NORGES TEKNISK-NATURVITENSKAPELIGE UNIVERSITET

FAKULTET FOR INFORMASJONSTEKNOLOGI, MATEMATIKK OG ELEKTROTEKNIKK

**HOVEDOPPGAVE**

| | |
|---|---|
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| Oppgavens tittel (norsk): | Antennesystem for NCUBE |
| Oppgavens tittel (engelsk): | Antenna system for NCUBE |

Oppgavens tekst:

Oppgaven vil bli en fortsettelse av et prosjekt utført høsten 2002. Der ble det utviklet og målt på enkle antennetyper for opplink, nedlink (unntatt S-bånd-antennen) og nyttelast. Oppgaven består i å videreutvikle antennesystemet både elektrisk og mekanisk. Hovedmålet med oppgaven blir å konstruere antenner som vil fungere tilfredsstillende (elektrisk og mekanisk) på en NCUBE prototyp som skal testes under et ballong-slipp fra Andøya våren 2003.

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Jon Anders Aas
Faglærer

# Antenna system for NCUBE

**Abstract:**

*This Diploma Thesis describes a solution for antenna design onboard the Norwegian Student Satellite, NCUBE. The antenna system has been a part of a bigger project where the participants have worked on different subsystems onboard the NCUBE. The aim of the NCUBE- project has been to build a satellite which is ready for a balloon test in June 2003. Eventually the main goal is to launch the NCUBE into space. The launch will take place from Dnepr in Ukraine in Mars/April 2004.*

*The use of omnidirectional monopole antennas made of carpenter measuring tape for the VHF- and UHF-frequencies, and one directional patch antenna for the S-band frequency are recommended in this Diploma Thesis. The antennas and all mechanical components will be placed on the nadir side, the side which faces earth after gravity boom deployment, so all other sides on the CubeSat can be used for solar panels.*

**Diploma Thesis**
**June 16, 2003**
**Jan Otterstad**

# Preface

This Diploma Thesis was written to conclude the five-year Master of Science study of Electronics and Telecommunication at the Norwegian University of Science and Technology (NTNU).

It was an easy choice to continue working on the NCUBE-projected based on the experience I got during my work on this project the autumn of 2002.

Though the antennas that are discussed are rather simple it was a challenge mounting them on to a small cube of 1000 $cm^3$.

**Acknowledgements**

I would like to thank everyone involved for valuable input and guidance during the work with the diploma thesis.

Associate Professor Jon Anders Aas has been my guidance teacher and provided insightful input and valuable feedback throughout the project.

Post.Doc. Egil Eide, the technical coordinator of NCUBE, has also been most helpful, especially with the mechanical considerations. He has also been a good motivator for the NCUBE-participants.

I have also work closely together with Fredrik Indergaard Mietle which has developed the gravitation boom which also will be used as an AIS-antenna.

Chief Mechanical Engineer Leif O. Malvik at the department of Telecommunications engineering workshop has made a model of the NCUBE for us. Malvik came up with many mechanical solutions that were very helpful.

Kjell Dahl at SINTEF Telecom and Informatics printed several patch-antennas for me.

Bjørn Bergheim, a student at the Faculty of Engineering Science and Technology, has assisted me with the CAD-drawings since I had no experience using CAD-tools.

I would also like to take the opportunity to say that the social environment in our shared antenna lab at NTNU was excellent. Thanks to all the students for making it prosperous to work with the diploma.

Jan Otterstad
Trondheim, June 16, 2003

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# 1 Introduction

This diploma thesis describes the antenna system onboard NCUBE, the Norwegian Student Satellite. The NCUBE-project's aim is to build a Cube satellite, CubeSat. The CubSat program has been founded by Stanford University.

In the introduction it will be given a description of the CubSat concept, the mission of the NCUBE and an overview of the antenna system on board the NCUBE. In chapter 2 the layout of the mechanical side where the antennas are going to be mounted are described. Chapter 3 will list some basic antenna theory which has been taken into consideration when designing the antennas. Chapter 4 and 5 will be about the antenna design, where chapter 4 are computer simulated models of the antennas and chapter 5 are measurements done on the actual antennas. In chapter 6 the construction of the deployment mechanism for the monopole antennas will be described. Finally the diploma thesis are summarised in chapter 7

## 1.1 The CubeSat concept

The CubeSat (Cube Satellite) program started in 1999. It was developed by Professor Robert Twiggs at Stanford University's Space System Development Laboratory in collaboration with California Polytechnic State University, [1].

The goal was to give students hands on experience in satellite designing. One of the advantages with this project is that it is low-cost and quick to launch. The CubeSat is a picosatellite, meaning it has to weigh a 1000 grams or less. It is also limited to a cube, which the name implies, and has to have the dimensions of 10 cm x 10 cm x10 cm to fit into the P-POD, Poly-Picosat Orbital Deployer. Such a standardized launce vehicle increases the launce opportunities for student satellites.

The CubeSats are loaded into this special launcher and then launched on rockets into low earth orbits. When the rocket reaches the specified orbit, it will eject the P-POD. After a specified time, the P-POD will eject the CubeSat. There can be up to 3 cubes per P-POD. The individual CubeSats will then begin their own missions. Figure 1-1 shows a P-POD and 3 CubeSats.

Currently more than 30 high schools, colleges, and universities from around the world are developing CubeSats.

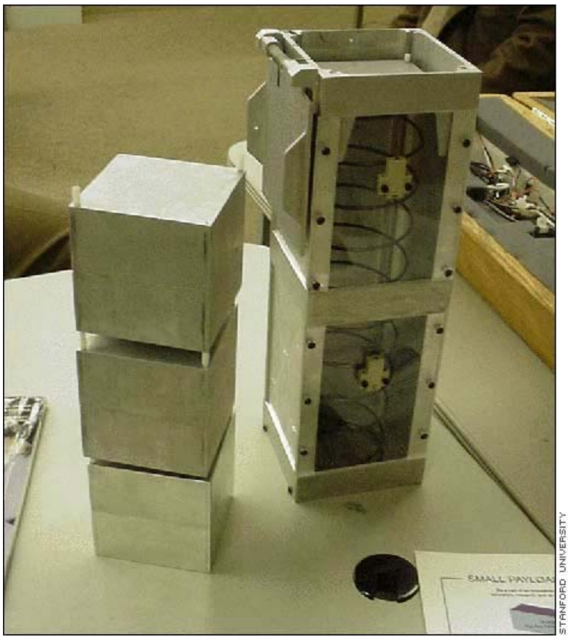



Figure 1-1: A P-POD and three CubeSats

## 1.2 NCUBE

The Norwegian Cubesat project, NCUBE, is collaboration between students at the University College of Narvik (HiN), the Agricultural University of Norway (NLH) and at the Norwegian Technical University (NTNU). The project is divided into several parts which different students are working on: The parts are:

- The Power system (HiN)
- The Ground station (HiN)
- ADCS- Attitude and Determination Control system (NTNU)
- OBDH- On Board data handling (NTNU)
- COM/AIS (NTNU)
- COM/Antenna system (NTNU)
- Radio collar for Reindeers (NLH)

The project goal is to launch the NCUBE from Dnepr, Ukraine March/April 2004. The satellite will have an orbit of 700-740 km with the inclination of 98 degrees. The system architecture of the NCUBE satellite can be viewed in figure 1-2.

Prior to this there will be a balloon test from Andøya rocketrange in June 2003, Appendix E. During this test a simplified model of the cube will be used. There will be no antenna deployment but the same deployment mechanism will be used to cut the balloon wire to retrieve the cube-model.

The satellite will be used in surveillance of ships and reindeers using AIS, Automatic Identification System. AIS was introduced in the shipping industry from July the 1sth 2002 to increase safety at sea.

The vessels that use AIS transmit information such as position, speed, course and they receives information from every ship within radio range. The main goal of the AIS system is to establish communication between ships so that collisions and dangerous situations can be avoided, as well as to establish communication with costal surveillance so the traffic can be coordinated.

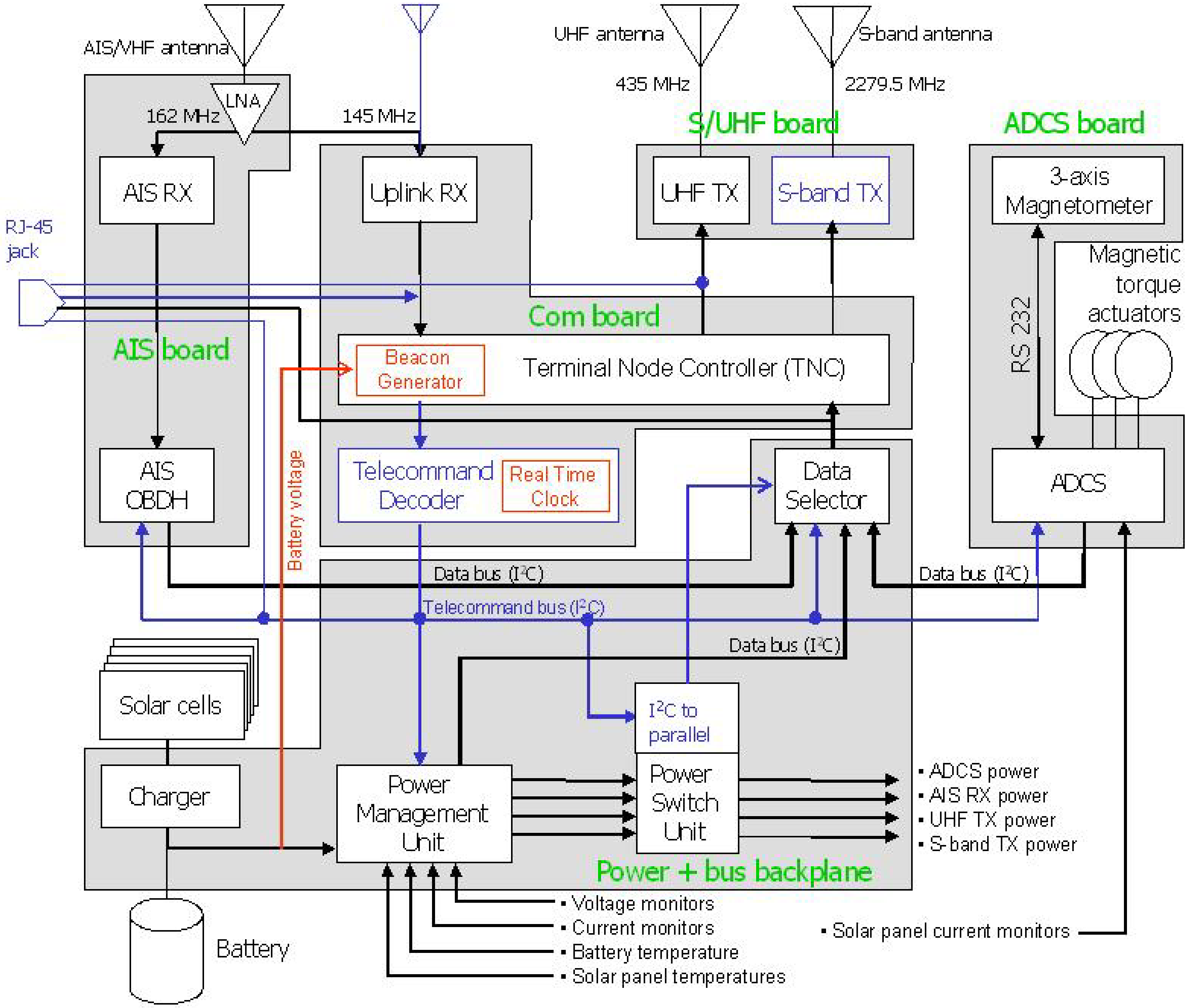



Figure 1-2: NCUBE system architecture

## 1.3 Antenna system

The antennas are essential components in a communication satellite. They are the interface between free-space and electronic devices. Their purpose is to provide a transition from a guided wave on a transmission line to a free-space wave and vice versa in the receiving case. If the antennas fail to work the satellite can be considered dead.

Among other CubSat projects antennas implemented using piano wire or carpenter measuring tape are commonly used to establish the communication links for VHF- and UHF-frequencies. Similar antennas have been tested in NCUBE's previous antenna project [2].

NCUBE, the Norwegian Student Satellite, is going to receive at 145 and 162 MHz and going to transmit at 435 MHz and 2279.5 MHz. The VHF- and UHF-frequencies will be received by monopole antennas and the S-band frequency by a patch antenna.

The Uplink RX, 145 MHz, is the frequency where the satellite receives commands from the ground segment and the UHF TX, 435 MHz, is the frequency with which the satellite transmits down to the ground segment. These two antennas have to be operational as soon as the satellite is in orbit so communication can start.

The 162 MHz, AIS (Automatic Identification System) frequency, is the frequency where the satellite is going to receive data from ships and reindeers. This antenna does not have to be operational before proper communication with the ground segment is established.

The VHF- and UHF-antennas will be made of carpenter measuring tape and stored inside antenna housing cups. These antennas have to be deployed when the satellite is in orbit. This can be done with a fishing line and an AWG 38 Nichrome wire, similar methods have been used by other cubesat projects [3] and [4].

The S-band, 2279.5 MHz, patch antenna, which is going to be used for downlink communication, demands that the antenna faces earth at all times. A stabile satellite will be provided by the satellites ADCS-system.

The ADCS-system is going to have a Gravitation boom mounted to the satellite to stabilize it. This boom is also going to be used as an antenna for the AIS frequency since it does not have to be operational before communication with the ground station is established.

In the rest of this diploma thesis the antenna that receives at 145 MHz will be called the VHF-antenna. The UHF-antenna is the antenna that transmits at 435MHz and the AIS-antenna is the antenna that receives the AIS-messages at 162MHZ.

# 2 Mechanical structure

In the previous antenna project for NCUBE, [2], two solutions for the antenna system were discussed. One was to have the VHF- and the UHF-antenna in a groove around the satellite with the Gravitation boom/AIS-antenna and the S-band patch antenna on one side. The other was to mount all antennas to one mechanical side. The latter solution was chosen because this would provide more space for the solar panels. This solution demanded more advance antenna mounting then having the antennas in a groove around the satellite. It was decided that the best solution would be to construct antenna housing boxes which were deployable.

The framework of the satellite was made at the University of Oslo (UiO), since much experience is gathered there from previous space environmental projects, where associate professor Torfinn Lindem was in charge of the development. It was however NTNU's responsibility to make the mechanical side and to mount it to the framework made at UiO.

## 2.1 Layout

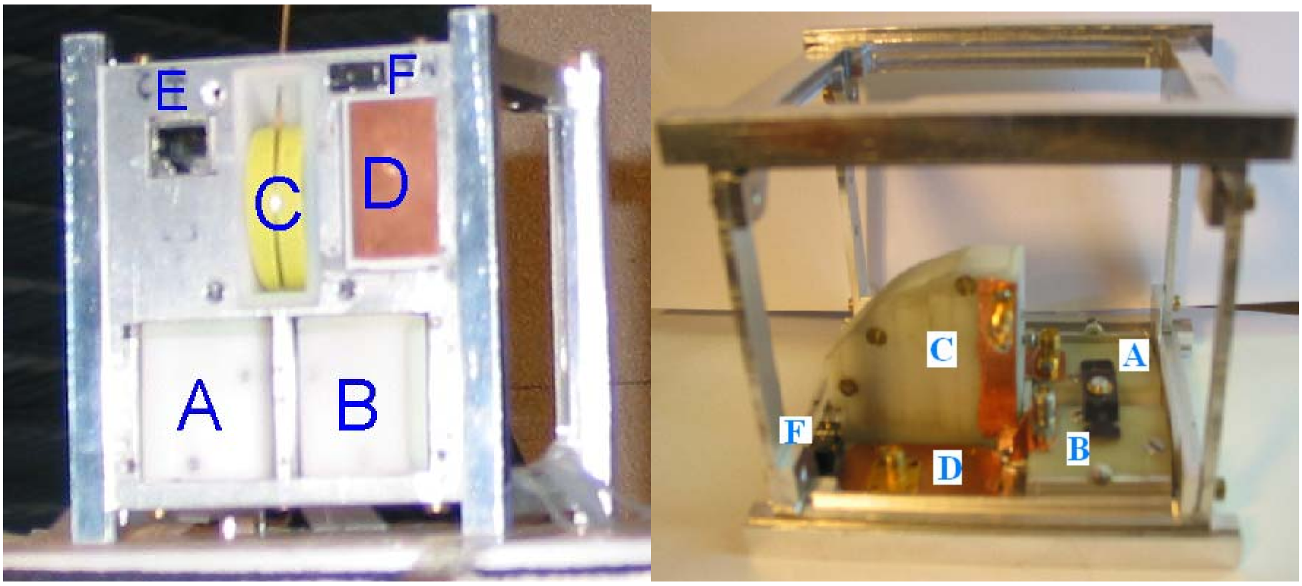
During transportation and launch all the deployable equipment will be hidden inside the cube. Deployment of the antennas can not be done until several minutes after the NCUBE has left the P-POD.

As seen in figure 2-1 the antennas and the gravitation boom are stored inside small boxes, antenna housing boxes, made of plastic. Similar solution for antenna storage is also used by the MEROPE-satellite made at Montana State University, [5]. CAD-drawing of MEROPE 's antenna housing box can be found in appendix B. A CAD-drawing of the Nadir side can also be found in the same appendix. Here the exact measures of the placing of the different components can be found.

The MEROPE-project had however mounted antennas onto more than one side, and the boxes themselves were not deployable as they are in the case of the NCUBE UHF- and VHF-antenna housing boxes. How the boxes are deployed is described in Chapter 6.

In figure 2-1 the different antennas are marked with letters from "A" to "D". The deployable antennas, all made of steal measuring tape, are rolled up inside their different antenna boxes. "Box A" is the box of the VHF-antenna. This antenna will be 52 cm long and 5.8 mm wide, all the antenna properties will be described in the latter chapters. "Box B" is the box of the 17 cm long and 5.8 mm wide UHF-antenna.

Antenna housing box "A" and "B" are of the same dimensions. The length is 36mm, the width 36mm and the height is 11mm.




(a) (b)

Figure 2-1: The mechanical side (Nadir)

The combined AIS-antenna/ Gravitation boom box is “Box C” in figure 2-1. This box is bigger then “A” and “B” be because the measure band that is going to be used is 144 cm long and 13 mm wide. It also has to room a lead weight of 40 grams which is going to be mounted at the end of the boom.

This box is not square-shaped like the VHF- ant UHF-antenna housing boxes. This is because of the strict weight limit, the satellite can maximum weigh a 1000 grams. The dimensions of the AIS-antenna/ Gravitation boom housing box are 53 mm * 13 mm if viewed from the front, figure 2-1 (a). The highest point of the box, inside view (c), is 50 mm and the lowest end is 19mm.

Placing of this box is important because the CubeSat specification document, Appendix A, states that the center of mass must be within 2 cm of the geometric center.

The patch antenna is placed at “D” in the figure 2-1 and on the contrary to the other antennas it does not need any deployment mechanism. The dimension of the hole where the antenna is placed is 39 mm* 21 mm.

Above the patch antenna the flight pin is placed, “F”. The purpose of the flight pin is to disable the power system during transport of the NCUBE. The last marked component marked “E” is a RJ-45-connector which will be used for communication with the satellite on ground.

## 2.2 Antenna housing box materials

Space has a rather rough environment compared to earth. I a height of 700 -740 km the satellite will experience a great difference in temperature. To cope with this we have to be sure that the materials in use can deal with these strict demands.

Two plastic types were tested out for the antenna housing boxes. One was POM, polyoxymethylene, and the other was PAI, polyamidimid.

The POM-plastic had the characteristics that it could withstand a temperature range from -40°C to +100°C for long term use and a maximum up to +140 °C for shorter periods. The PAI-plastics long term upper temperature was +260°C and +280°C for short term use. No lower temperature was listed for this material

The antenna housing boxes was first made of the POM-plastic but after several times of opening to change the antennas, the boxes got fractures at a number points.

Then the boxes were made out of PAI-plastic. This material was more robust to work with and the boxes did not crack even after several times of antenna changing.

Appendix D shows the properties of these to plastic materials.

## 2.3 Mass budget

The satellite is maximum going to weigh 1000 grams. It is therefore essential to keep track of the weight of all the components of the satellite. The mass budget of NCUBE can be found in table 2-1. Only the components marked with grey have their mass determined, the others are estimates. As can be seen from the table the antenna system is rather light.

The antenna system consists of the AIS-antenna/ Gravitation boom, the VHF-, UHF- and the S-band patch antenna. This system weighs 124 grams which is 12.4 % of the satellite's total weight. The heaviest component is the AIS antenna/ Gravitation boom of 91 grams. This component is so much heavier because of its bigger dimensions and because the lead weight of 40 grams which is mounted to the end of the boom.

If the NCUBE's mass budged were to be exceeded weight adjustments will be made by making the lead weight smaller.

## NCUBE Mass Budget

**Version 2** **Date: 09.05.2003**

| Subsystem | Type | Size (mm) | Quantity | Unit mass | Mass |
|---|---|---|---|---|---|
| Mechanical structure | 7074 Aluminum | 100 x 100 x 100 | 1 | 200 | 200 |
| Nadir plate | 7074 Aluminum | 83 x 100 x 2 | 1 | 46 | 46 |
| Solar panels | UiO/IFE custom design | 83 x 100 x 2 | 5 | 20 | 100 |
| Batteries | DLP 485368 (1500 mAh) | 53 x 68 x 4.8 | 2 | 33 | 66 |
| Battery mount | **TBD** | 60 x 75 x 10 | 1 | 20 | 20 |
| Magnetic coils | Copper wire | 80 x 80 x 3 x 6 | 3 | 17 | 51 |
| S-band transmitter | Andøya Rocketrange | 71 x 28 x 5 | 1 | 11 | 11 |
| Magnetometer | Honeywell HMR2300-D01-232 | 74.9 x 30.5 x 10 | 1 | 28 | 28 |
| VHF receiver | Including TNC + telecommand | 80 x 80 x 8 | 1 | 40 | 40 |
| ADCS subsystem | Microcontroller + driver | 80 x 50 x 10 | 1 | 30 | 30 |
| AIS receiver | RX + OBDH | 80 x 80 x 8 | 1 | 40 | 40 |
| Power management unit | PCB backplane | 80 x 80 x 8 | 1 | 50 | 50 |
| UHF transmitter | **TBD** | 75 x 30 x 8 | 1 | 50 | 50 |
| Kill switch | **TBD** | | 2 | 5 | 10 |
| AIS antenna /Gravity boom | Including end mass (40g) | 13 x 1380 | 1 | 91 | 91 |
| Flight pin | micoswitch + M3 | | 1 | 5 | 5 |
| RJ-45 jack | Elfa nr. + small PCB | 1.7 x 1.5 x 1.4 | 1 | 5 | 5 |
| VHF RX antenna | Monopole incl box | 6 x 510 | 1 | 16 | 16 |
| UHF antenna | Monopole incl box | 6 x 160 | 1 | 13 | 13 |
| S-band antenna | Patch | 30 x 30 x 3 | 1 | 4 | 4 |
| Connectors + harness | | | 1 | 50 | 50 |
| Misc mounting hardware | | | 1 | 50 | 50 |
| | | | | **Total** | **976** |

Table 2-1: Mass budget

# 3 Antenna fundamentals

As earlier mentioned the antennas used on this satellite will be 3 monopole antennas and a single patch antenna. These antennas are known as resonant antennas and they operate well at a single or selected narrow frequency. They have real input impedance, narrow bandwidth and low to moderate gain.

This section will take a brief look at some basic antenna theory and other antenna fundaments, [6] and [7], that have been considered in the building of the NCUBE antennas.

## 3.1 Antenna types

The monopole antenna has very similar properties to the dipole antenna so it will also be presented to give better understanding of the monopole antenna.

An antenna is a conductive element which converts electrical energy into an electromagnetic field (transmit), or converts an electromagnetic field into electrical energy (receive).
An important feature is the property of reversibility, the same antenna can be used with the same characteristics as transmit or as a receive antenna. An antenna is characterized by its center frequency, bandwidth, polarization, gain, radiation pattern and impedance.

### 3.1.1 Half-wave Dipole antenna

A half-wave dipole antenna is a straight electrical conductor connected at the center to a radio-frequency (RF) feed line. This antenna is one of the simplest and most common antennas. The dipole is inherently a balanced antenna, because it is bilaterally symmetrical. It is also omni directional.

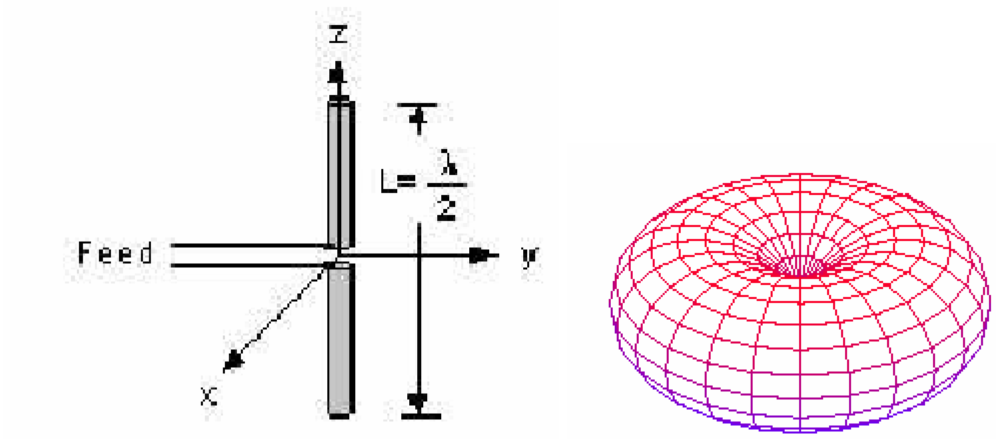



Figure 3-1: Principle of a half-wave wave dipole antenna with radiation pattern

Dipole antennas can be oriented horizontally, vertically, or at a slant as is the case for the VHF- and UHF-antennas for the NCUBE. The polarization of the electromagnetic field (EM) radiated by a dipole transmitting antenna corresponds to the orientation of the element. When the antenna is used to receive RF signals, it is most sensitive to EM fields whose polarization is parallel to the orientation of the element. The RF current in a dipole, formula (3-1), is maximum at the center (the point where the feed line joins the element, *z*=0), and is zero at the ends of the element. The RF voltage is maximum at the ends and is minimum at the center. The advantage of a half wave dipole is that it can be made to resonate and present zero input reactance.

$$I(z) = I_m \sin\left[\beta(\frac{\lambda}{4} - |z|)\right], \qquad |z| \leq \frac{\lambda}{4}, \qquad (3\text{-}1)$$

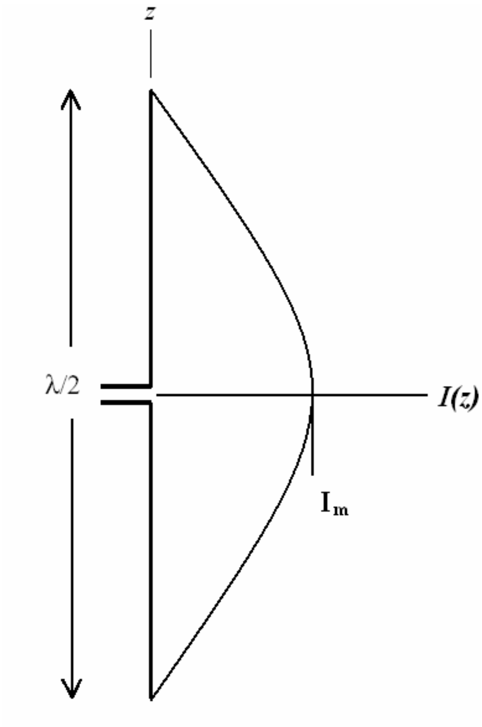



Figure 3-2: The current distribution of the half-wave dipole

### 3.1.2 Quarter-wave length Monopole antenna

A monopole is a dipole that is divided in half at the center feed point and fed against the ground plain. The current and charges are the same as the upper half of the dipole counterpart, but the terminal voltage is only half of the dipole. The radiation pattern of a monopole above a perfect ground plane is the same as that of the dipole similarly positioned in free space.

### 3.1.3 Microstrip patch antenna

The patch antenna, figure 3-3, is a type of microstrip antenna. These types of antennas are popular because of their low profile and because they easily can be fitted to different geometries. They are typically used at frequencies from 1 to 100 GHz. The patch antenna consists of a rectangular metal plate printed onto a dielectric substrate with ground plane on one side. The metal plate can be exited directly by a microstrip line, a coaxial connection through the substrate or indirectly from a microstrip on a substrate beneath the ground plane.

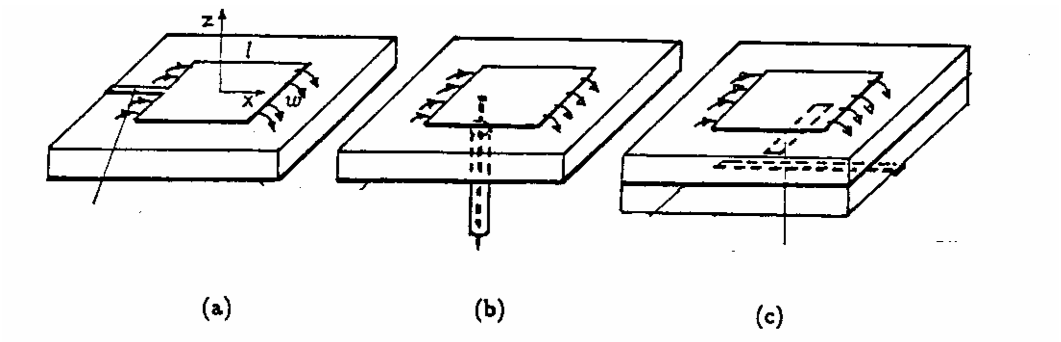



Figure 3-3: Rectangular microstrip patch antenna. (a) Microstrip-fed (b) Coaxial-fed (c) Aperture connected

This type of antenna requires a stable satellite with the antenna facing the earth all the time. When configured as an array, a relative high gain can be achieved. No deployment is required for such an antenna. The main drawback is that it has a very sharp bandwidth.

The substrate thickness is much less then a wavelength. It is most commonly operated near resonance in order to obtain real-valued input impedance. Formulas are available to estimate the resonant length, but adjustments are often necessary in practice. Formula (3-2) approximates the length, *L*, of a half wavelength patch.

$$L = 0.49\lambda_d = 0.49\frac{\lambda}{\varepsilon_r} \qquad (3\text{-}2)$$

$\lambda_d$ is the wave-length in the dielectric and $\varepsilon_r$ is the substrate dielectric constant.

Bellow follows some important factors in choosing the right kind of material for the patch.

**Antenna substrate dielectric constant:**
This primarily affects the bandwidth and radiation efficiency of the antenna, with lower permittivity giving wider impedance bandwidth and reduced surface wave excitation.

**Antenna substrate thickness:**
Substrate thickness affects bandwidth and coupling level. A thicker substrate, results in wider bandwidth, but less coupling for a given aperture size.

**Microstrip patch length:**
The length of the patch radiator determines the resonant frequency of the antenna.

**Microstrip patch width:**
The width of the patch affects the resonant resistance of the antenna, with a wider patch giving a lower resistance. Square patches may result in the generation of high cross polarization levels, and thus should be avoided unless dual or circular polarization is required.

## 3.2 Bandwidth

Bandwidth is defined as “the range of frequencies within which the performance of the antenna, with respect to some characteristic, conforms to a specified standard”. This standard can for example be VSWR, voltage standing wave ratio, of 2.0.

Often a radio needs to work on multiple frequencies. For example, the AIS-receiver, [8], uses two channels one at 161.975 MHz (AIS 1) and one at 162.025 MHz (AIS 2). It is however not unusual that that radio equipment have to operate in a much wider frequency band than this. This means that the antenna must perform well over a range of frequencies. So, the goal must be to make it resonant in the middle of that band.

For dipole/monopole-antenna case the general principle is that the thicker the antenna is the wider the bandwidth is.

## 3.3 Radiation patterns and antenna polarisation

The radiation pattern is a graphical representation of the radiation properties (far-field) of an antenna. Antenna radiation performance is usually measured and recorded in two orthogonal principal planes, such as E-Plane and H-plane. The pattern is usually plotted either in polar or rectangular coordinates. The pattern of most base station antennas contains a main lobe and several side lobes.

For a linearly polarised antenna, the plane containing the electric field vector and the direction of maximum radiation is called the E-plane. For base station antenna, the E-plane usually coincides with the vertical plane. For a linearly polarised antenna, the plane containing the magnetic field vector and the direction of maximum radiation is called H-plane. For base station antenna, the H-plane usually coincides with the horizontal plane.

Radio waves are built by two fields, one electric and one magnetic. These two fields are perpendicular to each other. The sum of the fields is the electromagnetic field. Energy flows back and forth from one field to the other. This is what is known as oscillation.

The position and direction of the electric field with reference to the earth’s surface determines wave polarization. In general, the electric field is the same plane as the antenna's radiator. Horizontal polarization is when the electric field is parallel to the ground and vertical polarization is when the electric field is perpendicular to the ground.

There is one special polarization known as Circular polarization. As the wave travels it spins, covering every possible angle. It can either be right handed or left handed circular polarization depending on which way it is spinning.

## 3.4 Impedance matching

Radio communication theory, [7], states that the antenna impedance, $Z_L$, has to be matched to the transmission line, $Z_0$. The reason for this is that maximum power transfer between source and load occurs when the system impedances are matched. It also improves the signal-to noise-ratio for the system and reduces amplitude and phase errors.

The match can be described by the reflection coefficient

$$\Gamma(f) = \frac{Z_L(f) - Z_0}{Z_L(f) + Z_0} \tag{3-1}$$

and the voltage standing wave ratio:

$$VSWR(f) = \frac{1 + |\Gamma(f)|}{1 - |\Gamma(f)|} \tag{3-2}$$

The reflection coefficient varies from -1, for short load, to +1, for open load, and becomes 0 for matched impedance load

VSWR is a measure of impedance mismatch between the transmission line and its load. The higher the VSWR is, the greater the mismatch. For a good match the voltage standing wave ratio should be under 2 for a specified frequency. When VSWR is 2.0 it is equal to 90 % power absorption.

The Return Loss, S11, is also a common expression used in antenna measuring. This is basically the same thing as reflection coefficient. If 50 % of the signal is absorbed by the antenna and 50 % is reflected back, we say that the Return Loss is -3dB. A very good antenna might have a value of -10dB, 90 % absorbed and 10 % reflected.

When studying a graph showing Return Loss/VSWR, a deep and wide dip of the curve is good since this shows an antenna with good bandwidth. Consequently, the narrower the dip is the bigger risk that also desired channels will be reflected away, narrow band.

When match in impedance is absent an impedance-matching system must be constructed, figure 3-4.

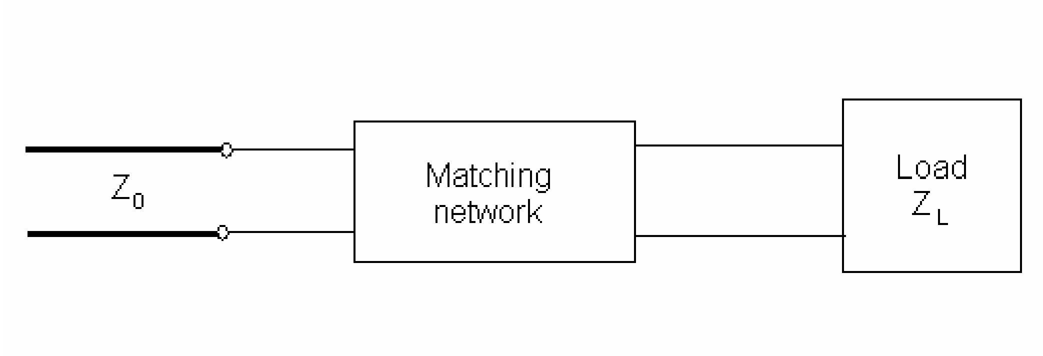



Figure 3-4: A lossless network matching a load-impedance to a transmission line

As long as the load impedance for the antenna, $Z_L$, has a nonzero real part, a matching network can always be found

The simplest type of matching network is matching with lumped elements (L network), which uses two reactive elements to match the antenna ($Z_0$) and the transmission line ($Z_L$). There are two possible configurations, shown in figure 3-5 that can be used. If the normalized load impedance is inside the 1+jX circle in the smith diagram circuit (a) of figure is used, if it is outside circuit (b) is used. The reactive elements can be inductors or capacitors, depending on the load impedance.

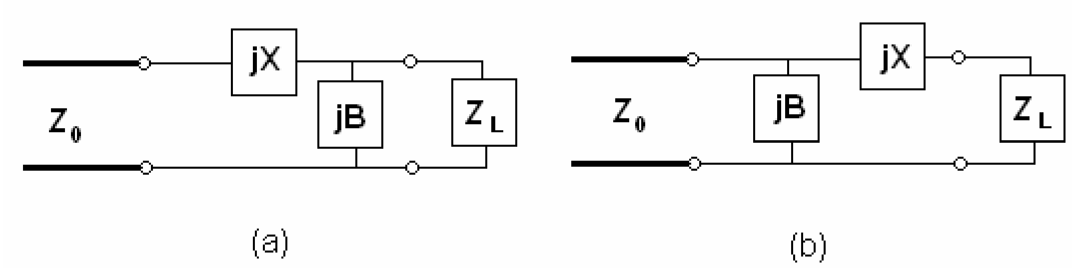



Figure 3-5: L section matching networks (a) ZL inside the 1+jX circle on the Smith chart. (b) ZL outside the 1+Xx circle on the Smith chart

This technique is feasible for frequencies up to about 1 GHz, if modern microwave circuits are used it is possible to use even higher frequencies.

When constructing a matching network in the latter chapters the computer program Smith v1.92 is used.

## 3.5 The Smith Chart

Antenna matching is critical in order to get the lowest VSWR and as much energy transmitted to the antenna as possible. Several techniques are available for antenna matching. The Smith's chart is the easiest because it is the most visual.

Figure 3-6 shows a smith chart. The "zero-line" represents in the smith chart represents the antennas resistance. In the center of the smith chart where the resistance-circle 1.0 crosses the "zero-line" the perfect impedance match accurse, 50Ω in the case of the NCUBE antennas.

At the left end of the ”zero-line” short circuit is found and at the right end open circuit. The advantage of using the smith chart for impedance calculations is that feed impedance can be measured when the measuring instrument is connected to the feed line and not necessarily directly to the feeding point.

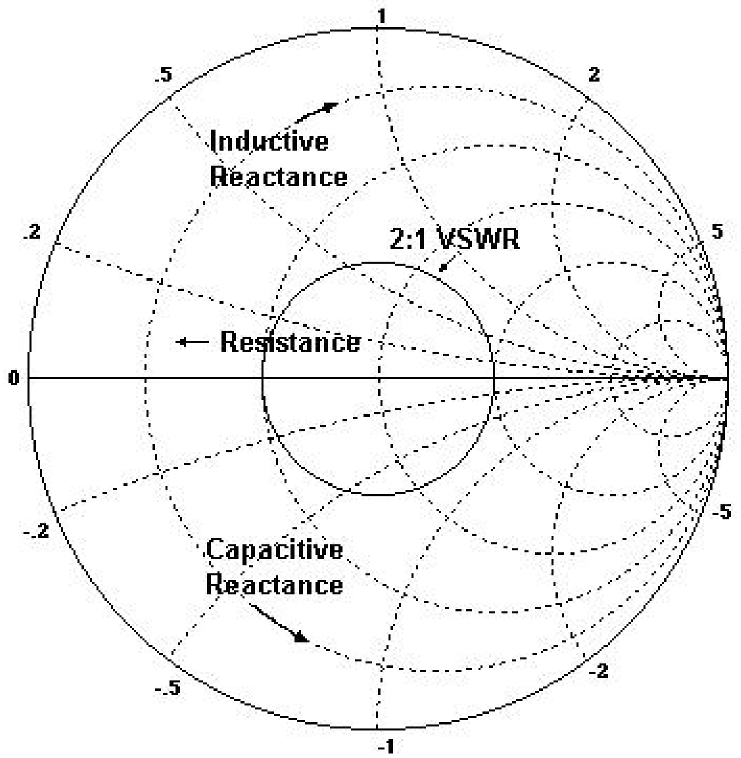



Figure 3-6: The principle of the smith chart

# 4 Computer simulation

The following chapter will show the computer simulated data results which is use for the realisation of the antennas in Chapter 5. For the UHF-, the VHF- and for the AIS antenna WIPL-D has been used and for the S-band patch antenna PCAAD has been used

WIPL-D [9], a fast and accurate computer program, allows analysis of metallic and dielectric/magnetic structure such as antennas, scatters, passive microwave circuits, etc. The calculations are done in the frequency domain and they are based on the method of moments [7, chap. 10]. The computer simulations returns radiation pattern, impedance and return loss among other things and the data can be displayed graphically or in lists of data.

PCAAD 4.0, Personal Computer Aided Antenna Design Software, [10] was used to find the right dimensions of the S-Band patch antenna.

## 4.1 WIPL-D simulations

The downlink UHF-antenna at 435MHz and the uplink VHF-antenna at145MHz are realized by making ¼-wavelength monopole antennas out of carpenter measuring tape and storing them in antenna housing cups, as explained in Chapter 2, until the satellite is in orbit before deploying the antennas.

Theoretically the length of the resonant antennas at these frequencies are 17.2 cm, for the UHF (435MHz) case, and 51.7 cm ,for the VHF (145MHz) case, which are a quarter of the wave length of the antennas at the given frequencies.

The wave length is given by:

$$\lambda = \frac{c}{f} \tag{4-1}$$

Where lambda, $\lambda$ , is the wave length $c$ is the speed of light, $3*10^8$ m/s, and $f$ is the frequency. To get the length of a ¼-wavelenth antenna division by four is of course necessary.

### 4.1.1 Before boom deployment

Before the Gravitation boom/AIS antenna has been deployed the, satellite is strictly dependent of the UHF- and VHF-antenna to communicate. The two antennas will after deployment have a slant of 17 degrees with the y-axis to go clear of the satellite structure, as shown in the WIPL-D generated figure 4-1.

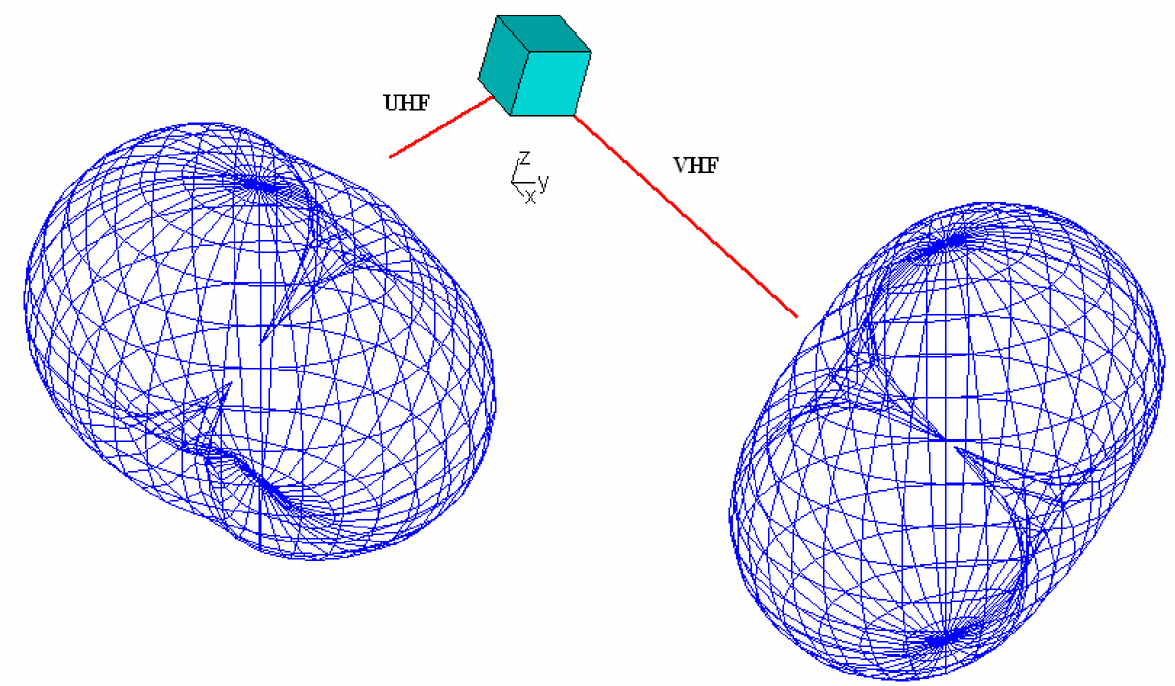



Figure 4-1: Radiation pattern of the UHF-and VHF-antenna

It was found that the length that gave the best impedance match was 172 mm for the UHF antenna. For the VHF antenna the best length was found to be 603 mm. The good properties are also stated by the fact that the voltage standing wave ratio, VSWR, for both antennas is 1.1 for their respective frequencies.

| Antenna Length [mm] | Frequencies [MHz] | Impedance ($Z_L$) | | VSWR |
|---|---|---|---|---|
| | | Re | Im | |
| 172 | 435 | 56.3 | 4.5 | 1.1 |
| 603 | 145 | 45.1 | 4.0 | 1.1 |

Table 4-1: Antenna properties before boom deployment

In figure 4-1 the simulated radiation pattern are shown radiation. Their shapes are similar since they both are ¼-wave length monopole antennas. The radiation patterns have the shapes of “doughnuts” with zero radiation in the direction of the antennas. It is an advantage to have this omni directional shape since the satellite position is not stabilized before the AIS-antenna/ Gravitation boom is deployed.

The VSWR for the antennas are plotted in figure 4-2. These plots are generated from the return loss factor, S11, which was calculated by WIPL-D. The plot is generated in MatLab and the MatLab-file used can be viewed in Appendix C.

The bandwidths of the simulated antennas are illustrated by the dotted lines. For the UHF antenna the VSWR is under 2.0 between 410 and 470 MHz. The same applies for the VHF antenna between 139 and 153 MHz.

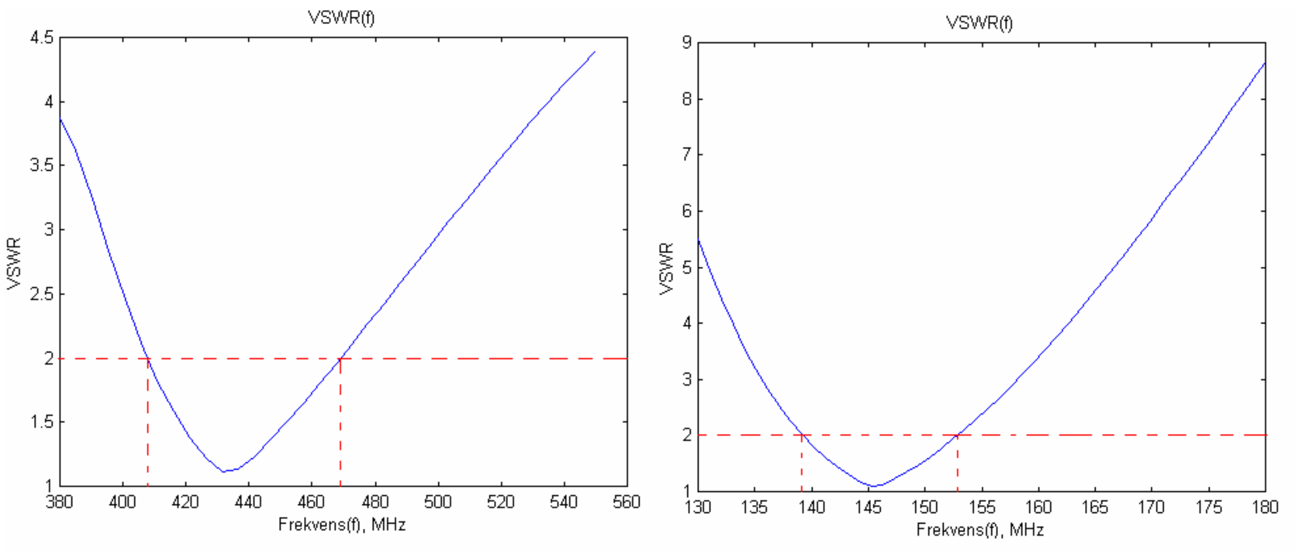



Figure 4-2: VSWR plot for the simulated UHF- and VHF-antennas

The reason that the UHF antenna has greater bandwidth than the VHF antenna is the antenna dimensions. Both antennas could be made more wide banded by using a wider measuring tape, this is however difficult due to the small dimensions of the NCUBE's antenna housing boxes.

### 4.1.2 After Gravitation-boom/ AIS-antenna deployment

Figure 4-3 shows the WIPL-D generated model of the satellite after the Gravitation-boom/ AIS-antenna deployment. The boom has to be this long to stabilize the satellite which is described in the report about the gravitation boom, [11].

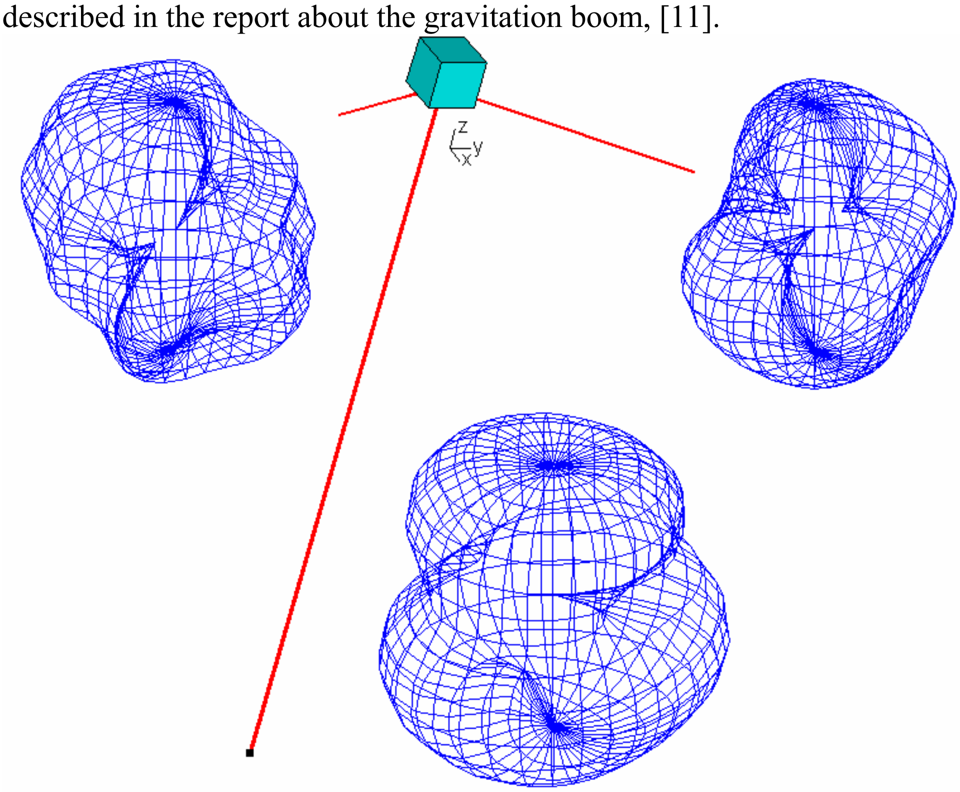



Figure 4-3: Radiation patterns after boom deployment

The gravitation boom has an influence on the other monopole antennas, this can bee seen from the radiation patterns in figure 4-3 and from the antenna properties in table 4-2.

| Antenna Length [mm] | Frequencies [MHz] | Impedance ($Z_L$) | | VSWR |
|---|---|---|---|---|
| | | Re | Im | |
| 172 | 435 | 44.7 | 7.5 | 1.2 |
| 603 | 145 | 56.2 | 40.1 | 2.1 |
| 1500 | 162 | 186.2 | -118.2 | 5.3 |

Table 4-2: Antenna properties after boom deployment

The properties the AIS-antenna are not satisfactory. A matching network can be made to compensate for this. Smith v1.92 was used to find a theoretical solution as shown in figure 4-4.

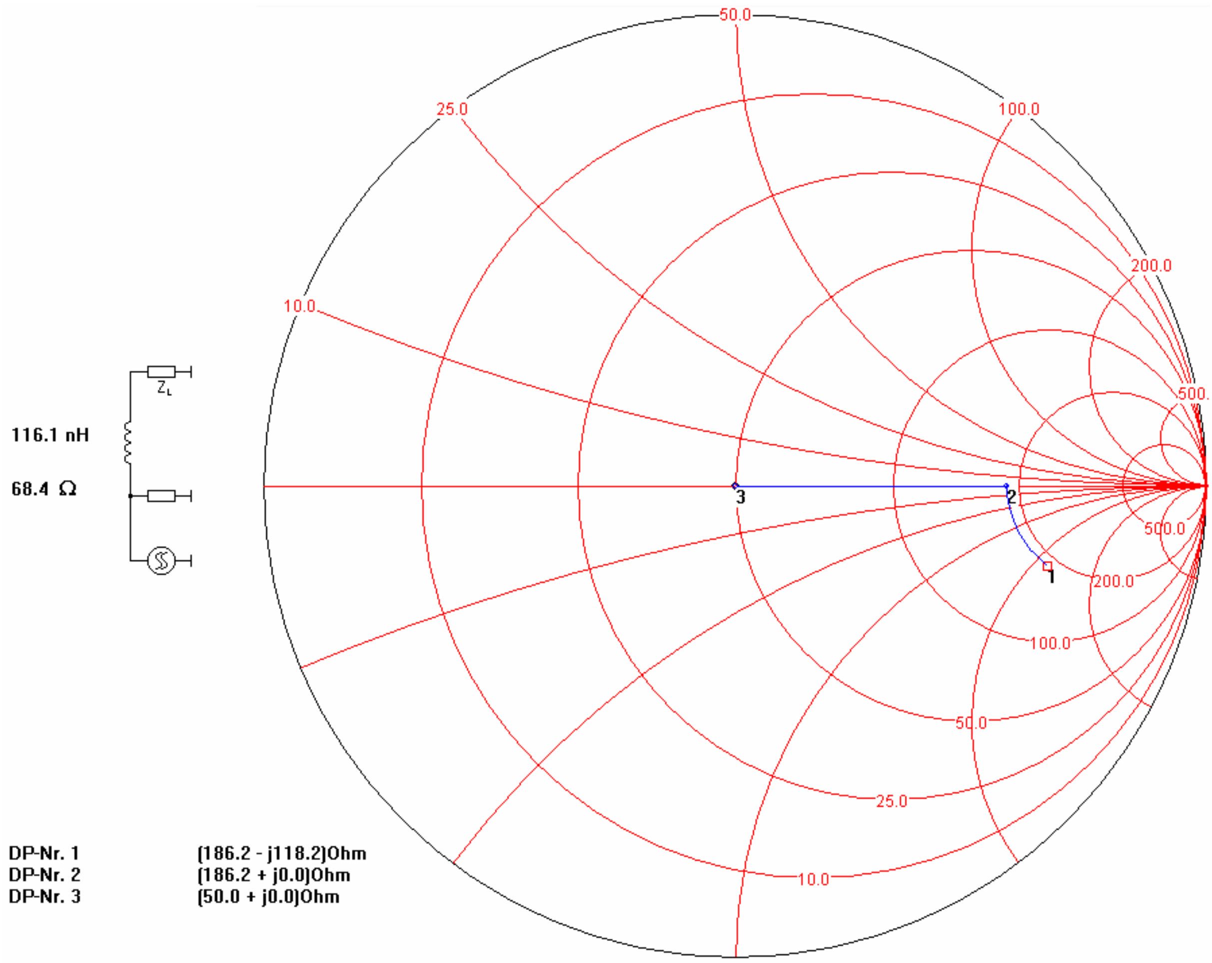



Figure 4-4: AIS impedance matching network

## 4.2 PCAAD

PCAAD was used to find an S-band patch antenna with 50 ohm antenna impedance to match the coaxial cable. It was found that an antenna which was 3.6 cm long, 2.0 cm wide and had the probe to edge distance of 1.4 cm would have an input impedance of 46.8 +j*15.7 ohm. In figure 4-5 the impedance plot generated by PCAAD is shown. This gives a VSWR of 1.4.

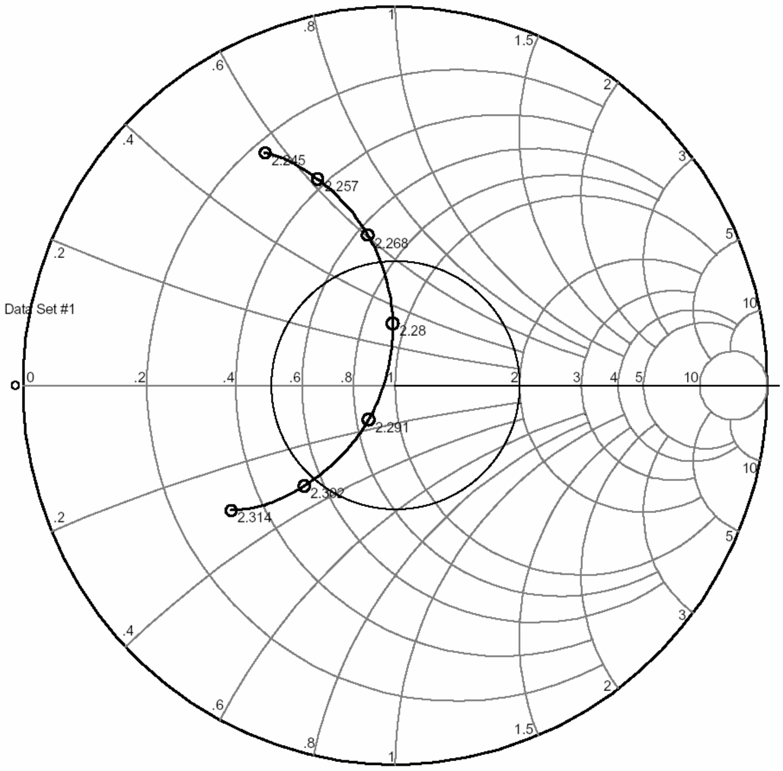



Figure 4-5: Impedance plotted in PCAAD of patch antenna

It can be seen from figure that the antenna is narrow banded. In the figure the 2.0 VSWR circle is plotted and the frequency band from 2.27 to 2.30 is inside it.

If formula (3-2) is used to calculate the patch length, it is found that this length is 3.51 cm which is close to the value found by PCAAD. The values are not the same because the simulated antenna is not perfectly resonant which in the case formula (3-2).

This antenna is however narrow-banded, the bandwidth can be increased by building a matching network.

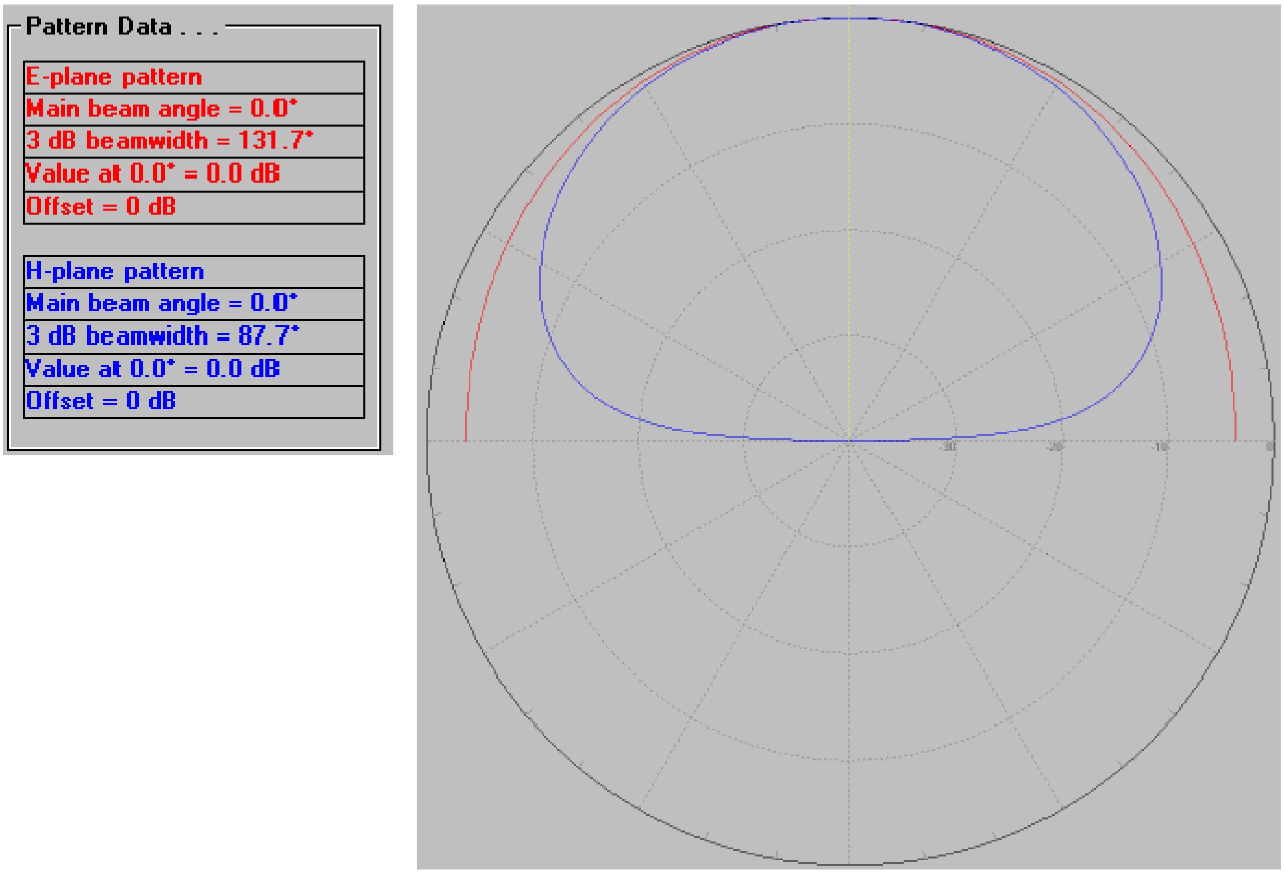



Figure 4-6: Radiation pattern generated by PCAAD

PCAAD also return an E- and H-plane radiation pattern. The E-plan pattern has the half power beamwidth (-3 dB) of 137.7˚ and the main beam angle is 0˚. The H-plane pattern has the half power beamwidth of 87.7˚ and the main beam angle of 0˚.

These results show that the patch antenna is directional and the ground station has to be inside the main beam for the satellite to receive. As earlier mentioned the rotation of the satellite is random before the Gravitation boom is deployed. After boom deployment the mechanical side (Nadir) of the NCUBE will face the earth and the S-band patch can receive radio waves.

# 5 Antenna measurements

An Automatic Network Analyzer, ANA - HP 8720C, was used to measure the input return loss, $S_{11}$, for the different antenna types. The ANA was designed for frequencies between 50 MHz and 20 GHz. The computer simulations in WIPL-D were used as base for the ANA measurements so that the antenna length could be found more easily. The measurements were carried out in the antenna laboratory at NTNU.

## 5.1 UHF-antenna

ANA measurements were done both with and without the gravitation boom deployed to see what kind of affects the boom had on the antenna properties. The UHF-antenna was made of carpenter measuring tape and was 6 mm wide and 175 mm long.

In figure 5-1, the smith diagrams of both cases are plotted.

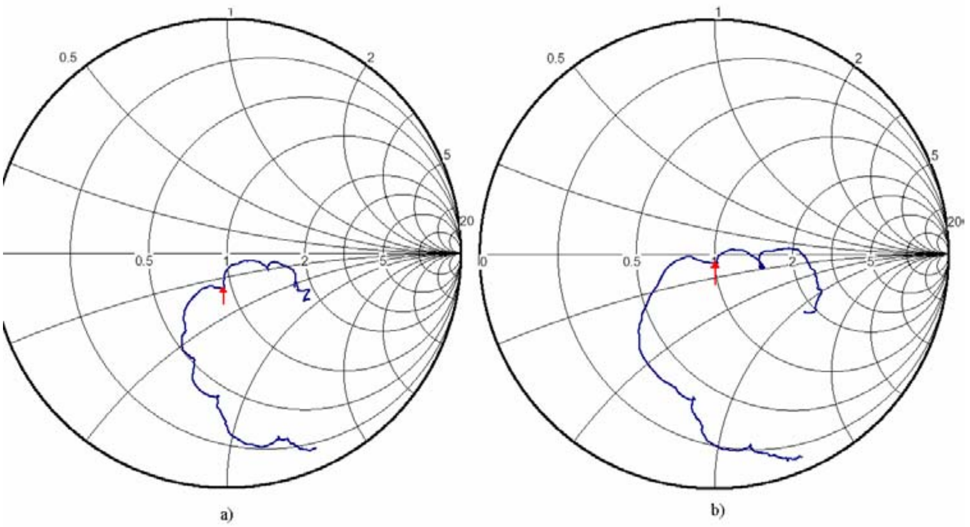



Figure 5-1: Smith diagram of UHF-antenna a) with out boom deployed b)with boom deployed

The impedance without the gravitation boom deployed was (37.1-14.0*j) Ohm and with gravitation boom it was (51.3-2.0j) Ohm. This gives a low VSWR for both cases, as also was shown from the WIPL-D simulations in chapter 4.

The dB plot, figure 5-2, shows that the conditions are best in case of a deployed boom. Before boom deployment the value is -22 dB and after it is -34 dB. If better properties for the case without boom are preferred, the antenna can be made longer but this is of course a trade off.

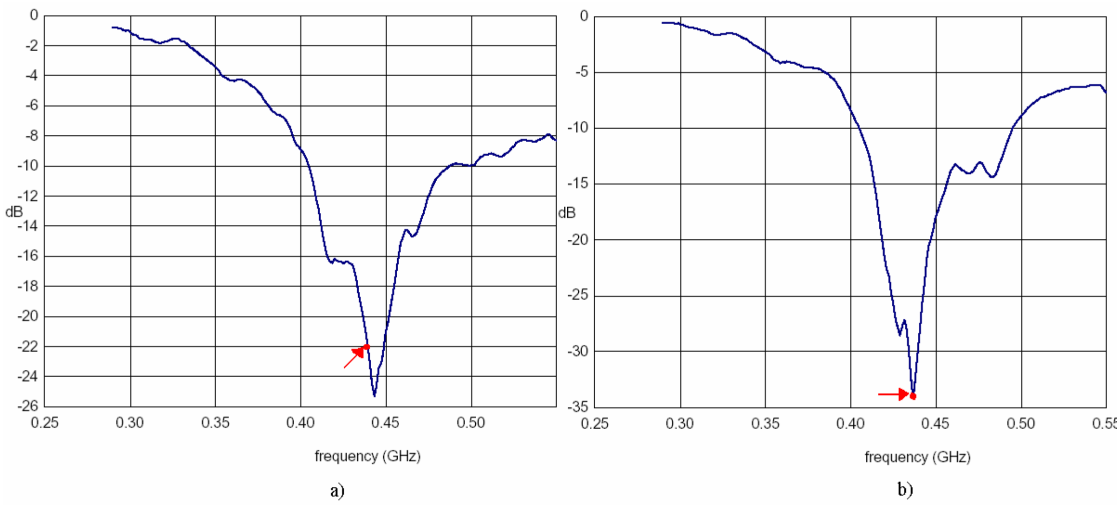



Figure 5-2: dB plot for UHF-antenna a) without boom deployed b) with boom deployed

The antenna is wide banded in both cases, figure 5-3. But before boom deployment the frequency band (a) is moved to the right compared to (b) after deployment.

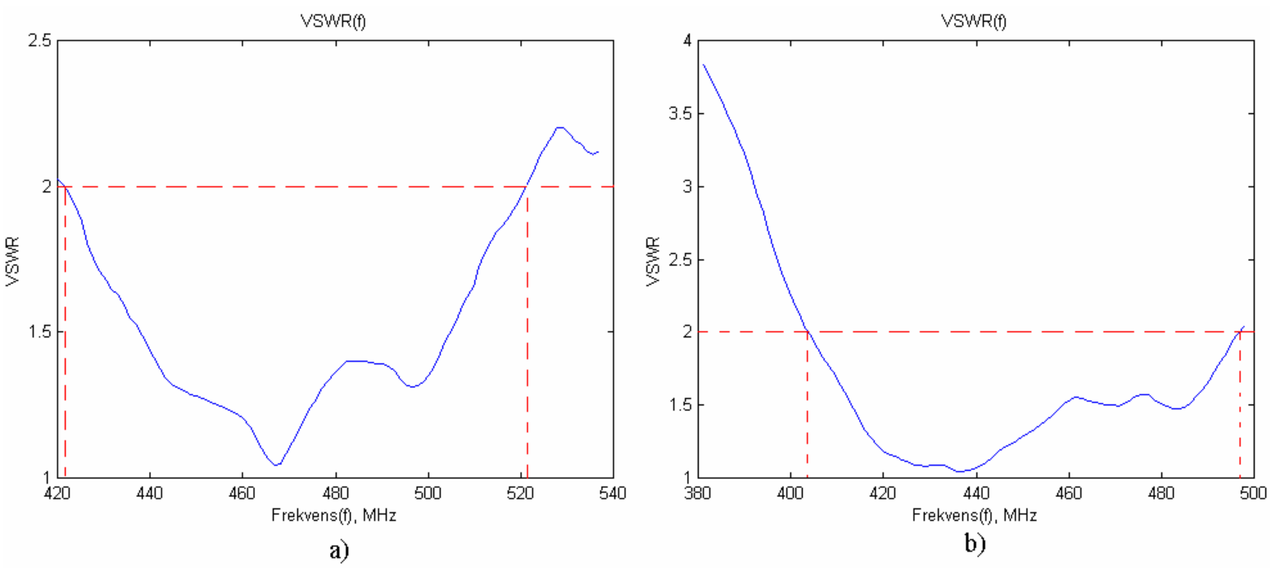



Figure 5-3: VSWR-plot for UHF-antenna a) without deployed boom b) with boom deployed

## 5.2 VHF-antenna

It was found that the antenna had the best properties at the length of 560 mm.
The impedance without gravitation boom deployed was (64.1+7.3*j) Ohm and (41.2-4.0*j) ohm with the boom deployed. The results can be viewed in the smith diagrams figure 5-4 where the VHF-antenna has been measured between 100 MHz and 600 MHz. (a) is the measurements without the boom deployed and (b) with the boom deployed. This gives the VSWR of 1.3 for (a) and 1.2 (b).

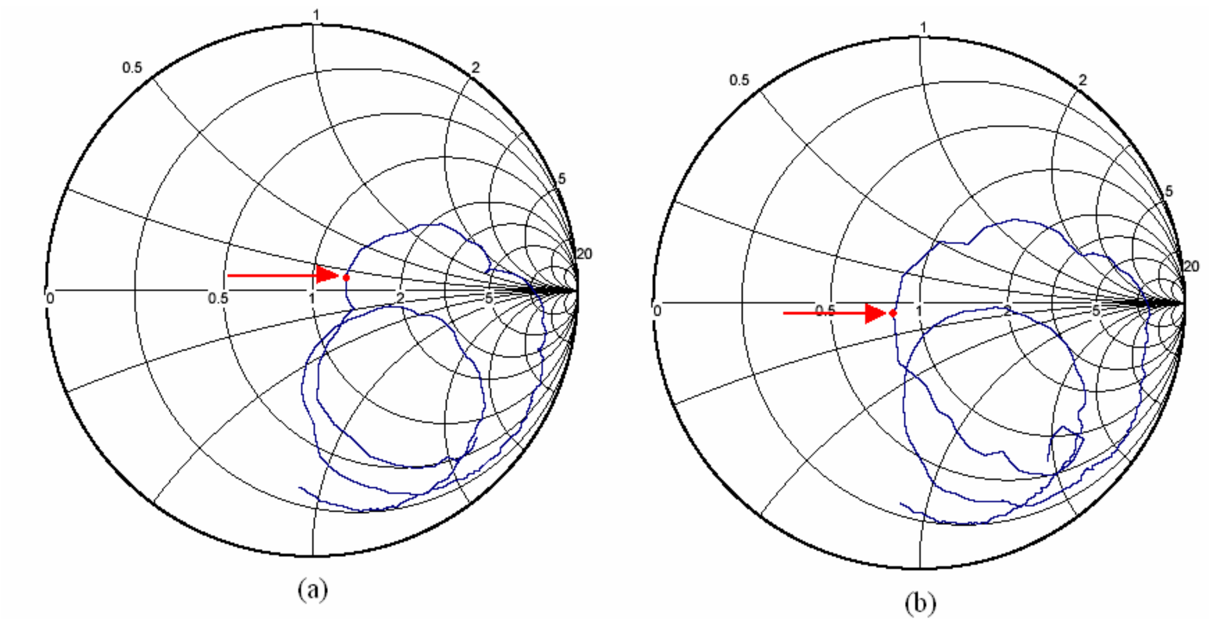
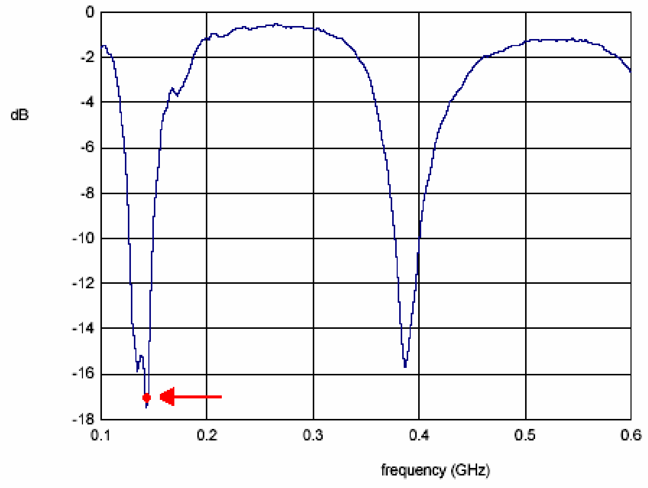


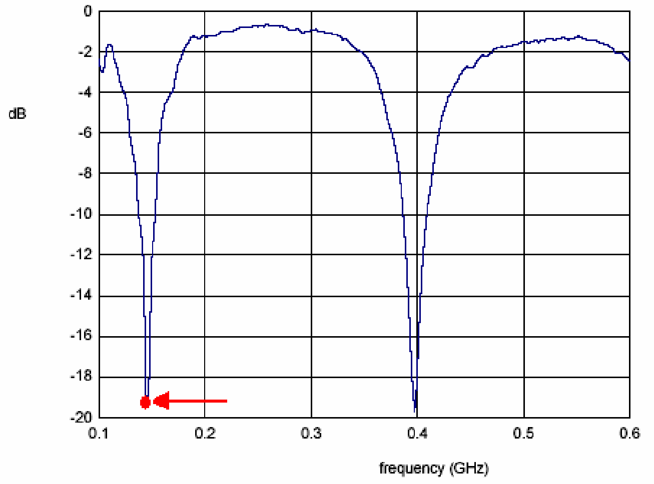

Figure 5-4: Smith-plot for VHF-antenna (a) without the gravitation boom deployed (b) with gravitation boom deployed

The dB plot, figure 5-5, shows that the conditions are best in case of a deployed boom. Before boom deployment the value is -17.5 dB and after it is -19.5 dB. These values differs very little, something that also was expected since the impedance values were very close.

The VSWR is plotted in figure 5-6. It can be seen that the antenna has a slightly narrower bandwidth after the Gravitation boom is deployed, but this should not be a problem because the bandwidth is close to 20 MHz. Before deployment it is close to 25 MHz.

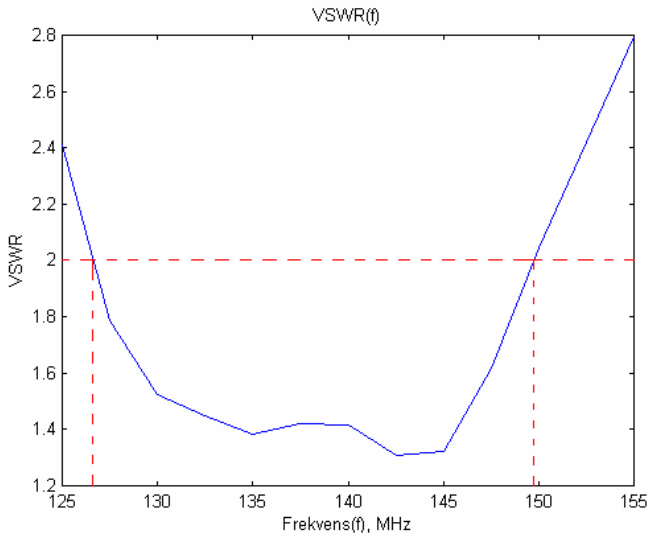


(a)

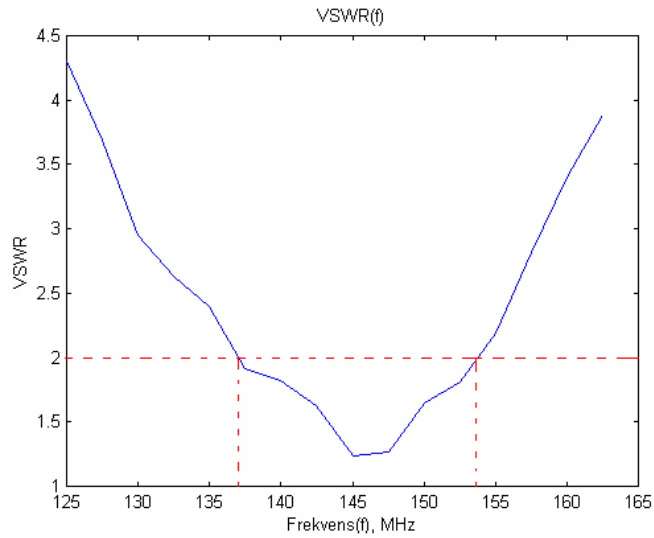


(b)

Figure 5-5: The dB-plot for the VHF-antenna (a) Without the Gravitation boom deployed (b) With the Gravitation boom deployed



(a)



(b)

Figure 5-6: The VSWR-plot for the VHF-antenna (a) Without the Gravitation boom deployed (b) With the Gravitation boom deployed

## 5.3 AIS-antenna

The AIS-antenna is going to receive AIS packages at 162 MHz from ships and reindeers. Since the NCUBE project is going to have a Gravitation boom of carpenter measuring tape it was decided to integrate an antenna with this boom.

As the mechanical section described, figure 2-1, the gravitation boom is going to be stored inside a housing box like the VHF and UHF antennas. This box is however bigger because of the length and the width of the measuring tape that is going to be used. It is feasible to have the gravitation boom as long as possible to get it as closer earth. This is described in [11].

Because the AIS-wavelength is 1.58 m a ¼-wavelength monopole antenna would only be 46.3 cm long. The gravitation boom group recommended that the boom should be about 1.5 m long. It was however stated that if the boom was 1.38m long it would have good impedance properties.

This can be explained because this length is three times the ¼-wavelength. This gives two points along the antenna were the current is zero, after ¼-wavelength and ¾-wavelength.

The ANA measurements showed that the best properties for AIS-antenna were reached when the measuring tape was 146cm and 13 mm wide.

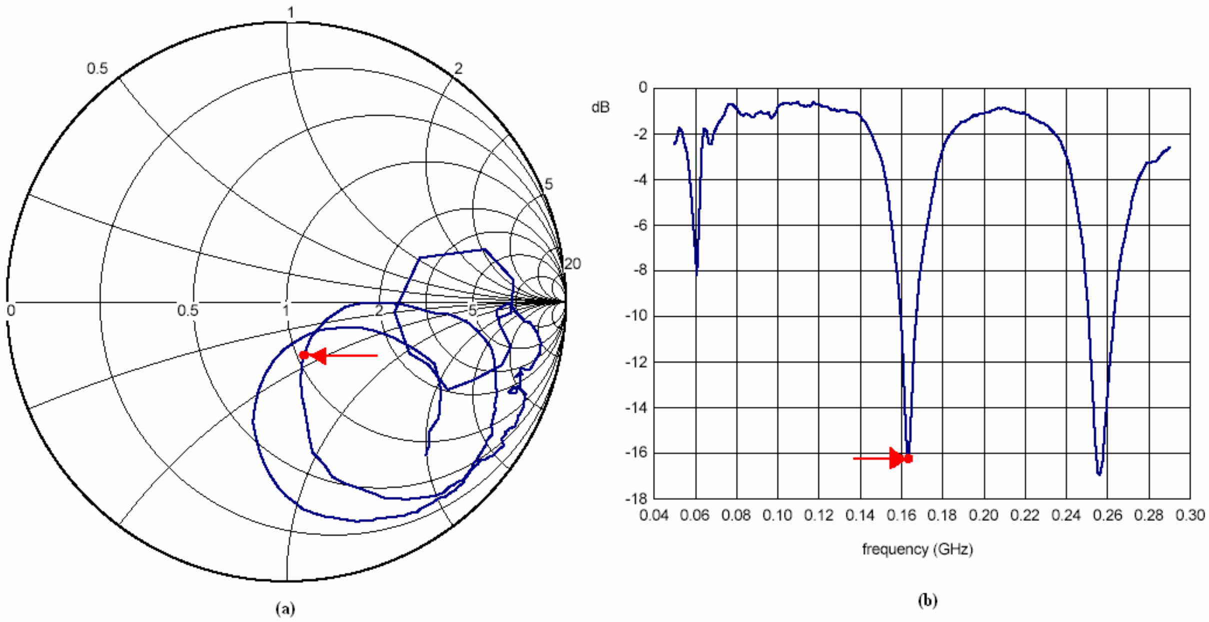



Figure 5-7: Properties of the AIS-antenna (a) Smith diagram (b) dB-plott

The return loss is measured to be -16 dB, (b), and the antenna impedance is (51.5-21.8*j) Ohm, (a), at 162 MHz .

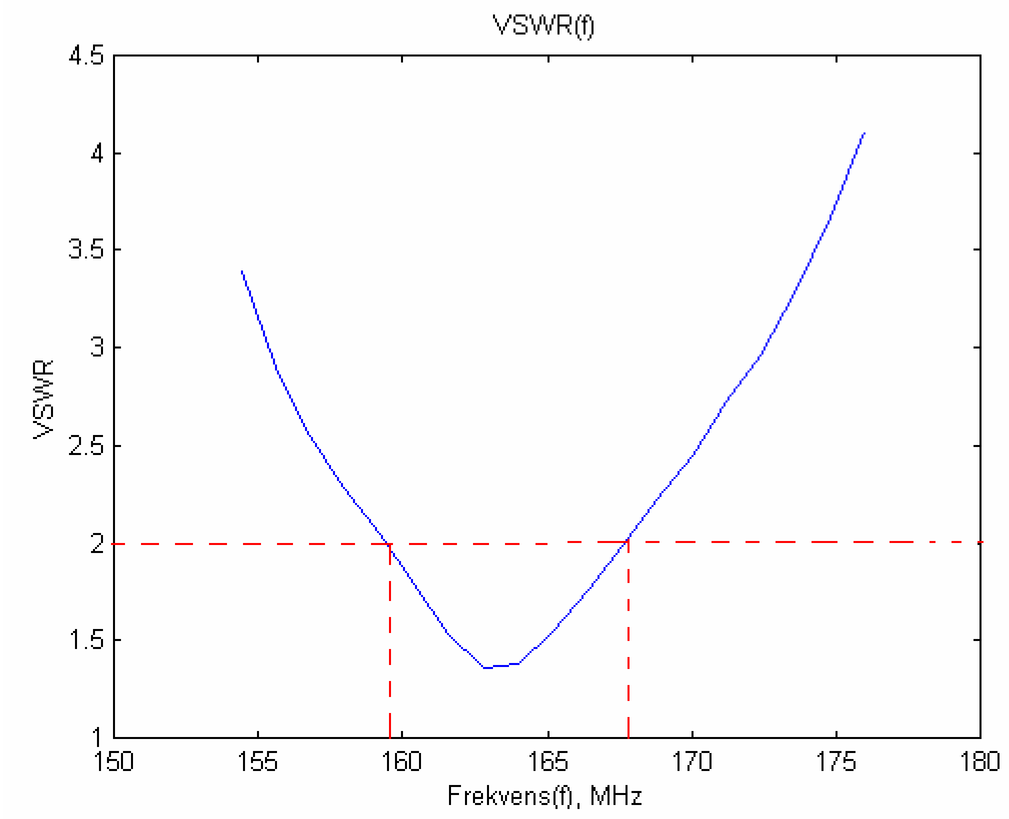



Figure 5-8: AIS antenna VSWR-plot

The voltage standing wave ratio, VSWR, is 1.5 at the AIS frequency and the bandwidth can be viewed in figure 5-8. As seen from the figure the antenna is rather narrow banded. To increase it matching network could be made as illustrated in figure 5-9.

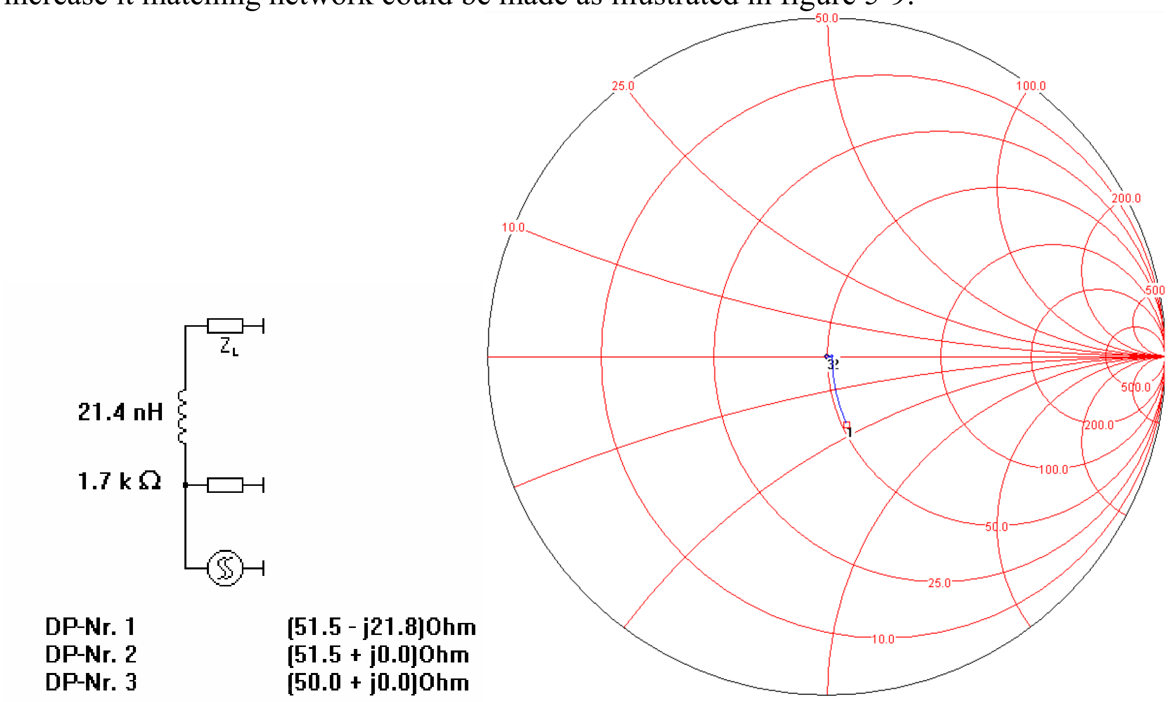



Figure 5-9: AIS-antenna matching network

## 5.4 S-band patch antenna

The satellite will have an S-band antenna for downlink communication. The S-band TX frequency is 2279.5 MHz. In earlier reports, [2] and [12], patch and helix antennas have been suggested as solutions. The patch antenna has been preferred because of its low profile. If a helix antenna would have been used it had to be deployed when the satellite was in orbit, using a patch antenna this problem does not have to be considered. The patch antenna requires a stable satellite with the antenna facing the earth all the time. Stability will be achieved when the gravity boom has been deployed

Rogers RO4003 QLAM 32 mil was found to be a suitable material. It was thicker then the other materials that NTNU could provide, something that made the antenna area smaller then if a thinner material were used. The dielectric constant, $\varepsilon_r$, was 3.38 and the loss factor was 0.0027.

The antenna was made after the dimensions found with PCAAD in chapter 4, which were 36 mm long and 20 mm wide. When measuring was started it was found that the antenna had to be shortened to get as good impedance as possible. This was done by cutting of 1 mm of the edge with a scalpel to make it 35 mm long.

An Automatic Network Analyzer, ANA - HP 8720C, was used to measure the input return loss, $S_{11}$, for the patch antenna. Figure 5-9 shows the plot of the smith diagram for the frequencies from 2.1 to 2.4 GHz. At 2.28 GHz (closest frequency to 2.2795 GHz this frequency resolution gave) the Return Loss is -26 dB and the VSWR is 1.1

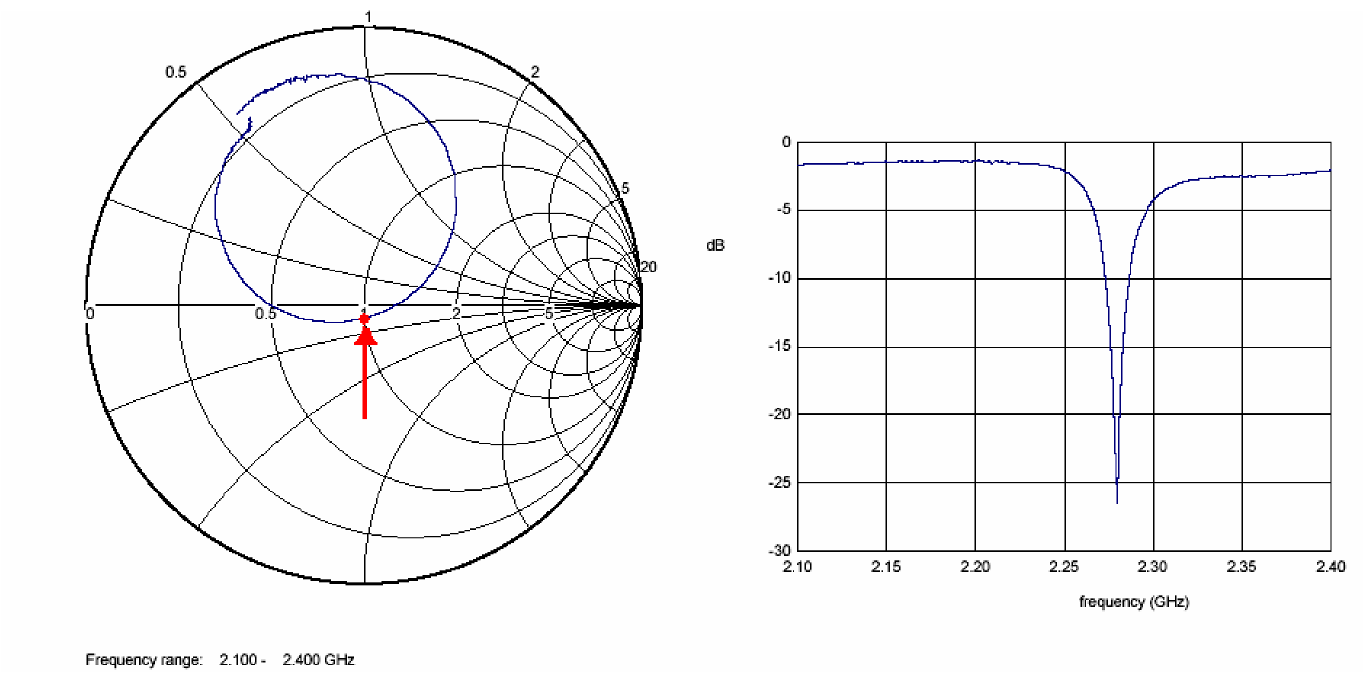



Figure 5-9: Input return loss plots for patch antenna generated with ANA

The antenna impedance is (46.9-4.7*j) Ohm which implies that the antenna has a very good match to the 50 Ohm coaxial cable as can be seen in the smith diagram, figure 5-9.

Tough the patch antenna has a very good match for this specific frequency it is rather narrow banded as the dB-plot in figure 5-9

The narrow banded properties of the antenna are further emphasized by the VSWR-plot in figure 5-10.

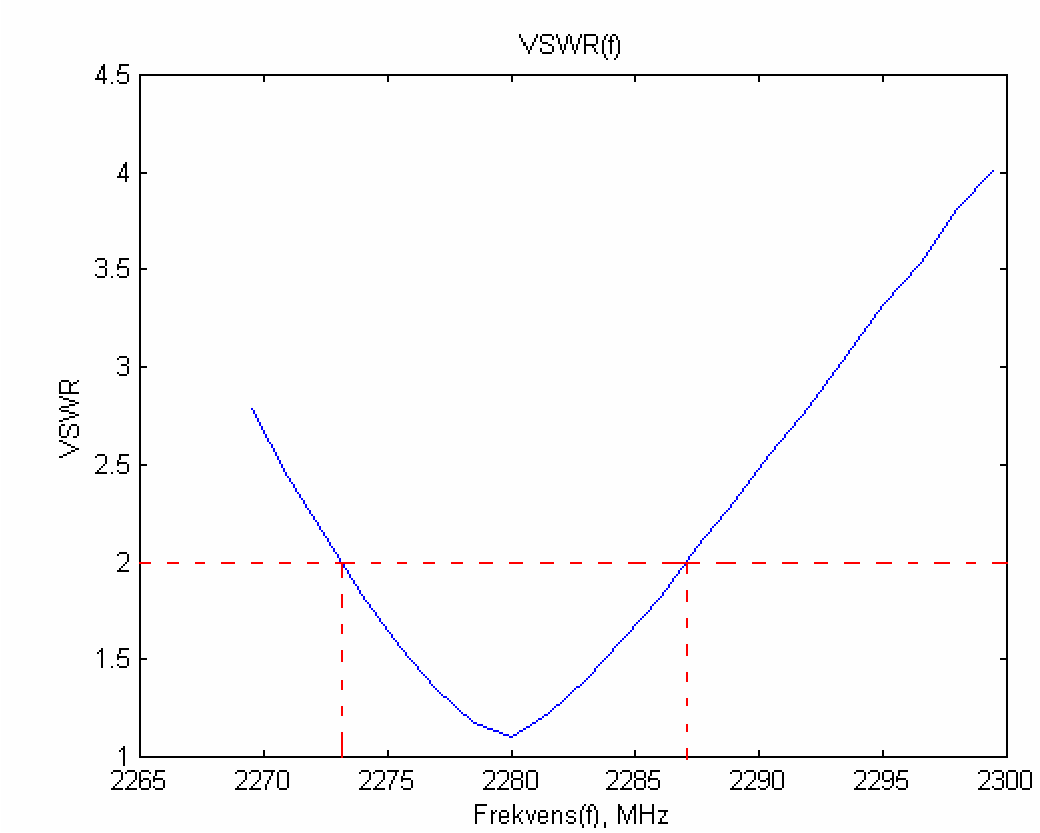



Figure 5-10: VSWR plot of S-band patch antenna

The VSWR is less then two between 2.273 and 2.287 GHz. This gives a bandwidth of only 14 MHz. The bandwidth can not be increased by building a matching network, since the antenna impedance is so close to being strictly resonant.

The input impedance is very similar to that which was calculated by PCAAD in the previous section. The final antenna was however made a little shorter by the use of a scalpel to get the best match possible.

### Radiation pattern

The far field antenna pattern measurements were done in the antenna laboratory at NTNU. The set-up consisted of the Hewlett-Packard Model 8720C Network Analyser and Newport Model MM4005 Motion Controller to perform far field antenna pattern measurements. The exact setup can be viewed in [13].

The absorber used in the anechoic chamber, were the patch antenna was placed, limits the lower end of the frequency range to 2GHz. Because of this, the radiation pattern measurements of the three monopole antennas have not been preformed.

As transmitting antenna during the measurements a double-ridge horn antenna was used. It was used because it has a wide frequency band, from 1- 10 GHz. This horn was placed in the opening in the opening in the anechoic camber.

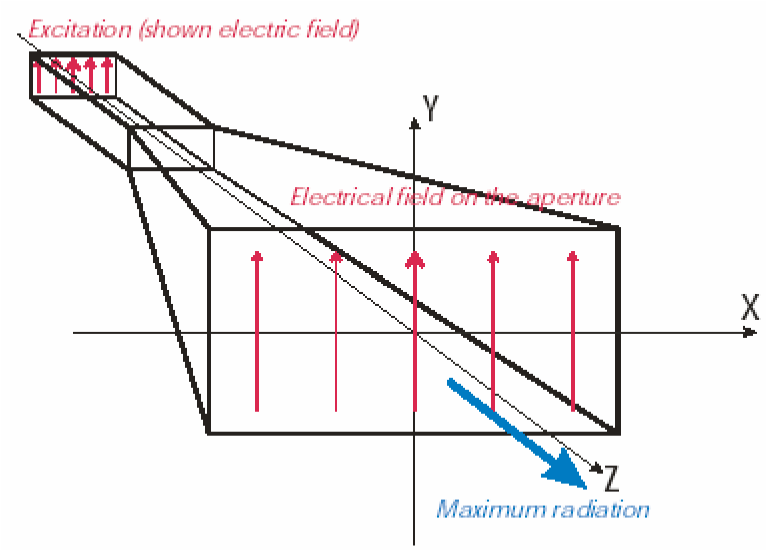
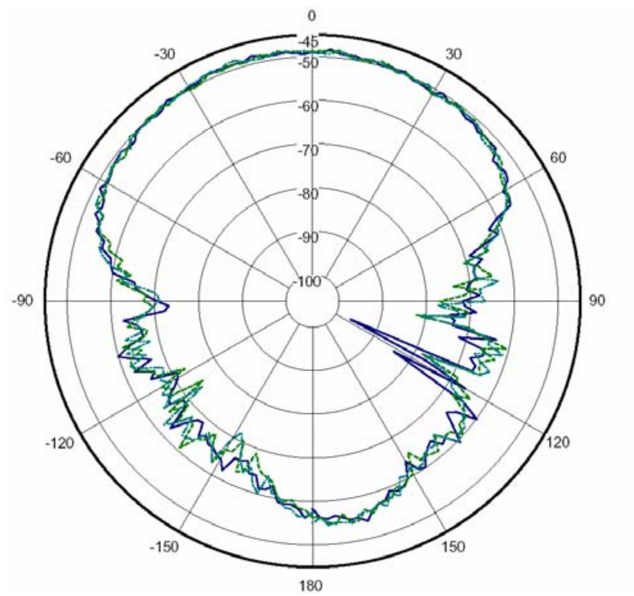



Figure 5-11: Horn antenna

The E-plane is determined by the direction of the electrical field. In Figure 5-11, the horn antenna is fed by a rectangular waveguide, where the electrical field has only components parallel to the narrower sides. Thus, the field distribution in the horn antenna should be similar – parallel to the Y-axis. The horn antenna has its maximum radiation in the Z-axis. These two directions (the direction of the electrical field and the direction of the maximum radiation) define the E-plane by the Y and Z.

The patch antenna was mounted inside the anechoic camber on a rotating antenna tower with the patch longest (35mm) side orientated in Y-direction and the wide side (20mm) in Z-direction. The antenna mast rotated the patch antenna in the horizontal plane, for measuring in the E-plane. The horn antenna was mounted with its E-plane parallel to the plane of rotation (horizontal plane).



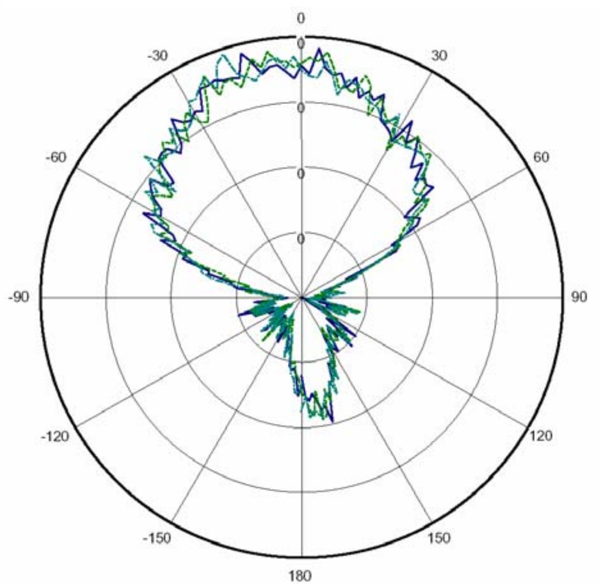



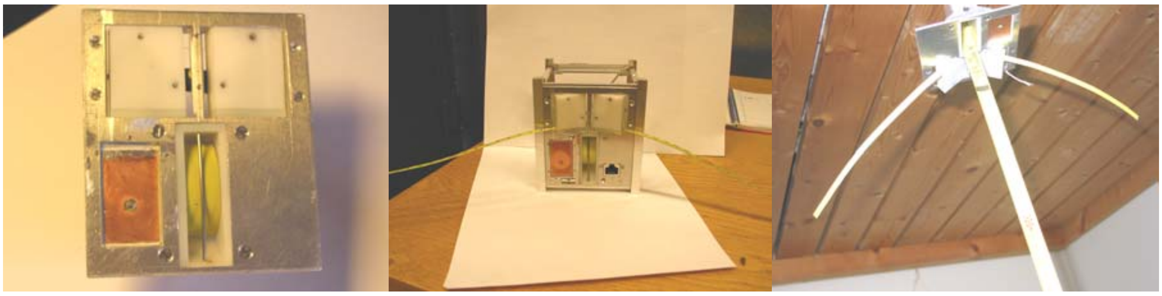

Figure 5-12: Patch's antennas E-plan radiation pattern
(Logarithmic to the left and linear to the right)

As seen of the E-plan Radiation pattern in figure 5-12 the half power (-3 dB) beamwidth is about 120˚. The main beam angle is slightly distorted compared to the 0˚. This can best be seen from the linear radiation pattern. This distortion can be caused by the patch antenna mounting inside the anechoic camber.

# 6 Antenna deployment

When the satellite is inside the P-POD the antennas have to be folded down.
The antennas will be stored inside antenna housing boxes as described in the mechanical section. After the satellite is launched we have to wait a certain amount of time before we can deploy the antennas. This has to be done autonomous, since there is no connection with the Ground station at this stage. If deployed too early they could come in contact with the launching tube or other cubesats.

The antennas will be deployed by using fishing lines to hold the antennas in side the housing boxes. To break the fishing line a nichrome wire can be used which will be coiled around a piece of the fishing line. This will be done at two places to make the system redundant. If one coil fails to break the wire there still is a second chance. The fishing line is broken by applying a voltage across the nichrome wire.



(a) (b) (c)

Figure 6-1: The three stages of the antenna deployment

The different antenna deployment stages can be viewed in figure 6-1. In (a) the antennas are stored inside the antenna housing cups. They are stored here until the NCUBE is deployed from the P-POD. As the CubeSat specification states, Appendix A, a time delay, in order of several minutes, must be present between release from the P-POD and any satellite hardware deployment.

After a specified time the VHF-antenna and the UHF-antenna will autonomously be deployed. In the power block diagram, figure 6-2, a timer will initialize the antenna release A and B mechanisms which sets a voltage over nichrome wire A and B which again melts the fishing line that holds down the UHF and VHF antenna housing boxes. The satellite will now be in the state which is shown in figure 6-1 (b).

When the ground station has established communication with the satellite the AIS-antenna/Gravitation boom will be deployed, as seen in figure 5-1(c). This will be done with a telecommand from the ground station. The command boom release goes over the telecommand-bus to the boom release mechanism C and D which sets a voltage over nichrome wire C and D which again melts the fishing line that holds down the UHF and VHF antenna housing boxes. As for the VHF and UHF antenna release case, the release mechanism for the AIS-antenna/Gravitation boom is also redundant.

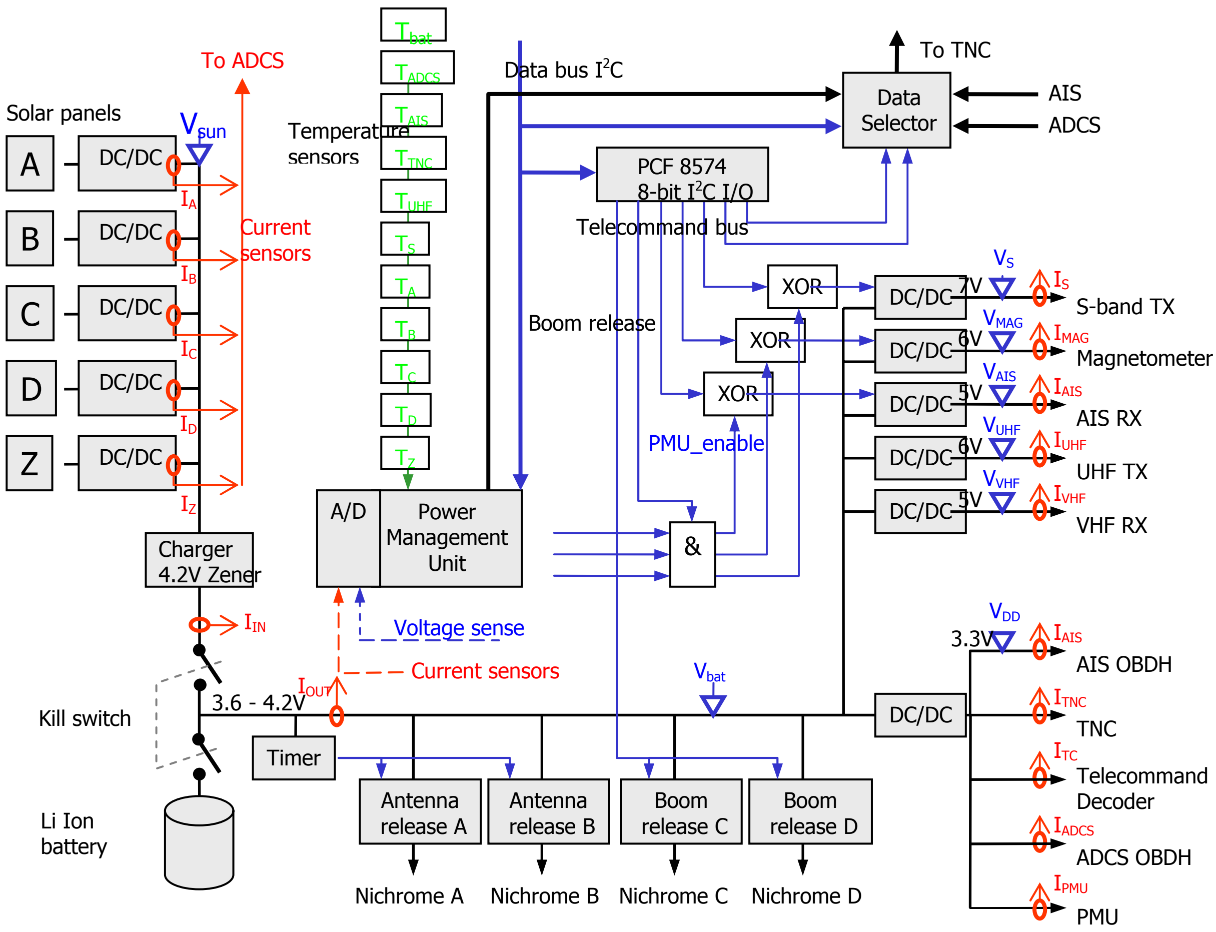
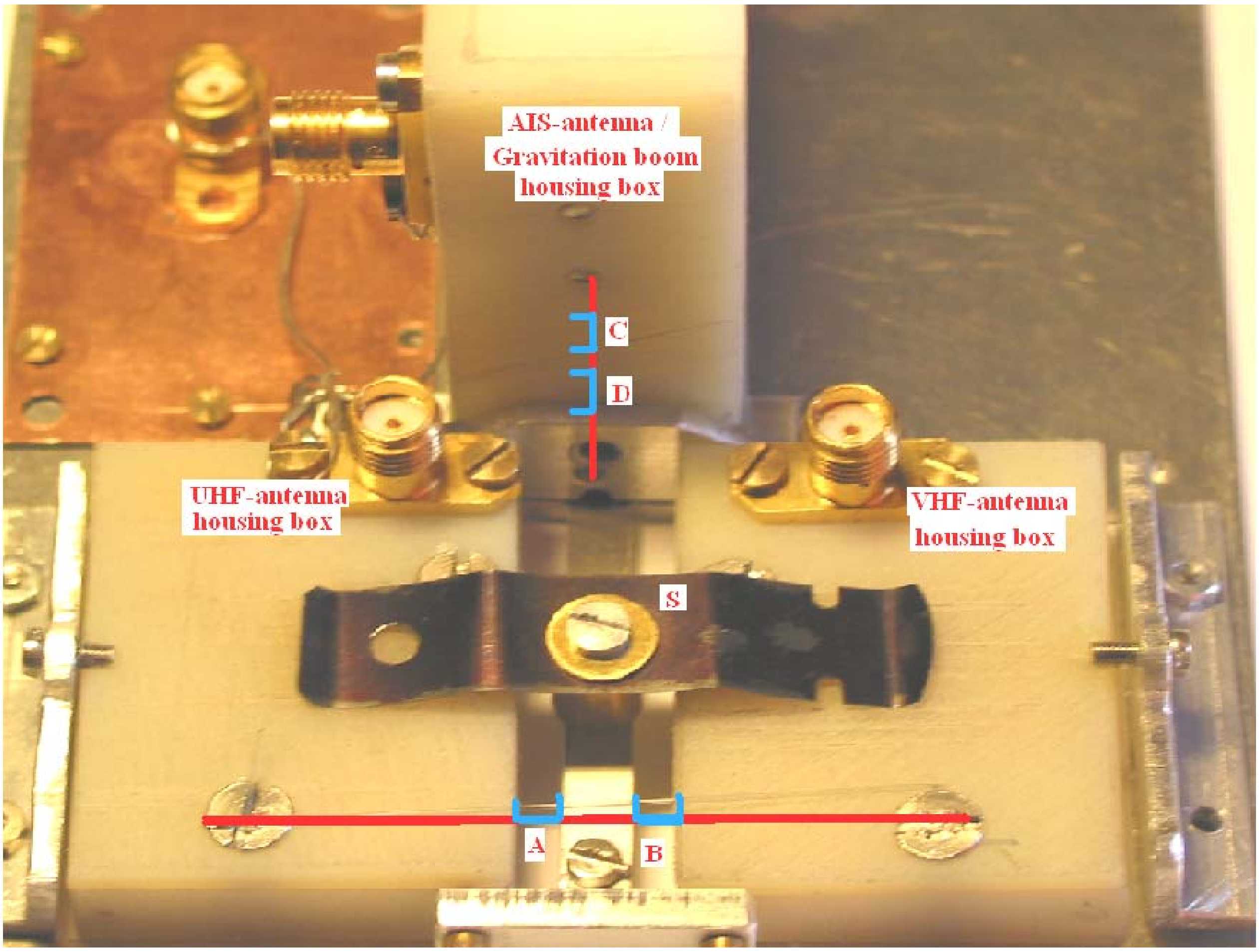


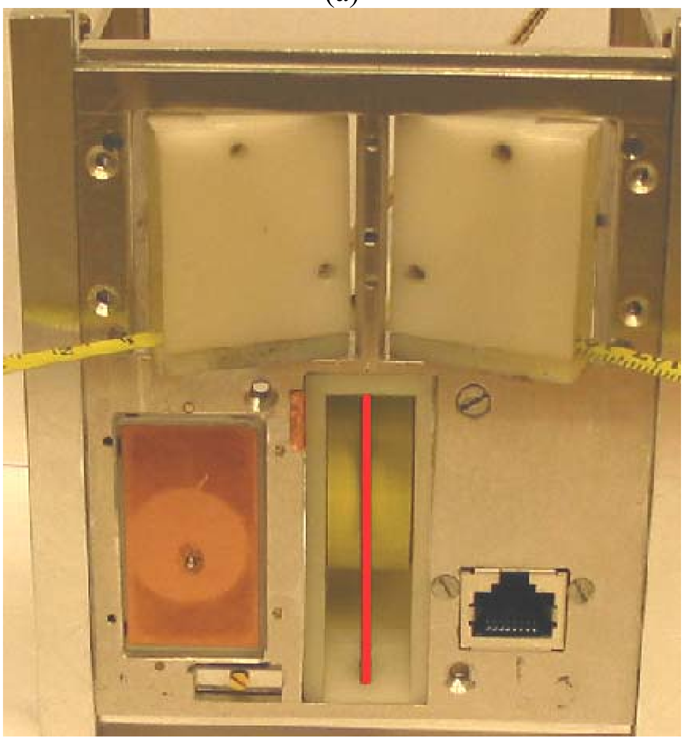

Figure 6-2: Power block diagram

The mounting of the antenna release mechanism is illustrated in figure 6-3 (a). The fishing line that is connected to the UHF-antenna housing box and the VHF-antenna housing box counteracts the momentum in the spring –mechanism, marked S in figure 6-3. Nichrome wire A and B are coiled around the fishing line and when they are heated by the applied voltage the fishing line breaks and the momentum in the spring-mechanism forces the housing boxes to swing to a position where the antennas are freed from the box as shown in figure 6-3 (b).

The AIS-antenna/Gravitation boom is kept in the housing box by a fishing line that is attached to the outer edge of the box as seen figure 6-3 (b). The other end of the fishing line is mounted, as seen in 6-3 (a), inside the satellite. When nichrome wire C and D are heated by the voltage and the fishing line breaks the AIS-antenna/ Gravitation boom deploys it self because of the momentum in the carpenter measuring tape.




(a)



(b)

Figure 6-3: Mounting of deployment mechanism

The voltage which has to be applied to the nichrome wire to break the fishing line has been tested and the results are displayed in table 6-1. The nichrome wire which has been used is produced by Wiretronic Inc [14] has the resistance of 41.65 ohm/ft. The tests are preformed in a vacuum camber.

| Nichrome wire vacuum test | | 2 cm wire, 3 coils |
|---|---|---|
| Voltage (V) | Current (A) | Comment |
| 1 | 0,2 | Plastic melts |
| 1,25 | 0,25 | |
| 2 | 0,4 | |
| 2,6 | 0,5 | nichrome gluing |
| 3,2 | 0,6 | |
| 3,9 | 0,7 | |
| 4,4 | 0,8 | |
| 4,5 | 0,8 | nichrome melts |

| Nichrome wire vacuum test | | 7 cm wire, 0 coils |
|---|---|---|
| Voltage (V) | Current (A) | Comment |
| 3,2 | 0,1 | |
| 8,7 | 0,25 | |
| 8,7 | 0,3 | Plastic melts |
| 8,7 | 0,5 | nichrome gluing |
| 8,7 | 1 | nichrome  gluing very intensely |

Table 6-1: Nichrome wire test preformed by the Power group

It was experienced that the fishing line broke in under a second when voltages between 3.6 and 4.2, as illustrated in figure 6-2, were applied.

The deployment mechanism was also tested in a “low-temperature camber” where the temperature was – 33 ˚ C. It was found that this temperature had no significant influence on the time it took to melt the fishing line. The line broke in less than one second for voltages between 3.6 and 4.2. It was also found that the low temperature did not effect the material booth in the AIS-antenna/ Gravitation boom in any significant way which had influenced the deployment.

Similar deployment mechanisms have also been used in other CubSat projects, [3] and [4].

# 7 Conclusion

The antenna system on board the NCUBE, Norwegian Student Satellite, will consist of three monopole antennas, made of carpenter measuring tape, and one S-band patch antenna.

Two of these antennas will be ¼-wave length monopole antennas, one for the uplink RX frequency, and one UHF TX frequency. The two ¼-wave length monopoles will be mounted to the satellite side which will be facing the earth after the gravitation boom is deployed, the nadir side. This solution saves space for the solar panel so they can cover the other five sides of the NCUBE.

The antenna for the AIS RX frequency is implemented in the gravitation boom. This solution is preferable because it reduces overall weight compared to a solution with separate AIS-antenna and Gravitation boom. When the antenna faces earth it will also have the same polarisation as the antennas onboard the ships. Both the ship and satellite antennas will have zero point along the same axis.

All the three monopole antennas will be stored in the inside small antenna housing boxes. The task of these boxes is to keep the monopole antennas inside the satellite until the satellite is in orbit .These boxes will be made of PAI- or POM-plastic. The antennas will be deployed using a deployment mechanism which consist of nichrome wires and fishing lines.

The patch antenna will be made of Rogers RO4003 QLAM 32 mil and will be mounted to the same side as the deployable antennas. If this antenna were to be more wide banded another antenna material should be used.  It could be thicker, or a material with another dielectric constant could be used since this affects the bandwidth.

**Further work**

The antennas have been mounted to the coaxial cables using SMA-connectors during the measurements described in this diploma thesis. This is however unnecessary, the coaxial cable can be mounted directly onto the antennas. This will save weight which is a precious resource on the NCUBE satellite.

Something that came up during the balloon test at Andøya was that the antennas made of steal measuring tape could influence the magnetometers used by the ADCS-system. This was brought to our attention be an experienced satellite designer, Asbjørn Søreiden, who had work with similar tasks. He suggested that we used Beryllium Copper.

Beryllium Copper has excellent spring properties due to a combination of low modulus of elasticity and high ultimate tensile strength. The alloy gains its physical properties by precipitation hardening. Beryllium copper is non-magnetic.  This material should be further investigated.

The rotation effect the antenna and Gravitation boom deployments have on the NCUBE will be measured in micro gravity. This will take place at the 6th Student Parabolic Flight Campaign at Bordeaux-Mérignac airport in France in the middle of July 2003.The campaign is arranged by ESA (European Space Agency). Four students from the NCUBE-project will participate, myself included. The results of these measurements will be documented in Fredrik M. Indergaards diploma thesis which will be finished in the middle of August.

# 8 References

[1] Official website of the International CubeSat Project: http://cubesat.calpoly.edu/

[2] J Otterstad; Antenna system for NCUBE, 2002 (http://www.rocketrange.no/ncube/active/Forum/dok_vis.html)

[3] T. Hiroshige: CubeSat Antenna Team, spring 2002 (http://cubesat.eng.hawaii.edu/~ttc/x96/Antenna/EE 396 Report.doc)

[4] Stensat, http://users.erols.com/hheidt/StenSat.htm

[5] MEROPE- Montana EaRth Orbiting Pico-Explorer, Montana State University (http://www.ssel.montana.edu/merope/)

[6] J.A Aas; Antenneteknikk, En introduksjon; 2002

[7] W.L. Stutzman; Antenna theory and design, 2nd ed. 1998

[8] P.E Furubotten; AIS mottaker som nytte last i NCUBE, november 2002 (http://www.rocketrange.no/ncube/active/Forum/dok_vis.html)

[9] B Kolundzija; WIPL-D: Electromagnetic modelling of composite and dielectric structures 2000

[10] PCAAD 4.0 (Personal Computer Aided Antenna Design), Antenna Design Associates, Inc., 1999.

[11] F.M Indergaard: Modeling and analysis/design of gravity boom for NCube, 2003 (http://www.rocketrange.no/ncube/active/Forum/dok_vis.html)

[12] EiT : Proposals for the communication subsystem onboard NCUBE, spring 2002 (http://www.rocketrange.no/ncube/documents/NCUBE-rapport-COM.pdf)

[13] Getting Started with Antenna Pattern Measurements 1D version, 2000 (http://www.tele.ntnu.no/radio/fag/SIE2080/AntennaLab/AntPatternMeas.pdf)

[14] WireTronic Inc.: www.wiretronic.com

## Appendix A - CUBESAT Design Specifications Document

**CUBESAT**
**Design Specifications Document**

**Revision VII**
**February, 2003**
**Contacts:**

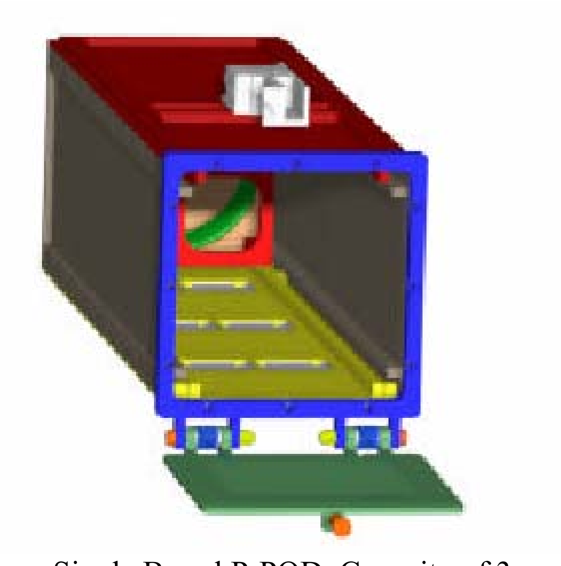
### GENERAL GUIDELINES

1. CubeSats must not present any danger to neighbouring CubeSats in the P-POD or o primary payloads:
• All parts must remain attached to the CubeSats during launch, ejection and peration. No additional space debris may be created.
• CubeSats must be designed so as to not jam on ejection.

2. All satellites must be powered off during integration and launch to prevent any lectrical or RF interference with the launch vehicle and primary payloads.

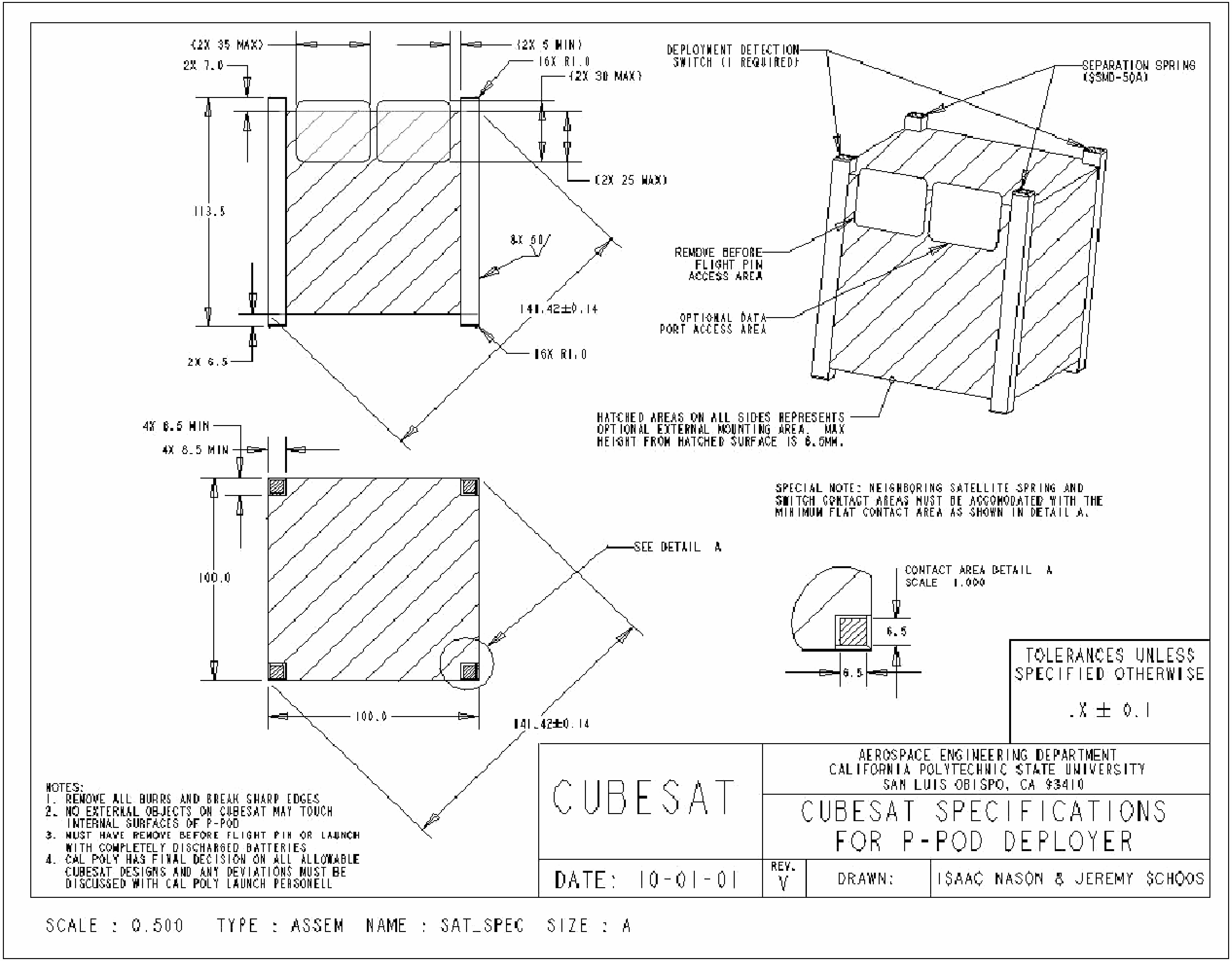
3. CubeSats must use designated space materials approved by NASA (http://epimsogsfc.nasa.gov/og/) to prevent contamination of other CubeSats and primary payloads during integration, testing, and launch.

4. Cal Poly and Stanford hold final approval of all CubeSat designs. Any deviations from this document must be discussed with Cal Poly/Stanford launch personnel before the final CubeSat design is approved for launch.



Single Barrel P-POD, Capacity of 3

Double Barrel P-POD, Capacity of 6


(2X 35 MAX)
(2X 5 MIN)
2X 7.0
16X R1.0
(2X 30 MAX)
(2X 25 MAX)
113.5
8X 50
141.42±0.14
16X R1.0
2X 6.5
4X 6.5 MIN
4X 6.5 MIN
100.0
100.0
141.42±0.14
SEE DETAIL A
DEPLOYMENT DETECTION SWITCH (1 REQUIRED)
SEPARATION SPRING ($SMD-50A)
REMOVE BEFORE FLIGHT PIN ACCESS AREA
OPTIONAL DATA PORT ACCESS AREA
HATCHED AREAS ON ALL SIDES REPRESENTS OPTIONAL EXTERNAL MOUNTING AREA. MAX HEIGHT FROM HATCHED SURFACE IS 6.5MM.
SPECIAL NOTE: NEIGHBORING SATELLITE SPRING AND SWITCH CONTACT AREAS MUST BE ACCOMODATED WITH THE MINIMUM FLAT CONTACT AREA AS SHOWN IN DETAIL A.
CONTACT AREA DETAIL A
SCALE 1.000
6.5
6.5
TOLERANCES UNLESS SPECIFIED OTHERWISE
.X ± 0.1
NOTES:
1. REMOVE ALL BURRS AND BREAK SHARP EDGES
2. NO EXTERNAL OBJECTS ON CUBESAT MAY TOUCH INTERNAL SURFACES OF P-POD
3. MUST HAVE REMOVE BEFORE FLIGHT PIN OR LAUNCH WITH COMPLETELY DISCHARGED BATTERIES
4. CAL POLY HAS FINAL DECISION ON ALL ALLOWABLE CUBESAT DESIGNS AND ANY DEVIATIONS MUST BE DISCUSSED WITH CAL POLY LAUNCH PERSONELL
CUBESAT
AEROSPACE ENGINEERING DEPARTMENT
CALIFORNIA POLYTECHNIC STATE UNIVERSITY
SAN LUIS OBISPO, CA 93410
CUBESAT SPECIFICATIONS
FOR P-POD DEPLOYER
DATE: 10-01-01
REV. V
DRAWN:
ISAAC NASON & JEREMY SCHOOS
SCALE : 0.500 TYPE : ASSEM NAME : SAT_SPEC SIZE : A

## REQUIREMENTS

In addition to the specifications presented in the attached drawing, CubeSats must comply with the following requirements:

**Mass**

- Each satellite may not exceed 1 kg of mass.
- The CubeSat center of mass must be within 2cm of the geometric center.

**Structure**

- All edges that contact the rails must be rounded. CubeSats must have at least 75% (85.125 mm of a possible 113.5mm) of flat rail contact with the deployer.
- To prevent cold-welding, raw metal is not allowed as the contact surface of the bottom standoff. Derlin inserts, or a hard anodize are examples of acceptable contact surfaces.
- The outer surfaces of the CubeSats are required to be hard anodized in order to prevent wear between the sliding rails and the CubeSats.
- Separation springs must be included at designated contact points (see drawing). Recommended springs are manufactured by M.J. Vail part number SSMD-50P (http://www.mjvail.com). A custom separation system may be used upon approval by Cal Poly/Stanford launch personnel.
- One deployment switch is required (two are recommended) for each CubeSat. The deployment switches should be attached to the top surface of at least one of the four feet of the CubeSat (refer to drawing).

**Material**

- The use of Aluminium 7075 or 6061-T6 is suggested for the main structure. If other materials are used, the thermal expansion must be similar to that of Aluminium 7075-T73 (the P-POD material) and approved by Cal Poly/Stanford launch personnel.

**Deployables**

- A time delay, on the order of several minutes, must be present between release from the P-POD and any satellite hardware deployment, to allow for satellite separation.
- P-POD rails and walls cannot be used to constrain deployables.

**Communication**

- There must be a time delay, on the order of several minutes to an hour, before all primary transmitters are activated. Low power beacon transmitters may be activated after deployment.
- Operators must provide proof of the appropriate license for frequency use.

**Power**

- CubeSats with rechargeable batteries must have the capability to receive a transmitter shutdown command, compliant with FCC regulations.
- Satellites that require testing and battery charging must provide an external hardware interface to access the power/data port. Developers can use any kind of connector in their CubeSat, but a proper interface must be provided between standard Cal Poly equipment and the satellite. This could include interface boxes, software, a laptop, etc. Contact Cal Poly with the desired design requirements.
- A ‘remove before flight pin’ is required to deactivate the CubeSats during integration outside the P-POD. The pin will be removed once the CubeSats are placed inside the P-POD.

**General**

• Absolutely no pyrotechnics are allowed inside the CubeSat.
• A final check of specifications will be conducted prior to launch.

## TESTING

All CubeSats must undergo testing prior to launch. Currently planned tests are outlined below.

**Vibration Qualification Test**

• A vibration and shock qualification test of 125% of launch-loads must be completed. This test must be preformed with the CubeSat in the test-pod provided by Cal Poly. This test may also be completed by CubeSat developer institutions (proper documentation will be required). With ample notification, Cal Poly can perform this test for a fee before final integration.

Τηερμαλ Τεστ

• Cal Poly will perform a thermal- vacuum test with the CubeSats inside the P-POD. Specific testing procedures will be provided at a later date. Note, that a number of CubeSats will undergo thermal-vacuum tests simultaneously. If a CubeSat has special contamination requirements, individual thermal-vacuum tests can be discussed.

**Vibration Acceptance Test**

• A vibration and shock acceptance test (100% launch-loads) inside the P-POD will be preformed at Cal Poly.

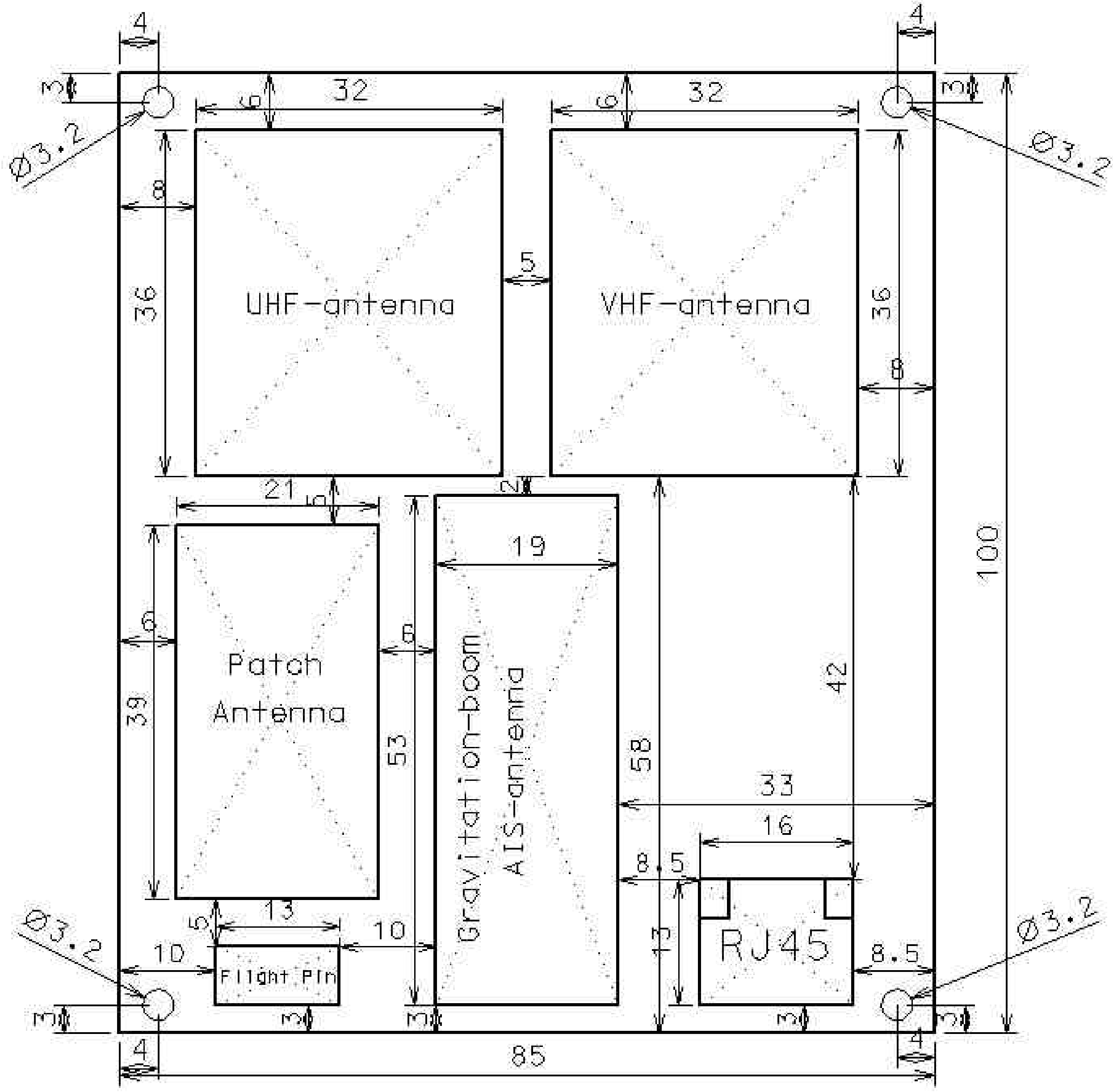
**Integration**

• An additional vibration and shock acceptance test (100% launch-loads) may be erformed upon final integration. This test is dependent on the requirements set y the launch provider.

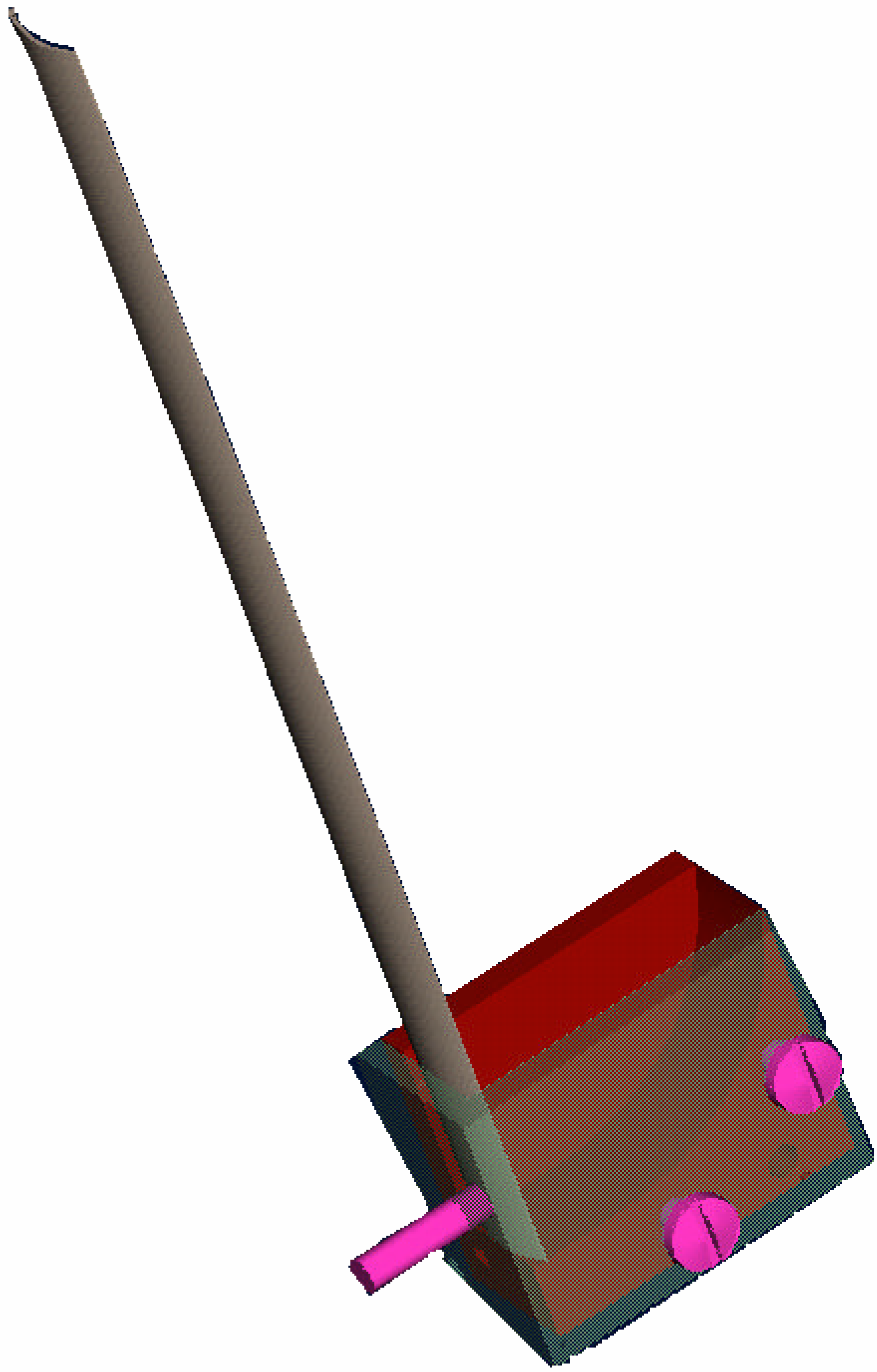
## Appendix B - CAD-drawings

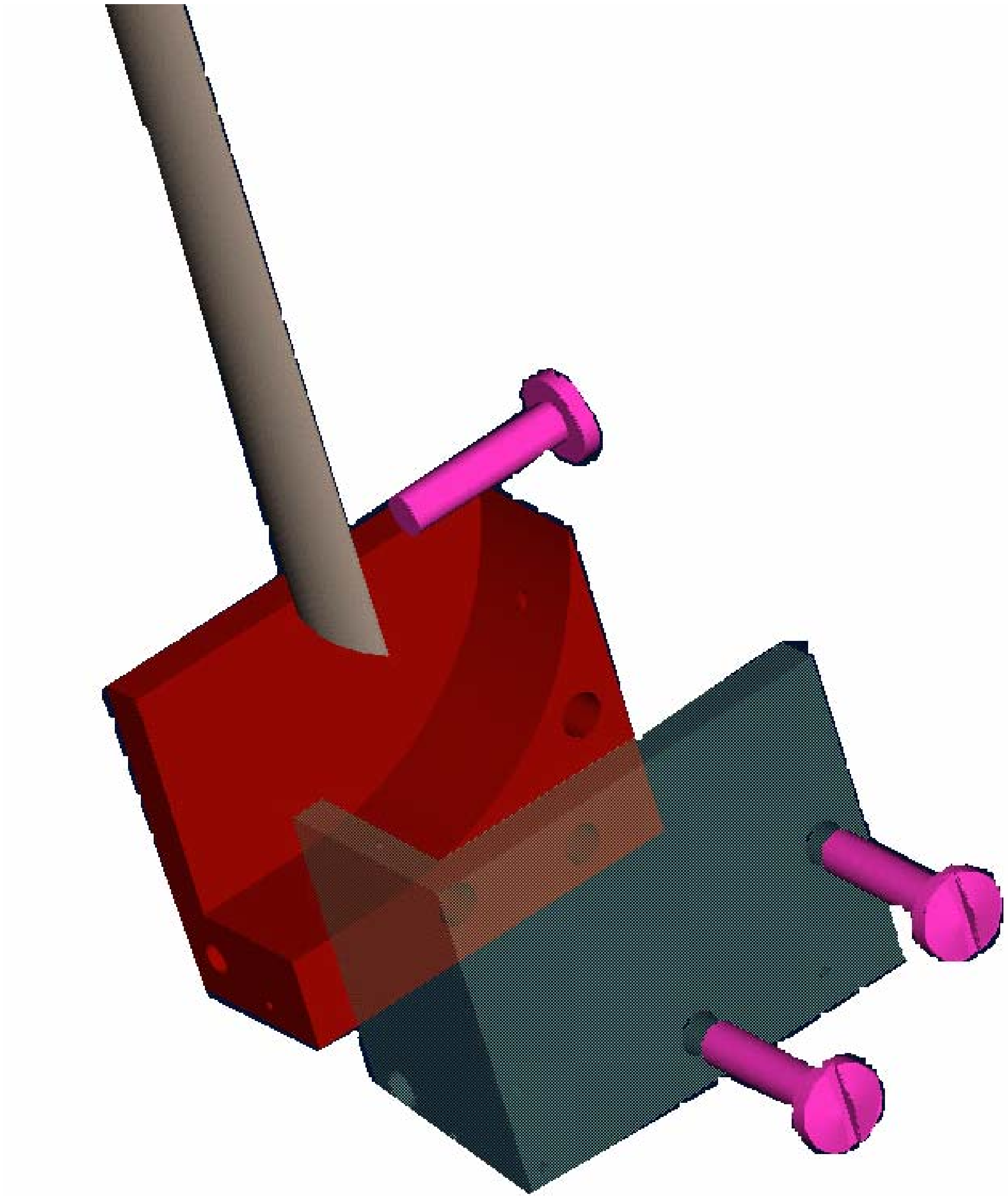
The CAD-drawings show the exact place ment of the mechanical components on the nadir side (also called mechanical side).

### Mechanical side



## MEROPE, Antenna housing cups





## Appendix C- MatLab files

### VSWR

MatLab file which calculates the voltage standing wave ratio.

```
==========================================================
clear;                                      % Clears all data stored
clf;                                        %Clears figure

disp('VSWR ut fra data fra WIPL-D')
disp('')

f0=input('Start frekvens[MHz]: ');
fN=input('Stopp frekvens[MHz]: ');

N=input('Antall frekvenser: ');

f_int=(fN-f0)/(N-1);                        %calculates freuqency interval
f_vektor=[f0:f_int:fN];                     %creates a frequency vector

S11=input('Refleksjons koeffesient-vektor: ');   % Put in the ANA generated S11-vector


i=0;
while(i<N)                                  % Calculates the VSWR for all the frequeies
    i=i+1;
    vswr(i)=(1+abs(S11(i)))/(1-abs(S11(i)));
  end

plot(f_vektor,vswr)                         %Plots the VSWR
title('VSWR(f)')
ylabel('VSWR')
xlabel('Frekvens(f), MHz')
==========================================================
```

## Appendix D – Datasheet of the antenna housing materials

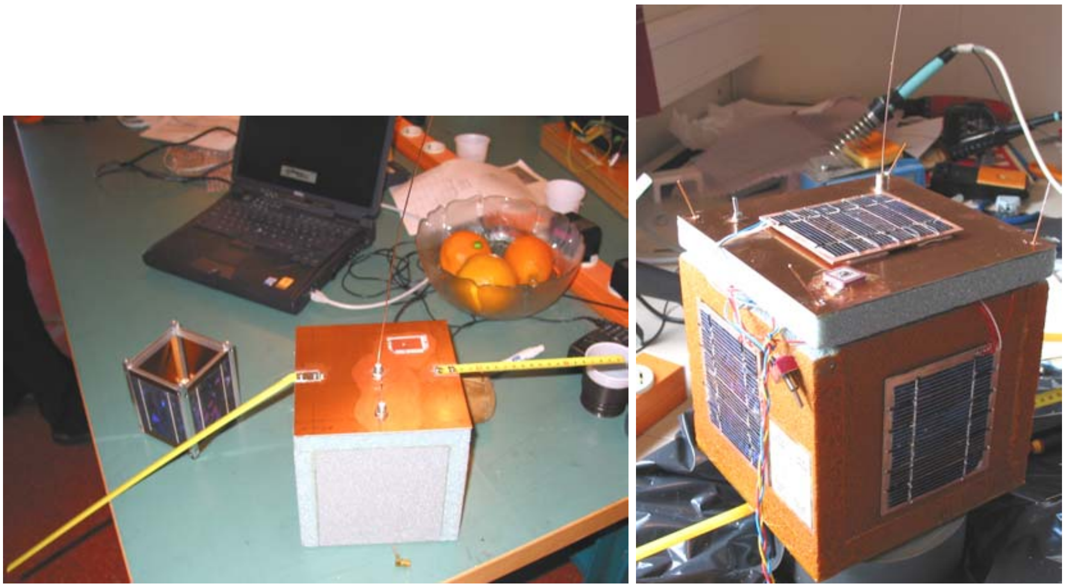
Data are provided by the engineering workshop at the Department of Telecommunications.

| **Plastic type, Shortened name** | **PAI** | **POM** |
|---|---:|---:|
| Full name of raw material | Polyamide-imide | Polyoxymethylene |
| Trademark | Torlon | Delrin |
| **Mechanical properties** | | |
| Own weight [g/cm3] | 1.4 | 1.41 |
| Flexural strength [N/mm2] | - | 117 |
| Tensile strength [N/mm2] | 152 | 65 |
| Tensile expansion [%] | 12 | >30 |
| E-module [N/mm2] | 4800 | 3000 |
| **Thermal properties** | | |
| User temp. max, temporary [ºC] | 280 | 140 |
| User temp. max, long-lasting [ºC] | 260 | 100 |
| User temp. min, long-lasting [ºC] | - | -40 |
| Expansion because of temperature change [mm/m/ºC] | 0.03 | 0.11 |
| **Electrical properties** | | |
| Dielectric constant | 3.2 | 3.8 |
| Dielectric loss factor | 0.034 | 3.50E-03 |
| **Other properties** | | |
| Moisture absorption | - | 0.25 |
| Water absorption | 0.4 | 0.5 |
| In flammability | Incombustible | Normal in flammability |

## Appendix E- Balloon test, Andøya June-2003

The balloon test took place at Andøya rocket range between the 11th and 13th of June, this late date is the reason only this short appendix is presented in this diploma thesis.

At Andøya a simplified model was built, figure E-1. This model was quite different than the original NCUBE. It had the dimensions of 20 cm * 20 cm * 20 cm. It was made of divinycell to be water resistant, since it could land at sea when the balloon was cut from the model. The weight of this model was nearly 2000 grams.



(a) (b)

Figure E-1: Balloon test model

It was decided that the antennas on the mechanical side were not going to be deployable. The model had the S-band patch antenna and the VHF-and UHF-antenna mounted to the Nadir side as shown in E-1 (a) as the original NCUBE will have. The AIS-antenna was made of piano wire and was much shorter than in the original case, it was a ¼-wavelength monopole, since there was no need for the Gravitation boom during the balloon test. On this side the there was also mounted an antenna for a video camera which were to be brought along. The balloon test model also had a GPS-antenna on the opposite side which was going to be used to track the satellite.

Unfortunately the balloon test was aborted just before initiation. This was due to failure with one of the radios inside the model, probably a power failure. There was no time to fix this due to short time limits. Many of the system were also not integrated because of various malfunctions.

A new balloon test will probably find place in August this year, 2003, since several participant of this project have got summer jobs on the project. For further development on this situation look at the NCUBE's homepage: http://www.rocketrange.no/ncube/