FM Discriminator for AIS Satellite Detection

Maria Angeles Jurado Gallardo[1,2] and Ghislain Ruy[1]

[1] LuxSpace, Chateau de Betzdorf, Building B, L-6815 Betzdorf, Luxembourg
[2] University of Luxembourg, 6 rue Coudenhove-Kalergi, L-1359 Luxembourg
marian.jurado@uni.lu, ruy@luxspace.lu

Abstract. The Automatic Identification System (AIS) is a tracking system used on ships for several decades to improve traffic monitoring and safety at sea in a short range. The modulation technique used is Gaussian Minimum Shift Keying (GMSK).

Recently, the idea of receiving AIS signals from space arose. This presents mainly two challenges. The first one is that received signals present a large Doppler range due to the satellite speed. The second one is the simultaneous reception of signals from ships because of the broad satellite coverage.

In this paper, a novel non-coherent GMSK demodulator is proposed to handle the large Doppler shift problem based on several FM discriminators in parallel. A frame collision detection algorithm is presented but the collision problem is not addressed.

In addition, computer simulated and real signals are used to study the receiver performance on an AWGN channel.

Keywords: AIS, GMSK, FM discriminator, Doppler.

1 Introduction

AIS stands for Automatic Identification System and is a telecommunication system defined for navigation safety purposes. It is required by the International Convention for the Safety of Life at Sea (SOLAS) convention and defined by the International Telecommunication Union (ITU) in Rec. ITU-R 1371-1 [1].

Ships exchange information such as position, speed, course and identification number every few seconds. The main objective is to avoid collisions among ships and also to localize certain vessels, for example, in search and rescue operations or ship carrying out illegal trade. In order to accommodate all vessel transmissions, a time multiplexing scheme is used.

This is of interest in areas close to the shore or between ships at open sea. However, the coverage range of AIS is not very large. It depends on the height of the antenna but nominally is around 20 nautical miles (nm) or 37 km. The position of vessels out of this range from the shore is unknown and it can only be received by ships nearby.

K. Sithamparanathan et al. (Eds.): PSATS 2010, LNICST 43, pp. 19–34, 2010.

The solution is to develop a space based system to receive AIS signals sent from these extensive maritime zones. This idea consists of implementing a constellation of Low Earth Orbit (LEO) satellites that detect and decode AIS messages and send them to the earth stations for database storing and further processing. Considering AIS signals with 12.5 W power transmission and an satellite altitude no longer than 1000 km for LEO orbits, reception of AIS signals from a spaceborne platform is feasible.

The main drawback of satellite detection is the Doppler range expected at reception. If a satellite speed of 7 km/s is considered, the Doppler range is approximately ±3.8 kHz. This maximum shift corresponds to approximately 40 % of the bit rate. Usually, frequency estimation methods handle shifts of 15 % of the bit rate like, for example, in [2]. In the effort to design a robust and efficient spaceborne AIS receiver that handles this Doppler range, we present a novel algorithm based on an FM discriminator.

Another important issue is that the coverage for an AIS sensor in space would be a much larger area on the ground than the system was originally designed for. As a consequence, collisions among signals from ships separated by a large distance will occur. More information about this is provided in the next section.

The structure of this paper is organized as follows. Section 2 presents the scenario for AIS satellite detection. The relevant technical aspects of AIS are introduced in Section 3 followed by the description of the signal model in Section 4. A novel algorithm for demodulating Gaussian Minimum Shift Keying (GMSK) signals with high Doppler range is derived in Section 5. Results for simulated and real AIS signals are contained in Section 6, as well as the Bit Error Rate (BER) performance of the system. Sections 7 and 8 finish with conclusions and possible future developments.

2 Scenario

This research work is part of a larger AIS project. The aim of this project is to improve the global maritime surveillance through the implementation of AIS message satellite detection using a constellation of LEO satellites. AIS signals are received and decoded. The resulting information is relayed via satellite feeder links to appropriately located ground stations, as shown in Fig. 1.

An initial demonstration system will consist of a single LEO satellite. For later operational systems, it is envisioned that a relatively small constellation of LEO satellites would be used; consequently satellite coverage of a given ship location will not be continuous.

As the satellite antenna beam covers a large geographical area, transmissions by multiple AIS ship transmitters are received simultaneously. With many ships in the Field Of View (FOV), interference problems will occur and AIS messages from some of the ships may not be detected. An example of this is described in [3] and is presented hereunder. Fig. 2 depicts the coverage area in North Sea for several AIS cells (small circles) and for an airplane at 12 km altitude (large circle). The observation area corresponding to the aircraft altitude is around 440 nm of

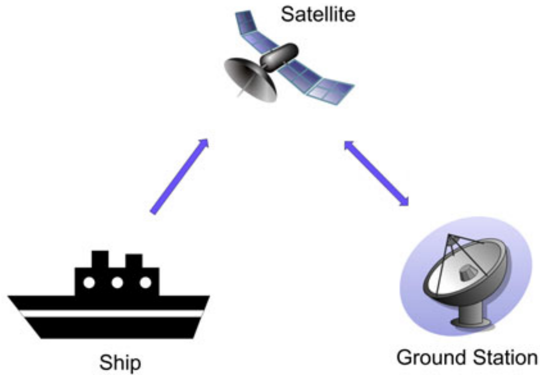

Fig. 1. Satellite Detection of AIS

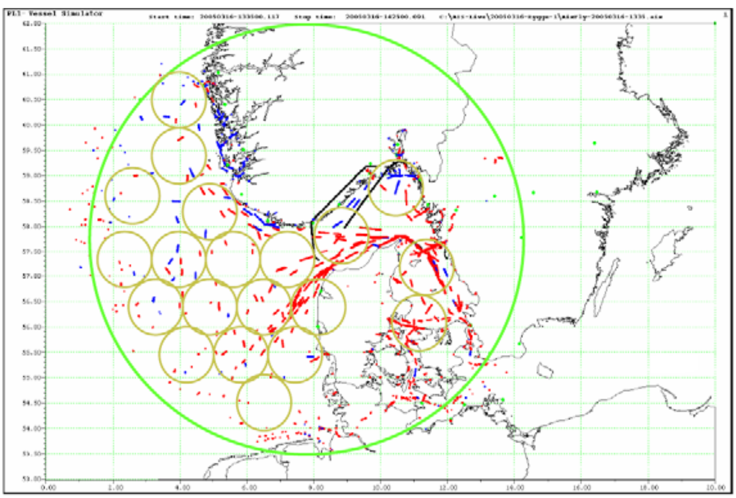

Fig. 2. Ship Distribution in North Sea [3]

diameter. In this range, multiple AIS cells become visible. As a consequence, simultaneous arrival of frames can produce collisions. For a LEO satellite, the coverage area is 2880 nm of diameter, including Europe and a wide sea area. Thus, the number of cells visible for the satellite is larger, increasing the probability of signal collision.

According to the study presented in [4], a satellite constellation with continuous coverage could handle up to 1300 ships with a ship information update rate of once per hour with a ship detection probability of better than 99 %. This shows that spaceborne AIS message reception is possible but not by a standard AIS receiver.

3 AIS Technical Description

In this section, a brief technical description of AIS is presented. Further information about the characteristics of AIS transmission can be found in [1].

The AIS system operates in the Very High Frequency (VHF) maritime mobile band. Two parallel channels have been allocated: *AIS 1* at 161.975 MHz and *AIS 2* at 162.025 MHz. Transmissions can use one of the two defined settings: *high* with 25 kHz bandwidth (most frequently utilized) and *low* with 12.5 kHz bandwidth. The modulation scheme specified for AIS is GMSK with maximum Bandwidth-Time product (BT) equals 0.4 for high setting mode and with data rate 9600 bps [1].

AIS works autonomously, automatically, continuously and operates primarily in broadcast mode using Time Division Multiple Access (TDMA) schemes. The access schemes to accommodate all users are Self Organized TDMA (SOTDMA), Random Access TDMA (RATDMA) and Fixed Access TDMA (FATDMA). Each channel AIS is divided into frames of one minute duration. Frames are synchronized with the Coordinated Universal Time (UTC) time standard and each one contains 2250 Time Slots (TS), thereby providing 4500 TS per minute considering both channels. The duration of a TS is: $60/2250 = 26.7$ ms or: $9600 \times 60/2250 = 256$ bits.

There are 22 AIS message types defined with different purposes. Their occupancy ranges from one to five TS depending of the type. The type relevant for us is the *position report* kind, used by ships to provide identification and navigational data. Its structure is shown in Fig. 3.

Fig. 3. Structure of the AIS Position Report Message

The transmission starts with an 8-bit ramp up followed by a 24-bit training sequence, consisting of alternating zeros and ones. Then a start flag, which is a standard High-level Data Link Control (HDLC) to identify the beginning of the frame. This is followed by the data, which has 168 bits length for position report messages type, and a Frame Check Sequence (FCS), that uses the Cyclic Redundancy Check (CRC) 16-bit polynomial to calculate the checksum. The end flag marks the end of the frame and is identical to the start flag. Finally, there is a 24-bit buffer to compensate bit stuffing, distance delays, repeater delay and jitter synchronization.

Each parameter field is defined with the most significant bit first. The total length is 256 bits, which corresponds to the length of one TS. The message duration is an important parameter because frequency and/or phase recovery algorithms for coherent demodulation usually require longer bit sequences, as in [5] for example, where around 1000 bits are required for the estimation.

Messages are Non-Return to Zero Inverted (NRZI) encoded before being output on the VHF data link.

4 Signal Model

The model of the transmitted AIS signal is presented in this section.

GMSK is a kind of Minimum Shift Keying (MSK) modulation with a Gaussian pulse shaping filter of an appropriate bandwidth defined by BT. The BT value is the product of B, the premodulation Gaussian filter bandwidth, and T the bit period, which is the inverse of the bit rate. Like MSK, the modulation index of GMSK is 0.5.

The advantage of using the Gaussian filter is that the generated signal has low side lobes, narrower main lobe than in MSK and smoother phase transitions. Another important property of MSK signals is that they have constant envelope making the modulation scheme more immune to noise and amplitude variations.

According to [6], two methods can be used to generate a modulated GMSK signal: a Gaussian filter followed by an FM modulator or a Gaussian filter and Quadrature Phase Shift Keying (QPSK) modulation.

The time domain impulse response of the Gaussian Low Pass Filter (GLPF) is given by [7]:

$$h(t) = \sqrt{\frac{2\pi}{\ln 2}} \mathrm{B} \exp\left(-\frac{2\pi^2}{\ln 2}\mathrm{B}^2 t^2\right) . \tag{1}$$

The impulse response has to be truncated and scaled depending on the BT value to ensure that the response of the filter to a single bit produces a phase change of $\pm\pi/2$. For BT $= 0.4$, the filter length is three symbol periods. The impulse response has to be also time shifted in order to have a causal signal.

When a rectangular pulse centred in the origin with unit amplitude and T duration passes through this filter, the response is:

$$g(t) = \frac{1}{2\mathrm{T}}\left[Q\left(2\pi \mathrm{B}\frac{t - \mathrm{T}/2}{\sqrt{\ln 2}}\right) - Q\left(2\pi \mathrm{B}\frac{t + \mathrm{T}/2}{\sqrt{\ln 2}}\right)\right] , \tag{2}$$

where $Q(t)$ is the Q-function:

$$Q(t) = \int_t \frac{1}{\sqrt{2}} \exp\left(-x^2/2\right) dx . \tag{3}$$

Therefore, the signal obtained after the Gaussian filter is:

$$x(t) = \sum_i s_i g(t - iT) , \tag{4}$$

being s_i the symbols to transmit.

The drawback of using GMSK is that since GMSK has a narrower main lobe than MSK, pulses spread over a longer time causing Intersymbol Interference (ISI). The presence of ISI makes the demodulation at the receiver more complex.

Either if the FM modulator or the quadrature modulator is used, the GMSK modulated signal is given by:

$$z(t) = \mathrm{A}\cos(2\pi f_c t + \theta(t) + \theta_0)\ , \tag{5}$$

with A constant amplitude, f_c carrier or modulation frequency and θ_0 the initial phase at $t = 0$. $\theta(t)$ is related to the message information by:

$$\theta(t) = 2\pi \mathrm{k_f} \int_{-\infty}^{t} x(\tau) d\tau\ , \tag{6}$$

where $\mathrm{k_f}$ is the frequency deviation in volts per hertz.

5 GMSK Demodulator

Three different techniques can be used for GMSK demodulation ([8]): coherent detection, differential detection and FM discriminator. The last two are non-coherent detection and are usually utilized to demodulate FM. The coherent detection method is similar to the one used for MSK demodulation. In this paper, we chose to utilize a non-coherent scheme. The reason behind is that coherent demodulation requires accurate frequency, phase and clock recovery and, as mentioned above, the maximum Doppler shift is out of the range of the frequency recovery algorithms studied.

The differential detection and the FM discriminator are compared in [9] drawing the conclusion that the BER performance of the FM discriminator is better. This is due to the fact that the differential detection utilizes the phase and the amplitude of the signal and the FM discriminator uses only the phase. As a result, the FM discriminator is not affected by the amplitude noise. This problem, could be overcome with a limiter but in any case, the results of our tests conclude also that the FM discriminator has better BER performance and thus it is the best option. The block diagram of the discriminator is based on [10] and described in the following.

5.1 Description

The spaceborne AIS receiver developed consists of several branches in parallel with an FM discriminator in each branch. Every discriminator is centred at a different frequency to cope with the large Doppler range of the received signals. This idea comes from the bank of filters used in radar to treat different frequencies.

The block diagram of each FM discriminator is shown in Fig. 4. It is composed of the following elements: an I & Q demodulator, a phase derivator and a GLPF. Basically, the discriminator maps the frequency of the I & Q components to a voltage using a differential estimation algorithm.

Considering an AWGN channel with noise $n(t')$, $r(t')$ is defined by:

$$r(t') = \mathrm{A}\cos(2\pi(f_c + f_d)t' + \theta(t') + \theta_0) + n(t')\ , \tag{7}$$

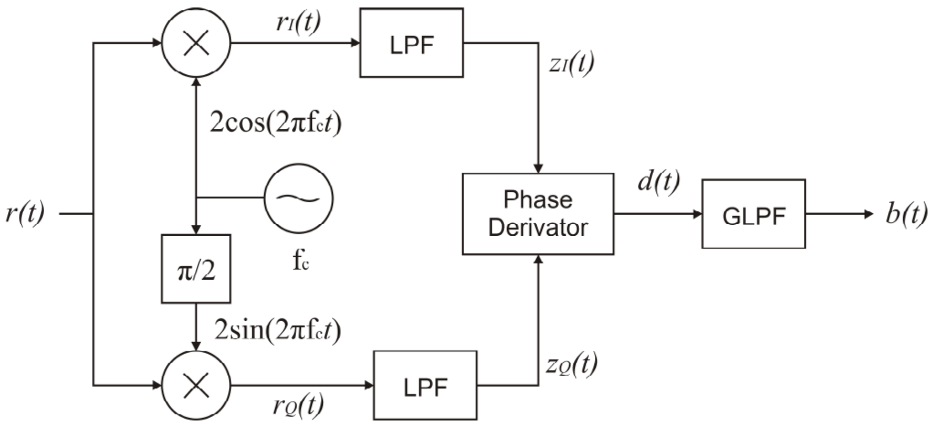

Fig. 4. FM Discriminator Block Diagram

being f_d the Doppler frequency shift and $t' = t + \varepsilon$. ε is the time needed by the signal to travel from the ship to the satellite. It needs to be estimated. From now on, and for the sake of simplicity, we consider $\theta_0 = 0$. We assume also, and only for the following mathematical description, that $\varepsilon = 0$ $(t' = t)$. The estimation of ε is explained afterwards.

The input passband signal $r(t)$, centred at an Intermediate Frequency (IF) is filtered by a reception filter with a wide enough bandwidth to consider the Doppler range. The filtered signal is input to the bank of branches and in each one is multiplied by a Local Oscillator (LO) centred at a different frequency, generating the I and Q signals in baseband. For the branch in the middle, the LO frequency is $\mathrm{f_c}$. The following mathematical development is for the middle branch. The same procedure can be applied for the other branches. Noise is not considered for simplicity.

$$\begin{aligned} r_I(t) &= r(t)2\cos(2\pi \mathrm{f_c} t) = 2\mathrm{A}\cos(2\pi(\mathrm{f_c} + f_d)t + \theta(t))\cos(2\pi \mathrm{f_c} t) \\ &= \mathrm{A}\left[\cos(2\pi f_d t + \theta(t)) + \cos(2\pi(2\mathrm{f_c} + f_d)t + \theta(t))\right] \\ r_Q(t) &= r(t)2\sin(2\pi \mathrm{f_c} t) = 2\mathrm{A}\cos(2\pi \mathrm{f_c} t + \theta(t))\sin(2\pi \mathrm{f_c} t) \\ &= \mathrm{A}\left[\sin(2\pi f_d t + \theta(t)) + \sin(2\pi(2\mathrm{f_c} + f_d)t + \theta(t))\right] . \end{aligned} \tag{8}$$

After that, the I and Q signals pass through a LPF to eliminate the $2f_c$ component generated by the mixer:

$$\begin{aligned} z_I(t) &= \mathrm{A}\cos(2\pi f_d t + \theta(t)) \\ z_Q(t) &= \mathrm{A}\sin(2\pi f_d t + \theta(t)) . \end{aligned} \tag{9}$$

First, the phase derivator obtains the phase of the baseband signal by computing the arctangent of $z_I(t)$ and $z_Q(t)$.

$$y(t) = \arctan(\frac{z_Q(t)}{z_I(t)}) = \arctan\left(\frac{\mathrm{A}\sin(2\pi f_d t + \theta(t))}{\mathrm{A}\cos(2\pi f_d t + \theta(t))}\right) = 2\pi f_d t + \theta(t) . \tag{10}$$

And as a second step, it performs the derivation of the arctangent respect to time. Taking into account Eq. 6:

$$d(t) = \frac{dy(t)}{dt} = 2\pi f_d + \mathrm{C}x(t) \text{ , where C is a constant .} \quad (11)$$

Finally, a GLPF eliminates the out of band noise facilitating the hard decision. The result is the demodulated signal $b(t)$.

The advantage of this demodulator is that is simple, not need of carrier or initial phase recovery, leading also to a very simple implementation in a Field Programmable Gate Array (FPGA). The demodulated signal at the output has constant amplitude independently of the signal level at the input.

Nevertheless, there are also disadvantages: the noise is amplified when no signal is received and there is a Direct Current (DC) offset when the received signal presents Doppler, as shown in Eq. 11. This is the reason why the discriminators are in parallel, as mentioned above.

However, an advantage can be gained from the DC offset because its value is proportional to the Doppler shift. Hence, Doppler is calculated and compensated, the signal is centred around zero and the symbol decision is correctly taken. To estimate the DC shift, a mean filter is used taking advantage from the fact that the training sequence consists of alternating zeros and ones. Consequently, the frame DC is obtained by calculating the mean value of this segment.

Now we consider the case that $\varepsilon \neq 0$. AIS signals are UTC synchronized but the exact moment of reception at the satellite is not known. For detecting the presence of a frame and also recovering the synchronization, the following technique is used.

At the same time that the signal is being demodulated, a correlation is performed to compare the demodulated signal at the output of the FM discriminator with the waveform of the training sequence and the start flag (32 bits in total) which are called preamble in the following. In this manner, when the preamble is contained in the demodulated signal, the correlation function has a peak marking the beginning of the frame and, hence, the beginning and end of a symbol. That is how ε is estimated. The peak can be a maximum or a minimum depending on the initial state of the NRZI encoding (1 or -1). The advantage of this technique is that is amplitude independent because, as mentioned above, the demodulated signals have the same output amplitude.

The correlation has to be performed in every branch of the demodulator. The reason is that when the training sequence is being demodulated, the frequency has not been compensated yet and the demodulated signal has a DC component, as it is shown in Section 6. Therefore, there are as many correlators as FM discriminators. Fig. 5 depicts the parallel structure that detects the peak correlation to estimate ε. If a frame is detected, the Doppler shift is estimated from the middle demodulated signal. $\lfloor\,\rfloor$ represents the rounding to the nearest integer smaller than the element.

Once the demodulation is done and the synchronization is recovered, the detection starts, working with the middle branch of the demodulator. The other branches are only utilized for detection of the correlation peaks. By using an

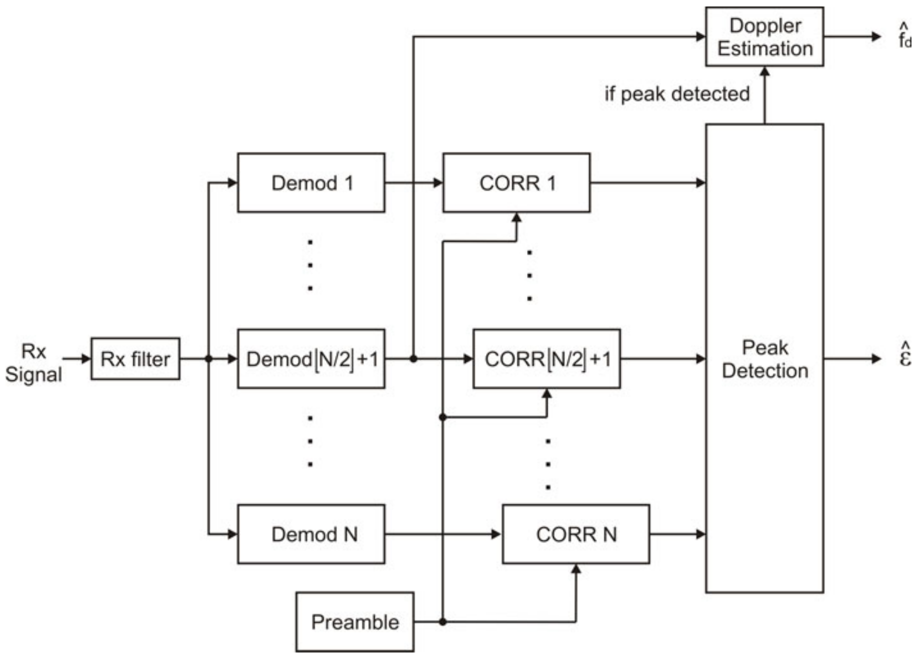

Fig. 5. Demodulator Block Diagram

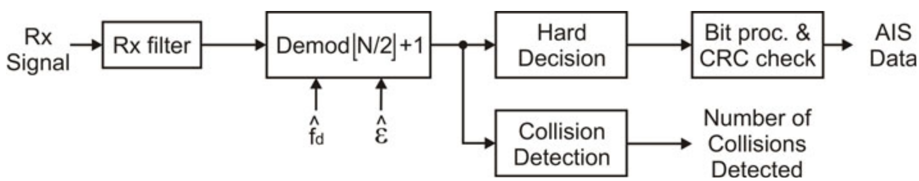

Fig. 6. Signal Detection and Further Processing

Integrate & Dump filter, the receiver integrates the signal over one symbol to take the decision. The process continues until the end of the frame (identified by the end flag). The CRC is checked and if the message is correct, further processing is done to obtain human read information. This is shown in Fig. 6.

Complexity is not added due to the parallel structure because the intention of the AIS project, is to implement the design in an FPGA, which allows the implementation of parallel configurations. Consequently, the receiver can perform in real time.

5.2 Collision Detection

A fairly high collision rate is expected over dense traffic zones. Therefore, every attempt must be made to retrieve the maximum information from the signals.

Based on the fact that GMSK signals have constant amplitude, if the received signal presents a change in the amplitude, it is likely that a collision between two or more frames has occurred. Therefore, the amplitude of the received signal is obtained by using the I and Q components defined in Eq. 9. Hence: $(z_I(t)^2 + z_Q(t)^2) = A^2$.

Then, to detect the amplitude variation, the variance of the amplitude is calculated, providing a method to detect the presence of collisions. This is a first attempt to estimate the collision rate. However, the focus of this research is on the large Doppler range rather than in the collision problem.

6 Results

In this section, the performance of the proposed demodulator is evaluated, firstly with computer simulated signals and then with real AIS signals recorded through an aircraft. Finally, the receiver BER performance is displayed and compared with theoretical results.

A compromise has to be found for the number of branches in the demodulator. The more branches, the smaller the frequency interval between LO frequencies and hence, the narrower the bandwidth of the LPFs from Fig. 3. As a consequence, there is less noise passing through the filter, making the detection easier. The drawback is that the complexity of the demodulator increases: several FM discriminators and correlation calculations running in parallel. For this case, five branches have been chosen.

The signals used (simulated and real) are passband centred at 12 kHz as IF. This frequency is high enough because, as BT = 0.4 and T = 1/9600, the GMSK signal bandwidth is B = 3840 Hz. The sampling rate is 96 ksps, therefore, there are 10 samples per symbol. The demodulator is implemented in ANSI C.

From the five branches, the middle one (number 3) has a LO centred at 12 kHz. Branches 1 and 2 have higher LO frequencies and branches 4 and 5 have lower LO frequencies.

6.1 Computer Simulated AIS Signals

Synthesized signals have been created to determine the performance of the demodulator. To simplify, an AWGN channel has been considered, though in reality some interference may disturb the communication.

The test consists of three AIS frames with different amplitudes and Doppler frequency shifts. They are synchronized in consecutive TS. The beginning of each TS is marked in the figures corresponding to this validation with synthesized signals. In the following, the amplitude and correlation values displayed in the figures are normalized to one.

Fig. 7 displays the demodulated baseband signals. The training sequences of the frames have a DC shift (indicated with a circle) because the mean value of the training sequence has still not been calculated. After the frequency compensation, the signal is centred around the axis, which is required for the bit

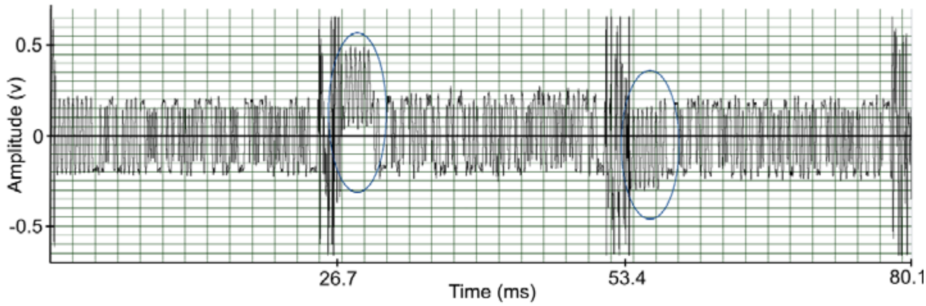

Fig. 7. Doppler Correction

decision. Since the first frame has a very small Doppler shift, 14 Hz, the demodulated signal is centred around the axis. The second one has a positive Doppler, 3547 Hz, being the training sequence above the zero axis. The training sequence of the last frame is below the axis because its Doppler is -1018 Hz.

In Fig. 7, one of the advantages of the receiver is appreciated: the demodulated signals have all the same amplitude. However, a disadvantage is also visible: the white Gaussian noise between the frames is amplified.

For detection, the synchronization needs to be recovered to identify the symbol start and end. To this aim, the correlation over the preamble is performed, as mentioned previously, for the different branches. Fig. 8 presents the parallel correlations for the three signals.

The correlation peak involved in the synchronization for the first frame corresponds to branch 3 because the first signal has a very small Doppler shift. The second one, has the peak at branch 1 (for large positive Doppler shift) and the third frame has two peaks: in branch 3 and 4, being the peak in branch 4 the minimum and the one involved in the synchronization recovery.

Fig. 9 illustrates the synchronization process. The upper part of the figure depicts the training sequence, start flag and the beginning of the first AIS frame from Fig. 7. The lower part corresponds to the correlation function. As can be seen, the correlation peak, a minimum in this case, corresponds to the end of the preamble, thus being possible to determine the bit beginning.

6.2 Real AIS Signals

For the test with real messages, the signals recorded from an aircraft have been used. The purpose of the flight was to record AIS signals sent from ships in similar conditions as with satellite reception. The altitude of the aircraft is 4500 m. As the speed of the airplane is much slower than the satellite speed, the expected Doppler range for these signals is small, around ±200 Hz and the frequency compensation is not needed. For LEO satellites, the expected Doppler range is ±3.8 kHz. For this reason, the presented AIS receiver is needed. The demodulated signals are depicted in Fig. 10.

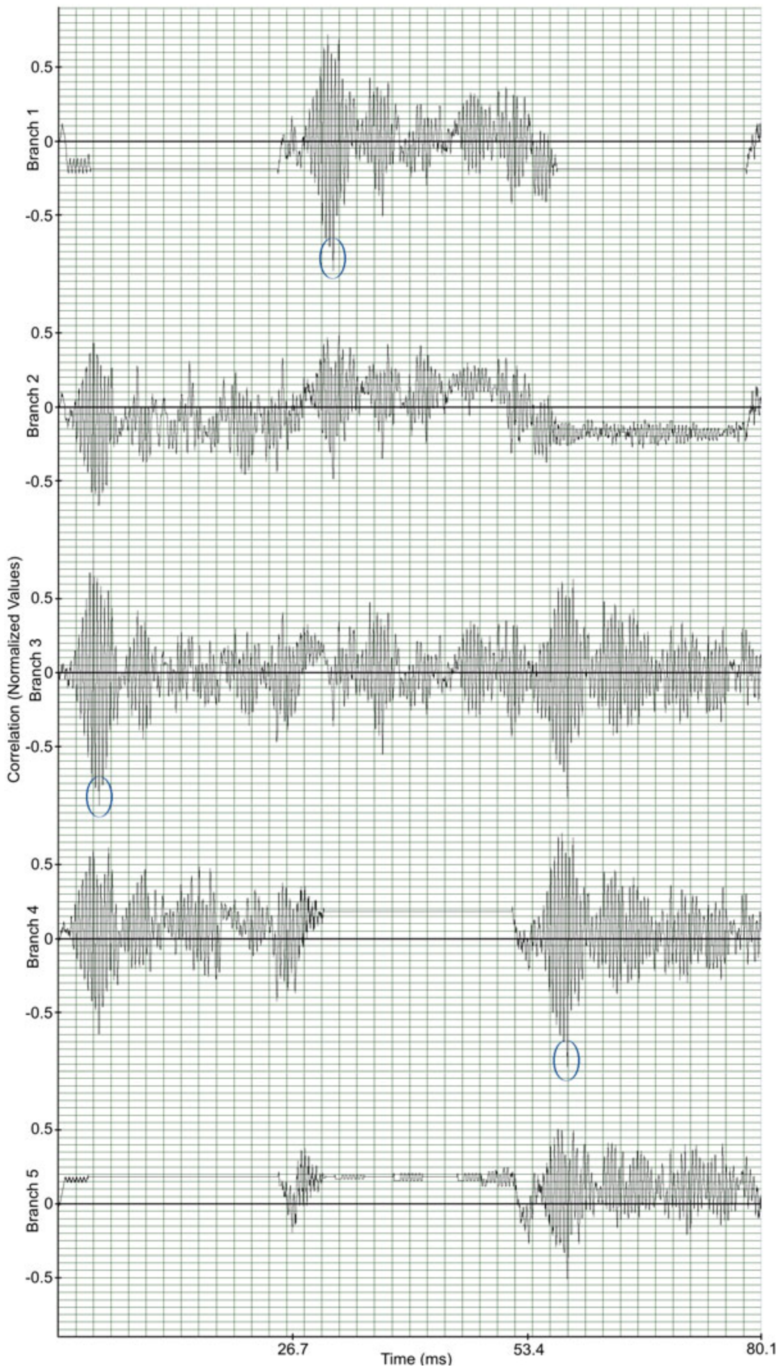

Fig. 8. Correlation Functions for Synchronization

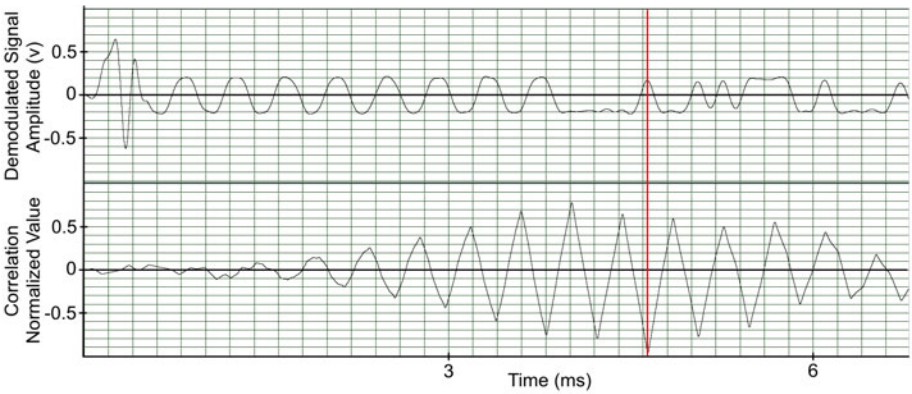

Fig. 9. Synchronization Through Correlation Function

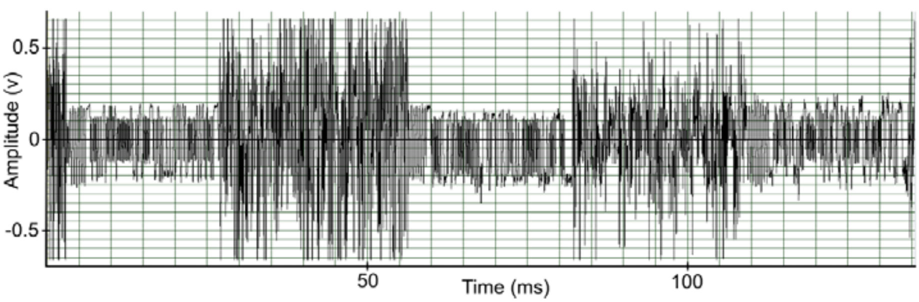

Fig. 10. Demodulated Real AIS Signals

The correlation peaks corresponding to branch 3 are displayed in Fig. 11. As mentioned above, peaks can be maximum or minimum. For the first two frames the peak is a maximum and for the last one is a minimum.

6.3 Receiver BER Performance

Finally, the BER performance of the GMSK receiver is shown in Fig. 12.

The line with round points is our receiver BER performance. It is compared to the theoretical BER curve achieved by a non-coherent MSK receiver (line with square points). For GMSK, the theoretical curve is slightly shifted to the right due to ISI. As can be seen, the curve of the receiver is, in average, 4 dB from the theoretical curve achieved by a non-coherent GMSK receiver with $BT = 0.4$.

In the received real signals, it has been observed that some signals have a very low Signal-to-Noise Ratio (S/N). For that reason, further improvements have to be done to make the BER performance closer to theory.

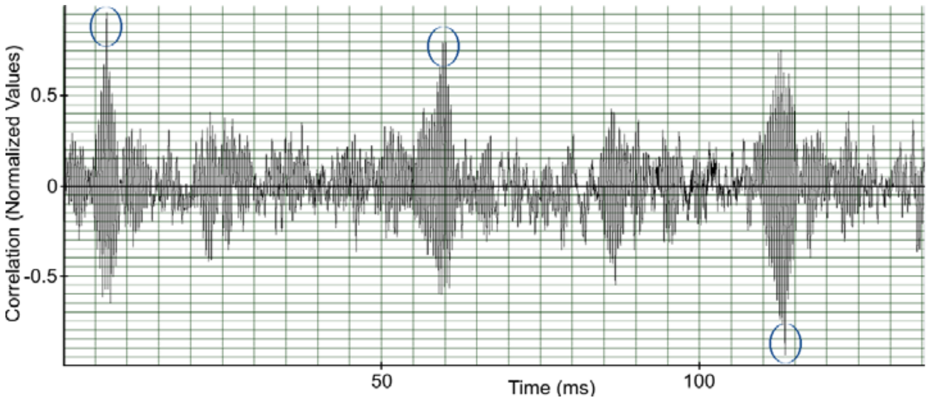

Fig. 11. Correlation Result of Real AIS Signals

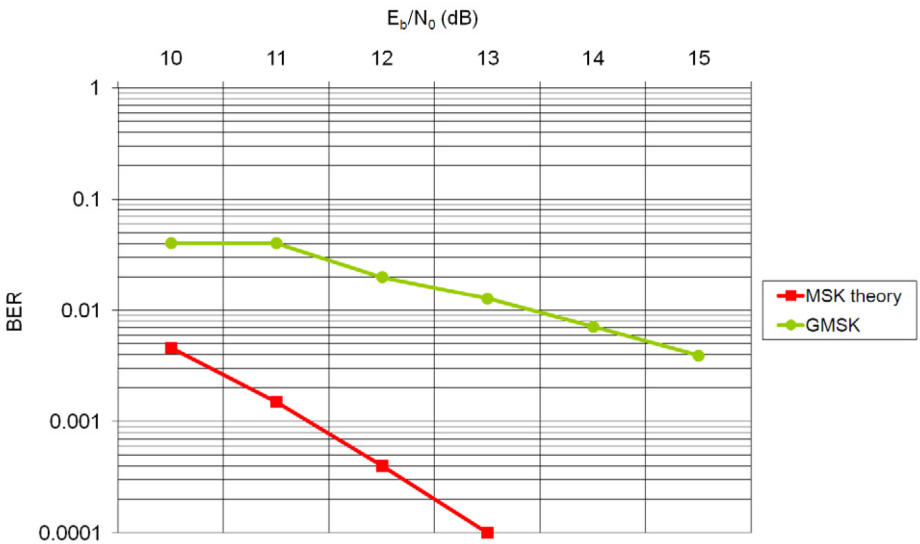

Fig. 12. Demodulator BER Performance

7 Conclusions

In this paper the structure of a spaceborne AIS receiver has been presented and analysed. The purpose of this demodulator is to receive the AIS messages sent by ships, in order to identify the position of all ships over the world, improving the maritime surveillance.

Space based reception introduces a large Doppler frequency shift of the received signals, which is in the range of $\pm 3.8\,\text{kHz}$ due to the satellite speed. To cope with this issue, the receiver is implemented with several branches in parallel centred at a different demodulation frequency. The number of branches of the proposed receiver is five. Each branch is based on an FM discriminator that performs the derivation of the arctangent to obtain the signal, which is contained in the phase of received signal.

The main advantages of this robust scheme is that, as it is non-coherent, there is no need to recover the frequency of the arriving signals with a small margin of error (± 1 Hz). Our algorithm performs a rough frequency compensation by the calculation of the signal DC offset. This approximation is good enough (± 100 Hz error) to centre the demodulated signal around the axis for hard detection, leading to an easier implementation.

In addition to the FM discriminator, the receiver includes a bit synchronization algorithm by obtaining the correlation of the demodulated signals with a known waveform, the preamble.

In presence of AWGN channel, the BER performance of the GMSK demodulator showed a 4 dB loss respect to the theoretical curve. The disadvantage is that a coherent demodulation scheme has always theoretically 3 dB better BER performance. For that reason, a coherent demodulator could be considered for further developments.

The receiver has also been tested with real AIS signals recorded from an airplane. Real messages can be demodulated properly and the information is recovered. However, some of the recorded frames have a very low S/N, not being possible to demodulate them with the receiver presented here.

The collision in a TS among signals from different ships is a quite likely event. Some preliminary tests performed with the receiver show that if two frames collide only the frame with higher amplitude can be obtained if the Signal-to-Interference ratio is large enough (10 dB). As a consequence, the receiver presented here can detect if a collision has occurred or not in a TS, but is not able to demodulate the two (or more) signals colliding.

8 Future Work

As a first implementation, the demodulator consists of five branches. Fewer amount of branches is not advisable because of the large Doppler range. A possibility is then to try seven branches, which complicates the demodulator structure. However, at the same time allows to reduce the bandwidth of the filters in the branches, increasing the S/N and improving the BER performance, placing it closer to the theoretical values.

Another detection schemes may be used instead of Integrate and Dump, such as Decision Feedback Equaliser (DFE), to cope with the ISI inherent to GMSK modulation. Moreover, possible designs for coherent demodulation schemes can be studied to increase the receiver performance respect to BER.

Finally, a scheme to deal with signal collisions will be analysed since, so far, these are only detected.

Acknowledgements. This research has been carried out in cooperation with LuxSpace and the University of Luxembourg. It is supported by AFR (Aides à la Formation-Recherche) from the Government of Luxembourg. Special thanks to Prof. Dr. Ulrich Sorger.

References

1. ITU: Recommendation ITU-R M.1371-2, Technical characteristics for a universal shipborne automatic identification system using time division multiple access in the VHF maritime mobile band, last version (2006)
2. Morelli, M., Mengali, U.: Joint Frequency And Timing Recovery For MSK-Type Modulation. IEEE Transactions on Communications (June 1999)
3. Narheim, B.T.: NCUBE-1 and 2 AIS Detection Probability, Norwegian Defence Research Establishment (2007)
4. Høye, G.K., Eriksen, T., Meland, B.J., Narheim, B.T.: Space-based AIS for Global Maritime Traffic Monitoring. Norwegian Defence Research Establishment (2007)
5. Bianchi, P., Loubaton, P., Sirven, F.: Blind Joint Estimation of the Technical Parameters of Continuous Phase Modulated Signals, France (2003)
6. Hull University: Appendix D: Digital Modulation and GMSK, `http://www.emc.york.ac.uk/reports/linkpcp/appD.pdf`
7. Haykin, S.: Communication Systems, 4th edn., pp. 396–400. John Wiley & Sons, New York (2001)
8. Mehrotra, A.: GSM System Engineering, The Artech House Mobile Communication Series, pp. 216–217 (1996) ISBN: 0-89006-860-7
9. Schiphorst, R., Hoeksema, F., Slump, K.: Bluetooth demodulation algorithms and their performance, Netherlands
10. Turletti, T.: GMSK in a nutshell. Massachusetts Institute of technology (1996)