CML Microcircuits

COMMUNICATION SEMICONDUCTORS

White Paper

A Knowledge Base document from CML Microcircuits

Marine AIS

The Automatic Identification System (AIS)

The AIS system provides the mariner with an indication and position of all other similarly equipped vessels within the immediate area, thus providing vital awareness of the conditions that may affect the navigation and safety of all vessels. In a similar manner, coastguard and harbour authorities can monitor the AIS transmissions from their land-based sites to control and organise shipping in their immediate area.
Recent regulations have mandated the installation of AIS systems on all Safety Of Life At Sea (SOLAS) vessels and vessels over 300 tons, but the systems in general provide a reliable collision avoidance method for all vessels, both commercial and leisure along with harbour authorities for monitoring overall traffic in an area.

AIS operates via a transponder on each vessel. The transponder interfaces the following devices and functions:

- Global Navigation Satellite System (GNSS) - usually GPS, but could equally be GLONASS or in the future, Galileo
- AIS encoder/decoder - which provides positioning information in the form of formatted data
- Radio transceiver - which transmits (and receives) the data and vessel information to/from all other vessels in the vicinity
- On-board peripherals to provide vessel/voyage information and a suitable presentation

Class A Marine AIS, which is targeted at large commercial vessels, is the full specification equipment, requiring the complete ITU 1371-1 specification to be implemented (ref: IEC 61193). Such an implementation results in a large heavy, power-hungry unit, with multiple connectors for sensors such as rudder positioning, compass, and to various display outputs. The units are expensive, but rugged and capable of operating in extreme conditions.

Class B Marine AIS is aimed at the lighter commercial and leisure markets. The units are smaller, rugged and more power efficient, and are available at a lesser cost.

Receive (Rx) Only Marine AIS monitors the AIS network (both Class A and Class B), and receives positional (data) reports for on-screen display. These units are primarily used by harbour authorities that wish to control and monitor shipping activity in their area and if necessary, take action and warn the vessels by VHF voice transmission.
The use of Rx only devices is also being implemented on smaller vessels for collision avoidance, as they can clearly see where the larger vessels are (which cannot manoeuvre so quickly), allowing them to take avoidance action against collision.

Aids To Navigation (AtoN) covers the fitting of buoys, search and rescue devices (AIS-SART) and fixed structures with AIS technology, allowing their location to be displayed at the same time as vessel data. Installation on offshore installations is a technical challenge in terms of environmental conditions and most significantly with regards to power-supply and consumption; units are often solar powered.
Various classes of AtoN are envisaged in the relevant IEC standard depending on the level of functionality and requirement.

The Technology

An (AIS) air-interface protocol known as SoTDMA (Self-organising Time Division Multiple Access) minimises the possibility of two vessels transmitting at exactly the same time. Two radio channels are used to increase system capacity, safety and resilience; transponders must be capable of receiving both channels simultaneously. Vessels receive the positional reports and can then display them (and selected vessel data) either on a dedicated AIS screen, overlaid on an Electronic Chart Display and Information System (ECDIS) or added to a radar display.

In addition to showing the position of vessels and structures, a chart-plotter software adds the facility to plot both the historical track of the vessels and the predicted future position (based on the reported course, speed and rate-of-turn) and so produce a collision alarm if required in plenty of time.

If needed, the data provided by the AIS system allows the mariner to call another vessel on VHF radio, either by its name or using the Maritime Mobile Service Identity (MMSI - the vessel's unique identity) information to place a DSC (Digital Selective Calling) call.

AIS Class A devices are necessarily robust, so as to survive the harsh commercial marine environment. It was always the intention of the marine community to provide low cost transponders suitable for the leisure and small boat markets; however, to do this at an acceptable cost required considerable changes to the original specifications. In addition to cost, enabling the unit to consume considerably less power is a requirement, as smaller vessels often have restrictions on battery capacity.
The result of widespread research on this subject is the AIS 'Class B' standard (IEC 62287).

Table 1 shows the significant differences between the two classes:

	Class A Marine AIS	**Class B Marine AIS**
Tx power	12W	2W
25kHz channel	Yes	Yes
12.5kHz channel	Yes[1]	No
DSC Tx	Yes	No
DSC Rx	Dedicated Rx	Time-shared with AIS
Protocol	SoTDMA	CSTDMA
Timing source	GNSS	Off-air
Tx msg length	1 to 5 slots (max of 3 slots recommended)	1 slot (using CSTDMA)
Tx PA rise time	8 bits	3 bits
Reporting rate	10 seconds to 3 minutes	30 seconds or 3 minutes
External interfaces	RoT, Gyro Compass, Log	None
Vessel information	Name, MMSI, IMO number, dimensions, draft	Name, MMSI, dimensions
Voyage information	Destination, Cargo type, ETA, status	None
Tx Binary messages	Yes	Limited

Table 1 – Marine AIS 'Class' differences

Channel Access Protocol
The original SoTDMA based AIS system splits the radio channels into a number of time-slots, all of which are 256 bits long (approx. 26ms at 9600baud) aligned to UTC clock using the GNSS receiver as the primary timing reference. Over a period of one minute, this provides 2250 slots on each AIS radio channel. The SoTDMA system implemented within AIS uses a 'listen-and-store' system that remembers the slot number that a particular vessel last transmitted on and then reserves that same slot in the next period, so that it doesn't try and use it for its own transmission. Vessels can also 'reserve' future slots (FATDMA), which are similarly marked as occupied by the receiving vessels. By building up a 'slot map' in this way, it is unlikely that a vessel would attempt to transmit in a slot that is already in use by another, thus making efficient use of the radio channel.

For a variety of reasons, including reduced complexity, AIS Class B adopts a different approach using a Carrier-Sense TDMA (CSTDMA) protocol, requiring the unit to 'listen-before-transmit'. The scheme was designed to be backwards-compatible with 'Class A' by delaying the time when the 'Class B' tries to transmit, allowing time for the unit to detect if another device is already using the slot, in which case it will abort its transmission and try again in another slot. This requires the Class B unit to monitor the background radio noise level and measure the incoming radio signal strength at the beginning of a slot – in the worst case, it could have only 312µs in which to accomplish the sensing process. This also restricts the CSTDMA units to single slot transmission.

Slot Timing is vital to the overall performance of the system; ensuring transmissions do not overlap and collide. In the SoTDMA system, timing is derived from the GNSS sensor, which provides an accurate UTC signal.
In the 'Class B' CSTDMA system, timing is derived from other units by listening to the Class A broadcasts around it and determining the timing from 'time of arrival' of the data fields for transmissions.

[1] It is anticipated that 12.5kHz channels will be removed from 'Class A' requirements, as they have never been implemented.

Transmission Format

The single Class A transmission burst is 256 bits long (~26ms) and consists of:

- Tx PA ramping (8)
- Preamble (24)
- Start character (8)
- Data (168 to 1008) – multi-burst
- CRC (16)
- End character (8)
- Tx PA ramping (8)
- Timing buffer (20)

Class A transmissions can consist of up to 5 'bursts' although current ITU recommendations suggest a maximum of 3.

The data and CRC fields are subjected to NRZI coding and bit stuffing (similar to the HDLC format). The timing buffer exists to allow for small differences in the timing of individual units and the propagation delay of the radio signals.

In the AIS Class B CSTDMA system, reduced Tx power means that the reception range is limited, thus the timing buffer can be reduced. When coupled with the shorter PA ramping periods this allows the CSTDMA unit to include a sensing period prior to activating its transmitter.

The Class B timings consist of:

- CS Timing buffer (8)
- Carrier-sense period (8 max)
- Tx PA ramping (3)
- Preamble (24)
- Start character (8)
- Data (168)
- CRC (16)
- End character (8)
- Tx PA ramping (3)
- Timing buffer (8)

The additional CS timing buffer at the start allows for possible transmissions from a distant Class A unit, so as not to affect the carrier-sense system.

The data is transmitted at 9600bps using GMSK modulation, filtered to fit within the confines of a 25kHz channel mask. For 'Class B' operation, the channel mask is specified for a slotted transmission burst, and so includes, and accounts for, the effects of transients at the beginning and end of the data burst.

Radio Performance

Compared to the existing standards for comparable radio systems, some of the radio performance requirements for 'Class A' units are particularly severe, due to the crowded nature of the radio spectrum, particularly in harbour areas where marine radio co-exists with land-based units in adjacent bands (in addition to the high density of marine traffic). The land-based systems may operate at very high transmission powers, a case in point being in the USA, where the NOAA NWR transmitters can be transmitting kilowatts only 150kHz away from the AIS channels. This gives rise to particularly stringent AIS requirements for Rx blocking and inter-modulation performance.

Class B requirements are generally more relaxed than Class A, however for both types the Rx co-channel performance is stringent as this effectively defines the system capacity in crowded areas where another transmitter may re-use an otherwise occupied slot. The limit of 10dB means that slots can be re-used effectively thus allowing the AIS system to operate in high traffic conditions.

Design Evolution

The design of AIS transponders has evolved over the years. The very first Class A units used a lot of conventional technology with the critical modems implemented using ICs such as CML's CMX589A (for AIS GMSK modulation) and the FX604 (for FSK used by DSC).
DSP based AIS Class A units were also implemented to meet the stringent Class A co-channel requirements.
Such solutions, although offering enhanced performance, often did not achieve any cost or size reduction advantages, some products contained as many as four DSP devices. A further problem with the DSP approach is the limited control lines available for managing the radio circuits; this tends to lead to a proliferation of external ADC, DAC and large FPGA or ASIC designs to manage the interface between DSP, ADC, DAC and various radio circuits.

To address this global market problem for efficient, economical Class A AIS, CML Microcircuits (CML) launched the CMX910 device, an IC that integrates dual modems for the AIS system supporting all Class A modes as well as Class B CSTDMA operation. This device solved the problem of proliferation of interfaces meaning that an AIS radio, for the first time, could be built without an FPGA or similar device/s.
All modem and signal processing is carried out in the same IC, as are all ADC and DAC functions. The CMX910 also simplifies the host controller requirements to a level that only an 8-bit microprocessor is required, whilst consuming very little power.

Class A AIS units are now fitted to all mandated ships so the on-going market is relatively small. The current stage being addressed is the larger market for smaller vessels, inland waterways, leisure crafts, etc. In this market the Class B standard offers the opportunity for consumer focused products.

As manufacturing attention turned to Class B many started on re-designing their existing Class A products. The solutions were good, but not ideal for a truly optimised Class B product. Furthermore new market opportunities arose, for example a strong market has grown for Receive Only (Rx) AIS products.
One way to achieve the goal for the AIS leisure market using Class B is to utilise a high level of integration, combining as much of the signal processing and data formatting into a single device as possible, thus allowing the use of lower-cost components to complete the design. At the same time the solution must support the lowest-cost radio architectures but without compromising performance.

Signal Processing

It had already been demonstrated in Class A that all signal processing could be combined into a single device (e.g. CML's CMX910). As previously discussed, the DSP solution has the disadvantage that to control radio circuits a number of external circuits are required (ADC for two receivers, DAC for transmitter, DAC for power amplifier control, 3-wire interfaces for phase locked loops, control lines for Tx / Rx switching etc.), whereas this is not required with the CMX910 solution.

Radio

In the radio unit, digital solutions have been investigated in a number of designs, such as using an I/Q format interface to achieve optimum performance in the receiver. Although these can be effective they are over-complex for Class B.
In the receiver, conventional superhetrodyne architecture with a limiter-discriminator FM demodulator offers an effective, low-cost/power solution. The technology is mature and effective and traditionally used in marine and land-mobile applications. Analysis has shown it is very difficult to find a lower-cost alternative.
Providing that Viterbi-type decoding is used in the modem, performance is not compromised.

In the transmitter a simple 'two-point' modulation scheme can be used. In this system a low-cost PLL IC can be used and modulation applied simultaneously to the VCO and PLL reference. The result is effective with a truly minimal cost. PLL modulation using fractional-N synthesisers has been employed and, although this scheme can be made to work, performance compromises are significant primarily due to increased noise and spurii.

CML's Integrated Solution

Considering all of the previous points, integrated solutions for low-cost AIS units are now established in the market. The first products specifically targeted at Class B AIS operation are CML's CMX7032 and CMX7042 products. These devices are based on the experience of several generations of Class A products and are specifically designed for Class B.
All modem signal processing is integrated along with a host of key additional features.

A block diagram of a Class B CSTDMA unit is shown in Figure 1.

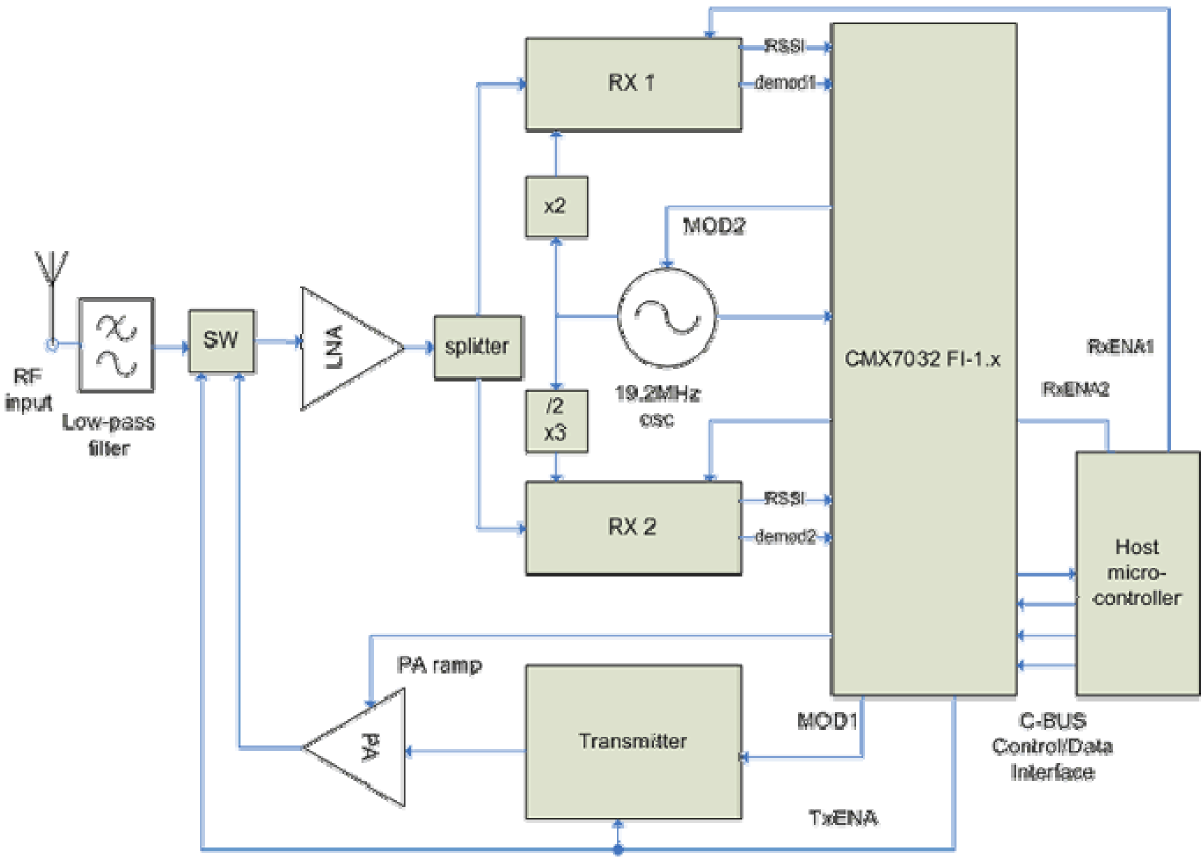

Figure 1 - Class B architecture

Combining all the above features into one device ensures that the performance of the final design is optimised for the AIS application, allowing the equipment designer to concentrate on higher level protocols, applications layer and user interfaces of the final design which can be significant market differentiators: in particular, the CML GMSK demodulator has been optimised to ensure that the co-channel specification can be met using standard RF components. In a similar manner, the PCB real-estate and power consumption is kept to a minimum and the overall component count reduced (when compared to discrete implementations). The extensive on-chip data decoding capabilities of the CMX7032 (and CMX7042) also allows the host/application processor to remain in a low power 'sleep' mode until a valid AIS message is received, so further lowering the overall power consumption of the design. As the host/application processor does not need to carry out any data decoding operations, the processing power required is reduced, allowing smaller, cheaper, lower-power host processors to be used. The CMX7032 additionally offers two separate on-chip RF synthesisers.

Receive Only AIS

The receive-only market is already well-established providing low-cost solutions, primarily aimed at the leisure market. In this market a variant of the CMX7032 is available that integrates all the receive functionality allowing the received data to be output directly as NMEA-0183 data. This solution completely eliminates the need for a host in such products where the output is to an external device such as a PC running chart-plotting software. As such the CMX7032 proves a true single chip baseband solution for Rx only products.

Aids to Navigation (AtoN)

The fitting of buoys and fixed maritime structures with AIS technology is a logical step, allowing their locations to be displayed at the same time as vessel data. Various classes of AtoN are envisaged in the relevant IEC standard depending on the level of functionality. In all cases, power is critical and here again the CMX7032/CMX7042 proves an ideal solution, having been optimised for low power in the Class B application. A unique feature of the CML devices is the ability to autonomously control the radio so as to sleep as long as possible, thereby consuming minimum power. Because slot timing is generally known in the Class B AIS system, the CMX7032/ CMX7042 can be made to monitor the RF channel only when the start of an AIS burst is expected. If a signal is not received the unit will automatically return the whole system to sleep, maximising power saving.

For AtoN operation, it may be necessary to sleep for extended periods and only monitor for updates intermittently. In this situation the CMX7032/CMX7042 can be put in ‘Deep Sleep’ Mode by the host microcontroller (current consumption typically 16µA).

The CML Design-in Solution

CML offers an AIS demonstration kit (DE70321). A complete AIS Class B (IEC 62287) technology demonstrator aimed at speeding manufacturers' design and development of AIS Class B transponders and AIS receiver products using the CMX7032 AIS Class B Basband Processor with RF Synthesiser IC.
For Receive-only applications, the DE70321 can be loaded with an EEPROM containing a configuration file for the CMX7032, known as a Function Image™. With this file loaded (FI) the unit will act as a fully functional AIS receiver - it is even possible to add an external GPS unit to the RS232/NMEA interface to allow display of ‘own position’ data. The configuration is simple and is shown in Figure 2.

The DE70321 design is revolutionary as it simplifies the AIS system to levels previously unattainable, with all the benefits of lower manufacturing costs that would be desirable. The DE70321 design has been carefully optimised for minimum-cost providing a bill-of-materials of approximately half that of previous generation products. Tests at various locations around the UK have demonstrated ranges in excess of 30 nautical miles even with a simple antenna mounted at deck level on a leisure sailing craft.
CML offers a design portfolio containing all the information (BOM and PCB and schematic layout information and datasheet/user manuals) required for an AIS design.

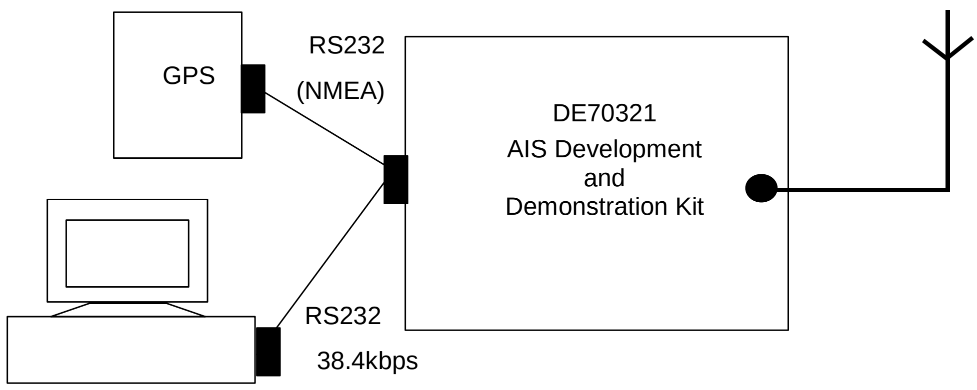

Figure 2 – ‘Rx only’ Operation using DE70321 and FI-2.x

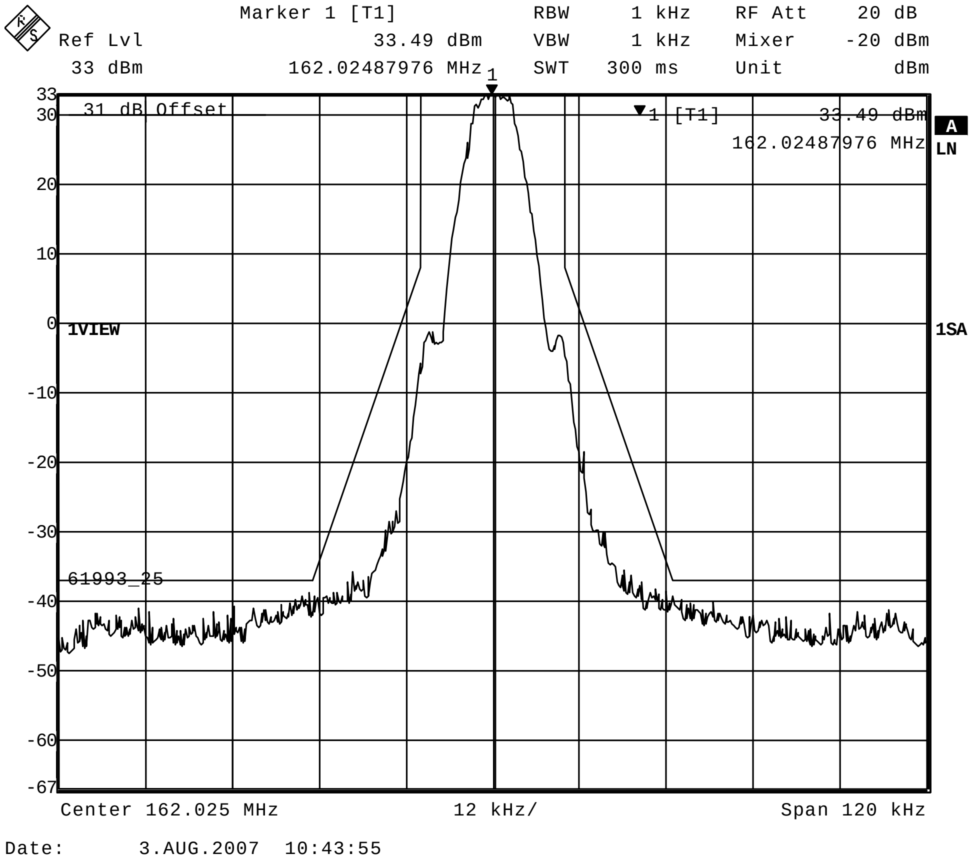

Figure 3 - DE70321 Continuous PRBS Modulated Tx Spectral mask (IEC61993-2, 'Class A') at +33dBm (2W), 162.025MHz

This Knowledge Base paper has shown, how over-time, the AIS market has evolved to-date, from professional mandatory 'Class A' equipments, to low cost, mass-market equipment for leisure markets.
Technology solutions have followed this trend with solutions like the DE70321 offering the prospect for truly low cost products providing the benefits of safety and information to all seafarers.

Current References

IEC 61993	IEC Standard for AIS Class A
IEC 62287	IEC Standard for AIS Class B
IEC 62320	IEC Standard for Base-stations (AIS shore stations - Minimum operational and performance requirements - methods of test and required test results)
ITU-R M1371	ITU-R Standard outlining the system parameters for AIS.
ITU-R M.493	ITU Standard for DSC
IMO	International Maritime Organisation (www.imo.org)
CML Microcircuits	www.cmlmicro.com
Innovations:	Marine AIS Processor ICs - Dedicated IC Processors for Maritime Safety products – an explanatory document
CMX7032	- AIS Baseband Processor IC with RF Synthesiser - AIS Rx Only Data Processor IC with NMEA 0183-HS Output
CMX7042	AIS Baseband Processor IC
DE70321	AIS Technology Demonstration Kit

Glossary

AIS	(Marine) Automatic Identification System
AtoN	Aids to Navigation (e.g. buoys and fixed structures)
COG	Course over ground
CSTDMA	Carrier Sense Time Division Multiple Access System used in class B units instead of SoTDMA
DSC	Digital Selective-Calling Data signalling system used as the primary emergency channel for Marine applications
ECDIS	Electronic Chart Display and Information System
EPFS	Electronic Position Fixing System
FATDMA	Fixed Access Time Division Multiple Access
GNSS - GLONASS	Global Navigation Satellite System
IEC 61993	IEC Standard for AIS Class A
IEC 62287	IEC Standard for AIS Class B
IEC 62230	IEC Standard for Base-stations
IMO	International Maritime Organisation
ITU-R M1371	ITU-R Standard outlining the system parameters for AIS
ITU-R M.493	ITU Standard for DSC
MMSI	Maritime Mobile Service Identity
RATDMA	Random Access Time Division Multiple Access
SOLAS	Safety of Life at Sea
SoTDMA	Self-organising Time Division Multiple Access The signalling scheme used in all AIS class A transponders
UTC	Co-ordinated Universal Time

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