ENG 4350 6.0 FW16/17- Space Hardware

Algonquin Radio Observatory Field Trip May 1st to May 4, 2017

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Submitted to:

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Contents

Purpose

The purpose of this field trip was to demonstrate a complete software project using C and practice debugging using eclipse tools and AGI's Systems Tool Kit (STK). I was able to apply the skills I've learned in the course based on RF equipment like spectrum analyzers, orbital mechanics, and RF transmission to perform antenna dish measurements and learn more about the receiving equipment at the Algonquin Radio Observatory (ARO). The ARO is Canada's largest radio telescope which we used to take measurements of the largest celestial source in the sky.

Activity 1: Spacecraft Tracking and Software Delivery

Purpose

Be the first group to demonstrate our software package's ability to track the satellite and confirm the power levels calculated with our link equations and a spectrum analyzer that was connected to the ARO.

Pre-Lab

1. Formatting change for Tracking Data Output File 'Tracking-Spec 16' Section 5.2.

We were instructed by the ARO operator that our format needed to be modified. Specifically, with the Azimuth-velocity and Elevation-velocity's number of significant digits to only 1 (one) decimal place. Also, fixed the tabs we had to spaces, and took out the extra comments in the header.

Format specifier to print to the file 'xp' which is the pointer to the file 'tracking_data.txt' or '2017-PRN-11-JK-V5.txt' in this case.

```
fprintf(xp,"%.0f.%03.0f.%02.0f:%02.0f:%02.0f %03.0f %02.0f %03.1f %03.1f %03.0f %02.0f %03.1f %03.1f\n", year, DOY, hh,
mm, se, AZd, AZm, AZs, LA->azimuth_velocity, ELd, ELm, ELs, LA->elevation_velocity);
```

2. Slight changes had to be made for the Power Level Calculation (i.e. our linkstrength function in propagate). We found that STK's chain analysis would result in about -140dBm to -160dBm, whereas, our results were closer to -75dBm. We ended up keep what we had which matched the received signal strength.

```
/*
 * Calculate link signal strength
 */
double linkstrength(double range){
    double fre = 1575.42; //centre frequency in MHz
    double eff = 0.5; // Efficiency of ARO
    double D = 46; // Diameter of ARO
    double c = 3*pow(10,8); //speed of light
    double Pt = 11.3988; //dBi from http://gpsinformation.net/main/gpspower.htm
    double Gt = 13; //dB Gain of the GPS Satellite Transmitter
    double Ll = -2.1; //estimation of the transmitter line loss
    double EIRP = Pt + Ll + Gt;//http://www.radio-electronics.com/info/propagation/path-loss/free-space-formula-
equation.php
    double La = -0.3; //atmospheric loss from 'rain/atmospheric attenuation graph'
    double Ls = 10*log10(pow((c/(4*PI*fre*range*1000)),2)); //space loss
    double Gr = 10*log10((((PI*PI)*(fre*fre)*(D*D) *eff)/(c*c))); //Receive gain
    double linksstren = EIRP + La +Gr +Ls+ 30;
    return linksstren;}
```

3. Realized a small typo within the core functionality of our AOS/LOS table computation. Where the highlighted 'or' statement is, there was mistakenly an '&&'.

```
if (LA->elevation <= stn->az_el_lim.elmax && LA->elevation >= stn->az_el_lim.elmin && acquired == 0){
    //Go in to this loop if the satellite is acquired.
    NUM[num] = j;
    NAME[num] = sats[j].name;
    NAME[num][strlen(NAME[num])-1] = '\0';
    NAME[num][strlen(NAME[num])-2] = '\0';
    AOS[num] = currentTime;
    acquired = 1;
}
if(LA->elevation >= stn->az_el_lim.elmax || LA->elevation <= stn->az_el_lim.elmin){
    // Go in to this loop if the satellite is lost.
    if(acquired == 1){
        LOS[num] = currentTime;
        lost = 1;
        break;
    }
}
```

4. Hard coded the STKout (ephemeris file) into the main because we had issues storing the fixed positions/velocity vectors into arrays to then be input to the STKout function and printing out in the proper format without memory leaks. This was done prior to ARO to confirm that our propagator would be within the accuracies required by the ARO beam-width.

Procedure

1. Updated to the newest NORAD TLE of the 32 GPS-operational satellites from Celestrak.
2. Adjusted the 'tracking_sched.txt' to our assigned tracking period on May 2nd, 2017 from 2:30PM to 3:30 PM local time or (6:30 pm to 7:30 pm UTC). 'tracking_data.txt' file looked like:

```
Tracking start date/time: 2017-05-02-18:30:00
 Tracking stop date/time: 2017-05-02-19:30:00
       Output time step (sec): 10.00
```

3. The AOS/LOS table output:

```
Complete

Sat No.        Name                  AOS                   LOS                Min. ExpectedLevel (dBm)
1        GPS BIIR-3  (PRN 11)   2017-05-02 18:30:00    2017-05-02 19:30:00     -76.597443
3        GPS BIIR-5  (PRN 28)   2017-05-02 18:38:39    2017-05-02 19:30:00     -77.201498
6        GPS BIIR-8  (PRN 16)   2017-05-02 18:30:00    2017-05-02 19:29:39     -77.750073
10       GPS BIIR-12 (PRN 23)   2017-05-02 18:30:00    2017-05-02 19:03:39     -77.574759
17       GPS BIIRM-6 (PRN 07)   2017-05-02 18:30:00    2017-05-02 19:30:00     -75.921569
20       GPS BIIF-2  (PRN 01)   2017-05-02 19:13:39    2017-05-02 19:30:00     -77.395482
22       GPS BIIF-4  (PRN 27)   2017-05-02 18:30:00    2017-05-02 19:30:00     -76.839072
23       GPS BIIF-5  (PRN 30)   2017-05-02 18:30:00    2017-05-02 19:30:00     -76.463913
25       GPS BIIF-7  (PRN 09)   2017-05-02 18:30:00    2017-05-02 19:30:00     -77.350011
28       GPS BIIF-10  (PRN 08)  2017-05-02 18:30:00    2017-05-02 19:30:00     -76.026924


Enter the satellite number you would like to track from the table (values in the first column): 1
```

4. We were instructed to view track PRN 11 (satellite 1 above), which resulted in our predicted values of:

UTC Time	AZ (deg)	EL (deg)	AZ-vel (deg/sec)	EL-vel (deg/sec)	Range (km)	Range-Rate (km/s)	Doppler (kHz)	Power Level (dBm)
2017-05-02 19:19	164.3985	36.16386	-0.003322	0.007255	22266.49809	3.069138	3.258215	-76.750582
2017-05-02 19:19	164.3652	36.23646	-0.003331	0.007255	22260.29689	3.069041	3.254854	-76.748162
2017-05-02 19:19	164.3318	36.30906	-0.00334	0.007256	22254.10197	3.068943	3.251483	-76.745745
2017-05-02 19:19	164.2982	36.38168	-0.003349	0.007257	22247.91335	3.068843	3.248102	-76.743329
2017-05-02 19:19	164.2646	36.4543	-0.003358	0.007257	22241.73105	3.068741	3.244709	-76.740915
2017-05-02 19:19	164.2309	36.52693	-0.003367	0.007258	22235.55509	3.068638	3.241307	-76.738503
2017-05-02 19:20	164.1971	36.59957	-0.003377	0.007258	22229.38549	3.068534	3.237893	-76.736092
2017-05-02 19:20	164.1632	36.67221	-0.003386	0.007259	22223.22227	3.068427	3.23447	-76.733684
2017-05-02 19:20	164.1292	36.74486	-0.003395	0.007259	22217.06545	3.06832	3.231035	-76.731277
2017-05-02 19:20	164.0951	36.81752	-0.003405	0.00726	22210.91505	3.06821	3.227591	-76.728872
2017-05-02 19:20	164.0609	36.89018	-0.003414	0.00726	22204.7711	3.0681	3.224135	-76.726469
2017-05-02 19:20	164.0266	36.96285	-0.003424	0.007261	22198.6336	3.067987	3.22067	-76.724068
2017-05-02 19:21	163.9923	37.03552	-0.003434	0.007261	22192.50259	3.067873	3.217193	-76.721669
2017-05-02 19:21	163.9578	37.1082	-0.003443	0.007262	22186.37808	3.067758	3.213707	-76.719271
2017-05-02 19:21	163.9232	37.18089	-0.003453	0.007262	22180.26009	3.06764	3.21021	-76.716876
2017-05-02 19:21	163.8885	37.25358	-0.003463	0.007262	22174.14865	3.067522	3.206702	-76.714482
2017-05-02 19:21	163.8537	37.32628	-0.003473	0.007263	22168.04377	3.067401	3.203184	-76.712091
2017-05-02 19:21	163.8188	37.39898	-0.003483	0.007263	22161.94547	3.06728	3.199656	-76.709701
2017-05-02 19:22	163.7838	37.47168	-0.003493	0.007263	22155.85378	3.067156	3.196117	-76.707313
2017-05-02 19:22	163.7487	37.54439	-0.003503	0.007264	22149.76871	3.067031	3.192568	-76.704927

note that this is a condensed output to confirm the results around 2017-05-02 7:19:29 PM

5. Our code output the tracking data called 2017-PRN-11-JK-V5.txt which was passed over to the ARO operator via USB and uploaded to the dish.
6. We setup the spectrum analyzer with:

Centre frequency:	Span:	Averaging value:	Amplitude:
1.57542 GHz	100 MHz (starting value to observe features, then went narrower and narrower) 20 MHz, and then 10 MHz	100 Added smoothing to the signal.	-70 dBm to -120 dBm Made sure it was within our expected range.

Observations

1. A few adjustments and calibrations of the dish had been performed by the operator before the signal was visible at the center frequency of 1.57542 GHz. The operator mentioned that wind, snow, and rain cause slight misalignments in the antenna. The average option was used with a setting of 100, this allowed for a smoother signal to be displayed, making it easier to analyze. We then identified the noise floor and could clearly see the peak at the center frequency. An amplitude between -75 and -80 dBm could be seen at the peak. This result matched closely with the expected result generated from the software we developed.

Figure 1 shows us starting to see a signal.

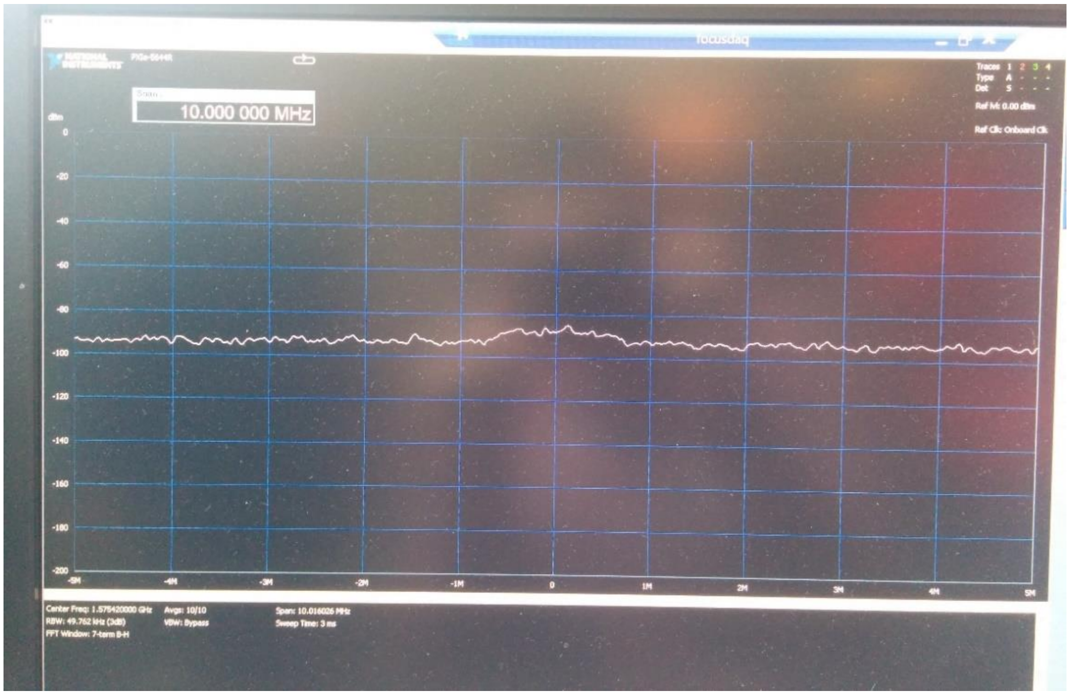


Figure 1: Pre-antenna dish calibrations and adjustments

Figure 2 shows that the satellite is starting to come within view.

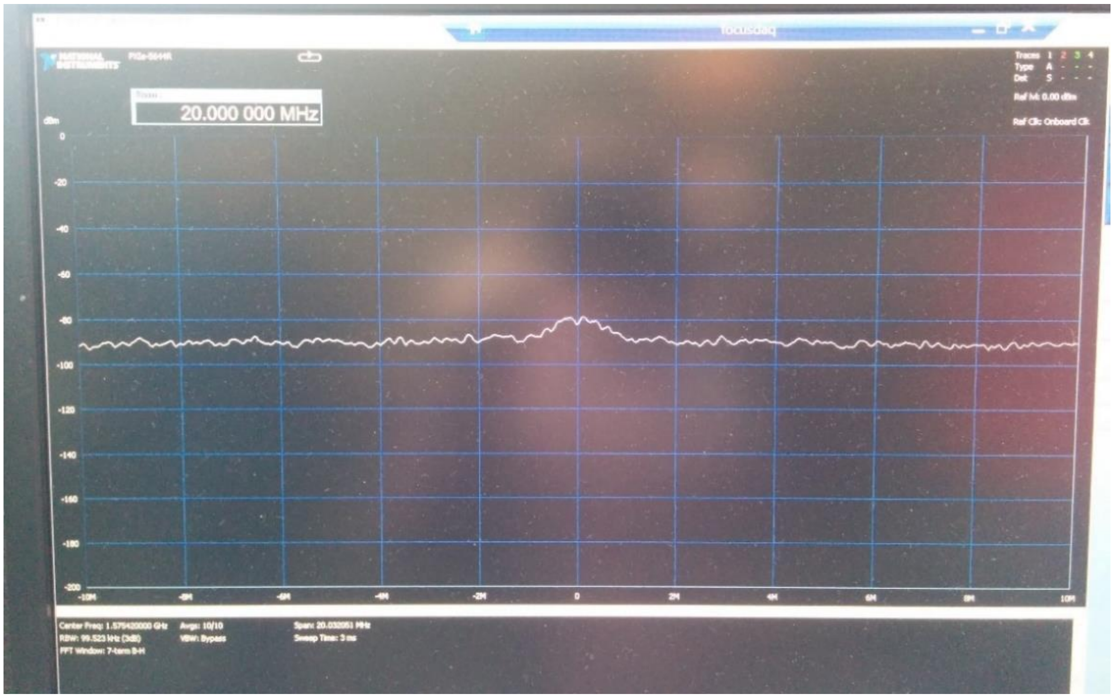


Figure 2: Satellite starts to come within view

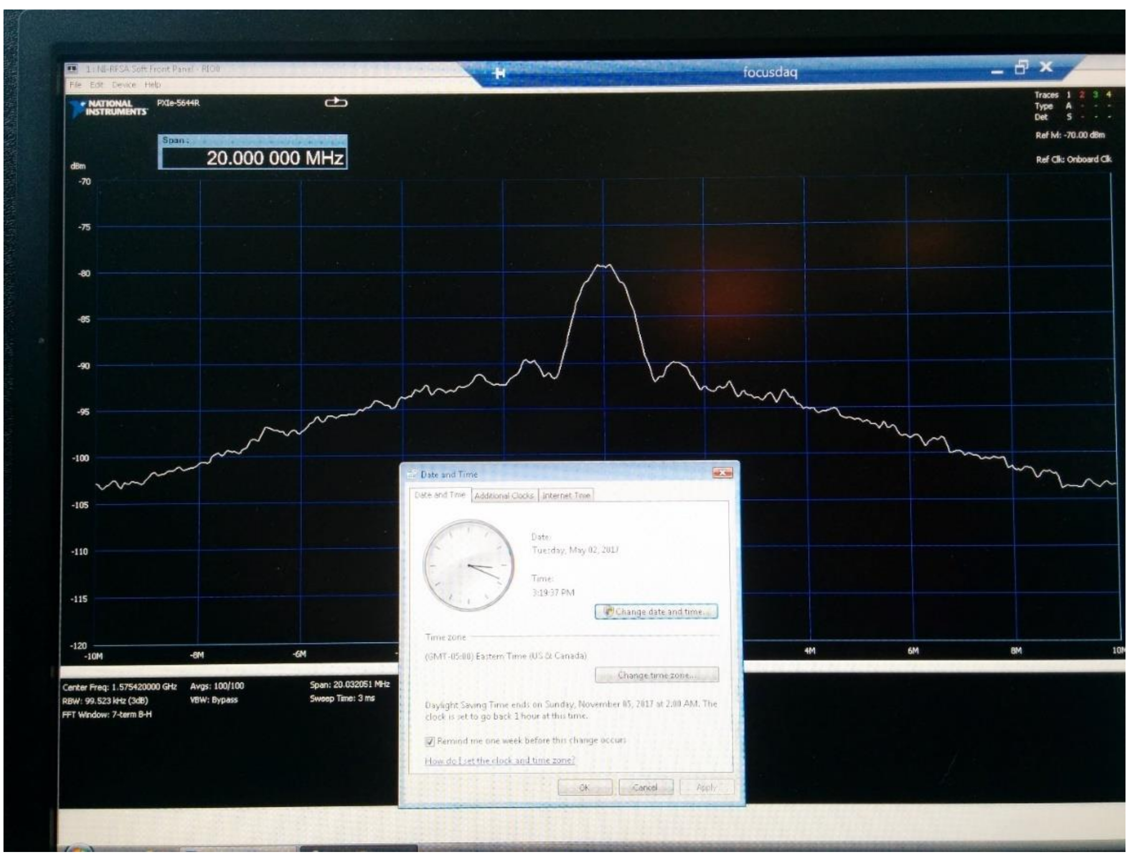
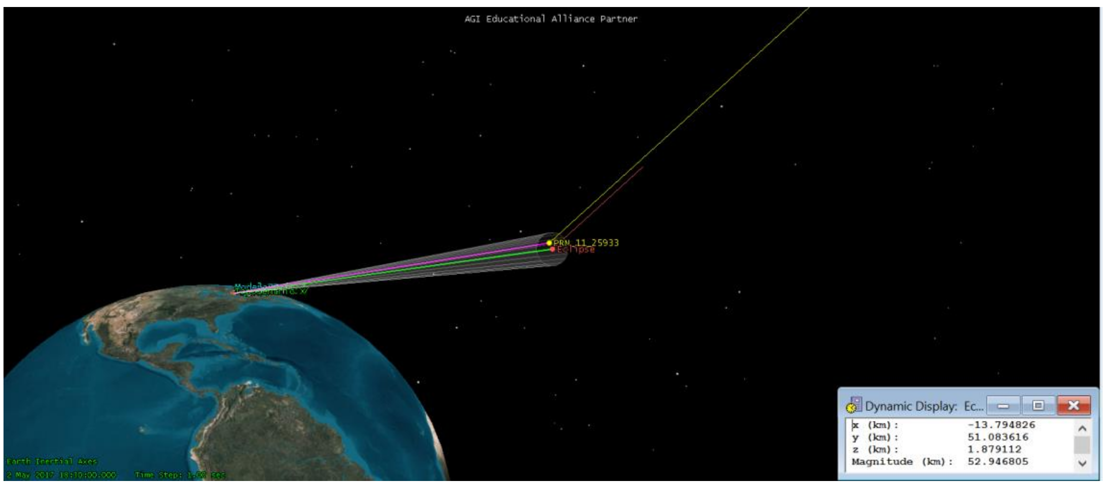


Figure 3: Peak reading for PRN 11 at 7:19pm UTC

Results

The result for the tracking of PRN-11 proved successful as we saw a spike in power at our center frequency of 1575.42 MHz. This spike appeared to extend to the -75dBm to -80 dBm range, while the noise floor varied around the -90 to -105 dBm range. This confirms with step 4 of the procedure where our calculated power level was expected to be around -76.7dBm.

We were quite confident in our software's ability to track the satellite and be well-within the beam width of the ARO's sensor due to our rigorous testing and validation we had performed during the course and documented for P3-P5. Here is the simulation we ran in STK to confirm our propagator. It is clear from the bottom right hand corner that we are mostly off in the range (y-direction) by about 51km, x-direction -13km and z direction only 1.8km. We knew being off in the range wouldn't matter as much as being off in the x or y (because we'd still be looking at the satellite). This may have caused the slight variation in power we detected along with other factors like the clouds and rain.



Conclusion

The tracking section was successful because we could confirm that our software had worked in a real-life situation with a very large parabolic dish. I was able to apply my theoretical knowledge of orbital mechanics and RF theory to this problem and I learned more about how large scale satellite tracking operations are ran and what benefit they have for military and industrial applications. I also learned a lot more about the programming language C and the debugging tools within the eclipse environment. I learned about managing a software project over Github ensuring that we tagged issues with the code along the way, documented every single update and commit, Github also made it easier to collaborate with my partner over the version control of the software.

To improve this project my suggestions would be to integrate Github version control and documentation into the software design part of the course. I think its very important for engineers to be aware of the tools that make our life much easier when developing software with other people involved. Lastly, some reasoning behind why STK's transmitter-link calculation expected -130dBm to -160dBm versus our -75dBm calculation (see ENG-4350-P4-JK.pdf). We spent a lot of time trying to figure out if our power values were wrong since we were comparing everything to STK. I think STK may have (or not) accounted for the degrade overtime of the satellite's transmitter, the losses within its system, or extra losses within the atmosphere/rain. My corrections would be to improve/update the documentation based on some formatting changes and other function calls that need to be updated to pointers in the P1, P2, and

TrackingSpec-16 documents which would have other teams. For example, we created a Look Angles Structure due to the memory leaks we found within our main.

Activity 2: Mystery GNSS Satellite Tracking

Purpose

The purpose of this activity was to test our understanding of the code we developed and to try to identify a mystery satellite given by the instructor only provided its TLE elements. This activity tested our ability to use a spectrum analyzer under time constraints of our tracking period and our ability to use conductive reasoning with the spectrum analyzer to determine which type of navigation satellite we could be looking at: i.e. Beidou, Glonass, Galileo, or GPS operational systems.

Prelab

1. Change my ReadNoradTLE function to read only 9 (nine) '*Mystery Satellites'* as opposed to the 32 GPS satellites from Celestrak.

```
int ReadNoradTLE(Satellite sats[], char *file) {
	FILE *fp = fopen(file,"r+");
	for (int i = 0; i < 9; i++) {
		ReadSingleNoradTLE(&sats[i], fp);
	}
	fclose(fp);
	return 0;
}
```

2. Change aspects of the Main to create an array of 9 satellite structures and adjust the for-loop to go through that array for the AOS/LOS table.

```
    printf("\nImporting TLE file sats...\n\n");
    char *file = "TLE.txt";
    Satellite sats[9];
    ReadNoradTLE(sats, file);

    for(int j=0; j<8; j++){
```

Procedure

1. Updated our TLE with the 'MysteryTLE.txt' file given by the instructor and ARO operator.
2. Updated our tracking_sched.txt to our allotted timeframe:

```
Tracking start date/time: 2017-05-03-19:40:00
 Tracking stop date/time: 2017-05-03-20:40:00
      Output time step (sec): 10.00
```

3. AOS/LOS table output:

Sat No.	Name	AOS	LOS	Min. ExpectedLevel (dBm)
1	Mystery2	2017-05-03 19:40:00	2017-05-03 20:39:59	-76.471906
2	Mystery3	2017-05-03 19:40:00	2017-05-03 20:39:59	-75.500213
3	Mystery4	2017-05-03 19:40:00	2017-05-03 20:39:59	-77.182862
4	Mystery5	2017-05-03 19:40:00	2017-05-03 20:39:59	-75.608122
7	Mystery6	2017-05-03 19:40:00	2017-05-03 20:39:59	-75.575504
8	Mystery7	2017-05-03 19:40:00	2017-05-03 20:27:09	-77.119331

4. We were instructed to track Mystery Satellite 2, so Satellite # 1 was selected. A similar output to Activity 2 step 4 was generated. Then the tracking data file was transferred over to the ARO operator via USB.

5. The spectrum analyzer was setup to a broad range of 1000 MHz to 1700 MHz based on the known bands provided for each navigation system within the 'ARO.pdf' and in figure 4 below.

Centre frequency:	Span:	Averaging value:
1.35 GHz	700 MHz	100

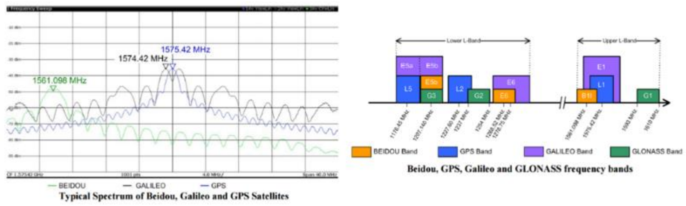


Figure 4: Important facts about the various navigational satellite systems frequency bands and power levels.

6. Once we identified a peak at a specific frequency, we tried to determine which band it was within from Figure 4. Through process of elimination of the upper/lower sidebands we narrowed down the possible frequency the satellite was transmitting to then confirm with the instructor.

Observations

Figure 5 shows the general structure of the signal and the environment around it we saw from the spectrum analyzer. We determine the noise floor to be around -87.84 dBm, which eliminated any artifacts and unwanted peaks that the smoothing did not get rid of.

Figure 5: Signal Peaks in view from 1000MHz to 1700 MHz

We identified peaks at 1561 MHz for the upper band and 1268 MHz and 1207 MHz for the lower band to investigate, see Figure 4. We could determine from the upper band that we could be looking at Beidou, GPS, or Galileo also because of the way these systems utilize the Code Division Multiple Access (CDMA) based on the spectrum seen in Figure 4.

Our first idea was to determine if it was Beidou B1l so we adjusted the centre frequency of 1.561 GHz as seen below.

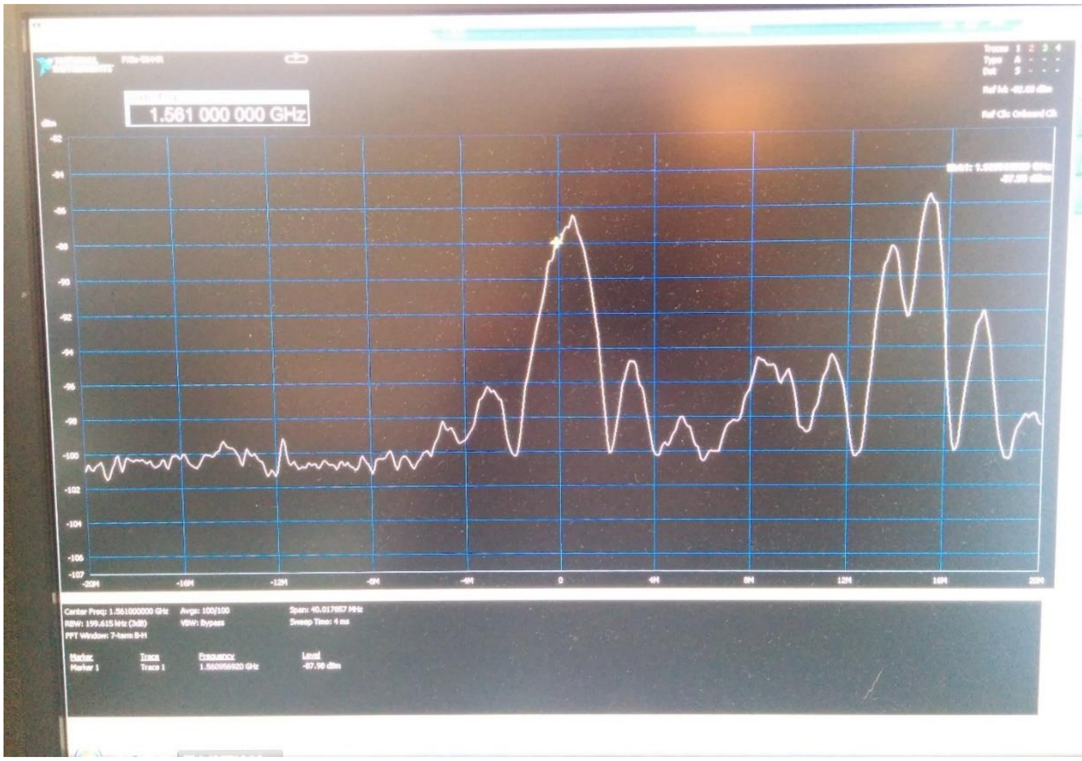


Figure 6: Beidou B1l at a centre frequency of 1.561 GHz (Upper band)

From Figure 6 we can see the expected peak at the Beidou B1l as well as the adjacent GPS L1 band at around 1575 MHz. The peculiar thing is that the Beidou satellite should not be transmitting both Beidou and GPS frequencies. We knew that there were no other satellites in an overlapping orbit that we could be reading. So, for confirmation that it was indeed Beidou we wanted to check the lower side band at 1268 MHz.

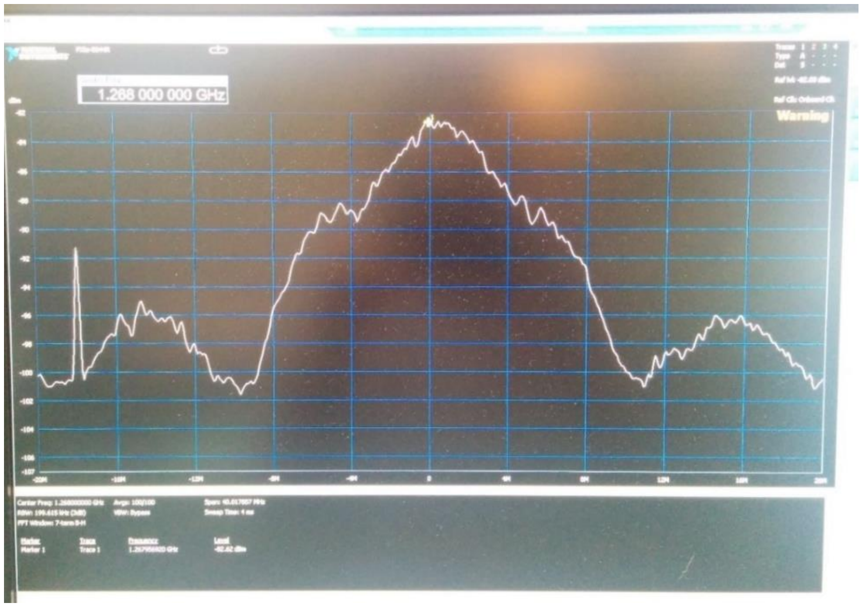


Figure 7: Beidou E6 at a centre frequency of 1.268 GHz (Lower band)

From Figure 7 we can conclude that Beidou is in view because of the clearly visible signal. Our last check before confirming our theory with the instructor was to view another lower band of the Beidou system at 1207MHz seen below.

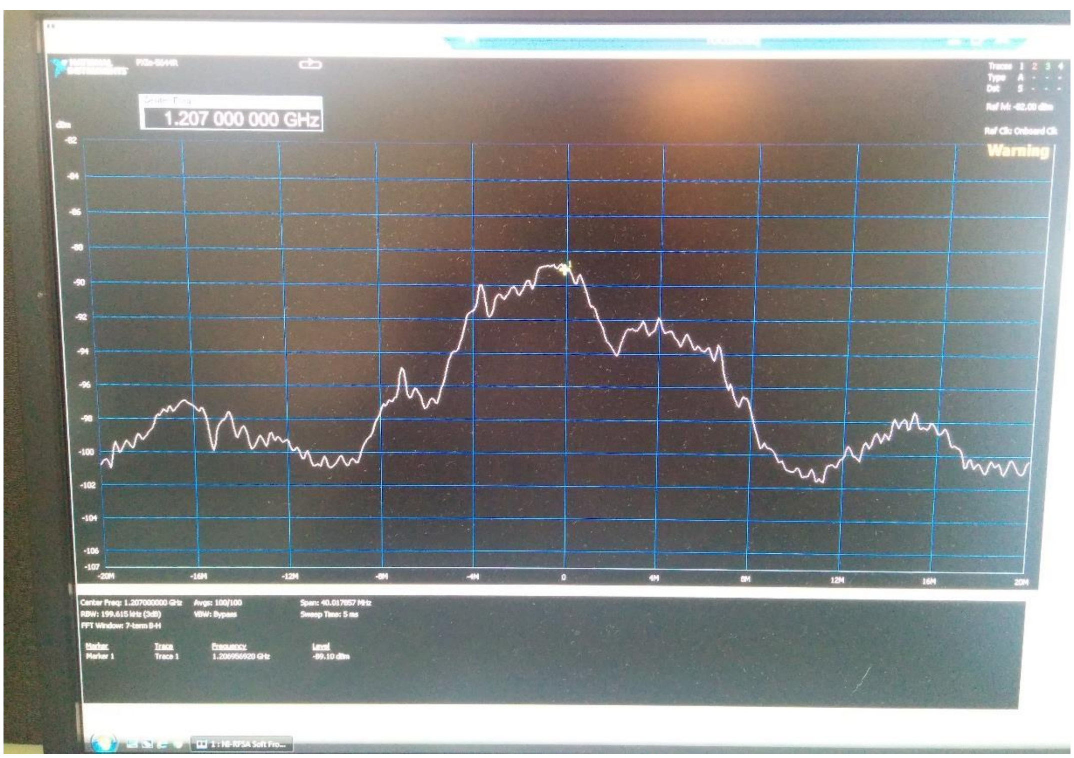


Figure 8: Beidou E5b at a centre frequency of 1.207 GHz (Lower band)

Figure 8 shows that there is indeed a signal above the noise floor.

Results

We confirmed that peaks were at the prime location for the BEIDOU system. The peaks in the lower band appeared at 1207 MHz and 1268 MHz, while the peak in the upper band appeared at 1561 MHz. As seen in figure 4, these frequencies can be confirmed for BEIDOU. This result was confirmed to be correct by the instructor.

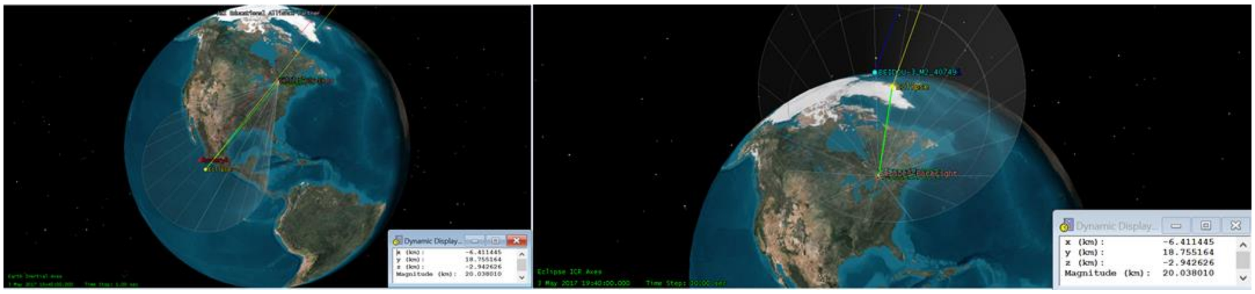


Figure 9: STK post processing for MysterySat

During the post-processing, we applied our skills with STK to confirm that the Mystery Satellite was in-fact from the Beidou navigation constellation by importing the Beidou TLE from Celestrak as well as the MysterySat TLE given to us by the instructor. We confirmed the particular satellite in the Beidou navigation constellation is Beidou-3-M2-40749 and our software was even more precise because it was almost directly overhead.

Conclusion

We were able to correctly determine the *mystery satellite* to be Beidou-3-M2-40749 from the Chinese navigational constellation Beidou by utilizing our robust software package that we developed over the latter quarter of the course. We utilized our skills with the spectrum analyzer to quickly change between peaks and the span to find and analyzer the spectrum the satellite what transmitting. We used our deductive reasoning skills to eliminate other possibilities upon viewing and analyzing the frequencies received.

Corrections to the lab would be to fix the names of the satellites in the TLE which had varying spaces after the name which cased some issues for us and other teams.

My suggestion to improve the learning outcomes of the lab would be to determine what specific satellite from the Beidou system the satellite that we were looking at was. We could've used the beidou.txt TLE from Celestrak to determine the specific satellite it was. Another suggestion would be to try to demodulate the signal to try and receive and/or process the GPS telemetry data as an extension to this lab which I'm very interested in doing for the future.

Activity 3: Measurements ARO Dish Antenna Pattern

Purpose

The purpose of this activity was to use the ARO to perform measurements of the strongest celestial radio source in the sky above 1 GHz, Cassiopeia A. I could utilize my skills with the spectrum analyzer and apply concepts related to the half-power beam-width and antenna patterns developed in other labs of the course.

Preparation for the Measurements and Procedure development

1. We determined the expected flux and power levels for each source received by the dish near the 1.4 GHz (L-Band) to be 2410 Jy. The bandwidth (BW) we assumed to be 10MHz, and there were losses from the low-noise amplifier and bandpass filter combined resulting in -4dB, and the gain of the amplifier added 18dB (which we were told by Prof. Quine and confirmed from RF-BAY datasheets of the LNA and BPF). The Area of the dish is known with its 23m radius and 50% efficiency. The formula used was 10log10(FluxDensity*Area*Efficiency*BW).

Table 1: Expected Power Levels to be received by ARO from each Celestial Source in the L-Band (except Cas-A at 750MHz)

Source	Flux Density	Area*n*BW	Expected Power (dBW)	+/- Gains & Losses (dBm)
3C 20	1.13E-25	8309512569	-150.2734601	-106.2734601
3C 196	1.39E-25	8309512569	-149.3740965	-105.3740965
3C 273	4E-25	8309512569	-144.7836446	-100.7836446
3C 295	2.24E-25	8309512569	-147.3017643	-103.3017643
3C 348	4.45E-25	8309512569	-144.3206444	-100.3206444
3C 380	1.44E-25	8309512569	-149.2206196	-105.2206196
Cygnus A	1.59E-23	8309512569	-128.7902733	-84.79027327
3C 123	4.58E-25	8309512569	-144.1955897	-100.1955897
3C 286	1.46E-25	8309512569	-149.160716	-105.160716
Cassiopeia A	2.41E-23	8309512569	-126.9840741	-82.98407408
Cassiopeia A at 750 MHz	3.88E-23	8309512569	-124.9159273	-80.91592725

2. The selected source was Cassiopeia A at the 1400MHz and 750MHz band. We ended up shifting the centre frequency for the second band to 770MHz because there was a noise spike which was giving false readings as seen below. The 770MHz frequency band was selected because it has a higher flux density than the L-band source and it was still within the bandpass filter range of 700-1600MHz. The table would simply have the angles in degrees on the x-axis and power levels we recorded on the y-axis.

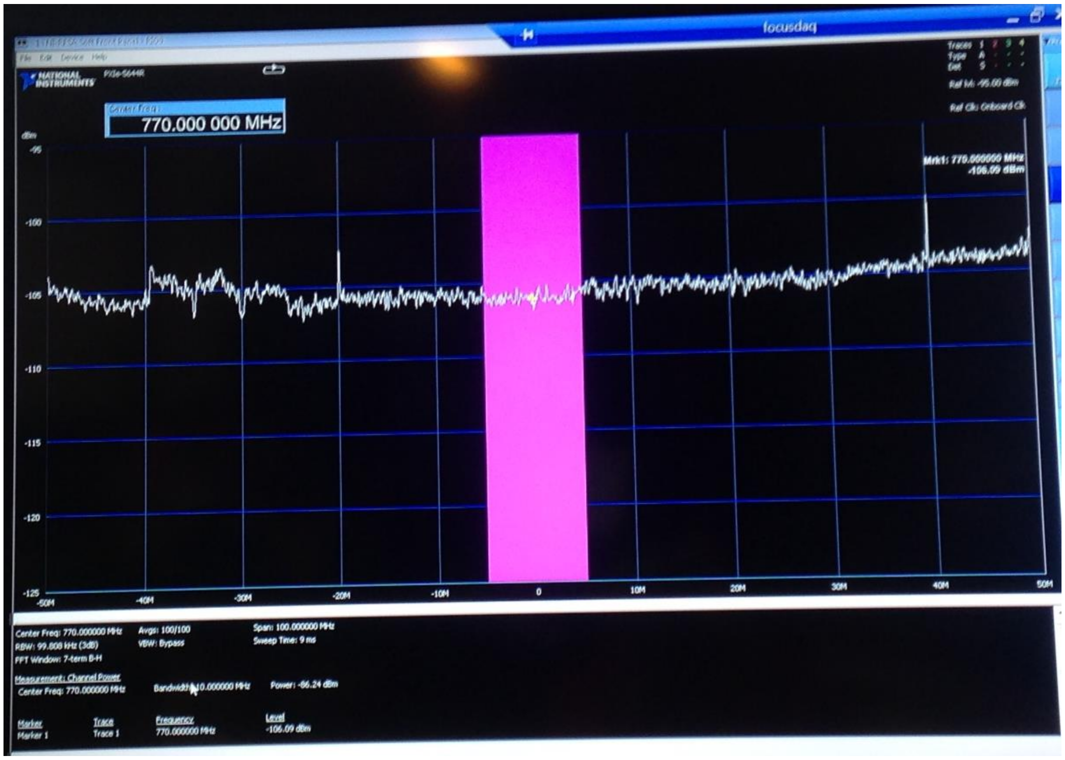


Figure 10: Spectrum Analyzer display with 770MHz as the centre frequency due to the noise spike at 750 MHz

3. The procedure we developed for measuring the half-power beam-width was determined by:
    a. Pointing the antenna at Cas-A by the right ascension and declination given.
    b. Use $G_{dBi} = 10\log\left(n * 4 * \frac{\pi}{\lambda^2} * A\right) = 10\log\left(\frac{31000}{\theta_{Az}\theta_{El}}\right)$ to solve for θ^2. Therefore, for 1400MHz the HPBW is about 0.3° and when we approximately half the frequency for 770 MHz we get 0.6°. These are the angular increments we used taking points at 0°, +/- 0.3°, +/- 0.6° for 1400 MHz and 0°, +/-0.6°, +/- 1.2° for 770 MHz.
    c. Excel will be utilized for the recording, plotting, and data processing of the results.

Measurement Observations

The ARO was directed to point to and track Cas-A. We followed our prescribed procedure above for the 1400 MHz and 770 MHz bands for the Cas-A source.

Observations

Table 2: HPBW Measurements for Cas-A at 1400 MHz

Angle (Degrees)	Power (dBm)
-0.9	-83.05
-0.6	-82.71
-0.3	-82.54
0	-82.68
0.3	-83
0.6	-83.09
0.9	-83.13

Table 3: HPBW Measurements for Cas-A at 770MHz

Angle (Degrees)	Power (dBm)
-1.2	-86.31
-0.6	-86.17
0	-86.23
0.6	-86.33
1.2	-86.39

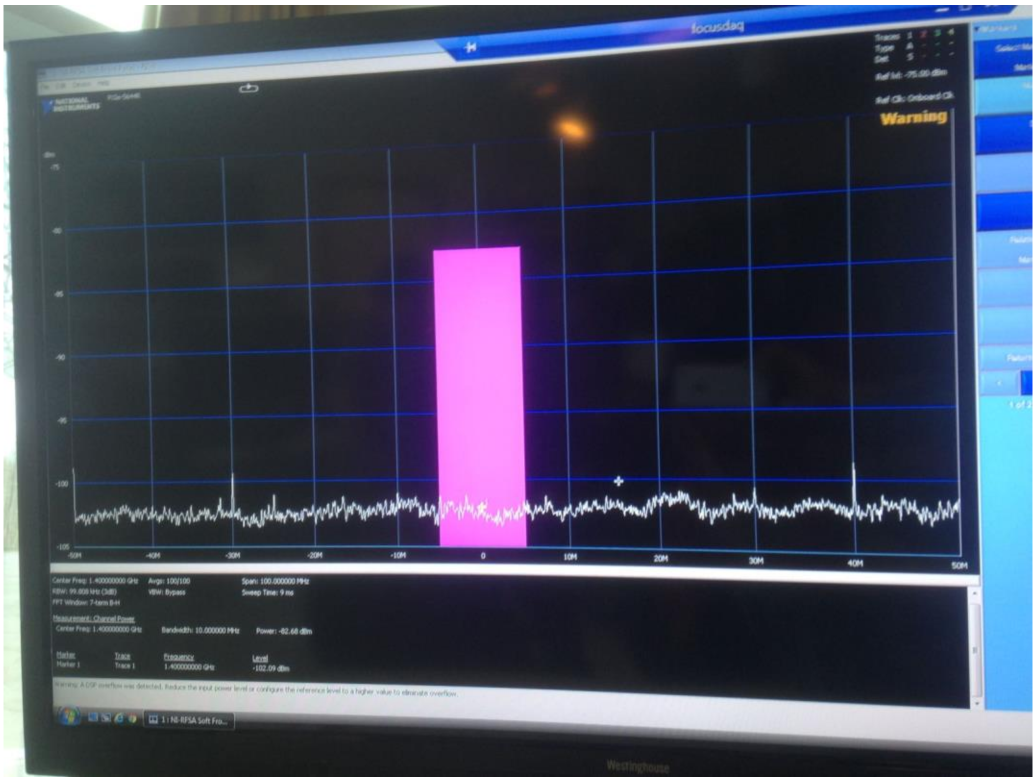
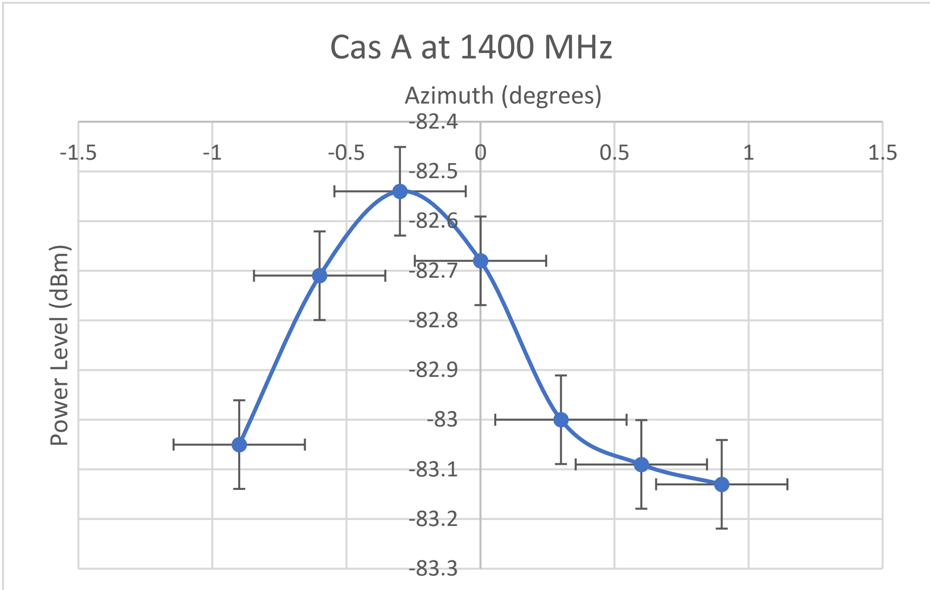


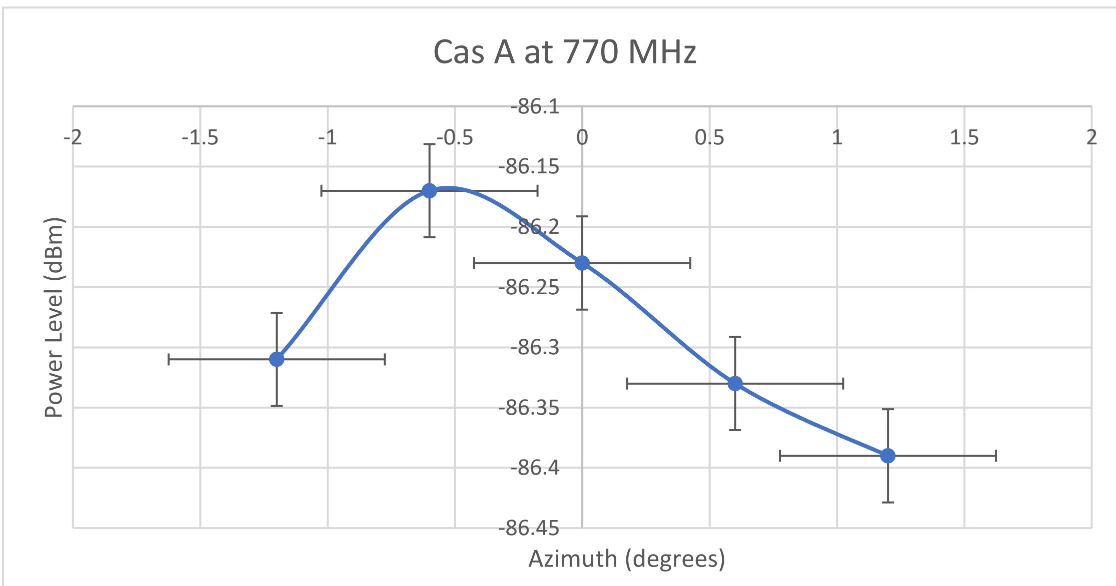
Figure 11: Display of the Spectrum Analyzer as we were collecting data at the L-band for Cas-A

Results

The plots below confirm the expected power level output of -82.984 dBm which is similar to the -82.54 dBm power level that measured. At the 770 MHz band we predicted -80.92 dBm although we measured -86.17 dBm. The discrepancy maybe due to the efficiency of the antenna/feed or the full 46 meters of the antenna may not have been utilized.

It is also clear that there is some symmetry with both bands that we would expect from a HPBW measurement, mainly with the L-Band measurement. For both graphs it seems we should have taken more measurements in the negative azimuth to see it flatten out much more to conclude the noise floor power level, which seems to be at around -83.2 dBm for the L-band and -86.5 dBm for the 770 MHz band. This results in a HPBW being very much over the 0.3 degrees and 0.6 degrees as expected, which is probably due to the fact that we were looking too closely to the noise floor which prevented us from getting any values that would verify the 3dB drop.





Conclusion

The power levels at the L-band were close to what we predicted. Although the signal we were receiving from Cas-A was not powerful enough for us to see a 3dB drop above the noise floor. The results at the 770 MHz band was much lower than predicted (-86.17dBm versus our calculated -80.92dBm). The noise floor for 770 MHz was around -86.5 dBm which means we were probably just measuring the noise. If we had power levels around our predicted -80.92 dBm then we probably would've been able to see our 3dB drop. There may have been some problems with the L-band receiver of the antenna and that the effective area of the antenna was probably much less than the 46 meters we used to calculate our expected power levels. Despite those errors, it seems that if we shifted the L-Band graph to the right by

0.3 degrees then it would be centred directly on the y-axis, which means the ARO alignment may have been off by 0.3 degrees.

I was able to use my understanding of steerable parabolic antenna to obtain power measurements of a celestial source. I confirmed my ability to understand the relationship between azimuth/elevation to right ascension/declination to point the ARO in the right direction of the celestial source. I was able to apply my skills of antenna patters and HPBW plots to confirm my understanding of what was going on during the lab as I was responsible for making adjustments to the spectrum analyzer. Its unfortunate that we were unable to obtain the HPBW of the antenna with the Cas-A source, although I was able to determine that there may have been some problems with the L-band receiver and a decrease of the ARO area which decreased the power we received.

Corrections to the lab would be to fix some of the problems that we were encountering during the lab, for example when we were taking measurements so close to the noise floor.

My suggestions to improve this lab would be to include measurements of the system noise temperature (Lab M4) by comparing the flux from Cas-A to the flux off of Cas-A and add the difference between the sources. It would have been nice to have this experiment work during Lab-M2 so we would've had a better understanding of what we'd be looking at.

Final Conclusion

I think field trip to ARO was the most beneficial experience I've had throughout my Space Engineering education. I really think the activities we performed -- especially the satellite tracking was extremely practical and applicable to us and our education. I'm happy that our software program worked flawlessly as we prepared for months to accomplish this goal. We were able to distinguish the satellite's signal and from which navigational constellation it was from. Its really gratifying to say that we've used the largest radio telescope in Canada and used it to track GNSS satellites. We proved our ability to develop software in C and debug using eclipse tools and STK. I learned a lot about RF electrical equipment like spectrum analyzers and oscilloscopes. I developed a further understanding of orbital mechanics and RF transmission through the ARO activities.

I got to learn about how an observatory is ran from the operations standpoint from Prof. Ben Quine. He mentioned a lot about how he became a space engineering entrepreneur through his company Thoth Technology which was inspiring.

My suggestion for this project would be to switch to an object orientated programming (OOP) language, which would make the understanding of how the code will all come together be understood more thoroughly by the students with only OOP skills/knowledge and background. Our work around for the Look Angles for example, was to create a structure for them. Another suggestion would be to include a graphical user interface component to the code. The prerequisite would be to actually have the code working but I think having it presented in a nice clean way instead of having the user enter commands into eclipse's console would be much better. For example, if someone could have a github page that automatically fetches the newest TLE from Celestrak and has a nice display of all the satellites in-view and plots their trajectories would be a step up. There are packages to help accomplish this goal which have various online support tools see Slide 4 of this link https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20160007351.pdf.

A lot of people didn't know how to use STK well enough couldn't test their code properly. An improvement would be to include a list of online resources that can easily be used for checking orbital, time and position parameters. I've gathered a list here for Julian Date, ECF positions, and much more (http://www.keithmenezes.ca/posts/2017/03/blog-post-4/).

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- "Creating Visualization tools for Space Missions" https://2017.spaceappschallenge.org/challenges/ideate-and-create/1d-2d-3d-go/details
- For the most recent software go to https://github.com/kmenezes/ARO-Tracking-Software