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Effect of Seasons on Millimeter Wave (35 GHz) Prevailing in Foliage Depth of Desert Region of India

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Abstract: Performance of millimeter wave is of interest to communication scientists, researchers, industrialist as it shown communication window with wide spectrum and fewer losses. Wavelength above 10 GHz is subject to molecular absorption which limits its uses for many purposes. In this paper effect of changing seasons is presented on basis of experimental results. A trans-receiver system of 35 GHz is used to quantify the effect of increasing foliage depth (Trees in line) with changing seasons. Molecular absorption of water molecules can be clearly pointed out in observations. It is observed that least attenuation occurred in autumn while spring offers maximum attenuation to signal due to water molecules. Non linear attenuation with increase in foliage depth also indicates phenomenon of coherent scattering of millimeter wave. Coherent scattering re-combines the scattered components which are in-phase. Total 35.16% of signal in autumn seasons is said to be coherently scattered while least coherency of 18.63 % is observed in summers. In winter and spring coherency of signal is observed as 25.88% and 23.33% respectively. Observations and calculations presented in the paper may help scientist to develop an algorithm for communication system which can work proper with varying seasons.

Introduction

For the process of photosynthesis, a leaf is above ground as specified in botany. Leaves of trees are generally flat (laminar) and thin which are helpful for getting exposed to light as their surface area is maximum. Furthermore, the internal structure of leaves has to maximize exposure of light on the photosynthetic organelles (the chloroplasts) so that the absorption of carbon dioxide becomes amplified. These changes are at the rate of water loss and most leaves have stomata which adjust carbon dioxide, oxygen and water vapor exchange with the atmosphere. The shape and structure of leaves varies significantly with climate due to the availability of light and water. In most plants leaves are also the predominant site, where transpiration and gutta tion take place. Leaves modified themselves in some ways so that they can keep food and water.

The incident wave interacts usually with the leaves and branches in case of attenuation via trees and vegetation. The trunk has less contribution in signal attenuation as volume of the trunk occupied is less than the total tree canopy volume.

Due to the influence able leaf size of foliage, it becomes necessary to keep watch of foliage attenuation in case of millimeter wave communication. The leaves and vegetation are dealt as a homogeneous layer beneath 1.25 GHz frequency and non-homogenous above that.

The attenuation is triggered by the transmitted wave being scattered and absorbed as it propagates through the field of foliage and vegetation. Vegetation in path of transmission affects the radio-waves with two phenomenon that are absorption and scattering. Absorption increases attenuation while scattering is known to reduce the signal-to-interference ratio (quality). The propagation losses due to foliage are dependent on parameters like the dielectric constant, water content, physical dimension, density, shape and size of the foliage. Only the canopies or tree crown influences the signal attenuation in the case of wave propagation between antennas located at heights. At greater frequency the signal wavelength is small and the obstacles are of the order of wavelength or greater in size which are responsible for signal attenuation. The existence of foliage in the propagation channel can lead to severe signal attenuation and impacts badly. This foliage attenuation has been identified as a major restriction to design communication system. It limits the use of higher frequency for line-of-sight microwave links, RADAR applications and high-speed information communication.

Consequently, the characteristics of signal attenuation due to foliage need to be nicely understood to realize communication capabilities through foliage prone environments. The signal attenuation due to foliage is very sensitive to the wavelength. Attenuation due to foliage mostly depends on dimensions and shapes of leaves and branches as the interaction between the tree and the electromagnetic wave is primarily affected due to it. When the wavelength is decreased, the losses increases due to a large interaction between the incident field and the vegetation elements. When wavelength approaches the equal size of scattering body and enters in Mie scatter region.

The propagation mechanism can be divided into two parts:
(i) The propagation through (not round or over) trees.
(ii) Propagation over trees.

The first mechanism can predominate for geometries in which antennas are beneath the tree tops and the distance via trees is small. The second predominates for geometries in which one antenna is placed above the treetops. Savage *et al.* (2003) stated that the attenuation is strongly affected by means of multipath scattering when a signal propagated through tree structures [4].

Mainly two parameters are considered for analysis of attenuation in any model. These parameters are-

i. Deciduous trees either moist or dry environmental conditions
ii. Leafy or nonleafy trees.

Dense forest creates more problems of attenuation rather than isolated trees.

Foliage depth decides the attenuation as signal propagates through that depth. Attenuation increases with increase in depth as well as increase in frequency. CCIR record (1990) says, the attenuation is 0.05 dB/m at 200 MHz, 0.2 dB/m at 1 GHz, 0.3 dB/m at 2 GHz and 0.4 dB/m at 3 GHz [5].

Attenuation of signal at lower frequencies appears higher with vertical polarization of antenna as compared with horizontal polarization. Canopy induced scattering affects appears more in horizontally polarized wave rather than vertical ones at higher frequencies. Due to this, excess path loss is experienced by signal when it propagates in hundred meters of foliage. Fortunately, there is also generous propagation via diffraction over the crowns, particularly if the antenna is placed near treetop and maintaining antennas at the angle which can avoid obstacles.

If photon energy radiation of electromagnetic signal got transferred to matter, it is known as absorption or attenuation in physics. If absorption of waves does not depend on their strength than the type of absorption is known as linear absorption. A nonlinear or saturation absorption is said to take place in case of change in transparency of medium through which wave propagates. Absorption is induced through obstacle during signal propagation in a medium.

1. MODELS FOR ATTENUATION PREDICTION IN FOLIAGE DEPTH

Models for prediction of attenuation by foliage in depth are classified as theoretical and empirical models. Physics based model of attenuation due to foliage has attained remarkable importance. Attenuation prediction by foliage is partially modelled by Radiative Energy Transfer (RET) theory or Wave theory.

Nice probable solutions of losses due to foliage by different vegetation geometries were shown by RET theory. RET provides highly precise and time efficient solutions for both horizontal and incline foliage paths. But RET theory can only be applicable for homogenous medium. To get over the limitation of homogeneous medium, RET theory was modified as dRET for non-homogenous medium and was proposed by Diadascalou. Model is further modified by Fernandes for vegetation which are in isolation.[7].

Fractal Generated trees were used to develop a simulation for coherent scattering due to tree canopies using Monte Carlo method. In contrast with incoherent models, Diadascalou model computes the coherent backscatter signal by forest canopies made of genuine tree structures. Relative phase information from each scatterer was conserved in his findings. Tree trunk was considered as cylinder and leaves as tilted plane to compute electromagnetic scattering. Total scattered field was computed as coherent addition of each scattered element illuminated by mean field. Single scattering theory is applied for above said computation. Foldy's approximation is invoked to calculate the mean field for a forest canopy in multilayer inhomogeneous medium. Backscatter statistics were obtained by Monte Carlo simulation for a huge amount of results.

Lin Y.C. *et al*. (1999) studied polarization states, attenuation and uncertainty of signal by the tree canopy. He developed a model based on Monte Carlo simulations [8]. In specifically, that model is used to evaluate the working of Global Positioning System (GPS) receivers under tree canopies. To generate the structure of coniferous or deciduous trees a fractal algorithm (Linden Mayer system) was used. Koh *et al.* (2002) applied Monte Carlo simulation for field calculation of tree cluster. Probability Density Function of the communicated field was used for estimation of the data for the channel parameters like free space path loss, scattered power (incoherent) and polarization state. Significant difference is not found in signal level at receiver with horizontal to horizontal and vertical to vertical polarizations. Propagation of 10 to 60 GHz appeared to be polarization independent for small foliage depths but considerable depolarization occurs at large foliage depths [45].

2. FOLIAGE LOSS PREDICTION MODELS

Arbitrarily scattered leaves, twigs, branches and tree trunks can cause losses in form of scattering and absorption of the emitted waves. These leaves and branches behave as distinct scatterers. These can affect badly and can constrain the design of modern wireless communication systems.

Effect of foliage on the wireless communications is generally discussed in terms of an isolated single tree, a contour or multiple lines of trees or a forested region. Rogers *et al*.

(2002) did semi-empirical modelling of losses due to foliage to establish a high-speed wireless link [9]. The thorough investigation of attenuation by single tree or by line of trees or by forest, is done by many researchers. Karaliopoulos *et al.* (1999) proposed model of losses by foliage in satellite communication. [17].

Study of the effect of lines of trees grown on the streets contributed by Bertoni (2000). His research work focused on the evaluation of performance of millimeter wave through single tree or lines of trees for finding utility of millimeter wave in RADAR and high-speed radio communication links [10].

3. EMPIRICAL MODELS

Ray geometry of propagating waves helps to model or to predict losses due to foliage (single tree or line of trees) in horizontal as well as slant paths. Elevation angle below ± 3◦ are under horizontal path and considered for both the short foliage path (1 or 2 trees) or long foliage path through many trees (a line or numerous lines of trees but not forestry). Modified exponential decay model (Weissberger model (1981)), Maximum attenuation (MA) model (1995), Dual Gradient (DG) model (1997), Fitted ITU-R (FITU-R) model (1998), Nonzero gradient (NZG) model (Seville and Craig 1995), COST235 model (1996), , and ITU Recommendation (ITU-R) model (1999) are known as empirical foliage loss models for the horizontal transmission path. For propagation measurements performed at UHF, ITU-R model was developed. The FITU-R mode is improved version of ITU-R model and Non zero gradient model is a more common model which is modified version of maximum attenuation model. Weissberger (1981) first proposed exponential decay model and its main modified versions included the COST235 model (1996), ITU-R model (1999) and FITU-R model [13] [15][16][17].

The main benefit of the exponential decay model is having the lesser complexity, but it has a major limitation that it does not consider the measurement geometry as pointed by Savage *et al.* (2003). Prediction methods for such attenuation exist, but are complex to implement or completely empirical and does not consider measurement geometry.

Many scientists provided theories to justify the decrement in rate of attenuation with increase in foliage depth. Many models are also proposed to estimate the attenuation by foliage. Recent justification in decrement in rate of attenuation with foliage depth used coherent scattering concept. According to coherent scattering, when a signal strikes the group of soft scatterer, it scatters in such a way that supports signal strength. Some of scattered field components scatters in-phase and rejoins to give strength to signal. Propagating power of signal get saved due to coherency shown by field components. In this Chapter, power saved by coherent components is calculated using Simpson's 1/3rd rule. Studies throughout four seasons are carried out to conclude the effect of seasons in foliage attenuation of millimeter wave. Second section of this chapter contains the comparison of observed attenuation with previously proposed models of foliage attenuation in depth. Following are the details of observational sight used for purpose of experimentation.

4. OBSERVATIONAL SIGHT

The locations of Govt. Engineering College campus is used for measurements of point -to - point path losses in clear sky and during natural environmental conditions in the Thar desert region.

During experimentation work, the millimeter wave (35 GHz) link system was installed outside for taking the observations. For effective operation of millimeter wave link system, a standby uninterrupted power supply (UPS) is provided at the sight of measurement. Therefore, the transmitter and receiver are connected with commercial power through UPS of 1 KVA.

For measurement of attenuation at foliage depth, campus of GECB have favorable tree lines of *neem trees* (*Methaazadircta*). Neem Trees (*Methaazadircta)* are planted on equal distance of 5 feet with each other and are of relatively same age and same canopy distribution with average leaf size of 5 cm in length and 1.5 cm in breadth. Continuous planted trees are having average height of 5 meters with average trunk height of 2.7 meters. Antenna height was kept at 3.75 meters for measuring attenuation by canopy.

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Figure 4.1: View of observational sight

5 OBSERVATIONS AND RESULTS

Four seasons are chosen for analysis of attenuation of millimeter wave through foliage depth is carried out. Following are the details of environmental conditions for all four seasons during observations, experimental results and its analysis-

5.1 AUTUMN SEASON

Table 5.1 : Environmental Conditions (Autumn)

ANTENNA/GEOGRAPHICAL DESCRIPTION (30/03/2017)	
Temperature	29 ^{o}C
Humidity	26%
Antenna Height	3.76 m
Wind speed	3 Kmph
Bias Voltage	2.54 volt
Atm. Pressure	1013 mbar
Transmitted Power	-35dBm
Distance between Tx and Rx - adjustable	

Table 5.2 : Attenuation with No. of Tree canopies (Autumn)

Canopy No (*x*)	**Distance b/w transmitter and receiver (in meters)**	**Received Power with Foliage (in dBm)**	**Attenuation Due to foliage (in dB)**
1	4.8	-50.1	15.1
2	9.6	-56.3	21.2
3	15.7	-61.4	26.4
4	21.8	-63.5	28.5
5	26.6	-69.3	34.3
6	32.7	-69.3	34.3
7	38.8	-69.4	34.4
8	45.5	-70.5	35.5
9	53.1	-71.1	36.1

10	57.9	-70.5	35.5
11	62.8	-69.9	34.9
12	67.7	-74.7	39.7

We assume that there are no coherent components, which may result in imposition of linear attenuation instead of observed non-linear attenuation through foliage depth. Following equation represents the linear relation between attenuation and foliage depth. This equation is derived by taking initial number of canopies on x-axis and losses in y-axis. Linear attenuation for next canopies is evaluated by using a straight-line equation

$y = 6.1x + 9$ ……. ………………….. 5.1

Calculated values are calculated using above equation and is given in tabular form-

Table 5.3 : Calculated Attenuation Vs Observed Attenuation (Autumn)

Canopy No. (X)	**Observed Attenuation (in dBm)**	**Calculated Linear Attenuation (in dBm)**
1	15.1	15.1
2	21.2	21.2
3	26.4	27.3
4	28.5	33.4
5	34.3	39.5
6	34.3	45.6
7	34.4	51.7
8	35.5	57.8
9	36.1	63.9
10	35.5	70
11	34.9	76.1
12	39.7	82.2

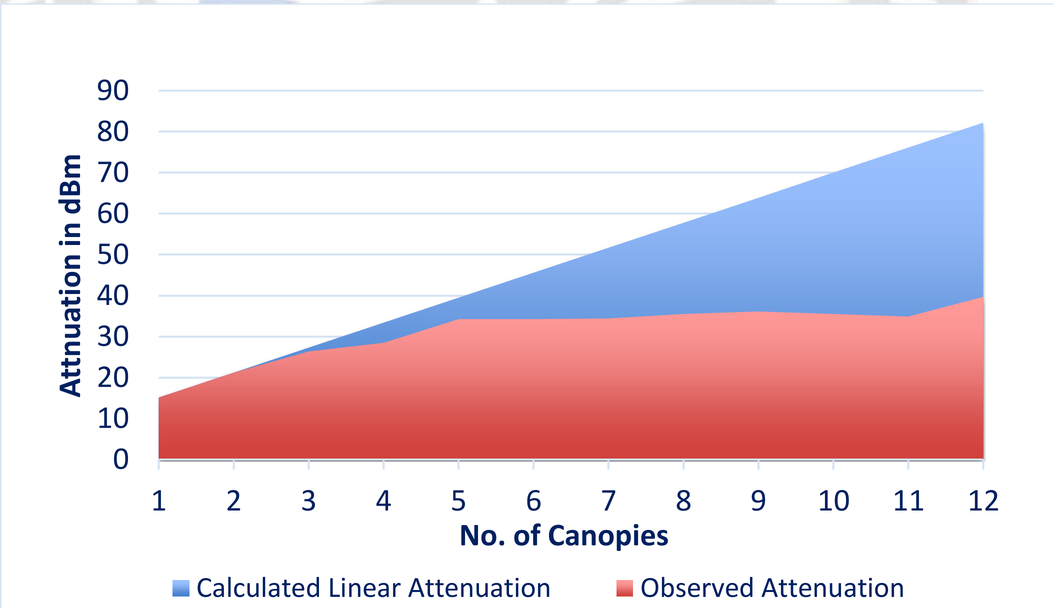

Figure 4.2 : Calculated Attenuation Vs Observed Attenuation (Autumn)

Computation of Coherent scattering area- Using Simpson's 1/3 rule [49] area under curve can be calculated as-

Area = 1/3 [(1st value + last value) + 4 (odd values) +2 (even values)] ……………… 5.2

Values of equation 4.2 are discrete attenuation values of observation curve with canopy step size of one. By putting values of attenuation curve, area under curve is calculated as-

Area under the attenuation curve = 343.06 Sq. unit

Area under curve made by discrete values of straight-line equation 4.1 is calculated as-

Area under straight curve = 529.16 sq. unit

Coherently saved power area = (529.16-343.06) / 529.16 = 35.16 %

SPRING SEASON

Table 5.4 : Environmental Conditions (Spring)

ANTENNA/GEOGRAPHICAL DESCRIPTION	
Temperature	32 ^{o}C
Humidity	45%
Antenna Height	3.76 meters
Wind Speed	17 Kmph
Bias Voltage	2.54 volt
Bias Current	0.54 A
Atm. Pressure	1007 mbar
Transmitted Power	-35dBm
Distance between Tx and Rx - adjustable	

Table 5.5 : Attenuation with No. of Tree canopies (Spring)

Canopy No.	Distance b/w transmitter and receiver (in meters)	Received Power with Foliage (in dBm)	Attenuation due to Foliage (in dB)
1	4.8	-62.1	27.1
2	9.6	-68.4	33.4
3	15.7	-72.7	37.7
4	21.8	-75.3	40.3
5	26.6	-77.8	42.8
6	32.7	-79.2	44.2
7	38.8	-83.3	48.3
8	45.5	-86.4	51.4
9	53.1	-88.1	53.1
10	57.9	-89.3	54.3
11	62.8	-91.0	56
12	67.7	-92	57

Following equation represents the linear relation between attenuation and foliage depth. This equation is derived by taking initial number of canopies on x-axis and losses in y-axis. Linear attenuation for next canopies is evaluated by using a straight-line equation

$$y = 6 \cdot 3x + 20.8$$

……………………..5.3

And from above equation calculated values are -

Table 5.6 : Calculated Attenuation Vs Observed Attenuation (Spring)

Canopy No. (x)	Observed Attenuation (in dB)	Calculated Linear Attenuation(in dB)
1	27.1	27.1
2	33.4	33.4
3	37.7	39.7

4	40.3	46.0
5	42.8	52.3
6	44.2	58.6
7	48.3	64.9
8	51.4	71.2
9	53.1	77.5
10	54.3	83.8
11	56	90.1
12	57	96.4

Computation of Coherent scattering area
By equation 4.2, area under observed attenuation curve of spring season is calculated as
Area under the attenuation curve = 494.3 Sq. unit

Area under curve made by discrete values of straight-line equation 4.3 is calculated as-Area under straight line = 669.16 sq. unit
Coherently saved power area = (669.16-494.3) /696.16 = 25.88%

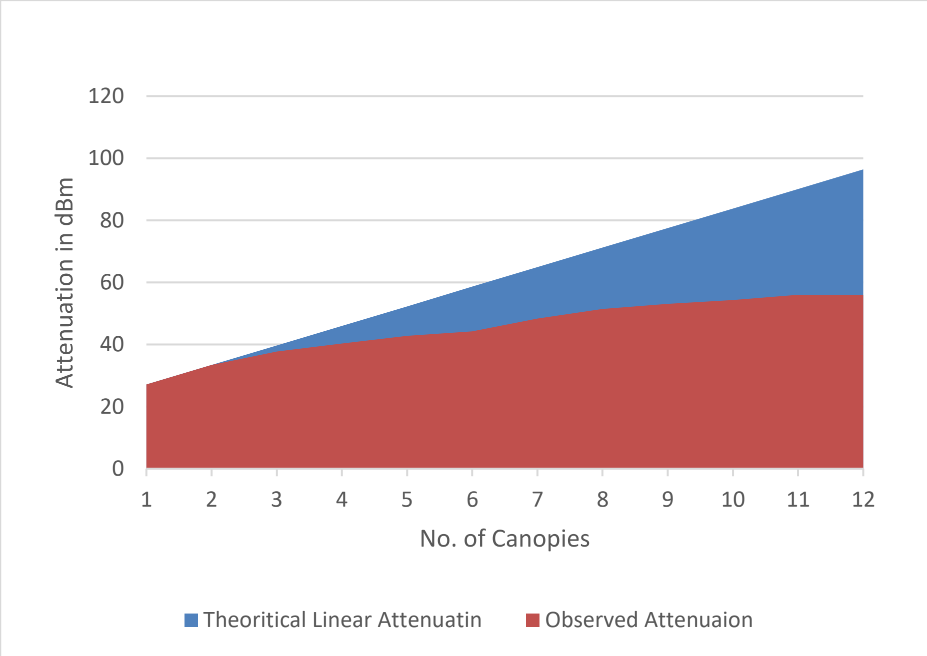

Figure 5. 3 : Calculated Attenuation Vs Observed Attenuation (Spring)

WINTER SEASON

Table 5.7 : Environmental Conditions (Winter)

ANTENNA/GEOGRAPHICAL DESCRIPTION	
Temperature	12 ^{o}C
Humidity	25%
Antenna Height	3.76 meters
Wind Speed	17 Kmph
Bias Voltage	2.54 volt
Bias Current	0.54 A
Atm. Pressure	1021 mbar
Transmitted Power	-35dBm
Distance between Transmitter and Receiver- adjustable	

Table 5.8 : Attenuation with No. of Tree canopies (Winter Season)

Canopy No. (x)	Distance b/w transmitter and receiver (in meters)	Received Power with Foliage (in dBm)	Attenuation due to Foliage (in dB)
1	4.8	-51.1	16.1
2	9.6	-56.3	21.3
3	15.7	-61.7	26.7
4	21.8	-66.1	31.1
5	26.6	-69.6	34.6
6	32.7	-71.2	36.2
7	38.8	-71.9	36.9
8	45.5	-73.1	38.1
9	53.1	-74.0	39.0
10	57.9	-76.1	41.1
11	62.8	-77.3	42.3
12	67.7	-78.1	43.0

Linear Equation-

$$y = 5.2x + 10 \cdot 9 \qquad \text{………………..5.4}$$

Table 5.9 : Calculated Attenuation Vs Observed Attenuation (Winter)

Canopy No. (x)	Observed Attenuation (in dBm)	Calculated Linear Attenuation (in dBm)
1	16.1	16.1
2	21.3	21.3
3	26.7	26.5
4	31.1	31.7
5	34.6	36.9
6	36.2	42.1
7	36.9	47.3
8	38.1	52.5
9	39.0	57.7
10	41.1	62.9
11	42.3	68.1
12	43.0	73.3

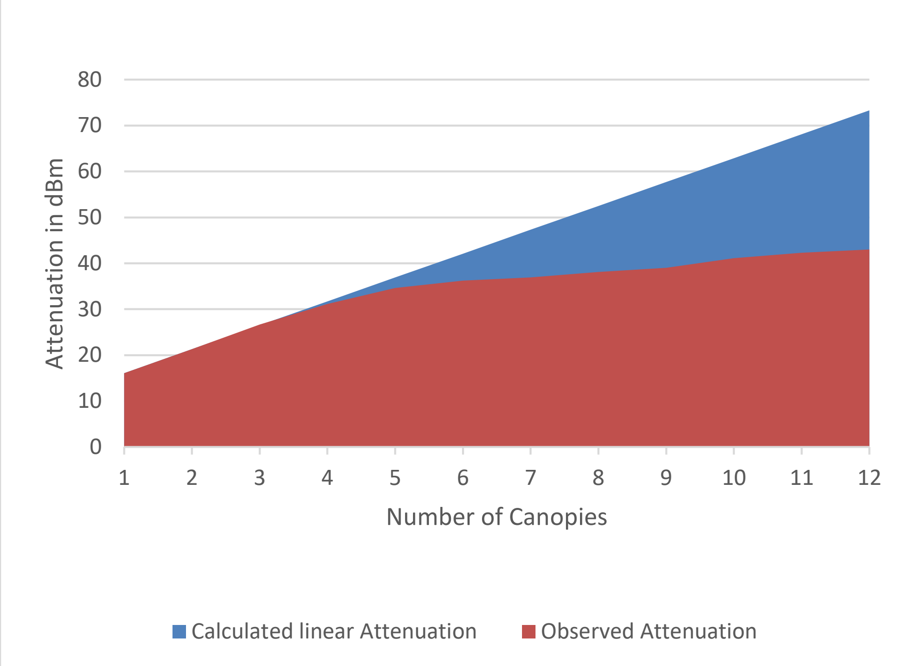

Figure 5.4 : Calculated Attenuation Vs Observed Attenuation (Winter)

Coherent scattering : Area under the Attenuation curve is By equation 4.2, area under observed attenuation curve of winter season is calculated as
Area under the attenuation curve = 370.9 Sq. unit
Area under curve made by discrete values of straight-line equation 4.4 is calculated as- Area under straight curve = 485.46 sq. unit

Coherently saved power area- (485.46- 370.9)/ 485.46 × 100 = 23.59 %

SUMMER SEASON

Table 5.10 : Environmental Conditions (Summer)

ANTENNA/GEOGRAPHICAL DESCRIPTION	
Temperature	42 °C
Humidity	20%
Antenna Height	3.76 m
Wind Speed	3 Kmph
Bias Voltage	2.54 volt
Atm. Pressure	1013 mbar
Transmitted Power	-35 dBm
Distance between Tx and Rx - adjustable	

Table 5.11 : Attenuation with No. of Tree canopies (Summer Season)

Canopy No. (*x*)	**Distance b/w transmitter and receiver (in meters)**	**Received Power with Foliage (in dBm)**	**Attenuation due to Foliage (in dBm)**
1	4.8	-52.1	17.1
2	9.6	-57.3	22.3
3	15.7	-62.6	27.6
4	21.8	-67.3	32.3

5	26.6	-70.5	35.5
6	32.7	-73.4	38.2
7	38.8	-77.3	42.3
8	45.5	-78.9	43.9
9	53.1	-79.3	44.3
10	57.9	-80.1	45.1
11	62.8	-81.4	46.4
12	67.7	-82.2	47.2

Linear Equation

$$y = 5.2x + 11 \cdot 9 \qquad \text{.... .... 5.5}$$

Table 5.12 : Calculated Attenuation Vs Observed Attenuation (Summer)

Canopy No. (*x*)	**Observed Attenuation (in dBm)**	**Calculated Linear Attenuation (in dBm)**
1	17.1	17.1
2	22.3	22.3
3	27.6	27.5
4	32.3	32.7
5	35.5	37.9
6	38.2	43.1
7	42.3	48.3
8	43.9	53.5
9	44.3	58.7
10	45.1	63.9
11	46.4	69.1
12	47.2	74.3

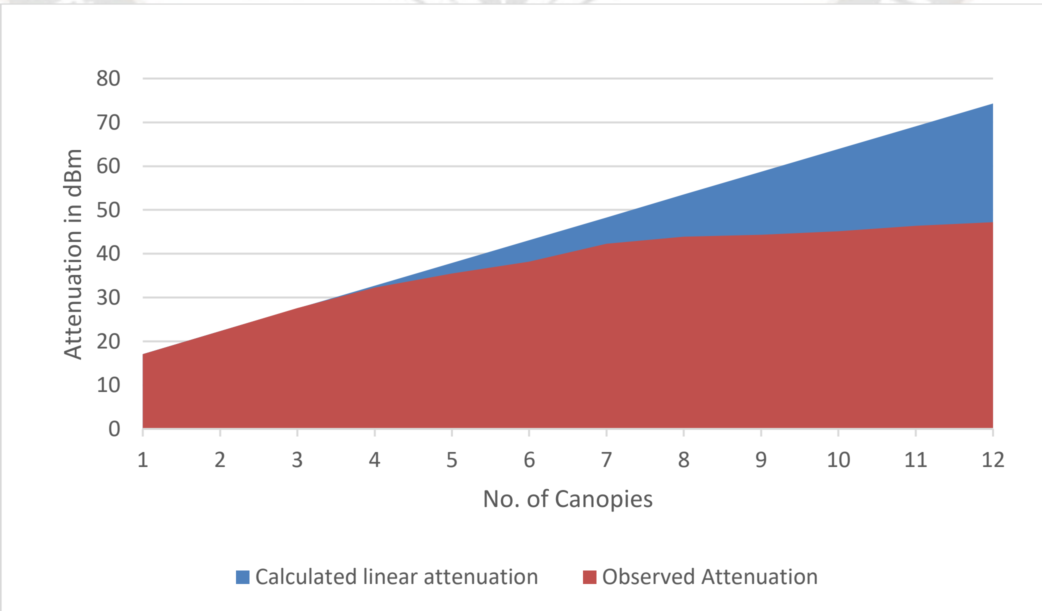

Figure 5.5 : Calculated Attenuation Vs Observed Attenuation (Summer)

Computation of Coherent scattering area : By equation 4.2, area under observed attenuation curve of summer season is calculated as Values are discrete attenuation data of straight line and observed attenuation curve.

Area under the attenuation curve = 403.7 Sq. unit

Area under curve made by discrete values of straight-line equation 4.5 is calculated as-Area under straight curve = 496.133 sq. unit

Coherently saved area- (496.133-403.7)/ 496.133 ×100 = 18.63 %

Table 5. 13 : Comparison of Attenuation in foliage depth in various season

No. of Canopies	Distance (in meters)	Attenuation in dBm			
		Autumn Season	Spring Season	Winter Season	Summer Season
1	4.8	15.1	27.1	16.1	17.1
2	9.6	21.2	33.4	21.3	22.3
3	15.7	26.4	37.7	26.7	27.6
4	21.8	28.5	40.3	31.1	32.3
5	26.6	34.3	42.8	34.6	35.5
6	32.7	34.3	44.2	36.2	38.2
7	38.8	34.4	48.3	36.9	42.3
8	45.5	35.5	51.4	38.1	43.9
9	53.1	36.1	53.1	39.0	44.3
10	57.9	35.5	54.3	41.1	45.1
11	62.8	34.9	56	42.3	46.4
12	67.7	39.7	57	43.0	47.2
Percentage of power saved due to coherent scattering		35.6 %	25.88 %	23.59 %	18.63 %

Least attenuation of signal seems in autumn season as attenuation offered by leaves is least due to fall. Very little attenuation difference is observed in summer and winter seasons. Coherent scattering re-combines the scattered components which are in-phase. 35.16% of signal in autumn seasons is said to be coherently scattered while least coherency of 18.63 % is observed in summers. In winter and spring coherency of signal is observed as 25.88% and 23.33% respectively.

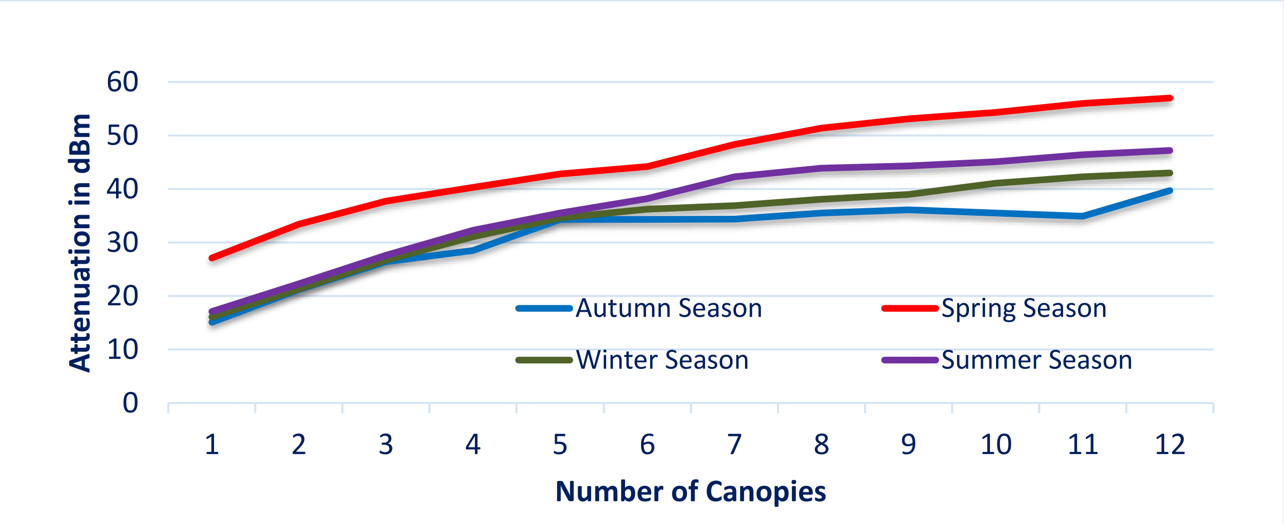

Figure 5.6 : Comparison of Attenuation in foliage depth with changing Seasons

Above figure compares attenuation at foliage depth with changing seasons. Spring season affects GHz signal most due to increased density of leaves. Water content of leaves as well as of the environment, leads signals to scatter and absorbed by water molecules which degrades signal strength.

Conclusions

Effect of weather on losses of millimeter wave in foliage depth- Experimentation were done on line of Neem trees with almost of equal age and are planted on equal distances in campus of Engineering College Bikaner. Four seasons were covered for the experimentation. It was observed that during autumn season least attenuation was there due to very less density of leaves on trees while maximum attenuation of millimeter wave was observed in spring season. Decrement in the rate of attenuation of millimeter wave with foliage depth was observed in all weather conditions. Rate of attenuation decreases in foliage depth due to coherent scattering. By computing difference between actual and theoretical attenuation, it is concluded that 35.6% in autumn, 23.33% in spring, 23.59% in winter and 18.63 % in summer of signal is coherently scattered. It signifies that stated percent of signal reconstructs due to scattering of in-phase components.

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