WIRELESS COMMUNICATION II
LAB 1 REPORT: MODELLING THE PROPAGATION OF RF SIGNALS

BY

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Abstract
This laboratory session on "Modeling the Propagation of RF Signals" explores the dynamics of Radio Frequency (RF) signal propagation. Rooted in the principles of the International Telecommunication Union's ITU-R P series recommendations, this session aims to unravel the complexities of free space path loss, rain-induced attenuation, fog and cloud effects, and atmospheric gas-induced propagation loss.

MATLAB is employed to calculate and graphically represent the frequency-dependent variations of the free space path loss model over different propagation distances. The subsequent exploration navigates the challenges posed by rain, where ITU models and MATLAB simulations depict the relationship between rain rate and signal polarization.
MATLAB-generated graphs also highlight the frequency-dependent fog attenuation under diverse conditions of liquid water density, offering a visual display of their impact on RF signal propagation. The study ends with an analysis of the effects of atmospheric gases on RF signal propagation.

Throughout this laboratory session, we gained hands-on experience in utilizing MATLAB as a tool for RF signal propagation modelling. The theoretical knowledge, combined with practical simulations provided a holistic and insightful exploration of the challenges posed by diverse environmental conditions on radar and wireless communication systems.

Introduction

Understanding the propagation environment is crucial for evaluating the performance of radar and wireless communication systems. This laboratory session delves into the modelling of various Radio Frequency (RF) propagation effects, incorporating essential aspects such as free space path loss, atmospheric attenuation induced by rain, fog, and gases, as well as multipath propagation caused by ground reflections. The foundation of this exploration rests upon the guidelines established by the International Telecommunication Union's ITU-R P series recommendations, which specifically focus on radio wave propagation.

To illustrate the complexity of RF signal propagation, particularly in the context of radars, we began by examining the received signal power through the radar range equation. This equation includes the transmitted power, antenna gain, target radar cross-section, wavelength, and propagation distance [1]. Notably, all propagation losses, excluding free space path loss, contribute to a consolidated term within this equation, paving the way for a detailed exploration of diverse scenarios.

The subsequent sections of this report investigate distinct propagation phenomena, starting with Free Space Path Loss (FSPL). FSPL is computed as a function of propagation distance and frequency, recognizing the constant speed of light in free space [2]. MATLAB graphically depicts how FSPL varies over frequencies ranging from 10 to 1000 GHz for different propagation distances.

The report then addresses the impact of rain on signal propagation. Rain, characterized by rain rate in mm/h, poses a substantial challenge for radar systems, particularly those operating above 5 GHz. Our analysis, based on ITU models, incorporates factors such as rain rate and signal polarization. Following this, the focus shifts to the effects of fog and cloud on RF signal propagation. These atmospheric phenomena, characterized by liquid water density, exhibit frequency-dependent propagation loss [2].

The final section explores propagation loss induced by atmospheric gases, emphasizing the impact of dry air pressure and water vapour density on signal attenuation. Each section will include the required MATLAB-generated graphs, providing a visual representation of the discussed phenomena. This comprehensive exploration aims to enhance understanding and facilitate meaningful analysis of RF signal propagation in various environmental conditions.

Objectives

1. To gain a comprehensive understanding of the key parameters influencing the performance of radar and wireless communication systems
2. To develop MATLAB-generated graphs for each propagation phenomenon
3. To gain hands-on experience in utilizing MATLAB for RF signal propagation modelling.

Methodology

Procedure

1. Utilizing the MATLAB code below, we implemented a script to compute the free space path loss as a function of propagation distance and frequency. This involved plotting the path loss over a frequency range of 10 to 1000 GHz for different distances (100 m, 1 km, and 10 km).

```
c = physconst('lightspeed');
R0 = [100 1e3 10e3];
freq = (10:1000).'*1e9;
apathloss = fspl(R0,c./freq);
loglog(freq/1e9,apathloss);
grid on; ylim([90 200])
legend('Range: 100 m', 'Range: 1 km', 'Range: 10 km')
xlabel('Frequency (GHz)');
ylabel('Path Loss (dB)')
title('Free Space Path Loss')
```

2. Moving forward, our focus shifted to the impact of rain on signal propagation. Employing the ITU model, we characterized rain by its rain rate (in mm/h) and explored its attenuation effects on RF signals. The MATLAB script below allowed us to generate a plot illustrating how rain attenuation changes with frequency for various rain rates.

```
R0 = 1e3; % 1 km range
rainrate = [1 4 16 50]; % rain rate in mm/h
el = 0; % 0 degree elevation
tau = 0; % horizontal polarization
for m = 1:numel(rainrate)
 rainloss(:,m) = rainpl(R0,freq,rainrate(m),el,tau)';
end
loglog(freq/1e9,rainloss); grid on;
legend('Light rain','Moderate rain','Heavy rain','Extreme rain', ...
 'Location','SouthEast');
xlabel('Frequency (GHz)');
ylabel('Rain Attenuation (dB/km)')
title('Rain Attenuation for Horizontal Polarization');
```

3. Next, we used the MATLAB code below to model the propagation loss due to fog by considering liquid water density and atmospheric temperature.

```
T = 15; % 15 degree Celsius
waterdensity = [0.05 0.5]; % liquid water density in g/m3
for m = 1: numel(waterdensity)
 fogloss(:,m) = fogpl(R0,freq,T,waterdensity(m))';
end
loglog(freq/1e9,fogloss); grid on;
legend('Medium fog','Heavy fog');
xlabel('Frequency (GHz)');
ylabel('Fog Attenuation (dB/km)')
title('Fog Attenuation');
```

4. Lastly, we examined the impact of atmospheric gases on signal propagation. Following the ITU model, we considered dry air pressure and water vapour density as factors

influencing atmospheric gas attenuation. We used the MATLAB code below to generate a plot illustrating the frequency-dependent propagation loss due to atmospheric gases.

```
P = 101300; % dry air pressure in Pa
ROU = 7.5; % water vapour density in g/m3
gasloss = gaspl(R0,freq,T,P,ROU);
loglog(freq/1e9,gasloss); grid on;
xlabel('Frequency (GHz)');
ylabel('Atmospheric Gas Attenuation (dB/km)')
title('Atmospheric Gas Attenuation');
```

Results and Discussion

The first aspect of our investigation involved the computation of free space path loss, a crucial factor in understanding signal propagation. The MATLAB-generated plot (Figure 1) illustrates the variation of free space path loss over the frequency range of 10 to 1000 GHz for different propagation distances (100 m, 1 km, and 10 km). As anticipated, the path loss increases with frequency and distance, affirming the inverse relationship between signal strength and distance [2].

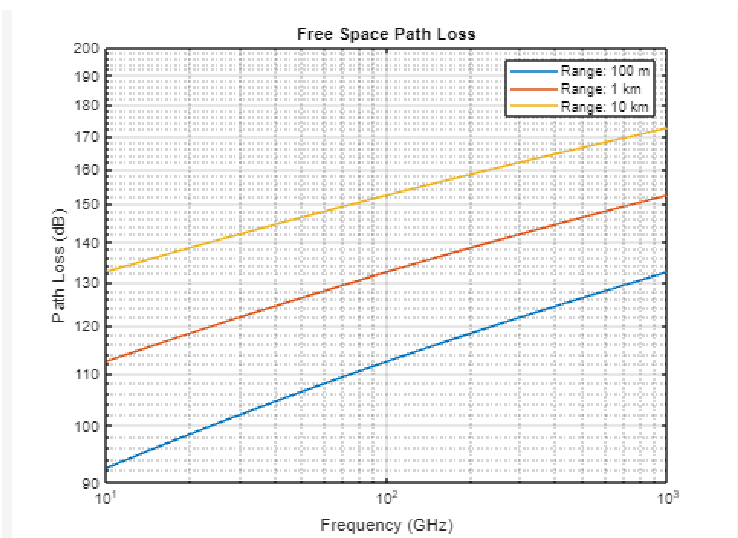

Figure 1: Free Space Path Loss

Moving on to the impact of rain on signal propagation, our MATLAB simulations produced a plot (Figure 2) depicting how rain attenuation varies with frequency for different rain rates (light rain, moderate rain, heavy rain, and extreme rain). As expected, higher rain rates correspond to increased signal attenuation. The attenuation due to rain rates also increases up to a certain frequency level (100 GHz), where it levels off and finally falls slightly [3]. This is a critical consideration for radar systems, especially those operating at frequencies above 5 GHz.

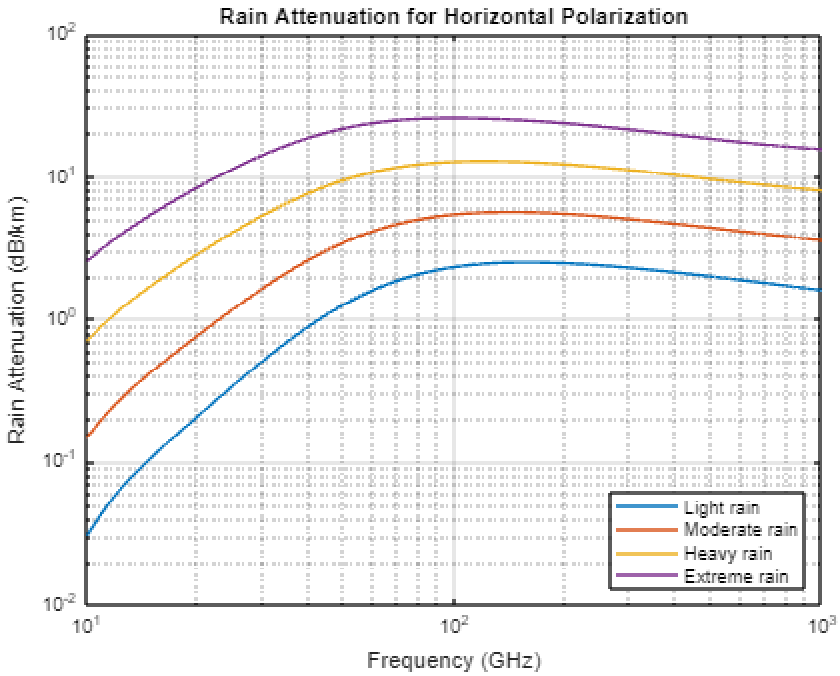

Figure 2: Rain Attenuation for Horizontal Polarization

Our investigation into the effects of fog and cloud on signal propagation yielded another set of MATLAB-generated plots (Figure 3). These plots illustrate how the propagation loss due to fog changes with frequency for medium and heavy fog conditions. Notably, the attenuation increases with frequency and the amount of fog (i.e. the attenuation is higher for the heavy fog condition than for the medium fog condition).

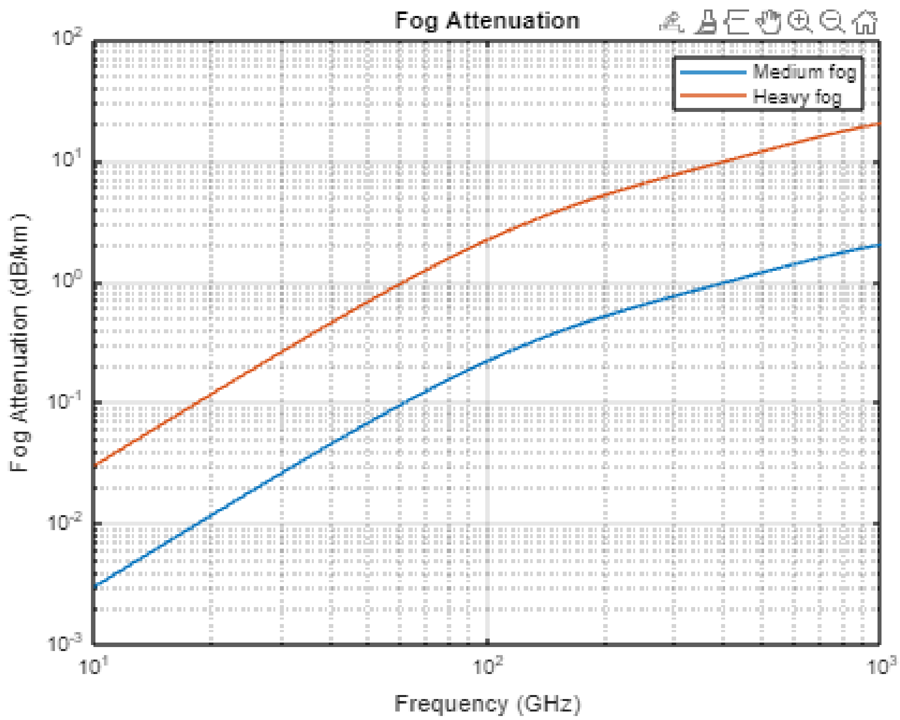

Figure 3: Fog Attenuation

The MATLAB-generated plot (Figure 4) showcases the frequency-dependent propagation loss due to atmospheric gases, considering dry air pressure and water vapour density [3]. This plot reinforces the idea that atmospheric gases, even in the absence of precipitation, contribute to signal attenuation.

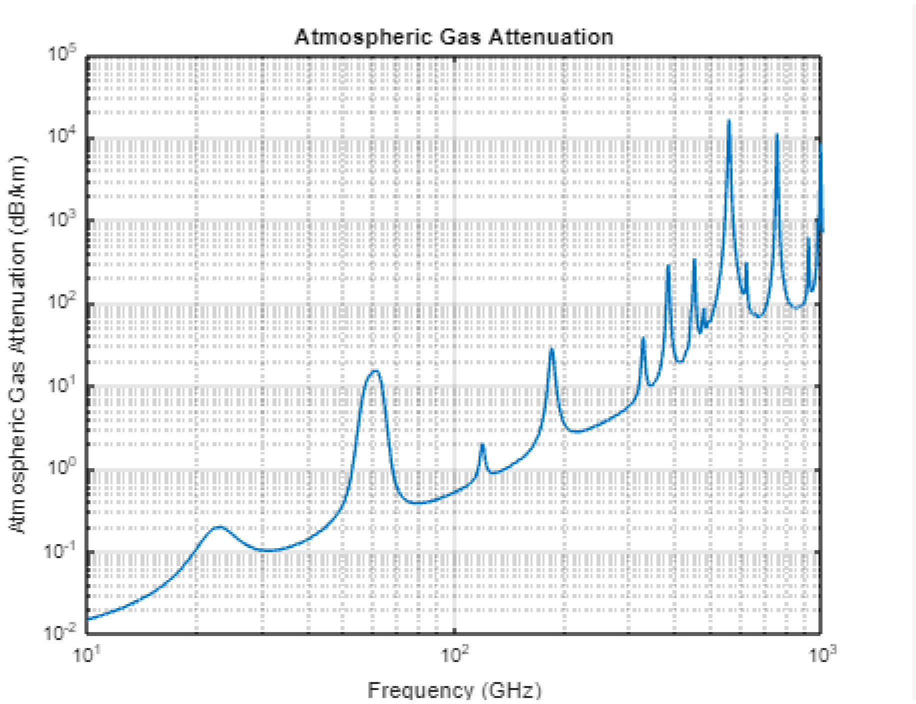

Figure 4: Atmospheric Gas Attenuation

Conclusion

In conclusion, this laboratory session provided a comprehensive exploration into the modelling of RF signal propagation using MATLAB. The simulations assisted in investigating various environmental factors and their impact on signal attenuation. The amalgamation of these results emphasizes how RF signal propagation is influenced by a myriad of environmental conditions.

References

[1] “The Radar Range equation,” *Principles of Modern Radar: Basic principles*, pp. 59–86, 2010. doi:10.1049/sbra021e_ch2

[2] C. K. Vithanawasam, Y. L. Then, and H. T. Su, “Calculation of data rates for varying scenarios using free space path loss and Okumura-hata model in the TVWS frequency band,” *2020 IEEE 8th R10 Humanitarian Technology Conference (R10-HTC)*, 2020. doi:10.1109/r10-htc49770.2020.9357022

[3] “Electromagnetics and RF propagation,” *Introduction to RF Propagation*, pp. 14–37, 2005. doi:10.1002/0471743690.ch2