Diploma Report

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Høgskolen I Narvik

Automated Remote Ground Station

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.   Abstract:

On the library roof of Narvik University College a ground station has been built during the diploma period spring and summer 2003. The ground station is to be used to communicate with a satellite built in the same period by students from Narvik University College, The Norwegian University of Science and Technology and The Norwegian University of Agriculture.

The satellite will try to pick up AIS messages, containing speed, position and possibly cargo from ships travelling in territorial waters, along with telemetry for housekeeping parameters as temperature, charge, lighting conditions, magnetic field and orientation. To communicate this information back to earth, and to command satellite operations the ground station uses much the same technology as AMSAT OSCAR ground stations do. This means that information is carried on radio frequencies in the area 144-146MHz and 430-440MHz amateur frequencies.

When constructing the ground station we have kept in mind not to exclude the possibility of participating in the Global Federated Ground Station Network. This network makes it possible for other users to use our station in its idle period, and at the same time gives us access to their ground station when our satellite is on their horizon.

Information is modulated into the carrier digitally using AX.25 protocol. This is almost becoming a standard for student satellites, making both us and other student satellite projects able to communicate with each others satellites.

The antenna system consists of four crossed 435 MHz Yagis for receiving, and two crossed 144MHz Yagis for transmitting. The signal is phased together using matched 50 Ohm's splitters, combiners and cables where lengths are tuned to the actual frequency of the satellite. For the receiving antennas a low noise amplifier of 23dB is installed in the antenna rig. All antennas are protected from lightening using a lightening arrestor preventing damage to the transceiver.

Antennas are steered by two independent axis rotor controllers, which are connected to a program that estimates satellite positions and pointing angles. The signal to and from the satellite is controlled via a transceiver with a built in terminal node controller, which acts almost like a modem.

The transceiver and rotor controller have a RS-232 serial port, enabling computer control. To these serial ports; "RS-232 to TCP/IP" bridges are installed, enabling the operators to be anywhere on earth Internet is available to use our ground station.

Programs on computers connected via Internet to these bridges as clients, acts as terminal emulators, data loggers, and can run predetermined scripts.

2   Contents

3   Introduction

Four Norwegian Educational institutes have from autumn 2001 to summer 2003 participated in the nCube project. The nCube project was to build the first Norwegian student satellite. The mission was given by Andøya Rocket Range in close cooperation with Norwegian space center.

The satellite is due to be launched from Dnepr in Russia, Autumn 2004. The launch vehicle will carry the satellite into a near circular polar orbit with perigee at approximately 700km and inclination close to 98 degrees.

My involvement in the project started in the course "Prosjektfag" at Narvik University College (HiN). At this time I was a 4th year Master degree student. During this course several project reports were created, these can be found in the appendix part of this report. My group had the responsibility proposing a method making it possible to communicate with the satellite when in orbit. Or more precisely, my group took responsibility for the Earth side of the communication.

As the project moved on it became apparent that that our task became to realize our proposal, by building a ground station here in Narvik. The ground station is now built and is located on the roof of the library building of the HiN complex. The ground station has its operations center located in Room E3041.

I was given these specific tasks to achieve my Master Diploma:
"
1. Mathematical presentation of the communication between satellite and earth station.
2. Calculation of the link budget and data rates between nCube and earth station.
3. Overall ground system design and communication architecture.
4. To present system / user data from nCube satellite and relay them to a remote user.
5. To store commands and data from communications for later retrieval.
6. To transmit a desired signal, possibly from a remote user that can be detected and interpreted onboard the satellite.
7. System analysis and test results.
"
The document which defines my tasks is enclosed as appendix A.

My goal is that this report shall have as few unresolved external references as possible. All derived and previous work with relevance to this subject is also being included in the external appendices section. Where a practical task, such as physical setup and programming was suggested in the Diploma Project description; the code it selves and the physical solution should be considered as a part of this work, along with commentaries in this document. A great amount of my time has been spent on the construction and assembly of the hardware itself. In addition much of the equipment needed to be understood in detail to be properly interfaced.

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One objective given from the project administration, was that our work should be made public available, to enhance the interest for mathematics, physics and science among undergraduate students. I will therefore try to write an easy to read report in a explanatory manner.

I also try to write my report so it can be used as a handbook or reference for future operators of our ground station, and therefore explaining in detail how both some of our hardware and software works.

.   Acknowledgements:

Figure 1: *Communications Tower – nCube Cubesat – Amateur radio bands.*

4   Mathematical Presentation of the communication

To ensure a common understanding of basic principles I start my report by introducing the reader to Maxwell's law of EM Propagation and terms used in linkbudget calculations.
I use this to show how the communication can be matemathically presented and showing how it is possible to detect an oscillation of current in a conductor from a distance. Also to show how we make use of these principles to transfer information between the nCube to the ground station

James Clerk Maxwell (1831-1879) discovered how a time changing magnetic field "B" induces a current in a nearby conductor, and the other way around how an accelerating charge creates a magnetic field.

4.1   The magnetic field of a current distribution:

$$\int_{path} \overline{B} * d\overline{L} = \mu_0 I \qquad (4.1)$$

Where 'μ0' is the magnetic constant $4*pi*10^{-7}$ [N/A^2] and 'I' is the charge carried thru a intersection of a conductor:

$$I = \frac{dQ}{dt} = \frac{d\phi_E}{dt}\varepsilon_0 \qquad (4.2)$$

'ε0' is the electric constant 8.85*10-12 [F/m]. And so can the magnetic field around a conductor be found:

$$\int_{path} \overline{B} * d\overline{L} = \mu_0\varepsilon_0 \frac{d\phi_E}{dt} \qquad (4.3)$$

Constants : NIST [13]

By assembling a capacitor "C" and a coil "L", and exiting this, causes the circuit to oscillate (fig. 4.1) And current sloshing back and forward thru the undisclosed wire.
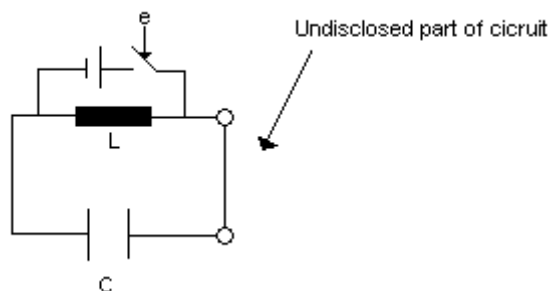
Figure 4.1: *Simple oscillator*

The frequency for which circuit in figure 4.1 oscillates is given by eq 4.2

$$f = \left(2\pi (LC)^{\frac{1}{2}} \right)^{-1} \qquad (4.4)$$

When current passes thru the undisclosed wire, a magnetic field is induced around the wire, because the movements of the charge-carrying electrons.
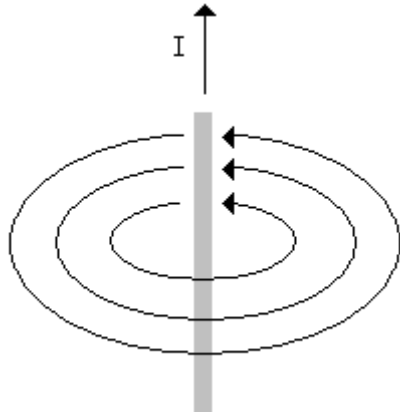
Figure 4.2: *Induced B field.*

By introducing a new circuit in the proximity of the first, the energy held by the magnetic field induces an oscillation in the neighboring circuit too.
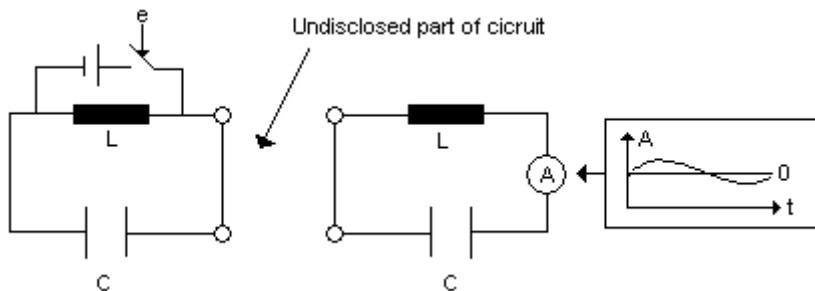
Figure 4.3: *Oscillation spreads over to the neighboring circuit.*

By investigating the behavior of the following circuit, an understanding of how the E field is generated is gained. When time increases, the charge on the conducting areas are changing:
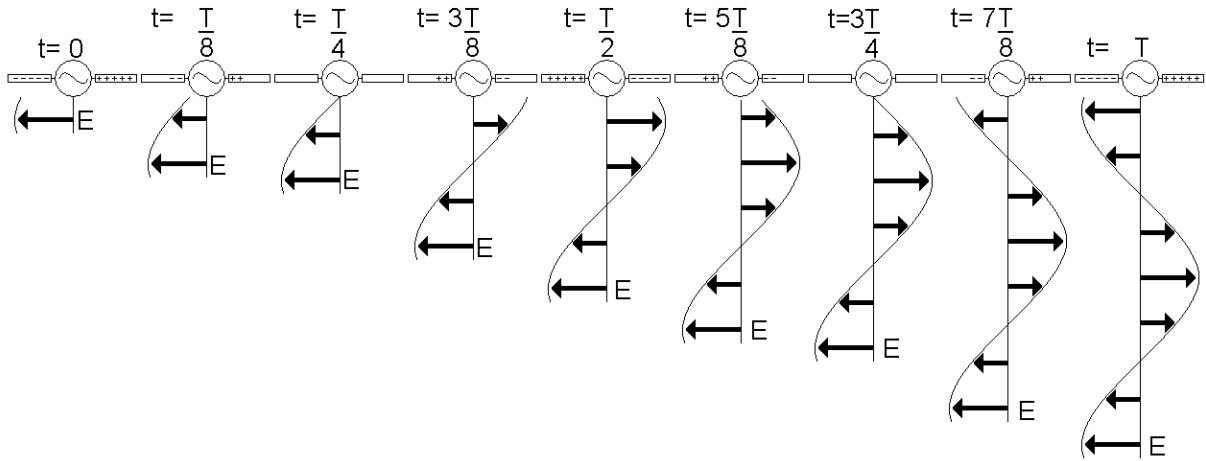
Figure 4.4: *Origination of an E field from a generator driven dipole.*

The panels on each side of the generator act as capacitors and:

$$T = f^{-1} \qquad (4.3)$$

4.2   The complete propagating EM wave

The E field induces a B field equal in amplitude but at right angles:
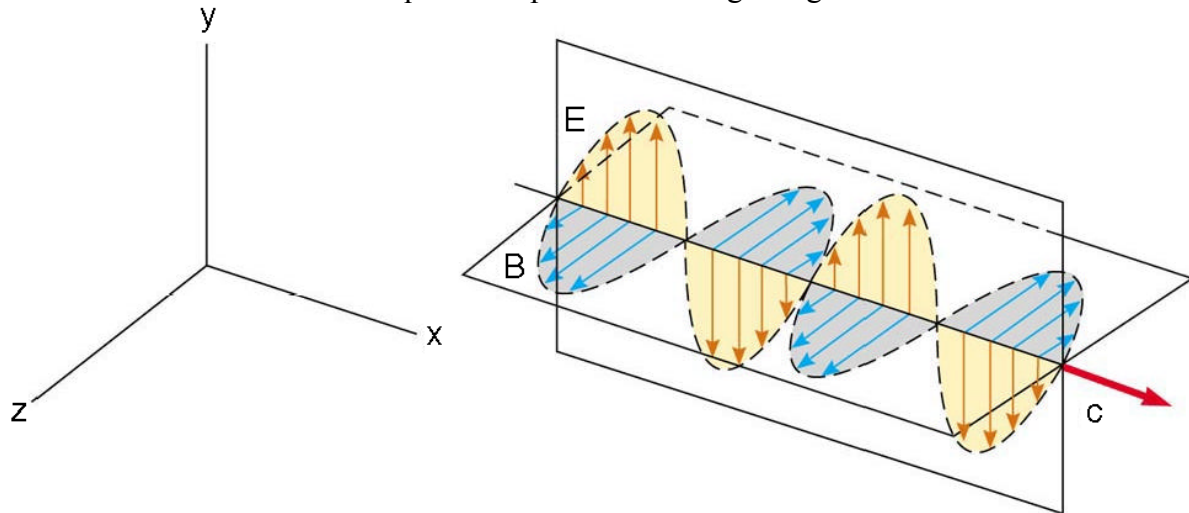
Figure 4.5: *The complete propagating EM wave.*

Where one wavelength is:
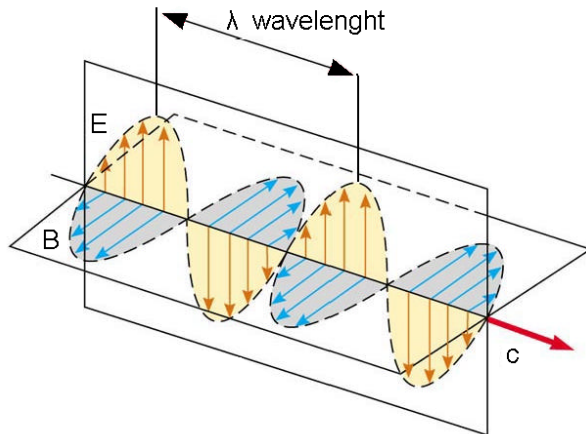
Figure 4.6: *Measuring wavelength*

The relationship between the frequency and the wavelength is:

$$f * \lambda = c \qquad\qquad (4.6)$$

c is the speed for which the EM field propagates, for vacuum c is:

$$c_0 = \left(\mu_0 * \varepsilon_0\right)^{-\frac{1}{2}} \qquad\qquad (4.7)$$

This is known as the speed of light. For other mediums, our cables and actually earths own atmosphere, c is slower than the speed of light, the difference between air and vacuum is negligible for our purpose. The speed in cables is given by the manufacturer and must be considered.

We assume that our satellite is an isotropic source, and we use the Effective Isotropic Radiated Power (EIRP) from the antenna onboard the satellite. The EM field power density and the power received from a distance "r" from a such source, thru a given area is given by:

$$S\left[W / m^2\right] = \frac{\hat{E} * \hat{B}}{2\mu_0} = \frac{\hat{E}^2}{2\mu_0 c} = \frac{c * \hat{B}^2}{2\mu_0} \quad (4.8)$$

For example; assume that the message we want to send can be carried in one bit, and this is achieved by modulating the carrier either on or off. The period for which the carrier is on or off is one second. Assume that sender is an Isotropic source, which means a perfect singular point in space, hence dividing its energy equally in every direction. At a distance we measure that the power density of the signal is one watt per square meter. The total energy across this section for one bit of our message is then:

S/f or S*T   (4.9)

In our example again if the bit is the 'on' state of the carrier, this is 1 watt per square meter for one second, or one Joule/m^2. As we see from equation 4.7, a doubling of the distance yields a quarter of the Energy per bit per area. So the power density is rapidly diminishing along its path. We can imagine *our bit* as a sphere where the 'r' is expanding in every

direction with the speed of light for that medium. This is known as the propagation or path loss.
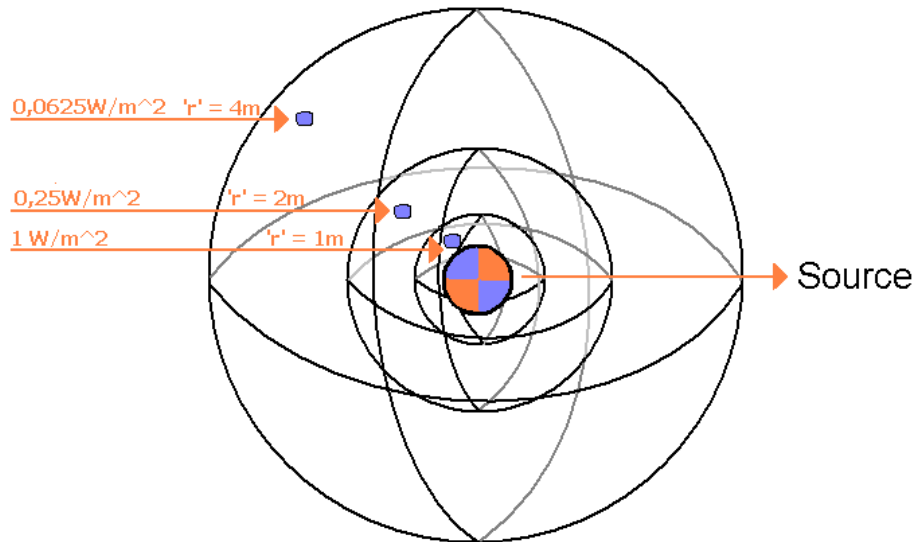
Figure 4.7: *The imagined shells or spheres of propagating EM waves, and power densities.*

From this relationship we see that the power density distributed on a such shell in a given area is:

$$S = \frac{EIRP}{4\pi r^2} \quad (4.10)$$

Where EIRP is the power emitted in the direction of the area measured. By using this term we introduce the possibility of replacing the singular isotropic point with a non isotropic source. And the EIRP is calculated from the gain given by adding directivity to our antenna source.

At some point of the spheres travel the power density of the signal is lower than the power density of the background noise from the surroundings. When this is the case, the probability of correct detection is lower than 50%. This is known as the Signal to Noise ratio S/N. We could also estimate the energy per bit (Eb) at this point if the effective area of our receiving antenna was known. The relation between the noises in the current bandwidth at this area and the energy per bit is known as:

Eb/No (4.11)

In my visualization in figure 4.6 the energy per bit corresponds to the volume of a section of a certain power density times the physical "length" of this signal passing thru the section with the speed 'c' of the current medium..

4.3   Detection of the signal:

The signal can be detected by placing a coil or conductor in the direction of the B field, or a conductor or capacitor in the direction of the E field, see figure 4.7
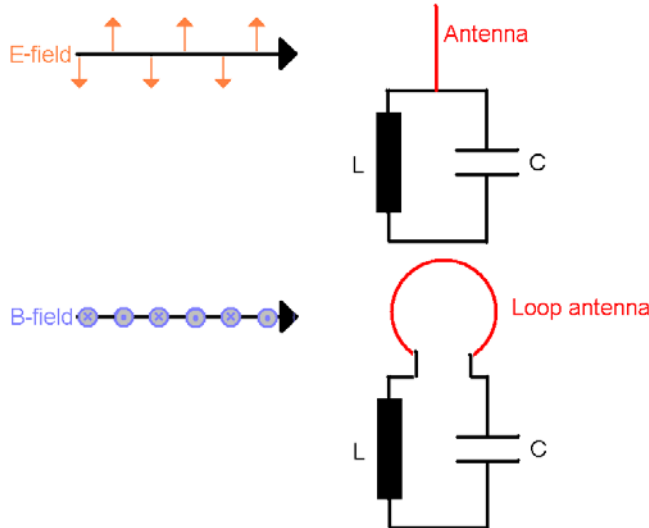
Figure 4.8: *Detecting E part and B part of the EM field*

An invention by two Japanese researchers Yagi and Uda in 1926 , The Yagi-Uda Array, or more commonly the "Yagi", is an antenna capable of converting an EM field back to an electrical signal. It is directional which means it reaches its highest sensitivity or gain when it point at the source of the EM. This antenna is especially popular among amateur radio and ground based satellite communication systems.

The Yagi consists of several stacked elements (figure 4.8), approximately half the wavelength of the desired EM field, only one of these elements acts as the actual detector, and is connected to the receiving or transmitting system. The other elements are either called directors or reflectors. The directors are successively shorter than the detector and are closer to the EM source in the pointing direction. The reflector, usually only one, is longer than the detector, and is placed behind this.

See also: Some additional properties with Yagi antennas and arrays, in chapter 5.

Source
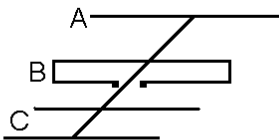
Figure 4.8: *Elements in the Yagi Uda Array*

A – Reflector

B – Dipole
C – Directors

For information-carrying EM waves, a link budget is commonly used to estimate the probability of detecting and reconstructing the information modulated into the carrier. Calculating this budget involves handling of exceptional large and small numbers. To manage this in a feasible manner, Alexander Graham Bel proposed the use of a logarithmic system, with base 10. This means that the size 1 is 0 Bel, 10 is 1 Bel, 100 is 2 Bel and so on. To convert back to base linear scale:

$$10^x \qquad (4.12)$$

where x is the number in Bel, the inverse operation of this is defined as:

$$\log_{10} y \qquad (4.13)$$

where y is the number in a linear scale.

When using this logarithmic scale, operations between numbers are affected,
The number 10 times 10, is 100 in a linear scale. Knowing that 10 is 1 Bel and 100 is 2 Bel, this gives:
$$10*10 = 100 \Leftrightarrow 1Bel + 1Bel = 2Bel$$
Hence replacing the multiplication, with addition, in the same way it can be shown that the exponential function is replaced by a multiplication, roots by division and division by subtraction in logarithmic scale.

The Bel is usually considered to big, and most commonly decibel is used where 0.1Bel = 1decibel, notated as dB. 0 dBm is one milliwatt. And 1dBm is one decibel greater than 0 dBm, or about 1.259 mW. Roughly an addition of 3 dB is a doubling of the reference.

4.4   Coding, Modulation and code gain.

Since the amateur radio standards only permits us to occupy 25 kHz, which is one voice band modulated on our carrier per link.

As simply turning carrier on and off generates massive transients in the RF-spectra, so when a larger amount of information needs to be transported a more clever method than just turning the carrier on and off must be used to save bandwidth. Different modulation techniques exist; I'll review a couple of them, and list / calculate their benefits and constraints.

Generally the modulation techniques can be put in two classes:

-Multi level modulation, when more than one bit is sent per change in modulation (baud).
This means that actual bit/s is higher than the baud rate. Examples on this are:
MFSK, Multi level frequency shift keying
QPSK, Quadrature phase shift keying
DQPSK, Differential Quadrature phase shift keying
QAM, Qadrature Amplitude modulation

-Two level modulation, where bit rate and baud rate are the same. These are reviewed in more detail below, since these are more relevant for amateur radio use due to lower complexity.

The Shannon/Hartley teorem states that the maximum theoretical datarate Rmax, which can be transmitted over a transmission channel with abandwith B is:

$$R_{max} = B \log_2\left(1 + \frac{C}{N}\right)$$

Where C/N is the average carrier-to-noise power ratio in the channel. But nearing this limit introdusces large costs and complexity in the modulation design. One important measure is the BER (bit error ratio), when nearing the Shannon limit the BER worsens. So reliability is a trade off between usage of fujuttushi the frequency spectrum and the actual bandwidth to ensure a high probability of detection. The most common BER demand is BER<10^-5 for data and BER<10^-7 for the command channel. We mix both these functions and accepts a BER<10^-6 for both.

4.4.1 Audio Frequency Shift Keying (AFSK),

Generally used for bit rates 1200 and 2400 per second, AFSK[19] is simple, reliable, and low cost method for transmitting data with radios made for simple voice communication; it is a modulation of the carrying EM wave with two different audible tones. 1200 bps signals are easily handled by almost all radios through connections to the microphone and speaker connectors.

2400 baud AFSK often presents too broad an audio signal for standard voice radios, but works well with telemetry grade (data) radios, like the TS-2000 and SmartRF CC1020[21] which is used aboard the nCube.

4.4.2 Minimum Shift Keying (MSK)

MSK modulation allows higher data rates to be used on voice radios via microphone and speaker connections.

The MSK modulation is also usable at 1200 and 2400 baud and use tone pairs at 1200/1800Hz for 1200 Baud and 1200/2400Hz for 2400 Baud. Transitions between tones occur at zero crossing points reducing transients and bandwidth spreading.

The MSK modulation is not compatible with 1200/2400 baud AFSK because of the different tone pairs and clock synchronization methods used. It can be mixed with AFSK on the same channel, but data connection between MSK and AFSK units will not occur.

4.4.3 DFM and Gaussian Minimum Shift Keying (GMSK)

For bit rates 4800, 9600, 19200, and above (GMSK), Direct Frequency Modulation is used where higher data rates are required. A key feature of the DFM modem design is digital generation of the transmit audio waveform. Precise shaping limits the signal bandwidth. Deviation of +/- 3KHz gives an RF spectrum 20KHz wide (-60dB).

Some modems, and among them TS-2000 and THD-7's integrated TNC from Tasco use a large scale integrated circuit which produces a waveform very similar to DFM. This modulation method is termed Gaussian Minimum Shift Keying (GMSK)

Using a DFM modem entails modification to a voice radio so that direct connection can be made to both the modulation varactor and receiver discriminator. These connection points are brought out to the data connector of our radio.

GMSK is based on the MSK with a Gaussian filtering at the output, the difference in frequency between the signal "0" and "1" is exactly half the datarate, so the modulation index for MSK is 0,5, this is defined as:

$$m = \Delta f * T \qquad (4.14)$$

where

$$\Delta f = \left| f_{logic0} - f_{logic1} \right| \qquad (4.15)$$

T=1/bit rate   (4.16)

The behavior of GMSK modulation and demodulation is discussed more extensively in the "Calculation of the link budget and communication rates between nCube and GS" chapter, as GMSK is the preferred modulation technique for amateur satellites to optimize the use of the accessible bandwidth.

5   Overall ground system design and communication architecture.

5.1   Selecting the location

The location, for which the ground station is now placed, was selected in an earlier phase of our project. We used a inclinometer to measure up the horizon finding where line of sight communications were possible, and estimated contact times for a given fictive day's pass from Ås, Trondheim, Narvik, Andenes and Ny-Ålesund, see our report "A System Requirements Recommendation" [5]. The MCC (Mission Control Centre) is Room E3041 in the E-block of the theoretical wing of HiN.

5.2   Communication Architecture

The SMAD [6] states that "*communications architecture* is the arrangement, or configuration, of satellites and ground stations in a space system, and the network of communication links that transfer information between them."

The determination of the communications architecture has been greatly influenced by the combination of micro controllers, transceivers, antennas and electronics aboard. By size demands certain tradeoffs were made since our systems in the satellite were not capable of relaying/ store and forward functionality or handling multiple connections at once. The system uses a connection oriented point to point protocol; AX.25 which is a revision of X.25, adapted for amateur radio purposes by ARRL and TAPR [7].

5.2.1 Identification of the communication requirements:

The data rates were decided not to exceed 9600 bits per second and duplex operation was considered unnecessary since it complicated the development of the onboard Terminal Node Controller (TNC). It also made it possible to build the entire ground station from commercial off the shelf components(COTS) at the same time. The satellite is placed in a low earth orbit, and could with advantage use more than one ground station to relay information to the mission control center. The experiments aboard the satellite does not actually require 9,6kb/s, so my approach in the rest of this report and the project is to build an over dimensioned system for 1200b/s communication, and still keeping in mind not to exclude the possibility of using 9,6kb/s which requires the more complex GMSK modulation technique, over AFSK for 1200 or 2400b/s operation.

5.2.2 Data sources:

The satellite carries an AIS receiving system, and is capable of relaying a specified number of such messages over the amateur transmitters. It is furthermore equipped with an attitude determination and control system, this system need to be remotely commanded, and readings from diverse attitude sensors needs to be relayed back to ground. The onboard power management system does continuously housekeeping tasks and measurements of temperatures, sunlit areas, currents, voltages and charge states of the batteries. This information is also necessarily relayed to ground for evaluation of the power systems quality of service.

5.2.3 End users:

For our purpose the end users are most commonly we ourselves, each group which has hardware onboard wants feedback from their projects. The most dominant end user is Agricultural University of Norway, which uses the AIS messages for Reindeer herding purposes. Other end users are; Norwegian Space Center and Andøya Rocket Range who use the information and experience gathered to plan further student satellite projects.

5.2.4 Link availability and reliability:

We have tried to construct the ground station to achieve the goal of at least 98% uptime. This gives us about 30 minutes each day to fix problems, upgrade software or suffer lack of operation due to power outages, lightening and other incidents we don't control. This is a relatively low uptime demand; commercial satellites commonly have demands in the range of 99 – 99.99% uptime.

5.2.5 Duty Factor:

At most in normal operation we will se the satellite on our horizon every 96 minutes for maximum 10 minutes. Hence a duty factor of 0.1 should be more than sufficient. The only thing limiting our duty factor is a recommendation from the positioner manufacturers to avoid continuous movements of the positioners for longer durations than 15 minutes.

5.2.6 Alternate communications architectures:

By designing the ground station for a future connection to the Federated Ground Network [8], we hope to participate in a mutual exchange of services, to be able to contact our satellite at times we cannot se it ourselves, by other student groups' ground stations. We have not considered the use of relay satellites.

5.2.7 Data processing location:

The primary location for processing data, except AIS packets, is Narvik University College, AIS packets are processed at Agricultural University of Norway. Software for presenting data directly to the user, independent of its location, is also under development.

The ground based section of the primary communications link consists of a radio capable of transmitting with up to 100 watts, with a narrow bandwidth, and relative sensitive receiving unit, connected to an array of Yagi antennas for both 144 and 435 MHz frequencies,

equipped with the possibility of being directed in both Azimuth and Elevation. AMSAT[18] demands that the transmitter aboard the satellite can be commanded in an off state to prevent unwanted frequency pollution.

For link budget analysis of individual links please se calculations in chapter 6.
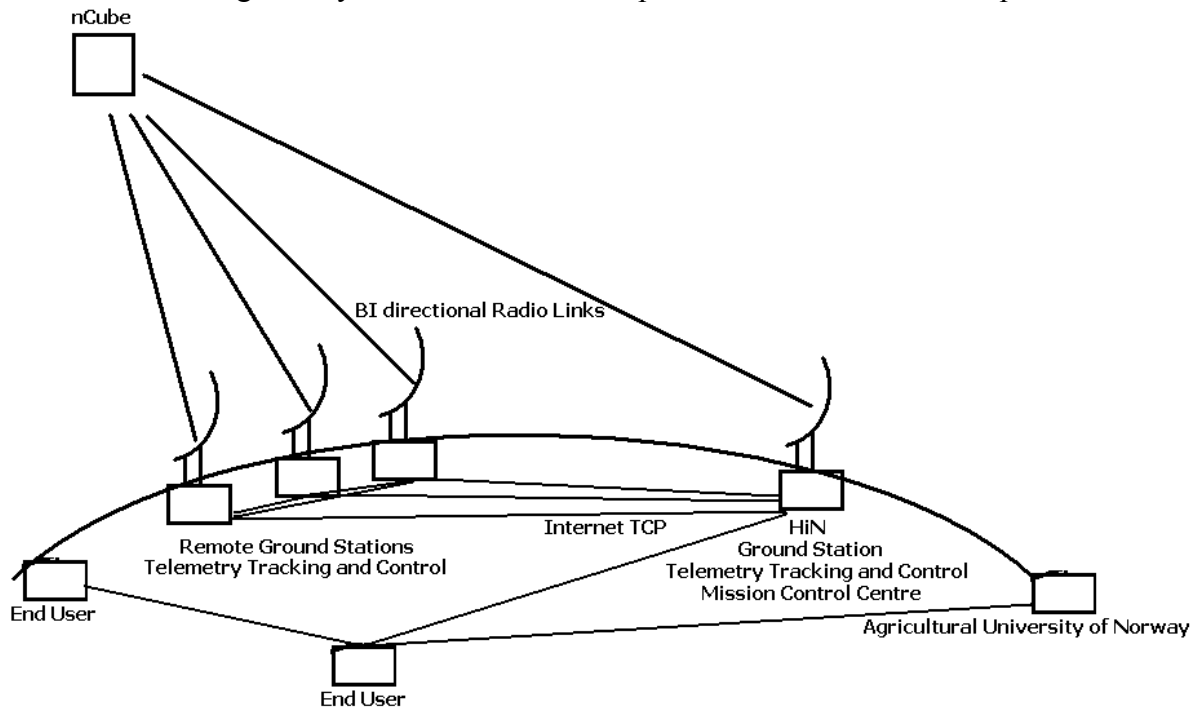
Figure 5.1: *Communications Architecture*

5.3 Hardware

5.3.1 Description of our antennas

We chose to use the Yagi Uda Array for our ground station. There are many different designs for Yagi antennas on the market, with slight variations in spacing between elements, length of elements, diameter, and last but not least the number of elements. The manufacturer Antennes Tonna (AFT F9FT)[12] is known to have an outstanding good Claim versus Theoretical performance gain. [4]. And their 9-el and 19-el, antennas were selected for our purpose.
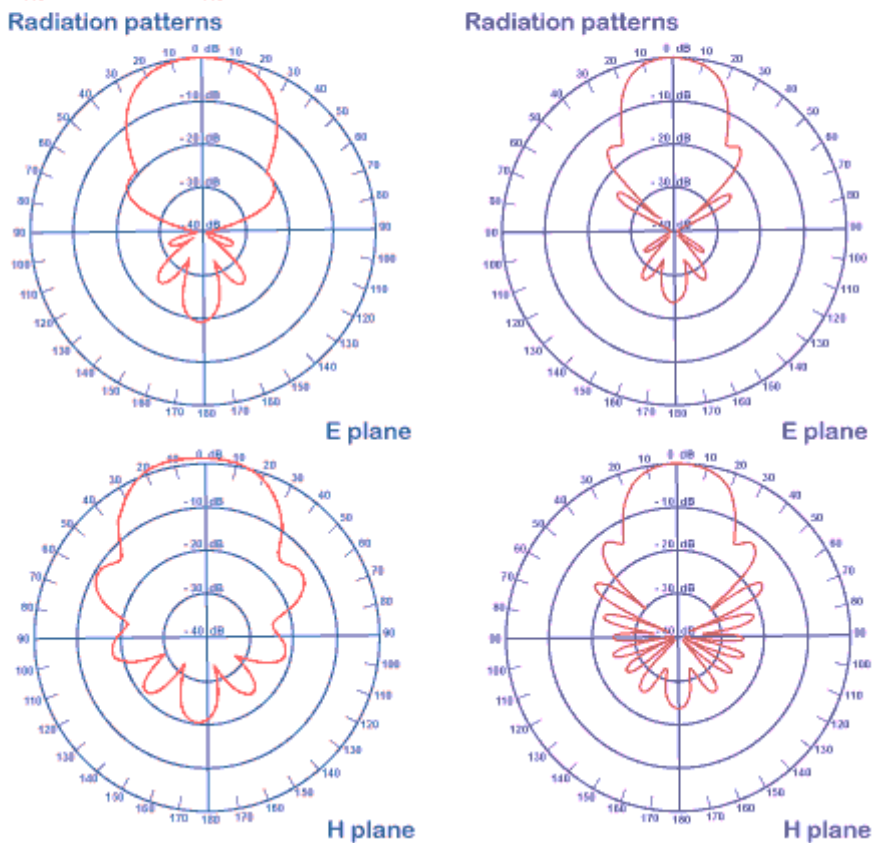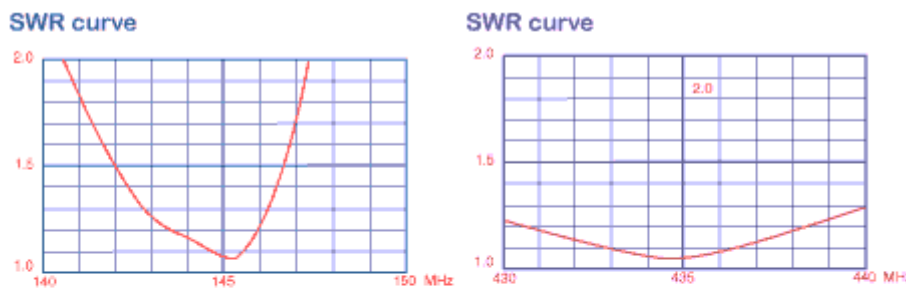
Figure 5.2:

Antenna lobe diagrams and standing wave ratio from the equipment manufacturer for the receiving 435 MHz antennas.

Figure 5.3:

Antenna lobe diagrams and standing wave ratio from the equipment manufacturer for the receiving 145 MHz antennas.

5.3.2 Some additional properties with Yagi antennas and arrays

More directors generally give the antenna more gain.
In addition two or more Yagi antennas can be stacked together. When two Yagis are stacked at an optimum distance the gain increases by 2.8 – 3.0 dB compared to a single antenna. The beam width in the plane the Yagis are stacked is approximately half the beam width of a single antenna. The other plane is not affected by this. The first side lobe in the plane of stacking is typically 13-14dB below the main lobe. In our design two planes of stacking is used. The Yagis used for downlink 435MHz consists of 19 elements in both the horizontal and vertical plane each. While the 145 MHz Uplink antenna is a 9 element crossed dipole Yagi.

The relative length of each element on the antenna can be calculated in the following manner:

Sn=Lambda*0,482*(1/1,005)^n   (5.3)

When building a crossed Yagi along the same boom, a phase delay is introduced to avoid collision between elements and dipoles, for our 430 to 440 MHz antennas this delay is 14 degrees, for the 144 to 146 MHz antennas the same delay is 72 degrees. Before combining and after splitting of the signals, a compensation must be done, see the cables part for the calculation of the intermediate cables lengths.

The optimum stacking distance for the Tonna-version of the Yagis is given from the manufacturer:
435 MHz E-plane: 1.25m
435 MHz H-plane: 1.25m
144 MHz E-plane: 2.77m
144 MHz H-plane: 2.77m

A empirical formula for optimum stacking distance can be used "S" the stacking distance is 51/"bw" the bandwidth of the single antenna in E-plane. [11]
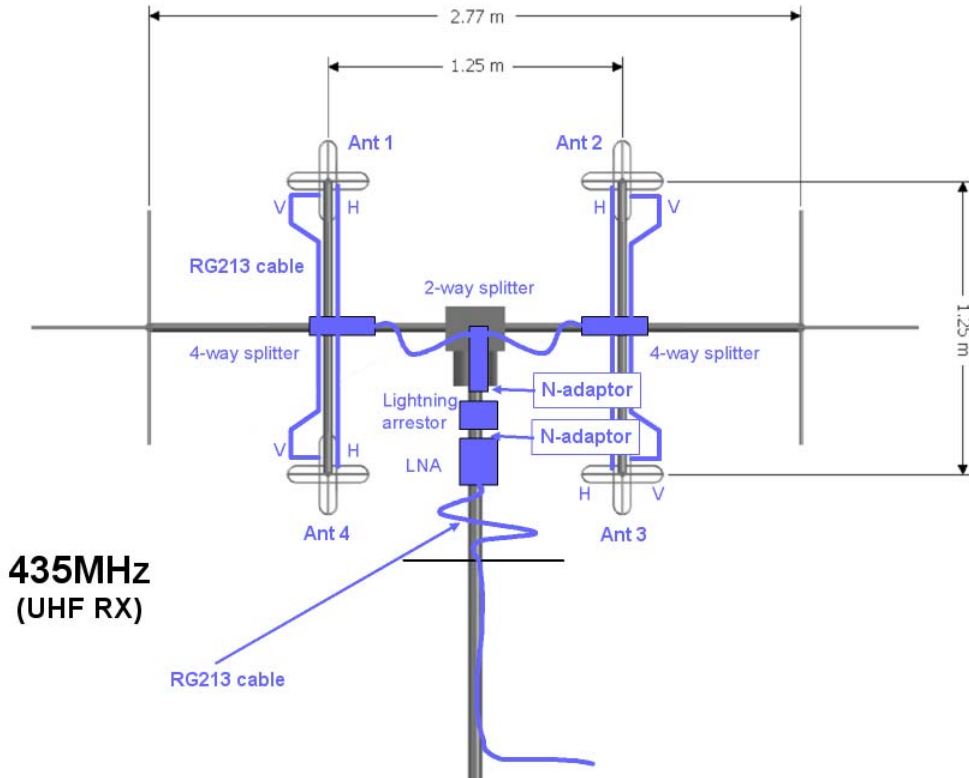
Figure 5.4: *Rig assembly, enumeration, active and passive components and cabling.*
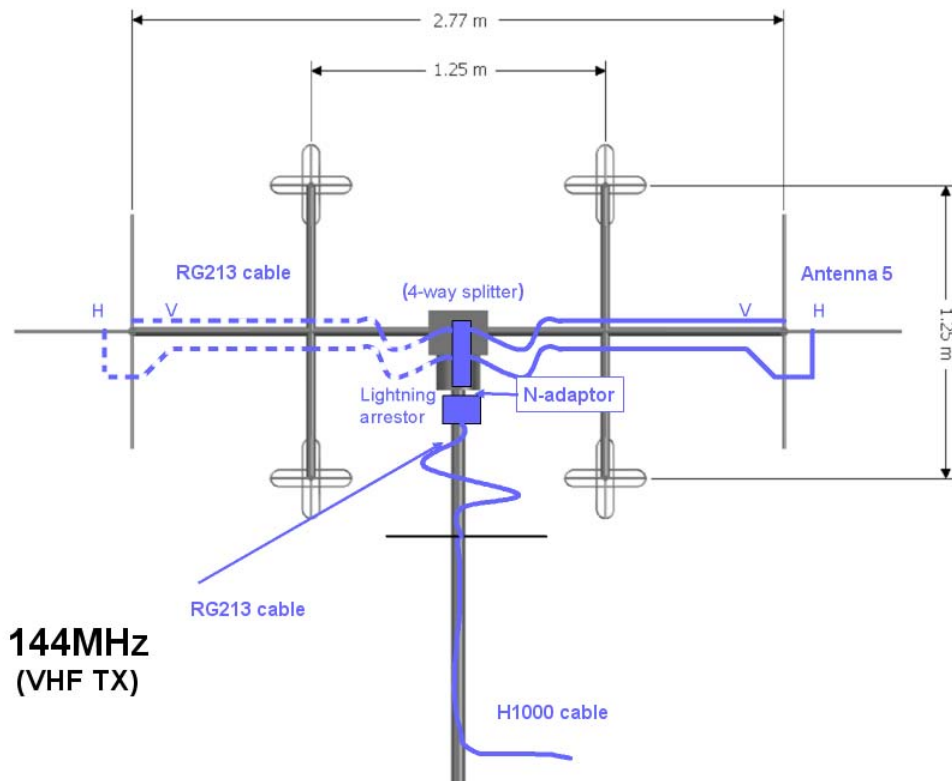
Figure 5.5: *Assembly of our 144MHx uplink, cables and passive components.*

The bore sight of the 2m systems is 20 deg before halving the power (-3dB), for the 70cm system it is 14 deg. After stacking this give a demand for pointing accuracy of 7 degrees along both axes for both systems to operate within their –3 dB margin.

Where n is the element number and Sn is the length. n=1 is the first element after the transmitting or receiving dipole n=2 the next and so on. Hence the reflector n=-1. This example is for our 4mm Ø elements.

By using a commercially available antenna lobe estimator, and inputting the above specification for our 4 stacked Yagi array the following lobe plots was achieved:
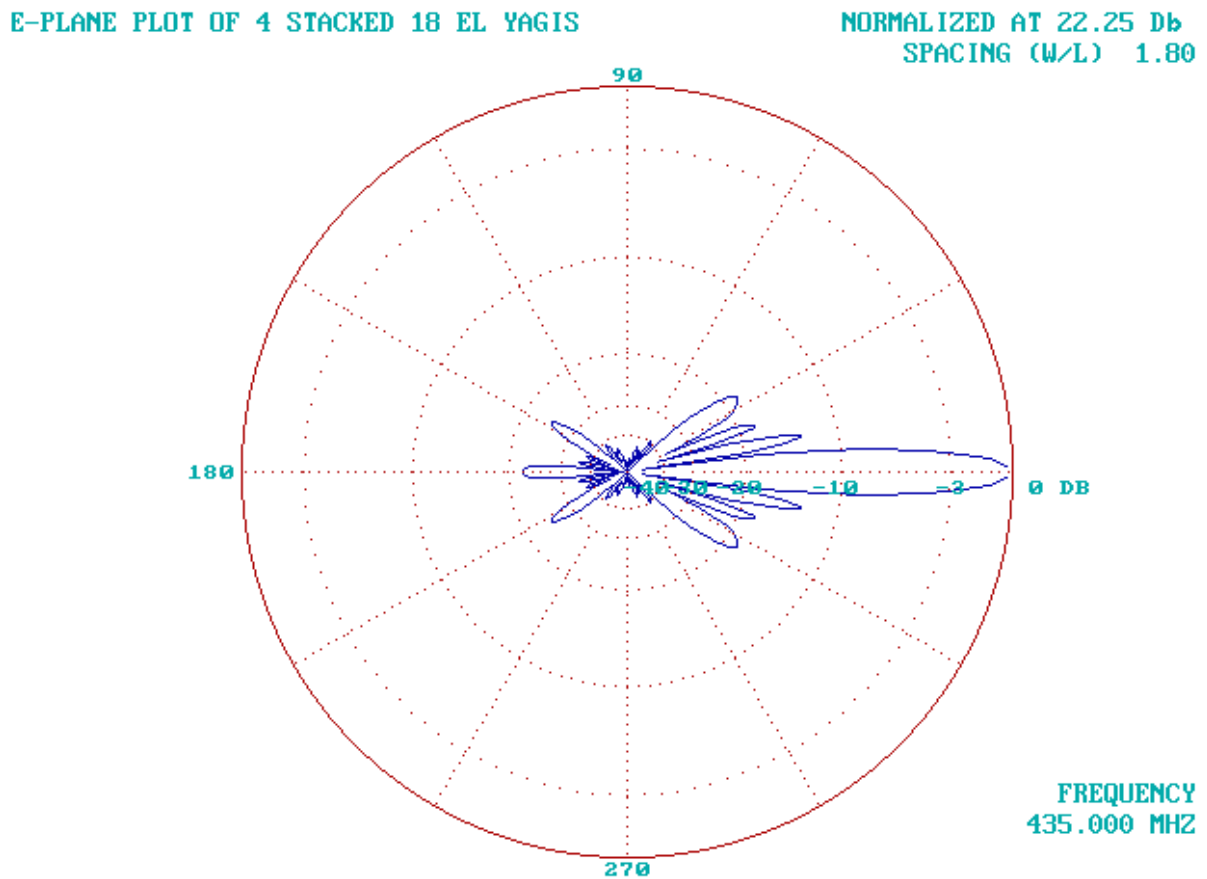
Figure 5.6: *Estimated antenna lobe, receiving subsystem*

Please see chapter 8, for testing and verification of the antenna properties.

5.4   Positioners

The antennas are rotated and held in place by two positioners. The positioners are an assembly built by M2 Inc [9]. The positioners are somewhat different in design and functionality. In case of problems with the assembly in the future its workings is explained in the following.

The azimuth OR2800P-DC (product datasheet in appendix H) positioner we use is built around a dc motor and a reed relay. The dc motor converts the electrical current to a torque. The torque is applied to an internal gear and transferred via an axel connected to a rod connecting our elevation positioner, which again carries the whole antenna rig assembly. In this way the azimuth positioner sets the rig into motion around an axis perpendicular to the ground plane. On the axel of the motor a dipole permanent magnet is fastened. The magnet rotates in the proximity of a reed relay, and opens and closes this as the axel spins. By adding a voltage to the reed relay a square pulse shaped signal current with frequency proportional to the revolutions per minute of the motor shaft is achieved. By counting the pulses, knowing the current heading of the antennas and the gear ratio, the exact position of the antenna rig is also known. This functionality is implemented in the rotor controller. The azimuth controller is capable of turning the rig 385 degrees, a limitation switch which physically cuts the connection to the motor is installed at 0-7,5 deg and 360+7,5 deg. to prevent a cable windup.

The elevation MT-3000 (product datasheet in appendix I) positioners mechanical design is very different from the azimuth, but electrically it is much the same. The elevation dc motor, transferees the torque thru a gear house to a chain. The chain is fitted into a rail shaped as a sector of a circle, this sector is in excess of 210 degrees, and depicts the different elevation angles possible. When the antenna boom is fastened on a clamp carried by this sector this act as an axel converting the force of the chain to a torque. This torque alters the antenna boom-plane angle relative to the ground plane. And position is reported thru the same measure as described in the previous paragraph. The elevation controller is capable of turning the top portion of the antenna rig from 15 thru -90 and to 15 degrees below the horizon in the opposite direction. There are physical limiting switches in the same manner as on the azimuth rotator, mounted on the ends of the chain rail.

The rotor controller unit consists of two independent sets of rotor controllers, one for each axis. The rotor controllers include a transformer, transforming the voltage either from 220 or 110 Volts to 48 Volt. The 48 Volt is applied to a relay capable being open, closed or closed with opposite polarity. These relays are connected directly to their respective

positioners thru a 2*2,5mm^2 and 45 meter long cable, and thereby able to turn both positioners both directions. The rotor controller is equipped with a micro controller. The micro controller can be interfaced by RS-232 or directly thru a buttons panel in front of the unit. The micro controller keeps track of the pulses generated by its positioners reed relay and displays the current heading on a screen. It also keeps track of the calibration of the rig and a number of preference positions. The micro controller can be queried about its positioner's current position and speed, and commanded into a new position. See the command reference for the rotor controllers in Table 6.1

Table 5.1 – *Command reference M2 inc PRK2800 rotor controller (RS-232)*

Command	Meaning	Lowest value	Highest value	Step size
S	Speed	1	9	1
A #	Azimuth position	0	360	0,5
E #	Elevation position	0	180	0,5

Table 5.2 – *Alternative command formatting*

Formatting	Explanation
A	Select Azimuth axis
E	Select Elevation axis
+	Increase selected axis by 0,5 degrees
-	Decrease selected axis by 0,5 degrees
Enter	Requests update of current position
U	Gives continious movement during operation
N	Returns to request update mode
S	Stop movement

Table 5.3 - *Communications parameters for PRK-2800 with RS-232*

Bitrate	Databits	Stopbits	Parity	Handshake
9600	8	1	None	NC

5.4.1 Calibration of the heading:
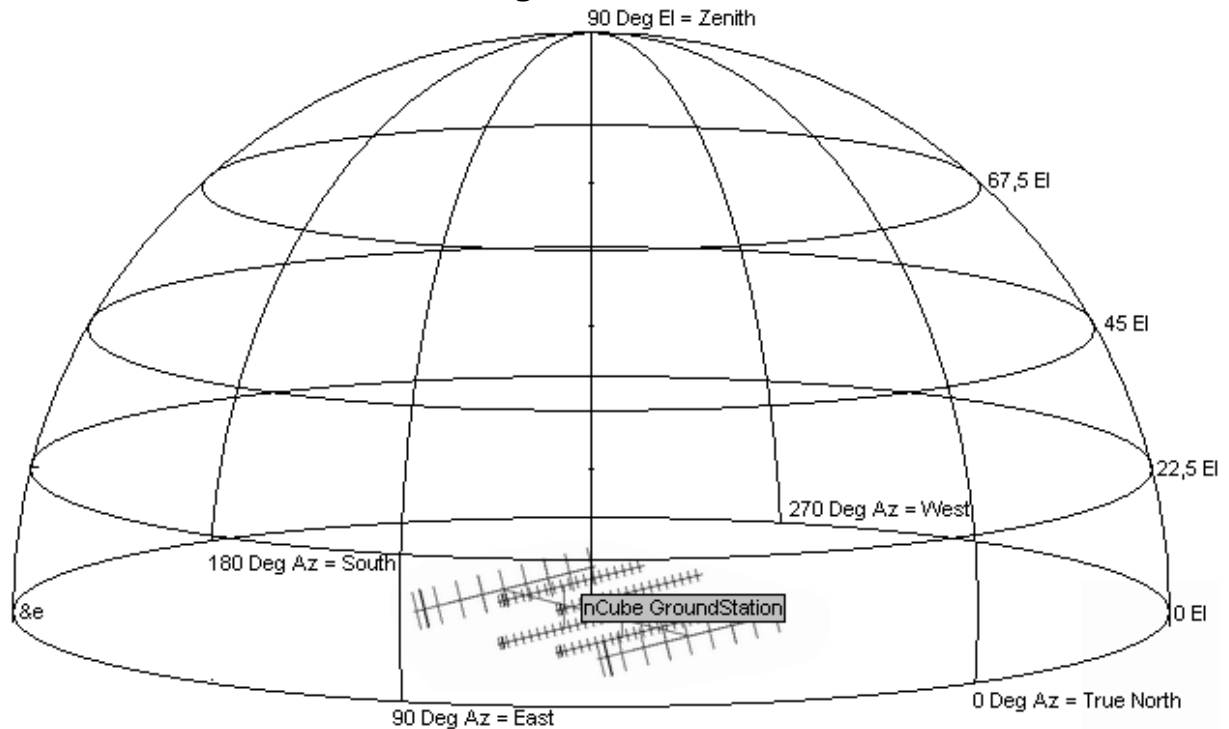
Figure 5.9: *Reference diagram for the positioners of the nCube ground station.*

To know the accurate heading or pointing direction the reference axis must be known both in elevation and azimuth.

5.4.2 Azimuth:

To calibrate the rig pointing directions in azimuth this method was used:
The accurate position of the antenna mast was measured using GPS and averaging over a 20-minute period, a LASER was fastened coaxial with one of the antennas, and the light hit a known landmark. Then the GPS was transported to the landmark and its position and heading was found. This heading was programmed into the Azimuth positioner.

The error introduced by this method:
The GPS reports that it has an estimated projection error of 3 meters. Even with the selective availability code turned off the GPS still has mechanisms that makes it more likely that the position is 2 or 3meter, or, 3 or 4meters askew than 0 or 1 meter [10]. So let's assume the worst-case situation where the measurements are 3 meters wrong in the opposite directions, see figure 5.9:
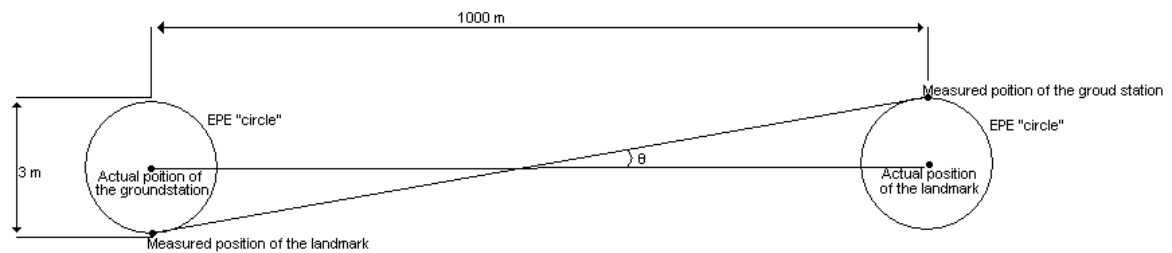
Figure 5.10: *Worst-case measurement of position and its heading.*

The angle θ:

$$\theta = \tan^{-1}\left(\frac{\pm 6}{1000}\right) = \pm 0{,}34\,\text{deg} \quad (5.1)$$

Standard deviation:

$$\theta^2 = \pm 0{,}12\,\text{deg}^2 \quad (5.2)$$

The resolution of our positioner is 0.1deg, but due to the inertia of the motor shaft it overshoots its position with 0.3 to 0.7 deg, so a more exact calibration is not really necessary, but could easily be done by collection GPS data over a two-day period and averaging. The linearity of the positioner was taken for granted, as it would be hard to compensate for eventual un-linearity when the positioner is commanded with exact angles, but this may be the greatest source of error. The gears free run or slack are by the manufacturer guaranteed to be within 0.5 degrees also in the same dimension of error.

5.4.3 Elevation:

The same method could not easily be done with the elevation angle, since it would demand a very high landmark. But by assuming a lead weight suspended in a thin thread would hang vertically. We simply plumbed the rig and sat that position as 90 deg elevation, and confirmed that the rig was horizontally at 0 and 180 deg. Also here assuming linearity of the positioner in-between. This positioner seems to overshoot from 0.3 to 1.4 deg when tracking a satellite.

The error introduced by both methods is well within the required 7 degrees for the 70cm set to operate within its 0 - –3dB lobe.

5.5 Cabling:

To feed signal from our transmitter into to the dipole and to feed signals from the dipoles of the 70cm antennas and into our receiver, intermediate cables with the same impedance as the antennas and the transceiver are used.

Formula for calculating coaxial cable impedance:

$$Z_0 = \left(\frac{138}{\sqrt{\varepsilon}}\right)\log_{10}\left(\frac{D}{d}\right) \text{ (5.4) [4 p 7-33]}$$

We use tree different types of cables in our rig. Since the rig consists of two sets of moving assemblies, flexible cables had do be used in that part of the structure. Generally the cable loss is less in a stiffer cable than in a flexible due to material constraints in the dielectric between the centre conductor and the shield. So to cover the distance between the rig and the transceiver, ca 40meter, the much stiffer, but low loss H1000 cable was used. (datasheet in appendix J). For the 70cm systems moving part RG-213 was used and for the moving part of the 2m RG214 was used, these have smaller bending radius than the H1000, and asserts less force on the tension relief.

The propagation speed in our cables is 0.66c, for both systems. For the 437MHz one wavelength:

Λ_{c437}=0.66c/f=452mm   (5.5)

giving a phase delay of:

Λ_{c437}/360deg=1,25mm/deg   (5.6)

So to compensate for the phase delay because of the offset assembly of the crossed antennas of 14 deg, the frontmost cable is prolonged with 17,5mm relative to the rearmost detectors cable for all four Yagis.

The same calculation for the 145MHz antennas:

Λ_{c145}=0.66c/f=1,37m   (5.4)
Λ_{c145}/360deg=3,8mm/deg   (5.5)

Prolonging the fromtmost cable of the 145MHz yagis with 273mm.

5.6   Lightening arrestors:

To prevent damage to the transceiver and to try to deflect lightening from entering the control room, lightening arrestors are installed and act as joints between the H1000 cables and RG-213/214 cables. The arrestors are capable of handling 2000W before grounding the signal.

5.7   Splitters:

To feed the array the signal has to be splitted evenly between the Yagis, and in the same time control phase and impedance, we use; two 4-way splitters and one 2-way splitter for the 70cm system, and one 4-way splitter for the 2-meter system. AFT F9FT also delivers our splitters. Se figures 5.2 and 5.4 for their relative positions on the rig. Their attenuation is guaranteed to be below 0.05dB.

Standing Wave ratio specification can be found in figure 5.10.

4 Way 144 MHz splitter

2 Way 435 MHz splitter

4 Way 435 MHz splitter

Figure 5.11: *SWR diagrams for the splitters*

5.8   LNA:

To further increase the gain from the 70cm system a low noise amplifier is placed as close to the 2-way 70cm splitter as possible. The LNA has to be tuned to the exact frequency of the satellite, and does **not** tolerate energy coming from the radio. Therefore be observant that the push to talk function never is enabled on the radio in the 435 MHx band! Our LNA has a 23dB gain for the planned frequency.

5.9   Environment and weather conditions:

Since our equipment is directly in contact with the outdoor environment, a study of the worst-case weather conditions where conducted.

5.9.1 Temperature

Temperature affects elasticity of cables, and lubricant viscosity. The Norwegian institute of meteorology [14] could report following absolute minimum temperatures for Narvik in the last 25-year period:

Table 5.4 - *Absolute minimum outdoor temperature Narvik 1976-2002*

Dato	Min ^{O}C
01.02.1980	-22.3
02.02.1980	-21.0
27.01.1999	-20.0
23.01.1986	**-19.5**
08.02.1985	-19.2
26.01.1999	-19.2
29.12.1976	-19.0
09.02.1985	-18.8
26.01.1979	-18.5
06.01.1987	-18.3

Our Belden [15] H1000® 50 cable is rated for temperatures between –20 and 50°C so the azimuth rotator (OR2800) should not be operated below -20 ^{O}C

The RG family cables have a 55 to –10°C specification, hence the elevation rig should not be operated below –10 ^{O}C

The OR2800 manufacturer gives no temperature ratings, but the motor has a starting torque of 4kgm, which should be enough to overcome lubricant sticktion down to -20 ^{O}C if needed.

5.9.2 Wind load

Table 5.5 - *Maximum wind measurements in [m/s] for Narvik [15]*

Stnr	Dato	FFM	FXX
84800	04.04.2001	23.0	30.9
84800	12.01.1990	23.0	28.3
84800	13.01.1990	15.4	28.3
84800	01.02.1993	21.3	28.3
84800	01.02.1995	5.8	28.3
84800	12.10.1996	18.3	28.3
84800	07.02.1998	25.4	28.3
84800	08.02.1998	16.6	28.3
84800	01.12.1998	10.8	28.3
84790	31.12.1972	11.6	26.8
84790	01.01.1973	9.1	26.8
84800	21.12.1975	5.1	26.8
84800	31.01.1995	11.8	26.8

Table 5.5 shows maximum wind velocity (FFX) and median for a 10 meter measurement (FFM) in the 1972 to 2002 period. Each of our 70cm antennas has a effective wind area of 0.09m^2, and each generates a force of 350N at 25m/s or a force of 1130N at 45m/s. Our 2 meter antenna has a wind area of 0.15m^2

Empirical formula for wind load:

$$F = A(2{,}5V)^2 \quad (5.1)$$

Where F is the total acting force, A is the effective wind area and V is the wind speed

All our antennas add up to a effective wind area of 0,66m^2 and a force of:

$$(4 * A_{70cm} + 2 * A_{2m})(2{,}5V_{FFX_{04.04.2001}}) = 4kN$$ at conditions as extreme as 4th of Mach 2001.

The manufacturer of the OR2800 guarantees its functionality up to a wind area of 5m^2

5.9.3 Wind speed and direction

Table 5.6 - *Probability distribution of wind speed and direction between 1975 and 2002:*

Sekt. °	0-3 ms⁻¹	3-6 ms⁻¹	6-9 ms⁻¹	9-12 ms⁻¹	12-15 ms⁻¹	15-18 ms⁻¹	18-21 ms⁻¹	21-24 ms⁻¹	24-27 ms⁻¹	27-30 ms⁻¹	>30 ms⁻¹	% sum	U ms⁻¹	Std ms⁻¹
N	2.8	0.1	0.0	0.0	0.0							3.0	1.61	1.27
NE	2.9	0.6	0.5	0.3	0.2	0.1	0.0					4.6	4.08	4.01
E	15.6	7.9	6.9	5.2	3.5	1.3	0.3	0.0	0.0		0.0	40.7	5.65	4.21
SE	1.0	0.2	0.1	0.1	0.0	0.0	0.0	0.0				1.5	3.38	3.29
S	1.7	0.4	0.2	0.3	0.2	0.1	0.0	0.0				2.9	4.33	4.29
SW	4.5	1.9	0.9	0.6	0.4	0.0	0.0	0.0	0.0			8.3	4.19	3.27
W	13.6	5.0	3.6	3.0	1.6	0.3	0.1	0.0	0.0			27.3	4.65	3.68
NW	2.1	0.3	0.1	0.0	0.0	0.0						2.5	2.23	1.98
Skift												0.0		
Stille	9.2											9.2		
Sum	53.3	16.3	12.4	9.4	6.1	1.9	0.5	0.1	0.0		0.0	100.0	4.38	4.02

5.9.4 Parking:

Whenever the station is not in use or in stormy conditions the antennas should be pointed along the axis the most frequent wind direction to reduce the load, see figure 5.1.
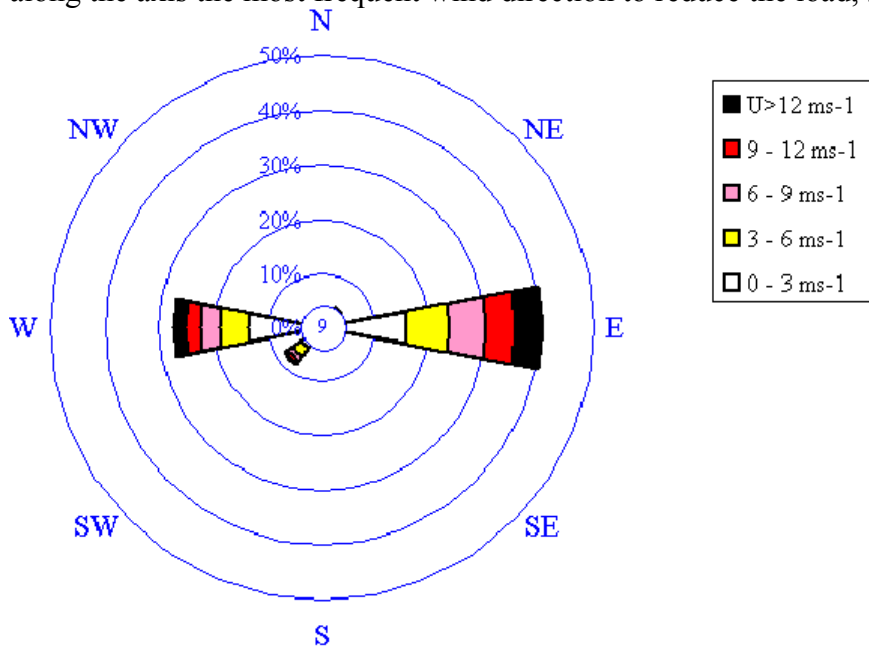

Figure 5.12 - *Parking of antenna / wind strength and direction distribution.*

5.10 Software

In addition to the hardware assembly process my time has been spent on learning the programming language C++ better. I should mention that to accomplish the tasks of programming a way to:
- present system / user data from nCube satellite and relay them to a remote user
- store commands and data from communications for later retrieval
- transmit a desired signal, possibly from a remote user, which can be detected and interpreted onboard the satellite.
I considered and realized to that studying the Microsoft Foundation Classes, to program a flexible and easy to use interface, was necessary. I studied and did the exercises in Sams" Teach Yourself Visual C++ in 21 days" [1] Along with following some examples in "C++ how to program" [2]. To handle serial port communication several attempts with different approaches was tried, but all handling was buggy due to lack of support in the Windows NT-kernel based operating system. The final and most promising way of solving the problem was a MFC wraparound the "CSerialPort" [3] was used. In all attempts the C++ Development environment seemed to act in a non-deterministic manner. Some times the best solution was to simply reboot the computer or transfer the workspace to another computer to be able to compile the program. Both I and my faculty advisor had to give up on solving problems several times, and had to start all over with a different approach as a common strategy.

To receive and store information from the satellite, and to retrieve and transmit information to the satellite a separate system capable in abstracting these functions needs to be closely interconnected with the hardware. This is implemented thru attaching computers running specially designed software to the different components of the equipment. Two possible approaches were clear to me for this purpose: First of all investigating the possibility of; and/or writing my own software, and secondly buying prewritten software, for a more general purpose amateur satellite ground station system. I have used a combination of both. This chapter will describe the design of the software, but the actual functionality of the software is explained in the user interaction chapter.

The system was intended for scalability and flexibility concerning the actual physical location of the equipment relative to the operator. Our system should be able to be completely remote controlled. To implement these goals I decided to interface all equipment with the widely used transmission control protocol and internet protocol (TCP/IP). By doing this all subsystem components could be anywhere in the world where internet is accessible. See figure 5.13 for the "wiring" diagram between the subsystems.
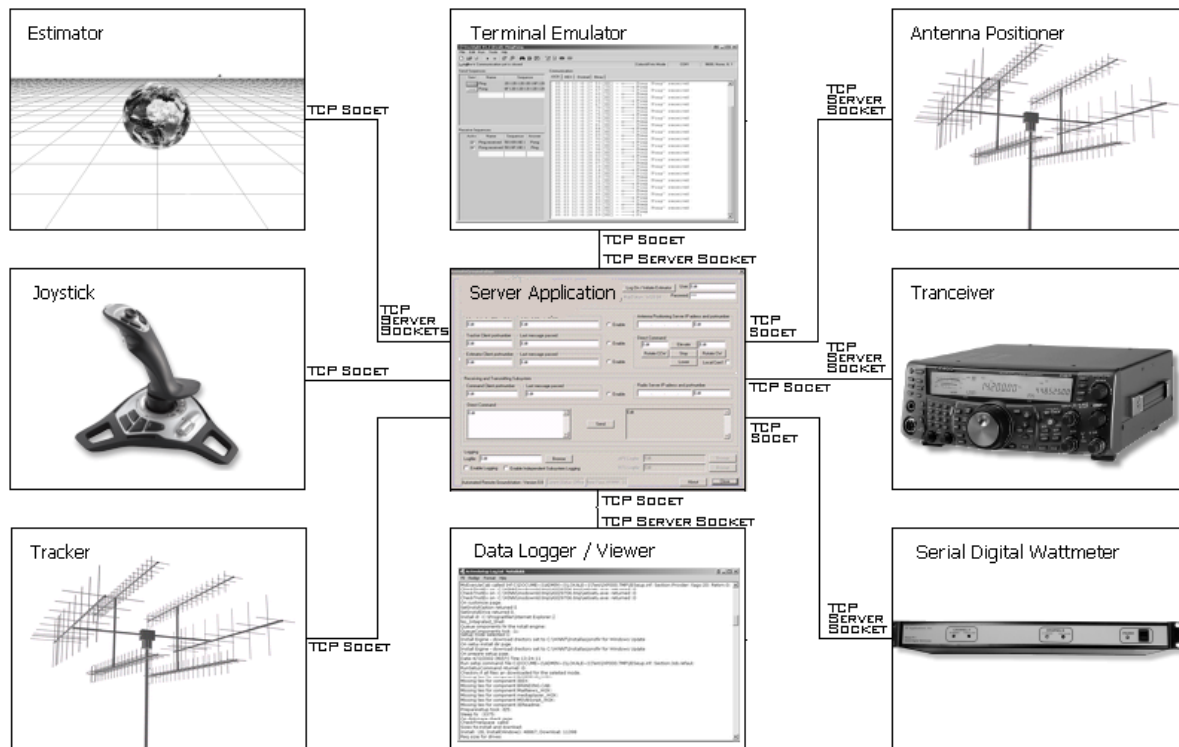
Figur 5.13: *"Wiring diagram" of the Internet connected modules*

My idea was to program a general TCP/IP to RS-232 bridge, so if two PC's are connected together via Internet, and my program runs on both PC's, equipment connected to the serial port of each of the two computers should talk to each other as if they actually was connected to each other only via RS-232, transparently of the eventual in-between TCP links. So I got 3 old PC's from our compuer labs and connected them to the positioners, radio, and the wattmeter. On each of these PC's a copy of the program is running bridging the equipment to the internet. The program has the following settings:

Port:
  Select the free serial port on the attached computer, where the cable is connected.
  Options:
    Com1, Com2, Com3 or Com4
Data rate:
  Select data for the RS-232 link
  Options:
    1 200bps to 115 200bps

Stop bits:
  Select stop bits for the RS-232 link,
  Options:
    1 is default, 1.5 and 2 for equipment with special demands
FlowControl:
  Select method of controlling the data flow for the RS-232 link, default is off
  Options:
    None, Xon/Xoff or Hardware

Portnumber:

      Select the port for which the TCP socket server should listen.

      Options:

            4000 is default, 0 – 65535 is the total range

            1024 and above is the recommended selection, since many internet services are commonly associated with lower port numbers.

IP Adress:

      Shows the address of the server (the PC where the program is running usually)

Listen:

      Press this button to enable the TCP Server Socket part, and set the program into listen mode

5.10.1   Member of the Federated Ground Station Network.

As mentioned in the Communications Architecture chapter, one of the top things on our whish list for the ground station, is to be able to connect with the Federated Ground station Network (FGN)[8] an Application Programmers Interface (API) is currently under development at Stanford University. The API is constructed for different hierarchical levels of access to the Ground Stations (GS).

For example: the furthest intended abstraction level of interaction with the GS via the FGN is that a user picks a satellite he or she wants to track, and the contact time. The FGN then autonomously assembles a virtual GS consisting of different core components, possibly from different physical ground stations, to exploit their different qualities. For an example, our ground station in Narvik acts as the receiving pipe only because we have a high sensitivity for this pass, but a nearby station is used as a transmitting pipe at a close frequency to prevent skipping back and forth betweens frequencies at our GS during the pass, and hence achieving full duplex communication altogether.

The closest abstractionlevel in the hierarchy may be that the user wants to specifically set up our hardware for a special complex operation the API was not scaled for, also allowing the user access directly to our equipment as radios, trackers and tuners to accomplish the task. The FGN conveys or masks these procedural idiosyncrasies and differs service levels.

The bridges mentioned in the paragraph above is specially intended and suited for this kind of action. When the bridges are set up the local operator can leave and lock the mission operations center at HiN for this purpose only. And then log on the FGN from another location actually tracking our nCube without even knowing if our station is used as a part of that track at all (which it most possible and hopefully is though).

5.10.2   Third party software running in our station.

Currently the 3 computers interacting directly with the equipment is installed with the Microsoft Windows NT4.0, running the bridges. The bridges could actually be replaced with a hardware counterpart, solely excluding the use of computers in our node from the Internet when the FGN is connected. The bridges should be firewalled or a Network Address Translator installed to prevent erroneous operation due to spurious packets, and authenticating the users connected to the FGN only. But currently other third party software is running on

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these computers while awaiting connection to the FGN. This software is described in the next paragraphs:

NOVA [ ] is a tracker and tuner software, we utilizes the tracking part only, as the antenna tuner part would require extra hardware. The tuning is performed manually. The tracker is fed with the stations location and a two-line element set of Keplerian elements of the orbit of the satellite we are currently tracking. NOVA keeps a library of two-lines which it updates as necessary by connecting to a NORAD[16] or third party server and downloading the latest elements. NOVA can keep track of multiple objects at once, and is able to connect to our rotor controller via the serial port directly tracking the satellite.

WiSP[] is a complete software amateur ground station, this is used secondary to NOVA as a backup.

HyperTerminal is a standard terminal emulator; this program is connected to the radio directly via the serial port, and the radio commanded directly by the user at the pc. This is especially needed when running in packet operation with the built-in Terminal Node Controller(TNC) of the TS-2000. The session is displayed in a terminal document, time stamped and logged for further reference.

Timing is achieved via shyncronisation with www.timeserver.com, using a special time protocol compensating for Internet lag. NOVA synchronizes with timeserver automaticly. Syncronisation can also be done manually by enterning controlpanel of Windows and selecting "Adjust date and time properties" / "Timeserver".

The FGN group has developed a multiplatform Java® applet which handles interconnection and user access levels, and our main MCC-PC runs both Linux Redhat® 9.0 and Windows® XP® professional edition, to platform future development of the FGN system.

6   Calculation of the link budget and data rates between nCube and GS.

Roughly deciding *effective receive antenna aperture area*: The following figure can be used to find the effective diameter of the antenna to be used, based on data rate and transmitter power.
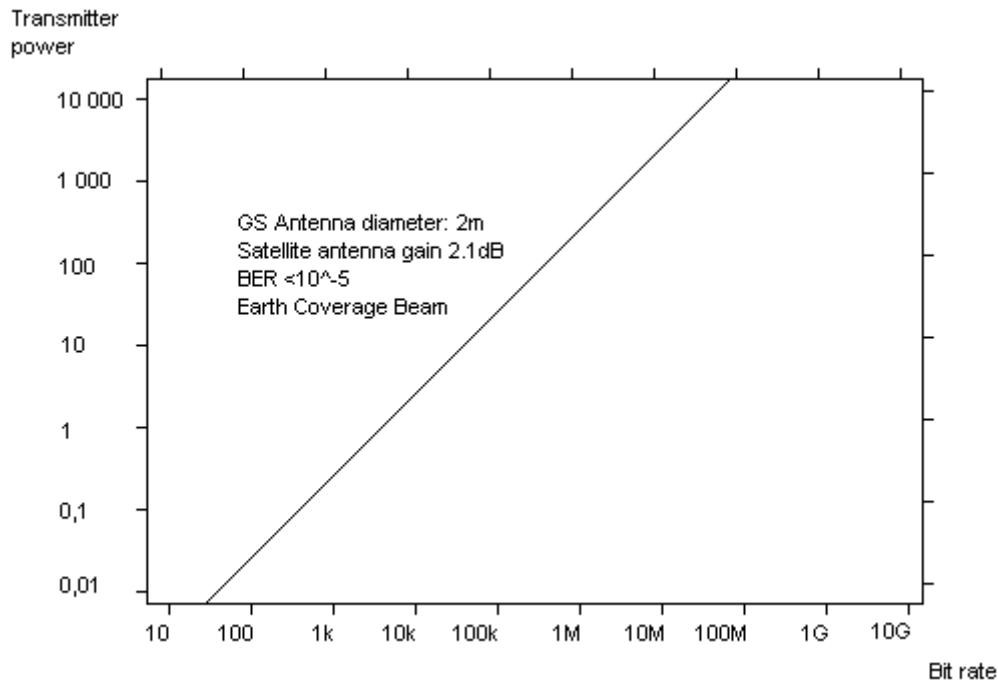
Figure 6.1: *Relationship between bandwith and antenna diameter.*

6.1   Downlink

I will calculate the transmission budget for our system, using the considerations and formulas described in chapter 4 like this:

All constants are taken from NIST [12].

The speed of light for vacuum is defined to be exactly: c=299792458m/s

Bolzmanns constant: k = 1.386503(24)*10^-23 J/K

Which in dB scale becomes: k [dB]=228.6dBW/HzK

The frequency proposed for our downlink: f=437.550 * 10^6/s

Which gives the wavelength: Lambda = c/f = 0.685m (6.1)

The onboard transmitter worst case power Ps=0,3W, there is some uncertainty in our favor in this number at writing moment as the end stage of the radio transmitter is not fully implemented yet. Its actual could be as much as 1W, adding 5dB to our link margin (5.20), the antenna attached to the satellite is made from 35 cm measuring tape has been tested to have a antenna gain Gs=2.10dBi, and loss in cablings from the transmitter and to the antenna should not exceed Lks=0.20dB, the antenna has en efficiency of 1.00.

This gives the transmitter power in dB:

10*LOG (Ps)=-5.23dBW   (6.2)

And combined with the antenna specifications I can calculate the Equivalent Isotropic Radiated Power:

EIRP = Ps [dBw]-Lks+Gs = -5.23dBW-0.20dB+2.10dBi = -3.33dBWi (6.3)

With a bit rate Rb=1200 bit/s
Modulation type M=2
The symbol rate is then given as:

Rs = (2/M)*Rb =1200 symbols/s ⇔ bit/s [/s]   (6.4)

The spectral factor for AFSK Sf=1.25 <ref: here>

Effective bandwidth= Sf*Rs = 1500 Hz   (6.5)

Maximum distance from transmitter to receiver:

Orbit: O=700*10^3m
Radius of Earth Re= 6378*10^3m

Rh=Re+O   (6.6)
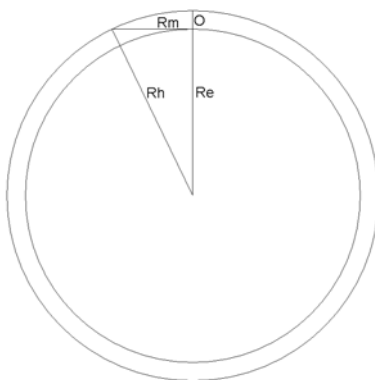
Figure 6.2: *Maximum distance to satellite, line of sight*

Rm=Rh^2-Re^2=3070*10^3m   (6.7)

Free space loss Ls[dB]:

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$$Ls = 10*LOG((4*pi*(Rm/Lamda)*1000)^2 = \underline{155dB} \quad (6.8)$$

Atmospheric loss La= 0,2

Total path loss Ltot=Ls+La = $\underline{155.2dB}$ (6.9)

Receiver antenna flux density:

$$Fm = 10^{((EIRP-La)/10)}/(4*pi*Rm^2)= \underline{3,75*10^{-15} \text{ W/m}^2} (6.10)$$

$Fm[dB]$ = -144.3 dBW/m^2
Antenna gain (4 à 16dBi Yagi Uda Array) Gm=22dBi
Polarization loss (worstcase) Lp = 3dB
Cable loss before LNA (combiner included) Lk= 0.3dB
Cable Noise Temperature Tk = 19K
Sky temperature Tsky = 180 K

Received Power at LNA input
Pm = EIRP+30[dBm/dBW] +Gm-Ltot-Lk-Lp= $\underline{-109.8dBm}$ (6.11)

LNA Noise Figure NF = 0.7dB
LNA Noise temeperature Tlna=51K
LNA Gain Glna=23dB
Cable Loss (50m H1000 cable) Lc=4.25dB
TS2000 sensitivity (12dB SINAD 12 kHz BW) S= 0.18
TS2000 receiver noise temperature Trx=247K
System noise temperature Tsys=54K
Effektive noise temperature:

Teff = Tsky+Tk1+Tsys = $\underline{253K}$ (6.12)

Spectral Noise Temperature:

No = 10*LOG(k*Teff*1000) = $\underline{-174.6 \text{ dBm/Hz}}$ (6.13)

Receiver noise in matched filter bandwidth:

Nm = 10*LOG(k*Teff*Bw)+30 = $\underline{-142.8 \text{ dBm/Hz}}$ (6.14)

G/T Receiving system:

GTeff = Gm-10*LOG(Teff) = $\underline{-2.0 \text{ dB/K}}$ (6.15)

The received power 'C' to noise ratio; "C/N":

CN = Pm-Nm=$\underline{32.98 \text{ dB}}$ (6.16)

Due to the possibility of the signal taking multiple paths to the receiving antenna, at low incident angles a fading margin of 10 is introduced: Lf=10dB

Eb/No after "fading margin":

$$EbNo = CN+10*LOG(Bw/Rb)-Lf = \underline{23.95\ dB} \qquad (6.17)$$

Energy per symbol at receiver system:

$$Es = 10^{((EbNo+(No-30[dBm/dBW]))/10)} = \underline{8.69*10^{-19}\ J/symbol} \qquad (6.18)$$

Required Eb/No to achieve a bit error rate (BER)<$1*10^{-6}$ for AFSK: BERmin = 10dB

And finally the link margin:

$$L = EbNo - BERmin = \underline{13,95\ dB} \qquad (6.19)$$

Estimating the Mean Time between Errors (MTBE) for the link

$$((1/BERmin)*(10^{'}LOG(L)))\backslash(2*Rs) = \underline{4\ 769s} \qquad (6.20)$$

The protocol used by the link does a checksum for each frame, and retransmits if errors occur, effectively ruling out loss of data.

6.2 Uplink

Actually the same calculations as for the downlink, but the hardware appear in reversed order.

Speed of light: cv=299792458m/s
Bolzmanns constant : k = $1,38*10^{-23}$ J/K
Frequency F=145.750 * 10^6/s
Wavelength:

$$Lambda = cv/f = \underline{2.057m} \qquad (6.21)$$

Transmitter power Ps=100W
Transmitter antenna gain Gs=13.1dBi
Transmitter cable loss Lks=0.20dB
Transmitting antenna efficiency = 1.00
Transmitter power in dB:

$$10*LOG(Ps) = \underline{20dBW} \qquad (6.22)$$

Equivalent Isotropic Radiated Power:

$$EIRP = Ps[dBw]-Lks+Gs = -5.23dBW-0.20dB+2.10dBi = \underline{32.90dBWi} \qquad (6.23)$$

Bitrate Rb=1200 bit/s
Modulation type M=2
Symbolrate:

$Rs = (2/M)*Rb = \underline{1200 \text{ symbols/s}} \Leftrightarrow \text{bit/s [/s]}$ (6.24)

Spectral factor for AFSK Sf=1.25

Effective bandwidth= Sf*Rs = $\underline{1500 \text{ Hz}}$ (6.25)

Maximum distance from transmitter to receiver:

Rm=Rh^2-Re^2=$\underline{3070*10^3 m}$ (6.26)

Free space loss Ls[dB]:

Ls = 10*LOG((4*pi*(Rm/Lamda)*1000)^2 = $\underline{145,5dB}$ (6.27)

Atmospheric loss La= 0,2

Total path loss Ltot=Ls+La = $\underline{145,7}$ (6.28)

Receiver antenna flux density:

Fm = 10^((EIRP-La)/10)/(4*pi*Rm^2)= $\underline{1,57*10^{-11} \text{ W/m}^2}$ (6.29)

Fm[dB] = -108 dBW/m^2
Antenna gain (2m measuring tape) Gm=2,1dBi
Polarization loss (worstcase) Lp = 3dB
Cable loss before LNA (combiner included) Lk= 0.3dB
Cable Noise Temperature Tk = 19K
Sky temperature Tsky = 180 K

Received Power at LNA input:

Pm = EIRP+Gm-Ltot-Lk-Lp+30 = $\underline{-83.8dB}$ (6.30)

LNA Noise Figure NF = 1dB
LNA Noise temeperature Tlna=75K
LNA Gain Glna=15dB
Antenna splitter and cable loss = 3.5dB
receiver noise temperature Trx=247K
System noise temperature Tsys=93K
Effective noise temperature:

Teff = Tsky+Tk1+Tsys = $\underline{292K}$ (6.31)

Spectral Noise Temperature:

No = 10*LOG(k*Teff*1000) = $\underline{-173.9 \text{ dBm/Hz}}$ (6.32)

Receiver noise in matched filter bandwidth:

Nm = 10*LOG(k*Teff*Bw)+30 = $\underline{-142.2 \text{ dBm/Hz}}$ (6.33)

G/T Receiving system:

GTeff = Gm-10*LOG(Teff) = <u>-22.4 dB/K</u>   (6.34)

C/N:

CN = Pm-Nm=<u>58.42 dB</u>   (6.35)

Fading margin Lf=10dB

Eb/No after "fading margin":

EbNo = CN+10*LOG(Bw/Rb)-Lf = <u>49.39dB</u>   (6.36)

Energy per symbol at receiver system:

Es =10^((EbNo+(No-30))/10) = <u>3.58*10^-16 J/symbol</u>   (6.37)

Required Eb/No to achieve a bit error rate (BER)<1*10^-6 for AFSK: BERmin = 10dB

Link margin:

L =EbNo – BERmin= <u>39.39 dB</u>   (6.38)

Estimating the Mean Time between Error (MTBE) for the link

MTBE=((1/BERmin)*(10^'LOG(L))\(2*Rb)=<u>6647s</u>   (6.39)

Probability for no errors, introduced due to uplink channel, during a pass:

Pbep = (600[s]/MTBE[s])=<u>0,91</u>   (6.40)

6.3   Further investigation on the use of GMSK as modulation standard:

The following is partially a transcript of the document Practical GMSK Data Transmission [22].

If we look at a Fourier series expansion of a digital bit pattern signal we see harmonics extending to infinity. When these harmonics are summed, they give the data signal its sharp transitions. Hence, an unfiltered NRZ or UART data stream used to modulate an RF carrier will produce an RF spectrum of considerable bandwidth. The Norwegian Post and Telecommunications office and AMSAT has strict regulations about spectrum usage and such a system is generally considered impractical. But if we start to remove the high frequency harmonics from the Fourier series (i.e. pass the data signal through a low pass filter), the transitions in the data will become progressively less sharp. This suggests that premodulation

filtering is an effective method for reducing the occupied spectrum for wireless data transmission. In addition to a compact spectrum, a wireless data modulation scheme must have good bit error rate (BER) performance under noisy conditions. Its performance should also be independent of power amplifier linearity to allow the use of class C power amplifiers.

For example, a 1200 bit per second baseband MSK data signal could be composed of 1200 Hz and 1800 Hz frequencies for a logical one and zero respectively (see Figure 1).
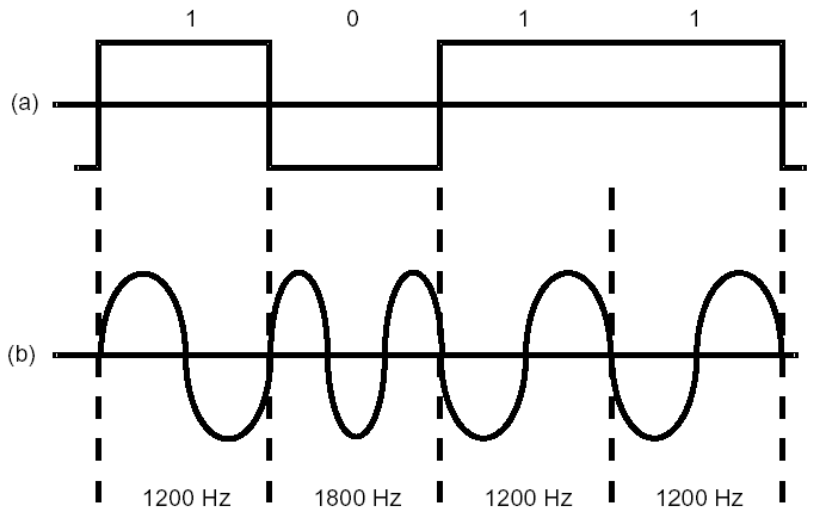
Figure 6.3: *Basic MSK modulation.*

Baseband MSK, as shown in Figure 5.8, is a robust means of transmitting data in wireless systems where the data rate is relatively low compared to the channel BW. An alternative method for generating MSK modulation can be realized by directly injecting NRZ data into a frequency modulator with its modulation index set for 0.5 (see Figure 5.9). This approach is essentially equivalent to baseband MSK. However, in the direct approach the VCO is part of the RF/IF section, whereas in baseband MSK the voltage to frequency conversion takes place at baseband.
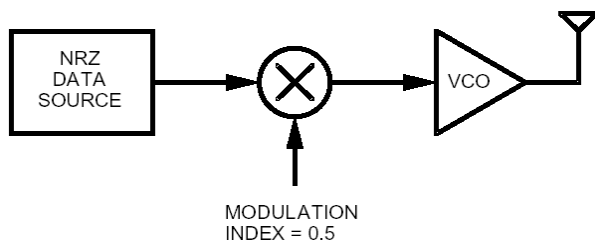
Figure 6.4: *Direct MSK modulation*

The fundamental problem with MSK is that the spectrum is not compact enough to realize data rates approaching the RF channel BW. A plot of the spectrum for MSK reveals side lobes extending well above the data rate (see Figure 5.10). For our transmission systems, which require more efficient use of the RF channel BW, it is necessary to reduce the energy of the MSK upper side lobes. Earlier we stated that a straightforward means of reducing this energy is low pass filtering the data stream prior to presenting it to the modulator (pre-modulation filtering). The pre-modulation low pass filter must have a narrow BW with a sharp cutoff frequency and very little overshoot in its impulse response. This is where the Gaussian filter characteristic comes in. It has an impulse response characterized by a classical Gaussian

distribution (bell shaped curve), as shown in Figure 5.10. Notice the absence of overshoot or ringing.
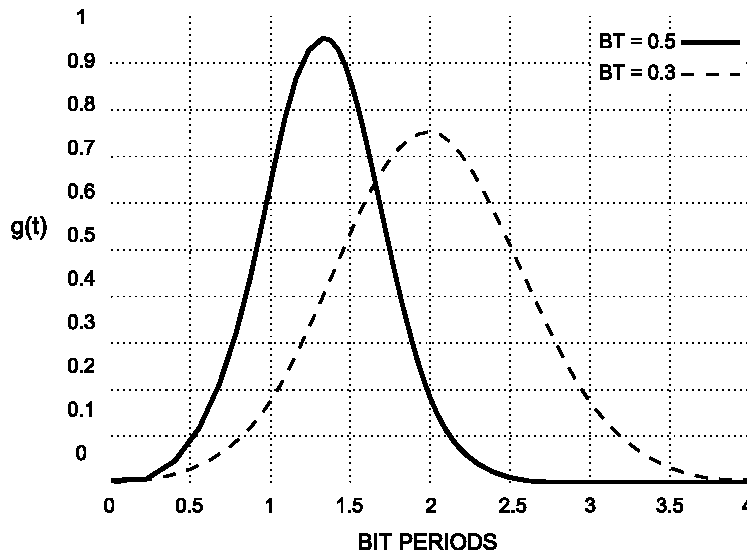
Figure 6.5: *Gaussian filter impulse response for BT=0.3 and BT=0.5*

Figure 6.5 depicts the impulse response of a Gaussian filter for BT = 0.3 and 0.5. BT is related to the filter's -3dB BW and data rate by:

$$BT = \frac{f_{-3dB}}{BitRate} \qquad (5.42)$$

Hence, for a data rate of 9.6 kbps and a BT of 0.3, the filter's -3dB cutoff frequency is 2880Hz. Still referring to Figure 5.10, notice that a bit is spread over approximately 3 bit periods for BT=0.3 and two bit periods for BT=0.5. This gives rise to a phenomenon called inter-symbol interference (ISI). For BT=0.3 adjacent symbols or bits will interfere with each other more than for BT=0.5. GMSK with BT=   is equivalent to MSK. In other words, MSK does not intentionally introduce ISI. Greater ISI allows the spectrum to be more compact, making demodulation more difficult. Hence, spectral compactness is the primary trade-off in going from MSK to Gaussian pre-modulation filtered MSK. Figure 4 displays the normalized spectral densities for MSK and GMSK. Notice the reduced side lobe energy for GMSK. Ultimately, this means channel spacing can be tighter for GMSK when compared to MSK for the same adjacent channel interference.
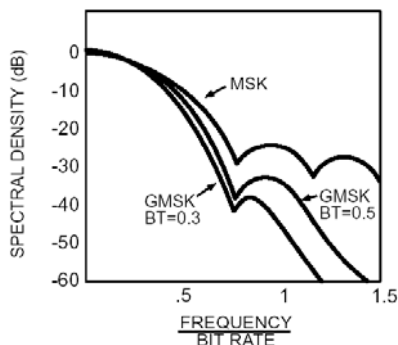
Figure 6.6: *Spectral density for MSK and GMSK.*

6.3.1 Performance Measurements

The performance of a GMSK modem is generally quantified by measurement of the signal-to-noise ratio (SNR) versus BER. SNR is related to Eb/N0 by:

$$\frac{E_b}{N_0} = \frac{S}{RN_0} = \frac{S}{N}\left(\frac{B_N}{R}\right) \qquad (5.43)$$

6.3.2 Implementation Considerations

The use of a GMSK modem is generally not that simple, many of the sections in our radio such as the synthesizer, IF filter, power amplifier, etc. have far from ideal behavior. In particular, the synthesizer presents a unique problem for GMSK modulation. Data patterns consisting of several consecutive ones or zeros have a spectral response extending down to near DC. Most frequency synthesizers will not respond to this low frequency signal (a typical synthesizer effectively has a high pass filter characteristic). Two of the most common modulation methods, which help considerably where the non-ideal behavior of the synthesizer is concerned, are "Two-point modulation" and "Quadrature modulation."

6.3.3 Demodulation:

Demodulation of the GMSK signal requires as much attention to the preservation of an unadulterated waveform as does modulation of the signal. The choice of a Gaussian shaped pre-modulation should be implemented for three main reasons:
1) Narrow bandwidth and sharp cutoff
2) Lower overshoot impulse response
3) Preservation of the filter output pulse area.

The first condition gives GMSK modulation its spectral efficiency. It also improves its noise immunity when demodulating. The second condition affords GMSK low phase distortion. This is a major concern when the receiver is demodulating the signal down to baseband, and care must be taken in the design of the IF filtering to protect this characteristic. The third condition ensures the coherence of the signal. While this is quite strict and not realizable with a physical Gaussian filter, the phase response can be kept linear and therefore sufficient for coherent demodulation.

In most systems the constraints on the above goals also include
- Data Rate
- Tx filter bandwidth (BT)
- Channel Spacing
- Allowable adjacent channel interference
- Peak carrier deviation
- Tx and Rx carrier frequency accuracy
- Modulator and Demodulator linearity
- Rx IF filter frequency and phase characteristics.

These constraints are all part of the balance that must be struck to provide a robust GMSK system. The data rate, Tx BT, peak carrier deviation, and carrier frequency accuracy between

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receiver and transmitter all contribute to the necessary width of the IF filter, the IF filter should have sufficient width to accommodate the maximum variations in the above parameters so that the received signal will not run into the skirts of the filter.

The skirts of the IF filter can introduce excessive amounts of group delay (phase distortion) in the higher frequency components of the received data. The pass band of the IF filter should have little or no group delay. The more group delay introduced, the more degraded the bit error rate (BER) performance of the receiver will become. Rules of thumb for group delay dictate less than 10% of a bit time are tolerable. Phase equalization measures can also be taken to help reduce group delay, but if there is control over the IF filter's design these steps can be avoided.

7   User interaction

7.1   The Server Application

The server application placed in the center of fig 5.13 is a hub point for all interactions with the ground station; the application is capable validating username and password from the operator before setting up the connection with the peripherial equipment. The application is realized thru C++ Microsoft Foundation Class programming, supporting TCP sockets. The code is enclosed in Appendix B. The code and executeable is also enclosed in the CD. The application itselves could be run anywhere.

The program sets up four TCP sockets connecting to: the data logger/viewer, the serial digital wattmeter, the transceiver, and the antenna positioner. Next it opens four server sockets and awaits connection from the tracker, the joystick, the estimator and a standard terminal emulator. The user sets up a routing matrix, and edits ip numbers and port numbers for all connections.

In fact the use of the server application is optional, by knowing the IP-address directly to the serial bridge a PC anywhere in the world could use RS-232 enabled COTS software as WiSP or NOVA in the following manner:

> -Set up the TCP/IP – RS-232 as a Client listening on a com-port, ex. COM 2
> -Buy or make a crossed serial cable, pins 2 and 3 crossed and 5 directly if no hardware control is necessary, and connect between COM 2 and; ex. COM 1 of the computer.
> -Set up the program (Terminal emulator, tracker, logger) to use COM 1 as if the equipment is actually connected to this computer.

Then the bridge makes the necessary communication transparent to the running program.

7.2   The Estimator

The estimator is the diploma work of Bent Christian Samuelsen at HiN, his application interconnects with mine in the same manner as the rest of the subsystems thru TCP and IP. His program estimates the current heading necessary pointing the antennas to communicate with the satellite. When enabled in the server application his program is relayed to the antenna positioner and the viewer. His code can be found in appendix C, and on the CD.

7.3   The Virtual Joystick / Joystick

The virtual joystick part has five buttons; elevate, lower, cw, ccw and stop. When the user presses one of these with a click of the mouse, the commands expressed are sent to the antenna rotator via the server application, or directly if the bridges IP address is supplied.

I have also programmed a routine reading a two axis commercial off the shelf game controller which can be connected thru any univesial serial bus (USB) port on the computer where the program runs.

The source code and executable can be found in appendix C.

7.4   The Tracker

The tracker is the Diploma Work of Nadejda Sokolova. It is a monopulse tracking system, which determines pointing deviations and updates the rotor controller as necessary. It may not be completed due to the complexity and cost of the hardware, but the program will accept a connection, if the tracker is completed in the future anyway. The lack of a hardware tracker is not critical as long as NORAD [16] maintains its service of tracking elements in the 10 cm area and generating two-line elements.

7.5   The Antenna Positioner

The antenna positioner program is a TCP to RS232 Bridge; the program must run on a pc in close vicinity of the rotor controller itself. It sets up a TCP server socket and awaits connection from the server application.

The source and executable is enclosed in both appendix D and on the compact disc.

The antenna positioner itself is equipped with a set of buttons capable of overriding the rotor system by a local operator. So that a local operator can park the antennas or run those in safe mode in case of bad weather, cracking etc.

The manual for the rotor controller is enclosed in appendix E

7.6   The Tranceiver

The transceiver program is the same as the program for the positioner. It runs on a second independent pc connected to the net.

A command reference for the transceiver operation over TCP/IP is found in appendix E

The transceiver itself has all functions accessible to a local user thru a buttons panel and a screen.

The transceivers manual is enclosed as appendix F.

7.7   The Serial Digital Wattmeter

The serial digital wattmeter measures standing waveratio and output wattage on the transmission feed, and is read by another RS232 to TCP/IP Bridge. The program is run on a third separate pc connecting directly to the wattmeter.

7.8   The Terminal Emulator

The terminal emulator connects bidirectionally; directly or thru the server application to the transceiver. The user's keystrokes are recorded and sent over TCP, and returning characters are echoed in a document-style listing window. The terminal emulator settings are IP-number and Port-number, and in addition Com port mumber for direct interconnection with the equipment.

7.9   The Data logger / Viewer

The datalogger is intended to show the same information as the terminal emulator software, but in addition timestamping events as they occure and saves the information to a file successively

8   Testing

This chapter covers testing, verification and analysis of the subsystems functions. The testing has been conducted in several stages, from each subsystem independently to the complete Ground station as a whole.

8.1   Testing of antenna rotators and controller:

8.1.1 Testing conditions:

The rig was mounted at its recommended location outside,
2 70cm antennas and one 145cm antenna attached.
Speed setting was 9 (max),
Control by local operator on the device's buttons panel

8.1.2 Results:

Operation around both axes successful
Full stroke azimuth revolution completed in 45s, 8deg/s
A change in azimuth orientation of 60 deg took 7s, 8,6 deg/s
0 – 90 degrees elevation completed in 47s; 1,9 deg/s
Command stall when changing direction for azimuth; 2,5s
Command stall when changing direction for elevation 0,5s

8.1.3 Limitations
Some temporary scaffolding is still inside the antennas operating cone. Elevation angles below 0 degrees will in most cases cause a collision Elevation angles over 45 degrees will in some cases cause a collision. The operator can observe the rig directly from the control room.

8.1.4 Conclusions:
The command stall is a safety measure to ensure that the DC motor is brought to a halt before changing direction. Satellites in a polar obit will not change their heading during a pass, so this function will not interfere during contact.

For a 700 km altitude pass, the peak d/dt angle is:

Gravity constant $G = 6{,}67 * 10^{-11} \dfrac{m^3}{kgs^2}$

Earth mass $M = 5{,}976 * 10^{24} \, kg$

Earth radius $r_e = 6378 * 10^3 \, m$

Orbit altitude relative to earth : $r_s = 700 * 10^3 \, m$

Semi major axis : $a = r_e + r_s = 7078 * 10^3 \, m$

Revolution time : $T = 2\pi \left(\dfrac{a^3}{M * G} \right)^{\frac{1}{2}} = 5{,}92 * 10^3 \, s$

Average angular rate : $360 \text{deg}/T = \underline{\underline{0{,}0607 \, \text{deg}/ s}}$

Orbit velocity $S = \left(\dfrac{M * G}{a} \right)^{\frac{1}{2}} = 7{,}50 * 10^3 \, m / s$

Maximum angular velocity $= \dfrac{360 \, \text{deg} * S}{2\pi * r_s} = \underline{\underline{0{,}614 \, \text{deg} /s}}$

The maximum angular rates are within the capability of the rotators.

8.2   Testing of joystick controlled operation

8.2.1 Testing conditions and setup:
-Rotor and rotor controller located in assembly hall.
-Specially designed program (source enclosed in appendix g) running on the ThinkPad, and directly connected to rotor controller via RS-232.
-A wireless Joystick with receiver connected to a USB port.

8.2.2 Results:
The rig could be turned clockwise, anticlockwise, elevated and lowered. The motion could be stopped at any moment by centering the joystick.

8.2.3 Limitations:
The program currently only supports the functions described in results, hence no programming or ramping in real-time operation are supported.

8.3   Testing of antenna diagram at ground level in Narvik, Ankenes, and Ballangen.

8.3.1 Testing conditions and setup:
Locations: Roof of library – Industriveien 100, Ankenes Marina and Kjeldebotn
Antenna rig located on the roof of the library, rotor controlled operation enabled. Portable Kenwood THD-7 capable of output power: 100mW, 1 Watt or 5 Watt. Stationary Kenwood

TS-2000 connected to the antennas on the rig, sending with 5 Watt. Both radios tuned to 145.525MHz as band A and 437.725MHz as band B.

The signal from the 437.725 was split in 2, between the TS-2000 and the Rhode & Schwarts FSP-7 Spectrum analyzer. The figures of either of the instruments are therefore governed by a 3dB loss due to the split signal. Only two pairs of antennas were attached due to problems with collision with temporary scaffolding around the rig.

While testing, an AX.25 session was set up and maintained during the whole test via the radios, all measurements was actually logged on a laptop using packet radio installed in the car used for transporting the transceiver, the car in the same time acting as a moving target. Doppler shift was of course not observed.

8.3.2 Results from Industriveien 100:

Table: 8.1- *Measurements on carrier power from Industriveien 100*

Power	Range	Location	Date	LNA
100mW	1000	Industriveien 100	03 06 02	No
Delta Az	Delta El	S	SA [- dBm]	SER [- dBm]
0	0	30	95	105
30	0	1	105	120
60	0	1	112	120
0	15	40	100	120
0	30	20	105	120
0	45	27	105	120
0	60	1	115	120

SA measurements were done by reading the maximum peak intensity of the 437.725 MHz carrier signal on the spectrum analyzer and averaging over a 30sec period. S is the built in S-meter on the TS2000 receiver and SER are Spurious Environment Radiation or noise floor. SER was measured when the carrier of the transmitter was off. The LNA was not attached to the receiving antennas. The range between the receiver and transmitter was 1000m. Delta AZ and Delta EL are the deviation between the direct line of sight and the actual receiving antenna heading.

8.3.3 Sources of error:

The measurements were done in the ground plane over a shallow valley in an urban area of Narvik. Since the transmitter was held merely 2,5 meter above ground reflections and multiple paths of the signal were probably present. The LOS(Line of Sight) heading was known accurately only within a margin of 5 degrees, because the calibration of the rigs heading was not commenced yet.

8.3.4 Results from Ankenes Marina:

Table 8.2 - *Measurements of average carrier peak power(ACPP) from Ankenes*

Power	Range	Location	Date	LNA	
100mW	2000M	Marina	03 06 02	No LNA	
Delta Az	Delta El		S	SA [- dBm]	SER [- dBm]
0	0		37	100	120
30	0		1	115	120
45	0		20	100	120
60	0		9	107	120
0	15		5	105	120
0	30		8	105	120

Marina:

The range was increased to 2000m and measurements were repeated as expected the signal roughly is attenuated 3-5dB all over; variations appear as predicted in "Sources of error".

8.3.5 Sources of error:

The transmitter was close to water surface and reflections from this may be significant. As only the top two sets of Yagis stacked together was used; their maximum sensitivity was in the vertical plane. In the finished rig we should experience a 3dB extra gain due to the other set of Yagis, and a narrower antenna bore sight.

8.3.6 Results from Kjeldebotn/Ballangen:

Table 8.3 - *Measurements of average carrier peak power from Kjeldebotn*

Power	Range	Location	Date	LNA	
1000mW	30km	Ballangen	03 06 03	No LNA	
Az No CAL	El		S	SA [- dBm]	SER [- dBm]
14	17,5			110	
8	17,5			108	
6	17,5			106	
4	17,5			108	
2	17,5			108	
0	17,5			106	

The range was further increased to 32000m, theoretically adding another 12dB path loss. The transmitter power was increased to 1W, adding 10dB to the link budget. These effects were observed as expected and we maintained a good link free of audible noise as we spoke. The AX.25 protocol was also maintained without errors. The peak power was found when holding the transmitter antenna vertically, and is the powers reported in table 7.3.

8.3.7 Sources of error:

The measurement was done from a point found when travelling along the beach line of Kjeldebotn to have LOS conditions and a strong signal. A strict forward acting ducting condition may have appeared is it was foggy and the fjord leading to Narvik could possibly act as a wave-guide. In this measurement the transmitter was held approximately 25 meter above the water surface, and reflections is believed to be significant and might have caused an

extra gain of up to 3dB, but it could also equally well be the other way around, that an attenuation was experienced due to signals with different ways, super positioning and phasing each other out.

8.3.6.1 Results from Kjeldebotn/Ballangen - continued.

Table 8.4 - *Measurement of ACPP from Kjeldebotn, transmitting with 5W*

Power	Range	Location	Date	LNA	
5W	30km	Ballangen	03 06 03	No LNA	
Az No CAL		EI	S	SA [- dBm]	SER [- dBm]
353		17,5 -		100 -	
356		17,5 -		99 -	
359		17,5		97	
0		17,5		98	
3		17,5		100	
6		17,5		100	
8		17,5		99	
14		17,5		102	

To test the consistency of our measurements the transmitter power was increased to 5W, hence adding 6-7dB to the link. And small pointing angle deviation was done around the LOS to try to determine lobe characteristics. And the results seem to be consistent, as we se a 6-7 dB increase in signal strength.

8.3.6.2 Sources of error: Same as previous.

8.3.2.1 Results from Industriveien 100 continued.

Table 8.5 - *Measurement of ACPP from Industriveien 100 with LNA attached.*

Power	Range	Location	Date	LNA	
100mW	1km	Industriveien 100	03 06 06		
Az		EI	S	SA [- dBm]	SER [- dBm]
-75		0 -		69	
-60		0 -		75	
-45		0 -		68	
-30		0 -		60	
-15		0 -		57	
0		0 -		57	
15		0 -		57	
30		0 -		58	
45		0 -		67	
60		0 -		63	
75		0 -		77	

The Low Noise Amplifier was attached and new measurements were taken from Industriveien 100 (range 1000m) adding 23dB to the link. The receiving radio was disconnected which should have a +3dB impact. The transmitter was rotated from horizontal polarization to vertical polarization to confirm the extra gain experienced in Ballangen due to polarization, adding further 3 dB. The scaffolding was removed and the last pair of antennas was attached

adding 3dB. The results are consistent with our expectations, without LNA and with the old setup the best ACPP from Industriveien 100 was as seen in *table 7.1* -95dB , adding LNA, splitter, antennas and polarization gain: 35dB, which gives a expected signal strength of 60dB. Table 7.5 shows figures actually slightly better than this too. The antenna lobe seems to be wider than expected but this could be due to "Sources of error" again.

8.3.2.2   Sources of error:

Scaffolding was removed, the closest interfering object is now the antenna mast it selves and better conditions is expected since there are less metal in the near field of the Yagi antennas. Except from this, the same sources of error govern as in the previous measurements from Industriveien 100.

8.4   Testing of communication with orbiting satellite.

8.4.1 Testing conditions and setup:

All equipment located at MCC E3041.
Scaffolding was removed.
Antennas was calibrated whitin -+2degrees azimuth and +-1degree elevation
One pc running a TeraTerm[24] connected to the TS-2000
One pc running Nova Satellite Tracker, connectred to PRK-2800DC
NORAD 2 line elements no older than 2 days.
Several tests has been conducted with this setup, and general results are listed in 8.4.2

8.4.2 General Results

When tracking audio relay amateur satellites, conversations is picked up mainly in German and English language, when passes goes far east Russian language can also be heard.

Many amateur satellites has been knocked out during sun storms lately, and runs in safe mode transmitting beacons now and then only, very few satellites supports packet forwarding at this moment, and information on which satellites runs in normal operation is sparse, a great resource for finding amateur satellites and status is Heavens Above[25]. No AX.25 communication has been successfully tested at this moment, but further attempts will be made during summer and autumn 2003.

8.5   Testing of standing wave ratios and return cable losses

General conditions: The Anritsu Company – Site master S331A instrument was used.

8.5.1 Return losses:

144 to 146 system testing conditions and setup:

The Anritsu instrument was calibrated at the local end and thus including our cabling and antenna. Only one of two sets of the 144 to 146 MHz system X-Yagis was connected, the two free ports of the power splitter was terminated by an N to BNC adapter with a standard 50Ohm impedance network terminator. The lightening arrestor was connected.

8.5.2 **Results**: See figure 8.1.
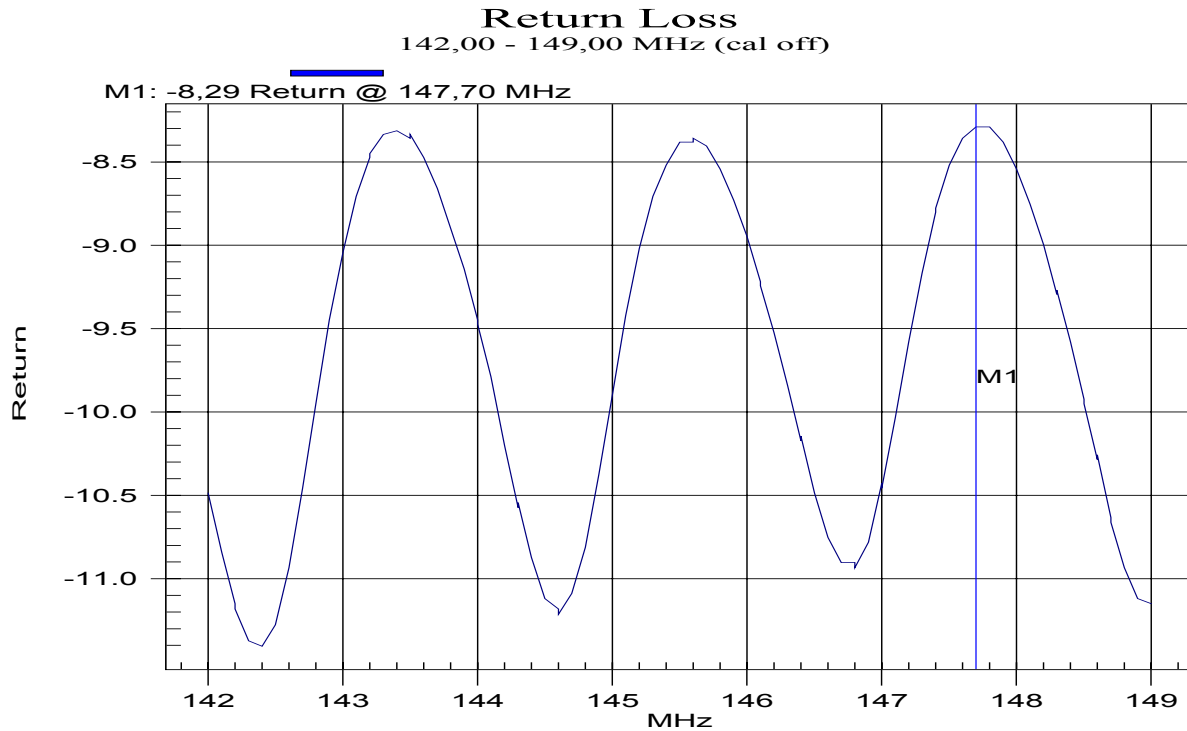

Figure 8.1: *Return cable loss for the 144 to 146 MHz system*

8.5.3 430 to 440 system testing conditions and setup:

Local Test port calibration procedure was followed. All four 430 – 440 X-Yagis was connected via two 4 Way combiner connected to one 2Way combiner. The lightening arrestor was connected, but the Low Noise Amplifier was omitted.

8.5.4 Results:

See figure 8.2.
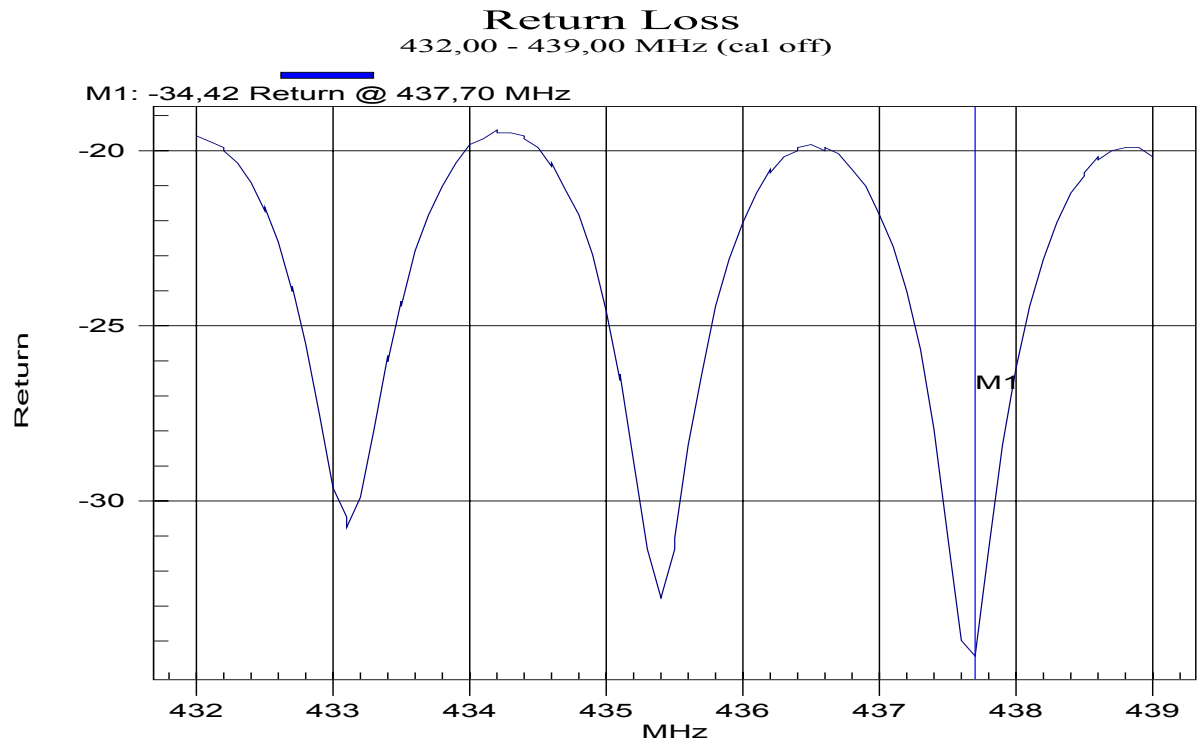
Figure 8.2: *Return cable loss for the 430 to 440 MHz system.*

8.6   Standing Wave Ratios (SWR).

8.6.1 General:

The same setup and calibration procedures as the above section were used.

Results in figure 8.3 and 8.4. A Smith diagram for the measurements were rendered, presented in figure 8.5 and 8.6.

VSWR
430,00 – 440,00 MHz (cal off, cw on)
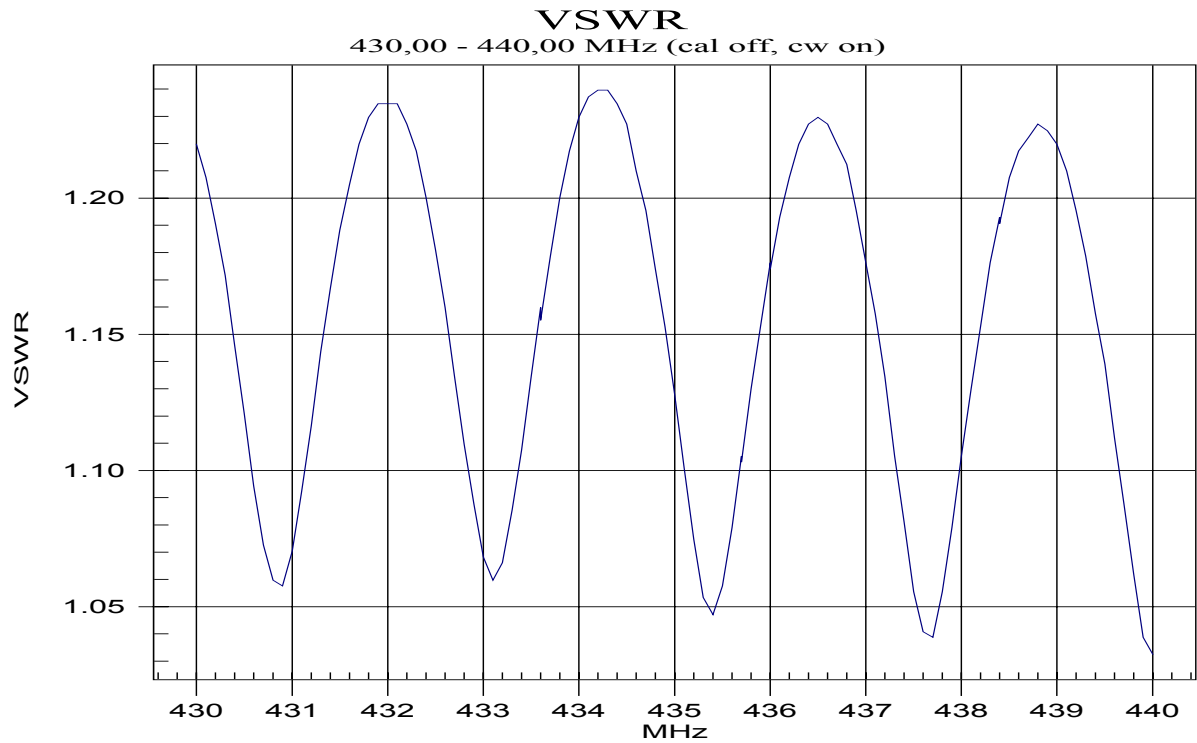
Figure 8.3: *SWR for all four X-Yagi and cabling, in the 430 to 440MHz system.*

VSWR
140,00 – 147,00 MHz (cal off, cw on)
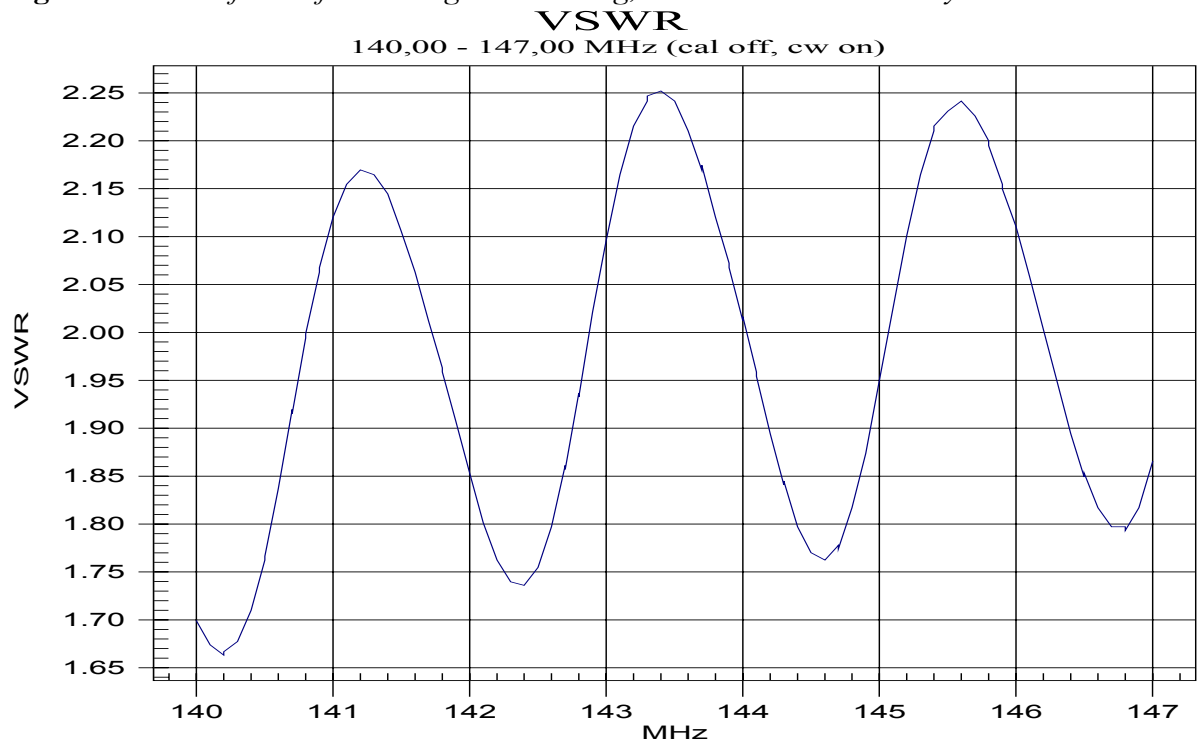
Figure 8.4: *SWR for one X-Yagi and cabling, in the 144 to 146 MHz system*

Smith Chart
430 - 440 MHz
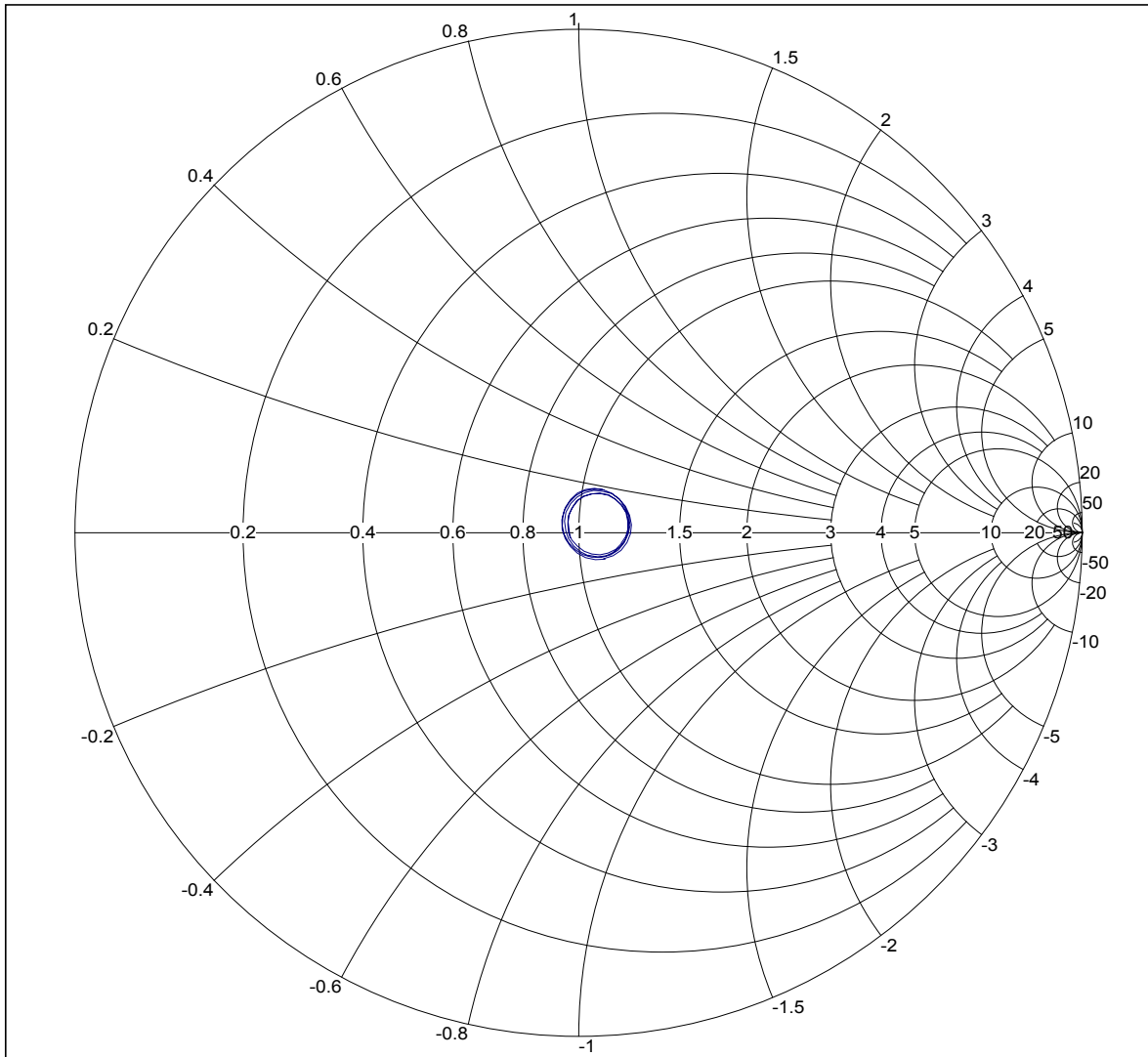
Figure 8.5: *Smith diagram for 430 to 440 MHz system.*

Smith Chart
140 - 147 MHz
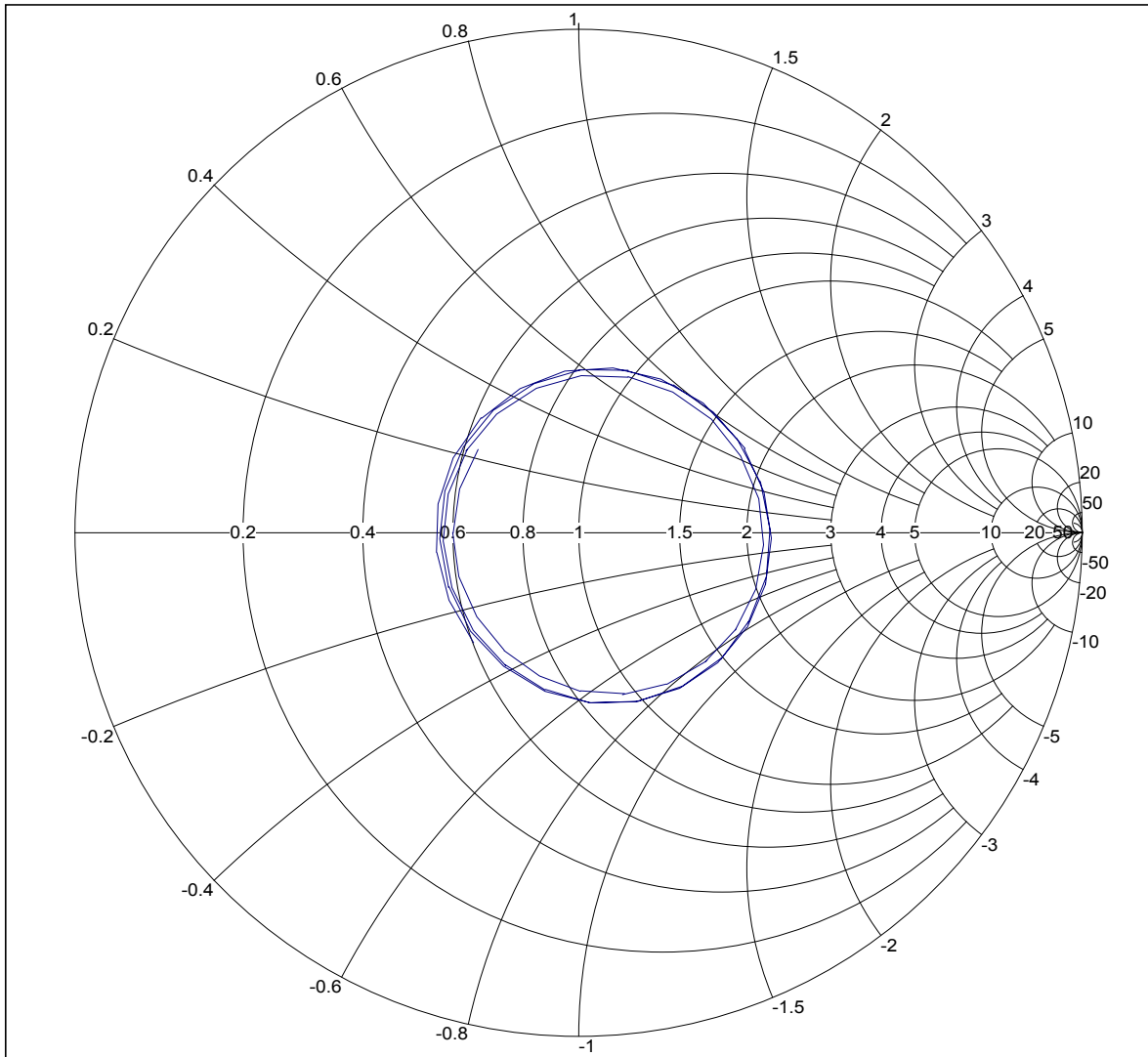
Figure 8.6: *Smith diagram for 144 to 146 MHz system (extended range).*

9 Remaining objectives

The stations main task, namely communication with nCube has not yet fully been tested since our satellite is not in orbit yet. And our 'ground working prototype only' has its transceiver under construction. The integration with FGN is neither tested, but the FGN group will have a working version during this autumn.

Intensive testing with AX.25, and bit rates of 9600 against orbiting satellite remains, and is expected to give failing conditions. See also '10 Conclusions'.

The server application was not finished, but all equipment can be interfaced directly both remotely and locally, and hence fulfilling the objectives. Security issues exist though.

10   Conclusions

I have during my diploma period spring and summer 2003, taken part in the assembly, installation and testing of the first Norwegian student satellite nCube's groundstation, and planning of its communications architecture.

I have programmed and installed both my own and third party software and made sure that the complete setup complies with the mission objectives and objectives related to the diploma.

The assembly is now finished, tested and ready to use.

Tests done suggest that the groundstation will be able to communicate with nCube when in orbit.

June 30, the first "cluster" of Cubesats was launched, containing among others Cute, QuakeSat, AAUsat and DTUsat. We have spent much time on supporting "Danmark Tekniske Universitet" [26] (DTU)'s DTUsat. We have tried to enable their transmitter by emitting a coded sequence downloadable from [26], but without success. No other radioamateur have succeeded with opening the transponder of this satellite either. We have hopes of contacting QuakeSat especially, but have had no time to commence with testing as other tasks and writing of this diploma report have taken all the time lately.

We are currently unable to communicate with satellites with uplink at 430-440 range, since our LNA does not tolerate power on its output port; a radiooperated switch could be installed to overcome this. But usually the uplink and downlink is separated, and downlink is placed in the 145 MHz band for AMSTAR-OSCAR satellites and this should therfore cause no problem with standard amateur ssatellites.

James W Cutler at Stanford University, reports that the Tasco Radio modems (TNC) installed in TS-2000 can cause a stack overflow at high troughput 9600bps, causing loss of data. We have ourself experienced stacking of data 2 times over a period of maybe 10 days of intensive testing of the AX.25 link, the stacking did then not cause loss of data only a delay of approx.30sec. A workaround for this involving the use of a PacComm – PicoPacket(TNC) instead is currently under investigation, and the problem should be solved before launch autumn 2004.

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.   List of acronyms:

AC	Alternating Current
ACPP	Average Carrier Peak Power
AFSK	Amplitude Frequency Shift Keying
AFT	Antennes France Tonna
AIS	Automated Information System
AMSAT	Amateur Satellite
ARGS	Automated Remote Ground Station
AZ	Azimuth
API	Application Programmers Interface
ARR	Andøya Rocket Range
ARRL	Amateur Radio Relay League / American Radio Relay League
BER	Bit Error Rate
bw	bandwidth
dB	desiBel
dBm	desiBel milliwatt
DC	Direct Current
CD	Compact Disc
COTS	Comercial Off The Shelf
Eb	Energy per bit
EIRP	Equivalent Isotropic Radiated Power
EL	Elevation
EM	Electro Magnetic
FGN	Federated Ground Network
GMSK	Gaussian Minimum Shift Keying
GPS	Global Positioning System
GS	Ground Station
HiN	Høgskolen i Narvik, Narvik University College
IP	Internet Protocol
LASER	Light Amplification by Stimulated Emission of Radiation
LNA	Low Noise Amplifier
LOS	Line Of Sight
MCC	Mission Control Centre
MFC	Microsoft Foundation Classes
MSK	Minimum Shift Keying
MTBE	Mean Time Between Errors
MTBF	Mean Time Before Failure
NAT	Network Address Translator
NF	Noise Figure
NIST	National Institute of Standards and Technology
NORAD	North American Aerospace Defense Command
NT	Network Terminal
NTNU	Norges Teknisk-Naturvitenskaplige Universitet
OSCAR	Orbiting Satellite Carrying Amateur Radio
PC	Personal Computer
RS-232	Recommended Standard number 232
SMAD	Space Mission Analysis and Design

SINAD	Signal, Noise and Distortion (audio measurement)
SAT	Satellite Access Time
SER	Spurious Environment Radiation
SWR	Standing Wave Ratio
TAPR	Tuscon Amateur Packet Radio
TCP	Transmission Control Protocol
TNC	Terminal Node Controller
TS	Tranceiver System
USB	Universal Serial Bus
X-Yagi	Crossed Yagi-Uda Array
WiSP	Windows Satellite Program

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