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A Norwegian Satellite for Space-based Observations of AIS in the High North

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ABSTRACT

The Automatic Identification System (AIS) for maritime vessels introduced by the International Maritime Organization (IMO) is basically an anti collision system for vessels at sea. Vessels are broadcasting messages on two channels in the maritime VHF band on regular basis to neighboring vessels for collision avoidance, and to shore stations for vessel traffic services (VTS). AIS messages can also be received by a VHF receiver in space for wide area observation of maritime activity.

Norway is about to build its first dedicated satellite (AISSat-1) for such space-based observation of AIS. The justification for the mission is based on careful modeling of the global AIS detection probability, with particular emphasis on observation of Norwegian ocean areas in the High North (and High South).

AISSat-1 is based on a dedicated low cost high-performance nano-satellite platform (just 20×20×20cm) with three-axis attitude control. The platform will be built by the Space Flight Laboratory at the University of Toronto (UTIAS/SFL), Canada. The AIS sensor is a software defined radio developed by Kongsberg Seatex (KSX), Trondheim Norway.

This paper will in some detail discuss AIS detection probability modeling results, mission architecture, satellite, payload, and AIS data distribution on ground. It is believed that AISSat-1 currently is one of the most advanced nano-satellites being developed and is possibly the only nano-satellite dedicated to demonstrate a much needed and future oriented national maritime situational awareness service.

INTRODUCTION

Norwegian waters amount in total to more than 2 million square kilometers, comprising the 200 nautical miles economic zone, the fishery zone around Jan Mayen, and the fishery protection zone around Svalbard as shown in blue in Figure 1.

New developments in the High North impose new challenges on managing this area of responsibility. The arctic region is an important fish habitat, and is rich on oil and natural gas. If the observed rate of climate change persists, increased maritime activity in the fragile Arctic areas can be expected. Monitoring current and future maritime activity is therefore of prime importance. In a strategy document for the development of the High North presented at the end of 2006 [1], the Norwegian government clearly recognized this and stated that it will be a national responsibility and priority to strengthen the monitoring of maritime activities in the High North. A major challenge though is frequent monitoring of these large ocean areas.

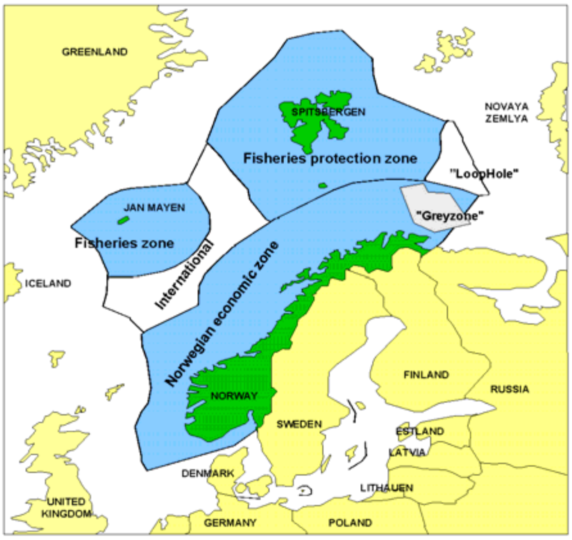

Figure 1: Ocean areas under Norwegian jurisdiction (blue).

Traditionally, maritime surveillance in the area has been performed by maritime patrol aircraft, Coast Guard and Navy vessels, coastal radars, and since 1998 Synthetic Aperture Radar (SAR) imagery from the Canadian RADARSAT-1 satellite. The introduction of the Automatic Identification System (AIS) by the IMO has provided an additional source of maritime traffic information. AIS is a ship-to-ship and ship-to-shore communication system intended to increase the safety of life at sea and to improve control and monitoring of maritime traffic. AIS equipped ships broadcast their identity, position, speed, heading, cargo, destination, etc. to vessels and shore stations within the range of the VHF transmission. Norway has more than 40 stations along the coast for receiving AIS messages to more than 40 nautical miles off shore.

The Norwegian Defence Research Establishment (FFI) has examined both technical and organizational aspects of monitoring AIS signals from space, to evaluate the possibility of extending the coverage area of AIS to all ocean areas under Norwegian jurisdiction. A comprehensive observation model for estimating the AIS signal environment in low Earth orbit has been developed, making it possible to evaluate various concepts for AIS satellite missions to meet Norwegian and more global requirements.

AIS SIGNAL AT LOW EARTH ORBIT

A first step in evaluating the prospects for space-based AIS is a careful AIS signal propagation analyses. Several factors such as output power, antenna configuration and gain, polarization, propagation distance, atmospheric and ionospheric conditions, free space loss and fading affect the received signal strength. The noise level of the system is -125dBm assuming a system noise temperature of 1000K and a bandwidth of 25000Hz leading to a 20% packet error rate at -117dBm. [2]

Figure 2 shows the received power (dBm) at a satellite altitude of 600km carrying a horizontal dipole antenna. The axes show the positions of transmitters relative to a sub-satellite point located at 75°N, 20°E. The link budget includes polarization mismatch losses due to Faraday rotation, which was estimated from the International Geomagnetic Reference Field and from global ionosphere maps produced by CODE.

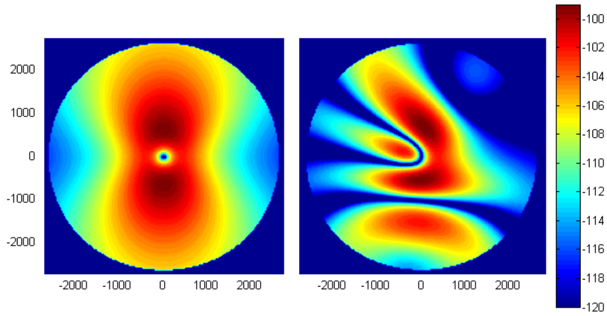

Figure 2: Ideal dipole antenna pattern (left) and corrected for polarization and Faraday rotation (right).

VESSEL DENSITY DISTRIBUTION

To study the detection probability for vessels in Norwegian and also European waters it is necessary to acquire vessel traffic conditions over much of the northern hemisphere due to a spacecraft's large field of view. A base estimate of the global vessel distribution was derived from the International Comprehensive Ocean-Atmosphere Data Set (ICOADS). Ship positions were extracted from six years of data to estimate a global vessel distribution. The number of ships reporting weather data is quite low and it was therefore necessary to rescale and update the global map with measured vessel distributions. Figure 3 is a graphical representation of the updated vessel densities on the northern hemisphere containing approximately 52,000 moving vessels operating AIS at any given time.

AIS Class B equipment is recently introduced by IMO and will be carried by yachts, leisure boats and other small vessels. This will increase the number of vessels transmitting on the two AIS channels. It is difficult to estimate how widespread such equipment will become. Fortunately, Class B transponders will have longer reporting intervals than Class A and transmit at 2 watts [3]. This implies that there is room for a large number of vessels with Class B equipment without significantly decreasing the detection probability of vessels carrying Class A equipment.

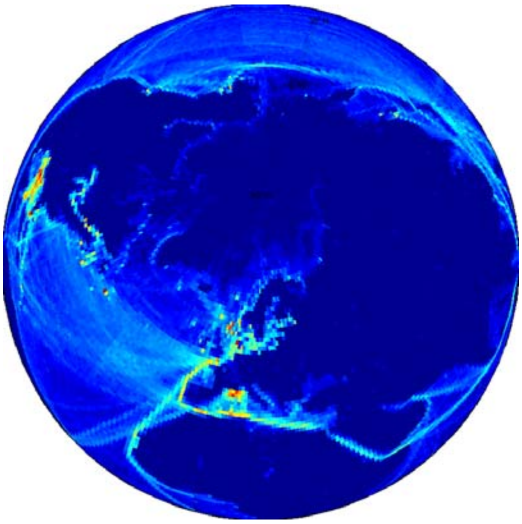

Figure 3: Class-A vessel distribution on the northern hemisphere.

DETECTION PROBABILITY SIMULATIONS

A simulation tool, AISDET, has been developed at FFI to perform vessel detection probability analysis. AISDET uses a global vessel density map to simulate reception of AIS messages at LEO. Each vessel transmits according to the SOTDMA [3] scheme on the two AIS channels. The signal strength of each message at the AIS receiver is computed to check if it can be decoded. In case of message collision, the received power ratio between the desired and undesired signal (D/U) at the receiver input determines whether the strongest message can be decoded or not. Message collisions occur when more than one message arrive at the AIS antenna during the same TDMA timeslot.

SIMULATION RESULTS

The simulations use sun-synchronous orbits, a satellite altitude of 600km, a receiver sensitivity of -117dBm, a D/U of 10dB and a single quarter-wave monopole antenna. Figure 4 shows the required observation time to achieve 95% detection probability as a function of the number of vessels seen by the satellite. A space-based AIS receiver can at most have 1,200 vessels within its field of view and still have acceptable performance before message collisions become a significant problem.

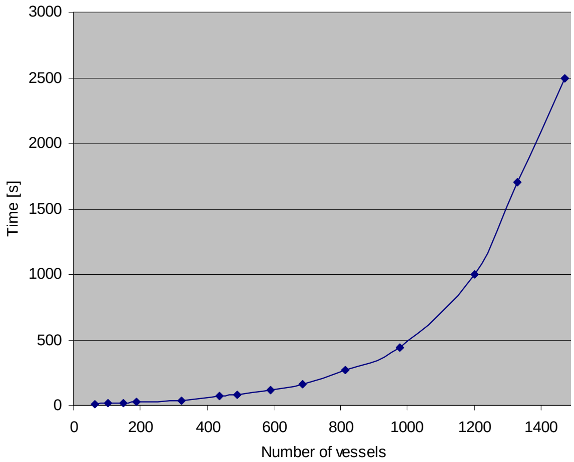

Figure 4: Observation time to achieve 95% detection probability.

Figure 5 shows the daily detection probabilities for the northern hemisphere.

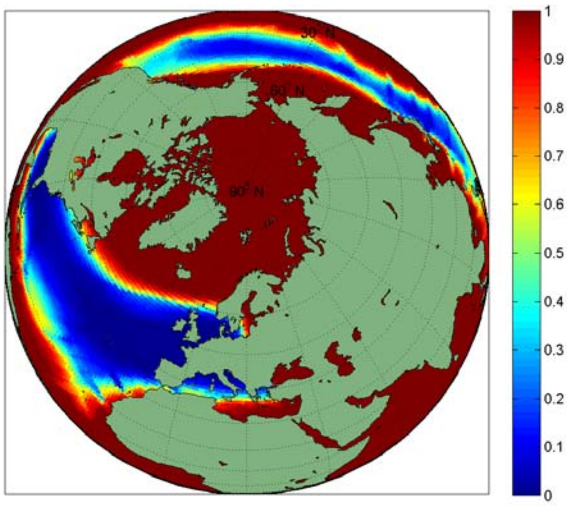

Figure 5: 24 hour detection probability map for a polar orbiting satellite.

AIS SATELLITE MISSION CONCEPT

The above short summary of an extensive AIS detection probability simulation process suggests that an AIS satellite in a 600-700km circular polar orbit can provide a future oriented national capability for enhanced maritime domain awareness in the Norwegian ocean areas in the High North and the High South, thus making a valuable contribution to meeting the goals of the national strategy [1].

A Norwegian AIS demonstration satellite (AISSat-1) is currently under development. The satellite is based on a cube shaped platform being developed by the Space Flight Laboratory at the University of Toronto (UTIAS/SFL), Canada, while the AIS sensor is being developed by Kongsberg Seatex (KSX), Trondheim Norway. The ground station will be managed by Kongsberg Satellite Services (KSAT), Tromso Norway and will be located at Svalbard (78°13'N 15°23'E), which will permit contact with the satellite in all of the 15 daily passes. The control center will initially be located at FFI, Kjeller Norway.

AISSat-1 will observe part of the ocean areas every orbit in the High North and will in 10 of the 15 daily orbits map the maritime activity inside the area of main interest indicated by the white circle shown in Figure 6. The overall mission architecture with location of ground sites are also shown in Figure 6.

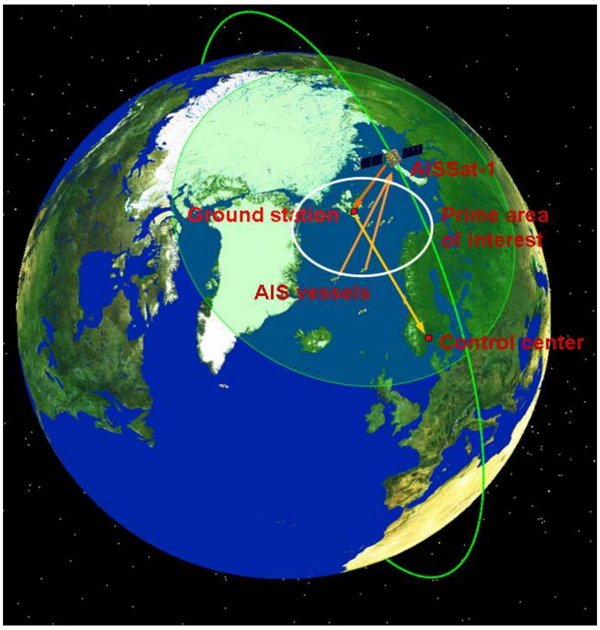

Figure 6: AISSat-1 mission architecture.

AIS SENSOR

The AIS sensor for this mission is basically a dual channel VHF receiver, which can be tuned to any of the VHF channels in the maritime VHF band ranging from 156.025 to 162.025 MHz [3]. When listening for AIS messages broadcasted on the two designated AIS channels, the radio will be tuned to VHF channels 87B and 88B (161.975 and 162.025 MHz respectively).

A prototype of the AIS sensor is already developed and is currently being modified and space qualified by Kongsberg Defence and Aerospace (KDA), Kongsberg Norway. It is a software defined radio (SDR) as indicated in Figure 7. The AIS signal is sampled and forwarded to the FPGA for further hardware processing. Using a reprogrammable FPGA enables in-flight fine tuning of the AIS sensor based on analysis of received AIS data, or allows the FPGA to be completely reprogrammed to take advantage of major future design and functionality improvements.

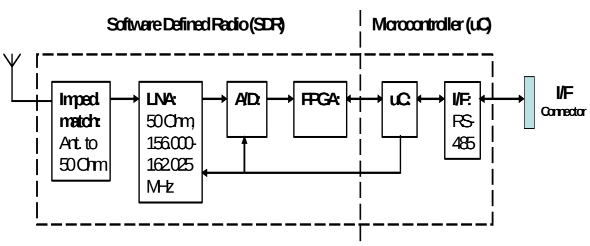

Figure 7: AIS Sensor for the AISSat-1 satellite.

The microcontroller communicates with the satellite platform by sending and receiving data packets on a serial RS-485 line. The controller also holds the radio setup information in addition to FPGA configuration images.

SATELLITE PLATFORM

The AISSat-1 satellite platform is based on the UTIAS/SFL Generic Nanosatellite Bus (GNB) developed at SFL. The GNB is a low cost spacecraft bus ideal for scientific and technology demonstration missions. AISSat-1 represents the third incarnation of the GNB platform; the first two being the 4-spacecraft astero-seismology BRITE-Constellation, and the dual spacecraft CanX-4/-5 formation flying mission. AISSat-1 can thus leverage the highly advanced and mature GNB design to achieve its mission goals. Much of the GNB platform draws heritage from SFL's CanX-2 and NTS nano-satellites now operating in orbit.

The GNB has a 20cm cubic form factor, weighing around 6 kg, with nearly 30% of its mass and volume dedicated to mission specific payloads. Power is generated by multiple strings of body mounted triple junction solar cells with energy storage in an on-board lithium-ion battery. The GNB also comes equipped with a suite of 3-axis attitude determination and control components to provide high precision pointing. The following sections give an overview of the subsystems and technologies used on AISSat-1. The external layout of AISSat-1 is shown in Figure 8 and Figure 9.

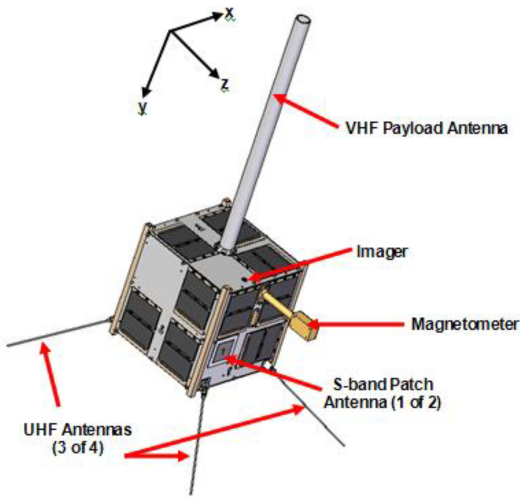

Figure 8: AISSat-1 External Layout.

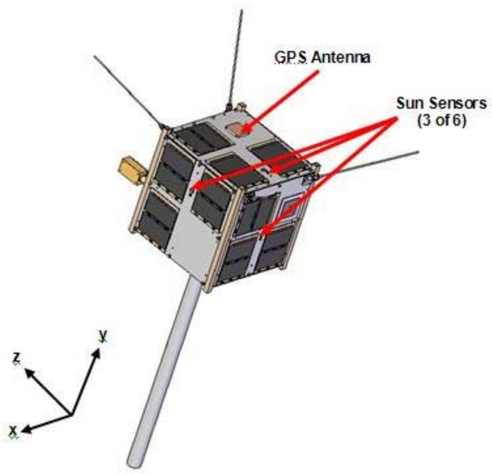

Figure 9: AISSat-1 External Layout.

Structure

The AISSat-1 structure consists of two trays and six external panels. A dual tray structure was selected in order to maximize the payload bay and provide ease of integration. The trays and panels can be manufactured from either aluminum or magnesium alloys, depending on the mass requirements of the mission. The two trays contain all the necessary components for a basic satellite mission, including communications, attitude determination and control, power and thermal/structural components. Figure 10 shows the internal structure of AISSat-1, with the two trays and the AIS sensor.

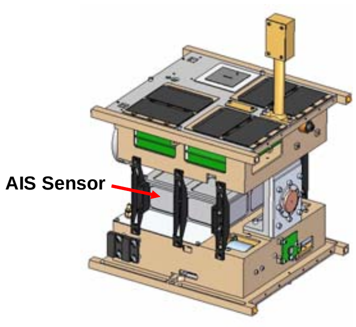

Figure 10: AISSat-1 Internal Structural Trays.

AISSat-1 also includes a custom designed VHF monopole payload antenna, as shown in Figure 8. The antenna is pre-deployed and designed to survive launch conditions in any orientation. It is also designed to be easily removed from the spacecraft without removing any of the spacecraft panels, allowing for easier testing, handling, and safety during shipment.

The thermal controls are incorporated into the structure of the satellite. In order to conserve power and reduce complexity of operations, AISSat-1 employs mostly passive thermal controls in the form of coatings and structures. As the battery possesses the most stringent thermal requirements, it requires thermal isolation and a trim heater in order to meet a large variety of orbital scenarios.

On-Board Computers

AISSat-1 is equipped with three on-board computers (OBCs). Each OBC features an ARM7 microcontroller, 2MB of EDAC protected SRAM and 256MB of flash memory. The Housekeeping Computer is responsible for communications with the ground station and collecting satellite telemetry. The Attitude Determination and Control Computer interfaces with the attitude sensors and actuators and runs the attitude control algorithms. On AISSat-1, a mission specific Payload OBC will be responsible for interfacing with and collecting data from the AIS sensor and GPS receiver. This computer allows different data collection, storage, and processing modes, and allows in-flight updates to the AIS sensor. Each OBC runs a custom made multi-threaded operating system called CANOE (Canadian Advanced Nanospace Operating Environment) allowing it to divide processing time between multiple tasks in parallel.

Power

Power is generated on AISSat-1 with 36 body mounted triple junction $GaInP_2/GaAs/Ge$ solar cells. These cells have a beginning of life efficiency of 26.8% delivering up to 967mW at their peak power point at 28°C. Energy is stored in a dual-5.3Ah lithium-ion battery system allowing the satellite to operate in extended eclipse periods and to reduce depth of discharge on the individual batteries. The power system architecture contains peak power tracking functionality and provides switched power to the loads and power regulation where required. Finally, overcurrent protection is provided to prevent damage to the payloads.

Peak power tracking is achieved using a Battery Charge and Discharge Regulator (BCDR). The BCDR maximizes solar array output power when required by controlling the bus voltage to optimize battery charging. Each battery has a dedicated BCDR.

Radios

The AISSat-1 platform contains two radio systems: a UHF receiver, and an S-Band transmitter. The UHF receiver, operating at 4 kbps, is used for data uplink from the ground station and uses four phased quad-canted monopole antennas which provide near omni-directional coverage. The S-Band transmitter will be used for data downlink. It is capable of data rates from 32 to 256 Kbps and uses two patch antennas mounted on opposite sides of the satellite for near omni-directional coverage.

Attitude Determination and Control

A full 3-axis attitude determination and control system provides attitude stabilization and fine pointing for AISSat-1. The satellite is able to point in either an inertial orientation, or an orbit-frame-fixed orientation, including at nadir. Attitude sensors consist of six sun sensors, a magnetometer and three rate gyros. Three orthogonally mounted reaction wheels shown in Figure 11 (developed in partnership with Sinclair Interplanetary) and three magnetorquer coils provide the attitude actuation for the nanosatellite. The magnetorquer coils are used for detumbling and momentum dumping while the reaction wheels provide fine attitude pointing capability. The attitude control system is able to maintain several degree level pointing accuracy and stability over the course of the entire orbit, including eclipse.

Figure 11: Sinclair-SFL Reaction Wheels.

OPERATIONS

After a successful launch and commissioning phase AISSat-1 will enter into two succeeding operational phases.

Phase-1 will be an experimental phase where mainly FFI will perform analysis of the space-based AIS concept in general, and where data from AISSat-1 will be analyzed and compared with the results from the detection probability modeling, particularly for the Norwegian ocean areas in the High North. The satellite will in this phase primarily store and forward AIS data, but will also push AIS data in real time to ground during periods of ground contact. Distribution of data to selected users will also be tested.

Phase-2 will be an operational demonstration phase where AISSat-1 will deliver data to selected users in an agreed form until end of satellite life. Some limited experimentation will also be performed during this phase.

It is currently assumed that AIS data in the form of AIS NMEA sentences will be distributed on ground. Users will have to develop software for acquisition, analysis and display of AIS data as required. Some software is, however, already in place for analysis of AIS data from the Norwegian costal AIS network. Adjustment of this software may be one interesting processing and display approach.

AIS data from the High South will be stored onboard AISSat-1 and forwarded to users when passing over the ground station.

GROUND STATION

In order to acquire data from AISSat-1 during all 15 daily passes over Norwegian ocean areas the ground station will be located at Svalbard, where KSAT already has a major facility for communicating with numerous satellites. Stored and real time data from the satellite will be acquired and stored at the ground station for subsequent forwarding to the mission control center located at FFI in southern Norway.

SUMMARY

Careful modeling of the AIS signal environment in space has been performed. The modeling shows that a satellite equipped with an AIS sensor can provide a much needed national maritime situational awareness service for the Norwegian High North (and High South). A satellite (AISSat-1) and an AIS sensor are being developed by UTIAS/SFL and KSX respectively. The satellite mission aims at confirming the modeling results and to demonstrate a future oriented national maritime observation service. It is believed that AISSat-1 is one of the most advanced nano-satellites being developed and possibly the only nano-satellite dedicated to demonstration of a national service. Operational satellites should follow this AISSat-1 demonstration satellite if the mission proves successful.

Acknowledgments

Norwegian Space Centre, Oslo Norway, and Kongsberg Seatex, Trondheim Norway, have both made significant contributions to the development of the AIS receiver and the AISSat-1 project.

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