Communication Link for a Cubesat

An SDR approach

This report is compiled in LaTeX, originally developed by Leslie Lamport, based on Donald Knuth's TeX. The main text is written in *Computer Modern* pt 11, designed by Donald Knuth. Flowcharts and diagrams are made using Microsoft Visio, Inkscape and Tikz, a TeXpackage for generating graphics.

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STUDENT REPORT

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Communication Link for a cubesat
- an SDR approach

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Abstract:

In this project, a communication link between a cubesat and a ground station is designed. This includes an investigation of available frequencies as well as performance characteristics of different antenna- and modulation types. From the investigation, it is chosen to use a 10.5 GHz link with a patch antenna and to use both OQPSK as well as 8-PSK modulation. A link budget is constructed, showing an SNR of 2.8 dB at the receiver, yielding a feasible bitrate of 1.3 Mbps in LEO (1000 km) and 900 bps in lunar orbit (384000 km). This link is simulated in MATLAB showing a plausible bit-error rate (BER) of $0.0251 \pm 0.5 \cdot 10^{-4}$ for the lunar link, and $0.0235 \pm 0.5 \cdot 10^{-4}$ for the LEO link, without forward error coding (FEC). Based on this, an Software Defined Radio (SDR) prototype is implemented on two USRP's using LabVIEW. The prototype has various reconfigurable parameters including modulation type, bitrate and carrier frequency. Synchronization issues are seen at low SNRs, and the BER is up to 18.5 times bigger than what the simulation shows. The end result is a reconfigurable SDR that can transmit and decode data using OQPSK and 8-PSK with a bitrate of up to 500 kbps, with a BER of 0.0239 (without FEC) at an SNR of 5 to 6 dB.

Contents

Preface

This bachelor project in Communication Systems has been carried out during the spring of 2016, by a group of three students from Electronics and IT at Aalborg University.

The project regards the development of a communication link between a satellite in space and a ground station, as well as the development of a prototype implementation of a software defined radio to be used in the link.

A general knowledge of electronic engineering and more specifically communication systems is needed to read the report.

References to sources are of the APA-style, i.e. of the type [*source name/author's surname, year, optional page number*]. Sources are listed in a bibliography at the end of the report, and PDFs, datasheets etc. can be found in the attached ZIP-file. Figures without a source are made by the project group.

This report is organized in three parts. The first part is a technical analysis that goes in depth with antennas, a link budget of the communication link between a satellite and a ground station at AAU, different suitable modulation types and, finally, a requirements for a prototype of the radio to be used in the communication link is established.
In part two, the theory, simulation and implementation of the prototype is described.
Part three contains the test of the prototype related to the requirements set up for it in part 1.

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1 | Worksheet

1.1 Friis

The reason why there is a loss through free space, is that the signal density gets lower, as it spread over a larger area, which happens when the distance, that the signal have travel, gets longer.

A example, is when using a isotropic antenna, the signal density is equal all the way around the antenna, forming a sphere around the antenna. As the power of the signal in total always is the same, the density of the signal power is depended on the surface of the sphere. As the signal travels longer away from the antenna, the sphere gets bigger and the surface bigger to, which means that the signal density gets lower. So the free space loss, is the loss of the signal that is not going in the direction of the receiving antenna.

Friis transmission equation is used to calculate the power, that is received at the receiving antenna, out from the gains in the antenna, the power of the transmitted signal and the free space loss.

$$P_r = P_t G_t G_r (\frac{\lambda}{4\pi d})^2 \tag{1.1}$$

Where:

P_r	is the received power at the receiving antenna	[W]
P_r	is the transmitted power at the transmitting antenna	[W]
G_t	is the gain in the transmitting antenna	[1]
G_r	is the gain in the receiving antenna	[1]
λ	is the wavelength of the transmitted signal	[m]
d	is the distance between the transmitting antenna and the receiving antenna	[m]

It is used to calculate the loss through the free space and do not take into account other waves, than the direct wave. The free space loss is equal to $(\frac{\lambda}{4\pi d})^2$ and is multiply by the gains in both antennas and the power transmitted, to get the received power level.

The free space loss comes from the spreading of the signal, which is compared to the spheres, which in the signal spread in, surface, which is calculated by $\frac{1}{4\pi d^2}$. Furthermore, there also comes the loss, when the signal is received at the receiver, where the effective antenna area is equal to $\frac{\lambda^2}{4\pi}$. These two losses give in total the free space loss. (Hans eberts pdf)

This is the simple form of friis formulae and it is only correct, if these conditions is met:

- d is much greater than λ. If d is smaller than λ, there will be gain power through the transmission between the antennas, which is a violation of the law of conservation of energy.
- The transmission goes through freespace, with no multipath. So no obstacle in the transmission line or around it (See worksheet about Line of sight (LOS)).
- The antennas is aligned and have the same polarization.
- The bandwidth is narrow enough, so that a single wavelength can be specified.
- P_r and P_t is the available power at the antennas, and do not take into account the loss through the cable running from antennas. Furthermore, the power will only be fully delivered and received, if the antennas and transmission lines are conjugate matched.

When the antennas is not aligned and/or not have the same polarization, the simple version of the equation can not be used. Another problem, is if the impedances is mismatched, which give a reflection at the antennas, which is another loss in the system. Also there is loss through the air, where the air absorb some of the power from the signal. With these losses, the equation is expanded to:

$$P_r = P_t G_t(\theta_t, \phi_t) G_r(\theta_r, \phi_r) (\frac{\lambda}{4\pi d})^2 (1 - \mid \Gamma_t \mid^2)(1 - \mid \Gamma_r \mid^2) \mid a_t \cdot a_r^* \mid^2 e^{-\alpha d} \tag{1.2}$$

Where:

P_r	is the received power at the receiving antenna	[W]
P_r	is the transmitted power at the transmitting antenna	[W]
$G_t(\theta_t, \phi_t)$	is the gain in the transmitting antenna	[1]
$G_r(\theta_t, \phi_t)$	is the gain in the receiving antenna	[1]
λ	is the wavelength of the transmitted signal	[m]
d	is the distance between the transmitting antenna and the receiving antenna	[m]
Γ_t	is the reflection constant a the transmitting antenna	[1]
Γ_r	is the reflection constant a the receiving antenna	[1]

a_t	is the polarization vector of the transmitting antenna	[1]
a_r	is the polarization vector of the receiving antenna	[1]
α	is the medium of transportations absorption coefficient	[1]

1.2 Two Ray Plane Earth

$P_r(d) = \frac{P_t G_t G_r}{L} \frac{h_t^2 h_r^2}{d^4}$

if $d > \frac{20 h_t h_r}{\lambda}$

else will the received power theoretically oscillates between local maxima of 6dB above free space to $-\infty$ dB at local minima.

LPE = 40 log10(d) − 20 log10(ht) − 20 log10(hr)

[Poole, 2016]

Bibliography

Poole, I. (2016). What is GMSK Modulation - Gaussian Minimum Shift Keying. http://www.radio-electronics.com/info/rf-technology-design/pm-phase-modulation/what-is-gmsk-gaussian-minimum-shift-keying-tutorial.php. Downloaded 7. March 2016.

Appendix