Proposals for the communication subsystem onboard nCube

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Abstract

We have in this report looked at some diffent alternatives for the communication subsystem of the Norwegian Student satellite, nCube. The work was conducted in the subject '*Eksperter i Team* at NTNU. This work is a part of the first step in the project for a Norwegian Student Satellite and it will make a foundation for further projects on nCube.

Our recommendation is based on the use of the amateur bands. We recommend a communication subsystem based on the Alinco DJ5T handset used in an amateur band. The transciever will communicate with the OBC using a TNC with AX.25 protocol.For antennas we recommend a redunant system with two antennas. One omnidirectional (crossed dipole) and one directed (microstrip or helix). We would also like to use PSK - modulation av the radio channel but this was not supported by the radio we chose.

Contents

Chapter 1

Introduction

1.1 "Eksperter i team-" Norwegian Student satellite

This report was written during the subject "Eksperter i team", *Experts in teams*, which was given the spring semester of 2002 at the Norwegian University of Science and Technology, NUST. The main topic for our group was "Norwegian student satellite". A topic we shared with five other groups. The reports from these groups are the first step towards a Norwegian student satellite. The next steps will be projects given in the autumn semester of 2002 and diploma projects given in the spring semester of 2003. We hope that the satellite will be launched into space in 2003.

"Eksperter i team " is a multi displinary subject given to fourth year students attending the sivilingeniør - studies at NUST. The students are divided into villages, each with a different main topic. In each village there are 30 students who are divided into 6 groups. Each group then decides on a specific problem under the main topic, which they want to work with. In each group there must be at least two students with different majors.

The goals for "Eksperter i team" are two-fold. The students should acquire knowledge through a challenging assignment in her own field. And she should develop skills and knowledge about problem solving and methods for problem solving.

1.2 CubeSat

CubeSat is a standard for picosatellites, mass $<$ 10 kg, which enables universities and colleges to design there own satellites and launch them into space without spending too much money. The CubeSat framework is a result of a project between Space System Development Laboratory (SSDL) at Standford University and California Polytechnic University. A CubeSat is a 10cm x 10cm x 10cm box with a mass of approximately 1 kg. It will be launched together with 3 (or 6) other Cubesats piggybacking a larger commercial payload in a P-Pod. See fig. Except from the restrictions given in "CubeSat Design Specifications Document, Revision V, November 2001" designers of CubSats are free to implement the different subsystems on the satellite in their own fashion.

1.3 The communication subsystem

We will in this report look at some alternatives for the communication subsystem for the Norwegian student satellite, nCube. This satellite conforms to the CubeSat specifications from Standford University . The major challenge has been the limited size of the satellite and therefore limited resources e.g. power and size.

Although we have cooperated with the other groups working on the Norwegian student satellite, we have had to take some choices of our own concerning numbers for available power, attitude control, size and placement of componets et.c.

We have focused on the onboard components and not so much on the ground segment The report is divided into five parts,

- Antenna, frequencies
- Tracking
- Transmission budget
- Radio hardware
- Protocols / modulation

In our group we where two telecommunication students, one cybernetic student, one naval engineer and one physicist. Our goal has been to give an overview over some different approaches to the design of the communication subsystem. Given the limited time and the scope of the project this report will only scratch the surface of the problem .

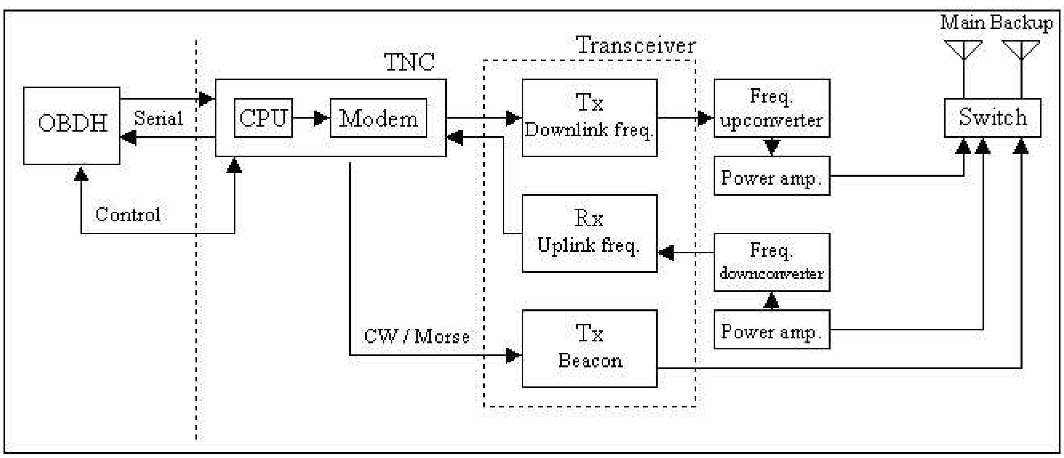

Figure 1.1: Communication subsystem block diagram.

Chapter 2

Frequency choise

2.1 Amateur frequency band

2.1.1 AMSAT

The Radio Amateur Satellite Corporation (AMSAT) is a non-profit scientific and educational corporation. It is a worldwide group of Amateur Radio Operators who share an active interest in building, launching and then communicating with each other through non-commercial Amateur Radio satellites. AMSAT groups have played a key role in significantly advancing the state of the art in space science, space education and space communications technology.

The International Amateur Radio Union (IARU) works closely with AMSAT organisations in many administration organisations, which primary goal are to co-ordinate and notify to maximise the use of the radio spectrum and to minimize interference.

2.1.2 Regulations

IARU and AMSAT has issued a paper [1] to aid prospective owners and operators of satellites planned to operate in frequency bands allocated to the amateur satellite service. Co-operating amateur groups have drawn band-plans to help minimize interference between different operations conducted in these frequency allocations. An AMSAT organisation can assist in the planning of operating, control and telemetry frequencies for best results in conjunction with other amateur satellites as well as terrestrial operators around the world.

Frequency allocations for the amateur-satellite service which are shared with other services are the bands: 144 - 148 MHz, 435 - 438 MHz, 1260 - 1270 MHz, 2400 - 2450 MHz and some higher frequencies. Formal ITU notification is not required for the use of bands allocated to the amateur-satellite service exclusively. Even so, international notification is an advantage to the amateur-community.

AMSAT state that organisations building satellites should determine if it is possible to comply with the requirements of the amateur-satellite service or if licensing and operation should be in some other radio service which is more consistent with the nature of the mission. According to AMSAT, the purposes of an amateur satellite should be:

"To provide communication resources for the general amateur radio community"

and / or

"To conduct technical investigations in all respects consistent with the Radio Regulations."

All stations operating in the amateur frequency bands, including space and earth stations, must be controlled by licensed amateur radio operators. International communication between amateur stations in different countries must be in plain language. This requirement includes telemetry and data exchange between users. To meet the plain language requirement, technical descriptions of all emissions, codes, and formats must be made publicly available. Space telecommand transmissions for critical spacecraft functions are generally accepted as exempt by AMSAT from the requirement to use plain language. All telecommunication (except telecommand) operating in amateur-frequencies should be open for use by amateur radio operators world-wide.

2.1.3 Cubesat HAM-Network

On of our objectives in using amateur frequencies, is that anyone who has amateur radio equipments can receive telemetry data from ncube. Thus we can share the data with amateur radio operators around the world, and use the ham network as a valuable assistance in tracking the satellite. We hope that the ncube project can offer technical contributions to amateur- / student-satellite projects. It can be difficult to identify the orbital parameters of the ncube immediately after launch. Therefore, sharing information and support from the worldwide ham network, is particularly indispensible on initial tracking.

2.1.4 Amateur frequencies for ncube

The frequency alternatives listed in table 2.1 are listed as "Exclusive Amateur /Amateur satellite band" in the official Norwegian Frequency Scheme, and these bands are internationally allocated.

	Alternative 1	Alternative 2	Alternative 3
Uplink frequency range	144 – 146 MHz	435 – 438 MHz	435 – 438 MHz
Wavelength (approx)	2m	70 cm	70 cm
Downlink frequency range	435 – 438 MHz	1260 – 1270 MHz	2400 – 2450 MHz
Wavelength (approx)	70 cm	24 cm	12.5 cm

Table 2.1: Amateur frequency alternatives for nCube.

The higher frequencies are suitable for downlink because they provide higher bandwith for the data transmission. Uplink frequencies are mainly used for telecommand and handshaking, where a low datarate is sufficient. Therefore, the lower frequencies, which provide cheaper power-generation, can be used.

2.2 License-free band

Another possible frequency-choise, is the unlicensed 433MHz, 868MHz and 915MHz SRD(Short Range Device)- bands. One major drawback with these bands which have no given protection, is the considerable noise which occurs especially in urban areas. Intended applications for these frequency locations, are among others Alarm and Security Systems, Home Automation, Remote Control, Surveillance, Toys and Remote keyless entry. Nevertheless, these frequencies may be used if the ground station is located in a place where noise from these short-range applications would not be a problem.

2.3 S-band

The S-band covers the frequency range 2-4GHz. At Andøya Rocket Range they have developed and used transceivers which utilize a part of the S-band, 2.2-2.4GHz. Most of this frequency range offer less noise and can be utilized with small antennas due to the short wavelength. Most of this band requires an official license, but there are exceptions like the amateur-allocated 2.4-2.45GHz.

2.4 Frequency recommendation

The license-free bands are the easiest accessable frequency range since they do not require a formal license. The fact that anyone can use these bands, will also introduce a considerable amount of noise especially from consumer-electronics. From the licensed bands we have considered, it is the requirements of the amateur-frequencies that is easiest to fulfil. Another major advantage with these frequencies are the valuable assistance from the HAM-network. It's desirable to use a high frequency to obtain more bandwith and smaller physical antenna-size in the satelite.

Chapter 3

The Antenna

The antenna is a very important component in the satellite communication system. A satellite without a functioning antenna can be considered a dead satellite, and is of course of no, or at the most, of little interest. Therefore it is not to exaggerate by stating that in this regard the dependency of the whole communication system is in the correct deployment and functioning of the antenna. In launch mode no part of the satellite may excide the physical limitations of the main structure. This structure is limited to 10 x 10 x 10 cm. As result we have to take an unconventional approach to the problem of fitting an antenna to the satellite. In the following discussion we will address this problem at a general level. Introduction to some important properties of the antenna is given in appendix.

3.1 Antenna Types

In this chapter the different properties of a few antennas will be analyzed. The physical properties are denoted in the appendix. We refer the reader to these pages if interested in the details.

3.1.1 The Microstrip Antenna

Function

The microstrip antenna is a fairly new concept. In fact the definition of the microstrip antenna is not yet well defined, but normally covers antennas constructed with pressed conductors on microwave substrata. In the following we will focus on the most common version of the micro strip antenna, the "patch antenna". The basic patch antenna consists of a rectangular metal plate pressed onto one side of a dielectrical substratum witch has a ground-plane on one side. The metal plate is excited either directly by a micro strip line, a coaxial connection led through the substratum or indirectly from a microstrip on a new substratum beneath the ground-plane.

The manner of operation for the microstrip antenna is simplest described by regarding the radiating metal plate as a microstrip line of a certain length l and width w. In short the radiation appears to be emitted from the edges of the metal plate. The micro strip line has an apparent disclosure at both ends, but because of the spray fields at the edge the microstrip line will radiate. The spray fields are confined to a small area along the microstrip line, thereof the seemingly edge radiation. Furthermore, as the spray fields are in phase and have the same

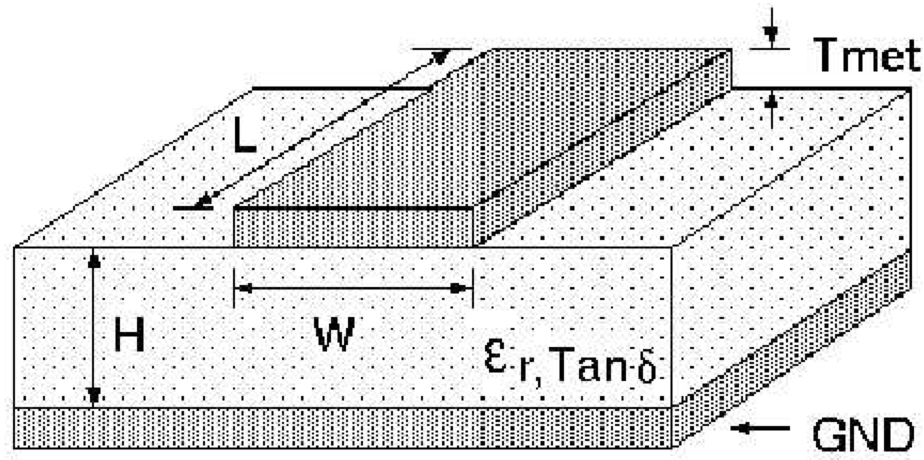

Figure 3.1: A microstrip

direction the resulting main lobe is in the z-direction. A single micro strip antenna has a relatively low directability. By connecting an array of micro strip antennas this problem a far higher degree of directivity can be achieved.

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Analysis

The main advantage with the microstrip is that it does not need deployment, and therefore is more secure. The risk of mechanical failure, as it were is largely reduced. Unfortunately it takes up rather a lot of space. A whole side will be lost. However, there are variations of the micro strip that are very much smaller. These are called GPS antennas, and should be studied in further detail. We will not pursue this possibility further, just state that it is a possibility. The micro strip antenna can be circular polarized, and when configured as an array have a relative high directivity. This implies high gain values. The downside is that

Dimension	Value
Ground plane	0.8 λ to 1.1 λ
Coil circumference	0.75 λ to 1.33 λ
Axial length of one turn	0.2126 ircumference of winding to 0.2867 Cy
Ground plane to first coil	0.12 λ to 0.13 λ

Table 3.1: Dimensions for a helix antenna

this antenna requires the satellite to be stable and facing in the direction of the antennas all the time. This demands a high degree of stability control, perhaps too much for practical purposes. The bandwidth is the lowest of all the antennas under review in this paper, just a few percent.

3.1.2 The Helix Antenna

Function

The helix antenna was introduced in the 1940s. There are a few characteristics that make this antenna very popular in space communications, especially for the uplink. The antenna can be used in two modes, transverse and longitude. When operating in transverse mode the helix behaves as a group of ring antennas. The radiation is directed perpendicular on the axis of the helix, and by adjusting s and D it is possible to attain circular polarization. In this mode the helix has a small radiation efficiency and a narrow bandwidth.

The helix is most popular in the longitude mode. In this mode the antenna is circular polarized main lobe in the axial direction. Another interesting property of the helix antenna is its predictable pattern, gain and impedance over a wide frequency range. The antenna behaves as a row of array antennas. The physical configuration of the helix antenna bares resemblance with an air wound coil. One end is unconnected while the other end is connected to a ground plate. The directionality is dependent of the number of coils. The more coils a helix antenna has the more directional it is. This is also true for the antennas gain. The longer the antenna the more gain it will produce. However the bandwidth is good, approximately 20 of center frequency.

Typical dimensions as given in table 3.1 are as following.

Analysis

In regard to the ncube the employment of the helix antenna does imply some restrictions to the overall construction. First of all the main strength of the helix lies in it's capability to produce a rather directional beam. And it is the directionality of the antenna that is of major concern. A highly directional antenna will demand a stable satellite. Another issue is size. The basic calculations for the desired frequencies show that the helix antenna is only applicable for the highest frequency ranges, in the region above 2,4 GHz. Thus complicating the designing of the radio equipment on board. The ncube's physical limitations do present a problem for the construction of such an antenna. The antenna has to be transported in a compressed state and deployed in orbit. One approach is to compress the antenna as a spring and locking it in the superstructure of the satellite. When in orbit, one can unlock the "spring" and thereon deploying the helix antenna. Another issue to consider is that the helix will use one whole side and some internal space of the ncube. The advantages of the helix antenna are mainly its energy efficient beam, dependent of directionality and it's good bandwidth. Also the antenna is apparently very forgiving to design imperfections.

3.1.3 The Dipole Antenna

Function

A very common and simple antenna the dipole antenna has proven to be reliable and sufficient within many working areas. The dipole antenna consists of one or more thin conductors, often circular in shape. These conductors are either self bearing or strung up between several points of attachment. With the ncube in mind the latter choice is evidently inconvenient. Therefore we will concentrate on the self-bearing conductor. The dipole is fed through terminals as shown in figure 3.2.

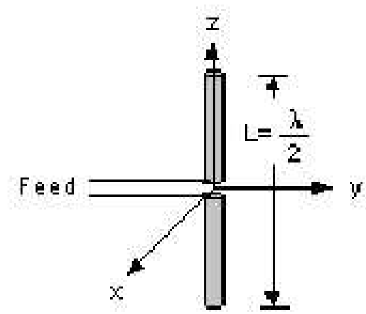

Figure 3.2: The principles of a dipole antenna

The current is nearly sinusoidal distributed along the conductor. This is the result of the open ends on each conductor. The electrical current is reflected at the ends and a standing wave occurs. In technical terms the dipole antenna has a biconical transmission line. At small lengths the dipole will behave as an infinite dipole. The directivity increases in proportion with the length of the conductors until a maximum level at 1,25 lambda. Further incensement will result in a disruption of the main lobe and give birth to several side lobes. A factor even more important is the effects on the impedance by varying the dipole lengths. The dipole has an ideal impedance at about 0,5 lambda , varying to some extent with the width of the conductor.

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3.1.4 The Ring Antenna

Function

This is in many ways an alternative configuration of the dipole antenna. Instead of independent conductors the ring antenna consists of a single conductor in a ring, as a square or as a triangle configuration as illustrated in figure 3.3

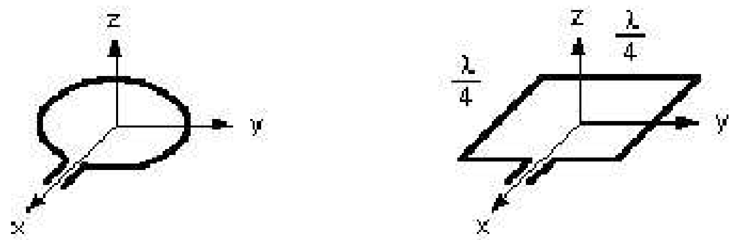

Figure 3.3: Different ring antennas

In either of the above configuration the main issue of interest is the area within the loop. One can regard the enclosed area as the main source of inducing waves. The larger the loop the larger the amount of emitted power. There are of course some disadvantages with the ring antenna. Firstly there is little radiation resistance in the antenna. Witch results in low radiation efficiency values and problems with adjusting the impedance. One solution is to wind a secondary conductor around the primary conductor. When the circumference is approximately one lambda the ring antenna is resonant. Again this implies ideal impedance.

Analysis

In regard to the ncube the ring antenna is in demand of deployment. However, the antenna has a wide radiation pattern. This does reduce the necessity for satellite stability control. Also the antenna can be deployed in such a manner as to avoid using valuable space on the outer sides of the satellite. The antenna has an ideal work area between 50 and 1000 MHz. The antenna is linear polarized and has low gain values. These properties make this antenna interesting for the uplink secondary antenna.

3.2 Antenna Materials

When it comes to antenna materials one has to look at the different relevant properties. In this regard the to main properties are conductivity and elasticity or physical properties as the latter is also called. In regard to the conductivity any electrical leading body will do the trick. But there are some materials that are better suited than others. Normal copper is the most used antenna material. There are unknown amounts of alloys with different characteristics. Unfortunately the problem in choosing a material is a bit more complicated than that. We also have to take into consideration the elasticity of the material. This property is in fact much more important than the ideal conducting material. It is necessary to find a material with good spring like capabilities. Memory shape alloys are materials that have to shapes in memory. They use temperature to change their shape. Below a temperature the coils of for instance a helix antenna can be cramped together, and when the temperature rises above a certain level the metal changes its shape to erect form. However it would be rather negative to have the antenna shape changing every time the satellite went behind the earth and the temperature fell! To summarize we can say that the antenna material must be conducting and have the possibility to change shape to some extent. The most likely metal to use is the standard metal - copper.

3.3 Conclusion

There is no right or wrong when choosing an antenna. As we have seen they all have to some extent properties that will fulfill the needs of the ncube. However most of the antennas have the disadvantages that they need deployment. This is of course something preferably avoided. The micro strip is in this regard a safer antenna. The dipole antenna has been used before by other cubesat projects. And not surprisingly it has the overall best properties for a satellite with out special stability control. The helix antenna will deliver a far larger amount of data if the conditions are right. But it demands a stable satellite. The ring antenna is suitable for the downlink. It is best suited for lower frequencies. As we can see there is no straightforward conclusion. Before the choice for an antenna for downlink and uplink is made, it would be advantageous to see the needs versus the possibilities in context with the satellites other specifications.

Chapter 4

Link Budget

4.1 Link Budget

The Link Budget is a survey of the elements in a radio transmission. The link budget can often include the data rate and the quality for the modulation method so that the necessary $Eb/N0$ can be given and its margin can be estimated. $Eb/N0$ is the bit energy over the noise power density and is given by the transmission equation. $Eb/N0$ is the parameter that is dependent of the modulation type and is also the one that decides the bit-error-probability. Figure 4.1 shows a curve of the bit- error-probability as a function of $Eb/N0$.

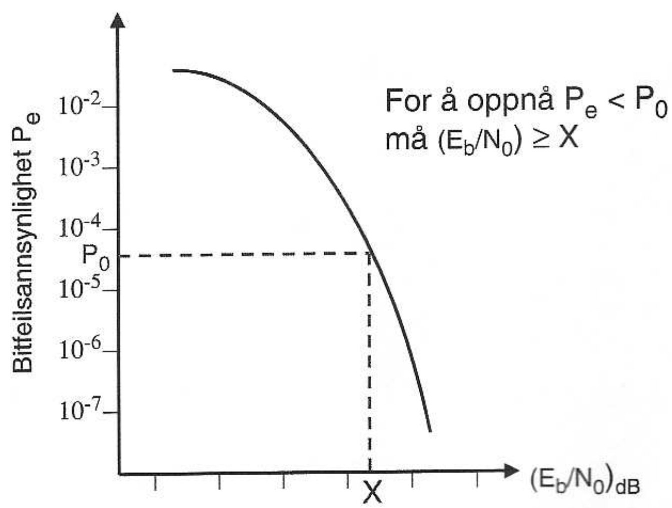

Figure 4.1: Bit-error-probability as a function of Eb/N0

It is no recipe for how the link budget is set up, it all depends of the system and the intention with the link budget. If it is a estimate it will only contain a few elements, but if it is a delivery of a total system with defined total contribution will each element be looked at with grate attention.[Romteknologi, Stette Gunnar] The link budget is based on the element in the transmission equation.

A simple block scheme for a transmission channel from source to receiver over a radio channel is given in figure 4.2

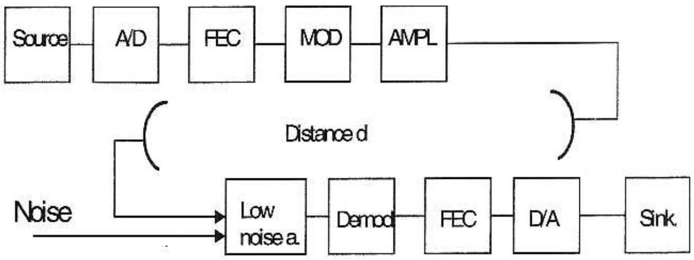

Figure 4.2: Simplified block scheme for the information transmission over a radio channel

4.2 Transmission equation

This equation gives the parameters that are included in the information transmission between the satellite and the ground station.

$$\frac{E_{\mathrm{b}}}{N_0} = (P_{\mathrm{sat}} \cdot G_{\mathrm{sat}}) \cdot \left(\frac{\lambda}{4\pi d}\right)^2 \cdot \frac{1}{k} \cdot \frac{1}{L} \cdot \frac{G_{\mathrm{m}}}{T_{\mathrm{m}}} \cdot \frac{1}{R} \cdot (KG) \tag{4.1}$$

The different factors in the equation are:

- $P_{\mathrm{sat}} \cdot G_{\mathrm{sat}}$ is often named EIRP (Effective Isotropic Radiated Power) and is a goal for the source intensity.
- $\frac{\lambda}{4\pi d}$ is the free space loss, a signal loss that is due to the scattering of waves over a spherical shell.
- $\frac{1}{k}$ is the resiproce Boltzmann's constant.
- $\frac{1}{L}$ are diverse losses caused by Earth's atmosphere, e.g. rain.
- $\frac{1}{R}$ is the data rate.
- KG is the coding gain

This equation gives the satellite link and all the parameters that are included in the transmitter line.

Chapter 5

Tracking control

5.1 Why tracking?

When the satellite is sucessfully launched the need for being able to know where the satellite is situated at any given time is important. The ground stations ”looks” constantly for satellites by ”listening” to beacon signals. To ”look for” or see the satellite means to be able to pick up its signals using maximum gain on the ground station.A beacon signal is defined as a light or electronic source which emits a distinctive or characteristic signal used for the determination of courses or location. In our project we have chosen the beacon signal to be a morse-signal with information of identity, battery-status and other data of interest. Since each satellite has it’s own unique beacon it is easy for the ground stations to know which satellite they ”see”. Because we are using amateurradio frequencies people with amateurradio equipment can also recieve the beacon-signal.

5.2 Orbit mechanics

To be able to know when the satellite will be in the area of the ground station we need to model the satellite path using orbit mechanics. This work was started by Kepler and Newton in the 17th century.

5.3 Newton

Newton’s law of gravitation from the 1667 expresses the force interaction between two bodies. We have in this project only taken two masses into consideration. Gravitational influence from other planets or bodies are neglicted.

Newton’s second law is given as

$$F = m \cdot a \tag{5.1}$$

The gravitational force is given as

$$F = -\frac{m \cdot M}{r^2} G \tag{5.2}$$

where M is the mass of the earth, m is the mass of the satellite and r is the distance between the earth and the satellite.

Newton's law in r-direction is given as

$$F = -mr\dot{\theta}^2 \tag{5.3}$$

combining equation 5.3 and 5.2 gives

$$-mr\dot{\theta}^2 = -\frac{m \cdot M}{r^2}G \tag{5.4}$$

Solving this equation and doing a series expansion in $\frac{h}{R}$gives

$$\dot{\theta} = \sqrt{G\frac{M}{R^2}\frac{1}{R}}\left(1 - \frac{3h}{2R} + ...\right) \tag{5.5}$$

$$= \sqrt{\frac{g}{R}}\left(1 + \frac{3h}{2R} + ...\right) \tag{5.6}$$

$$\tag{5.7}$$

Plugging in the numbers h=600 km, R=6400 km and g=9.81m/s^{2}in equation (5) gives the orbit time

$$\begin{aligned} T &= \frac{2\pi}{\omega} = 2\pi\sqrt{\frac{R}{g}}\left(1 + \frac{3h}{2R} + ...\right) \\ &= 2\pi\sqrt{\frac{6400 \cdot 10^3}{9.81}}\left(1 + \frac{3 \cdot 600 \cdot 10^3}{2 \cdot 6400 \cdot 10^3}\right) \approx 5800\text{sec} \approx 1\text{h}37\text{min} \end{aligned}$$

Theoretical frequency of contact a day

$$\frac{24\frac{\text{h}}{\text{day}}}{1\text{h}37\frac{\text{min}}{\text{revolution}}} \approx 15\frac{\text{times}}{\text{day}}$$

This gives a possibility of "seeing" the satellite around 15 times a day. However, there are influences from other parameters that changes this.

1. Atmospheric drag. Airfriction will slow down the satellite
2. The earth is not a perfect sphere. It is thicker around equator.
3. Forces from other planets, the moon and the sun.
4. The sun radiation can induce a pressure on the satellite.
5. Earth rotation.

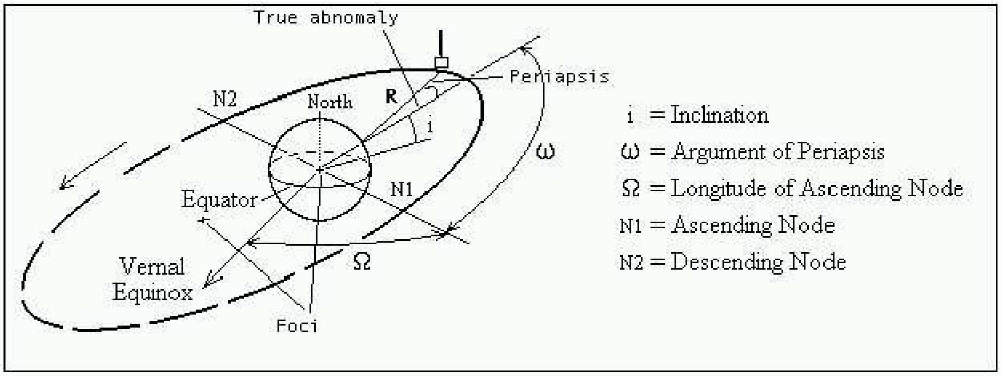

Figure 5.1: Orbit parameters

5.4 Orbit parameters

To describe where the satellite is and where it is going to be in the future six parameters is used. The parameters are listed and shown in figure 5.1.

The eccentricity is given as

$$e = \frac{\text{Distance between foci}}{\text{Major axis}} \tag{5.8}$$

We have assumed an eccentricity, no distance between the foci and hence e=0, which means circular orbit movements. Another parameter of our interest is i, the inclination. Inclination has a range of 0 to 180 degrees. A polar incliniation, which is an inclination of about 90 degrees, is not affected so much by the earth rotation due to it's position relative to the spinning axis. It is therefore in this project focused on this inclination orbit.

5.5 Ground stations

5.6 Norwegian ground stations

There are many ground stations throughout the world tracking and downloading information from satellites. In Norway there are two of interest. Tromsø Satellite Station AS, located on 69°39‘ N 18°56‘ E and Svalbard Satellite Station located on Spitsbergen, Svalbard (78°N).

On Tromsø Satellite Station AS the primary focus of the station is on the use of SAR (Synthetic Aperture Radar) data, which is capable of observing independent of clouds and darkness. Based on data from satellites, TSS offers earth observation products and monitoring services to customers in near real-time[2].

The other station, Svalbard Satellite Station (abbreviated as SvalSat) was established by the Norwegian Space Centre in 1997. It has an ideal location for tracking and commanding of satellites in polar orbits because of its northern locality which gives access to all 14 polar satellite orbits. The business idea for Svalbard Satellite Station (SvalSat) is to provide cost-effective services to polar satellite operators. However, TSS is responsible for SvalSat operations, under a contract with the Norwegian Space Centre (NSC)[4].

Figure 5.2: Antenna at Svalbard

5.7 Federated Ground station Network (FGN)

At Stanford University, California, USA, James Cutler et. al and his students are working on a global network for downloading of information. Their work will federate networked ground stations that are under different administrative domains. Ground station facilities can dynamically join and leave the federation. In this way the network makes it possible to download data at any ground station in the network throughout the world and send it electronically via internet if you need data at a certain time a day. Currently this network is being used by Stanford University's satellites Sapphire and OPAL in addition to NASA's OMNI project. [http://swig.stanford.edu/public/projects/satellite/]

5.8 Satellite Tool Kit

In a simulation done in STK it was found that the satellite will pass Andøya five times and Svalbard eight times during a day with a duration of contact of 15 minutes and 45 minutes respectively. The simulations were done with an inclination of 80 degrees and altitude of 600 km and the summaries from the simulations are given in table 5.3 and 5.4.

Access	Start Time (UTCG)	Stop Time (UTCG)	Duration (sec)		
1	6/1/00 6:44	6/1/00 6:47	143.226		
2	6/1/00 8:21	6/1/00 8:25	253.297		
3	6/1/00 10:01	6/1/00 10:02	70.855		
4	6/1/00 14:57	6/1/00 15:00	183.203		
5	6/1/00 16:35	6/1/00 16:39	252.963		
Global Statistics					
Min Duration	3	6/1/00 10:01	6/1/00 10:02	70.855	
Max Duration	2	6/1/00 8:21	6/1/00 8:25	253.297	
Mean Duration				180.709	
Total Duration				903.544	

Figure 5.3: Satellite access at Andøya, inclination 80°, height 600 km

Access	Start Time (UTCG)	Stop Time (UTCG)	Duration (sec)	
1	6/1/00 6:46	6/1/00 6:50	251.509	
2	6/1/00 8:22	6/1/00 8:28	351.153	
3	6/1/00 10:00	6/1/00 10:06	383.398	
4	6/1/00 11:38	6/1/00 11:44	388.863	
5	6/1/00 13:15	6/1/00 13:22	388.829	
6	6/1/00 14:53	6/1/00 15:00	382.791	
7	6/1/00 16:31	6/1/00 16:37	348.719	
8	6/1/00 18:09	6/1/00 18:13	244.608	
Global Statistics				
Min Duration	8	6/1/00 18:09	6/1/00 18:13	244.608
Max Duration	4	6/1/00 11:38	6/1/00 11:44	388.863
Mean Duration				342.484
Total Duration				2739.869

Figure 5.4: Satellite access at Svalbard, inclination 80°, height 600 km

The path that the satellite was leaving in the simulation is shown in figure 5.5.

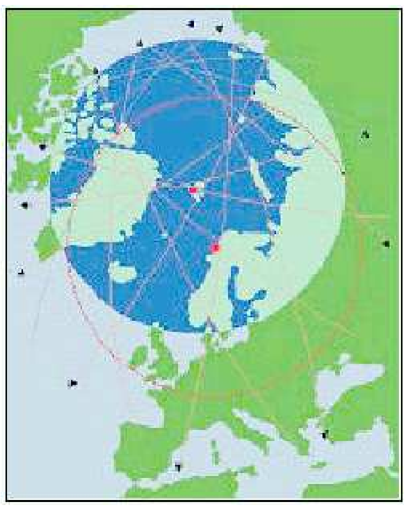

Figure 5.5: Ground stations

5.9 Distance measurement

The ground station is continuously polling for beacon signals. When the groundstation picks up the beacon-signal it starts to calculate the distance to be able to adjust the gain to the needed value for downloading. The ground station sends out a signal that is reflected by the satellite. The received signal's phase is then compared with the initial signal's phase, and the phase-difference enables the round-trip time to be obtained (see equation 5.9.

$$\Delta\phi = 2\pi f \frac{2R}{c} \tag{5.9}$$

To adjust the gain, from the tracking point of view, the parameters of interest is the angle θ, indirectly how far the satellite is from the ground station, ϕ, how accurate the satellite's attitude control is, and the power density spectrum of the antenna (see figure 4). Once the gain is calculated downloading of information can begin. The calculation of the gain is described more thoroughly in the link budget in chapter XX.

Figure 4 The satellite's beacon signal is picked up by the ground station

5.10 2 References

http://www.nrk.no/magasin/magi/newton/893178.html

Elementært om baner og mikrogravistasjon, Ytrehus, Februar 2002

[http://swig.stanford.edu/public/projects/satellite/]

Chapter 6

Modulation

6.1 Introduction

The main problem in radio systems is to transmit information with so little use of power and bandwidth as possible at the same time that the equipment is caped as simple as possible. [Radiokommunikasjon, Stette Gunnar] Modulation is when the carrier wave in a signal is changed to match the channel it is transmitted over. The carrier wave can be modulated in two different ways by changing the amplitude or changing the phase. In satellite communication the amplifier is near saturation and if we want to reinforce a modulated carrier wave, we have to keep the amplitude or the envelope for the carrier wave constant. So the best is to keep the amplitude constant and modulate the phase or the frequency. Phase Shift Keying (PSK) is very effective modulation methods and is commonly used in satellite communication. [Romteknologi, Stette Gunnar]

In this section we are going to look at two modulation types, these are Phase Shift Keying (PSK) and Frequents modulation (FM) because these are the modulation types that the radio types we have been recommending are using.

Figure 6.1 is a block scheme over a transmission channel from the source to the receiver where the modulation and demodulation is the two blocks in the middle.

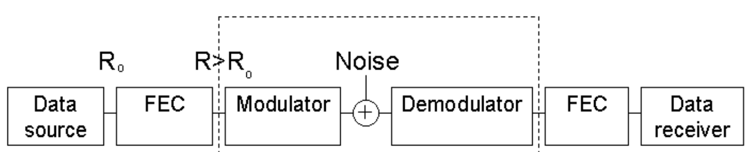

Figure 6.1: Block scheme over transmission channel

6.2 Phase shift keying

We are first going to look at Phase Shift Keying (PSK). We got three different types of PSK these are BPSK (Binary Phase Shift Keying), QPSK/4PSK (Quarternary Phase Shift Keying) and 8PSK (8 Phase Shift Keying). These three modulation types have the same property that the theoretical bit-error-probability for a given Eb/N0 situation is minimum. Eb is received energy per bit and N0 is received power density in Watt per Hz for the noise specter in the same point in the receiver chain. For BPSK you can see this with that the signal vector for the two symbols points in the opposite direction, and that they then have the larges possible distance between each other in the signal room (see figure 2.2). [Radiokommunikasjon, Stette Gunnar]

6.2.1 Binary Phase Shift Keying (BPSK)

In BPSK the carrier wave have one of two possible phase states, and each symbol can send one bit. BPSK is an antipodal modulation and have the lowest energy per bit for a given bit-error-rate The equation for the carrier wave:

$$m(t) = A \cdot \cos(2\pi f t + a_i \cdot \pi) a_i = 0, 1 \tag{6.1}$$

[Romteknologi, Stette Gunnar]
The modulated carrier wave can be written:

$$x(t) = \sqrt{2C} \cdot \cos(2\pi f_0 t) \tag{6.2}$$

Where $a(t) = m(t)$ and C = carrier wave power.
This is a signal with constant envelope and can be written as:

$$x(t) = \sqrt{2C} \cdot \cos(2\pi f_0 t + \Phi(t)) \tag{6.3}$$

The relationship between $a(t)$ and $\Phi(t)$ is given in table 6.2.1

$a(t)$	$\Phi(t)$
+1	0
-1	π

Table 6.1: Relation between $a(t)$ and $\Phi(t)$

In a pointer diagram $x(t)$ will be in the point $((\sqrt{2C}, 0)$ when $a(t) = 1$, and in the point $(-(\sqrt(2C), 0)$ when $a(t) = -1$ This is shown in figure 6.2

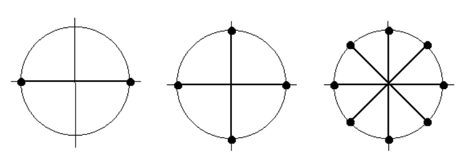

Figure 6.2: a: Pointer diagram for BPSK, b: Pointer diagram for QPSK and c: 8PSK

The bit-error-probability is given by the distance between the end points for the two sent vectors together with the power density for the noise and with the integration time in the demodulator. For BPSK the distance between the two endpoints for the sent signal is equal to $2\sqrt(2C)$

6.2.2 Quarternary Phase Shift Keying (QPSK/4PSK)

QPSK is used in systems with a strong bandwidth limitation because this modulation type makes it possible to transmit a great number of bit per symbol, and it ensures a good use of the frequency.

In QPSK/4PSK the carrier wave has one of four possible values for the phase. Each symbol can transmit two bits, this involves that the bit rate per bandwidth unit relative to BPSK will double. The equation for the carrier wave:

$$m(t) = A \cdot \cos(2\pi f t + a_i \cdot \frac{\pi}{2}) a_i = 0, 1, 2, 3 \tag{6.4}$$

[Romteknologi, Stette Gunnar]

We can imagine that we got two data flows, each with a rate R bit/s representing with the signals $a(t)$ and $b(t)$. The data rate is then double. The element length for this two is then T, and we can imagine that the signal is in phase, this means that the sign is changing at the same time. The modulated carrier wave can than be written:

$$x(t) = a(t) \cdot \sqrt{2C} \cdot \cos(2\pi f_0 t) + b(t) \cdot \sqrt{2c} \cdot \sin(2\pi f_o t) \tag{6.5}$$

The modulation rate for $a(t)$ and $b(t)$is the same that for $m(t)$ (carrier wave), the amplitude for sin and cosine is also the same so the carrier wave power is double. QPSK with double data rate gives double power and same bandwidth.[Radiokommunikasjon, Stette Gunnar]

The signal can also be written as a phase modulation:

$$x(t) = \sqrt{2C} \cdot \cos(2\pi f_0 t + \Phi(t)) \tag{6.6}$$

The relationship between $a(t)$, $b(t)$ and $\Phi(t)$ is given in table 6.2.2

$a(t)$	$b(t)$	$\Phi(t)$
$+1$	$+1$	$\frac{\pi}{4}$
-1	$+1$	$\frac{3\pi}{4}$
$+1$	-1	$\frac{-\pi}{4}$
-1	-1	$\frac{3\pi}{4}$

Table 6.2: Relation between $a(t)$, $b(t)$ and $\Phi(t)$

In a pointer diagram $x(t)$, the pointer length for the result vector, will be $\sqrt{2}$ bigger than for BPSK, and the points will be like showed in figure 6.2.

6.2.3 Quarternary Phase Shift Keying (8PSK)

8PSK has 8 possible states, and each symbol can transmit 3 bits because $23 = 8$. 8PSK have got three times the bit rate per bandwidth unit relative to BPSK. It has also higher energy per bit relative to BPSK and QPSK. The equation for the carrier wave:

$$m(t) = A \cdot \cos(2\pi f t + a_i \cdot \frac{\pi}{4}) a_i = 0, 1, 2, 3 \tag{6.7}$$

6.2.4 Offset Quarternary Phase Shift Keying (OQPSK)

With $a(t)$ and $b(t)$ in phase will the sign change at the same time. In OQPSK the two bit streams for sin and cosine are staggered with $\frac{1}{2}$ bit length. This leads to that the times you have phase shifts will double, but the phase plunges will never be grater then +/- 90 degrees. The modulated carrier wave can be written:

$$x(t) = a(t) \cdot \sqrt{2C} \cdot \cos(2\pi f_0 t) + b(t-T) \cdot \sqrt{2c} \cdot \sin(2\pi f_o t) \tag{6.8}$$

in stead of a phase shift in the distance 2T with possibility for 180 degrees phase (sprang) gives this the possibilities for a phase shift in the distance T, but with maximal phase shift on +/- 90 degrees. This causes that only one of the coordinates in the pointer diagram can change at the same time. If we look at the QPSK as two times 2PSK on orthogonal waves, cos2?ft and sin2?ft, it is easy to see that this modification do not have any influence on the bit-error-probability. It do not either change the power spectrum for the modulated wave.

6.2.5 Power spectrum

The power spectrum for BPSK signals is given by the function around the carrier wave and with a distance 2R between they first zero points in the specter. The specter has got a theoretical infinite width, but it will be possible to bind the width without affecting the bit-error- probability. If we keep the main lobe in the signal and use a filter to take away the higher frequency components will the signal have a spectral width of 2R Hz. This means that it is transmitted 1/2 symbol per second per Hz bandwidth, or 1/2 bits/s per Hz.

In QPSK the spectrum has the same shape, but the data rate is double. You can alternatively say that the total data rate is the same but that the spectral width halves. This doubles the data transmit rate per bandwidth unit and we can correspondingly say that we can transmit 1 bit/s per Hz bandwidth.

The power spectrum for BPSK, QPSK and 8PSK is shown in figure 6.3 with transmission of the same data rate. Because the number of bit per symbol increase with the number of Phase states will the symbol rate with constant data rate be lower. The necessary bandwidth is decided of the symbol rate. This means that necessary bandwidth will decrease with increasing number phase states. The power spectrum for the carrier wave do we find by looking at the signal as a sum of two orthogonal components. We can then add the power spectrum for each of the two signals. Each of the components has the spectrum as for BPSK. If we now return to QPSK with the same total transmission rate R bit/s, then the symbol length will double and the spectral width halves. The power will be the same as for BPSK. The spectral intensity for QPSK with f0 will therefore double respective to BPSK.

In table 6.2.5 you see a list over necessary bandwidth for the different types of PSK modulation types.

6.2.6 Power need

We are now going to look at the power need for transmission with a desired data rate. It is decided by the demand for the bit-error-probability. Figure 6.4 shows the bit-error-probability as a function of the relationship between the bit energy and the noise density, Eb/N0. This parameter is suitable because it does not take consideration to the bandwidth. It shows that

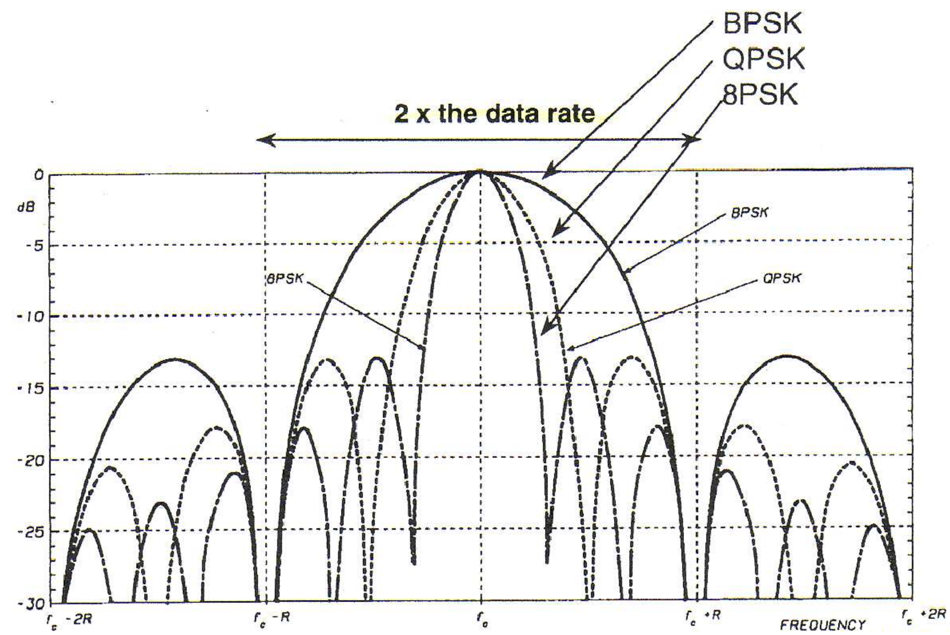

Figure 6.3: Power spectra

Mod. method	Number of states	Number of bit per symbol (bandwidth with $\alpha = 0$	Symbol rate with $\alpha = 0.3$	Bandwitdh with
BPSK	2	1	60 Mbaud	78 MHz
QPSK	4	2	30 Mbaud	39 MHz
8PSK	8	3	20 Mbaud	26 MHz

Table 6.3: Comparison of different PSKs

the demand to the sender power is the same for BPSK and QPSK. If you on the other hand look at 8PSK you see that the power has to be higher. The reason for this is that the different signals are getting to close enough in the signal room.

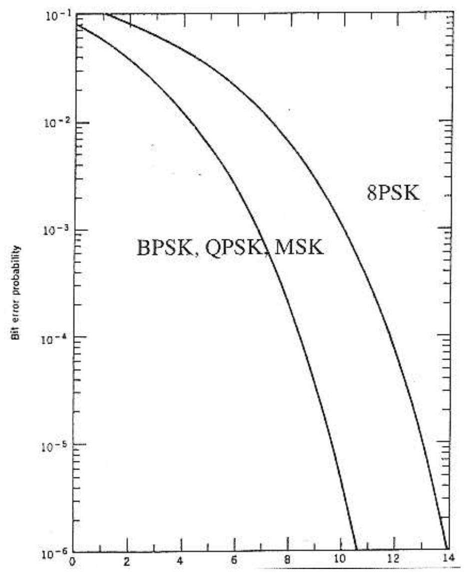

Figure 6.4: Bit-error-probability as a function of Eb/N

6.3 Frequency Modulation (FM)

Frequency modulation is when the immediately frequent is changed in time with the information carried signal.

Frequency modulation has properties that make it possible to save power on the expense of the bandwidth. Besides has the FM signal a constant envelope and can therefore amplifies in strong nonlinear channels. In FM the instant frequency $fi(t)$ for the carrier wave given by:

$$f_i(t) = f_0 + k_f \cdot m(t) \tag{6.9}$$

$f0$ is the frequency for the unmodulated carrier wave. $m(t)$ is the modulated signal, basis band signal. ki gives the sensitivity for the modulator in Hz/Volt.

The general FM signal is given by:

$$s(t) = \sqrt{2C} \cdot \cos(\Phi_i(t)) \tag{6.10}$$

C is the carrier wave power $\Phi_i(t)$ is the instant value for the phase

There are two types of FM this two are small band FM and broadband FM.

Small band FM is when the specter stands of one carrier wave component on $f0$ and two sidebands on ($f0$ +/- fm). The power spectrum is the same as for usual amplitude modulated signals. If we look at the signal representation in form of a pointer diagram will it be a important different between the two modulation forms. The one sideband has 180 degrees phase difference respective to amplitude modulation. This is the reason why the FM-signal has constant envelope.

Broadband FM has a greater number of frequency components in a distance from the carrier wave given by the multiple of the modulation frequency fm.

6.4 Recommendation

We have now been looking at the modulation of the signal that is transmitted between the satellite and the ground. We have been concentrated around two different types of modulation, Phase Shift Keying and Frequency Modulation. The reason for this is that these are the two modulation types that the radios are supporting. We have looked at the different types of PSK and seen how much data the can transmit and how much power they use respective to the bandwidth. We have also been looking at two different types of frequency modulation. The conclusion is that the modulation type you are going to use is dependent of the radio and the data that is transmitted over the line. PSK is often used in satellite transmission because it is stable and can transmit a great amount of data. QPSK is a good choice to use in NCUBE because it is a modulation type that suits for use in systems with a strong bandwidth limitation. This modulation type makes it possible to transmit a great number of bit per symbol, and it ensures a good use of the frequency.

Chapter 7

Hardware

7.1 Transceiver

7.1.1 Handheld HAM transceiver

Introduction

Alinco, Icom, Kenwood and Yaesu are some manufactors of handheld amateur transceivers which have become sufficently small during the last years. They transmit at the 2m- and 70cm-amateur frequencies. We have compared some of their top models (Appendix C), mainly with regard to physical size, weight, transmit power, frequency coverage, current consumption and operating temperature. These handset can be "stripped" from unnecessary equipment like the speaker, antenna (not suitable for our purpose), the display and the cover. The remaining device (print board) will have a sufficent size for the nCube- purpose. This equipment have been used with success in other Cubesat-projects, like Stanfords satellite.

Recommendation

From the comparison in table C.2 in Appendix C, we see that the transceivers have different qualities. The most critical factors for the nCube-mission, will be output power, current consumption, dimensions and weight. Alinco DJ-C5T have the best over-all performance in this comparison, especially regarding our critical factors. This transceiver has the lowest current consumption and weight, and are one of the smallest transceivers in the comparison. The physical measures are shown in figure 7.1 below. This radio has also been used in Stanfords cubesat.

Figure 7.1: Alinco's DJ-C5T, with physical measurements.

7.1.2 Integrated transceiver chips

Introduction

Norway have several firms, which in the recent years have done much research and development on integrated transceiver chips. Nordic VLSI, Chipcon and Bluechip Communication are the major norwegian producents in this field. These chips are mainly intended for short range communication, and have a low power output, typical 10mW. Therefore we need a power amplifier to use this solution at the nCube mission. These transceivers operate in the unlicensed, short range device (SRD), 433/868/915 MHz band. If another band is preferable, we can use a frequency converter in addition to these transceiver chips to move the carrier to the desired frequency. Few external components are required to make a complete transceiver-module with these chips, as seen on figure 7.2 below.

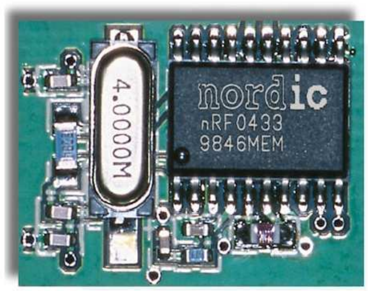

Figure 7.2: Nordic VLSI transceiver chip with external components.

Recommendation

The most critical facors for the nCube-mission, in the comparison in table C.1 in Appendix C, are output power, current consumption and bit rate. Although the specifications of these chips are quite similar, does Chipcons CC1050 offer some extra output power and consumes less current than the other transceivers. Therefore this chip is preferable for our purpose. Since the transceiver-chips from Chipcon and Nordic VLSI have about the same performance and their physical size is quite small, we could implement both to ensure redundancy. If we use two transceivers, from different manufactorers, with different weaknesses, the propability for both failing would decrease.

Figure 7.3: Chipcon's CC1050 transceiver chip.

7.1.3 S-band

At Andøya Rocket Range, they have used transceivers which utilize part of the S-band. Their transmitter can operate at 2.2-2.4 GHz, and the frequency can be adjusted by the micro-controller onboard. At Andøya they use 2279.5 MHz for downlink from their rockets. The transmitter has 100mW output power, which may require an additional amplifier for our purpose. It operates at 6-12VDC, and the current consumption at 9V is approximately 150mA. The physical dimensions of this module is 2.8x7.1cm (all components are Surface Mounted Device - SMD), and the weight is about 20-30g. This transceiver-module has been used with success at Andøya Rocket Range.

7.1.4 Additional components

Frequency converter

A frequency converter can move the transmission to another desired band. As shown in figure 7.4, the frequency converting is done by mixing the signal with another frequency to obtain the new carrier wave. Then the signal is filtrated to remove harmonics, and amplified to compensate for loss in the process. A typical loss in such a converter, would be about 6dB.

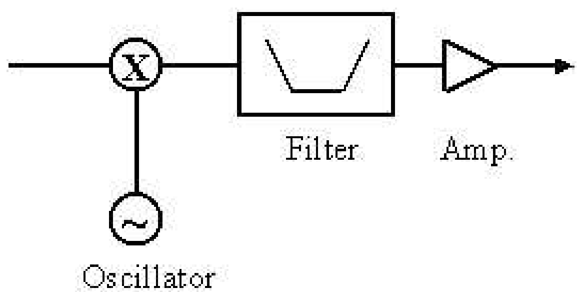

Figure 7.4: Frequency converter block diagram.

Power amplifier

The power amplifier can be used to compensate for loss in the frequency converter, antenna switch and cables. In addition it can generate more power if the transmission output is insufficient, or the received signal is weak. A low noise amplifier (LNA) is preferrable, and the outcome must be filtred to remove unwanted harmonics.

7.1.5 Transceiver conclusion

The handheld HAM transceivers would be an simple and reliable solution for nCube. These transceivers are compact, robust, quality tested by the HAM-society, designed to work with the Terminal Node Controller and offers enough output power at low current consumption.
The norwegian produced integrated transceiver chips would be an exciting solution, especially since the nCube is the first satellite made by norwegian students. The fact that these chips are intended for short range communication will be a problem. Low output power can be

corrected by additional power amplifier, but this will introduce additional error-sources in the system.
Andøya Rocket Range's S-band module has been used with success as transceiver in their rockets. It is a compact design with low current consumption. The fact that the module is thoroughly testet by one of nCube's external partners, which could lead to valuable assistance in further work with the student satelite.

Chapter 8

Protocols

8.1 Why protocols?

The brain of the satellite, the onboard computer OBC, must be able to communicate with the hardware on the ground station. This communication must be efficient and reliable. The satellite's communication subsystem and the communication subsystem on the ground station need some mean to decide if the data transmitted through the radios are not corrupted. To accomplish this we need some common ground rules for how the communication should take place. These rules, called protocols, will then say how the different parts of the communication subsystems should communicate to work properly.

8.2 Reference model for nCube

The communication subsystem on nCube has two main purposes:

- Transmit a beacon with telemetry data.
- Provide a mean for the satellite to communicate with ground station and vice versa.

The first point is the least demanding. The communication subsystem needs only to transmit a signal with the correct data. The second point is more demanding. The subsystem should be able to recieve a signal from the ground station, establish a connection, recieve and send data and close the connection i a proper way. We will here look at some possible solutions on the software part of this problem. We will limit this discussion to the data link layer, see figure 8.1. We will not give any constraints on which layer(s) should be implemented above the data link layer. Although we will point out that what we expect the higher layer(s) to do.

8.3 The data link layer

The physical layer performs the task of transmitting raw bits over the communication channel. The data link layer's task is to take this stream of bits and transform it into a form that seems uninterrupted and without errors from the application layer. This is done by breaking the input data from the application layer into frames. These frames are transfered to the data link layer at the other end of the connection where the data is assembled and send to the application layer. The data link layer checks for errors in frames and missing frames and takes

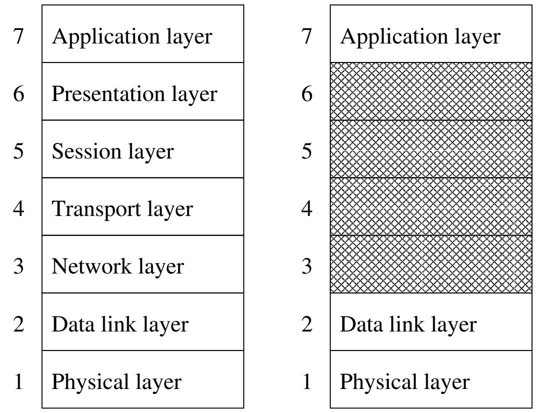

Figure 8.1: The OSI reference model[5]. a is the standard model while b is the modified model for nCube.

apropriate actions to correct this. The data link layer looks after flow control to prevent a fast sending source from drowning a slow reciving sink.

8.4 The protocols

We have considered frecuencies in the amateur bands and in the S-band. We will here focus on the amateur bands following the recommodation from section 2.4. The use of amateur bands impose some restrictions on the choice of potocols. All communication execpt from telecommand must be open, i.e. the data must be in a format that everybody has the opportunity to comprenhend. The most used data link layer protocol between radio amateurs is AX.25, and it is also well documented. AX.25 is also implemented in most comercial TNCs. We will look at the AX.25 protocol below. In addition we will say something on how TCP/IP can be implemented with TNCs and AX.25.

8.5 AX.25

We have chosen to look at the AX.25 protocol in more detail because this is the most promising choice for use with a amateur radio. The AX.25 protocol is described in [3]. It gives an complete overview of the structure of the Data link layer and the interfaces between the Data link layer and the layer above and the Physical layer. Some of the properties with the protocol is listed below.
Properties of AX.25

- confirms to High-level Data Link Control, HDLC
- supports amateur call names
- supports connected links
- supports connection less links, needed for beacon

- supports half / full duplex
- supports error detection

The structure of the lowest layers of the communcation system will follow easily from the simplyfied OSI-model with only tree layers,see figure 8.1. AX.25 corresponds to the data link layer. The layer above the data link layer will depend how the OBC will be implemeted.

8.5.1 AX.25 Frames

The data units of the data link layer are called frames. Therer are tree different types of frames:

- a) Information frame (I frame)
- b) Supervisory frame (S frame)
- c) Unnumbered frame (U frame)

The I frames carries the data that are to be transmitted. The S frames take care of acknowledging and requests for retransmission of lost or corrupted data. The U frames are responsible for establishing and terminating link connections. With the U frames it is also possible to transmit data outside the normal flow. This is done with the Unnumbered Information UI frame.

The AX.25 protocol envelops the data it sends to the physical layer in a frame. The structure of such a frame is seen in figure 8.2

Flag	Address	Control	PID	Info	FCS	Flag
01111110	112/224 bits	8/16 bits	8 bits	N*8 bits	16 bits	01111110

Figure 8.2: Information frame construction
PID=Protocol Identifier Field
FCS=Frame Check Sequence

8.5.2 Limitations in AX.25

Due to the nature of satellite communication there are some properties of the communication system which AX.25 cannot handle. These properties must be implemeted in a higher layer.

A satellite will not, as a stationary radiostation, be within range all the time. In fact the satellite will only be able to communicate with the ground station for a limited duration. If the amount of data the satellite needs to transmit is larger then the amount it can transmit during one pass it needs to transmit it over several passes. Even if the amount of data is small it is possible that the satellite needs to retransmit the last frames which where not acknowledged during the last pass, if such frames exist. The AX.25 protocol discards the buffered data when a connection is lost.

To solve this problem we need a system which keep track of which data are transfered and can be erased from memory, and which data it need to keep in memory until next time the satellite can transmit. This system must be implemented in a higher layer.

A propertie that AX.25 lacks is the ability to handle priorities. All data is transmitted in the order it is sent to the TNC. Prioritation between different data sources in the satellite must also be implemented in the OBC. It is possible to send UI - frames and therby avoiding the normal flow control, but this is a very unreliable procedure.

8.5.3 Connection/Connection less

The AX.25 protocol supports connection oriented frames with I-frames, and connectionless frames with UI-frames. The connectionless mode can be used for the satellites beacon since this form of communication is one way only and need no acknowledge responses. The connection oriented mode will be used when a ground station asks for a connection.

8.6 Terminal Node Controllers

This component connects the computer to the radio. It's function is like those of a normal analog computer modem[8]. It converts the digital signals recieved from the computer to analog signals send to the radio. And the other way around for analog signals from the radio. Most TNCs implements AX.25 as firmware. Since the TNCs are used with packet radio they are sometimes called *packet modems*. TNCs are designed for working with amateru radios.

Native/Host mode

In these modes the AX.25 implementation in the firmware of the TNC completly controls the whole process of assembling packets.

Keep It Simple Stupid! mode

In this mode only the assambling of the HDLC-packets are done in the TNC. What goes inside the HDLC-packets are controlled from the attached computer. This allows for transmission av other packets like TCP/IP and others. The KISS protocol is for communicating between a computer and the TNC.

When the computer wants to send some data it assambles the packets in the computer, and appends a FEND character and a KISS type byte at the start of the packet and another FEND character at the end. THE FENDs and KISS type byte are removed in the TNC and the packet is transmitted over the physcical channel.

8.7 TCP/IP

8.7.1 Overview of TCP/IP and packet amateur packet radio

There is also a possibility to transmit TCP/IP packets with the TNC and amateur radio[7]. This is achieved by useing the TNC in KISS-mode. Since IP is a connectionless protocol all error detection and packet accounting will have to be taken care of in a higher layer. TCP/IP packets can also be sent inside AX.25 frames.

TCP/IP is one protocol used to create networks of amateur radio stations. Other protocols for this use is NET/ROM and ROSE

8.7.2 Example of AX.25 and TCP/IP implementation

An example of an implementation of the AX.25 and TCP/IP protocols for packet radio is *Linux Amateur Radio AX.25*[6]. This implementation puts IP packets inside AX.25 frames.

8.8 Protocols on non-amateur frecuencies

Since the AX.25 protocol is well documented and also implemeted in the open source operation system Linux[6] we could also use this protocol in a non-amateur band. Here it could also be easier to modify the protocol since it don't have to conform with the AX.25 specification. Since we will most probaly use amateur radios and TNC as hardware components the use of Ax.25 will be easier to implement.

8.9 Recommandation

Since we recommend amateur bands2.4 and amateur radio hardware7.1.5 the use of AX.25 for a layer 2 protocol is the best solution. It conforms to the demands from AMSAT that the transmissions should be open, it is well documented and is implemeted in most comercial TNCs. If we choose non-amateur frequncies we but uses amateur handsets it could be possible to design an custome protocol based on AX.25.

Chapter 9

Conclusion

9.1 Recommendation

We have in this report looked at some diffent alternatives for the communication subsystem of the Norwegian Student satellite, nCube. Our conclusion will point out those choices we think best will satisfy the requirements. Still, we have not conducted any testing so it is a possibility that our recommandation can not be implemented.

Our recommendation is based on the use of the amateur bands. This choice has influenced the choice of transciever and data link layer protocol as well as antennas.

We recommend a communication subsystem based on the Alinco DJ-C5T handset used in an amateur band. The transciever will communicate with the OBC using a TNC with AX.25 protocol. For antennas we recommend a redunant system with two antennas. One omnidirectional (crossed dipole) and one directed (microstrip or helix). We would also like to use PSK - modulation av the radio channel but this was not supported by the radio we chose.

9.2 To do

Get correct values for non-abundant resources as electrical power, space, etc. Create interfaces with the other satellite subsystems. Purchase hardware components and design, build and test the communication subsystem. This will include the selection of a TNC which will fit into the nCube. Design antennas and implement it in the satellite structure. Write the software for the communication subsystem both on the OBC and on the ground station. There must also be decided where the ground stations should be placed.

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Appendix A

Matlab script for link budget

We simulated how the $\frac{E_b}{N_0}$ varied as the satellite moves acrosse the sky over the ground station. We are only considering a direct pass over the ground station $\Rightarrow$ *a best case situation*. The simulation was done in Matlab, the script is listed below in figure ??. Two results from the simulation are seen i figure A.2 and figure A.3.

```
clear;
clf;

Ps = 0.3;           %Power sat
Gsat = 10^(2/10);     %Gain sat
F  = 435*10^6;     %Frequency
Gm = 10^(10/10);    %Gain groundstation
Tm = 293;           %Noise temp.
R  = 1200;          %Data rate

d =600000;          %Distance
Lamda =((3*10^8)/F);%Wavelength
KG = 1;             %Coding gain
k =1.38*10^-23;     %Boltzman
L=2;                %Attenuation


%Formel for avstand til satelitt
r=6378000.144;
h=600000;
r2=(r+h)^2+r^2;
rh2=2*(r+h)*r;
theta_max =23/180*pi;
theta_min =-23/180*pi;
phi_max = theta_max;
phi_min = theta_min;
theta = [theta_min:0.01:theta_max];

d=sqrt(r2-rh2.*cos(theta) );
```

```
% Gain er en funksjon av retningen til antennen.
% alpha = vinkel mellom vektoren mellom satelitten og jordsentrum og vektoren mellom
% satelitten og bakkestasjonen.
alpha=acos((sqrt(r2-rh2.*cos(theta) ).^2+(r+h).^2-r^2)./(2.*sqrt(r2-rh2.*cos(theta) ).*(r+h) )
Gs=10*log10(Gsat)*cos(alpha); %./alpha;
% Lineært strålingdiagram
figure(1)
subplot(2,2,1), plot(theta,Gs);
title('Linear radiation pattern');
ylabel('Gs [dB]');xlabel('[Rad]');

subplot(2,2,2),
title('Main factors');
text(0.01,0.90,'Gain sat.: ');     text(0.55,0.90,num2str(10*log10(Gsat)));text(0.72,0.90,'[dB
text(0.01,0.75,'Power sat.: ');    text(0.55,0.75,num2str(Ps));            text(0.72,0.75,'[W]
text(0.01,0.60,'Frequency: ');     text(0.55,0.60,num2str(F/(10^6)));      text(0.72,0.60,'[MH
text(0.01,0.45,'Gain groundst.: ');text(0.55,0.45,num2str(10*log10(Gm)));  text(0.72,0.45,'[dB
text(0.01,0.30,'Noise temp.: ');   text(0.55,0.30,num2str(Tm));            text(0.72,0.30,'[K]
text(0.01,0.15,'Data rate: ');     text(0.55,0.15,num2str(R/1000));        text(0.72,0.15,'[kb
axis off;

% Strålingsdiagram i polarkoordinater
% figure(3)
% ezpolar('10*log10(123)*cos(alpha)',[-1.16,1.16])

E = ((Ps.*Gs).*(Lamda./(4*pi.*d)).^2.*(1/L).*(1/k).*(Gm/Tm).*(1/R)*(KG));

% E s.f.a theta
subplot(2,1,2), plot(theta,10*log10(E),'color','blue');
ylabel('Eb/No [dB]');xlabel('[Rad]');
title(['Bit energy-to-noise spectral density ratio, Eb/No - versus \theta']);
print -depsc trans_fig2.eps
```

Look at figure A.1 to see what the different angles are.

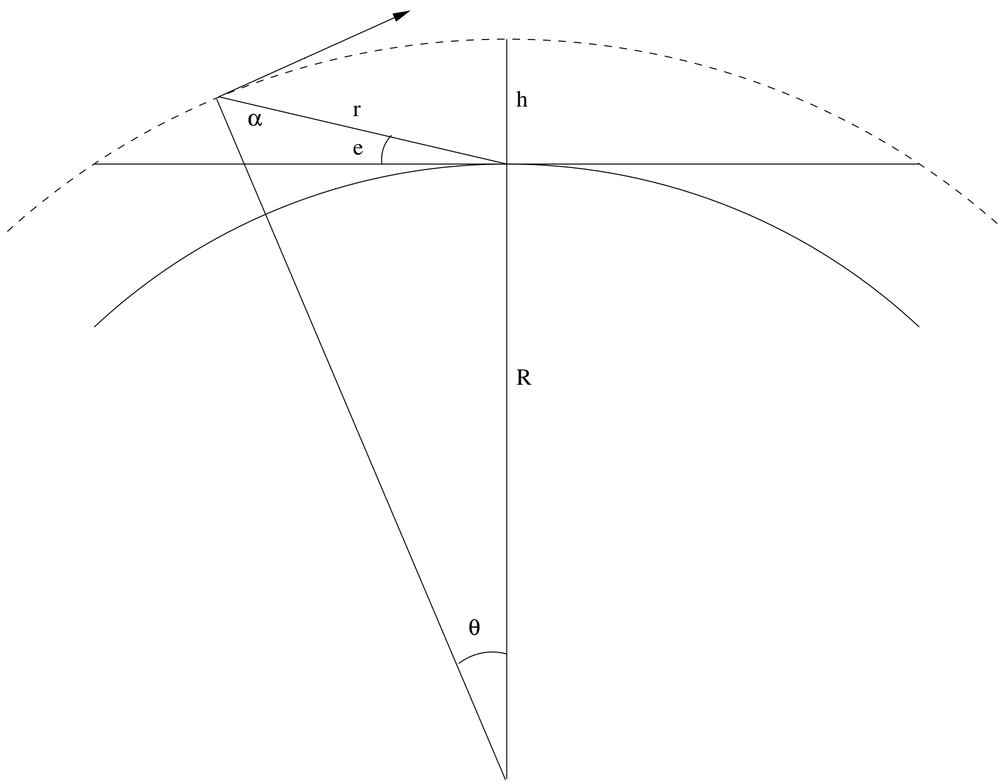

Figure A.1: Figure for Matlab script

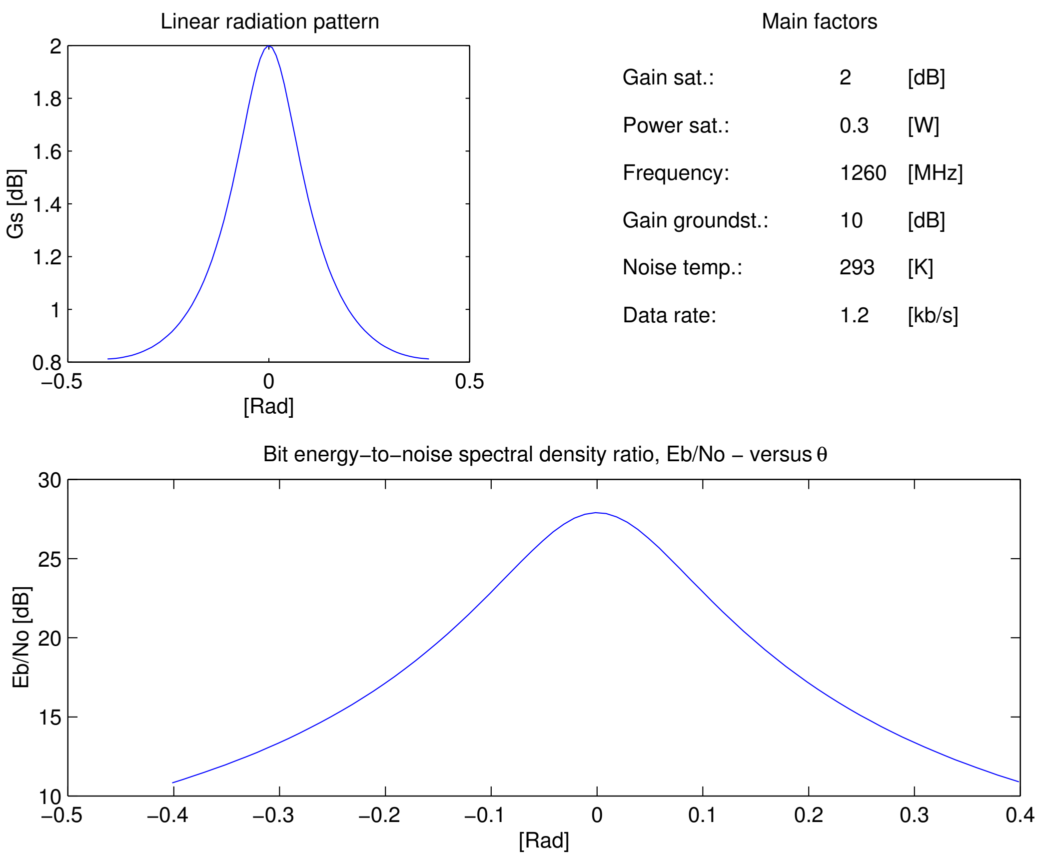

Figure A.2: $\frac{E_b}{N_0}$ versus θ, $f = 1260$

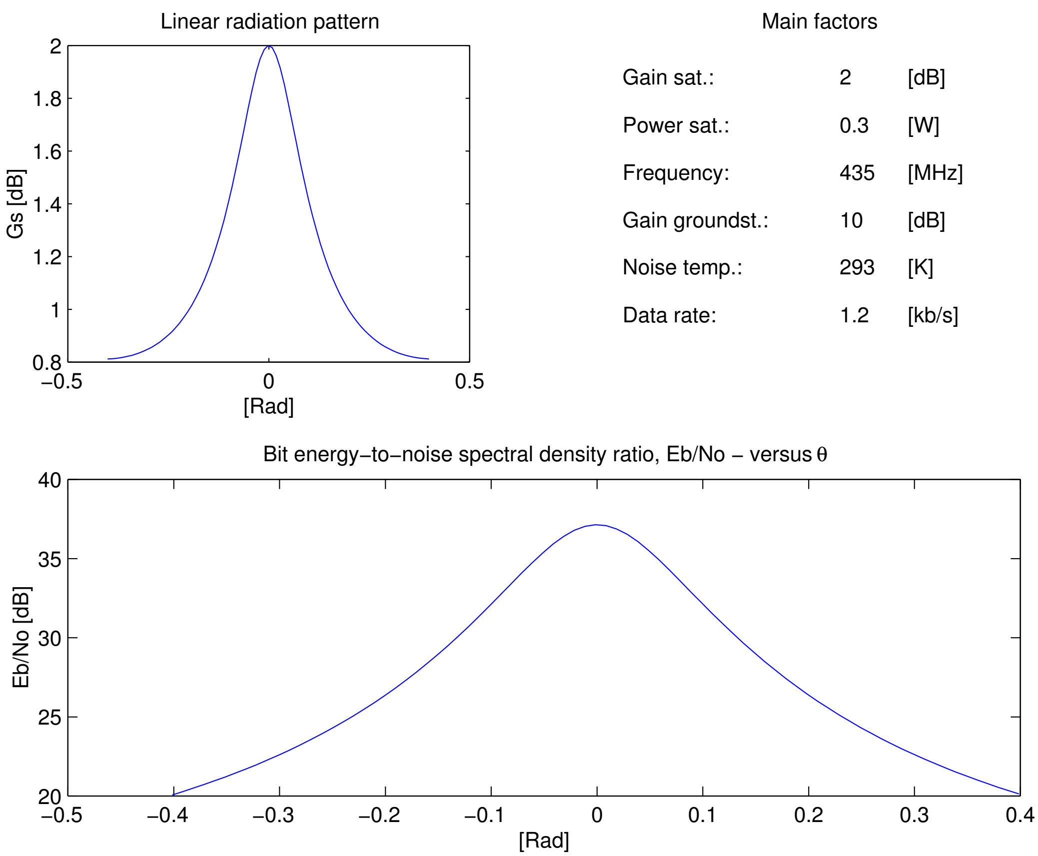

Figure A.3: $\frac{E_b}{N_0}$ versus θ, $f = 435$

Appendix B

Antenna Fundamentals

In the following we will explain the fundamentals of the antenna concept.

B.1 Introduction

In basic terms the antenna is an electrical circuit that radiates electromagnetic energy. However, this does not imply that every electrical circuit can function as a practical antenna. Most circuits are built up by micro components, for example transistors, capacitors, wiring and so on in a computer chip. When the size of the circuit is very small in comparison with a usable wavelength, most of electromagnetic energy will be retained within the circuit itself. This energy is then either used for useful work or is dissipated as heat. But when the components or wiring are of a certain dimension appreciable compared with a defined wavelength, some of the energy escapes in the form of radiation. It is feasible to promote the radiation effects of a circuit. When a circuit is intentionally optimized in regard to radiating energy it is defined as an antenna. We are now capable to define an antenna: " An antenna is a component used to emit and receive electromagnetic waves in the radio frequency area".

B.2 Fundamental properties

This chapter will give a crude introduction to some important properties of the antenna.

B.2.1 Radiation Pattern

As a result of the above definition antennas may be designed in more or less an unlimited amount of shapes. Every antenna has its own radiation characteristics. The radiation intensity varies as a function of the direction from the antenna system. In most cases the antenna has certain directivity in witch the radiation is focused. Nevertheless, every antenna will radiate in all directions to some extent. The radiation pattern is a graph showing the radiation intensity in either two or three- dimensional space.

Many radiation patterns have a lobe structure. The lobe about the maximum radiation intensity is defined as the main lobe, and the rest are called side lobes. HP or "Half power bandwidth" is defined as the value where the intensity is reduced by 3dB in a specific plane.

B.2.2 Directivity

Definition

"An antennas directivity for a given direction is equal to the relations between the antennas radiation intensity in this direction and the antennas average radiation intensity."

This property is a measurement for how well the emitted radiation is concentrated in a specific direction. When the intensity is equal in every direction one defines the antenna as isotropic.

B.2.3 Gain

The fact is that all electrical leading bodies have ohmic resistance, apart from super conductors. For all practical purposes the input energy is dissimilar with the radiated energy. The gain of an antenna is defined: "An antenna's gain in a given direction is equal to the radiation intensity i this direction and the radiation intensity of a isotropic, loss less antenna with same input power".

B.2.4 Noise

It is common knowledge that every body emits electromagnetic radiation because of microscopic thermal motion. By applying Rayleigh-Jeans distribution law one can achieve a good approximation of the noise in the radio wave frequency. This law states that emitted noise, as a function of solid angle, is proportional with the area, the absolute temperature, band wave and the square of the frequency. The predominant noise source is found in the background radiation of space. The sun and the moon are by far the most prominent sources. But in addition we also have internal noise originating in the internal loss.

B.2.5 Bandwidth

The term bandwidth is not easily described. A practical definition:

An antenna's bandwidth is the frequency area where it satisfies given specifications.

B.2.6 Effective Area

Definition:

An antenna's effective area for a given angel of attack is the relation between available power and the power density to a plane incident wave adjusted with regard to its polarization.

There is a close connection between an antenna's gain and its effective area. The effective area should be regarded as a abstract supplementary property.

B.2.7 Impedance

Impedance can be regarded as the total resistance within a system. The impedance for an antenna is dependent of its environment and other near by antennas. Hence the necessity to map all influential factors.

The fundamental impedance is the impedance achieved when an antenna is radiating in open space without any obstacles. This is called the antenna's isolated impedance. The antenna is often connected to a transmission line, with varying impedance along the line. It therefore becomes important to specify a point of reference for the impedance. This is usually defined to be at the intersection point between the antenna and the transmission line. That is if there is one. This point is referred to as an input port.

B.2.8 Radiation Resistance

Some of the effect put into the antenna will dissipate as radiation. However, a fair share of it will never leave the antenna as explained earlier. The latter is referred to as radiation resistance.

B.2.9 Polarization

An electromagnetic wave consists of two elements, naturally an electric- and a magnetic wave. The waves are perpendicular to the direction of travel. How they propagate as a function of time and space can be described by polarization. A linear polarized electromagnetic wave occurs when the direction of travel for the waves components are fixed with time. Similarly, if the direction is not fixed with time the wave is said to have elliptical polarization. If the full rotation is equal to the wavelength circular polarization is achieved.

Appendix C

Transceiver comparison

C.1 Integrated transceiver chips

	Nordic VLSI nRF903	Chipcon CC1050	Bluechip Com. RFB433
Frequency coverage	433 - 435 MHz 868 – 870 MHz 902 - 928 MHz	300 – 1000 MHz (250Hz step)	433 / 868 / 915 MHz
Tx output	10mW	15.8mW	10mW
Power Supply Requirements	2.7 – 3.3 VDC	3.0 VDC	2.5 – 3.3 VDC
Current Consumption	~31mA	~24mA	~45mA
Operating Temperature	-40°C - +85°C	-40°C - +85°C	-40°C - +85°C
Bit Rate	0 –76.8 kbit/s	0.6 – 76.8 kbit/s	19.2 kbit/s

Figure C.1: Integrated transceiver chips comparison.

C.2 Handheld amateur transceiver

The physical dimensions are given with the plastic body

	Alinco DJ-C5T	ICOM IC-Q7E	Kenwood TH-F6A	Yaesu VX-1R	Yaesu VX-5R
Frequency Coverage Tx	144 – 148 MHz 420 – 450 MHz	144-148 MHz 430-440 MHz	144 – 148 MHz 222 – 225 MHz 430 – 450 MHz	144 – 146 MHz 430 – 440 MHz	50 –54 MHz 144 – 148 MHz 430 – 450 MHz
Frequency Coverage Rx	118 – 174 MHz 420 – 450 MHz	30 – 1310 MHz	0.1 – 1300 MHz	0.5 – 1.7 MHz 76 – 999 MHz	0.5 – 16 MHz 48 – 729 MHz 800 – 999 MHz
Frequency Stability	± 5ppm	± 6ppm	± 5ppm	± 5ppm	± 5ppm
Tx Output	300mW	350mW (VHF) 300mW (UHF)	0.5 W	1W (6V DC) 0.5W (3.6V DC)	5W (50MHz/144MHz) 4.5W (430MHz)
Power Supply Requirements	3.7V DC	3.0V DC	5.5V – 7.5V	3.6V / 6V DC	4 – 16V DC
Current Consumption	Tx: 240mA [VHF], 300mA [UHF] Rx: 30mA [VHF], 40mA [UHF]	Tx: 440mA (max) 380mA (typical) Rx 95mA (max) 38mA (typical)	Tx: 800mA Rx: 30mA	Tx: 400 mA (0.5W) Rx: 150 mA	Tx: 1600mA (5W, 50MHz) 1700mA (5W, 144MHz) 1900mA (4.5W, 430MHz) Rx: 150mA
Operating Temperature	-10°C - +60°C	-10°C - +60°C	-20°C - +60°C	-20°C - +60°C	-20°C - +60°C
Dimensions*	56(W)x94(H)x13.6(D) mm	58(W)x86(H)x27(D) mm	58(W)x87(H)x30(D) mm	47(W)x81(H)x25(D) mm	58(W)x87(H)x28(D) mm
Weight	85g	170g	250g	125g	255g

Figure C.2: Handheld HAM-transceiver comparison.