A Wireless Test Bed for Data Rate Maximization

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Abstract

In order to experiment different methods of increasing the energy efficiency in wireless networks, a test bed must first be set up and benchmarks for the transmissions found. The transmissions used were one way and two way transmissions of a data file using different types of digital modulation as well as different bandwidths to find the benchmark data rates that the radios could manage. The project used GNU Radio and two USRP B200 software defined radios to transmit and test these data rates. The modulation schemes used were BPSK, QPSK, 8PSK, 16PSK, 32PSK, 16-QAM, 64-QAM, GMSK, and OFDM. The setup and implementation of a software defined radio programming environment is discussed within detail as well as the results of each transmission.

Keywords: OFDM, GNU Radio, Test bed, PSK, QAM, GMSK

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SECTION 1: INTRODUCTION

Background

There exists an increase in global mobile traffic over the last decade. Traffic increased 66 times with an annual growth rate of 131 percent between 2009 and 2014. The data rates have not kept up as quickly with the increase in demand. The peak data rate used in the third generation and fourth generation wireless systems only increased annually by 55 percent during this period. As the world turns more towards wireless technology, there exists an excess of demand that the current systems cannot handle. Greater demand in wireless traffic warrants an increase in building infrastructure for more wireless systems. With more infrastructure built, this will cause an increase in energy consumption and increase the overall amount of greenhouse gases used in total by mobile networks across the world.

The Green Radio project proposed by IEEE focuses on making current and future infrastructure of wireless systems energy efficient when possible. This infrastructure includes retail, data center, core transmission, mobile switching networks, and base stations. Retail would include mobile handsets and personal Wi-Fi routers. For current cellular networks, more than 50 percent of the entire power consumption is taken up by base stations. The second highest is mobile switching clocking in at 20 percent of the energy used. Base stations are nodes in a wireless network that can repeat and amplify a wireless signal. They are stationed at specific GPS locations to understand the user's location within the system. The majority of the energy used at a base station is for amplifying signals to be transmitted. The transmission of signals is accomplished by using radio transceivers, power amplifiers, and transmit antennas. The defined goal for the Green Radio project was to develop a way to increase the energy efficiency of these base stations while still providing the same quality of service that is currently provided.

One way to save energy is to use adaptive modulation for the transmission of signals. This means that the modulation scheme used can be switched from one that is fast but is not energy efficient, to one that is energy efficient, but lacks spectral efficiency. This could be done when the traffic in the area is lower than the average traffic levels, meaning that there aren't as many users who need the system. This frees up the allotted bandwidth able to be used by the system to enable a tradeoff of spectral efficiency to energy efficiency. This tradeoff can be done by switching the modulation scheme used by the transceiver. This could be done based on the average traffic within an allotted time frame. To understand how different modulation schemes affect the energy and spectral efficiency of transmissions, a test bed must be created to experiment with the different types of modulation.

Definition

By creating a Software Defined Radio Programming Environment, the data rates, spectral efficiency, and energy efficiency of one way, two way, half duplex, full duplex, and multi-hop transmissions utilizing BPSK, QPSK, 8PSK, QAM, 64QAM, GMSK, and OFDM can be found and compared to existing standards.

Plan

The plan was to first research whether or not a sensor network should be utilized or if two software-defined radios (SDR) should be used. The second task was to find software that was compatible with the chosen hardware. If a sensor network was to be used, then the nodes had to be programmed to transmit data to a computer that can gather all the information. If SDRs were to be used, then a software environment was needed to program the radios.

An environment consistent of two SDRs was used for this experiment. This was chosen so that the modulation schemes could be modified easier. Using an SDR also meant that the bandwidth and speed of the data transmission could be changed with ease. The tradeoff of using this type of environment meant that the price of each node (each SDR) was to be significantly more expensive than each node in a simple sensor network. The next milestone after the environment was set up was to transmit a file one way. "One way" meant that one radio was the transmitter and the other radio was the receiver and a file could be sent wirelessly from one radio to the other. A two way transmission was the next milestone where one radio could both receive and transmit a file. Half duplex is the term that describes the type of file transmission set up. With half-duplex, each radio can transmit and receive, but not at the same time. Full duplex is when both radios and transmit and receive simultaneously. Multi-hop was the last milestone that was to be achieved. With a multi-hop environment, one radio would transmit a file. Next, a second radio would receive that file and repeat it to a third receiver out of the range of the first transmitter. When each of these situations could be set up, then the transmission speed of the file using each of the digital modulation schemes previously listed would be found.

Equipment List

(2) USRP B200

(1) USRP N210

(3) Laptops

- (1) Lenovo G50, (2) Dell Latitude E5430

(6) VERT 900 Antennas from Ettus Research

(3) USB 3.0 cables

Software List

Ubuntu 14.04 LTS

GNU Radio 3.7.5

UHD 3.8.2

Script_Install_Xubuntu_Packages.pl (provided by Neel Pandeya from Ettus Research)

Hardware Discussion

At first, the plan was to mesh sensor network out of radio nodes. The three nodes considered were a series 2 Xbee node, a JeeNode, and a Nordic nRFN2401. The Xbee nodes were very popular nodes with a lot of documentation and resources to learn from. They had great range, they were easy to program, and the network could be expanded easily to provide for more complex projects. The JeeNodes were specialized nodes made for student sensor network projects, but the resources were not very popular. There was documentation provided, but only on the website, and there were minimal to no resources listed elsewhere on the internet. The third sensor node that was considered to implement a network was the Nordic nRFN2401. It was the cheapest of all the nodes, but it was the least popular of all of the considered nodes used. It also needed an interface to program and a computer with Linux on it to communicate with the other nodes in the ad hoc network.

The thought to use cheaper nodes was supposed to be a money saving decision. After discussing the budget some more it was decided that using SDRs would be a better decision. The reasons were that the radios were easier to program than each of the nodes, other researchers in the lab had experience using GNU Radios and SDRs, and the complex radios meant that the network could be expanded upon in the future for more research.

The USRP B200 has a range from 70 MHz - 6 GHz and is compatible with GNU Radio and languages C++ and Python. It uses USB 3.0 and has a data rate of 64.11 MS/s with a 12 bit ADC/DAC. It is capable of up to 56 MHz bandwidth during 1 to 1 communication. It is fully programmable using GNU Radio. It was chosen due to its large bandwidth range and its compatibility with GNU Radio.

Setup and Implementation of the Software Environment

There is a lengthy process to get the SDR Development Environment set up on a computer. To set up the SDR Environment it involves installing the appropriate software, firmware, and buying the appropriate hardware for the job. The software to install is an open source SDR software programming tool called GNU Radio. The hardware used to transmit the signals is a USRP B200 provided by Ettus Research. The firmware that links the USRP B200 to GNU Radio is a program called the Universal Hardware Driver (UHD). This code is provided by Ettus Research and is updated often.

In order to effectively install these programs, it is strongly advised against using a virtual machine to install these programs. In the past, Ettus Research has had many problems with different types of virtual machine simulators. UHD and GNU Radio work best when installed on a system running Linux directly. Also, when installing UHD and GNU Radio, using apt-get as your primary installer is not advised. The packages that apt-get fetches are out of date and will not work as expected. It is better to install directly from source code than use a package manager to install these programs.

First, install Ubuntu 14.04 LTS on a computer. Next, copy the provided source code from the last pages of this document into a new text file. Save it as a ".pl" file as a perl file. Make sure the file is executable and execute it as a perl script. This will install all of the possible dependencies for UHD and GNU Radio. Sit with the script for awhile, it takes a bit of time to execute. Run as root user.

After the perl file executes, go to the address provided:

http://code.ettus.com/redmine/ettus/projects/uhd/wiki/UHD_build#Get-the-Source-Code

Scroll halfway down the page to the link "Source archives for release tags." This will display all of the latest stable releases for UHD. Download he latest version. At the time of this writing, the latest version was 3.8.2. Download the tar.gz file.

https://github.com/EttusResearch/UHD/tags

Move tarball file to a desired location. Execute the following command on the file. Instead of "file.tar.gz" it will be "uhd-release_003_008_002.tar.gz" or whatever your file is named.

```
tar -xzvf file.tar.gz
```

Move into the newly created uhd directory. Click on the following link. This will bring up the USRP Hardware Driver and USRP Manual where in it has the build instructions for Unix. Scroll down until the **Build Instructions (Unix)** heading is found.

http://files.ettus.com/manual/page_build_guide.html

Move into the host directory in uhd. Execute the following commands. This will make a new build directory then generate the make files in order to install UHD on the computer.

```
cd <uhd-repo-path>/host
mkdir build
cd build
cmake ../
```

Next, execute the following commands. These instructions were pulled directly from the manual.

```
make
make test
sudo make install
sudo ldconfig
```

UHD should now be downloaded and installed. However, there is one post-installation task that needds to be done in order to work with a USB device such as the B200. Click on the following link.

http://files.ettus.com/manual/page_transport.html

These are the transport notes. A transport is the layer between the packet interface and a device IO interface. The USB transport is implemented with LibUSB. LibUSB provides an asynchronous API for USB bulk transfers. Scroll down to the **Setup Udev for USB (Linux)** heading. Execute the following instructions. This will enable a rule that lest non-root users access the device.

```
cd <install-path>/lib/uhd/utils
sudo cp uhd-usrp.rules /etc/udev/rules.d/
sudo udevadm control --reload-rules
sudo udevadm trigger
```

UHD should now be installed and set up. Now to setup GNU Radio. Click on the following link. This will show the 3 step process that goes towards installing GNU Radio onto a computer. Most of the dependencies should already have been filled if the perl script ran without error.

http://gnuradio.org/redmine/projects/gnuradio/wiki/BuildGuide

Download a release tarball from the download page of GNR Radio. Download the tar.gz version of the latest release. You can download from the list of releases at the following link.

http://gnuradio.org/releases/gnuradio/

Move the downloaded file to a desired location. Run the following command on the tar.gz file. This step is similar to the process stated before.

```
tar -xzvf file.tar.gz
```

Move into the newly created gnuradio directory. From here, execute the following commands. This will create a new build directory, generate the make files, test the files, then install GNU Radio onto the computer.

```
mkdir build
cd build
cmake ../
make && make test
sudo make install
sudo ldconfig
```

Use a USB cable to connect the B200 to the computer through a USB 3.0 or 2.0 port. Run the command “uhd_find_devices” in the terminal. If UHD installed correctly it should display the output of Figure 1. This method is used to find radios connected to the main computer. It loads firmware specific to each type of radio from the driver onto the radio.

Figure 1: Successful Run of uhd_find_devices

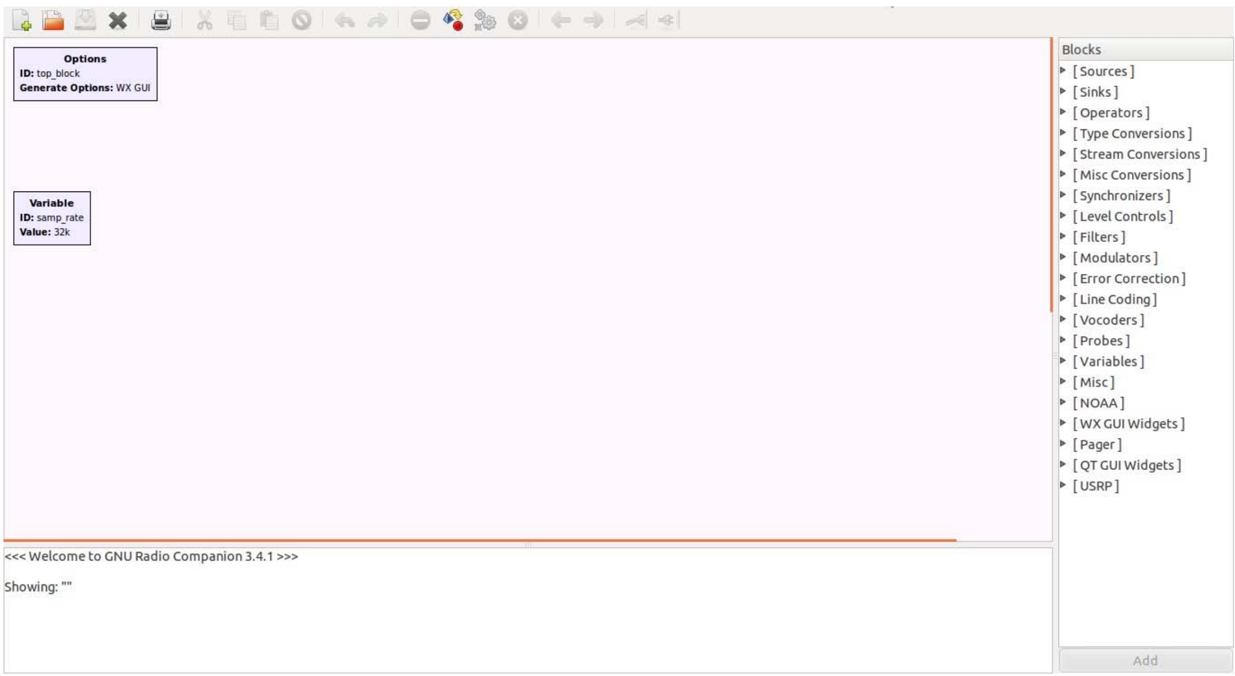
```
cns-lab@cnslab-Linux4:~/uhd$ uhd_find_devices
linux; GNU C++ version 4.8.2; Boost_105400; UHD_003.008.002-102-gd9241b78

-- Loading firmware image: /usr/local/share/uhd/images/usrp_b200_fw.hex... done
--------------------------------------------------
-- UHD Device 0
--------------------------------------------------
Device Address:
    type: b200
    name:
    serial: F5EA38
    product: B200


cns-lab@cnslab-Linux4:~/uhd$ 
```

Run the command “sudo gnuradio-companion” in the terminal. If GNU Radio installed successfully then the text similar to that of Figure 2 should appear in the terminal window. GNU Radio Companion should also start to run and you'll see an application like Figure 3.

Figure 2: Successful GNU Radio Companion Execution

```
cns-lab@cnslab-Linux4:~/uhd$ sudo gnuradio-companion
[sudo] password for cns-lab:
linux; GNU C++ version 4.8.2; Boost_105400; UHD_003.008.002-102-gd9241b78


(gnuradio-companion:21458): IBUS-WARNING **: The owner of /home/cns-lab/.config/ibus/bus is
 not root!
<<< Welcome to GNU Radio Companion 3.7.5 >>>

Preferences file: /home/cns-lab/.grc
Block paths:
        /usr/local/share/gnuradio/grc/blocks
        /home/cns-lab/.grc_gnuradio

Loading: "/home/cns-lab/GNU Radio Creations/fm_example.grc"
>>> Done

Showing: "/home/cns-lab/GNU Radio Creations/fm_example.grc"
```

Figure 3: Basic GNU Radio Companion start up screen.



Click on the following link. This will bring up a tutorial on how to make an FM receiver using GNU Radio. By following the steps provided in the tutorial a simple program can be made to program the B200. This will test if the B200 is operational and is ready for further use.

https://www.youtube.com/watch?v=KWeY2yqwVA0

SECTION 2: SYSTEM FUNCTIONALITY

GNU Radio

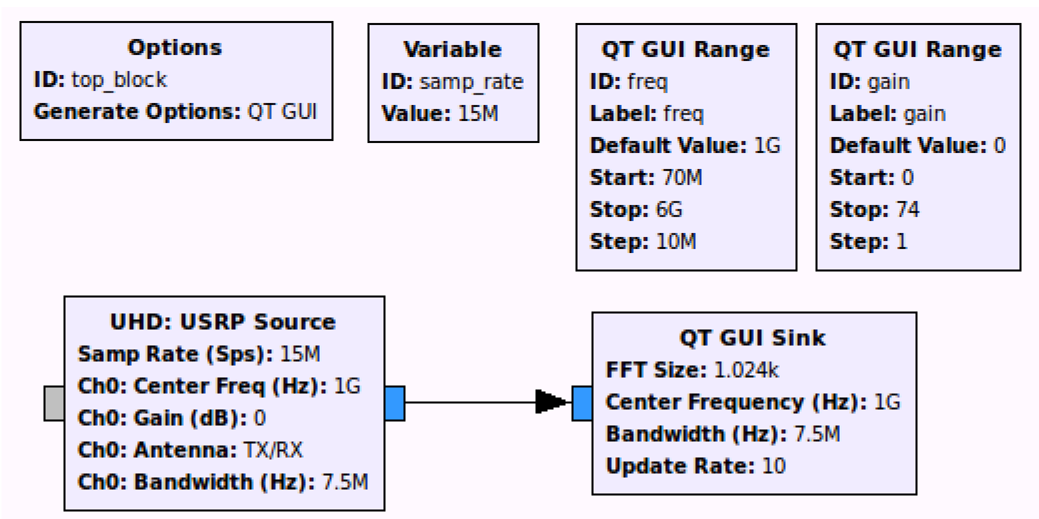
GNU Radio is a free open source software used to simulate signal processing systems and program software-defined radios. It uses a graphical user interface (GUI) called GNU Radio Companion. In GNU Radio Companion there are programs are called flow graphs which are signal processing blocks lined in a logical order. Each block is a different signal process that describes a different function that can be performed with a radio system, such as a BPSK modulator. Each of these blocks is coded in C++ or Python. Custom blocks can be coded and imported into GNU Radio Companion.

Flow graphs need a source and a sink to operate. The source is where the data comes from and the sink is where the data is going. The other blocks modify the data as it passes from the source to the sink. There can be multiple sources and sinks for a flow graph, but for most programs there is only one source while multiple sinks can be common.

Spectrum Analyzer

The first flow graph that was created for testing the USRP B200s was a spectrum analyzer flow graph. The purpose of this flow graph was to program all the abilities a spectrum analyzer has into an SDR and see if it could pick up a signal or not.

Figure 4: Spectrum Analyzer Flowgraph



This flow graph shown in Figure 4 is very simple, it has a source block and a sink block. The source block is taking in data from the USRP according to the values specified by its internal options. The sample rate is set by a variable named samp_rate which is given the value of 15,000,000 or in this case 15MHz. The center frequency is defined by the variable freq which is specified in the QT GUI Range box. This box maps out a variable that can be changed during run time using a GUI. The range is specified by the start and stop values. The accuracy is dependent of the step value. The default value is what the variable starts at. The gain range is used by the USRP source block to determine what the gain of the SDR is during run time. The bandwidth is a value that determines the range of frequencies used at a given band. For this example, the center frequency is at 1GHz with a bandwidth of 7.5MHz, which means the range of frequencies received will be between 1.0075GHz and 0.9925GHz.

Figure 5: Spectrum Analyzer GUI

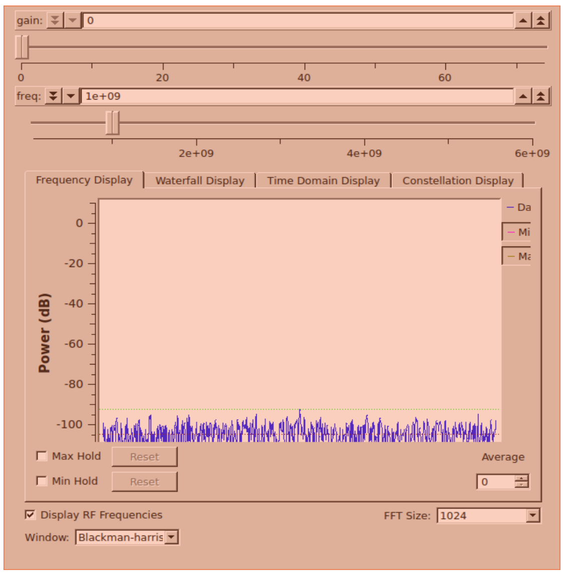


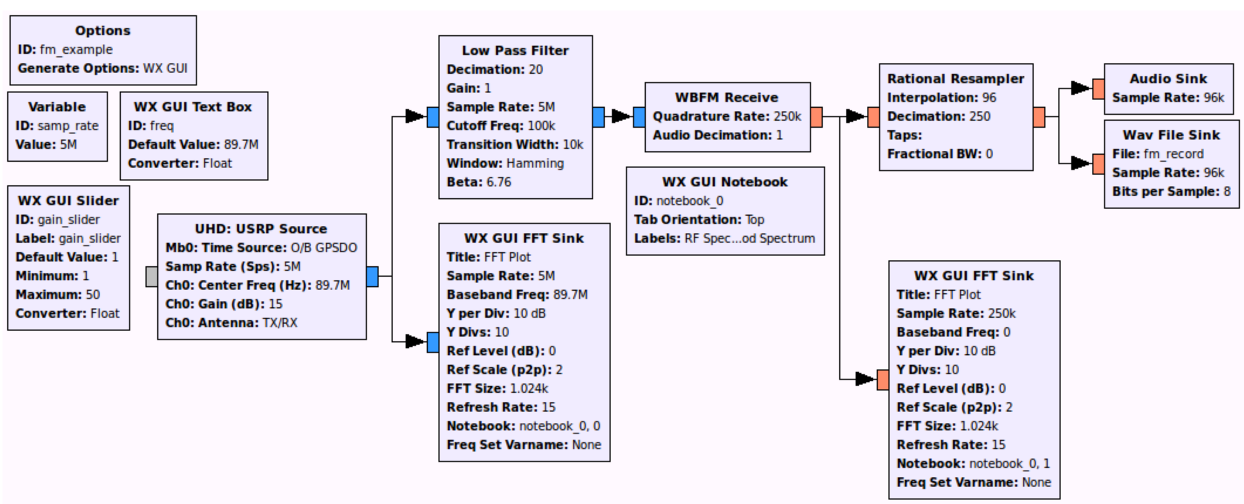
Figure 6: Overruns

```
Generating: "/home/cns-lab/GNU Radio Creations/top_block.py"

Executing: "/home/cns-lab/GNU Radio Creations/top_block.py"

linux; GNU C++ version 4.8.2; Boost_105400; UHD_003.008.002-102-gd9241b78

-- Operating over USB 2.
-- Initialize CODEC control...
-- Initialize Radio control...
-- Performing register loopback test... pass
-- Performing CODEC loopback test... pass
-- Asking for clock rate 32.000000 MHz...
-- Actually got clock rate 32.000000 MHz.
-- Performing timer loopback test... pass
-- Setting master clock rate selection to 'automatic'.
-- Asking for clock rate 15.000000 MHz...
-- Actually got clock rate 15.000000 MHz.
-- Performing timer loopback test... pass
-- Successfully tuned to 1000.000000 MHz
--
Using Volk machine: avx_64_mmx
```

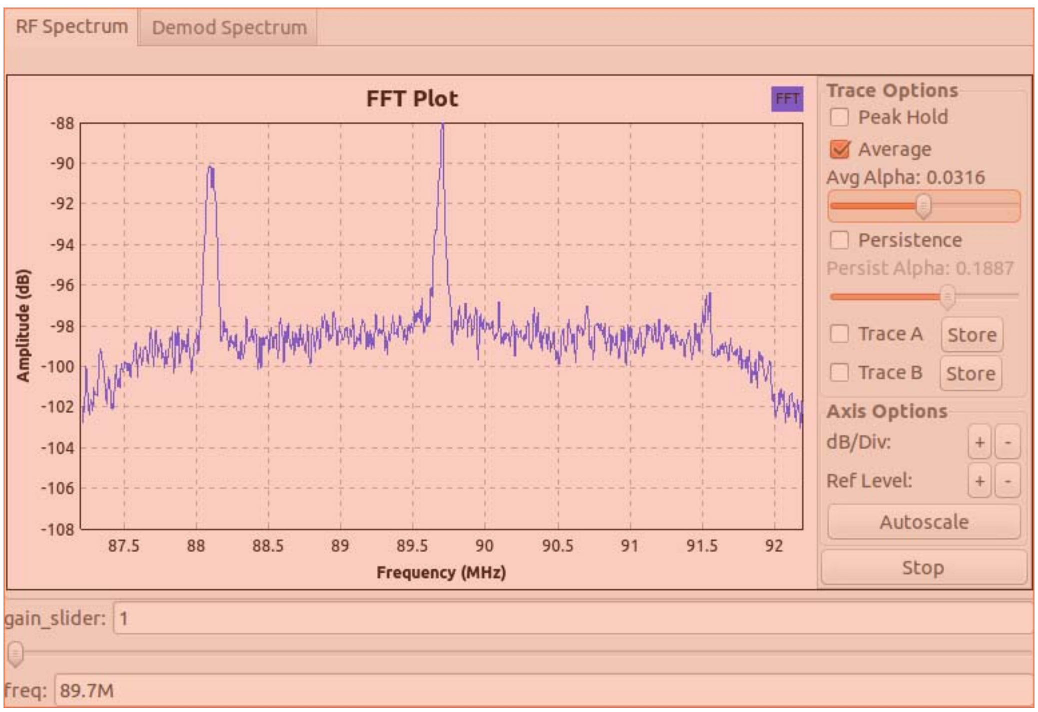
The Spectrum Analyzer GUI is shown in Figure 5. The SDR is currently tuned to 1GHz as described by the freq variable. The gain of the SDR is set to zero, which means there is no additional amplification other than the internal amplification intrinsically in the SDR. The Power to Frequency chart can be seen here. The signal seen hovering around -110db is the average noise floor as seen by the B200 in the laboratory. There were no significant signals being broadcast at 1GHz at the time. If there were signals known that were to be there, then the gain should have been increased in order to increase the receiving sensitivity of the USRP in order to perceive said signals.

Figure 6 shows a common problem associated with external sensing equipment. When there are too many samples coming into the computer from an outside piece of hardware, and the computer can't keep up with the processing of the samples, that means that there are overruns being caused and some data being lost. The solution to getting rid of overruns is to either get a faster computer that can handle more data or slow down the data rate transfer. It is important to check to see if the data rate used by GNU Radio Companion is the same as the one used by the SDR, but usually GNU Radio has default setting to prevent miscommunication between the two systems. Underruns are also common problems that are similar to overruns. And underrun occurs when a piece of hardware requests data at a certain rate from another computer and it doesn't get the data fast enough. This happens when there is a drop in connection between the radio and the computer. Many times underruns will occur when the host computer is busy processing another request and not feeding data to the SDR. For example, if I moved the mouse and opened another application while transmitting using GNU Radio, some underruns will occur because the computer needs to pause and open the application before returning to the SDR's needs. Underruns are a problem because the buffers in the SDR will fill with garbage when and will have to waste time flushing the internal buffers instead of transmitting to the other radio. In summary, overruns happen when there is too much data to process, and underruns happen when there is not enough data to process.

FM Radio Receiver



The second flow graph that was made was an FM Radio Receiver. This receiver was a bit more complicated than the spectrum analyzer. It started off with a USRP source block which had a variable center frequency defaulting to 89.7MHz which is a local radio station in the Omaha metro area. The specified antenna to be used was the TX/RX antenna on the B200 which was a special line that could both receive and transmit a signal. This received signal was then sent to a Low Pass Filter block and a WX GUI FFT Sink block. The WX GUI FFT Sink is a GUI that shows up during run time and displays the frequency to power characteristics of the inputted signal. In other words, it shows the FFT of the analog signal. The Low Pass Filter is there to cut off all frequencies that are above 100kHz. The WBFM Receive block stands for Wide Band Frequency Modulation Receiver. This block is the FM demodulator block for the flow graph. This also has the option of decimating the audio from the output of the demodulator to a specific sample rate, but this step will instead be done in the Rational Resampler block instead of here. The output of this demodulator is fed into another FFT sink and a Rational Resampler block. This block will resample the audio to a sample rate that matches the audio card used in the host computer. In this case, the audio is interpolated up by a factor of 96 then decimated by a factor of 250 to get a sample rate of 96kHz on the output. This file is then fed to an Audio Sink and a Wav File Sink. The Audio Sink will feed this signal straight to the sound card on the host computer and play it through the speakers. The Wav Sink File is a block that saves the passed signal to a .wav file. The location of this file is specified within the block.

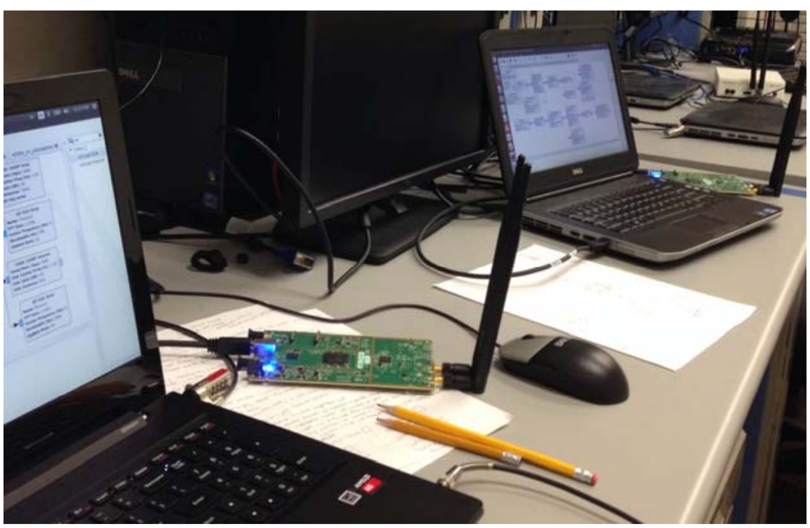


The spectral display of the FM Receiver is shown on the previous page. The radio station 89.7 is coming through at a peak power of -88db. The spike in the middle of the screen is the station while the spike towards the left of it is another neighboring station. The noise level is about -99db and varying depending on the stations surrounding it. The gain of the radio can be increased and decreased using the gain_slider variable. In this picture it is currently set to 1 but can be set to 80 or more. Usually the gain on the SDR is set below 90.

Implementation of PSK Signal Transmissions

```
Generating: "/home/pki120/Downloads/psk_test_top.py"

Executing: "/home/pki120/Downloads/psk_test_top.py"

linux; GNU C++ version 4.8.2; Boost_105400; UHD_003.008.002-0-unknown

-- Operating over USB 3.
-- Initialize CODEC control...
-- Initialize Radio control...
-- Performing register loopback test... pass
-- Performing CODEC loopback test... pass
-- Asking for clock rate 32.000000 MHz
-- Actually got clock rate 32.000000 MHz
-- Performing timer loopback test... pass
-- Successfully tuned to 900.000000 MHz
--
Using Volk machine: avx_64_mmx

Modulator:
bits per symbol:    5
RRC roll-off factor: 0.35
UUUUUUUUUUUUUS
>>> Done
```

Above shows the standard operational procedure of generating and executing a GNU Radio flow graph. The connection should be done over USB 3.0 but GNU Radio Companion (GRC) has been known to change to USB 2.0 inconsistently. By using the verbal aspects of certain blocks, they will print their setting to the log to see what was set where. Underruns and overruns are printed in the log as well.



The first digital modulation scheme to gather a benchmark for was Binary Phase Shift Keying (BPSK). Phase shift keying is a digital modulation scheme that transmits data by shifting the phase of a signal back and forth. It uses a specific number of similar signals to represent data.

For BPSK, it can be defined that the phase shift of 0 degrees would be a data bit value of 1 while a phase shift of 180 degrees can be defined to be a data bit value of 0. BPSK is Binary because it uses only two states, 0 and 180, to translate the data. As the carrier signal is phase shifted back and forth, it creates different states which can be interpreted as a data point. BPSK can also be called 2PSK for 2 different data values to be transferred. BPSK can also be functionally equivalent to another digital modulation scheme 2-QAM.

BPSK Constellation Plot

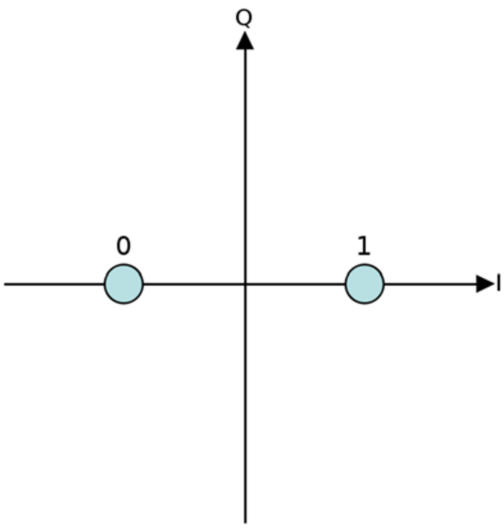
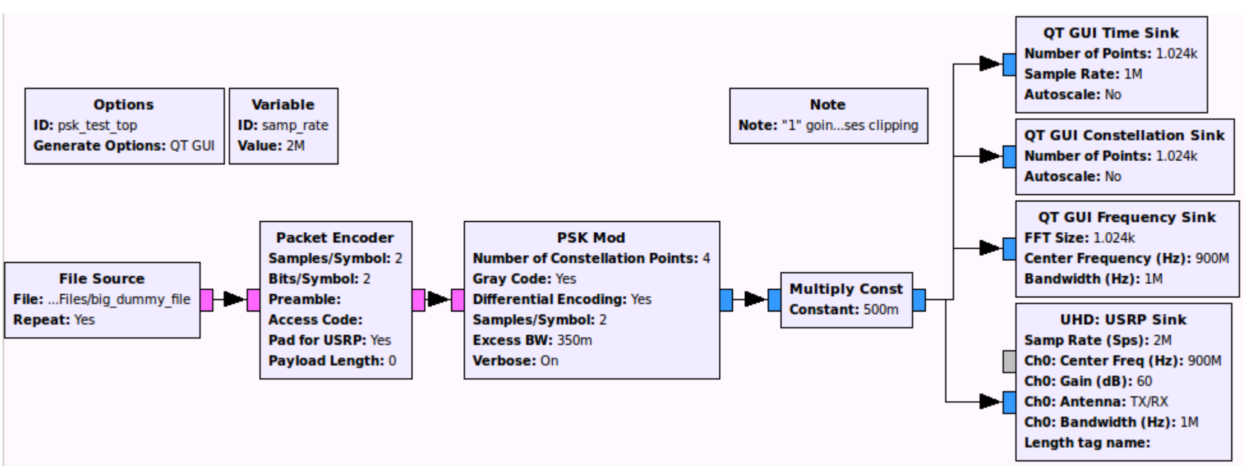


Figure 7: PSK Flow Graph



The signal transferred is a combination of sine and cosine components. A cosine wave can be transmitted over a sine wave without interference. For a constellation plot, shifting the phase of a sine wave changes the X axis value while shifting the phase of the cosine component changes the Y axis value of the state. For BPSK, there is a 180 degree phase shift between the two states, but it doesn't have to specifically be at 0 phase shift for the cosine component.

The flow graph for all of the PSK transmissions is shown above. First the File Source is supplying data to modulate for the PSK Modulator. The file is a large dummy file of numbers measuring in the low megabytes. It is set to constantly stream the file and repeat the transmission of the file if the ending is reached.

This file is sent into the Packet Encoder block. This block is responsible for the framing of the incoming data. A symbol is what was being described earlier as a state in which the carrier is phase shifted, or in a more general sense, the state in which the carrier symbol is modulated in comparison to the specified constellation key. The number of samples taken of each symbol can be specified here. The higher the samples/symbol rate is, the higher the overall sample rate should be. The number of bits/symbol is also specified here. This value is decided on depending on the modulation scheme being used. For BPSK there are only 2 states in which the carrier signal could be in which means there is only 1 bit of information being transmitted. For framing purposes, the preamble can be specified. A preamble is used in communications to tell the receiver when a packet of data is incoming. Leaving this spot blank will let GRC assign the default preamble and apply it to all transmitted packets. The Access Code works to secure the data even more so that only the receiver with a similar access code can decode the transmitted data. Leaving this blank will let GRC assign the default access code to the packets.

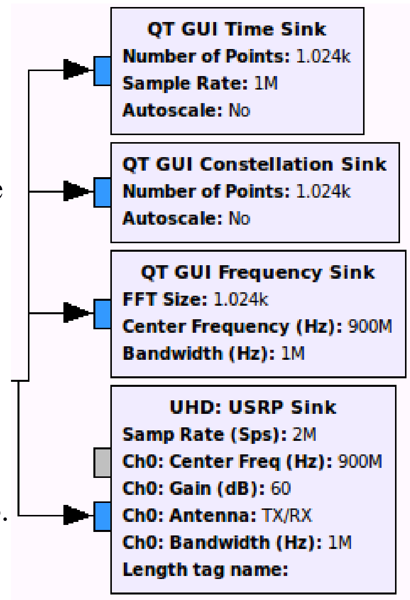
The encoded data packets are then fed into the PSK Modulator to prepare them for the USRP. The PSK Mod block is used for this job. An alternative in GNU Radio is to use a constellation object where each symbol can be given a specific point in the constellation plot. For PSK data transfer though, the PSK Mod block can get the job done efficiently and all the values that need to be changed can be modified easily within this block.

The Number of Constellation Points parameter housed within the PSK Mod block defines how many different symbols there can be depending on the type of PSK modulation that is used. For BPSK there are only two different symbols that are transferred. For QPSK which will be discussed later, there are four symbols possible to transfer. Gray code for BPSK doesn't matter if it is on or off. Gray code is an encoding of the symbols so that adjacent symbols differ by only 1 bit in a similar digit place. For example, if the data symbol at one location was 0110 then an adjacent symbol could be 0100 because only one bit differs in value. Gray code mapping will be better for higher degrees of phase shift keying because adjacent constellation points will only differ in one bit. This means that a case of incorrect mapping will only be one bit wrong instead of a large number of bits. Noise in the transmission could affect the position of the data symbol and skew the placement of the mapping.

The excessive bandwidth setting on the PSK Mod block defines how much bandwidth to pad the existing bandwidth with. Differential Encoding should be set to Yes for all PSK transmission purposes. Verbose turned on will post the settings to the log in GRC.

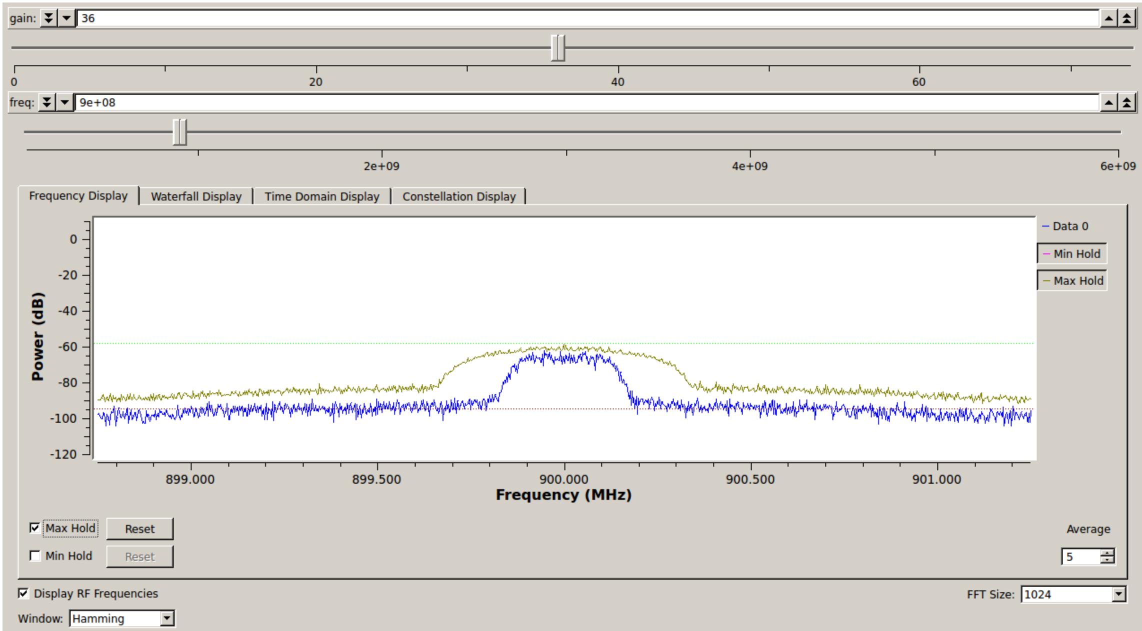
The PSK Modulation block then passes the signal into a multiplier that divides the amplitude of the signal in half. This is done to prevent clipping inside the USRP. A value of 1V from GNU Radio saturates the digital to analog converter (DAC) on the USRP. Even when multiplied by one half, the amplitude still seems to extend up to 1V sometimes on the output. The finished product is then sent to the USRP.

The USRP sink has many settings that affect the transmitted signal. The sample rate of the radio is specified here. The minimum bandwidth possible is described by the sample rate. According to the Nyquist rate, a signal can only be sampled if the sampling rate is twice the bandwidth or more. For communications, the bandwidth is specified first and the sample rate is adjusted to meet it appropriately. Different data speeds were tested for different bandwidths and sample rates. Each of the modulation schemes were tested at 1MHz and 0.5MHz bandwidth in the lab. This meant that the sample rate had to be at least 2MHz or 1MHz.

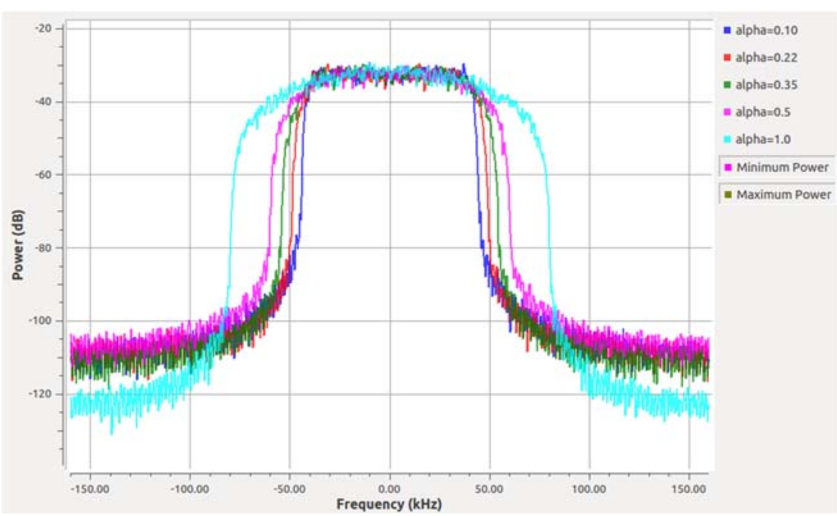


The center frequency was specified at 900MHz. The 33-centimeter is a portion of the Ultra High Frequency Range (UHF) radio spectrum internationally allocated to amateur radio. Specifically, this band is from 902 to 928MHz. This frequency was chosen because of the absence of traffic experienced in the lab as well as having open season to transmit as I want without fear of interrupting any other transmission.

The QT GUI Time Sink block shows the time versus amplitude graph of the inputted signal at the given sample rate. A lower sample rate provides a lower quality plot and may misrepresent the data. The QT GUI Constellation Sink shows the constellation plot of the inputted signal. The QT GUI Frequency Sink shows the frequency versus amplitude characteristics of the inputted graph. Each of these plots has a specific purpose and can show the characteristics of the modulated signal.



Above is a frequency graph of two BPSK signal transmissions with different bandwidth settings. This was done to prove that the bandwidth of the USRP could be changed using GNU Radio. The center frequency, or tuning frequency, of the radio can be changed during runtime, but the bandwidth used by the signal cannot be altered during this time. The bandwidth is set and stuck with at the beginning of the sequence. The green line indicates a bandwidth of 1MHz and the blue line is a measurement of 0.5MHz. The cutoff points aren't exactly at 900.5MHz and 899.5MHz because of the excess bandwidth setting of 0.35 set by the PSK modulator. This excess bandwidth setting it the alpha variable used in a root raised cosine pulse shaping filter. The shape of different alphas used to transmit in GNU Radio is shown below.



PSK Data Rate Testing

The next pages showcase the different degrees of PSK signal transmission that were performed. The test performed involved two different SDRs, one as a transmitter, the other as a receiver. The transmitter continuously sent a dummy file to the receiver at a specified channel frequency using a specified bandwidth, receiver sensitivity, transmission gain, and signal amplitude. For each transmission, the transmitted amplitude was 0.5 of the initial waveform. The receiver gain was set to a value of 20 dBm. The transmitter gain was set to a value of 60 dBm. The center frequency was set to 900MHz for each transmission. The distance transmitted was measured to be 5.1ft from antenna to antenna. There were two sets of five measurements taken for each degree of PSK modulation with one set at 0.5MHz bandwidth and one at 1MHz bandwidth. This meant that BPSK, QPSK, 8PSK, 16PSK, and 32PSK all had two different measurement sets for each bandwidth.

The data fields being measured were the Signal to Noise Ratio (SNR), the time of the transmission, the amount of data received, the data rate, the average data rate, and the average signal to noise ratio. The data rate, the average data rate, and the average signal to noise ratio were calculated depending on the other measurements. The SNR level was measured using the Signal to Noise Ratio Estimator Probe block. This probed the signal and outputted an average SNR level as a message stream. This message stream was then printed to the log. The last SNR level to show up at the end of the transmission was recorded. The time of transmission was taken using a stopwatch. Originally, it was proposed to use a Linux time stamp to do more accurate measurements of the execution of the program. However, it wasn't possible to time just the transmission of the signal. The time stamp taken when the program was executed included the time it took to initialize all the settings and adjust the radio to them. This tacked on an extra five to six seconds inconsistently every time, which meant a single number couldn't have been subtracted from the total every time. To reduce timing inconsistencies, the measurement was taken five times, and the values were averaged to produce the most accurate result.

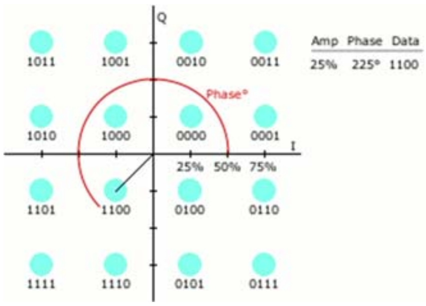
The transmitter was constantly running and sending out a continuous signal at 900MHz. The transmission time was taken as soon as the green light on the receiver turned on to signal it had begun receiving at the tuning frequency. The transmission was allowed to run for approximately 10 seconds for each run. The receiving flow graph saved the received data to a text file. The data received (measured in Mb) was taken from looking at the size of the text file after the transmission. The data rate (measured in Mbit/s) was calculated by dividing the data received by the time it took to transmit it. This was performed 5 times for a bandwidth of 1MHz then 5 times for a bandwidth of 0.5MHz. The average data rate of each set was found by averaging the five data rates. The average SNR of each set was found by averaging the five SNR readings.

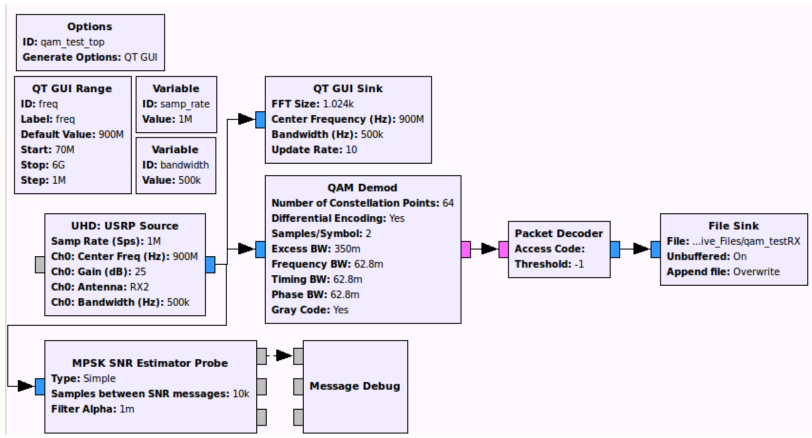
PSK Transmission Data Table

Mod Scheme	Tx Amp	Tx Gain	Rx Gain	Center Freq	Bandwidth	Distance	SNR	Time	Data Received (Mb)	Data rate (Mbit/s)		
BPSK	0.5	60	25	900M	1M	4.5ft	24.6904	10.33	1.267	0.9812	Avg noise Db	-100
							24.3456	10.01	1.219	0.9742	Avg DR:	0.95862214
							24.2096	10.06	1.15	0.9145	Avg SNR:	24.61858
							24.8442	20.1	2.436	0.9696		
							25.0031	30	3.576	0.9536		
BPSK	0.5	60	25	900M	0.5M	4.5ft	24.5803	10.11	0.615	0.4866		
							24.9176	10.11	0.618	0.4890	Avg DR:	0.48865525
							24.8996	10.16	0.617	0.4858	Avg SNR:	24.8065
							24.8319	10.13	0.619	0.4888		
							24.8031	10.76	0.663	0.4929		
4QPSK	0.5	60	25	900M	1M	5.1ft	27.4002	10.18	2.471	1.9418		
							26.7363	10.06	2.412	1.9181	Avg DR:	1.92581648
							26.4533	10.03	2.427	1.9358	Avg SNR:	26.98356
							27.4306	10.11	2.42	1.9149		
							26.8974	10.1	2.422	1.9184		
4QPSK	0.5	60	25	900M	0.5M	5.1ft	26.0029	10.06	1.21	0.9622		
							26.8220	10.13	1.216	0.9603	Avg DR:	0.96114116
							27.4754	10.31	1.238	0.9606	Avg SNR:	27.00602
							27.4306	10.21	1.222	0.9575		
							27.2992	10.28	1.215	0.9455		
8PSK	0.5	60	25	900M	1M	5.1ft	27.5007	10.25	3.668	2.8628		
							27.2301	10.1	3.604	2.8547	Avg DR:	2.83683869
							28.1614	10.05	3.609	2.8728	Avg SNR:	27.3976
							27.3454	10.08	3.544	2.8127		
							26.7504	10.2	3.546	2.7812		
8PSK	0.5	60	25	900M	0.5M	5.1ft	27.1271	10.2	1.807	1.4173		
							26.6950	10	1.784	1.4272	Avg DR:	1.42181431
							27.0570	10	1.763	1.4104	Avg SNR:	26.80716
							26.2246	10.3	1.841	1.4299		
							26.9321	10.2	1.816	1.4243		
16PSK	0.5	60	25	900M	1M	5.1ft	27.2588	10.06	4.834	3.8441		
							24.2602	9.75	4.769	3.9130	Avg DR:	3.84459614
							28.8989	9.9	4.814	3.8901	Avg SNR:	27.70462
							29.0863	10.25	4.886	3.8135		
							29.0189	10.15	4.772	3.7612		
							19.7940	10.16	4.884	3.8457		
16PSK	0.5	60	25	900M	0.5M	5.1ft	19.8208	10	2.389	1.9112		
							20.9082	10.23	2.413	1.8870	Avg DR:	1.8939106
							20.9276	10.3	2.447	1.9006	Avg SNR:	20.81348
							21.6255	10.63	2.483	1.8687		
							20.7853	10.01	2.38	1.9021		
32PSK	0.7	80	25	900M	1M	5.1ft	19.2305	9.9	26.03			
							14.4988	10.08	43.95			
							18.4647	10.06	0.788			

This table describes all the data gathered for the PSK Transmissions. BPSK using 0.5MHz bandwidth had the slowest data rate, but that was to be expected of it. A higher bandwidth usually means a higher data rate associated with the data transfer. Doubling the bandwidth used approximately doubled the data rate for each modulation scheme. The highest data rate achieved with PSK was using 16PSK at 1MHz for a data rate of 3.84 Mbit/s. The SNR levels rose when the modulation scheme became more complex. BPSK had an average SNR level of 24.6 while 16PSK had an average SNR level of 27.7. 16PSK had an average 20.8 however, which reflects what would be expected of a higher degree of modulation. As the degree of modulation increases, there is a tradeoff of lower SNR. BPSK isn't affect as much from noise in the environment because the positions of the phase are very far apart. When transmitting with 32PSK, the SNR level was significantly lower than the other modulation schemes. The data received varied wildly as well from 26Mb to 0.7Mb which was assumed due to error in the system. Higher transmission power may be able to fix the error in the constellation spacing. Screenshots of the PSK transmissions can be seen later in the report.

QAM Data Rate Testing





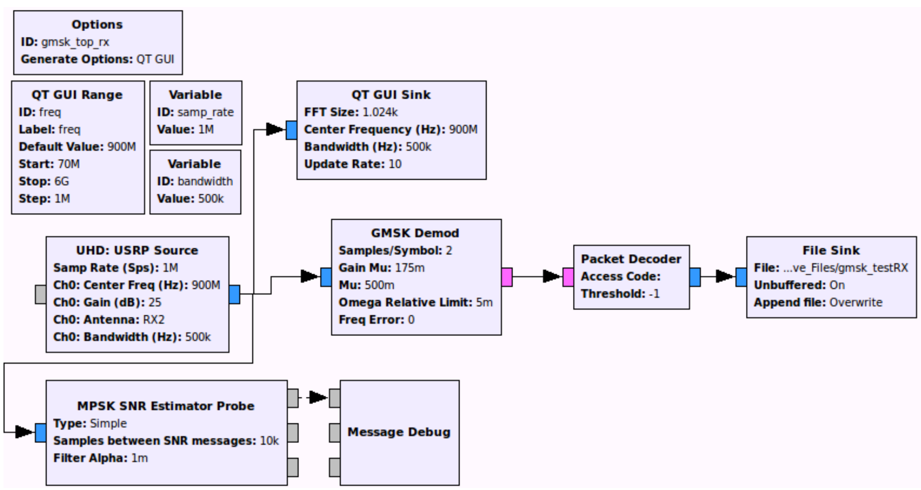
Quadrature Amplitude Modulation (QAM) is a form of modulation that combines both an analog and digital modulation. Like phase shift keying, QAM shifts the carrier signal to different phases to signal different symbols. It also uses the amplitude of the signal to indicate different positions on the constellation graph. As shown in the picture above, the signal currently exhibits a phase angle of 225 degrees and amplitude of 0.25 of the normal specified voltage. This shows that under these circumstances, the binary data to associate the signal with is 1100. The benefit of using QAM versus PSK is that a higher spectral efficiency can be achieved with QAM which is limited by noise level of the environment. QAM has to change the amplitude of its signal to change the data transferred. This means that using QAM, the data is susceptible to noise spikes in the environment which can cause errors in the data transfer. QAM can have different degrees which specify how many symbols the type of scheme can support. The higher degree, the more sensitive the scheme is to noise. QAM16 and QAM64 were tested in the laboratory, but up to QAM256 is used in industry.

QAM Transmission Data Table

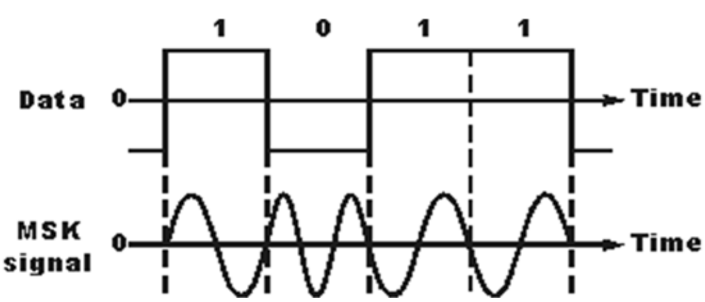
16QAM	0.5	60	25	900M	1M	5.1ft	23.0932	10.33	4.923	3.8126		
							22.8093	10.08	4.814	3.8206	Avg DR:	3.84566494
							22.5156	10.08	4.89	3.8810	Avg SNR:	22.41146
							21.3267	10.03	4.819	3.8437		
							22.3125	10.13	4.901	3.8705		
16QAM	0.5	60	25	900M	0.5M	5.1ft	21.4695	10.13	2.432	1.9206		
							22.8766	10.06	2.405	1.9125	Avg DR:	1.90917453
							23.0005	10.23	2.437	1.9058	Avg SNR:	22.54434
							22.8422	10.08	2.403	1.9071		
							22.5329	10.3	2.446	1.8998		
64QAM	0.5	60	25	900M	1M	5.1ft	21.0713	10.13	6.118	4.8316		
							21.0095	10.08	6.155	4.8849	Avg DR:	4.88357196
							21.2619	10.3	6.241	4.8474	Avg SNR:	21.19602
							21.2497	10.24	6.305	4.9258		
							21.3877	10.11	6.228	4.9282		
64QAM	0.5	60	25	900M	0.5M	5.1ft	23.3102	10.18	1.563	1.2283		
							24.677	10.3	0.922	0.7161	Avg DR:	0.67856181
							23.07	10	1.297	1.0376	Avg SNR:	24.8614
							25.8122	10.06	0.47	0.3738		
							27.4376	10.15	0.047	0.0370		

Above is the data gathered from transmitting a file using QAM16 and QAM64. QAM16 had a comparable data rate to 16PSK but a lower SNR. This is to be expected because of the sensitivity QAM has to noise. QAM64 had a much higher data rate using the same bandwidth of 4.88Mbit/s. The SNR was about the same if a bit lower than QAM16. There was a significant error rate associated with each QAM64 test. For a bandwidth of 1MHz, there was not a lot of space available between symbols on the constellation plot; the plot looked pretty scattered but still readable. For a bandwidth of 0.5MHz, there was not enough space between the constellation points to discern one data symbol from the other. The average data rate reflected this with value of 0.68Mbit/s. The transmission photos for this modulation scheme can be found at the end of this report.

GMSK Data Rate Testing



Gaussian minimum shift keying (GMSK) is a continuous phase frequency-shift keying modulation scheme. MSK is a standard type of keying while GMSK has the data stream modified by a Gaussian filter before frequency modulation is applied to the signal. Reducing the sideband power decreases the interference between two adjacent frequency channels. GMSK is used mostly for the Global System for Mobile Communications and the Automatic Identification System for maritime navigation.



GMSK works by shifting the frequency of the carrier wave to generate different data symbols. GMSK has a continuous phase scheme as well; there are no discontinuities within the phase because the frequency changes occur at the zero crossing points. The data is transmitted by the frequency shifting which means that it can function effectively in a noisy environment. The signal can also be amplified without the data being distorted because there is no data that relies on the amplitude changing.

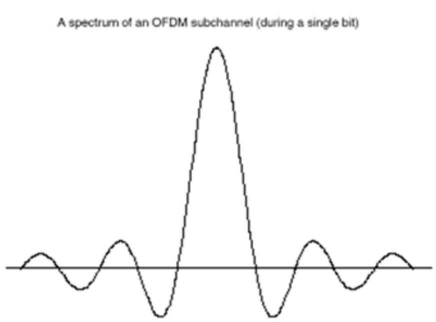
GMSK Transmission Data Table

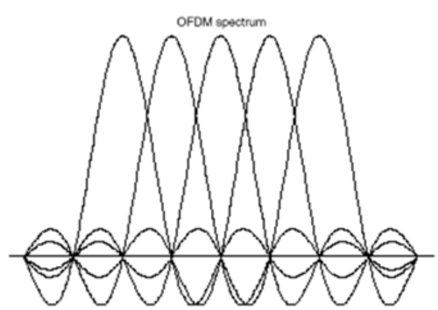
GMSK	0.5	60	25	900M	1M	5.1ft	36.3139	10.21	1.165	0.9128		
							37.5399	10.2	1.166	0.9145	Avg DR:	0.90801498
							36.8603	10.28	1.164	0.9058	Avg SNR:	36.00414
							36.7458	10.28	1.167	0.9082		
							32.5608	10.21	1.147	0.8987		
GMSK	0.5	60	25	900M	0.5M	5.1ft	33.4098	10.18	0.579	0.4550		
							32.9188	10.11	0.572	0.4526	Avg DR:	0.45417445
							33.4562	9.98	0.568	0.4553	Avg SNR:	33.25318
							33.2617	10.1	0.575	0.4554		
							33.2194	10.06	0.569	0.4525		

The data rates for GMSK compare to the rates found with BPSK. GMSK exhibited a much higher SNR level than BPSK did with a value of 36 for 1MHz and 33.3 for 0.5MHz. For a multi-channel system, it would be more useful to use GMSK over BPSK because of the reduced sideband power. In a noisy environment, GMSK would be the better modulation rate over PSK variants because the SNR level of MSK style modulation is significantly higher than PSK. BPSK is much more resistant to phase noise, or jitter, caused by the jitter of a clock on a microprocessor system, while GMSK would be greatly affected by the minute phase changes caused in the system.

OFDM Data Rate Testing

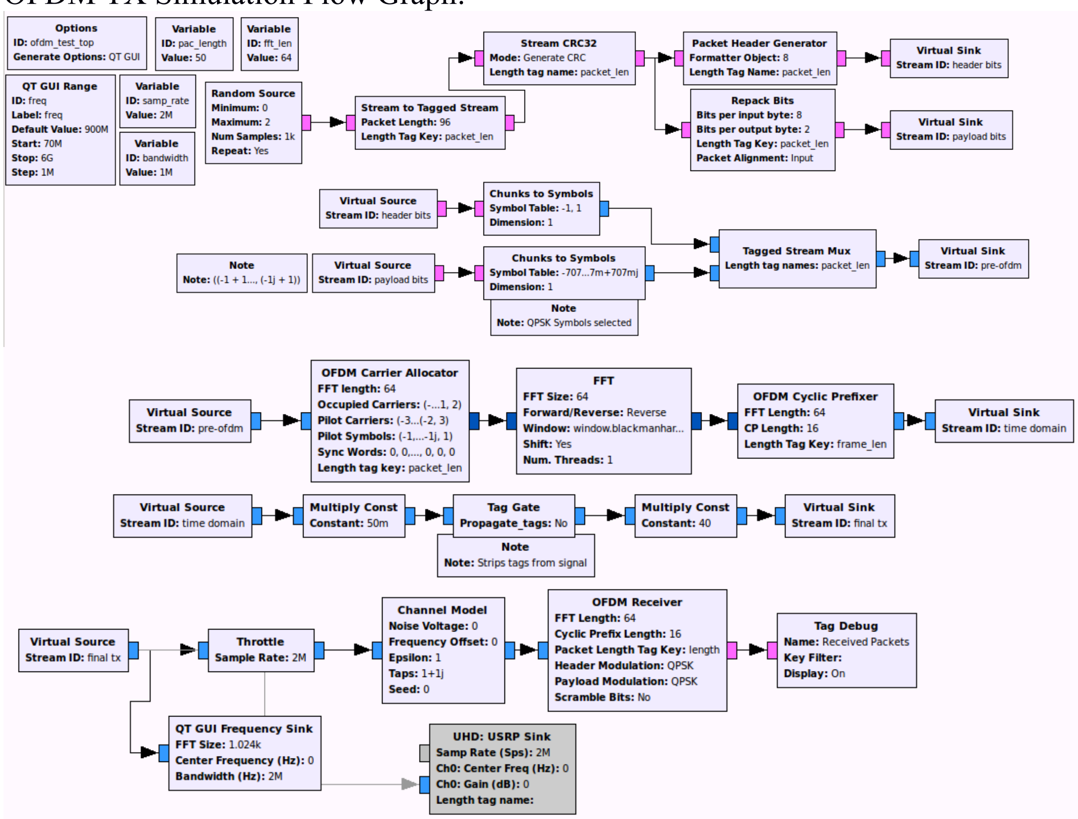
Orthogonal Frequency Division Multiplexing (OFDM) is a method of encoding data on multiple carrier frequencies. OFDM is most widely used for DSL Internet Access, Wireless networking, and 4G LTE networks. OFDM works by transmitting many orthogonally spaced sub-carrier signals at once that all transmit part of the data stream independently. The main advantage of using OFDM to transmit a signal is to combat narrowband interference and frequency-selective fading. By transmitting across multiple frequencies slowly in a very small band, instead of quickly in a wide band, data that would be lost due to narrowband interference can be minimized.





The drawback to OFDM is that it has a high sensitivity to synchronization errors. Any phase jitter in the system causes symbols to sub-carriers to overlap and cause errors in the data. OFDM also has a very high Peak to Average Power Ratio (PAPR). This is caused by the mixing of many different subcarriers all with frequency components of their own. When all the signals exhibit positive amplitude at the same time, there is a massive spike in requested power to transmit the signal. This means that the peak power is significantly greater than that of the average power. This is problem because the amplifier needs to operate in a state that can supply the peak power whenever possible to make sure that the signal is transmitted correctly. This leads to a very inefficient system since the amplifier is operating most of the time at an RMS level that requires far less power than the peak amplitude.

OFDM TX Simulation Flow Graph:

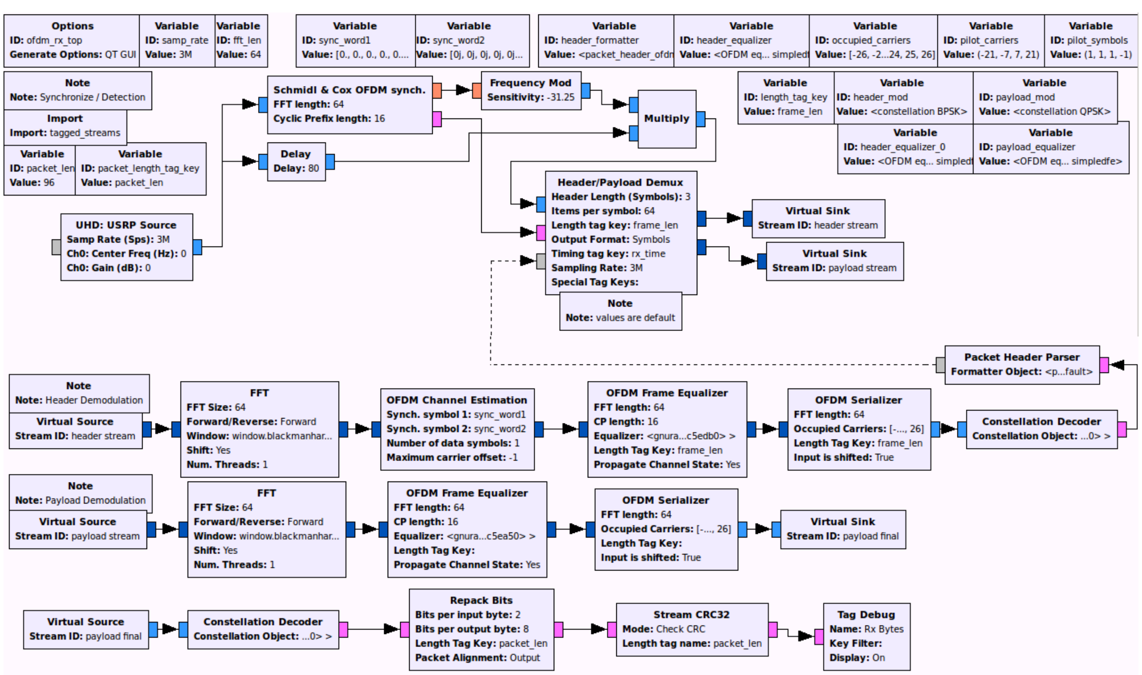


Above is the transmission flow graph for the OFDM system implemented in the laboratory. Each block of the system is related to an actual component of an OFDM system. The first section of the block generates the header and playload bits for the package. The header bits define the overhead bits such as the parity, stop, and start bits. The payload bits are the actual data pieces of the OFDM package. The bits are then combined into chunks of data and transferred into a tagged stream. This tagged stream of symbols is then sent to an OFDM carrier allocator which breaks up each symbol and puts it onto its own sub-carrier. The signal is put though a fast fourier transform (FFT) and put through a Cyclic Prefixer. The Cyclic Prefixer is used to add a delay between each OFDM symbol transmitted in order to reduce inter-symbol interference. Tags are then stripped from the signal and sent through the Channel Model. The Channel Model block simulates the conditions of an actual transmission medium for the signal. Noise voltage in the surrounding area can be specified through this block to test different SNR readings. The signal is then sent through an OFDM Receiver block and the message is decoded and displayed on the screen. The OFDM Receiver block is a catch all block that has contained within it the entire receiver package for an OFDM system.

Going block by block, the process starts first by transmitting a set of random data bits using the Random Source block. The Stream to Tagged Stream block specifies the packet length of the signal that is being sent. The Stream CRC32 block attaches a Cyclic Redundancy Check (CRC) stream to the header. This signal is split into two streams, one going into a Packet Header Generator and another into a Bit Repacker. These two steams are both converted from chunks of data to coherent symbols that the OFDM carrier allocator can understand. The streams are combined together in a Tagged Stream Multiplexor. The tags associated with the stream are used to specify how long the packet is and at what points the headers for the packets begin and end.

Next, the stream is sent to an OFDM Carrier Allocator which takes the different packets and allocates them to different sub-carrier frequencies. These sub-carriers are modulated using another data modulation technique like QPSK or QAM. The modulated signal is sent through an FFT plot that converts the signal from time to frequency. This is done so that the Cyclic Prefixer can insert a delay between the two transmitted symbols. After the delay is inserted, the tags are stripped from the signal because the data has already been allocated to the correct sub-carriers. The signal produces is now the OFDM signal ready to be transmitted.

OFDM RX Flow Graph:



The OFDM RX Flow Graph simulation is on the page previously. The USRP Source feeds into the Header/Payload Demultiplexor. This splits the header information from the payload information. The header is fed into another stream of blocks and then back into the demultiplexor in order to time which blocks of data are a part of the header and which are the payload. The header is put through an FFT block which converts the data from time to frequency domain. This is done so that the OFDM Channel Estimation block can output the channel coefficients of the signal. The Frame Equalizer then is used for the equalization of all the frames. The Serializer performs the inverse operation of the carrier allocator. This puts the signal in a serial data stream for the constellation decoder which takes the binary data from the constellation plot so that the packet header parser can strip the header from the rest of the payload data. The header data is fed back into the Header/Payload Demultiplexor which uses it to demux the payload from the header. The payload data is fed through similar blocks that the mixed signal was fed through in order to serialize the data. The serialized payload data is fed into a constellation decoder which extracts the data bits from the complex signal. The bits are repacked into bytes and the CRC is checked. The tags are debugged and the data is displayed in the log.

SECTION 3: FINAL STATEMENTS

Conclusion

For future work, the OFDM transmitter and receiver need to be implemented and tested. All bugs need to be removed from the existing software so that transmission can occur. A more detailed OFDM system was used so that all of the components can be experimented on instead of just transmitting the signal. Also, the bit error rate needs to be tested for to find a value for the most efficient model for a given SNR and bandwidth. Spectral Efficiency can be measured for the transmission that exhibits the best Mbit/sec/hz. General Efficiency can be measured by testing for which transmission can transmit the furthest while exhibiting the lowest power output.

Another branch to take the research currently is to add a third node and measure the efficiency and baseline transmission data of a multi-hop network using a suite of digital modulation schemes. Currently in the lab are two USRP N210 SDRs that are able to be used with a host computer in order to provide a third and fourth node if desired for more testing. These have multiple input multiple output (MIMO) support as well which is useful for implementing a real world OFDM system. Once an OFDM system is established, then Wi-Fi protocols can be implemented to create a Wi-Fi test bed.

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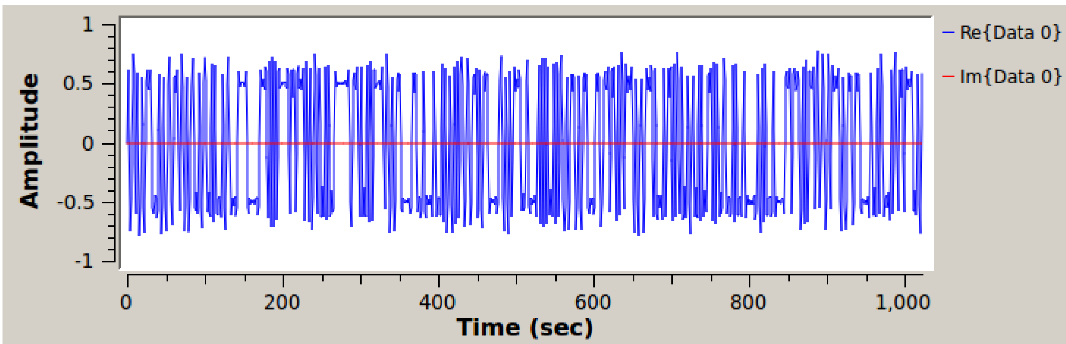
http://static1.1.sqspcdn.com/static/f/679473/23654454/1381240741710/grcon13_braun_ofdm.pdf?token=1xSPx8PonQIuaaLB861TUEKIpnY%3D

GNU Radio Manual and C++ API Reference
https://gnuradio.org/doc/doxygen/

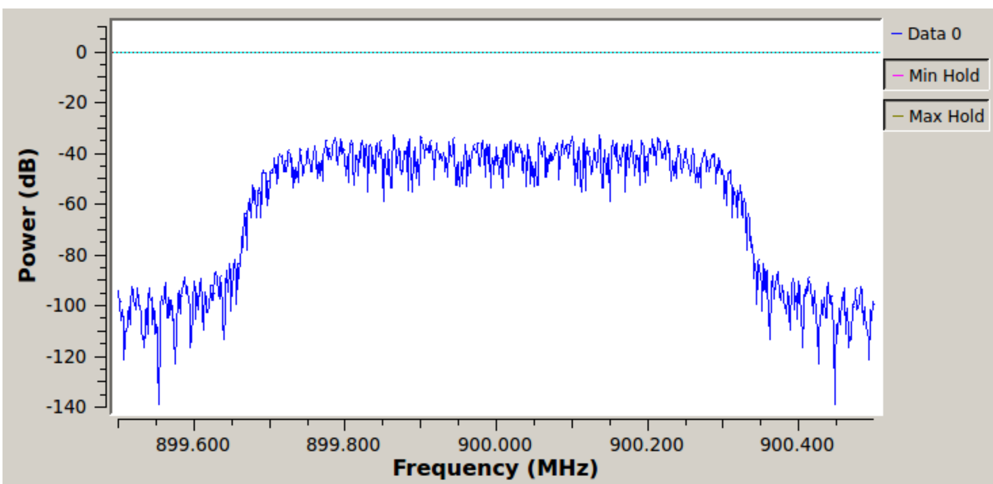
USRP Hardware Driver and USRP Manual
http://files.ettus.com/manual/

Screenshots of Transmissions

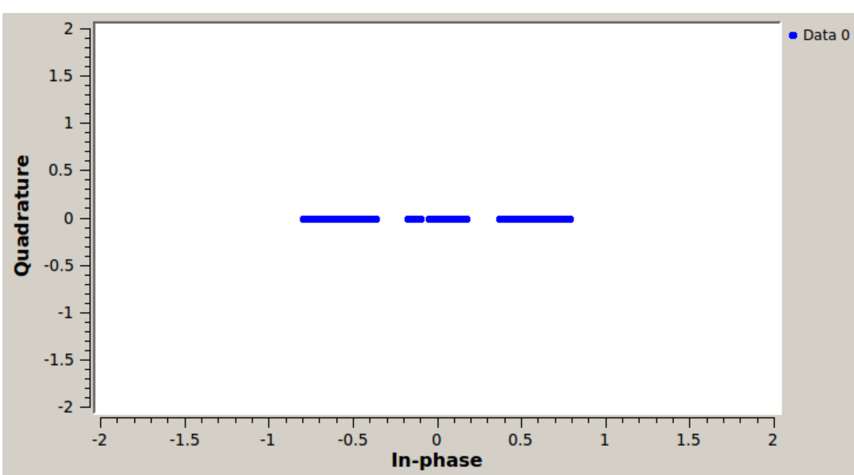
BPSK: Time vs Amplitude



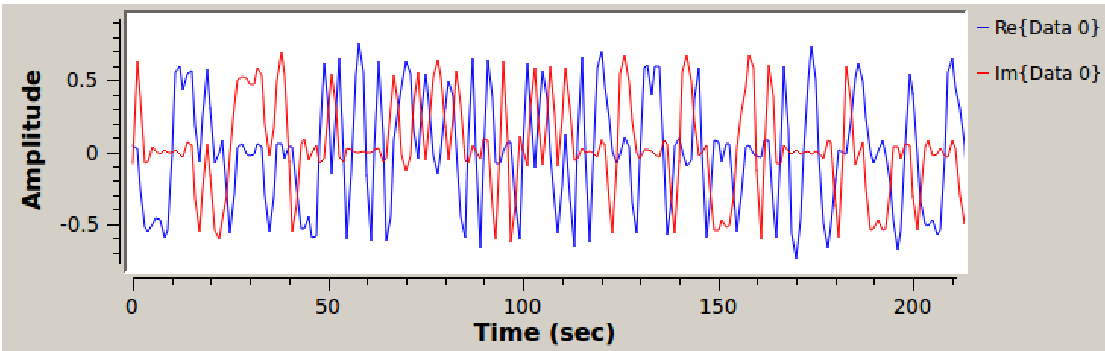
BPSK: Frequency vs Power



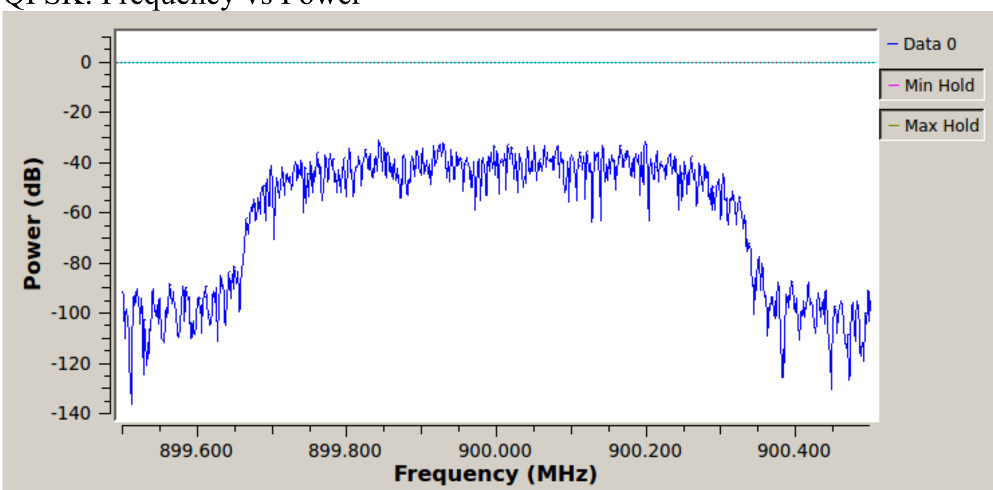
BPSK: Constellation Plot



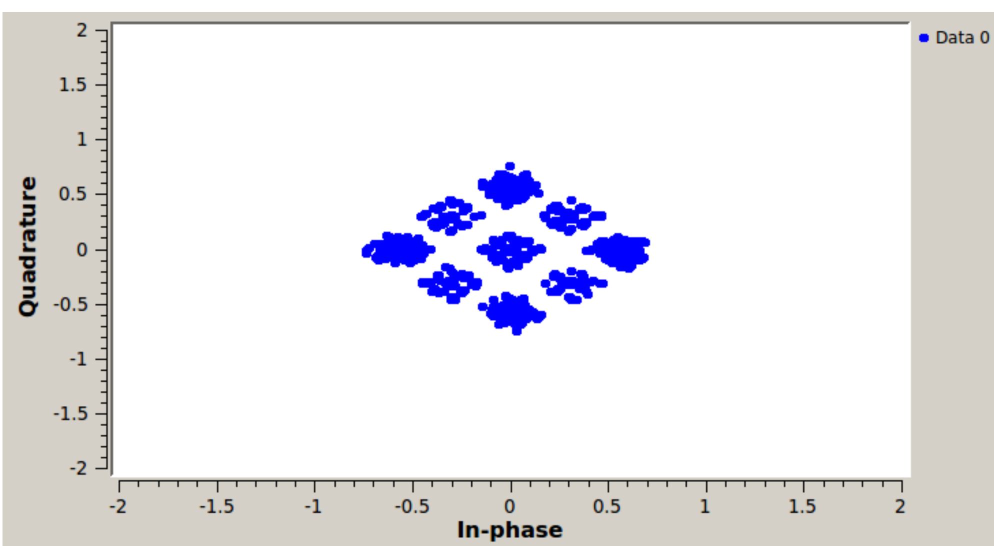
QPSK: Time vs Amplitude



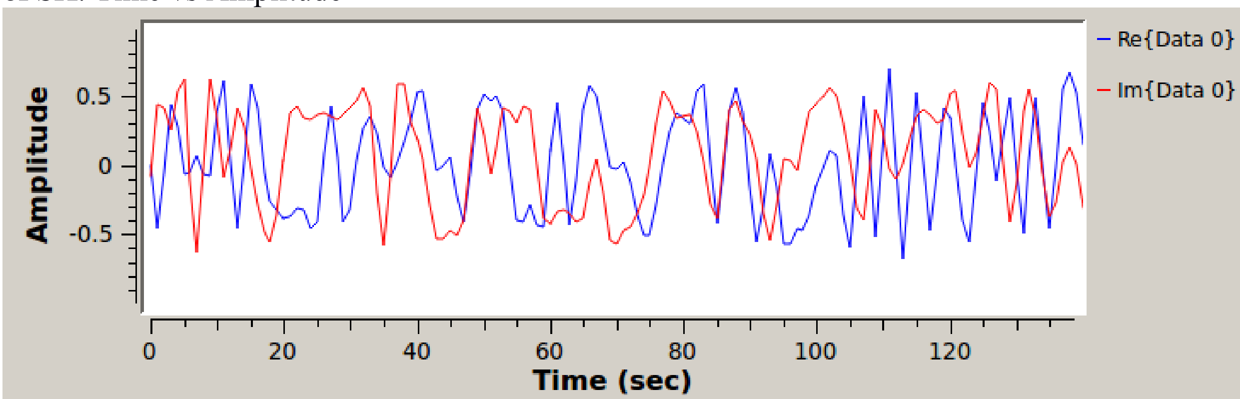
QPSK: Frequency vs Power



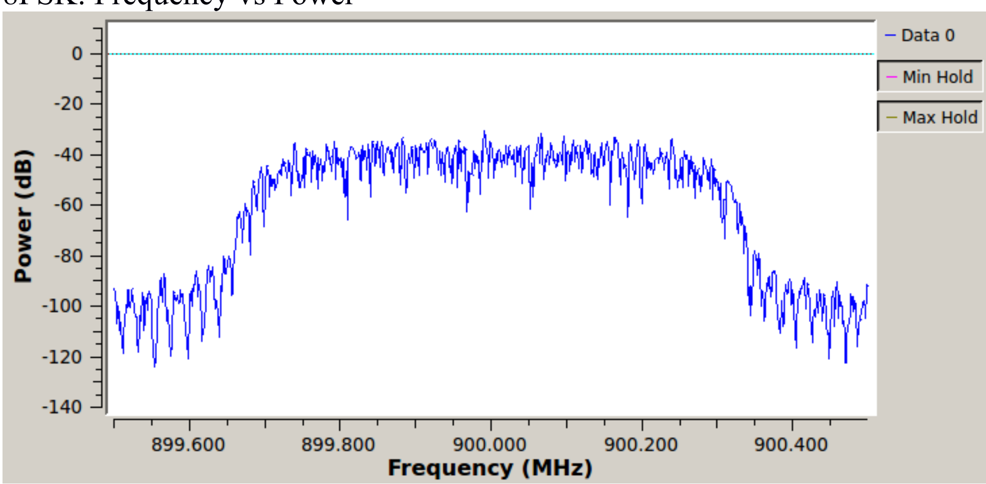
QPSK: Constellation Plot



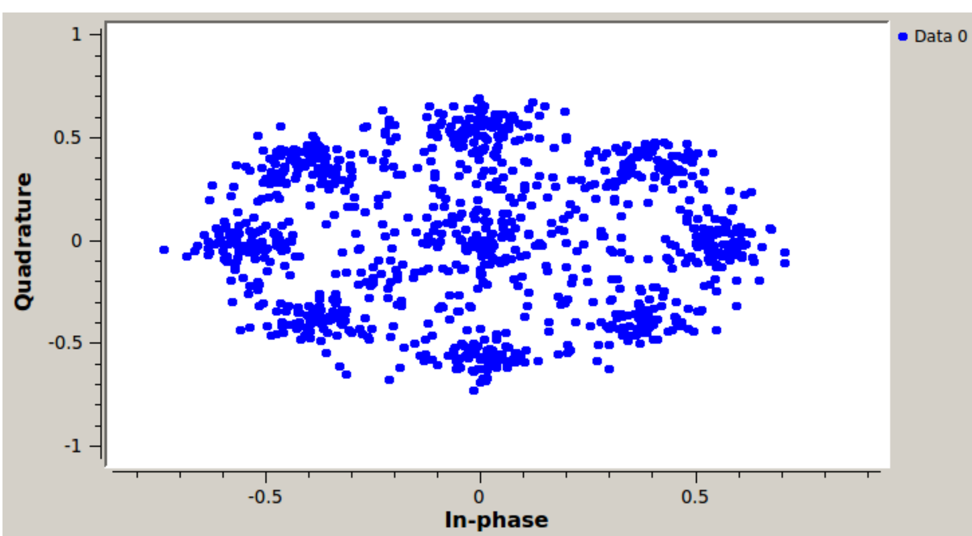
8PSK: Time vs Amplitude



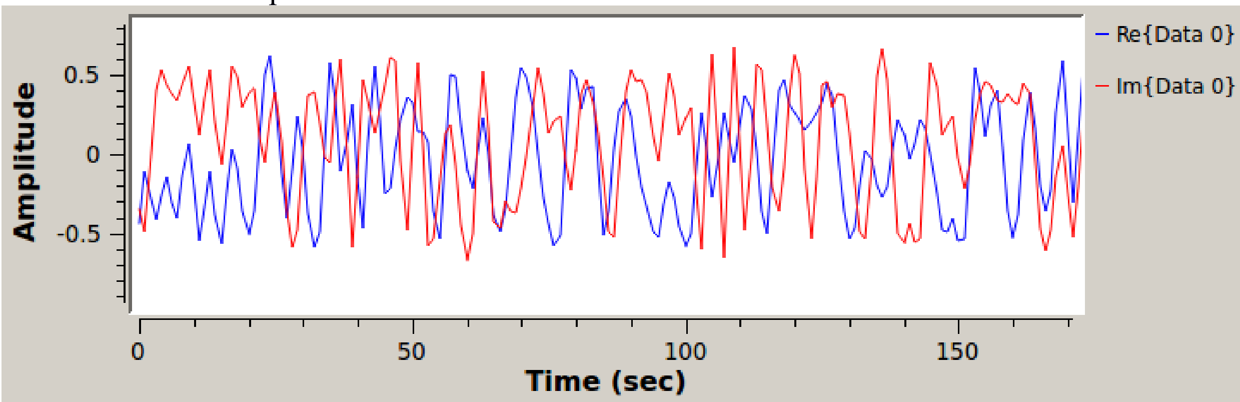
8PSK: Frequency vs Power



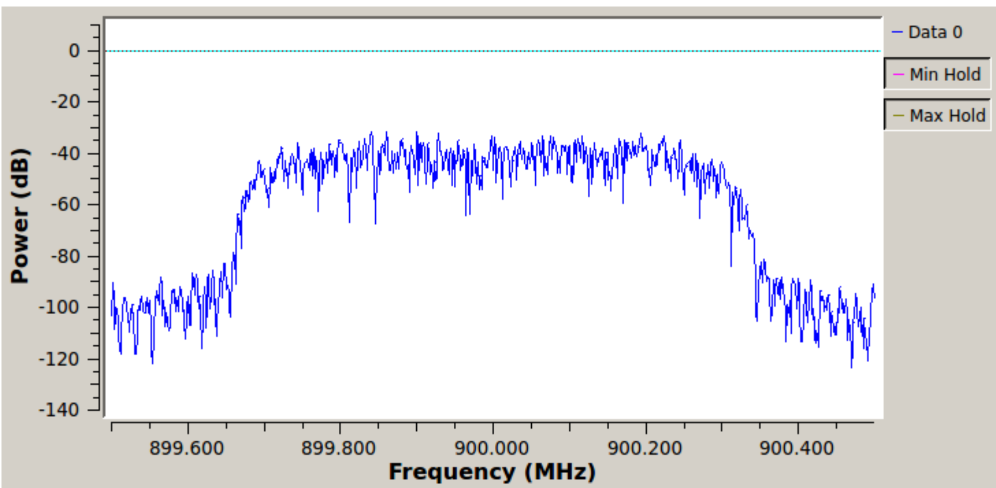
8PSK: Constellation Plot



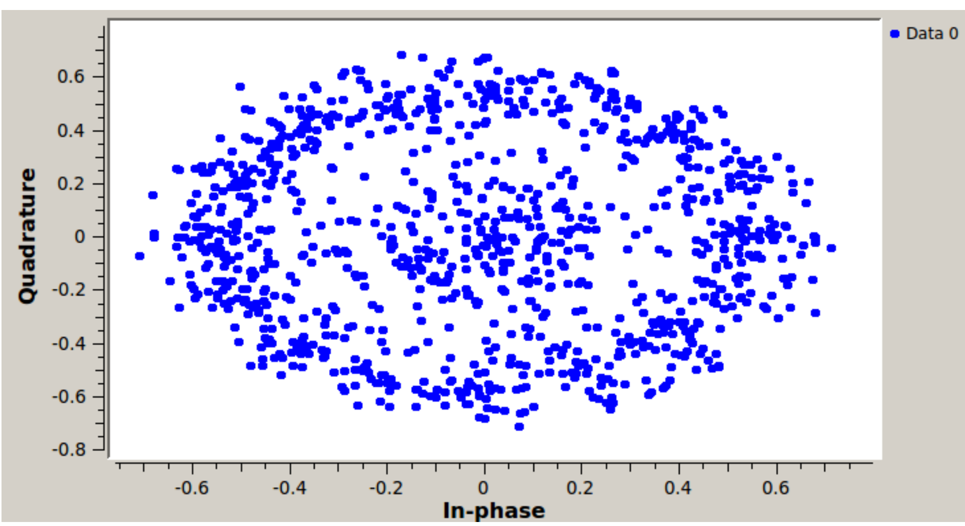
16PSK: Time vs Amplitude



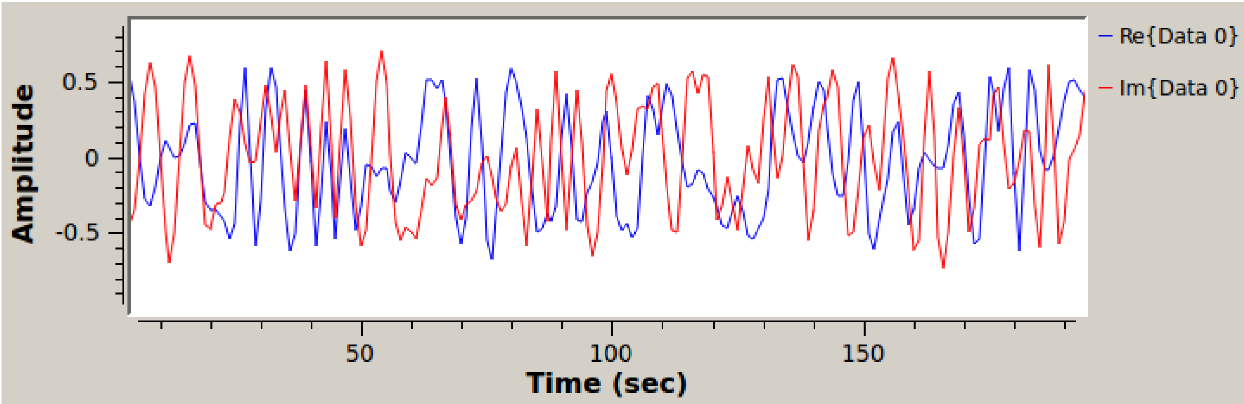
16PSK: Frequency vs Power



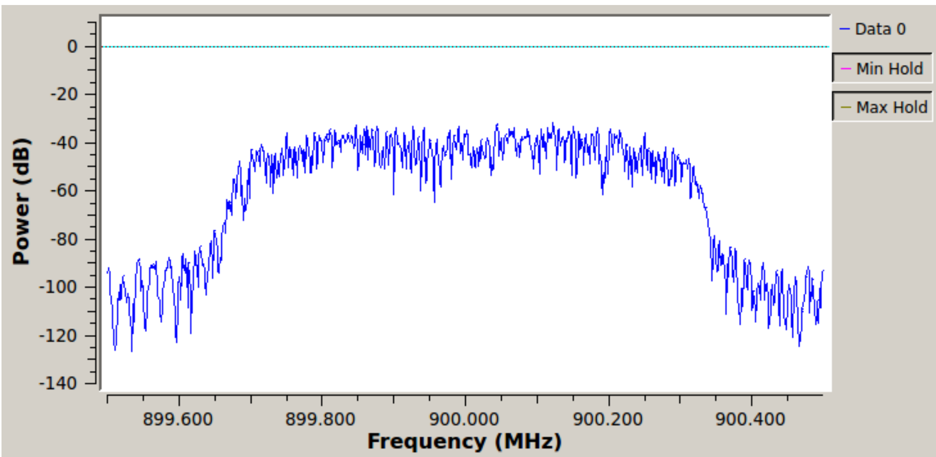
16PSK: Constellation Plot



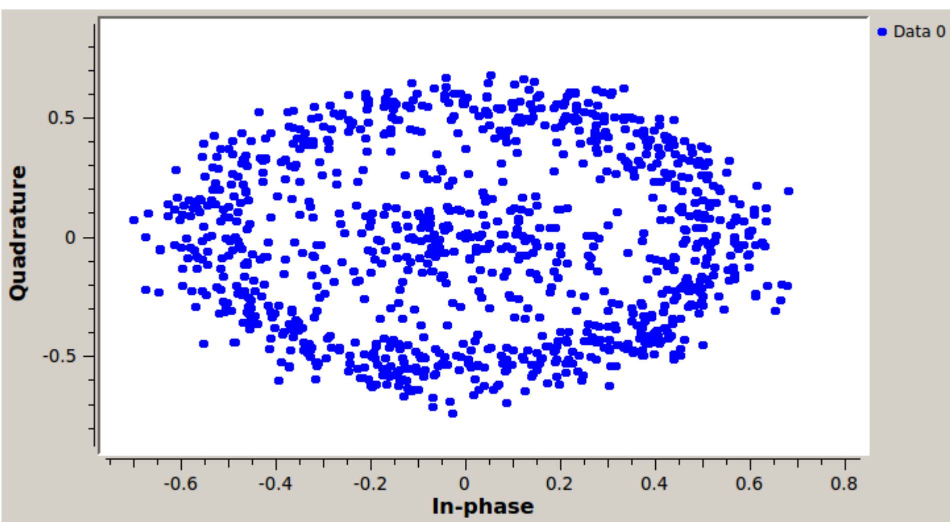
32PSK: Time vs Amplitude



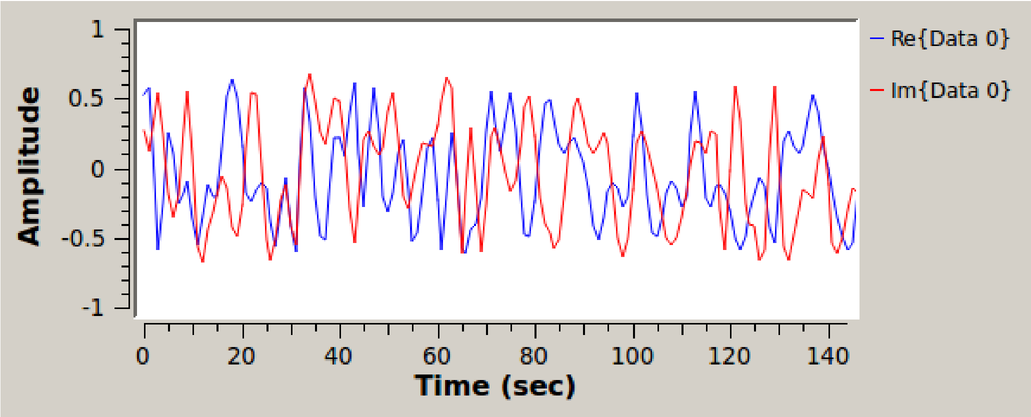
32PSK: Frequency vs Power



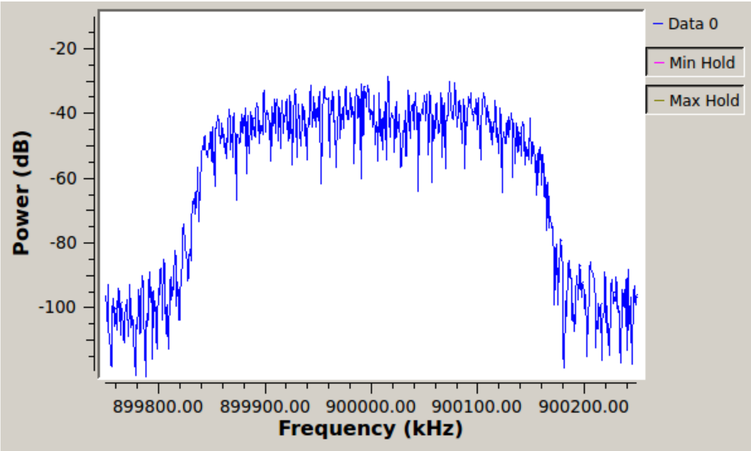
32PSK: Constellation Plot



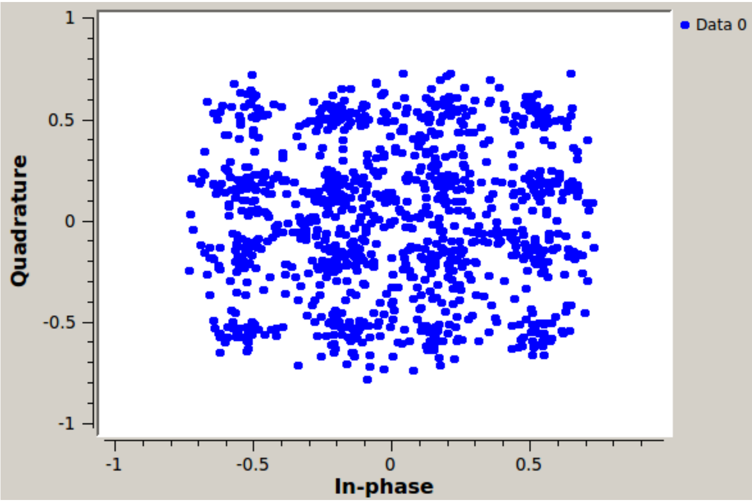
QAM16: Time vs Amplitude



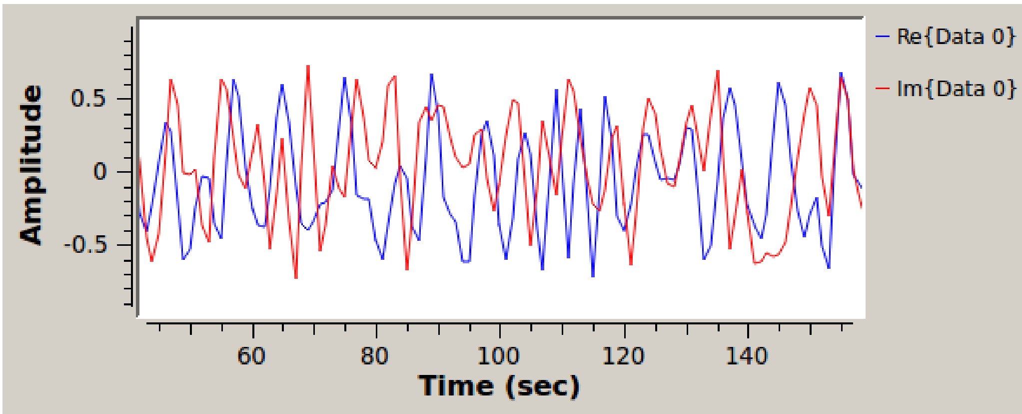
QAM16: Frequency vs Power



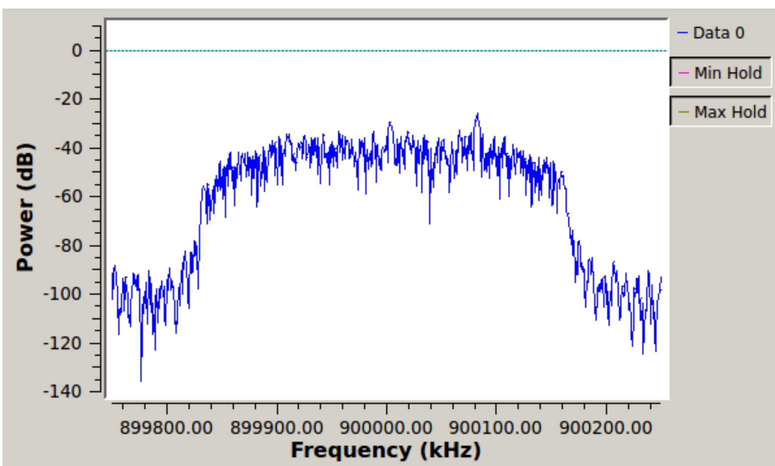
QAM16: Constellation Plot



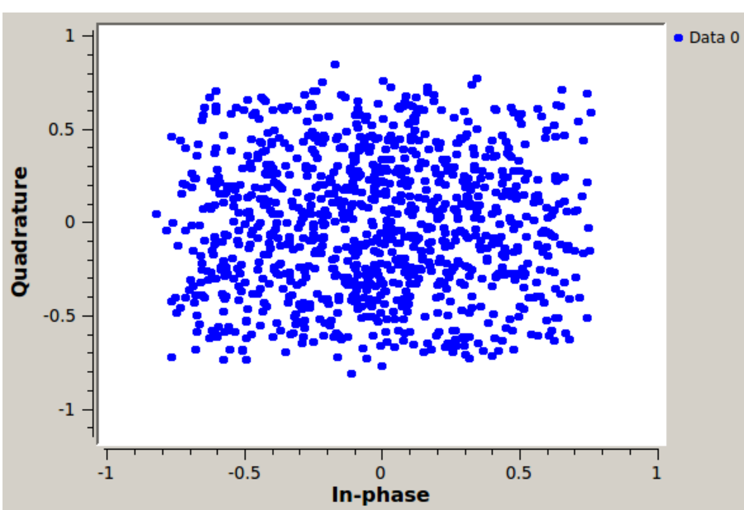
QAM64: Time vs Amplitude



QAM64: Frequency vs Power



QAM64: Constellation Plot



Prerequisite Installation Code

```
#!/usr/bin/perl

# Written for Ubuntu and Xubuntu 14.04 LTS (64-bit)

use strict;

my $command;
my $exit_code;
my @packages;

@packages = (
    "aptitude",
    "apt-show-versions",
    "pv",
    "hwloc",
    "lshw",
    "inxi",
    "gawk",
    "smartmontools",
    "hardinfo",
    "gnome-disk-utility",
    "gparted",
    "libdatetime-perl",
    "libreoffice",
    "tree",
    "libautobox-list-util-perl",
    "wireshark",
    "openssh-server",
    "libboost-all-dev",
    "ntp",
    "build-essential",
    "htop",
    "gedit",
    "geany",
    "diffuse",
    "meld",
    "ghex",
    "gnuplot",
    "octave",
    "octave-pkg-dev",
    "liboctave-dev",
    "octave-signal",
    "libgl1-mesa-dev",
    "icedtea-7-plugin openjdk-7-jre openjdk-7-jdk",
    "gnome-screenshot",
    "whois",
    "scsitools",
    "lftp",
    "ethtool",
    "ngrep",
    "nmon",
    "subversion",
    "git",
    "doxygen",
    "gvncviewer",
    "graphviz",
    "mscgen",
    "vim-gnome",
    "lcov",
    "cppcheck",
    "astyle",
    "simple-scan",
    "simple-scan-dbg",
    "python-matplotlib",
    "python-matplotlib-doc",
    "python-numpy",
    "python-numpy-doc",
    "python-numpy-dbg",
    "python-scipy",
    "python-qt4",
    "python-qt4-doc",
    "qt4-doc",
```

```
    "ipython",
    "cccc",
    "synaptic",
    "sqlite3",
    "libsqlite3-dev",
    "sqliteman",
    "ncurses-bin",
    "libncurses5",
    "libncurses5-dev",
    "libusb-1.0-0",
    "libusb-1.0-0-dev",
    "audacity",
    "epstool",
    "transfig",
    "pstoedit",
    "collectl",
    "nfs-common",
    "cifs-utils",
    "wkhtmltopdf",
    "cnee",
    "gnee",
    "cpufrequtils",
    "procinfo",
    "stress",
    "cmake",
    "python-pip",
    "libfftw3-bin libfftw3-dev libfftw3-doc",
    "swig",
    "libcppunit-1.13-0 libcppunit-dev libcppunit-doc",
    "python-opengl",
    "python-pyudev",
    "python-docutils",
    "python-cheetah",
    "python-gtk2 python-gtk2-dbg python-gtk2-dev python-gtk2-doc python-gtk2-tutorial",
    "gsl-bin gsl-ref-html gsl-ref-psdoc gsl-doc-info gsl-doc-pdf libgsl0-dbg libgsl0-dev libgsl0ldbl",
    "python-wxgtk2.8 python-wxgtk2.8-dbg python-wxtools",
    "python-lxml python-lxml-dbg python-lxml-doc",
    "python-qt4 python-qt4-dbg python-qt4-dev python-qt4-doc python-qt4-sql python-qt4-sql-dbg",
    "libqwt5-qt4 libqwt5-qt4-dev libqwt5-doc python-qwt5-qt4 python-qwt5-doc python-guiqwt",
    "liblog4c3 liblog4c-doc liblog4c-dev liblog4cplus-1.0-4 liblog4cplus-dbg liblog4cplus-dev liblog4cpp5 liblog4cpp5-dev liblog4cpp-doc",
    "libsdl1.2debian libsdl1.2-dev libsdl1.2-dbg libsdl-image1.2 libsdl-image1.2-dbg libsdl-image1.2-dev libsdl-mixer1.2 libsdl-mixer1.2-dbg libsdl-mixer1.2-dev
libsdl-net1.2 libsdl-net1.2-dbg libsdl-net1.2-dev libsdl-sound1.2 libsdl-sound1.2-dev",
    "libzmq3 libzmq3-dev libzmqpp3 libzmqpp-dev",
    "EOF"
    );


if ( $> != 0 ) {
    printf("\n\nERROR: this script must be run as root\n\n");
    exit(-1);
}


$command = `/bin/cat /etc/issue`;
if ($command !~ m/Ubuntu 14.04/) {
    printf("\n\nERROR: this script is only meant to be run on Ubuntu 14.04 (64-bit)\n\n");
    exit(-1);
}


$command = "/usr/bin/apt-get update";
printf("\n\n\n\n");
for (my $i=0; $i < 120; $i++) { printf("-"); }
printf("\n---> \"%s\"\n\n", $command);
system($command);
$exit_code = ($? >> 8);
if ($exit_code != 0) {
    printf("\n\nERROR: the exit code is %d\n\n", $exit_code);
    exit(-1);
}

foreach my $item (@packages) {
    next if $item eq "EOF";
    $command = "/usr/bin/apt-get --yes install $item";
    printf("\n\n\n\n");
```

```
    for (my $i=0; $i < 120; $i++) { printf("-"); }
    printf("\n---> \"%s\"\n\n", $command);
    system($command);
    $exit_code = ($? >> 8);
    if ($exit_code != 0) {
        printf("\n\nERROR: the exit code is %d\n\n", $exit_code);
        exit(-1);
    }
}

printf("\n\n\n---> Success, Done!!\n\n");
exit(0);
```

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