PRATHAM
IIT BOMBAY STUDENT SATELLITE

Critical Design Review Report
Communication and GroundStation Subsystem

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Chapter 1

Introduction

The Communication and GroundStation Subsystem has the major goal of providing a robust link between the satellite and the Groundstation for the purpose of achieving Health monitoring data and Telemetry. The Groundstation is also equipped to switch off the satellite using Telecommand. The Communication and Groundstation Subsystem is also responsible for the development of hardware necessary for the success of the Satellite Payload. The subsystem has also undertaken the task of involving other Universities in the task of setting up Groundstations across the country to generate the TEC Map of India. The report describes, in detail, the tasks completed as a part of this project towards the completion of the Ground station and on board segments and the course of action to be taken to complete the remaining tasks for integration of the entire subsystem.

1.1 Objectives

The objectives of the subsystem are as follows

- To design an onboard system comprising of a Beacon, a telemetry Downlink and an Uplink
- To design a receiving segment at the Groundstation for the purpose of telemetry and beacon
- To design an uplink segment at the Groundstation to operate the telecommand
- To design a polarization measurement system for Payload subsystem for TEC measurements
- To develop low cost Groundstation for other Universities which are part of the Social Goal
- To design an automated system to track satellites at the GroundStation

1.2 Subsystem Requirements

1.2.1 Power Subsystem

- Telemetry: 1.75 watt when operational. This includes the power consumed by the transmitter circuit as well as the amplifiers and other transmission line losses. The power required will drop to about 0.06 watts when the monopole is in power down mode.
- Beacon: 1.75 watt when operational. This includes the power consumed by the amplifier and the modulator circuit. The duty cycle of the beacon is 100 % throughout the orbit.

- Uplink: The power consumption of the Uplink module is negligible. However, the uplink module is always switched on as there should be a provision of shutting down the satellite from any groundstation incase it strays from the allocated frequency.

1.2.2 On Board Computer

The On Board Computer has 2 separate microcontrollers on its Printed circuit board, a master and a slave. The Master microcontroller signals the start of communication by giving an interrupt to the Slave microcontroller after entering in the region of transmission. The region is determined by the GPS readings. Apart from these, the OBC should also perform the following tasks:

- The OBC team should provide AX.25 data packets to the CC1101 transmitter chip.
- The OBC team will also control the power modes of the transmitter.
- The data provided to the chip should be in the NRZ format.
- The Slave microcontroller should implement CRC on the data packets

1.2.3 Controls

The controls subsystem is responsible for the following tasks:

- Position determination - To determine the position of the satellite in space
- Attitude Determination - To determine the attitude of the body frame of the satellite with respect to orbit frame
- Attitude control - To bring the satellite into earth pointing orientation after ejection and to maintain this attitude throughout the period of operation

The following are the requirements on the ADCS subsystem:

Requirement on	To achieve	Purpose
Position determination	1 km	Start of Communication with the Ground station. The value, however, comes from Payload resolution requirements.
Attitude determination	Yaw – 5 degrees Roll – 5 degrees Pitch -5 degrees	This is required to achieve attitude control of the satellite. This will also be essential in case of an emergency due to antenna failure
Attitude Control	10 degrees	To minimize pointing error. The value, however, comes from Payload requirements.

1.2.4 Integration

The Integration team is responsible for Integration of the entire structure, both mechanically and electrically. Thus, the integration of the PCB on the satellite and the connections between different modules of the communication system shall be done by the Integration Subsystem. The requirements on the Subsystem from communication point of view are:

- The monopole holder should be rigid mechanically and should withstand Vibration loads

- The monopole should be insulated from the satellite body using an epoxy and heat shrinkable tube.
- The onboard antennae should be parallel to each other and any error in parallelism should be measured beforehand and should be quoted as bias error. This value should not change during the mission life of the satellite.
- The PCB's should be mounted in a way to transfer all the vibration loads to the structure.
- The PCB's should be potted before mounting on the flight model
- The CC and PA daughter boards should be fixed to their mounts using an epoxy based glue which shall withstand the launch loads.

1.2.5 Thermals

The thermals subsystem is responsible for maintaining the operating temperature of the satellite between 10 and 30 degree Celsius. The requirements from the thermal subsystem are:

- To maintain the temperature of the modules within their operating range.
- The dissipation of heat from the amplifiers during communication with the Ground station is an essential requirement from the thermals subsystem.
- The temperature of the monopole should not exceed 100 degree Celsius.

Chapter 2

Onboard Communication System

The onboard segment consists of a telemetry unit, an uplink and a beacon. There are 2 monopole antenna onboard for the purpose of transmission. The beacon and uplink are independent units and the telemetry is controlled by the On board computer. The following is a block diagram of the 3 modules- the uplink, telemetry and beacon.

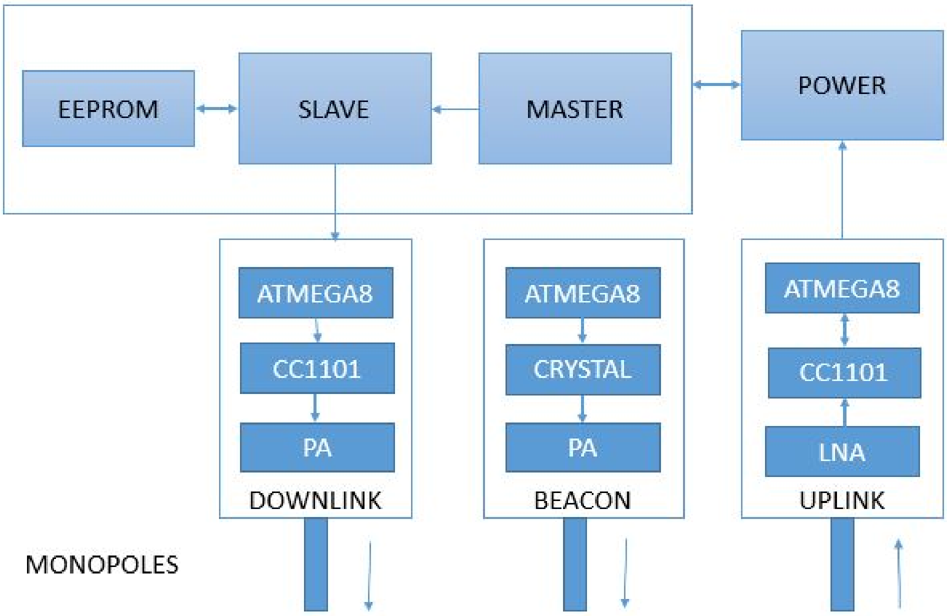

Figure 2.1: Telemetry Unit

Parameter	Downlink	Beacon	Uplink
Frequency	437.45 MHz	145.98 MHz	437.45 MHz
Modulation	FSK	CW	FSK
Telemetry EIRP	20 dBm	10 dBm	-
Command receiver G/T	-	-	-24 dB/K
Antenna type	Monopole	Monopole	Monopole

Table 2.1: Overview of On-Board Communication system

2.1 Telemetry

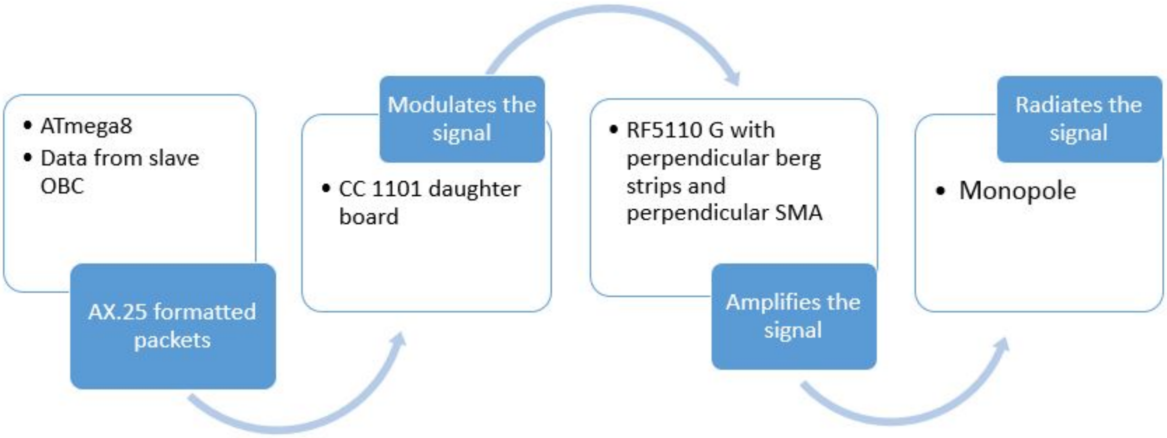

Figure 2.2: Telemetry Unit

The telemetry unit is activated by the Slave mcu when the GS is above India and France. The position is detected by the Master mcu and the start of the communication is communicated to the Slave mcu. The Slave mcu transmits data to the downlink mcu using UART communication. The downlink mcu codes the telemetry transmitter using SPI. The Power sub-system will send "Health Monitoring" data (HM Data) regarding the status of each of the major loads on the satellite to the On-Board Computer when polled for this data. The OBC is required to send this data in packets encoded using the AX.25 communication protocol, at a rate of 1.2 kbps. The Slave will receive temperature data from its ADC pins and will include it in the HM data.

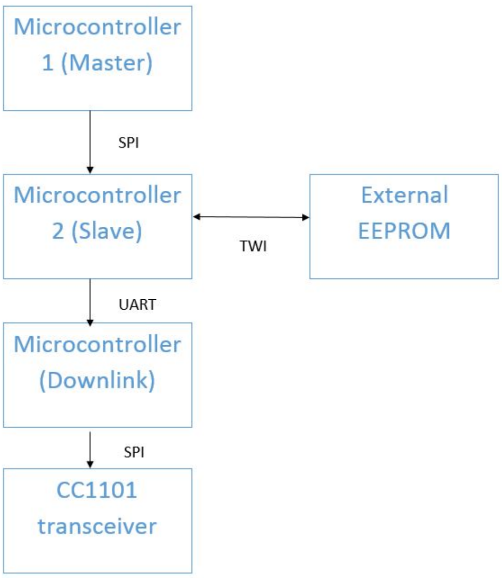

Figure 2.3: Schematic of OBC

2.1.1 CC1101 daughter board

The downlink microcontroller provides the benefit of encoding the CC1101 using SPI instead of GPIO bit banging. The CC1101 goes into the sleep mode after each data packet is transmitted. After every packet, the CC is checked for PLL lock, for register values and CRC is implemented on the data packets.

The data related to the operating parameters of the CC1101 are the following

Parameter	Operating Range	Operating value
Frequency	402 – 470 MHz	437.45 MHz
Voltage	2.3 V – 3.6 V	3.3 V
Current	15 mA	15 mA
Bit rate	0.45 - 156.2 kbps	1.2 kbps
Modulation	NA	FSK
Transmission time frame	NA	Off for 15 seconds in every 120 seconds
Input power	Max 10 dBm	10 dBm
Output power	Max 10 dBm	10 dBm
Temperature	-40 to 85 degree Celsius	10 to 30 degree Celsius

The schematic for programming interfacing with the CC1101 using the downlink microcontroller is shown below

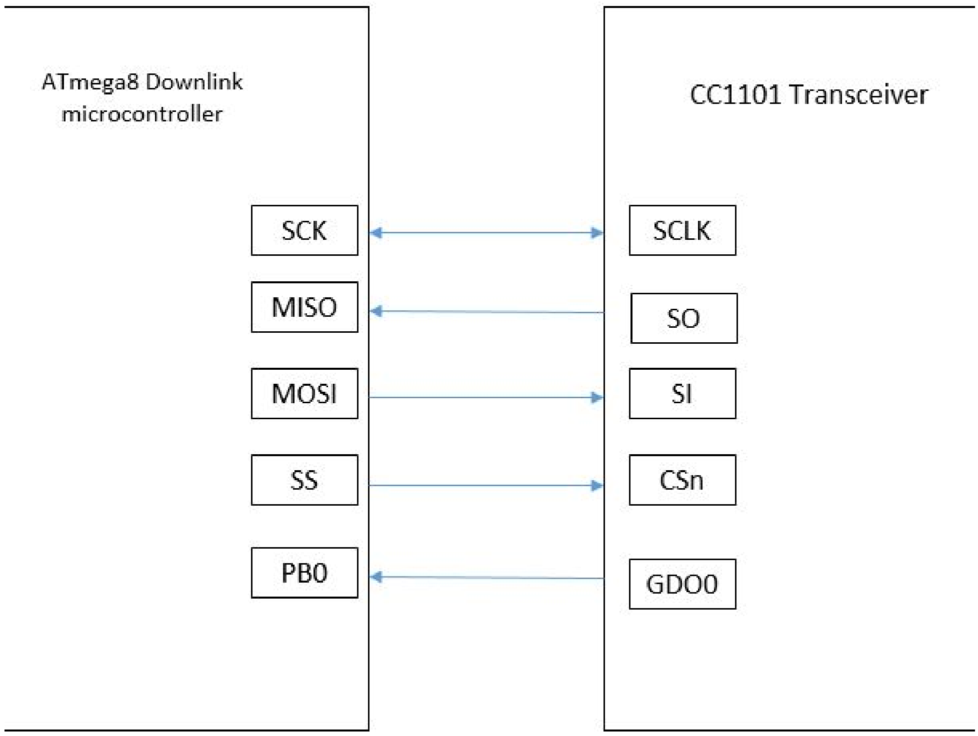

Figure 2.4: CC1101

2.1.2 AX.25 protocol

The AX.25 protocol is of the following format:

Flag	Address	Control	PID	Info	FCS	Flag
1111110	112/224 Bits	8/16 Bits	8 Bits	N*8 Bits	16 Bits	1111110

The flag field is 8 bit. Flag is used to delimit frames, it occurs at both the beginning and end of each frame. Two frames may share one flag, which would denote the end of the first frame, and the start of the next frame. A flag consists of a zero followed by six ones followed by another zero, or 01111110 (7E hex). As a result of bit stuffing, this sequence is not allowed to occur anywhere else inside a complete frame.

The Address bits identify both the source of the frame and its destination. It can also contain command/response information facilities for level 2 repeater operation. The control field is used to identify the type of frame being passed and control attributes of the level 2 connection.

The General types of AX.25 frames are

- Information frame (I frame)
- Supervisory frame (S frame)
- Unnumbered frame (U frame).

The Protocol Identifier (PID) field shall appear in information frames (I and UI) only. It identifies what kind of layer 3 protocol, if any, is in use. If 0x0F is used then it indicates that No level 3 protocol implemented. The information field is used to convey user data from one end of the link to the other. Range is from 32 bits to 1024 bits.

2.1.3 Frame check sequence (CRC)

The frame-check sequence (FCS) is a sixteen-bit number calculated by both the sender and receiver of a frame. It is used to ensure that the frame was not corrupted by the medium used to get the frame from the sender to the receiver. To assure that the flag bit sequence doesn't appear accidentally anywhere else in a frame. The sending station monitors the bit sequence for a group of five or more contiguous one bit. Any time five contiguous one bits are sent the sending station shall insert a zero bit after the fifth one bit. During frame reception, any time five contiguous one bits are received, a zero bit immediately following five one bits shall be discarded. With the exception of the FCS field, all fields of an AX.25 frame shall be sent with each octet's leastsignificant bit first. The FCS shall be sent most-significant bit first.

2.1.4 CC1101 Testing

- The CC1101 chips in transmitter and receiver mode were tested by connecting one microcontroller to the transmitter and one to the receiver.
- The receiver was coded to check the received data and give visual LED signals to indicate progress and errors. Data was also observed on computer terminal.
- AX.25 was implemented. Succesfull decoding at receiver confirmed validity of data.
- Finally, it was tested in a closed loop while connected with the OBC and the power boards.

2.1.5 Telemetry Link budget

Parameter	Value	Units
Spacecraft Transmitter Power Output:	0.4	W
In dBW:	-4.0	dBW
In dBm:	26.0	dBm
Spacecraft Total Transmission Line Losses:	0.4	dB
Spacecraft Antenna Gain:	-3.0	dBi
Spacecraft EIRP:	-7.4	dBW
Downlink Path:		
Spacecraft Antenna Pointing Loss:	0.3	dB
S/C-to-Ground Antenna Polarization Loss:	0.2	dB
Path Loss:	151.0	dB
Atmospheric Loss:	1.1	dB
Ionospheric Loss:	0.3	dB
Rain Loss:	0.0	dB
Isotropic Signal Level at Ground Station:	-160.3	dBW
Ground Station (EbNo Method):		
——- Eb/No Method ——-		
Ground Station Antenna Pointing Loss:	0.3	dB
Ground Station Antenna Gain:	9.0	dBi
Ground Station Total Transmission Line Losses:	0.2	dB
Ground Station Effective Noise Temperature:	307	K
Ground Station Figure of Merrit (G/T):	-16.1	dB/K
G.S. Signal-to-Noise Power Density (S/No):	51.9	dBHz
System Desired Data Rate:	1200	bps
In dBHz:	30.8	dBHz
Telemetry System Eb/No for the Downlink:	21.1	dB
Demodulation Method Seleted:	G3RUH FSK	
Forward Error Correction Coding Used:	None	
System Allowed or Specified Bit-Error-Rate:	1.0E-04	
Demodulator Implementation Loss:	0	dB
Telemetry System Required Eb/No:	16.7	dB
Eb/No Threshold:	16.7	dB
System Link Margin:	4.4	dB
Ground Station Alternative Signal Analysis Method		
——— SNR Method ————		
Ground Station Antenna Pointing Loss:	0.3	dB
Ground Station Antenna Gain:	9.0	dBi
Ground Station Total Transmission Line Losses:	0.2	dB
Ground Station Effective Noise Temperature:	307	K
Ground Station Figure of Merrit (G/T):	-16.1	dB/K
Signal Power at Ground Station LNA Input:	-151.6	dBW
Ground Station Receiver Bandwidth (B):	2000	Hz
G.S. Receiver Noise Power (Pn = kTB)	-170.7	dBW
Signal-to-Noise Power Ratio at G.S. Rcvr:	19.1	dB
Analog or Digital System Required S/N:	10.0	dB
System Link Margin	9.1	dB

Table 2.2: Telemetry Link Budget

2.2 Beacon unit

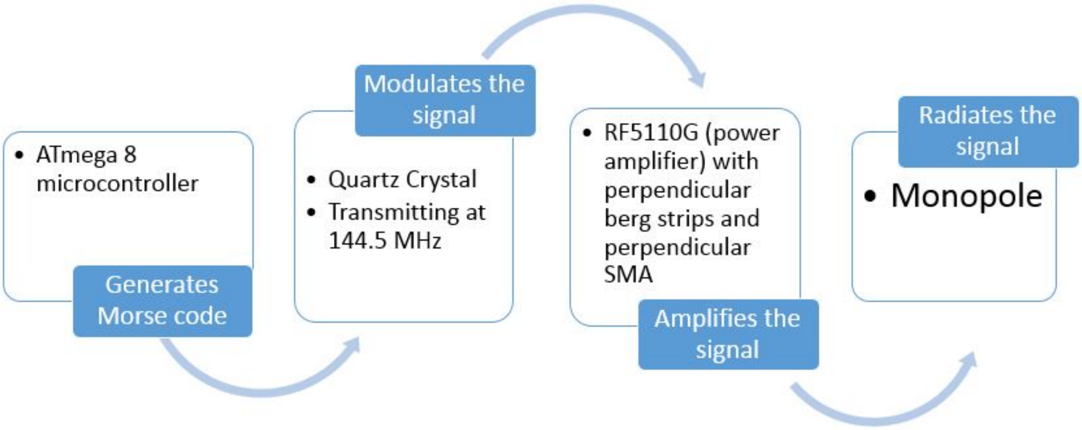

Figure 2.5: Beacon Unit

2.2.1 Beacon data format

Mode of communication is Simplex as per ANSI definition. The data transmitted from the beacon shall have the following components:

- Callsign: VU2MDQ
- IIT Bombay Student Satellite, Pratham

This has to be transmitted using Morse code. The Morse code would follow the International Standards.
Each part would have the following format: Part no./header – “partname” – Information.
Part 1:
Header = 0 Morse equivalent: ——
Part name: Call sign Morse equivalent: -.-. .- .-.. .-.. ... .. –. -.
Information: VU2MDQ Morse equivalent: ...- ..- ..— – -.. –.-
Part 2:
Header: 1 Morse equivalent: .—-
Part name: Identification Morse equivalent: .. -.. . -. - .. ..-. .. -.-. .- - .. — -.
Information: IIT Bombay Student Satellite, Pratham Morse equivalent: .. .. - -... — – -... .- -.– ... - ..- -.. . -. - ... .- - . .-.. .-.. .. - . –..– .–. .-. .- - .....- –

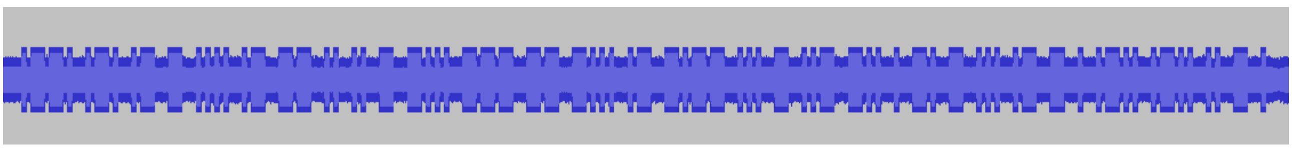

Figure 2.6: Beacon morse code recorded

2.2.2 Beacon Link Budget

Parameter	Value	Units
Spacecraft Transmitter Power Output:	0.03	W
In dBW:	-15.2	dBW
In dBm:	14.8	dBm
Spacecraft Total Transmission Line Losses:	0.4	dB
Spacecraft Antenna Gain:	-3.0	dBi
Spacecraft EIRP:	-18.7	dBW
Downlink Path:		
Spacecraft Antenna Pointing Loss:	0.3	dB
S/C-to-Ground Antenna Polarization Loss:	0.2	dB
Path Loss:	141.0	dB
Atmospheric Loss:	1.1	dB
Ionospheric Loss:	0.3	dB
Rain Loss:	0.0	dB
Isotropic Signal Level at Ground Station:	-161.6	dBW
Ground Station (EbNo Method):		
—— Eb/No Method ——		
Ground Station Antenna Pointing Loss:	0.3	dB
Ground Station Antenna Gain:	9.0	dBi
Ground Station Total Transmission Line Losses:	0.2	dB
Ground Station Effective Noise Temperature:	1065	K
Ground Station Figure of Merrit (G/T):	-21.5	dB/K
G.S. Signal-to-Noise Power Density (S/No):	45.2	dBHz
System Desired Data Rate:	1200	bps
In dBHz:	30.8	dBHz
Telemetry System Eb/No for the Downlink:	14.4	dB
Demodulation Method Seleted:	User Defined	
Forward Error Correction Coding Used:	None	
System Allowed or Specified Bit-Error-Rate:	1.0E-05	
Demodulator Implementation Loss:	0	dB
Telemetry System Required Eb/No:	9.6	dB
Eb/No Threshold:	9.6	dB
System Link Margin:	4.8	dB
Ground Station Alternative Signal Analysis Method		
——— SNR Method ———		
Ground Station Antenna Pointing Loss:	0.3	dB
Ground Station Antenna Gain:	9.0	dBi
Ground Station Total Transmission Line Losses:	0.2	dB
Ground Station Effective Noise Temperature:	1065	K
Ground Station Figure of Merrit (G/T):	-21.5	dB/K
Signal Power at Ground Station LNA Input:	-152.8	dBW
Ground Station Receiver Bandwidth (B):	2000	Hz
G.S. Receiver Noise Power (Pn = kTB)	-165.3	dBW
Signal-to-Noise Power Ratio at G.S. Rcvr:	12.5	dB
Analog or Digital System Required S/N:	10.0	dB
System Link Margin	2.5	dB

Table 2.3: Beacon Link Budget

2.3 Uplink unit

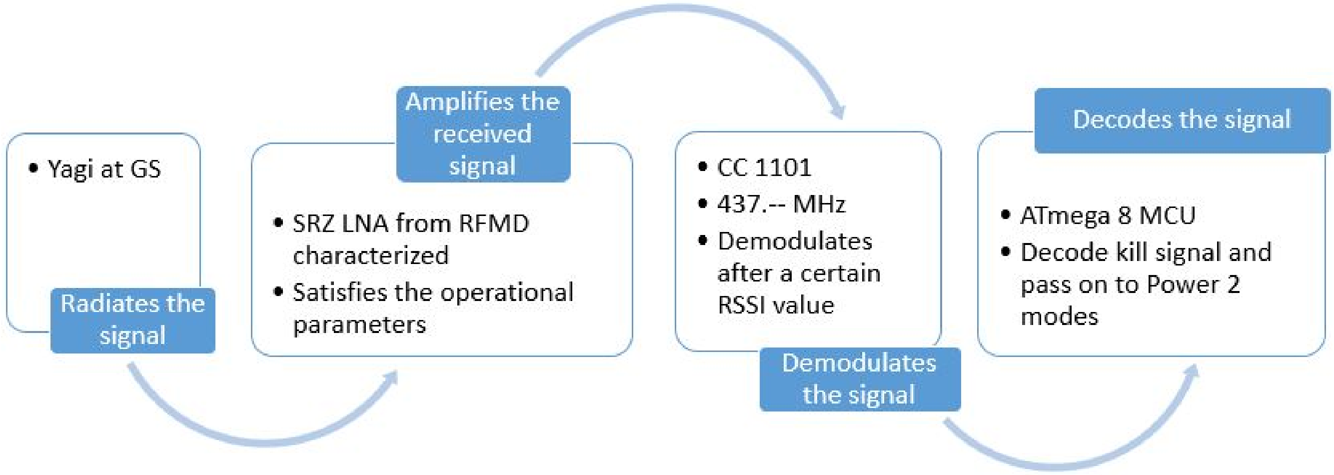

Figure 2.7: Uplink Unit

Uplink is used to reset the satellite or switch it off if required. Only these two functions are controlled by command. All other functions of the satellite are autonomously performed.

2.3.1 Allocation of frequency by IARU

The operation of a transmitter or a receiver in an amateur band requires the authorization of the International Amateur Radio Union. The union has a charter and a bandplan of its own for various regions of the world. The bandplan allocates certain bandwidth in the amateur band for amateur satellite operation. However, the frequency allocation is subject to fulfillment of certain prerequisites. The agency needs to be informed about the entire onboard as well as groundstation system. The following requirements need to be fulfilled:

- Amateur Ham License or a Custodian
- Detailed link budget analysis
- Telemetry sequence
- Details about the GS and Onboard circuity and their functionalities
- Uplink or telecommand to control the satellite.

The telemetry sequence is yet to be worked upon alongwith the encryption of the telecommand. The daughter board that we are using for Uplink is CC1101. Hence, the programming and coding aspects are similar to the one for the telemetry unit.

Parameter	Value	Units
Ground Station(GS) Transmitter Power Output:	1.0	W
In dBW:	0.0	dBW
In dBm:	30.0	dBm
GS Total Transmission Line Losses:	3.6	dB
GS Antenna Gain:	9.0	dBi
GS EIRP:	5.4	dBW
Downlink Path:		
Spacecraft Antenna Pointing Loss:	0.5	dB
S/C-to-Ground Antenna Polarization Loss:	0.2	dB
Path Loss:	141.9	dB
Atmospheric Loss:	1.1	dB
Ionospheric Loss:	0.7	dB
Rain Loss:	0.0	dB
Isotropic Signal Level at Ground Station:	-139.0	dBW
Spacecraft (EbNo Method):		
——- Eb/No Method ——-		
Spacecraft Antenna Pointing Loss:	4.7	dB
Spacecraft Antenna Gain:	2.2	dBi
Spacecraft Total Transmission Line Losses:	2.0	dB
Spacecraft Effective Noise Temperature:	261	K
Spacecraft Figure of Merrit (G/T):	-24	dB/K
S/C Signal-to-Noise Power Density (S/No):	60.9	dBHz
System Desired Data Rate:	1200	bps
In dBHz:	30.8	dBHz
Command System Eb/No :	30.1	dB
Demodulation Method Seleted:	Non-coherent FSK	
Forward Error Correction Coding Used:	None	
System Allowed or Specified Bit-Error-Rate:	1.0E-04	
Demodulator Implementation Loss:	1.0	dB
Telemetry System Required Eb/No:	13.4	dB
Eb/No Threshold:	14.4	dB
System Link Margin:	15.7	dB
Spacecraft Alternative Signal Analysis Method		
———- SNR Method ————		
Spacecraft Antenna Pointing Loss:	4.7	dB
Spacecraft Antenna Gain:	2.2	dBi
Spacecraft Total Transmission Line Losses:	2.0	dB
Spacecraft Effective Noise Temperature:	261	K
Spacecraft Figure of Merrit (G/T):	-24	dB/K
Signal Power at Spacecraft LNA Input:	-143.5	dBW
Spacecraft Receiver Bandwidth (B):	15,000	Hz
Spacecraft Receiver Noise Power (Pn = kTB)	-162.7	dBW
Signal-to-Noise Power Ratio at S/C Rcvr:	19.2	dB
Analog or Digital System Required S/N:	14.4	dB
System Link Margin	4.8	dB

Table 2.4: Uplink Link Budget

2.3.2 Uplink Link Budget

2.4 Onboard Antenna System

The onboard antenna system can be broadly divided into 2 sections based on the purpose it is to accomplish:

- Downlink RF antenna
- Uplink RF antenna

The downlink antenna needed a robust mounting mechanism which would be feasible to fabricate. The uplink RF antenna had to be simulated using 4NEC2 with the given design constraints.

2.4.1 Polarization purity

The simulations showed that a monopole designed from aluminium and having radius 1mm will have an axial ratio of more than 30 dB. The experimental verifications showed an axial ratio of close to 20dB.

2.4.2 Directivity towards earth: Simulation Results

The simulations were done using IE3D and the following was the pattern observed towards the earth when both the monopoles are radiating:

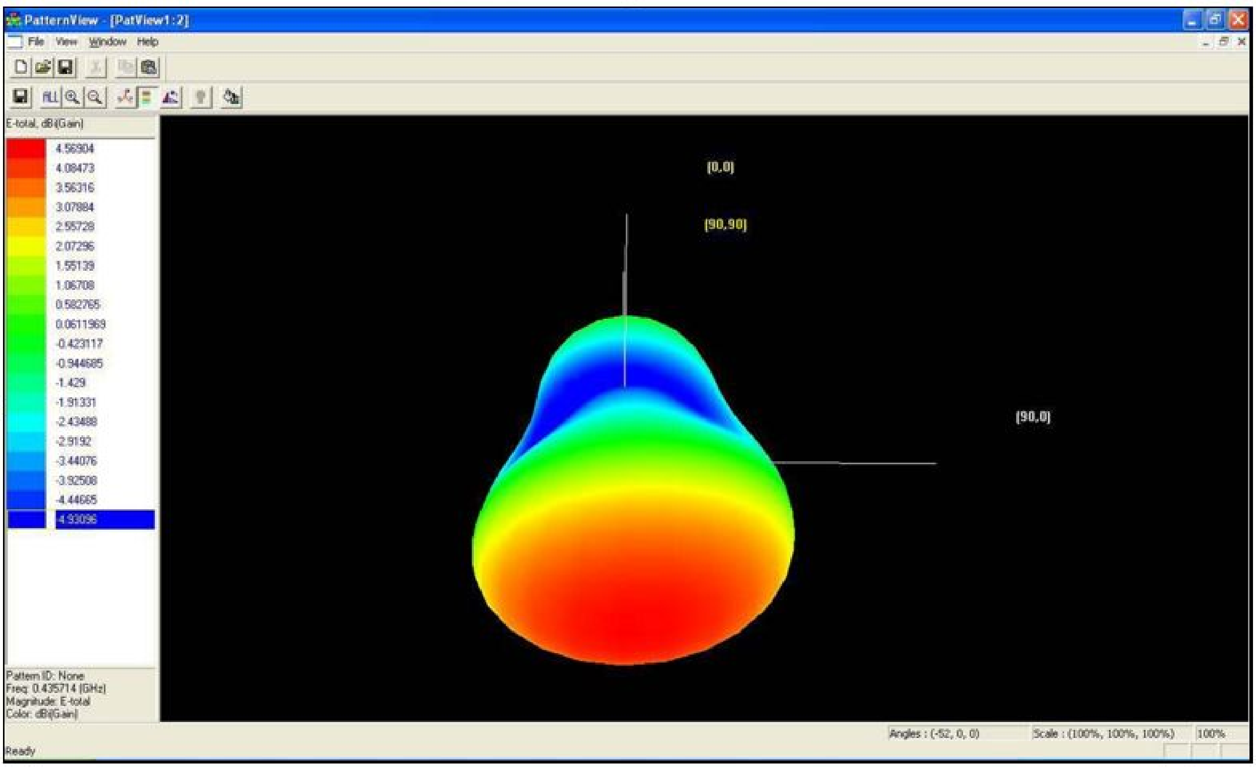

Figure 2.8: Directivity towards earth: Simulation Result

The red portion is towards the earth. The maximum gain is in the direction of earth and the value observed is 4.5 dB.

2.4.3 Effect of coating monopoles with dielectric: Simulation results

The gain of the antenna decreased by about 2-3 dB on being coated with a dielectric with a dielectric value of 6. The reduction was more or less uniform throughout the pattern and the directionality of the pattern remained constant. Thus the only effect this had was to reduce the efficiency of the antenna drastically.

2.4.4 Effect of change of Satellite size on the monopole simulations

There was hardly any change (0.1 dB) due to change in the satellite dimensions. The reasons for the same can be sighted as the wavelength of two monopoles are 70 cm and 200 cm respectively and hence the critical distance at which electrical properties change significantly is the lambda by 4 wavelength which in either case is high compared to a change of 3 cm. We tried to verify this claim by making our satellite dimension of the order of 17 cm and we did observe a sharp change in the pattern and after that the results did not vary much even after changing the satellite body dimension from 20 to 30 cm.

2.4.5 Monopole Holder

It is a fixture that holds a monopole in place on the satellite in the correct specified orientation

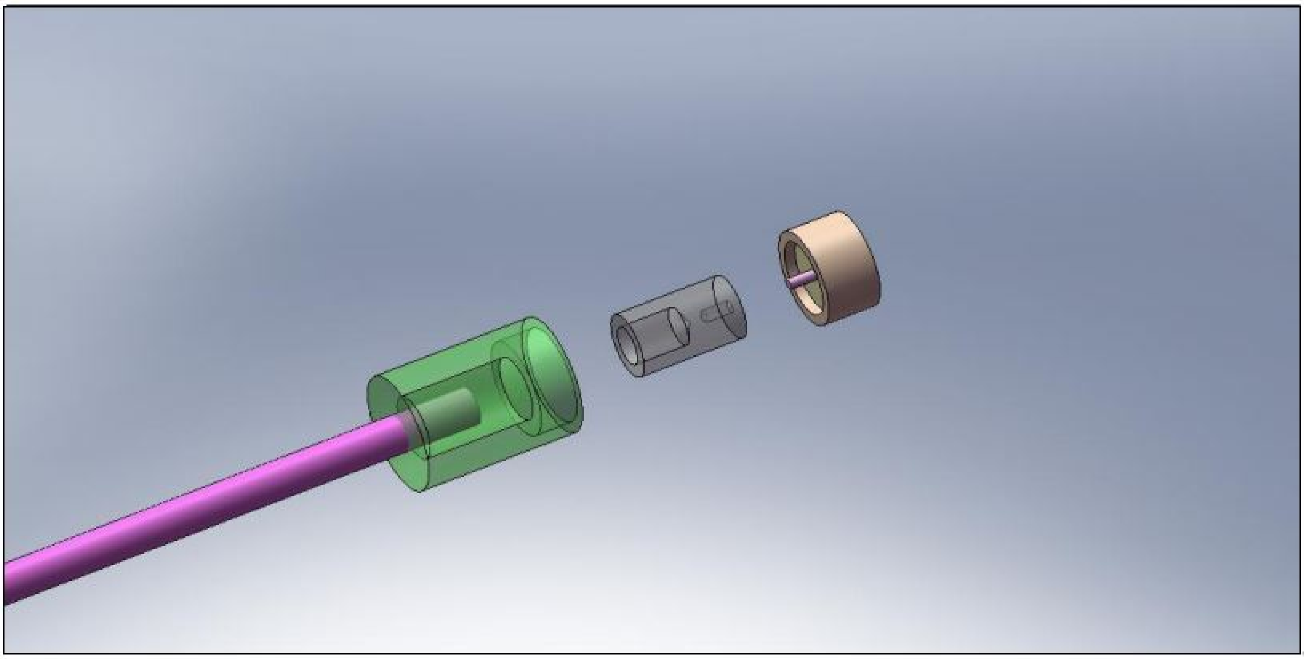

Figure 2.9: Monopole Holder

- Materials: Al-6061
- Dimensions of monopole holder:
  - outer diameter = 20mm
  - inner diameter = 8mm (see pic)
  - length = 29 mm + 2mm (thickness of square base)

- length of square base = 25 mm

- Requirements:
  The monopole holder was designed keeping into mind the following constraints:

  - The monopole had to be insulated from the satellite body while maintaining electrical connection with the feed point.For the same we are using insulation in the form of space grade Heat Shrinkable tubes between the monopole and the holder.

    Monopole is a V+ and other (holder OR satellite body) is grounded. No insulation results in the following consequences:

    * Short circuiting Formation of current loop.
    * Obstruction in the path of transmission of RF signals.

  - The load transfer during vibration should not happen onto the electrical connection.

    The length of the sleeve helps the root of the cantilever to be shifted from the point of solder contact to further down the monopole. Thus on tip loading, maximum stress is produced on the stronger aluminium monopole and not on the soldered joint. The stress produced at the soldered joint also reduces to 1/5th of the value it would have otherwise been if the sleeve were absent. Since epoxy is applied, the soldered joint is held rigid and stress becomes almost zero.

    * Cantilever motion and cantilever beam loading
      Take the example of door
      Theoretically:

      $$Yieldstress = \frac{P_{max} * len * d/3}{d^4/32} \tag{2.1}$$

      $\sigma = 70GPa$. Approximately 200Mpa is yield stress for aluminium.

      $$P_{max} = \frac{PI * d^3 * \sigma}{16 * len} \tag{2.2}$$

      $$P_{max} = \frac{1}{len} \tag{2.3}$$

    * Theoretical observations (ANSYS : Software for structure simulations) :
      The load on the holder is 1.8889 MPa
      And on the antenna is 4.3875 MPa

  - The mounting mechanism should be easily fabricated and must be space grade.
    We came up with the following design of the monopole holder after several considerations. Problems faced in the previous design were that the material selected (CFRP) wasn't space grade.

2.4.6 Antenna Configuration

The antenna configuration was simulated in NEC software and various configurations of the 3 antennae were tried before adopting a linear configuration of 3 monopoles on the anti sun side. The decision was taken keeping in mind the communication and integration constraints. The length of all the three monopoles is 17 cm. Two monopoles are fixed at the vertex of the edge joining Anti-sunside panel and zenith side panel. The third monopole is placed at various locations. The maximum gain is observed when the antennae are arranged in one single line on the edge of the cube. The results are as shown below:

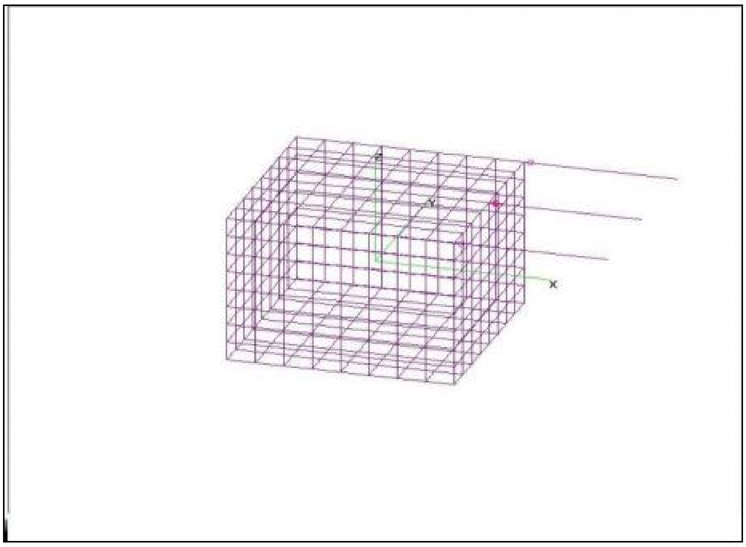

Figure 2.10: Satellite modelled in NEC

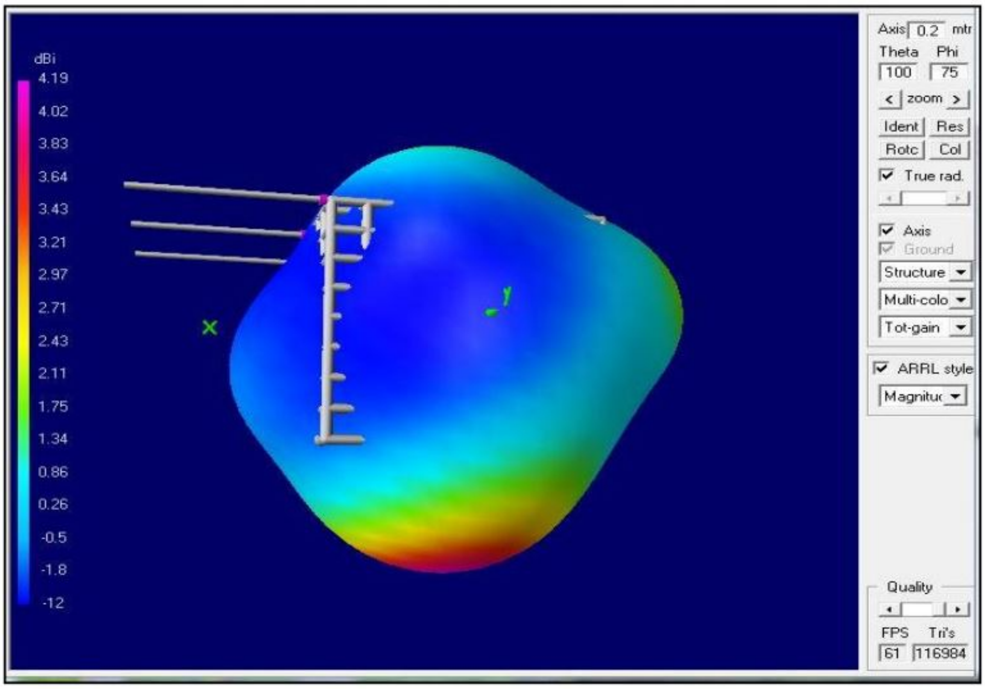

Figure 2.11: Radiation pattern with all antennae aligned in one line

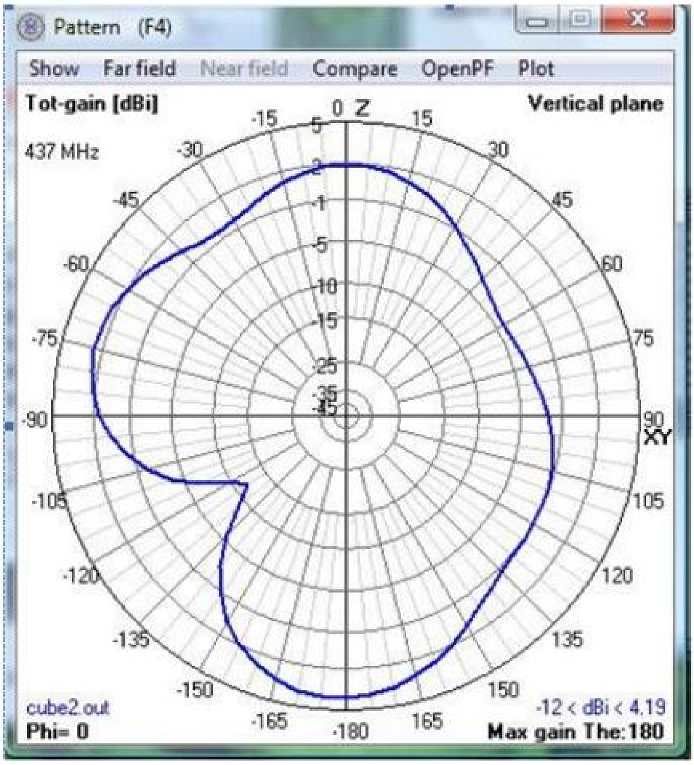

Figure 2.12: Vertical plane radiation pattern

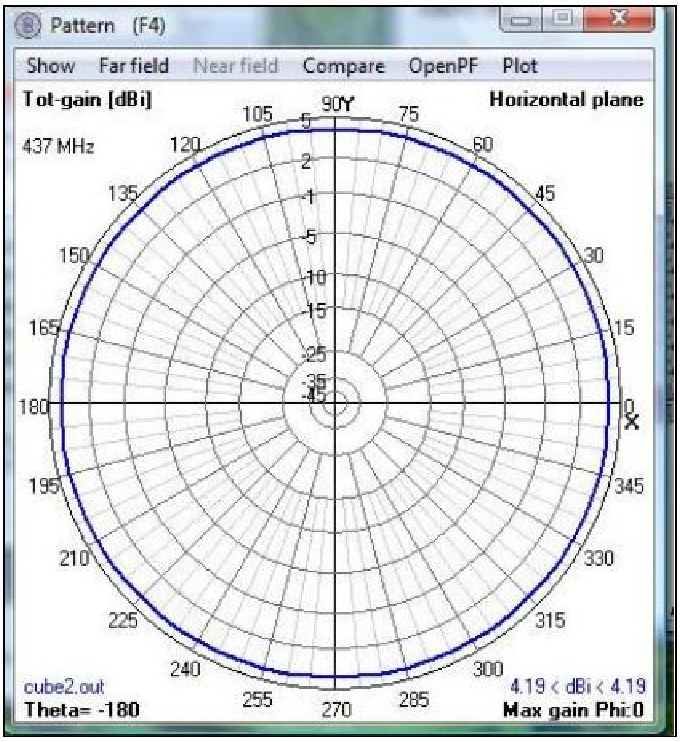

Figure 2.13: Horizontal plane Radiation pattern

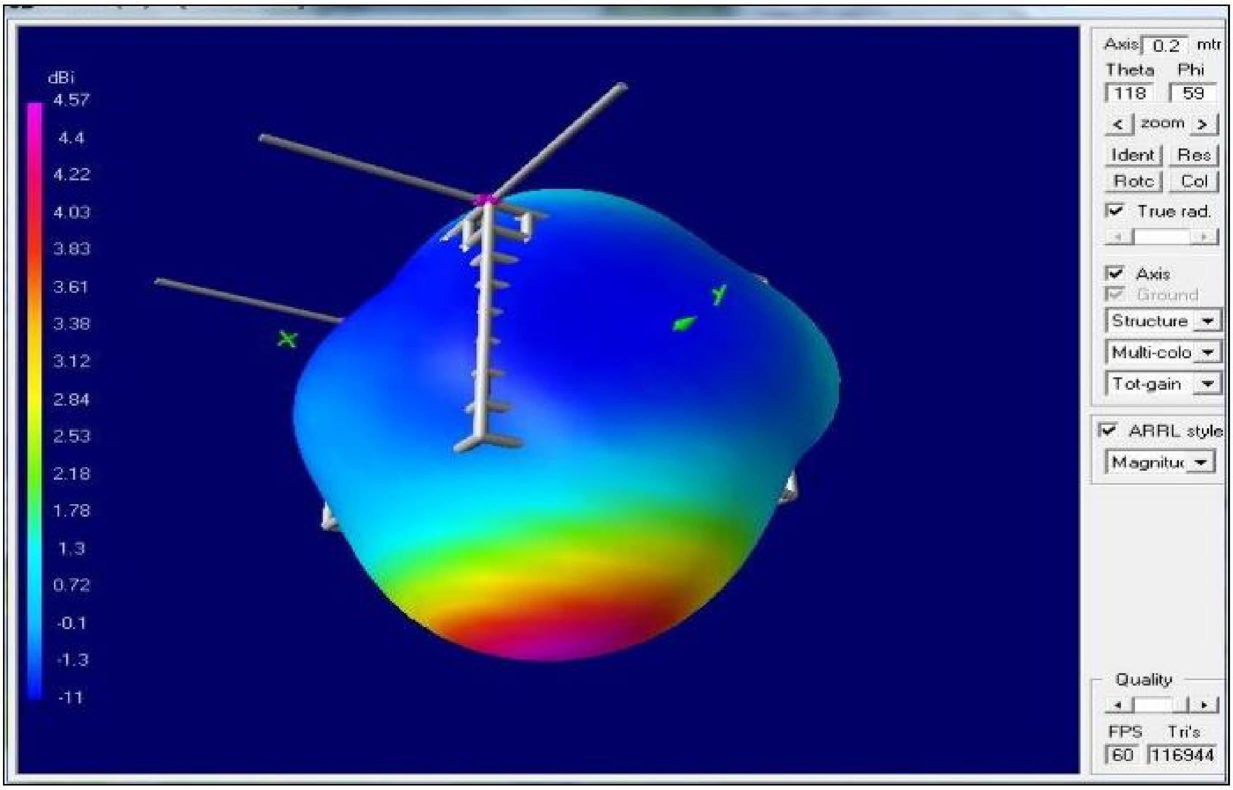

Figure 2.14: Radiation pattern with one antenna on a perpendicular edge

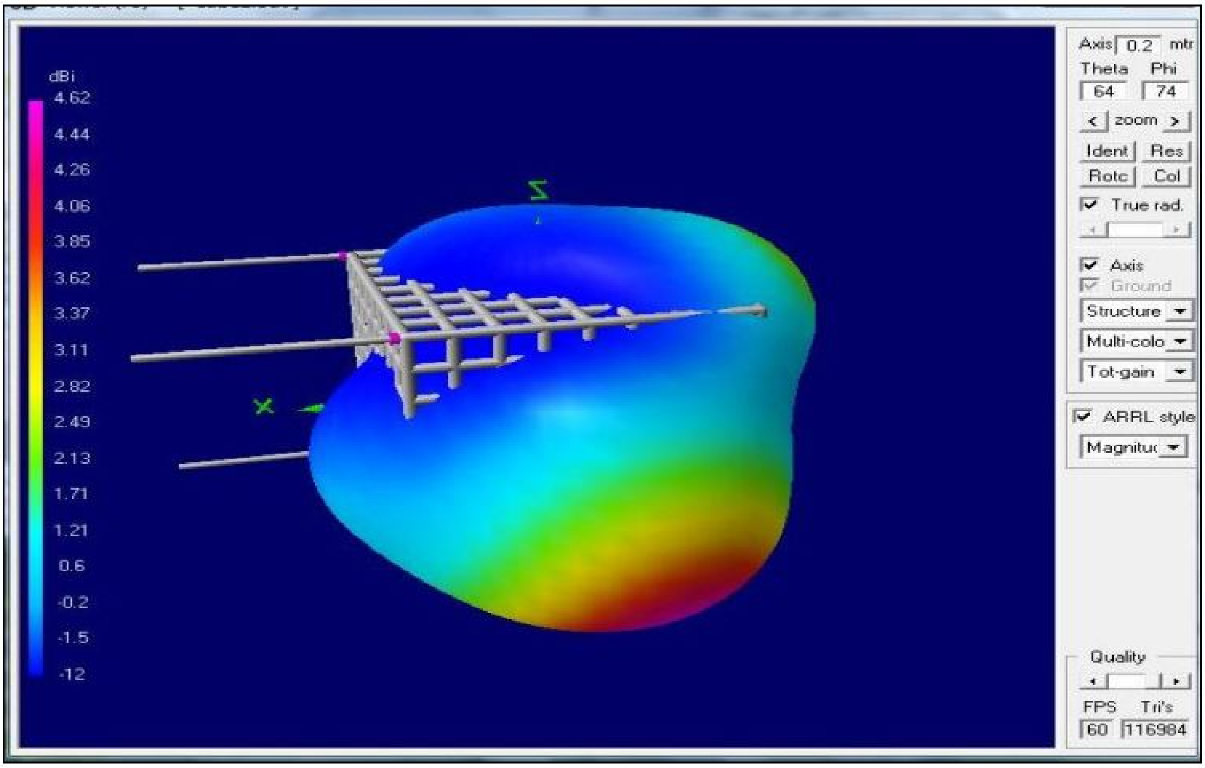

Figure 2.15: Radiation pattern when one monopole is on the corner of the opposite edge

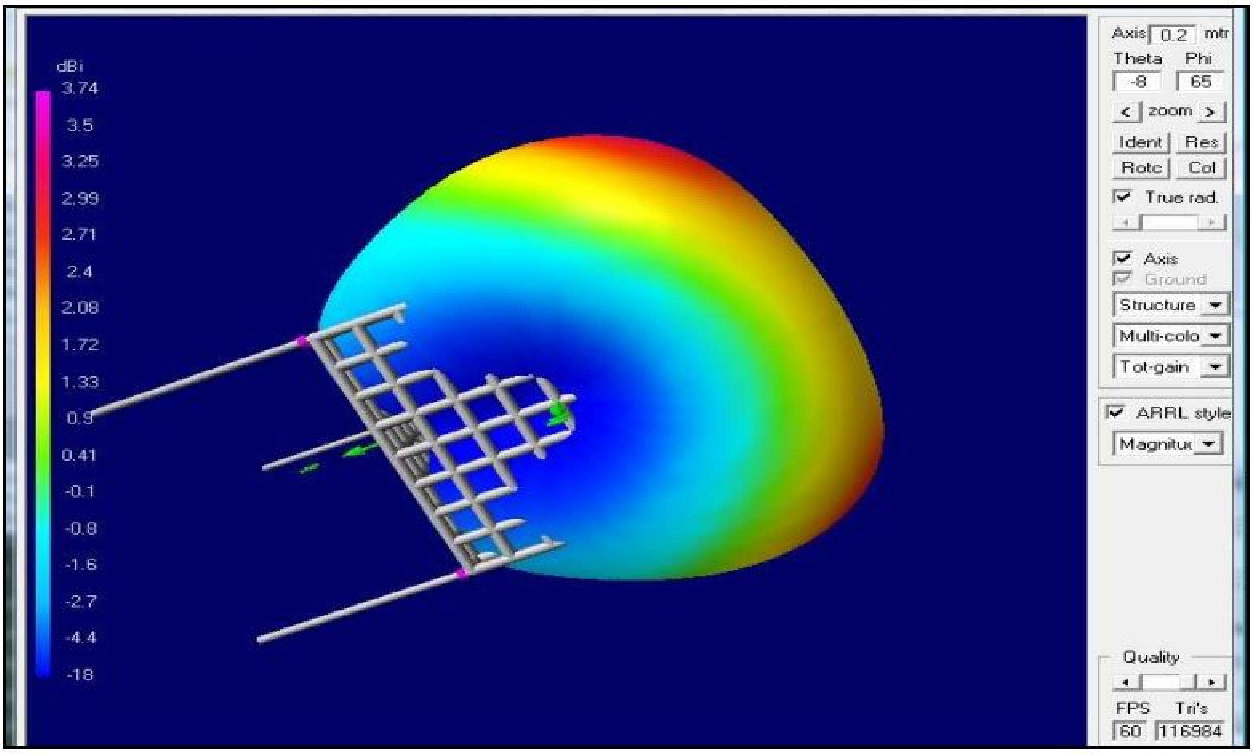

Figure 2.16: Radiation pattern when one of the monopoles is at the face centre

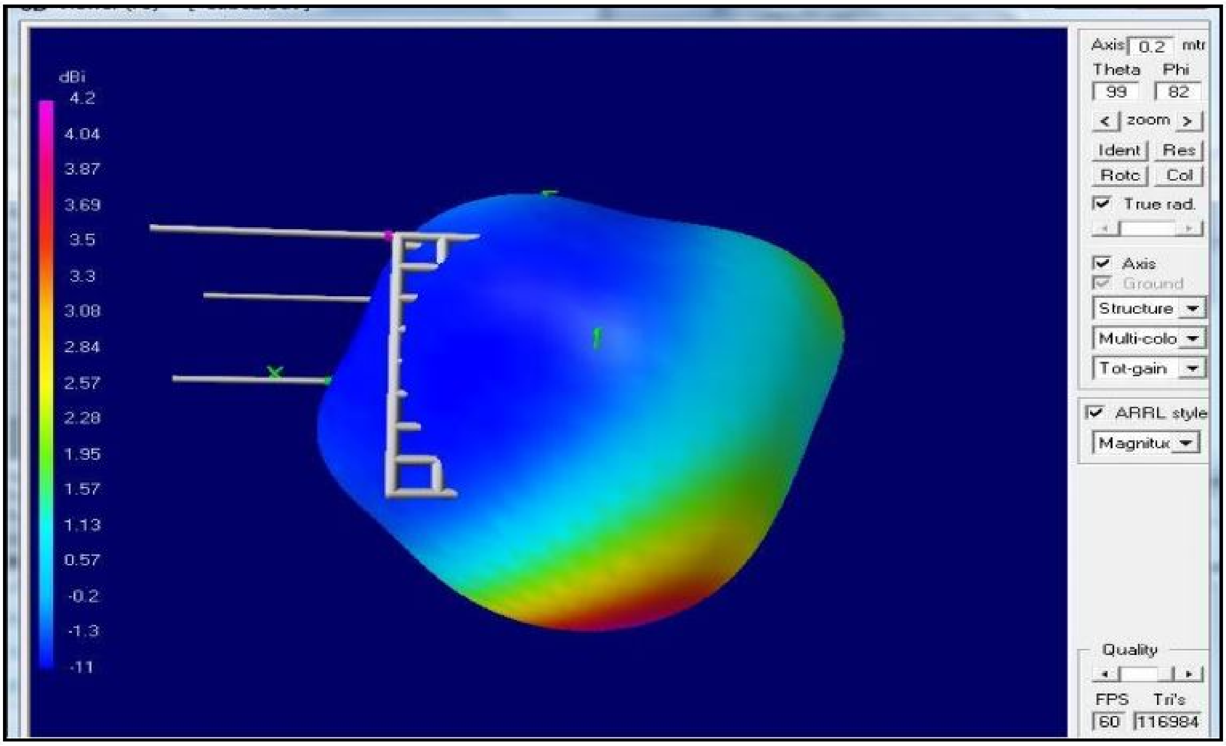

Figure 2.17: Radiation pattern when one monopole is at the centre of the opposite edge

2.4.7 Impedance matching

The impedance matching of the telemetry and uplink monopole was carried out before the anechoic chamber testing. The minimum return loss that was required for the satisfactory testing of the radiation pattern without damaging the equipments was -10 dB. The analysis of S11 parameter of the antenna using a network analyser showed that the antenna was matched to a lower frequency. Thus, it had to be trimmed in order to increase its resonant frequency to 437.5 MHz. The following table shows the variation of the resonant frequency with the length of the monopole and the conditions of testing the impedance.

Length(mm)	Resonant f(MHz)	Return loss at resonance	Return loss at 437.5 MHz	Conditions
170	412	-19 dB	-5 dB	Outside Anechoic chamber
164	421	-20 dB	-7 dB	Outside Anechoic chamber
160	426	-15 dB	-9 dB	Outside Anechoic chamber
155	429	-20 dB	-11 dB	Outside Anechoic chamber
150	433.04	-17 dB	-12 dB	Inside Anechoic chamber

Table 2.5: SWR of monopole for various lengths

2.5 PCB design

The communication PCB's have the following design

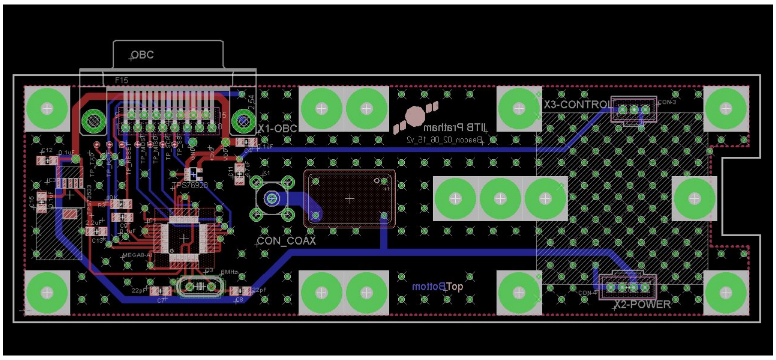

Figure 2.18: Schematic of Beacon Board

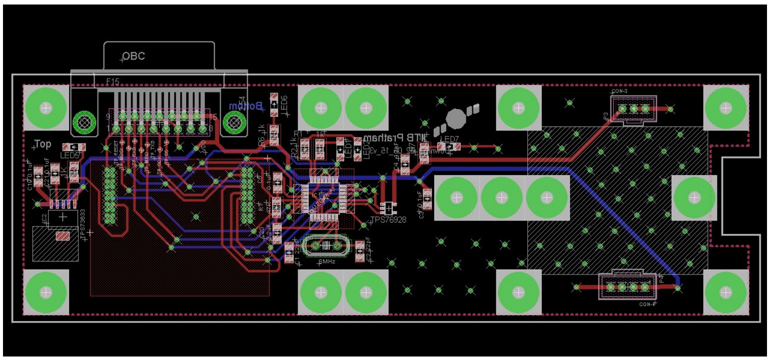

Figure 2.19: Schematic of Downlink Board

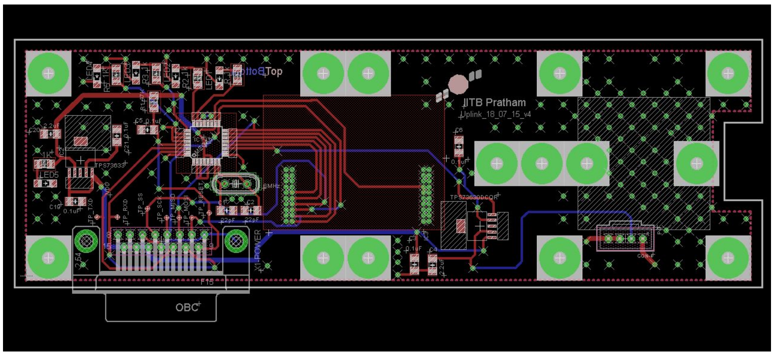

Figure 2.20: Schematic of Uplink Board

All the microcontrollers work at 3.3V. The CC1101 works at 3.3V. The power amplifier works at 2.8V and the LNA works at 3V.

2.6 Amplifier testing

The amplifier was tested at VHF frequency in order to characterise the following properties

- Gain of the amplifier
- VSWR of the amplifier
- Frequency response of the amplifier
- Voltage and current consuming characteristics of the amplifier
- Heat dissipation of the amplifier

The following are the results of testing:

Parameter	Observed value	Datasheet value
Gain	26 dB	30 dB
VSWR	-5.9	-20
Current consumption	0.4 A	0.4 A

Table 2.6: Power Amplifier test results

The following can be the sources of errors:

- The coaxial cables and the connectors can be sources of noise for the amplifier
- On chip connectors may not be matched to 50 ohms
- The chip can operate in ISM bands along with VHF and that maybe a reason for the spurious emissions
- The thickness of the PCB was not according to design thus affecting its RF properties.
- The heat dissipation can be controlled by controlling the Vapc voltage level. The thermal grounding for the PCB might be faulty as only local heating was observed.

2.7 Hot and Cold testing of RF cards at ISAC

Hot and cold testing of RF communication boards of Pratham was conducted at Indian Space Research Center (ISAC), Bangalore on 20^{th} and 21^{st} of May 2015. The following RF components were tested in Hot and Cold temperature cycles:

- Crystal 145.988 MHz
- Power Amplifier
- CC1101 evaluation board
- Low noise amplifier

2.7.1 Components Required

The following components were taken to ISAC:

1. PCBs:-

   a. Beacon board (with crystal of 145 MHz)- Quantity: 2

   b. Downlink board (with CC1101)- Quantity: 2

   c. Uplink board(with one LNA)- Quantity:1

2. Power board V4 : Quantity 1
3. Preflight board
4. Working LNAs- Quantity: 2
5. Working Power amplifiers- Quantity:2
6. Laptop and charger (containing codes for hot and cold, schematics of all the boards, datasheets of LNA, power amplifier, CC1101 and crystal 145 MHz)
7. Co-axial cables- Quantity:4
8. Connecting wires
9. SMA connectors box
10. SMA plug to plug cables
11. USB cable, Quantity:2
12. AVR ISP Programmer
13. Multi-meter

14. Antistatic wrist straps

15. NI-DAQ

16. Wire stripper

17. Solder iron and solder metal

List of components provided by ISAC:

1. Thermistor

2. Spectrum Analyzer

3. RF generator

4. 50 Ω loads

5. Thin co-axial RF cables

2.7.2 Execution Plan

The following temperature profile is set for testing.

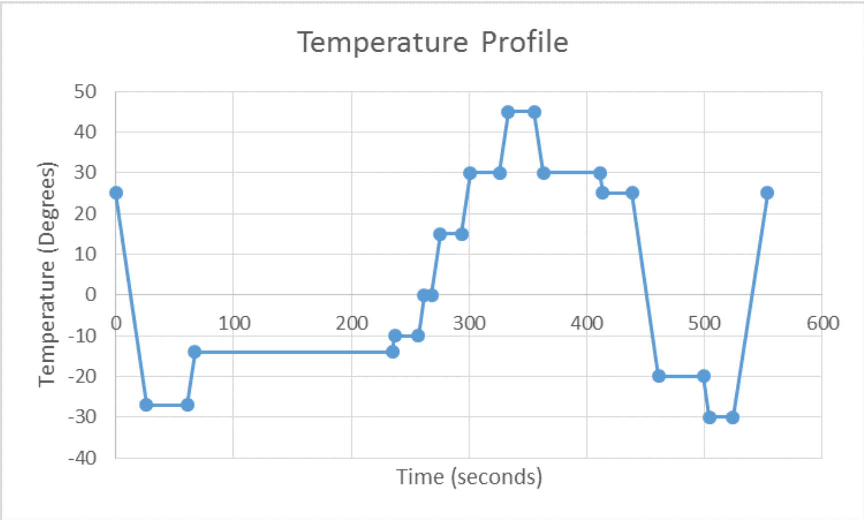

Figure 2.21: Temperature profile for the test

The soak time is kept 20 minutes.

2.7.3 Testing of Crystal

Provide 5 V and Ground externally to the power board. Connect co-axial cable at the output of Crystal and connect the co-axial cable to spectrum analyzer or oscilloscope to monitor frequency and gain variation.

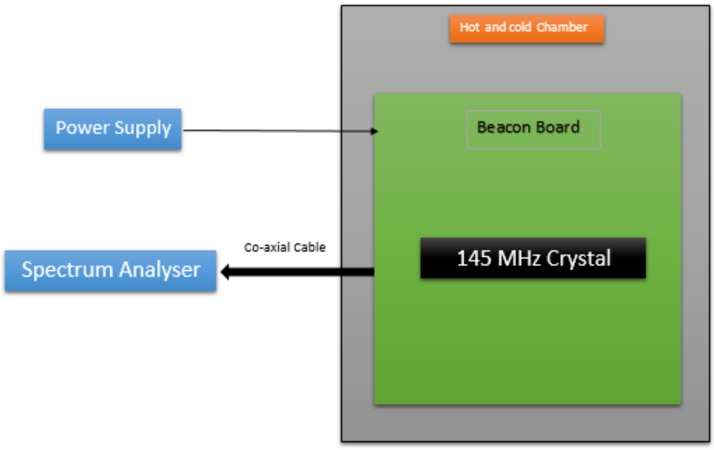

Figure 2.22: Crystal Testing schematic

2.7.4 Testing of Power Amplifier

Provide 5 V and Ground to the power amplifier. Also connect 3.3 V to enable pin of the Power amplifier. Connect input terminal of power amplifier to signal generator and output terminal to spectrum analyzer/ oscilloscope using co-axial cable. Monitor gain variation for the whole duration.

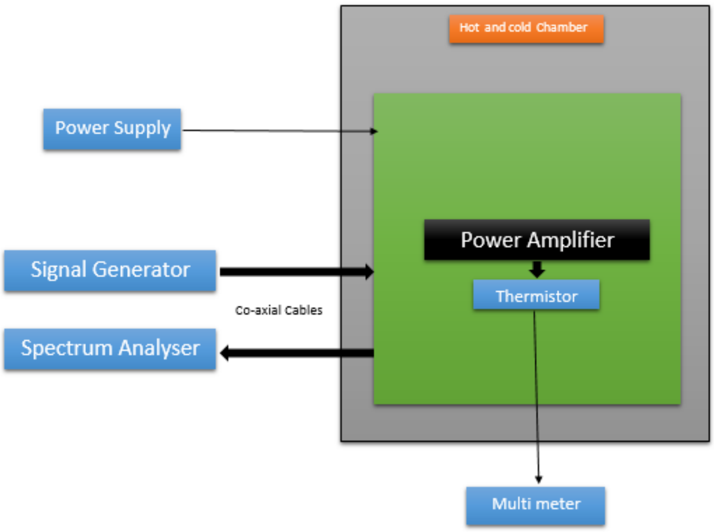

Figure 2.23: Power Amplifier Testing schematic

2.7.5 Testing of CC-1101

Provide 5V and connect ground to downlink board externally. Connect co-axial cable at the end of CC1101 to Spectrum analyzer/ oscilloscope outside the chamber. We will monitor the central frequency and gain.

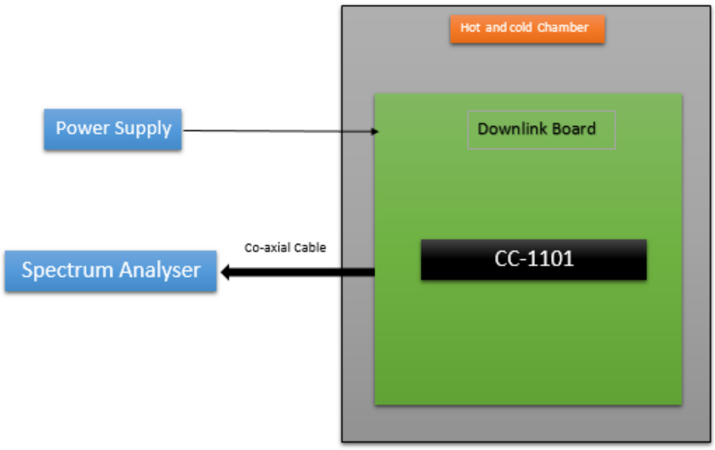

Figure 2.24: Power Amplifier Testing schematic

2.7.6 Testing of LNA

Power up the LNA from external power source. Connect input terminal of LNA to signal generator and output terminal to spectrum analyzer/ oscilloscope via co-axial cable.

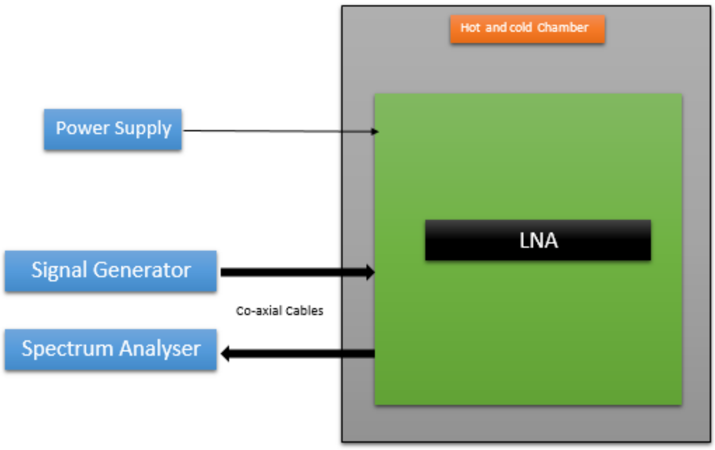

Figure 2.25: Low noise Amplifier Testing schematic

2.7.7 Results for CC1101

1. Power Output Variation
   Power output varied by about 1 dBm with increase in temperature. According the program power output should be 0 dBm. Smaller power output is due to SWR and power loss of cable.

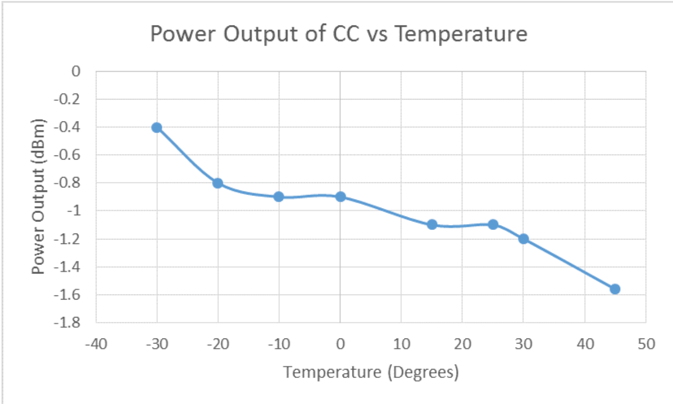

Figure 2.26: Power output variation of CC1101 with temperature

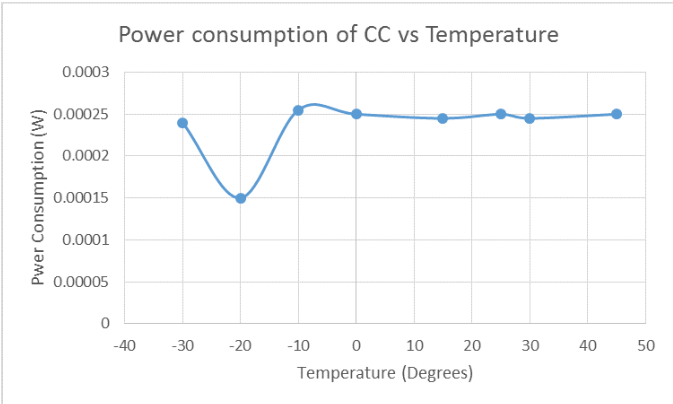

Figure 2.27: Power consumption variation of CC1101 with temperature

2. Power Consumption Variation
   Power comsumption by CC1101 was very less. There was no significant variation in it with temperature. It matched with the specification given in datasheet.

2.7.8 Results for low noise amplifier

1. Power Consumption Variation

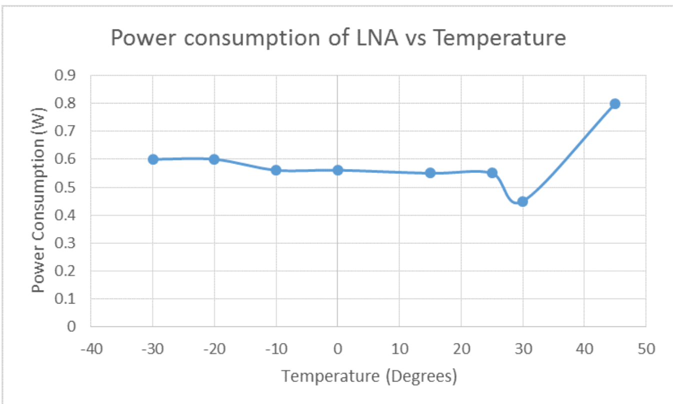

Figure 2.28: Power consumption variation of LNA with temperature

Power consumption is almost constant throught the cycle . There is an abrupt increase in power consumption at the hot peak. We think it is an anomaly in data recording.

2. Gain Variation

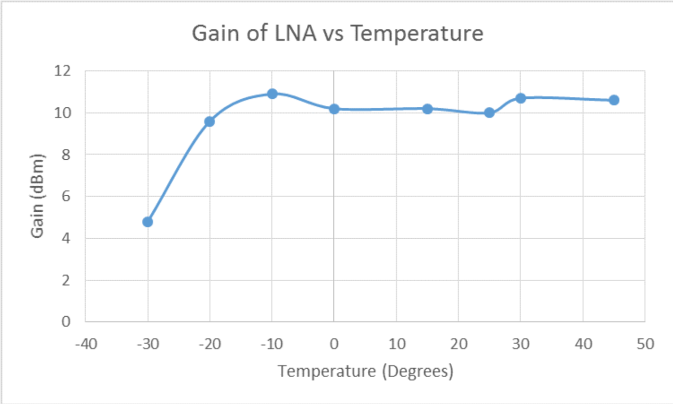

Figure 2.29: Gain variation of LNA with temperature

Gain is less at lower temperature. Above -20$\deg C$ gain is almost constant. It is less than the value specified in datasheet. This may be due to SWR of cable.

2.7.9 Results for power amplifier

1. Power amplifier temperature variation with chamber temperature

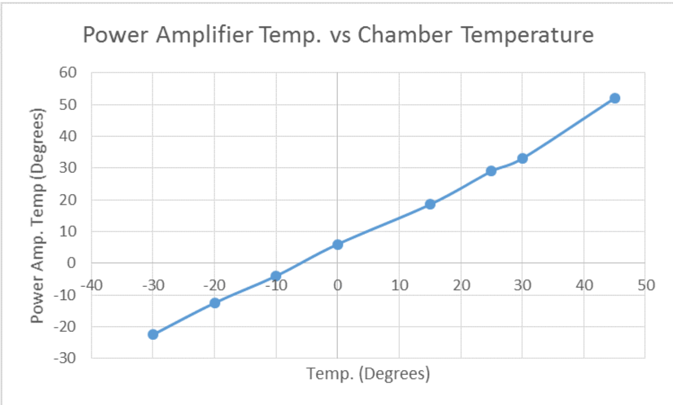

Figure 2.30: Power amplifier temperature variation with chamber temperature

Temperature of PA increases with increasing temperatue as expected. It did not exceed the operational temperature range (+80$\deg$C) at the hot peak.

2. Resistance of power amplifier thermistor variation with temperature
Resistance of thermistor decreases which is because temperature increases.

3. Power output variation with different frequencies
Power output is maximum at 145.98 MHz as expected. Second harmonic is at 5 dBm than the central frequency. All other harmonics are less than 20 dBm from the central frequency.

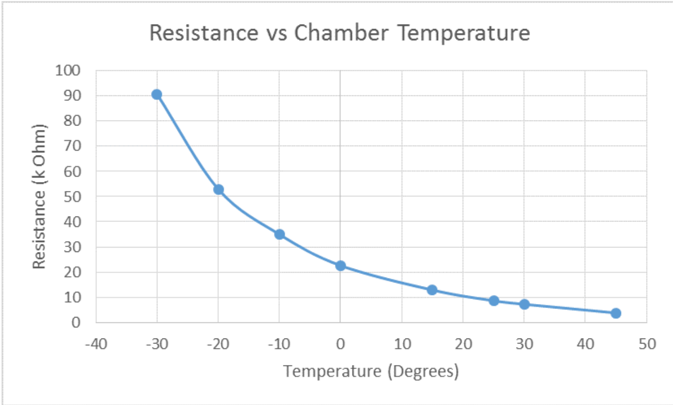

Figure 2.31: Resistance of power amplifier thermistor variation with temperature

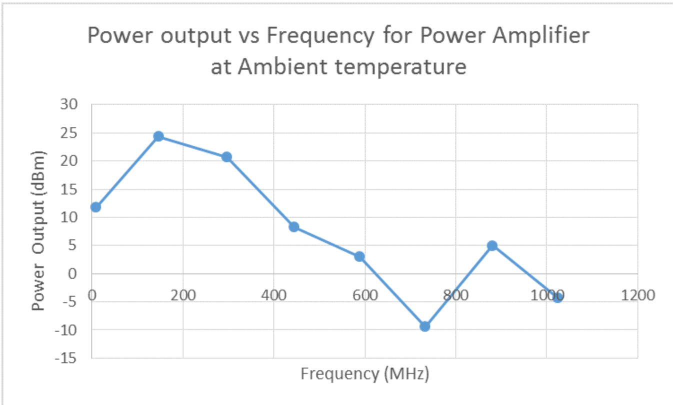

Figure 2.32: Power output variation with different frequencies

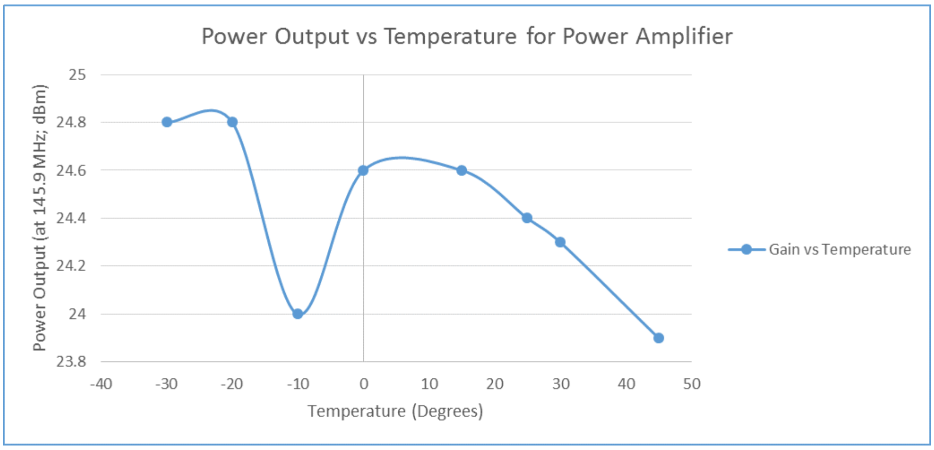

Figure 2.33: Power output variation with temperature

4. Power output variation with temperature
   Power output varies within 1 dBm. Output is less than the value specified in datasheet. This is due to SWR and power loss of cable. Also there will be impedance mismatch between crystal output and PA input. So the input mighth be less than 0 dBm.

2.7.10 Results for Crystal

1. Power Consumption of crystal

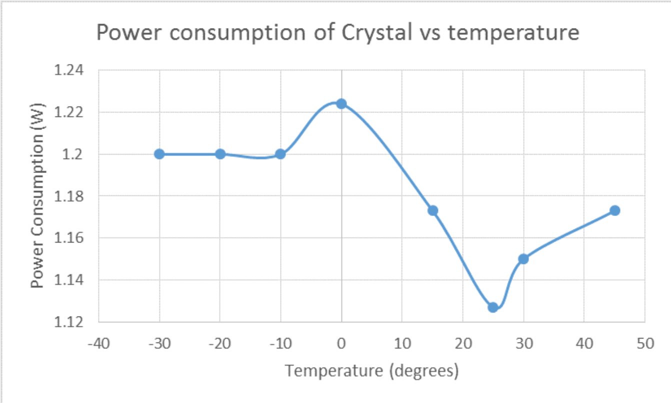

Figure 2.34: Variation of power consumption of crystal with temperature

Power consumption is more than the value specified in the datasheet. This may be because we were measuring the current consumed by the whole beacon board. The extra power might be consumed by other components, importantly Atmega8 and TPS voltage regulator.

2. Power output of crystal

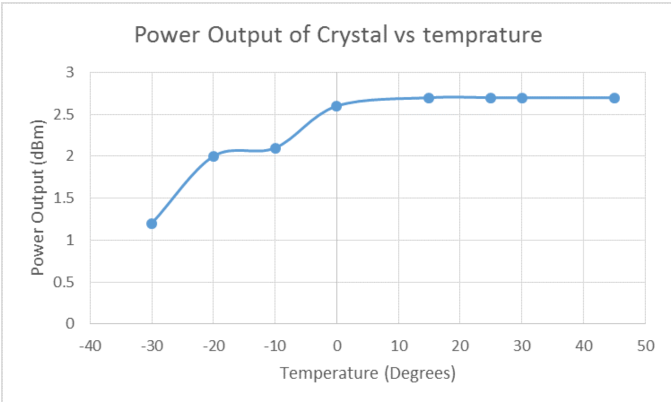

Figure 2.35: Variation of power output of crystal with temperature

Power output does not vary much which is good for estimating link budget.

2.7.11 Actions taken after testing

It was pointed out during testing that the power amplifier was operated at 3V which is the maximum allowed voltage. This can lead to damage to the PA. It was decided that voltage should be 2.8V. A different voltage regulator of the same series (TPS) was chosen - TPS76928. Beacon board and Downlink board was redesigned accordingly and new board was tested.

Chapter 3

Groundstation segment

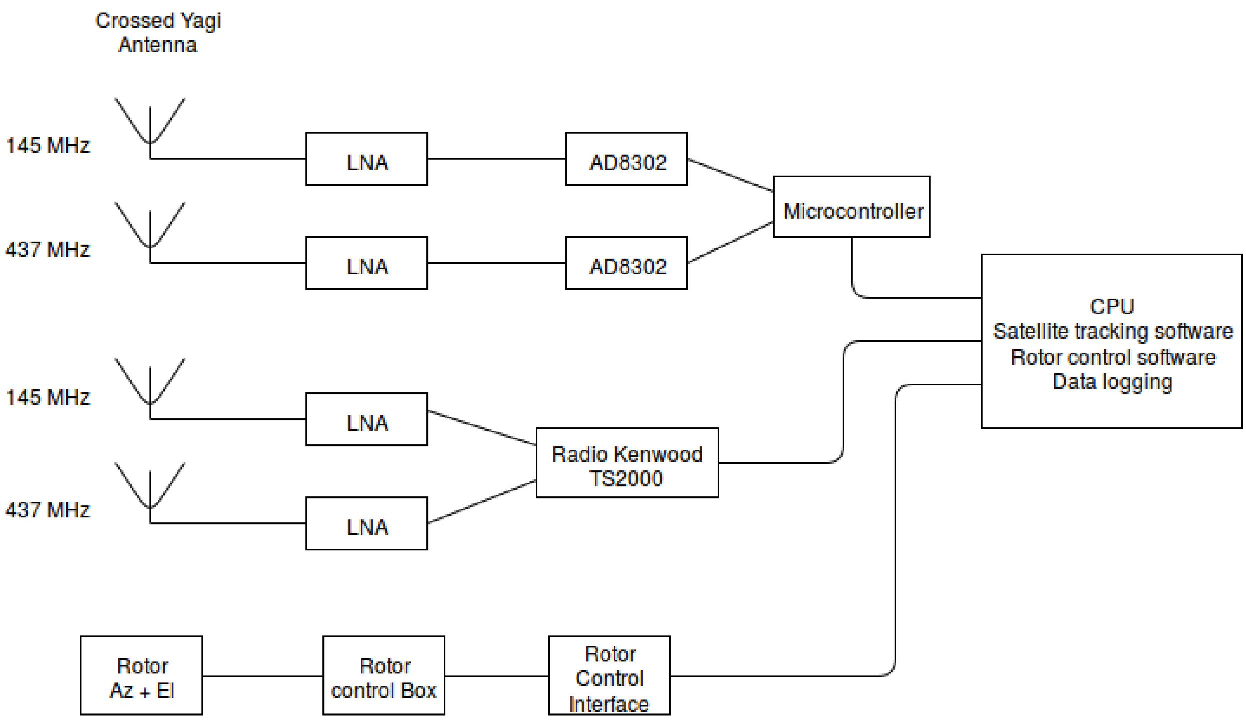

Figure 3.1: Ground station flow diagram

The ground segment for Pratham at IITB has following major functions

- Satellite tracking and receiving segment
- Uplink transmission segment
- Payload data logging

Towards these ends various off the shelf as well as self-fabricated components are used. These are:

- Antennas: Two pairs of crossed yagi antennas, one pair for each frequency band i.e. central frequency 145.8 Mhz, 437.5Mhz)

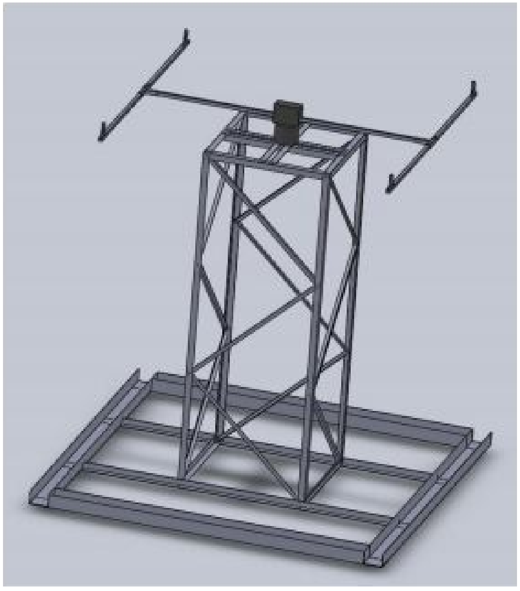

Figure 3.2: Ground station antenna mount

- Transceiver base station: Kenwood TS2000 radio demodulates the FSK signal and stores the data in the mainframe.
- A pair of AD8302 modules measures RF gain and phase value between the two inputs it takes Uses Log amplifiers to calculate the value of log (InpA/ InpB)
- Low Noise Amplifiers: 4 low noise amps are being used on the distinct feeds from antennas
- Rotor arrangement with an Interface circuit to integrate the device with software architecture. Rotor (Yeasu G-5500) is being used to orient the antenna structure to the required inclination with respect to reference level. The rotor interacts with the mainframe via Rotor Controller Interface (RCIUSB by EA4TX)

Figure 3.3: Ground station equipments

3.1 Antennas

As per the requirement set forth by the payload subsystem, the antenna should be able to capture the component of the plane of polarisation along both the X and Y planes. For this purpose crossed-yagi antennae are used at GS. These consist of a couple of dipole antennae perpendicular to each other mounted on a boom along with a few other elements. The elements placed in front of the dipole are termed as directors. These help in increasing the antenna gain in the forward direction thus adding to the directivity of the antenna. Similarly the elements placed behind the dipole adds to the power collected/transmitted by the dipole, affecting the front to back ratio.

Simulations were done in the antenna design software NEC and the results were optimized giving maximum weight age to the Impedance of the antenna being as close to 200 as possible to give perfect matching.

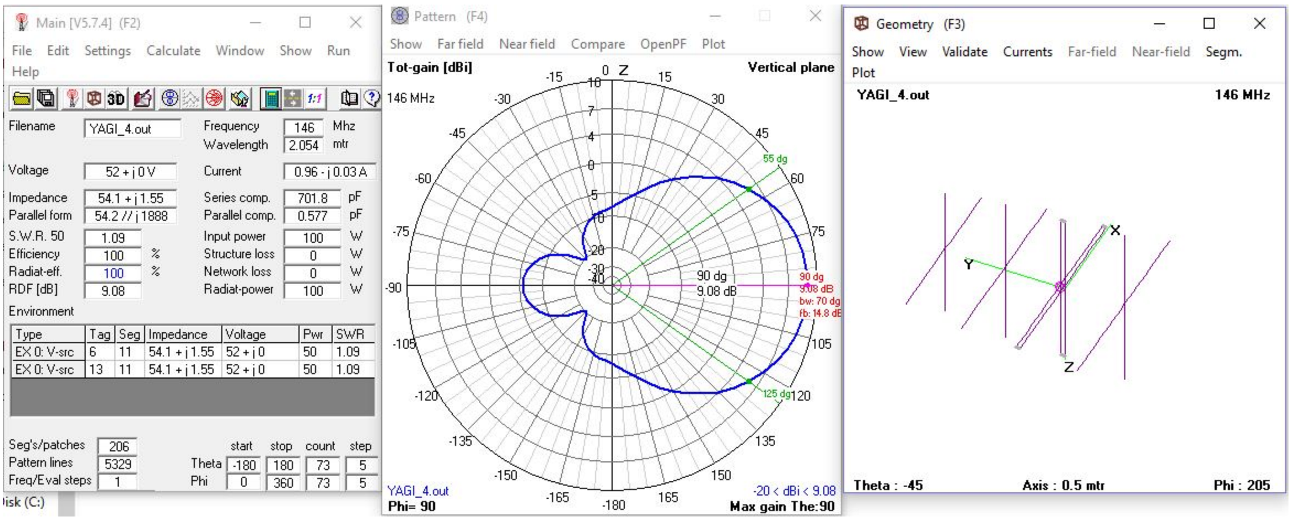

Figure 3.4: NEC2 Antenna simulations results

The simulation results were the following

- Gain : 9.08 dB
- Beam width : 70 degrees
- VSWR : 1.09
- F/B ratio : 14

3.1.1 Experimental characterization

The impedance of the antenna was designed to be 200 ohms +- 10 ohms. Testing of balun was done with the help of Simple resistances and Surface mount resistances. The performance of the yagi was tested with the help of a network analyzer and the following results were obtained.
SWR vs. frequency 437MHz - 1: 1.1667 24
S11 vs. frequency 436.95MHz -1: -25.047 dB
Smith chart 46.9 ohms

For a perfectly working antenna, the S11 value below -10dB represents a 90 percent efficient antenna, so the value of -19dB is a good enough for sound reception.

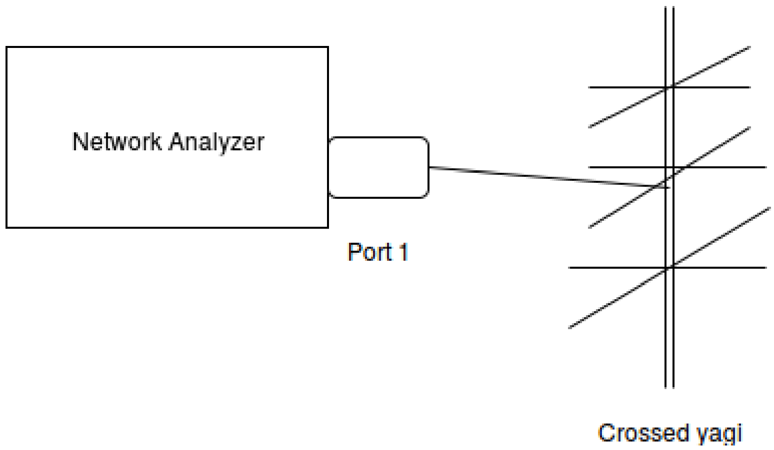

Figure 3.5: Yagi test setup

3.1.2 Design and Production

We decided to design the Crossed yagis to be used at our Ground station ourselves after receiving encouraging results from the Yagi that we had designed earlier. We decided to use an Aluminium boom instead just to make the yagi more rigid and robust. We verified that the electrical characteristics of aluminium would not affect the characteristics of the yagi by a great deal using simulations and by consulting with Professor K.P. Ray of SAMEER. We designed couplers to be used with the help of professionals. The designs for the couplers were made in Solidworks and the same were forwarded to professionals. The Couplers too were of aluminium and their design was approved by Professor K.P. Ray.

3.2 Payload Data

The main agenda of the GS is to measure the TEC in the atmosphere from the signal received from the point where it stands. This is obtained by measuring the change in the plane of the plane polarised waves which are transmitted from the monopoles on the satellite. As we are unaware of the initial angle of the plane, we use two separate waves of considerable different frequencies (145.98 MHz and 437.5 MHz) and then subtracting the angle to get rid of the initial component. This angle is then substituted in the equation given below as $\Delta\phi$

$$\Delta\phi = 4.87x10^{-4}xf^{-2}\int_{h_1}^{h_2} NBcos\theta dl \tag{3.1}$$

N:electron density; B:Magnetic field; θ:angle between magnetic field and direction of propagation

The measurement of the intensities are done by a Polarization measuring unit, namely AD8302 connected at the lines of the feed. The data obtained from the IC is automatically logged into a text file using a microcontroller.

3.3 AD8302 Polarisation Measurement Unit

The AD8302 is a fully integrated system for measuring gain/loss and phase in numerous receive, transmit, and instrumentation applications. The major blocks consist of two demodulating log amps, a phase detector, output amplifiers, a biasing cell, and an output reference voltage buffer. The log amps and phase detector process the high frequency signals and deliver the gain and phase information in current form to the output amplifiers. The output amplifiers determine the final gain and phase scaling. The reference buffer provides a 1.80 V reference voltage that tracks the internal scaling constants.

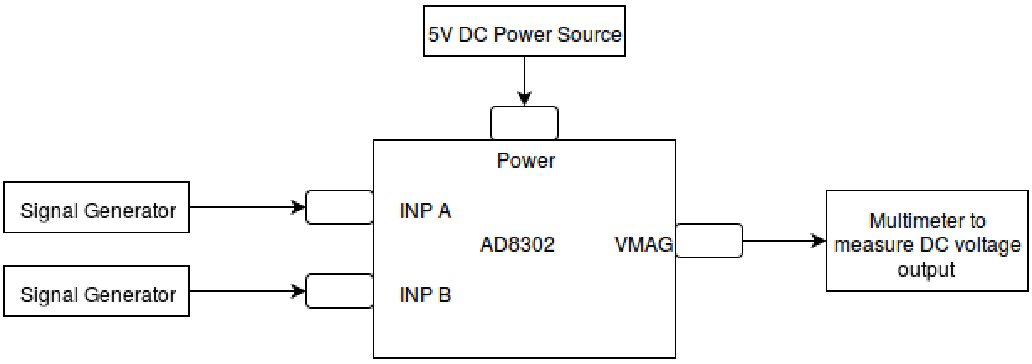

Figure 3.6: A8302 test setup

- We provided same input power to the pins INPA and INPB and obtained the output voltage from the pin VMAG
- Further we provided INPA and INPB with power having difference of -5 and increasing that difference up to -30 with a difference of 5 units and similarly for difference from 5 to 30 dB
- Plotted INPA-INPB vs. VMAG. The average of the VMAG values is taken plotting the graph

The results of the characterization can be seen below:

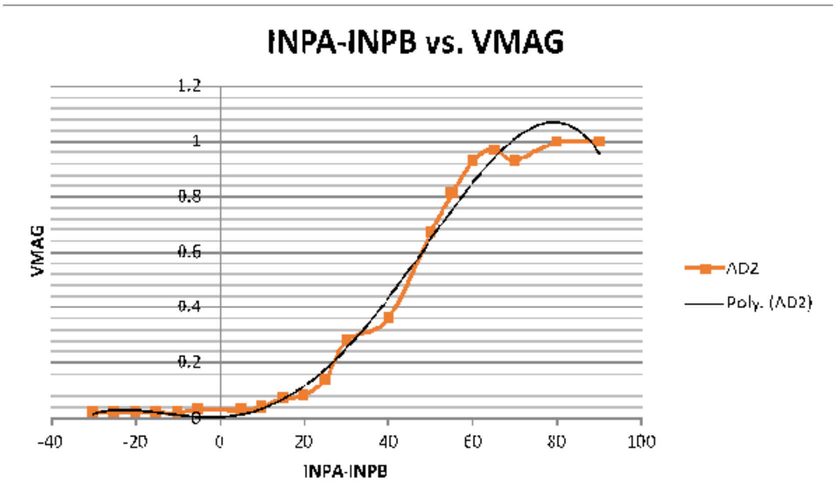

Figure 3.7: A8302 test data

3.4 Kenwood Transceiver

TS 2000 is used for receiving beacon and telemetry signal. The transceiver is being tested for operation in the VHF and UHF bands. The transceiver requires a high power source of 13.8V and 20 A current. The power source currently being used is from Yaesu. We switched on the receiver to the satellite mode and checked the

squelch from the transceiver. We performed the Kenwood transceiver characterisation for Bandwidth, least signal strength detected, Demodulation of signal
The setup was as follows:

- A simple monopole served as a transmitter antenna.
- It was connected to the 145 MHz crystal on the beacon board without the power amplifier. Power output of crystal is 0 dBm. The power output from monopole is -10 dBm.
- The receiving antenna was a crossed yagi connected to the VHF input.

The cable loss for one cable was 2 dB. We used 2 cables and hence cable loss 4 dB. Considering the following parameters:
Cable loss = 2 dB
Transmitting antenna gain 3 dB
Receiving Antenna Gain 9 dB
Transmitted power = -10 dBm
Distance between the transmitting and receiving yagi = 10 cm - 0.5 m
Path loss = 5.25 dB - 19.32 dB
The transceiver S-meter (signal stregth) showed a received power of -105 dBm. The bandpass region is less than 50 KHz which is good enough for our purpose. Infact , the response is so sharp that the signal strength falls to zero from a good enough value by changing the central frequency by 25 kHz on either side. Thus, the floor noise level for the device is absolutely low from kTB formula.

3.5 Rotor and Tracking Software

3.5.1 Rotor and controller

We are using Yaesu G5500 Azimuth Elevation rotor. It comes with a Rotor Control Box which can be used manually as well as through computer.

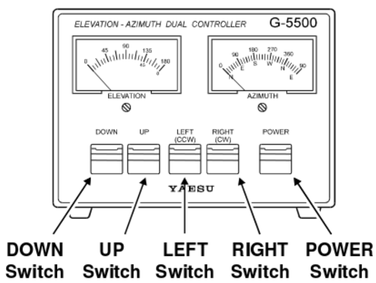

Figure 3.8: Rotor control box front

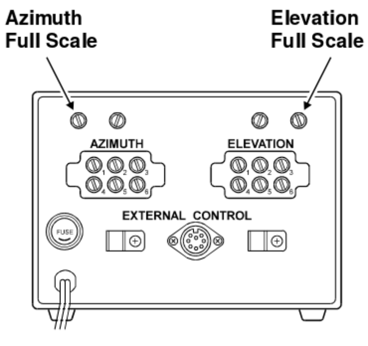

Figure 3.9: Rotor control box back

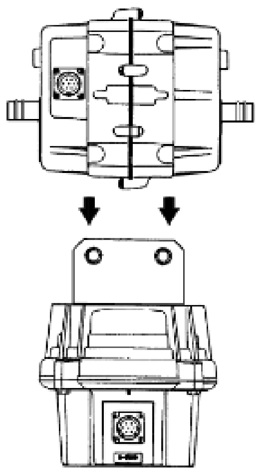

Figure 3.10: Rotor Azimuth(bottom) and Elevation(top)

For controlling by software EA4TX RCI-USB Rotor control Interface is used. This board serves as the interface between the mainframe computer and the rotor controller box, orienting the antenna. The RCI-USB circuit fulfils the two following objectives:

- It reads the current antenna position by means of an incorporated A/D converter.
- It controls the movement of the rotor. For an azimuth rotor, this would be right or CW and left or CCW. This is accomplished through relays using the data obtained from the A/D converter.

The following is the RCI-USB circuit schematic

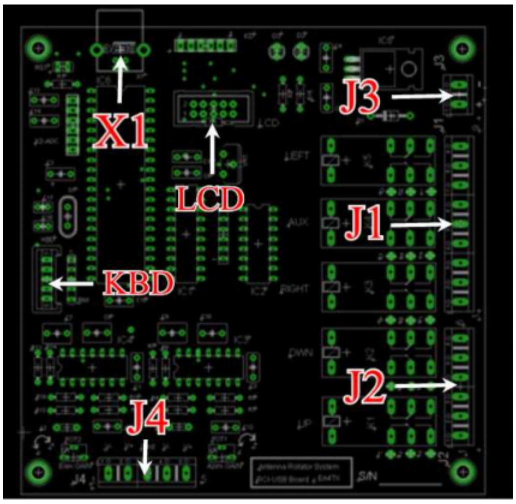

Figure 3.11: RCI-USB schematic

Here J1 is used for control of the azimuth of the rotor, J2 is for the elevation control and J3 is the Power input, J4 is for the ADC operation. Also, the RCI-USB has a potentiometer for each input providing all of these adjustments:

- Azimuth input: Pot1 adjusts the Gain/Attenuation between 3-24V.
- Elevation input: Pot2 adjusts the Gain/Attenuation between 3-24V.

3.5.2 Software

- Satellite Tracking Software
  The satellite orbital elements are available on the internet and keep updating. There are softwares available that take these two line elements and predict the satellite path. The G-predict software on Ubuntu systems has a library package named "Predict" for the same environment to calculate and predict the positions for the satellite. These satellite positions are then written into a file.
- Rotor controlling software
  The file written above is checked regularly by another program. Once it finds a visible pass for the marked satellite, it activates the rotor and passes on the respective azimuth and elevation angles to the RCI interface. This is been done with the help of the rotctl package in the hamlib library for Ubuntu.
- Rig Control The TS2000 rig is being controlled to sync its functionalities with the passes of satellite. This can be done using the rigctl package of hamlib library for Ubuntu.

3.6 Anechoic chamber testing

- An **anechoic chamber** is a shielded room designed to attenuate sound or electromagnetic energy.
- The free surface was covered with square pyramid shaped foams made of a special material composed of Carbon.
- The pyramids were placed with their tips pointing towards the chamber.
- There was an arrangement for placing the receiver on a mast inside the chamber.
- The satellite body was stuck to the mast using DST.
- The transmitting antenna was a yagi placed at one end of the chamber.
- The yagi was fed from one port of a network analyser and the receiving monopole was connected to another port of the same analyser.

Figure 3.12: Anechoic Chamber

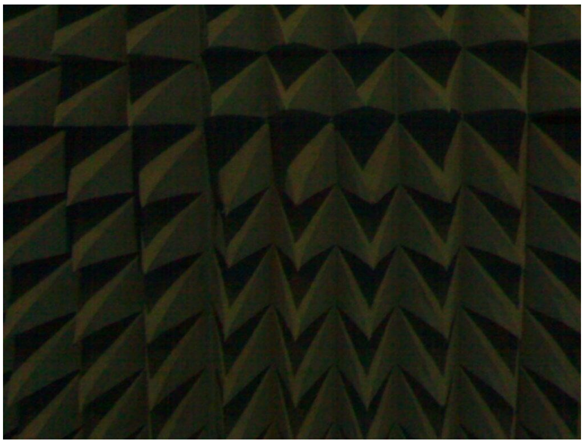

Figure 3.13: Foam design in anechoic Chamber

Thus, we can conclude from the anechoic chamber test that the maximum directivity of the monopoles is in the direction of the groundstation.

Figure 3.14: Mast in anechoic Chamber

Figure 3.15: Antenna rotator in anechoic chamber

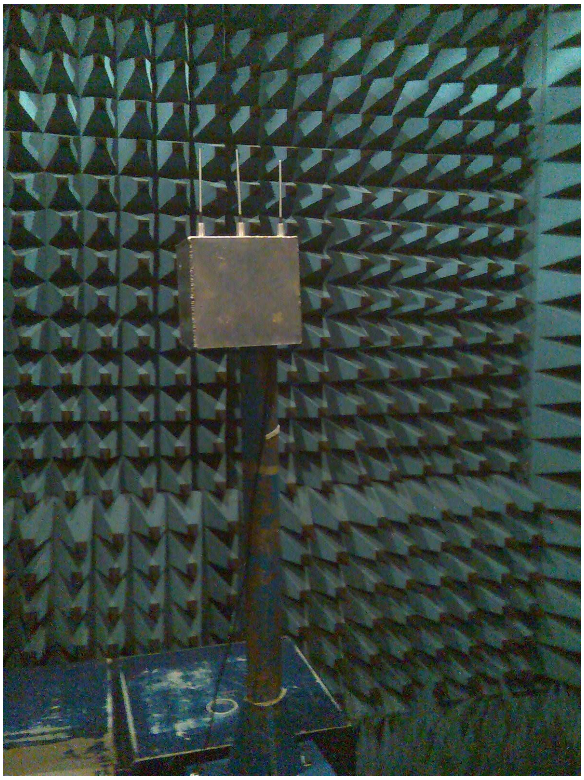

Figure 3.16: Antenna mounted in chamber

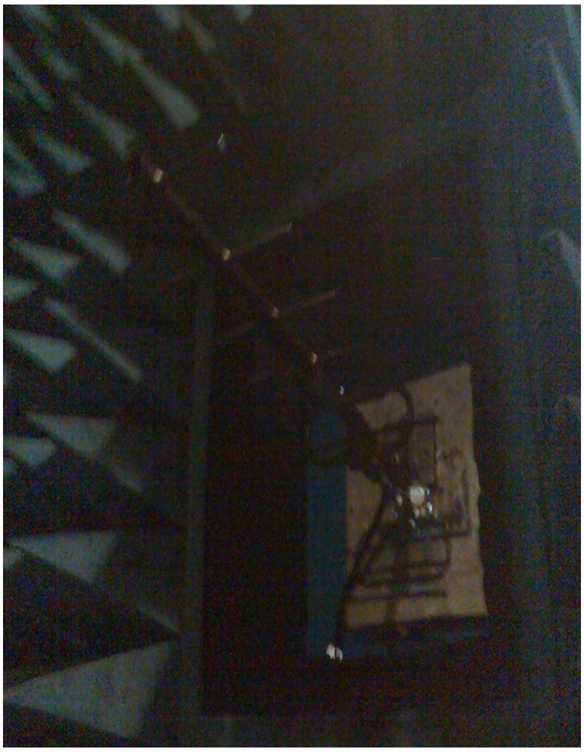

Figure 3.17: Yagi mounted in chamber for transmission

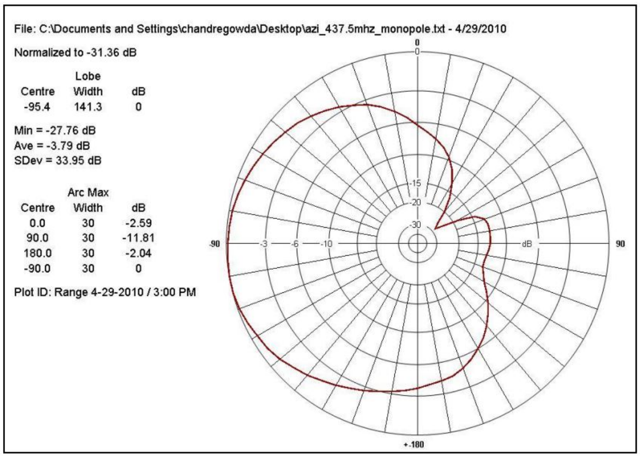

Figure 3.18: Azimuthal pattern with 3 antennae in line

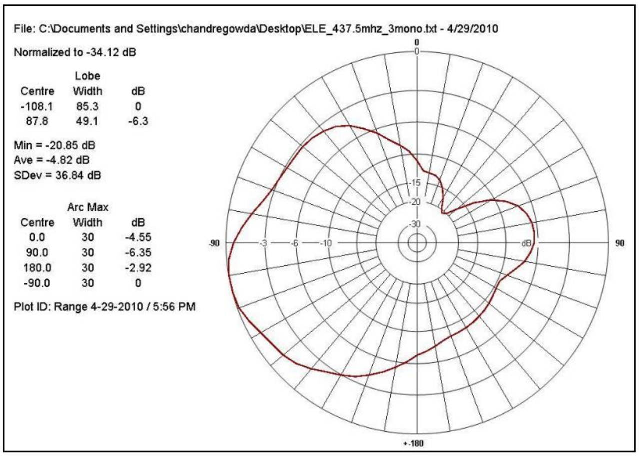

Figure 3.19: Elevation pattern with 3 monopoles

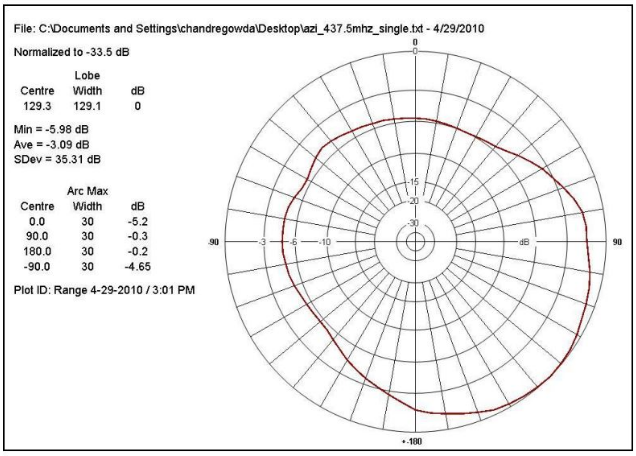

Figure 3.20: Elevation pattern with 1 monopole at corner

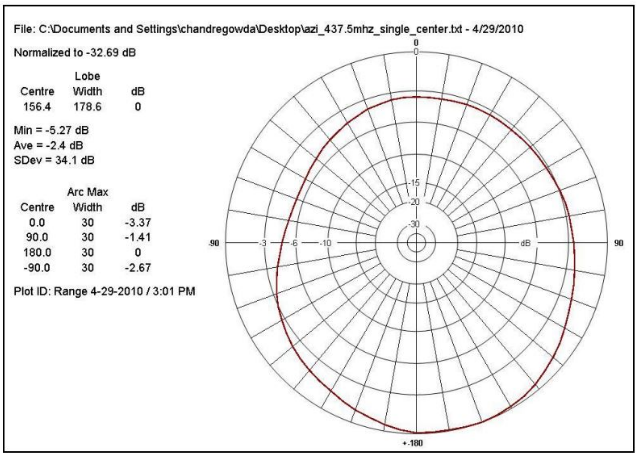

Figure 3.21: Azimuthal pattern with 1 monopole at center

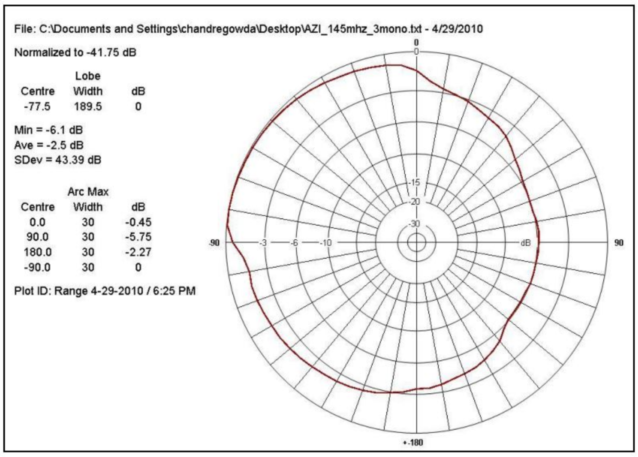

Figure 3.22: Azimuthal pattern at 145 MHz with 3 monopoles

Chapter 4

Thermo-Vaccuum Test

4.1 Beacon Test

Following parameters were monitored on Beacon board:

- Temperature of Power Amplifier RF5110
  Two thermistors were placed on the PA board to monitor temperature. One reading was obtained in HM data by Master via Slave microcontroller on the OBC board and other was through NI-DAQ.
- Output of the Power Amplifier on a Multi Domain Oscilloscope
  The gain at desired output frequency, the corresponding harmonics and bandwidth was observed whenever the satellite was active.

4.1.1 Observations and inferences

- The beacon board was not working properly for a certain range of temperature. This problem was later solved after extensive tests. The details can be found in the “Beacon Debugging" report

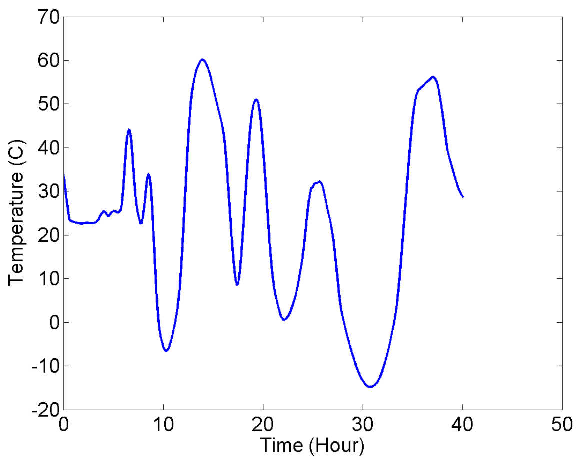

Figure 4.1: Beacon Power Amplifier temperature as observed on NI-DAQ

- Whenever the beacon was working, the output of the Power Amplifier on the beacon board was, as expected, consistently between +21 to +23 dBm at the central frequency (145.98 MHz)

- The output of the first harmonic (292 MHz) was 12 dBm, which is 10 dBm less than the central frequency. Subsequent harmonics have output less than 30 dBm from the central frequency.

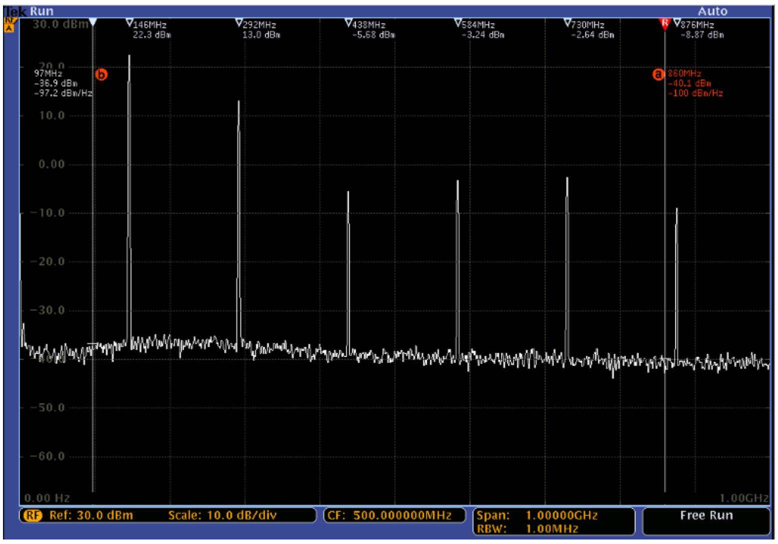

Figure 4.2: Beacon PA output during the HOT peak of first stress cycle

4.2 Downlink test

- The data stored in the EEPROM was transmitted via the downlink to the uplink on the receiving side. The accuracy of the data was determined by comparing it with the corresponding house-keeping telemetry.
- The temperature of the downlink Power Amplifier (PA) was observed using two thermistors. The output of one thermistor was a part of the house-keeping telemetry. The output of the other thermistor was measured separately and continuously using NI-DAQ.

4.2.1 Observations and inferences

- Downlink board was switched on whenever commanded to do so from the GUI. Telemetry data was successfully received at the GUI end. It matched well with the housekeping data from OBC.

  Cold Soak

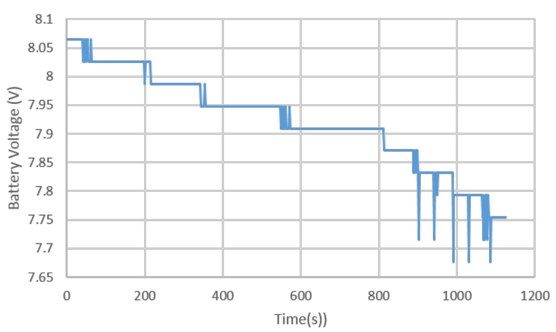

Figure 4.3: Battery Voltage - Payload Telemetry

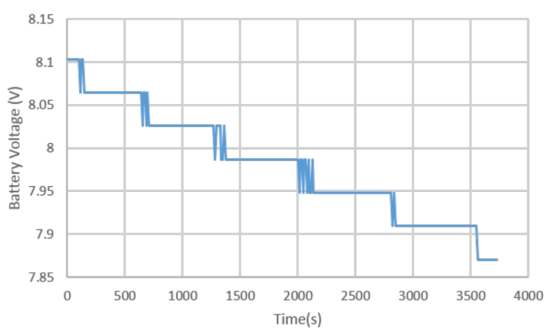

Figure 4.4: Battery Voltage - House-keeping telemetry

  Hot Soak

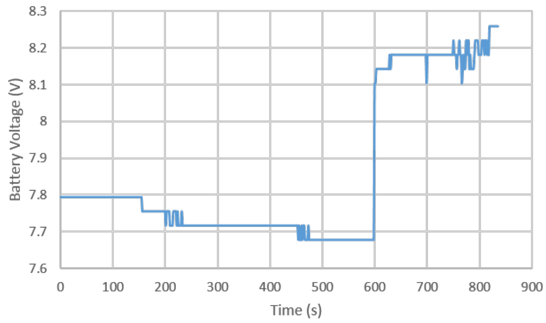

Figure 4.5: Battery Voltage - Payload Telemetry

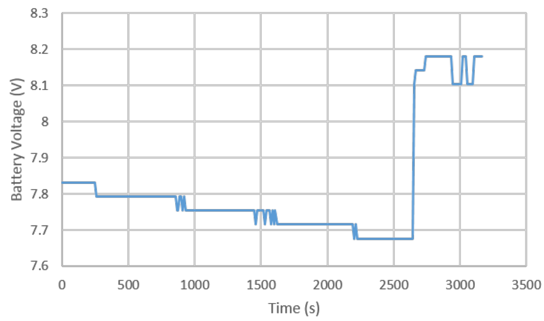

Figure 4.6: Battery Voltage - House-keeping telemetry

- Temperature was within the operational limits as expected. It worked in both Hot and Cold soak. Board is tested successfully for qualification level temperatures.

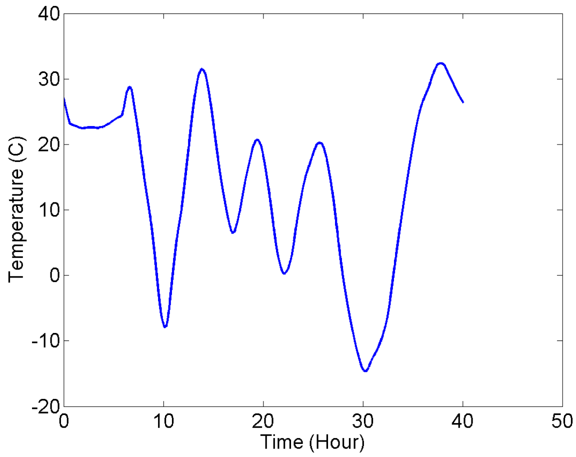

Figure 4.7: Downlink Power Amplifier temperature as observed on NI-DAQ

4.3 Uplink test

- Reset Command was sent to the satellite when the Uplink was ON and the subsequent reset of the satellite was verified using house-keeping telemetry.
- The temperature of the uplink Low Noise Amplifier (LNA) was observed using two thermistors. The output of one thermistor was a part of the house-keeping telemetry. The output of the other thermistor was measured separately and continuously using NI-DAQ.

4.3.1 Observations and inferences

- Temperature was within the operational limits.

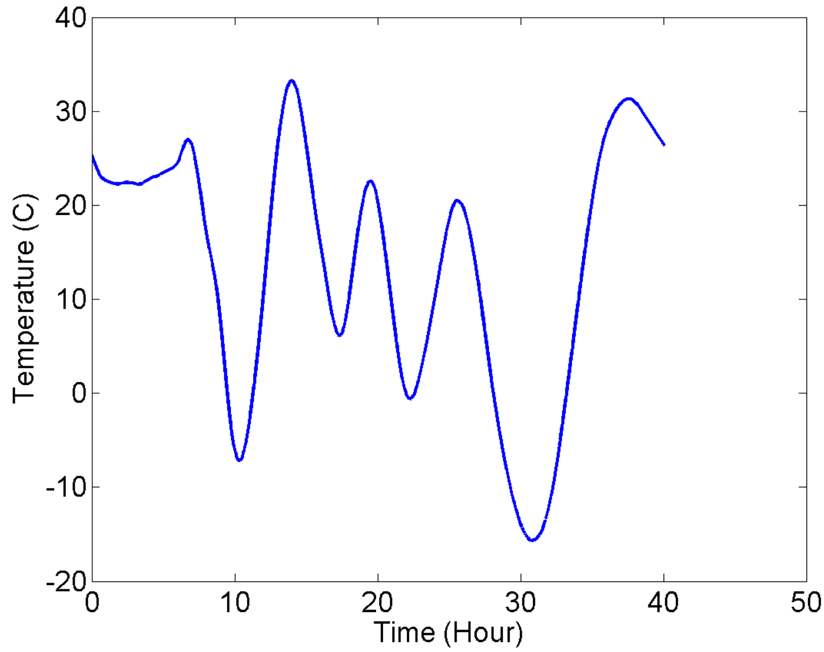

Figure 4.8: Temperature Variation: LNA on Uplink Board

- Uplink was turned on by sending a wireless signal from the GUI. As expected it reset the whole satellite by turning off all the loads on the Power board and then turning them back on. It worked in both hot and cold soaks.

4.4 Component specifications

Component	S11	S21	S12	S22
Power Amplifier	-10.4 dBm	21.9 dBm	-70 dBm	-2.4 dBm
Co axial cable betwwen PA output and monopole input	-72 dBm	-0.32 dBm	-0.77 dBm	-75 dBm
Co axial cable from chamber to CC1101 at GUI	-70.7 dBm	-1.2 dBm	-2.15 dBm	-68.3 dBm
Monopole 145.98	-0.3 dBm	-	-	-
Monopole 437.45	-3 dBm	-	-	-
Coaxial cables at GS	-29 dBm	-1.6 dBm	-1.6 dBm	-29

NOTE: There was no difference in the co-cxial cable parameters in the bent mode. This might be due to our frequency been in the VHF range. The cable length is 3 inch which is not comparable to the wavelength which is 2m.

The SWR of monopole at both the frequencies is not in the desirable range. This is because the monopole lengths are less than the recommended quarter-wavelength. Longer monopoles were not possible due to constraints of satellite envelope and structural strength. To ensure that the signal strength is enough we have tested the output power of the antenna. From the link budget calculations (in the "On-Board Communication" chapter) we are able to receive a positive system link margin. Moreover to validate this we are trying to receive signal from satellites whose EIRP is 40 - 100 mW which is close to our satellite's EIRP.