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Radiocommunication Study Groups

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Annex 8 to Working Party 5B Chairman's Report

PRELIMINARY DRAFT NEW RECOMMENDATION ITU-R M.[VDES]*

Technical characteristics for a VHF data exchange system in the VHF maritime mobile band

Scope

This Recommendation provides the technical characteristics of a VHF data exchange system (VDES) which integrates the functions of VHF data exchange (VDE), application specific messages (ASM) and the automatic identification system (AIS) in the VHF maritime mobile band (156.025-162.025 MHz).

Keywords

[TBD]

Glossary

ACPR: Adjacent channel power ratio
AIS: Automatic identification system
AOS: Acquisition-of-signal
ASM: Application specific messages
CIRM: Comité International Radio Maritime
CSTDMA: Carrier sense time division multiple access
DA: Doherty amplifier
DPD: Digital pre-distortion
ET: Envelope Tracking
FATDMA: Fixed access time-division multiple access
FEC: Forward error correction
IALA: International Association of Marine Aids to Navigation and Lighthouse Authorities
ICAO: International Civil Aviation Organization

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* This Recommendation should be brought to the attention of the International Maritime Organization (IMO), the International Civil Aviation Organization (ICAO), the International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA), the International Electrotechnical Commission (IEC) and the Comité International Radio Maritime (CIRM).

IEC: International Electrotechnical Commission
IMO: International Maritime Organization
ITDMA: Incremental time division multiple access
LEO: Low-earth orbiting
MEO: Medium-earth orbiting
MMSI: Maritime mobile service identity
OFDM: Orthogonal frequency division multiple access
PAPR: Peak to average power ratio
PFD: Power flux-density
RR: Radio Regulations
RSSI: received signal strength indication
SOLAS: Safety of life at sea convention
SOTDMA: Self-organized time division multiple access
TDMA: Time division multiple access
VDE: VHF data exchange
VDES: VHF data exchange system
VDL: AIS VHF data link

The ITU Radiocommunication Assembly,

considering

a) that the International Maritime Organization (IMO) has a continuing requirement for a universal shipborne automatic identification system (AIS);

b) that the use of a universal shipborne AIS allows efficient exchange of navigational data between ships and between ships and shore stations, thereby improving safety of navigation;

c) that the VHF data exchange system (VDES) should use appropriate access schemes that ensure the protection of AIS while making efficient use of the spectrum and accommodate all users;

d) that while AIS is used primarily for surveillance and safety of navigation purposes in ship to ship use, ship reporting and vessel traffic services applications, a growing need for other maritime safety related communications has developed;

e) that the VDES shall give priority to AIS, and also accommodate future expansion in the number of users and diversification of data communications applications, including vessels which are not subject to IMO AIS carriage requirements, aids to navigation and search and rescue;

f) that the VDES has data communications capacity and technical characteristics that support the harmonized collection, integration, exchange, presentation and analysis of marine information onboard and ashore by electronic means to enhance berth to berth navigation and related services for safety and security at sea and protection of the marine environment,

recognizing

that the implementation of VDES must ensure that the functions of digital selective calling, AIS and voice distress, safety and calling communication (Channel 16), are not impaired,

noting

that the report ITU-R M.[VDES-SELECT] describes the use cases and requirement for VDES,

recommends

1 that VDES should be designed in accordance with the operational characteristics given in Annex 1 and the technical characteristics and examples given in the following Annexes;

2 that applications of the VDES which make use of application specific messages (ASM) designed for AIS, as defined in Recommendation ITU-R M.1371 should also take into account the international application identifier branch, as specified in IMO SN Circ. 289, maintained and published by IMO;

3 that the design and installation of VDES should also consider relevant technical requirements, recommendations and guidelines published by IMO, IEC and IALA.

ANNEX 1

Operational characteristics of a VHF data exchange system in the VHF maritime mobile band

4 General

1.1 The system should give its highest priority to the automatic identification system (AIS) position reporting and safety related information.

1.2 The system installation should be capable of receiving and processing the digital messages and interrogating calls specified by this Recommendation.

1.3 The system should be capable of transmitting additional safety information on request.

1.4 The system installation should be able to operate continuously while under way, moored or at anchor.

1.5 The system should use for the terrestrial links time-division multiple access (TDMA) techniques, access schemes and data transmission methods in a synchronized manner as specified in the Annexes.

1.6 The system should be capable of various modes of operation, including the autonomous, assigned and polled modes.

1.7 The system should provide flexibility for the users in order to prioritize some applications and consequently adapting some parameters of the transmission (robustness or capacity) while minimizing system complexity.

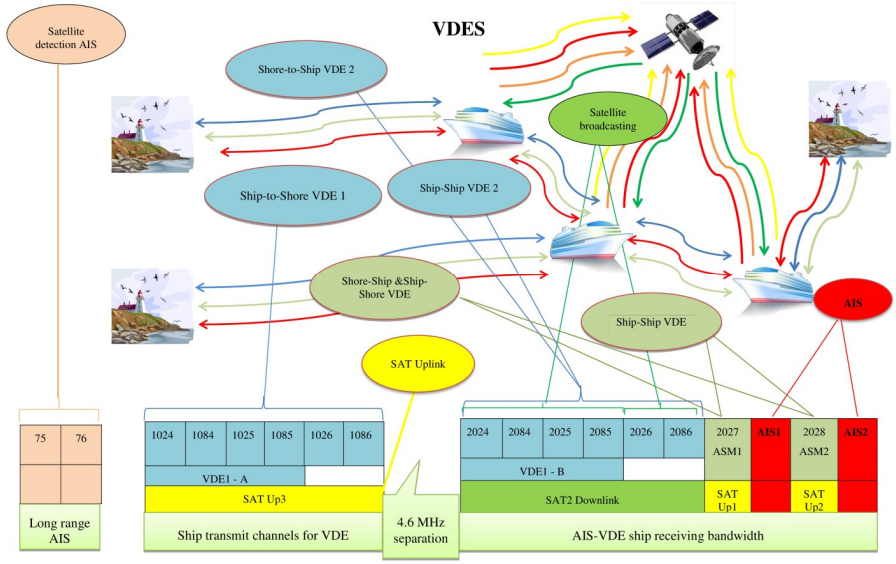
1.8 The system should address the use cases identified in the report ITU-R M.[VDES-SELECT].

5 VHF data exchange system functions and frequency usage

VDES functions and frequency usage are illustrated pictorially in Figure 1~~Figure 1~~.

FIGURE 1

VHF data exchange system functions and frequency usage



NOTE – SAT Up is receive-only by satellite.

5.1 VHF data exchange system channel usage in accordance with RR Appendix 18

5.1.1 VHF data exchange system data exchange between terrestrial stations

– AIS 1 (channel 2087) and AIS 2 (channel 2088) are AIS channels, in accordance with Recommendation ITU-R M.1371;

– ASM 1 (channel 2027) and ASM 2 (channel 2028) are the channels used for application specific messages (ASM);

– VDE1-A lower legs (channels 1024, 1084, 1025, 1085) are ship-to-shore VDE;

– VDE1-B upper legs (channels 2024, 2084, 2025, 2085) are shore-to-ship and ship-to-ship VDE.

5.1.2 VHF data exchange system data exchange between satellites and terrestrial stations

– AIS 1 (channel 2087) and AIS 2 (channel 2088) are terrestrial AIS channels that are also used as uplinks for receiving AIS messages by satellite;

– Long Range AIS using channel 75 and channel 76 are specified channels to be used as uplinks for receiving AIS messages by satellite. SAT Up1 (channel 2027) and SAT Up 2 (channel 2028) are used for receiving ASM by satellite;

– SAT Up3 (channels 1024, 1084, 1025, 1085,1026 and 1086) are used for ship-satellite VDE uplinks;

– SAT Downlink (channels 2024, 2084, 2025, 2085, 2026 and 2086) are used for satellite-ship VDE downlinks.

5.1.3 Technical characteristics

5.1.3.1 Shipborne VHF data exchange system receivers are protected

As in AIS, shipborne VDES receivers are on the upper legs of RR Appendix **18**, 4.6 MHz above the lower legs, which facilitates protection by filtering from receiver blocking by ships VHF radios.

5.1.3.2. SAT Downlink

The satellite downlink complies with the power flux-density (PFD) mask described in Table 8~~Table 6~~ (section 10) to minimize interference to terrestrial services and to maximize reception by ship VDES stations.

5.1.3.3 VDE1 uses both legs of the duplex channels

Channel capacity is utilized for the duplex channels in VDE1 by using the lower legs (VDE1-A) for ship to shore and the upper legs (VDE1-B) for shore-to-ship and ship-to-ship digital messaging.

Table 1 describes the RR Appendix **18** channels used for the various applications of VDES.

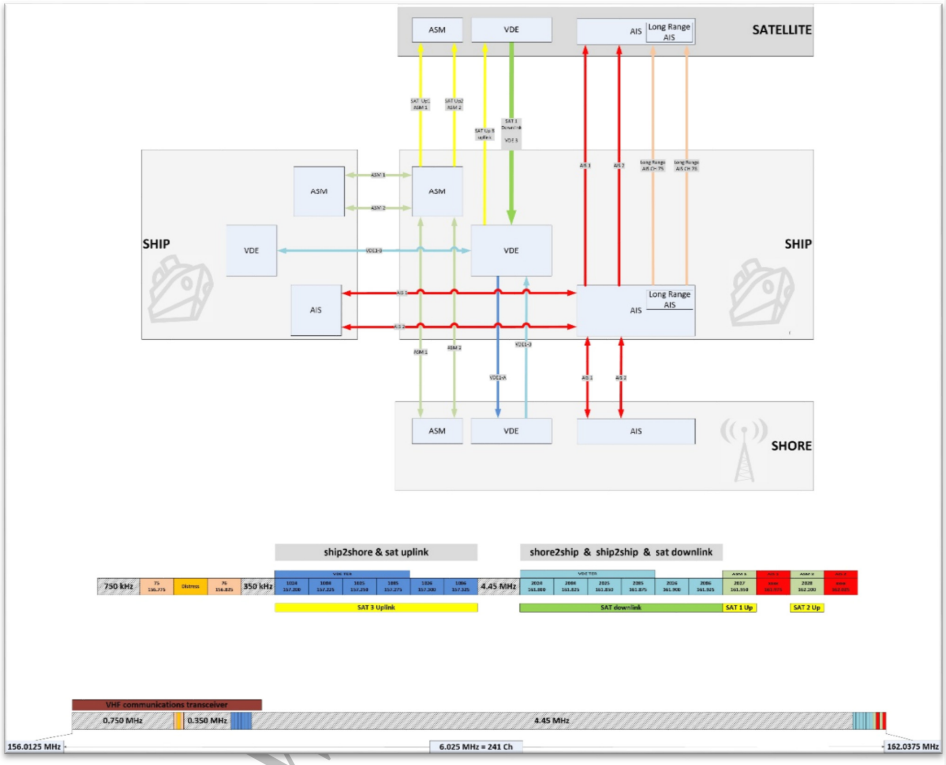
TABLE 1

RR Appendix 18 channels for VHF data exchange systems applications: Automatic identification system, application specific messages, VHF data exchange

RR Appendix 18 channel number		**Transmitting frequencies (MHz)**	
		Ship stations (ship-to-shore) (long range AIS) Ship stations (ship-to-satellite)	**Coast stations Ship stations (ship-to-ship) Satellite-to-ship**
AIS 1		161.975	161.975
AIS 2		162.025	162.025
75 (long range AIS)		156.775 (ships are Tx only)	N/A
76 (long range AIS)		156.825 (ships are Tx only)	N/A
2027 (ASM 1)		161.950 (2027)	161.950 (2027)
2028 (ASM 2)		162.000 (2028)	162.000 (2028)
24/84/25/85 (VDE 1)	24/84/25/85/26/86 (Ship-satellite, satellite-ship)	100/150 kHz channel (24/84/25/85, lower legs (VDE1-A) merged) Ship-to-shore (24/84/25/85/26/86,) Ship-to-satellite	100/150 kHz channel (24/84/25/85, upper legs (VDE1-B) merged) Ship-to-ship, Shore-to-ship (24/84/25/85/26/86,) Satellite-to-ship
24 84 25 85	24 84 25 85 26 86	157.200 (1024)	161.800 (2024)
		157.225 (1084)	161.825 (2084)
		157.250 (1025)	161.850 (2025)
		157.275 (1085)	161.875 (2085)
		157.300 (1026)	161.900 (2026)
		157.325 (1086)	161.925 (2086)

FIGURE 2

VHF data exchange system functions and frequency usage engineer's perspective



6 Identification

Identification and location of all active maritime stations is provided automatically. All VDES stations should be uniquely identified. For the purpose of identification, the appropriate numerical identifier, for example maritime mobile service identity (MMSI), could be used, as defined in the latest version of Recommendation ITU-R M.585. Recommendation ITU-R M.1080 should not be applied with respect to the 10th digit (least significant digit). Automatic identification system

AIS is a part of VDES. AIS should have the highest priority in the VDES, and all other functions should be organized such that the AIS is not adversely affected.

6.1 Automatic identification system VHF data link non-controlling stations

6.1.1 Automatic identification system shipborne station

The AIS part of the shipborne VDES should conform to requirements for Class A shipborne mobile equipment using SOTDMA technology as described in Recommendation ITU-R M.1371, except that the channel switching aspect of channel management should not be used.

6.2 Automatic identification system VHF data link controlling stations

6.2.1 Automatic identification system shore base station

The AIS part of the VDES shore base station should conform to the requirements for AIS base stations as described in Recommendation ITU-R M.1371, except that the channel switching aspect of channel management should not be used in conjunction with VDES. AIS should have the highest priority of all functions in the VDES shore base station, and all other functions should be organized such that the AIS is not adversely affected.

ANNEX 2

Technical characteristics of the Application Specific Messages (ASM) for the VDES in the VHF maritime mobile band

1 Structure of the application specific messages

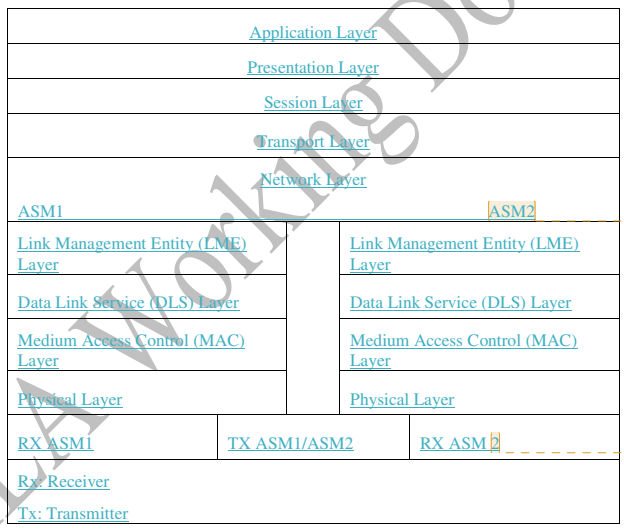
This Annex describes the characteristics of the TDMA access schemes which include random access TDMA (RATDMA), incremental TDMA (ITDMA), fixed access TDMA (FATDMA) techniques.

1.1 Application specific messages layer module

This recommendation covers layers 1 to 4 (physical layer, link layer, network layer and transport layer) of the open system interconnection (OSI) model.

Figure 1 illustrates the layer model of the ASM station (physical layer to transport layer) and the layers of the applications (session layer to applications layer):

FIGURE 1



1.2 Responsibilities of layers for preparing ASM data for transmission

1.2.1 Transport layer

The transport layer is responsible for converting data into transmission packets of correct size and sequencing of data packets.

1.2.2 Network layer

The network layer is responsible for the management of priority assignments of messages, distribution of transmission packets between channels, and data link congestion resolution.

Commented [PB1]: Convert all reference to timing defined by bits to actual time;

Commented [AM2]: Explain subheadings here

Commented [AM3]: The labeling here is confusing – is it necessary?

1.2.3 Link layer

The link layer is divided into three sub-layers with the following tasks:

1.2.3.1 Link management entity

Assemble ASM message bits.

Order ASM message bits into 8-bit bytes for assembly of transmission packet.

1.2.3.2 Data link services

Calculate frame check sequence (FCS) for ASM message bits.

Append FCS to ASM message to complete creation of transmission packet contents.

Complete assembly of transmission packet.

1.2.3.3 Media access control

Provides a method for granting access to the data transfer to the VHF data link (VDL). The method used is a TDMA scheme using a common time reference.

1.2.4 Physical layer

Convert digital transmission packet to π/4 Quadrature Phase-Shift Keying (QPSK) to modulate transmitter.

2 Physical layer

2.1 Parameters

2.1.1 General

The physical layer is responsible for the transfer of a bit-stream from an originator, out on to the data link. The performance requirements for the physical layer are summarized in Tables 1 to 5.

The low setting and the high setting for each parameter is independent of the other parameters.

TABLE 1

Symbol	Parameter name	Units	Low setting	High setting
PH.CHS	Channel spacing (encoded according to RR Appendix 18 with footnotes)(1)	kHz	25	25
PH.ASM1	ASM 1 (2027)(1)	MHz	161.950	161.950
PH.ASM2	ASM 2 (2028)(1)	MHz	162.000	162.000
PH.TXP	Transmit output power	W	1	12.5

(1) See Recommendation ITU-R M.1084, Annex 4.

2.1.2 Constants

TABLE 2

Symbol	Parameter name	Value
PH.DE	Data encoding	Not used
PH.FEC	Forward error correction	Turbo (selectable)
PH.IL	Interleaving	Not used
PH.BS	Bit scrambling	Not used
PH.MOD	Modulation	$\pi/4$QPSK

Commented [JS4]: We should be able to use or not use FEC depending on the environment. This can be encoded into the training sequence.

Commented [AM5]: Alternative is an encoded message type field, such as used for VDES sat downlink format.

Commented [AM6]: Recommend change to TBD, all FEC schemes benefit from interleaving. Interleaver design is based on knowledge of channel/fading characteristics of the ASM channel. There will be more than one model, space and ground link as a minimum, may vary versus mast height and sea state.

Commented [AM7]: Recommend trade was between pi/4 and offset QPSK, without differential encoding.

2.1.3 Transmission media

Data transmissions are made in the VHF maritime mobile band. Data transmissions should use ASM 1 and ASM 2 channels.

2.1.4 Multi-channel operation

The ASM should be capable of receiving on two parallel channels and transmitting on two independent channels. Two separate TDMA receiving processes should be used to simultaneously receive on two independent frequency channels. One TDMA transmitter may be used to alternate TDMA transmissions on two independent frequency channels.

2.2 Transceiver characteristics

The transceiver should perform in accordance with the characteristics set forth herein.

TABLE 3

Minimum required time division multiple access transmitter characteristics

Transmitter parameters	Requirements
Carrier power error	±1.5 dB
Carrier frequency error	± 500 Hz
Slotted modulation mask	Δfc < ±10 kHz: 0 dBc ±10 kHz < Δfc < ±25 kHz: below the straight line between –25 dBc at ±10 kHz and –70 dBc at ±25 kHz ±25 kHz < Δfc < ±62.5 kHz: –70 dBc
Transmitter output power versus time	Power within mask shown in figure 2 and timing in table 4
Spurious emissions	–36 dBm 9 kHz ... 1 GHz –30 dBm 1 GHz ... 4 GHz

Commented [AM8]: Fairly high, a spec of +/- 250 Hz should be economically achievable.

TABLE 4

Definitions of timing for Figure 2

Reference		Bits	Time (ms)	Definition
T_0		0	0	Start of transmission slot. Power should NOT exceed –50 dB of P_{ss} before T_0
T_A		0-12	0-0.625	Power exceeds –50 dB of P_{ss}
T_B	T_{B1}	12	0.625	
	T_{B2}	16	0.833	
T_E ()		466	24.271	
T_F ()		482	25.104	Power should be –50 dB of P_{ss} and stay below this
T_G		512	26.667	Start of next transmission time period

TABLE 5

Minimum required time division multiple access receiver characteristics(1)

Receiver parameters	Requirements
Sensitivity	[20% PER @ –107 dBm]
Error behaviour at high input levels	[1% PER @ –77 dBm] [1% PER @ –7 dBm]
Adjacent channel selectivity	[20% PER @ 70 dB]
Spurious response rejection	[20% PER @ 70 dB]
Intermodulation response rejection	[20% PER @ 74 dB]
Spurious emissions	[–57 dBm (9 kHz to 1 GHz)] [–47 dBm (1 GHz to 4 GHz)]
Blocking	[20% PER @ 86 dB]

Commented [AM9]: Are these from 1371 AIS? If so, I would suggest TBC beside the numbers, once modulation and bit rate/coding are selected, the requisite numbers for equivalent performance may change.

2.3 Modulation scheme

The modulation scheme is π /4 Quadrature Phase-Shift Keying (QPSK).

2.3.1 π /4 QPSK

2.3.1.1 The encoded data should be π /4 QPSK coded before modulating the transmitter.

2.3.1.2 The modulator transmitter roll off used for transmission of data should be maximum 0.35 (highest nominal value).

2.3.1.3 The demodulator used for receiving of data should be designed for a receiver roll off of maximum 0.35 (highest nominal value).

2.3.2 Phase modulation

The coded data should modulate the VHF transmitter.

2.3.3 `Frequency stability

The frequency stability of the VHF radio transmitter/receiver should be ± 500 Hz or better.

2.4 Data transmission bit rate

The transmission bit rate should be max 19.2 kbit/s ± [10] ppm.

2.5 Training sequence /synchronisation header

Data transmission should begin with a 24-bit demodulator synchronisation header (preamble) consisting of one segment synchronization. This segment should consist of [1111100110101 01111110 xx www].

000 – no coding

001 – 1/2 coding

010 – 3/4 coding

011 – 5/6 coding

www – selects waveform

000 - π /4 QPSK

2.6 Data encoding

Not used.

2.7 Forward error correction

Forward error correction is used. Forward error correction will be performed using turbo coding and defined in the synchronisation header.

2.8 Interleaving

Interleaving is not used.

2.9 Bit scrambling

Bit scrambling is not used.

2.10 Data link sensing

Data link occupancy and data detection are entirely controlled by the link layer.

2.11 Transmitter transient response

The attack, settling and decay characteristics of the RF transmitter should comply with the mask as defined in Table 4.

2.11.1 Switching time

The channel switching time should be less than 25 ms

The time taken to switch from transmit to receive conditions, and receive to transmit conditions, should not exceed the transmit attack or release time. It should be possible to receive a message from the slot directly after or before own transmission.

Commented [JS10]: We should consider a training sequence which implements Barker codes and allows for multiple waveforms and coding rates. I would suggest using a combination the 13 bit Barker Code and a start flag: 1111100110101 01111110 xx www.
xx selects the FEC coding:
000 – not coding
001 – 1/2 coding
010 – 3/4 coding
011 – 5/6 coding

www – selects waveform
000 - π /4 DQPSK

Commented [AM11]: Some form of encoding on the waveform/coding selection bits to increase Hamming distance desired, as per discussions on VDES sat downlink modulation / waveforms.

Commented [AM12]: Inconsistent with earlier text.

Commented [AM13]: Should be investigated, and used if forward error correction coding is employed.

Commented [AM14]: What is the switching time as used here? Earlier requirement specified full-time reception of channels ASM1 and ASM2 by suitable receiver. Transmit switching time is another matter, and depends on how other AIS frequencies and ASMs behave for transmissions.
If this is transmit/receive switching time, it is longer than desired, this would imply lost reception in slot before and after an ASM message is transmitted?

The equipment should not be able to transmit during channel switching operation.

The equipment is not required to transmit on the other ASM channel or AIS channels in the adjacent time slot.

2.12 Transmitter power

The power level is determined by the link management entity (LME) of the link layer.

2.12.1 Provision should be made for two levels of nominal power (high power, low power) as required by some applications. The default operation of the ASM station should be on the high nominal power level.

2.12.2 The nominal levels for the two power settings should be 1W and 12.5 W, Tolerance should be within ±1.5 dB.

Commented [AM15]: I would recommend 2 W as a minimum for space detection. Some units could be compliant to standard at 1 W to save battery life. Spec could read 1 or 2 W (low power).

2.13 Shutdown procedure

2.13.1 An automatic transmitter hardware shutdown procedure and indication should be provided in case a transmitter continues to transmit for more than 2 s. This shutdown procedure should be independent of software control.

2.14 Safety precautions

The ASM installation, when operating, should not be damaged by the effects of open circuited or short circuited antenna terminals.

3 Link layer

The link layer specifies how data is packaged in order to apply error detection and correction to the data transfer. The link layer is divided into three (3) sub-layers.

3.1 Sub-layer 1: medium access control

The medium access control (MAC) sub layer provides a method for granting access to the data transfer medium, i.e. the VHF data link. The access scheme is a TDMA scheme using a common time reference.

Commented [AM16]: The way I would explain it, the medium access control is SOTDMA, RATDMA, etc., TDMA is just the multiple access scheme, not the method itself.

3.1.1 TDMA synchronization

TDMA synchronization is achieved using an algorithm based on a synchronization state as described below. The sync state flag within ITDMA communication state, indicates the synchronization state of a station.

The TDMA receiving process should not be synchronized to slot boundaries.

Synchronization other than UTC direct may be provided by the AIS system.

3.1.1.1 Coordinated universal time direct

Commented [JS17]: This could be a problem if the AIS has different timing (semaphore monde) and the ASM box has UTC direct.

A station, which has direct access to coordinated universal time (UTC) timing with the required accuracy should indicate this by setting its synchronization state to UTC direct.

3.1.1.2 Coordinated universal time indirect

Commented [AM18]: These assume synchronization similar to AIS – we can limit the cases from those available for AIS, or widen them – the key issue will be how we expect transponders to behave on the AIS channels.

A station, which is unable to get direct access to UTC, but has access to the AIS system, may get its synchronization from the AIS system. It should then change its synchronization state to indicate the type of synchronization which is being provided by the AIS system.

3.1.2 Time division

The system uses the concept of a frame. A frame equals one (1) minute and is divided into 2250 slots. Access to the data link is, by default, given at the start of a slot. The frame start and stop coincide with the UTC minute, when UTC is unavailable the AIS system may provide the frame synchronization.

3.1.3 Slot phase and frame synchronization

Slot phase synchronization and frame synchronization is done by using information from UTC or from the AIS System.

3.1.3.1 Slot phase synchronization

Slot phase synchronization is the method whereby the slot boundary is synchronized with a high level of synchronization stability, thereby ensuring no message boundary overlapping or corruption of messages.

3.1.3.2 Frame synchronization

Frame synchronization is the method whereby the current slot number for the frame is known.

Commented [AM19]: Introducing definations for super frames or other structures from other annexes may provide future flexibility, for example in specifying behavior of infrequent transmitters (at minutes, 10s minutes or longer intervals in a day). Benefits to hardware can include power savings for battery operated devices with long, well defined sleep cycles.

3.1.3.2.1 Coordinated universal time available

A station, which has direct access to UTC, should continuously re-synchronize its transmissions based on UTC source. A station, which has indirect access to UTC should continuously resynchronize its transmissions based on those UTC sources.

3.1.3.2.2 Coordinated universal time not available

When the station determines that its own internal slot number is equal to the semaphore slot number, it is already in frame synchronization and it should continuously slot phase synchronize.

3.1.3.2.3 Synchronization sources

The primary source for synchronization should be the internal UTC source (UTC direct). If this source should be unavailable the synchronization should be derived from the AIS system.

3.1.4 Slot identification

Each slot is identified by its index (0-2249). Slot zero (0) should be defined as the start of the frame.

3.1.5 Slot access

The transmitter should begin transmission by turning on the RF power at slot start.

The transmitter should be turned off after the last bit of the transmission packet has left the transmitting unit. This event must occur within the slots allocated for own transmission. The default length of a transmission occupies one (1) slot. The slot access is performed as shown in Fig. 3:

FIGURE 3

M.1371-05

3.1.6 Slot state

Each slot can be in one of the following states:

– Free: meaning that the slot is unused within the receiving range of the own station. Externally allocated slots that have not been used during the preceding three frames are also Free slots. This slot may be considered as a candidate slot for use by own station.

– Internal allocation available: meaning that the slot is allocated by own station and can be used for transmission of ASM messages.

– Internal allocation unavailable: meaning that the slot is allocated by own station for the purpose of AIS or ASM transmissions and cannot be a candidate for slot reuse.

– External allocation: meaning that the slot is allocated for transmission by another station and cannot be a candidate for slot reuse.

– Available: meaning that the slot is externally allocated by a station and is a possible candidate for slot reuse.

– Unavailable: meaning that the slot is externally allocated by a station and cannot be a candidate for slot reuse.

- Garbled: meaning that there is significant energy within the slot and no packet received and therefore should not be a candidate for slot reuse.

3.2 Sub layer 2: data link service

The data link service (DLS) sub layer provides methods for:

– data link activation and release;

– data transfer; or

– error detection, correction and control.

3.2.1 Data link activation and release

Based on the MAC sub layer the DLS will listen, activate or release the data link. A slot, marked as free or externally allocated, indicates that own equipment should be in receive mode and listen for other data link users. This should also be the case with slots, marked as available and not to be used by own station for transmission.

3.2.2 Data transfer

Data transfer should use a bit-oriented protocol and should be in accordance with this standard.

3.2.2.1 Packet format

Data is transferred using a transmission packet as shown in Fig. 4:

Commented [PB20]: Update figure to delete 100/80%

Field Code Changed

Formatted: Normal

Commented [JS21]: May be message type dependent

FIGURE 4

Ramp up 16 bits	Training Sequence 24 bits	Data 384 bit	CRC 32 bits	End Flag 8 bits	Buffer 48 bits

The packet should be sent from left to right. The training sequence should be used in order to synchronize the VHF receiver. The total length of the default packet is 512 bits. This is equivalent to one (1) slot.

3.2.2.3 Ramp-up

The ramp-up portion of the waveform provides for a gradual transition to transmission state from transmitter off state. A gradual ramp-up period provides important spectral shaping to reduce energy spread outside the desired signal modulation bandwidth, and reduces interference to other users of the current and adjacent channel.

Synchronisation Header

The synchronisation header should be a bit pattern consisting of 1111100110101 01111110 xx www(ref 2.5). The synchronisation header is not subject to coding but is included in the CRC .

3.2.2.4 Data

The data portion is 384 bits long in the default transmission packet. The content of data is undefined at the DLS. Transmission of data, which occupy more than 384 bits, is described in § xxx.

3.2.2.5 Frame check sequence

The FCS uses the cyclic redundancy check (CRC) 32-bit polynomial to calculate the checksum as defined in ISO/IEC 13239:2002. The CRC bits should be pre-set to one (1) at the beginning of a CRC calculation. The synchronisation header and data should be included in the CRC calculation.

3.2.2.6 End flag

The end flag should be 8 bits long. It is used in order to detect the end of a transmission packet. The end flag consists of a bit pattern, 8 bits long: 01111110 ($7E_h$). The CRC is used to ensure the proper end flag has been found.

3.2.2.7 Buffer

The buffer is 40 bits long and should be used as follows:

–
– distance delay: 28 bits
– synchronization jitter: 12 bits

Commented [PB22]: Training sequence needs to be updated;

Field Code Changed

Commented [AM23]: Default packet can be shorter, to minimize space-based interference between packets on adjacent slots. Using code of less than rate ½ will still provide substantial message 'payload' data volume (prior to coding).

Commented [PB24]: Add header numbering

Commented [PB25]: Add reference when defined

Commented [AM26]: Not necessarily required, per discussions for sat to ship VDES downlink. Predefined length of message with given coding rate should suffice (as bit stuffing is not recommend as well).

Commented [PB27]: Should reference time rather than bits

Commented [PB28]: Should be the same as AIS

3.2.2.7.1 Distance delay[1]

A buffer value of 28 bits is reserved for distance delay. This is equivalent to 235.9 nautical miles (NM). This distance delay provides protection for a propagation range of over 120 NM. For messages intended for satellite reception a buffer value of 196 bits is reserved for distance delay.

Commented [PB29]: Should reference time

Commented [AM30]: Can expand this definition for space reception case - ?

3.2.2.7.1 Synchronization jitter

For synchronization jitter refer to Recommendation ITU-R M.1371 Annex 2

3.2.2.8 Summary of the default transmission packet

The data packet is summarized as shown in Table 6:

TABLE 6

Commented [PB31]: Need to try to make this generic to accommodate different modulation techniques;

Ramp up	16 bits	T0 to TTS in Fig. 8
Training sequence	24 bits	Necessary for synchronization
Data	384 bits	Default
CRC	32 bits	Only the data field is included in the CRC
End flag	8 bits	Fixed value of 7E
Buffer	48 bits	Bit stuffing distance delays, repeater delay and jitter
Total	512 bits	

Commented [PB32]: How likely is it that turbo coding could create an invalid end flag?

3.2.2.9 Transmission timing

There should be no modulation during the ramp down period.

3.2.2.10 Long transmission packets

A station may occupy at maximum 5 consecutive slots for one (1) continuous transmission. Only a single application of the overhead (ramp up, training sequence, flags, FCS, buffer) is required for a long transmission packet. The length of a long transmission packet should not be longer than necessary to transfer the data; i.e. the ASM should not add filler.

3.2.3 Error detection and control

Error detection and control should be handled using the CRC polynomial as described in § 3.2.2.5. CRC errors should result in no further action by the ASM.

3.2.4 Forward Error correction

Turbo Coding – selectable rate

3.3 Sub layer 3 – link management entity

The LME controls the operation of the DLS, MAC and the physical layer.

[1] 1 Nautical mile = 1 852 metres

235.9 Nautical miles = 436 886.8 metres; 120 Nautical miles = 222 240 metres

3.3.1 Access to the data link

There should be different access schemes for controlling access to the data transfer medium. The application and mode of operation determine the access scheme to be used. The access schemes are ITDMA, RATDMA, [SOTDMA], and FATDMA.

3.3.1.1 Cooperation on the data link

The access schemes operate continuously, and in parallel, on the same physical data link. They all conform to the rules set up by the TDMA. The ASM systemmust give priority to the AIS system when accessing the physical data link.

3.3.1.2 Candidate slots

Slots, used for transmission, are selected from *candidate slots* in the selection interval (SI) which is defined as 150 slots for an ASM transmission. The selection process uses received data. There should be at minimum four candidate slots to choose. When selecting candidates for messages longer than one (1) slot, a candidate slot should be the first slot in a consecutive block of free. The candidate slots are selected from free slots.

The purpose of maintaining a minimum of four candidate slots within the same probability of being used for transmission is to provide high probability of access to the link. To further provide high probability of access, time-out characteristics are applied to the use of the slots so that slots will continuously become available for new use.

3.3.2 Modes of operation

There should be three modes of operation. The default mode should be autonomous and may be switched to/from other modes.

3.3.2.1 Autonomous

A station operating autonomously should determine its own schedule for transmission. The station should automatically resolve scheduling conflicts with other stations.

3.3.2.2 Assigned

A station operating in the assigned mode takes into account the transmission schedule of the assigning message when determining when it should transmit.

3.3.2.3 Polled

A station operating in polled mode should automatically respond to interrogation messages. Operation in the polled mode should not conflict with operation in the other two modes. The response should be transmitted on the channel where the interrogation message was received.

3.3.3 Initialization

At power on, a station should monitor the TDMA channels for one (1) minute to determine channel activity, other participating member IDs, current slot assignments, and possible existence of shore stations. During this time period, a dynamic directory of all stations operating in the system should be established. A frame map should be constructed, which reflects TDMA channel activity. After one (1) minute has elapsed, the station may be available to transmit ASM messages according to its own schedule.

Commented [PB33]: Verify that 1371 describes RATDMA such that multiple slots entry is supported;

Commented [PB34]: Must VDE give priority to ASM or vice-versa?

Commented [AM35]: Why 150 candidate slots? Is this from 2,250?

Commented [PB36]: Need to think through a more appropriate means than the 1371 definition of slot reuse

3.3.4 Channel access schemes

The access schemes, as defined below, should coexist and operate simultaneously on the TDMA channel. For all access schemes there should be a minimal interval of x slots between transmissions, and the unit should not be rude.

Commented [PB37]: Replace with reference to 1371 provided RATDMA as described in 1371 is adequate for multi-slot; Also include FATMDA (missing here)

Commented [PB38]: The minimal interval should be tied to the channel load rather than a fixed interval (look into repeater standard for threshold), and should consider AIS activity as well

3.3.4.1 Incremental time division multiple access

The ITDMA access scheme allows a station to pre-announce additional transmission slots.

3.3.4.1.1 Incremental time division multiple access algorithm

Commented [PB39]: Taken directly from 1371

A station can begin its ITDMA transmission by allocating a new, unannounced slot, using RATDMA.

Prior to transmitting in the first ITDMA slot, the station may randomly select the next following ITDMA slot and calculate the relative offset to that location. This offset should be inserted into the ITDMA communication state. Receiving stations will be able to mark the slot indicated by this offset, as externally allocated. The communication state is transmitted as a part of the ITDMA transmission. The process of allocating slots continues as long as required. In the last ITDMA slot, the relative offset is set to zero and no new slots are allocated.

3.3.4.1.2 Incremental time division multiple access parameters

The parameters of Table 7 control ITDMA scheduling:

TABLE 7

Symbol	Name	Description	Minimum	Maximum
LME.ITINC	Slot increment	The slot increment is used to allocate a slot ahead in the frame. It is a relative offset from the current transmission slot. If it is set to zero, no more ITDMA allocations should be done	0	8 191
LME.ITSL	Number of slots	Indicates the number of consecutive slots, which are allocated, starting at the slot increment	1	5
LME.ITKP	Keep flag	This flag should be set to TRUE when the present slot(s) should be reserved in the next frame also. The keep flag is set to FALSE when the allocated slot should be freed immediately after transmission	False = 0	True = 1

3.3.4.2 Random access time division multiple access

RATDMA is used when a station needs to allocate a slot, which has not been pre-announced. This is generally done as the first transmission slot for a message group, or for messages that cannot be pre-announced by a previous transmission.

3.3.4.2.1 Random access time division multiple access algorithm

The RATDMA access scheme should use a probability persistent (p-persistent) algorithm as described in this paragraph (see Table 8).

An ASM station should avoid using RATDMA when possible. A previously scheduled message should be used to announce a future transmission when possible to avoid RATDMA transmissions.

Messages, which use the RATDMA access scheme, are stored in a priority first-in first-out (FIFO). When a candidate slot is detected, the station randomly select a probability value (LME.RTP1) between 0 and 100. This value should be compared with the current probability for transmission (LME.RTP2). If LME.RTP1 is equal to, or less than LME.RTP2, transmission should occur in the candidate slot. If not, LME.RTP2 should be incremented with a probability increment (LME.RTPI) and the station should wait for the next candidate slot in the frame.

The SI for RATDMA should be 150 time slots, which is equivalent to 4 s. The candidate slot set should be chosen within the SI, so that the transmission occurs within 4 s.

Commented [AM40]: This implies very fast transmission rate on the average per device – there may be many cases where much more infrequent operation is adequate, and sharing of the channel should ideally also be efficient in such a scenario.

Each time that a candidate slot is entered, the p-persistent algorithm is applied. If the algorithm determines that a transmission shall be inhibited, then the parameter LME.RTCSC is decremented by one and LME.RTA is incremented by one.

LME.RTCSC can also be decremented as a result of another station allocating a slot in the candidate set. If LME.RTCSC + LME.RTA < 4 then the candidate set shall be complemented with a new slot within the range of the current slot and LME.RTES following the slot selection criteria.

3.3.4.2.2 Random access time division multiple access parameters

The parameters of Table 8 control RATDMA scheduling:

TABLE 8

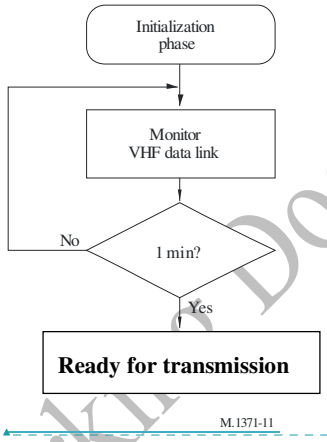
Symbol	Name	Description	Minimum	Maximum
LME.RTCSC	Candidate slot counter	The number of slots currently available in the candidate set. NOTE 1 – The initial value is always 4 or more (see § 3.3.1.2). However, during the cycle of the p-persistent algorithm the value may be reduced below 4	1	150
LME.RTES	End slot	Defined as the slot number of the last slot in the initial SI, which is 150 slots ahead	0	2 249
LME.RTPRI	Priority	The priority that the transmission has when queuing messages. The priority is highest when LME.RTPRI is lowest. Safety related messages should have highest service priority (refer to § 4.2.3)	1	0
LME.RTPS	Start probability	Each time a new message is due for transmission, LME.RTP2 should be set equal to LME.RTPS. LME.RTPS shall be equal to 100/LME.RTCSC. NOTE 2 – LME.RTCSC is set to 4 or more initially. Therefore LME.RTPS has a maximum value of –25 (100/4)	0	25
LME.RTP1	Derived probability	Calculated probability for transmission in the next candidate slot. It should be less than or equal to LME.RTP2 for transmission to occur, and it should be randomly selected for each transmission attempt	0	100
LME.RTP2	Current probability	The current probability that a transmission will occur in the next candidate slot	LME.RTPS	100
LME.RTA	Number of attempts	Initial value set to 0. This value is incremented by one each time the p-persistent algorithm determines that a transmission shall not occur	0	149

LME.RTPI	Probability increment	Each time the algorithm determines that transmission should not occur, LME.RTP2 should be incremented with LME.RTPI. LME.RTPI shall be equal to (100 – LME.RTP2)/LME.RTCSC	1	25

3.3.4.4 Initialization phase

The initialization phase is described using the flowchart shown in Fig. 10.

FIGURE 10



Monitor VHF data link

At power on, a station should monitor the TDMA channel for one (1) min interval to determine channel activity, other participating member IDs, current slot assignments and reported positions of other users, and possible existence of base stations. During this time period, a dynamic directory of all members operating in the system should be established. A frame map should be constructed, which reflects TDMA channel activity.

Network access and entry of a new data stream

- Initial network entry using RATDMA
- Entry of new data stream using previously allocations by ITDMA
- For periodic transmissions using ITDMA schedule
- Single message transmission using RATDMA or scheduled ITDMA
- Dynamic allocation of additional slots using existing ITDMA
- Priority of transmissions
- Limits how many slots
- Required intervals between transmission, adaptive to the channel load;
- Respect for AIS channel activity (both for transmission and reception);

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Field Code Changed

Commented [AM41]: Is such a slot or frame map similar to Class-A, and subject to license fee if used for lower tier transponders? If so, should a slot-map free variation be also available?

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Commented [PB42]: We need to define in a stand-alone section what we mean by "respect AIS" similar to the slot reuse description;

Assigned operation

A controlling station may:

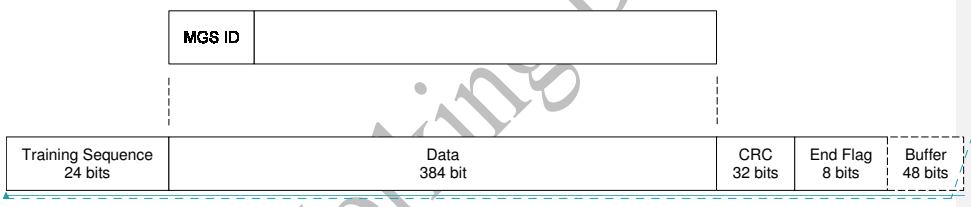
- Assign slots to a mobile station
- Exclude slots for autonomous use by other stations
- Limit the amount of slots for a specific station or in an area
- The controlling station needs to support authentication

Entering assigned mode
Operating in the assigned mode
Returning to autonomous and continuous mode

Message structure

Messages, which are part of the access schemes, should have the following structure shown in Fig. 11 inside the data portion of a data packet: TBD

FIGURE 11



Each message is described using a table with parameter fields listed from top to bottom. Each parameter field is defined with the most significant bit first.

Parameter fields containing sub-fields (e.g. communication state) are defined in separate tables with sub-fields listed top to bottom, with the most significant bit first within each sub-field.

Character strings are presented left to right most significant bit first. All unused characters should be represented by the @ symbol, and they should be placed at the end of the string.

When data is output on the VHF data link it should be grouped in bytes of 8 bits from top to bottom of the table associated with each message in accordance with ISO/IEC 13239:2002. Each byte should be output with least significant bit first.

Unused bits in the last byte should be set to zero in order to preserve byte boundary.

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Commented [PB43]: Make this clear that the message length here is the maximum for a single slot, however the message can be up to 5 slots; variable length field

Field Code Changed

Generic example for a message table:

TABLE 11

Parameter	Symbol	Number of bits	Description
P1	T	6	Parameter 1
P2	D	1	Parameter 2
P3	I	1	Parameter 3
P4	M	27	Parameter 4
P5	N	2	Parameter 5
Unused	0	3	Unused bits

Logical view of data as described in § 3.3.7:

Bit order	M----L--	M-------	--------	--------	--LML000
Symbol	TTTTTTDI	MMMMMMMM	MMMMMMMM	MMMMMMMM	MMMNN000
Byte order	1	2	3	4	5

Output order to VHF data link (bit-stuffing is disregarded in the example):

Bit order	--L----M	-------M	--------	--------	000LML--
Symbol	IDTTTTTT	MMMMMMMM	MMMMMMMM	MMMMMMMM	000NNMMM
Byte order	1	2	3	4	5

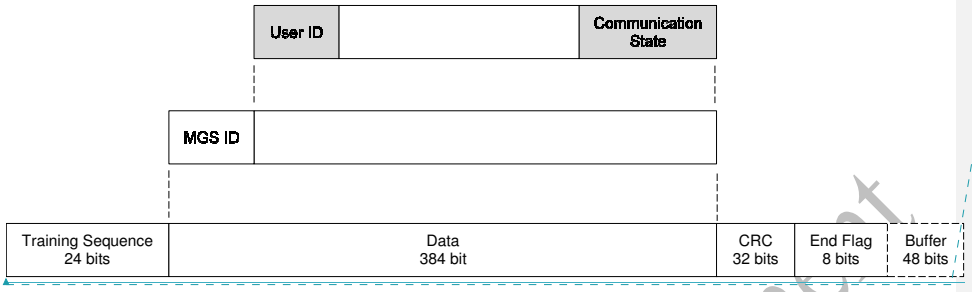
Message identification

The message ID should be 6 bits long and should respect the current definitions of message IDs as defined for AIS in ITU-R M.1371.

Incremental time division multiple access message structure

The ITDMA message structure supplies the necessary information in order to operate in accordance with § xxx. The message structure is shown in Fig. 12:

FIGURE 12



Field Code Changed

User identification

The user ID should be a unique identifier and is [30] bits long.

Incremental time division multiple access communication state

The communication state provides the following functions:

– it contains information used by the slot allocation algorithm in the ITDMA concept;

– it also indicates the synchronization state.

The ITDMA communication state is structured as shown in Table 12:

TABLE 12

Parameter	Number of bits	Description
Sync state	2	0 UTC direct (see § 3.1.1.1) 1 UTC indirect (see § 3.1.1.2)
Slot increment	13	Offset to next slot to be used, or zero (0) if no more transmissions
Number of slots	3	Number of consecutive slots to allocate. 0 = 1 slot, 1 = 2 slots, 2 = 3 slots, 3 = 4 slots, 4 = 5 slots, 5 = 1 slot; offset = slot increment + 8 192, 6 = 2 slots; offset = slot increment + 8 192, 7 = 3 slots; offset = slot increment + 8 192. Use of 5 to 7 removes the need for RATDMA broadcast for scheduled transmissions up to 6 min intervals
Keep flag	1	Set to TRUE = 1 if the slot remains allocated for one additional frame (see Table 13)

The ITDMA communication state should apply only to the slot in the channel where the relevant transmission occurs. ASM 1 and ASM 2 are independent channels.

4 Optional message for long-range application (satellite)

Long-range applications may be provided by VDES equipment. It also may provide, by dedicated equipment, for long-range application.

Commented [PB44]: Make sure that whatever is defined here does not violate the rules of "politeness" as defined for terrestrial comms

4.1 General

The medium access control (MAC) sub layer provides a method for granting access to the data transfer medium, i.e. the VHF data link. The method used is a TDMA scheme using a common time reference.

4.1 Long-range applications by broadcast

Long-range ASM receiving systems may receive long-range ASM broadcast messages, provided these messages are appropriately structured and transmitted to suit the receiving systems.

4.2 Packet bit structure for long-range broadcast message

Long-range ASM receiving systems require suitable guard period and buffering in order to preserve the integrity of the ASM message in the ASM slot boundaries. Table ** shows an example of a modified packet bit structure that is designed to support reception of ASM messages by satellites with orbital altitudes up to 600 km.

TABLE **

Modified packet bit structure for long-range ASM message reception

Slot composition	Bits	Notes
Guard period	100	Propagation time delay difference = 144 bits Propagation time delay difference of the other ASM messages = 28 bits Ramp up = 16 bits Note - Propagation time delay difference may be changed in accordance with the target satellite orbital altitude
Ramp up	16	Standard
Training sequence	24	Standard
Data field	170	Data field is 384 bits for other single-slot ASM messages. This field is shortened by 194 bits to support the long-range receiving system Message ID = 6 bits User ID = 30 bits Spare = 6 bits Binary data = 128 bits Note – Binary data length may be changed in accordance with the target satellite orbital altitude
CRC	32	Standard
End flag	8	Standard
Long-range ASM receiving system buffer	162	Bit stuffing = 8 bits Synch jitter (mobile station) = 6 bits Synch jitter (mobile/satellite) = 2 bits Propagation time delay difference = 144 bits Spare = 2 bits Note - Propagation time delay difference may be changed in accordance with the target satellite orbital altitude

Commented [PB45]: Bit stuffing will not be used this needs to be adjusted as appropriate

Total	512	Standard

4.2.1 Long-range automatic identification system broadcast message

The long-range ASM broadcast message data field is shown in Table **.

This message should be transmitted by shipborne mobile station.

TABLE **

Long-range ASM broadcast message data field

Parameter	Number of bits	Description
Message ID	6	Identifier for this message; always **
User ID	30	MMSI number
Binary data	138	
Spare	16	Set to zero, to preserve byte boundaries
Total number of bits	190	

4.3 Transmission method for the long-range automatic identification system broadcast message

The long-range ASM broadcast message may be transmitted using an arbitrary ASM channel at the current power setting as a transmit-only function.

4.3.1 Access scheme

There should be different access schemes for controlling access to the data transfer medium. The application and mode of operation determine the access scheme to be used.

The access schemes for the long-range ASM are ITDMA, RATDMA and CSTDMA. The ITDMA and RATDMA should be used in accordance with § 3.3.

4.3.2 Carrier sense time division multiple access

The CSTDMA access scheme may be selected by the long-range ASM message application as an optional.

4.3.2.1 Carrier sense detection method

Within a time window of 1 146 µs starting at 833 µs and ending at 1 979 µs after the start of the time period intended for transmission (T_0) ASM equipment using CSTDMA should detect if that time period is used (CS detection window).

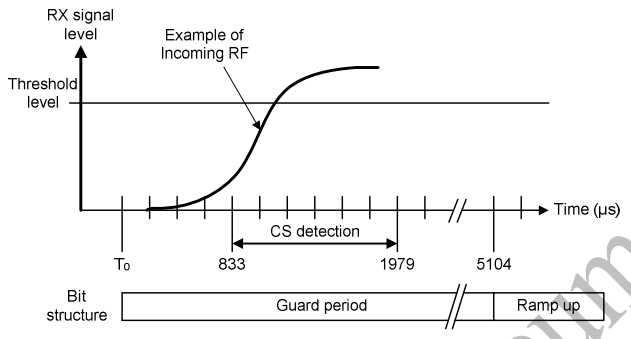
NOTE 1 – Signals within the first 16 bits (833 µs) of the time period are excluded from the decision (to allow for propagation delays and ramp down periods of other units).

ASM equipment using CSTDMA should not transmit on any time period in which, during the CS detection window, a signal level greater than the "CS detection threshold" (§ 4.3.2.2) is detected.

The transmission of a CSTDMA packet should commence 90 bits (4 688 µs + T_0) after the nominal start of the time period (see Fig. 35).

FIGURE **

Carrier sense timing



Field Code Changed

4.3.2.2 Carrier sense detection threshold

The carrier sense (CS) detection threshold should be determined over a rolling 60 s interval on each Rx channel separately. The threshold should be determined by measuring the minimum energy level (representing the background noise) plus an offset of 10 dB. The minimum CS detection threshold should be –107 dBm and background noise should be tracked for a range of at least 30 dB (which results in a maximum threshold level of –7 dBm)[2].

4.3.2.3 Multi-channel operation

If ASM uses only for long-range application with only CSTDMA access scheme. The ASM should be capable of receiving on two independent channels and transmitting on two independent channels. At least one TDMA receiving process should be used to receive on two independent frequency channels. One TDMA transmitter should be used to alternate TDMA transmissions on two independent frequency channels.

4.4 Transmitting the long-range broadcast message

The long-range ASM broadcast message should be transmitted only on ASM channels and not on the AIS channels (channels 75, 76, AIS 1, AIS 2 or regional channels).

[2] The following example is compliant with the requirement:

Sample the RF signal strength at a rate >1 kHz, average the samples over a sliding 20 ms period and over a 4 s interval determine the minimum period value. Maintain a history of 15 such intervals. The minimum of all 15 intervals is the background level. Add a fixed 10 dB offset to give the CS detection threshold.

Annex 3 – VDE-Terrestial specific

Annex 3 shall contain the general information suitable for ITU-R M.VDES-0.

Overall document structure

Annex 1 VDES Operation

Annex 2 (ASM)

Annex 3 (VDE-TER)

Annex 4 (VDE-SAT-Downlink)

Annex 5 (VDE-SAT-Uplink)

Annex 6 TER-SAT sharing

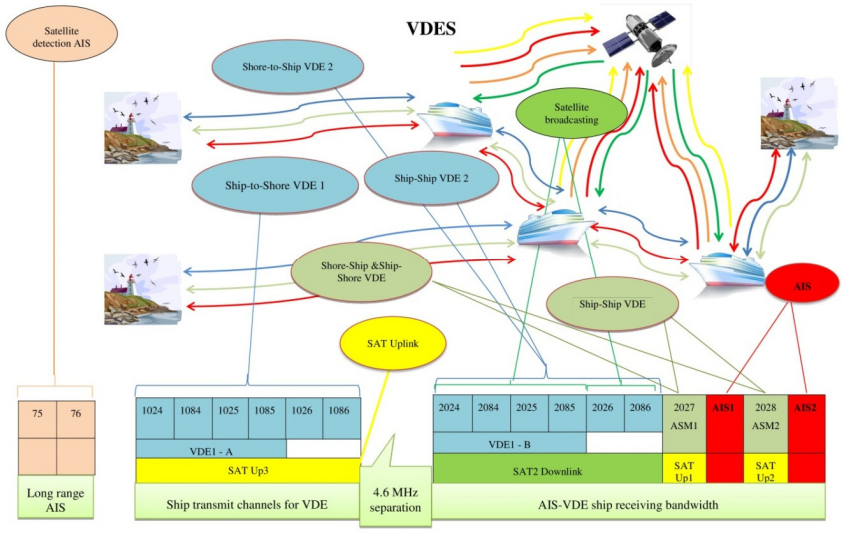
Review/working group:

Johan Lindborg,
Stefan Bober,
Mark Johnson,
Hans Haugli , - Synchronisation (Preamble, postamble?) + Pysical Layer Header
Arunas (Exact Earch),-Link budget table
Hiroyasu (Furuno),
Yoshi (JRC), -Input for link budget, Spectrum mask input
Giuanluigi DLR, - Review error correction coding, interleaver suggestion
Nader (ESA), - Interleaver input
Krysztof Bronk, - scrambling, Synchronisation (Preamble, postamble?) + Pysical Layer Header

Table of Contents

Annex 3

Technical characteristics of VDE-terrestrial in the maritime mobile band



1.1 VHF data exchange system channel usage in accordance with RR Appendix 18

1.1.1 5.1.1 VHF data exchange system data exchange between terrestrial stations

- VDE1-A lower legs (channels 1024, 1084, 1025, 1085) are ship-to-shore VDE;
- VDE1-B upper legs (channels 2024, 2084, 2025, 2085) are shore-to-ship and ship-to-ship VDE.

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2 OSI Layer (from Annex 2)

The VDES architecture utilizes the open systems interconnection (OSI) model as illustrated in Figure 7~~Figure 3~~.

The first four layers (physical, link, network and transport) are described with-in this recommendation. These layers for the VDE, ASM and AIS sub-systems need to be coordinated. AIS should have the highest priority in the VDES, and all other functions should be organized such that the AIS is not adversely affected.

FIGURE 4

Application Layer		
Presentation Layer		
Session Layer		
Transport Layer		
Network Layer VDE1-A VDE1-B		
Link Management Entity (LME) Layer		Link Management Entity (LME) Layer
Data Link Service (DLS) Layer		Data Link Service (DLS) Layer
Medium Access Control (MAC) Layer		Medium Access Control (MAC) Layer
Physical Layer		Physical Layer
RX (shore)/ TX(ship)		RX(ship/shore?) / TX (shore)
Rx: Receiver Tx: Transmitter		

The VDES architecture should utilize the open systems interconnection layers 1 to 4 (physical layer, link layer, network layer, transport layer) as illustrated in **Figure 7**~~Figure 3~~.

FIGURE 3

open systems interconnection layers 1-4

Layer 4	Transport	Layer 1 – Layer 3
Layer 3	Network	
Layer 2	Data Link	

Commented [PB46]: Harmonize this across all annex's

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Commented [PR47]: Consider physical channels and logical channels

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Layer 1b	Access		
Channels	VDE	ASM	AIS

2.1 Transport layer

The transport layer is responsible for converting data into transmission packets of correct size and sequencing of data packets.

2.1.1 Network layer

The network layer is responsible for the management of priority assignments of messages, distribution of transmission packets between available channels, and data link congestion resolution.

2.1.2 Link layer

The link layer orders VDE messages into 8bit bytes for assembly of transmission packets.

Applies error correction coding, scrambling and interleaving. Calculate CRC and appends to data to complete creation of transmission packets.

1.2.3.3 Media access control

Provides a method for granting access to the data transfer to the VHF data link (VDL). The method used is a TDMA scheme using a common time reference.

2.1.3 Physical layer

Converts binary data into transmission symbols. Assembles transmission symbols, synchronization, and other overhead symbols to transmission packets. Converts transmission packets to appropriate analogue signal for the transmitter, according to the selected modulation and channelization scheme.

3 Physical layer (Ship/Shore)

3.1 Parameters

3.2 General

3.3 Transmission media

Data transmissions are made in the VHF maritime mobile band. Data tranmissions are made within the spectrum allocated for VDE1-A and VDE1-B. The spectrum may be used as 25kHz, 50 kHz and 100kHz channels. Additional spectum may be available for VDE communication on a regional basis.

3.4 Multi-channel operation

3.4.1 Ship to ship communication uses the VDE1-B spectrum in a simplex mode

3.4.2 Ship to shore communication uses the VDE1-A spectrum for transmission and VDE1-B spectrum for reception.

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Shore to ship communication uses the VDE1-B spectrum for transmission and VDE1-A and VDE1-B spectrum for reception.

When 25kHz channels are combined to form either a 50kHz or 100kHz bandwidth, the following methodology shall be used ... (bulletin board???)

3.5 Transceiver characteristics

3.5.1 Transmit power

The maximum average power shall not exceed 25W per 25kHz, 50kHz and 100Khz used spectrum at a time. Spectral mask, Emission Assumptions

-Insert figures from 1842 or 1371

25kHz as AIS.

Possible Modulation schemes for future considerations
(Create table of modulation, and related parameters)
GFSK
GMSK
PI/4 QPSK
OQPSK (Pi/4 QPSK)
8PSK
16APSK, 16PSK
64 APSK
4x16QAM
32APSK
32OFDM (multicarrier)
Current Transmission waveforms for VHF data exchange

Bandwidth	25 kHz		50 kHz	100 kHz
Modulation	π/4 QPSK		16-QAM, 16 multi-carriers, 2.7 kHz spacing	16-QAM, 32 multi-carriers, 2.7 kHz spacing
Modulation Category	PSK modulation		QAM modulation	QAM modulation

3.6

3.6.1 Carrier Frequency error

3ppm

3.6.2 Symbol timing accuracy

10 ppm

3.6.3 Transmitter Timing Jitter

1% RMS of symbol duration (or may be expressed as 104 microseconds but will need a table based on symbol rate)

Commented [LJ48]: Needed for link coordination from shore side

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Commented [LJ49]: Shore stations may use a ouput power higher than that of mobile stations

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Commented [PB50]: Harmonize the 25kHz channel behavior between VDE and ASM

Commented [PB51]: If possible add GMSK to this table and into Annex 2

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3.6.4 Slot Transmission Accuracy

UTC Direct operation:104 Micro sec for a mobile unit

3.7 Bit rates

3.8 Adaptive modulation and coding scheme mechanisms

The VDE terrestrial link should enable the usage of different modulation and coding schemes. This mechanism needs to work in an adaptive and autonomous manner without the necessity of the base station participation in the process.

3.8.1 Training sequence

The particular modulation coding schemes (MCS) should be encoded into the training sequence as follows:

(D_0, D_0, D_0, D_0, D_0, D_0, D_0, D_0, D_0, D_0, D_0 + 1, 0, 1, 1, 0, 1, 1, 1, 0, 0, 0) Modulo 2

(D_1, D_1, D_1, D_1, D_1, D_1, D_1, D_1, D_1, D_1, D_1 + 1, 0, 1, 1, 0, 1, 1, 1, 0, 0, 0) Modulo 2

(D_2, D_2, D_2, D_2, D_2, D_2, D_2, D_2, D_2, D_2, D_2 + 1, 0, 1, 1, 0, 1, 1, 1, 0, 0, 0) Modulo 2

(D_3, D_3, D_3, D_3, D_3, D_3, D_3, D_3, D_3, D_3, D_3 + 1, 0, 1, 1, 0, 1, 1, 1, 0, 0, 0) Modulo 2

Where 1, 0, 1, 1, 0, 1, 1, 1, 0, 0, 0 is a Barker code (length 11) with a very low autocorrelation function (sidelobe level ratio about -20,8 dB). This will maximize the detection probability. The potential 180 degrees phase error may be eliminated for instance with the usage of the start flag (or any known sequence within the header).

Training sequence should be always modulated using GMSK.

Only the data block should be coded, scrambled and modulated according to the selected MCS scheme. Modulation and coding schemes should be for instance defined according to the given below table.

Modulation and coding scheme	D_0, D_1, D_2, D_3 values	CQI value	Total throughput [kbps]*	Total data bitrate (user data + framing overhead) [kbps]
No transmission		0	-	-
MCS-1 (GMSK, CR=1/2)	0, 0, 0, 1	1	76,8	38,4
MCS-2 (GMSK, CR=3/4)	0, 0, 1, 0	2	76,8	57,6
MCS-3 (π/4 DQPSK, CR=1/2)	0, 0, 1, 1	3	153,6	76,8

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Commented [PB52]: Need a table for each modulation as defined in table above

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Commented [PB53]: May make more sense to have this above the «possible modulation schemes»

Commented [PB54]: Christof Bronk has input to this …

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Commented [PB55]: What is meant here?

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Commented [PB56]: Not understood

Commented [PB57]: We need to use this in Annex 2 (no coding on the CRC)

Commented [PB58]: Need for 25kHz and 50kHz;

Modulation and coding scheme	D_0, D_1, D_2, D_3 values	CQI value	Total throughput [kbps]*	Total data bitrate (user data + framing overhead) [kbps]
MCS-4 (π/4 DQPSK, CR=3/4)	0, 1, 0, 0	4	153,6	115,2
MCS-5 (8PSK, CR=3/4)	0, 1, 0, 1	5	230,4	172,8
MCS-6 (8PSK, CR=5/6)	0, 1, 1, 0	6	230,4	192
MCS-7 (16QAM SC, CR=3/4)	0, 1, 1, 1	7	307,2	230,4
MCS-8 (16QAM SC, CR=5/6)	1, 0, 0, 0	8	307,2	256
MCS-9 (16QAM 32MC, CR=7/8)	1, 0, 0, 1	9	307,2	268,8
TBD	1, X, X, X	TBD		
*) An assumption: 76,8 ksym/s in 100 kHz bandwidth (Roll-off factor: 0,3)				

CQI (Channel Quality Indicator) values should correspond directly to the BER.

The calculation of the BER should be based on the known sequences within the frame.

CQI value of the received message should be contained within the ACK/NACK messagesuch that the next transmission may use a different MCS.

ACK/NACK message should be modulated with GMSK.

3.9 The change of the MCS should be initiated by the link layer and the transmission should start with the GMSK. The slot time duration should be the same regardless of the MCS chosen.

3.10 Data encoding (Bit-to-symbol mapping)

-Wait for more Krzysztof input

The bit to symbol mapping shall for FSK and GMSK modulations be gray coded.

3.11 Forward error correction –DLR to provide more input

The turbo code with the code rate of ½ or lower should be used. Different code rates will be obtained with the puncturing technique.

3.11.1 Signalling FEC

3.11.2 Data packet FEC Turbo is 3 GPP.

3.11.3 Performance measure, Packet error ratio (1e-1, 1e-2 with ARQ, 1e-3)

Commented [PB58]: Need for 25kHz and 50kHz;

Commented [PB59]: This needs to be defined.

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Commented [PB60]: Make sure this is defined – 26ms(?)

Commented [PB61]: Not understood

Commented [PB62]: Need from Annex 4 and then harmonized with Annex 2

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3.11.3.1 Channel definition (e.g. AWGN)

Signal to noise ratios thresholds per MODCODS

3.12 Interleaving (multi-packet) -DLR input and ESA

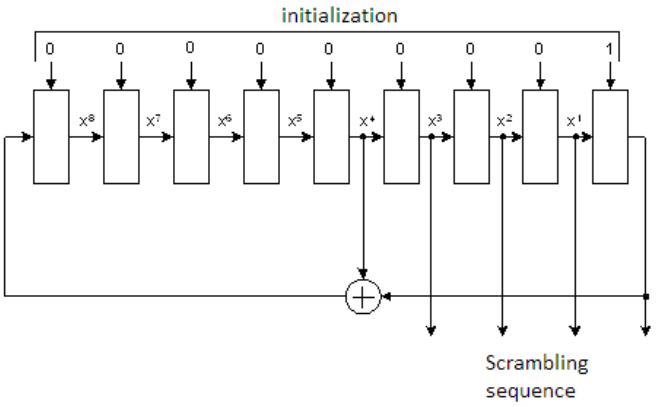
3.13 Synchronisation (Preamble, postamble?) + Pysical Layer Header

-Hans input, Krzysztof input

3.14 Bit scrambling

Scrambling of the user data is required to avoid the power spectral density to be concentrated in the narrow band.

Scrambler should be based on the linear feedback shift register (LFSR). For instance it may be defined by the polynomial $x^9 + x^4 + 1$. The scrambling pseudo-random sequence in this case would be 511 bits long (2^9-1) and the scrambler scheme would be as follows:



The scrambling sequence (least significant bits of the register) should be added modulo-two with the data bits obtained after the FEC encoding. The number of bits will depend on the modulation scheme used in the particular case. When the 16QAM modulation is exploited then the last four bits of the register need to be XOR-ed with the four bits creating the 16QAM symbol. For each consecutive symbol the register should be shifted by the number of bits creating the scrambling sequence (i.e. 4 in a case of 16QAM).

The scrambler should be initialized with the sequence 00000001 for each frame.

3.14.1 Data link sensing

Handled by link layer

3.14.2 Transmitter power

The transmitter may use several power level settings, not to exceed 25W.

3.14.3 Shutdown procedure

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Commented [LJ63]: Add table for each modulation scheme that may be defined?

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The transmitter shall have an automatic shutdown procedure after 1 seconds, to prevent stuck transmitters. The function shall be independant from software control.

3.15 Link budget analysis

3.15.1 Assumed parameters

3.15.2 Range vs throughput

MODCOD Table (PER=10^-2) of Bitrate/Modulation/Coding scheme / Eb/No

Transmission waveforms for VHF data exchange

Bandwidth	25 kHz		50 kHz	100 kHz
Modulation	π/4 DQPSK		16-QAM, 16 multi-carriers, 2.7 kHz spacing	16-QAM, 32 multi-carriers, 2.7 kHz spacing
Modulation Category	PSK modulation		QAM modulation	QAM modulation
Data Rate (raw)*	28.8 kbit/s		153.6 kbit/s	307.2 kbit/s
Sensitivity**	-107 dBm (min) -112 dBm (typical)		-98 dBm (ships) -103 dBm (base stations)	-98 dBm (ships) -103 dBm (base stations)

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Commented [PB64]: Add in GMSK if possible

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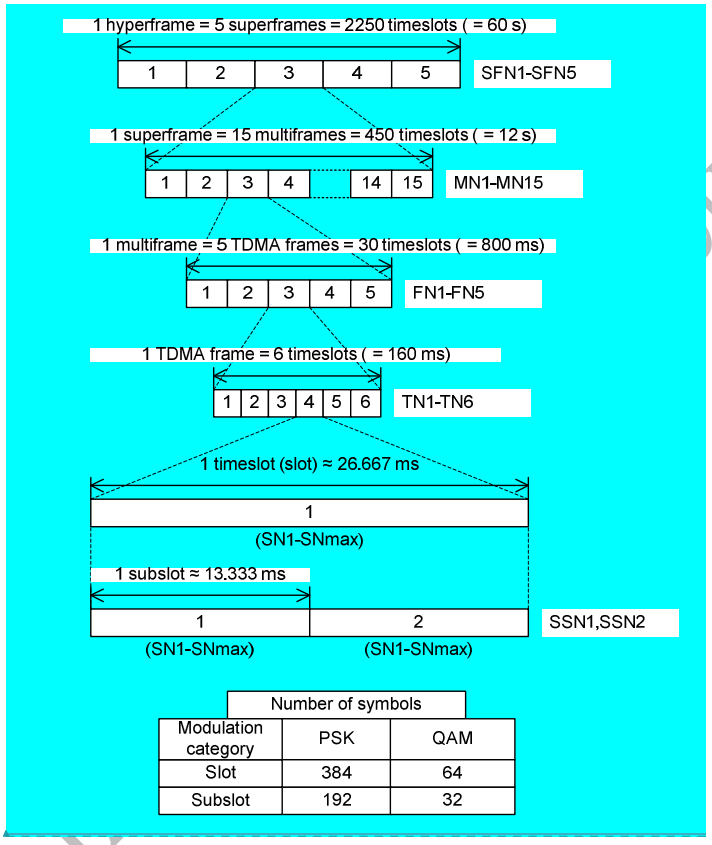
3.17 Framing Structure

VDE communication uses the concept of frames and slots, as defined by ITU-R M.1371, to quantize the communication channel into time segments and should be synchronized to slot boundaries of AIS A VDE frame is divided into 2250 slots. The VDE slot is the minimum adressable time segment of the VDE data link. The VDE frame is in turn part of a VDE superframe, spanning a number of VDE frames. The number of VDE frames shall correspond to the largest adressable VDE Data Link time unit. Each frame is 60s long, syncronized to UTC.



TDMA frame

Six timeslots should form a TDMA frame. The TDMA frame has duration of 160 ms.

The TDMA frames should be numbered by a Frame Number (FN). The FN should be cyclically numbered from 1 to 5. The FN should be incremented at the end of each TDMA frame.

2.2.2.2 Timeslot numbering

The timeslots within a TDMA frame should be numbered from 1 to 6 and a particular timeslot should be referenced by its Timeslot Number (TN).

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Field Code Changed

Subslot

The timeslots may be divided into 2 subslots. The subslots within a timeslot should be numbered from 1 to 2 and a particular subslot should be referenced by its SubSlot Number (SSN).

2.2.2.4 Multiframe

Five TDMA frames should form a multiframe. The multiframe should have duration of 800 ms.

The multiframes should be numbered by a Multiframe Number (MN). The MN should be cyclically numbered from 1 to 15. The MN should be incremented whenever the TDMA FN returns to 1.

2.2.2.5 Superframe

Fifteen multiframes should form a superframe. The superframe should have duration of 12 s.

The superframes should be numbered by a SuperFrame Number (SFN). The SFN should be cyclically numbered from 1 to 5. The SFN should be incremented whenever the MN returns to 1.

2.2.2.6 Hyperframe

The hyperframe should be the longest recurrent time period of the TDMA structure. Five superframes should form a hyperframe. The hyperframe should have duration of 60 s.

3.17.1 VDES Slots

The VDE slot is an integer fraction of an AIS slot. The VDE slot size shall therefore be 2/(75*n) seconds, where n is an integer. The slot determines the the minimum amount of link load to be occupied by short messages. Short slots allowes access to the data link to more actors, and reduces unnessescary large link overhead for short messages. The slot size shall be long enough to fit control channel data amount, such as FATDMA reservations and acknowledgements, with the most robust MSC (modulation and coding sheme) available.

The time slot is a time interval of approximately 26.667 ms (60000/2250 = 80/3 ≈ 26.667). For PSK modulation, the time slot corresponds to 384 symbol durations, each one with a duration of approximately 69.4 µs ((60000000/2250)/384 = 625/9 ≈ 69.4). For QAM modulation, the time slot is divided into 64 modulation symbol durations, each one with a duration of approximately 416.7 µs ((60000000/2250)/64 = 1250/3 ≈ 416.7). The timeslots may be subdivided into 2 subslots.

The physical content of a time slot is carried by a burst.

3.17.2 Data transfer packet size

The data transfer packet size may vary depending on the amount of data to be transmitted. The minimum size is one VDE slot, and the maximum consists of multiple VDE slots corresponding in time to a five AIS slots

3.18 zModulation

3.18.1 Channel Bandwidth

VDE capable systems shall be able to operate on the four 25kHz duplex channels, 24,84,25,85, allocated for data communication according to RR Appendix 18.

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The 100kHz channel on VDE-A may be divided into two 50kHz channels or four 25kHz channels. The 100kHz channel on VDE-B may be divided into two 50kHz channels or four 25kHz channels.

The lower set of 25 kHz channels, 1024, 1084, 1025, 1085, are refered to as VDE1-A. The corresponding upper set of channels, 2024, 2084, 2025, 2085, are referred to as VDE1-B.

3.18.2 Symbol rates

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Bandwidth	25 kHz	50 kHz	100 kHz
Symbol rate			

4 Link layer

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4.1 MAC layer (Media access control)

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Provides a method for granting access and coordinating traffic for the data transfer s on the VHF data link (VDL). The method used is a TDMA scheme using a common time reference based on UTC.

4.1.1 Base station media access

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Base stations are configured to create fixed FATDMA allocations for periodic tranmissions, and will use the control channelling mechanism to pre allocate additional link access.

4.1.2 Ship-ship media access

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4.1.3 Ship-shore media access

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To distinguish between ship-to-ship and shore to ship, ship to shore

The AIS-based TDMA slot structure (2250 slots/minute/frame) and access schemes (ITDMA, CSTDMA and FATDMA) that are used for VDES are defined in Recommendation ITU-R M.1371-5. This TDMA organization scheme protects the integrity of the AIS and is used in a similar way to organize and synchronize the ASM and VDE transmissions.

4.1.4 Channel access schemes

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The access schemes, as defined below, should coexist and operate simultaneously on the TDMA channel.

4.1.5 Incremental time division multiple access

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ITDMA should be used for creation of transmission chains for multi transmission data packets;

4.1.6 Carrier sense time division multiple access

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Used for single VDE slot transmissions or as initial transmission when starting ITDMA transmission chain.

4.1.7 Random access time division multiple access

RATDMA is used when a station needs to allocate a slot, which has not been pre-announced. This is generally done for the first transmission slot during data link network entry, or for messages of a non-repeatable character.

4.1.8 Random access time division multiple access algorithm

The RATDMA access scheme should use a probability persistent (p-persistent) algorithm as described in ITU-R M.1371 Annex ? Section ?.

4.1.9 Fixed access time division multiple access

FATDMA should be used by base stations only. FATDMA allocated slots should be used for repetitive messages, as well to reserve slots for remote targets that has requested to transmit on the VDE1-A channel.

4.1.10 Fixed access time division multiple access algorithm

Access to the data link should be achieved with reference to frame start.

FATDMA reservations apply within a range of 120 nautical miles from the reserving base station. VDE stations (except when using FATDMA) should not use FATDMA reserved slots within this range. FATDMA reservations do not apply beyond 120 nautical miles from the reserving base station. All stations may consider these slots as available.

4.1.11 Fixed access time division multiple access parameters

- Start slot - The first slot (referenced to frame start) to be used by the station
- Increment - Increment to next block of allocated slots.
- Block size - Determines the default number of consecutive slots which are to be reserved at each increment

4.1.12 Broadcast

4.1.13 Assignement (resoure allocation)

4.1.14 Slotted ALOHA random access

4.1.15 Multipacket transfer

4.2 Signalling (control) protocol (VDE Base station) – Hans input.

4.3 Data transfer protocol

4.4 Automati Repeat Request

To facitilate control of ship-shore communication -Johan input

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5 Link layer –JRC,HANS,Others?

5.1 Packet format signalling

3.1.1 Cyclic redundancy check

5.2 Packet format data transfer

5.2.1 Cyclic redundancy check

Recommended to increase from 16 bits to minimum 20, preferable 32

5.2.2 Encapsulation (e.g Packet ID,)

6 Transport layer

INFORMATIVE ANNEX – Link budget

6.1.1 Transmit (minimum) antenna gain (Antenna Pattern)

Since the shipborne antenna is required to receive the VDES satellite downlink at high elevation angles, the 0dBd (2.1dBi) option is selected. To achieve optimum satellite reception, this antenna should be mounted as high as possible, preferably on an extension pole, on the ship to minimize obstructions to the antenna's view of the horizon. For the terrestrial VDES base station, the 6dBd (8dBi) option is selected. These two antennas are used in the propagation range predictions in Annex 2.

Figure 7 presents a mask for the receiving antenna gain as a function of elevation that would allow the received signal from satellite to be at constant power level at the receiver input for a wide range of elevation angles, taking into account the PFD constraints imposed on the VDE-SAT downlink (ref. Table 3 of Annex 1). Although this mask may not represent the antenna pattern associated with a commercially available antenna, it could serve as a guide for designing an antenna to enhance the satellite reception. The same mask is also applicable to the design of shipborne antenna for VDE terrestrial link due its high directivity in the horizontal direction. Annex 3 provides further rationale for the selection of this mask.

Antenna type	1 element	2 elements stacked	3 elements stacked	4 elements stacked
Gain to horizon	2 dBi	3 dBi	6 dBi	9 dBi

For antenna patterns, refer to Annex 4 (VDES-SAT)

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6.1.2 Range (min and max)

Propagation range predictions for VHF data exchange system terrestrial links

7 1 Introduction

This is an informative annex. The excellent propagation characteristics of AIS are well established and appreciated. The propagation range predictions for the 100 kHz VDE ship-to-shore and shore-to-ship links follow below.

8 2 Ship-to-shore application

8.1 2.1 Basis for the coverage assessment

This coverage assessment is based on Recommendation ITU-R P.1546-4 (assuming no ducting), taking into account the antenna height and the seawater propagation path.

Height of antenna (Base Station): 75 meters (see graph for various heights)

Assumed Transmitter power for ships: 12.5 Watts

Tx ships antenna minimum gain: 2dBi (0dBd)

Rx shore antenna gain: 8dBi (6dBd)

P_R: -103dBm (VDE shore station sensitivity)

8.2 2.2 Purpose for use of the Recommendation ITU-R P.1546-4 propagation curves

Recommendation ITU-R P.1546-4 prescribes the use of the propagation curves (§3 from Annex 5 and Figure 4 (Figures 13 and 14 of this Annex) from Annex 1, see below), assuming no ducting and a smooth earth/sea surface. This analysis may be used as a reference point for field test measurements that usually include some ducting, depending on weather, atmospheric conditions and other factors.

8.3 2.3 Determination of transmitting/base antenna height, h_1

Recommendation ITU-R P.1546-4 specifies (§3 of Annex 5) the transmitting/base antenna height, h_1, to be used in calculation depending on the type and length of the path. For sea paths h_1 is the height of the antenna above mean sea level; for land paths h_1 is the height above average terrain.

8.4 2.4 Determination of the minimum field strength (sensitivity threshold) at the VHF data exchange base receiving site

For ship-to-shore:

Power received (linear formula): $P_r = G_r E_r^2 c^2/480\pi^2 f^2$

Rearranged: $E_r = \sqrt{(480\pi^2 f^2 P_r / G_r c^2)}$, where

E_r = field strength in volts/meter

G_r = gain of receiving antenna = 6.3 = 8dBi

c = speed of light in free space = 3 x 10^8 meters/second

f = VDE ship-to-shore frequency = 1.57 x 10^8 (157 MHz)

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Commented [PR68]: We may have higher gain antennas

Commented [PR69]: Will depend on modulation used. Sensitivity should be expressed as noise floor at this point in the link budget calculation. The later analysis of link budget should use this noise floor required Eb/No at prescribed packet/message error rate for each modulation and coding scheme.

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$P_r = 5x10^{-14}$ watts = -133dBW = -103dBm

Thus,

$E_r = 3.21 \times 10^{-6} = 3.21$ µV/m = +10.1dB µV/m

The logarithmic formula can also be used to calculate Pr (dBm):

Pr (dBm) = 42.8 - 20logF + 20logE + G, where

G = antenna gain in dBi = 8dBi

F = frequency in MHz = 157

Pr (dBm) = 42.8 – 43.9 – 109.9 + 8 = -103dBm (-133dBW)

Commented [PR70]: Simlify this calculation, this is too detailed

8.5 2.5 Determine the range to the +10.1dBu (-103dBm) coverage limit for a seawater propagation path

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Calculate the effective radiated power:

$P_e = P_T + G$

$P_T = 10 \log 12.5 - 30 = -19$dBk (19dB below 1 kW)

G = 2dBi = +0dBd (0dB over a dipole)

Thus $P_e = -19 + 0 = -19$dBk ERP

$E_R = E + P_e$ (vertical scale reference for the propagation graph in Figure 4 of Recommendation ITU-R P.1546-4, Figure 13 of this Annex)

E = +10.1dBu

$P_e = -19$dBk

Thus $E_R = 10.1 - (-19) = +29.1$dB

8.6 2.6 Determine the seaward ship-to-shore coverage range from Figure 13:

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The +10.1dBu (-103dBm) range is 85km, which is 46NM (use h_T = 75m).

8.7 2.7 Determine the received signal strength indication values for various other ranges

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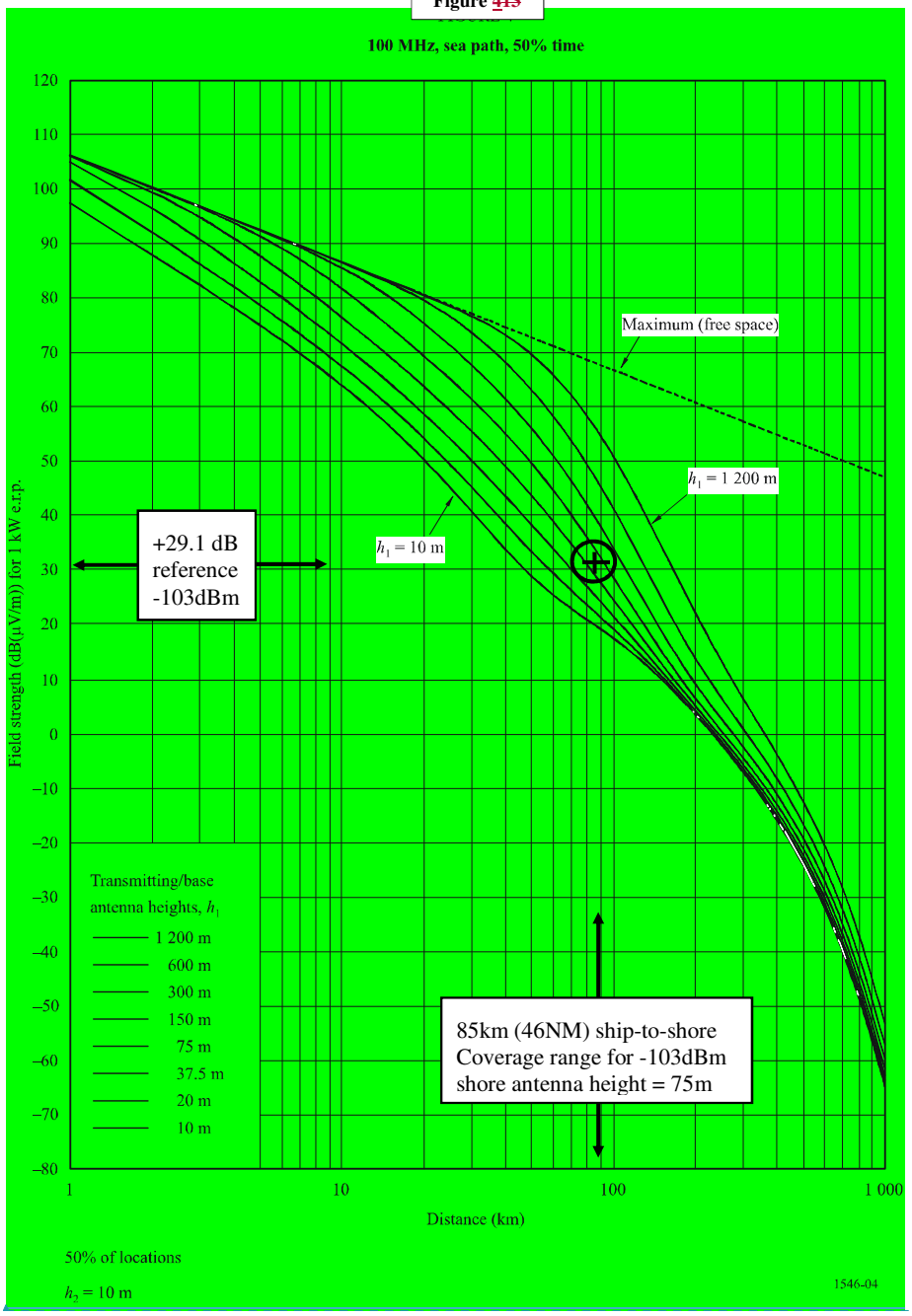
The reference point received signal strength indication (RSSI) = -103dBm at a range of 85km (46NM) is determined above. For other ranges, the RSSI value is determined from the propagation curve (Figure 13) for the assumed antenna height of 75m. RSSI values in 10dB increments above the sensitivity threshold are shown in Table 7 below.

TABLE 7

VHF data exchange base station received signal strength indication value vs. distance ship-to-shore

-103 dBm	85 km (46NM)
-93 dBm	60 km
-83 dBm	40 km
-73 dBm	25 km
-63 dBm	15 km
-53 dBm	8 km
-43 dBm	4.5 km

Figure 413



Field Code Changed

9 3 Shore-to-ship application

9.1.3.1 Basis for the coverage assessment

Referring to section 2 above, consider the reverse direction, shore-to-ship, signal levels at the ship receiving site. The shore transmitter power of 50 Watts and the shore-to-ship frequency of 162 MHz.

Height of antenna (VDES Base Station): 75 meters (see graph for various heights)

Transmitter power of VDES on shore: 50 Watts (at base of shore antenna)

Tx shore antenna gain: 8 dBi (6 dBd)

Rx ships antenna gain: 2 dBi (0 dBd)

P_R: -98 dBm (VDE ship station sensitivity)

9.1.1 3.1.1 Determination of the minimum field strength (sensitivity threshold) at the VHF data exchange ship receiving site

For shore-to-ship:

Power received (linear formula): $P_r = G_r E_r^2 c^2/480\pi^2 f^2$

Rearranged: $E_r = \sqrt{(480\pi^2 f^2 P_r / G_r c^2)}$, where

E_r = field strength in volts/meter

G_r = gain of receiving antenna = 1.62 = 2.1 dBi

c = speed of light in free space = 3×10^8 meters/second

f = VDE shore-to-ship frequency = 1.62×10^8 (0.62 MHz)

$P_R = 1.58 \times 10^{-13}$ watts = -128 dBW = -98 dBm

Thus,

$E_r = 11.61 \times 10^{-6} = 11.61$ µV/m = +21.3 dB µV/m

The logarithmic formula can also be used to calculate Pr (dBm):

Pr (dBm) = 42.8 - 20logF + 20logE + G, where

G = antenna gain in dBi = 2.1 dBi

F = frequency in MHz = 162

Pr (dBm) = 42.8 – 44.1 – 98.7 + 2.1 = -98 dBm (-128 dBW)

9.1.2 3.1.2 Determine the range to the +21.3 dBu (-98 dBm) coverage limit for a seawater propagation path

Calculate the effective radiated power:

$P_E = P_T + G$

$P_T = 10 \log 50 = 30 = +13$dBk (13dB below 1 kW)

G = 8dBi = 14dBd (6dB over a dipole)

Thus $P_E = 13 + 6 = 7$dBk ERP

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$E_c = E - P_r$ (vertical scale reference for the propagation graph in Figure 4 of Recommendation ITU-R P.1546-4, Figure 2 of this Annex)

$E = +21.3$ dBu

$P_r = -7$ dBu

Thus $E_c = 21.3 - (-7) = +28.3$ dB

Note that since this value of E_c is within 1dB of the value calculated in Section 2.5 because the reduced sensitivity of the ship station is compensated by the higher power and antenna gain of the shore base station.

~~2.1.3~~ 3.1.3 Determine the seaward shore-to-ship coverage range from Figure 14

The +28.3 dBu (-98 dBm) range is 85 km, which is 46 NM (use $h_1 = 75$ m). This is the same as the ship-to-shore coverage range, an ideal balanced two-way coverage, which confirms the proposed choices of antennas and transmitter power values for the shipborne and shore VDES stations.

~~2.1.4~~ 3.1.4 Determine the received signal strength indication values for various other ranges

The reference point: RSSI = -98 dBm at a range of 85 km (46 NM) is determined in 2.6 above. For other ranges, the RSSI value is determined from the propagation curve (Figure 14) for the assumed antenna height of 75 m. RSSI values in 10 dB steps above and below the -98 dBm threshold sensitivity for the shipborne VDE receiver are shown in Table 10~~Table 8~~ below.

TABLE ~~8~~38

VHF data exchange ship station received signal strength indication value vs. distance shore-to-ship

-148 dBm	170 km
-108 dBm	130 km
-98 dBm	85 km (46NM)
-88 dBm	60 km
-78 dBm	40 km

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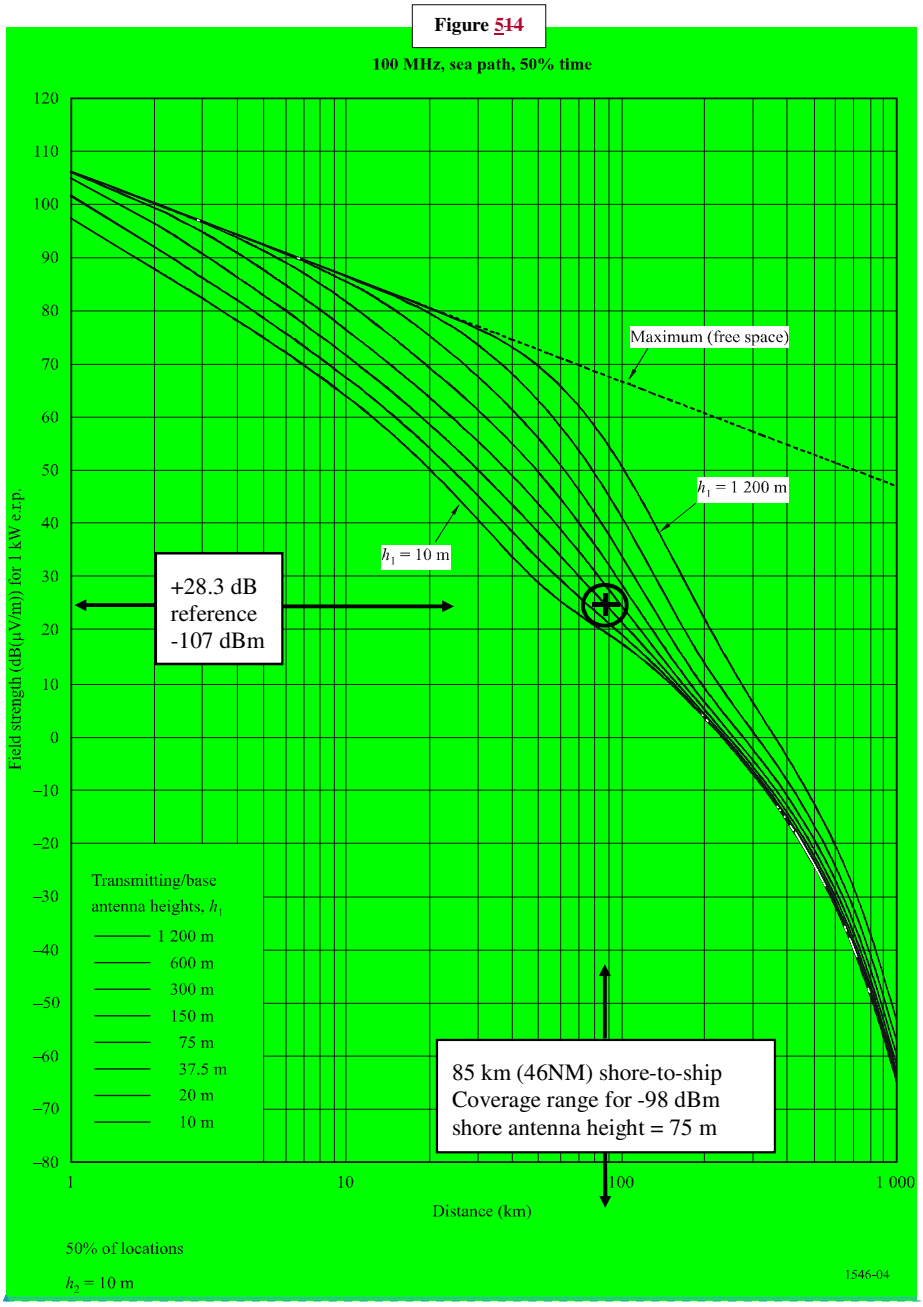
Figure 514



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9.1.4.1 Anomaly Due to Inversion (Delay Tolerance due to the distance up to a few msec)

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9.1.5 Receive antenna gain

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9.1.6 Receive noise floor

9.1.7 Link C/N0

9.1.8 Source of Self Interference (assumptions about the interference)

9.1.9 Received signal to noise plus Interference level

Annex 4

Technical characteristics of VDES-satellite downlink in the maritime mobile band

1. Introduction

This Annex describes the characteristics of the satellite downlink of the VHF Data Exchange System (VDES) according to the identified requirements.

In particular, VDE Satellite Downlink is assumed to support the following services:

- Downlink multicast multi-packet data transfer;
- Shore originated unicast multi-packet data transfer via satellite.

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In this Annex, Low Earth Orbit (LEO) satellites with 600 km altitude are considered to present typical examples of VDE Satellite Downlink solutions. It should be noted that other orbital selections are also possible according to the overall system design consideration.

2. OSI Layers

This Annex describes the four lower layers of the OSI model; the physical, the link, the network and the transport layers as shown in Figure 1.

Application layer
Presentation layer
Session layer
Transport layer
Network layer
Link layer
Physical layer

Figure 1. Seven layer OSI model

2.1 Responsibilities of the OSI layers for preparing VDE data for transmission

2.1.1 Transport layer

This layer ensures reliable transmission of the data segments between a ship and a satellite, including segmentation, acknowledgement and multiplexing.

2.1.2 Network layer

This layer is responsible for the management of priority assignments of messages, distribution of transmission packets between channels, and data link congestion resolution.

2.1.3 Link layer

This layer ensures reliable transmission of data frames between a satellite and a ship. The link layer is divided into three sub-layers with the following tasks:

2.1.3.1 Link management entity

Assemble unique word, format header, pilot tones, subframe headers and VDES message bits into packets.

2.1.3.2 Data link services

Applies bit stuffing (if required), calculates and adds CRC check sum and completes the subframe/packet.

2.1.3.3 Media Access Control

Provides methods for granting data transfer access. Both random access and assigned access are used.

2.1.4 Physical layer

This layer provides transmission and reception of raw bit streams over a physical medium including signal modulation, filtering/shaping upon transmission, and amplification, filtering, time and frequency synchronization, demodulation, and decoding upon reception.

3. Physical layer

3.1 Range (minimum and maximum)

The orbit height determines the satellite range variations. For example, for a 600 km LEO the maximum range is 2830 km. For timing purposes a maximum range of 3000 km will be used

The minimum range is equal to the orbit height. For a LEO satellite at 300 km altitude the minimum range will be 300 km. This value is used to determine the minimum propagation delay time.

Considering these exemplary values for the minimum and maximum ranges, the path delay will vary from 10 ms to 1 ms, a variation of 9 ms as shown in Figure 2.

In addition to the relative delays between signal receptions at a vessel from different satellites, there could be absolute delay due to other sources. The satellite service provider should pre-compensate for absolute delay.

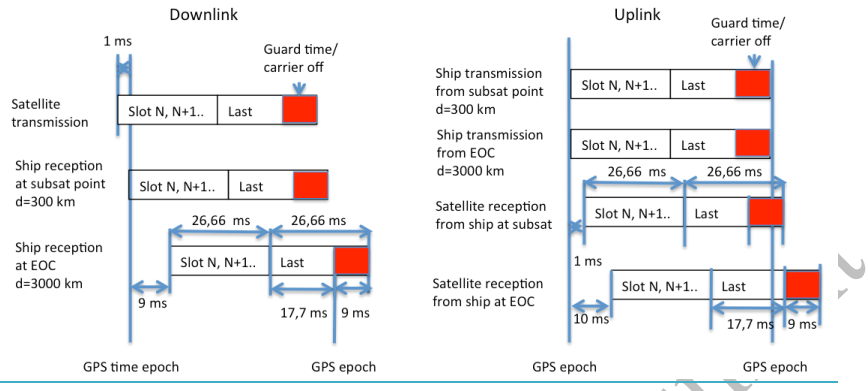

Figure 2. Downlink and uplink slot timing for 600 km LEO

3.2 Carrier Frequency error

The frequency error is the sum of the satellite transmission frequency error and Doppler and the frequency uncertainty at the receiver. The transmit frequency error at the satellite shall be less than 1 ppm TBC, i.e. +/- 160 Hz.

A small LEO satellite will move at a speed of about 8 km/s and this will cause a maximum Doppler of +/- 4 kHz at VHF.

3.3 Downlink example link budget

The link C/N_0 is determined by the satellite EIRP, path losses, propagation losses, receiver sensitivity/figure of merit and local interference levels.

3.3.1 Satellite downlink EIRP

The EIRP can be derived from Power and Flux spectral Density (PFD) mask given in Table 1.

Table 1

Proposed power spectral and flux density (PFD) mask

$$\theta^\circ = earth - satellite\ elevation\ angle$$

$$PFD(\theta^\circ)_{\ (dBW/(m^2 * 4\ kHz))} = \begin{cases} -149 + 0.16 * \theta^\circ & 0^\circ \le \theta < 45^\circ; \\ -142 + 0.53 * (\theta^\circ - 45^\circ) & 45^\circ \le \theta < 60^\circ; \\ -134 + 0.1 * (\theta^\circ - 60^\circ) & 60^\circ \le \theta \le 90^\circ. \end{cases}$$

Table 2 shows the theoretical maximum satellite EIRP as a function of elevation angles for this mask.

Table 2. Satellite maximum EIRP vs. elevation angle.

Elevation angle θ	Powerflux density on ground	Satellite range	Maximum downlink satellite EIRP
(degrees)	(dBW/m²/4 kHz)	(km)	(dBW in 25 kHz)
0	-149,0	2831	-1,0
10	-147,4	1932	-2,7
20	-145,8	1392	-4,0
30	-144,2	1075	-4,6
40	-142,6	882	-4,7
50	-139,4	761	-2,8
60	-134,0	683	1,6
70	-133,0	635	2,0
80	-132,0	608	2,6
90	-131,0	600	3,5

3.3.2 Example satellite EIRP vs. elevation

Most of the satellite coverage area and visibility time will be at low elevation angles, and high elevation angle coverage may be sacrificed without significant system capacity loss.

The example link budget is optimised for 0 degrees ship elevation angle using a three element Yagi antenna at the satellite pointed at the horizon is given in Table 3.

Assuming a peak antenna gain of 8 dBi, a transmit RF power of -12,4 dBW in 25 kHz will ensure compliance with the PFD limit. Example satellite EIRP vs. ship elevation is shown in Table 3.

Table 3. Example satellite EIRP vs. elevation using a Yagi antenna

	Yagi antenna							
Ship elevation angle	Nadir offset angle	Boresight offset	Satellite antenna gain	Satellite EIRP in circular polarization	Satellite range	PFD	Table 1 PFD limit	PFD margin
degrees	degrees	degrees	dBi	dBW	km	dBW/m²/4 kHz	dBW/m²/4 kHz	dB
0	66,1	0	8	-4,4	2830	-152,4	-149,0	3,4
10	64,2	1,9	8	-4,4	1932	-149,1	-147,4	1,7
20	59,2	6,9	8	-4,4	1392	-146,2	-145,8	0,4
30	52,3	13,8	7,8	-4,6	1075	-144,2	-144,2	0,0
40	44,4	21,7	6,9	-5,5	882	-143,4	-142,6	0,8
50	36	30,1	5,5	-6,9	761	-143,5	-139,4	4,1
60	27,2	38,9	3,6	-8,8	682	-144,5	-134,0	10,5
70	18,2	47,9	0,7	-11,7	635	-146,7	-133,0	13,7
80	9,1	57	-2,2	-14,6	608	-149,2	-132,0	17,2
90	0	66,1	-5,5	-17,9	600	-152,4	-131,0	21,4

3.3.3 Receive antenna gain

Existing ship antennas shall be used for VDES. The maximum antenna gain for these range from 2 to 10 dBi with respect to a vertically polarized reference antenna. Representative antenna patterns are shown in Figure 3.

A ship antenna with a minimum gain at 0 degrees elevation of 3 dBi at the receiver input is required. The antenna gain and noise level can be traded as long as the sum of the two exceeds -113 dBm.

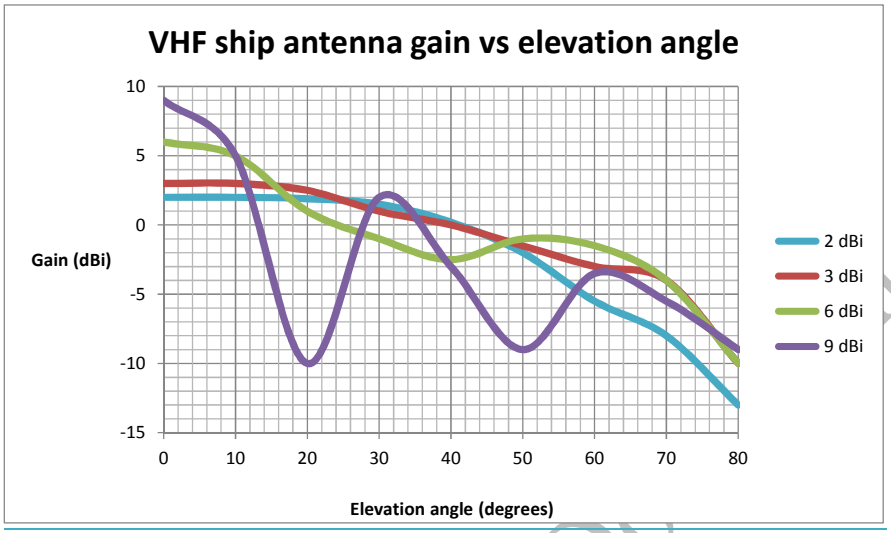

Figure 3. Ship antenna gain vs. elevation angle.

3.3.4 Received signal to noise plus interference level

The noise floor is a function of many sources such as vessel electronics, other radio equipment, power supplies, etc., and sensitivity is also reduced by RF cabling losses, LNA noise figure. The downlink assumes an expected equivalent noise and interference level that is less than - 116 dBm/25 kHz at the receiver input.

3.3.5 Link $C/(N_0+I_0)$

The nominal signal level and $C/(N_0+I_0)$ vs. elevation for a 25 kHz channel is given in Table 4. The signal level and $C/(N_0+I_0)$ increase 3 dB for 50 kHz channels and 6 dB for 100 kHz wide channels respectively.

High elevation coverage applies to few satellite passes, and only for a short period, and system operator may select the operational elevation range.

The nominal downlink $C/(N_0+I_0)$ is 41 to 47 dBHz for ship elevation angles between 0 and 65 degrees in a 25 kHz channel.

The maximum PFD from the satellite transmissions in 4 KHz bandwidth is the same as calculated above and in Table 3, however the increased channel and modulated signal bandwidth increase the maximum transmitted total RF power by the increased bandwidth ratio, i.e. 3 and 6 dB for the 50 and 100 kHz channels over than of a single 25 kHz channel.

It should also be noted that the analyses based on single satellite visibility.

Table 4. Nominal link budget vs. ship elevation for a 25 kHz channel.

Ship elevation angle	Satellite EIRP in circular polarization	Satellite range	Pathloss	Polarization loss	Ship antenna gain	Antenna signal level	Noise level in 25 kHz BW	$C/(N_0+I_0)$
degrees	dBW	km	dB	dB	dBi	dBm	dBm	dBHz
0	-4,4	2830	144,6	3	3	-119,0	-116	41,0
10	-4,4	1932	141,2	3	3	-115,7	-116	44,3
20	-4,4	1392	138,4	3	2,5	-113,3	-116	46,7
30	-4,6	1075	136,2	3	1	-112,8	-116	47,2
40	-5,5	882	134,4	3	0	-113,0	-116	47,0
50	-6,9	761	133,2	3	-1,5	-114,6	-116	45,4
60	-8,8	683	132,2	3	-3	-117,0	-116	42,9
70	-11,7	635	131,6	3	-4	-120,3	-116	39,7
80	-14,6	608	131,2	3	-10	-128,8	-116	31,2
90	-17,9	600	131,1	3	-20	-142,0	-116	18,0

3.4 Propagation effects

The received signal level on-board a ship will vary due to a number of causes. A Rice distribution with a Carrier to Multipath (C/M) ratio of 10 dB and fading bandwidth of 3 Hz is assumed, however the system shall be adaptable to handle significantly worse and better propagation conditions.

Table 5. Ionospheric effects for elevation angles of about 30° one-way traversal (derived from Recommendation ITU-R P.531)

Effect	Frequency dependence	0.1 GHz	0.25 GHz	1 GHz
Faraday rotation	$1/f^2$	30 rotations	4.8 rotations	108°
Propagation delay	$1/f^2$	25 µs	4 µs	0.25 µs
Refraction	$1/f^2$	< 1°	< 0.16°	< 0.6′
Variation in the direction of arrival (r.m.s.)	$1/f^2$	20′	3.2′	12″
Absorption (auroral and/or polar cap)	$\approx 1/f^2$	5 dB	0.8 dB	0.05 dB
Absorption (mid-latitude)	$1/f^2$	< 1 dB	< 0.16 dB	< 0.01 dB
Dispersion	$1/f^3$	0.4 ps/Hz	0.026 ps/Hz	0.0004 ps/Hz
Scintillation (1)	See Rec. ITU-R.P.531	See Rec. ITU-R P.531	See Rec. ITU-R P.531	>20 dB peak-to-peak

* This estimate is based on a TEC of 1018 electrons/m^2, which is a high value of TEC encountered at low latitudes in day-time with high solar activity.

(1) Values observed near the geomagnetic equator during the early night-time hours (local time) at equinox under conditions of high sunspot number.

Table 6. Mid-latitude fade depths due to ionospheric scintillation (dB)

Percentage of time (%)	Frequency (GHz)			
	0.1	0.2	0.5	1
1.0	5.9	1.5	0.2	0.1
0.5	9.3	2.3	0.4	0.1
0.2	16.6	4.2	0.7	0.2
0.1	25.0	6.2	1.0	0.3

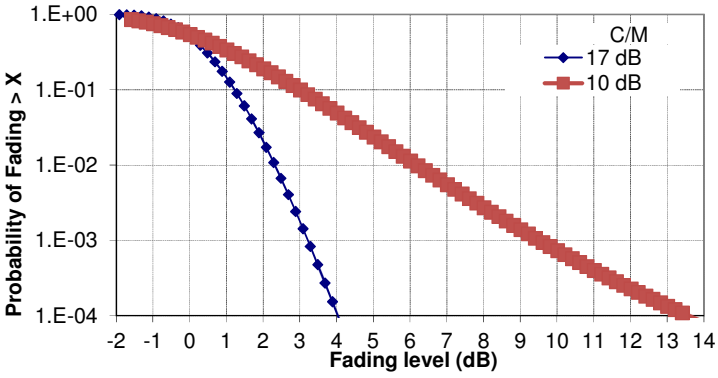

Figure 4. Ricean fade depth probability

3.5 Modulation

VDES uses adaptive modulation and coding to maximise spectral efficiency and throughput. The supported modulation methods are given in Table 7.

Table 7. Downlink modulation methods

Index	Bits/symbol	Modulation type	Bit mapping	Maximum Adjacent Channel Interference level with worst case Doppler
1	2	Grey encoded QPSK	Fig. 5	- 18 dBc
2	3	Grey encoded 8PSK	Fig. 6	- 18 dBc
3	4	16APSK	Fig. 7	- 18 dBc

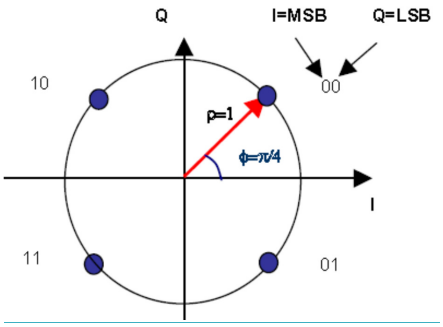

Figure 5. QPSK symbol to bit mapping

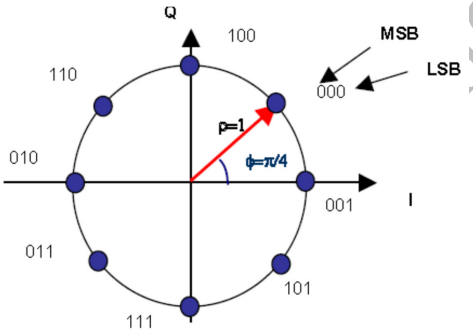

Figure 6. 8PSK symbol to bit mapping

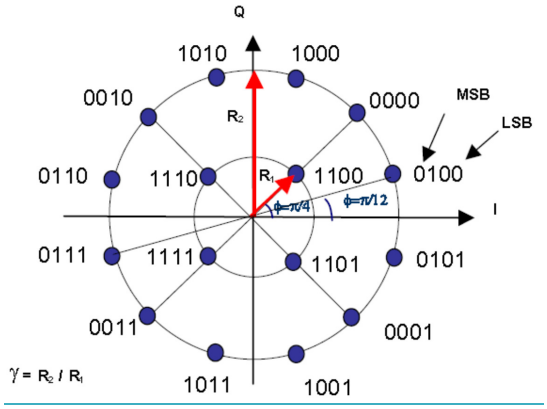

Figure 7. 16APSK bit to symbol mapping

The 16APSK modulation constellation shall be composed of two concentric rings of uniformly spaced 4 and 12 PSK points, respectively in the inner ring of radius R_1 and outer ring of radius R_2.

The ratio of the outer circle radius to the inner circle radius ($\gamma = R_2/R_1$) shall be equal to 3. R_1 shall be set to $1/\sqrt{7}$, R_2 shall be set to $3/\sqrt{7}$ in order to have the average signal energy equal to 1.

Similar to AIS, when data is output on the VHF data link it should be grouped in bytes of 8 bits from top to bottom of the table associated with each message in accordance with ISO/IEC 13239:2002. Each byte should be output with least significant bit first.

3.6 Symbol timing accuracy (at the output of satellite)

Less than 5 ppm

3.7 Transmitter Timing Jitter

Less than 5% symbol interval (peak)

3.8 Slot Transmission Accuracy at the satellite output

Less than 50 micro sec (peak) relative for example to GNSS reference timing.

3.9 Half duplex and full duplex satellites

The system can be configured for both half and full duplex satellites as shown in Figure 8.

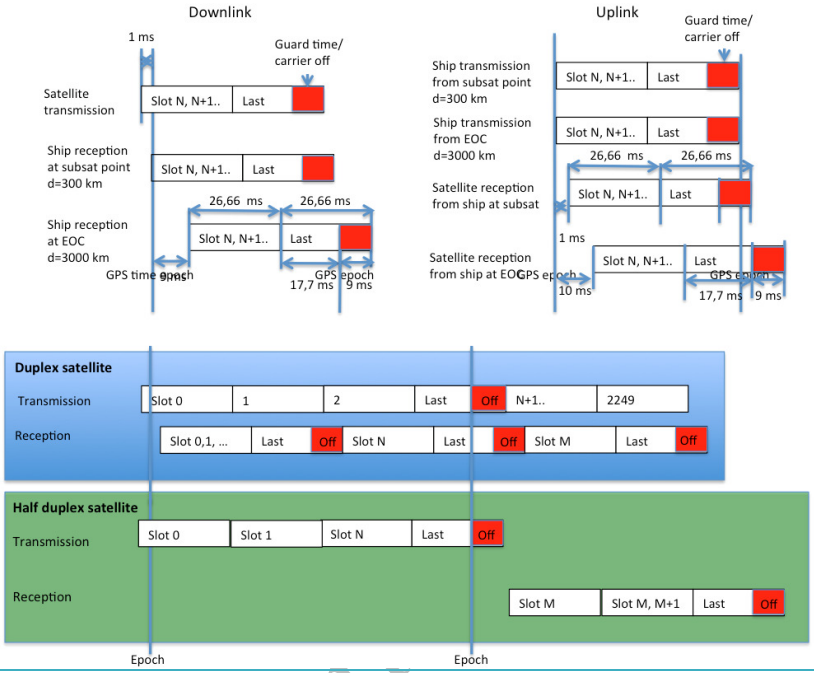

Figure 8. Half and full duplex satellite operation

3.10 Frame hierarchy

The VDES frame structure is identical and synchronized in time on the earths surface to UTC (as in AIS) and the frame hierarchy for a subframe of N slots is shown in Figure 9. Each element is described in the subsequent sections.

Frame 0 starts at 00:00:00 UTC, and there are 1440 frames in a day. The impact of leap second should be accounted for to avoid any propagation of error.

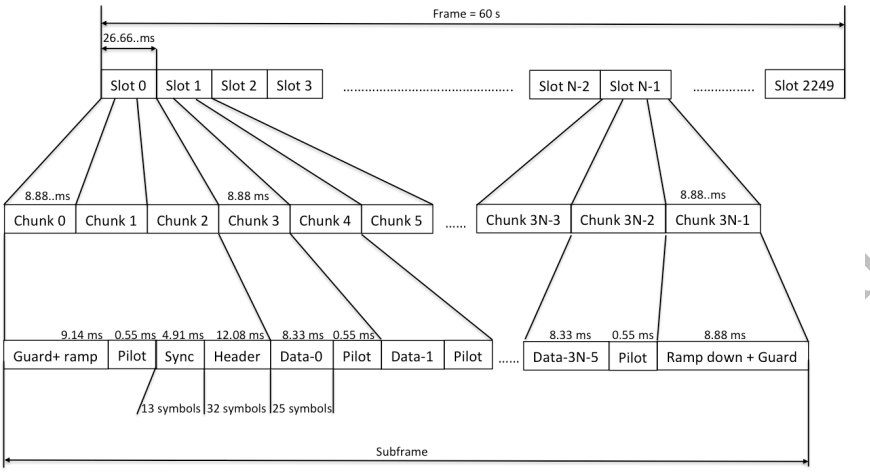

Figure 9. VDES frame hierarchy

3.10.1 Guard time and ramp up

The ramp up time from -30 dBc to -1,5 dBc of the power shall occur in less than or equal to 300 usec ..for 50 kHz channel occupancy. This is a means to maintain compliancy with the adjacent channel interference requirements.

The guard time at the beginning of a subframe may not be required, but has been provided to allow for future expansion of the pilot, synchronisation word and the subframe format header.

3.10.2 Synchronisation pilot

This CW signal before the synchronisation word and after every data chunk has a fixed duration of 0,55 ms.

3.10.3 Synchronization word

The subframe synchronisation word and header format is fixed for all transmissions. The 13 bit Barker code unique word is defined in Table 8. It is modulated with BPSK at a symbol rate of 2.65 kbps (TBC) . Bit 0 is transmitted first. The duration is 4,91 ms.

Table 8. Barker sequence unique word

Bit number												
0	1	2	3	4	5	6	7	8	9	10	11	12
1	1	1	1	1	-1	-1	1	1	-1	1	-1	1

The missed detection and false detection probabilities are shown in Figure 10 for a $C/(N_0+I_0)$ of 37 dBHz. For a 50 kHz channel, this corresponds to a fade depth of 7 dB, which occurs less than 1% of the time for the Ricean channel (C/M=10 dB). During these short periods a constant false alarm rate threshold set to 1E-4 will result in 2% of subframes not detected during the fade.

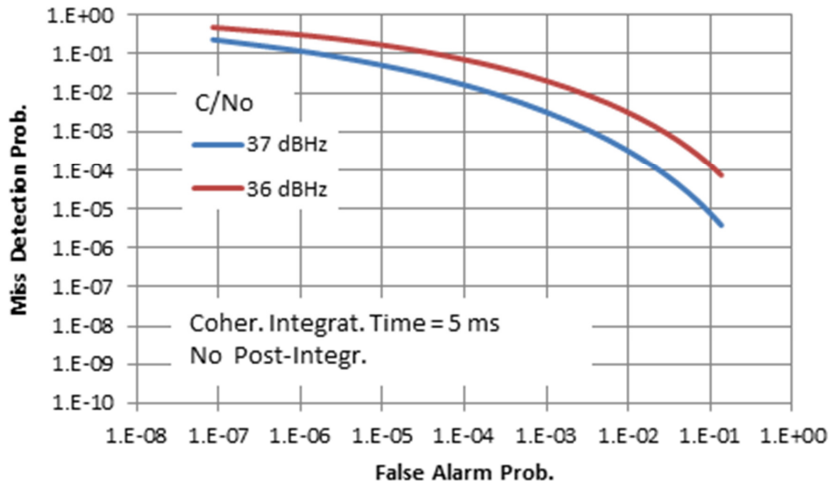

Figure 10. Synch loss and false detection probabilities

3.10.4 Direct Sequence Spreading

The first pilot and BPSK symbols are spread using a 8 bit sequence to a chiprate of 21 kcps to fit in a 50 kHz channel. Spreading sequence SS0 from Table 9 is used.

Table 9. Spreading sequences TBC

Sequence name	Chip number							
	0	1	2	3	4	5	6	7
SS0	-1	-1	-1	1	1	-1	1	1
SS1	-1	-1	1	-1	1	1	1	-1
SS2	-1	1	-1	1	1	1	-1	-1
SS3	-1	1	-1	-1	-1	-1	1	-1

3.10.5 Subframe header

The header is BPSK modulated and spread the same way as the synchronisation word described above. This header defines the following characteristics for the remainder of the subframe:

- Subframe duration
- Number of data chunks
- Symbol rate
- Modulation type
- FEC type
- FEC rate
- Interleaver type
- Scrambler type (to be added at symbol)
- Spreading code length (if used)
- Spreading codes (if used)

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The header provides 7 bits to define up 128 subframe formats and uses (32,7) quad orthogonal forward error correction coding. The performance of this FEC is shown in Figure 11. During a 7 dB fade the E_s/N_0 dips to 2,8 dB, resulting in a header loss of less than1E-6, which is insignificant.

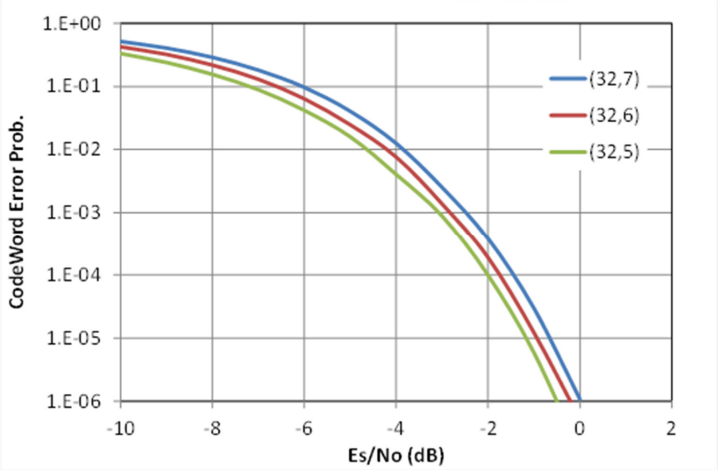

Figure 11. Header error probability

3.10.6 Data-N

Segment N of interleaved data. (see sub-frame format for interleaver definition).

3.10.7 Ramp down

The ramp down time from 90% to 10% of the power shall occur in less than 100 uS.

3.10.8 Guard time

No transmissions shall occur during the guardtime to avoid partly overlap with terrestrial AIS/VDES slots. The guard time is 8.9 ms.

3.10.9 Downlink subframe formats

The startpilot. sync word and the header are fixed for all subframe formats. It is envisaged that several format will be used based on type of information carried, interference and throughput/latency optimisation.

Currently two subframe formats have been defined, the first intended for multiple access and one way reliable transmission and is defined in Table 10.1.

The second in Table 10.2 is intended for high throughput where lost subframes are recovered using retransmissions.

Table 10.1 Subframe format SF0

Parameter	Value	Unit
Function	Multiple access reliable one way transmission	
Usage	Bulletin Board	
Header value	0x1	Hex
Channel bandwidth	50	kHz
Single satellite nominal C/N_0	44	dBHz
Interfering satellite I_0/N_0 (equal rx level)	-3,0	dB
$C/(N_0+I_0)$ with two overlapping satellites	42,2	dBHz
Symbol rate	2,625	kbaud
Modulation	QPSK	-
Channel bits/symbol	2	-
FEC type	3GPP2	-
FEC rate	0,5	-
Information rate	2,625	kbps
Nominal $Eb/(N_0+I_0)$	8,0	dB
Required subframe error rate	0,1	%
Required $Eb/(N_0+I_0)$ for Rice C/M=10 dB	4,5	dB
Margin	3,5	dB
Subframe size	100	slots
Frame duration	2,67	s
Frame duration in chunks	300	-
Chunk duration	8,89	ms
Pilot duration	0,55	ms
Data duration/chunk	8,34	ms
Information bits in a chunk	22	bits
Numer of data chuncks	96	chunks
Number of data bits in subframe	2 101	bits
Number of bytes in subframe	263	bytes
Spreading factor	8	chips
I/Q channel chip rate	21	kchip/s

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I spreading code	SS0	Table 9
Q spreading code	SS1	Table 9
Block interleaver height	40	bits
Block interleaver width	53	bits

Table 10.2 Subframe format SF1

Parameter	Value	Unit
Function	Dedicated high throughput channel	
Usage	Announcements, messages	
Header value	0x2	Hex
Channel bandwidth	50	kHz
Nominal C/N_0	44	dBHz
Symbol rate	21	kbaud
Modulation	QPSK	-
Channel bits/symbol	2	-
FEC type	3GPP2	-
FEC rate	0,25	-
Information rate	10,5	kbps
Nominal E_b/N_0	3,8	dB
Required subframe error rate	1,0	%
Required E_b/N_0 for Rice C/M=10 dB	0,5	dB
Margin	3,3	dB
Subframe size	100	slots
Frame duration	2,67	s
Frame duration in chunks	300	-
Chunk duration	8,89	ms
Pilot duration	0,55	ms
Data duration/chunk	8,34	ms
Information bits in a chunk	88	bits
Numer of data chuncks	96	chunks
Number of data bits in subframe	8 406	bits
Number of bytes in subframe	1 051	bytes
Spreading factor	1	chips
I/Q channel chip rate	NA	-
I spreading code	NA	-

Q spreading code	NA	-
Block interleaver height	88	bits
Block interleaver width	96	bits

4. Link layer

4.1 Data encapsulation

A subframe consist of multiple variable length datagrams and these are encapsulated. Each datagram contain the following encapsulation fields:

- Datagram type (1 byte)
- Datagram size (3 bytes)
- Destination (4 bytes, optional)
- Transaction ID (4 bytes, optional)
- Datagram sequence number (2 bytes, for multisegment datagrams)
- Source ID (8 bytes, optional)
- Datagram payload (variable)
- Data padding (variable, less than 8 bits)
- CRC (4 bytes)

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4.2 Cyclic Redundancy Check

The 32 bit ITU polynomial 0x04C11DB7 CRC is appended to the last segment of the datagram. The CRC is calculated over all fragments of the datagram.

F(x)=x32 + x26 + x23 + x22 + x16 + x12 + x11 + x10 + x8 + x7 + x5 + x4 + x2 + x + 1

Initial state: 0xFFFF

4.3 Automatic repeat request (ARQ)

Datagrams may or may not use ARQ, this is defined for each datagram type. An ARQ will request selective retransmission of a specific lost datagram segment.

4.4. Acknowledgement (ACK)

All datagrams without CRC errors are acknowledged over the satellite link.

4.5 End delivery notification (EDN)

All datagrams successfully delivered to the destination will be notified to the source.

4.5 End delivery failure (EDF)

All datagrams not successfully delivered within the timeout or retry limit will be notified to the source.

4.6 Physical and Logical channels

VDES uses several channels to carry data. These channels are separated into Physical and Logical channels. Every satellite transmits a Bulletin Board that defines the configuration of these channels.

4.7 Physical Channels

The Physical Channels (PC) are determined by the center frequency, subframe format and start timeslot.

4.8 Logical Channels (LC)

The logical channels are divided into signalling and data channels. These are described below.

4.9 Signaling Logical Channels

The following downlink signalling channels are used:

- Bulletin Board
- Datagram announcements
- Media Access Control (MAC)
- Uplink and downlink resource allocation
- Repeat requests/Acknowledgements/End delivery notifications

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4.9.1 Bulletin Board Signalling Channel (BBSC)

The Bulletin Board defines the network configuration parameters such as signalling channels (control channels) and data channel(s), protocol versions and future network configuration.

A logical channel is defined by function, index, center frequency , subframe format and startslot. The logical channels are normally repeated every frame, unless a network configuration change has taken place to optimises capacity.

Satellite parameters and network ID are also provided. Information about other satellites and networks may be provided. The Bulletin Board information does not change often, and for a small LEO satellite it is sufficient that the Bulletin Board is received once per pass, a repeat rate of once per minute is sufficient for most passes.
The BBSC uses subframe format SFF0 defined in Table 10.1 and shall be transmitted once every minute, starting at slot 0, the duration is 2.67 s. CDMA is used to allow multiple satellites with overlapping coverage to transmit the Bulletin Board at the same time. The ship receiver shall be able to receive Bulletin Boards from up to 8 satellites at the same time.

The full bulletin board messages may be transmitted over several frames. Essential information of the bulletin board will be repeated over every frame (every 60 s).

4.9.2 Announcement Signalling Channel (ASC)

This channel will normally carry Annoucements, MAC information, up/downlink resource allocation, ARQs, ACKs and EDNs.

The channel is received by a large number of ships and a high margin subframe format is used.

To reduce protocol latency the ASC may be repeated several times (different content) during a frame.

Announcements include uni- and multi-cast (broadcast) datagrams.

The ASC uses subframe format SFF0 or SFF1. The format the start slots are given defined in the Bulletin Board.

The MAC information includes network version, congestion control (randomization interval, hold-off and minimum priority level).

The uplink resource allocation provides uplink data channel information to an individual ship following a resource request.

4.9.3 Multicast Data Channel (MDC)

This downlink channel is received by a large number of ships and a high margin subframe format is used.

4.9.4 Unicast Data Channel (UDC)

This downlink channel is allocated a specific ship for the duration of a unicast datagram. This channel is set up after a ship responds to an announcement, and the response includes received signal quality information allowing the satellite to maximise throughput.

5. Network layer

5.1 Downlink data transfer protocols

The following downlink protocols shall be supported:

- Bulletin Board transmission (network configuration)
- Multicast (icemaps, weather info, notices to mariners)
- Unicast (shore to ship file transfer, up to 100 kBytes)

The protocols are shown in Figures 12-14.

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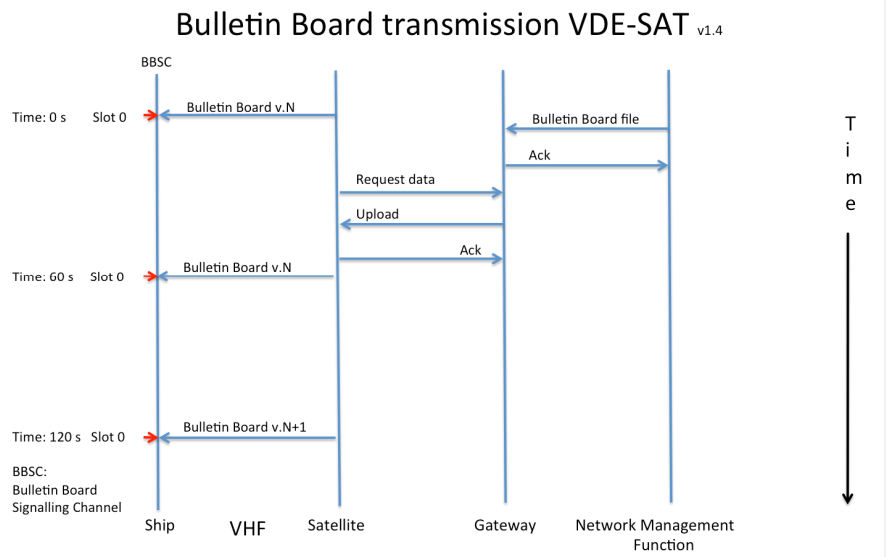

Figure 12. Bulletin Board with network version change

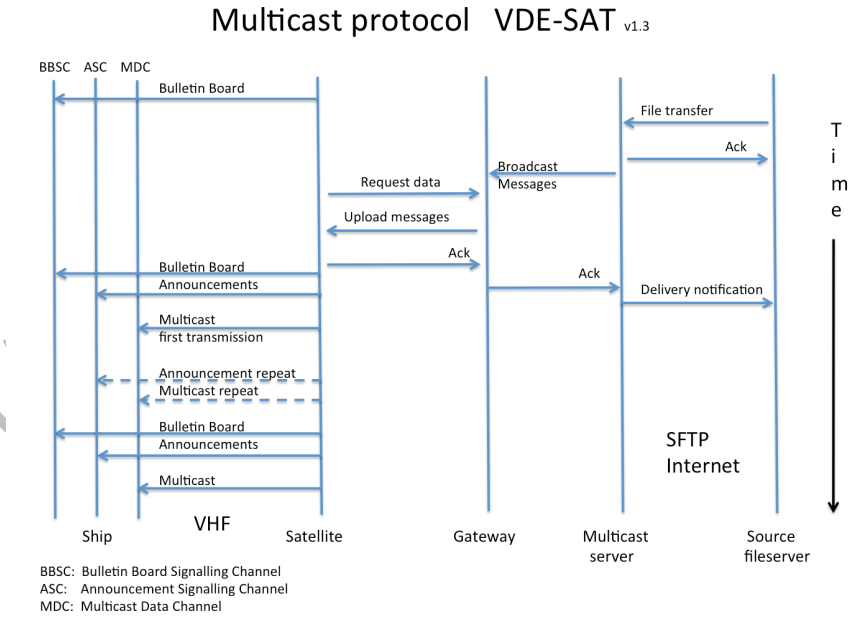

Figure 13. Multicast protocol (one-way)

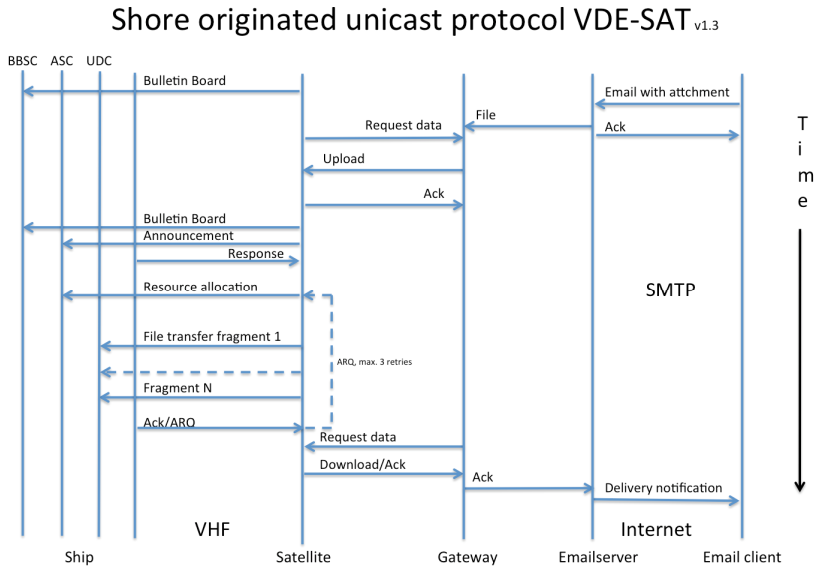

Figure 14. Shore originated unicast (file transfer) protocol

6. Transport layer

6.1 End to end protocols

Existing Internet protocols such as UDP, SNMP, Secure File Transfer Protocol (SFTP), Simple Mail Transfer Protocol (SMTP) as shown in Figures 12 to 14 are used.

Terrestrial IP protocols are assumed to be terminated at the satellite gateway.

6.2 Ship, gateway and device physical addressing

Most commercial ships use a 7 digit IMO number of which the last is a checksum, thus the IMO system can address 1 million ships. The 3 byte VDES physical addressing field has 16,7 million unique IDs.

The number of networked devices on ships is growing fast and there is a need to directly address local gateways and devices.

In addition to the 3 byte address field, a 1 byte subadressing has been added. The ship, local gateway and device addressing are shown in Table 11.

Table 11. Ship, Gateway and Device addressing

Adressing field	Usage	Range
24 bit physical address (all messages)	Ship terminal ID	16 Million
16 bit subaddress (encapsulated)	Ship gateway and device IDs	Configurable e.g. Gateway 4 MSB: 16 gateways Device 12 LSB: 4096 devices

6.3 Shore addressing of ships, gateways and devices

VDES will be accessed from shore using Internet, and it is desirable to use standard protocols such as email.

A database at the Gateway will allow shore users to define their own meaningful ship, gateway and device names. Below are some examples:

6.3.1 Setting engine exhaust gas temperature alarm level

mail address:

olympic.engine1.exhaustgaslimit@nca.no

Main body:

id:whitestar

pw:19101020

egtlimithigh: 250

6.3.2 Sending an icechart

mail address:

olympic.navsystem1.chartplotter@nca.no

Main body:

id:whitestar

pw:19101020

Attachment:

nmiis201504101500.jpg

Annex 5

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Technical characteristics of VDES-satellite uplink in the maritime mobile band

22 April 2015 v1.1

1. Structure of the VDES

This Annex describes the characteristics of the satellite uplink of the VHF Data Exchange System (VDES).

The following types of functionality are envisaged:

Two-Way:

- Shore initiated polling of information from ships

- Ship initiated enquiry for information from shore

- Ship initiated data transfer to shore

Transmit Only:

- Collection of information from transmit only VDES-terminals. This could be either event driven or periodic. (only a limited time assignment and frequency allocation)

2. OSI Layers (could be moved to Annex 1)

This Annex describes the four lower layers of the OSI model; the physical, the link, the network and the transport layers as shown in Figure 1.

Application layer
Presentation layer
Session layer
Transport layer
Network layer
Link layer
Physical layer

Figure 1. Seven layer OSI model

2.1 Responsibilities of the OSI layers for preparing VDE data for transmission

2.1.1 Transport layer

This layer ensures reliable transmission of the data segments between a ship and a satellite, including segmentation, acknowledgement and multiplexing.

2.1.2 Network layer

This layer is responsible for the management of priority assignments of messages, distribution of transmission packets between channels, and data link congestion resolution.

2.1.3 Link layer

This layer ensures reliable transmission of data frames between a satellite and a ship. The link layer is divided into three sub-layers with the following tasks:

2.1.3.1 Link management entity

Assemble unique word, format header, pilot tones, subframe headers and VDES message bits into packets.

2.1.3.2 Data link services

Applies bit stuffing, calculates and adds CRC check sum and completes the subframe/packet.

2.1.3.3 Media Access Control

Provides methods for granting data transfer access. Both random access and assigned access are used.

2.1.4 Physical layer.

This layer provides transmission and reception of raw bit streams over a physical medium.

3. Physical layer (Only in Annex 4, to be removed from here)

3.1 Range (minimum and maximum)

The orbit height determines the satellite range variations. For a 600 km LEO the maximum range is 2830 km. The minimum range is the orbit height.

For timing purposes a maximum range of 3000 km shall be used. The minimum range shall be 300 km. The path delay will therefore vary from 10 ms to 1 ms, a variation of 9 ms as shown in Figure 2.

Need to consider higher orbits

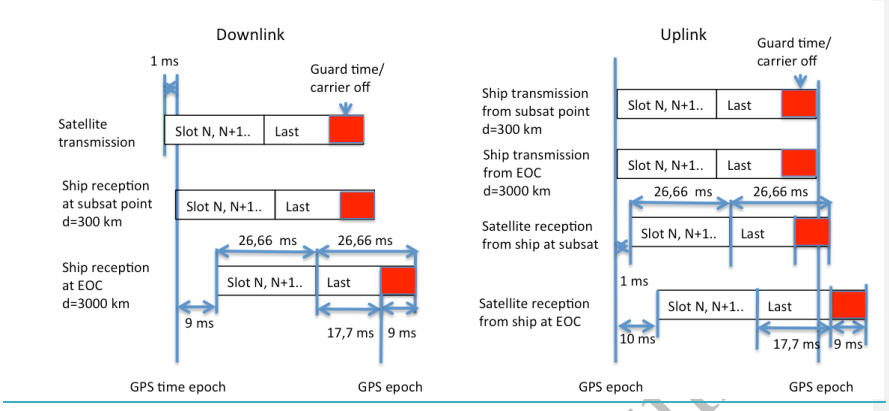

Figure 2. Downlink and uplink slot timing
(Source: Haugli, Space Norway)

3.2 Frequency error

The frequency error is the sum of the satellite transmission frequency error and Doppler. The transmit frequency error at the satellite shall be less than 2 ppm TBC, i.e. +/- 320 Hz.

A small LEO satellite will move at a speed of about 8 km/s and this will cause a maximum Doppler of +/- 4 kHz at VHF.

3.3 Uplink nominal link budget

The link C/N_0 is determined by the ship EIRP, path losses, propagation losses, satellite G/T and interference levels.

3.3.1 Ship transmit power

The saturated transmit power from a ship is the same as for AIS, i.e 12,5 W and this power level is used for fixed envelope modulation methods such as CW, BPSK, QPSK and 8PSK. For non-constant envelope such as 16APSK and filtered signals the baseline transmit power is 6 W linear.

A lower transmit power close to saturation could be envisaged (nominal saturated power below 1 W),

3.3.2 Transmit antenna gain

(If there is any other input we will input it here, otherwise we refer to Annex 4 with the exact picture).

Existing ship antennas shall be used for VDES. The maximum antenna gain for these range from 2 to 10 dBi. Representative antenna patterns are shown in Figure 3.

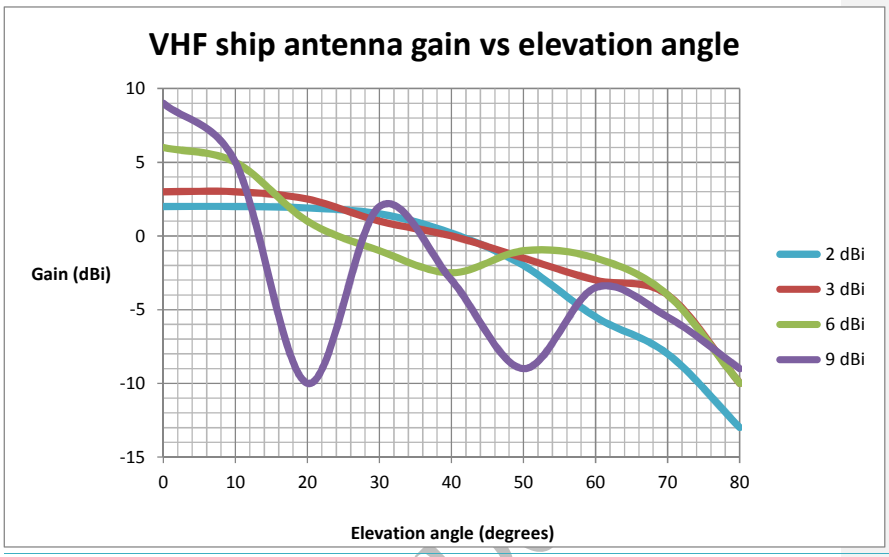

Figure 3. Ship antenna gain vs. elevation angle.

(Source: Haugli, Space Norway, derived from Comrod datasheets)

3.3.3 Ship EIRP vs elevation angle

The minimum ship EIRP vs elevation angle is shown in Table 1. There are no minimum EIRP requirements above 80 degrees elevation. Table 1 is based on a linear transmitter meeting the maximum Adjacent Channel Interference levels defined in the subframe format tables. For saturated operation the EIRP shall be 3 dB higher.

Table 1. Minimum ship EIRP vs. elevation angle (iso C/N0)

Ship elevation angle	Min. antenna gain with 6 W transmitter	Minimum ship EIRP
degrees	dBi	dBW
0	1,5	9,26
10	-1,8	5,95
20	-4,7	3,1
30	-6,7	1,06
40	-7,5	0,24
50	-7,4	0,36
60	-6,5	1,32
70	-4,2	3,58

80	-1,7	6,11
90	1,5	(9,29)

3.3.4 Satellite antenna gain

The worst case linkbudget occurs at 0 degrees ship elevation angles and the highest satellite antenna gain should be in this direction.

A suitable antenna is a crossed 3 element Yagi with a peak gain of 8 dBi. The satellite antenna gain vs. ship elevation angle is shown in Table 2.

Commented [NA71]: Alternative could be AIS dipole. If there is any input we may include that here.

Table 2. Satellite antenna gain vs. ship elevation angle (Source: Haugli, Space Norway)

Ship elevation angle	Nadir offset angle	Boresight offset angle	Satellite antenna gain
deg.	deg.	deg.	dBi
0	66,1	0	8
10	64,2	1,9	8
20	59,2	6,9	8
30	52,3	13,8	7,8
40	44,4	21,7	6,9
50	36	30,1	5,5
60	27,2	38,9	3,6
70	18,2	47,9	0,7
80	9,1	57	-2,2
90	0	66,1	-5,5

3.3.5 Satellite system noise temperature

The satellite noise level at the receiver input is shown in Table 3. Without external interference the system noise temperature is 25.7 dBK.

Table 3. Satellite receiver system noise temperature

Antenna noise temperature	200,0	K
Feed losses	1,0	dB
LNA noise figure	2,0	dB
LNA noise temperature	159,7	K
Feedloss noise temp. at LNA	56,1	K
Antenna noise temp. at LNA	158,9	K

System noise temp. at LNA	374,7	K
System noise temp. at LNA	25,7	dBK

3.3.6 Uplink C/N0

The baseline uplink linkbudget is given in Table 4. It is optimised for 0 degree ship elevation angles and the ship minimum EIRP is reduced at higher elevation angles to achieve a constant C/N0 of 70 dBHz for all elevation angles up to 80 degrees.

For most elevation angles the ship EIRP will be higher than the minimum, and C/N0 up to 10 dB higher may be expected. It is not envisaged that VDES will use uplink power control.

Table 4. Baseline uplink link budget.

Ship elevation angle	Ship miniumum EIRP	Polarisation and propagation losses	Range	Pathloss	Satellite G/T	C/N0
deg	dBW	dB	km	dB	dB/K	dBHz
0,0	9,7	6,0	2830,0	144,6	-17,7	70,0
10,0	6,3	6,0	1932,0	141,3	-17,7	70,0
20,0	3,5	6,0	1392,0	138,4	-17,7	70,0
30,0	1,5	6,0	1075,0	136,2	-17,9	70,0
40,0	0,6	6,0	882,0	134,4	-18,8	70,0
50,0	0,8	6,0	761,0	133,2	-20,2	70,0
60,0	1,7	6,0	683,0	132,2	-22,1	70,0
70,0	4,0	6,0	635,0	131,6	-25,0	70,0
80,0	6,5	6,0	608,0	131,2	-27,9	(70,0)
90,0	9,7	6,0	600,0	131,1	-31,2	(70,0)

3.4 Propagation effects

Refer to Annex 4 (only new content will be reported here).

The received signal level on board a ship will vary due to a number of causes. A Rice distribution with a Carrier to Multipath (C/M) ratio of 10 dB and fading bandwidth of 3 Hz is assumed, however the system shall be adaptable to handle significantly worse and better propagation conditions.

Table 5. Ionospheric effects for elevation angles of about 30° one-way traversal

(Source: Gallinaro, Space Engineering, derived from Recommendation ITU-R P.531)

Effect	Frequency dependence	0.1 GHz	0.25 GHz	1 GHz
Faraday rotation	$1/f^2$	30 rotations	4.8 rotations	108°
Propagation delay	$1/f^2$	25 µs	4 µs	0.25 µs
Refraction	$1/f^2$	< 1°	< 0.16°	< 0.6′
Variation in the direction of arrival (r.m.s.)	$1/f^2$	20′	3.2′	12″
Absorption (auroral and/or polar cap)	$\approx 1/f^2$	5 dB	0.8 dB	0.05 dB
Absorption (mid-latitude)	$1/f^2$	< 1 dB	< 0.16 dB	< 0.01 dB
Dispersion	$1/f^3$	0.4 ps/Hz	0.026 ps/Hz	0.0004 ps/Hz
Scintillation (1)	See Rec. ITU-R.P.531	See Rec. ITU-R P.531	See Rec. ITU-R P.531	>20 dB peak-to-peak

* This estimate is based on a TEC of 1018 electrons/m^2, which is a high value of TEC encountered at low latitudes in day-time with high solar activity.

(1) Values observed near the geomagnetic equator during the early night-time hours (local time) at equinox under conditions of high sunspot number.

Table 6. Mid-latitude fade depths due to ionospheric scintillation (dB)

Percentage of time (%)	Frequency (GHz)			
	0.1	0.2	0.5	1
1.0	5.9	1.5	0.2	0.1
0.5	9.3	2.3	0.4	0.1
0.2	16.6	4.2	0.7	0.2
0.1	25.0	6.2	1.0	0.3

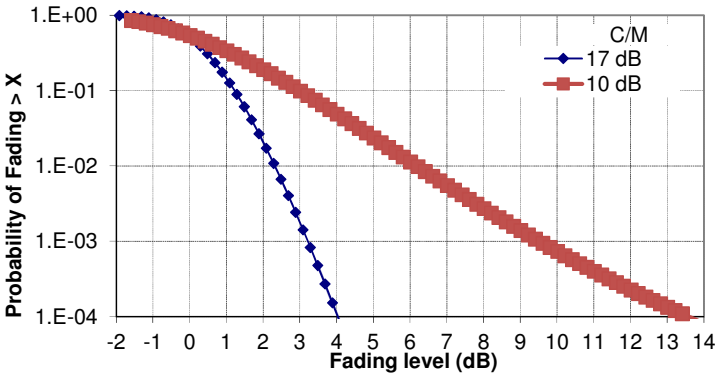

Figure 4. Ricean fade depth probability

(Source: Gallinaro, Space Engineering)

3.5 Modulation

VDES uses adaptive modulation and coding to maximise spectral efficiency and throughput. The supported modulation methods are given in Table 7.

Table 7. Downlink modulation methods

Index	Bits/symbol	Modulation type	Bit mapping	Maximum adjacent channel interference level with worst case Doppler
		BPSK or CPM		
1	2	Grey encoded QPSK	Fig. 5	- 18 dB

2	3	Grey encoded 8PSK	Fig. 6	- 18 dB
3	4	16APSK	Fig. 7	- 18 dB

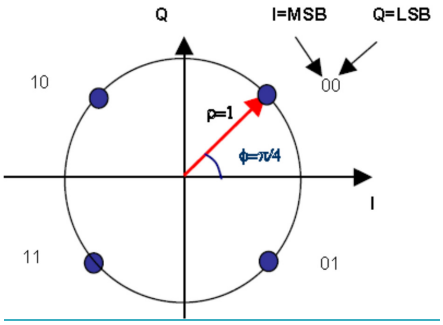

Figure 5. QPSK symbol to bit mapping

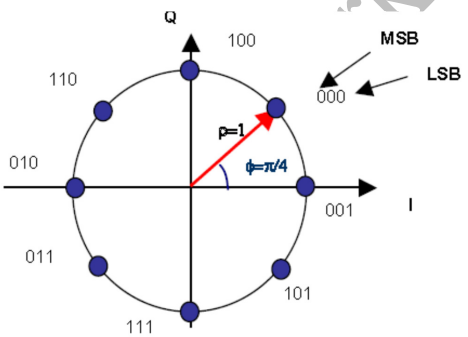

Figure 6. 8PSK symbol to bit mapping

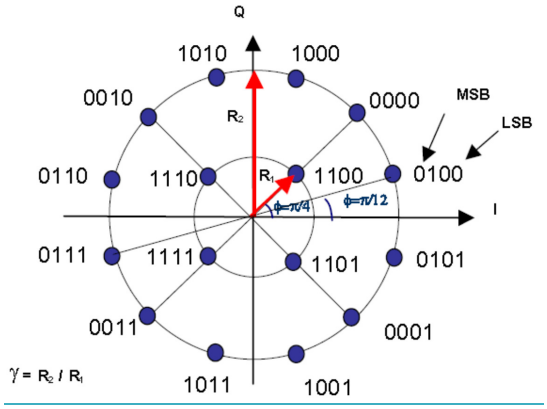

Figure 7. 16APSK symbol to bit mapping

The 16APSK modulation constellation shall be composed of two concentric rings of uniformly spaced 4 and 12 PSK points, respectively in the inner ring of radius R_1 and outer ring of radius R_2.

The ratio of the outer circle radius to the inner circle radius ($\gamma = R_2/R_1$) shall be equal to 3. R_1 shall be set to $1/\sqrt{7}$, R_2 shall be set to $3/\sqrt{7}$ in order to have the average signal energy equal to 1.

3.6 Symbol timing accuracy

~20 ppm TBC

3.7 Transmitter Timing Jitter

<5% rms TBC

3.8 Slot Transmission Accuracy

+/-100 micro sec TBC

3.9 Half duplex and full duplex satellites

To be referred to Annex 4.

The system can be configured for both half and full duplex satellites as shown in Figure 8.

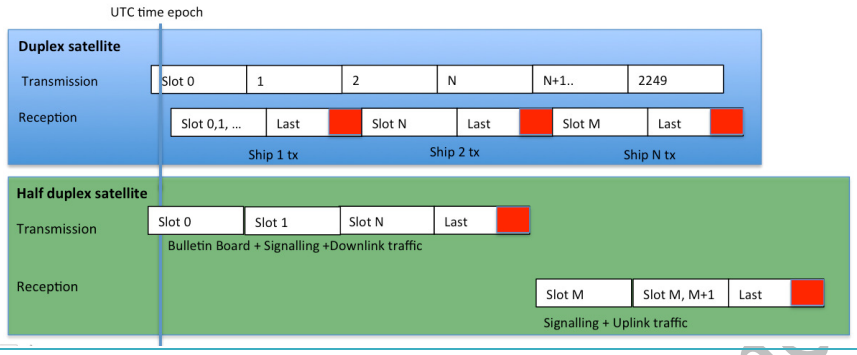

Figure 8. Half and full duplex satellite operation

(Source: Haugli, Space Norway)

3.10 Uplink frame hierarchy

Open Points:

1) Guard Time (do we need it to dela with the variable propagation delay?)
2) We use 1 or more slots for uplink
3) The bandwidth and the centre frequency will be part of the Sub-frame format
4) Announcement channel will be used for assigning capacity (ASC), updates to Annex 4 if needed.
5)

The VDES frame structure is identical and synchronized in time on the earths surface to UTC (as in AIS) and the frame hierarchy for a subframe of N slots is shown in Figure 9. Each element is described in the subsequent sections.

Frame 0 starts at 00:00:00 UTC, and there are 1440 frames in a day.

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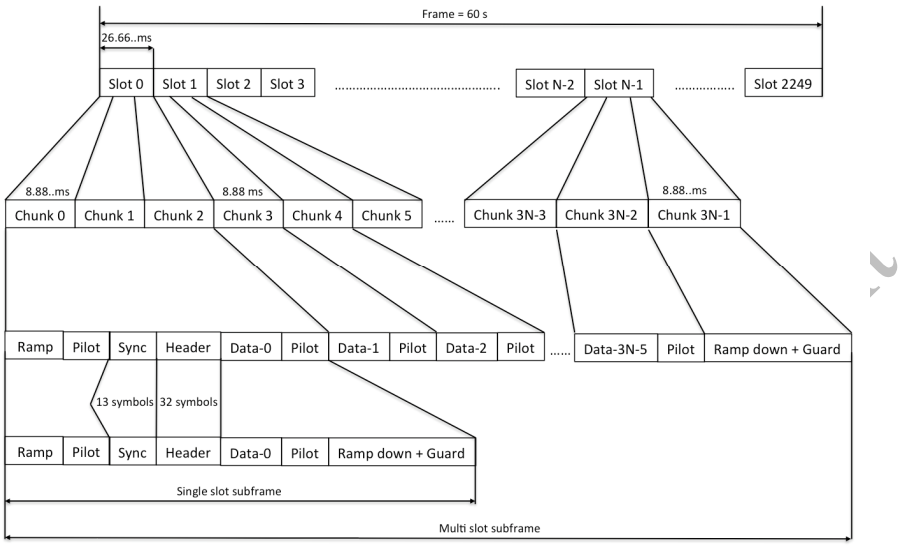

Figure 9. VDES uplink frame hierarchy (draft) (updated to remove the sub-sub segments)
(Source: Haugh, Space Norway)

3.10.1 Guard time and ramp up

The ramp up time from 10% to 90% of the power shall occur in less than 300 uS.

The guard time at the beginning of a subframe may not be required, but has been provided to allow for future expansion of the pilot, synchronisation word and the subframe format header.

3.10.2 Synchronisation pilot

This CW (before scrambling) signal before the synchronisation word and after every burst has a fixed duration of x ms.

3.10.3 Synchronization word

(keep in mind the impact of interference in order to define the length of pilot, sync and (known header).

The subframe synchronisation word and header format is fixed for all transmissions. The 13 bit Barker code unique word is defined in Table 8. It is modulated with BPSK at a symbol rate of x kbps. Bit 0 is transmitted first.

Table 8. Barker sequence unique word

Bit number												
0	1	2	3	4	5	6	7	8	9	10	11	12
1	1	1	1	1	-1	-1	1	1	-1	1	-1	1

3.10.4 Direct Sequence Spreading

The BPSK symbols are spread using a 8 bit sequence to a chiprate of 21 kcps to fit in a 50 kHz channel. Spreading sequence SS0 from Table 9 is used.

Table 9. Spreading sequences TBC

Sequence name	Chip number							
	0	1	2	3	4	5	6	7
SS0	-1	-1	-1	1	1	-1	1	1
SS1	-1	-1	1	-1	1	1	1	-1
SS2	-1	1	-1	1	1	1	-1	-1
SS3	-1	1	-1	-1	-1	-1	1	-1

Commented [NA72]: Update according to the input from Thibaud)

3.10.5 Subframe header (7 bits)

This could be known a priori (via bulletin board on the downlink).

To look at the right mapping to get a good correlation property for most used sequence.

The header is BPSK modulated and spread the same way as the synchronisation word described above. This header defines the following characteristics for the remainder of the subframe:

- Subframe duration
- Number of data chunks
- Symbol rate
- Modulation type
- FEC type
- FEC rate
- Interleaver type
- Scrambler type (if used)
- Spreading code length (if used)
- Spreading codes (if used)

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The header provides 7 bits to define up 128 subframe formats and uses (32,7) quad orthogonal forward error correction coding. The performance of this FEC is shown in Figure 11.

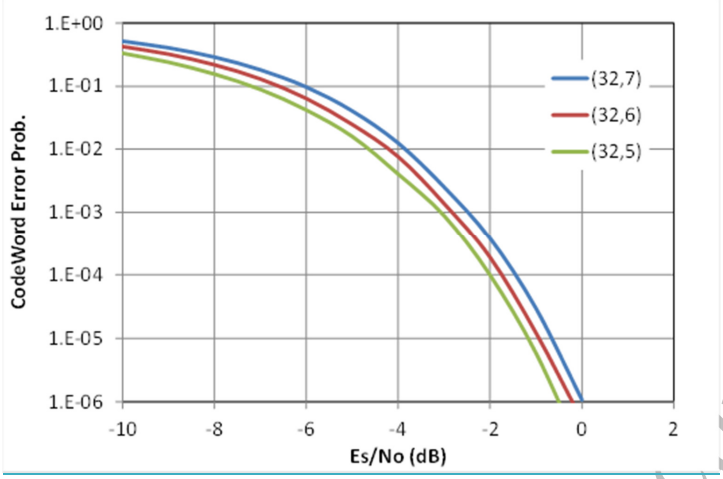

Figure 11. Header error probability

(Source: Gallinaro, Space Engineering)

Commented [NA73]: May need to be updated for the uplink C/N0+I0.

3.10.6 Data-N

Segment N is encoded one burst at a time..

3.10.7 Ramp down

The ramp down time from 90% to 10% of the power shall occur in less than 100 uS.

3.10.8 Guard time

No transmissions shall occur during the guardtime to avoid partly overlap with terrestrial AIS/VDES slots. The guard time is 8.9 ms.

Commented [NA74]: To be reviewed. This is a big hit on the overhead.

3.10.9 Subframe format

(Examples of packet types to be mapped to each format ACK, NACK. Capacity Request).

The following formats are envisaged:

-
- CDMA random access short subframe (x slots) To be determined depending on the minimum message size per transmission. (minimum message bits 100 bits), Question on the interference level .
- CDMA random access medium length subframe (y slots)

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- TDMA random access/TDM single slot subframe (Action to compare ACRDA and E-SSA to make a decision).
- DAMA: TDM assigned medium length subframe(25 slots) Decide on the minimum duration to deal with the Ricean fading.

These formats are defined in Tables 10.1 to 10.3(4) (to be added)

4. Link layer

4.1 Data encapsulation

A subframe consist of multiple variable length datagrams and these are encapsulated. Each datagram contain the following encapsulation fields:

- Datagram type (1 byte)
- Datagram size (3 bytes)
- Transaction ID (4 bytes, optional)
- Datagram sequence number (2 bytes, for multi-segment datagrams)
- Source ID (8 bytes, optional)
- Datagram payload (variable)
- Data padding (variable, less than 8 bits)
- CRC (4 bytes)

(Action HCH: To provide some packet definitions especially for short packets to assess the overhead)

4.2 Cyclic Redundancy Check

The 32 bit ITU polynom 0x04C11DB7 CRC is appended to the last segment of the datagram. The CRC is calculated over all segments.

F(x)= x32 + x26 + x23 + x22 + x16 + x12 + x11 + x10 + x8 + x7 + x5 + x4 + x2 + x + 1

Initial state: 0xFFFF

4.3 Automatic repeat request (ARQ)

Single slot format with a payload

Datagrams may or may not use ARQ, this is defined for each datagram type. An ARQ will request retransmission of a specific lost datagram segment.

4.4. Acknowledgement (ACK)

All datagrams without CRC errors are acknowledged over the satellite link.

4.5 End delivery notification (EDN)

All datagrams successfully delivered to the destination will be notified to the source.

4.5 End delivery failure (EDF)

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All datagrams not successfully delivered within the timeout or retry limit will be notified to the source.

4.6 Physical and Logical channels

VDES uses several channels to carry data. These channels are separated into Physical and Logical Channels. The satellite transmits a Bulletin Board that defines the configuration of these channels.

4.7 Physical Channels

The Physical Channels (PC) are determined by the center frequency, subframe format and start timeslot.

4.8 Logical Channels (LC)

The logical channels are divided into signalling and data channels. These are described below.

4.9 Signalling Logical Channels (or bursts?)

The following uplink signalling channels are used:

- Random access resource request
- Announcement response
- Acknowledgement
- Automatic repeat request

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4.9.1 Random access resource request (RQSC)

A ship uses this channel to access the network. This channel is a pure Aloha channel. A ship will randomly select the transmission time within the slots allocated for this channel on the Bulletin Board.

The request includes a downlink C/N0 estimate and message size.

4.9.2 Announcement response channel (ARSC)

A ship uses this channel to inform the satellite that it is ready to receive a message. The response includes a downlink C/N0 estimate.

4.9.3 Acknowledgement (ACSC)

A ship uses this channel to inform the satellite that it has received a message correctly (CRC match).

4.9.4 Automatic repeat request (ARQSC)

A ship uses this channel to inform the satellite that it has not receive a message correctly (CRC failure). The ship can request retransmission of the whole message or up to 4 fragments. The acknowledgement includes a downlink C/N0 estimate.

4.10 Data Logical Channels

The following data channels are used:

- Random access short messages
- Assigned data transfer

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4.10.1Random access short messaging (RADC)

This channel is used for short messages that fit in a single transmission

4.10.2 Assigned data transfer (ADDC)

This channel is assigned by the satellite following a resource request from a ship. It is intended for longer messages and is optimised for throughput.

5. Network layer

5.1 Uplink data transfer protocols

The following protocols shall be supported:

- Ship originated single packet data transfer
- Ship originated multi-packet data transfer

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The protocols are shown in Figures 12 and 13.

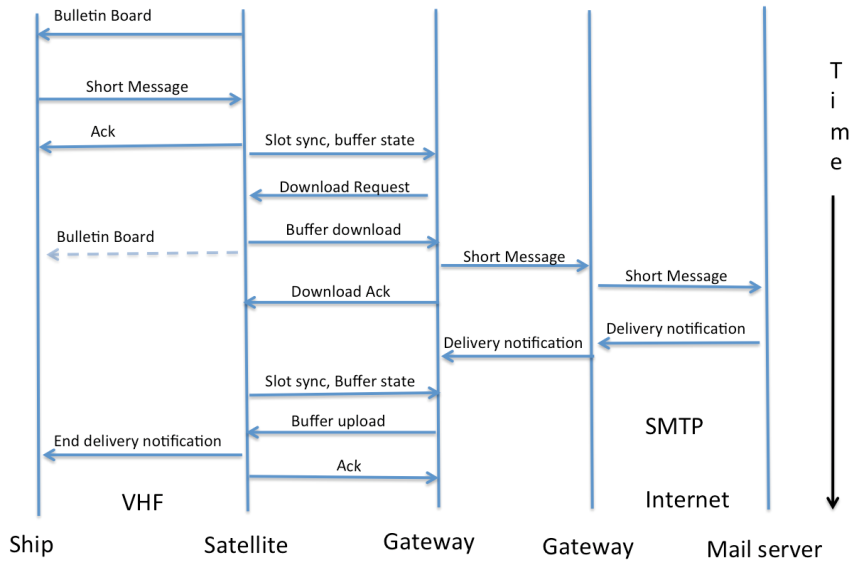

Figure 12. Ship originated single packet data transfer (draft)

(Source: Haugli, Space Norway) update the figure, add:
1) Annuncment channel
2) To be random access

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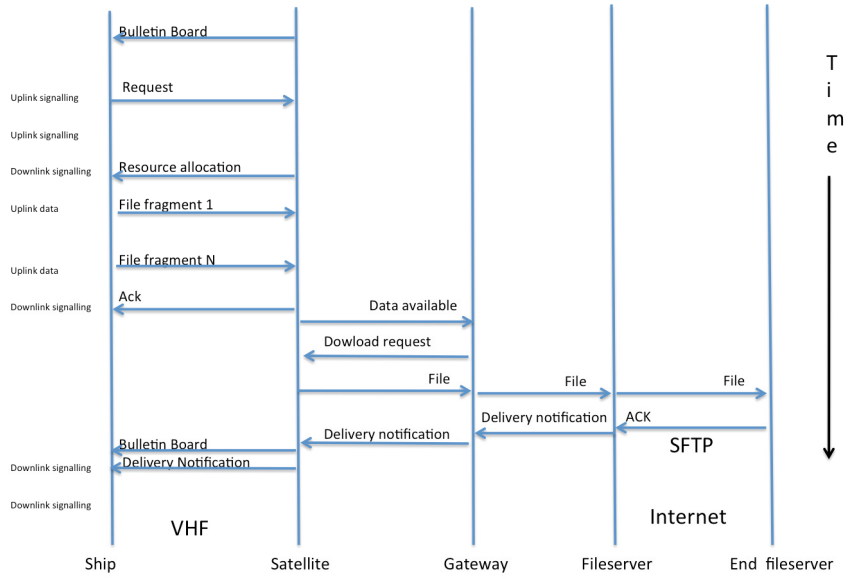

Figure 13. Ship originated multi-packet data transfer (draft) To be reviewed (applicable to DAMA)

(Source: Haugli, Space Norway)

The figure should include: time slot and non-exclusive bands.

Figure 14. Ship originated Transmit Only Protocol (No ACK), Random Access

6. Transport layer

Reference to Annex 3

6.1

ANNEX 6

Sharing options for the VDE Terrestrial and VDE Satellite services

Scope

This Annex presents methods to share the VHF spectrum available to VDES between terrestrial and satellite services. Methods for sharing spectrum among different VDE satellite systems are also presented. The baseline frequency assignment per each service is according to the frequency usage illustrated in Figure 1 of Annex 1 and described in the following clauses thereof. Proposed methods rely on the characteristics of VDE terrestrial and VDE Satellite components as described in Anne 3 to Annex 5 of this recommendation.

Frequency Sharing Considerations

VDE-SAT Downlink

Although the PFD mask is selected to minimize interference to the land mobile service and to maximize reception by ship VDES stations, there is a potential effect of raising the noise floor for reception of the terrestrial VDES links during satellite VDE downlink transmissions when the satellite is the field of view.

Issues to be considered for the sharing the VDE1-B frequencies and the VDE-SAT Downlink are:

- When shipborne VDES transceivers are simplex they cannot receive while transmitting.
- VDE-SAT downlink transmission levels, by raising the noise floor, will potentially have an impact on reception of ship-to-ship and shore-to-ship VDES.
- Ship-to-ship and shore-to-ship VDES transmissions, depending on the distance, by co-channel interference, will potentially interfere with reception of the VDE-SAT downlink

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Frequency division multiple access (FDMA)

Frequency division multiple access is accomplished by using only the upper 50 kHz for the VDE-SAT downlink, i.e., only the two channels 2026 and 2086. The frequency division multiple access would mitigate the last two issues stated above. Compared to other techniques proposed below, the FDMA would be the most straightforward to implement. However it would result in a reduction of the bandwidth to 1/3, and cause the VDE-SAT downlink transmissions to last three times longer for the same payload, and it would not mitigate the first issue stated above.

Time division multiple access (TDMA)

Time division multiple access approach for shore-ship/ship-ship and VDE SAT downlink services would allow the full use of the spectrum assigned to each service in a time sharing manner. Time sharing can mitigate all the three of the issues stated in Section 6 above. However, it would impose some design challenges for the VDE-SAT components and compromise the throughput of the VDE-SAT Downlink.

The AIS-based TDMA slot structure (2250 slots/minute/frame) and access schemes (ITDMA, CSTDMA and FATDMA) that are used for VDES are defined in Recommendation ITU-R M.1371-5. This TDMA organization scheme protects the integrity of the AIS and is used to organize and synchronize the ASM and VDE transmissions.

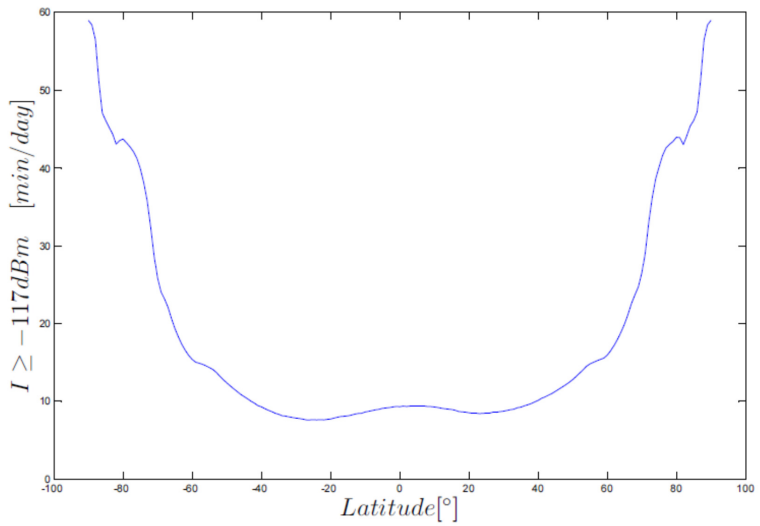
Full Frequency reuse (superposition)

In this approach, the terrestrial and satellite components are allowed to simultaneously use channels 2024, 2084, 2025 and 2085. The VDE-SAT downlink will additionally use channels 2026 and 2086. The VDE-SAT downlink could continuously broadcast to maximize the data dissemination to a large number of ships in its field of view. This would allow for more efficient implementation of the VDE-SAT receivers. The interference caused by the VDE-SAT downlink on the VDE terrestrial could, in principle, be compensated for by the use of more protected coding scheme in the terrestrial link, only during the satellite passage.

For a most likely scenario of Low Earth Orbit satellites with a polar orbit, the impact of satellite interference could be limited to only less than 15 minutes per day per satellite for geographical locations with latitudes within ±50 degrees, as shown in Figure 9~~Figure 5~~.

Figure 6~~5~~

Time duration where signal level exceeds -117dBm as a function of geographical position



VDE Terrestrial (VDE1-A) and VDE-SAT Uplink

Due to the large field of view, a passing satellite would receive a number of colliding messages from different VDE-terrestrial links (ship-to-shore) simultaneously that would interfere with ship to

satellite links (channel 1024, 1084, 1025, 1085). The following multiple access schemes can be envisaged to mitigate/minimize the impact of VDE terrestrial link on VDE satellite uplink.

Frequency Division Multiple Access (FDMA)

The frequency division multi-access scheme separates the satellite channels into two groups: Channels 1024, 1084, 1025 and 1085 that are subject to terrestrial interference are considered as a single or multi-carrier satellite uplink channel(s). Highly robust waveforms would be selected for these channels to allow for interference mitigations caused by VDE terrestrial.

The second group of carriers are considered to occupy Channel 1026 and 1086 where no VDE terrestrial transmission is present.

Time Division Multiple Access (TDMA)

VDE-SAT uplink follows the same frame structure as VDE terrestrial occupying VDE1-A channels. There are pre-assigned time slots dedicated to satellite transmission preventing interference from any VDE terrestrial link.

Alternatively, noting that Recommendation ITU-R M.1371-5 specifies the access schemes for the AIS Messages, including ITDMA, on the AIS channels, and it specifies the structure for ASM with various contents. VDES takes ASM to another level by providing dedicated ASM channels to relieve congestion on the AIS channels. Under VDES, the access scheme for using the ASM channels could be initially by CSTDMA (Carrier-Sense TDMA) for the first transmission in a frame, followed by ITDMA for subsequent transmissions in that frame. This scheme mitigates simultaneous transmissions by ships and/or shore stations on the ASM channels.

Full Frequency reuse

The terrestrial and satellite components are allowed to simultaneously use channels 1024, 1084, 1025 and 1085. The VDE-SAT uplink would use properly designed waveforms occupying the VDE-SAT uplink channels to minimize the impact of interference caused by the VDE terrestrial transmissions.

Sharing Strategies among different VDE Satellite systems

Example of Deployment Method

VDE-SAT Downlink and VDE Terrestrial

This section provides an example of frequency sharing that allows experiments using VDE-SAT and VDE terrestrial. Figure below illustrates an interim use of frequency bands:

- Channel 2014 and 2084 are used for terrestrial VDE
- Channel 2016 and 2086 are dedicated to VDE Satellite downlink
- Channel 2025 and 2085 are assigned according to the time sharing strategy described in Section 2.1.2.

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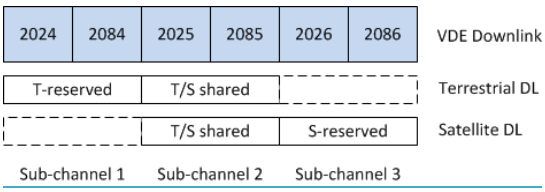

VDE-SAT Downlink and VDE Terrestrial

This section describes examples of frequency assignment for VDE-Sat uplink.

Ideas to be explored:

- Channel bandwidth
- Interference mitigation
- Load control strategies.

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Implementation of resource Sharing

The example of a LEO satellite with downlink (only) or with downlink and uplink capability.

Bulletin Board Definition: (Possible use of the terrestrial signaling).

- In line with Annex 4
- Static and Dynamic
- BBSC Validity 11 bits (x0 = indefinite) this is to remove the need to go through the whole table.
- The resource allocation plan (time, frequency and U/L, D/L)
- Define the random access and dedicate access
- Announcement channel will defined in BBSC
- TLE
- Backup frequency for the BSSC
- Network ID 8 bits
- Satellite ID 8 bits
- Pointing to NIT (Network Information table)

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Note: We may add example of BBSC to support a half-duplex scenario (5 sec up and 10 sec down).

(Action: To tabulate this information)

Actions: Nader to write

Observation:: The solution allow to implement all three proposed methods of resource sharing (to be elaborated (NA).

Annex 7 – Retained working text

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7 Application specific messages

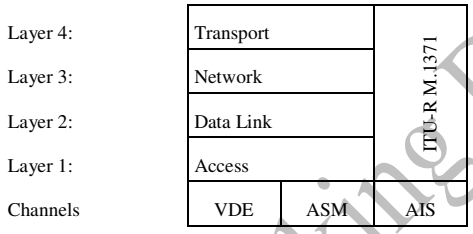
For the VDES, to mitigate AIS VDL loading effects, ASM should conform to the data structure specified in Recommendation ITU-R M.1371 and may use the two channels designated for ASM in Table 1 (ASM 1 and ASM 2) instead of AIS 1 and AIS 2. Transmission method should be according to Section 0~~0~~.

8 Protocol layer overview

The VDES architecture should utilize the open systems interconnection layers 1 to 4 (physical layer, link layer, network layer, transport layer) as illustrated in Figure 7~~Figure 3~~.

FIGURE 7~~3~~

open systems interconnection layers 1-4



9 Technical considerations for VHF data exchange system access schemes

This section provides technical considerations in designing access schemes for VDE terrestrial, VDE Satellite and the interaction between these VDES components.

From Figure 1~~Figure 1~~, the satellite downlink shares the spectrum with the terrestrial ship-ship and shore-ship links, and the satellite uplink shares the spectrum with the terrestrial ship-shore link. Thus, access schemes should be considered to mitigate potential conflicts between the links.

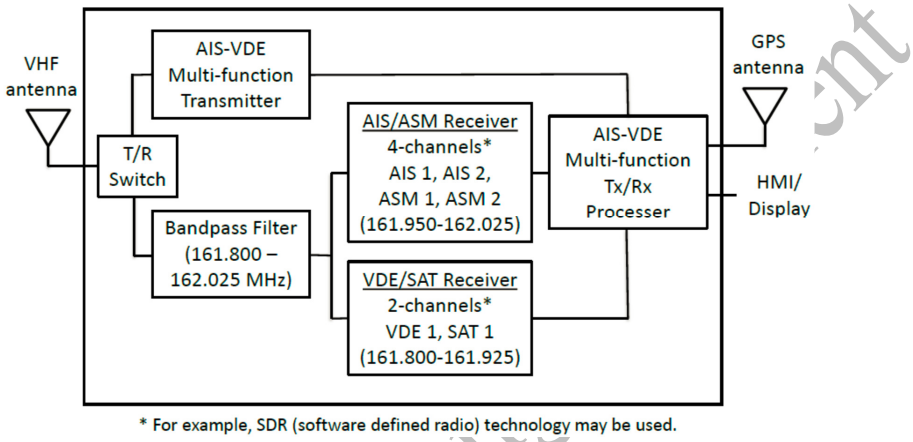
9.1 Time division multiple access scheme for the VHF date exchange terrestrial service

The VDES terrestrial service is comprised of ASM, VDE ship-shore, VDE shore-ship and VDE ship-ship. An example shipborne VDES transceiver implementation is illustrated in Figure 4 below. Note that in this implementation example all receivers, including the AIS receivers, are protected from blocking from the shipborne VHF radio by the band-pass filter that attenuates signals from the

lower side of the Appendix 18 band. The AIS receiver blocking issue, along with the fact that the AIS can share the same antenna with the other VDES functions, is incentive for manufacturers to consider this implementation for their VDES system designs.

FIGURE 84

Example VHF data exchange system transceiver implementation



9.1.1 Time division multiple access scheme for the VHF data exchange system application specific message channels

Note that Recommendation ITU-R M.1371-5 specifies the access schemes for the AIS messages, including incremental time division multiple access (ITDMA), on the AIS channels, and it specifies the structure for ASM with various contents. VDES takes ASM to another level by providing dedicated ASM channels to relieve congestion on the AIS channels. Under VDES, the access scheme for using the ASM channels could be initially by Carrier-Sense TDMA (CSTDMA) for the first transmission in a frame, followed by ITDMA for subsequent transmissions in that frame. This scheme mitigates simultaneous transmissions by ships and/or shore stations on the ASM channels. An ASM transmission should not exceed five contiguous slots.

9.1.2 Time division multiple access scheme for the VHF data exchange system ship-shore link

The TDMA access scheme for the VDE1-A ship-shore link could be by reservation through ITDMA from an ASM on either one of the ASM channels, as described in 0~~0~~. A VDE1-A ship-shore transmission should not exceed five contiguous slots.

9.1.3 Time division multiple access scheme for the VHF data exchange system ship-ship link

The TDMA access scheme for the VDE1-B ship-ship link could be the same as for the ASM channels, i.e., initially by CSTDMA for the first transmission in a frame, followed by ITDMA for subsequent transmissions in that frame. This scheme mitigates simultaneous ship-ship transmissions. A VDE1-B ship-ship transmission should not exceed five contiguous slots.

9.1.4 Time division multiple access scheme for the VHF data exchange system shore-ship link

The TDMA access scheme for the VDE1-B shore-ship link could be the same as for the VDE1 ship-shore link, i.e., by reservation through ITDMA from an ASM on either one of the ASM channels. This is necessary because the shore station has a very wide coverage area compared to ships, and it needs to have priority access to the VDE1 channel in its coverage area. A VDE1-B shore-ship transmission should not exceed five contiguous slots.

9.2 Sharing options for the VHF data exchange terrestrial and VHF data exchange satellite services

9.2.1 VHF data exchange terrestrial links on the upper legs (VDE1-B) and VHF data exchange satellite downlink

Table 3 provides the PFD at the Earth's surface from the satellite downlink at various elevation angles from 0^0 to 90^0. Although the PFD mask is selected to minimize interference to the land mobile service and to maximize reception by ship VDES stations, there is a potential effect of raising the noise floor for reception of the terrestrial VDES links during satellite VDE downlink transmissions when the satellite is the field of view.

Issues to be considered for the sharing the VDE1-B frequencies and the VDE-SAT Downlink are:

– When shipborne VDES transceivers are simplex they cannot receive while transmitting.

– VDE-SAT downlink transmission levels, by raising the noise floor, will potentially have an impact on reception of ship-to-ship and shore-to-ship VDES.

– Ship-to-ship and shore-to-ship VDES transmissions, depending on the distance, by co-channel interference, will potentially interfere with reception of the VDE-SAT downlink.

9.2.1.1 Frequency division multiple access

Frequency division multiple access is accomplished by using only the upper 50 kHz for the VDE-SAT downlink, i.e., only the two channels 2026 and 2086. The frequency division multiple access would mitigate the last two issues stated above. Compared to other techniques proposed below, the FDMA would be the most straightforward to implement. However it would result in a reduction of the bandwidth to 1/3, and cause the VDE-SAT downlink transmissions to last three times longer for the same payload, and it would not mitigate the first issue stated above.

9.2.1.2 Time division multiple access

Time division multiple access approach for shore-ship/ship-ship and VDE SAT downlink services would allow the full use of the spectrum assigned to each service in a time sharing manner. Time sharing can mitigate all the three of the issues stated in Section 6 above. However, it would impose some design challenges for the VDE-SAT components and compromise the throughput of the VDE-SAT Downlink.

The AIS-based TDMA slot structure (2250 slots/minute/frame) and access schemes (ITDMA, CSTDMA and FATDMA) that are used for VDES are defined in Recommendation ITU-R M.1371-5. This TDMA organization scheme protects the integrity of the AIS and is used to organize and synchronize the ASM and VDE transmissions.

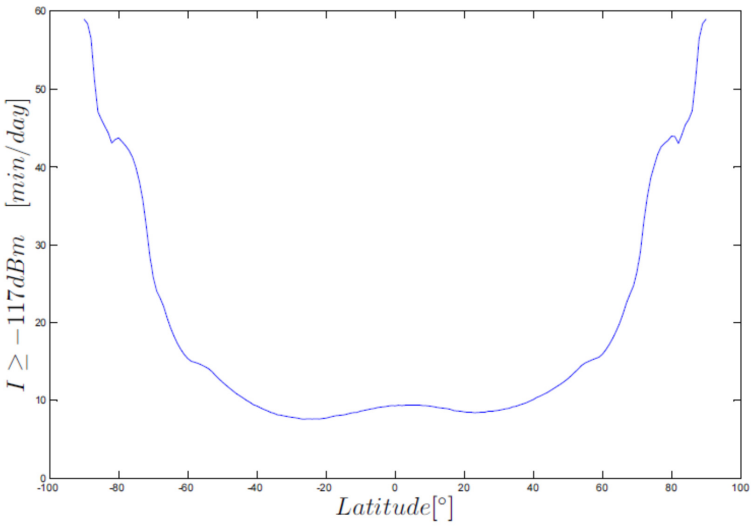
9.2.1.3 Full frequency reuse (superposition)

In this approach, the terrestrial and satellite components are allowed to simultaneously use channels 2024, 2084, 2025 and 2085. The VDE-SAT downlink will additionally use channels 2026 and 2086. The VDE-SAT downlink could continuously broadcast to maximize the data dissemination to a large number of ships in its field of view. This would allow for more efficient implementation of the VDE-SAT receivers. The interference caused by the VDE-SAT downlink on the VDE terrestrial could, in principle, be compensated for by the use of more protected coding scheme in the terrestrial link, only during the satellite passage.

For a most likely scenario of Low Earth Orbit satellites with a polar orbit, the impact of satellite interference could be limited to only less than 15 minutes per day per satellite for geographical locations with latitudes within ±50 degrees, as shown in Figure 9~~Figure 5~~.

FIGURE 9~~5~~

Time duration where signal level exceeds -117 dBm as a function of geographical position



9.2.2 VHF data exchange terrestrial (VDE1-A) and VHF data exchange satellite uplink

Due to the large field of view, a passing satellite would receive a number of colliding messages from different VDE-terrestrial links (ship-to-shore) simultaneously that would interfere with ship to satellite links (channel 1024, 1084, 1025, 1085). The following multiple access schemes can be envisaged to mitigate/minimize the impact of VDE terrestrial link on VDE satellite uplink.

9.2.2.1 Frequency division multiple access

The frequency division multi-access scheme separates the satellite channels into two groups: Channels 1024, 1084, 1025 and 1085 that are subject to terrestrial interference are considered as a single or multi-carrier satellite uplink channel(s). Highly robust waveforms would be selected for these channels to allow for interference mitigations caused by VDE terrestrial.

The second group of carriers are considered to occupy Channel 1026 and 1086 where no VDE terrestrial transmission is present.

9.2.2.2 Time division multiple access

VDE-SAT uplink follows the same frame structure as VDE terrestrial occupying VDE1-A channels. There are pre-assigned time slots dedicated to satellite transmission preventing interference from any VDE terrestrial link.

Alternatively, noting that Recommendation ITU-R M.1371-5 specifies the access schemes for the AIS Messages, including ITDMA, on the AIS channels, and it specifies the structure for ASM with various contents. VDES takes ASM to another level by providing dedicated ASM channels to relieve congestion on the AIS channels. Under VDES, the access scheme for using the ASM channels could be initially by CSTDMA (Carrier-Sense TDMA) for the first transmission in a frame, followed by ITDMA for subsequent transmissions in that frame. This scheme mitigates simultaneous transmissions by ships and/or shore stations on the ASM channels.

9.2.2.3 Full frequency reuse

The terrestrial and satellite components are allowed to simultaneously use channels 1024, 1084, 1025 and 1085. The VDE-SAT uplink would use properly designed waveforms occupying the VDE-SAT uplink channels to minimize the impact of interference caused by the VDE terrestrial transmissions.

10 Transmission waveforms for VHF data exchange terrestrial links

ITU-approved waveforms for spectrum-efficient data transmission in the VHF maritime band are described in Recommendation ITU-R M.1842-1. These waveforms have been demonstrated in the land-mobile service and in maritime trials, to provide robust data service and to mitigate multipath degradation at extended propagation ranges in intense electromagnetic environments. Table 2 below provides a comparison of performance between the current AIS standard, Recommendation ITU-R M.1371, and the new applications introduced for the terrestrial VDES links, ASM and VDE. Note that the spectrum efficiency for the AIS is much lower than for VDES, but the AIS modulation has superior co-channel rejection which provides better range discrimination and improved safety of navigation for ships. Each modulation type is intended to best fit its designated application (AIS, ASM and VDE).

Propagation range predictions for the terrestrial links are provided in Annex 3 in accordance with the ITU propagation standard Recommendation ITU-R P.1546-4.

TABLE 42

ITU-standard transmission waveforms for automatic identification system, application specific message and VHF data exchange terrestrial links

	25 kHz Channels for AIS	**25 kHz Channels for ASM**	**100 kHz Channels for VDE**
ITU Standard	ITU-R M.1371-5	ITU-R M.1842-1 Annex 1	ITU-R M.1842-1 Annex 4 ***
Digital Modulation	GMSK, single carrier	π/4 DQPSK, single carrier	16-QAM, 32 multi-carriers, 2.7 kHz spacing
Data Rate (raw)*	9.6 kbps (1X)	28.8 kbps (3X)	307.2 kbps (32X)
Sensitivity**	-107 dBm (min) -112 dBm (typical)	-107 dBm (min) -112 dBm (typical)	-98 dBm (ships) -103 dBm (base stations)
Co-channel rejection (CCR)**	10 dB	19 dB	19 dB
AIS Message types	1, 2, 3, 5, 18, 19, 27 …	6, 7, 8, 12, 13, 14, 25, 26 and ASM	VDE messages
Rationale	Optimum choice (better CCR) for position reports in a ship-to-ship navigation safety environment.	Provides higher (3X) data transmission than AIS. Inferior CCR (+9dB) and range discrimination compared to AIS.	Provides much higher (32X) data transmission than AIS. Inferior CCR (+9dB) and range discrimination compared to AIS.

** These figures are raw, over the air, bit transmission rates. The data rates are less, subject to coding, packet structure and forward error correction (FEC)*

*** These figures are based on published standards. For AIS, the standard is IEC 61993-2 and for VDE the standard is ETSI EN 300 392-2 version 3.4.1, which refers to a land mobile application TETRA.*

**** For greater robustness where needed, ITU-R M.1842-1 Annex 1 may be used.*

10.1 Transmission waveform for the 25 kHz application specific message channels

Transmission of ASM on 25 kHz channels should be by π/4 DQPSK single-carrier modulation as described in Recommendation ITU-R M.1842-1 Annex 1. FEC is applied due to the fact that the ASM messages are not repeated as are AIS position reports (which do not have FEC). The waveform is recommended because it has high sensitivity, 70 dB adjacent channel power ratio (ACPR) and 28.8 kbps data rate.

– It is generated by phase modulation with an inter-symbol rotation of π/4 radians. This produces an amplitude envelope with very moderate peak to average power ratio (PAPR);

– It has excellent characteristics for detection by satellites as required by the channel plan.

10.2 Transmission waveform for the 100 kHz VHF data exchange channels

Transmission of VDE on 100 kHz channels should be by 16-QAM, 32 multi-carriers, with 2.7 kHz spacing and 307.2 kbps data rate as described in Recommendation ITU-R M.1842-1 Annex 4. This multi-carrier scheme is not OFDM (orthogonal frequency division multiple access) since the carrier spacing is 2.7 kHz which provides more inter-carrier margin than OFDM which would require 2.4 kHz spacing. This waveform is comprised of 32 multi-carriers. Each carrier is modulated by 16-QAM to generate 4-bit symbols at 2400 symbols/second (2400 symbols/sec/carrier X 4 bits/symbol = 9600 bits/sec/carrier).

The long symbol duration (2400 symbols/sec = 416.7 µs/symbol) is designed to mitigate multi-path inter-symbol interference, since (ref: Document 5B/636 Annex 28) reflections in a 100 kHz maritime channel environment have been found to be contained primarily within the first 10.4 µs. It is noted that further reflections were beyond this, some as far as 50 µs. By comparison, note that AIS uses GMSK to generate 2-bit symbols at 4800 symbols/second (9600 bits/second) and that its excellent propagation characteristics have been proven in practice.

The modulation, coding and scrambling techniques described in EN 300 392-2 v.3.4.1 are combined to reduce the amplitude envelope PAPR (PAPR ≤ 10dB) to mitigate the RF power transmitter design difficulty. Both analog, e.g. Doherty Amplifier (DA), and digital, e.g. Envelope Tracking (ET) and Digital Pre-Distortion (DPD), design techniques for RF power amplifiers are available to provide better than 50% efficiency with this waveform. By comparison, the AIS power amplifiers used by ships and base stations are also approximately 50% efficient. A technical report describing these techniques and others for modern high efficiency power amplifiers with actual test results can be found at:

http://www.microwavejournal.com/articles/21965-modern-high-efficiency-amplifier-design-envelope-tracking-doherty-and-outphasin g

Note that the analog design approach using Doherty Amplifiers provides efficiency over 50% and the original patent for this technology has expired. Solid state Doherty Amplifiers are currently in service in cellular terrestrial infrastructures which produce the range of power levels needed for shipborne VDES transceivers (12.5 Watts) and VDES base stations (50 Watts).

11 Antenna options for VHF data exchange system terrestrial stations

Commercially available antenna options for the VDES terrestrial stations are characterized in Figure 6 below. Since the shipborne antenna is required to receive the VDES satellite downlink at high elevation angles, the 0dBd (2.1dBi) option is selected. To achieve optimum satellite reception, this antenna should be mounted as high as possible, preferably on an extension pole, on the ship to minimize obstructions to the antenna's view of the horizon. For the terrestrial VDES base station, the 6dBd (8dBi) option is selected. These two antennas are used in the propagation range predictions in Annex 2.

Figure 7 presents a mask for the receiving antenna gain as a function of elevation that would allow the received signal from satellite to be at constant power level at the receiver input for a wide range of elevation angles, taking into account the PFD constraints imposed on the VDE-SAT downlink (ref. Table 3 of Annex 1). Although this mask may not represent the antenna pattern associated with a commercially available antenna, it could serve as a guide for designing an antenna to enhance the satellite reception. The same mask is also applicable to the design of shipborne antenna for VDE terrestrial link due its high directivity in the horizontal direction. Annex 3 provides further rationale for the selection of this mask.

FIGURE 10~~6~~

Antenna options for shipborne VHF data exchange system stations

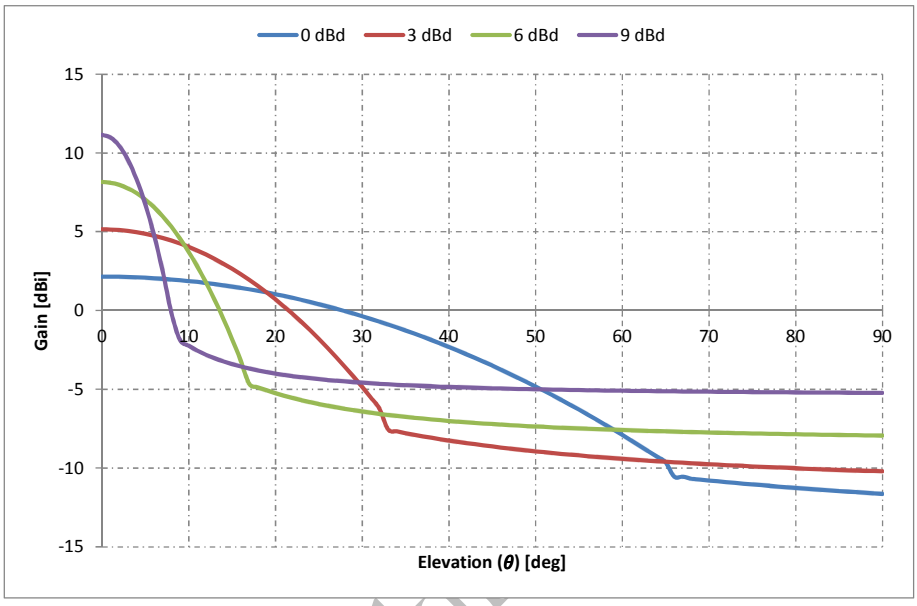
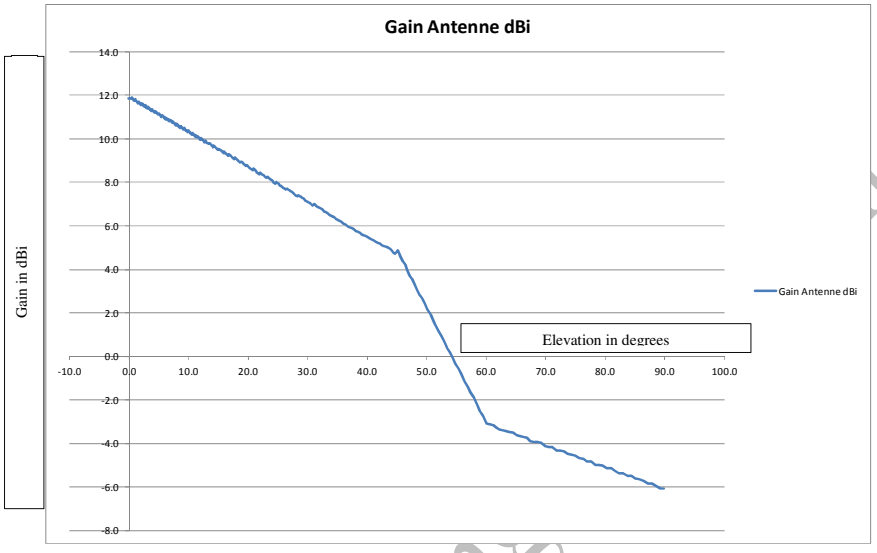


FIGURE 117

Mask for 'Ideal' antenna



12 Presentation interface protocol

For VDES transceivers:

- Data to be transmitted by the VDES device should be input via the presentation interface;
- Data received by the VDES device should be output through the presentation interface.
- The formats and protocol used for data streams should be in accordance with IEC 61162.

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13 VHF data exchange by satellite

VHF data exchange by satellite should use the channels designated for satellite in Table 1 and should be in accordance with this Recommendation. This is further described below.

13.1 General

13.1.1 VHF data exchange system satellite component

The VHF data exchange VDE satellite component is an effective means to extend the VDES to areas outside of coastal VHF coverage. Hereafter, the satellite component is referred to as the VDE-SAT.

Satellite communications is able to deliver information in a broadcast, multicast or unicast mode to a large number of ships, i.e. efficiently addressing many ships using only minimal radio spectrum resources.

The VDE-SAT provides a communication channel that is complementary to the terrestrial components of the VDES system (i.e. coordinated with terrestrial VDE, ASM and AIS functionalities and their supporting systems).

13.1.2 Applications

Continuous exchanges with the maritime community will provide further insight into the priorities, quality of service, security, integrity and other requirements of future VDES services.

There is a large population of smaller size ships – which have no satellite communication equipment on board, but do have regular VHF/AIS reception equipment – that could benefit from the services mentioned above. This would be of particular benefit for vessel populations in areas with limited shore based infrastructure.

Using low-cost satellite reception technology, VDE-SAT can address a large population of ships and offer services for non-SOLAS vessels, fishing vessel, recreational users, life rafts, and even individuals in distress.

13.2 Overall architecture, operational characteristics and assumptions

13.2.1 Architecture

The VHF data exchange system architecture is shown in Figure 8 below. The VDE-SAT is composed of one or more satellites transmitting and receiving in the maritime VHF bands – this is the *space segment*.

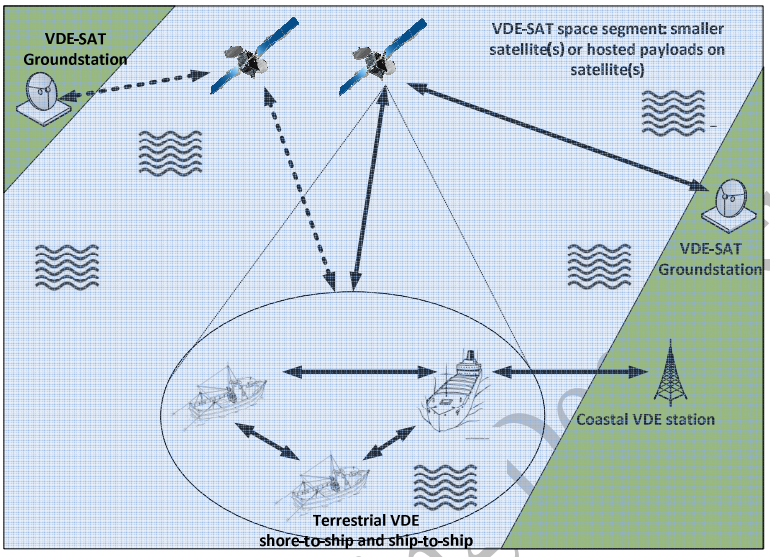
Due to the frequencies used, it is likely that VDE-SAT will consist of low-earth orbiting (LEO) or medium-earth orbiting (MEO) satellites. VDE-SAT could also consist of hosted payload on spacecraft in such orbits.

The VDE-SAT user terminals may be integrated in ship-borne VDES equipment. This is called the *user segment*. These terminals could be integrated in the terrestrial VDE equipment along with ASM and AIS functionalities. Also VDE-SAT receive-only terminals can be considered: these would provide a very cost-effective means to disseminate maritime information to smaller ships outside terrestrial VHF coverage, for example in areas with limited shore based infrastructure.

There will be a *ground segment* which consists of one of more ground stations that will send and receive maritime information to/from ships for further processing or dissemination, via the space segment. Communication between the coastal VDE station, maritime information provider, VDE-SAT ground station and feeder link is not part of the VDES architecture.

FIGURE 12~~8~~

VHF data exchange-satellite component architecture



13.2.2 Operational characteristics

The VDE-SAT should complement the VDE terrestrial in areas in which no terrestrial VDE coverage is available, i.e. at the high-seas.

The VDE-SAT should provide a downlink capability (i.e. allow to send information from a ground station to one or more ships). Note that VDE-SAT will likely use its specific unicast, multicast or broadcast capability which is inherent in a satellite downlink.

The VDE-SAT should provide an uplink capability (i.e. allow a ship to send information to the satellite, for further relaying to a ground station).

As VDE-SAT will be based on LEO or MEO satellite(s), provisions will need to be taken for the discontinuous contact that ships will have with individual satellites. Furthermore, if there are multiple VDE-SAT satellites or payload footprints that overlap, some coordination between them may be required.

It is proposed that VDE-SAT supports priority, pre-emption and precedence for different services; this could be mapped into different downlinks.

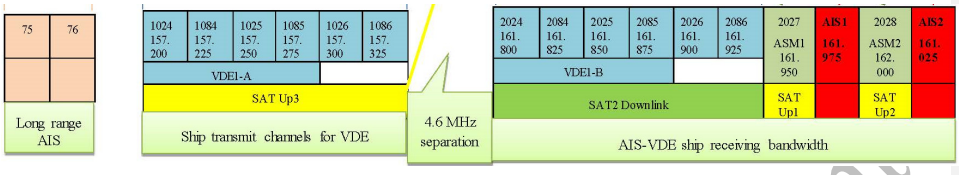
13.3 Technical characteristics

13.3.1 VHF data exchange-satellite channels and spectrum

The VDE-SAT downlink should be used for data downlink from the satellite to vessels in a broadcast, multicast or unicast manner. The VDE-SAT should also provide data uplink from vessels to satellites using one or several multiple-access schemes. The VHF data exchange system via satellite uses the channel allocation shown in Figure 13~~Figure 9~~.

FIGURE 13~~9~~

VHF data exchange system channel allocation



13.3.1.1 SAT downlink

The satellite downlink frequency spectrum consists of six 25 kHz channels (2024 to 2086). These channels may be bundled into one 150 kHz channel to reduce the guard band (needed due to the frequency Doppler shift of incoming signals from LEO satellites), increase the throughput, and more importantly, improve the power efficiency of the satellite power amplifier (avoiding multi-carrier transmission which typically requires a larger output back-off). (refer to section 6)

Due to the PFD limit imposed on the VDE-SAT downlink (as part of sharing the frequencies with land mobile), a certain level of redundancy (in the form of frame repetition, forward error correction or higher layer redundancy) is implemented in the VDE-SAT protocol in order to mitigate the error and enhance the data detection probability.

The VDE-SAT downlink signal also includes repeated known symbols (e.g. pilots, preamble, post-amble) to facilitate signal detection and synchronization as well as possible interference mitigation and channel estimation. In order to avoid unwanted in-band spectral lines, the data symbols are scrambled with a known sequence. The example in section 0~~0~~ concludes that a downlink data rate of 240 kbps is possible.

The signal level generated by the satellite should be kept below the PFD mask limit (referred to the earth's surface) specified in Table 3 below. Note that this is based on coordination with terrestrial VHF services and that the PFD level refers to the vertical component of radiation normal to the earth's surface.

TABLE 5~~3~~

Power flux-density mask

$$\boldsymbol{\theta^\circ = earth - satellite\ elevation\ angle}$$

$$PFD(\theta^\circ)_{(dBW/(m^2 * 4\ kHz))} = \begin{cases} -149 + 0.16 * \theta^\circ & 0^\circ \le \theta < 45^\circ; \\ -142 + 0.53 * (\theta^\circ - 45^\circ) & 45^\circ \le \theta < 60^\circ; \\ -134 + 0.1 * (\theta^\circ - 60^\circ) & 60^\circ \le \theta \le 90^\circ. \end{cases}$$

This PFD mask is to ensure that there is no harmful interference caused by the satellite downlink on non-maritime terrestrial services sharing the same frequency (ensuring in-band carrier-to-interference requirements of terrestrial service receivers).

13.3.1.2 SAT 3 uplink

The frequency spectrum corresponding to 6 lower VDE channels (starting from Channel 1024) are used for satellite data uplink. Compared to the AIS channels, and long range AIS, these 6 channels provide a significant data uplink capability via satellite.

The access scheme protocol for data uplink via satellite is designed to take into account the entire satellite field of view and to maximize the probability of message detections by avoiding message collisions.

13.3.2 Rationale of channel allocation for VHF data exchange-satellite

The frequency plan for the entire VDES, as depicted in Figure 9 above, facilitates a realistic implementation of the proposed system in co-existence with, and complementing, the current AIS. The following points regarding the frequency plan are highlighted:

– The requirements for VDES concentrate the reception frequencies on board of the ship to a limited range of 250 kHz at the upper maritime VHF band. This provides an efficient implementation of VDES on-board receivers by narrowing the input filter bandwidth, reducing potential impairments due to other activities within the maritime VHF band.

– The VDE-SAT downlink shares the same frequency range as the terrestrial VDE and AIS. This allows sharing the same antenna as well as the receiver front-end design.

– Satellite and shore reception frequencies of shipborne VDE signals occupy the lower end of the VHF maritime band. This allows for a complementary service close to the shore and at the high sea while sharing the same spectrum. The frequency separation between the upper and lower spectra (with 4.6 MHz separation) provides an acceptable level of isolation between VDES receiving chain and the VDE ship-borne transmitters.

– The frequency separation between the uplink and downlink allows hosting VDE-SAT transmitter and receiver on the same satellite which allows for a more cost-effective satellite mission concepts (i.e. reduce number of satellites, improved efficiency and possible interactivity).

13.4 Example VHF data exchange system satellite implementation

The following example VDES satellite implementation fits the PFD angular mask and supports the requirements of this Recommendation.

13.4.1 Determine the VHF data exchange system satellite orbital characteristics

The following VDES satellite implementation is considered. The satellite orbital characteristics that are needed to support this application are determined as follows.

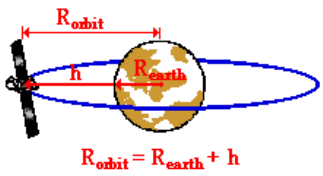
13.4.1.1 Determine the satellite's orbit

The example VDES satellite employs a polar orbit at a height of 550 km above the surface of the earth. The velocity, acceleration and orbital period of the satellite are determined, given: $M_{earth} = 5.98 \times 10^{24}$ kg, $R_{earth} = 6.37 \times 10^{6}$ m.

The satellite's orbit and the known and unknown parameters are shown in Figure 10 below.

FIGURE 14~~10~~

Satellite orbital characteristics



Given/Known:	Unknown:
$R = R_{earth}$ + height = 6.92×10^6 m	v = ???
$M_{earth} = 5.98 \times 10^{24}$ kg	a = ???
$G = 6.673 \times 10^{-11}$ N m²/kg²	T = ???

The radius of a satellite's orbit can be determined from the earth's radius and the height of the satellite above the earth. As shown in Figure 10, the radius of orbit for a satellite is equal to the sum of the earth's radius and the height above the earth. These two quantities are added to yield the orbital radius. The 550 km altitude is first converted to 0.550×10^6 m and then added to the radius of the earth.

Determine the velocity of the satellite

$v = SQRT [(G \bullet M_{Central}) / R]$

$v = SQRT [(6.673 \times 10^{-11} N m^2/kg^2) \bullet (5.98 \times 10^{24} kg) / (6.92 \times 10^6 m)]$

$v = 7.594 \times 10^3$ m/s

Determine the acceleration of the satellite

$a = (G \bullet M_{central})/R^2$

$a = (6.673 \times 10^{-11} N m^2/kg^2) \bullet (5.98 \times 10^{24} kg) / (6.92 \times 10^6 m)^2$

$a = 8.333$ m/s²

Determine the orbital period of the satellite

$T = SQRT [(4 \bullet pi^2 \bullet R^3) / (G*M_{central})]$

$T = SQRT [(4 \bullet (3.1415)^2 \bullet (6.92 \times 10^6 m)^3) / (6.673 \times 10^{-11} N m^2/kg^2) \bullet (5.98 \times 10^{24} kg)]$

T = 5725.7 s = 1.59 hrs

13.4.2 VHF data exchange system satellite antenna and downlink characteristics

A directional vertically polarized Yagi-Uda antenna is used for communicating with ships' vertical antennas and also for conformance with the PFD angular mask.

13.4.2.1 Determine the earth's rotation at the equator between each satellite orbit:

The period of the earth $\mathbf{T_e}$ is approximately 24 hours (86.4×10^3 s), the radius of the earth $\mathbf{R_e}$ is 6.37×10^6 m and the circumference of the earth (distance around the equator) is $\mathbf{C_{earth}} = 2 \bullet (3.1415) \bullet (6.37 \times 10^6 m) = 40.0239 \times 10^6$ m. Therefore, in each pass of the satellite, the earth will have rotated at the equator by $\mathbf{ROT_{equator} = C_{earth} \bullet T / T_e} = 40.0239 \times 10^6 m \bullet 5725.7 s / 86.4 \times 10^3 s = 2.6524 \times 10^6 m =$ **2652.4 km**.

13.4.2.2 Determine the slant distance to the earth's horizon:

The slant distance $\mathbf{D_s}$ from the satellite to the earth's horizon is $\mathbf{D_s}$ = SQRT [($\mathbf{R^2} - \mathbf{R_e^2}$] = SQRT [$(6.92 \times 10^6\ m)^2 - (6.37 \times 10^6\ m)^2$] = 2.7036×10^6 m = **2703.6 km**.

Determine the slant downward tilt angle to the earth's horizon:

13.4.2.3 The satellite's downward tilt angle to the earth's horizon is:

$\boldsymbol{\theta_d} = 90^0 - \sin^{-1}(\mathbf{R_e} / \mathbf{R}) = 90^0 - \sin^{-1}(6.37 \times 10^6\ m / 6.92 \times 10^6\ m) = 90^0 - 67^0$ = **23 degrees**.

13.4.2.4 Determine the width of the antenna coverage path:

The example VDES satellite antenna pattern is shown in Figure 11 below. The beamwidth (+/- 3 dB) of the antenna is 80 degrees. The width of the satellite antenna's coverage path is:

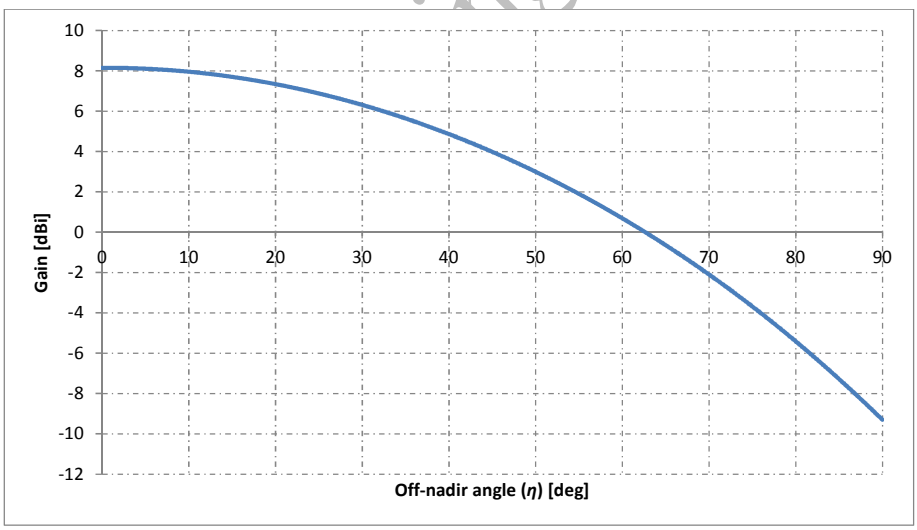
$\mathbf{W_c} = 2(\mathbf{D_s} \cos(90^0 - \boldsymbol{\theta_a}/2))$

$\mathbf{W_c} = 2 \bullet 2.7036 \times 10^6\ m \bullet \cos(90^0 - 80^0/2) = 3.4757 \times 10^6\ m$ = **3475.6 km**.

Note from 4.2.1 that since $\mathbf{ROT_{equator}}$ = 2652.4 km, this antenna beamwidth ($\boldsymbol{\theta_a} = 80^0$) is sufficiently wide for contiguous earth coverage by one satellite every 24 hours. This vertically-polarized Yagi-Uda antenna is pointed in the forward direction with an optimized downward tilt angle to provide the vertical component of radiation for reception by ships' vertical dipole antennas.

FIGURE 15~~11~~

Example VDES satellite antenna pattern



13.4.2.5 Determine the maximum Doppler frequency shift (f_d) between the satellite and ships in the satellite's antenna coverage area

The maximum Doppler frequency shift **(f_d)** between the satellite and a ship will occur when the relative velocity between them is a maximum, i.e., when the ship is situated on the satellite's earth horizon. Note that the coverage for this satellite is only in the forward direction and that the satellite's antenna pattern will cover ships in the range of 23 degrees (earth's horizon) downward from the satellite's velocity vector. Therefore, the maximum Doppler shift is $\mathbf{f_d}$ (max) = f_{VDES} (**v**/c) • cos $\boldsymbol{\theta_d}$ **=** 162 x 10^6 (7.594 x 10^3)/(3 x 10^8) • cos 23^0 = **3775 Hz**. The satellite transmitter frequency should be reduced by half of $\mathbf{f_d}$ (max) to provide a range of **+/- 1887.5 Hz** in the coverage area.

Determine the optimum downward tilt angle for the satellite VDES antenna for coverage of ships in the forward direction

From the VDES satellite antenna characteristics in Figure 11 above, note that the response is flat to approximately 12^0. This supports an additional downward tilt of 12^0 below the horizon of 23^0 for an optimized total downward tilt angle of **35 degrees** below the line that is tangent to the satellite's orbital path. This provides a sufficient vertical radiation component for ships in the coverage area.

13.4.2.6 Consideration of the angular power flux-density mask limits for transmission by the VHF data exchange system satellite

The PFD angular mask (the maximum allowable PFD in dB(W/(m2*4kHz)) as a function of the elevation angle from the earth), is shown in Table 3 of Section 10.3.1.1. Note that the PFD mask at 0^0 (horizon) is -149 dB(W/(m2*4kHz)), at 45^0 elevation is -142 dB(W/(m2*4kHz)), at 60^0 elevation is -134 dB(W/(m2*4kHz)) and at 90^0 (overhead) is -131 dB(W/(m2*4kHz)). Note also that since the PFD mask level refers to the vertical component of radiation normal to the earth's surface, the polarization loss (≈ 3 dB @ 45^0 elevation angle) based on the angular relationship between the vertical axis of the satellite antenna and the earth's surface should be considered in the determination of the satellite VDES transmitter power.

13.4.2.7 Determine the power flux density levels at elevations of 0^0, 10^0, 30^0, 60^0 and 90^0 when the power flux density level at 45^0 elevation is set to -142 dB(W/(m2*4kHz))

This section confirms that the elevation angle of 45^0 is the CPA (closest point of approach) between the PFD mask and the actual radiated VDES space-earth downlink signal.

Calculations of the **slant ranges** and **elevation angles** note from the previous calculations that the slant range from the satellite earth horizon is 2703.6 km. The results of these calculations are shown in Table 2 below. Note that the "orbital angle" (the angle of rotation of the satellite's orbit above the earth) is used as a reference for geometric calculations (angles and distances) and for time-keeping (elapsed time from the horizon to the point of rotation).

The slant ranges from the satellite to an earth station are determined from the law of cosines (c = SQRT (a^2 +b^2 +c^2 -2ab cos (C)), where c = slant range, a = R_e + h, b = R_e and C = the satellite orbital angle. The calculations start with C = 23^0 (the angle to the horizon) and proceed to C = 0^0 (the directly above/below position), shown in Table 4.

To find the elevation angles, reference angles are determined from the inverse law of cosines (C = $\cos^{-1}$ ((a^2 + b^2 + c^2)/(2ab)) where C = the reference angle between the slant range (line of observation) and the earth radius (line from the earth station to the center of the earth), a = slant range, b = earth radius and c = R_e + h. The elevation angles for the earth stations are determined by subtracting 90^0 from the reference angles, also shown in Table 4 below.

13.4.2.8 Determine reference levels based on the 45^0 elevation angle

From Table 3, the slant range to the satellite at 45^0 elevation is 748.3 km and the PFD at 45^0 elevation is set to the mask limit of **-142 dB(W/(m2*4kHz))**. Since the relative angle of the satellite antenna (down-tilted by 35^0) in that direction is approximately ($45^0 – 35^0$) = 10^0, the gain of the satellite antenna in that direction, from Figure 7, is **8 dB**. These values were used as the **set point values** (the 0 dB reference levels) to calculate the PFD levels for the other elevation angles.

13.4.2.9 Determine the power flux density level for the elevation angle of 0^0

The slant range at 0^0 (horizon) is 2703.6 km, the satellite relative angle to the horizon is -23^0, the satellite antenna relative angle with a 35^0 down-tilt is (35^0-23^0) = 12^0 and the gain, from Figure 7, is 8 dB. Since the relative range loss is (20 log (748.3/2703.6) = -11.2 dB, the PFD at 0^0 is 11.2 dB below the 45^0 level (-142 – 11.2) = **-153.2 dB(W/(m2*4kHz))** which is (-149 - (-153.2)) = 4.2 dB below the 0^0 mask limit.

13.4.2.10 Determine the power flux density level for the elevation angle of 10^0

The slant range at 10^0 elevation is 1818.4 km, the satellite relative angle to the horizon is -23^0, the satellite antenna relative angle with a 35^0 down-tilt is (35^0-23^0-10^0) = 2^0 the gain, from Figure 7, is 8 dB (the same as the reference), the relative range loss is 20 log (748.3/1818.4) = -7.7 dB and thus the PFD at 10^0 is (-142 – 7.7) = **-149.7 dB(W/(m2*4kHz))** which is 2.3 dB below the 10^0 mask limit of -147.4 dB(W/(m2*4kHz)).

13.4.2.11 Determine the powe flux density level for the elevation angle of 30^0

The slant range at 30^0 elevation is 993.5 km, the satellite relative angle to the horizon is -23^0, the satellite antenna relative angle with a 35^0 down-tilt is (35^0-30^0) = 5^0 the gain, from Figure 7, is 8 dB (the same as the reference), the relative range loss is 20 log (748.3/993.5) = -2.5 dB and thus the PFD at 30^0 is (-142 – 2.5) = **-144.5 dB(W/(m2*4kHz))** which is 0.3 dB below the 10^0 mask limit of -144.2 dB(W/(m2*4kHz)).

13.4.2.12 Determine the power flux density level for the elevation angle of 60^0

The slant range at 60^0 elevation is 632.7 km, the satellite relative angle to the horizon is -23^0, the satellite antenna relative angle with a 35^0 down-tilt is (35^0-60^0) = -18^0 the gain, from Figure 7, is 7.5 dB (0.5 dB below the reference), the relative range is 20 log (748.3/632.7) = +1.5 dB (1.5 dB above the reference) and thus the PFD at 60^0 is (-142 - 0.5 + 1.5) = **-141.0 dB(W/(m2*4kHz))** which is 7.0 dB below the 60^0 mask limit of -134.0 dB(W/(m2*4kHz)).

13.4.2.13 Determine the power flux density level for the elevation angle of 90^0

The slant range at 90^0 (overhead) is the satellite altitude of 550 km, the gain of the satellite antenna in that direction, from Figure 7, with a down-tilt of 35 degrees is the gain at (35^0-90^0) = -55 degrees is 2 dB (6 dB below the reference), the relative range factor is 20 log (748.3/550) = +2.7 dB (2.7 dB above the reference) and thus the PFD at 90^0 is (-142 -6 + 2.7) = **-145.3 dB(W/(m2*4kHz))** which is 14.3 dB below the 90^0 mask limit of -131 dB(W/(m2*4kHz)).

The PFD values for elevation angles from 0^0 to 90^0 are shown in Table 4 below.

TABLE 64

Power flux density for various elevation angels

Orbital angle (degrees)	Elapsed time from horizon (sec)	Slant range (km)	Reference angle (degrees)	Elevation angle (degrees)	PFD (actual/mask/margin, in dB(W/(m2*4kHz)))
23	0	2703.6	90	0	-153.2/-149/4.2
22	15.9	2592.7	90.5	0.5	-152.8/-148.9/3.9
21	31.8	2481.6	91.0	1.0	-152.4/-148.8/3.6
20	47.7	2370.5	93.2	3.2	-152/-148.5/3.5
19	63.6	2259.6	94.4	4.4	-151.6/-148.3/3.3
18	79.5	2148.8	95.6	5.6	-151.2/-148.1/3.1
17	95.4	2038.3	97.0	7.0	-150.7/-147.9/2.8
16	111.3	1928.1	98.4	8.4	-150.2/-147.7/2.5
15	127.2	1818.4	100.0	10.0	-149.7/-147.4/2.3
14	143.1	1709.2	101.6	11.6	-149.2/-147.1/2.1
13	159.0	1600.6	103.5	13.5	-148.6/-146.8/1.8
12	175.0	1493.0	105.5	15.5	-148/-146.5/1.5
11	190.9	1386.5	107.8	17.8	-147.4/-146.1/1.3
10	206.8	1281.4	110.3	20.3	-146.7/-145.8/0.9
9	222.7	1178.1	113.2	23.2	-145.9/-145.3/0.6
8	238.6	1077.3	116.6	26.6	-145.2/-144.7/0.5
7.145	252.2	993.5	120.0	30.0	-144.5/-144.2/0.3
7	254.5	979.6	120.6	30.6	-144.3/-144.1/0.2
6	270.4	886.3	125.3	35.3	-143.5/143.35/0.15
5	286.3	798.7	131.0	41.0	-142.5/-142.4/0.1
4.38	296.1	748.3	135.0	45.0	-142/-142/0 *(reference)*
4	302.2	719.2	137.8	47.8	-141.7/-140.5/1.2
3	318.1	650.6	146.2	56.2	-141.5/-136.1/5.4
2.7	322.9	632.7	150.0	60.0	-141/-134/7
2	334.0	596.8	156.1	66.1	-141.8/-133.4/8.4
1	349.9	562.1	167.6	77.6	-143.1/-132.2/10.9
0	365.8	550.0	180	90	-145.3/-131/14.3

Notes for Table 4:

*1. When the PFD level is set to the mask limit of -142dB(W/(m2*4kHz))) at 45^0 elevation angle, the PFD levels at all other elevation angles are below the mask.*

*2. The maximum PFD level is -141dB(W/(m2*4kHz)) at 60^0 elevation angle, which is 7 dB below the mask limit level of -134dB(W/(m2*4kHz)).*

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13.4.2.14 Consider the shipborne VHF data exchange system antenna and receiver characteristics

The shipborne antenna and receiver characteristics are considered, along with the satellite radiated PFD levels, to determine the performance of the example VDES satellite downlink.

13.4.2.15 Specify the shipborne VHF data exchange system antenna characteristics

The available shipborne antenna options are comprised of stacked vertical dipole elements of various lengths and gain values, were previously shown in Figure 10~~Figure 6~~ in section 0~~0~~. This analysis considers the 0 dBd antenna because it has the best performance for the elevation angles required for satellite detection.

13.4.2.16 Determine the shipborne VHF data exchange system receiver characteristics

The shipborne VDES receiver characteristics and the coordination levels for the terrestrial service are considered, and the set of metrics in Table 5 below are used to determine a reference value of C/N (carrier-to-noise ratio) for the example shipborne VDES receiver.

TABLE 7~~5~~

Metrics for considering ITU-R coordination levels and calculating C/N in a VDES Receiver

Power received (referred to the Rx antenna) by a shipboard VHF receiver (reference 25 kHz channel):

Power received (linear formula): $Pr = GE^2c^2/480\pi^2f^2$, where

G = gain of a half-wavelength (λ/2) dipole antenna = 1.64

E = field strength = 4 x10exp-6 volts/ meter (4 µV/m = +12dBu)

c = speed of light in free space = 3 x 10exp8 meters/second

f = VDES downlink frequency = 161.9x10exp6 (161.9 MHz)

λ = 1.852 meters (at 161.9 MHz)

Pr = 19.02x10exp-15 watts = -137.2dBW = -107.2dBm

The logarithmic formula can also be used to calculate Pr (dBm):

Pr (dBm) = 42.8 - 20logF + 20logE + G, where

G = antenna gain in dBi = 2.1dBi (2.1dB over isotropic)

F = frequency in MHz = 161.9

Pr (dBm) = 42.8 – 44.1 – 108 + 2.1 = -107.2dBm (-137.2dBW)

PFD = dB(E) -153.72 = 12-153.72 = -141.72dB(W/(m^2*4kHz)) from a vertically-polarized source

A_e = effective area for a dipole antenna = $0.13\lambda^2 = 0.446m^2$

P_r (25 kHz channel) = PFD + 10logA_e + 10log(25/4) = -141.7 -3.5 +8 = -137.2dBW = -107.2dBm

Power received by a shipboard VDES receiver (reference 150 kHz channel):

Noise floor in a 150 kHz bandwidth: kTB = 10log((1.38x10exp-23)(290)(150x10exp3))= -152.2dBW

Rx carrier power (reference) in a 150 kHz bandwidth: C = 10log((19.02x10exp-15)(150/25))= -129.4dBW

Applying adjustments for cable loss (2dB) and Rx noise figure (4dB), the C/N calculation follows:

C/N (150 kHz bandwidth): C/N_{ref} = (-129.4-2) – (-152.2 +4) = **16.8dB** (Rx 0dBd antenna, 0^0 elevation)

NOTE: These calculations serve to confirm the applicability of the metrics and reference levels.

13.4.2.17 Determine the values of carrier to noise vs. elevation angle for the shipborne VHF data exchange system receiver

Based on the C/N reference level (C/N_{ref}) from Table 5, determine the C/N for the PFD values and elevation angles in Table 4, taking into account the shipborne antenna angular gain values for the 0 dBd antenna in Figure 6. For this antenna, G_a = 2.1 dBi at 0^0 elevation angle.

$C/N = C/N_{ref} - (-142 – PFD – (2.1- G_a))$, where G_a = shipborne antenna gain at the elevation angle.

~~1.~~ At 0^0 elevation angle, C/N = 16.8 – (-142 – (-153.2) - (2.1-2.1)) = 5.6 dB.
~~2.~~ At 10^0 elevation angle, C/N = 16.8 – (-142 – (-149.7) - (2.1-1.9)) = 8.9 dB.
~~3.~~ At 30^0 elevation angle, C/N = 16.8 – (-142 - (-144.5) - (2.1-(-0.3)) = 11.9 dB.
~~4.~~ At 45^0 elevation angle, C/N = 16.8 – (-142 – (-142) - (2.1-(-3.5)) = 11.2 dB.
~~5.~~ At 60^0 elevation angle, C/N = 16.8 – (-142 – (-141) - (2.1 – (-7.6)) = 8.1 dB.
~~6.~~ At 90^0 elevation angle, C/N = 16.8 – (-142 - (-145.3) - (2.1-(-11.6)) = -0.2 dB.

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The C/N values for elevation angles from 0^0 to 90^0 are shown in Table 6 below.

TABLE 8~~6~~

Carrier to noise and power flux density for various elevation angels

Orbital angle (degrees)	Elapsed time from horizon (sec)	Slant range (km)	Elevation angle (degrees)	PFD (actual/mask/margin, in dB(W/(m2*4kHz)))	C/N ship receiver (dB)
23	0	2703.6	0	-153.2/-149/4.2	5.6
22	15.9	2592.7	0.5	-152.8/-148.9/3.9	6
21	31.8	2481.6	1.0	-152.4/-148.8/3.6	6.4
20	47.7	2370.5	3.2	-152/-148.5/3.5	6.8
19	63.6	2259.6	4.4	-151.6/-148.3/3.3	7.2
18	79.5	2148.8	5.6	-151.2/-148.1/3.1	7.6
17	95.4	2038.3	7.0	-150.7/-147.9/2.8	8
16	111.3	1928.1	8.4	-150.2/-147.7/2.5	8.5
15	127.2	1818.4	10.0	-149.7/-147.4/2.3	8.9
14	143.1	1709.2	11.6	-149.2/-147.1/2.1	9.4
13	159.0	1600.6	13.5	-148.6/-146.8/1.8	9.7
12	175.0	1493.0	15.5	-148/-146.5/1.5	10.2
11	190.9	1386.5	17.8	-147.4/-146.1/1.3	10.8
10	206.8	1281.4	20.3	-146.7/-145.8/0.9	10.9
9	222.7	1178.1	23.2	-145.9/-145.3/0.6	11.5
8	238.6	1077.3	26.6	-145.2/-144.7/0.5	11.8
7.145	252.2	993.5	30.0	-144.5/-144.2/0.3	11.9
7	254.5	979.6	30.6	-144.3/-144.1/0.2	11.9
6	270.4	886.3	35.3	-143.5/143.35/0.15	11.9
5	286.3	798.7	41.0	-142.5/-142.4/0.1	11.7
Orbital angle (degrees)	**Elapsed time from horizon (sec)**	**Slant range (km)**	**Elevation angle (degrees)**	**PFD (actual/mask/margin, in dB(W/(m2*4kHz)))**	**C/N ship receiver (dB)**
4.38	296.1	748.3	45.0	-142/-142/0 *(reference)*	11.2

4	302.2	719.2	47.8	-141.7/-140.5/1.2	11.0
3	318.1	650.6	56.2	-141.5/-136.1/5.4	8.6
2.7	322.9	632.7	60.0	-141/-134/7	8.1
2	334.0	596.8	66.1	-141.8/-133.4/8.4	4.4
1	349.9	562.1	77.6	-143.1/-132.2/10.9	2.4
0	365.8	550.0	90	-145.3/-131/14.3	-0.2

13.4.2.18 Determine the data rate for elevation angles 0^0 to 60^0 using the digital video broadcast by satellite standards

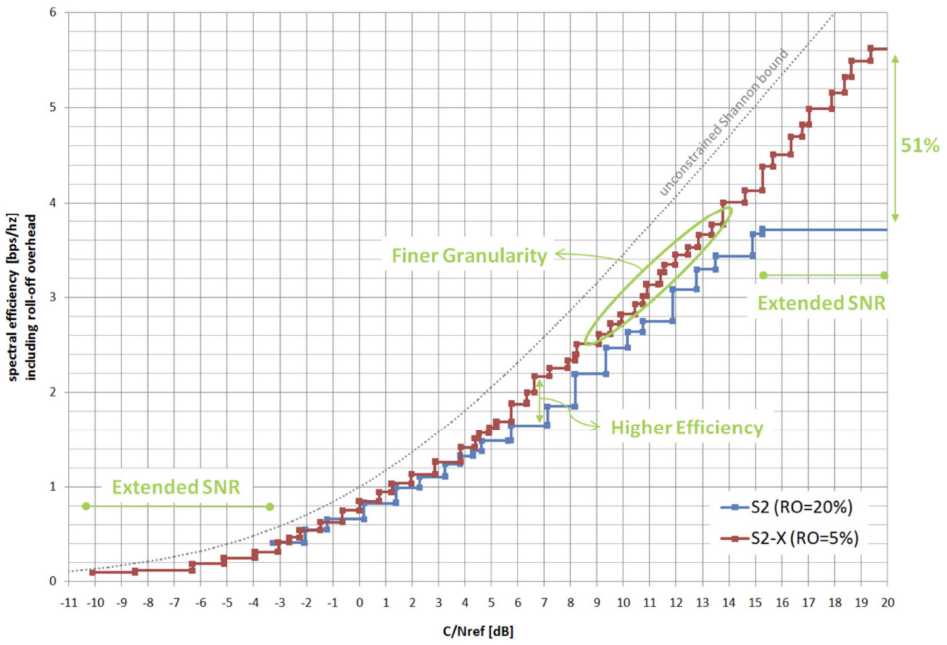
The digital video broadcast by satellite (DVB-S) standards are designed to provide the maximum utilization of the available bandwidth in a low-to-moderate C/N ratio. The spectral efficiencies for DVB-S2X and DVB-S2 are shown in Figure 12 below.

DVB-S2X is based on the well-established DVB-S2 specification. It uses the proven and powerful LDPC FEC scheme in combination with BCH FEC as outer code and introduces the following additional elements:

- Smaller roll-off options of 5% and 10% (plus 20%, 25% and 35% in DVB-S2)
- A finer gradation and extension of number of modulation and coding modes
- New constellation options for linear and non-linear channels
- Additional scrambling options for critical co-channel interference situations
- Channel bonding of up to 3 channels
- Very Low SNR operation support down to -10 dB SNR
- Super-frame option

FIGURE 16~~12~~

Performance of DVB-S2X and DVB-S2



13.4.2.19 Performance conclusion

From Figure 12 above, it is concluded that the DVB-S2X standard transmission applied to the VDES satellite downlink provides spectral efficiency of 1.6bps/Hz and a date-rate of **240 kbps** in a 150 kHz bandwidth for C/N ≥ 5 dB, which, from Table 6, includes **elevation angles from 0^0 to 60^0**.

14 Summary of operational capability and performance

This Recommendation provides the following operational capability and performance:

- Protection of AIS
- Relief of AIS VDL congestion
- Raw ASM data transfer at 28.8 kbps
- Raw VDE data transfer ship-to-ship, ship-to-shore and shore-to-ship at 307.2 kbps
- Raw VDE satellite data transfer up to 240 kbps
- VDE satellite downlink that satisfies the PFD mask requirements
- VDE shore-to-ship and ship-to-shore service to 85km (46NM)
- Channel access and sharing schemes that organize the links and mitigate conflicts
- Full VDES satellite and terrestrial functionality from a single shipborne antenna

ANNEX 2

Propagation range predictions for VHF data exchange system terrestrial links

1 Introduction

This is an informative annex. The excellent propagation characteristics of AIS are well established and appreciated. It is expected that the ASM will have similar performance to AIS. The propagation range predictions for the 100 kHz VDE ship-to-shore and shore-to-ship links follow below.

2 Ship-to-shore application

2.1 Basis for the coverage assessment

This coverage assessment is based on Recommendation ITU-R P.1546-4 (assuming no ducting), taking into account the antenna height and the seawater propagation path:

Height of antenna (Base Station):	75 meters (see graph for various heights)
Transmitter power for ships:	12.5 Watts
Tx ships antenna gain:	2dBi (0dBd)
Rx shore antenna gain:	8dBi (6dBd)
P_r:	-103dBm (VDE shore station sensitivity)

2.2 Purpose for use of the Recommendation ITU-R P.1546-4 propagation curve

Recommendation ITU-R P.1546-4 prescribes the use of the propagation curves (§3 from Annex 5 and Figure 4 (Figures 13 and 14 of this Annex) from Annex 1, see below), assuming no ducting and a smooth earth/sea surface. This analysis may be used as a reference point for field test measurements that usually include some ducting, depending on weather, atmospheric conditions, and other factors.

2.3 Determination of transmitting/base antenna height, h_1

Recommendation ITU-R P.1546-4 specifies (§3 of Annex 5) the transmitting/base antenna height, h_1, to be used in calculation depending on the type and length of the path. For sea paths h_1 is the height of the antenna above mean sea level; for land paths h_1 is the height above average terrain.

2.4 Determination of the minimum field strength (sensitivity threshold) at the VHF data exchange base receiving site

For ship-to-shore:

Power received (linear formula): $P_r = G_r E_r^2 c^2/480\pi^2 f^2$

Rearranged: $E_r = \sqrt{(480\pi^2 f^2 P_r / G_r c^2)}$, where

E_r = field strength in volts/meter

G_r = gain of receiving antenna = 6.3 = 8dBi

c = speed of light in free space = 3×10^8 meters/second

f = VDE ship-to-shore frequency = 1.57×10^8 (157 MHz)

$P_r = 5\times10^{-14}$ watts = -133dBW = -103dBm

Thus,

$E_r = 3.21 \times 10^{-6} = 3.21\ \mu V/m = +10.1dB\ \mu V/m$

The logarithmic formula can also be used to calculate Pr (dBm):

Pr (dBm) = 42.8 - 20logF + 20logE + G, where

G = antenna gain in dBi = 8dBi

F = frequency in MHz = 157

Pr (dBm) = 42.8 – 43.9 – 109.9 + 8 = -103dBm (-133dBW)

2.5 Determine the range to the +10.1dBu (-103dBm) coverage limit for a seawater propagation path

Calculate the effective radiated power:

$P_s = P_t + G$

$P_t = 10 \log 12.5 – 30 = -19$dBk (19dB below 1 kW)

G = 2dBi = +0dBd (0dB over a dipole)

Thus $P_s = -19 +0 = -19$dBk ERP

$F_e = F – P_s$ (vertical scale reference for the propagation graph in Figure 4 of Recommendation ITU-R P.1546-4, Figure 13 of this Annex)

F = +10.1dBu

$P_s = -19$dBk

Thus $F_e = 10.1 – (-19) = +29.1$dB

2.6 Determine the seaward ship-to-shore coverage range from Figure 13:

The +10.1dBu (-103dBm) range is 85km, which is 46NM (use $h_1 = 75$m).

2.7 Determine the received signal strength indication values for various other ranges

The reference point received signal strength indication (RSSI) = -103dBm at a range of 85km (46NM) is determined above. For other ranges, the RSSI value is determined from the propagation curve (Figure 13) for the assumed antenna height of 75m. RSSI values in 10dB increments above the sensitivity threshold are shown in Table 7 below.

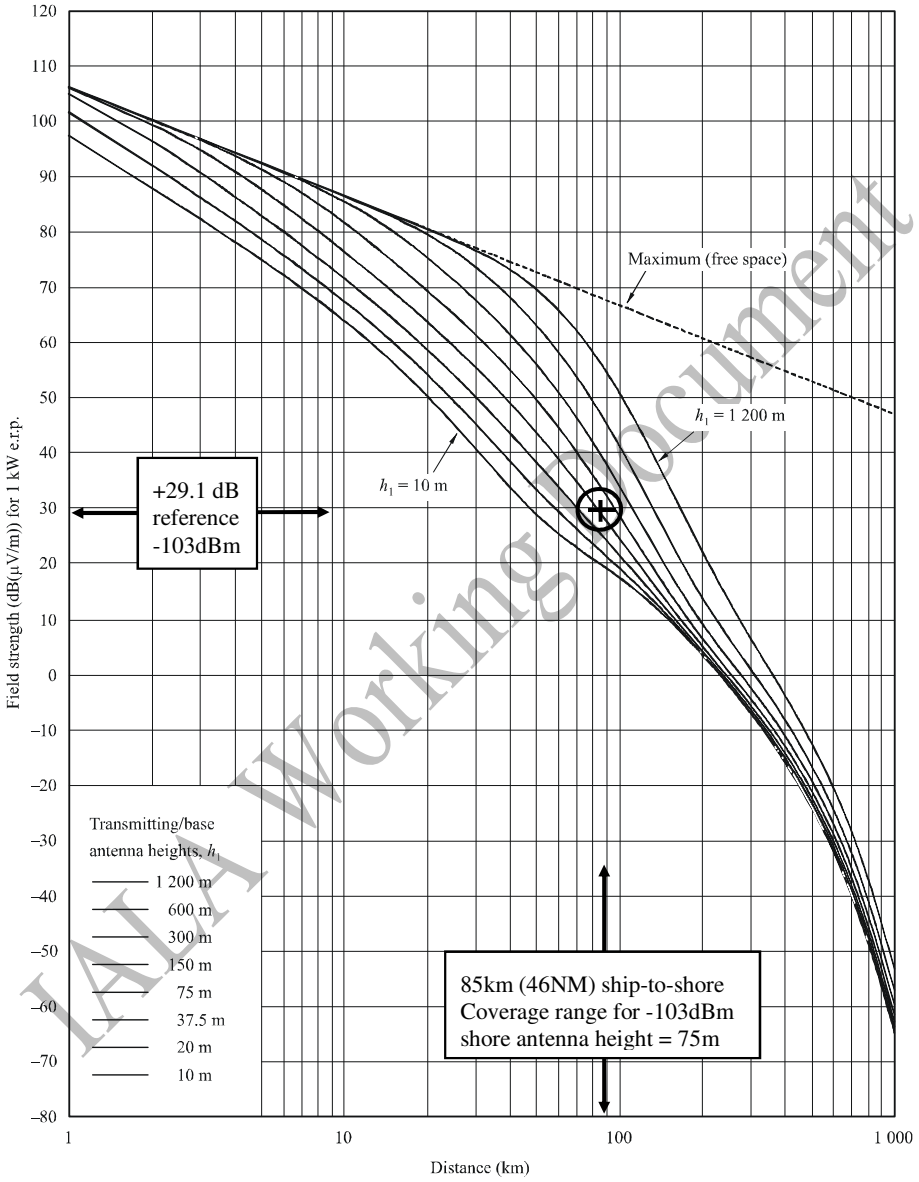
TABLE 9~~7~~

VHF data exchange base station received signal strength indication value vs. distance ship-to-shore

-103 dBm	85 km (46NM)
-93 dBm	60 km
-83 dBm	40 km
-73 dBm	25 km
-63 dBm	15 km
-53 dBm	8 km
-43 dBm	4.5 km

Figure 17~~13~~

100 MHz, sea path, 50% time



50% of locations

h_2 = 10 m

1546-04

3 Shore-to-ship application

3.1 Basis for the coverage assessment

Referring to section 2 above, consider the reverse direction, shore-to-ship, signal levels at the ship receiving site, the shore transmitter power of 50 Watts and the shore-to-ship frequency of 162 MHz:

Height of antenna (VDES Base Station):	75 meters (see graph for various heights)
Transmitter power of VDES on shore:	50 Watts (at base of shore antenna)
Tx shore antenna gain:	8 dBi (6 dBd)
Rx ships antenna gain:	2 dBi (0 dBd)
P_r:	-98 dBm (VDE ship station sensitivity)

3.1.1 Determination of the minimum field strength (sensitivity threshold) at the VHF data exchange ship receiving site

For shore-to-ship:

Power received (linear formula): $P_r = G_r E_r^2 c^2/480\pi^2 f^2$

Rearranged: $E_r = \sqrt{(480\pi^2 f^2 P_r / G_r c^2)}$, where

E_r = field strength in volts/meter

G_r = gain of receiving antenna = 1.62 = 2.1 dBi

c = speed of light in free space = 3×10^8 meters/second

f = VDE shore-to-ship frequency = 1.62×10^8 (162 MHz)

$P_r = 1.58 \times 10^{-13}$ watts = -128 dBW = -98 dBm

Thus,

$E_r = 11.61 \times 10^{-6} = 11.61\ \mu V/m = +21.3$ dB μV/m

The logarithmic formula can also be used to calculate Pr (dBm):

Pr (dBm) = 42.8 - 20logF + 20logE + G, where

G = antenna gain in dBi = 2.1 dBi

F = frequency in MHz = 162

Pr (dBm) = 42.8 – 44.1 – 98.7 + 2.1 = -98 dBm (-128 dBW)

3.1.2 Determine the range to the +21.3 dBu (-98 dBm) coverage limit for a seawater propagation path

Calculate the effective radiated power:

$P_s = P_t + G$

P_t = 10 log 50 – 30 = -13dBk (13dB below 1 kW)

G = 8dBi = +6dBd (6dB over a dipole)

Thus P_s = -13 +6 = -7dBk ERP

$F_e = F - P_s$ (vertical scale reference for the propagation graph in Figure 4 of Recommendation ITU-R P.1546-4, Figure 2 of this Annex)

F = +21.3 dBu

P_s = -7 dBk

Thus F_e = 21.3 – (-7) = +28.3 dB

Note that since this value of F_e is within 1dB of the value calculated in Section 2.5 because the reduced sensitivity of the ship station is compensated by the higher power and antenna gain of the shore base station.

3.1.3 Determine the seaward shore-to-ship coverage range from Figure14

The +28.3 dBu (-98 dBm) range is 85 km, which is 46 NM (use h_1 = 75 m). This is the same as the ship-to-shore coverage range, an ideal balanced two-way coverage, which confirms the proposed choices of antennas and transmitter power values for the shipborne and shore VDES stations.

3.1.4 Determine the received signal strength indication values for various other ranges

The reference point: RSSI = -98 dBm at a range of 85 km (46 NM) is determined in 2.6 above. For other ranges, the RSSI value is determined from the propagation curve (Figure 14) for the assumed antenna height of 75 m. RSSI values in 10 dB steps above and below the -98 dBm threshold sensitivity for the shipborne VDE receiver are shown in Table 10~~Table 8~~ below.

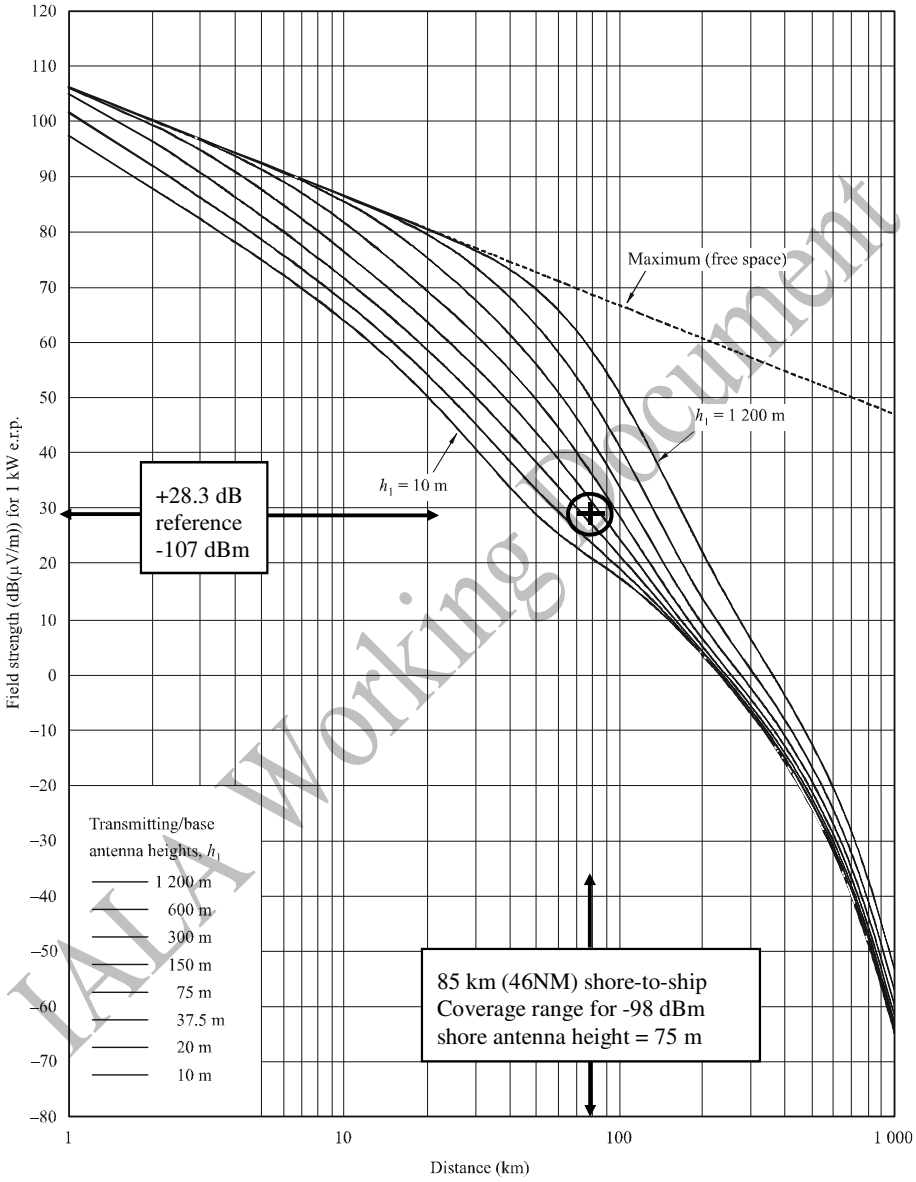
TABLE 10~~8~~

VHF data exchange ship station received signal strength indication value vs. distance shore-to-ship

-118 dBm	170 km
-108 dBm	130 km
-98 dBm	85 km (46NM)
-88 dBm	60 km
-78 dBm	40 km

Figure 18~~14~~

100 MHz, sea path, 50% time



50% of locations

h_2 = 10 m

1546-04

ANNEX 3

Example of VHF data exchange satellite downlink implementation and analysis

1 Introduction

This is an informative annex providing an example of implementing the VDE-SAT downlink component and presenting performance results.

2 VHF data exchange satellite orbital characteristics

The spacecraft flies in a circular orbit of 600 km and 68° inclination compliant with orbital debris regulations and safe de-orbiting of the spacecraft after its lifetime. The satellite counts with attitude control mechanisms to guarantee a stable antenna pointing in the nadir direction (i.e. satellite to Earth).

Under these assumptions Figure 19~~Figure 15~~ shows the elevation (left axis) of the spacecraft as a function of time as seen by a ground terminal during an overhead pass. The right axis of the same figure depicts the signal delay.

FIGURE 19~~15~~

Satellite elevation and delay for the selected orbit as a function of time

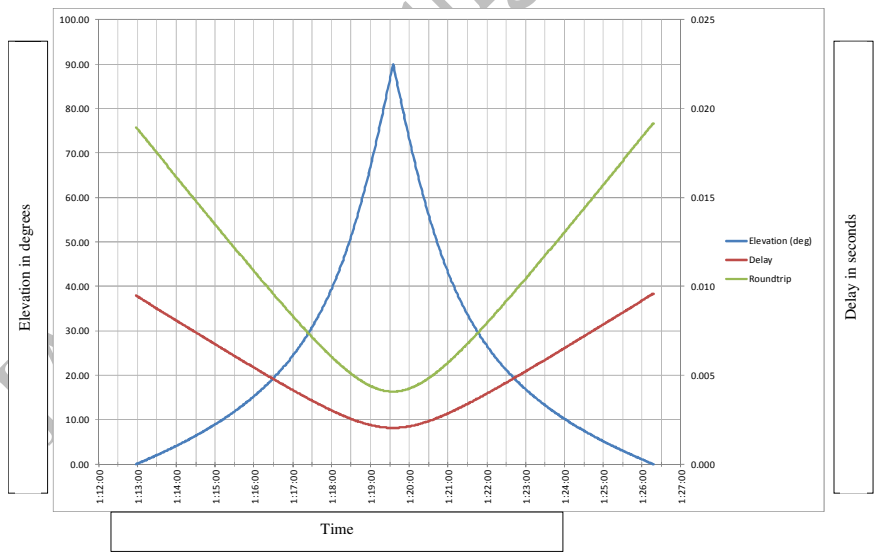


Figure 19~~Figure 15~~ shows that the satellite is just over 4 minutes above 30° elevation, thus 9 minutes under 30° elevation from acquisition-of-signal (AOS) to loss-of-signal for a pass duration of about 13 minutes. The roundtrip delay varies from 19 ms at AOS down to 4ms at zenith (i.e. 90° elevation). During that pass the Doppler shift varies from -3.73 kHz to + 3.73 kHz and the Doppler rate reaches 47 Hz/s at Zenith.

FIGURE 20~~16~~

Pass elevation scheme for selected orbit over 24 hours

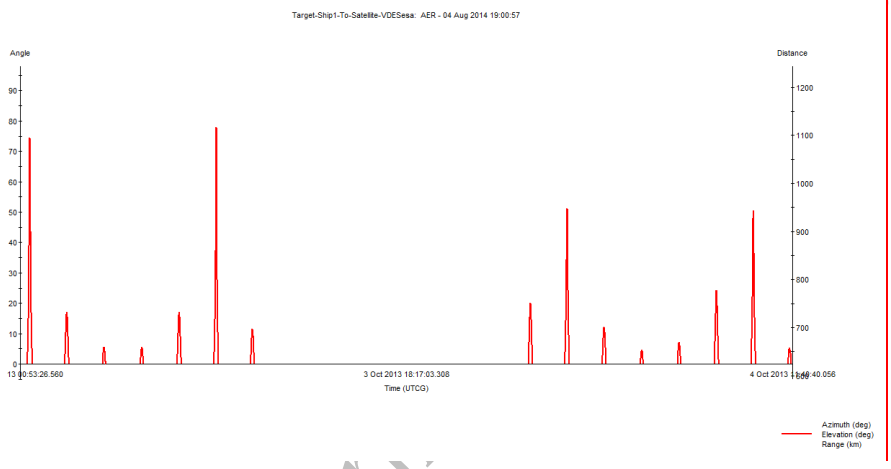


Figure 20~~Figure 16~~ illustrates the satellite elevation as a function of time, as seen by a ground terminal at a fixed location in a 24 hour period. As shown the contact periods are short and low. Depending on the latitude, the duration and the number of contact periods will vary. *(distance is provided in km)*

FIGURE 21~~17~~

Satellite field of view

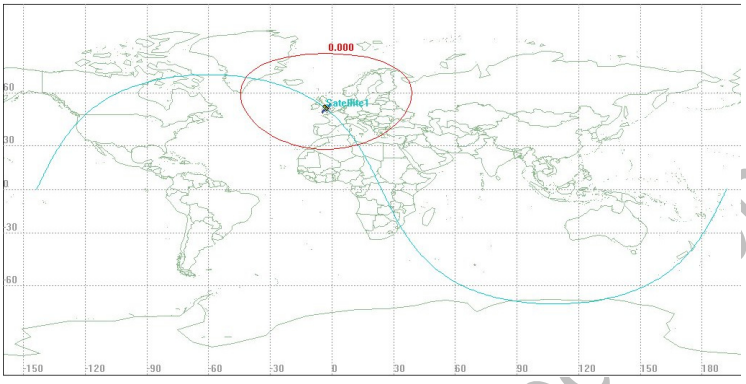


Figure 21~~Figure 17~~ presents the satellite field of view. A wide geographical area is covered by the satellite field of view at any given point of the orbit. For this area, the average instantaneous ship count is 22 000 respectively as shown in Figure 22~~Figure 18~~. The ship count is based on combined received terrestrial and satellite data for AIS class A.

FIGURE 22~~18~~

Field of view case for ship instantaneous number

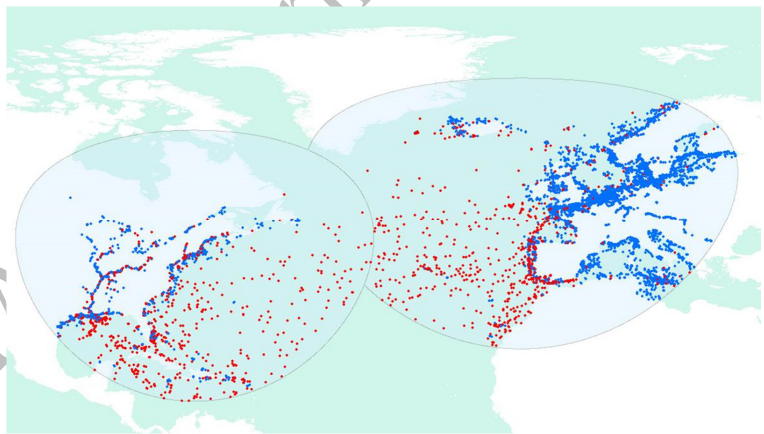


Figure 22~~Figure 18~~ is indicative of the AIS received by terrestrial stations is displayed in blue while AIS received by satellite is displayed in red.

2.1 VHF data exchange satellite downlink characteristics

The power flux density mask to be respected is (as also presented in Table 3 of Annex 1).

$$PFD(\theta°)_{\,(dBW/(m^2*4\,kHz))} = \begin{cases} -149 + 0.16 * \theta° & 0° \le \theta < 45°; \\ -142 + 0.53 * (\theta° - 45°) & 45° \le \theta < 60°; \\ -134 + 0.1 * (\theta° - 60°) & 60° \le \theta \le 90°. \end{cases}$$

which translates to:

	dBW	14.0	10Log10(100/
Theta	Flux / 4khz	Flux / 1Hz	Flux100kHz
0	-149.00	-185.00	-135.00
5	-148.20	-184.20	-134.20
10	-147.40	-183.40	-133.40
15	-146.60	-182.60	-132.60
20	-145.80	-181.80	-131.80
25	-145.00	-181.00	-131.00
30	-144.20	-180.20	-130.20
35	-143.40	-179.40	-129.40
40	-142.60	-178.60	-128.60
45	-142.00	-178.00	-128.00
50	-139.35	-175.35	-125.35
55	-136.70	-172.70	-122.70
60	-134.00	-170.00	-120.00
65	-133.50	-169.50	-119.50
70	-133.00	-169.00	-119.00
75	-132.50	-168.50	-118.50
80	-132.00	-168.00	-118.00
85	-131.50	-167.50	-117.50
90	-131.00	-167.00	-117.00

FIGURE ~~23~~19

Power flux density mask

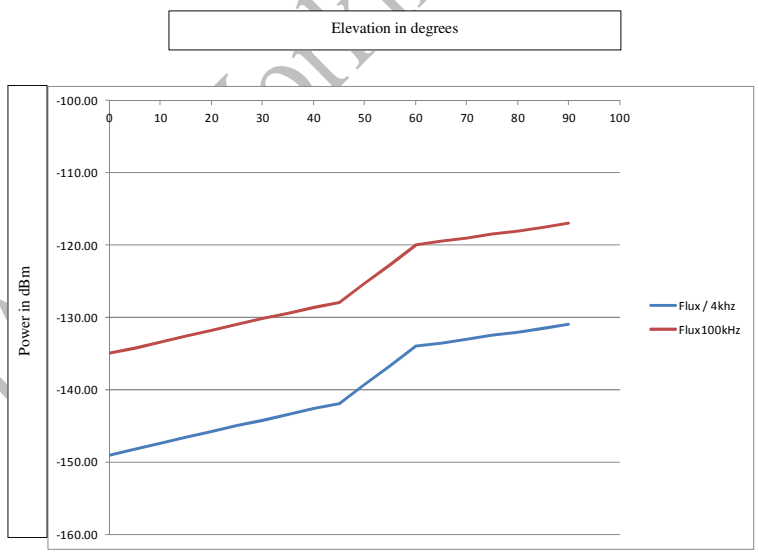
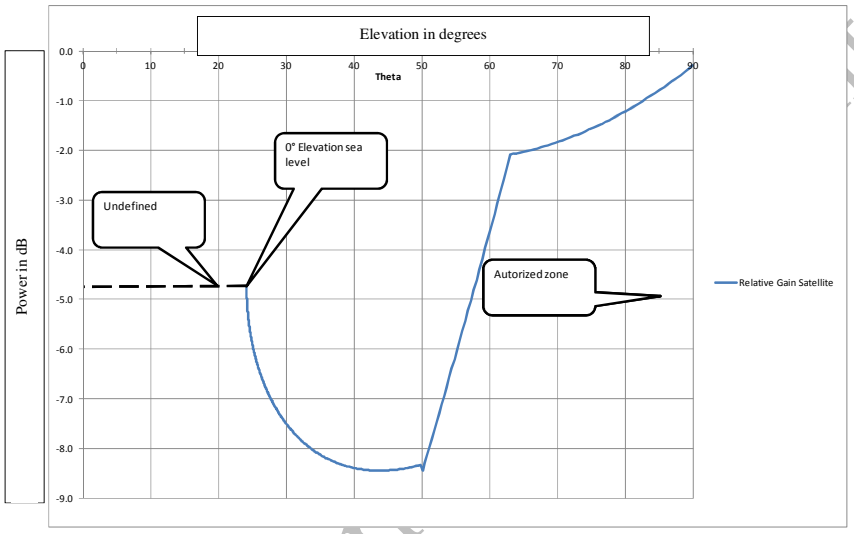


Figure 19 depicts the PFD mask in dBm as a function of elevation in a reference bandwidth of 4 kHz and in 100 kHz bandwidth.

The corresponding e.i.r.p. mask seen by the satellite corresponds to a transformed version of the PFD mask dictated by the Earth-satellite geometry. Figure 24~~Figure 20~~ shows the e.i.r.p. mask which is symmetric around the nadir direction (90° angle in the figure).

FIGURE 24~~20~~

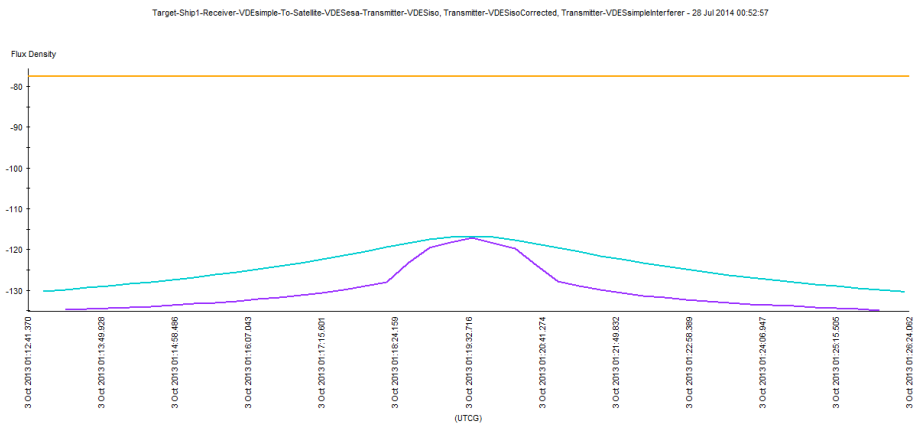
Satellite equivalent isotropic radiated power mask



Assuming a circularly polarized downlink signal from the satellite meeting the e.i.r.p. mask in Figure 24~~Figure 20~~, then the PFD in 100 kHz seen in an overhead pass by a ground terminal is shown as a violet curve in Figure 25~~Figure 21~~. In this figure the signal power of a nearby ship (shown in yellow) is also presented as a benchmark reference. The green line represents the realization of an antenna on the satellite compliant with the e.i.r.p. mask.

FIGURE 25~~21~~

Receiver carrier input for a 0 dB gain antenna. Iso and compensated satellite transmitter antenna + nearby ship (for the sake of completeness, not relevant for this example)



2.2 VHF data exchange satellite receiver characteristics

On the receiver side, the ship's system temperature is considered to be between 630°K (noise figure of 3 dB and 2 dB of cable loss) and 1 500°K. Variations can occur, but it is not expected that the system temperature falls below roughly 900°K in a standard installation. The system temperature accounts for the noise source integrated in the antenna patterns. Some onboard 'industrial' noise is yet to be added, but will be ignored for the remainder of the document.

2.3 'Ideal' Receiving antenna

For the sake of completeness, the receiver antenna mask that would allow the received signal to be at constant power level at the receiver input is calculated and shown as a function of elevation angle in Figure 26~~Figure 22~~.

FIGURE 26~~22~~

"Ideal" receiver antenna mask, zenith is 90°

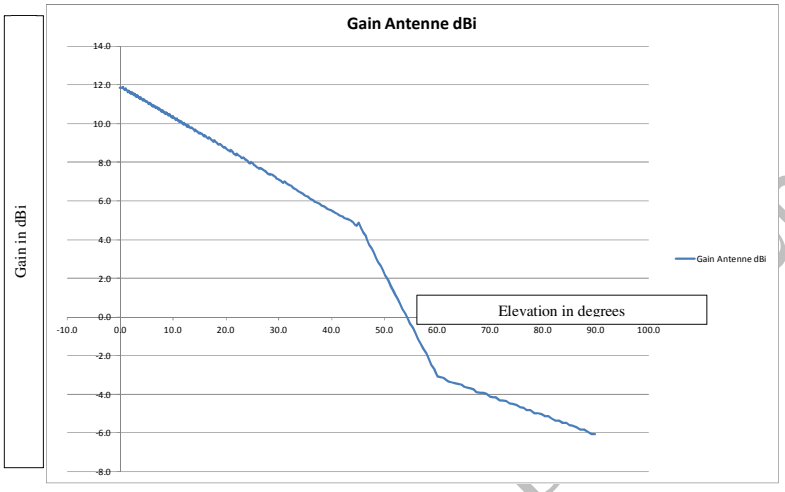


FIGURE 27~~23~~

Received carrier power for a receiver with an "ideal" antenna.

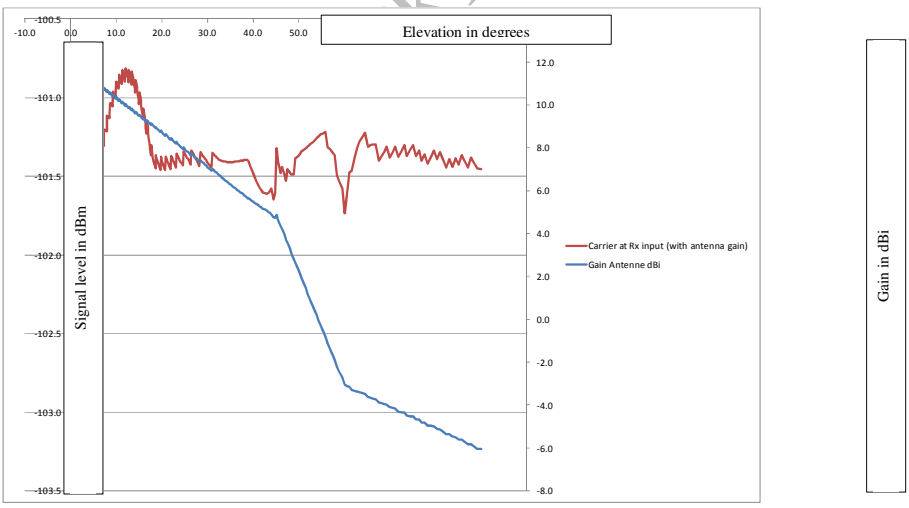


Figure 27~~Figure 23~~ shows the received signal power in dBm at the input of a receiver with the "ideal" receiving antenna as a function of elevation. The link analysis is computed using professional commercial software tools for satellite communications that account for the signal propagation impairments.

The software tool however, does not account for possible loss of power strength at very low elevation (<1°). The power loss could be as high as 6 dB due to reflecting surface of seawater, mainly in circular or horizontal polarizations. It is worth noting that the signal power at the receiver input is around -101 dBm, and this is 3 dB lower than the ITU-R M.1842 recommended sensitivity for 16-QAM for ship stations.

FIGURE 28~~24~~

Eb/N$_0$ compensated patterns for 'ideal' antenna

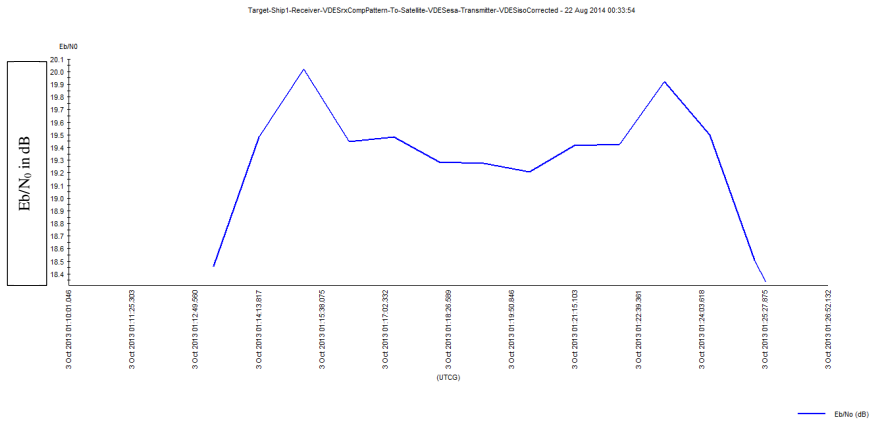


Figure 28~~Figure 24~~ shows the corresponding Eb/N$_0$ observed for the 100 kHz carrier in an overhead pass for the 'ideal' antenna.

2.4 Realistic receiving antenna

Four different antennas are considered:

– The 0dBd point in the Recommendation ITU-R F.1336-4 antenna pattern and vertical polarization (antenna 1).

– A 1.25 λ vertical antenna (commercially available antenna, computed pattern when mounted on the top of the bridge a 200 m long tanker), vertical polarization (antenna 2).

– A satellite dedicated Turnstile, with Right Hand Circular Polarization (RHCP) (antenna 3).

– A hemispherical 0dBi gain antenna, vertical polarization (antenna 4).

Using professional software tools for satellite communications, simulations have been carried out to determine the carrier power level at the receiver input and to determine the Eb/N$_0$ in the following cases:

- Overhead pass
- Side pass
- Very low pass

Results corresponding to each scenario are reported in the following sections.

3.1.5 Overhead pass

FIGURE 29~~25~~

Overhead pass, Carrier level at receiver input

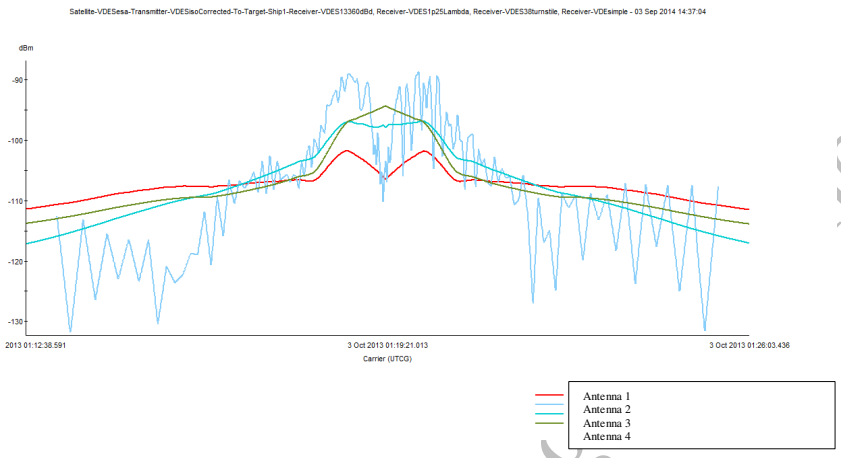
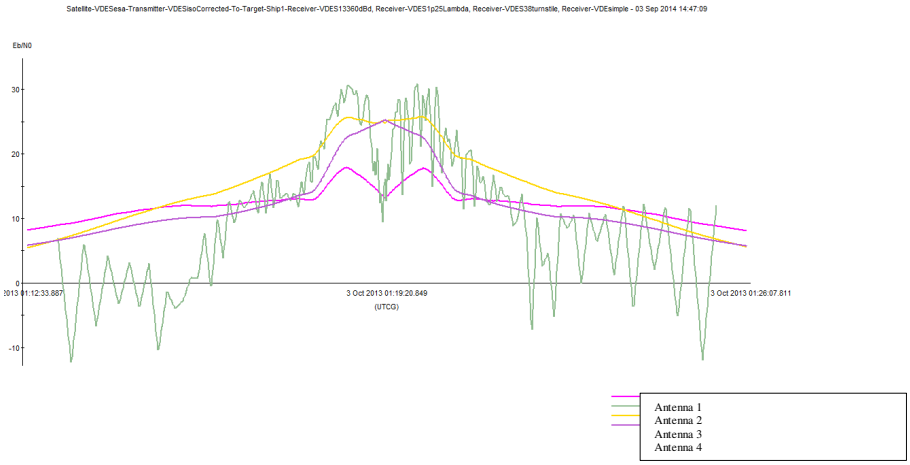


FIGURE 30~~26~~

Overhead pass, Eb/N0 at demodulator input



3.1.6 Side pass

Consider a 16° elevation pass, the signal power and corresponding signal quality measured in Eb/N_0 are presented in the following figures. Due to the variation of the signal strength at the receiver over time (due to the change of elevation and distance), the signal may fall below the detection threshold.

The use of highly robust waveform (as a combination of modulation, coding and frame structure) can potentially improve the performance at the expense of reduced throughput.

FIGURE 31~~27~~

Carrier level at receiver input, side pass

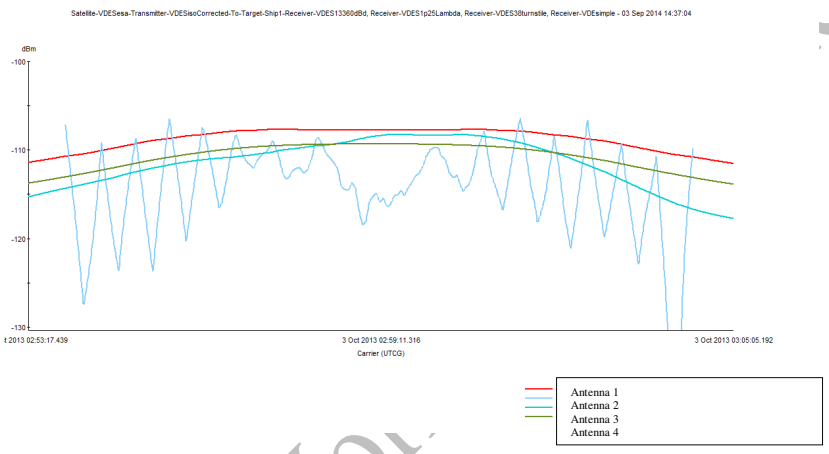
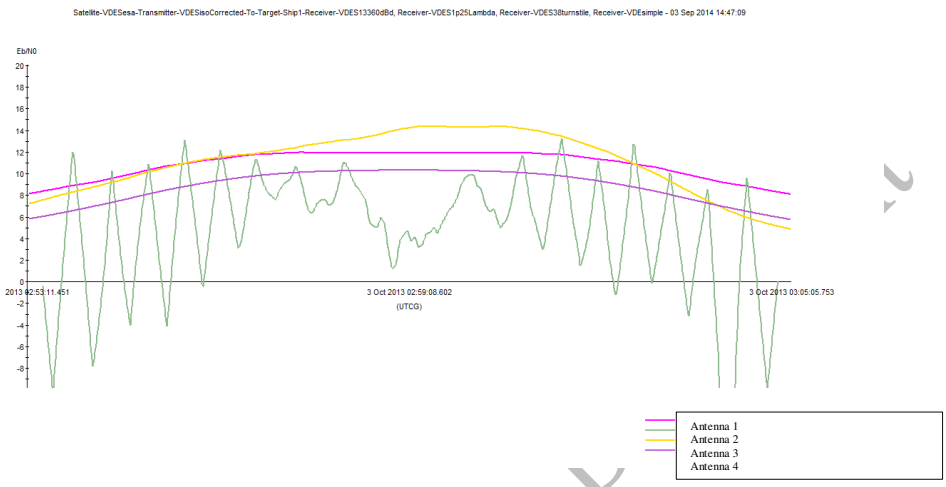


FIGURE 32~~28~~

Eb/N0 at demodulator input, side pass



3.1.7 Very Low side pass

Results for a very low side pass (below 5° elevation) are presented in figures below.

FIGURE 33~~29~~

Carrier input at receiver input, very low side pass

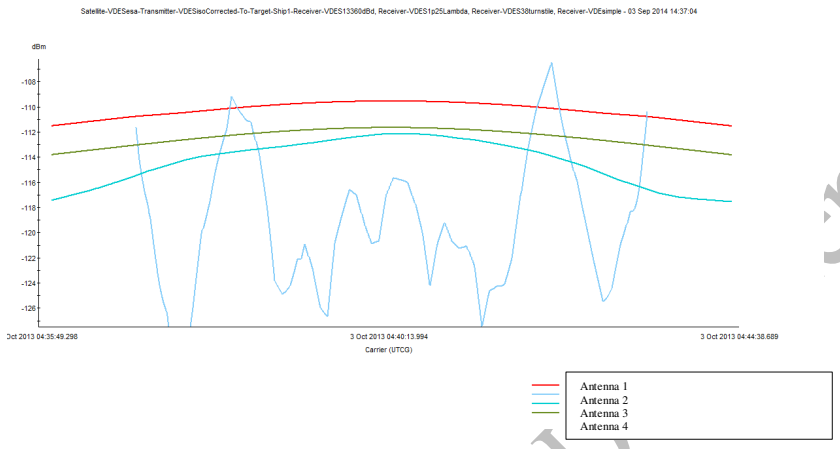
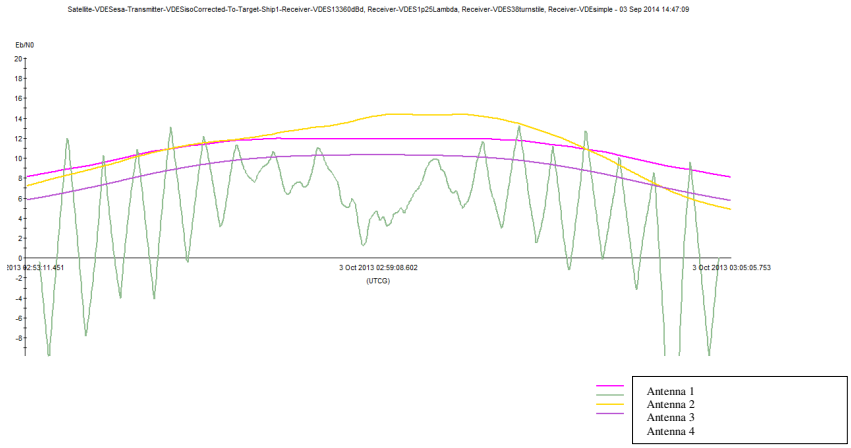


FIGURE 34~~30~~

Eb/N0 at demodulator input, very low elevation side pass.



2.5 Waveform choice

As shown in previous sections, for a realistic antenna the signal to noise ratio at the input of the receiver can vary considerably as a function of elevation angle. The choice of the waveform modulation, coding and frame structure has a significant impact on the link throughput and its availability.

The decision on continuous versus intermittent transmission of the signal will impact the acquisition, tracking and the overall performance (bit rate, probability of error, etc.) of the VDE satellite broadcasting. At the system level, a time slot-based transmission (time division) may increase the complexity of the satellite-terrestrial system interactions and reduce the overall efficiency. However, the coexistence of VDE broadcasting and terrestrial shore-to-ship or ship-to-ship may also impact the detection performance of the terrestrial signal.

The choice of modulation scheme has an impact on the efficiency of the power amplifier on board of the satellite. The use of (quasi-) constant envelope reduces the peak to average power ratio and allows the transmitter to operate at a more power efficient mode with less signal distortion.

In order to facilitate synchronisation and signal detection at the receiver, the use of known symbols (as pilot or preamble) is essential as part of the air interface definition.

The use of data sequence randomisation (scrambling) facilitates the synchronisation and mitigates spectral abnormality.

A system capability to allow more than one coding rate (and modulation scheme) may provide more flexibility in the system dimensioning and service availability.

There are a number of existing open standards with air interface specifications, such as Digital Video Broadcasting via satellite DVB-S2x , DVB-SH and DVB-RCS2, that offer mature technical solutions as a starting point for such design trade-offs. The performance characteristics of DVB-RCS2 waveforms are reported in Table 1. Figure 35~~Figure 31~~ presents the spectral efficiency (information bits/symbol) as a function of E_s/N_0 for these waveforms.

Note - DVB-RCS2 reference: ETSI TS 101 545-1 V1.2.1 (2014-04) available at: http://www.etsi.org/deliver/etsi_ts/101500_101599/10154501/01.02.01_60/ts_10154501v010201p.pdf

TABLE 119

Waveform Efficiency in additive white Gaussian noise channel

Frame Size (symbols)	Guard (symbols)	Payload (bits)	Efficiency (Bits/Symbol)	E_s/N_0 @ PER=10^{-5}
266	4	408	1.51	7.3
266	4	440	1.63	8.71
266	4	496	1.84	10.04
266	4	552	2.04	11.59
266	4	672	2.49	11.73
266	4	744	2.76	13.18
536	4	304	0.56	0.22
536	4	472	0.87	2.34
536	4	680	1.26	4.29
536	4	768	1.42	5.36
536	4	864	1.60	6.68
536	4	920	1.70	8.08
536	4	1040	1.93	9.31
536	4	1152	2.13	10.85
536	4	1400	2.59	11.17
536	4	1552	2.87	12.56
1616	4	984	0.61	-0.51
1616	4	1504	0.93	1.71
1616	4	2112	1.30	3.69
1616	4	2384	1.47	4.73
1616	4	2664	1.64	5.94
1616	4	2840	1.75	7.49
1616	4	3200	1.98	8.77
1616	4	3552	2.19	10.23
1616	4	4312	2.66	10.72
1616	4	4792	2.96	12.04
3236	4	984	0.30	-3.52
3236	4	1504	0.46	-1.3

FIGURE 35~~31~~

Spectral efficiency of DVB-RCS2 waveform