Week 3 Instructor Notes

Lecture Notes

This is the first of two weeks designed to introduce students to the fundamentals of radio astronomy. Day 1 introduces why we can, and want to, do astronomy at radio frequencies. Day 2 introduces students to how single dish radio telescopes are designed and how they work. Day 3 covers the basics of the signal processing necessary for radio astronomy. If your primary focus is to prepare students for the lab, then it is suggested to focus on the material covered in day 3 in your lectures.

Example GRC files have been created for the day 3 material to demonstrate important signal processing concepts, these can be found on the course website in the Week 3 GRC Files folder. The files are listed below along with instructions for how to use them.

1. `Nyquist.grc`

   This simple flowgraph illustrates the Nyquist theorem and the significance of the sample rate in processing a signal. It shows the effects of aliasing and waveform degradation, while also introducing the concept of a fast Fourier transform. The Signal Source block produces a sine wave with an adjustable frequency. The Throttle block samples the signal at an adjustable sample rate. The QT GUI Time Sink displays the waveform of the sampled signal. The QT GUI Frequency Sink block computes and displays the fast Fourier transform (FFT) of the sampled signal, allowing you to see which measured frequencies are present in the sampled signal.

   The default sample rate is 16KhZ, at which, according to the Nyquist theorem, you can sample a signal with a frequency of up to 8KhZ. When you run the flowgraph, the sliders at the top of the window allow you to adjust either the sample rate or the signal frequency. Increase the frequency past the Nyquist frequency of 8KhZ. At this point you should see a measured alias frequency that no longer corresponds to the actual signal frequency. As you increase the frequency further past this point, the measured frequency will actually decrease. If you increase the frequency to match the sample rate, then you'll see no measured signal, because the signal is being sampled at the same place along the wave for every wavelength. You will also see a degraded

waveform, which can be easier to see by zooming in on a section of the waveform display (drag a box around the region of interest).

2. `AM_transmitter.grc` and `AM_receiver.grc`

   These two flowgraphs demonstrate how AM modulation and demodulation work. Download a WAV audio file of your choosing and input the path into the **Wav File Sink** block on the `AM_Transmitter.grc` flowgraph. The blocks in the flowgraph are easy to correlate with the math behind AM modulation. The message signal $m(t) = A_m \cdot sin(\omega_m t)$ (the Wav File Sink block) is multiplied by a constant for gain control and 1 is added. The signal is then multiplied with the carrier signal $c(t) = A_c \cdot cos(\omega_c t)$ (the Signal Source block) to produce the modulated signal $S(t) = [1 + m(t)] \cdot A_c \cdot cos(\omega_c t)$ which is then sent to the **ZMQ PUB Sink** block for "transmission". The modulation factor $[1 + m(t)]$ determines how much the carrier signal's amplitude varies based on the message signal's amplitude.

   The transmitted signal is received in the `AM_Receiver.grc` flowgraph by the **ZMQ SUB Source** block. Demodulating an AM signal is relatively straightforward. The demodulated signal is given by $D(t) = |S(t)|$, where $S(t)$ is the modulated signal given by $S(t) = [1 + m(t)] \cdot A_c \cdot cos(\omega_c)$.

   The signal is sent through an Finite Impulse Response (FIR). As stated in the documentation for this block, "The main use of this block is an effective channelizer, to pull out a narrowband portion of a wideband signal, without that narrowband portion having to be centered in frequency." The signal is sent through an Automatic Gain Control (AGC) block which equalizes the average volume of different radio stations due to differences in received signal strength, as well as variations in a single station's radio signal due to fading. The magnitude of the signal is found when the data type of the signal is converted from complex to real with the Complex to Mag block, and sent through a Band Pass Filter which further isolates the message signal while removing noise. Finally the demodulated signal is sent to the QT GUI Time Sink block to display the waveform, and the Audio Sink block to play the audio.

   Note that the `AM_Transmitter.grc` flowgraph must be running for the ZMQ SUB Source block in the `AM_Receiver.grc` flowgraph to receive the data. Instruction for setting up the address in these block can be found here: ZMQ PUB Sink, ZMQ SUB Source, Understanding ZMQ Blocks. If you don't want to go through the procedure of setting up the address in the ZMQ PUB Sink and ZMQ SUB Source blocks, then you can delete these blocks, and copy the rest of the `AM_Receiver.grc` flowgraph over to the `AM_Transmitter.grc` flowgraph and connect them together directly. You can copy a group of blocks by dragging a box around them and pressing Ctrl+C or by right clicking on the highlighted blocks and selecting Copy.

3. `Fourier_Transform.grc`

   This flowgraph demonstrates how a Fourier transform can detect the frequencies present in a signal. Five Signal Source blocks are each producing a cosine wave with different frequencies ranging from 1KhZ to 1.775KhZ. These five signals are added together along with a noise source, and sampled by the Throttle block. The combined signal is sent to a QT GUI Time Sink block to display the waveform, and a QT GUI Frequency Sink block which computes and displays the fast Fourier transform (FFT). While it's not obvious which frequencies are present in the signal by looking at the waveform, you should see peaks in the Fourier transform display corresponding to the original signal frequencies. For a clearer view, you may want to zoom out on the waveform display (using your mouse scroll wheel), and zoom in on the peaks in the Fourier transform display (draw a box around the region of interest).

Lab Notes

Installing GNU Radio and RTL-SDR Software

Installation GNU Radio is straightforward, instructions can be found here: InstallingGR.

Installing the necessary software for the RTL-SDR takes a little longer but is not too difficult, instructions can be found here: RTL-SDR Quick Start Guide. The Week 3 Pre-Lab Reading also contains the same instructions to install both GNU Radio and the RTL-SDR software for students; these should both be installed and working before students arrive to the lab. Installation of the RTL-SDR software differs depending on which device you have, so make sure to communicate with students which version RTL-SDR you will be using for the lab.

Getting Data from the RTL-SDR

As your lab class may not have access to enough RTL-SDR devices for the entire class, there are two options for how students can access the data from the device.

1. If your class has enough devices for each student, or for small groups of students to work together, then their flowgraphs should use the **RTL-SDR Source** block to receive data directly from the device. Depending on which model RTL-SDR you are using, the source block might automatically detect the device once it's plugged in, or you may have to enter "rtl=0" for the Device Arguments.

   An example GRC flowgraph can be found on the course website under Week 3 GRC Files as `FM_RTL_SDR_Source.grc`

2. If you only have a single RTL-SDR for the class, then you can receive the data from

the device and send it through the internet to each student. To do this, connect the **RTL-SDR Source** block to a **ZMQ PUB Sink** block. Students can then begin their flowgraphs with an **ZMQ SUB Source** block, which will receive the data input to the ZMQ PUB Sink block. Instructions to set up the appropriate address can be found at the following links: ZMQ PUB Sink, ZMQ SUB Source, Understanding ZMQ Blocks.

Note that your flowgraph containing the ZMQ PUB Sink block must be running for the students to receive data on their end. If your class is using this method, then students will not be able to adjust the center frequency on their flowgraphs, that must be done on your flowgraph, as it contains the RTL-SDR Source block which controls the center frequency.

Example GRC flowgraphs can be found on the course website under Week 3 GRC Files as `RTL_SDR_to_ZMQ_PUB_Sink.grc` and `FM_ZMQ_SUB_Source.grc`.