PERFORMANCE EVALUATION OF AIS RECEIVING CUBESAT PROTOTYPE USING STRATOSPHERIC BALLOON FLIGHT

Troels Laursen, Jeppe Ledet-Pedersen, Hans Peter Mortensen, Nikolaj B. Pedersen, and Ulrik W. Rasmussen

{*trlau,jledet,hp000,markem,wilken*} *@space.aau.dk*

Aalborg University, Department of Electronic Systems, Fredrik Bajers Vej 7, 9220 Aalborg , Denmark

ABSTRACT

This paper documents the NAVIS (North Atlantic Vessel Identification System) project: a prototype test of the AAUSAT3 student satellite on a stratospheric balloon flight in October 2009 as part of the BEXUS programme. The mission objective is to evaluate the quality of space based reception of AIS (Automatic Identification System) messages using a Low Earth Orbit satellite. AIS is a ship identification and position exchange protocol used to enhance safety at sea. The main payload of AAUSAT3 is two student developed AIS receivers. The aim of the balloon flight is to verify the satellite design in a realistic environment and to investigate the severity of message collisions for AIS receivers with an extended field of view (FOV). This is an important issue for satellite based AIS, and the main goal is a feasibility study to find out to what extent an increased FOV is acceptable. To investigate this, a high altitude balloon was flown carrying the prototype to an altitude of 24 km. The prototype performed as expected for the entire flight, and collected valuable sampled AIS data. More than 25000 AIS messages were successfully received from ships in northern Scandinavia during the three hour flight. An analysis of the message reception ratio, based on interpolation showed that 15.9 % of expected transmission were received by the receivers. The satellite power supply and a newly developed communication system were also successfully tested.

Key words: AAUSAT3, AIS, Cubesat, BEXUS, Balloon Experiment.

1. INTRODUCTION

The NAVIS project (North Atlantic Vessel Identification System) is the name given to a stratospheric balloon test of a prototype of AAUSAT3, the third Cubesat satellite developed by students from Aalborg University. The satellite is the successor to AAUSAT-II which was launched in 2008 and has now been operational for more than two years – longer than any other Danish student satellite. The AAUSAT3 project was initiated in the fall of 2007 and the satellite is expected to be launched in the first half of 2011. The primary payload of AAUSAT3 is two AIS (Automatic Identification Systems) receivers designed to study the quality of AIS reception from a Low Earth Orbit (LEO) satellite.

The satellite prototype was tested on a stratospheric balloon flight in October 2009 as part the BEXUS (Balloon Experiments for University Students) programme, which allows European students to test scientific experiments in high altitude conditions. The balloon test was an excellent opportunity to test the AIS receivers with an extended FOV and to evaluate signal strength and collision effects as a preliminary step in the construction of the final payload receivers. The NAVIS project also includes a test of the general satellite design, including the power supply, batteries, radio link, and ground segment.

The paper is structured as follows. The following section contains a brief introduction to AIS and the challenges of constructing a satellite based receiver. Section 2 describes the experiment setup and subsystems, while Section 3 presents the obtained results.

1.1. Automatic Identification System

AIS is a data exchange protocol standardized by the International Telecommunication Union (ITU) and designed to enhance safety at sea by automatic exchange of ship identification and positioning data. All ships with a gross tonnage of more than 300 tons and all ships carrying passengers are required by law to have an AIS transponder on board. For all other ships it is an optional safety feature. At regular intervals, AIS transponders broadcasts information such as their Maritime Mobile Service Identity (MMSI) number, position, speed, and name to nearby ships as well as shore based stations. The system is designed to function autonomously and allow ships to exchange information without influence of an operator. AIS is also used to monitor ship traffic using strategically placed ground stations and buoys and as an additional aid in search and rescue operations. The ground stations are e.g. placed along the Danish coast line and are used to receive identification signals from ships and act as electronic lighthouses.

Around Greenland and in many other regions of the world, a ground station based network of AIS receivers is impractical. Due to Greenland's extensive coast line the number of ground stations required would be very high. Furthermore, the environment in Greenland is so hostile that maintenance of the ground station network would be a considerable challenge. Recently, investigations on the possibility of receiving AIS signals in space has therefore received much attention, since a satellite based receiver will be able to cover a much wider area than conventional ground station networks. AIS was originally designed as a completely ground-based system, and reception of AIS signals in space thus impose a number of challenges, such as reduced signal strength and packet collisions, that must be addressed.

AIS transponders have a communication range limited by line of sight, which gives a range of approximately 50-60 km at ground level, depending on the antenna position and configuration. The system operates on two parallel reserved maritime VHF channels on 161.975 and 162.025 MHz, with transmissions alternating between both channels for added redundancy[1]. The data packets are NRZI encoded (Non-Return to Zero Inverted) and GMSK modulated (Gaussian Minimum Shift Keying) and sent with a transmission rate of 9.6 kb/s. Figure 1 shows the AIS framing format, which is based on the High-level Data Link Control (HDLC) format. The default packet length is 256 bits, where 168 bits are used for data content and 16 bits are used for the CRC16-CCITT Frame Check Sequence (FCS). The data field content depends on which of the 26 available message types is used.

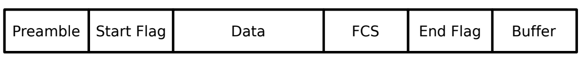

Figure 1. AIS packet format. The encapsulation is based on HDLC. The default packet length is 256 bits.

AIS is provided for ships as two different transponder types: Class A and Class B. All vessels that are legally required to carry AIS equipment must have a Class A on board, transmitting with a power of 12.5 W. Ships that are not required to carry an AIS transponder have the opportunity of using a Class B transponder, that are often smaller and cheaper since they only transmit with 2.5 W and only support a subset of the AIS message types.

AIS uses a SO-TDMA (Self Organizing Time Division Multiple Access) medium access scheme to coordinate the transmissions on the two channels. The transmission behaviour of AIS messages is dynamically controlled by each independent AIS transponder, based on ship conditions such as speed and rate of turn. Since ships only synchronize their transmissions with other ships within line of sight, a satellite with a large FOV, will receive colliding AIS messages from unsynchronized transmissions. The situation is illustrated in Figure 2 where transmissions from ships in Group A are not synchronized with ships in Group B. If both groups are covered by the FOV of the satellite, unsynchronized transmissions may occur, resulting in colliding messages.

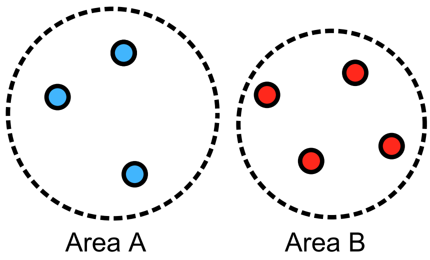

Figure 2. Multiple SO-TDMA zones. Transmission are synchronized by the ships within each group but not across both groups. If the satellite FOV covers both groups, packet collisions may occur.

2. METHOD

Before the launch of AAUSAT3, the effect of colliding messages due to unsynchronized TDMA zones must be investigated. This requires a test of the AIS receivers in a high altitude setting with an extended FOV and coverage of multiple TDMA zones. Furthermore, a methodology for calculation the percentage of received messages as a quality measure is required to evaluate the receivers and to compare them with a traditional network of ground based receivers.

2.1. System Overview

This section describes the experiment subsystems. The experiment consists of a subset of the AAUSAT3 subsystems, as illustrated in Figure 3. The main payload is two AIS receivers based on two different receiver structures and demodulation methods. These are used for testing how different solutions will react to the ambient environment and to evaluate the two solutions for further development of an AIS receiver for the final satellite. The AIS1 subsystem performs demodulation of the signals with a commercial radio front-end and processes a serial output to decode the AIS messages. AIS2 is a software defined receiver, that samples a down converted intermediate frequency output and stores it for later processing. Because the two AIS systems are completely independent, the probability of success is increased even if one of the systems should malfunction during the flight.

To house the extra batteries and an additional subsystem, the AAUSAT3 1U Cubesat frame was extended with 6 cm in one dimension to 10x10x16 cm. The satellite frame was enclosed in an outer box with 5 cm of insulation to protect the electronics from ambient temperatures. The outer box simplifies mounting on the gondola and carries mechanically stable connectors.

In order to keep the system as modular as possible, the internal communication between subsystem is handled on a

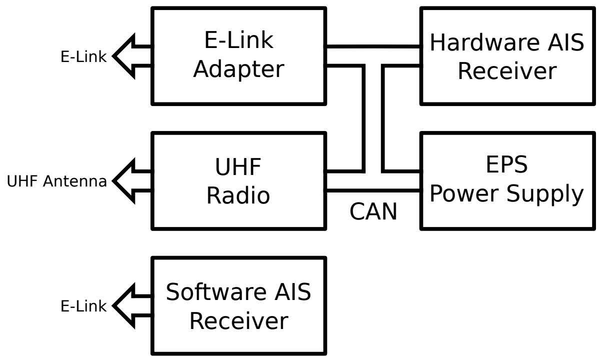

Figure 3. Subsystem structure and communication interfaces.

CAN-bus (Controller Area Network) using the network-layer Cubesat Space Protocol (CSP). CSP was originally developed for use in AAUSAT3, but is now jointly maintained by the AAUSAT3 project and the AAUSAT-II spin-off company GomSpace ApS. CSP is freely available under an open source license[7]. The protocol allows subsystem programmers to use socket-like communication between subsystems by assigning addresses to subsystems and ports to available services. All subsystems except AIS2 are based on Atmel AVR8 micro controllers. The AIS2 receiver has high requirements for processing power and therefore uses the ADSP-BF537 digital signal processor from Analog Devices. AIS2 is equipped with a dedicated E-Link connection to allow transfer of large AIS samples to ground. The ELA (E-Link Adapter) is developed specifically for use on the BEXUS flight to bridge the internal CAN-bus network with the Esrange E-Link, as a redundant communication channel from the ground segment to the subsystems.

AIS1 AIS1 is a hardware receiver based on the Analog Devices ADF7021 radio transceiver. The transceiver demodulates the radio signals from one of the two AIS channels to a 9.6 kb/s data stream. This is connected using SPI (Serial Peripheral Interface) to a Atmel AVR micro controller that processes and decodes the data. The received AIS messages are decoded and messages with both correct and incorrect FCS and stored on permanent storage for analysis of the reception quality. Messages and reception statistics can be downlinked during the flight, using either the UHF of ELA[2].

AIS2 AIS2 is an SDR (Software Defined Radio) prototype. The subsystem samples the raw Intermediate Frequency (IF) output of a hardware down conversion of the AIS radio signals. A 200 kHz wide frequency spectrum covering both AIS channels around 162 MHz, is down converted to a 200 kHz IF and is sampled with 1 MSPS simultaneously on the Inphase and Quadrature output. A Digital Signal Processor (DSP) is used for filtering and demodulation of the data[6]. Each sample is 8 MB in size and contains 2.175 seconds of sampled data. The size of a continuous sample is limited by the size of high speed memory on AIS2. The raw sample files are saved on permanent storage during the BEXUS flight, so that demodulating algorithms can be optimized before the launch of AAUSAT3. AIS2 is equipped with a dedicated E-link connection so a number of samples can be downlinked to ground during the flight.

EPS The main task of the Electronic Power Supply (EPS) is to monitor the batteries and to supply regulated voltages to the individual subsystems. The EPS has one dedicated power channel per subsystem and is able to turn these on and off individually, and to monitor the power consumption of each subsystem. The EPS is also in charge of monitoring if subsystems are running nominally or if a subsystem fails to respond on the internal communication interface. As a fault recovery mechanism in case of software failure, the EPS reboots all of the experiment subsystems, including the EPS itself, if an internal timer is not manually reset from the ground station every 20 min. This resets the ELA and UHF to their default settings and prevents the subsystems from staying in a locked-up state for the entire balloon flight. For the BEXUS flight, the EPS was equipped with 3 times the battery capacity of AAUSAT3 because all subsystems were powered on during the entire flight, and due to the fact that the prototype did not carry any solar panels for recharging the batteries. Furthermore, the EPS was connected to 10 temperature sensors in the satellite and an 8 W regulated heating system, in order to heat up the experiment box if needed.

UHF The UHF radio is newly developed for AAUSAT3 and is based primarily on the work of a master thesis[5]. The thesis focus on the development of a new radio system for amateur spacecrafts and uses a commercial off-the-shelf radio transceiver. The coding and space link protocol design is based on the CCSDS standard, and uses a concatenation of convolutional and Reed-Solomon error correction codes. This is a large improvement over traditional AX.25 based Cubesat radio systems. Flying the UHF radio on the high altitude balloon will influence the system in ways similar to that of a LEO satellite, and provides a unique possibility for a long range test not otherwise possible. The goal of the test is to predict and model the effect of these influences and to test the ability to maintain a reliable data-link for telemetry. The UHF radio operates on an allocated channel at 437.475 MHz in the amateur satellite frequency band.

ELA The ELA acts as a gateway between the BEXUS E-Link, and the internal CAN-bus by encapsulating CSP packets in UDP datagrams and forwarding them to ground. By using both E-Link and the AAUSAT3 UHF subsystems, the experiment subsystems have completely transparent redundant communication channels.

3. RESULTS

The BEXUS balloon flight took place on October 11th 2009, from Esrange Space Center in northern Sweden. The total flight had a duration of almost 4 hours, and had a float period in a constant altitude of 24 km for 2 hours. The AAUSAT3 prototype was working during the flight with all systems running operational. Monitoring and control was done from the NAVIS ground station placed in the Cathedral at Esrange, using both the E-Link and the UHF radio.

In total AIS1 received 25196 AIS messages with correct FCS, where 17000 were received in the float period. Furthermore, 70000 AIS messages was detected with correct length and start/stop flag, but with invalid FCS. AIS2 saved 200 sample files each containing 8 MB of raw data each, corresponding to 2.175 sec of traffic.

This section further explains to results from all the subsystems.

3.1. AIS1

The AIS1 data has been subject to a post-flight analysis, which is explained in detail in [3]. A total of 25196 AIS messages with valid FCS was received and stored during the flight. The messages have been decoded and analysed with a custom developed MATLAB tool. AIS messages of type 1, 2 and 3 contains position reports from ships carrying Class A transponders. These contain the MMSI number, position, speed, and course over ground.

The received data set has been compared with reference data from the coverage area provided by the Danish Maritime Safety Administration (DaMSA). Table 1 identifies the number of messages received by AIS1 and the messages received by the reference ground stations in the same time window. Of the unique MMSIs received by AIS1 and the reference data, 151 were located in both data sets. AIS1 received in average 69 AIS messages per MMSI, while the reference data from DaMSA on average contained 9 AIS messages per ship, which is due to the message filtering used in the reference database.

Description	AIS1 Data	Ref. Data
Total messages	25196	2833
Ships	339	309
Ground Stations	24	-

Table 1. Number of decoded AIS1 messages and reference data.

A subset of AIS position reports also contains the number of other ships within range of the transmitting ship. These numbers can be exploited to estimate the average size of the TDMA zones by calculating the average number of ships within range. The average number of ships within range of another ship was found to be 12. In comparison, each ground station synchronized its transmission with 21 transponders in average. The histogram in Figure 4 illustrates the number of ships within range of each ship, as reported in the AIS messages.

The histogram shows that there is a large amount of ships with only few ships within range. This can be explained by ships located inside the fjords of Norway, where mountains block the signals from ships that would otherwise be within range. Larger zones with many ships indicate that the size of a TDMA zone vary a lot from ship to ship and place to place.

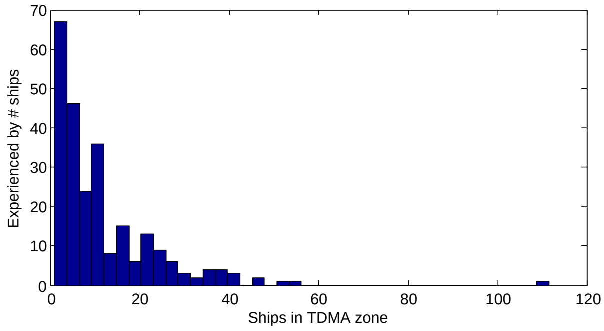

Figure 4. Number of ships within range of each ship.

Figure 5 shows the theoretical coverage area around the balloon flight and a plot of the received position reports. The balloon trajectory is illustrated by the black line, and line of sight from the balloon gondola is indicated by a circle of 550 km in radius. The AIS1 data is plotted with blue circles illustrating ground stations and red crosses indicating a received position report from a ship.

The theoretical FOV is limited by the curvature of the earth and the antenna configurations for both AIS1 and the transponders. The estimated coverage area appears to agree well with the received position reports. A number of messages were received from a Finnish ground station 70 km outside the expected coverage area, which is believed to be explained by a high position of the antenna at the ground station.

The received data shows that the most common dynamic condition was ships sailing at 0-14 knots. This was observed in 72 % of the cases and yields a reporting interval of 6 s. The second most common dynamic condition was ships sailing at 0-14 knots while changing course, which was the case for 20 %, corresponding to a reporting interval of 3⅓ s. It is noted that only few messages were received from ships at anchor, which is due to the low reporting interval of 3 minutes.

The 158 ships detected in the reference data set, but not by AIS1, can be partially explained by 20 ships located outside the theoretical FOV. Also, four ships had Class B transponders and 14 Class A transponders were at anchor resulting in a high reporting interval. The rest can not be sufficiently explained by these reasons. From DaMSA's database is not possible to decide whether these were

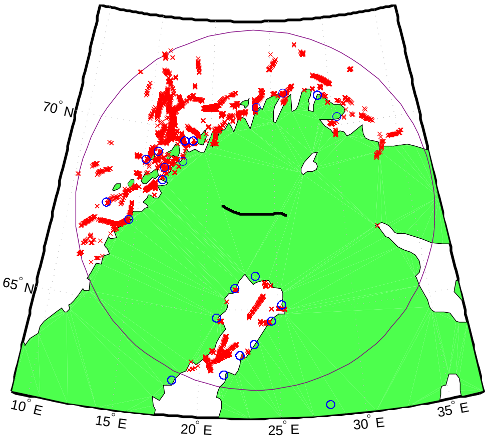

Figure 5. Balloon flight trajectory, AIS1 data and theoretical coverage area. Blue circles show ground station positions and red crosses illustrates messages from ships.

Class A or B transponders. However, this still indicates that not all ships within the FOV were detected by AIS1.

The reference data can not be used to estimate the detection ratio, since the reference data was not limited to ships within FOV nor did it cover the entire FOV.

The ships detected by AIS1 that where not in the reference data, was mostly outside the range of the ground stations, because the reference data did not cover the far north of Norway, nor the Finnish coast. However, the AIS1 receiver did detect ships within the area of the reference data that were not detected by other ground stations. This indicates that the landscape might have caused problems both for the ground stations and the balloon, and this is also indicated by the closely placed AIS ground stations in the northern fjords of Norway.

3.2. Interpolatation of Transmissions and Estimation of Loss Ratio

The transmission interval of AIS transponders is dependent of the dynamic conditions of the ship. The transmissions from a ship at anchor will thus have a lower reporting interval than from a ship sailing at open sea. Other conditions such as change of course also affect the transmission behaviour. The somewhat predictable reporting interval can be used to interpolate the expected message transmissions which can then be used to estimate the packet loss. The data interpolation is based solely on the data received by AIS1 during the float period. For ships, the data interpolation extended the AIS1 data set from approximately 17000 to 106000 AIS messages. A segment of the data interpolation from the AIS messages received from one ship is shown in Figure 6. The interpolated expected transmissions are shown in the upper part of the figure as green lines and the received messages are shown in the lower part.

The message reception percentage, $AIS1_{RXaverage}$, can

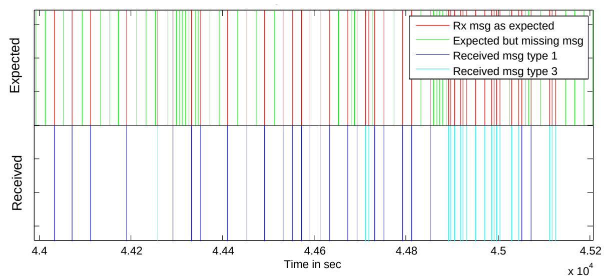

Figure 6. A segment of the interpolation of the data received from MMSI 212390000. Each vertical line represents a received package. The height of the lines are at a fixed value for illustrative purposes.

be estimated to 15.9% from the received and interpolated AIS1 data, as shown in Equation 1:

$$AIS1_{RXaverage} = \frac{R_{success}}{R_{success} + R_{missed}} = 15.9\ \% \quad (1)$$

where $R_{success}$ is the number of received messages and R_{missed} is the number of expected messages from the interpolation that were not received.

Table 2 identifies the number of messages interpolated divided into the different AIS reporting intervals.

State	AIS1	Interpolated	R. Interval
1	14	68	3 min
2	11892	49971	10 sec
3	334	2428	6 sec
4	3302	41445	3.33 sec
5	924	10913	2 sec

Table 2. Number of messages divided into the different reporting intervals before and after the interpolation. Data only included from the float period.

During the balloon flight the average reporting interval observed, can be calculated according to Equation 2:

$$P_s = \frac{\sum^a n_a \cdot T_a}{\sum^a n_a} = 13.09\ \mathrm{s/message} \quad (2)$$

where n_a is the number of interpolated messages in state a, T_a is the reporting interval. n_a and T_a are summed for each state in 2. Since the transmission of AIS messages is equally distributed on both AIS channels, the AIS messages transmission rate is equal to $AIS_{TXrate} = \frac{P_s}{2} = 6.55\ \mathrm{s/package}$. The measured average reporting interval of 6.55 s is not far from the 6 s assumed in similar studies[4].

3.3. Software Defined AIS receiver

AIS2 was working as expected during the balloon flight. More that 200 raw samples were saved, with each sample containing 2.175 s of data. Of approximately 1.6 GB of data sampled during the flight, around 350 MB was downloaded in flight using E-Link. All samples were stored on permanent storage for post flight analysis.

The first AIS message was received in 4.3 km altitude from a ground station located 180 km from the gondola. Figure 7 shows the frequency content as a Fast-Fourier Transform (FFT) waterfall plot of one of the 200 sample files that AIS2 saved during the flight. The two AIS channels are clearly seen at the two frequencies 161.975 and 162.025 MHz. During the balloon flight AIS2 detected 27 AIS messages in average on each channel in the 2.175 s. With a channel capacity of 37.5 messages pr. second pr. channel, this gives an estimated channel usage of 33.1 % - enough to know statistically that some of the multiple samples contains colliding messages.

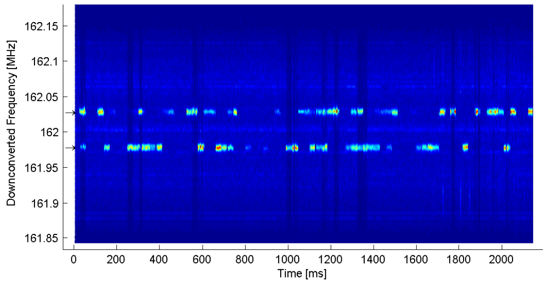

Figure 7. Frequency analysis of a raw sample file from AIS2 in 24 km altitude.

The current algorithm for demodulation is implemented in MATLAB, and uses 11 s to analyse a raw sample file of 2.175 s of data. The structure of the demodulator is fairly simple. A 5th order Butterworth filter is used to filter out the two AIS channels, and a matched quadrature FIR filter is used to demodulate the GMSK modulated signal. An example of the soft output of the demodulator is shown in Figure 8, where the preamble of an AIS message is detected. The crosses indicates the clock recovery (bit placement) of the 9.6 kb/s AIS data transmission. By taking the sign of the soft demodulator output in these points, the transmitted data can be recovered. The figure shows an NRZI encoded training sequence of alternating ones and zeros and followed by a HDLC start flag of 0x7E.

3.4. UHF

The radio equipment on both ground station and the experiment were similar except for the antenna configuration. An half-wave omni directional monopole antenna was hanging beneath the balloon gondola, while a 15 elements Yagi-Uda antenna was used on the ground station. A transmission power of 30 dBm was used for both the experiment and ground station, with a 2FSK modulation scheme and adjustable data rate, modulation index and error correction code. The default data rate was 9.6 kb/s with both convolutional and Reed-Solomon encoding enabled. The link was tested at speeds ranging

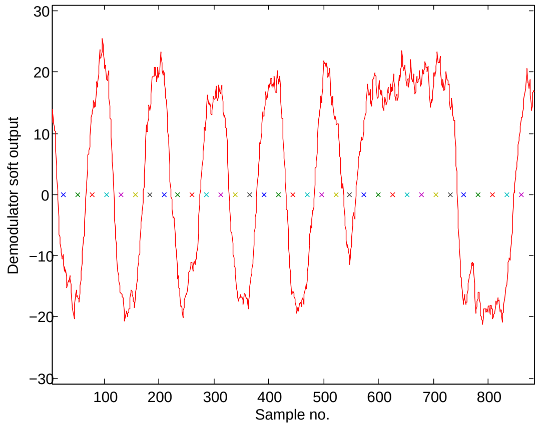

Figure 8. Start of AIS package, demodulated by AIS2.

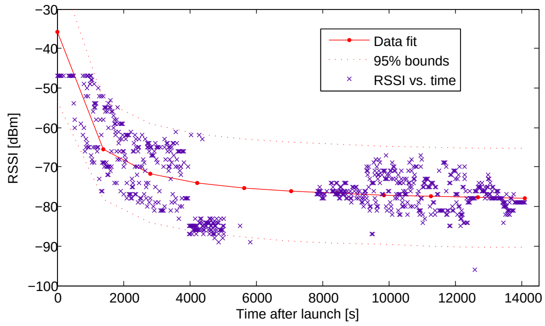

Figure 9. UHF RSSI (Received Signal Strength Indicator).

from 1.2 to 19.2 kb/s. Even at the maximum range between balloon and ground station of 200 km, a telemetry data rate of 19.2 kb/s was maintained without problems. The UHF ground station was placed at Esrange, and a total of 10.400 packages was transmitted through this link. Figure 9 shows the Received Signal Strenght Indicator (RSSI) for the UHF datalink. The silent period in the middle was due to a time windows allocated to receive AIS without possible interference from the radio link to verify that the EMC design was sufficient for the UHF subsystem not to disturb the AIS receivers. The lower period from 4000 to 5000 s after launch can possibly be explained by the UHF ground station antenna pointing close to the E-BASS antenna setup.

3.5. Electronic Power Supply

The EPS monitored healthy batteries during the entire flight and registered enough spare capacity after the flight for at least 5 additional hours of full operation. No subsystems exceeded their power limit and all regulated voltages where stable during the flight. The internal temperature sensors measured values in the range from 9°C to 26°C, with the warmest being the UHF power amplifier and the coolest being the batteries. The high internal temperatures compared to the ambient temperature of less than -40°C, was achieved with 5 cm insulation and active heating on the batteries. The heating was automatically enabled when the internal temperature dropped below 10°C, but was only briefly used near the end of the balloon float stage even though the whole experiment dissipated less than 2 W. During the flight, the EPS was used to shut down subsystems temporarily, mostly for subsystems containing radio receivers when measuring the noise floor and to compare the AIS quality with the UHF powered on and off.

3.6. E-link Adapter

The ELA was responsible for converting the internal CAN-based CSP traffic to Ethernet UDP datagrams for communication through the E-link provided by the launch provider. The ELA generally performed as expected and routed 36522 packets between the experiment and the ground segment. The subsystem did have three temporary failures due to wrong error handling. The ELA watchdog timer was however able to perform a reboot to recover original functionality. During normal operation, no packet loss was experienced. As the subsystem was only designed to be used for the balloon experiment, and will not be used in the satellite, no further investigation of the cause of the errors have been carried out.

4. CONCLUSION

The satellite prototype was working as planned and the only problems were small and manageable. The quality and quantity of AIS data exceeded the expectations prior to the flight and supported the possibility that AAUSAT3 will be able to receive AIS messages in LEO when launched.

The NAVIS experiment has taken the development of AAUSAT3 through a key iteration, both regarding hardware and software prototyping. All key subsystems for the satellite was prototyped and tested for the balloon flight and a list of design improvements has been specified after the NAVIS experiment, including missing features and new requirement revealed by the balloon test. Furthermore, it has been a valuable opportunity for the students to gain experience in design and production of high quality hardware and software, with a broad aspect from high frequency circuits to high speed digital signal processing. In software design, prototyping and testing, fault tolerant principles were used to increase the chances of success and to confine errors within the subsystems.

The extent and size of this student managed project has been a unique experience for all involved students, that will help in the final phase of the AAUSAT3 project. The knowledge and practice of applying ECSS standards has made our internal documentation more structured and useful.

More information can be found on the NAVIS website at http://aausat3.space.aau.dk/navis.

ACKNOWLEDGMENTS

The authors would like to thank all colleagues from the satellite system engineering group at Aalborg University and everyone involved in development of AAUSAT3. We would also like to thank the Danish Maritime Safety Administration for collaboration and for providing us with reference data.

We would especially like to thank the REXUS/BEXUS programme for accepting the NAVIS project. The development of AAUSAT3 has gained tremendous advancement due to the participation in BEXUS.

The AAUSAT3 and NAVIS projects are jointly sponsored by Aalborg University and the Danish Maritime Safety Administration who is responsible for the safety in the seas around Denmark, Greenland and the Faroe Islands. A special thanks goes out to all other sponsors of the project, in particular the C.W. Obel Fund and others who helped make this project a reality.

The REXUS / BEXUS programme is realised under a bilateral Agency Agreement between the German Aerospace Center (DLR) and the Swedish National Space Board (SNSB). The Swedish share of the payload has been made available to students from other European countries through a collaboration with the European Space Agency (ESA). EuroLaunch, a cooperation between the Esrange Space Center of the Swedish Space Corporation (SSC) and the Mobile Rocket Base (MORABA) of DLR, is responsible for the campaign management and operations of the launch vehicles. Experts from ESA, SSC and DLR provide technical support to the student teams throughout the project. REXUS and BEXUS are launched from Esrange Space Center in northern Sweden.

REFERENCES

[1] IEEE, 1998-2001-2006-2007, ITU-R_M.1371-3 Technical Characteristics for a Universal Automatic Identification System using Time Division Multiple Access in the VHF Maritime Mobile Band.

[2] Mads Hjort Andersen, Nikolaj Bisgaard Pedersen, Ulrik Wilken Rasmussen and Troels Laursen, 2009, Satellite AIS Receiver, Aalborg University

[3] Troels Laursen, Hans Peter Mortensen, Nikolaj Bisgaard Pedersen, Ulrik Wilken Rasmussen, Tatiana K. Madsen and Jens Dalsgaard Nielsen, 2009, Performance Modelling of Automatic Identification System with Extended Field of View.

[4] Miguel A. Cervera and Alberto Ginesi, 2008, On the Performance Analysis of a Satellite-based AIS System.

[5] Johan De Claville Christiansen, 2008, Next Generation Spacelink for Cubesats.

[6] Hans Peter Mortensen, Troels Jessen and Jeppe Ledet-Pedersen, 2009, Software Defined AIS Receiver for AAUSAT3.

[7] Cubesat Space Protocol project website, Google Code Hosting, http://code.google.com/p/cubesat-space-protocol/