Simulink and USRP Starters' Guide

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1. Introduction

Since you will be using MATLAB/Simulink for the experiments, this tutorial has been prepared and is intended for you to become familiar to Simulink. If you have experience in Simulink, this tutorial will help you to familiarize for the experiments that we will start soon. However, if you do not have an extensive experience with Simulink, this tutorial has been provided for you to get started with Simulink. Please note that the tutorisal is mainly based on the Getting Started Guide presented in [1]. Here the most important sections and fundamentals were extracted, therefore you can quickly understand. We encourage you to refer to other materials in the references. Before we start, if you do not have MATLAB, you can download from the following link:

https://ist.njit.edu/software/.

You can always upgrade the latest version of the software using MathWork's web site. As a reminder, you should be aware that if you use the MATLAB's version earlier than 2015b, you should upgrade it. 2015b, 2016a and 2016b versions are acceptable for the ECE 489 labs.

During the lab, you are free to use your laptops for simulations. However, the course materials have been already uploaded into the lab computers. For some simulations, such as music simulations and OFDM that you are not required to build. You will be kept responsible to the effect of changing parameters for the specified models.

In the ECE489 Lab, you are required to use both Simulink and USRP hardware. There will be no additional tool needed for the lab. In addition, all the course materials are supposed to be read and pondered carefully.

2. Getting Started with Simulink

[2] Simulink, simulation and link, is an extension of MATLAB generated by MathWorks Inc. It is integrated with MATLAB to offer modelling, simulation, and analysis of dynamical systems within a graphical user interface environment. Simulink includes a comprehensive block library of toolboxes for both linear and nonlinear analysis. To more specific, Simulink supports system-level design, automatic code generation, continuous test and embedded systems.

This tutorial introduces the basic features of Simulink and is focused on Communications toolbox.

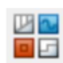
a) To start a Simulink Model

First of all, you need to run MATLAB to start a Simulink session. Then, you can either type ">> `Simulink`" in the command window, or click on the Simulink icon on the toolbar as shown

You can either click on "Blank Model" or use the keyboard shortcut CTRL+N to create a new model. You will be constructing and simulating your model in this window. You can always save your model in a specific destination by clicking save on the toolbar.

b) Important Toolboxes and Libraries related to the Experiments

You can access the Simulink library by clicking on



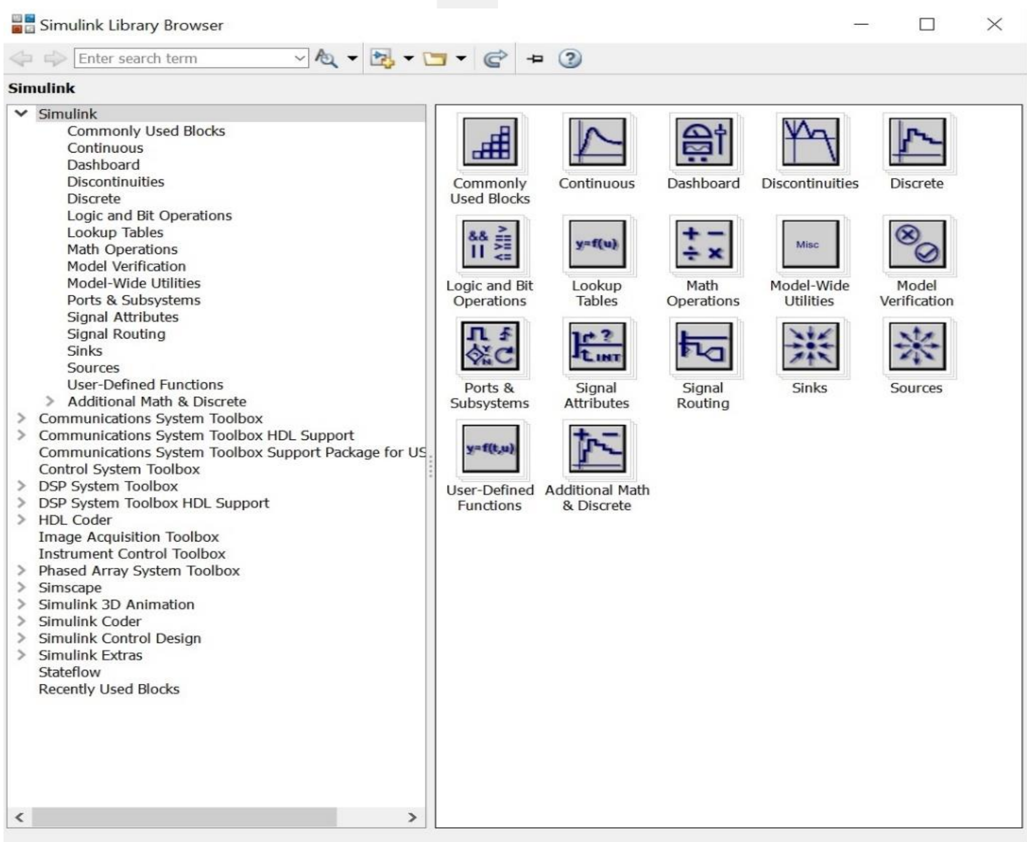


Figure 1: Simulink Library Browser

In the experiments, we will mostly use the tools in Commonly Used Blocks, Communication Systems Toolbox as well as DSP Toolbox. Also, an additional library was added into the lab computers which is named USRP Toolbox.

Simulink Library blocks used throughout lab tasks are summarized:

- **Simulink**
  - **Commonly Used Blocks**
    - Gain
    - Constant
    - Delay
    - Scope
    - In1
  - **Math Operators**
    - Abs
    - Add
    - Complex to Real-Imag
    - Product
    - Sqrt
    - Sign
    - Trigonometric Function
  - **Sinks**
    - Display
    - Scope
    - Out
    - Simout
  - **User Defined Functions**
    - Fnc
    - MATLAB Function
    - MATLAB System

- **Communications System Toolbox**
  - **Channels**
    - AWGN Channel
    - MIMO Channel
  - **Comm Sinks**
    - Constellation Diagram
    - Error Rate Calculation
    - Eye Diagram
  - **Comm Resources**
    - **Random Data Sources**
      - Bernoulli Binary
      - Random Integer Generator
    - **Sequence Generators**
      - Barker Code Generator

- **MIMO**
  - MIMO Channel
- **Modulation**
  - **Analog Baseband Modulation**
    - FM Demodulator Baseband
    - FM Modulator Baseband
  - **Analog Passband Modulation**
    - DSB AM Demodulator Passband
    - DSB AM Modulator Passband
    - FM Demodulator Passband
    - FM Modulator Passband
  - **Analog Baseband Modulator**
    - OFMD modulator and demodulator
    - PM: BPSK and QPSK, modulators and demodulator
- **Synchronization**
  - **Components**
    - Phase-Locked Loop
    - Continuous Time VCO

- **Communication System Toolbox Support Package for USRP® Radio**
  - SDRu Receiver
  - SDRu Transmitter

- **DSP System Toolbox**
  - **Filtering**
  - **Signal Management**
    - **Buffers**
  - **Sinks**
    - Spectrum Analyzer
    - Vector Scope
    - Time Scope
    - Audio Device Writer
    - Display
    - To Workspace
  - **Sources**
    - Sine Wave
    - From Multimedia File
    - Colored Noise
  - **Transforms**
    - Magnitude FFT

3. Sample Models

In this section, we will quickly start analyzing signals in time and frequency domains. Of course, knowing and applying math in the simulation environment are the key point of understanding. Therefore, this material represents only one side of the equation. You should be aware of the other side is in the Review Manual.

a) A Sinusoidal Wave Implementation

[3] The theoretical spectrum, $X(f)$ of $x(t) = Acos(2\pi f_c t)$ is

$$X(f) = \frac{A}{2}\delta(f - f_c) + \frac{A}{2}\delta(f + f_c)$$

and its power spectral density (PSD), $S_x(f)$, is

$$S_x(f) = \frac{A^2}{4}\delta(f - f_c) + \frac{A^2}{4}\delta(f + f_c)$$

The example presented here with A=1, f_c=100Hz. Therefore, the peak value of the spectrum is ½ or -3Db.
The average power is $A^2/2=0.5$
The peak of the power spectrum is $A^2/4=1/4$ and is expressed in dBW as $10\log(1/4) = -6\text{dBW}$.

The Simulink Model is expressed in the reference [3]:

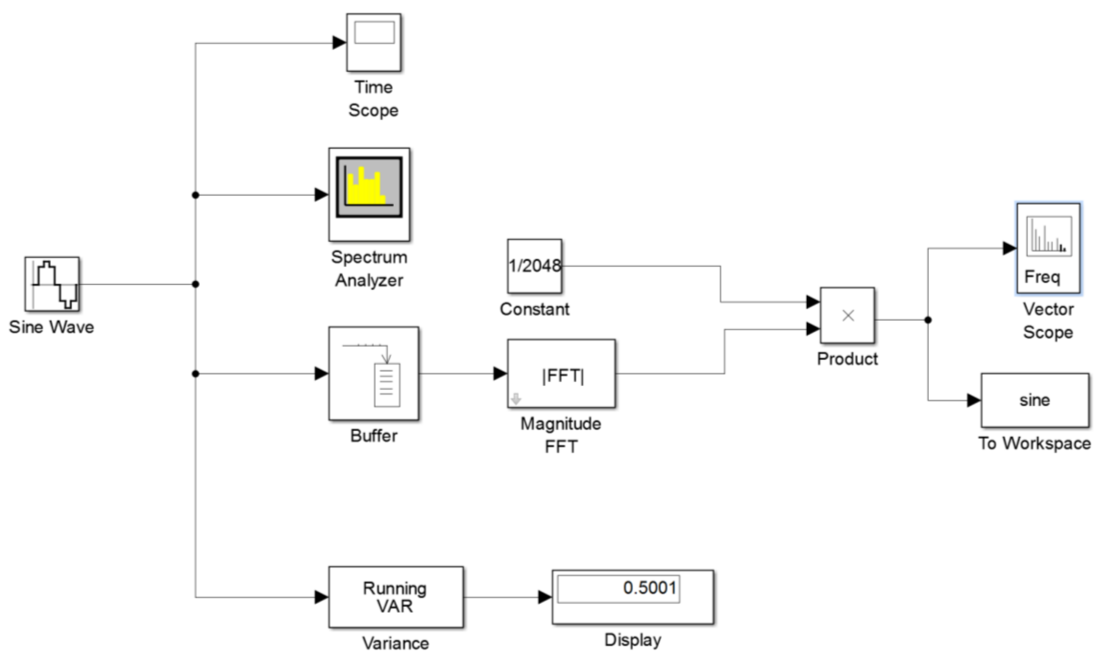


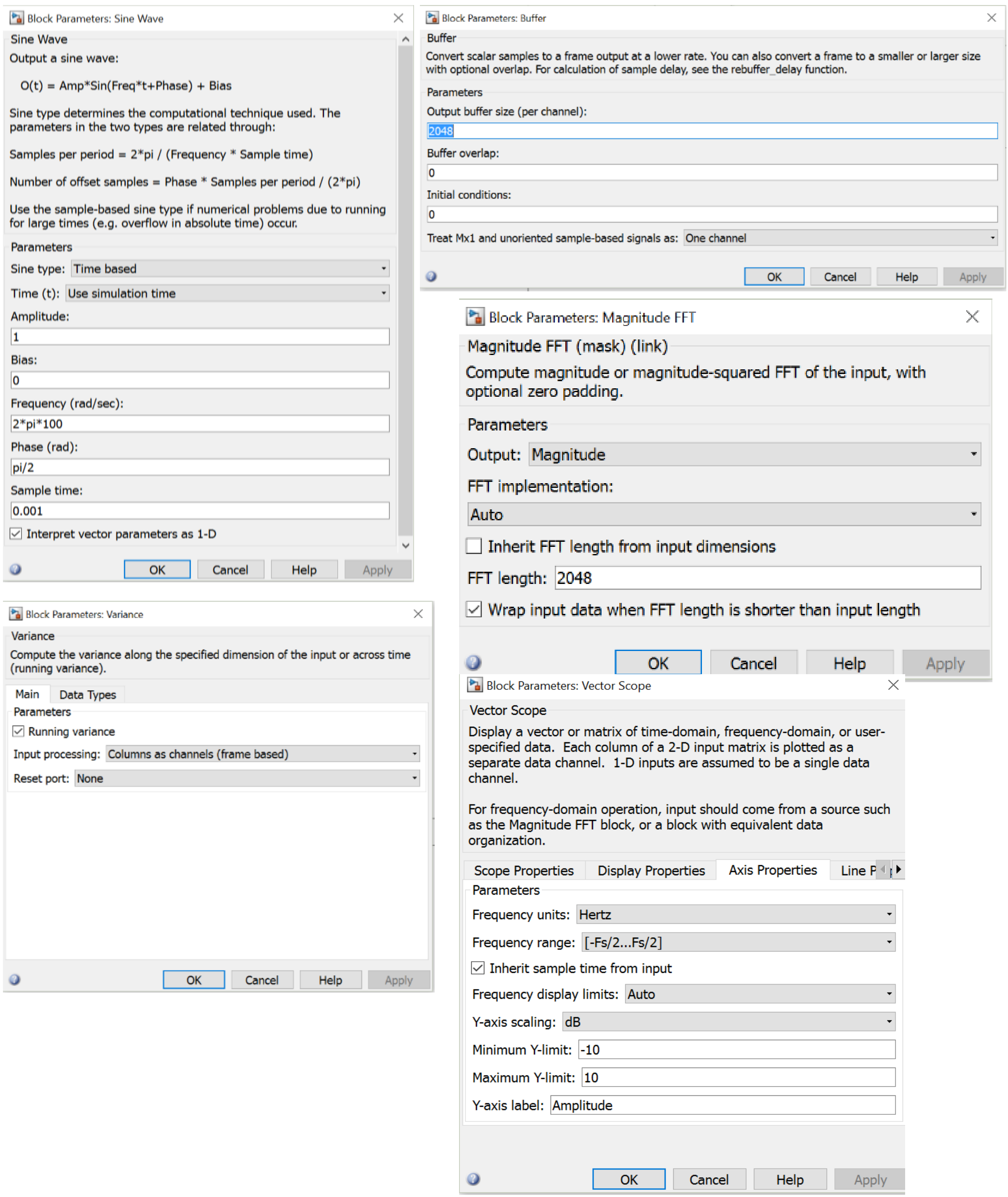
Figure 2: Simulink® Model of a Sinusoidal Wave for determining the Spectrum and Power Spectrum

Time Scope is used to observe the signal in time domain. Also, the **spectrum analyzer** shows us the signal's power in frequency domain in dBm. **Vector scope** is simply used to verify each impulse has the magnitude of $\frac{1}{2}$ or -3dB. The running variance shows the power of the signal in watts.

You should be very comfortable with the conversion into the logarithmic scale:

$$20\log_{10}(X) = Y\ [dB]$$

The block parameters are set to be as followings:



When the model is compiled, you will observe the followings:

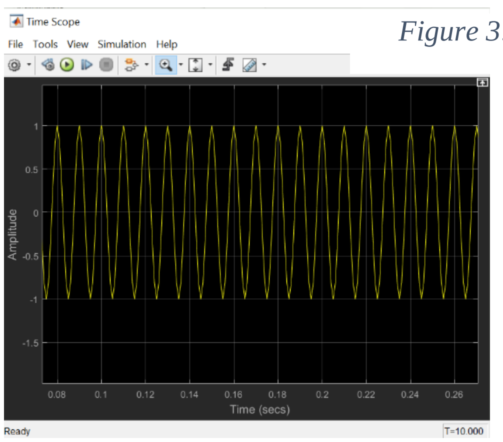
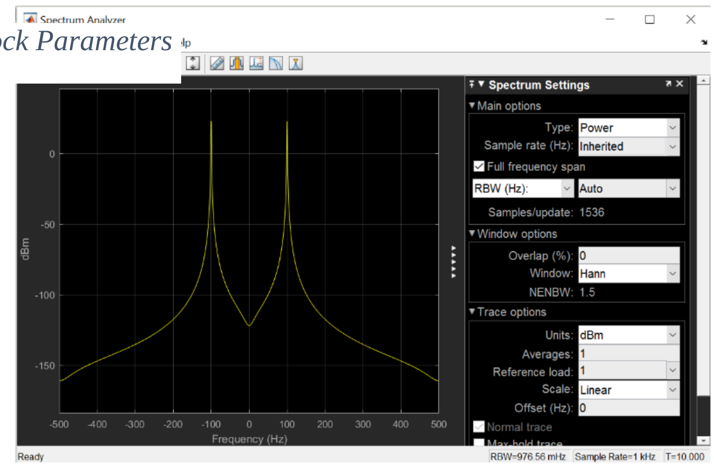


Figure 3: Block Parameters



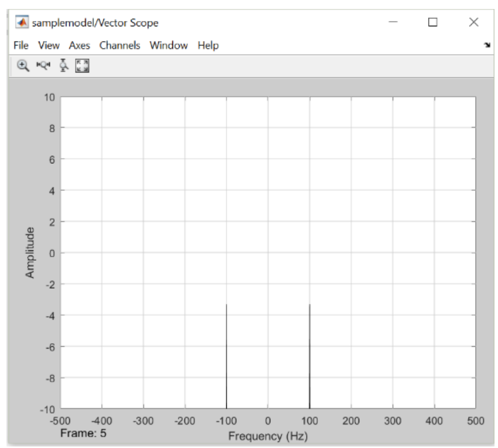


Figure 4: Analyzing the Sinusoidal Wave in Time and Frequency Domains

b) To Run a Multimedia (Speech) File

You can also run a speech file using the same model by changing the source block to "From Multimedia File", which is already provided in the Simulink library. The model's block parameters can be kept same except the FFT length and Buffer size. Both values are now set to be 16384 for a better resolution.

The Simulink Model is expressed as:

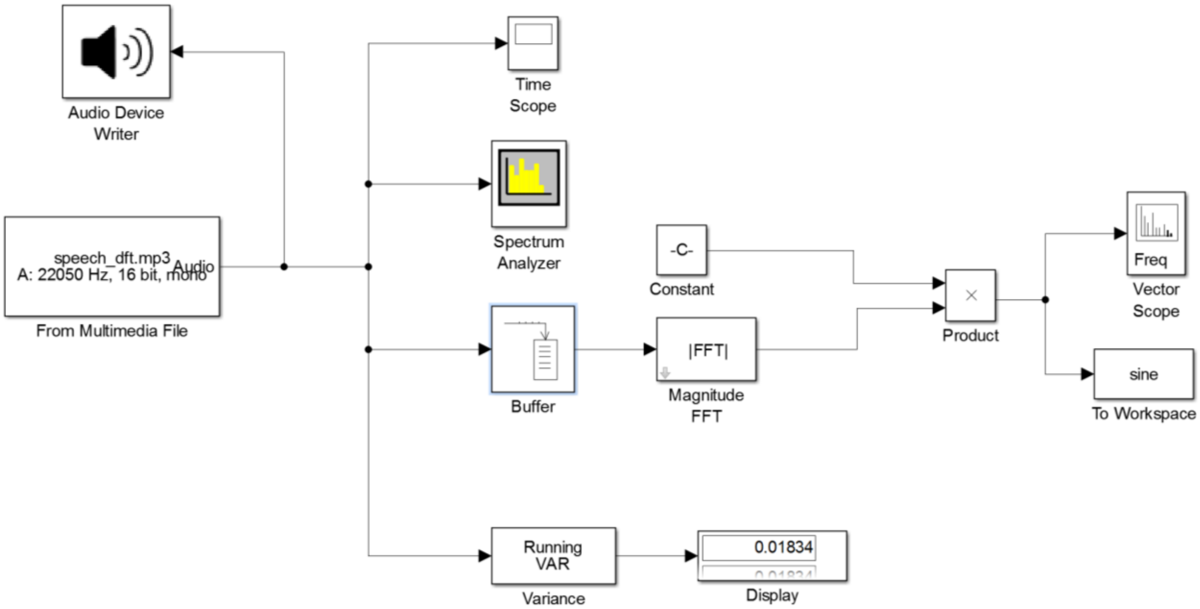


Figure 5: A Speech File analyzed in Simulink

Similarly, when the model is compiled, you will observe the followings:

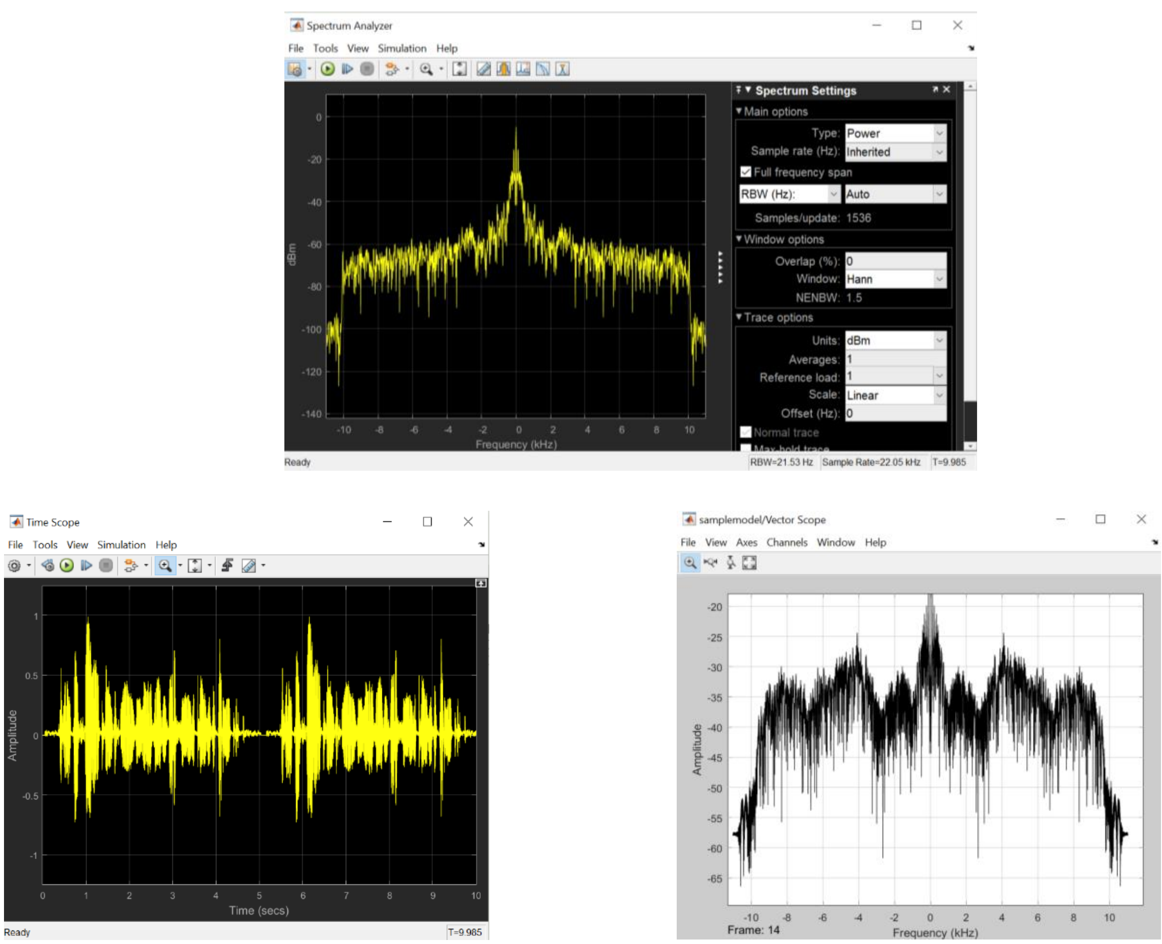


Figure 6: Observing a Speech in Time and Frequency Domain

Summary

- As you can observe that the peak value of the magnitude spectrum $|X(f)|$ at frequencies +100 and -100 is -3.298dBW or 0.468W with FFT length of 2048, which is very close to the expected theoretical value.
- Spectrum Analyzer shows us the power&/power spectral density. When the peak value is observed at frequencies +100 and -100 is 6.28dBm or 0.236 with FFT length of 2048, which is very close to the theoretical value.
- The output of the running variance block shows the average power of the sinusoid, which is 0.5001. It can be clearly seen that it is very close to the theoretical value.
- For the speech signal, you can observe that the record is 5 secs in time scope. You can clearly observe the bandwidth, sampling rate, power spectrum, average power in power spectrum and display, respectively.

Remark: As the source's frequency is set to be 100Hz, when you run the model, make sure to zoom in to observe the sinusoid. You may need to do a couple of modifications in order to scale the figures as shown.

4. Basics of USRP Hardware: Software Defined Radio

A software defined radio is a set of Digital Signal Processing (DSP) primitives, a multilevel system for combining the primitives into communications systems functions (transmitter, channel, model, receiver…) and set a target processor on which software radio is hosted for real-time communications. Typical application is speech/music, modem, packet radio, telemetry and High Definition Television [4]. A software defined radio hardware that we use NI USRP-2921 in the lab is capable of transmitting analog information using directly to the air (no modulation needed) or using communication modulation schemes, such as analog, i.e., AM, FM, PM, etc., as well as digital modulations techniques i.e. QPSK, BPSK, QAM, etc. It is possible to implement the channel access techniques, namely, FDMA, TDMA, CDMA, etc. along with the multiplexing techniques such as OFDM.

The trans-receiver hardware that is being used in the lab has the following specifications [5]:

<u>Transmitter</u>

- Center frequency varies between 2.388 GHz to 6.012 GHz
- Gain range is between 0 dB to 35 dB
- Maximum instantaneous real-time bandwidth for 16-bit sample rate is 24 MHz, and for 8-bit sample is 48 MHz

<u>Receiver</u>

- Center frequency varies between 2.388 GHz to 6.010 GHz
- Gain range is between 0 dB to 92.5 dB
- Maximum instantaneous real-time bandwidth for 16-bit sample rate is 19 MHz, and for 8-bit sample is 36 MHz
- Noise figure is between 0 dB to 92.5 dB

For further information, you can always read the data sheet by National Instruments (NI).

5. Tutorial Questions

Answer to the following questions:

1) Design and analyze the Simulink® models given in the part-3 for both a. and b.
2) Use the input source as a White Gaussian Noise. What do you observe? Comment your result from the frequency point of view.

6. References

[1] MathWorks, *Getting Started Guide*, http://www.mathworks.com/help/simulink/getting-started-with-simulink.html

[2] Di Pu, A. M. Wyglinki, *Digital Communications Systems Engineering with Software Defined Radio*, pp. 253-266, 2013, Artech House

[3] Arthur A. Giordano, Allen H. Levesque, *Modelling of Digital Communication Systems Using Simulink*®, pp. 32-40, 2015, Wiley

[4] J. Mitola, *Software Radios Survey, Critical Evaluation and Future Directions*, National Telemetry Conference at 1990, published at 1993, IEEE

[5] Data Sheet, National Instruments, *Device Specifications NI USRP™-2911*, accessed 7/16, http://www.ni.com/pdf/manuals/375867b.pdf