

International Telecommunication Union



**Report ITU-R M.2169**  
(12/2009)

# **Improved satellite detection of AIS**

**M Series**  
**Mobile, radiodetermination, amateur**  
**and related satellites services**



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## REPORT ITU-R M.2169

**Improved satellite detection of AIS**

(2009)

**1 Introduction**

Satellite detection of AIS messages has been requested by administrations. In response, studies were made that were documented in Report ITU-R M.2084 – Satellite detection of automatic identification system messages. The report considered the operational and technical characteristics of the shipborne AIS and the requirements and limitations of reception of AIS messages from satellites. Further studies were proposed to deal with the technical limitations that hinder detection of AIS-equipped target ships in high-traffic areas (e.g. the Dover Straits, Singapore, North East United States of America, and the northern Gulf of Mexico) on the designated AIS VDL (VHF Data Link). The technical limitations specifically cited were:

- 1 the length of the AIS message in the time slot (insufficient time buffer for the satellite detection range);
- 2 the large number of messages in the satellite antenna footprint (excess reuse of the time slots in the VDL as detected by the satellite);
- 3 the difficulty satellite AIS has in distinguishing signals between AIS messages and communications from terrestrial services within the satellite antenna footprint (coverage pattern).

This report on further studies shows the need for a special AIS message that is shortened in length and can be transmitted on a special reporting schedule on two other frequencies when those frequencies are designated. Accordingly, a new Recommendation ITU-R M.1371 AIS message (Message 27) and new Radio Regulations (RR) Appendix 18 (AP18) frequencies for this service are proposed.

**2 Solving the problem of overlapping messages (blurred reception)**

The differences in propagation delay between vessels and the satellite causes the AIS messages to overlap. Thus, the slot composition must be adjusted to increase the time buffer so that the AIS transmissions can be received by the satellite in separate slots without a time overlap. Table 1 serves as the basis for the proposed new Message 27 slot composition shown in Table 5 based on an allowance for the “propagation time delay difference (bits)”. Tables 2 to 4 show the technical parameters, reporting intervals and data packet structure of the AIS messages that are currently approved.

TABLE 1  
Satellite AIS reception technical parameters

AIS satellite propagation calculations			
<b>Constants:</b>			
Speed of light (m/s)	299 792 458		
AIS bit-time @ 9 600 bit/s (ms)	0.1041667		
Nautical mile (km/nm)	1.852		
<b>Calculations:</b>	<b>Orbit No. 1</b>	<b>Orbit No. 2</b>	<b>Orbit No. 3</b>
Satellite orbital altitude (km/nm)	600/324	948/512	1 000/540
Slant range to horizon (km/nm)	2 831/1 529	3 604/1 946	3 709/2 003
Ground range to horizon (km/nm)	2 664/1 438	3 281/1 772	3 359/1 814
Difference in propagation distance (km/nm)	2 231/1 205	2 656/1 434	2 709/1 463
Propagation time delay difference (ms)	7.44	8.86	9.04
Propagation time delay difference (bits)	71	85	87
Typical satellite visibility (min) <sup>(1)</sup>	10.2	13.6	14.0

<sup>(1)</sup> These satellite visibility periods are for a typical overhead pass of the satellite based on a circular, polar-orbiting satellite for the indicated satellite altitudes and a target ship located at 40° latitude. Typical visibility periods will vary depending on a number of factors including satellite inclination angle and target ship latitude.

TABLE 2  
Overview of shipboard AIS technical parameters

AIS parameters	Values
Frequencies	161.975 and 162.025 MHz
Channel bandwidth	25 kHz
Platforms	Class A ships, Class B ships, coast stations, navigation aids
Power	12.5 W (Class A); 2 W (Class B)
Antenna type <sup>(1)</sup>	1/2 $\lambda$ dipole
Antenna gain <sup>(1)</sup>	2 dBi with cosine-squared vertical elevation pattern; Minimum gain = –10 dBi
Cable loss <sup>(1)</sup>	3 dB (estimated)
Receiver sensitivity	–107 dBm for 20% packet error rate (PER) (minimum) –109 dBm for $\leq$ 20% PER (typical)
Modulation	9 600 bits/s GMSK
Multiple access mode	TDMA (self-organizing, random, fixed and incremental)
TDMA frame length	1 min; 2 250 time-slots

TABLE 2 (*end*)

<b>AIS parameters</b>	<b>Values</b>
TDMA slot length	26.7 ms; 256 bits (see Table 4)
Message types	26 types
Message length	1 to 5 slots with 1 slot being the dominant type
Periodic message interval	2 s to 6 min transmit intervals (see Table 3)
Required D/U protection ratio	10 dB at PER = 20% <sup>(2)</sup>

<sup>(1)</sup> Typical parameters not defined in Recommendation ITU-R M.1371.

<sup>(2)</sup> Parameter specified in IEC 61993-2.

TABLE 3

**Reporting intervals for AIS messages**

<b>AIS platform</b>	<b>Reporting interval</b>
Dynamic information:	
Coast station	3 1/3 to 10 s interval (10 s nominal)
Class A ship	2 s to 3 min interval (approximately 7 s average) (see Table 4)
Class B ship	5 s to 3 min interval (30 s nominal)
Search and rescue aircraft	10 s interval
Aid to navigation	3 min interval
Static and voyage information	6 min interval
Safety and administrative messages	As required
Data message	As required

TABLE 4

**Default AIS data packet bit structure**

Power ramp up	8 bits	
Training sequence	24 bits	Necessary for synchronization
Start flag	8 bits	
Data field	168 bits	Default length
Cyclic redundancy code	16 bits	Necessary for error detection
End flag	8 bits	
Buffer	24 bits (typically, the last 20-bit positions are empty)	Necessary to accommodate bit stuffing, propagation and repeater delays, and jitter
Total	256 bits	

TABLE 5

**Modified AIS packet bit structure for satellite reception**

Slot composition	Bits	Notes
Ramp up	8	Standard
Training sequence	24	Standard
Start flag	8	Standard
Data field	96	Data field is 168 bits for other single-slot messages. This field is shortened by 72 bits to support the satellite AIS system buffer
CRC	16	Standard
End flag	8	Standard
Satellite AIS system buffer	96	Bit stuffing = 4 bits Synch jitter (mobile station) = 3 bits Synch jitter (mobile/satellite) = 1 bit Propagation time delay difference = 87 bits Spare = 1 bit
Total <sup>(1)</sup>	256	Standard

<sup>(1)</sup> Only 160 bits are used in the 17 ms transmission.

Thus the proposed data field for Message 27 is shown in Table 6.

TABLE 6

**Proposed new data field for AIS satellite detection Message 27**

Parameter	Number of bits	Description
Message ID	6	Identifier for this message (similar to all other messages)
Repeat indicator	2	Repeat indicator value should be 3
User ID	30	MMSI number
Position accuracy	1	As defined for Message 1
RAIM flag	1	As defined for Message 1
Navigational status	4	As defined for Message 1
Longitude	18	Longitude in 1/10 min ( $\pm 180^\circ$ , East = positive, West = negative)
Latitude	17	Latitude in 1/10 min ( $\pm 90^\circ$ , North = positive, South = negative)
SOG	6	Knots (0-62); 63 = not available = default
COG	9	Degrees (0-359); 511 = not available = default
Status of current GNSS position	1	0 = Position is the current GNSS position; 1 = Reported position is not the current GNSS position = default
Spare	1	Set to zero, to preserve byte boundaries
<b>Total number of bits</b>	<b>96</b>	

NOTE 1 – There is no time stamp in this message. The receiving system is expected to provide the time stamp when this message is received.



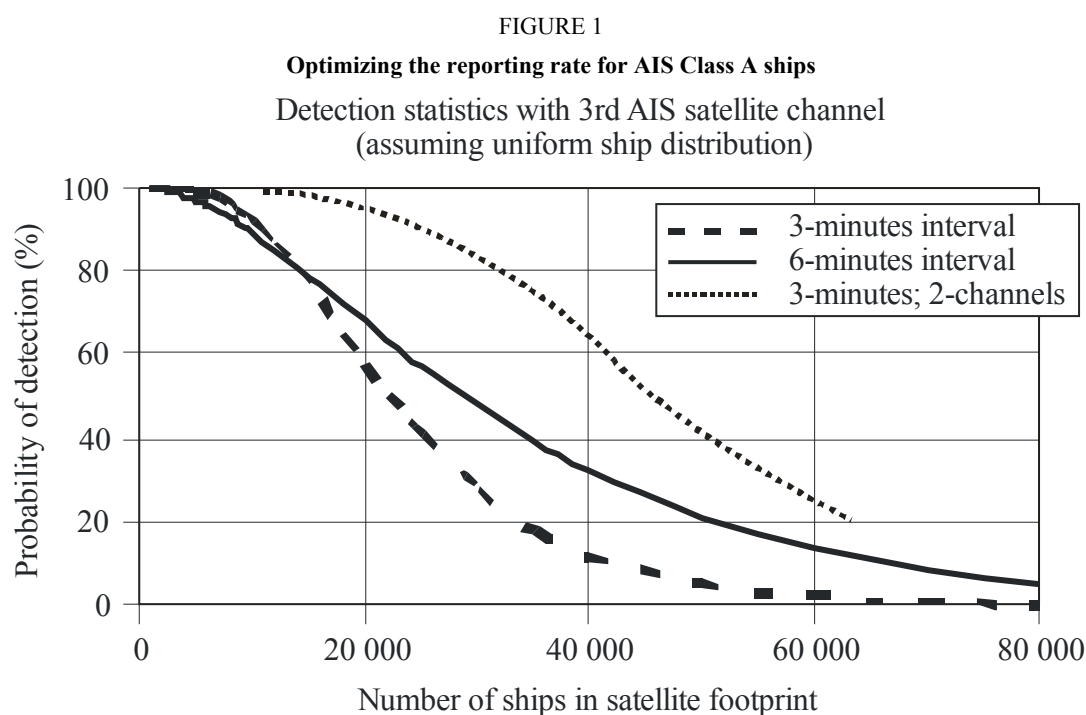
### 3 Solving the problem of the large number of messages in the satellite antenna footprint

The large number of messages in the satellite antenna footprint (excess reuse of the time slots in the VDL as detected by the satellite) is attributable to both the large number of ships and the reporting rate. Studies show that 100% of AIS Class A ships can be detected if:

- an appropriate reporting rate for the AIS Class A ships is selected;
- coastal ships within range of an AIS base station are eliminated; and
- the AIS Class B is eliminated from satellite reception.

#### 3.1 Selecting a reporting interval for satellite reception of the AIS Class A

The proposed reporting interval for the proposed new Message 27 is 3 min in order to give the best detection probability at a typical observation time of 13.6 min as shown in Fig. 1. The reports from administrations on simulation results (for AIS Class A) also support this proposed reporting interval. Note that a 2-channel system doubles the loading capacity and provides interference protection.



Report 2169-01

#### Assumptions:

- 1 Uniform ship distribution
- 2 Target ship located at 40° latitude
- 3 160 bit packet length (256 bits normal packet – 96 bits buffer for Message 27)
- 4 Polar orbiting satellite with 13.6 min average satellite visibility period.

#### Conclusions:

- 1 A 3-minutes reporting interval can achieve 100% detection of AIS Class A ships
- 2 AIS Class A already has an available 3-minutes schedule (refer to Table 3)
- 3 A 2-channel system increases loading capacity and provides interference protection.

### 3.2 Eliminating coastal ships within range of an AIS base station

An AIS base station transmits a special base station Message 4 that is received by all ships within radio range of that station. Since that AIS base station presumably receives AIS position reports from all ships within that range, it is not necessary for those ships to transmit the proposed AIS satellite Message 27. Therefore, it is proposed that when a ship receives an AIS base station Message 4, the ship should reset the 3-minutes message timer for the proposed Message 27. This provision will greatly improve the probability of detection by reducing the number of reports.

### 3.3 Eliminating the AIS Class B from the satellite reception

Reports from administrations on simulation results indicate that both AIS Class A transmissions at 12.5 W and Class B “CS” transmissions at 2 W have sufficient signal margins to support satellite AIS reception. However, the satellite footprint is too wide to accommodate the expected combined population of both classes of AIS. Furthermore, some administrations have stated the need, based on simulation results, to request that special frequencies be designated for transmitting the proposed new Message 27. Therefore, this proposal is to add the new proposed Message 27 to the AIS Class A only with a message priority level 4 and on the other frequencies. In that case, the AIS Class A equipment would not be required to receive on those frequencies and the reporting interval could be implemented with RATDMA based solely on the activity of AIS 1 and AIS 2 without the need to monitor the satellite-designated channel to further qualify candidate time slots for transmission.

## 4 Operating frequencies for satellite detection of AIS

Separate frequencies for satellite detection of AIS should be considered from within RR AP18 because the tuning range of the shipborne AIS Class A is limited to these frequencies.

At the time of development of this report, besides the secondary mobile satellite service (MSS) allocations referred to in RR No 5.227A, there is no other MSS allocations within the frequency range covered by RR AP18. With respect to possible additional AIS frequencies for satellite detection, Report ITU-R M.2084 indicated that the interference environment resulting from the existing services in those bands must be taken into account in determining the feasibility of accommodating satellite AIS in any given band or channel, due to the satellite antenna footprint that overlaps both land and sea. Examination of RR AP18 indicates that only 4 frequencies (channels 16, 70, 75 and 76) are exclusively dedicated to maritime use and restricted from terrestrial use on a global basis.

Channel 70 is exclusively dedicated for DSC for distress and calling and channel 16 is exclusively dedicated for distress and calling, therefore making them both unavailable for AIS purposes.

Footnote *n*), referring to channels 75 and 76, currently limits power to 1 W for radio transmissions because they are adjacent channels to channel 16 (the distress and calling channel). It should be noted that at least one administration uses channels 75 and 76 for low-power (1 W) maritime communications in-port.

Transmission of Message 27 at 12.5 W only once every 3 min for 17 ms, alternating between channels 75 and 76 together with the restriction to not transmit when the ship is within range of an AIS base station, would not interfere with voice communications on any of these channels 16, 75 and 76, and it would be detectable over a 1 W radio transmission.



Indeed, studies<sup>1</sup> (the JSC Report) have shown that AIS transmissions do not significantly degrade voice communications on the adjacent channels due to the shortness of the duration of one AIS time slot compared to the time intervals used by human speech. The JSC Report used the metric of “voice articulation score” (VAS) to make this assessment, and it concluded that the VAS on the channel adjacent to the AIS was 90-95% for the normal reporting interval of the shipborne AIS. In this particular case, the proposed new satellite AIS Message 27 is significantly shorter (only 17 ms) than one AIS time slot (27 ms), and the interval of the proposed transmission is significantly less (only once every 3 min) than the AIS reporting interval (2-10 s). It is unlikely that this short burst will open the squelch of shipborne VHF radios. The burst may possibly be detected during the reception of a voice call from a distant station, but the duration of the proposed burst will not spoil the detect-ability of human speech, based on the VAS metrics used in the JSC Report.

Since the coastal (covered by an AIS base station) SOLAS ships (AIS Class A) and the non-SOLAS ships (AIS Class B) are proposed to be eliminated, the effects of the SOLAS ships at sea can be assessed on their potential deterioration of the voice communications quality on the shared channels (75 and 76) and the adjacent channel (16). This analysis is based on the aggregate duty cycle of the potential radio interference from the total number of SOLAS ships in close proximity (ship-ship radio range) of each other.

For the adjacent channel 16, the required (IEC 61097-3) adjacent channel rejection ratio (70 dB) of the receiver reduces this to a co-site interference problem, or, at most, a problem of two ships passing in the shipping lanes. In this case, the deterioration of the communications on channel 16 is based on the duty cycle ( $D_N$ ) of the proposed Message 27 transmissions by two ships.

$$D_N = N(B/T)$$

where:

- N: number of adjacent ships (2)
- B: burst length (0.017 s)
- T: time interval between scheduled transmissions (180 s).

Thus, for the effect on channel 16,  $D_2 = 2(0.017/180) = 0.000189 = 0.0189\%$  and from the VAS metrics in the JSC Report, this would be imperceptible to a human listener on the radio channel.

For channels 75 and 76, the duty cycle ( $D_N$ ) on each channel from the Message 27 (independent of voice communications on these channels) is:

$$D_N = N(B/T)$$

where:

- N: number of ships (ships far offshore, excluding coastal ships) within ship-ship radio range of each other (this is an assumed distance of 5 NM, based on the 1 W power level setting for voice communications on these channels)
- B: burst length (0.017 s)
- T: time interval between scheduled transmissions on each of the two channels (360 s).

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<sup>1</sup> JSC Report (JSC-PR-04-007) – EMC Analysis of Universal Automatic Identification and Public Correspondence Systems in the Maritime VHF Band, primarily addresses the effects of AIS on the VPC service, but the information is useful in assessing this type of co-channel and adjacent channel interference. This document is freely available on the United States of America Coast Guard Navcen website: <http://www.navcen.uscg.gov/enav/ais/JSC-PR-04-007.pdf>.

Within a 5 NM radius in the offshore shipping lanes, assuming 1 NM minimum separations, there could be at most 10 ships, and that would result in  $D_{10} = 10(0.017/360) = 0.000472 = 0.0472\%$  and this would result in a very high VAS (voice articulation score) using the metrics set out in the JSC Report.

Note that since the ships that are within range of an AIS base station (assumed to be 50 NM) are eliminated from this scenario, any coastal assignments of the channels 75 and 76 (assumed to be limited to 1 W power level) are not affected and thus are of no consequence to this analysis.

## 5 Conclusion

This report addresses the technical limitations cited in Report ITU-R M.2084 that invited further studies. The possible solutions reached herein are:

- 1 A special short AIS message (proposed Message 27, of only 96 bits) that is tailored for satellite reception would solve the problem of blurred reception.
- 2 A special reporting interval (proposed 3 min) is needed for the satellite AIS message.
- 3 Ships within range of an AIS base station should suppress transmission of this message.
- 4 Satellite detection of the shipborne AIS should be limited to the AIS Class A (SOLAS Class) because the AIS Class B population is too large to be included.
- 5 Separate operating frequencies in addition to AIS 1 and AIS 2 are needed that are not subject to terrestrial use.
- 6 Frequencies should be considered only from RR AP18 due to the limited tuning range of the shipborne AIS.
- 7 RR AP18 contains only 4 frequencies (channels 16, 70, 75 and 76) that are exclusively dedicated to maritime use. Channels 16 and 70 cannot be considered because of their specific status. Should channels 75 and 76 of RR AP18 be considered together with the transmission mode described in this report, studies show the requirement of footnote *n*) to RR AP18 is met.
- 8 Recommendation ITU-R M.1371-3 could consequentially be revised to add the new Message 27 along with its transmission characteristics and the AIS Class A equipment could be upgraded through software update via the pilot port fitted on all installed AIS transponders.

Additional studies on AIS satellite detection are encouraged by administrations. Annex 1 provides an example.

## Annex 1

### Technical alternative for further consideration for satellite detection of AIS messages

#### Solving the problem of overlapping messages (blurred reception)

The differences in propagation delay between vessels and the satellite causes the AIS messages to overlap. Table 7 serves as the basis to evaluate the propagation time delay difference. Tables 8 to 10 show the technical parameters, reporting intervals and data packet structure of the AIS messages that are currently approved.

TABLE 7  
Satellite AIS reception technical parameters

AIS satellite propagation calculations			
<b>Constants:</b>			
Speed of light (m/s)	299 792 458		
AIS bit-time @ 9 600 bit/s (ms)	0.1041667		
Nautical mile (km/nm)	1.852		
<b>Calculations:</b>	<b>Orbit No. 1</b>	<b>Orbit No. 2</b>	<b>Orbit No. 3</b>
Satellite orbital altitude (km/nm)	600/324	948/512	1 000/540
Slant range to horizon (km/nm)	2 831/1 529	3 604/1 946	3 709/2 003
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Difference in propagation distance (km/nm)	2 231/1 205	2 656/1 434	2 709/1 463
Propagation time delay difference (ms)	7.44	8.86	9.04
Propagation time delay difference (bits)	71	85	87
Typical satellite visibility (min) <sup>(1)</sup>	10.2	13.6	14.0
<b>Effect of angle nadir-satellite-user (Altitude 1 000 km):</b>			
Nadir-Satellite-User angle	60°	55°	50°
Slant range to horizon (km/nm)	3 709/2 003	2 195/1 185	1 787/965
Difference in propagation distance (km/nm)	2 709/1 463	1 195/645	787/425
Propagation time delay difference (ms)	9.04	3.99	2.63
Propagation time delay difference (bits)	87	38	25

<sup>(1)</sup> These satellite visibility periods are for a typical overhead pass of the satellite based on a circular, polar-orbiting satellite for the indicated satellite altitudes and a target ship located at 40° latitude. Typical visibility periods will vary depending on a number of factors including satellite inclination angle and target ship latitude.

TABLE 8  
Overview of shipboard AIS technical parameters

AIS parameters	Values
Frequencies	161.975 and 162.025 MHz
Channel bandwidth	25 kHz
Platforms	Class A ships, Class B ships, coast stations, navigation aids
Power	12.5 W (Class A); 2 W (Class B)
Antenna type <sup>(1)</sup>	1/2 $\lambda$ dipole
Antenna gain <sup>(1)</sup>	2 dBi with cosine-squared vertical elevation pattern Minimum gain = –10 dBi
Cable loss <sup>(1)</sup>	3 dB (estimated)
Receiver sensitivity	–107 dBm for 20% packet error rate (PER) (minimum) –109 dBm for $\leq 20\%$ PER (typical)
Modulation	9 600 bits/s GMSK
Multiple access mode	TDMA (self-organizing, random, fixed and incremental)
TDMA frame length	1 min; 2 250 time-slots
TDMA slot length	26.7 ms; 256 bits (see Table 4)
Message types	26 types
Message length	1 to 5 slots with 1 slot being the dominant type
Periodic message interval	2 s to 6 min transmit intervals (see Table 3)
Required D/U protection ratio	10 dB at PER = 20% <sup>(2)</sup>

<sup>(1)</sup> Typical parameters not defined in Recommendation ITU-R M.1371.

<sup>(2)</sup> Parameter specified in IEC 61993-2.

TABLE 9  
Reporting intervals for AIS messages

AIS platform	Reporting interval
Dynamic information:	
Coast station	3 1/3 to 10 s interval (10 s nominal)
Class A ship	2 s to 3 min interval (approximately 7 s average) (see Table 4)
Class B ship	5 s to 3 min interval (30 s nominal)
Search and rescue aircraft	10 s interval
Aid to navigation	3 min interval
Static and voyage information	6 min interval
Safety and administrative messages	As required
Data message	As required

TABLE 10  
Default AIS data packet bit structure

Power ramp up	8 bits	
Training sequence	24 bits	Necessary for synchronization
Start flag	8 bits	
Data field	168 bits	Default length
Cyclic redundancy code	16 bits	Necessary for error detection
End flag	8 bits	
Buffer	24 bits (typically, the last 20-bit positions are empty)	Necessary to accommodate bit stuffing, propagation and repeater delays, and jitter
Total	256 bits	

The 32 last bits of the AIS message (end flag + spare bits) presented in Table 10 can be overlapped.

Considering a margin of 8 bits for jitters, it remains a margin of 24 bits for propagation delay difference. It means that two messages sent by ships with a nadir-satellite-ship angle under  $49.5^\circ$  will eventually collide if they are sent on the same TDMA slot, but they will never overlap one on the other if they are sent on different TDMA slots.

The interest of a relatively directive antenna is then twofold:

- it eliminates the blurred reception;
- it improves the probability of detection, the diminution of the coverage being more than compensated by the diminution of the instantaneous collision.

Even considering a large antenna, the overlapping case happens when a signal emitted from a ship with a nadir-satellite-ship angle over  $49.5^\circ$  is sent on a TDMA slot so that at least an other ship closed to nadir send is message on the following TDMA slot.

In this case, it is interesting to note that the Doppler shift and the power are different between the two signals, and that the beginning of a message (ramp up, training sequence, start flag) are common to all messages, allowing correlation. If only one message has been sent from nadir, it is possible by correlation to determine the phase, power and time of arrival of its training sequence, to remove it from the collision, and then to end the demodulation of the first received signal.

The overlapping probability is then relatively reduced.

In order not to reduce the data delivered in AIS messages, two solutions are possible:

- reduce the on-satellite antenna beamwidth to keep the same message than for ground;
- modify the order of the message to ensure the demodulation of the most interesting part, as described in Tables 11 and 12.

TABLE 11

**Modified AIS packet bit structure for satellite reception**

<b>Slot composition</b>	<b>Bits</b>	<b>Notes</b>
Ramp up	8	Standard
Training sequence	24	Standard
Start flag	8	Standard
Data field	184	See Table 12
End flag	8	Standard. Propagation time delay difference = 8 bits
Buffer	24	Bit stuffing = 4 bits Synch jitter (mobile station) = 3 bits Synch jitter (mobile/satellite) = 1 bit Propagation time delay difference = 16 bits
Total	256	Standard

Thus the proposed data field for Message 27 is shown in Table 12.

TABLE 12

**Proposed new data field for AIS satellite detection Message 27**

<b>Parameter</b>	<b>Number of bits</b>	<b>Description</b>
Core message	96	Message ID, MMSI number, latitude, longitude, speed, course, ...
CRC 16	16	CRC on core message
Information message	72	Destination, ...
<b>Total number of bits</b>	<b>184</b>	