Exploring the RF Spectrum

Lab Objectives

When this lab exercise is completed, the student should be able to:

1. Setup the RTL-SDR demonstration and display the output on the spectrum analyzer
2. Setup a spectrum analyzer in SIMULINK to capture the max-hold trace and explain what the max hold trace is showing
3. Demonstrate how to see the Spectrogram of the RF signal using SIMULINK and the RTL-SDR
4. Identify different signals in the RF spectrum

Introduction

To do this lab you will need to have installed MATLAB and Simulink on your computer. You will also have to load the RTL-SDR hardware support package from The MathWorks. Instructions to install these packages can be found in myCourses.

Lab Procedure

Part 1: Setting up the RTL-SDR and FM Broadcast Receiver in Simulink

1. Connect the suction cup or the tripod mount to the dual antenna mount. Screw each of the longer telescoping antennas into the antenna mount. Connect the long coaxial cable to the SMA connector on the output of the dual antenna mount. Connect the other end of the long coaxial cable to the SMA connector on the RTL-SDR. Attach the suction cup or tripod mount to a hard surface or other object. Extend each of the telescoping antennas to approximately 30 inches. This will create a half-wave dipole antenna. The exact length is not that critical for this application as long as there are reasonably strong FM Broadcast signals in your area.

2. Plug the RTL-SDR receiver into a USB port on your computer.

3. Download the Simulink files from myCourses into a directory that you can access and start MATLAB. Once MATLAB has started, navigate to the directory where you saved the Simulink files and load the "FM_Broadcast_CE2251.slx" model by double clicking the file name. This should open the model that looks like

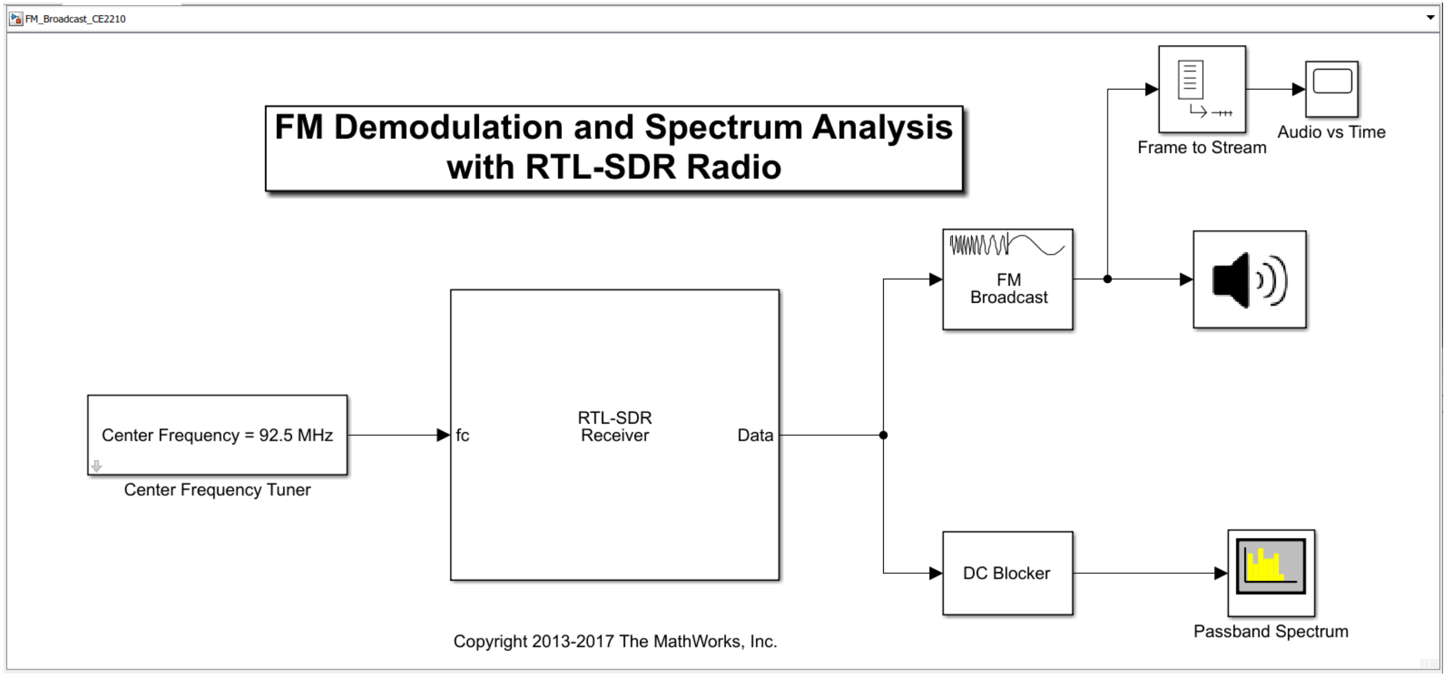


Figure 1 FM Broadcast Receiver Model using RTL-SDR

4. The model includes the RTL-SDR block that interfaces to the RTL-SDR hardware. Double click on the RTL-SDR receiver and you will see some of the parameters that can be set for the block (Figure 2). We will not change any of these for now. These include the radio address, the source of the center frequency information, the sampling rate and a frequency correction value. There are options to determine the available output ports and the data type. Lastly the number of samples per frame. MATLAB is a highly vectorized language meaning that it can operate on a vector of values very efficiently. Simulink, which is built on MATLAB also has this capability. By placing values in frames (essentially vectors) a single block can operate on all the values in the vector at once. This is faster and more efficient than operating on each sample individually. To process the samples coming from the receiver fast enough to get real time demodulation operations must be performed on frames.

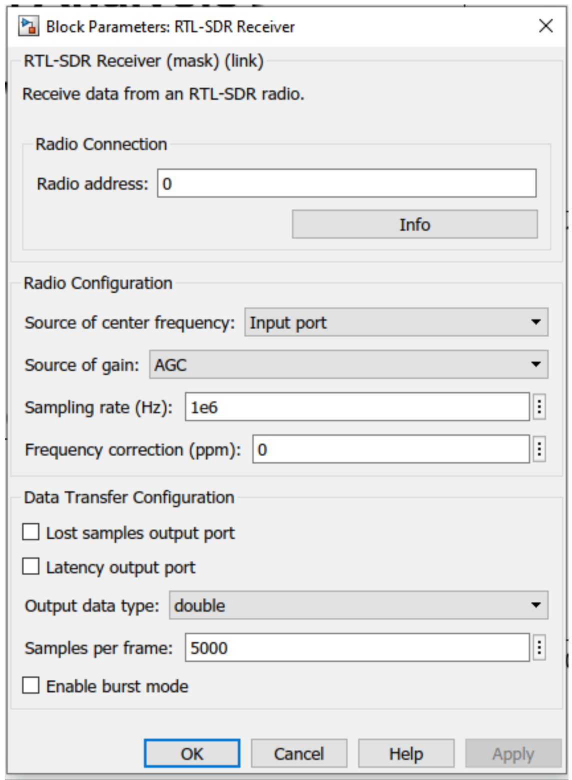


Figure 2 RTL-SDR Parameters

5. Double click on the block labeled "Center Frequency Tuner". This block provides a simple GUI to control the frequency that the RTL-SDR is tuned to as shown in Figure 3. The center frequency can be adjusted using the dial or just by changing the value in the edit box. The range of valid frequencies for the tuning knob can be set as well. Set the center frequency to a value that you know is occupied by a local FM radio station. Close the GUI by hitting OK.

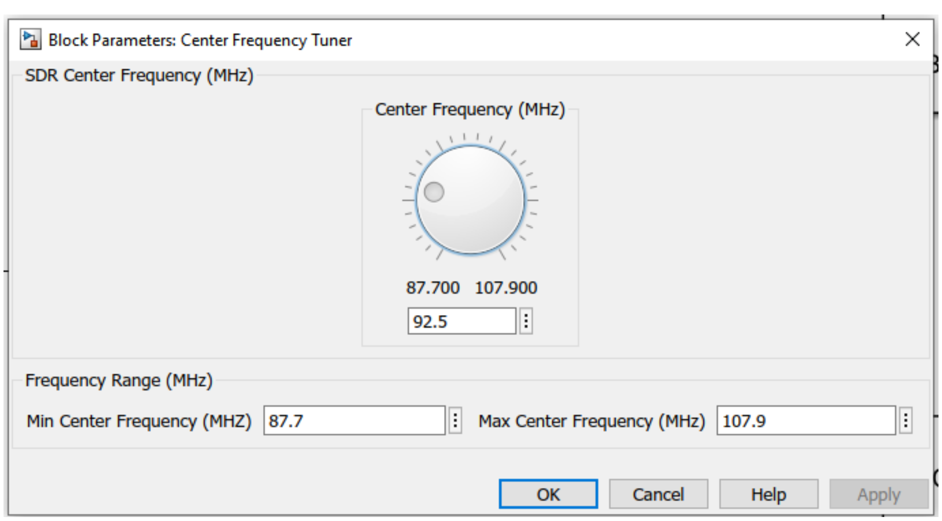


Figure 3 Center Frequency Tuning GUI

6. Double click on FM Demodulator block. This block allows one to set several parameters for the demodulator (Figure 4). It is important that sample rate of this block matches the output sample rate of the RTL-SDR. The output sample rate of the block is also set here. This is the rate that demodulated audio samples are sent to the CODEC and then the speaker. Leave all these settings as they are here for now.

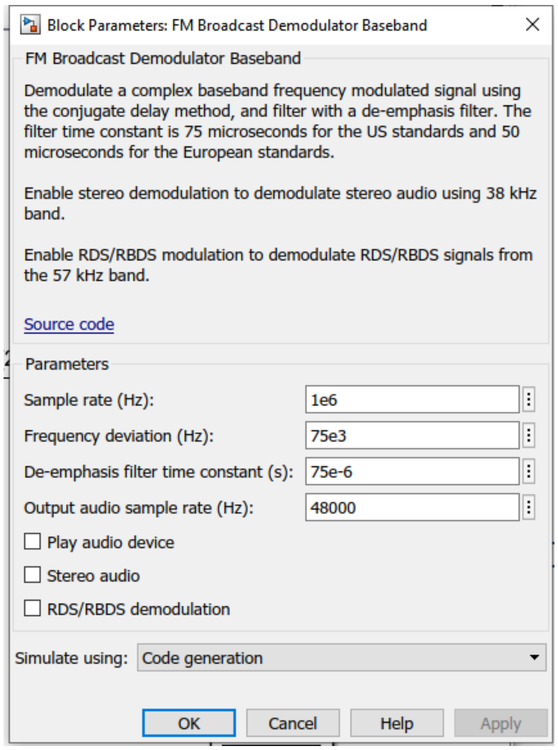


Figure 4 FM Demodulator Parameters

7. “The Frame to Stream” block converts the frame-based samples to a single sample stream which is displayed on the oscilloscope versus time.
8. The “DC Blocker” removes the average or DC value of the samples.
9. Finally, the Passband spectrum block displays the signal in the frequency domain. We will be modifying the settings of this block to measure different signal characteristics.
10. Open both the oscilloscope and the spectrum analyzer blocks by double clicking them (they may already be open from when you started the model). When you initially open the spectrum analyzer and the oscilloscope blocks they will look something like Figure 5.

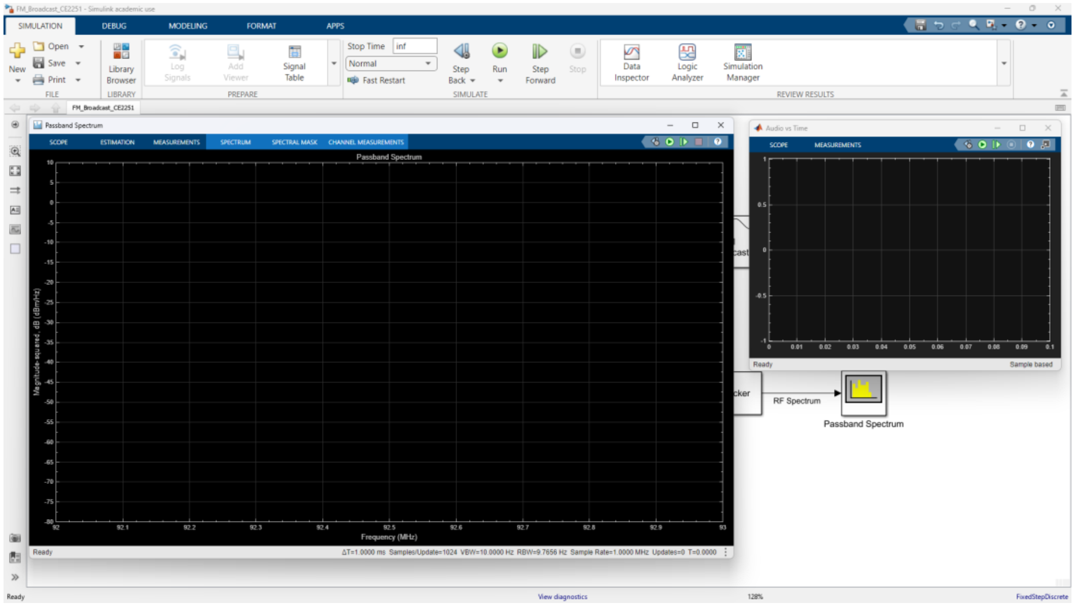


Figure 5 Spectrum Analyzer and Oscilloscope Blocks

Part 2: Receiving a Broadcast FM Station

1. Start the simulation by clicking on the green run button  on either the spectrum analyzer, the scope or on the toolbar in the model. It may take 15-30 seconds for the model to compile the first time and begin to run. Adjust your volume so that you can hear the demodulated audio of the station that you selected.

2. You should see the spectrum of the RF signal on the spectrum analyzer. This is a view of the signal versus frequency and should look something like Figure 6 (I rearranged the colors of the plot below so yours may look different). Note that the x-axis is in units of frequency and the y-axis is in magnitude squared (dBm/Hz). This is a power level per unit of frequency and is in decibels relative to 1 milliwatt.

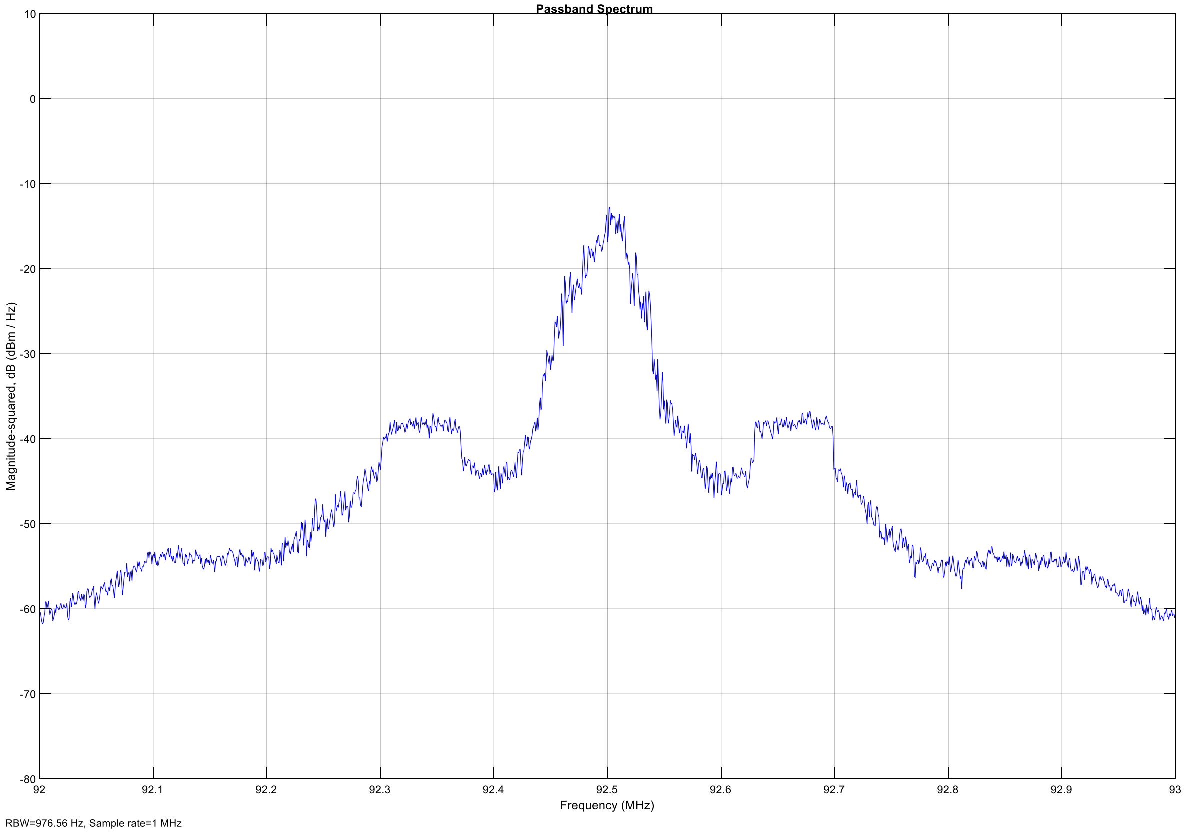


Figure 6 Frequency Spectrum of an FM Broadcast Signal

3. Capture a plot of the received FM Broadcast signal. You can do this by selecting SCOPE/Copy to Clipboard. You can paste the clipboard to Word or PowerPoint or other application. You can change the way the figure appears by selecting SCOPE/Settings Options in the menu. Then using the COLOR AND STYLING menu adjusting the Axes and Trace color as desired. Paste the capture of the spectrum into your report.

Part 3: Measuring Signal Bandwidth

The bandwidth of a signal is the amount of frequency spectrum occupied by a selected percentage of the total energy in the signal. Common percentages of total energy are 90% and 99%. You will notice that the bandwidth of the signal does not stay fixed over time and it is difficult to measure a fixed value. Therefore, usually the measurement is made by holding the spectrum to the maximum value. To do this select the option for SPECTRUM/Max-hold trace as shown in Figure 7. What do you notice happens on the spectrum analyzer when this is selected?

Exploring the RF Spectrum

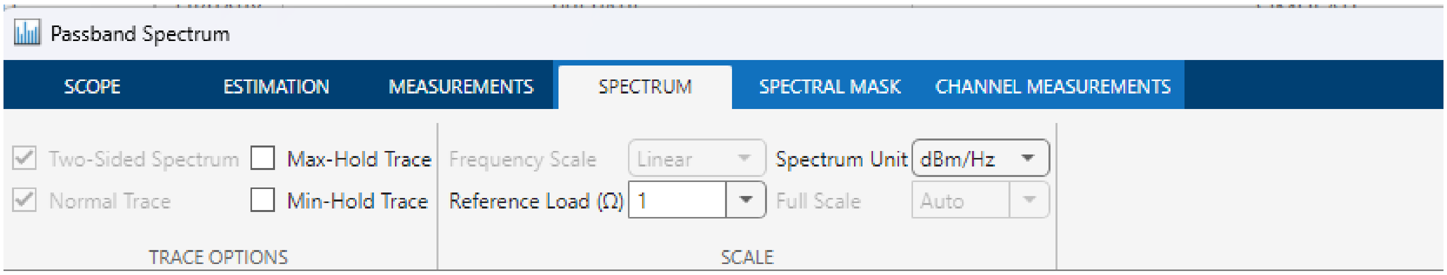


Figure 7 Max-hold trace selection

If you want to restart the Max-hold trace just uncheck and re-check the box.

To measure the occupied bandwidth of the signal from the menu select CHANNEL MEASUREMENTS on the tool bar (see Figure 8). Select the "Channel Measurements" icon. This will turn on two vertical dashed lines. Under CHANNEL/Channel Selector you can choose either the live RF Spectrum or the RF Spectrum Max-Hold display.

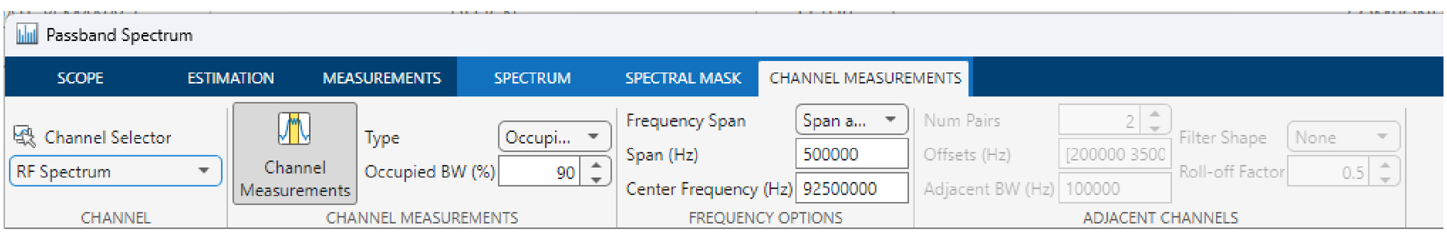


Figure 8 Occupied Bandwidth Measurement Options

In the "Type" drop down, select Occupied BW. In the "FREQUENCY OPTIONS" section set the span to 500 kHz. This is the span of frequencies over which the Channel Power measurement is made. Make sure that the center frequency is set to the frequency of your radio station. Under "Occupied BW (%)" set the value to 90% to begin. This is the bandwidth that is occupied by 90% of the total power of the signal. Change the percentage to 99% and record the occupied bandwidth. How do the two values compare? An example view of the channel measurements is shown in Figure 9.

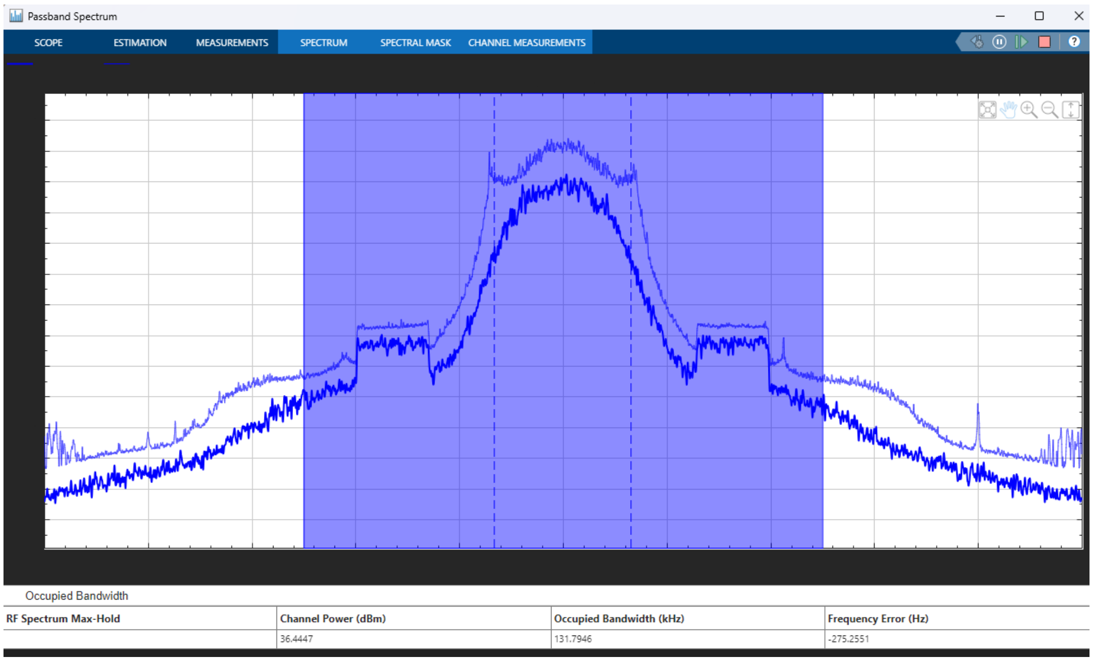


Figure 9 Example Channel Measurements View

Looking at the Spectrogram

You may have noticed that the spectrum is not constant over time. One way to observe these changes is to use a view known as a spectrogram. This view shows the frequency spectrum in both the frequency domain and in the time domain. Signal amplitudes are still shown but as varying colors. First STOP the simulation. Then turn off the Channel Measurements (CHANNEL MEASUREMENTS/Channel Measurements) and deselect the Max-hold trace (SPECTRUM Tab). To select the spectrogram display select the SCOPE/Spectrogram Settings button dropdown select Spectrum and Spectrogram. You will see a view as in Figure 11.

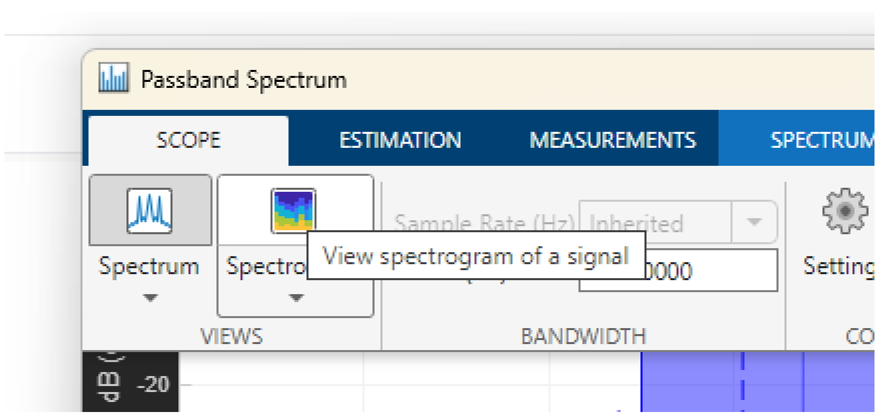


Figure 10 Spectrum or Spectogram View Selection

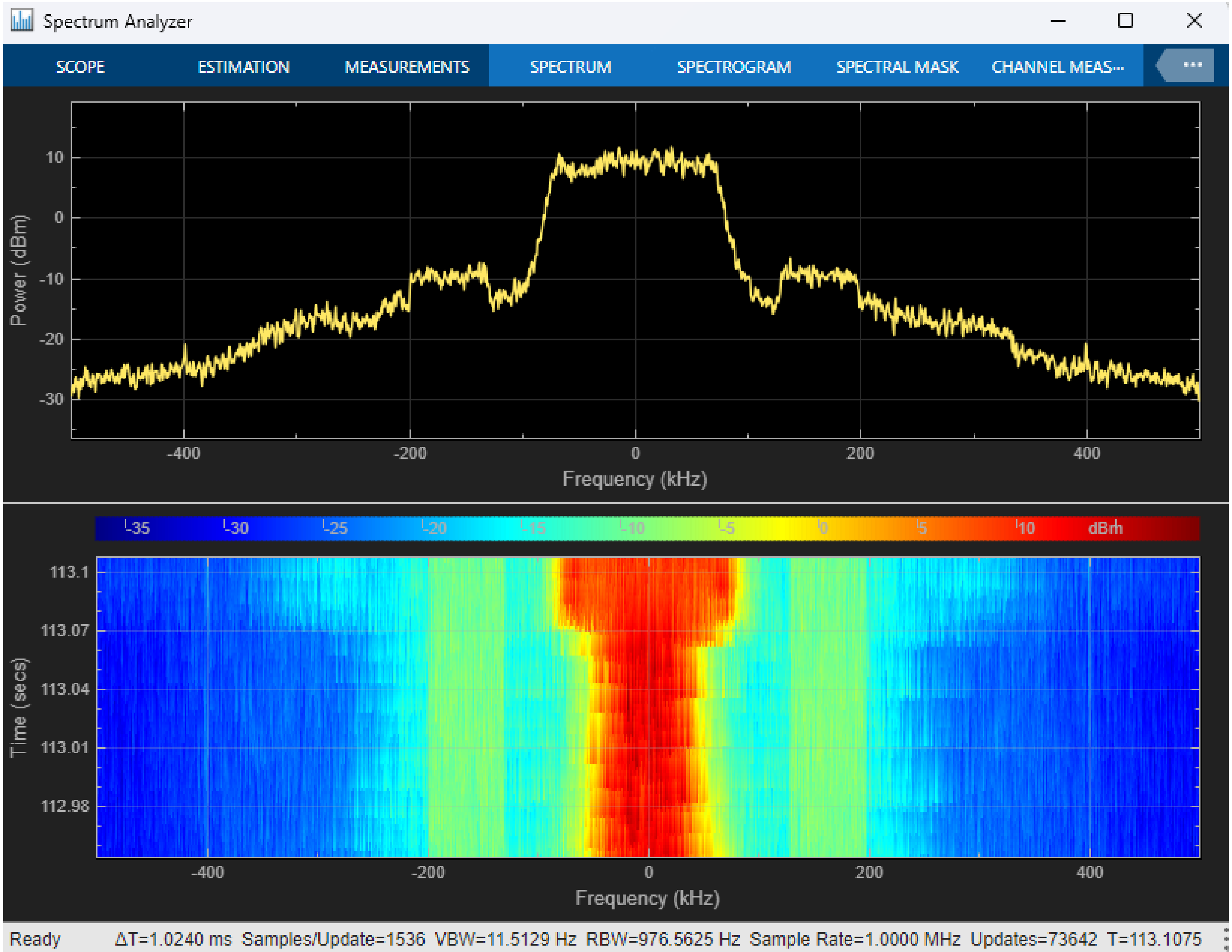


Figure 11 Spectrum and Spectrogram View

The top display is the spectrum view as before. The bottom display is a view of the signal in both the frequency domain and the time domain. The time domain is along the vertical axis and frequency is along the horizontal axis. The colors in the display indicate the amplitude of the signal. This view is very helpful when trying to capture events that cause a rapid change in the spectrum.

Capture a plot of the spectrum and spectrogram display of your signal and include it in your report and include observations of what you see in the spectrogram display. Close the Simulink model.

Part 4: Exploring Public Safety Spectrum

Exploring the RF Spectrum

Radio communications is an important tool for public safety organizations such as police, fire and ambulance. They use a different mode of communications than FM broadcast. The signals are often digitally modulated and cannot be converted to audio directly with the same method as the FM broadcast signals.

Common frequency bands used by public safety are in the 150 MHz and the 460 MHz region. You can often search for scanner frequencies in your area to find out what organizations are using which frequencies. In the Rochester area frequencies can be found using this link.

https://www.radioreference.com/apps/db/?ctid=1852

Open the model for observing spectrum in the public safety band "Public_Safety_Spectrum_CE2251.slx". You will notice that this model is very similar to the FM Broadcast receiver model, but doesn't have the FM Demodulation block. Another difference is that this model uses a higher sample rate and will capture more spectrum at a time. Start the model by pressing the green run button. The receiver is initially centered at 460.5 MHz and will begin to capture signals using the Max-hold trace. Adjust the center frequency of your receiver to align with the public safety frequencies that you find in your area.

Capture the spectrum over time while observing the spectrogram. It may take 15 to 20 minutes to capture enough signals to analyze. Be patient.

Here is what my capture looked like after about 5 minutes.

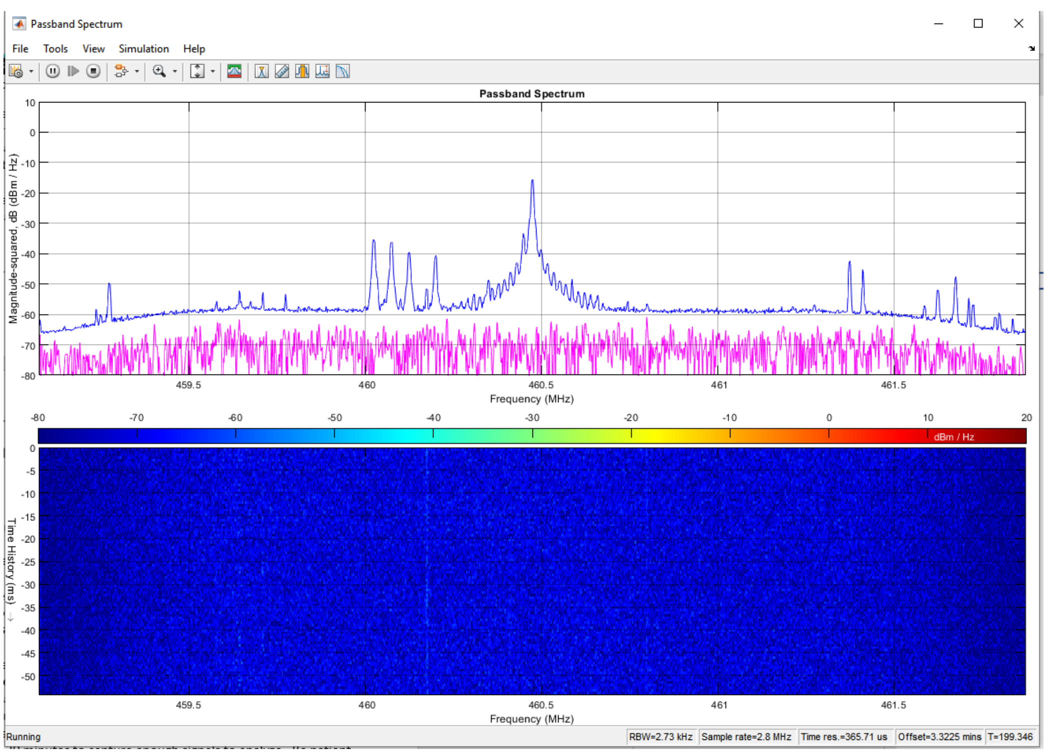
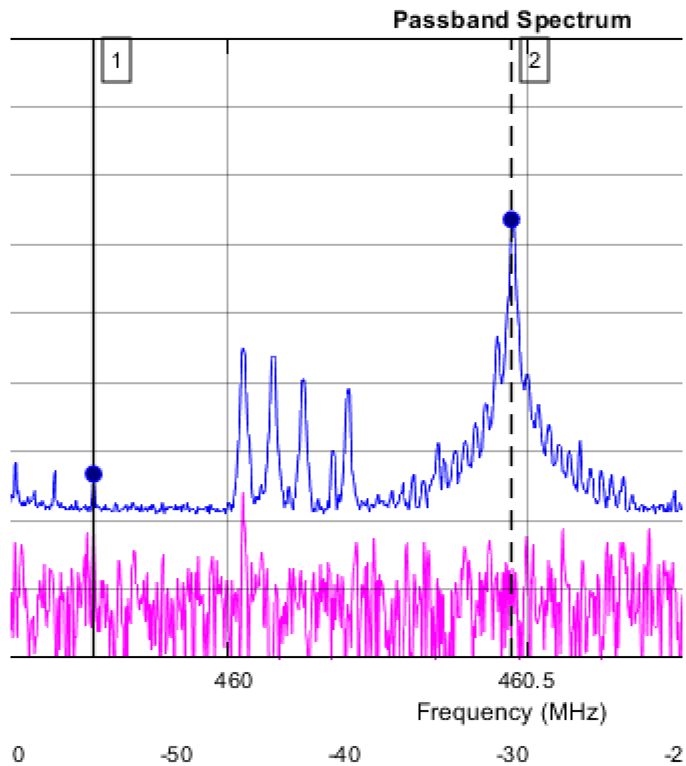


Figure 12 Public Safety Band Spectrum Capture

Exploring the RF Spectrum

You can find the frequency of any one of the signals by using the measurement cursors. Turn these on by selecting the MEASUREMENTS/Data Cursors drop down. You will see two cursors.

Two cursor lines will appear on the screen. You can move the cursor around with a mouse and fine tune the locations with the arrow keys.



The cursors drop down box will show the frequency of the signals. Measure the frequency of at least five of these signals and correlate them to the public safety organization that is assigned to the frequency as best you can . Copy a picture of your spectrum capture and list the frequencies and the corresponding organizations that you found in your spectrum capture.

What do you observe that is different about the nature of these signals when compared to the FM Broadcast signals? Include your observations in your report.

The FM Broadcast receiver model looked at a single signal within the band, but what does the rest of the signals look like? What is the duration of the signals? What else do you observe?

Measuring Bandwidth of Public Safety Signals

After capturing the spectrum for a while, find the largest and most prevalent signal. Measure its center frequency and adjust the frequency of the receiver to this frequency. We want to “zoom in” on this signal and measure its bandwidth. In order to look at less spectrum we need to change the sample rate of the RTL-SDR. Stop the model from running and double click on the RTL-SDR block. This will open the parameter gui. Set the sample rate to 250 kHz. This will change the display to show just 250 kHz of spectrum. Restart the model and capture data for enough time to get a good capture of the spectrum of the signal.

As before select Tools/Measurements/Channel Measurements. If there is more than one signal shown in the capture make sure that the span is set so that it is looking at only the desired signal as in Figure 13. Measure the 90% and the 99% occupied bandwidth of the signal. How does this compare with the bandwidth of the FM broadcast signal?

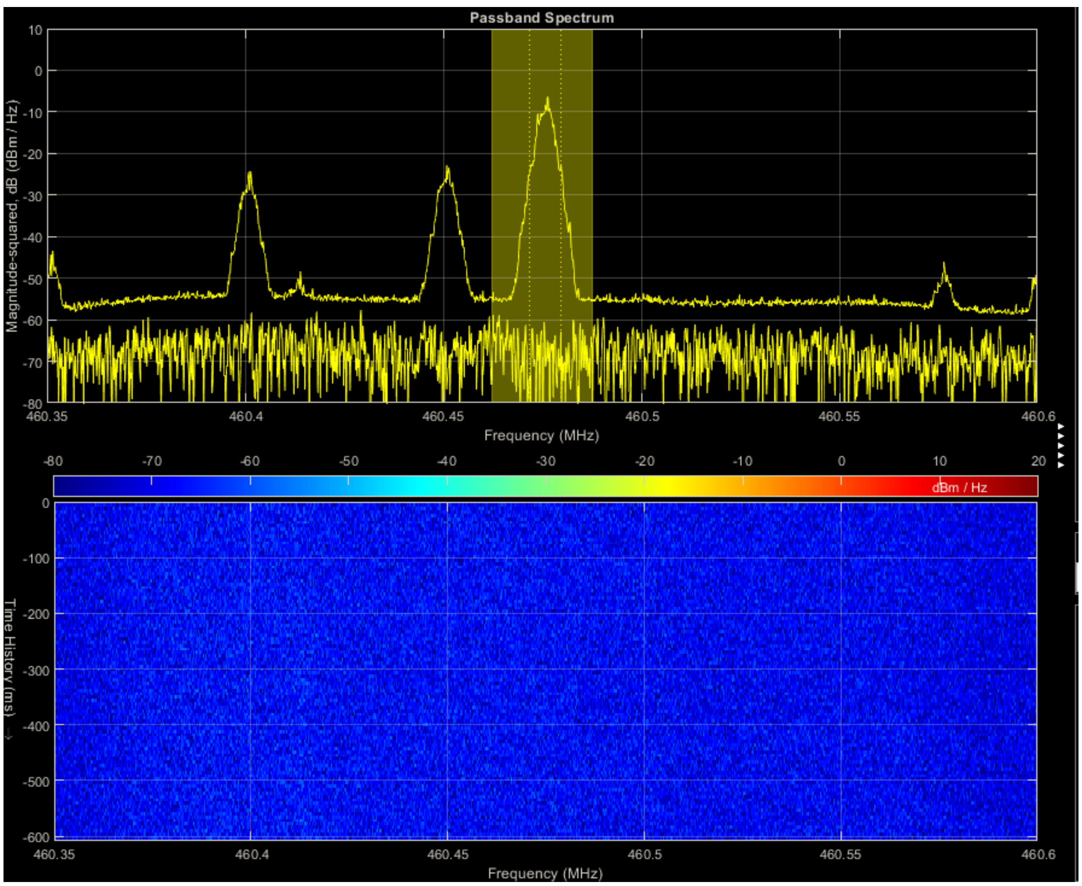


Figure 13 Spectrum Capture for Bandwidth Measurement

Part 5: Exploring Digital Signals

Many radio transmissions today are actually digital data, even many voice signals are converted to a digital mode then transmitted over the air. One very common source of digital data is a key fob that you may have for your car. Key fobs usually transmit on one of two frequencies depending on your vehicle. The two frequencies are 315 MHz and 433.92 MHz. The digital format is different for both.

Open the Simulink File Key_Fob_CE2251.slx. This file contains the same RTL_SDR block but doesn't have the FM demodulator. The model is shown below in Figure 14.

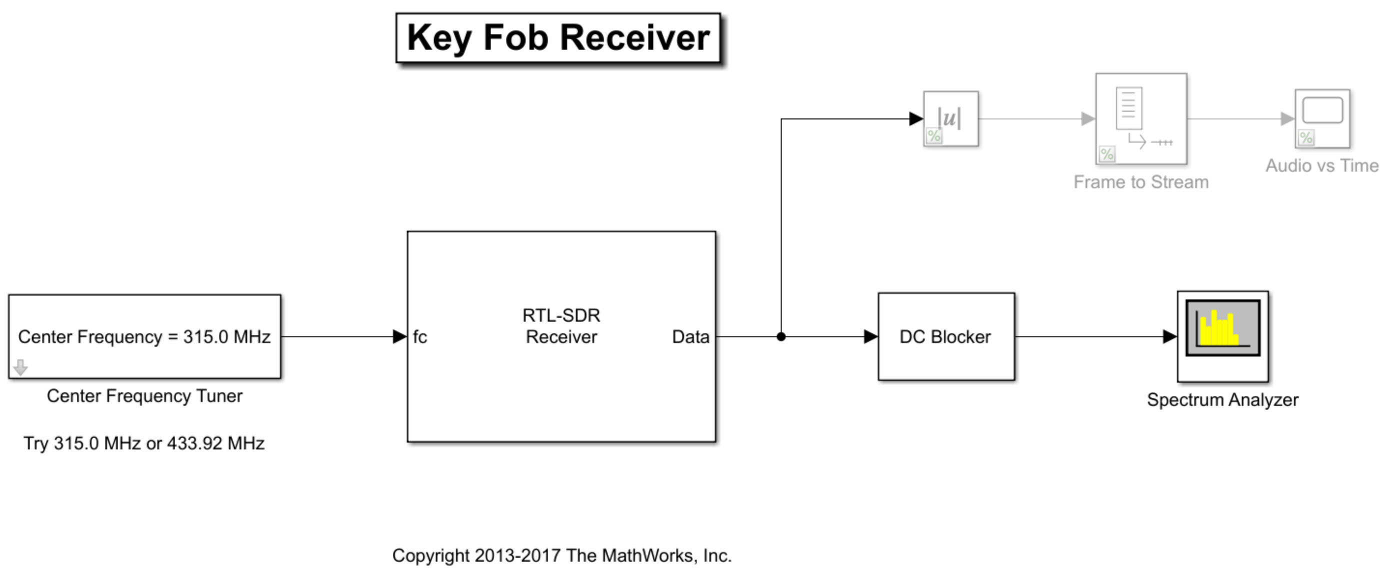


Figure 14 Simulink Key Fob Receiver Model

Run the model and look to see if it can receive your key fob transmission. If you don't see it on one of the frequencies, try the other. Since the signal is a burst the model has the MAX HOLD trace on the Spectrum Analyzer turned on. The time scope elements are initially commented out. If you want to use the time scope, select the three components (Magnitude, Frame to Stream and Scope) right click and select Uncomment. You set up the scope similar to the scope in the lab. It has the ability to trigger on a signal so that you can see what it looks like in the time domain. Look under the MEASUREMENTS tab for trigger settings.

Capture a spectrum display and a display from the scope and include that in your report. Also include some observations of the key fob signal an how it may differ from the audio signal.

Part 6: Exploring Other Radio Bands

Now explore other portions of the radio spectrum. The RTL-SDR can receive over the frequency range from 500 kHz to 1.75 GHz. The antennas that are provided with the kit may be too short to receive the very low frequency signals but depending on signal strengths you may be able to receive some signals. For higher frequencies (say above 300 MHz) you may want to try the smaller antenna set.

Search the internet for signals that may be of interest to you and capture their spectrum on the RTL-SDR. Reset the sample rate of the RTL-SDR to 2.8 MHz (its stable maximum) and adjust the center frequency of the receiver to the desired frequency. Measure the 90% bandwidth of different signals that you find. Capture and measure at least 2 other frequencies that are not in the FM Broadcast band or in the public safety band. Try searching for a radio spectrum chart that shows the frequency usage over a large part of the spectrum.

Some suggested signals (but there are many others)

Amateur radio frequencies
4G LTE bands
TV Channels
FRS radio
IoT bands
Key Fob Frequencies (315 MHz and 433.92 MHz)

Exploring the RF Spectrum

Lab Report Requirements:

Your lab report should be a neatly formatted report in electronic format that shows your design approach, schematic, simulation results, measurement results (including any graphs and plots). Also include the answers to any questions asked in the lab with the question clearly restated and your answer. Be sure to include your partner's names in the lab. The lab report should be in electronic format (PDF Only) and be submitted using the assignments section (dropbox) in MyCourses.

Grading Rubric

Lab Section	Result Description	Points Available
Introduction	In your own words describe the purpose of the lab and the basic approach	10
Part 2	Plot of the FM Broadcast signal	20
Part 3	Correct measurement of the signal bandwidth showing the 90 and 99% bandwidth values. Answers to questions posed in the lab.	20
Part 4	Capture of frequency spectrum for the public safety band. Measurement of the bandwidth Answers to questions posed in the lab	20
Part 5	Plot of the spectrum of the key fob signal at either frequency Observations of the digital spectrum and the time domain	10
Part 6	Plots showing capture of 2 other signals in the frequency spectrum. Measurement of the 90% bandwidth of those signals	10
Conclusion	A paragraph in your own words on what you learned from this lab.	10

Instructor comments: