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Electronic Product Development

AIS: A Guide to System Development

Thoughts on AIS system design from an R&D perspective

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Abstract

This document addresses design challenges for Automatic Identification Systems (AIS). Designed to prevent marine collisions, AIS is a marine band data network based on a self-organizing TDMA access protocol. The SOTDMA protocol poses significant hurdles for electronic designers. In this paper we discuss and clarify protocol structures and specifications, as well as architecture implementation. We present a step-by-step process for encoding or decoding AIS messages. We highlight key, system-level considerations for the data-link layer, GPS and transmit synchronization, DSC and AIS channel deviation, power challenges and testing. As well, we shed light on NMEA 0183's frequently misconstrued terms concerning back-end interface design. We outline a new, software-defined radio approach to AIS design, developed by RF experts at Fidus Systems.

AIS: A Guide to System Development provides practical guidance for design engineers, project managers and engineering leaders in the fields of AIS, RF and software-defined radio.

About Fidus

Fidus specializes in Electronic Product Development, developing products for a wide range of industries. Fidus has extensive design experience and expertise in System Design and Architecture, Hardware, Signal Integrity, PCB layout, DSP/FPGA/ASIC, Software and Mechanical design. Our clients include companies in the aerospace, defence, consumer, medical, industrial, semiconductor and communications industries.

We offer our clients greater flexibility and capability in their product development through access to the right combination of expertise, process and tools. We are focused on transforming our clients' innovative concepts into great products on schedule and on budget.

Whether it is turnkey product development or targeted assistance on a project, Fidus has the bench strength to offer highly qualified and experienced engineers. With a highly responsive and growing team of over 60 engineers, Fidus is continually expanding the services and capabilities that we offer to our clients.

Fidus uses proven product development and design methodologies combined with a comprehensive suite of tools and equipment. Our experienced team of engineers and seasoned project managers ensure on time delivery of our clients' projects and that quality is a focal point at every step of the project.

Recognized as a trusted partner, Fidus is dedicated to developing long-term relationships with clients built on integrity, quality and open communications. With a 97% referral rate, we are proud to say our clients love our work.

Fidus has delivered more than 700 projects for over 140 clients, from Tier-1 multinationals to SMEs to start-ups across North America. Fidus has its headquarters in Ottawa, Canada with design centers in Ottawa, Toronto, Silicon Valley and Lebanon.

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1. Introduction

On the surface the Automatic Identification System (AIS) protocol appears to be a straight-forward scheme for generating a self-organized data network between marine vessels. Deeper investigation into the protocol structure and mass of ITU, IALA, and IMO specifications, however, can quickly fog the picture and discourage an unsuspecting system designer. From specific AIS protocol comprehension to conceptual architecture implementations, one faces a number of design challenges when designing an AIS system. This document complements the specifications and guides readers to an easier understanding of AIS and related issues.

2. What is AIS?

Designed to prevent marine collisions, AIS is essentially a VHF marine band data network based on a self organizing TDMA access protocol.[1] Although ships are generally equipped with radar, AIS has the advantage that it can "see around corners:" it remains useful in the presence of obstacles.

The system operates on 2 default channels within the marine band radio spectrum:
(AIS1 = 161.975 MHz and AIS2 = 162.025 MHz).

This allows vessels to communicate automatically with each other, as well as with aids to navigation, search and rescue aircraft and coastal base stations. Data communicated may include anything from a ship's physical size, course, speed and rate-of-turn, to its destination, cargo and number of passengers. Provisions are also made for AIS control and channel management messages, as well as broadcast or addressed binary and safety-related messages.

AIS systems are typically integrated with vessel radar systems capable of overlaying and correlating AIS data with conventionally-detected radar targets. Such integrated systems can turn the AIS display on or off. They often include algorithms to sort and filter AIS data to elegantly extract specific information. Stand-alone AIS installations are also readily found that take advantage of commercial, off-the-shelf display software such as *Rose Point's Coastal Explorer.*

Combined with positional data, geographic maps, radar images and depth charts, AIS information provides a maritime vessel with a complete view of its surrounding environment. AIS data communication is a powerful tool that easily lends itself to such applications as vessel trafficking services, collision avoidance and search and rescue missions.

3. AIS System-Level Considerations

Designing an AIS system is a significant undertaking that involves subtle intricacies. The subsections that follow begin to explore these intricacies and key aspects for AIS system designers to consider. Armed with this knowledge you may avoid unexpected surprises. We assume that readers already have some knowledge of AIS and the ITU-R M.1371-2 specification.

3.1 The Data Link Layer

Scattered throughout the AIS specifications are hints about processing in the data link layer. There is some mention of what isn't done (forward error correction, interleaving, bit scrambling, etc.) and some about what is (NRZI and HDLC encoding, byte reversing, etc.), but it's not easy to extract the tangible details of how to formulate or decode an accurate AIS message for RF transmission.

It takes a considerable amount of time to determine the order in which to perform the encoding or decoding, and what particular data is relevant at each stage of the process. Even the description for CRC calculation is not straight forward. Eventually, with enough consulting between different specifications and clarifications, a designer can come up with an appropriate algorithm for creating or decoding an AIS message. It's tedious, but luckily, unnecessary. You can generate a proper AIS message by following the sequential steps shown in figure 1. [2]

Once you have completed the algorithm outlined in Figure 1 your system will be ready to generate accurate base band AIS messages for RF transmission, but before you power up that transmit amplifier be sure you've synchronized your TDMA frame to the UTC minute!

[1] SOTDMA is a patented technology invented by Swedish engineer Håkan Lans

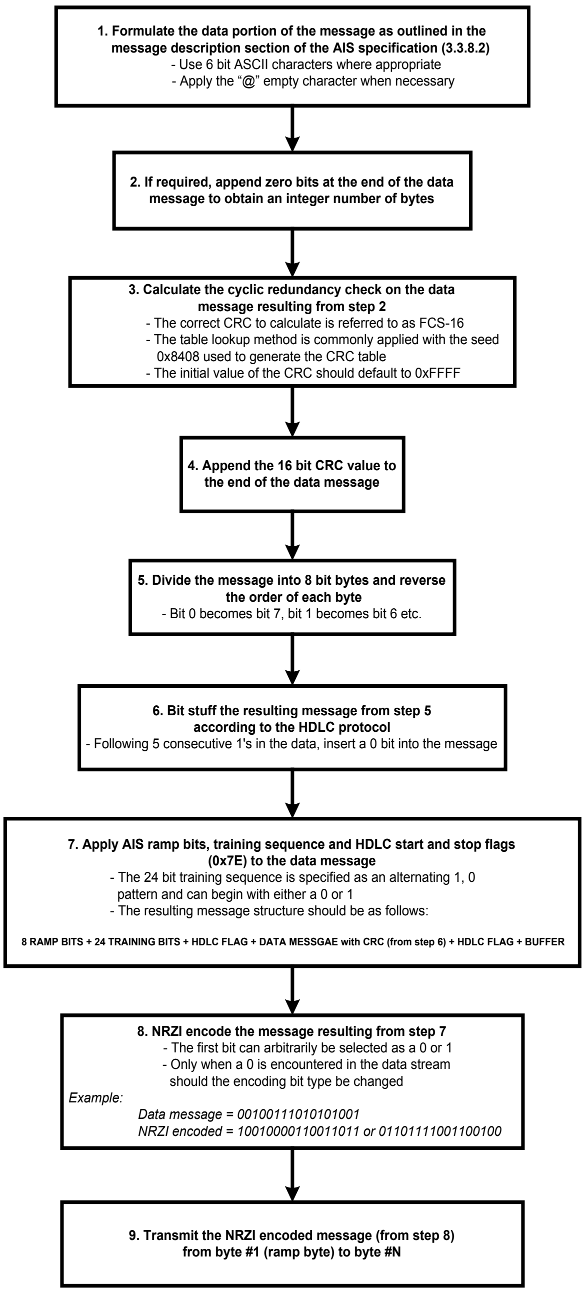
[2] Applying these steps in reverse order will allow successful decoding of a received AIS data transmission. **Note:** Since the training sequence can start with either a 1 or a 0 and the NRZI encoding can start with a 1 or a 0 there are a number of different bit combinations that can be detected for indication of a valid start/stop flag

3.2 GPS and Transmit Synchronization

The AIS specification describes a number of methods in which a single participant can synchronize their system with the rest of the AIS world. Synchronization is critical in this TDMA-based system, particularly for transmit functionality.

An accurate frame map must be generated that reflects RF activity on the network and indicates which slots have been allocated and which are free for use.With a complete frame map along with accurate frame and slot timing, an AIS system can select suitable transmission slots without the risk of data collisions. More stringent synchronization is required than just slot selection, however. RF power for the AIS transmission must reach its target level within 1 ms of the slot start and must decay to zero before the start of the adjacent slot. Such precise synchronization is most easily achieved by providing a local system UTC (coordinated universal time) source. Integrating a local GPS receiver will provide the AIS system with local access to standard NMEA 0183 GPS sentences (RMC, GGA, GSA, etc.) and possibly a very accurate, 1-pulse-per-second (1 PPS) signal. Many GPS receivers will generate such a pulse that is aligned to the UTC second and guaranteed within 1µs accuracy. Depending on how involved the AIS system becomes, processing delays will slightly skew NMEA sentences from the actual GPS time. With the presence of a precise 1 PPS signal, you can make timing corrections that provide the AIS system with excellent synchronization accuracy.

Figure 1: AIS Data Link Layer Processing



A few simple hardware components and a bit of software, using the GPS NMEA sentences in combination with the 1 PPS signal, make it easy to line up the AIS TDMA frame and generate accurate slot synchronization.

Of course, in the event that information from the dedicated GPS is interrupted, the AIS system should still be capable of synchronizing using alternate methods as described in the specification. (ITU-R M.1371-2 section 3.1.1)

3.3 DSC and AIS Channel Deviation

Although marine band channels 87b and 88b are generally accepted worldwide as AIS channel 1 and AIS channel 2, this is still not 100 percent clear. In the United States, several VHF channels in the maritime band, including one of the AIS channels, had been previously licensed for use by a company called MariTEL. Once these channels had been allocated internationally for use by AIS, MariTEL was not initially willing to give back rights to its previously-purchased AIS channel. Negotiations between the U.S. Coast Guard, MariTEL and the FCC have finally resolved this issue, but similar conflicts may eventually re-surface.

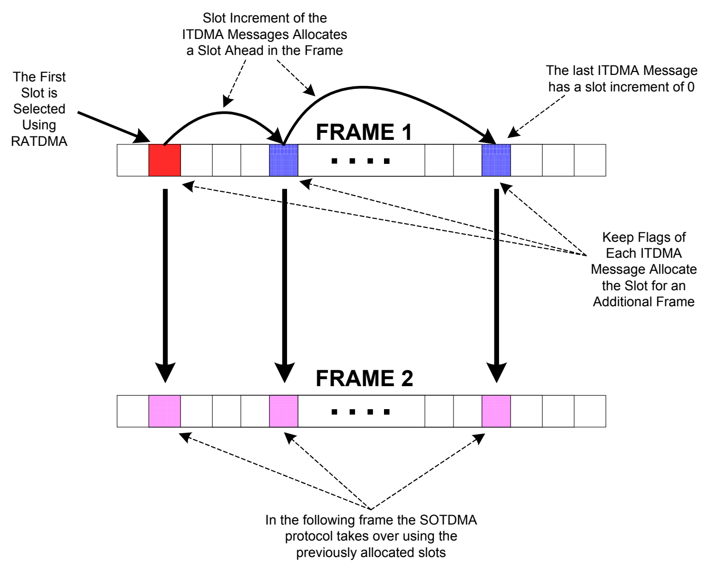
For primarily this reason, AIS systems are required to be frequency agile and support the use of alternate AIS channels. To ensure proper operation in all circumstances AIS systems should contain built-in RF flexibility. The system should be capable of adjusting to different center frequencies within the VHF marine band spectrum, and switching between 25 kHz and 12.5 kHz channel bandwidths. AIS systems are directed to the appropriate RF settings under command from regional authorities such as base stations. These commands can travel over a specific AIS message (message 22) or DSC expansion symbols added specifically for this purpose.

A fully-compliant AIS system must therefore contain a dedicated receiver fixed to marine band frequency 156.525 MHz (DSC channel 70) and be capable of decoding all required message symbols (00, 01, 09, 10, 11, 12 and 13). In addition to the fixed DCS receiver, transmissions must also be supported for responding to DSC polling messages. These DSC transmissions may occur using the existing AIS transmitter, but must not interfere with scheduled AIS data transmissions. Your means to achieve RF flexibility (via DSC or AIS message 22) will vary depending on how your radio front-end is implemented.

3.4 A Suite of Protocols

A fully functional AIS system should support each of the ITDMA (incremental TDMA), RATDMA (random access TDMA) and SOTDMA (self organized TDMA) protocols. Although not applicable for the majority of AIS installations, base stations must also support the FATDMA (fixed access TDMA) protocol. Under normal operation, the AIS system runs in SOTDMA mode, but some situations call for the use of ITDMA and RATDMA and these should be considered equally important. One such situation is the network entry phase. During network entry, the first transmission slot is selected using the RATDMA protocol. The transmission in this slot is then executed using the ITDMA format with a keep flag set so that, in the next frame, autonomous operation using the SOTDMA protocol can take over. (See Figure 2)

Figure 2: AIS Protocols During the Network Entry Phase



Besides the network entry phase, RATDMA and ITDMA are used in other circumstances, including interrogation responses, temporary message transmissions, request responses and binary or safety message acknowledgements. The advantage of ITDMA is that it permits the transmission of non-repeatable messages while SOTDMA can only reserve slots for repeatable messages that will continue for an extended duration (i.e. Messages 1, 2 and 9).

An ITDMA message contains a slot increment field that allows slots to be allocated for temporary transmission in future time slots. The benefit of RATDMA lies in its random nature. Selection of transmit slots using a randomized algorithm gives an equal probability for any vessel to occupy a given time slot. The RATDMA algorithm assigns a probability value between 0 and 100 to each message to be sent. It then stores the message in a FIFO. When a candidate slot arrives, a current probability value (derived from several variables) is compared to the assigned probability value. If the current probability is larger, the message is sent and the current probability reset. Otherwise, the current probability is incremented and the algorithm repeats at the next candidate slot.

The latest version of AIS specification recently added a CSTDMA (carrier sense TDMA) protocol to the group. This carrier sense TDMA technology is intended for use only by class B AIS vessels. The idea is that a class B AIS unit would listen to the VHF data channels and determine which slots are available for use. In addition, a class B vessel using CSTDMA should maintain a detection window at the start of each slot. During this detection window, RF activity should be sensed to guarantee that the slot is, in fact, free. Transmission using the CSTDMA protocol then would occur only after the system ensures that the network is available and no interference with regular class A operations will occur. Aside from the network access technique, AIS systems that employ only the CSTDMA protocol are subject to a majority of the same specifications as are class A systems.

3.5 AIS Message Specifics

Most AIS message types are straight forward, although further explanation may clear up minor details. This section addresses some of these details, starting with the representation of geographic position. Longitude and latitude coordinates are specified as being accurate to 1/10000 minute and are to be represented to this precision in binary format. The decimal representation of either the longitude or latitude value can be calculated as follows and is easily converted to binary form:

$$DataValue = \begin{bmatrix} (600000 \times |Degrees|) + \\ (10000 \times Minutes) + \\ (Seconds) \end{bmatrix}$$

NOTE: If the degrees value of the position is negative than the 2's complement representation of the above value must be used.

Several other messages require more attention. Message 9 is the standard SAR aircraft position report. The communication state for this report is specified to be SOTDMA, while the data link access scheme can be either SOTDMA or ITDMA. For a SAR aircraft, during the network entry phase, the access scheme should be ITDMA (with an ITDMA communication state). The SOTDMA communication state should not be used in this instance, but using the ITDMA version does not appear to be valid.

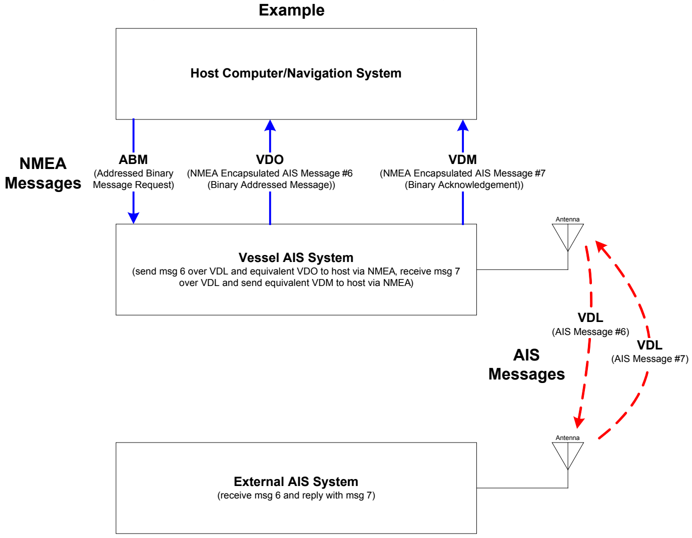
Messages 15, 16 and 20 should also be examined in detail to ensure that slot offsets and increments are correctly handled and the AIS unit responds appropriately.

3.6 Back End Interface and System Integration

Two questions arise with any AIS system: What should I do with all this information? and How should AIS integrate with other systems? ITU-R M.1371-2 specifies that the system communicate externally, using the IEC 61162 series protocol. The 61162 series of formats is the international version of the NMEA 0183 protocol. This limited specification provides a flexible design approach when it comes to integrating the AIS unit, but leaves a significant amount of processing up to the AIS system itself. Within this large amount of processing, pay careful attention to the following details:

VDL, VDM and VDO are three terms used throughout the NMEA 0183 specification. Don't confuse one with the other. VDL is the name given to the VHF data link. It refers to any communication that occurs between separate AIS systems.

Figure 3: VDO, VDM and VDL Messaging Example



In contrast, VDM and VDO sentences are sent between a single AIS unit and the host system it is connected to. VDM and VDO sentences both consist of encapsulated AIS messages wrapped in NMEA 0183 format. Both are outputs of the AIS system. Whenever a vessel transmits an AIS message over the RF link, a corresponding NMEA 0183 sentence returns to the host. This sentence is the encapsulated "own vessel" AIS message, called VDO.

The VDM sentence, although also sent from the AIS unit to the host system, has no relation to "own vessel" messages. A VDM sentence transfers the entire contents of a received AIS message to an external system by encapsulating it into a NMEA 0183 sentence. See Figure 3 for an example of VDO, VDM and VDL messaging.

While most NMEA 0183 sentences used by AIS are straight-forward one-way communications, ABM (UAIS addressed binary and safety related message), BBM (UAIS broadcast binary message) and AIR (UAIS interrogation request) sentences are more complex. They require two-way interaction between vessel instrumentation and AIS equipment. By sending NMEA 0183 sentences ABM, BBM and AIR to the AIS unit, an external host can initiate transmission, from the AIS unit, of such messages as: addressed binary, broadcast binary and interrogation.

Two tests help you determine whether these messages have transmitted successfully

1. Analyse future VDM (UAIS VHF data link message) sentences, and
2. Check whether you've received an ABK (UAIS addressed and binary broadcast acknowledge) sentence from the AIS unit.

Confusion may arise because the ABK sentence has a different function depending on the type of host request. When an ABM message is requested, the AIS unit will respond with an ABK to acknowledge the addressed binary message result. The ABK sentence can indicate:

- An invalid ABM message
- Success or failure of message 6 or 12 transmission, and
- Success or failure of message 7 or 13 reception from the addressed station.

In the case of a requested BBM or AIR, the ABK sentence from the AIS unit is used only to indicate an invalid BBM/AIR or acknowledge the success or failure in broadcasting the requested AIS message. There is no acknowledgement status for received AIS messages in response to the BBM or AIR. It is therefore the responsibility of the host system to monitor VDM sentences from the AIS unit and determine whether the appropriate response was received.

Another important consideration with the NMEA 0183 interface concerns the handling of multiple-sentence messages. The NMEA 0183 specification defines the maximum number of characters in an NMEA 0183 sentence to be 82. AIS systems are inevitably going to receive multi-slot AIS messages that would far exceed this 82 character limit when translated to NMEA 0183 sentences for transfer to external systems. The NMEA specification gives no indication as to where the division point between multiple sentence messages should occur, but a maximum of 9 sentences can be used for 1 message. Each sentence should be long enough to fit within the 9 sentence limit.

Each sentence will contain its own preamble and checksum, but only the last sentence should contain a fill bit field for ensuring the total message is an integer number of 6 bit characters.

Although normally quite flexible, the NMEA 0183 interface format presents considerable difficulty in certain situations. For example, many manufacturers desire to fully integrate an AIS system within their current navigational equipment. Their system may presently operate within a VME or similar type chassis that uses a high-speed backplane interface. By restricting this interface to the AIS unit at the lower-speed NMEA 0183 standard, we may introduce a bottleneck for backplane data transfers. Under such circumstances, it should be reasonable to maintain any externally required interfaces at the NMEA 0183 standard, while allowing communication between the AIS unit itself and the rest of the system to use the current communication standard.

3.7 Transmit Power Challenges

ITU-R M.1371-2 states that an AIS system should be capable of transmitting at 2 and 12.5 Watt power levels with the default being 12.5. While many AIS installations are intended for large oceanic vessels, where the physical size of an AIS transponder is not an issue, in certain applications it may be ideal to have a relatively compact AIS unit. For example, many pleasure boaters may be interested in the wealth of data that can be gathered via AIS. An attractive solution for these individuals would be a handheld, battery-powered unit that could plug into their laptop computer. But high transmit power requirements mean the system must include reasonably large power amplifiers, not to mention a significantly-sized source for all this power. Such applications provide a significant challenge for designers in developing compliant systems small and sleek enough to appeal to this market segment.

3.8 Testing the AIS System

Complete RF and hardware testing of an AIS system will typically require familiar test equipment such as signal generators, spectrum analyzers, network analyzers, oscilloscopes, etc. Such instruments are readily available in most hardware labs and this aspect of testing is reasonably straight forward.

System-level AIS tests, on the other hand, present a challenge. Very little equipment is available on the market for testing AIS devices. Furthermore, what is offered has limited functionality. Before investing significantly in regulatory testing, you're going to want to answer a few questions:

- How can I know that my system is operationally close to where it needs to be? You might compare the operation of your design to a commercial, off-the-shelf system, but that will leave major gaps in the required testing.
- How can I fill up both AIS communication channels with valid AIS data and test the system throughput?
- Can I verify that my AIS protocol is executing properly?
- Am I transmitting in correct time slots according to UTC synchronization? How will I know whether my UTC synchronization is correct?
- Does any test equipment exist to generate all AIS messages for a full receiver functionality test? Will I need to develop my own test software?
- System-level AIS testing poses a major dilemma and deserves serious consideration before you enter the development phase.

3.9 Evolution of the AIS Specification

A potentially critical obstacle in AIS system designs is the evolution of AIS protocol. As this system becomes more widely used, official specifications undergo constant enlargements and improvements. Designers need to consider such unknowns as:

- Will future specifications add a requirement to ensure that vessel-specific data is accurate and up-to-date?
- Will more channels be added to increase the traffic capacity?
- Are 6.25 kHz bandwidth channels going to be used?
- Are more AIS messages types going to be added?
- Will your system design adapt to such changes in AIS operation?

Software revisions may be simple, but many RF front-end solutions are not very flexible. Classical, super-heterodyne radio architectures may not adapt easily to specification changes, but other methods can provide the answer.

Fidus has developed a software-defined radio employing DSP-and FPGA-based architectures. With capabilities of modern high-speed ADCs and under-sampling techniques, Fidus' design can digitally capture and process the entire VHF marine band directly from RF in the digital domain. Such a solution permits major design changes to accommodate almost any new AIS specifications. For further details please contact Fidus.

4. The Future of AIS

Despite challenges faced by AIS system designers, the utility, wide application range and value added through AIS messaging all point to a bright future for this technology. There is indeed room for development. To date little advancement has occurred in long-range applications: not just long-range data re-broadcasts, but also in other methods to increase the availability of AIS information. It may be possible, for example, to link aids to navigation—and extend the range of useful—information by joining AIS networks that are currently too distant for communication.

Advancements are also possible in the areas of data encryption and error correction to make the system more secure and reliable.

Although development potential remains, AIS already appeals to a broad range of organizations from Coast Guard Search & Rescue (SAR) aircraft to ocean tankers and afternoon pleasure boaters. AIS will continue to develop as a key part of the mariner's tool kit.

5. Relevant AIS Specifications

I. **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

II. **ITU-R M.1084** Interim Solutions for Improved Efficiency in the use of the Band 156-174MHz by Stations in the Maritime Mobile Service

III. **ITU-R M.493-11** Digital Selective Calling System for use in the Maritime Mobile Service

IV. **ITU-R M.541-9** Operational Procedures for the use of Digital Selective Calling Equipment in the Maritime Mobile Service

V. **ITU-R M.825-3** Characteristics of a Transponder System using Digital Selective Calling Techniques for use with Vessel Traffic Services and Ship to Ship Identification

VI. **NMEA 0183** Standard for Interfacing Marine Electronic Devices

VII. **IEC 60936-5** Guidelines for the use and Display of AIS Information on Radar

VIII. **IEC 60945** Maritime Navigation and Radio-communication Equipment and Systems – General Requirements – Methods of Testing and Required Test Results

IX. **IEC 61162-1** Maritime Navigation and Radio-communication Equipment and Systems – Digital Interfaces – Part 1: Single Talker and Multiple Listeners

X. **IEC 61162-2** Maritime Navigation and Radio-communication Equipment and Systems – Digital Interfaces – Part 2: Single Talker and Multiple Listeners, High-Speed Transmission

XI. **IEC 61162-410** Maritime Navigation and Radio-communication Equipment and Systems – Digital Interfaces – Part 410: Multiple Talkers and Multiple Listeners – Ship Systems Interconnection – Transport Profile Requirements and Basic Transport Profile

XII. **IEC 61174** Maritime Navigation and Radio-communication Equipment and Systems – Electronic Chart Display and Information System – Operational and Performance Requirements, Methods of Testing and Required Test Results

XIII. **IEC 61993-2** Maritime Navigation and Radio-communication Equipment and Systems – Automatic Identification Systems – Part 2: Class A Shipborne Equipment of the Universal Automatic Identification System Operational and Performance Requirements, Methods of Test and Required Test Results

XIV. **IALA Technical Clarification on ITU Recommendation ITU-R M.1371-1** Edition 1.4 December 2003

XV. **IALA Guidelines on the Universal Automatic Identification System** Volume 1, Part I – Operational Issues Edition 1.1

XVI. **IALA Guidelines on the Universal Automatic Identification System** Volume 1, Part II – Technical Issues Edition 1.1

XVII. **ISO/IEC 3309: 1993** Information Technology – Telecommunications and Information Exchange Between System – High Level Data Link Control Procedures Frame Structure