INTER-SATELLITE COMMUNICATION LINK FOR A SPACE BASED INTERFEROMETER

R. Grootjans
University of Twente
Faculty of Electrical Engineering, Mathematics and Computer Science
Telecommunication Engineering Group
P.O. Box 217, 7500 AE, Enschede, The Netherlands
E-mail: r.grootjans-1@student.utwente.nl

M. J. Bentum[t], R.Grootjans[:t], M.F. Brethouwer[:t], R.A. de Vries[:t] and S.K. van Langen[:t]

Abstract - Radio astronomy has been moving towards lower frequencies in recent years. This trend started with Earth bound large arrays like the low frequency array called LOFAR. After that an initiative to measure even lower frequencies started like the Orbiting Low Frequency Array (OLFAR) in space using a swarm of nano-satellites. Inspired by these initiatives, the goal of the TwenteSat student project is to create a space based interferometer using two tethered nano-satellites. A crucial part of this project is the inter satellite communication which allows data to be shared and control signals to be send between the separated satellites. The possibility of wired communication is examined, as well as wireless communication. In this paper a simple low power wireless communication system is proposed, with the use of commercial off the shelf (COTS) parts.

I. INTRODUCTION

The TwenteSat project is a student project which focuses on an experimental setup for low frequency radio astronomy using interferometry. The project is inspired by initiatives like the Orbiting Low Frequency Array for Radio Astronomy (OLFAR) [1][2]. An initiative using conventional satellite technology is the DARIS project. This is however bulky and expensive [3]. Other solutions need to be used in order to make it easier to do space based radio astronomy. The purpose of the OLFAR project is to have a swarm of nano-satellites in space forming a large radio telescope for radio astronomy on ultra low frequencies. Something that is hard to do on Earth due to the attenuation of the ionosphere and the man made radio interference [4]. The satellites contained in OLFAR are small and relatively inexpensive, so a lot of them can be used. If one unit breaks down, the mission can continue without problems. The step to make everything small and distributed brings its own problems. There is not much room for payload, and also the solar cells can generate less power. The TwenteSat mission aims to launch a satellite into low earth orbit (LEO). This satellite is deployed in two units which are tethered to each other. The goals of the TwenteSat mission are to research inter satellite links, space based interferometry for radio astronomy and perform measurements of the man made noise [5].

Inter-Satellite Links (ISL) are becoming increasingly important with the rise of satellite networks. There are several examples of past missions that used multiple satellites with the purpose of constellation flying [6]. One of the crucial parts of a system with multiple satellites in an orbit is the communication between them, because information has to be shared. Examples of this information are: attitude data [7], control signals and the measurement data of the radio telescope in order to do distributed correlation [4].

The communication between the two units consists of measurement data, attitude control signals and system information. Very expensive and bulky systems are not an option since the satellite is going to be small (one CubeSat unit can contain 10x10x10 cm of payload). The power level is limited, because the satellites solar cells can not generate high power levels. In the Delfi c3 mission, 4 solar panels on a 3U CubeSat generated a minimum power of 3 watts [8]. So it can be assumed that a 1U cubesat will generate a minimum power of 1W. From these characteristics the specifications of the communications system can be derived.

The specifications for this system are:

- The system has to be built with commercial off the shelf parts (COTS).
- The system has to support a data rate of 250kb/s [5].
- The system has to fit easily in a 10cmx10cmx10cm CubeSat.
- The system has to function with distances of 100 meters minimum with a maximum of 1000 meters.
- The system has to use as little power as possible (preferably<5mW).

In this paper a ISL communication is considered. The goal is to present a system which meets the before mentioned specifications. Since this is a tethered system, there are three possibilities for communication between the two units.

- Optical communication
- Wired communication
- Wireless communication

[t]M. J. Bentum is with the Telecommunication Engineering Group, Faculty of Electrical Engineering, Mathematics and Computer Science, University of Twente, 7500 AE Enschede, The Netherlands, and with ASTRON, P.O. Box 2, 7900 AA Dwingeloo, The Netherlands (e-mail: m.j.bentum@utwente.nl).

[:t]TwenteSat foundation, University of Twente, Drienerlolaan 5, Postbox 217, 7500 AE Enschede, The Netherlands. E-mail: iedereen@twentesat.nl. In coooperation with Telecommunication Engineering Group, Faculty of Electrical Engineering, Mathematics and Computer Science, University of Twente, 7500 AE Enschede, The Netherlands

Optical communication shall not be discussed in this paper since it is rather complex and costly and also too large for a low cost ISL communication system [9]. In this paper first the possibilities for wired communication will be discussed in Section II. After that in Section III the wireless option will be discussed. In Section IV a communication system is proposed. In Section V some further research is proposed. Finally the paper will be concluded in Section VI.

II. WIRED COMMUNICATION

Tethers have been used in space missions as early as 1966. The Gemini program conducted the first experiments with space tethers [10]. The most important and well known space tether missions were the Tethered Space System missions conducted with the space shuttle Atlantis [11]. These experiments incorporated electrodynamic tethers, which are conductive tethers between spacecraft.

For communication, one would require a conductive tether, since electrical signals have to be transmitted on the line. The TwenteSat mission is planned to orbit at an altitude of 500-600 kilometers, which is inside the ionosphere. Introducing an electrodynamic tether in the ionosphere has an effect on the electrical characteristics. An overview of the system is shown in Figure 1

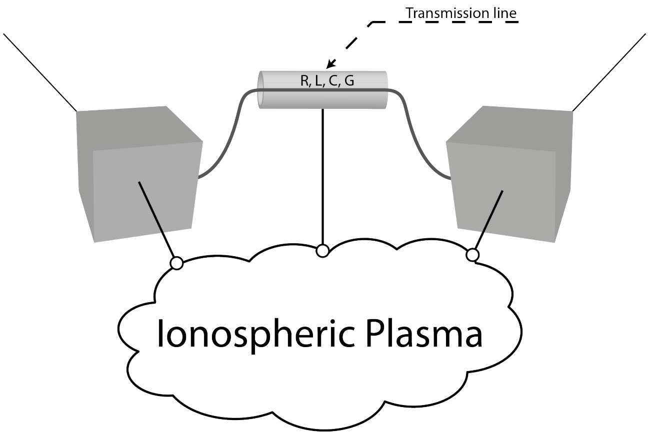

Figure 1: Schematic view of the transmission line formed with the ionosphere as return conductor.

The first important effect is that a current traveling through the tether together with the Earth magnetic field. will create a Lorenz force This creates inductive drag which can be used for attitude control and fast de-orbiting and orbiting [12]. This will not be discussed in this paper and is subject to further research.

The second important effect is that electrons are transferred from the ionosphere to the tether and ultimately to the satellite system. Energy can be generated from the satellite passing through the ionosphere [13]. This means that a current will be passing through the conductor, but also means losing orbit because of the Lorenz force.

Finally the electrical characteristics of the tether depend on these situations. Since current passes through a conductive tether, voltages will be generated across the tether. The conductor together with the ionosphere can be modeled as a transmission line [14]. There are some transmission line models generated using the data collected during the TSS-1 and TSS-1R missions [15]. However these transmission line models are generally developed for transients of several hundreds of volts. Another problem with this transmission line is that the characteristics depend a lot on several factors like: ionospheric plasma density (since it is the return conductor is the ionosphere), tether voltage, tether current and the ion frequency.

Experiments on measuring the transient response of an electrodynamic tether have been done in the TSS missions. These measurements have been verified by a computer model [16]. Several conclusions can be obtained from this result. The tether will generate high voltages, in the order of several hundred volts depending on the length of the tether and the plasma density.

Once the system is deployed in orbit a large transient is induced in the tether, because the potential difference will induce current until the charge of both the CubeSats are equal. Because a large current will go through the tether in combination with a large voltage, there is a risk of failure of the mission. A failure in the tether will result in a failure of the mission.

The tether can conduct a time domain pulse, so information can be send through this channel [17]. However there has not been any research further than using this pulse as a time domain reflectometer (TDR) for detecting tether faults. The subject of using an electrodynamic tether in the ionosphere has not been examined deep enough to develop a simple communication system using this tether.

Finally it can be concluded that the electrodynamic tether is not a suitable choice for the TwenteSat mission. First of all, the tether will generate high voltages, which requires the right equipment to deal with. This adds more electronics to the CubeSat, which in turn takes up more space. Secondly the tether is vulnerable to arcing as is with all electrodynamic structures in the ionosphere [18], if the tether fails the mission is over. So it adds more risk to the mission. Thirdly the communication is not yet fully researched, which makes implementing it in the TwenteSat mission interesting, but risky. Finally keeping in mind that the designed communication system can be used for future missions, which means that it should be easily expandable if more units are used, which is not possible with wired communication.

III. WIRELESS COMMUNICATION

In order to design the wireless communication link, several factors have to be examined. First of all, it is important to choose a suitable modulation scheme, which is energy efficient. Secondly the channel has to be characterised. It is also important to consider the antenna and the possibility of error coding.

III.1. Modulation scheme/frequency

The chosen frequency is 2.4 GHz because this is a frequency which is suitable for a minimal data rate of 250kb/s while being available in large amounts of off the shelf parts, making the selection of components a lot easier. A suitable modulation scheme has to be chosen. The two most efficient modulation schemes regarding power per bit and detection E_b/N_0 for a certain bit error rate are QPSK and BPSK as can be seen in Figure 2 [19]. So these schemes are most suitable for energy efficient reliable communication. QPSK requires more twice the power of BPSK, but can also send twice as much data.

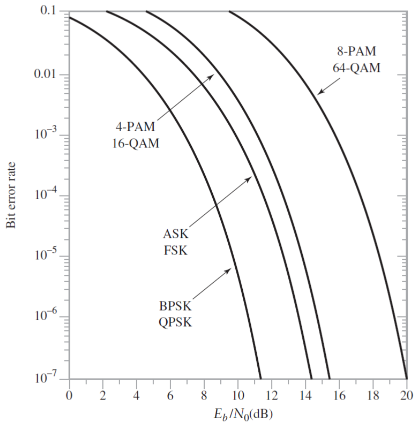

Figure 2: Bit Error Rate vs. E_b/N_0 for different modulation schemes [19].

III.2. Channel

The channel can be considered a free space channel, since there are no objects in the path which can cause multipath components. The tether is considered non-conductive, so it does not influence the propagating radio waves. The path loss (L_{pl}) is therefore calculated using Friis law of free space path loss given by Equation 1.

$$L_{PL} = 20 \cdot log\left(\frac{4 \cdot \pi \cdot d}{\lambda}\right)(dB) \quad [1]$$

- d is distance in meters.
- λ is the wavelength of the propagating wave.

The losses for different distances at a frequency of 2.4 GHz is shown in Table 1.

Table 1: Calculated path loss for different distances at 2.4 GHz.

Distance d(m)	Path loss L_{PL}(dB)
100	80
500	94
1000	100

Furthermore there is little or no interference present, because the system is at an altitude of 500 km. This means that the loss in the link is dominated by the path loss. Other losses that might contribute are pointing losses and feed losses. The effects of the ionospheric losses are about 1 dB [20], so they do not affect the link very much.

III.3. Antenna

The antenna is an important part of the system. The antenna determines the directivity of the the transceiver. Because the system is tethered, the direction of the other CubeSat is known. This means that one antenna placed correctly in each CubeSat will suffice for the tethered system. However if the system position is not exactly know, then smarter solutions have to implemented as is proposed in [21]. A suitable antenna for the propposed communication system is a microstrip patch antenna. A microstrip path antenna is a low profile easily integrable antenna which is normally manufactured directly on a printed circuit board [22]. A well designed rectangular patch can have a gain of 6-9dBi, and a half power beamwidth of up to 70 degrees [23].

III.4. Error Coding

If the demanded BER needs to be higher, error coding can be applied to reduce the required E_b/N_0 or to decrease the error probability. Examples for good error-codes are Turbo codes or low density parity checks [24]. The downside of this is that the system will need a lot more processing power, meaning that the power of the transceiver will also be increased. So initially the choice is to do not incorporate complex error coding schemes.

III.5. Conclusion

Overall the wireless system is better suited for the hostile ionospheric environment. The most important drawbacks of the conductive tether have to do with the fact that the ionosphere interferes with long conductors. Therefore it is better suited to choose a wireless system instead of a wired system. Another drawback is that tethered solutions are not easily expandable if in the future more satellites form a network. For the TwenteSat mission this is not an issue, but it is good to keep in mind that the design might be expanded for other missions. Therefore the optional addition of a multiple access technology is also of importance.

IV. PROPOSED SOLUTION

The proposed system utilizes a wireless system that is built with commercial off the shelf parts. For this system first the link budget has to be calculated in order to see what kind of transceiver has to be build. The link budget is presented in Table 2.

Table 2: Link budget for the inter-satellite link.

Parameter	Symbol	Value
Bandwidth	B	$500kHz$
Carrier Frequency	fc	$2.4GHz$
Temperature	T	$353K$
Distance	d	$100m$
Transmit Power	P_{TX}	$0dBm$
Tranmit Antenna Gain	G_{TX}	$6dBi$
Transmitter Losses	L_{TX}	$2dB$
Path Loss	L_{PL}	$80dB$
Ionospheric Loss	L_i	$1dB$
Received Power	P_{RX}	$-77dBm$
Receive Antenna Gain	G_{RX}	$6dBi$
Receive Losses	L_{RX}	$2dB$
Received SNR	SNR_{in}	$43dB$
Required BER	BER	10^{-5}
Required E_b/N_0	E_b/N_0	$9.5dB$
Link Margin	LM	$33.5dB$
Noise Floor	P_N	$-116dBm$

As can be seen in the link margin, the system is very can be easily upgraded with extra bandwidth and range, since there is such a large link margin. If for example extra range is needed the link margin can be reduced, and the link can still terminate successfully. Since the link margin is 33.5 dB the range can be increased without changing the communication system, so the distance can be easily increased to 1000 meters. Introducing an better receiver can increase the data rate substantially, and even the requirements on the transmit power can be relaxed.

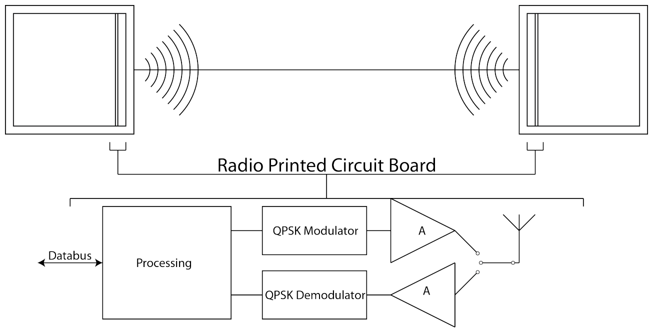

Figure 3: Overview of the radio system for the TwenteSat mission.

The proposed system (Figure 3) needs to feed data through a wireless connection. There has to be some type of connection between the central processor of the satellite and the transceiver. The best solution for this is to use a reliable high speed data bus. There are several bus standards with their own specifications. The three mostly used simple bus connections are serial peripheral interface (SPI), controller area network (CAN) and I^2C. An overview of the important characteristics is shown in Table 3.

Table 3: Comparison of different data busses.

Connection Type	Speed (max)	Pins	Robustness
SPI	∞	4	+/-
CAN	1 Mbps	4	++
I^2C	3.4 Mbps	2	+

The most commonly used and easily available technique is I^2C, so this protocol is chosen for the data transfer to the receiver.

The modulation type that is chosen is QPSK, this is chosen for reasons described in section III.I. That means that after the data processing a QPSK modulator has to be constructed. After that the signal needs amplification to reach the required transmit power level.

The power consumption of the system should not be much higher than the transmitted power. Very efficient processors can be used. Also the receiver can be periodically shut down when little or no data has to be send.

The components of the system can be integrated solutions or even discretely built. The patch antenna for 2.4 GHz does not have to be big if a correct dielectric is used [22].

V. FURTHER RESEARCH

Further research can be done in the wired communication field. If there is a conductive tether between the two units, so it should be possible to communicate between them using this conductive channel. It can be investigated how much the high voltages and charging of the satellites influences the communion channel in order to determine if it is even feasible to use it for communications. Other interesting topics include using a Time Domain Reflectometer to find tether faults. Furthermore attitude control using electrodynamic tethers is still an important subject. Another possibility is to use the tether as a large antenne. These subjects can all be further researched.

For the wireless communications, a simple multiple access technique can be researched, which does not need sophisticated systems or much processing to be implemented correctly.

For the TwenteSat mission however it is important to implement the system, and verify if it is in agreement with the designed system.

VI. CONCLUSION

In this paper an inter-satellite communication system for a tethered satellite system is presented. The possible options of wired and wireless transmission have been examined. The wired system proves to be not suitable for the application, since the ionosphere has a high impact on the electrodynamics of a conducting tether. The wireless system proves to be the most viable way to make a simple system that will meet the specifications, and is easily expandable. The proposed system can be built with commercial off the shelf parts. It has a minimum data-rate of 250kb/s. The transmit power can easily be reduced to 1mW, and the entire system can be low power. It can work with a minimum distance of 100 meters, and can be easily expanded. And finally the system can fit in the 10x10x10 centimeters CubeSat.

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