A Study on RF Propagation Effects and Multipath Effects

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***Abstract*—**

In this paper, multi-path effects, a phenomenon in wireless propagation that causes signals to travel along two or more paths before reaching the receiving antenna are discussed in detail. Multi-path effects also result in Path loss, Macroscopic Fading, and Microscopic Fading in wireless signals. We have also discussed RF propagation effects in Matlab, including free space path loss, atmospheric attenuation from rain, fog, and gas, and multipath propagation from ground bounces. This paper also describes the narrowband two-ray propagation channel, the most fundamental type of multipath channel.

***Index Terms*—Multipath , Fading , Propogation , Macroscopic fading , Microscopic fading**

I. Introduction

Radio signals can experience multipath propagation when they take two or more different paths to the receiving antenna. Multipath can be caused by refraction, reflection from water bodies, ionospheric reflection, atmospheric ducting, and terrestrial structures like mountains and buildings. The same signal may experience interference and phase shifting if it is received via many paths. Fading results from destructive interference, which can make a radio signal too weak to be received correctly in some locations. This phenomenon is sometimes referred to as multipath interference or multipath distortion for this reason [1].

Each signal path will typically have a different overall length. As a result, each path's time delay will also differ, resulting in a variation in the phase of each signal that is received. The strength of the received signal increases if the signals arrive approximately in phase. Signals that arrive out of phase are attenuated. When multiple signals from the transmitting antenna reach the receiving antenna through a direct line of sight or by reflecting off of things like walls, furniture, or trees, this phenomenon is known as multipath [2]. These signals collide with the receiving antenna and can result in destructive interference, which can weaken or completely obstruct the signal. The effect of multipath can be reduced by spatial diversity.

In order to achieve spatial variety, a wireless device typically has two or more antennas connected to separate radios [3]. Due to multipath, antennas in the actual world would be taking up numerous signals, and there is a possibility that one of them may be in a "dead" zone. Antennas will have the choice to select the best signal. Due to this reason, WiFi routers have two, three, or even six antennas. The router only uses the antenna with the strongest signal out of all the signals it receives from the various antennas.

II. Related Works

The elements involved and how they affect the emitted signal were explained in a paper by I.E. Portuguese. The propagation effects that must be taken into account when creating algorithms for partial discharge categorization based on time/frequency and apparent charge levels are then described, based on preliminary site experiments [4].

In his analysis of the physical factors that affect propagation loss, Mark Dapper also creates a mathematical model to forecast this loss. These hypotheses are tested against actual propagation measurements for distances up to 500 meters, both in open fields and in dense vegetation [5].

The main problems pertaining to the transmission of an electromagnetic wave via the Earth's atmosphere were thoroughly investigated by Robert Roussel-Dupre [6]. T. Rama Rao presented about short-range, close-to-the-ground radio links that primarily target plant environments and wireless sensor networks [7].

III. Fading in Wireless Propagation

While a signal is being transmitted, it changes as it makes its way to the receiver along the propagation path. The result of these modifications is frequently referred to as fading. The three main causes of signal power loss are microscopic fading, macroscopic fading, and mean path loss.

A. Path loss

A radio wave's path loss is the decrease in power attenuation that occurs as it travels through space. It depends on the range and is impacted by a variety of physical conditions, including reflection, refraction, absorption, and diffraction. The loss model of the inverse square law is most commonly used in perfect free space propagation, and the received signal power is given by

$$P_r = P_t \left(\frac{\lambda_c}{4\pi d}\right)^2 G_t G_r$$

where $lambda$ represents the wavelength, Pt, Pr represents the transmitted and received power, and Gr, Gt represents the power gains of the received and transmitted antennas, respectively. d represents the distance between the antennas. It is commonly referred to as the Fris equation.

B. Macroscopic fading

This fading, sometimes referred to as long-term fading or shadowing, is a result of obstructions such as buildings and natural features. A long-term fluctuation with a statistical performance of a log-normal distribution will be experienced by signals through the macroscopic fading [8]. Consequently, the received power's probability density function (PDF) is given by

$$f(x) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$$

where μ and α are the mean and standard deviations of the variable x, which represents the long-term signal power at the dB level.

C. Microscopic fading

Short-term fading, which comes from the mixture of constructive and destructive effects of a signal transmitted across a multipath environment, is referred to as microscopic fading. The scatterers in between the link ends are the reason behind it. The impact of microscopic fading on wireless signals will result in a Rayleigh density function, presuming that wireless signals are transmitted and reflected by a large number of independent scatterers [8].

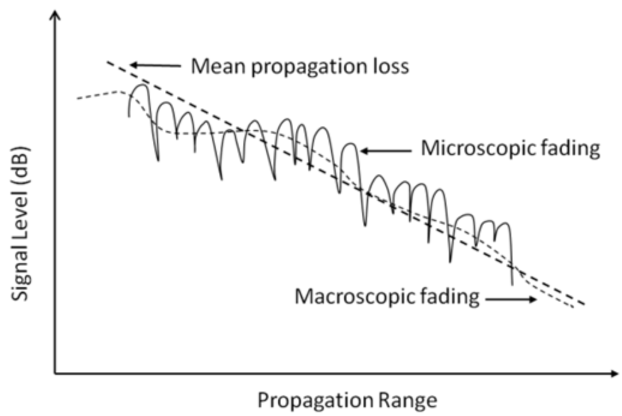

Fig. 1. Comparison of Fading effects as propogation range increases

IV. Modeling RF propagation effects

A. Free Space Path Loss

Free space path loss is calculated as a function of frequency and propagation distance. RF signals move in all directions at the speed of light in open space. When the source is suitably far, it appears as a point in space, and the wavefront shapes a sphere of radius R. The power density at the wavefront is inversely proportional to R^2. Free space path loss, also known as spreading loss, is the term used to describe the loss associated with this kind of propagation. Free space path loss quantitatively depends on the frequency and is given by

$$L_{fs} = 20 * \log_{10}(\frac{4\pi R}{\lambda}) \quad dB$$

Propagation losses are commonly represented in dB as a convention. By simply doubling the one-way free space loss, this convention makes it considerably simpler to calculate the two-way free space path loss [9]. We compute the free-space path loss using the fspl function in Matlab.

B. Propagation Loss Due to Precipitation and Atmosphere

Since signals don't always travel in a vacuum, in reality, only a portion of the signal attenuation is described by free space path loss. Signals interact with atmospheric pollutants and lose energy as they travel. Temperature, water density, and Pressure are some variables that affect loss.

Loss Due to Rain and snow

For radar systems, rain can be a significant limiting factor, especially when operating above 5 GHz. Rain is defined by the rain rate (in mm/h) in the ITU model. From less than 0.25 mm/h for very light rain to more than 50 mm/h for heavy storms, the rate of precipitation can vary. The propagation loss due to rain is also a function of signal polarization because of the shape of the raindrop and its size in relation to the RF signal wavelength [10]. The worst situation for propagation loss due to rain is typically horizontal polarisation.

To calculate rain-related losses using the ITU and Crane models, we use the Matlab programs rainpl and cranerainpl respectively. Between 1 GHz and 1 THz, both models are effective. Let the signal propagate parallel to the ground with a horizontal polarisation, resulting in a tilt angle of zero, and an elevation angle of zero.

Snowfall can significantly affect RF signal propagation, much like rainfall does. Even though this method tends to somewhat overestimate the loss, it is a frequent practice to treat snow as rain and compute the propagation loss using the rain model. It is believed that frequency has a much greater influence on attenuation owing to transmission over snow than polarisation [11]. Instead of using volume as a parameter, the model for snow-related losses uses the comparable liquid content. Snow needs around ten times the amount of rain for given water content. To calculate snow-related losses in Matlab, we use the snowpl function, and we plot the losses against frequency. The Gunn-East attenuation model, which is typically valid up to roughly 20 GHz, is what the function employs by default.

C. Loss Due to Atmospheric Absorption

The environment is filled with gases that nevertheless interfere with signal propagation even when there isn't any fog or rain. According to the ITU model, atmospheric gas attenuation depends on both the density of water vapour ($g/m3$) and dry air pressure (hPa), which are both used to measure atmospheric gas attenuation.

To calculate losses from air absorption in Matlab, we use the tropopl function. By default, this function calculates typical values of pressure, temperature, and water vapour density for a specified height using the Mean Annual Global Reference Atmosphere (MAGRA) model. To employ a model designed for a particular range of latitudes, we can also provide a latitude model.

D. lensing

The angular extent of transmission is enhanced with the range due to a refractive gradient in this phenomenon. Altitude affects atmospheric pressure and, thus, refractivity. Therefore, losses resulting from this effect can be determined for a given height using the propagation path's elevation angle. We compute these losses in Matlab using the lenspl function.

E. Multipath Fading

Signals may not always travel in a straight line of sight; instead, they may take different routes to their destination and may combine in a constructively or destructively way. The received signal power may experience large fluctuations as a result of this multipath effect. A common occurrence for many radar or wireless communication systems is ground reflection. For instance, when a radar on land or at sea illuminates a target, the signal not only travels in a straight line but is also reflected by the surface.

A system's channel capacity can be increased by increasing its bandwidth. Higher data speeds in communication systems and improved range resolutions for radar systems are made possible as a result [12].

V. RF Propagation and Visualization

The behavior of signals as they move across the environment is described by RF propagation models. Using Site Viewer, an interactive 3-D viewer, we can show RF propagation visualizations, receiver sites, and transmitter sites. we can see propagation models both inside and outside using Site Viewer.

A. Visualize Outdoor Wireless Coverage

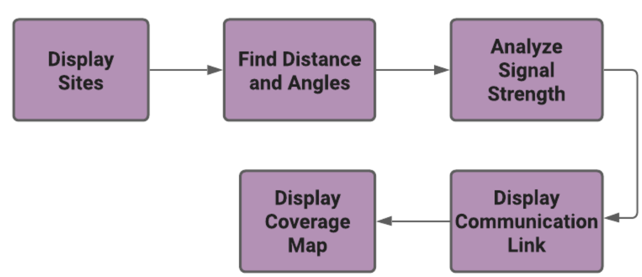

Fig. 2. Flowchart on process to Visualize Outdoor Wireless Coverage

We can provide a transmitter position and a receiving site and specify the location using the degrees of the geographic coordinates to view the places. By default, the distance function calculates the distance in a straight line between the sites. The Earth is not taken into account in the Euclidean path, which is a straight line. We can also determine the azimuth and elevation angles between the locations. The angle function returns the azimuth angle for a point in degrees, measured counterclockwise from the east, and also returns the elevation angle in degrees from the horizontal plane. We calculate the signal strength at the desk receiver point. Signal strength is calculated via the sigstrength function by default in power units (dBm).

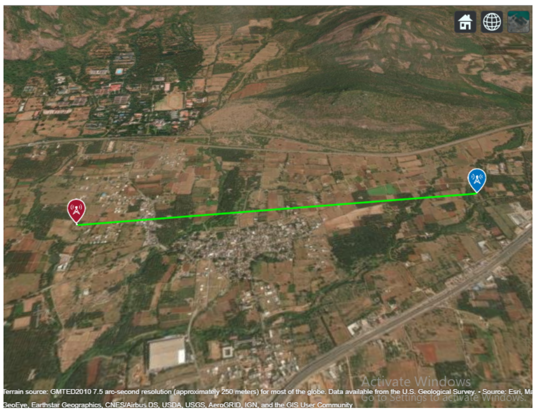

Fig. 3. Communication link between transmitter and receiver

From Fig. 3, we can see the status of the site's communication links. The strength of the link depends on the power that the transmitter sends to the receiver. A green line often shows that the received power is more than or equal to the receiver sensitivity. The failure of communication is shown by a red line.

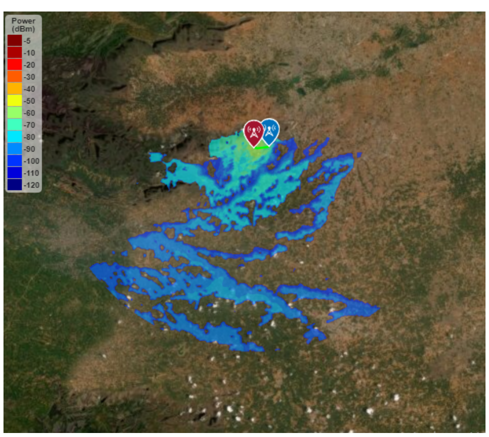

Fig. 4. coverage map for the transmitter

Fig. 4 depicts the coverage map for the transmitter. A coverage map shows the transmitter's service area, which is the region where the sensitivity of a reference receiver is met by the received signal strength of the transmitter. The signal intensity can be displayed on coverage maps as either a power quantity (often expressed in dBm) or a voltage quantity (typically expressed in dB$/mu$V/m).

B. Visualize Indoor Propagation Paths

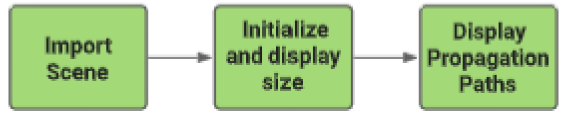

Fig. 5. Flowchart on process to Visualize Indoor Wireless Coverage

We demonstrate propagation inside a room or other enclosed location using this model. The 3-D scene model of a meeting room is imported. In addition to displaying the sites, we find propagation routes between them. In the file's depiction of an indoor workplace, a conference room and an open area are separated by a piece of a wall. STL files primarily save geometry-related data; they don't store information about colours, surfaces, or textures. We place one transmitter near the ceiling in the conference room. Place one receiver on a desk in the open area, and another receiver on a shelf or in any other way, and indicate the position using Cartesian coordinates in meters.

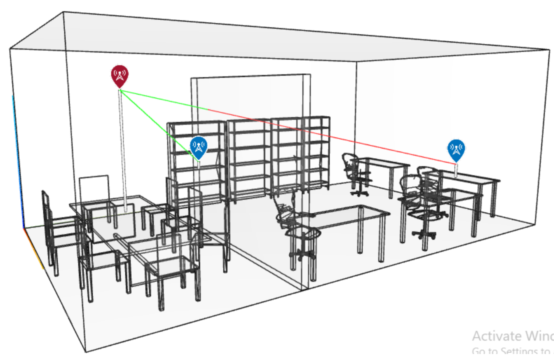

Fig. 6. Receivers and the lines-of-sight paths

Fig. 6 depicts the Direct line of sight paths from the transmitter to the receiver. The green line indicates the direct line of sight and the red line indicates the direct line of sight path is not possible. The shelf receiver can be reached but the desk receiver's path is obstructed. To visualize propagation paths, we use the shooting and bouncing rays (SBR) ray tracing propagation model. Line-of-sight propagation paths can be displayed by setting the MaxNumReflections value to 0.

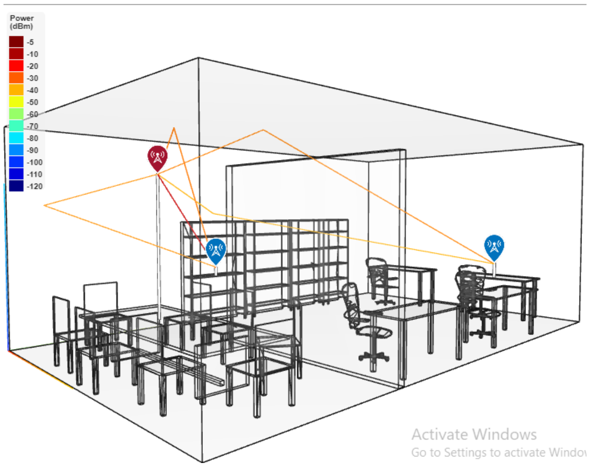

Fig. 7. Propagation paths with up to one reflection

Fig. 7 depicts the Propagation paths with up to one reflection. In contrast to the los function, the raytrace function does not provide blocked paths; nevertheless, by setting the MaxNumReflections attribute to 1, we can obtain propagation paths with up to one reflection; etc.

VI. Two-ray propagation channel

A two-ray narrowband propagation channel is modeled by the twoRayChannel. The most basic type of multipath channel is a two-ray propagation channel [13]. Signal transmission in a homogeneous, isotropic medium with a single reflecting barrier can be simulated using a two-ray channel. Line-of-sight (direct) propagation between two points and a ray path that is reflected off the border are the two propagation paths available in this kind of medium. The signals are subjected to range-dependent time delays, gains or losses, phase shifts, and boundary reflection loss by the twoRayChannel System object.

A. Scalar Field Propagating in Two-Ray Channel

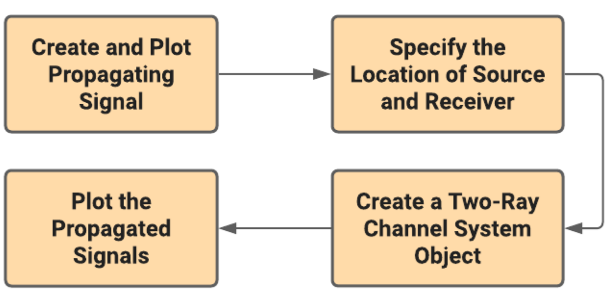

Fig. 8. Flowchart on process of Scalar Field Propagating in Two-Ray Channel

step 1: Create and Plot Propagating Signal

Using two rectangular waveform pulses with a carrier frequency of 100 MHz, create an electromagnetic field that is not polarised. With a 1 MHz sampling rate and a 10 ms pulse width, let's start. A 0.1 MHz bandwidth characterises the pulse. In order for the pulse width to be equal to the pulse repetition interval, use a 50 percent duty cycle. Make a two-pulse wave train. To simulate a reflective surface with strong ground, set the GroundReflectionCoefficient to 0.9. The field is propagated from a stationary source to a stationary receiver. Between the source and receiver, there are roughly 10 kilometres in the vertical direction.

step 2: Indicate the Source and Receiver's Locations

Predict the signal delays by positioning the source and receiver roughly 1000 metres apart horizontally and 10 km apart vertically.

step 3: Create a Two-Ray Channel System Object

Make a two-ray propagation channel System object, and then send the signal along the reflected as well as the line-of-sight ray pathways.

step 4: Plot the Propagated Signals

Plot the signal's line-of-sight propagation. The signal propagation map along the reflected path should then be superimposed. The coherent total of the two signals should then be plotted on top.

B. Polarized Field Propagation in Two-Ray Channel

Make a linear FM waveform electromagnetic field with polarisation. Use a crossed-dipole antenna element to transmit the field from a stationary source to a stationary receiver about 10 kilometres away. There are 100 metres between the ground and the transmitting antenna. A crossed-dipole serves as the receiving antenna as well. Plot the signal that was received.

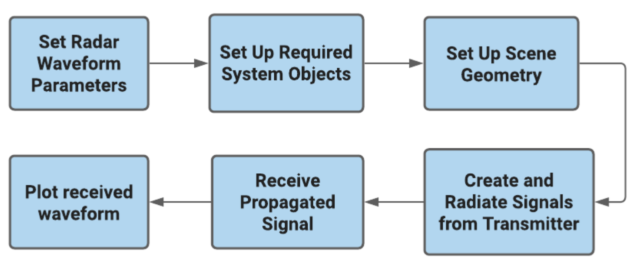

Fig. 9. Flowchart on process of Polarized Field Propagation in Two-Ray Channel

Step 1: Set Radar Waveform Parameters

Assume that the sampling frequency is 10 MHz and the pulse width is 10 mu s. The pulse has a 1 MHz bandwidth.

Create a wave train using two pulses.

Step 2: Configure Necessary System Objects

Initialize the waveform, antenna, radiator, channel, and collector with a GroundRelativePermittivity of 10.

step 3: Establish the scene geometry

Indicate the locations, speeds, and orientations of the transmitter and receiver. Horizontally, space the source and receiver apart by roughly 1000 m.

Step 4: Create and emit signals from the transmitter

Calculate the angles of transmission for the two rays that are headed in the receiver's direction. According to the transmitter local coordinate system, these angles are determined. the phasing These angles are used by the Radiator System object to apply different antenna strengths to the two signals.

Step 5: receive the propagated signal

Calculate the two rays' respective reception angles as they approach the receiver. According to the receiver local coordinate system, these angles are specified. the phasing These angles are used by the Collector System object to apply different antenna strengths to the two signals.

VII. Fading Channels

One or more significant reflected paths make up the Rayleigh fading channel [14]. One straight line-of-sight path, maybe paired with one or more significant reflected channels, makes up a rician fading channel.

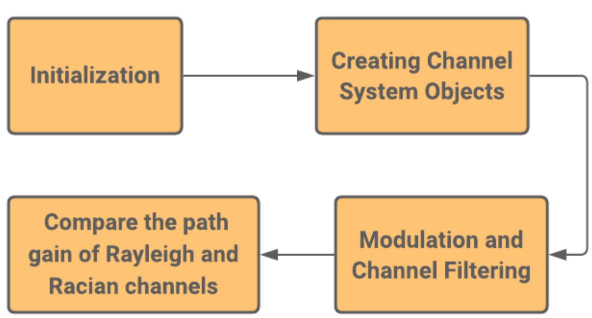

Fig. 10. Flow chart to create fading channels

The following actions are involved in signal processing utilising a fading channel:

Step 1: Create a channel System object to represent the channel you intend to use. An example of a channel object is a MATLAB variable that holds details about the channel, like the greatest Doppler shift.

step 2: Modify the System object's properties. You can alter the average path gains or the path delays, for instance.

Step 3: Apply the channel System object to your signal using the step method. This filters the input signal and provides random discrete path gains.

VIII. Results

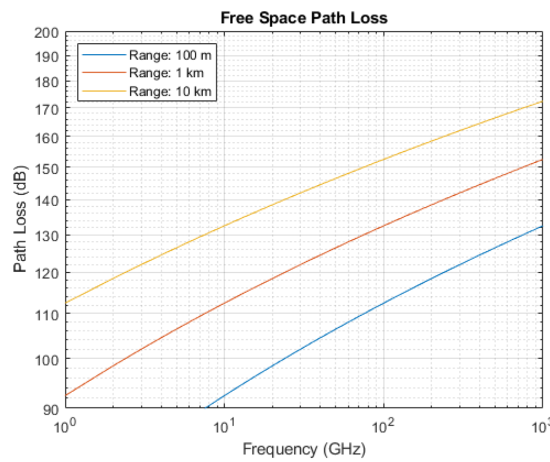

Fig. 11. Free Space Path Loss

Fig. 11 depicts how the propagation loss rises with frequency and range.

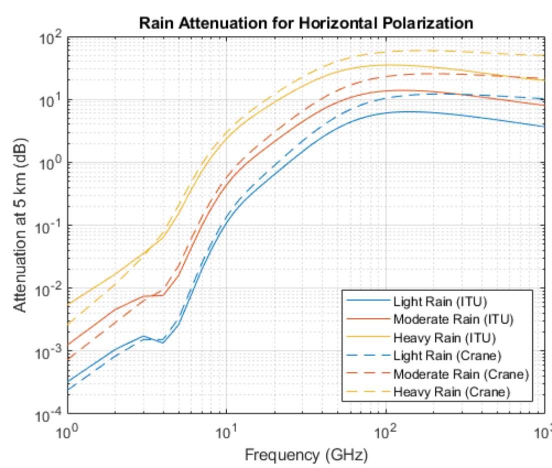

Fig. 12. Rain Attenuation for Horizontal Polarization

Fig. 12 depicts the losses calculated using the Crane model are typically higher than the losses calculated using the ITU model.

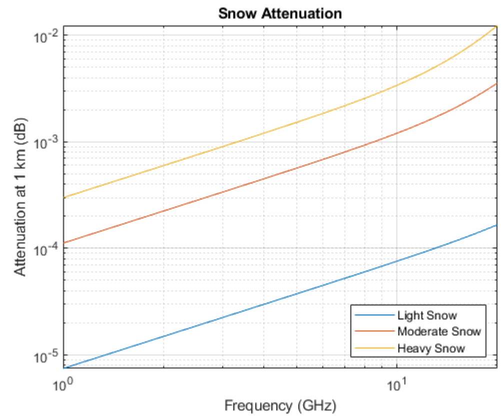

Fig. 13. Snow Attenuation

Fig. 13 depicts At 1 KM, high snow has more attenuation than light snow, which has less effect.

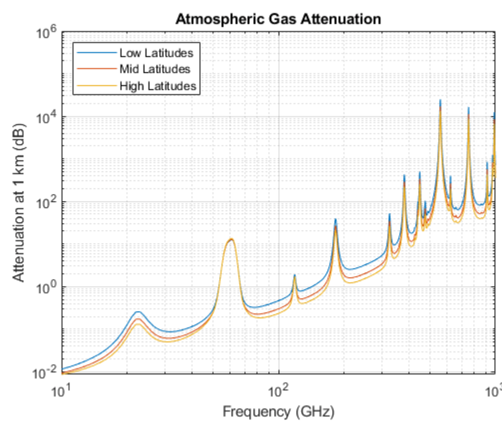

Fig. 14. Atmospheric Gas Attenuation

Fig. 14 depicts that there is a significant absorption at about 60 GHz caused by atmospheric gases. Attenuation rises as frequency rises.

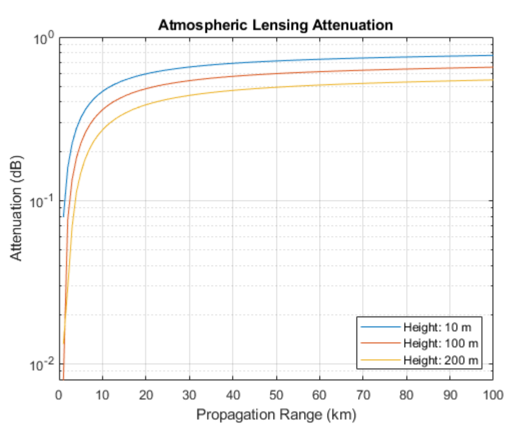

Fig. 15. Atmospheric Lensing Attenuation

Fig. 15 depicts as altitude rises, lensing-related attenuation diminishes.

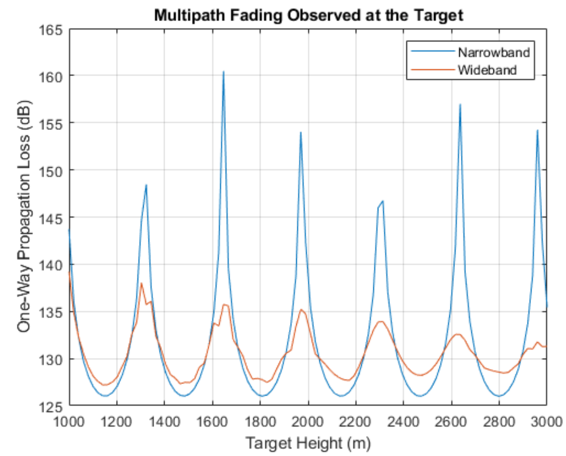

Fig. 16. Multipath Fading Channel

The target performs significantly better on the wideband channel over a wide range of heights. In reality, the effect of multipath fading almost entirely vanishes as the height of the target rises. This is due to a decrease in the coherence between the direct and bounce path signals when they are received at the target as a result of the growing propagation delay difference between them.

Scalar Field Propagating in Two-Ray Channel

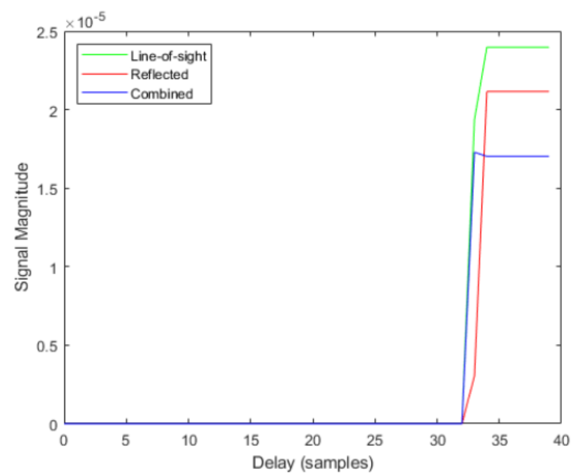

Fig. 17. Scalar Field Propagating

Fig. 17 demonstrates that the signal delay on the reflected path matches the expected delay. Coherently combining two signals results in a signal with a smaller magnitude than either of the transmitted signals, indicating some interference between the two signals.

Polarized Field Propagation in Two-Ray Channel

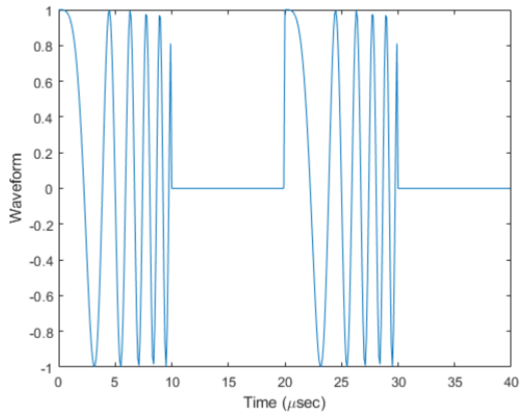

Fig. 18. Transmitted Waveform

Fig. 18 depicts the Transmitted Waveform

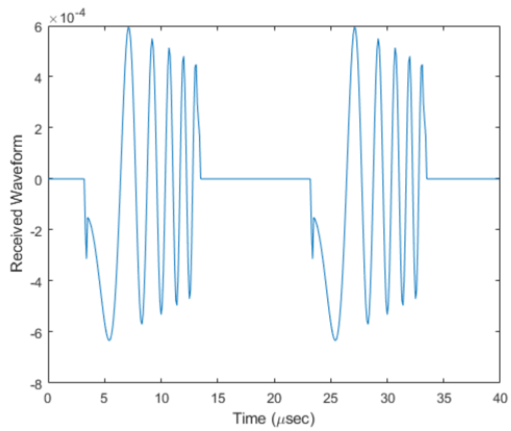

Fig. 19. Received Waveform

Fig. 19 depicts the Received Waveform. Due to multipath effects, we can see that there is a significant change in both the sent waveform and the received waveform.

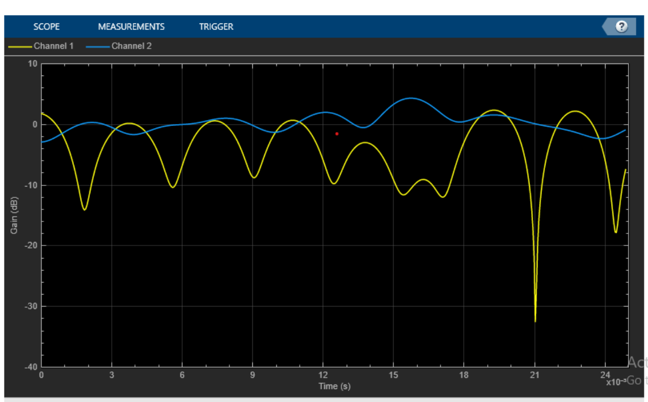

Fig. 20. Rayleigh and Rician Fading Channel

The Rician fading channel System object simulates diffuse multipath scattering as well as line-of-sight propagation. The size of path gains vary less as a result of this. We utilise a timescope object to view the path gains of the Rayleigh and Rician channels over time in order to compare the differences between them. The Rician fading channel's magnitude changes across a range of about 10 dB (blue curve), whereas the Rayleigh fading channel's range is 30–40 dB. (yellow curve).

IX. Conclusion

Multipath can lead to mistakes and degrade the quality of communications in digital radio communications (like GSM). The defects are caused by interference between symbols (ISI). By adding a ground map of the radar's surroundings and removing all echoes that appear to come from below the ground or over a particular height, these issues can be reduced.

Techniques to improve received signal quality and link performance a) Equalization b) Diversity c) Channel coding

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