	0.171447
1.503093	0.937085	1.221263	1.031028	0.951176	0.685786	0.36403
1.512488	1.040422	1.150806	0.89481	0.833747	0.92769	0.958222
1.514836	1.132017	1.315207	1.049817	0.84549	0.683438	0.850187
1.498396	1.070954	1.319904	1.12732	0.810261	0.699878	0.575403
1.531276	0.864279	1.221263	0.998148	0.92769	0.814958	0.746849
1.543019	0.892462	1.150806	1.021634	0.939433	0.504945	0.897159
1.479607	0.831398	1.338692	1.265886	0.716318	0.657603	1.108531
1.517185	0.617677	1.270584	1.092091	0.805564	0.791473	0.897159
1.503093	0.857233	1.186035	1.221263	0.622375	0.883067	0.655255
1.521882	1.009891	1.221263	1.099137	0.760941	0.850187	0.751547
1.19308	0.558963	1.240052	0.915947	0.782078	0.742152	0.782078

1.174292	0.76329	1.12732	1.329298	0.92769	0.838444	0.681089
1.162549	0.859581	1.221263	0.951176	0.775032	0.897159	0.474414
1.19308	0.859581	1.317555	1.223612	0.683438	0.836096	0.857233
1.178989	1.026331	1.19308	1.021634	0.897159	0.850187	0.56366
1.254143	0.890113	1.279978	1.021634	0.692832	0.807913	0.988754
1.312858	0.859581	1.298767	0.833747	0.777381	0.688135	0.382819
1.34339	0.981708	1.22596	0.798518	0.866627	0.504945	0.685786
1.254143	0.833747	1.103834	0.537826	0.897159	0.897159	0.180841
1.284675	0.890113	1.221263	0.328802	0.798518	0.866627	0.655255
1.20952	0.859581	1.115577	0.239555	0.728061	0.807913	0.864279
1.254143	0.981708	1.19308	0.34759	0.681089	0.798518	0.223115
1.312858	0.890113	1.244749	0.704575	0.655255	0.864279	
1.37627	0.678741	1.270584	0.681089	0.746849	0.767987	
1.254143	0.864279	1.338692	0.706924	0.807913	0.681089	
1.195429	0.979359	1.303464	0.51434	0.833747	0.897159	
1.139063	1.012239	1.315207	0.64586	0.866627	0.892462	
1.188383	0.887764	1.373921	0.822004	0.716318	0.810261	

APPENDIX B: Microwave Transmitter 2.8cm wavelength



APPENDIX C: Microwave Receiver 2.8cm wavelength



APPENDIX D: Creation of artificial rain



APPENDIX E: EM wave measurement in the foliaged environment