REU Research Overview Summer 2016

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End of Spring Semester

Most experiments performed during the spring were done with two USRP B200's. Getting familiar with the process of setting up the USRP N210 was one of the first objectives before taking on more practical experiments. Once operating the N210 to send data to a receiving B200 became comfortable, plans were made to perform experiments that tested how effectively and efficiently the transmitted data reaches its destination.

Benchmark_TX and Benchmark_RX Programs

Among the example programs provided in the GNURadio packages are two programs named *benchmark_tx.py* and *benchmark_rx.py*. The *benchmark_tx.py* program sends packets of data from one radio that are received by another radio using the *benchmark_rx.py* program which then prints the total number of received packets as well as how many arrived with errors.

A modified version of *benchmark_rx.py* was made that printed out the percentage of received packets and the percentage of error-free packets. Later modifications were made to save these percentages to a .mat file for use in MATLAB software. These modifications were made with plans of performing future experiments of data loss with respect to radio distance and power level.

usrp_spectrum_sense Program

Another example program from GNURadio named *usrp_spectrum_sense.py* was modified and named *usrp_spectrum_sense_power_data.py*. This version was made to output the received power level (dBm) to a *.mat* file for processing in MATLAB. The code was also modified to display how far along the testing process was. The code within *usrp_spectrum_sense_power_data.py* that extracted the data into a *.mat* file can be seen in Figure 15 in the Appendix.

Figure 1: Output of usrp_spectrum_sense_power_data.py

```
2016-06-16 18:28:16.782855 center_freq 900093750.0 freq 900000000.0 power_db 28.3461041232 noise_floor_db -116.547006827
2016-06-16 18:28:17.289325 center_freq 900093750.0 freq 900000000.0 power_db 29.1310570448 noise_floor_db -116.145711833
2016-06-16 18:28:17.788537 center_freq 900093750.0 freq 900000000.0 power_db 28.2941862726 noise_floor_db -116.426936933
2016-06-16 18:28:18.287294 center_freq 900093750.0 freq 900000000.0 power_db 28.0166418919 noise_floor_db -115.895368679
2016-06-16 18:28:18.785745 center_freq 900093750.0 freq 900000000.0 power_db 29.3090659937 noise_floor_db -116.594473156
2016-06-16 18:28:19.284808 center_freq 900093750.0 freq 900000000.0 power_db 28.2465843467 noise_floor_db -115.87035208
Test 8 Done
2016-06-16 18:28:19.783533 center_freq 900093750.0 freq 900000000.0 power_db 28.1570170338 noise_floor_db -115.983482834
2016-06-16 18:28:20.290358 center_freq 900093750.0 freq 900000000.0 power_db 28.5839173126 noise_floor_db -116.339242252
2016-06-16 18:28:20.788883 center_freq 900093750.0 freq 900000000.0 power_db 26.9943619909 noise_floor_db -114.75644429
2016-06-16 18:28:21.287906 center_freq 900093750.0 freq 900000000.0 power_db 28.8666586013 noise_floor_db -115.788306203
2016-06-16 18:28:21.786297 center_freq 900093750.0 freq 900000000.0 power_db 29.0580215229 noise_floor_db -116.249828796
2016-06-16 18:28:22.284881 center_freq 900093750.0 freq 900000000.0 power_db 27.5391073701 noise_floor_db -114.98907266
```

The overall measurement was 10 “tests” consisting of 10 samples each for a total of 100 samples that would later be used to find the average power at various frequencies and distances.

Received Power Level VS. Radio Distance Experiments

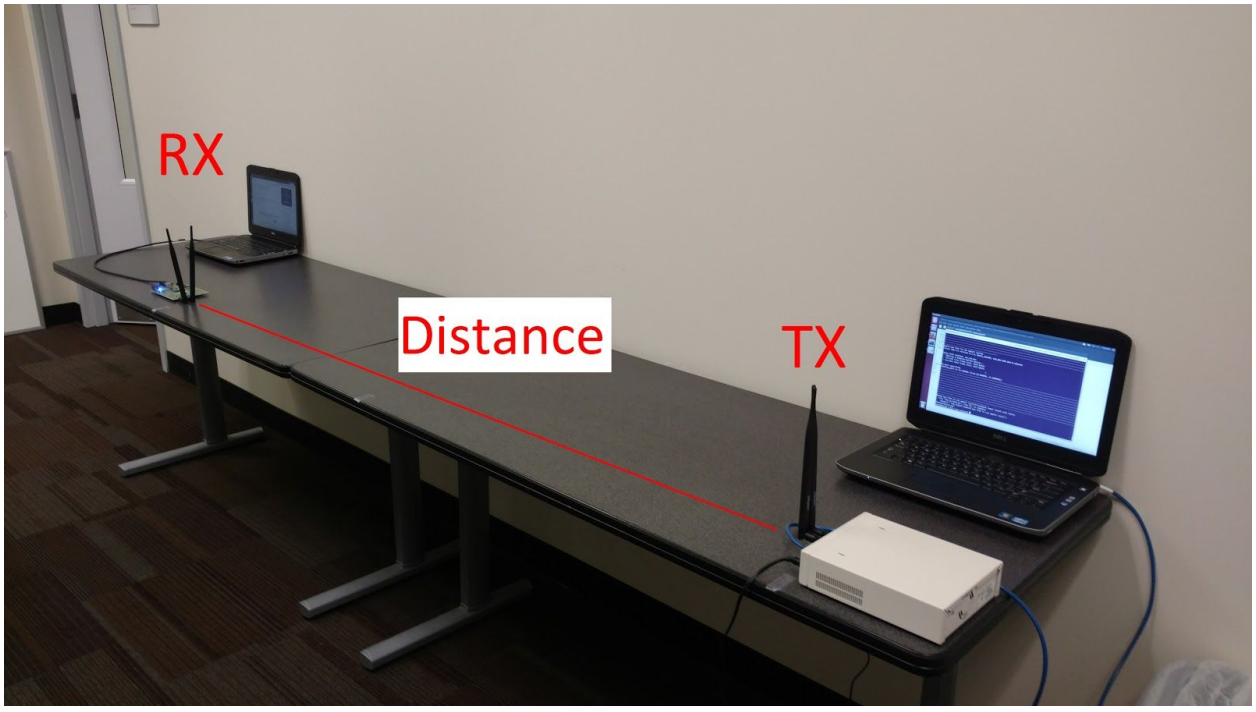
Experiments were performed within the lab workspace as well as the shop area just outside of the lab to gain a better understanding of the relationship between the power received by a USRP B200 and its distance from a transmitting USRP N210.

Initial Testing

The first tests of this setup were done with the following settings:

- Frequency: 900MHz
- TX gain factor: 1
- RX gain factor: 1
- Bit rate: 250k
- Modulation scheme: gmsk

Figure 2: Setup in Lab Workspace



From the results of the measurements in the lab, taken at 1 meter intervals, it was seen that the drop in received power was relatively drastic from 1 meter to 2 meters, however, between 2 and 4 meters, the power seemed to center around the 23dBm level with the power at 4 meters jumping higher than 2 or 3 meters. This seemed strange because the transmit power level was estimated to be about 20dBm according to the Test Report from Ettus Research in Figure 14. The assumed cause is the closeness to the wall of the lab as well as the size of the room and potential interference from other devices in the room (desktop computers, fluorescent lights, etc.).

Figure 3: Testing in Lab

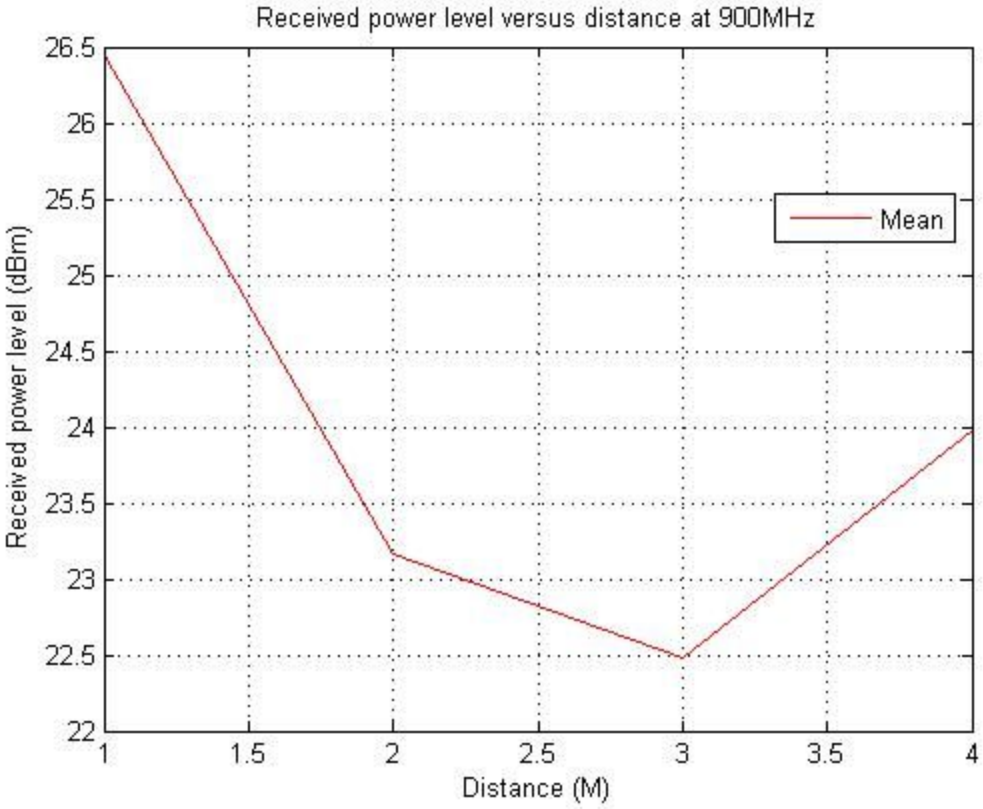
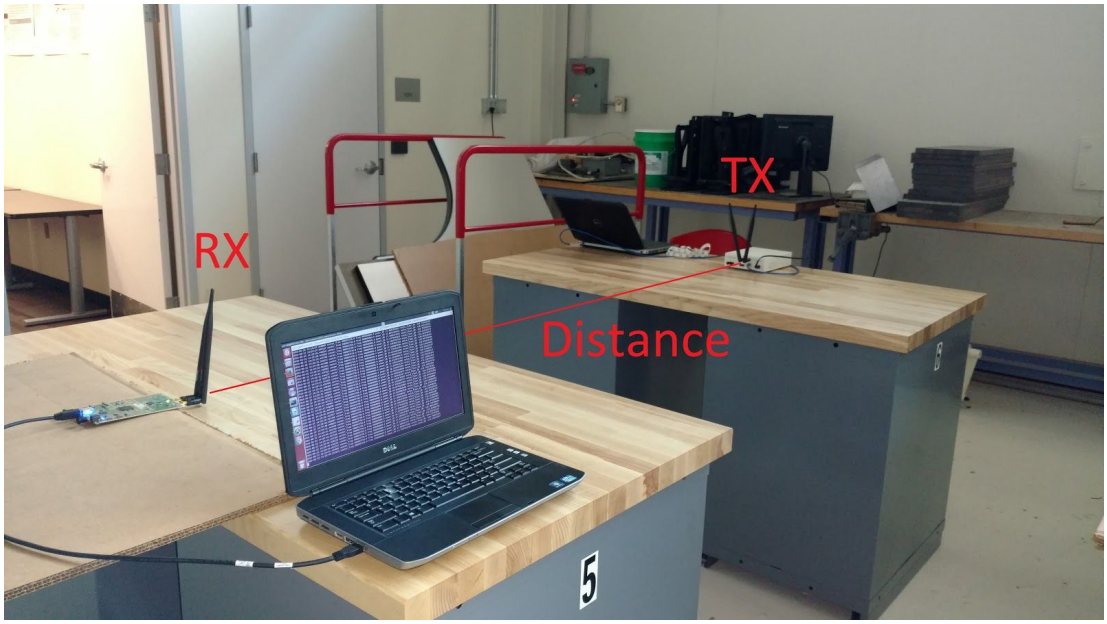
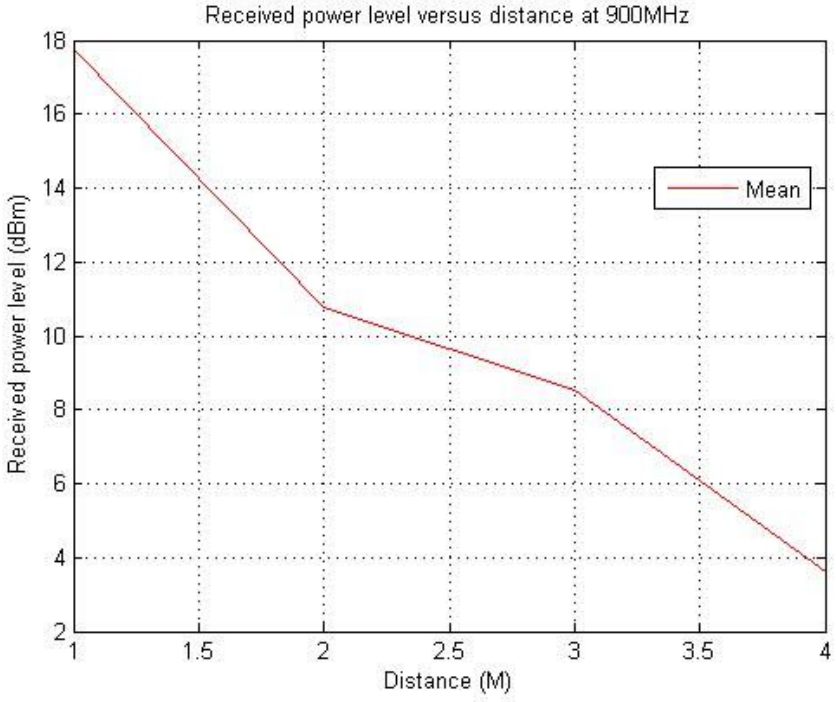


Figure 4: Setup in Shop



From the results of the measurements in the shop area, taken at 2 meter intervals, the received power had a more expected pattern than in the lab workspace. The decline in received power was much steadier and the initial power of 17.75dBm made more sense for the assumed transmit power of ~20dBm. In this wider open space, there was less interference from devices and lights as well as fewer nearby surfaces to reflect the transmission.

Figure 5: Testing in Shop



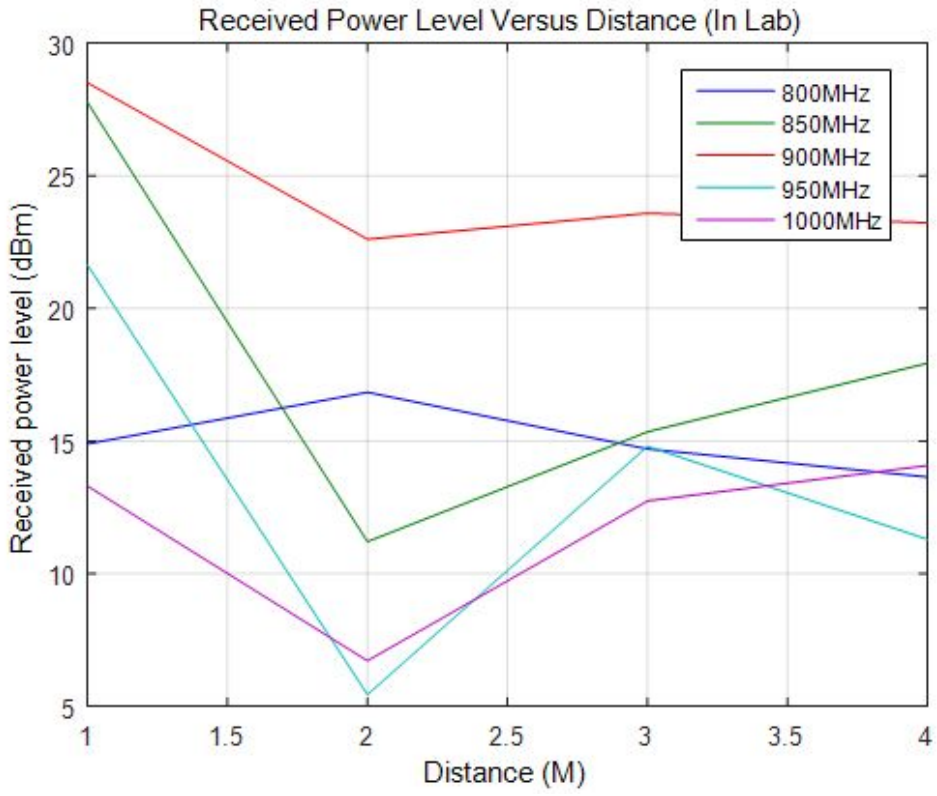
Testing Multiple Frequencies

The settings for the second experiment were as follows:

- Frequency range: 800MHz to 1000MHz
- TX gain factor: 1
- RX gain factor: 1
- Bit rate: 250k
- Modulation scheme: gmsk

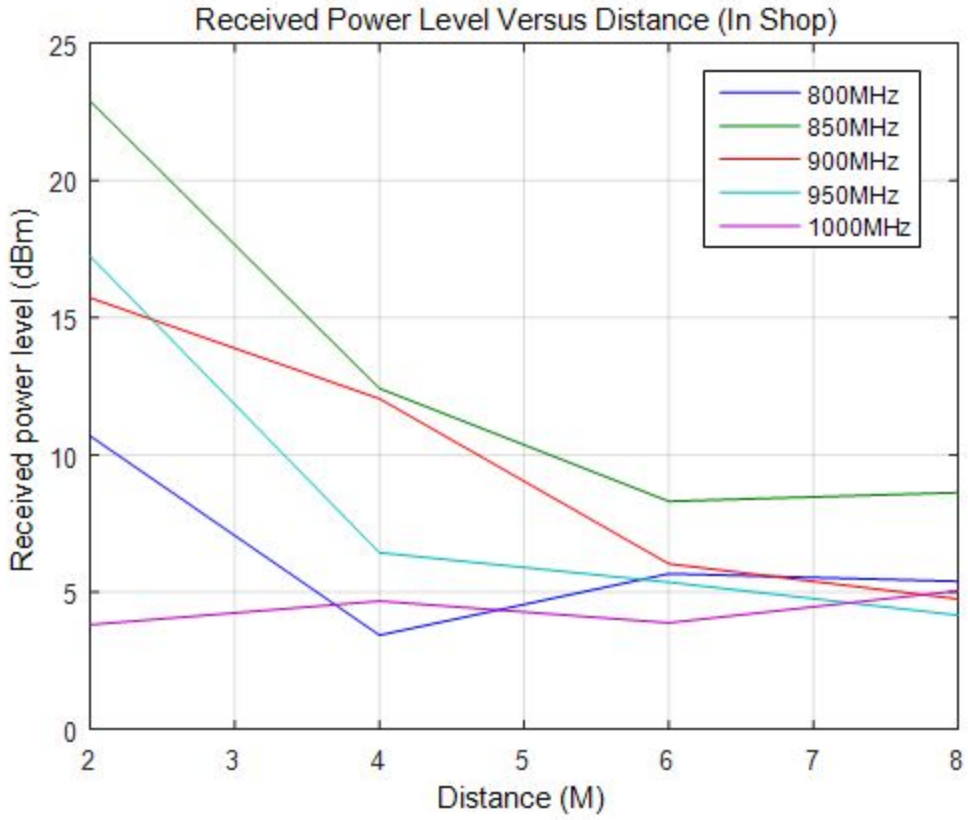
More measurements were taken at various frequencies in the lab and the shop. The results of the measurements in the lab show that there was a drastic drop at a distance of 2 meters. This was assumed to be an anomaly at first, but after repeated measurements, the drop occasionally appeared again. Tests were run later to determine if anything was wrong with the antenna of the receiving radio. These tests showed a small variance, but nothing as drastic as seen in the experimental measurements. It is assumed that because the lab workspace is generally small, small variations in the environment may cause these fluctuations. For example, angles of computer monitors and chairs at the desks as well as the position of any person within the room. Regardless, the general pattern of the results show how the receiving radio's capability to receive power decreases with an increase of either distance or the carrier frequency.

Figure 6



As in the first experiment, the measurements taken in the shop are seemingly more predictable. The results show the same trend with the received power decreasing with increased distance and frequency. In both the lab and the shop, the lowest frequency of 800MHz appeared much lower than expected according to the trend. Upon investigation, the range of the antenna used on the radios, the Ettus Research VERT900, was found to have a range of 824MHz-960MHz and 1710MHz-1990MHz. Therefore, the measurements at 800MHz and 1000MHz should be expectedly low.

Figure 7

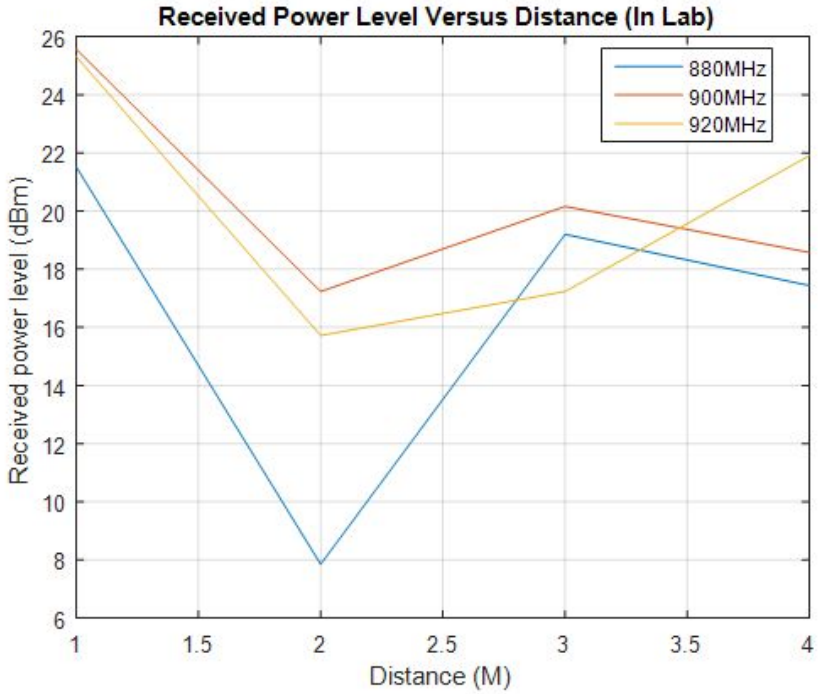


Refined Testing at Multiple Frequencies

In the next set of measurements, the out-of-range measurements were removed, the two separate frequency ranges were measured individually, and the measurements in the shop were taken in 1 meter intervals instead of 2 to get more fine results.

The results yielded by the lower frequency test in the lab raised more questions about the proper operation of the VERT900 antenna. The received power level took a dramatic dive at 2 meters just like it had in the earlier experiments, yet at 3 meters and beyond, it rises back to a reasonable level. This prompted the experiment on page 9 to determine if anything was wrong with the current antenna.

Figure 8



At the higher frequency range, the results plainly represent the relationship between the received power, radio distance, and carrier frequency.

Figure 9

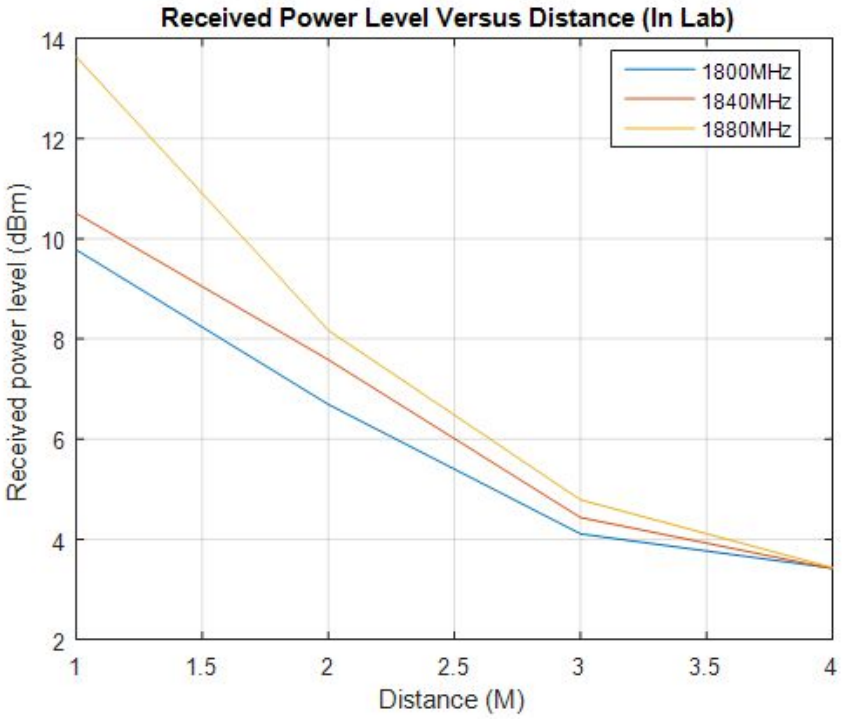


Figure 10

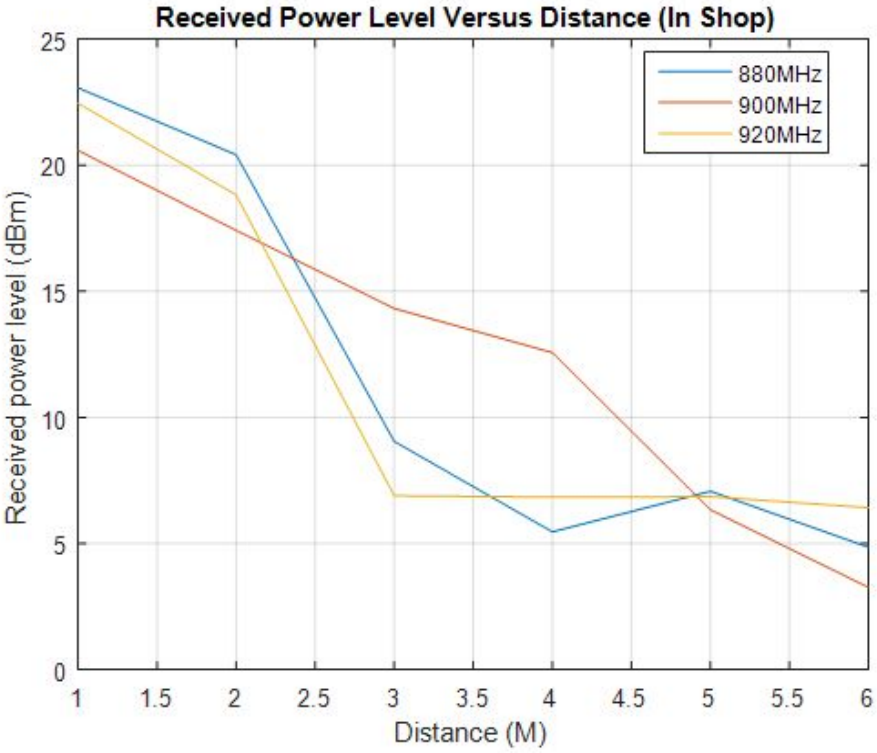
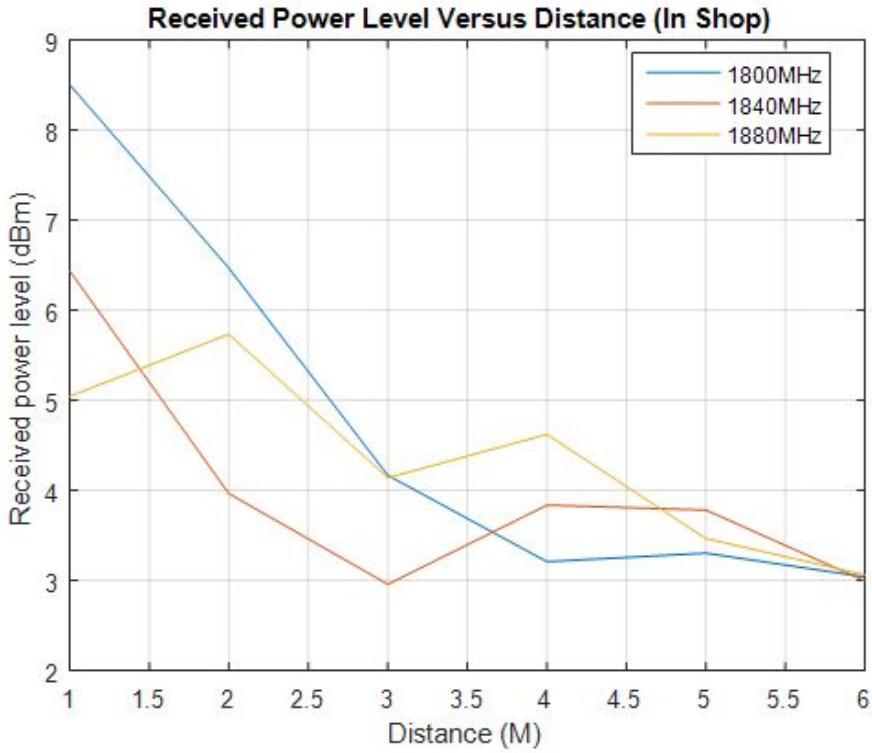


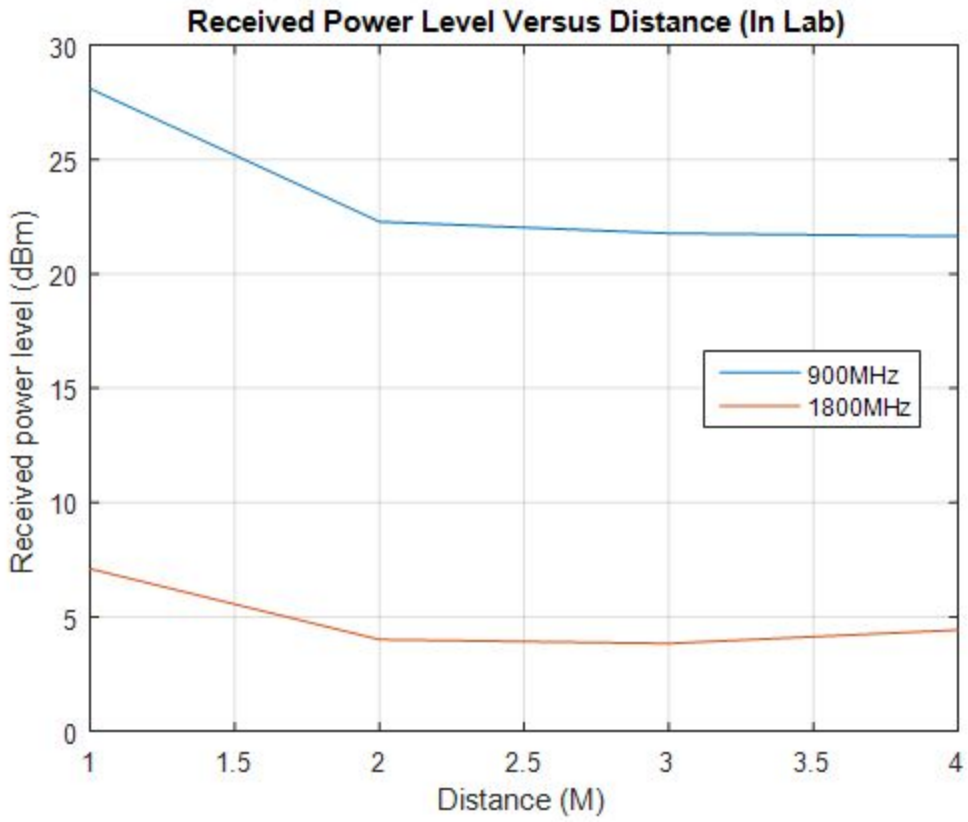
Figure 11



Antenna Testing

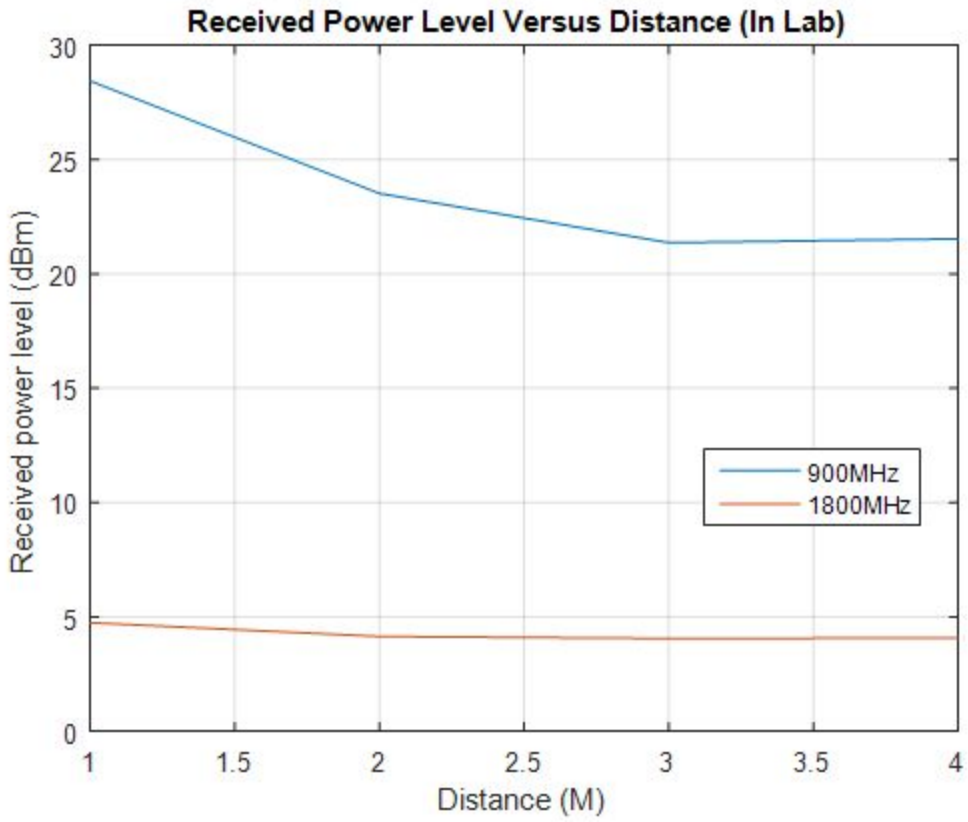
As mentioned previously, the questionable results of the experiments at 2 meters around 900MHz led to suspicion that the antenna on the receiving radio, the USRP B200, may not be operating properly. Therefore, tests were performed to see if the USRP B200 performed any better when the old antenna was replaced with a different VERT900 antenna. Both the results at 900MHz and 1800MHz were plotted together to show the large difference in received power at these two different frequencies.

Figure 12: Old Antenna



A slight improvement can be seen at the 2 meter mark for 900MHz. However, this improvement is only about 2dB improvement. This is not significant enough to justify the enormous deficits in received power observed in previous experiments. Therefore, the effect is assumed to be circumstantial rather than caused by a faulty antenna. It is more likely that the culprit is environmental factors in the small testing area, such as the positions of furniture or persons in the workspace.

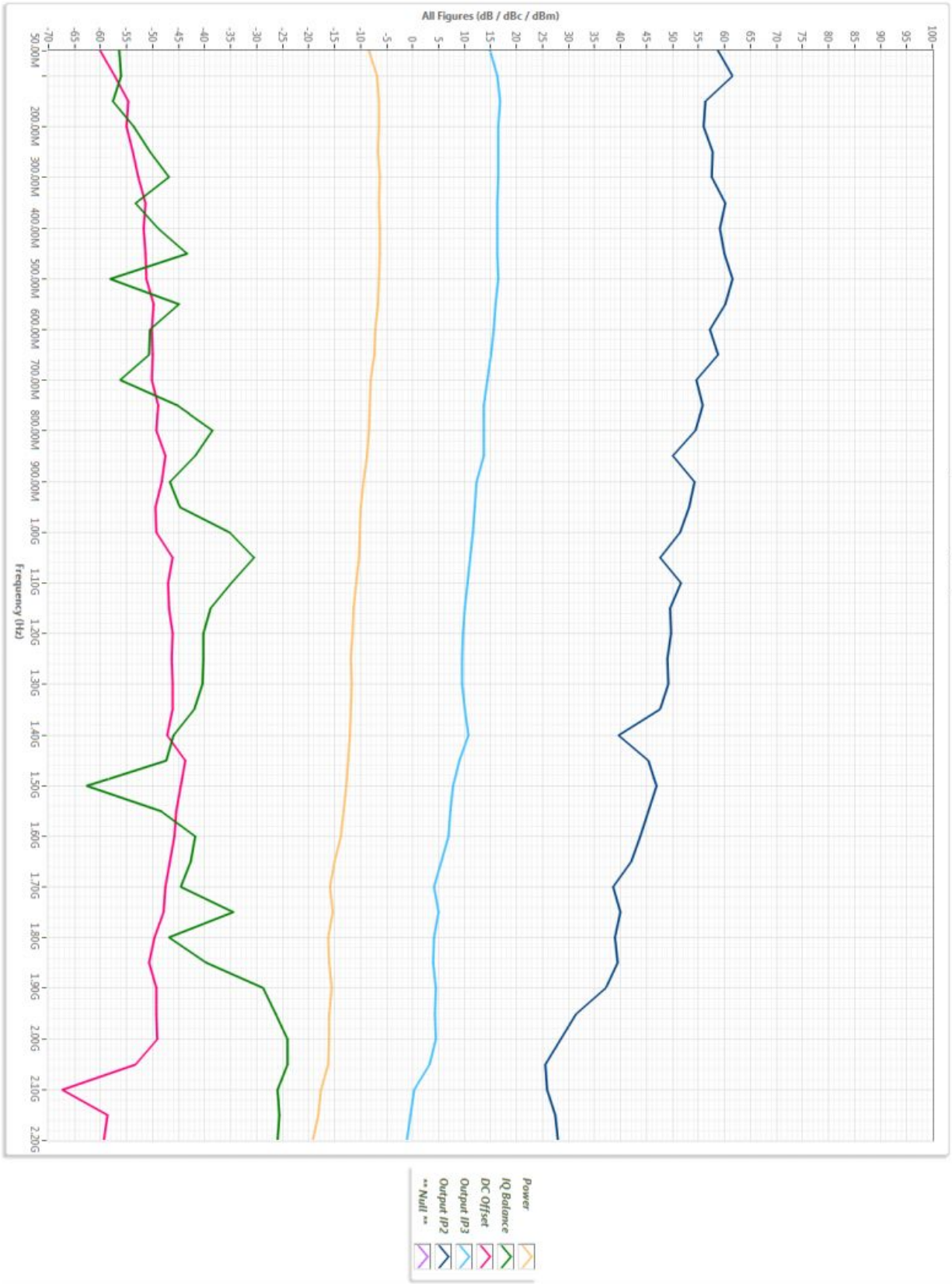
Figure 13: New Antenna



Ettus Research Test Report

Since the transmit power of the N210 can only be set by giving it a gain factor rather than a specific power in dBm, resources were sought out to estimate the transmit power of the N210. Test reports for various daughterboards available from Ettus Research were found that display the output power at different gains with a fixed frequency, or vice versa, different frequencies with a fixed gain. The N210 in the lab uses a WBX Daughterboard, so the test report for the WBX was used to estimate its output power. The plot for the output power at a fixed gain of 1dB and various frequencies can be found on the next page of this report or on page 123 of **http://files.ettus.com/performance_data/wbx/WBX-without-UHD-corrections.pdf**.

Figure 14: Ettus Research Test Report of WBX Daughterboard @ Gain = 1dB



Current Research

At the time of the writing of this report, the current research pursuit is to measure the maximum bitrate at which a file of a specified size can be successfully received at a set transmit power and a set distance between radios. The closest current setup to perform similar measurements is the modified *benchmark_rx.py* program which outputs the percentage of error-free packets received during transmission. However, a more practical solution is being looked into currently because the desired output is how long it takes for fully successful transmission rather than how many packets of a single transmission were received successfully.

Multiple solutions are being considered right now to perform these measurements. Among them are further modifying the *benchmark_rx.py* program, examining the uses of example programs *tx_samples_from_file* and *rx_samples_to_file*, and if necessary, the creation of gnuradio blocks and/or flow-graphs. Research is being done on stream tags and end-of-file indicators to become familiar with the tools available to ensure that a file has arrived in its entirety.

Appendix

Figure 15: usrp_spectrum_sense_power_data.py extraction of data to .mat file

```
1     data_out = []
2     counter = 0
3     num = 0
4     path = 'Path/To/MATLAB/Data/File/'
5     title = 'title_of_MATLAB_data_file'
6     print datetime.now(), "center_freq", center_freq, "freq", freq,
      "power_db",   power_db, "noise_floor_db", noise_floor_db
7     data_out.append(power_db)
8     if len(data_out) >= 10:
9           scipy.io.savemat(path + title, {title: data_out}, appendmat=True,
            oned_as='row')
10          if counter >= 9:
11                sys.exit()
12          else:
13                data_out = []
14                print("Test %d Done" % (num))
15                counter += 1
16                num += 1
17                break
```