Personal Assignment Report

Observation of Satellites with the ISU Ground Station

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ABSTRACT

This report describes all the work I have done from January to February 2011 for the satellite tracking using the ISU Ground Station. ISU ground station can receive signals in VHF, UHF and S-bands. My PA mainly focused on the UHF cubesats Cubsat XI-IV, Cute-1, Cubesat XI-V and Compass-1. I recorded the satellite signal strength and tried to determine an accurate system gain of the ISU ground station. I also attempted to pick up other satellites such as Nanosail-D and ElaNa during this period. But nothing was observed except rushing noise because the batteries had run down or the launching failed. In the initial phase of observation, results were not very satisfying. After we had done the receiver recalibration and antenna rotator calibration, results returned to normal. Many good observation data were obtained by tracking Cubesat XI-IV and Cute-1. For the data analysis, I developed criteria to match observed and predicted data: Firstly, the predicted data should match all the peaks in the observed data. Secondly, the predicted curve should not fall below two peaks of the observations by more than 1.5dB. Thirdly, more emphasis was placed on the three highest peaks in the observed data than on the other peaks. Finally, an isolated observed datum is not taken into account in the same way as a real peak if it makes the predicted curve difficult to meet other real data peaks. The estimated ISU ground station gain is very convergent based on the observations of a specific satellite. The average gains from the observation of Cubesat XI-IV and Cute-1 are 30.05±0.65 dB and 32.97±0.78 dB, respectively. No systematic differences were found in the station gain when the satellite passing over in different directions. I conclude that the station works in all directions as it should. The finding by Kaupo Voormansik that sometimes the measured signals were significantly higher than expected was not found in this year. Maybe it was an unstable phenomenon or erroneous data. There is a perspective that we can use the observed data to measure the satellites' tumbling rates.

Key words: Satellite, Tracking, Ground Station, Gain

摘 要

本报告总结了我在 2011 年 1 月和 2 月间用国际空间大学地球站所做个人作业的工作。空间大学的地球站能够接收 VHF，UHF 和 S 频段的信号，但我的个人作业主要使用 UHF 频段来观测卫星，这些卫星包括 Cubsat XI-IV, Cute-1,Cubesat XI-V 和 Compass-1，最后通过记录接收的卫星信号的强度和数据分析来确定一个准确的地球站系统增益。我还尝试跟踪了 Nanosail-D 和 ELaNa 卫星，但由于卫星的电池故障或发射故障没有跟踪成功。我早期的卫星跟踪结果并不理想，在进行了接收机和天线角度指示的标定后数据恢复正常，并通过跟踪 Cubesat-XI-IV 和 Cute-1 得到了许多宝贵的观测数据。在数据分析时，我主要采用了以下几个标准来进行观测数据和预测数据的匹配：第一，让预测数据和所有观测数据峰值匹配；第二，不要让预测数据低于两个观测数据峰值超过 1.5dB；第三，让最高的三个观测数据峰值比其他峰值获得更大的权重；最后，一个单独的观测峰值数据并不能作为一个实际的峰值来对待。最后发现空间大学的地球站增益是稳定的，用这两颗卫星的观测数据得到的增益分别是 30.05 ±0.65 dB 和 32.97 ±0.78 dB。地球站观测来自在各个方向的卫星得到的增益数据并没有系统性的差别，因此可以下结论说地球站在各个方向工作都正常。原来 Kaupo Voormansik 发现的现象并没有再次发生，估计是临时现象或是数据错误。未来可以利用国际空间大学的地球站的观测数据来测量卫星的滚动频率。

关键词： 卫星，跟踪，地球站，增益


Courtesy of my daughter Jingyi WU

Dedicated to my family, especially to my lovely daughter.

本文献给我的家庭，特别是我可爱的女儿。

Table of Contents

1 Introduction

In summer 2008, ISU installed a GENSO satellite tracking station, which works on frequencies of 144, 432, and 2400 MHz. In 2009, Kaupo Voormansik, one ISU student, observed several passes of satellites and compared the measured signal strengths with expectations from link budget calculations. He discovered that sometimes the measured signals were significantly higher than expected. Whether this is due to unusual propagation conditions or linked to our ground station environment, is not yet known. Therefore, the objective of this PA is to investigate this effect more thoroughly and more systematically by observing many more satellite passes under various conditions, in order to build up a clearer picture and to confirm that this effect is indeed systematic.
This PA was performed from January to February 2011, using the ISU Ground Station (Figure. 1.1), which is a member of the Global Educational Network for Satellite Operations (GENSO).

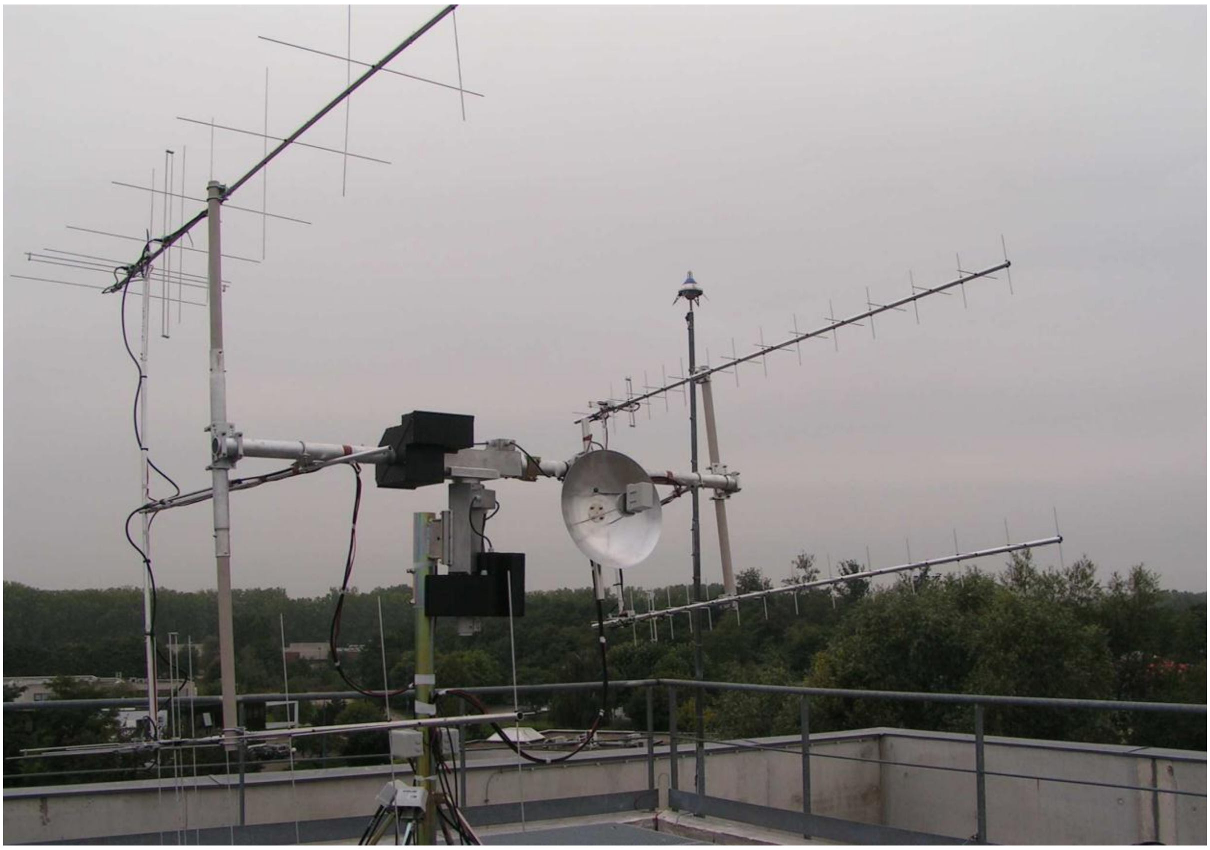

Figure 1.1: Antenna System of the ISU Ground Station

The ground station can receive signals in VHF, UHF and S-band. My PA mainly focused on some UHF cubesats, to record the satellite signal strengths and to try to determine an accurate system gain of the ground station through data analysis.

2 Methods of Observation and Analysis

2.1 Finding an Observation Pass

The passes of satellites can be found using PassFinder program (http://astro.u-strasbg.fr/~koppen/PassFinder/) provided by Prof. Köppen. All the observation parameters can be calculated by PassFinder shown in Figure 2.1. PassFinder does not use the current TLE (Two-Line Elements), but those dating from late January. For the cubesats there is not much difference with current TLEs in predicting the pass details. The predicted received power of the satellite's signal is also produced by this program.

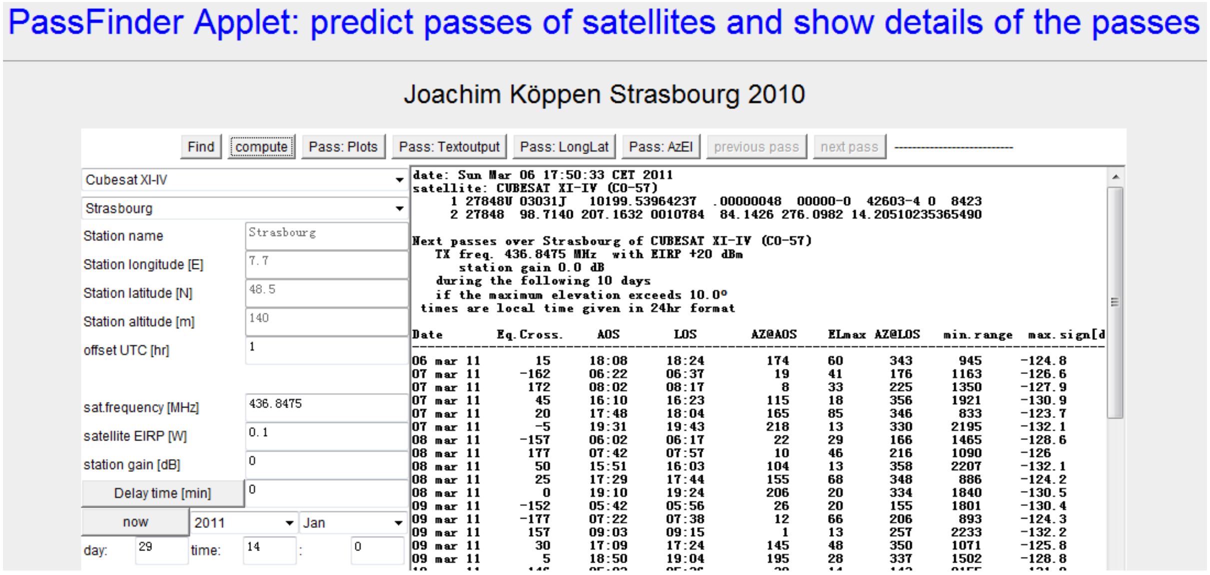

Figure 2.1: The PassFinder Applet for finding observable passes

2.2 Tracking a satellite

The antenna rotators of the ISU ground station are controlled automatically by the NOVA software shown in Figure 2.2. This program downloads the current TLE at its initialization

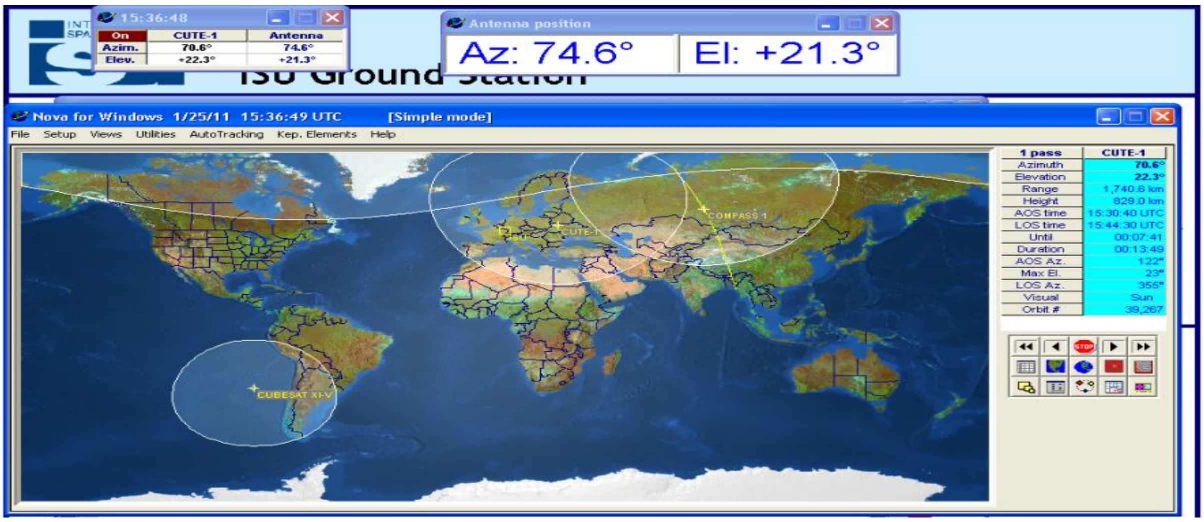

Figure 2.2: NOVA for windows used for satellite tracking

phase, and uses it in the later calculation. For each observation, three important predicted parameters produced by NOVA software were recorded, which are the azimuth at Acquisition of Signal (AZ@AOS), the maximum Elevation (maxEL) and the azimuth at Loss of Signal (AZ@LOS). This was done in order to be able to reconstruct the pass at any later time. In order to use the latest TLE and to avoid unexpected antenna control problems during satellite tracking, NOVA software usually needs to be restarted before an observation begins.

2.3 Recording the power level

The software IC910H is used to connect the station's VHF/UHF transceiver IC-910H and record the power level received from the observed satellite.

Figure 2.3: Power level recording software

2.4 Analyzing the data

The recorded data is analyzed to find the proper value of the ISU ground station gain by matching the observed signal power level with the predicted signal. This is done by adjust the level of the predicted curve to place in the observed data. Usually, the predicted times agree well with those of the observations. But a few times we also needed to align the predicted curve with the observed data in both time and signal level because the predictions are not completely synchronized with the observations due to the TLE differences between PassFinder and NOVA.

For the matching of observed and predicted data I follow several criteria, based on the definition of a "peak" in the observed data: This refers to a group of data points which is higher than the neighboring data as shown in Figure 2.4.

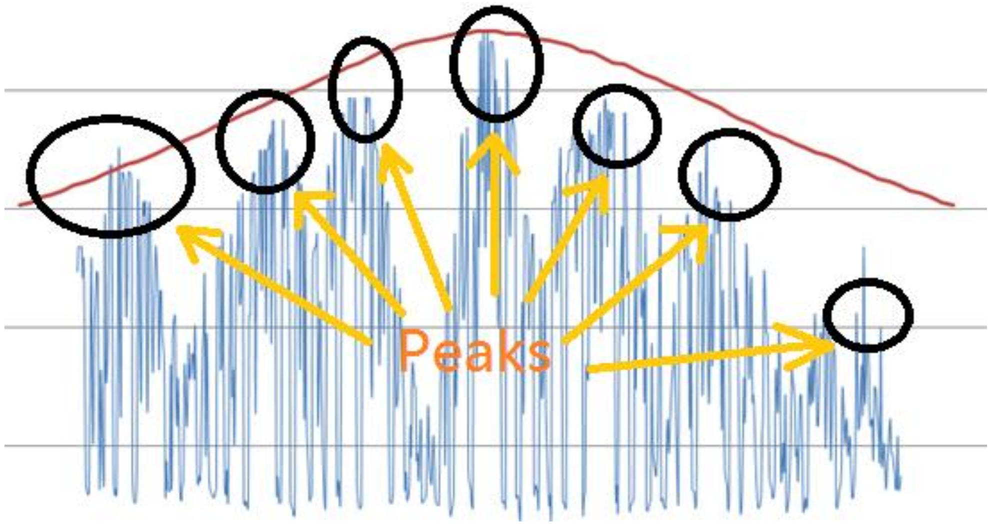

Figure 2.4: Peak Definition

Then, I follow these criteria:

1) Let the predicted curve match all the peaks of observed data.
   We cannot demand that all the observed data points agree with the predicted data because of the strong signal variations due to the tumbling of the satellites.
2) Do not let the predicted curve fall below two peaks of observations by more than 1.5dB.
   In order to realize a good fit of all the observed peaks, the predicted curve can be lower than the observed peak within the measurement errors (1.5dB, described in chapter 5) in most cases. Sometimes one of the observed peaks might exceed the predicted curve more than 1.5dB, if the peak data are considered as “wild” points.
3) We shall place more emphasis on the three highest peaks in the observed data than on the other peaks.
4) An isolated point of observed data shall not be taken into account in the same way as a real peak if it makes the predicted curve difficult to meet other real data peaks.

3 Initial Investigations

I started satellite observation from Jan. 5th, 2011. For each observation, I could receive the signal correctly. But the results were not very satisfying. In particular, I noticed that the satellite power level received by the transceiver differed only very little from the signal recorded without any satellite present. Take an observation of satellite Compass-1 as an example as shown in Figure 3.1. It seemed that the system had a strong background noise

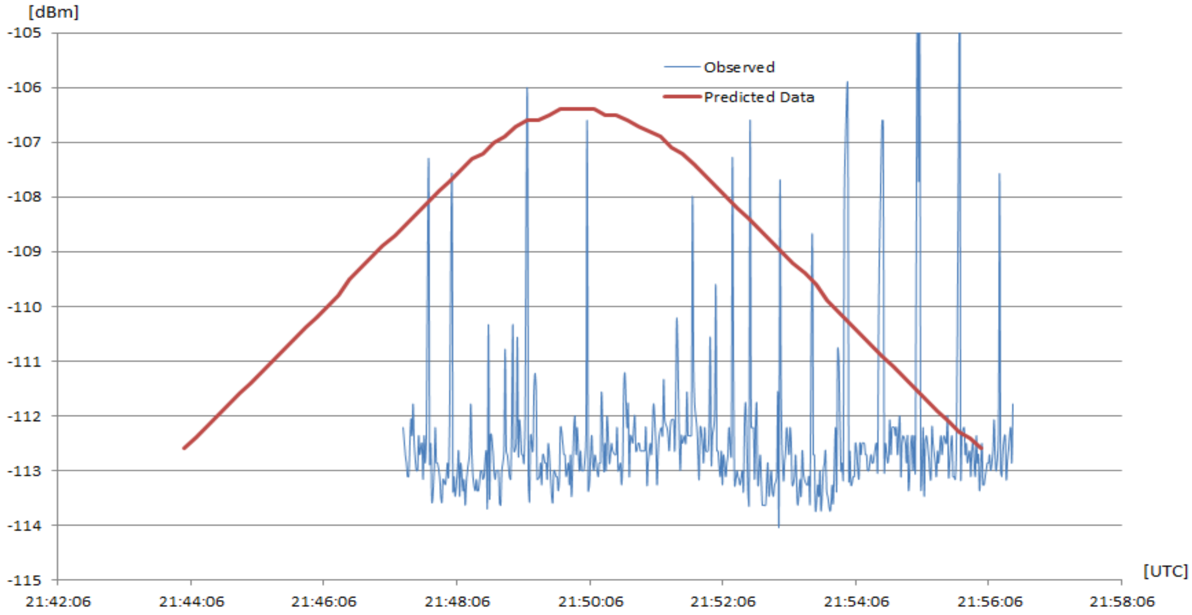

Figure 3.1: Compass-1 Observation on Jan 19th , 2011

around -113dBm. As a consequence, we recalibrated the receiver on Jan. 21st, 2011. This showed that the receiver was more sensitive: The background noise decreased to -117dBm as shown in Figure 3.2.

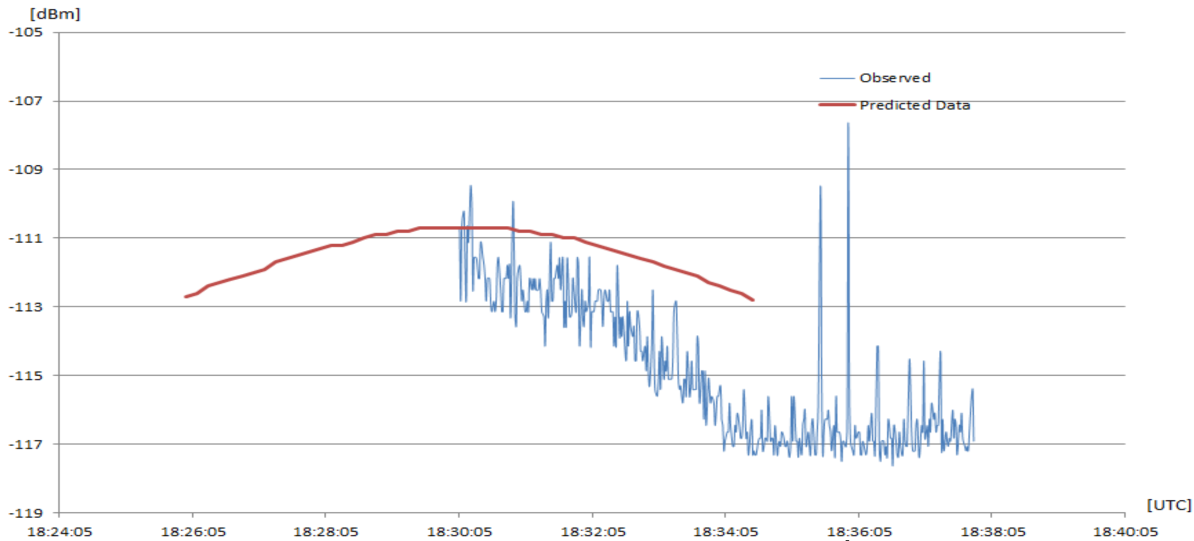

Figure 3.2: Compass-1 Observation on Jan 24th , 2011

Then I noticed another phenomenon when I was observing a satellite. The received signal power increased often after the antenna had stopped and waited for the next tracking command issued by the NOVA software. It was very strange because the automatic tracking was performed according to the precise antenna pointing data derived from orbital predictions. This tracking should have made the antenna point to the observed satellite accurately and a peak value should have been obtained and the signal should decrease when the antenna movement ceased. But if the signal increases, there must be some error in the antenna pointing. We checked the antenna subsystem and re-calibrated the antenna rotator indicators on Jan 29th, 2011. Elevation tracking system was found OK. On the other hand, a difference of 14° in azimuth was setting an offset of -14° in the Nova software. Later, after the observations had been done, it was realized that the azimuth comes to a mechanical stop at 0° when moved counterclockwise, but the display shows 346°, as this would be the standard position to orient the antenna, recommended by the manual. But such a 14° error in azimuth does not compromise the present results, because the horizontal width of the antenna's main lobe is about 27°.

4 Observations and Analyses

Several cubesats have been observed during these two months. The parameters of these cubesats are shown in Table 4.1.

Table 4.1 Cubesat Beacon Frequencies

No.	Satellite	Frequency (MHz)
1	Cubesat XI-IV	436.848
2	Cute-1	436.834
3	Cubesat XI-V	437.465
4	Compass-1	437.275
5	Nanosail-SAT	437.270/437.250

4.1 Observations of Cubesat XI-IV

4.3.1 Observation C1 on Jan 29th 2011

The three pass parameters are: AZ@AOS=129°, maxEL=28°, AZ@LOS=354°. The signal was first captured on 436.857MHz. The comparison of observed data and predicted data are shown in Figure 4.1. This pass was observed nearly completely, giving an Observation Pass ratio = Observed Pass/Whole Pass = 0.88.

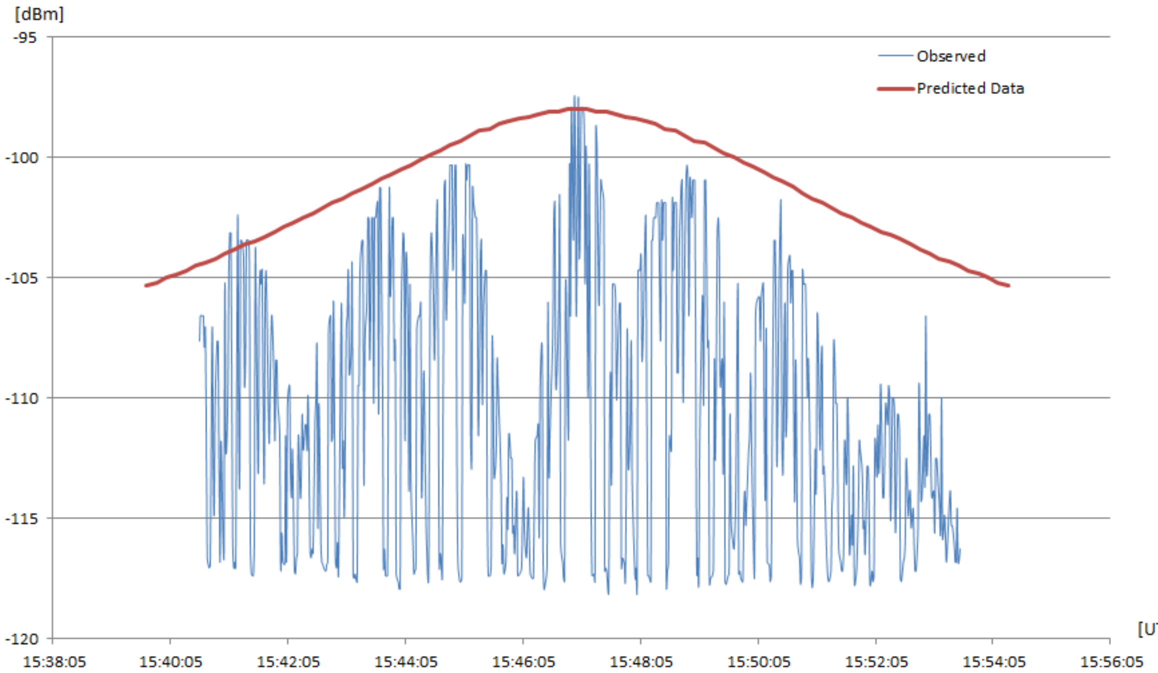

Figure 4.1: Observation C1 with Station Gain = 30.6 dB

4.3.2 Observation C2 on Jan 29th, 2011

The three predicted pass parameters are: AZ@AOS=179°, maxEL=52°, AZ@LOS=342°. The signal was first captured on 436.857MHz. There was no tracking in azimuth at the beginning of the pass, which was solved by restarting the NOVA software. This pass ended at the frequency of 436.839MHz. The comparison of observed data and predicted data are shown in Figure 4.2. The Observation Pass ratio = 0.85.

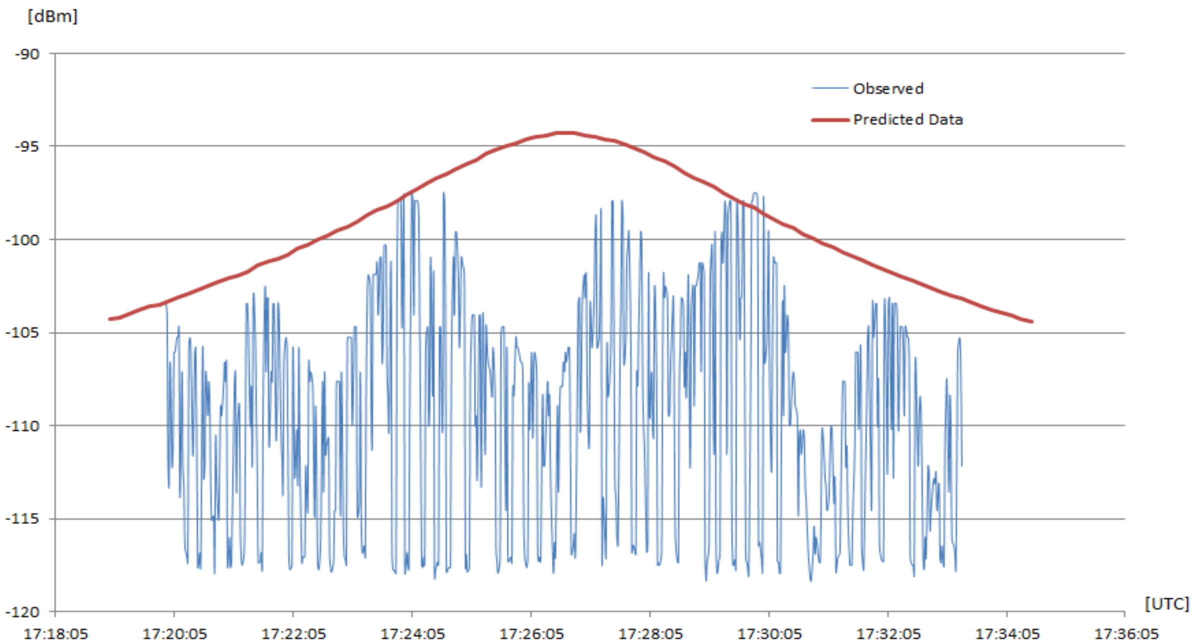

Figure 4.2: Observation C2 with Station Gain = 31.5 dB

4.3.3 *Observation C3 on Feb. 1st 2011*

The three predicted pass parameters are: AZ@AOS=149°, maxEL=55°, AZ@LOS=349°. The antenna performed a full azimuth turn between 16:31 and 16:32 UTC. The satellite was caught again at Azimuth = 355° and Elevation = 10°.The comparison of observed data and predicted data are shown in Figure 4.3. The Observation Pass ratio = 0.71.

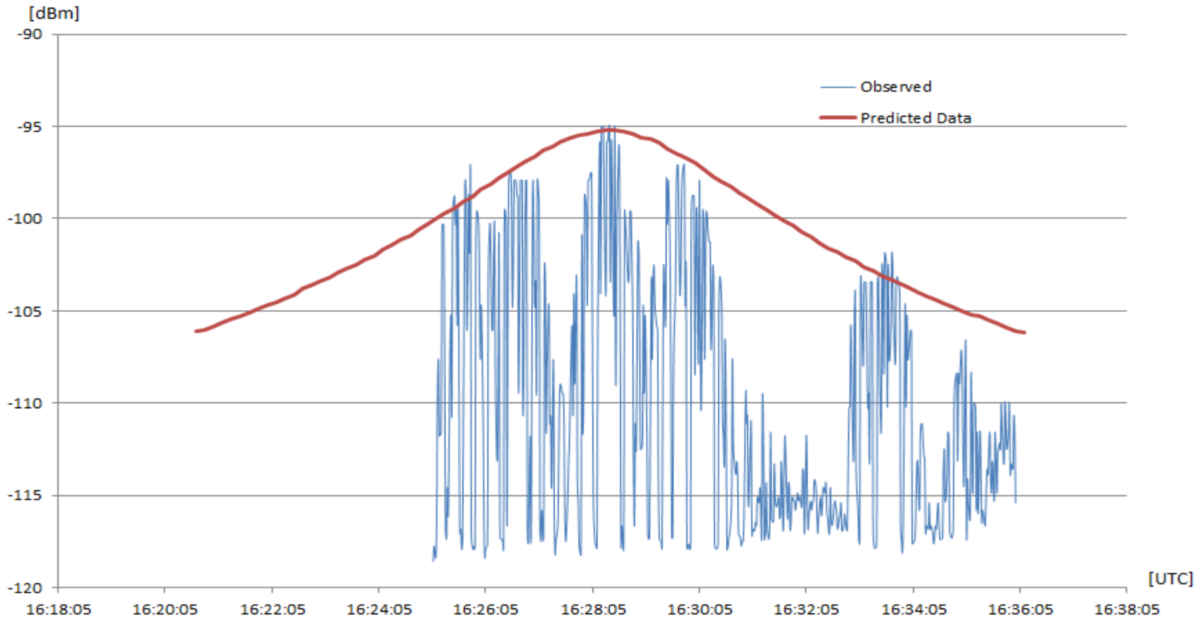

Figure 4.3 Observation C3 with Station Gain = 29.7 dB

4.3.4 *Observation C4 on Feb. 2nd 2011*

The three predicted pass parameters are: AZ@AOS=139°, maxEL=39°, AZ@LOS=351°. The signal was first captured on 436.857MHz. The data near the end of the pass was lost, due to a full turn of the antenna in azimuth. The comparison of observed data and predicted data are shown in Figure 4.4. The Observation Pass ratio = 0.8.

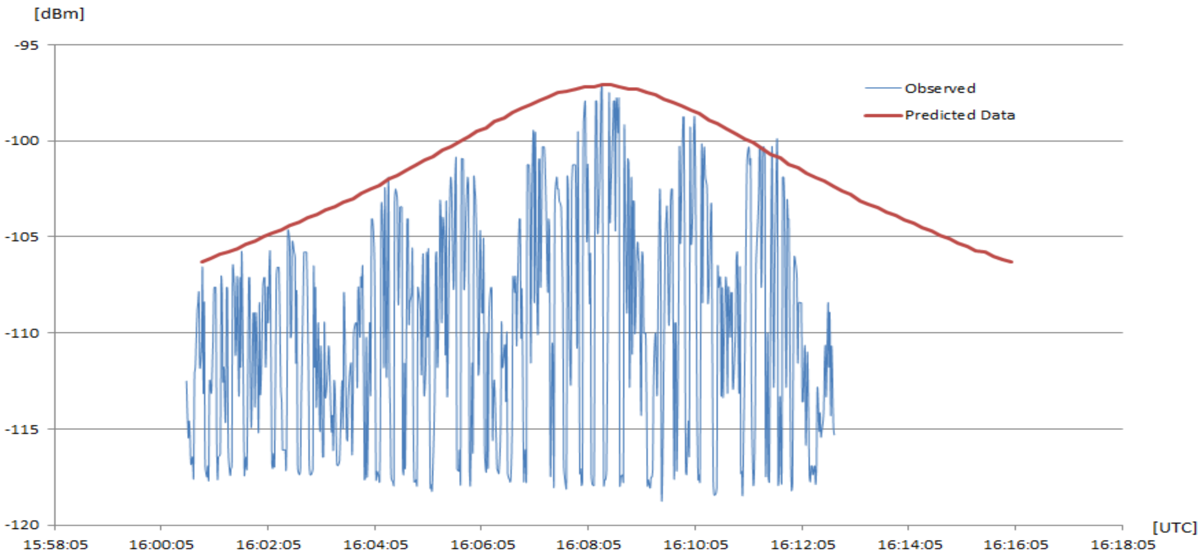

Figure 4.4: Observation C4 with Station Gain = 29.6 dB

4.3.5 *Observation C5 on Feb. 6th 2011*

The three predicted pass parameters are: AZ@AOS=150°, maxEL=57°, AZ@LOS=349°. The signal was first captured on 436.857MHz when elevation was 1°. The azimuth crossed from 0° to 359° at 16:31 UTC and the antenna started a full turn. But then, this observation was stopped because the device was needed for tracking the whole pass of satellite Cute-1. The comparison of observed data and predicted data are shown in Figure 4.5. The Observation Pass ratio = 0.57.

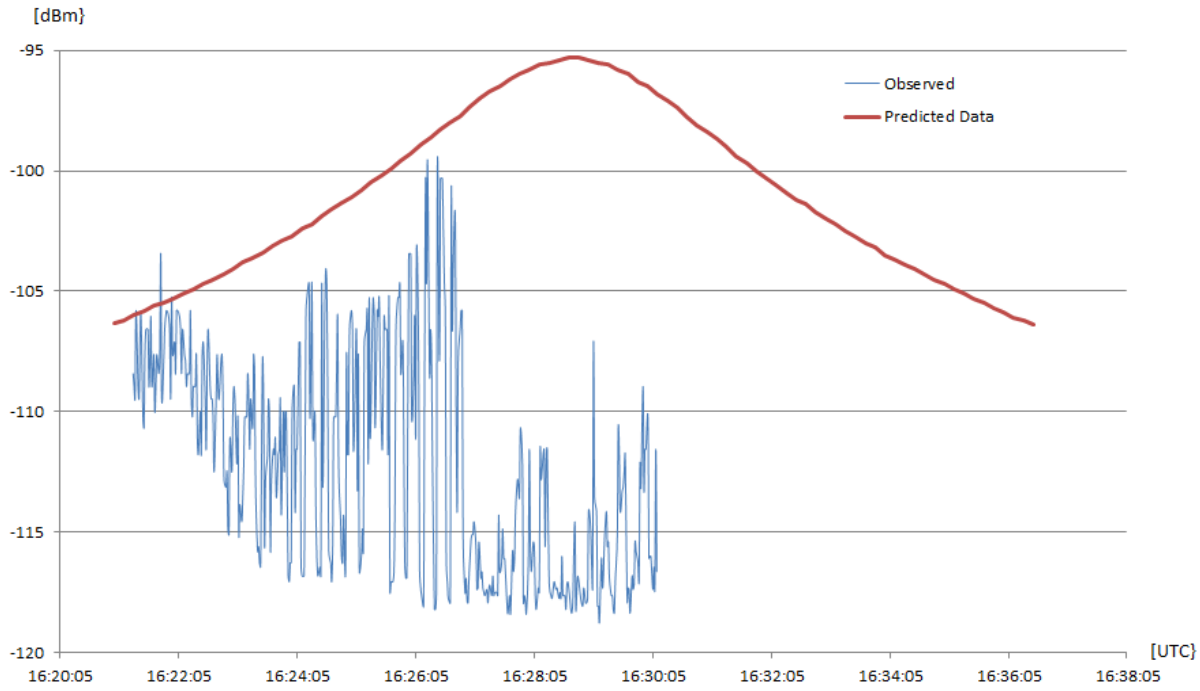

Figure 4.5: Observation C5 with Station Gain = 29.5 dB

4.3.6 *Observation C6 on Feb 6th 2011*

The three predicted pass parameters are: AZ@AOS=201°, maxEL=24°, AZ@LOS=335°. The signal was first captured on 436.856MHz. There was an anomaly without elevation tracking at the first part of the pass, which was solved by restarting NOVA software at 18:11 UTC. During this period, the azimuth tracking system worked well. This pass ended at the frequency of 436.839 MHz. The comparison of observed data and predicted data are shown in Figure 4.6. The Observation Pass ratio = 0.95.

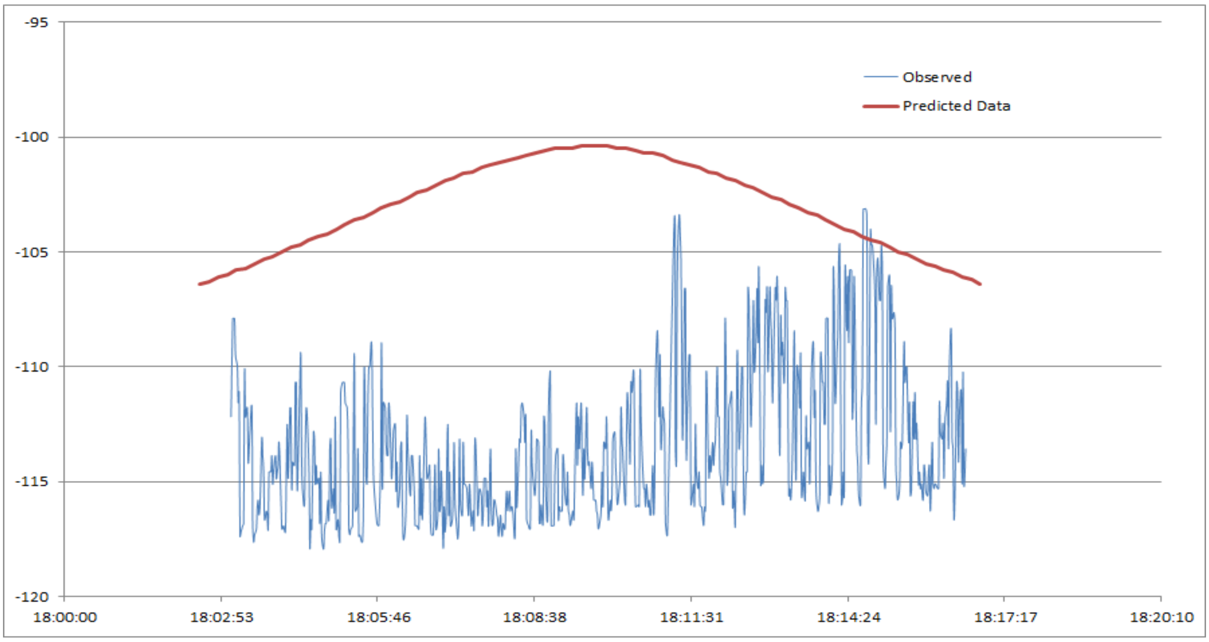

Figure 4.6: Observation C6 with Station Gain = 29.5 dB

4.3.7 Observation C7 on Feb. 8th 2011

The three predicted pass parameters are: AZ@AOS=180°, maxEL=49°, AZ@LOS =342°. The signal was very good and the first acquisition appeared when elevation was 0.8°. The comparison of observed data and predicted data are shown in Figure 4.7. The Observation Pass ratio = 0.98.

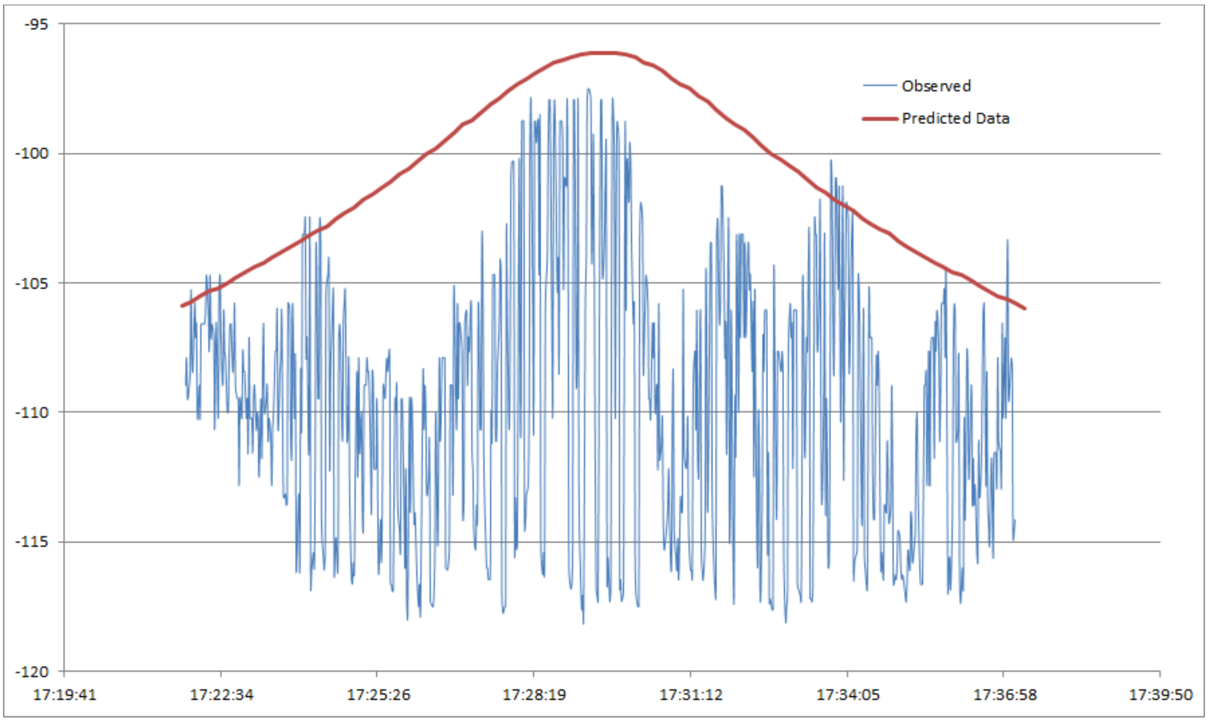

Figure 4.7: Observation C7 with Station Gain = 30 dB

4.3.8 Observation C8 on Feb. 13th 2011

The three predicted pass parameters are: AZ@AOS=153°, maxEL=63°, AZ@LOS=348°. The signal was first captured on 436.857MHz. The comparison of observed data and predicted data are shown in Figure 4.8. The Observation Pass ratio = 0.98.

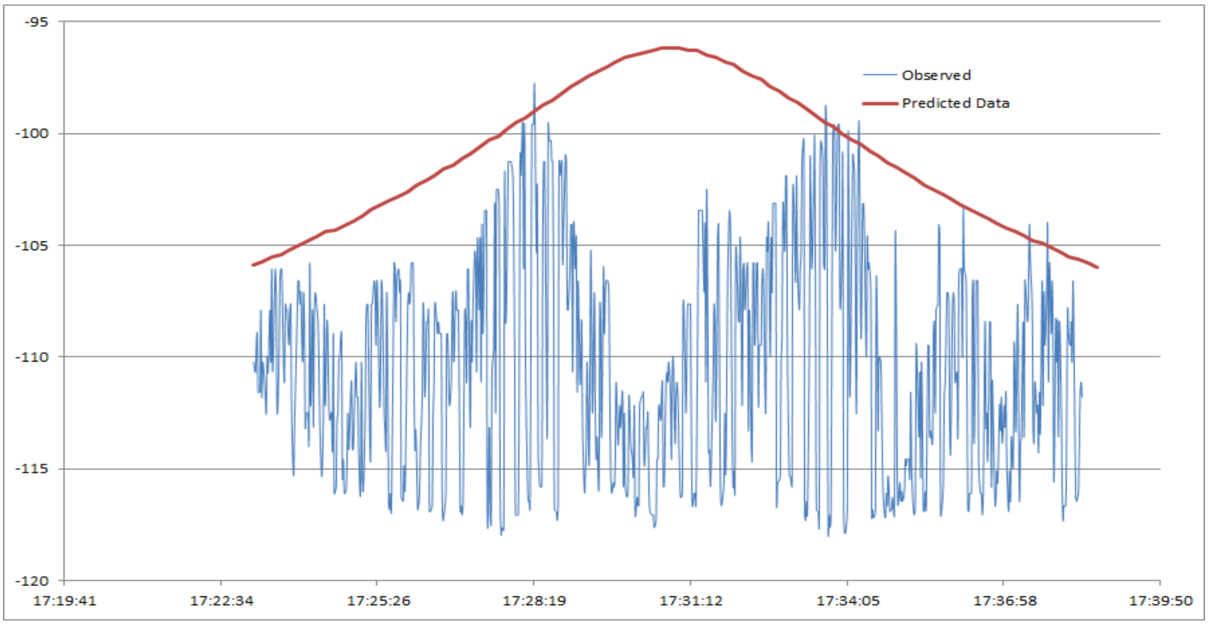

Figure 4.8: Observation C8 with Station Gain = 30 dB

4.2 Observations of Cute-1

4.2.1 Observation Q1 on Jan. 29th 2011

This observation pass followed the observation pass of Cubesat XI-IV. Since the two satellites are on nearly the same orbit, the two passes strongly overlapped. So the beginning phase of this pass was not observed. The three predicted pass parameters are: AZ@AOS=132°, maxEL=31°, AZ@LOS=353°. The signal was first captured on 436.840MHz.The comparison of observed data and predicted data are shown in Figure 4.9. It is not easy to align the predicted data with the observed data when the whole pass was not observed completely. Because of the TLE differences, the predicted data were plotted with a time difference 1m20s ahead. The Observation Pass ratio = 0.54.

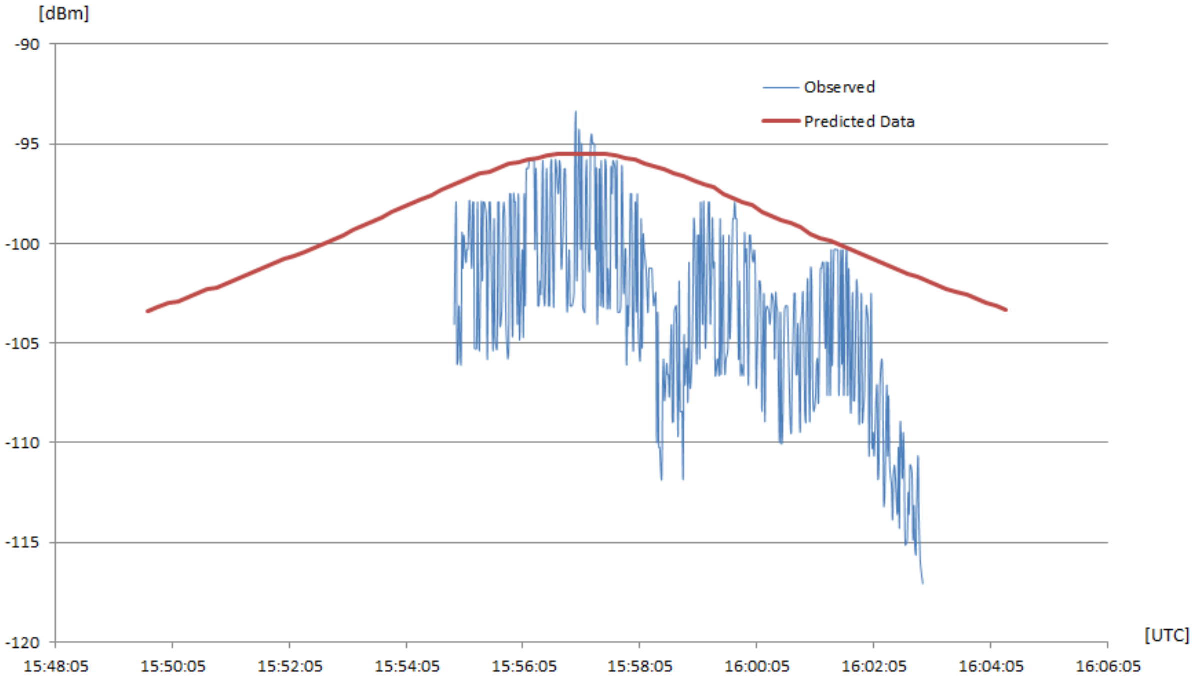

Figure 4.9: Observation Q1 with Station Gain = 32.5 dB

4.2.2 Observation Q2 on Jan 29th 2011

This observation pass followed the observation pass of Cubesat XI-IV with an overlap. So the beginning phase of this pass was not observed. The three predicted pass parameters are: AZ@AOS=182°, Maximum Elevation = 45°, AZ@LOS=341°. The comparison of observed data and predicted data are shown in Figure 4.10. The Observation Pass ratio = 0.52.

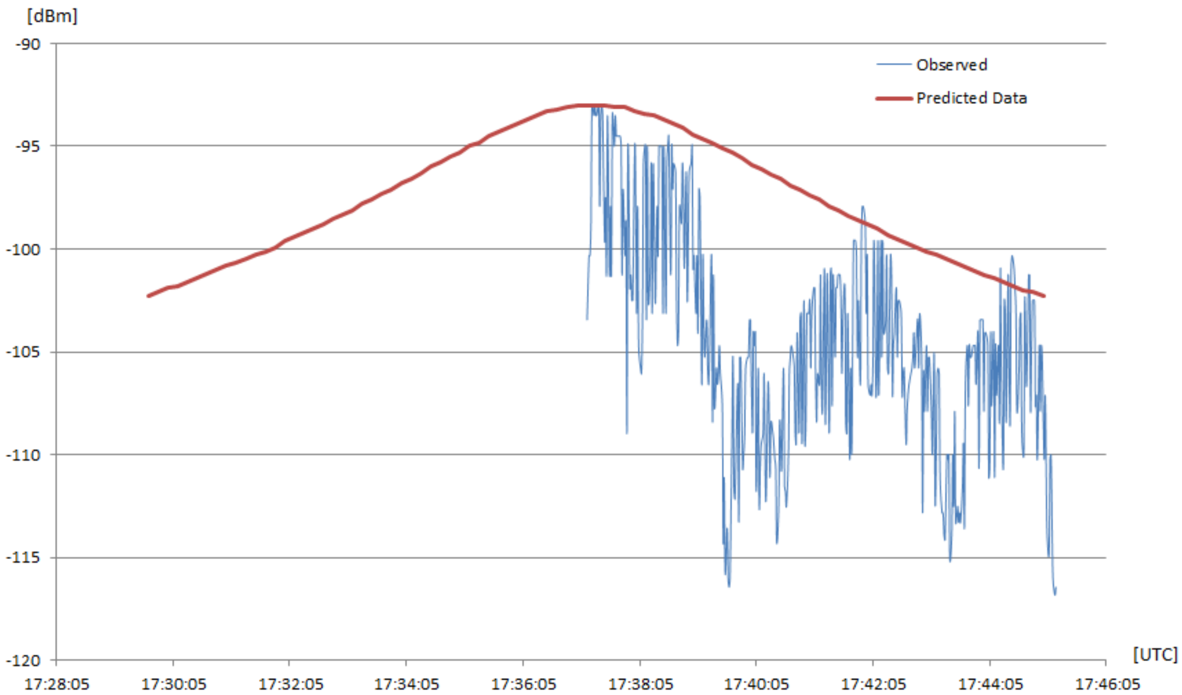

Figure 4.10: Observation Q2 with Station Gain = 33.6 dB

4.2.3 Observation Q3 on Feb. 1st 2011

The three pass parameters are: AZ@AOS=154°, maxEL=66°, AZ@LOS=348°. The signal was caught at Azimuth = 80° and elevation = 62°. There was a full azimuth turn between 16:40 and 16:42 UTC. The satellite was caught again at Azimuth = 352° and elevation = 14°.The comparison of observed data and predicted data are shown in Figure 4.11. The Observation Pass ratio = 0.62.

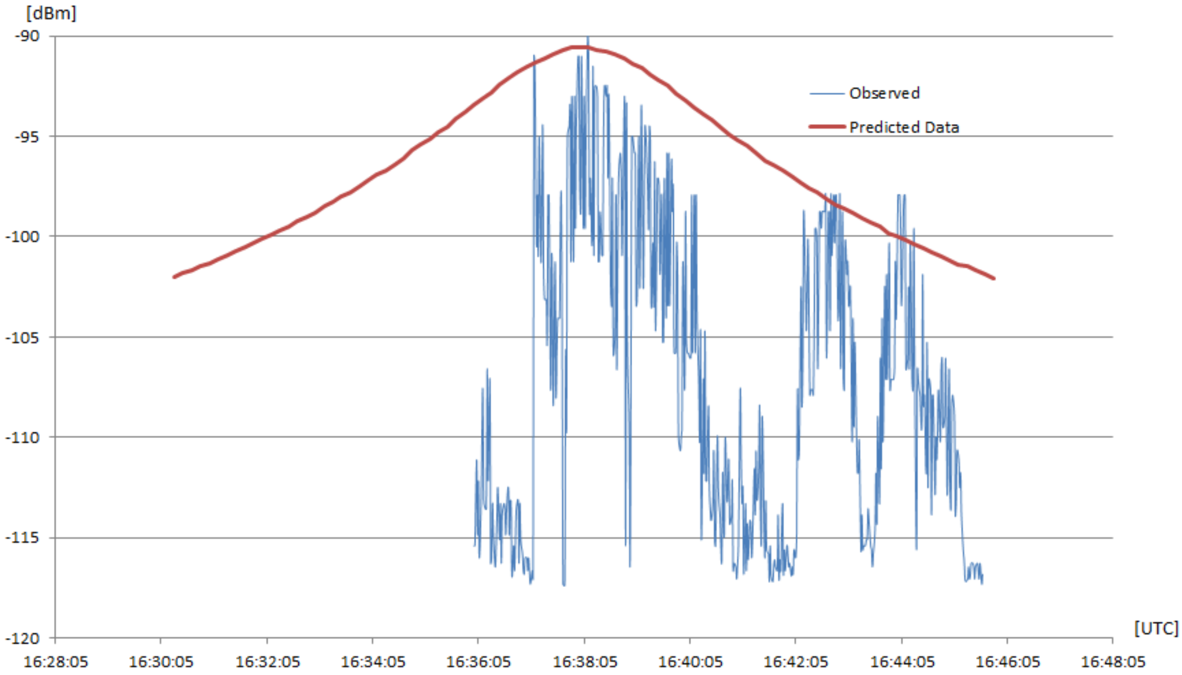

Figure 4.11: Observation Q3 with Station Gain = 33.8 dB

4.2.4 Observation Q4 on Feb. 2nd 2011

The three predicted pass parameters are: AZ@AOS=142°, maxEL=44°, AZ@LOS=351°. The signal was first captured on 436.841MHz. The azimuth passed from 0° to 359° at 16:21 UTC, the signal decreased sharply after that time, and the satellite was not re-acquired. The comparison of observed data and predicted data are shown in Figure 4.12. The Observation Pass ratio = 0.56.

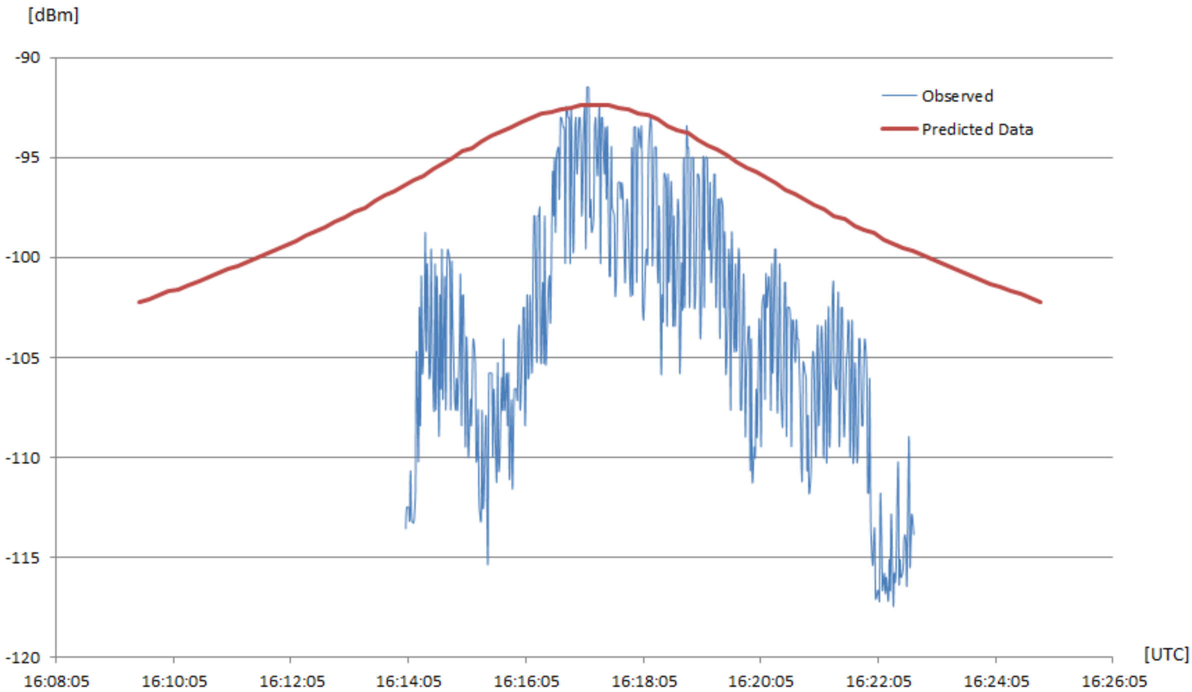

Figure 4.12 Observation Q4 with Station Gain = 33.7 dB

4.2.5 Observation Q5 on Feb. 6th 2011

The three predicted pass parameters are: AZ@AOS=152°, maxEL=62°, AZ@LOS=348°. The signal was first captured on 436.841 MHz. The azimuth went from 0° to 359° at 16:40 UTC, the antenna moved from 16:40 to 16:42 and the signal was lost. The frequency at re-acquisition was 436.826 MHz. This pass ended at the frequency of 436.825MHz. The comparison of observed data and predicted data are shown in Figure 4.13. The Observation Pass ratio = 0.82.

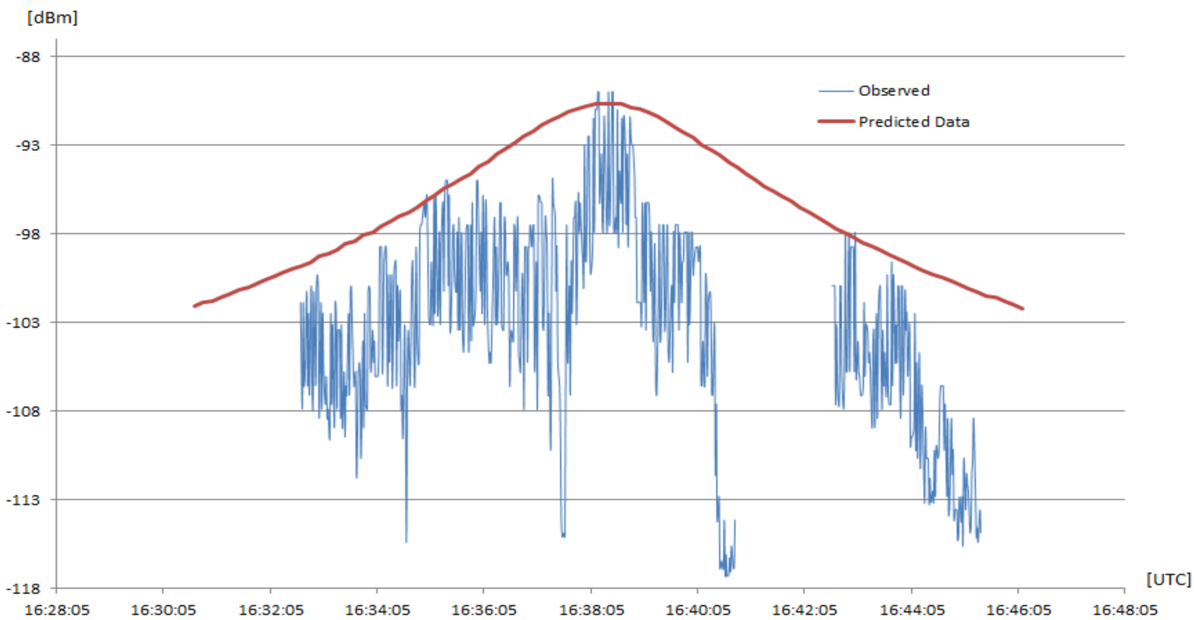

Figure 4.13 Observation Q5 with Station Gain = 33.7 dB

4.2.6 *Observation Q6 on Feb. 6th 2011*

The three predicted pass parameters are: AZ@AOS=204°, Maximum Elevation = 22°, AZ@LOS=334°. This pass followed the pass of Cubesat XI-IV with an overlap. The beginning phase of this pass was not observed. The signal was first captured on 436.835MHz. This pass ended at the frequency of 436.826 MHz. The comparison of observed data and predicted data are shown in Figure 4.14. The Observation Pass ratio = 0.54.

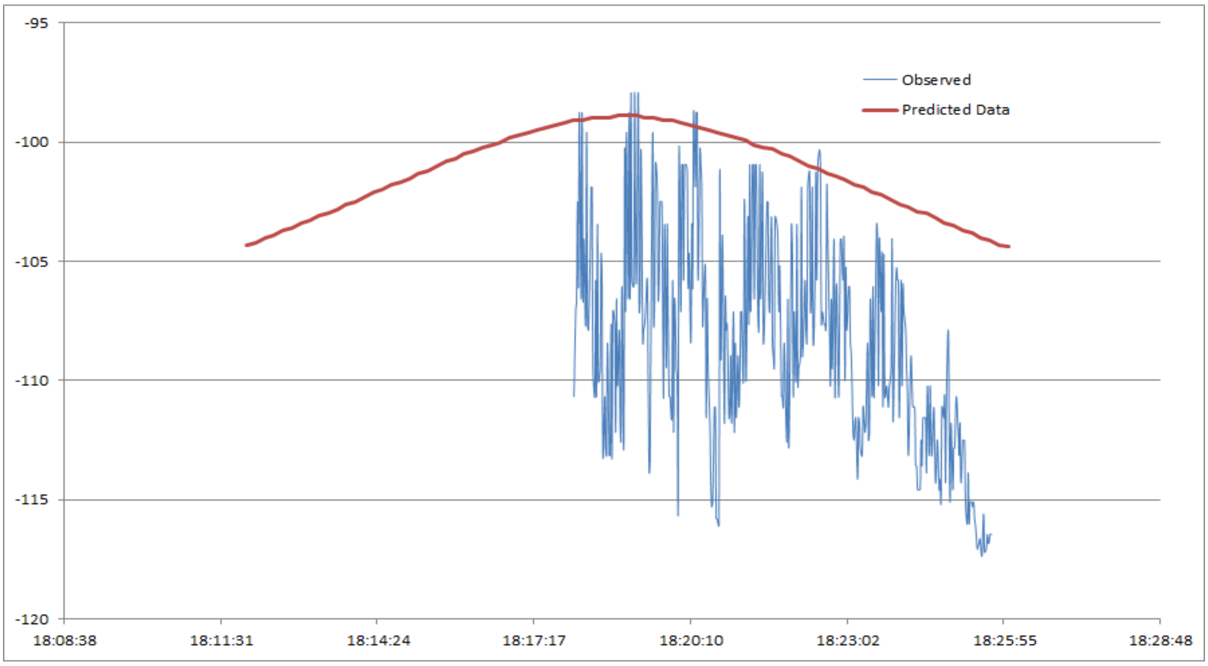

Figure 4.14: Observation Q6 with Station Gain = 31.5 dB

4.2.7 *Observation Q7 on Feb. 8th 2011*

The three predicted pass parameters are: AZ@AOS=182°, maxEL=45°, AZ@AOS=341°. The signal was good and the first acquisition frequency was 436.830MHz. This pass did not show the strong power level variation from tumbling. But nothing unusual was noticed in the audio signal. It ended at the frequency of 436.826 MHz. The comparison of observed data and predicted data are shown in Figure 4.15. The Observation Pass ratio = 0.43.

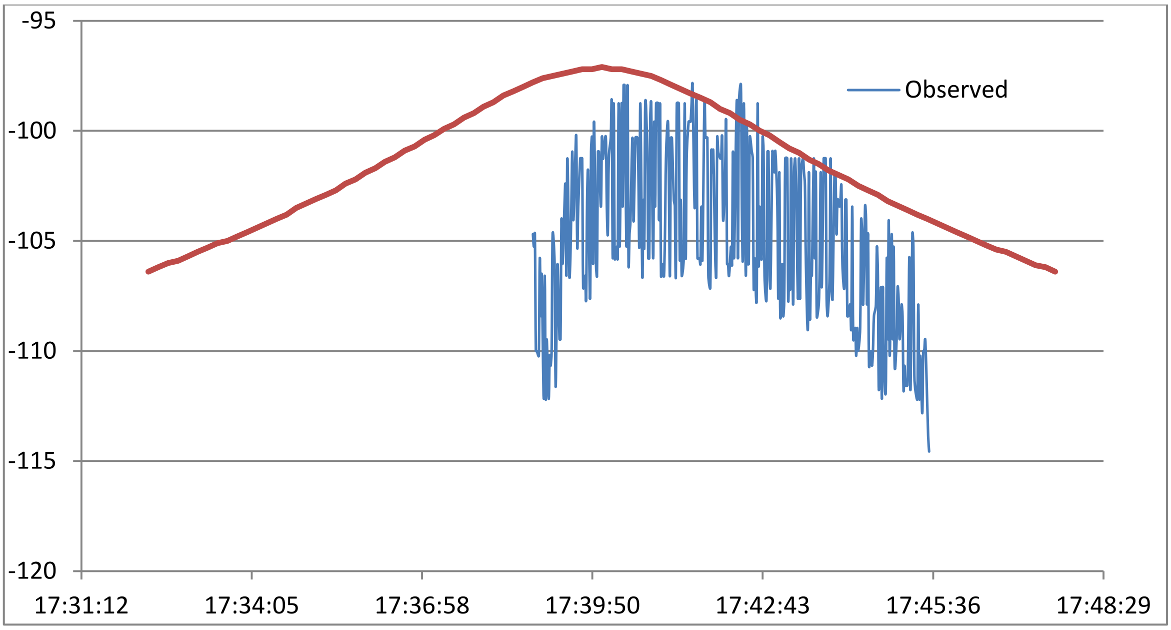

Figure 4.15 Observation Q7 with Station Gain = 29.5 dB

4.2.8 Observation Q8 on Feb. 10th 2011

The three predicted pass parameters are: Azimuth = 162° at Acquisition of Signal, Maximum Elevation = 88°, Azimuth = 346° at Loss of Signal. The signal was first captured on 436.843MHz. At the beginning part of the pass, the other satellite Cubesat XI-IV was still in the view of ISU ground station. Some signal power from Cubesat XI-IV made the recorded power a little bit higher than the expected values. There was an azimuth transition from 0° to 359° at 16:57 UTC. The signal was captured again at 17:00 UTC. This pass ended at the frequency of 436.824 MHz. The comparison of observed data and predicted data are shown in Figure 4.16. The Observation Pass ratio = 0.82.

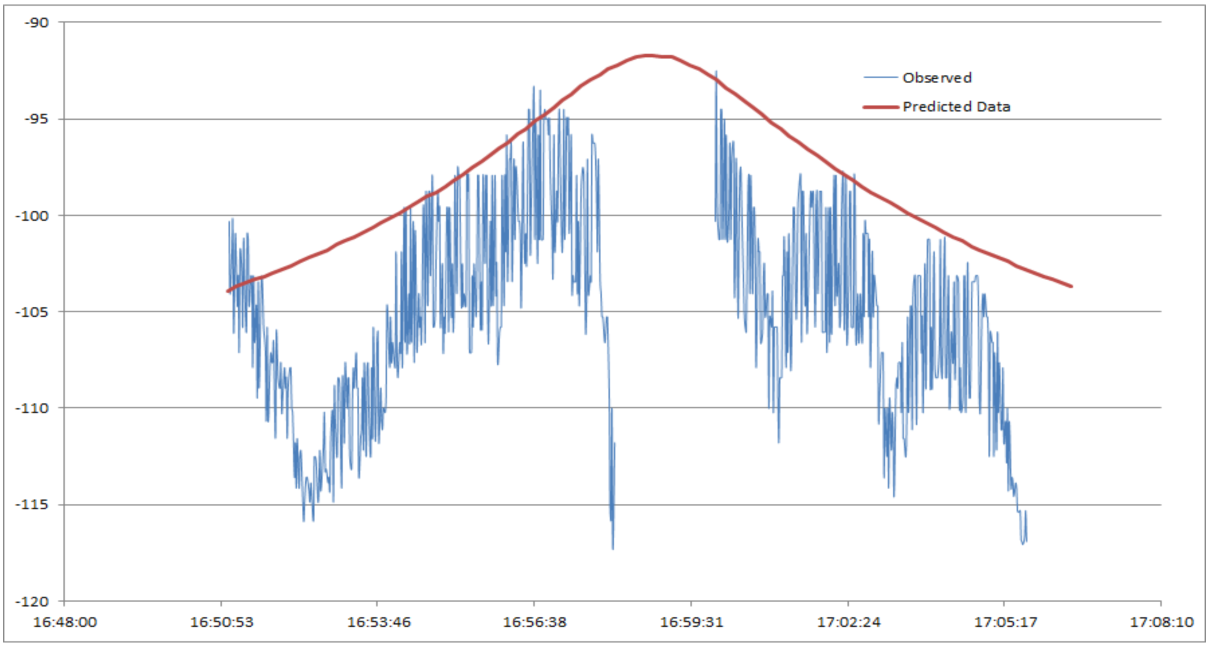

Figure 4.16: Observation Q8 with Station Gain = 32 dB

4.2.9 Observation Q9 on Feb. 13th 2011

The three predicted pass parameters are: AZ@AOS=182°, maxEL=45°, AZ@LOS=341°. This observation followed the pass of Cubesat XI-IV which terminated at 17:39 UTC. So this observation was only partial, and the beginning phase of this pass was not observed. The signal was first captured on 436.828 MHz. This pass ended at the frequency of 436.820 MHz. The comparison of observed data and predicted data are shown in Figure 4.17. The Observation Pass ratio = 0.37.

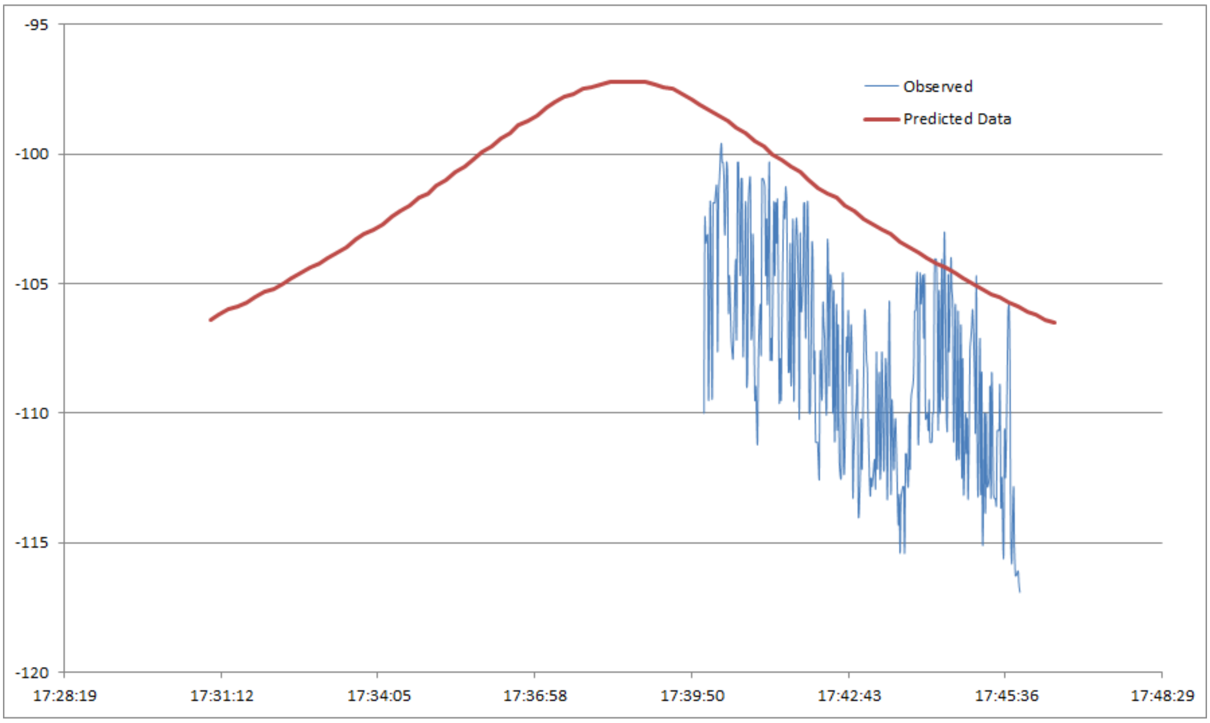

Figure 4.17: Observation Q9 with Station Gain = 29.5 dB

4.3 Other satellites

I attempted to track Nanosail-D on Jan. 25th ~26th, 2011, but nothing was observed except rushing noise because its batteries were already dead. I also made some preparations for tracking the Elana satellites in the end of February. However, the launch failed on Mar. 4th after a postponement.

4.3.1 Observation of Cubesat XI-V on Feb. 1st 2011

The three pass parameters are: AZ@AOS=18°, maxEL=45°, AZ@LOS=178°. The comparison of observed data and predicted data are shown in Figure 4.18. The Observation Pass ratio = 0.59. The gain equals 25.5 dB based on the condition that the satellite transmitting power is +20dBm. If one assumes the same station gain 31dB as found with the other satellites, this would imply that the actual transmitting power of Cubesat XI-V should be +14.5 dBm or 28mW.

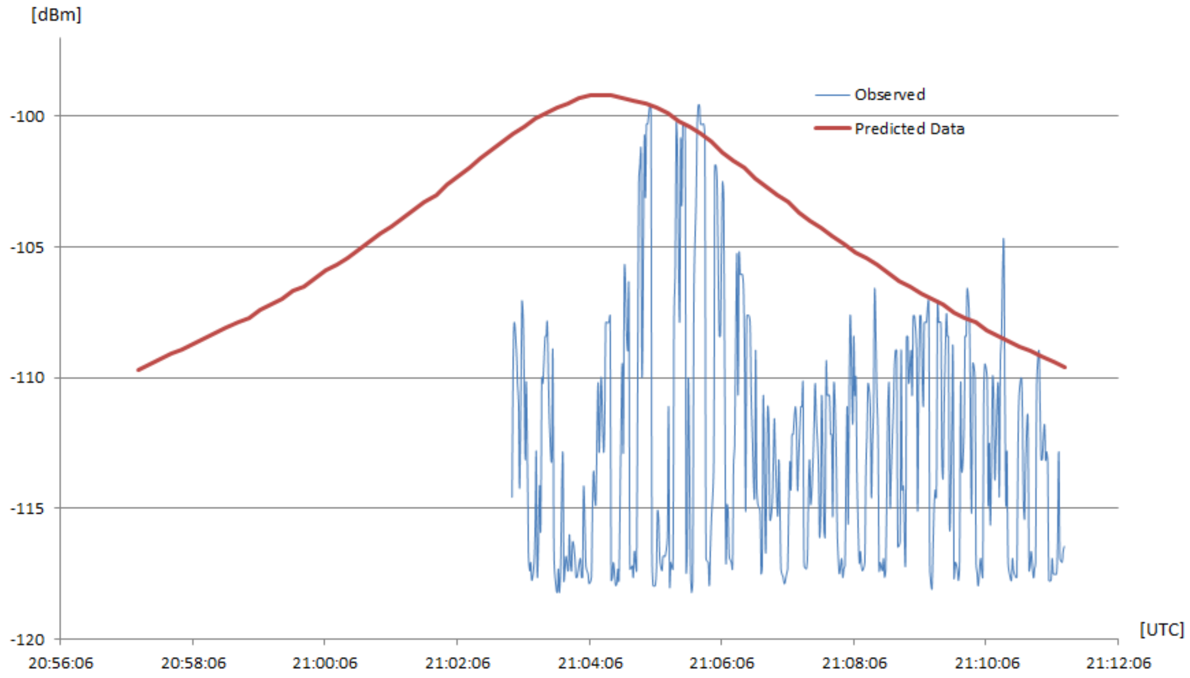

Figure 4.18: Observation on Cubesat XI-V with Station Gain = 25.5 dB

4.4 Data Analysis Summary

The results from the observations of Cubesat XI-IV are summarized in Table 2, Figure 4.19 and 4.20. Those of Cute-1 are shown in Table 3, Figure 4.21 and 4.22.

Table 2 Estimated Station Gain based on Cubesat XI-IV observations

No	Date	Obs.Pass Ratio	AZ@AOS	maxEL	AZ@LOS	Gain
C1	2011-01-29	0.88	129°	28°	354°	30.6
C2	2011-01-29	0.85	179°	52°	342°	31.5
C3	2011-02-01	0.71	149°	55°	349°	29.7
C4	2011-02-02	0.8	139°	39°	351°	29.6
C5	2011-02-06	0.57	150°	57°	349°	29.5
C6	2011-02-06	0.95	201°	24°	335°	29.5
C7	2011-02-08	0.98	180°	49°	342°	30
C8	2011-02-13	0.98	153°	63°	348°	30
	Average					30.05
	Dispersion					0.65

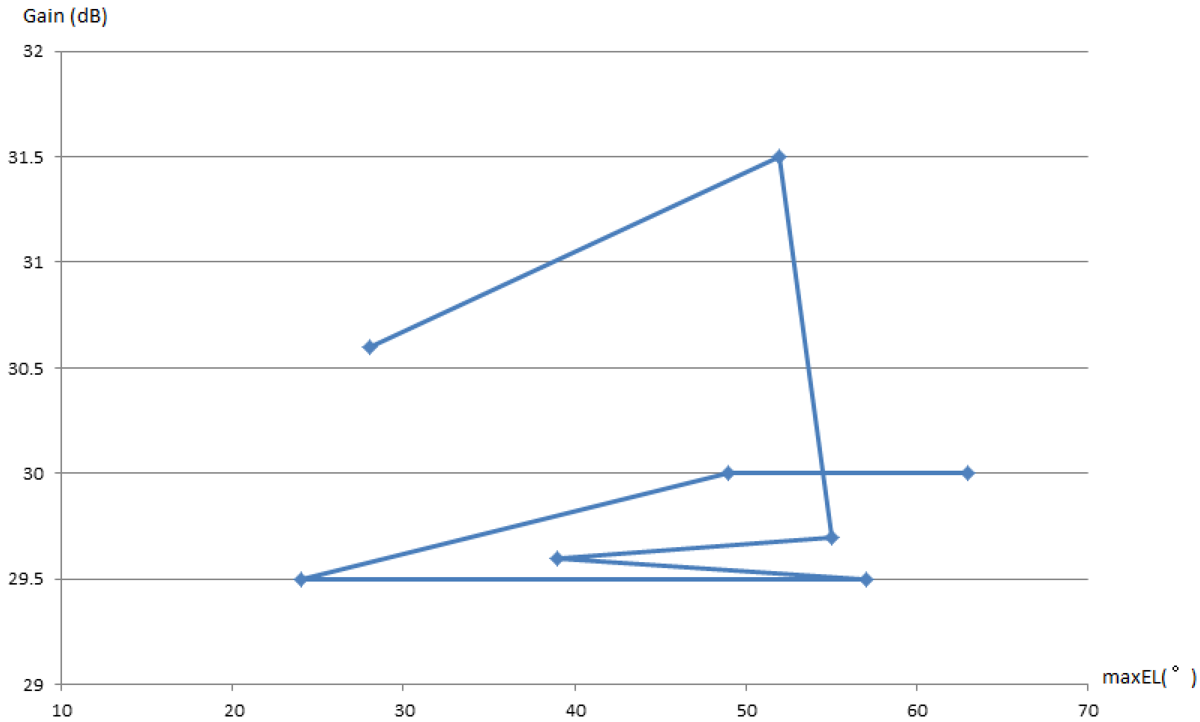

Figure 4.19: Station Gain as a function of maxEL for Cubesat XI-IV observations

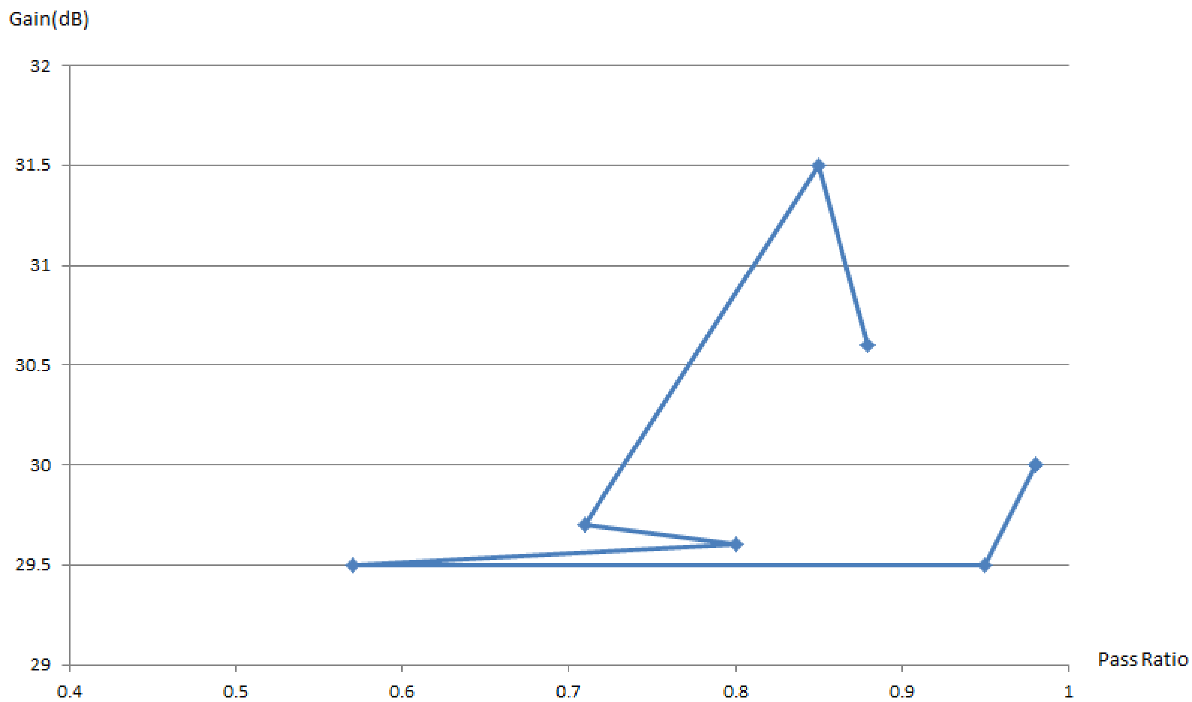

Figure 4.20 Station Gain as a function of the Pass Ratio of Cubesat XI-IV observations

Table 3 Estimated Station Gain based on Cute-1 observations

No	Date	Observation Pass Ratio	AZ@AOS	maxEL	AZ@LOS	Gain
Q1	2011-01-29	0.54	132°	31°	353°	32.5
Q2	2011-01-29	0.52	182°	45°	341°	33.6
Q3	2011-02-01	0.62	154°	66°	348°	33.8
Q4	2011-02-02	0.56	142°	44°	351°	33.7
Q5	2011-02-06	0.82	152°	62°	348°	33.7
Q6	2011-02-06	0.54	204°	22°	334°	31.5
Q7	2011-02-08	0.43	182°	45°	341°	29.5
Q8	2011-02-10	0.82	162°	88°	346°	32
Q9	2011-02-13	0.37	182°	45°	341°	29.5
	Average					32.97
	σ					0.78

** Q7 and Q9 are not taken into account on the Gain estimation due to their poor Observation Pass Ratios.

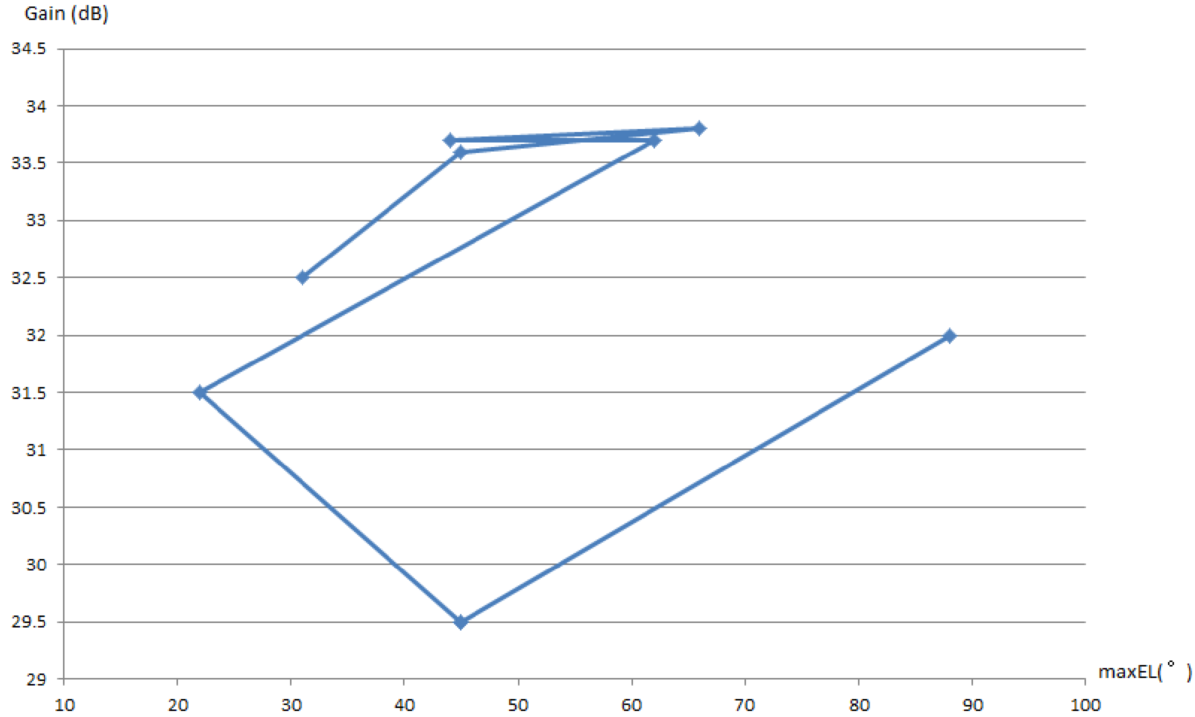

Figure 4.21 Station Gain as a function of maxEL for Cute-1 observations

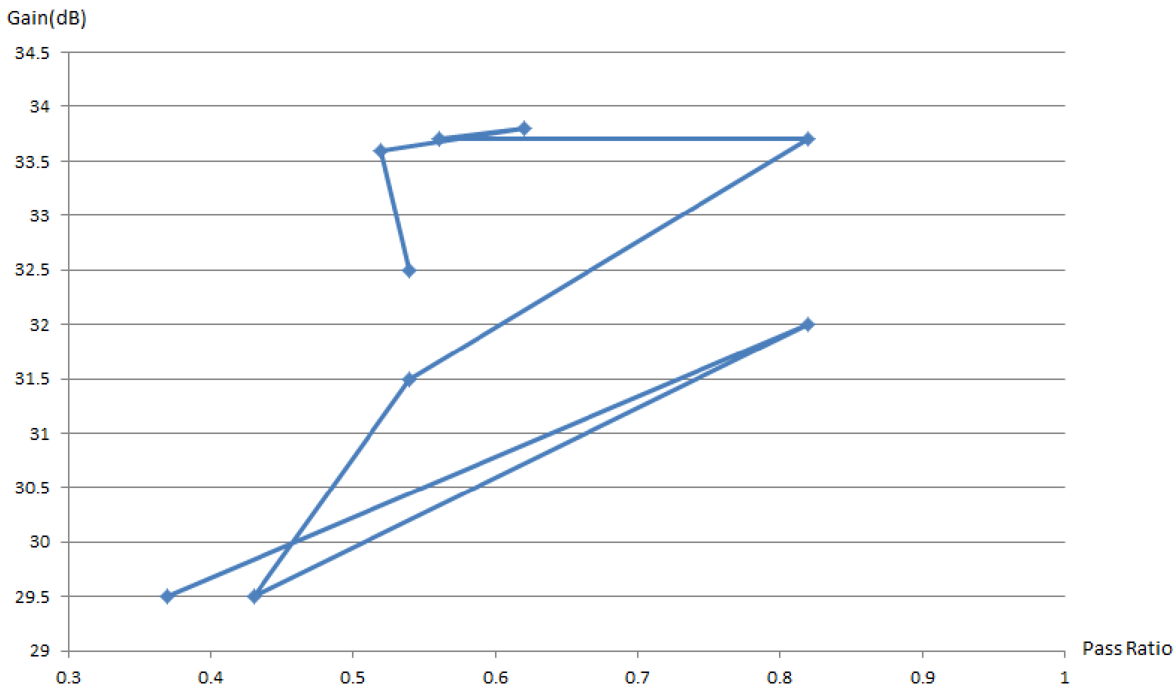

Figure 4.22 Station Gain as a function of Pass Ratio for Cute-1 observations

According to the data shown in the above tables and figures, we can draw some conclusions as follows.

1) The Observation Pass Ratio has much more influence on estimated ISU ground station gain than what the maximum elevation does. Result are reliable if the observation pass ratio is larger than 0.5.
2) Generally, we found no systematic differences on station gain with the satellite passing over in diverse directions. So the station can work in all directions as it should.
3) The estimated ISU ground station gain is very well defined and constant based on the observations of a specific satellite.

5 Error Considerations

There are some errors which should be taken into account. The most important two are the random error of the individual measurement and the systematic error in the instrument calibration.

5.1 Measurement error

The following Figure 5.1 shows the background signal of the measurement system including antenna, receiver, pre-amplifier and cables etc., when observing the empty sky, so that we record only the noise from the pre-amplifier. The average noise level was -116.8 dBm with standard deviation σ = 1.14 dB. Hence, the measurement error can be considered as 1 dB.

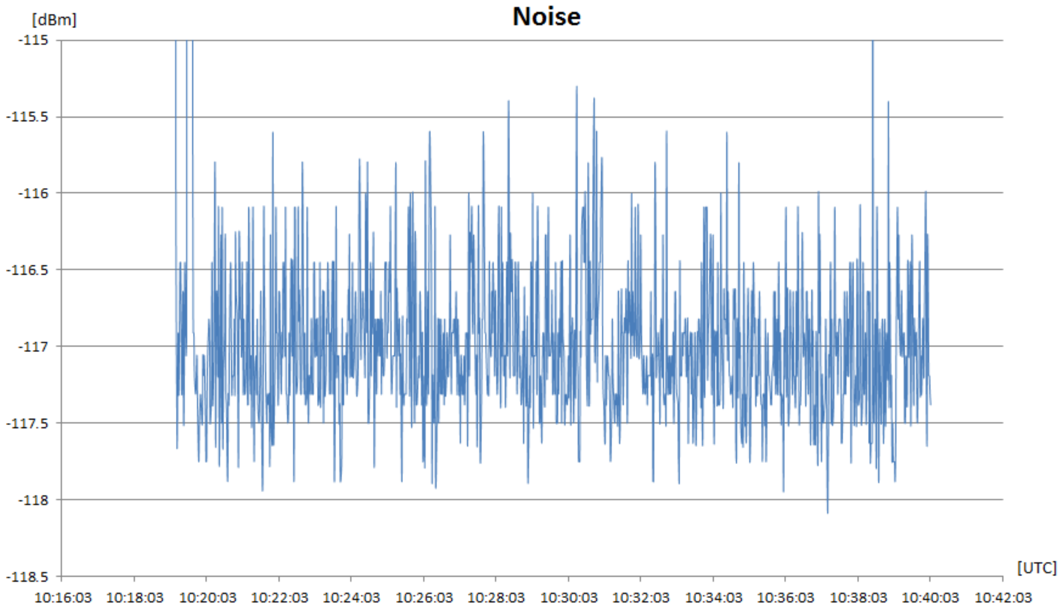

Figure 5.1 Noise measured at an empty sky position

5.2 Instrument error

The calibration of the receiver was performed by using one of the signal generators in ISU. It is a gift from ESA, and it was used until a few years ago, but it has not had a maintenance and calibration check ever since. So we don't really know whether it is still accurately calibrated. We can consider that the instrument error is still within ±1 dB.

5.3 Total error

Because the measurement error is transferred into the dispersion of the estimated gain, the total error of the estimated gain should be ± standard deviation ± 1 dB. All the gain estimations in this report are based on the assumption that the transmitting power of the satellite is +20 dBm. For example, if the real transmitting power of Cubesat XI-IV is +20 dBm, the estimated ISU ground station gain can be expressed as 30.05±0.65±1dB.

6 Conclusions

1) What Kaupo Voormansik discovered that sometimes the measured signals were significantly higher than expected was not found in this year. Maybe it was an unstable phenomenon or erroneous data.
2) The ISU Ground station has a stable gain for a specific satellite. The worst standard deviation is 0.78 dB, which is smaller than the measurement error (1 dB). So it is a reliable method to estimate the gain of the ISU ground station if we have the transmitting power of the satellite. On the contrary, it is also a reliable method to estimate the transmitting power of the satellite if the gain of ISU ground station is known.

3) The estimated station gains derived from these two satellites differ by 2.92 dB, which is probably caused by the different transmitting power of the satellites. This implies that the transmitter power of Cute-1 is twice higher (3 dB) than that of Cubesat XI-IV, because the ground station gain must be the same.
4) There is a perspective that we can use the observed data to measure the satellites' tumbling rates because the station works in a stable manner.

7 References

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8 Appendix: Initial Satellite Observations

(1) Observation of Cubesat XI-IV (20110105)

The three pass parameters are: AZ@AOS=165°, maxEL=83°, AZ@LOS=345°. The comparison of observed data and predicted data are shown in Figure 8.1.

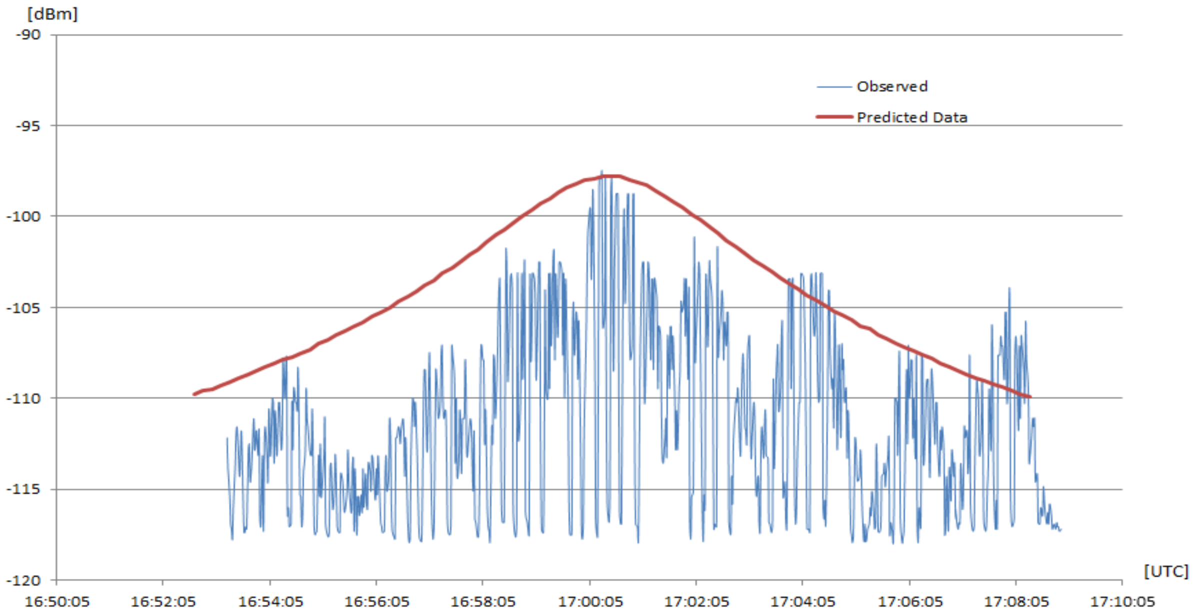

Figure 8.1: The First CubesatXI-IV Observation (20110105) with Station Gain = 26 dB

(2) The first Observation of Cubesat XI-IV (20110119)

The three pass parameters are: AZ@AOS=128°, maxEL=27°, AZ@LOS=354°. The comparison of observed data and predicted data are shown in Figure 8.2.

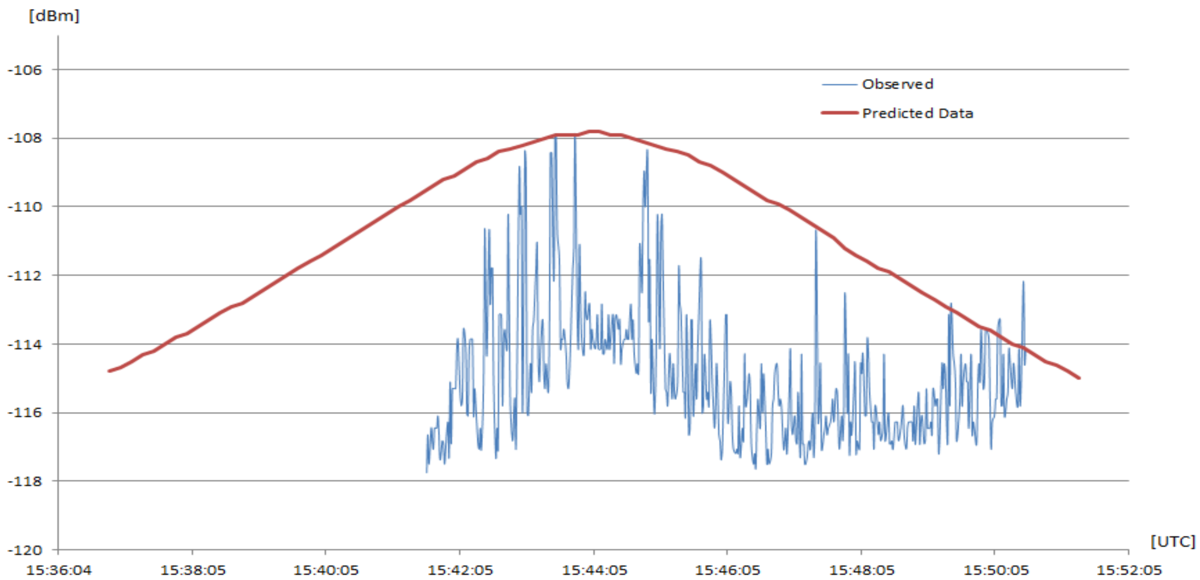

Figure 8.2: The First CubesatXI-IV Observation (20110119) with Station Gain = 21 dB

(3) The first Observation of Cute-1 (20110119)

The three pass parameters are: AZ@AOS=132°, maxEL=31°, AZ@LOS=353°. The comparison of observed data and predicted data are shown in Figure 8.3.

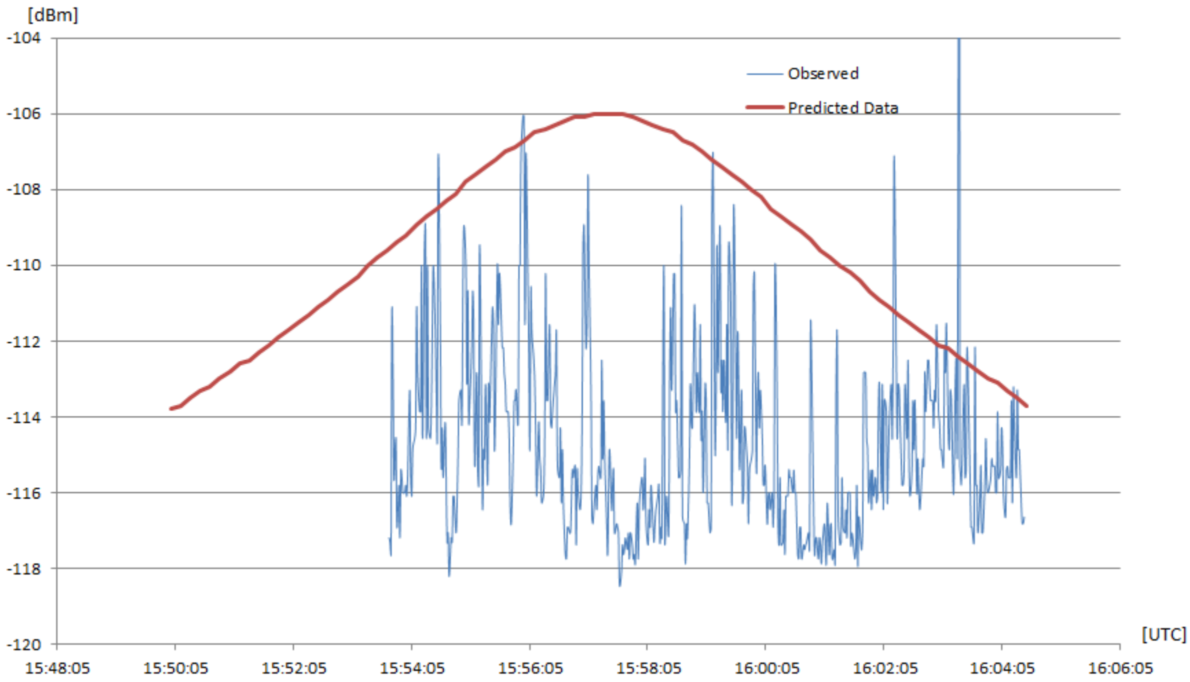

Figure 8.3: The First Cute-1 Observation (20110119) with Station Gain = 22 dB

(4) The Second Observation of Cubesat XI-IV (20110119)

The three pass parameters are: AZ@AOS=177°, maxEL=54°, AZ@LOS=342°. The comparison of observed data and predicted data are shown in Figure 8.4.

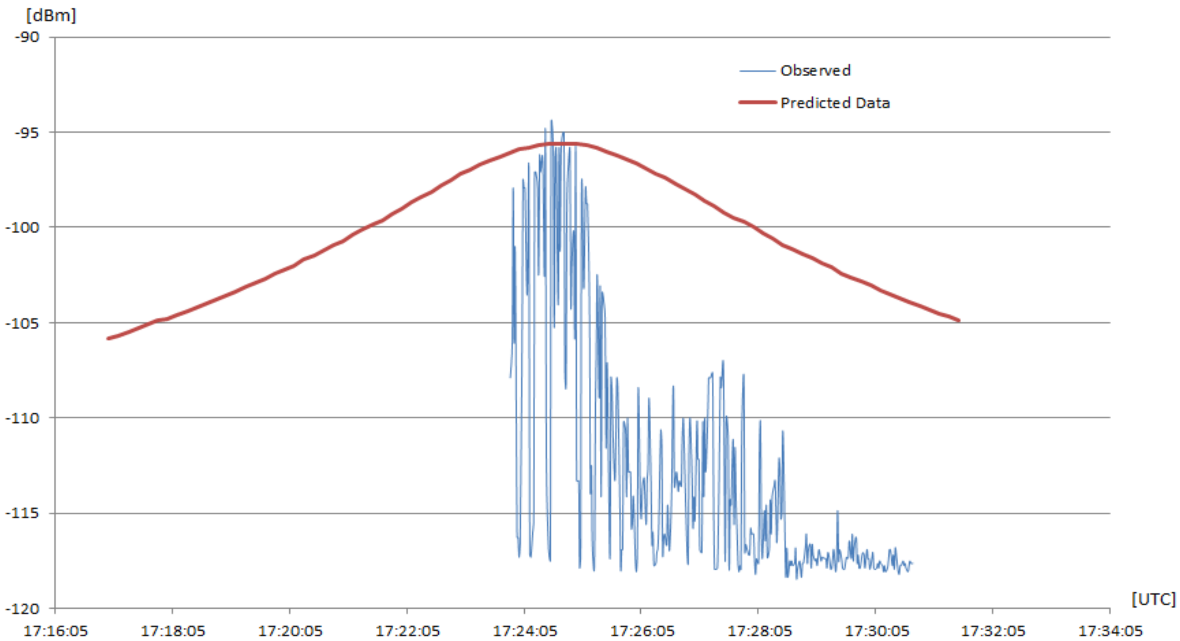

Figure 8.4: The Second CubesatXI-IV Observation (20110119) with Station Gain = 30 dB

(5) **The Second Observation of Cute-1 (20110119)**

The three pass parameters are: AZ@AOS=182°, maxEL=46°, AZ@LOS=341°. The comparison of observed data and predicted data are shown in Figure 8.5.

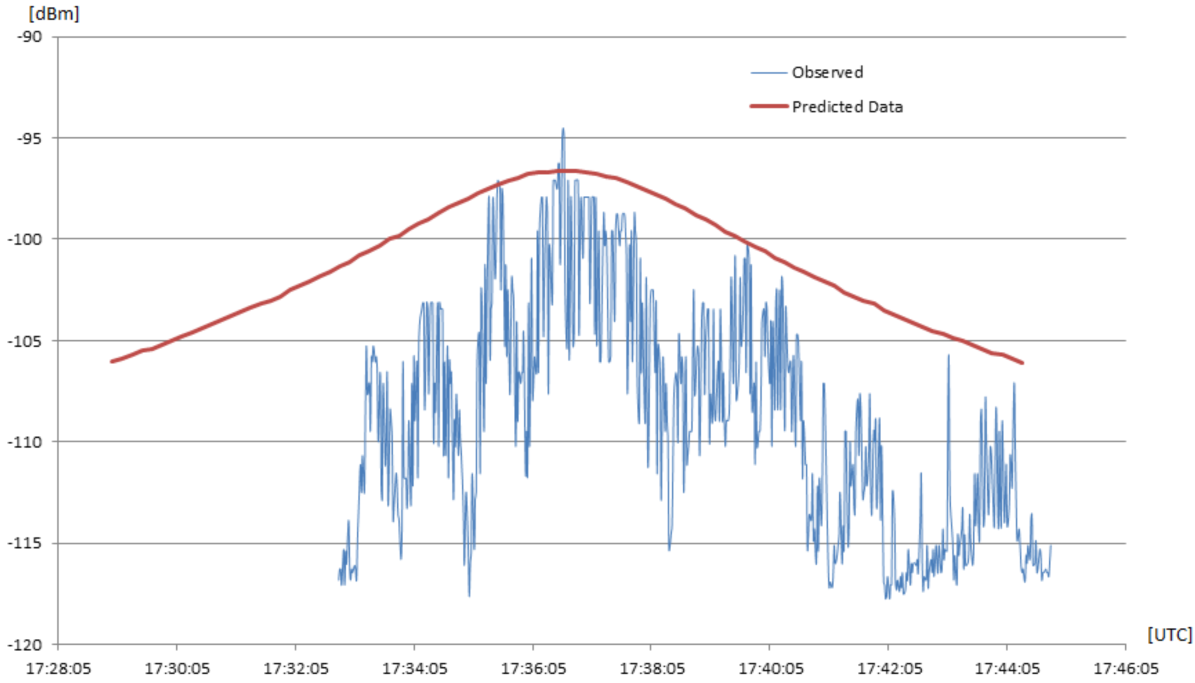

Figure 8.5: The Second Cute-1 Observation (20110119) with Station Gain = 29.8 dB

(6) Observation of Compass-1 (20110119)

The three pass parameters are: AZ@AOS=201°, maxEL=22°, AZ@LOS=334°. The satellite signal was very weak. The comparison of observed data and predicted data are shown in Figure 8.6.

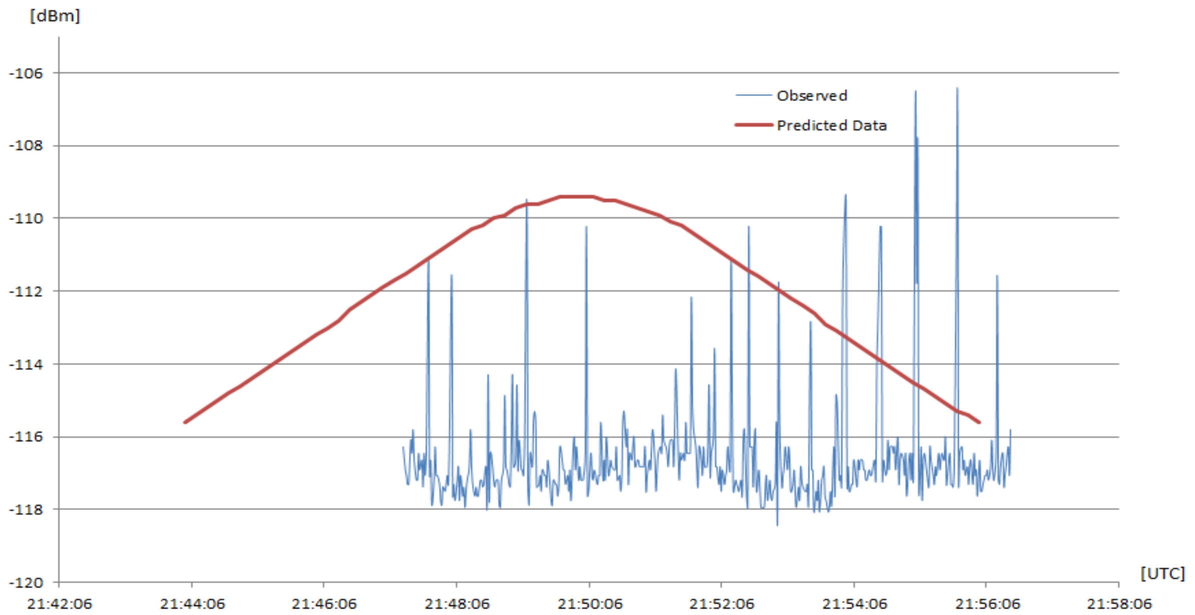

Figure 8.6: Compass-1 Observation (20110119) with Station Gain = 19 dB

(7) Observation of Cubesat XI-V (20110119)

The three pass parameters are: AZ@AOS=9°, maxEL=48°, AZ@LOS=212°. There was an azimuth transition from 0 to 359 at 22:06 UTC. The comparison of observed data and predicted data are shown in Figure 8.7.

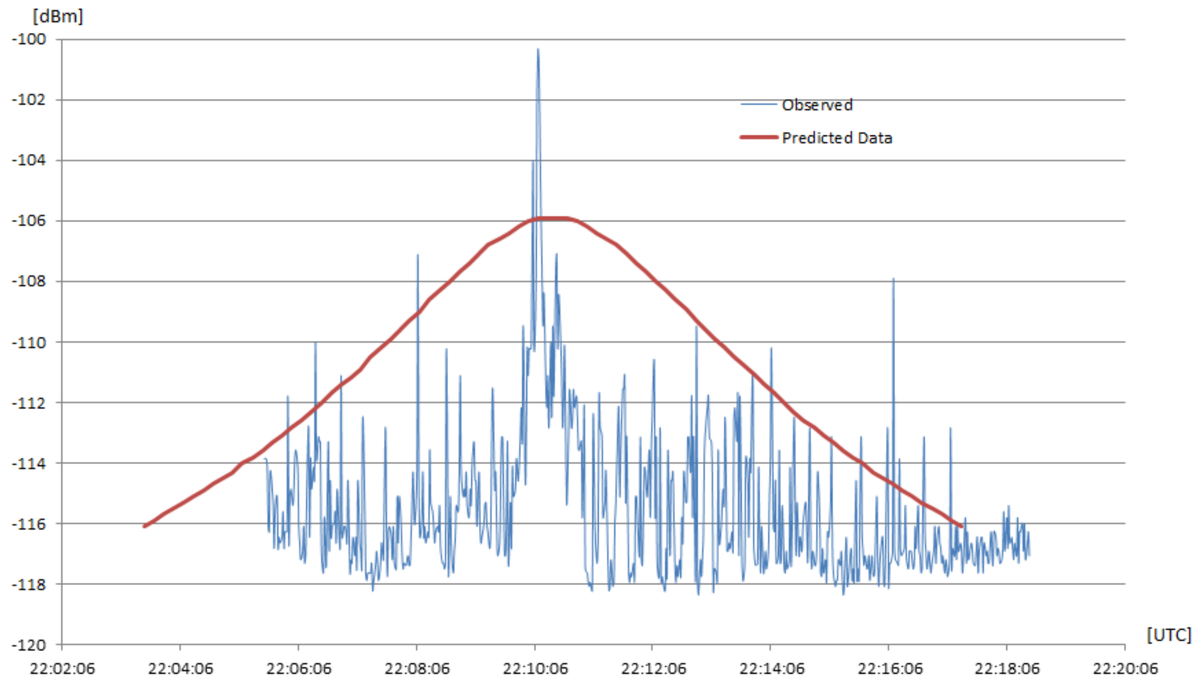

Figure 8.7: Cubesat XI-V Observation (20110119) with Station Gain = 19 dB

(8) Observation of Cubesat XI-IV (20110121)

The three pass parameters are: AZ@AOS=158°, maxEL=75°, AZ@LOS=347°. The comparison of observed data and predicted data are shown in Figure 8.8.

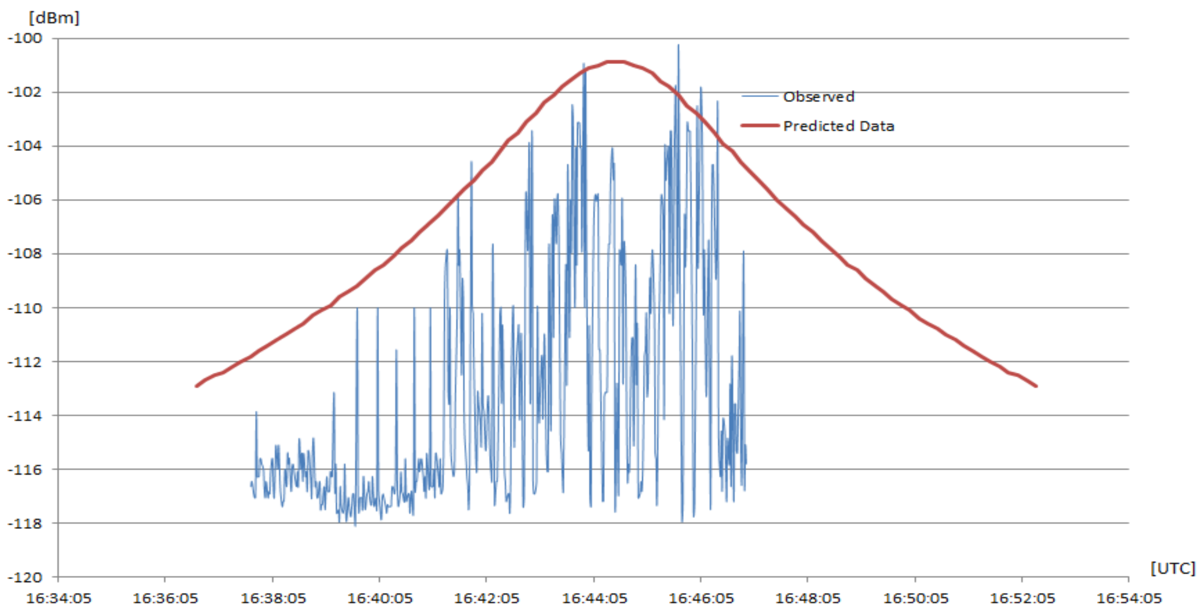

Figure 8.8: Cubesat XI-IV Observation (20110121) with Station Gain = 23 dB

(9) Observation of Cute-1 (20110121)

The three pass parameters are: AZ@AOS=162°, maxEL=87°, AZ@LOS=346°. The comparison of observed data and predicted data are shown in Figure 8.9.

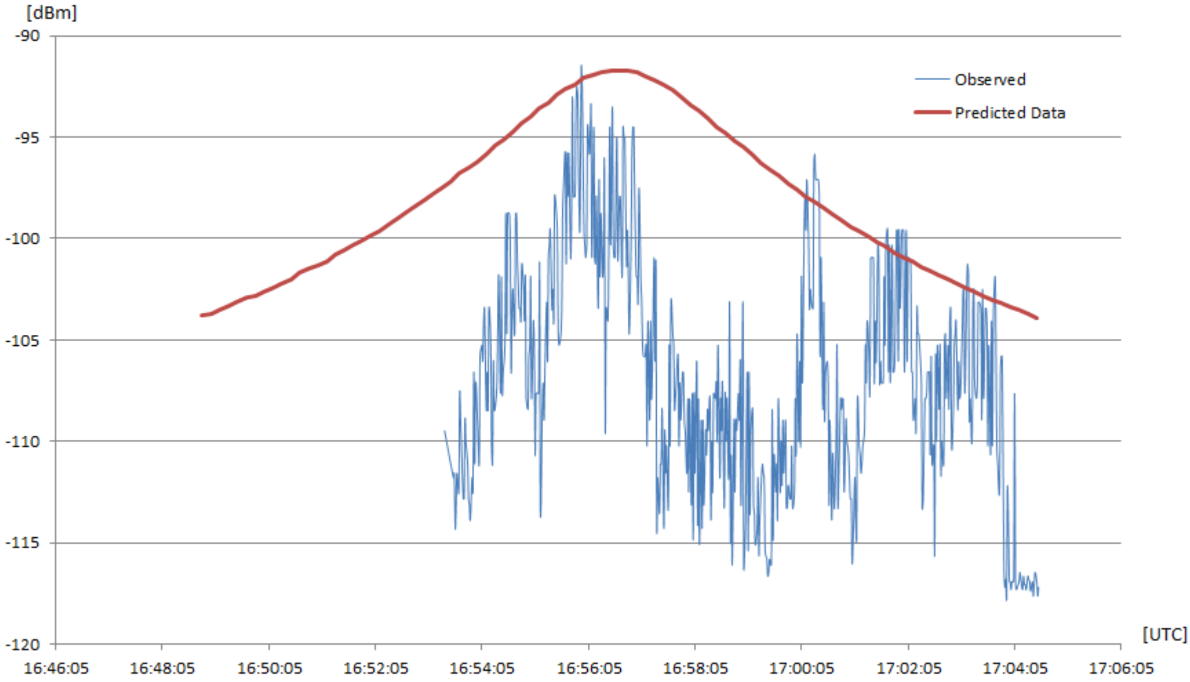

Figure 8.9: Cute-1 Observation (20110121) with Station Gain = 32 dB

(10) The First Observation of Compass-1 (20110124)

The three pass parameters are: AZ@AOS=87°, maxEL=6°, AZ@LOS=11°. The comparison of observed data and predicted data are shown in Figure 8.10.

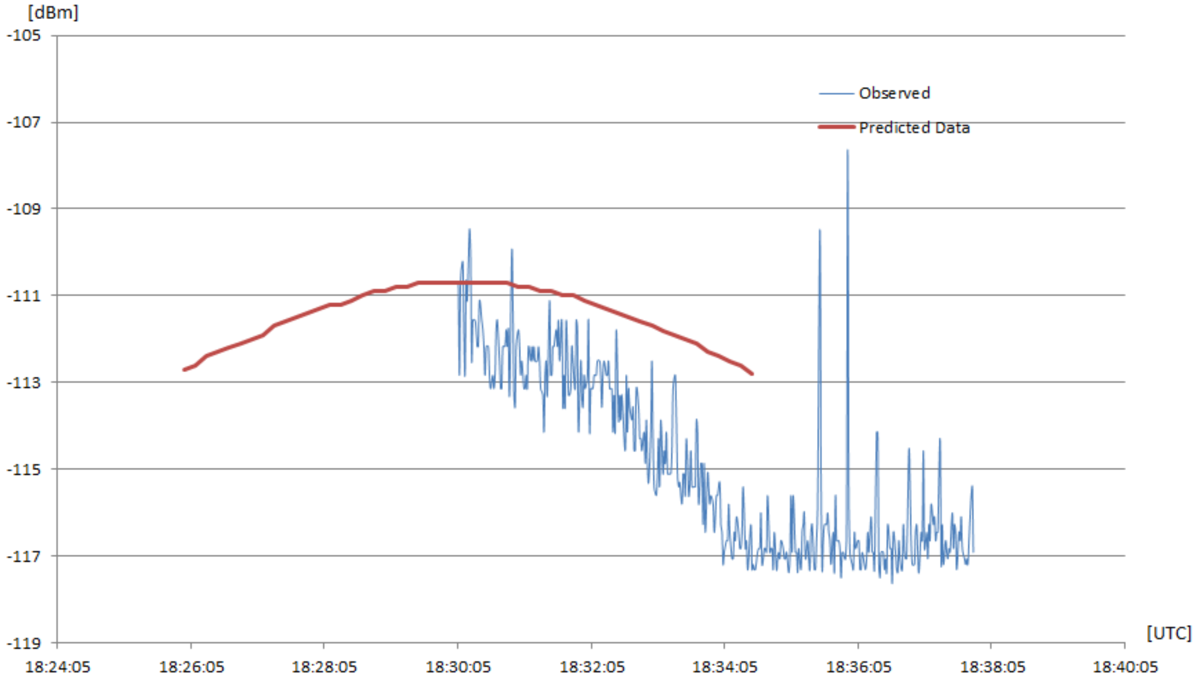

Figure 8.10: The First Compass-1 Observation (20110124) with Station Gain = 22 dB

(11) Observation of Cubsat XI-IV (20110124)

The three pass parameters are: AZ@AOS=237°, maxEL=7°, AZ@LOS=321°. The comparison of observed data and predicted data are shown in Figure 8.11.

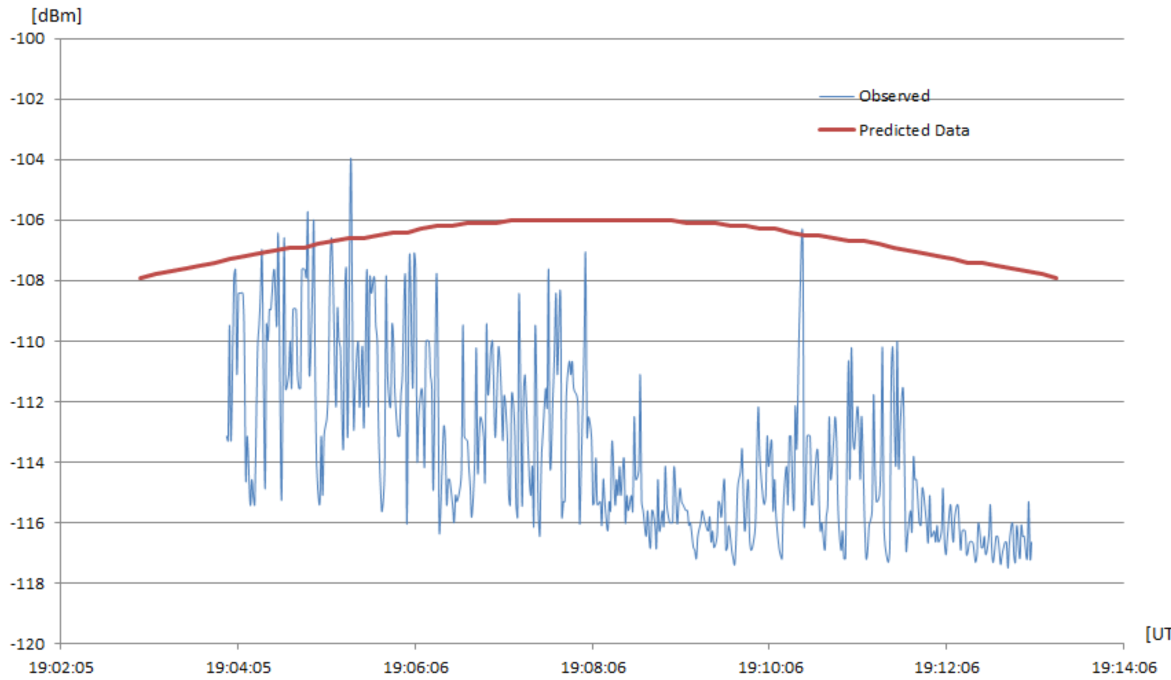

Figure 8.11: Cubesat XI-IV Observation (20110124) with Station Gain = 28 dB

(12) Observation of Cute-1 (20110124)

The three pass parameters are: AZ@AOS=243°, maxEL=5°, AZ@LOS=318°. The comparison of observed data and predicted data are shown in Figure 8.12.

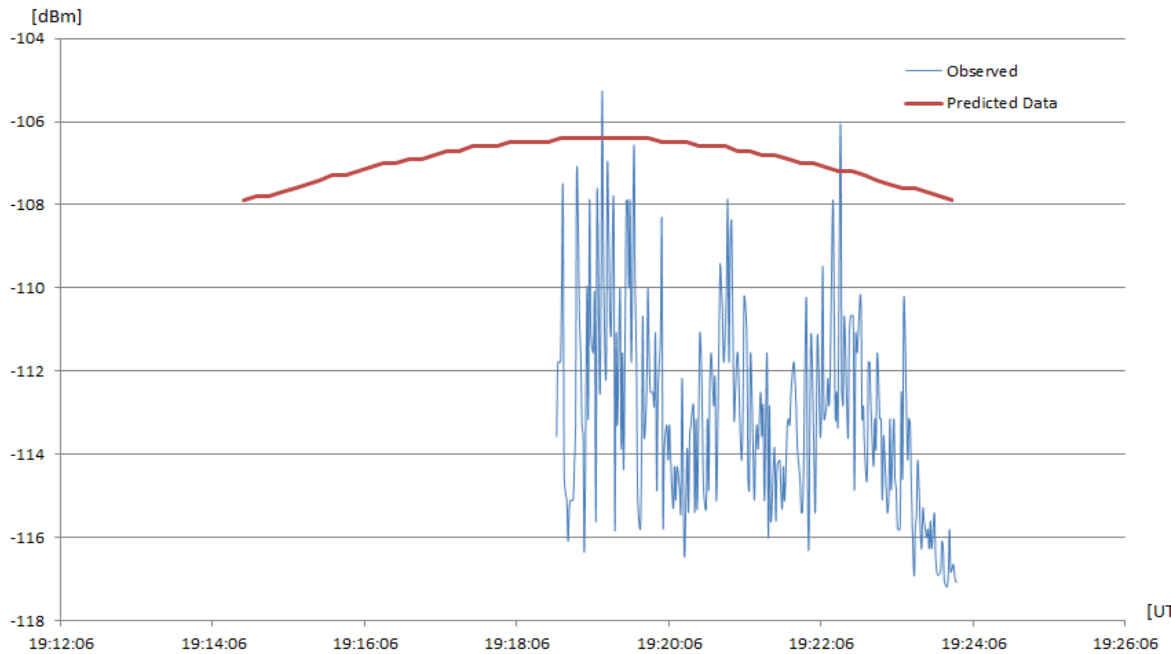

Figure 8.12: Cute-1 Observation (20110124) with Station Gain = 28 dB

(13) The Second Observation of Compass-1 (20110124)

The three pass parameters are: AZ@AOS=144°, maxEL=40°, AZ@LOS=353°. The comparison of observed data and predicted data are shown in Figure8.13.

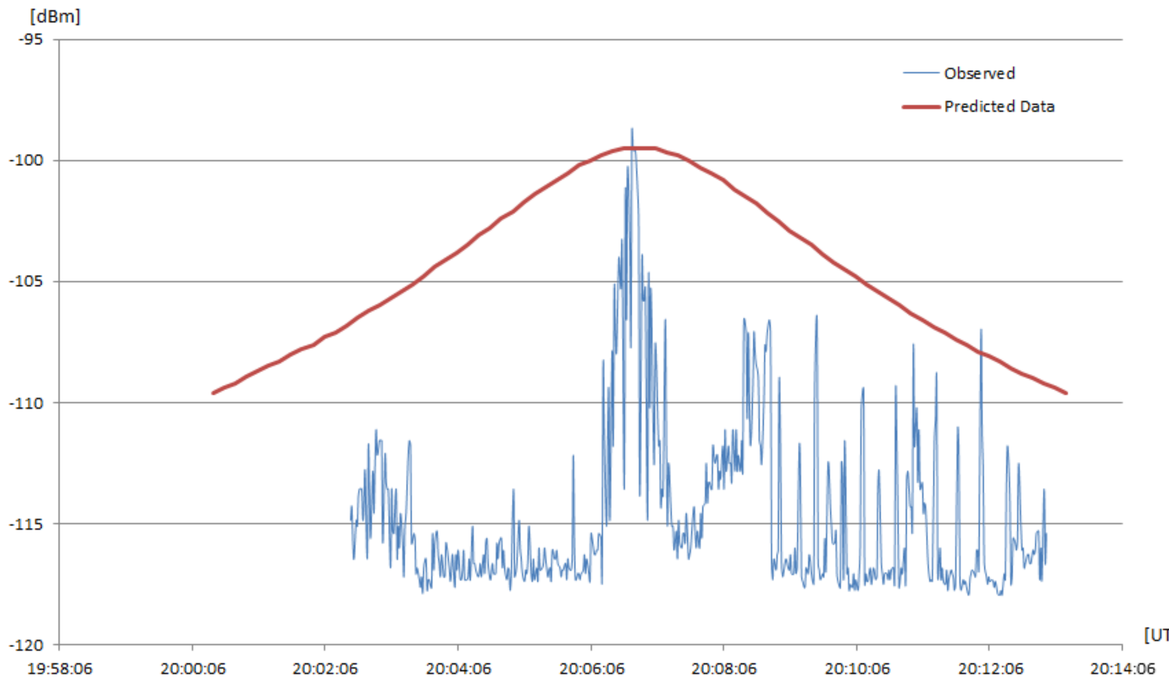

Figure 8.13: The Second Compass-1 Observation (20110124) with Station Gain = 25 dB

(14) Observation of Cubsat XI-IV (20110125)

The three pass parameters are: AZ@AOS=118°, maxEL=20°, AZ@LOS=356°. The comparison of observed data and predicted data are shown in Figure 8.14.

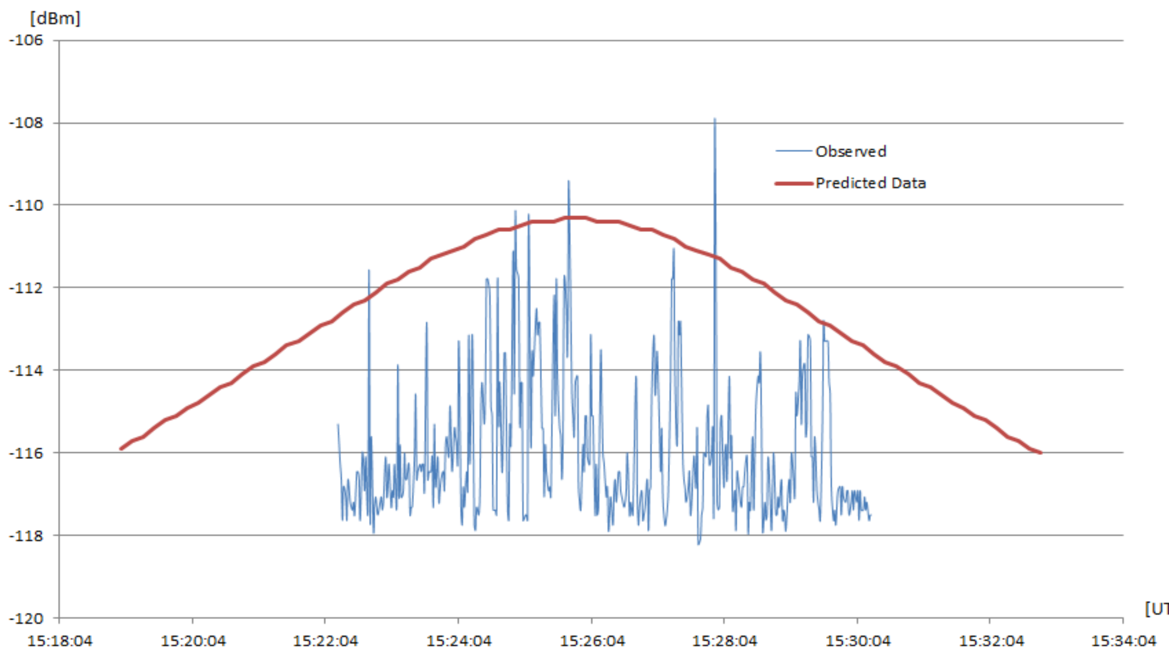

Figure 8.14: Cubesat XI-IV Observation (20110125) with Station Gain = 20 dB

(15) The First Observation of Cute-1 (20110125)

The three pass parameters are: AZ@AOS=122°, maxEL=23°, AZ@LOS=355°. The comparison of observed data and predicted data are shown in Figure 8.15.

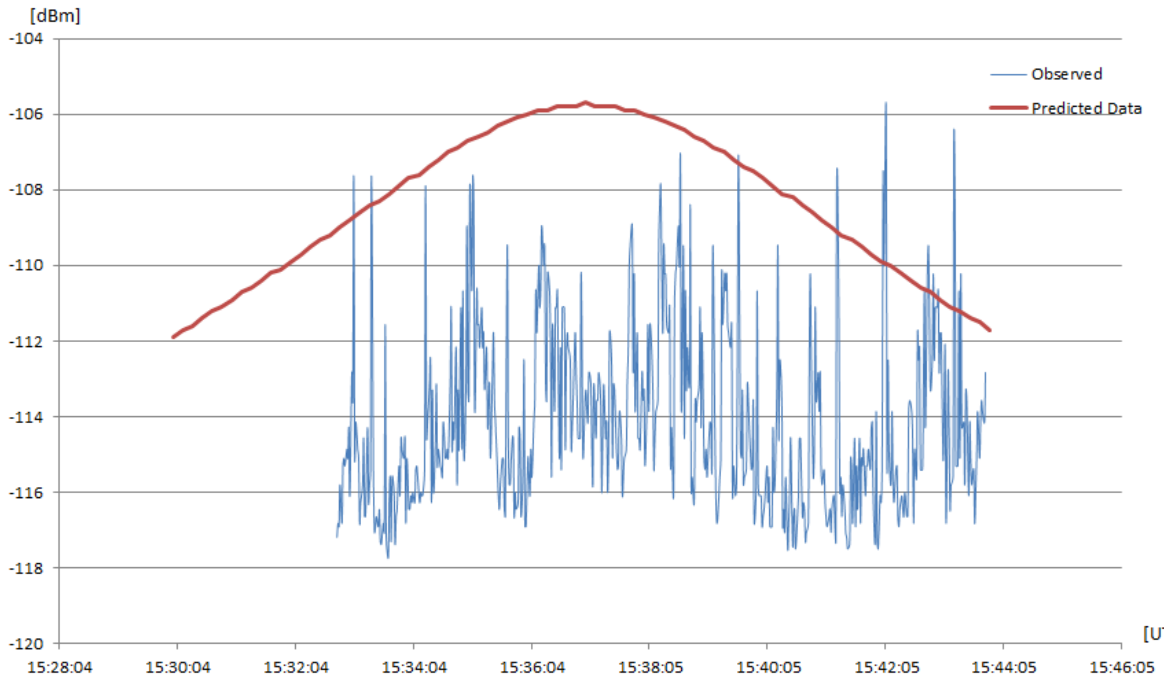

Figure 8.15: The First Cute-1 Observation (20110125) with Station Gain = 24 dB

(16) **The Second Observation of Cute-1 (20110125)**

The three pass parameters are: AZ@AOS=172°, maxEL=66°, AZ@LOS=344°. The signal was very good. The comparison of observed data and predicted data are shown in Figure 8.16.

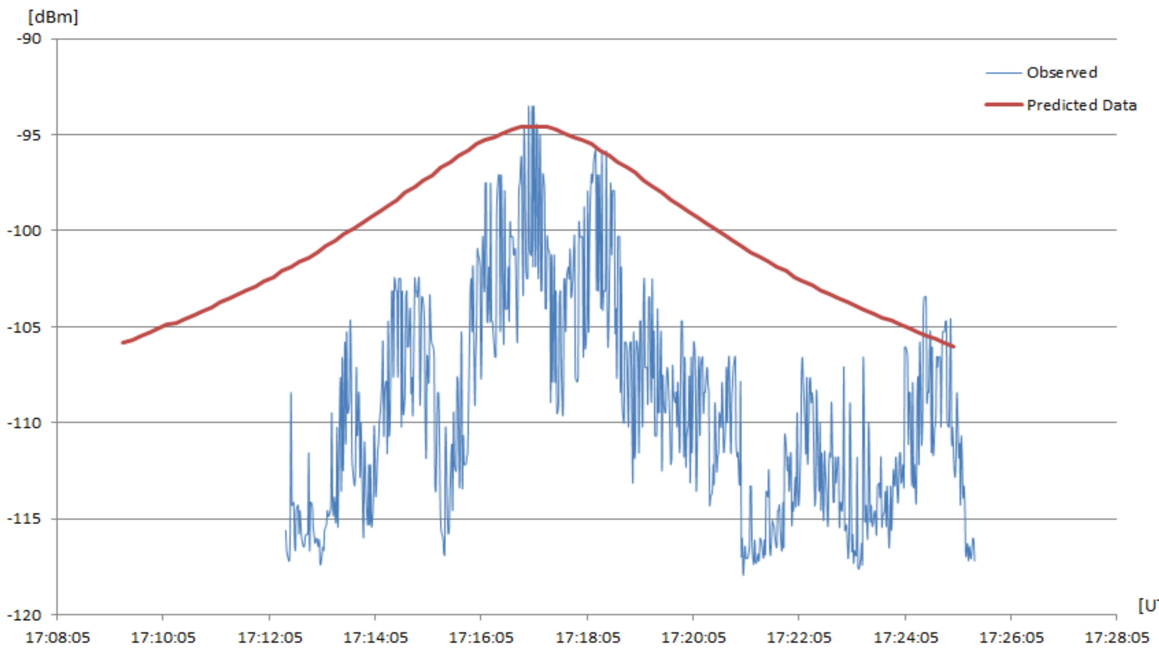

Figure 8.16: The Second Cute-1 Observation (20110125) with Station Gain = 30 dB

(17) Observation of Cubsat XI-IV (20110126)

The three pass parameters are: AZ@AOS=108°, maxEL=15°, AZ@LOS=358°. The comparison of observed data and predicted data are shown in Figure 8.17.

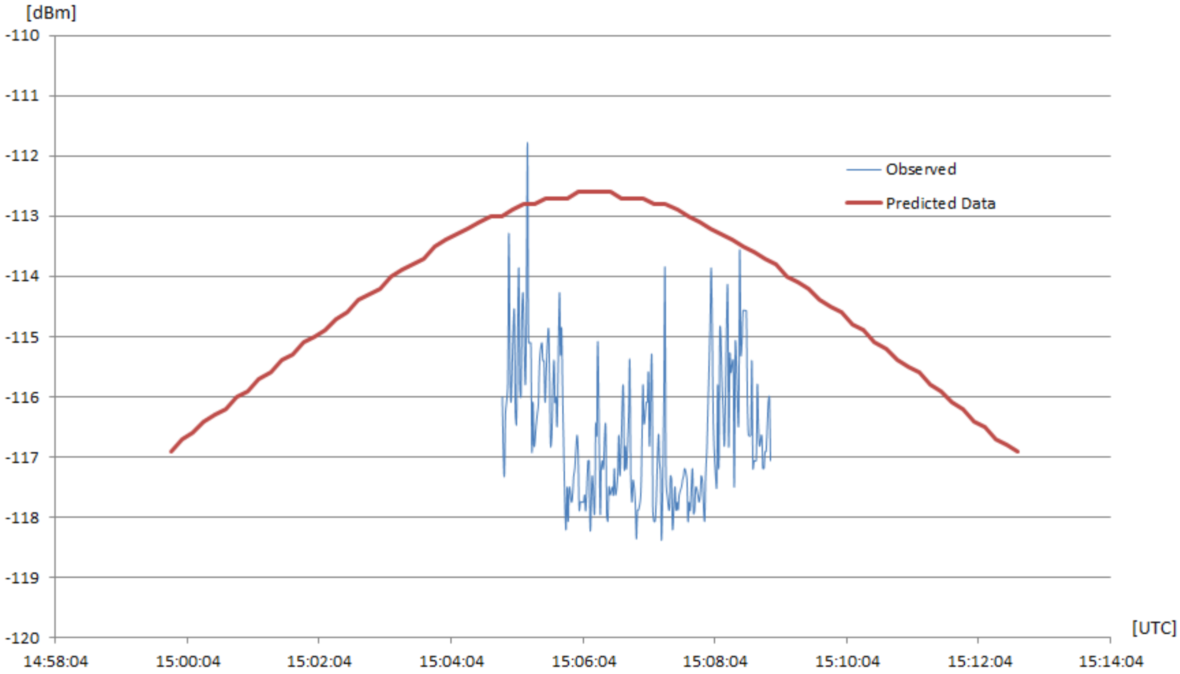

Figure 8.17: Cubesat XI-IV Observation (20110126) with Station Gain = 19 dB

(18) Observation of Cute-1 (20110126)

The three pass parameters are: AZ@AOS=112°, maxEL=17°, AZ@LOS=357°. The signal was first captured on 436.841MHz. The comparison of observed data and predicted data are shown in Figure 8.18.

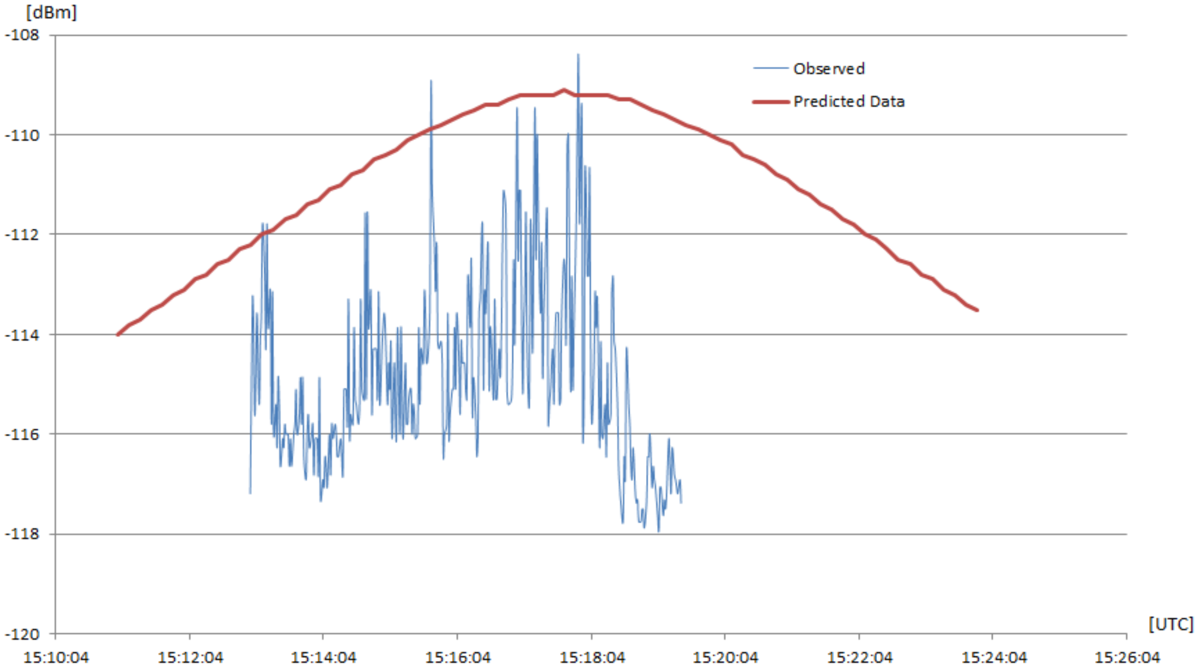

Figure 8.18: Cute-1 Observation (20110126) with Station Gain = 22 dB

(19) Observation of Cute-1 (20110127)

The three pass parameters are: AZ@AOS=152°, maxEL=62°, AZ@LOS=348°. The comparison of observed data and predicted data are shown in Figure 8.19.

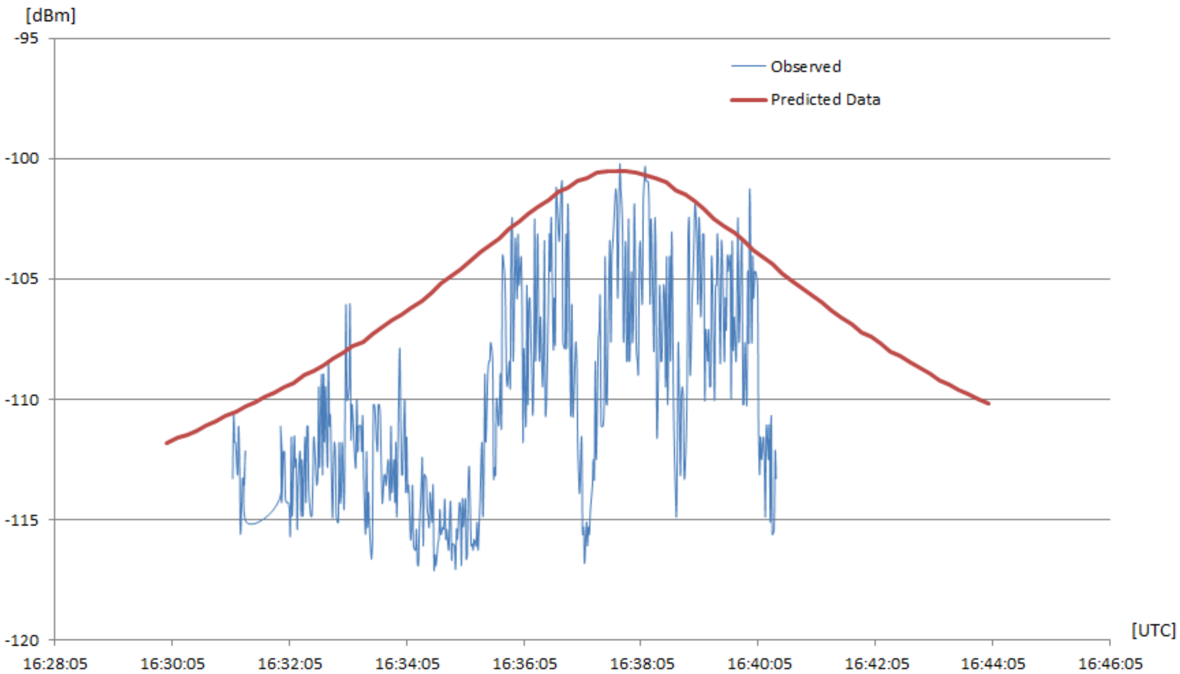

Figure 8.19: Cute-1 Observation (20110127) with Station Gain = 24 dB

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