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EUCLID JP 9.16: SPACE-BASED AIS RECEPTION FOR SHIP IDENTIFICATION

HØYE Gudrun, NARHEIM Bjørn, ERIKSEN Torkild,
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8) ABSTRACT

This report documents the results of Work element 3100 “Space-based AIS reception for ship identification” of the WEAG study JP 9.16 “Emerging Satellite Technologies, System Trends and Space Utilization”.

The Automatic Identification System (AIS) will be mandatory on larger ships over the next few years. The system is developed for ship-to-ship and ship-to-shore communication. The report focuses on the capabilities of a possible space-based AIS sensor for ship traffic monitoring on the open oceans with respect to the following elements; 1) AIS signal power in low Earth orbit, 2) Ship detection probability from space, 3) AIS sensor/satellite design.

The conclusion from this feasibility study is that space-based AIS reception for ship identification seems feasible. The ship detection probability is better than 99% for swath widths up to 800 nm for realistic scenarios.

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EUCLID JP 9.16: SPACE-BASED AIS RECEPTION FOR SHIP IDENTIFICATION

1 INTRODUCTION

This report documents the results of Work element 3100 “Space-based AIS reception for ship identification” of the WEAG study JP 9.16 “Emerging Satellite Technologies, System Trends and Space Utilization”.

The Universal Shipborne Automatic Identification System (AIS) is mandatory on all SOLAS ships built after 30 June 2002, and on older ships by 1 July 2008. The system is a ship-to-ship and ship-to-shore reporting system based on broadcasting of short messages in the maritime VHF-band. The VHF transmission has a typical range of only 20 nm, and the system therefore has its highest value in dense traffic areas as an anti-collision and traffic management system. An overview of the AIS system, the regulations, and the concept is given in Chapter 2 of this document.

The focus of this study has been on a space-based AIS sensor for identification and positioning of ships also on the open oceans. Chapter 3 discusses the feasibility of such a space-based AIS concept by looking at the AIS signal power in Low Earth Orbit (LEO), the ship detection probability, and a possible AIS satellite design. A discussion of the concept is given in Chapter 4, followed by a summary in Chapter 5. The space-based AIS concept is illustrated in Figure 1.1.

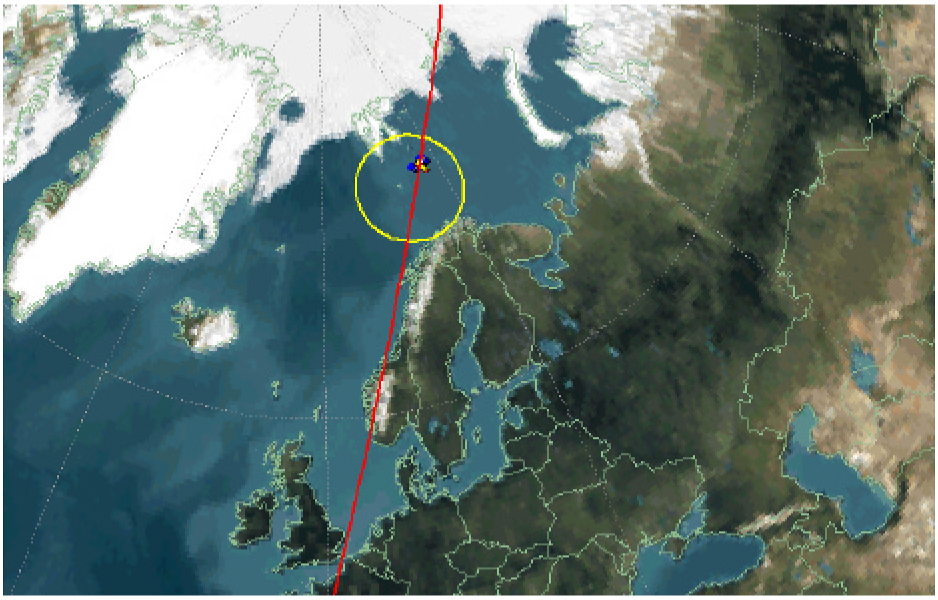


Figure 1.1 An illustration of an AIS sensor in orbit. The yellow circle indicates the sensor’s field of view.

2 THE AIS SYSTEM

2.1 Background

The Universal Shipborne Automatic Identification System (AIS) is a maritime information system that will greatly improve the safety of navigation at sea. The basic concept for this ship-to-ship communications system was introduced by the International Association of Lighthouse Authorities (IALA) in the early 1990's, and gained a significant momentum with the development and introduction of the Self-organizing Time Division Multiple Access (SOTDMA) technology in the mid 1990's. In May 1998 the Resolution MSC.74(69) containing "Recommendation on Performance Standards for an Universal Shipborne Automatic Identification System (AIS)" (1) was formally adopted by the International Maritime Organization (IMO), and the AIS ship and shore broadcasting system became a reality.

The basic principle of the AIS is relatively simple, but the practical implementation is rather complex and challenging. Standards, guidelines, and clarifications for the AIS and its implementation have therefore been developed by IMO (2) together with IALA (3),(4), the International Telecommunications Union (ITU) (5), and the International Electrotechnical Commission (IEC) (6). The implementation plan and some basic requirements resulting from this work are outlined in Subparagraph 2.4 of Regulation 19 of Chapter V of the International Convention for the Safety of Life at Sea (SOLAS) (7).

Ships covered by regulation 19 are defined as SOLAS Class A ships, and a mobile AIS station is mandatory on these ships. The process of installing AIS is to be completed by 1. July 2008. However, the majority of the world's ships are not Class A ships. Work is therefore under way at IEC to develop an equipment recommendation also for the SOLAS Class B ships (8), but AIS on these ships will for the time being not be mandatory.

2.2 The AIS concept

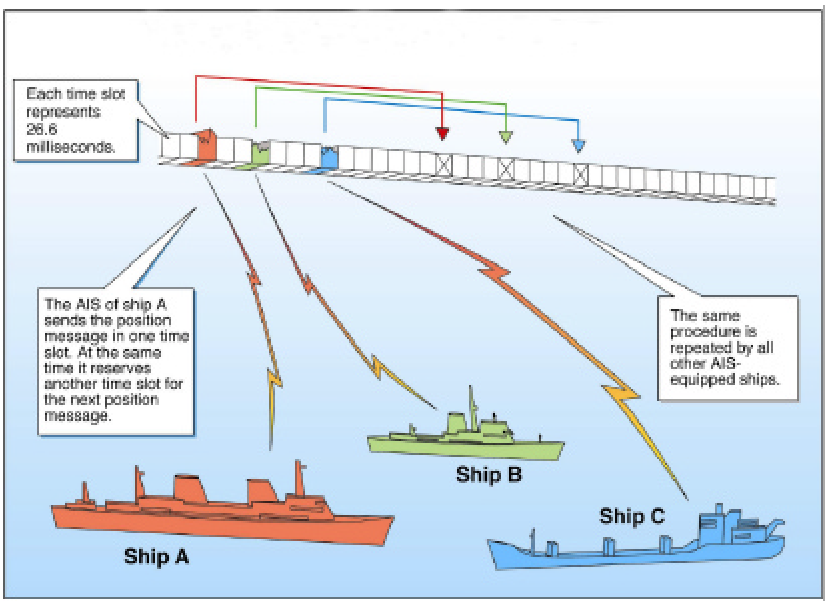
The AIS is a ship-to-ship and ship-to-shore reporting system basically developed for the safety of navigation at sea. The ships are broadcasting information such as identity, position, heading, etc. to neighbouring ships and shore stations within reach. Figure 2.1 illustrates the AIS concept.

The reporting system is based on the broadcasting of fixed length digital messages using the Time Division Multiple Access (TDMA) communication technology. The messages are entered into a 1 minute long message frame of 2250 message slots. The message entry is synchronized to the universal time coordinated (UTC), and the length of each message is limited to 256 bits. The two VHF maritime mobile channels 87B (AIS1) and 88B (AIS2) are

Figure 2.1 The AIS ship-to-ship and ship-to-shore concept. (Courtesy of Seatex, Norway).

allocated to the AIS. Messages are broadcasted alternately on the two channels giving the system a total capacity of 4500 message slots per minute.

A mobile AIS station gains access to the AIS network by using the RATDMA (Random Access), ITDMA (Incremental), and SOTDMA (Self-Organizing) access schemes (5). SOTDMA will be the access scheme normally used on the open oceans. The TDMA technology provides for automatic contention resolution, it makes the radio link robust, and communications integrity is maintained even in overload situations. Figure 2.2 illustrates the ITDMA principle.



Each time slot represents 26.6 milliseconds.

The AIS of ship A sends the position message in one time slot. At the same time it reserves another time slot for the next position message.

The same procedure is repeated by all other AIS-equipped ships.

Figure 2.2 The AIS ITDMA principle.

2.3 Basic AIS characteristics

The AIS mobile stations are designed in accordance with the technical characteristics given in the ITU-R M.1371-1 (5) and with the IALA technical clarifications on the ITU-R M.1371-1 (4). The stations must also be designed in accordance with the ITU Radio Regulations (RR) (9) and the ITU Recommendations (10). A summary of some basic characteristics of the AIS derived from these documents is given in Table 2.1.

Parameter	**Characteristics**
VHF Frequencies	161.975 and 162.025 MHz (channel 87B (AIS1) and 88B (AIS2)) 156.525 MHz (channel 70 (DSC)) for frequency management
VHF Wavelength	1.85 m
Transmit power	2 and 12.5 W
Bandwidth	12.5 and 25.0 kHz
Modulation	Gaussian Minimum Shift Keying (GMSK)
Modulation index	0.25 for 12.5 kHz and 0.5 for 25kHz
Receiver sensitivity	-107 dBm for 25 kHz and –98 dBm for 12.5 kHz bandwidth
Bit rate	9600 bit/s
Message length	256 bits
Capacity	2250 messages/minute/channel (4500 total for the 2 AIS channels)
Access schemes	RATDMA, ITDMA, SOTDMA

Table 2.1 Some basic AIS characteristics.

2.4 The AIS messages

There is a set of 22 message templates available, which fall into the following four message categories:

- *Static messages* containing the ship IMO number, call sign & name, length & beam, etc.
- *Dynamic messages* containing the ship position, time, course over ground, speed over ground, heading, etc.
- *Voyage related messages* containing destination, cargo type, waypoints, etc.
- *Safety related messages* being reported as required.

The reporting interval for the Class A AIS messages is defined as follows:

- *Static messages* every 6 min.
- *Dynamic messages* at regular intervals ranging from 2 sec to 3 min depending on speed and course alteration as given in Table 2.2.
- *Voyage messages* every 6 min.
- *Safety messages* as required.

The reporting intervals for the Class B messages can be found in (5).

The message parameters and corresponding number of bits that carry information relevant to an ocean surveillance system are shown in Table 2.3. The table indicates that less than 50% of the total message length of 256 bits contains relevant information.

Ship's dynamic conditions	**Nominal reporting interval**
Ship at anchor or moored and not moving faster than 3 knots	3 min
Ship at anchor or moored and moving faster than 3 knots	10 s
Ship 0-14 knots	10 s
Ship 0-14 knots and changing course	3 1/3 s
Ship 14-23 knots	6 s
Ship 14-23 knots and changing course	2 s
Ship >23 knots	2 s
Ship >23 knots and changing course	2 s

Table 2.2 Class A ship borne mobile equipment nominal reporting intervals for dynamic messages.

Parameter	**Number of bits**
User ID (MMSI number)	30
Longitude	28
Latitude	27
Speed over ground	10
Course over ground	12
True heading	9
Time stamp	6
Total number of bits	**122**

Table 2.3 The parameters and corresponding number of message bits that carry information of value to a space-based AIS ocean surveillance system.

2.5 The mobile AIS station

Each mobile AIS station consists of one VHF transmitter, two VHF TDMA receivers, one VHF DSC receiver, and an integrated display or a standard marine electronic communication link to a shipboard display system. The station transmits and receives messages on the two VHF channels 87B (AIS1) and 88B (AIS2). In areas where the local authorities have allocated different channels for the AIS the Digital Selective Calling (DSC) channel will resolve the channel selection automatically. A typical AIS station is shown in Figure 2.3.

Figure 2.3 The Seatex AIS 100 mobile AIS station with an integrated display.

2.6 Communication range and SOTDMA

The communication range of a mobile AIS station will be limited by the local horizon and the AIS transmitter power to about 20 nm. AIS communication areas can then be partly overlapping or next to each other as illustrated in Figure 2.4.

In Figure 2.4 ship A sees no other ships, while ship B sees ship C, and ship C sees ships B, D and F, etc. Ship C will have to organize its reporting with ships B, D and F, while ship D will also have to get organized with ship E, which will have to get organized with the shore station. Evidently, when more ships enter this picture the organizing gets more complex. The SOTDMA scheme is, however, designed to handle a large number of ships. In the event of an overload situation, the AIS stations has the ability to further reduce its communication range, thereby giving priority to collision avoidance for the closest ships.

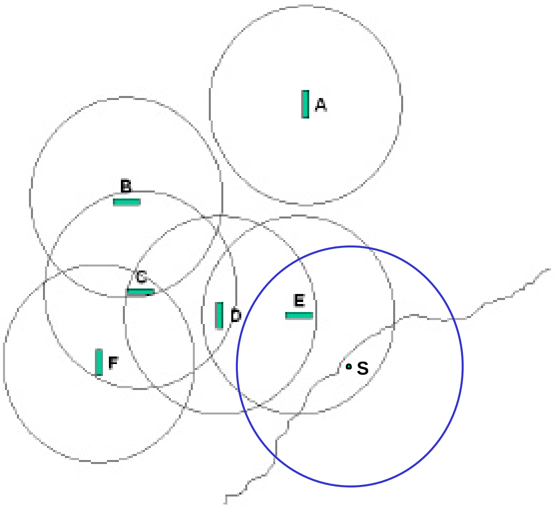


Figure 2.4 Communication range (circles) for individual ships, within which the TDMA organizes the AIS reporting. The radius of each ship (A-F) circle is about 20 nm, and somewhat bigger for an elevated ground station (S).

3 SPACE-BASED AIS CONCEPT

The Norwegian Defence Research Establishment (FFI) has for some time been studying the prospects for doing ocean surveillance by a space-based AIS sensor in LEO. The idea was presented at the 4th IAA Symposium on Small Satellites for Earth Observation in Berlin in April 2003 (13). A spin-off of this activity is the student satellite NCUBE currently under development at the Norwegian University of Science and Technology (NTNU) (15).

The feasibility of a space-based AIS system for identification and positioning of ships at sea is discussed below with focus on the following subjects:

1. AIS signal power in LEO
2. Ship detection probability from space
3. AIS sensor/satellite design

3.1 General considerations

3.1.1 Organized areas

The reporting between ships within communication range is organized by the TDMA-algorithm, in order to avoid coinciding transmissions (Section 2.5). From space, the AIS sensor will see more than one such area. To be able to analyse the situation, we have defined what we call an *organized area*. Within an organized area the AIS transmissions are organized to avoid coinciding transmissions. Ships in different organized areas transmit independently of each other.

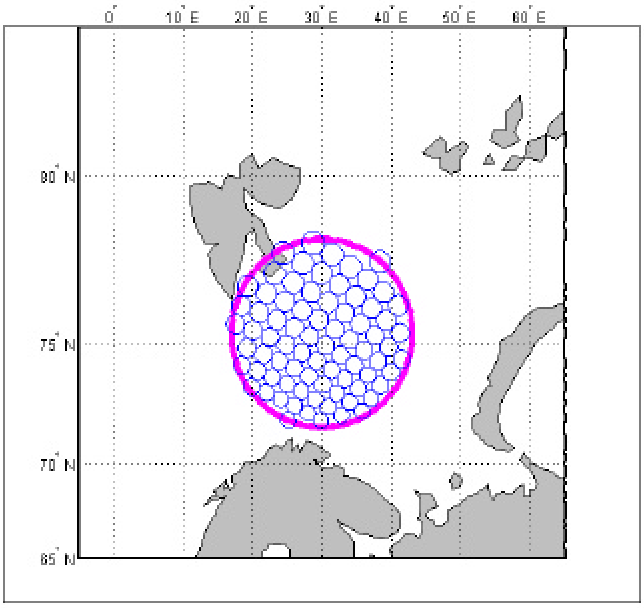


Figure 3.1 Illustration showing organized areas as blue circles. The AIS sensor's FOV is marked as a red circle.

The small blue circles in Figure 3.1 illustrate organized areas, while the big red circle illustrates the field of view (FOV) for the space-based sensor.

3.1.2 Two mechanisms for coinciding transmissions

The emission of AIS messages is synchronised to UTC, and the allocation of message slots is coordinated within each organized area. A space-based AIS-sensor will see many organized areas within its FOV, and the possibility of simultaneous reception of AIS messages at the satellite arises. The content of such coinciding AIS messages will be lost.

There are two possible mechanisms for coinciding transmissions within the FOV:

1. AIS-messages are sent in the same time slot from different organized areas.
2. AIS-messages are sent in different time slots from different organized areas, but are received simultaneously at the satellite due to different signal path lengths.

The first mechanism has been included in the statistical analyses of Section 3.3.

The second mechanism applies only when the observation area is large enough to give a significant difference in the signal path lengths. The AIS uses distance delay bits in the AIS message buffer to prevent overlap between messages that are sent in adjacent timeslots as long as the difference in the signal path lengths is less than 202 nm. For a nadir-pointing AIS-antenna at 600 km above the ground this translates into a slant range difference of 202 nm corresponding to a ground range of 394 nm relative to nadir, ref. Figure 3.2. The statistical analyses have been restricted to observation areas of 800x800 nm and less (corresponding to a FOV of 96º), so that the second mechanism for coinciding transmissions could be excluded from the calculations.

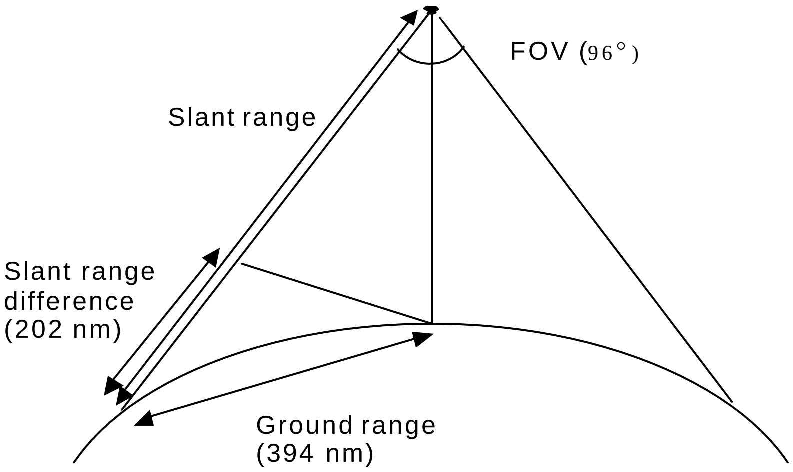


Figure 3.2 Definition of slant range, ground range, difference in signal path lengths, and the FOV.

3.2 AIS signal power in LEO

For the ship-to-satellite link the received signal power P_r can be calculated using Friis transmission equation

$$P_r = P_t G_t G_r \left[\frac{\lambda}{4\pi d} \right]^2 \tag{3.1}$$

where P_t is the transmitted power, G_t the transmitter gain, and G_r the receiver gain. The term $[4\pi d / \lambda]^2$ is known as the path loss, where d is the path length and λ the wavelength.

The signal power calculations assume default AIS settings, which will be applied on the open oceans. The transmitter power is 12.5 W, and the channel spacing is 25 kHz. Both carrier frequencies correspond to a wavelength of 1.85 m.

The shipborne VHF transmitter antenna has an omnidirectional radiation pattern with approximately 3 dB gain horizontally. A simple cosine elevation pattern is anticipated, resulting in a drop in gain of 3 dB at 60°.

The calculations are based on a satellite receiver antenna gain of 3 dB towards the ground. Figure 3.3 shows the received power vs ground range for an orbit altitude of 600 km.

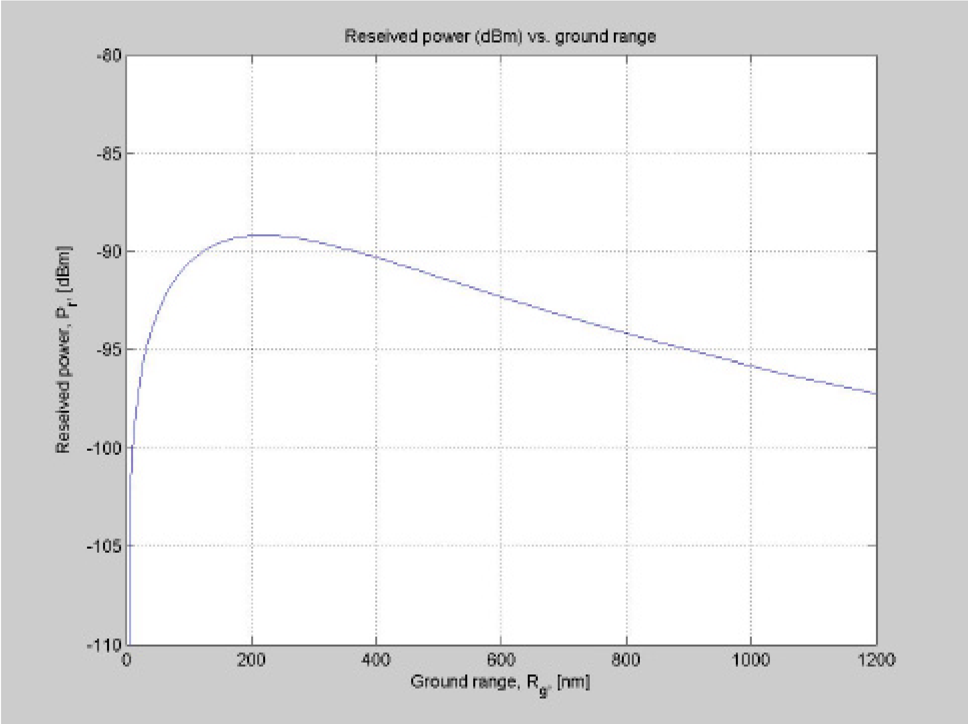


Figure 3.3 Received signal power at 600 km for 3 dB receiver antenna gain.

The received signal peaks to a value of –89 dBm at a ground range of 200 nm. The peak is a result of the angular dependency of the transmitter antenna gain and path loss being a function of distance. The signal received from a transmitter close to the horizon is -97 dBm. For closer ground ranges the received signal is stronger except for a small "hole" around nadir, caused by the null of the transmitter antenna diagram at 90°. The "hole" is, however, only 20 nm (-97 dBm level), and coverage around the "hole" ensures reception of messages from ships passing through the centre of the observation area.

For a standard AIS receiver with sensitivity of -107 dBm, the signal power is 18 dB above the receiver sensitivity at peak and 10 dB above the sensitivity close to the horizon. This indicates adequate margin for AIS message reception in LEO during default operations.

3.3 Ship detection probability from space

Statistical analyses of the ship detection probability from space have been performed (12). The analyses are based on the following assumptions:

1) The observation area is quadratic.
2) The size of each organized area is 40x40 nm.
3) The ships are evenly distributed within the observation area.
4) All ships transmit with the same reporting interval, $\Delta T = 10\ \mathrm{s}$.

The system has been modelled realistically with respect to the SOTDMA access-scheme used by the AIS-system (Section 2.2 and (5)).

The detection probability P for a given ship within the observation area can be written

$$P = 1 - \left[1 - \left(1 - \frac{N_{tot}}{75 \cdot M \cdot \Delta T} \right)^{M-1} \right]^{\frac{T_{obs}}{\Delta T}} \tag{3.2}$$

where M is the number of organized areas, N_{tot} is the total number of ships, ΔT is the reporting interval, and T_{obs} is the observation time. Equation (3.2) assumes an even ship distribution within the observation area, but analyses (12) have shown that Equation (3.2) also can be used as a good approximation for more realistic ship distributions.

Three parameters in Equation (3.2) relates directly to the swath width; M, N_{tot}, and T_{obs}. Analyses (12) have shown that the number of organized areas M within the observation area does not affect the detection probability significantly.

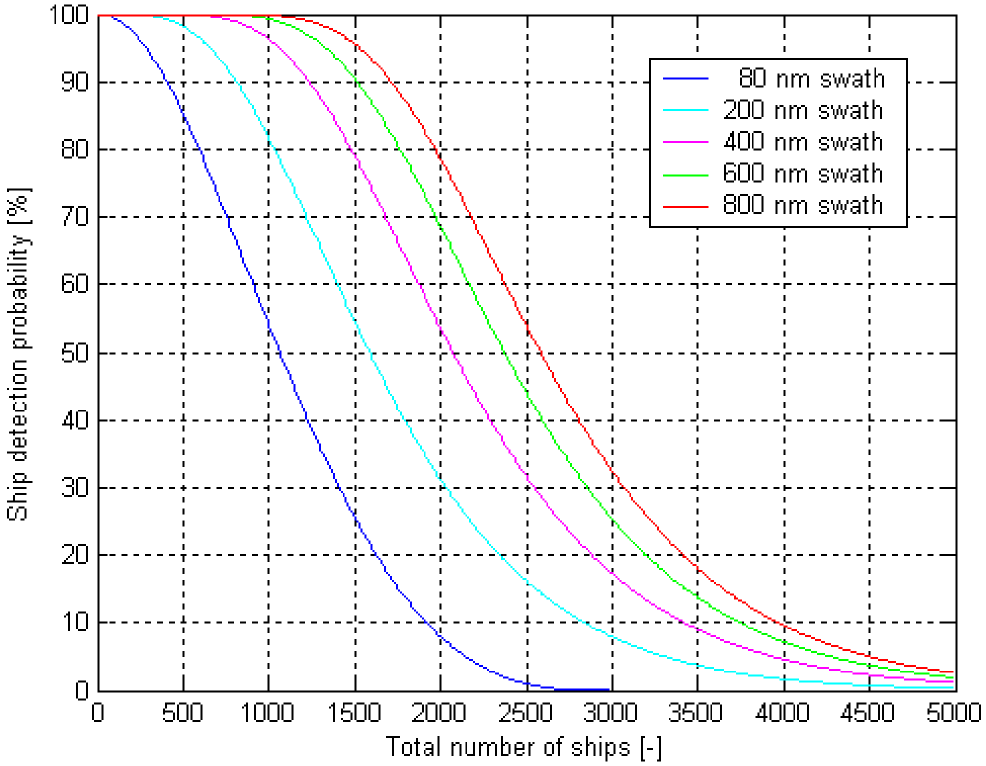


Figure 3.4 *Ship detection probability as a function of total number of ships for different swath widths. The ships are assumed to be evenly distributed within the observation area.*

Two parameters then remain that are important for the detection probability:

1) The total number of ships within the observation area, N_{tot}
2) The observation time, T_{obs}

Increasing the swath width increases the observation time[1], and thereby the detection probability for a given total number of ships. This can be seen from Figure 3.4, which shows the ship detection probability as a function of the total number of ships for swath widths of 80, 200, 400, 600, and 800 nm. However, increasing the swath width also increases the total number of ships within the observation area, thereby lowering the detection probability. Which one of these two factors that will dominate depends on the scenario, and the optimum swath width will therefore be scenario-dependent.

Two scenarios have been developed for the analyses (14). The first scenario is a typical scenario from open ocean areas where the ship density is low. The second scenario is a worst-case scenario where traffic in coastal areas has been included. The scenarios represent realistic ship distributions, and results were found through modelling and simulations of the observation system. Detection probabilities were calculated for swath widths of 120, 160, 280, 400, and 560 nm for the typical

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[1] For a quadratic observation area an increase in swath width is equivalent to an increase in the length (along track) of the observation area, which gives a longer observation time.

scenario, and for swath widths of 80, 200, 400, 600, and 800 nm for the worst-case scenario. The swath widths for the worst-case scenario correspond to the swath widths used in Figure 3.4. Results are shown in Table 3.1 and Table 3.2.

Table 3.1 shows that the typical scenario from open ocean areas is so sparsely populated that the ship detection probability is 100% for all swath widths. Table 3.2 shows that for the worst-case scenario the detection probability is still better than 99% for all swath widths between 80 and 800 nm. The maximum swath width of 800 nm is not an absolute physical limit, but the statistical analyses are not valid for swath widths larger than this.

Note that the worst-case scenario assumes high-density ship traffic only in part of the observation area. For scenarios with high ship densities over large areas the results from the analyses will be different.

Swath width (nm)	**Obs time (s)**	**Total # of ships**	**Ship density (per nm^2)**	**Detected ships (%)**
120	32	36	0.0025	100
160	43	50	0.0020	100
280	75	88	0.0011	100
400	107	138	0.0009	100
560	150	172	0.0005	100

Table 3.1 Ship detection probabilities and total number of ships for different swath widths in the typical scenario.

Swath width (nm)	**Obs time (s)**	**Total # of ships**	**Ship density (per nm^2)**	**Detected ships (%)**
80	22	122	0.019	99.8
200	54	296	0.007	99.5
400	107	700	0.004	99.5
600	161	906	0.003	99.7
800	214	1110	0.002	99.6

Table 3.2 Ship detection probabilities and total number of ships for different swath widths in the worst-case scenario.

3.4 Satellite design

A space-based AIS sensor could be accommodated on a larger satellite or be the prime sensor on a dedicated satellite platform. Some considerations on a dedicated AIS satellite are discussed in the following.

Designing a dedicated AIS satellite is not expected to be very complicated, since the requirements for attitude control and knowledge, power, data processing, and communications will be modest. The total amount of electronics should therefore be small, which leads to the assumption that a micro-satellite platform could be suitable for a space-based AIS sensor. The element of some concern is the VHF antenna for the AIS receivers, and its field of view.

3.4.1 AIS receiver antenna

From the literature it appears that one of the prime VHF antenna candidates for a space-based AIS sensor would be a helix antenna. Extensive modelling has been performed on this type of antenna by D T Emerson (11). His modelling suggests that the minimum length of a helix antenna should be about 2λ, corresponding to 3.7 m for the AIS frequencies. This will limit the FOV to 40°, which for a nadir pointing satellite at 600 km altitude will give a swath width of approximately 250 nm. The antenna diameter would be 70 cm, the gain would be 12.5 dB, and the side lobe level would be 8 dB lower.

This AIS antenna is rather big, and would have to be deployable. Also, for the antenna to function properly the satellite would have to deploy a ground plane with a diameter of approximately 1 m. Deploying both the antenna and the ground plane is a challenge, but should be possible. The antenna can be made very light, and could even be inflatable.

3.4.2 AIS receivers

For the space-based AIS sensor to receive AIS messages world wide, three VHF receivers for the maritime mobile bands AIS1, AIS2 and DSC are required. Calculations show that the sensitivity of standard mobile AIS station receivers is adequate also in space (Section 3.2). A data processing unit would be needed for receiver management and for extraction and storage of the AIS message information. The size of the mobile AIS station receivers available on the market suggests that the total volume and weight of the space-based AIS sensor electronics would amount to approximately 2 litres and 3 kg, which is rather small even for a micro-satellite.

3.4.3 Satellite composition

There is a large number of micro-satellites already orbiting the Earth, carrying satellite subsystems similar to or better than what would be required for an AIS satellite. Figure 3.5 shows the subsystems required for a dedicated AIS micro-satellite. The gravity gradient boom will keep the AIS antenna nadir pointing, while minimising the attitude control power requirements.

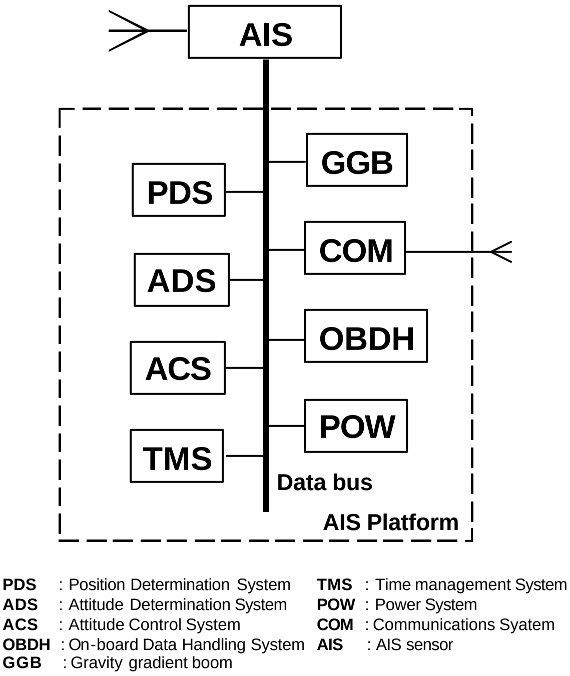

Figure 3.5 The micro-satellite platform subsystems required for a dedicated AIS satellite.

3.4.4 Satellite subsystems

The performance requirements given in Table 3.3 should be adequate for an AIS application. The background for these requirements is:

- *PDS:* There are no specific position requirements beyond the orbit knowledge required by the ground station to find the satellite. The 2-line elements from NORAD should be adequate.
- *ACS:* The requirements are defined by the acceptable displacement of the observation area caused by off nadir pointing of the AIS antenna. For an antenna beam width of 40° a displacement of up to 5° seems acceptable. This would extend the observation area by 5.4 nm. The attitude control system should also keep the satellite spinning to achieve good thermal balance.
- *ADS:* The requirement should be a factor of 10 better than the control requirement. A determination accuracy of 0.5° would be adequate.
- *TMS:* The AIS sensor should be able to timestamp the reception of messages. As the messages are 26.67 ms long, a timing accuracy of 1 ms should be adequate for this purpose.
- *POW:* Requirements will have to be defined later.

- *OBDH:* The maximum volume of relevant message information that can be generated by the AIS over one full orbit (5760 s) is 7 Mbyte. However, the large ocean areas and polar regions with low ship density will bring this volume down to about 5 Mbyte, which must be stored on-board. For a regional observation time of 1000 s the data volume is further reduced to 1 Mbyte. Other requirements will have to be defined later.
- *COM Tx:* The telemetry requirements will depend on the observation time per orbit. For an average ground contact time of 450 s per orbit the maximum telemetry bit rate defined by the 5 Mbyte data volume is about 90 kbit/s. For a regional observation time of 1000 s the bit rate requirement is reduced to about 16 kbit/s. Satellite housekeeping data must be added to these numbers.
- *COM Rx:* No intensive commanding of the satellite is expected. A standard 2 kbit/s command-link would therefore be adequate.

Subsystem	**Requirements**	**Remarks**
PDS	None	- Can use active ranging or the 2 line elements from NORAD
ACS	5° in X & Y-axes TBD° in Z-axis	- Keeps the AIS antenna nadir pointing - Compensates for drag and solar pressure - Controls the spin rate of the satellite
ADS	0.5° in X & Y-axes TBD° in Z-axis	- Determines the AIS antenna pointing
TMS	1 ms	- UTC clock is updated from ground
POW	TBD W	TBD
OBDH	TBD MIPS	TBD
COM Tx	< 100 kbit/s	- Depends on observation length - Includes satellite housekeeping
COM Rx	2 kbit/s	

Table 3.3 AIS satellite subsystem requirements.

3.4.5 Satellite platform

A satellite shape that looks favourable to a nadir pointing AIS satellite is shown in Figure 3.6. If this satellite is launched into a 600 km dusk/dawn orbit it will produce electrical energy during the whole orbit, except for a short eclipse period during some weeks every year. All electronics would be mounted inside the satellite structure, and a rotation of the satellite around the Z-axis will assure good thermal stability. Solar panels will cover the satellite body and produce the required electrical energy. The ground plane elements will be folded towards the centreline and keep the deployable AIS antenna contained during launch. The overall dimensions would be in the order of 75x75x50 cm^3, and the weight would probably be less than 50 kg. The launch configuration of this AIS satellite is shown in Figure 3.7.

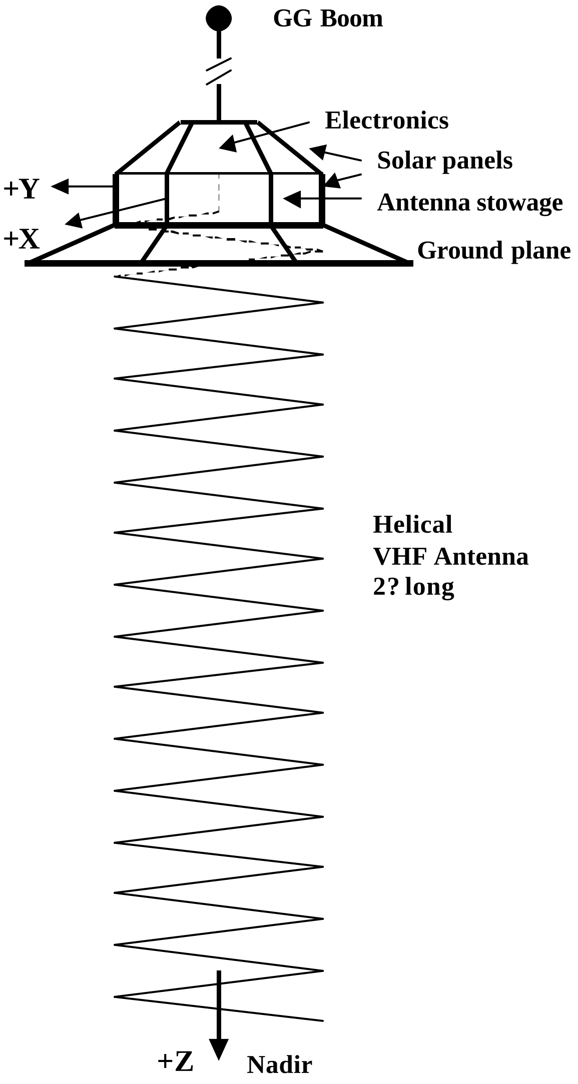

Figure 3.6 A possible AIS satellite design with the AIS antenna and its ground plane deployed.

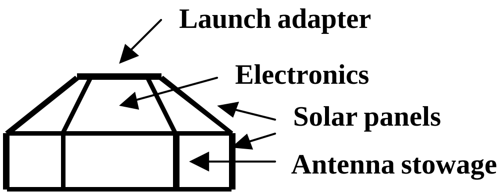

Figure 3.7 The AIS satellite in launch configuration.

4 DISCUSSION

This report has studied the feasibility of space-based AIS reception for ship identification. The following elements have been evaluated:

1) AIS signal power at LEO
2) Ship detection probability from space
3) AIS sensor/satellite design

Results of the analyses will be discussed in the following, and some considerations will be made regarding swath width.

The analyses have assumed an AIS sensor at 600 km altitude. From this altitude the distance on the ground from horizon to horizon is 2880 nm, corresponding to a maximum possible FOV of 132º. The sensor FOV should be as large as possible to obtain the best possible coverage, but as discussed below the elements listed above may put some constraints to what the practical FOV would be.

Calculations of the AIS signal power at LEO (Section 3.2) have shown that the AIS-messages can be received in space with a standard AIS receiver. For a standard AIS receiver at 600 km altitude, the power margin is 10 dB when receiving AIS signals from a transmitter close to the horizon. For closer distances the power margin is even better. As a result, the AIS signal power in LEO puts no constraints on the swath width.

Statistical analyses (Section 3.3) have shown that the ship detection probability for a worst-case scenario is better than 99% for swath widths up to 800 nm. Larger swath widths could be considered, but this would require new analyses of the ship detection probability that would have to include the second mechanism for coinciding transmissions (Section 3.1.2). Present analyses of the ship detection probability limit the swath width to 800 nm.

Finally, a possible AIS antenna design was considered in Section 3.4. The suggested helix antenna has a maximum FOV of 40º, corresponding to a swath width of about 250 nm for a nadir-pointing antenna at 600 km altitude. Lifting the antenna to an altitude of 1000 km would increase the swath width to about 400 nm. It might also be possible to find a better antenna that could give a larger swath width.

The conclusion from this feasibility study is that space-based AIS reception for ship identification seems feasible, with ship detection probabilities better than 99% for swath widths up to 800 nm. The AIS sensor antenna might, however, be the element that eventually limits the FOV.

5 SUMMARY

In this document we have presented the results of a feasibility study on space-based AIS reception for ship identification and positioning. The AIS reporting system has been described, and it has been demonstrated that a space-based AIS sensor will receive the AIS messages with an acceptable signal margin of 10-20 dB. Ship density scenarios have been developed based on real data, and subsequent statistical modelling has shown that the ship detection probability will be better than 99% for a sensor swath width of 800 nm or less. The volume of information relevant to ship identification and positioning per orbit (5760 sec) has been calculated to 7 Mbyte. It has been demonstrated that a 100 kbit/s telemetry link to ground will allow this information to be returned to a single ground station during an average ground contact time of 450 sec. Finally, a concept for a dedicated AIS micro-satellite has been suggested. The satellite subsystem requirements are demonstrated to be quite moderate, and subsystems of this type are already available on the market.

The conclusion is that space-based AIS reception for ship identification seems feasible, and that a dedicated AIS micro-satellite could be designed and carried aloft as a secondary payload. The overall cost for such an AIS satellite is expected to be moderate.

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List of Acronyms

ACS	Attitude Control System
ADS	Attitude Determination System
AIS	Universal Shipborne Automatic Identification System
COM	Communication system
DSC	Digital Selective Calling
FFI	Norwegian Defence Research Establishment
FOV	Field of view
GGB	Gravity Gradient Boom
GMSK	Gaussian Minimum Shift Keying
IAA	International Academy of Astronautics
IALA	International Association of Lighthouse Authorities
IEC	International Electro Technical Commission
IMO	International Maritime Organisation
ITDMA	Incremental Time Division Multiple Access
ITU	International Telecommunications Union
JP	Joint Program
LEO	Low Earth Orbit
MIPS	Million Instructions Per Second
MMSI	Maritime Mobile Service Identities
MSC	Maritime Safety Committee
NORAD	North American Strategic Defence Command
NTNU	Norwegian University of Science and Technology
OBDH	On Board Data Handling
PDS	Position Determination System
POW	Power system
RATDMA	Random Access Time Division Multiple Access
RR	Radio Regulations
SOLAS	Safety of Life at Sea
SOTDMA	Self-Organizing Time Division Multiple Access
TBD	To be determined
TDMA	Time Division Multiple Access
TMS	Time Management System
UTC	Universal Time Coordinated
VHF	Very High Frequency
WEAG	Western European Armament Group