Experiment 02: Delay Spread and Doppler Spread

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Abstract
In this lab you will study delay spread and doppler spread; two fundamental concepts in wireless communications.

Keywords
Spectrum — Radio Frequencies

Contents

Introduction

This experiment will involve two main concepts: Delay Spread and Doppler Spread. These are fundamental concepts in the study of wireless communications, in particular in understanding multi-path fading. At the end the experiment, you should be capable of understanding the inverse relation between Delay Spread and Coherence Bandwidth.

Doppler spread is a variation in bandwidth caused by the combined frequency shifts of the multipath components of a signal arriving at a receiver, when there is relative movement between a signal source and destination. If you are standing at the side of the road and an approaching motorist sounds the horn continuously as his car passes you, you will clearly hear the variation in frequency for the direct component. This variation is called "Doppler Effect". One of many the challenges faced by designers of mobile communications systems is the effective use of a given bandwidth by multiple users. In this experiment you will see the effect of user mobility on the bandwidth utilized.

Before starting the lab, complete the **lab preparation** and submit it to the T.A. as instructed. The course lab site is `https://www.comm.utoronto.ca/~bkf/comm/ECE464`.

1. Delay Spread

This portion of the experiment is divided into four main parts. All parts will involve simulation in `Simulink`, with models provided to you. You will simulate the effect of presenting an impulse, tones and bandlimited signals to channels with multipath fading. You will use channels with different delay spreads. Report your results in the spaces provided on the answer sheet.

1.1 Background Reading and Preparation

The relevant reading for this experiment can be found in [1].

1.2 Impulse on a Channel

From `Simulink`, open the model found in `part_a.mdl` from the course lab site. A model as the one presented below should appear. This model will help you to develop the concept of impulse response and delay spread. Differently from the channel being simulated, real channels are of infinite duration, i.e., the reflections fade with time, but do not stop suddenly. The channel presented in the model below has finite duration: there are four delay blocks, representing the direct (or line of sight) path and three reflected paths. In signal processing such structure is called a *Finite Impulse Response* filter. Recall from pg. 19 on the notes: *a transmitted signal is received as a sum of superimposed multi-path components with different excess propagation delays. The distribution of delays weighed by the signal power in the components is referred to as the delay spread.*

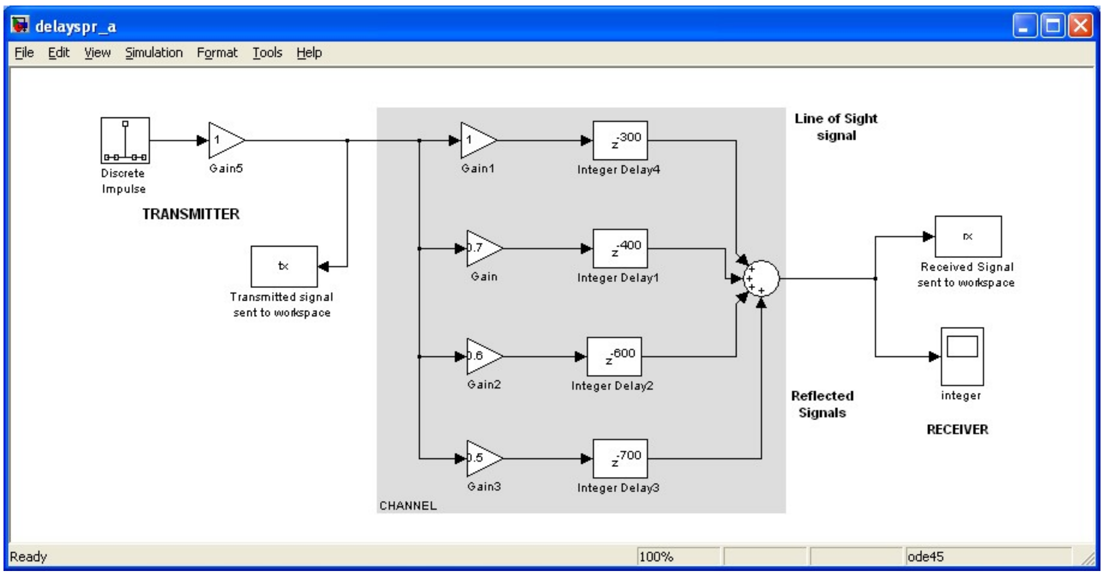

Figure 1. Impulse Response Model

In this model, a transmitter will send an impulse through the channel, and you will analyze the signal received. You will use the `Matlab` script called `viewa.m` to display your results. You may also, in some cases, use the scopes provided in the model to display results. The models are set to run for a length of time (a few seconds) after you press "run". Every time you run a simulation, wait until it is finished, and then run the script to display the results. Now run the simulation, and run the `Matlab` script given. You should see the picture below.

The numbers on the X-axis represent number of samples, since this is a discrete-time simulation. In your results, you notice that the reflected versions of your transmitted signal decay (or *fade*) in time. Move to the answer sheet and answer the questions pertaining to this section.

1.3 Tones Through a Channel

In this part of the experiment you will send first a single tone through the channel, and then two tones, in order to observe the effect on the received signal. You will see that channels which introduce multiple paths to the transmitted signal may very well cause constructive interference to occur, resulting in a received signal (in this case a tone) of greater magnitude than the one transmitted. Keep in mind that the signal paths here do **not** change over time, and that transmitter and receiver are **not** moving relatively to one another (this will be the next experiment).

Think of a number of reasons why the propagation delays introduced by the multiple signal paths change in time even when transmitter and/or receiver are not moving. Recall the notes, on pp.19-24:

- Multi-path propagation causes multi-path fading, i.e., a pattern of constructive and destructive interference.

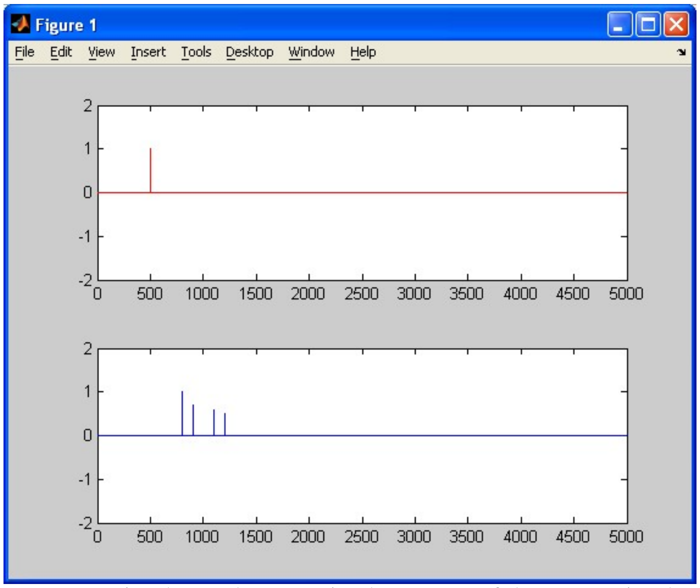

Figure 2. Transmitted Impulse, Received *Versions* of the Transmitted Impulse

- At a specific place the degree of fading depends on the frequency of the transmitted signal.

1.3.1 One Tone

The script you used to plot your results will be used again here, so leave it opened. Now close the previous model and open the model found in `part_b.mdl` from the course lab site. This model presents a sinusoidal source fed through the channel.

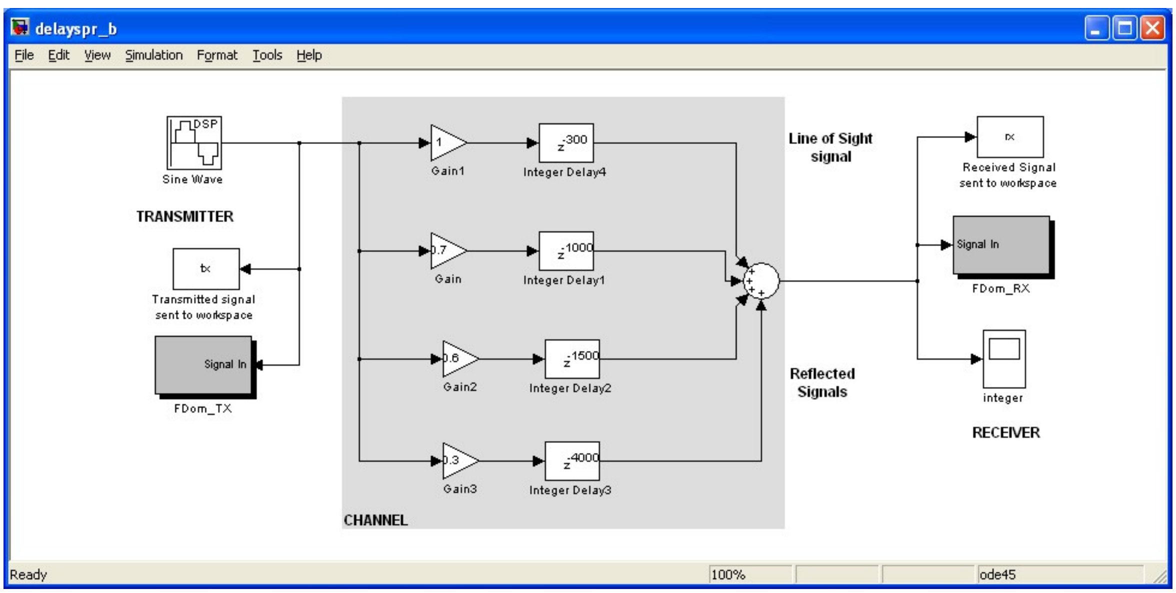

Figure 3. One Tone Signal Passing Through a Channel

Run the model. Two frequency-domain scopes will appear. After the simulation ends (few seconds), run the script to plot the results. You should see pictures for the time domain and frequency domain. The frequency domain plot shown below is a zoomed-in version of the one you will get by running the script.

Move to the answer sheet and answer the questions pertaining to this section.

Above you have experimented with only one frequency (a single tone) and a channel with paths introducing fixed delay. This this is to say that receiver and transmitter do not move relatively to one another, and that there are no reflectors moving as well in any of the signal paths. Of course, this part of the experiment is to give you a hint of what happens to bandlimited signals: some frequencies will be attenuated, some frequencies will be enhanced, and the degree these changes to the signal will depend on the delay spread introduced by the channel with multiple paths.

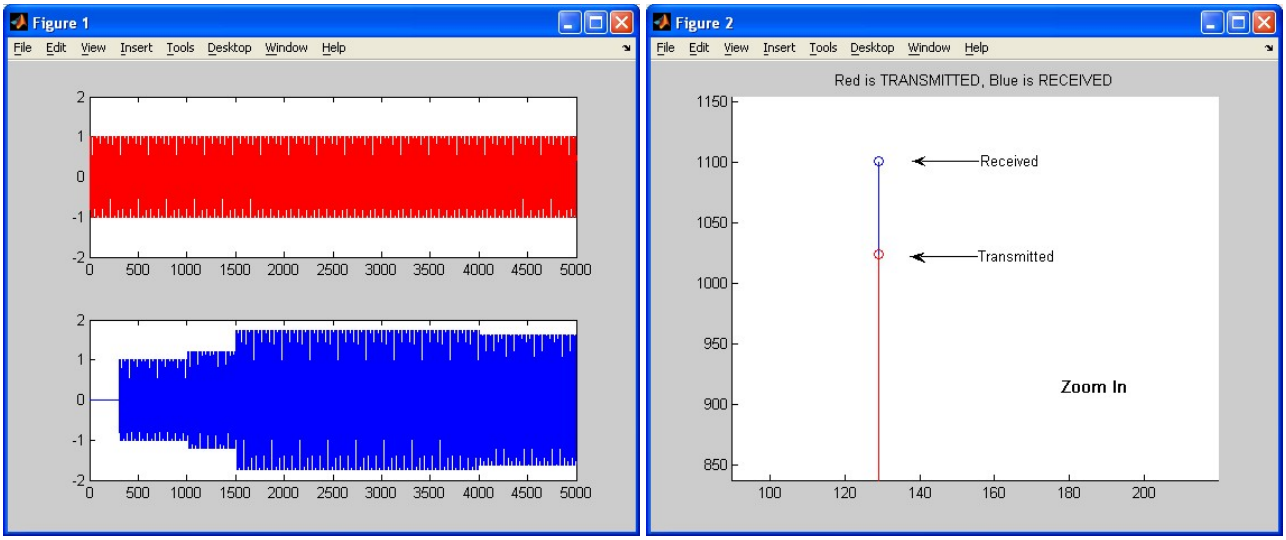

Figure 4. Transmitted and Received, Time Domain and Frequency Domain

This is a simplistic view of the channel and its different paths, for it assumes there is no variation at all over time. One clear way to see how simple this model is would be to think of the signal received by a base-station tower from a user placing a cellular phone call from a moving car. The communication channel varies the entire time while the user is within the boundaries of the footprint illuminated by the antenna on the tower.

Before you experiment with a bandlimited signal, however, you should verify what happens to two single tones presented to the channel.

1.3.2 Two Tones

Now close the previous model and open the one labeled `part_c.mdl`. This model will have two sinusoids added together which are presented to the channel. They have the same amplitude, but different frequencies.

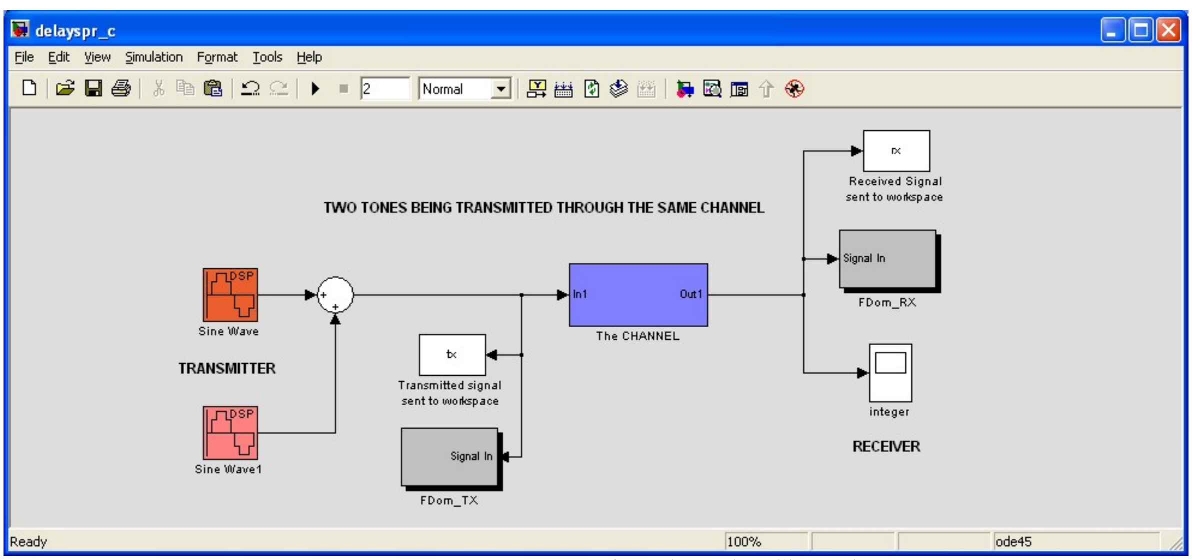

Figure 5. Two Tones Passing Through a Channel

When you run the simulation, two frequency-domain scopes will appear. They should show you the pictures as presented below.

By running this simulation you will see that the two frequencies are affected differently by the channel. Now open the channel and change the delay in only one of the reflections to verify that the outcome is different again. Also note that you have been using the frequency domain to interper your results. As more components are introduced to the signal input to the channel, looking at it in the time domain will not make much sense. This will become clear in the next portion of the experiment.

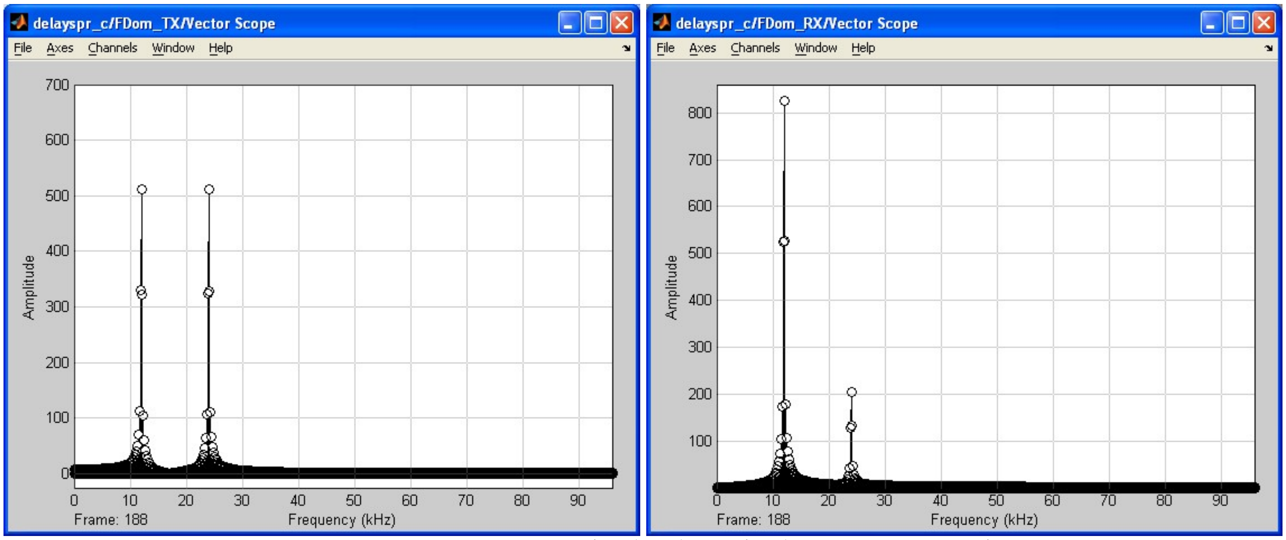

Figure 6. Two Tones, Transmitted and Received, Frequency Domain

1.4 Bandlimited Signals

In this section you will experiment with two band-limited signals passing through channels with different delay spreads. You will be able to notice the effect of delay spread on the components of the signals. First, take a look at the model for the simulation, presented below and found at `part_d.mdl`.

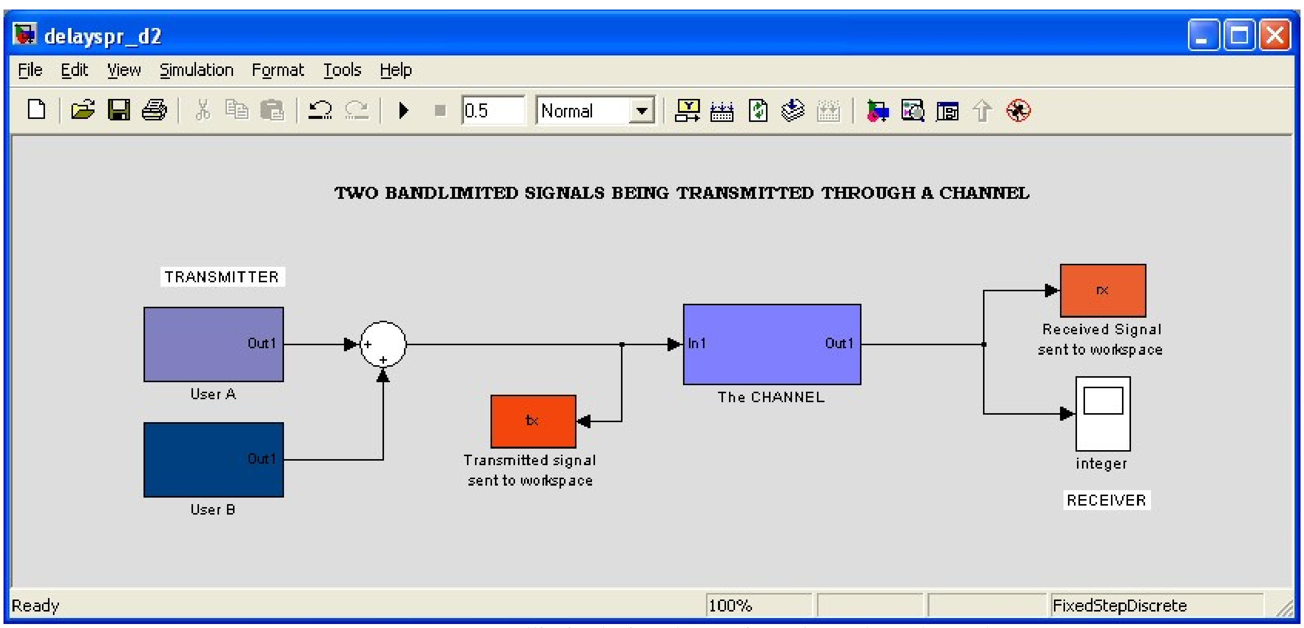

Figure 7. Two Bandlimited Signals Passing Through a Channel

Each user is simulated by an impulse which passes through a bandpass filter and is given a gain. The centre frequencies are different, so that the effects resulting from the delay spread will be clear. The model for each user is presented below (you can double click on the block to check it out).

The model is preset to run for a length of time (a few seconds). You must use the `Matlab` script given to visualize the outcomes. The script is called `viewb.m`, from the course lab site.

The first model that you will run is the one with a large delay spread. The concepts used here are presented on page 27 of the course notes. The model for that channel is represented below (double click on the channel block).

Make the model run. After it stops, run the `Matlab` script. First, the time-domain representation:

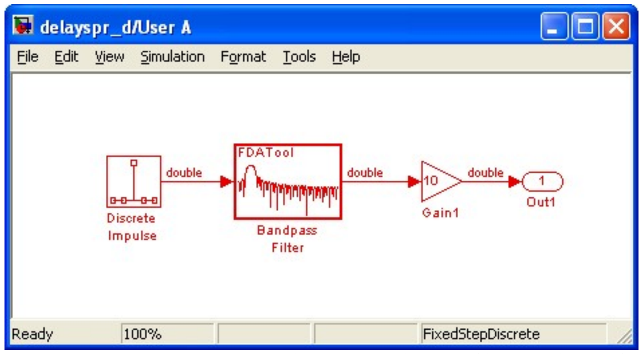

Figure 8. A User: an Impulse, a Bandpass Filter and a Gain

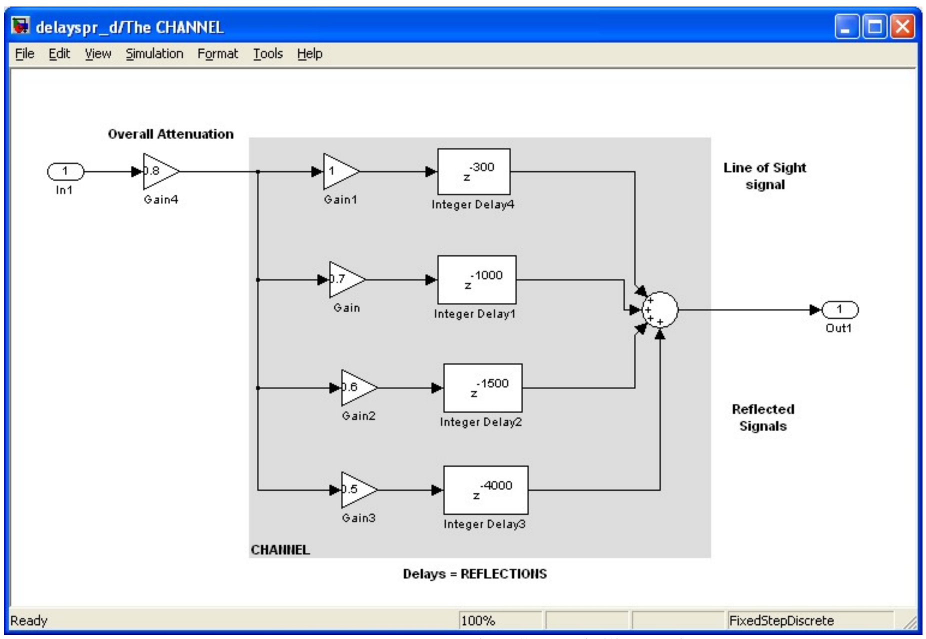

Figure 9. A Large Delay Spread Channel

A second plot will represent the frequency domain, as below:

Now open the model found at `part_d2.mdl`. This is the model with small delay spread. Look at the delays on the channel block and see if they meet your expectation. After you run the model, you will get the frequency domain plot presented below.

1.5 First accomplishment

It is hoped that you have realized this:

- **Large Delay Spread == Fast variation of the frequency response == Small Coherence Bandwidth**
- **Small Delay Spread == Slow variation of the frequency response == Large Coherence Bandwidth**

2. Doppler Spread

2.1 Background Reading and Preparation

The relevant reading for this experiment can be found in [1]. Some extra details can be found in the course notes as posted, or the lectures (see [2]). As an illustration related to the topic, one can read about the communication problems between the space probe *Huygens* as it descended towards Saturn's largest moon: *Titan*. See references [3] and [4].

2.2 Experiment

This experiment is divided into four main parts. All parts will involve simulation in `Simulink`, with models provided to you. You will simulate the effects of doppler spread on one tone, two tones and bandlimited signals, representing two distinct users.

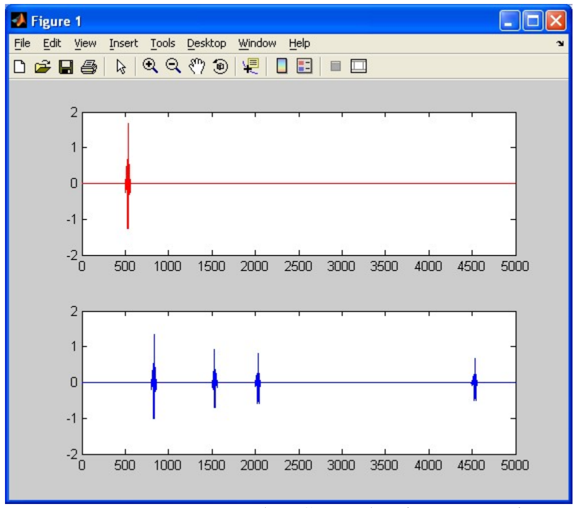

Figure 10. Large Delay Spread: Time Domain

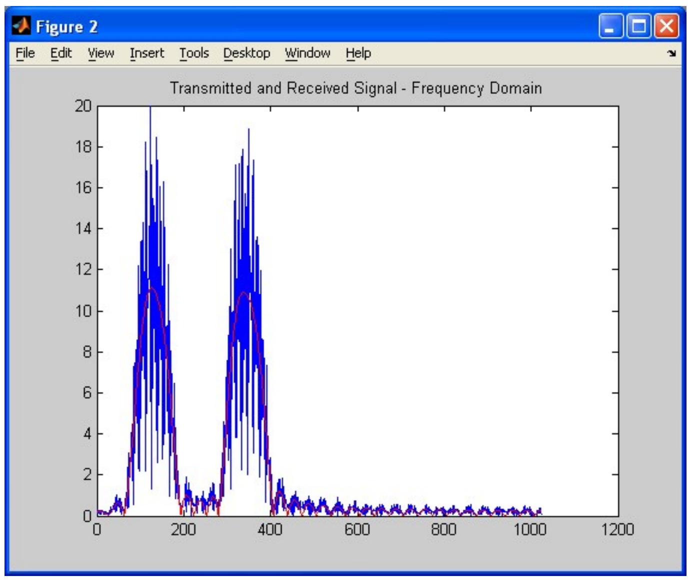

Figure 11. Large Delay Spread: Frequency Domain

Finally, you will combine the concepts seen in this experiment and the last one by adding reflections to the signals originating from the users.

2.3 Doppler on a single tone

From `Simulink`, open the model found in `doppler_a.mdl`. A model as the one presented below should appear. The model presents a varying delay in the signal path. This effect will simulate a constantly varying doppler shift on the single tone, a shift which occurs between lower and upper limits. You can view the variation from low frequency to high frequency as the effect caused by the transmitter moving towards the receiver. Note that there is no "channel" block to add multiple paths for now (these will be added towards the end of the experiment). However, by having the delay varying as it is (sinusoidally) you are in fact simulating reflections with different arrival angles.

This explains the difference in frequency amplitudes at the lowest and the highest portion of the spectrum, as the sinusoid "moves" in the frequency domain. Note that the amplitude of the **time domain** signal does not change, whereas the amplitude in the frequency domain does change.

Run the model and observe the scopes. Then answer the questions below.

Now you will vary the velocity between transmitter and receiver. Remember from the course notes that **large velocity**

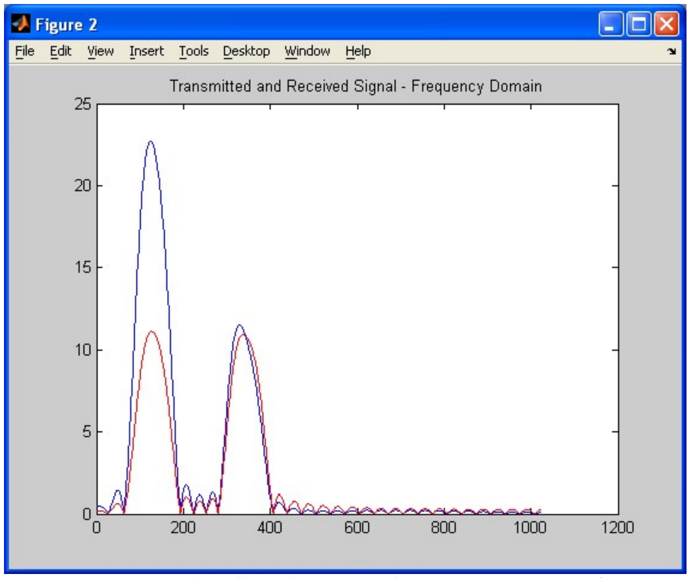

Figure 12. Small Delay Spread: Frequency Domain

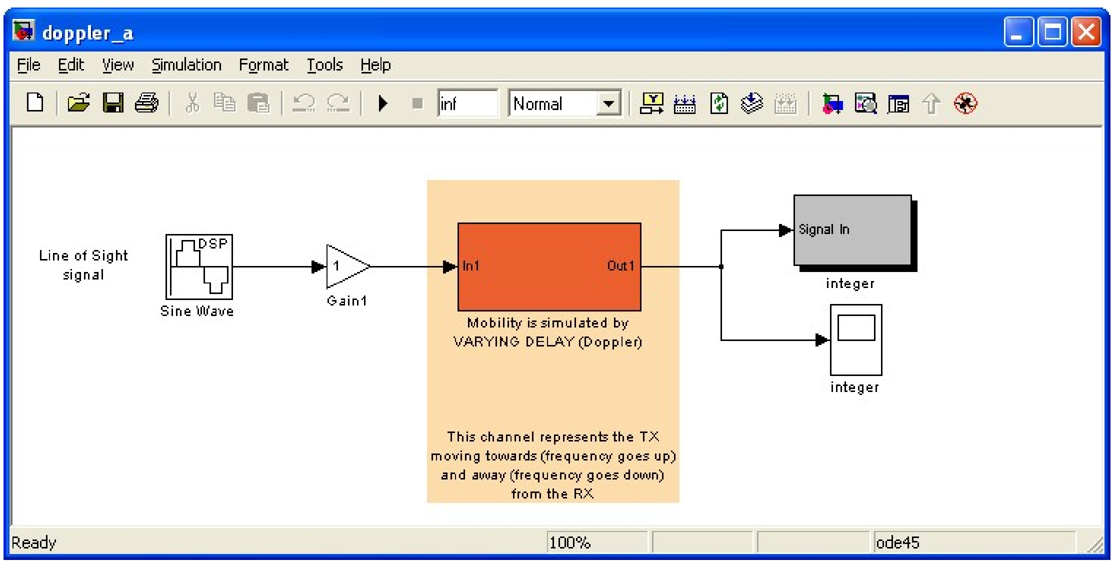

Figure 13. Doppler on one tone

means large Doppler spread, small coherence time and that the signal varies rapidly in time. Likewise, **low velocity means small Doppler spread, large coherence time and that the signal varies slowly with time**. This is what you will be guided to see.

Double click on the Mobility block. For the model you have, the velocity is varied by changing the **frequency** of the sinusoid which determines the varying delay. Double click on the sinusoid block and change the frequency to twice of what it is. Now run the model. You should see that the spread in the frequency domain is much larger than before. Also, you should be able to notice that the signal is now varying rapidly in time (time domain plot). Change the frequency of the sinusoid to a smaller value and you should see the opposite effect on both time and frequency domain. In the course notes, note that the plots that indicate the time variation are scaled in decibels and therefore will look different than the ones you have running with the simulation. If you feel corageous, feel free to export the time domain output signal and perform the operation to change it to dB. Your reference signal will be, of course, your input, so you will need to export that too into the workspace.

Please remember to change the frequency back to the original value.

2.4 Two Tones Moving In Different Directions

In this part of the experiment you will see the effect of two transmitters sending single tones to a receiver while moving in opposite directions relative to the receiver. Open the model found in `C:/Matlab/Work/ECE464/Exp03/doppler_b.mdl`.

The model should look like the figure below. Run it and answer the questions in the answer sheet.

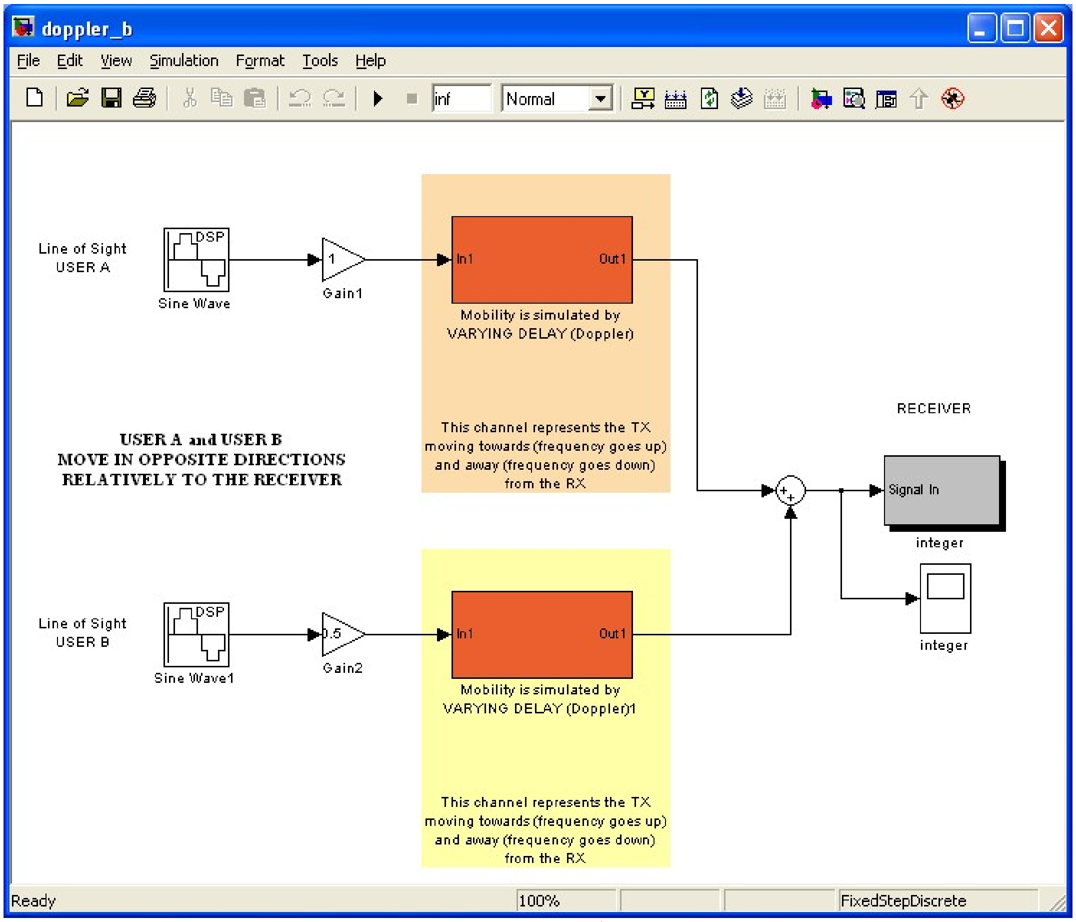

Figure 14. Two Moving Tones

2.5 Bandlimited Signals On The Move

Now close the previous model and open the one labeled `doppler_c.mdl`. This model will have two "users" represented by bandlimited signals. You will need to open (from the main `Matlab` window) the viewing script provided under the same working directory. After the simulation is done running, you should run the viewing script. The model will look like the picture below.

Note that the viewing script will provide you with plots which represent a **snapshot** of the signal at a certain time. Run the model. After it stops, run the viewing script in `Matlab`.

- *Based on the model you have just run, draw below the plot you see and explain who are the transmitted signals, who are the received signals and what are the observed features in the received signals. Explain why these features are there. You will need this plot for the next section.*

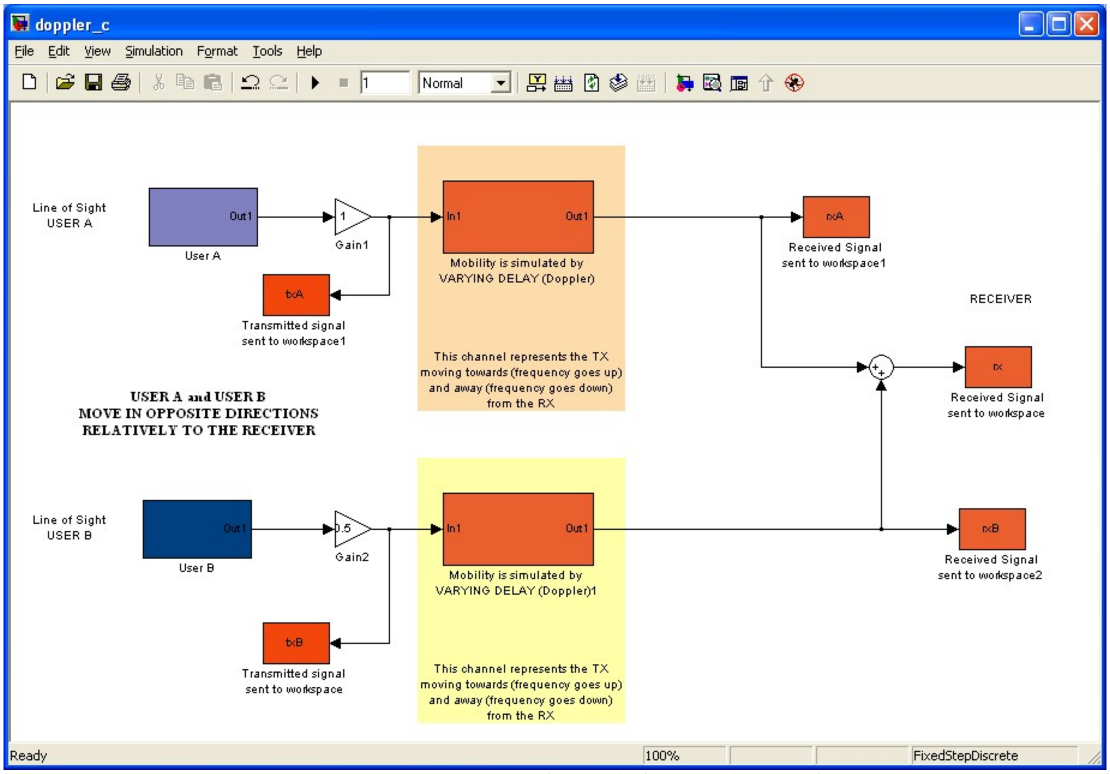

Figure 15. Two Users Moving Relative To The Receiver

2.6 Two Moving Users And Multiple Signal Paths

This last part of the experiment will add multiple paths to each of the users. Open the model found at `C:/Matlab/Work/ECE464/Exp03/c` It should look like the figure below.

Run the model, and after it is done, run the viewing script (the same script you ran in the previous part). In this model, you are deliberately adding multiple paths to your signal. The **time domain** picture you obtained from the viewing script shows you that multiple attenuated versions of your direct signal (for each user) arrive at different times. Think back to the previous section (Delay Spread) and answer the questions in the answer sheet.

2.7 Second accomplishment

From this experiment, it is hoped that you have realized this:

- **Large Doppler Spread == Fast Time Variation == Small Coherence Time**
- **Small Doppler Spread == Slow Time Variation == Large Coherence Time**

References

[1] J.W. Mark and W. Zhuang, *Wireless Communications and Networking*. Prentice Hall, 2003.

[2] E. Sousa, *ECE464 Course Notes*, Spring 2006

[3] Cassini-Huygens, Nasa Jet Propulsion Laboratory, *http://saturn.jpl.nasa.gov/*

[4] IEEE Spectrum Magazine: *Titan Calling http://www.spectrum.ieee.org*

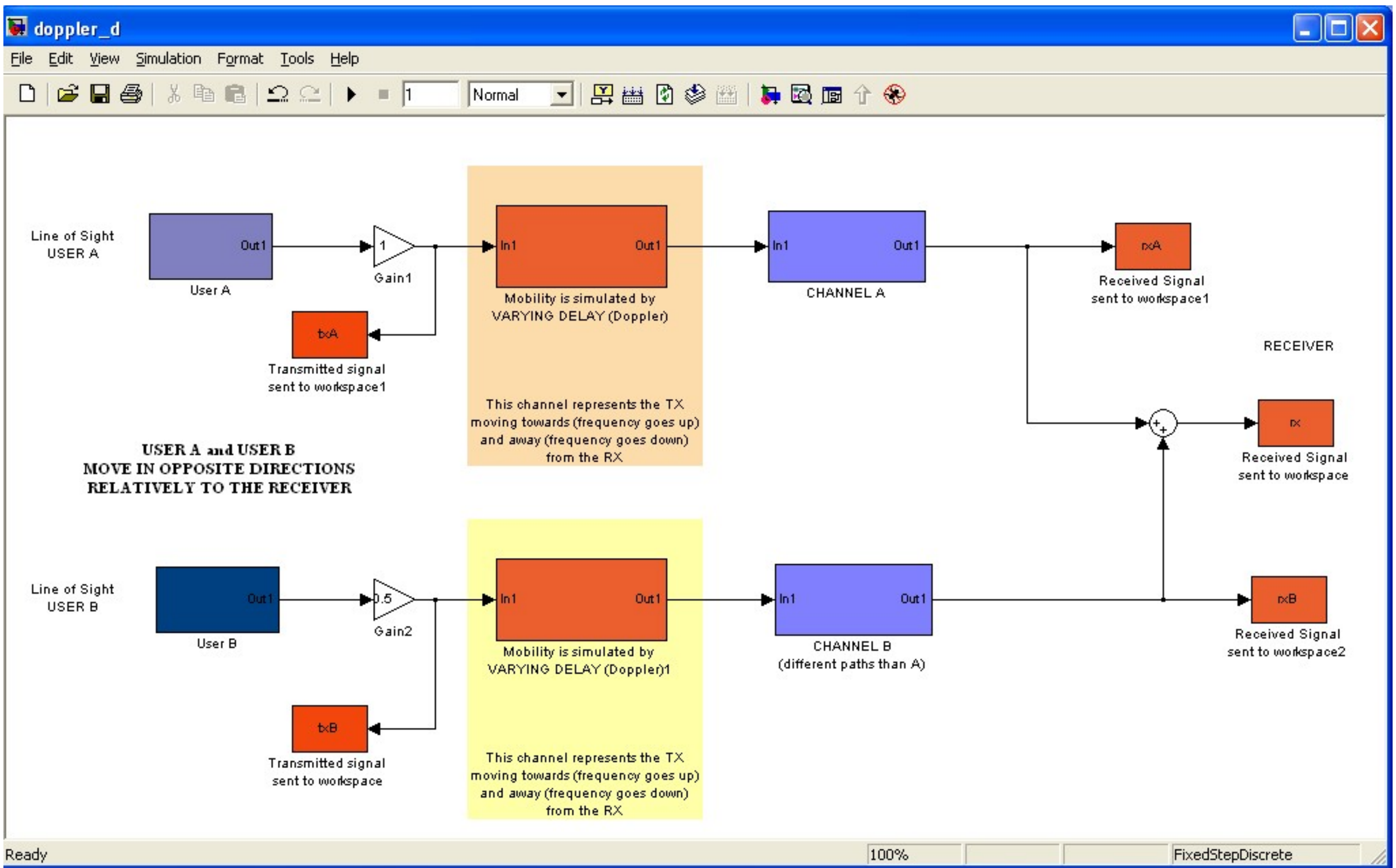

Figure 16. Two Bandlimited Signals Passing Through a Channel With Multiple Paths