International Telecommunication Union

ITU-R
Radiocommunication Sector of ITU

Recommendation ITU-R M.2092-0
(10/2015)

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

M Series
Mobile, radiodetermination, amateur and related satellite services

150
1865-2015

International Telecommunication Union

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SA	Space applications and meteorology
SF	Frequency sharing and coordination between fixed-satellite and fixed service systems
SM	Spectrum management
SNG	Satellite news gathering
TF	Time signals and frequency standards emissions
V	Vocabulary and related subjects

Note: *This ITU-R Recommendation was approved in English under the procedure detailed in Resolution ITU-R 1.*

Electronic Publication
Geneva, 2015

RECOMMENDATION ITU-R M.2092-0[*], [**]

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

(2015)

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

Maritime, VHF, VDES, ASM, data, exchange

Glossary

3GPP	Third generation partnership project
ACK	Acknowledgement
ADDC	Assigned data transfer
ACPR	Adjacent channel power ratio
AIS	Automatic identification system
AOS	Acquisition-of-signal
APSK	Amplitude phase shift keying
ARQ	Automatic repeat request
ARSC	Announcement response channel
ASC	Announcement signalling channel
ASM	Application-specific messages
AWGN	Additive white Gaussian noise
BBSC	Bulletin board signalling channel
BCH	Bose Chaudhuri Hocquenghem, an error-correcting-code
BER	Bit error rate
BPSK	Binary phase shift keying
BT	Bandwidth-time
CEPT	European conference of postal and telecommunications administrations
CDMA	Code division multiple access
CG	Coding gain
CIR	Carrier to interference ratio

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[*] The use of some frequencies in the band 156-164 MHz, contained in this Recommendation, do not comply with the RR currently in force. This Recommendation therefore should not be seen as prejudging the decisions of WRC-15. ITU-R Study Group 5 is invited to review this Recommendation taking into account the decisions made by WRC-15.

[**] Note by the BR Secretariat – The figures in this Recommendation are available in English only. The other languages will be prepared in due course.

C/M	Carrier to multipath
CNR	Carrier to noise ratio
COMSTATE	Communication state
CPM	Continuous phase modulation
CQI	Channel quality indicator
CR	Code rate
CRC	Cyclic redundancy check
CRL	Configuration revision level
CS	Carrier sense
CIRM	Comité international radio maritime
CSTDMA	Carrier sense time division multiple access
CW	Continuous wave
DA	Doherty amplifier
DLS	Data link service
DPD	Digital pre-distortion
EDN	End delivery notification
EDF	End delivery failure
EIRP	Equivalent isotropic radiated power (e.i.r.p.)
ERP	Effective radiated power (e.r.p.)
ET	Envelope tracking
FATDMA	Fixed access time-division multiple access
FCS	Frame check sequence
FEC	Forward error correction
FIFO	First-in first-out
GMSK	Gaussian-filtered minimum shift keying
GNSS	Global navigation satellite system
HS	Hexslots
IALA	International association of marine aids to navigation and lighthouse authorities
ICAO	International civil aviation organization
ID	Identification
IEC	International electrotechnical commission
IMO	International maritime organization
IP	Internet protocol
ITDMA	Incremental time division multiple access
LC	Logical channels
LEO	Low-earth orbiting
LFSR	Linear feedback shift register
LME	Link management entity
LNA	Low noise amplifier
LOS	Loss-of-signal

LSB	Least significant bit
MEO	Medium-earth orbiting
MAC	Media access control
MCS	Modulation and coding scheme
MDC	Multicast data channel
MMSI	Maritime mobile service identity
MSB	Most significant bit
NF	Noise figure
NM	Nautical mile
NRZI	Non-return to zero inversion
OFDM	Orthogonal frequency division multiplexing
OSI	Open systems interconnection
PAPR	Peak to average power ratio
PC	Physical channels
PL	Physical layer
PFD	Power flux-density
ppm	parts per million
PSK	Phase shift keying
QAM	Quadrature amplitude modulation
QPSK	Quadrature phase shift keying
RADC	Random access short messaging channel
RATDMA	Random access time-division multiple access
RAC	Random access channel
RF	Radio frequency
RSC	Recursive systematic convolutional
RQSC	Random access resource request
RR	Radio regulations
RSSI	Received signal strength indication
SCTDMA	Slot carrier sense time division multiple access
SFTP	Secure file transfer protocol
SI	Selection interval
SMTP	Simple mail transfer protocol
SNMP	Simple network management protocol
SNR	Signal to noise ratio
SOLAS	Safety of life at sea convention
SOTDMA	Self-organized time division multiple access
SS	Spreading sequences
Sym	Symbol
SYNC	Synchronization
TBB	Terrestrial bulletin board

TBBSC	Terrestrial bulletin board signalling channel
TDMA	Time division multiple access
UDC	Unicast data channel
UDP	User data protocol
UTC	Coordinated universal time
VDE	VHF data exchange
VDES	VHF data exchange system
VDE-SAT	VHF data exchange-satellite
VDL	VHF data link
VHF	Very high frequency

References

{RD-1} ETSI EN 302 583 (V1.2.1) – Digital Video Broadcasting (DVB); Framing Structure, channel coding and modulation for Satellite Services to Handheld devices (SH) below 3 GHz.

{RD-2} TM Synchronization and Channel Coding. Recommendation for Space Data System Standards, CCSDS 131.0-B-2. Blue Book. Issue 2. Washington, D.C.: CCSDS, August 2011.

{RD-3} R. Mueller, On Random CDMA with Constant Envelope, ISIT 2011.

{RD-4} Recommendation ITU-R P.372 – Radio Noise.

{RD-5} Recommendation ITU-T V.42 (03/2002) – Series V: Data Communication over the Telephone Network – Error control – Error-correcting procedures for DCEs using asynchronous-synchronous conversions.

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 on board 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 Report ITU-R M.2371 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 Annexes 2 to 7;

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.1/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

1 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, adapt some parameters of the transmission (robustness or capacity) while minimizing system complexity.

1.8 The system should address the use cases identified in Report ITU-R M.2371.

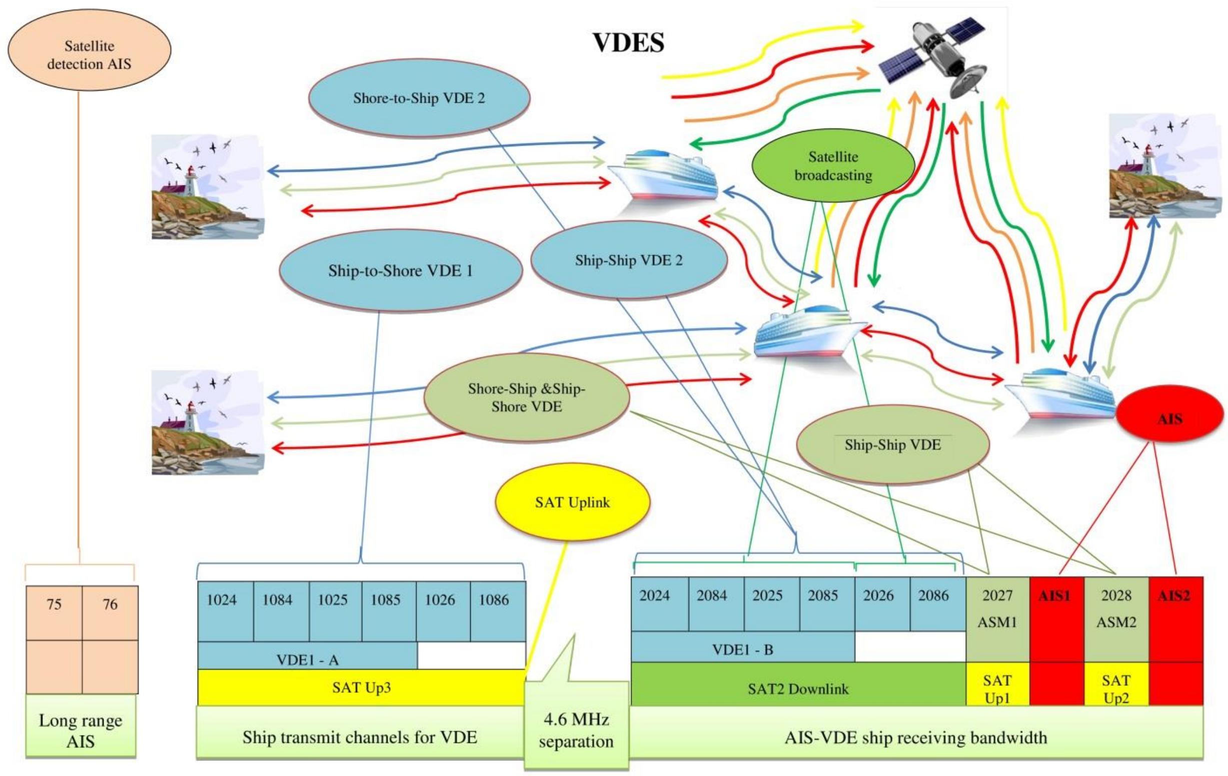
2 VHF data exchange system functions and frequency usage

VDES functions and frequency usage are illustrated pictorially in Fig. A1-1.

Figure A1-2 illustrates the VDES defined in this Recommendation from a system engineering perspective.

FIGURE A1-1

VHF data exchange system functions and frequency usage



NOTE – SAT Up is receive-only by satellite.

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

2.1.1 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.

2.1.2 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-to-satellite VDE uplinks

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

2.1.3 Technical characteristics

2.1.3.1 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.

2.1.3.2 SAT Downlink

The satellite downlink complies with the power flux-density (PFD) mask described in Table A4-1 to minimize interference to terrestrial services and to maximize reception by ship VDES stations.

2.1.3.3 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 A1-1 describes the RR Appendix **18** channels used for the various applications of VDES.

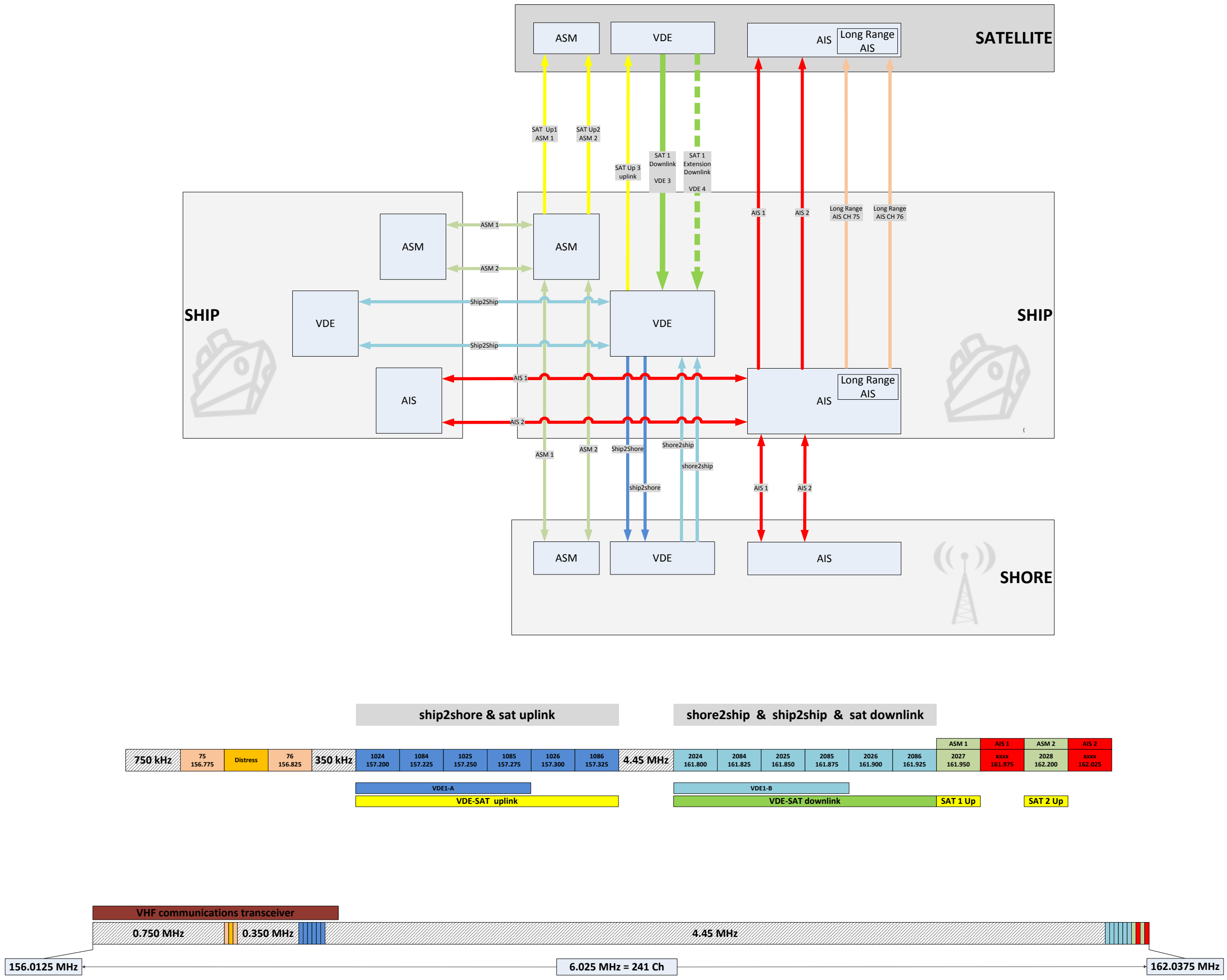
TABLE A1-1

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-to-satellite, satellite-to-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	24	157.200 (1024)	161.800 (2024)
84	84	157.225 (1084)	161.825 (2084)
25	25	157.250 (1025)	161.850 (2025)
85	85	157.275 (1085)	161.875 (2085)
	26	157.300 (1026)	161.900 (2026)
	86	157.325 (1086)	161.925 (2086)

FIGURE A1-2

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



3 Common Elements of the VDES

3.1 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).

3.2 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 Fig. A1-3.

FIGURE A1-3

Seven layer OSI model

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

Responsibilities of the OSI layers for preparing VDES data for transmission:

3.2.1 Transport layer

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

3.2.2 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.

3.2.3 Link layer

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

3.2.3.1 Link management entity

Assemble unique word, format header, Physical Layer Frame (PL-Frame) headers, pilot tones (satellite) and VDES message bits into packets.

3.2.3.2 Data link services

Calculates and adds CRC check sum and completes the PL-Frame/packet.

3.2.3.3 Media Access Control

Provides methods for granting data transfer access.

3.2.4 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.

3.3 Frame Structure

The system uses the Recommendation ITU-R M.1371 concept of a frame. A frame equals one (1) minute and is divided into 2 250 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.

3.4 Presentation interface protocol

For VDES transceivers:

– data may be input via the presentation interface to be transmitted by the VDES station;

– data received by the VDES station should be output through the presentation interface.

3.5 Forward Error Correction

3.5.1 Encoder Structure

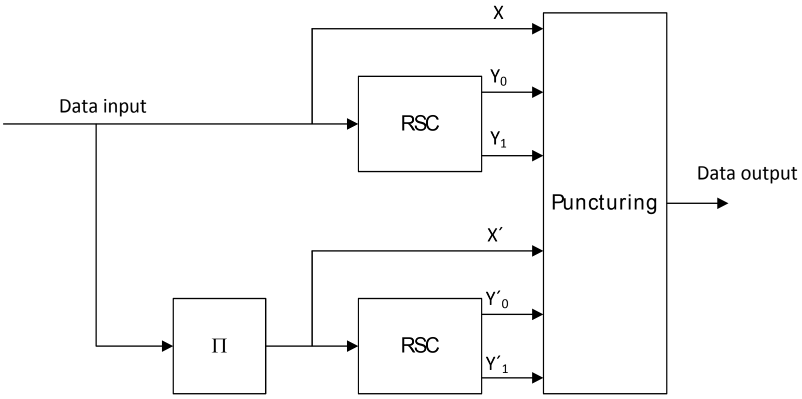
This paragraph defines the general structure of the forward error correction encoder to be used on the satellite and the terrestrial component of the VDES. The overall structure follows the specification in the ETSI EN 302 583 standard {RD-1}.

The general encoder structure is depicted in Fig. A1-4. The encoder consists of two recursive systematic convolutional (RSC) encoders concatenated in parallel. Each encoder produces 3 output bits per input bit. The first RSC encoder produces the bits X, Y_0 and Y_1, while the second encoder produces the bits X’, $Y’_0$ and $Y’_1$.

The first encoder gets as input a word **u** of k bits, with k, as specified in § 3.5.3. The second encoder input is denoted by **u**’ and it is a permuted version of the vector **u**. The permutation is performed according to the definition provided in § 3.5.3 below.

FIGURE A1-4

Turbo encoder structure (high-level)



3.5.2 Constituent codes

The constituent codes are specified by the transfer function

$$G(D) = \begin{bmatrix} 1 & \frac{n_0(D)}{d(D)} & \frac{n_1(D)}{d(D)} \end{bmatrix}$$

where

$$n_0(D) = 1 + D + D^3$$

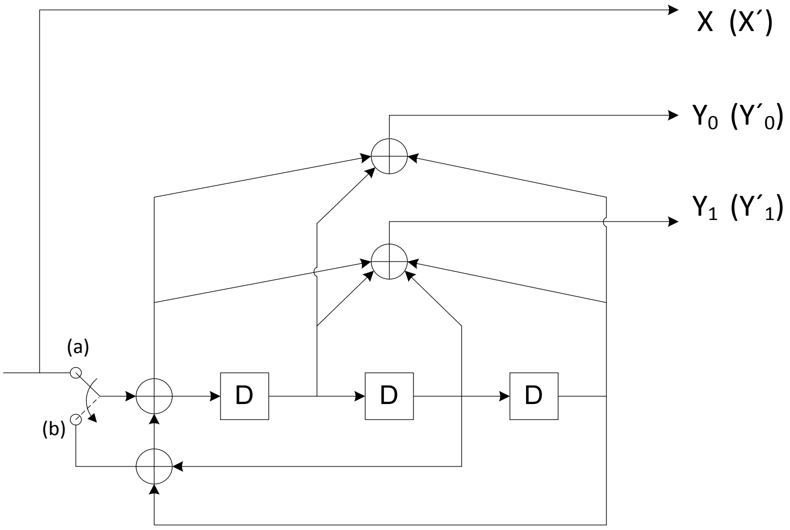
$$n_1(D) = 1 + D + D^2 + D^3$$

$$d(D) = 1 + D^2 + D^3.$$

The constituted encoder definition is provided in Fig. A1-5. For the first k clocks the switch is in position (a), i.e. information is fed into the encoder. For the subsequent 6 clocks, the switch is moved to position (b) to handle the RSC trellis termination. In the first 3 termination clocks, only the RSC 1 (upper branch) is output, while in the subsequent 3 termination clocks, only the output of RSC 2 (lower branch) is provided. The termination is thus given by the sequence of 6 termination bits (X, Y_0, Y_1, X’, $Y’_0$, $Y’_1$) with X output first.

FIGURE A1-5

RSC code encoder



3.5.3 Interleaver definition

The interleaver specification follows {RD-2}.

First factorize $k = k_1 k_2$, where the parameters k_1 and k_2 depend on the choice of the respective code, where k is the information block length. The values are given in Table A1-2.

TABLE A1-2

Interleaver parameters for different information lengths/code rates

Nominal code rate	**Information length**	**k₁|k₂**
1/4	23552	8|2944
1/3	128	2|64
1/2	1920	4|480
1/2	23056	8|2882
3/4	136	2|68
3/4	296	2|148
3/4	32800	10|3280

This Table will be extended as different information block lengths are defined.

This FEC will be calculated by first choosing prime numbers p_q, $q \in (1, ..., 8)$

$p_1 = 31$

$p_2 = 37$

$p_3 = 43$

$p_4 = 47$

$p_5 = 53$

$p_6 = 59$

$p_7 = 61$

$p_8 = 67$

The following operations shall be performed for $s \in (1, ..., k)$ to obtain the permutation numbers $\pi(s)$:

$$m = (s - 1)\ mod\ 2$$

$$i = floor\ ((s - 1)\ /(2k_2))$$

$$j = floor\ ((s - 1)\ /2)) - ik_2$$

$$t = (19i + 1)\ mod\ (k_1/2)$$

$$q = t\ mod\ 8 + 1$$

$$c = \left(p_q j + 21m\right)\ mod\ k_2$$

$$\pi(s) = 2(t + ck_1/2 + 1) - m$$

The permutation numbers shall be interpreted such that the s^{th} bit read out after interleaving is the $\pi(s)^{\text{th}}$ bit of the input information block.

3.5.4 Rate Adaptation

Rate adaptation is obtained by puncturing the encoder output as in § 5.3.1 of {RD-1}, as recalled in Table A1-3 for the first *k* clocks, and as in {RD-1}.

The puncturing table for the termination part is given in Table A1-3. The last row of the Table is note part of {RD-1}.

Table A1-3 is for the terminations. The last row with ID 8 is introduced in this fdocument to obtain higher rates and is not part of {RD-1}.

TABLE A1-3

Puncturing patterns for data bit periods

Punc. Pattern ID	Code Rate	Punc. Pattern (X; Y_0; Y_1; X’; Y'_0; Y'_1 | X; Y_0; Y_1; X’; Y'_0; Y'_1 | ...)
0	1/5	1;1;1;0;1;1
1	2/9	1;0;1;0;1;1 | 1;1;1;0;1;1 | 1;1;1;0;0;1 | 1;1;1;0;1;1
2	1/4	1;1;1;0;0;1 | 1;1;0;0;1;1
3	2/7	1;0;1;0;0;1 | 1;0;1;0;1;1 | 1;0;1;0;0;1 | 1;1;1;0;0;1
4	1/3	1;1;0;0;1;0
5	2/5	1;0;0;0;0;0 | 1;0;1;0;0;1 | 0;0;1;0;0;1 | 1;0;1;0;0;1 | 1;0;1;0;0;1 | 0;0;1;0;0;1 | 1;0;1;0;0;1 | 1;0;1;0;0;1 | 0;0;1;0;0;1 | 1;0;1;0;0;1 | 1;0;1;0;0;1 | 0;0;1;0;0;1
6	1/2	1;1;0;0;0;0 | 1;0;0;0;1;0
7	2/3	1;0;0;0;0;0 | 1;0;0;0;0;0 | 1;0;0;0;0;0 | 1;0;1;0;0;1
8	3/4	1;0;1;0;0;0 | 1;0;0;0;0;0 | 1;0;0;0;0;0 | 1;0;0;0;0;0 | 1;0;0;0;0;0 | 1;0;0;0;0;1

For each rate, the puncturing table shall be read first from left to right and then from top to bottom.

Within a puncturing pattern, a ‘0’ means that the symbol shall be deleted and a ‘1’ means that a symbol shall be passed. A ‘2’ or a ‘3’ means that two or three copies of the symbol shall be passed. This is relevant for the termination periods. In particular

- For the rate 1/5 turbo code (Punct_Pat_ID=0), the tail output symbols for each of the first three tail bit periods shall be $XXXY_0Y_1$, and the tail output symbols for each of the last three tail bit periods shall be $X'X'X'Y'_0Y'_1$.
- For the rate 2/9 turbo code (Punct_Pat_ID=1), the tail output symbols for the first and the second output period shall be $XXXY_0Y_1$, for the third output period XXY_0Y_1, for the fourth and fifth output period $X'X'Y'_0Y'_1$, and for the sixth (last) output period $X'X'X'Y'_0Y'_1$.
- For the rate 1/4 turbo code (Punct_Pat_ID=2), the tail output symbols for each of the first three tail bit periods shall be XXY_0Y_1, and the tail output symbols for each of the last three tail bit periods shall be $X'X'\ Y'_0Y'_1$.

All other code rates shall be processed similar to the given examples above with the exact puncturing patterns to be derived from {RD-1}.

The puncturing table for the termination part is given in Table A1-4. The last row of the table is introduced in this document to obtain higher rates and is not part of {RD-1}.

TABLE A1-4

Puncturing and repetition patterns for tail bit periods (last 6 clocks)

Punct. Pattern ID	Code Rate	Punct. / Rep. Pattern (X; Y_0; Y_1; X'; Y'_0; Y'_1 | X; Y_0; Y_1; X'; Y'_0; Y'_1 | …)
0	1/5	3;1;1;0;0;0 | 3;1;1;0;0;0 | 3;1;1;0;0;0 | 0;0;0;3;1;1 | 0;0;0;3;1;1 | 0;0;0;3;1;1
1	2/9	3;1;1;0;0;0 | 3;1;1;0;0;0 | 2;1;1;0;0;0 | 0;0;0;2;1;1 | 0;0;0;2;1;1 | 0;0;0;3;1;1
2	1/4	2;1;1;0;0;0 | 2;1;1;0;0;0 | 2;1;1;0;0;0 | 0;0;0;2;1;1 | 0;0;0;2;1;1 | 0;0;0;2;1;1
3	2/7	1;1;1;0;0;0 | 2;1;1;0;0;0 | 2;1;1;0;0;0 | 0;0;0;2;1;1 | 0;0;0;1;1;1 | 0;0;0;1;1;1
4	1/3	2;1;0;0;0;0 | 2;1;0;0;0;0 | 2;1;0;0;0;0 | 0;0;0;2;1;0 | 0;0;0;2;1;0 | 0;0;0;2;1;0
5	2/5	1;1;1;0;0;0 | 1;1;1;0;0;0 | 1;0;1;0;0;0 | 0;0;0;1;1;1 | 0;0;0;1;1;1 | 0;0;0;1;0;1
6	1/2	1;1;0;0;0;0 | 1;1;0;0;0;0 | 1;1;0;0;0;0 | 0;0;0;1;1;0 | 0;0;0;1;1;0 | 0;0;0;1;1;0
7	2/3	1;0;0;0;0;0 | 1;0;1;0;0;0 | 1;0;1;0;0;0 | 0;0;0;1;0;0 | 0;0;0;1;0;1 | 0;0;0;1;0;1
8	3/4	1;0;1;0;0;0 | 1;0;1;0;0;0 | 1;0;1;0;0;0 | 0;0;0;1;0;1 | 0;0;0;1;0;1 | 0;0;0;1;0;1

For each rate, the puncturing table shall be read first from left to right and then from top to bottom.

3.6 CRC

The 32 bit ITU-T V.42 {RD-5} polynomial 0x04C11DB7 CRC is appended to the last segment of the datagram. The CRC is calculated over all fragments of the datagram.

$F(x) = x^{32} + x^{26} + x^{23} + x^{22} + x^{16} + x^{12} + x^{11} + x^{10} + x^{8} + x^{7} + x^{5} + x^{4} + x^{2} + x + 1$

Initial state: 0xFFFFFFFF

3.7 Antenna configurations for VDES ship stations

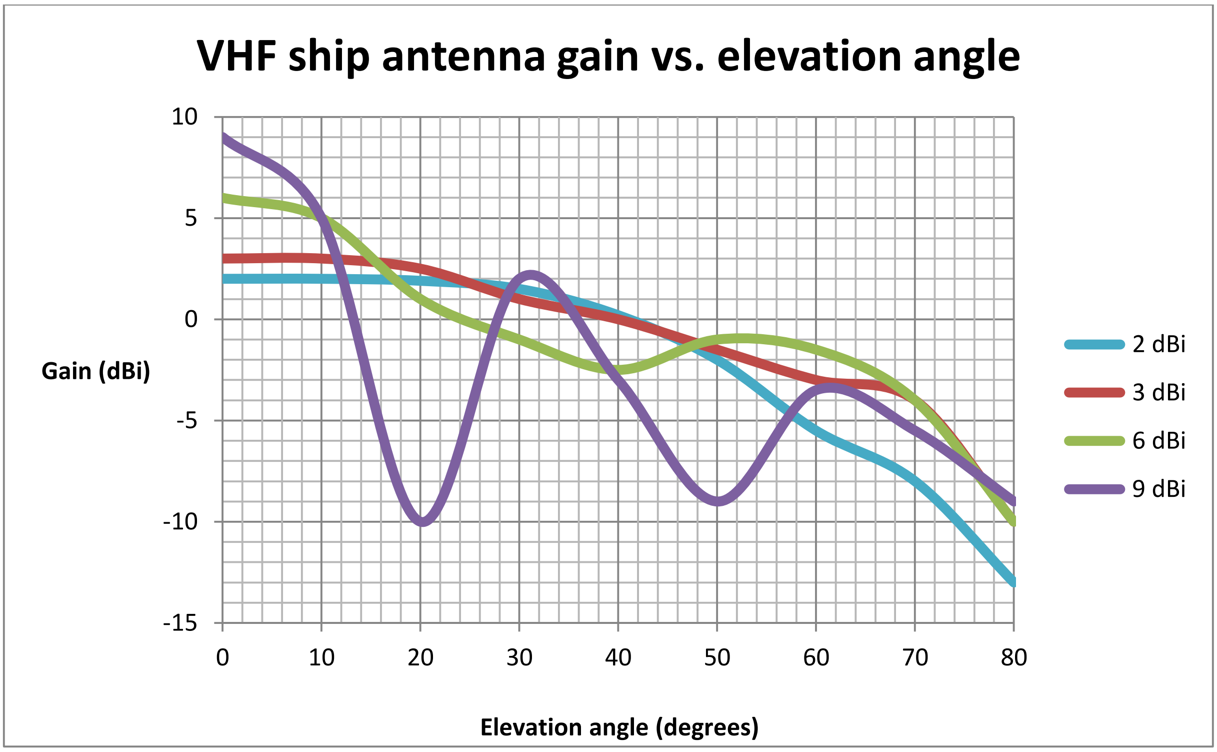
3.7.1 Antenna Gain

Existing ship antennas may be used for VDES. The maximum antenna gain for these antennas ranges from 2 dBi to 10 dBi. Representative antenna patterns are shown in Fig. A1-6.

A ship antenna with a minimum gain at 0 degrees elevation of 3 dBi at the receiver input is required.

FIGURE A1-6

Ship antenna gain vs. elevation angle



3.7.2 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 and the LNA noise figure. Table A1-5 presents representative values for the receiver noise figure.

TABLE A1-5

Ship receiver noise figure calculations

Antenna noise temperature*	245.0	K
LNA noise figure	6.0	dB
LNA noise temperature	813.8	K
Feed loss noise temp at LNA	0.0	K
Antenna noise temp at LNA	245.0	K
System noise temp at LNA	1058.8	K
System noise temp at LNA	30.2	dBK

* The galactic background antenna noise temperature is 245 K at 160 MHz {RD-4}.

3.8 Ship e.i.r.p. vs. elevation angle

The minimum ship e.i.r.p. vs elevation angle is shown in Table A1-6. There are no minimum e.i.r.p. requirements above 80 degrees elevation. Table A1-6 is based on a linear transmitter meeting the maximum Adjacent Channel Interference levels defined in Table A1-7. For saturated operation the e.i.r.p. shall be 3 dB higher.

TABLE A1-6

Minimum ship e.i.r.p. vs. elevation angle

Ship elevation angle	Ship antenna gain	Minimum ship e.i.r.p. with 6 W transmitter
degrees	dBi	dBW
0	3	10.8
10	3	10.8
20	2.5	10.3
30	1	8.8
40	0	7.8
50	−1.5	6.3
60	−3	4.8
70	−4	3.8
80	−10	−2.2
90	−20	−12.2

3.9 Transmitter requirements for VDES ship stations

3.9.1 Transmitter power

Table A1-7 defines the requirements for the VDES ship station transmitters.

TABLE A1-7

Transmitter parameters mobile station

Transmitter parameters	Requirements	Condition
Frequency error	3 ppm	normal
Transmit power	Transmit average power should be at least 1 watt and not exceed 25 watts as declared by the manufacturer. ±1.5 dB normal, +2/−6 dB extreme	Conducted
Maximum adjacent power levels for 25 kHz channel	0 dBc −25 dBc −60 dBc	Δfc < ±12.5 kHz ±12.5 kHz < Δfc < ±25 kHz ±25 kHz < Δfc < ±75 kHz
Maximum adjacent power levels for 50 kHz channel	0 dBc −25 dBc −60 dBc	Δfc < ±25 kHz ±25 kHz < Δfc < ±50 kHz ±50 kHz< Δfc < ±100 kHz
Maximum adjacent power levels for 100 kHz channel	0 dBc −25 dBc −60 dBc	Δfc < ±50 kHz ±50 kHz < Δfc < ±100 kHz ±100 kHz < Δfc < ±150 kHz
Spurious emissions	−36 dBm −30 dBm	9 kHz to 1 GHz 1 GHz to 4 GHz

3.10 Shutdown procedure

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.

3.11 Safety precautions

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

4 Functions of the VDES

The VDES should support the following:

4.1 Automatic Identification System

The AIS will operate as defined by Recommendation ITU-R M.1371.

4.2 Application-Specific Messages – Annex 2

Annex 2 describes the characteristics of the ASM channel that will support applications specific messages in order to improve the efficiency of application-specific message transmissions and to protect the original function of the AIS.

4.3 VDE terrestrial – Annex 3

Annex 3 describes the characteristics of the VDE terrestrial channels providing an efficient terrestrial data transfer link enabling a wide variety of applications for the maritime community.

4.4 VDE satellite downlink – Annex 4

Annex 4 describes the characteristics of a satellite downlink that will support multi-cast multi-package data transfers and shore originated unicast multi-package data transfers via satellite.

4.5 VDE satellite uplink – Annex 5

Annex 5 describes the characteristics of a satellite uplink that will support the collection of information from VDES stations and support long range ship-to-shore communications.

4.6 VDES sharing options – Annex 6

Annex 6 describes the characteristics necessary for each component of the VDES to share the available spectrum such that impact between services is minimized and AIS is respected.

4.7 VDES original design considerations – Annex 7

Annex 7 is an informative annex that provides additional information on the technical consideration of the VDES. It identifies aspects of both terrestrial and satellite VDE components, including access scheme options, antenna designs, and system sharing.

Annex 2

Technical characteristics of the Application Specific Message (ASM) channels 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), and slot carrier sense TDMA (SCTDMA) techniques.

For application specific messages refer to Recommendation ITU-R M.1371 in general.

1.1 Specific responsibilities of the OSI layers as defined in Annex 1 for preparing ASM data for transmission

1.1.1 Physical layer

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

1.1.2 Link layer

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

1.1.2.1 Link management entity

This sub layer has the following functions:

- Assemble ASM message bits
- Order the ASM message bits into 8-bit byte for assembly of transmission packet.

1.1.2.2 Data link services

This sub layer has the following functions:

- Calculate frame check sequence (FCS) of the ASM message bits (see § 3.2.2.3).
- Append FCS to ASM message to complete creation of transmission packet contents.
- Complete assembly of transmission packet.

1.1.2.3 Media access control

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.

1.1.3 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.

1.1.4 Transport layer

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

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 A2-1 to A2-3.

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

TABLE A2-1

Minimum required time division multiple access transmitter characteristics

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

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

2.1.2 Transmission media

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

2.1.3 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 enable TDMA transmissions on one of two independent frequency channels.

2.2 Transceiver characteristics

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

TABLE A2-2

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	$\Delta fc < \pm 10$ kHz: 0 dBc ± 10 kHz $< \Delta fc < \pm 25$ kHz: below the straight line between −25 dBc at ±10 kHz and –70 dBc at ±25 kHz ± 25 kHz $< \Delta fc < \pm 62.5$ kHz: −70 dBc
Spurious emissions	−36 dBm: 9 kHz ... 1 GHz −30 dBm: 1 GHz ... 4 GHz

TABLE A2-3

Minimum required time division multiple access receiver characteristics

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

2.3 Modulation scheme

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

2.3.1 π/4 Quadrature Phase-Shift Keying (π/4 QPSK)

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

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 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 19.2 kbit/s ±10 ppm for π/4 QPSK.

2.5 Training sequence

The training sequence is 111111001101010000011001010.

2.6 Signal information

The signal information should follow the training sequence.

The signal information consists of 4 bits encoded into a sequence of 7 bits using Hamming (7,4) code. The signal information selects the modulation and coding schemes are used and allows for adding new modulation and coding schemes in the future.

Signal information “XXXX” – selects the modulation scheme and coding:

0000 – π/4 QPSK no coding

0001 – π/4 QPSK 1/2 code rate

0010 – π/4 QPSK 3/4 code rate

0011 – π/4 QPSK 5/6 code rate

0100 – 1111 – reserved for future use.

2.7 Data encoding

Data coding is not used.

2.8 Forward error correction

When forward error correction is used, it will be used as defined in Annex 1. Interleaving and bit scrambling are used, as defined by the FEC designated in the signal information.

2.9 Transmitter transient response

2.9.1 Switching time

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.

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

2.10 Transmitter power

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

2.10.1 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.

2.10.2 The nominal levels for the two power settings should be 1 W and 12.5 W (average power); tolerance should be within ±1.5 dB.

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 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 TDMA using a common time reference.

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 the 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

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

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 slot and frame are as defined in Annex 1. 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.

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. A2-1.

FIGURE A2-1

Slot Access

3.1.6 Slot state

Each slot on an ASM channel can be in one of the following states:

- Free: meaning that the slot is unused on the channel within the receiving range of the own station
- Internal allocation: meaning that the slot is allocated by own station for the purpose of ASM transmission
- External allocation: meaning that the slot is allocated for the purpose of ASM transmission by another station.

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.

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. A2-2:

FIGURE A2-2

Packet Format

Ramp up	**Training sequence**	**Signal Information**	**Data Length**	**Data**	**CRC**	**Buffer**
16	27	7	10	380 (Maximum)	32	40

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 (π/4 QPSK).

3.2.2.2 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.

3.2.2.3 Frame check sequence

The FCS uses the cyclic redundancy check, see § 3.2.3.

3.2.2.4 Buffer

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

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

The distance delay should provide protection for a propagation range of approximately 222.24 km (120 NM)[1].

3.2.2.5 Summary of the default transmission packet

The data packet is defined in Table A2-4.

TABLE A2-4

Single slot packet bit structure for π/4 QPSK modulation scheme

Ramp up	16 bits	
Training sequence	27 bits	Necessary for synchronization
Signal information/FEC	7 bits	Decoded from Hamming (7,4) 0000 – no coding 0001 – 1/2 code rate 0010 – 3/4 code rate 0011 – 5/6 code rate
Data length	10 bits	Default: “0110011100” (412) encoded data and CRC;
Data	380 bits	Without encoding: 380 bits With encoding: varies according to coding rate defined in the Signal Information field
CRC	32 bits	Without encoding: 32 bits; With encoding: varies according to coding rate defined in the Signal Information field; Only the data length and data field are included in the CRC
Buffer	40 bits	Distance delay and jitter
Total	512 bits	Maximum 512 bits for 19.2 kbits/s π/4 QPSK

3.2.2.6 Transmission timing

There should be no modulation during the ramp down period.

3.2.2.7 Long transmission packets

A station may occupy a maximum of 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

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[1] 1 Nautical mile = 1 852 metres.

necessary to transfer the data; i.e. the ASM should not add filler, however necessary block coding sizes and/or data fill to byte boundaries is permitted.

3.2.3 Error detection and control

Error detection is accomplished using a CRC polynomial as described in Annex 1.

3.2.4 Forward Error correction

Forward error correction should be handled as described by the signal information.

3.3 Sub layer 3 – link management entity

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

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, SCTDMA 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 system must 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.

The selection process uses received data from AIS and ASM.

There should be, at minimum, a set of four candidate slots to choose from.

The candidate slots are primarily selected from slots that are free on AIS and ASM.

The available slots are as defined in Recommendation ITU-R M.1371 and must only be taken from the most distant station(s) within the SI.

If the candidate slot set contains less than four slots, additional candidate slots can be obtained by using the following rules and order (rule 1 followed by rule 2):

Rule 1: available slot on an AIS channel and free on all other AIS and ASM channels

Rule 2: available slot on both AIS channels and free on all ASM channels.

When selecting candidates for messages longer than one (1) slot, a candidate slot should be the first slot in a consecutive block of slots that conform to the selection criteria stated above.

If the station cannot find sufficient number of candidate slots, the station should not transmit and should re-schedule the transmission.

The candidate slot selection process also has to consider time periods reserved for the reception of the bulletin board.

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.

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.

3.3.4 Channel access schemes

The access schemes, as defined below, should coexist and operate simultaneously on the TDMA channel. The access schemes ITDMA, RATDMA and FATDMA are as defined in Recommendation ITU-R M.1371.

3.3.4.1 Slot carrier sense time division multiple access (SCTDMA)

SCTDMA may be used for satellite-uplink transmissions.

3.3.4.2 Slot carrier sense time division multiple access algorithm

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

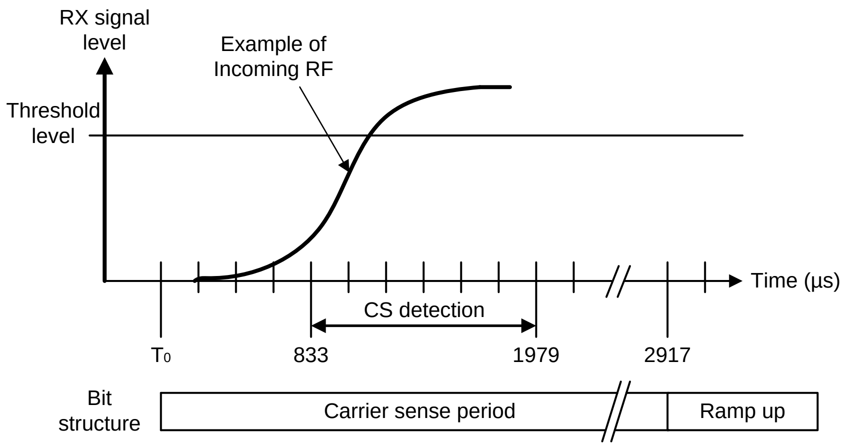
VDES stations using SCTDMA should detect if the slot is used by examining the CS detection window of 1 146 µs starting at 833 µs and ending at 1 979 µs after the start of the slot intended for transmission (T_0). Signals within the first 833 µs of the time period are excluded from the decision to allow for propagation delays and ramp down periods of other units.

VDES stations using the SCTDMA access scheme should not transmit on any slot in which, during the CS detection window, a signal level greater than the "CS detection threshold" is detected.

The transmission of a SCTDMA packet should commence 2 917 µs after the nominal start of the time period (see Fig. A2-3).

FIGURE A2-3

Carrier sense timing



3.3.4.3 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 −77 dBm)[2].

3.3.4.4 Network access and entry of a new data stream

For ITDMA and RATDMA 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, as shown in Fig. A2-4. 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.

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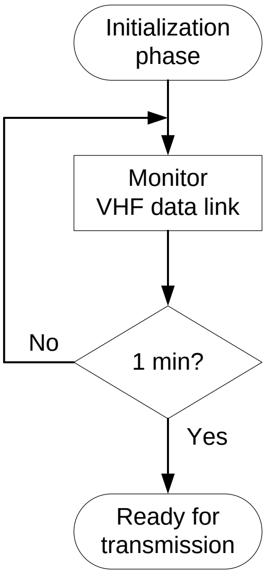
[2] The following example is compliant with the requirement:

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.

FIGURE A2-4

Network Access for ITDMA and RATDMA



3.3.4.5 Priority of transmissions

There are 4 (four) levels of message priority:

Priority 1 (highest): Critical link management messages

Priority 2: Safety related messages

Priority 3: Interrogation and responses to interrogation

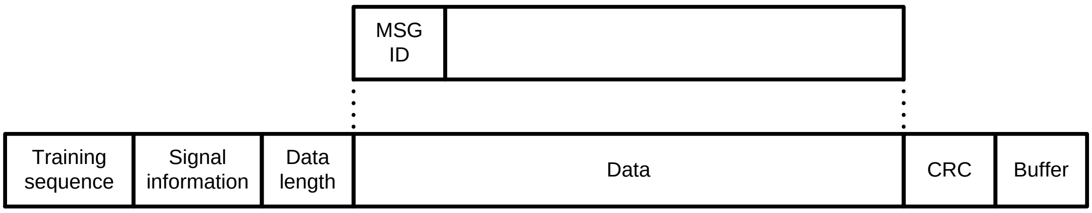
Priority 4 (lowest): All other messages.

3.3.5 Message structure

The messages should have the following structure shown in Fig. A2-5 inside the data portion of a data packet.

FIGURE A2-5

Message Structure



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. Each byte should be outputted with least significant bit first.

A generic example for a message table is provided in Table A2-5.

TABLE A2-5

Generic Message Table

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

The logical view of data is provided in Table A2-6.

TABLE A2-6

Logical view of data

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

The output order to VHF data link is provided in Table A2-7.

TABLE A2-7

Output order to VHF data link

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

3.3.5.1 Message identification

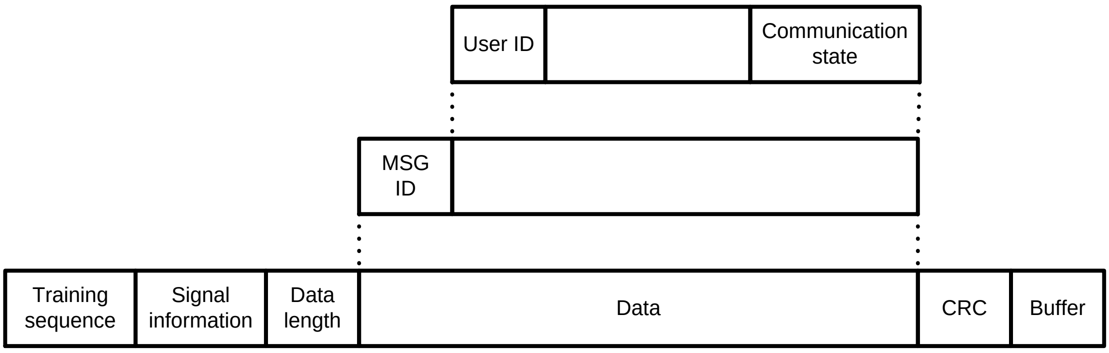
The message ID should be 6 bits long and should respect the current definitions of message IDs as defined for AIS in Recommendation ITU-R M.1371.

3.3.5.2 Incremental time division multiple access message structure

The ITDMA message structure supplies the necessary information in order to operate in accordance with Recommendation ITU-R M.1371. The message structure is shown in Fig. A2-6.

FIGURE A2-6

ITDMA Message Structure



3.3.5.2.1 User identification

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

3.3.5.2.2 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 defined in Recommendation ITU-R M.1371. 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 Network layer

The network layer should be used for:

- Establishing and maintaining channel connections
- Management and priority assignments of messages
- Distribution of transmission packets between channels
- Data link congestion resolution.

5 Transport layer

The transport layer is responsible for:

- converting data into transmission packets of correct size;
- sequencing of data packets;
- interfacing protocol to upper layers.

The interface between the transport layer and higher layers should be performed by the presentation interface.

5.1 Definition of transmission packet

A transmission packet is an internal representation of some information which can ultimately be communicated to external systems. The transmission packet is dimensioned so that it conforms to the rules of data transfer.

5.2 Transmission packets

5.2.1 Addressed Messages

Addressed messages are point to point communications between VDES stations. Addressed messages may require an acknowledgment. When an acknowledgement is required and not received, the VDES stations may retransmit the message.

5.2.2 Broadcast messages

A broadcast message lacks a destination identifier ID. Therefore receiving stations should not acknowledge a broadcast message.

5.2.3 Conversion to presentation interface messages

Each received transmission packet should be converted to a corresponding presentation interface message and presented in the order they were received regardless of message category. Applications utilizing the presentation interface should be responsible for their own sequencing numbering scheme, as required. For a mobile station, addressed messages should not be output to the presentation interface, if destination User ID (destination MMSI) is different to the ID of own station (own MMSI).

5.2.4 Conversion of data into transmission packets

The transport layer should convert data, received from the presentation interface into transmission packets.

5.3 Presentation interface protocol

Data, which is to be transmitted by the station, should be input via the presentation interface; data, which is received by the station, should be output through the presentation interface. The formats and protocol used for this data stream are defined by IEC 61162 series.

6 Satellite uplink message

Satellite uplink may be provided by VDES equipment. It also may provide by dedicated equipment using slot carrier sense TDMA (SCTDMA) access scheme to consolidate AIS communications and terrestrial ASM communications.

6.1 Packet bit structure for satellite uplink message

The data packet for ITDMA, RATDMA and FATDMA is defined in Table A2-8.

The data packet for SCTDMA is as defined in Table A2-9.

TABLE A2-8

Modified packet bit structure for satellite uplink

Slot composition	Bits	Notes
Ramp up	16	Standard
Pre training sequence	100	0011 (repeat for 100 bits)
Training sequence	27	Standard
Signal information	7	Decoded from Hamming (7,4) 0000 – not coding 0001 – 1/2 code rate 0010 – 3/4 code rate 0011 – 5/6 code rate
Data length	10	Default: "0011000110" (198) encoded data and CRC;
Data field	166	Without encoding: 166 bits With encoding: varies according to coding rate defined in the Signal Information field
CRC	32	Without encoding: 32 bits; With encoding: varies according to coding rate defined in the Signal Information field; Only the data length and data field are included in the CRC
Buffer	154	Synch jitter (mobile station) = 6 bits Synch jitter (mobile/satellite) = 2 bits Propagation time delay difference = 144 bits Spare = 2 bits
Total	512	Maximum 512 bits for 19.2 kbits/s π/4 QPSK

TABLE A2-9

Modified packet bit structure for satellite uplink ASM message with SCTDMA

Slot composition	Bits	Notes
Carrier sense period	56	Not transmitting (2 917 µs, equivalent to 56 bits)
Ramp up	16	Standard
Pre training sequence	44	0011 (repeat for 44 bits)
Training sequence	27	Standard
Signal information	7	Decoded from Hamming (7,4) 0000 – not coding 0001 – 1/2 coding 0010 – 3/4 coding 0011 – 5/6 coding
Data length	10	Default: "0011000110" (198) encoded data and CRC;
Data field	166	Without encoding:166 bits With encoding: varies according to coding rate defined in the Signal Information field

TABLE A2-9 (*end*)

Slot composition	Bits	Notes
CRC	32	Without encoding: 32 bits; With encoding: varies according to coding rate defined in the Signal Information field; Only the data length and data field are included in the CRC
Long-range ASM receiving system buffer	154	Synch jitter (mobile station) = 6 bits Synch jitter (mobile/satellite) = 2 bits Propagation time delay difference = 144 bits Spare = 2 bits
Total	512	Maximum 512 bits for 19.2 kbits/s π/4 QPSK

6.2 Transmitting the satellite uplink broadcast message

The satellite uplink ASM broadcast message should be transmitted only on ASM channels and not on the following channels: 75, 76, AIS 1, AIS 2 or regional channels.

Annex 3

Technical characteristics of VDE-terrestrial in the maritime mobile band

1 Introduction

This annex describes the characteristics of the terrestrial VDES. It contains a description of the different protocols according to the OSI layer model and recommends implementation details for each layer.

Data transmission is made in the VHF maritime mobile band. Data transmissions are made within the spectrum allocated for the VDE1-A and VDE1- B. The spectrum may be used as 25 kHz, 50 kHz or 100 kHz channels.

The system should use TDMA techniques in a synchronized manner.

2 OSI layer

Refer to Annex 1.

3 Physical layer

3.1 Range

The communication range of terrestrial VDE is typically 20−50 NM.

3.2 Transmitter Parameter settings

Refer to Annex 1 for transmitter parameter settings for mobile stations.

Transmitter parameter settings for shore station are defined in Table A3-1.

TABLE A3-1

Transmitter parameters shore station

Transmitter parameters	Requirements	Condition
Frequency error	3 ppm	normal
Transmit power	Transmit average power shall be at least 12.5 watts and not exceed 50 watts as declared by the manufacturer. ±1.5 dB normal +2/−6 dB extreme	conducted
Modulation spectrum 25 kHz channel	0 dBc −25 dBc −60 dBc	$\Delta fc < \pm 12.5$ kHz ±12.5 kHz < $\Delta fc < \pm 25$ kHz ±25 kHz < $\Delta fc < \pm 75$ kHz
Modulation spectrum 50 kHz channel	0 dBc −25dBc −60 dBc	$\Delta fc < \pm 25$ kHz ±25 kHz < $\Delta fc < \pm 50$ kHz ±50 kHz< $\Delta fc < \pm 100$ kHz
Modulation spectrum 100 kHz channel	0 dBc −25 dBc −60 dBc	Δfc < ±50 kHz ±50 kHz < $\Delta fc < \pm 100$ kHz ±100 kHz < $\Delta fc < \pm 150$ kHz
Spurious emissions	−36 dBm −30 dBm	9 kHz ... 1 GHz 1 GHz ... 4 GHz

3.3 Antenna

Terrestrial VDE may share the same antenna(s) with the other subsystems AIS, ASM, VDE-SAT.

Refer to Annex 1.

3.4 Modulation

3.4.1 Waveforms

The waveforms are defined in TABLE A3-2. The modulation and coding options and raw channel throughput rates are provided for a range of bandwidths and modulation and coding schemes (MCS). Three MCSs are detailed while 13 others are reserved for future expansion.

TABLE A3-2

Modulation and coding schemes

Modulation and coding scheme	**Signal Information D_0, D_1, D_2, D_3 values**	**CQI value**	**Total throughput bitrate (kbits/s)* 25 kHz**	**Total throughput bitrate (kbits/s)** 50 kHz**	**Total throughput bitrate (kbits/s)*** 100 kHz**
No transmission		0	–	–	–
MCS-1 (π/4 QPSK, CR = 1/2)	0, 0, 0, 1	1	38.4	76.8	153.6
MCS-2	0, 0, 1, 0	2	Placeholder for future MCS		
MCS-3 (8PSK, CR = 3/4)	0, 0, 1, 1	3	57.6	115.2	230.4
MCS-4	0, 1, 0, 0	4	Placeholder for future MCS		
MCS-5 (16QAM, CR = 3/4)	0, 1, 0, 1	5	76.8	153.6	307.2
Placeholder for future MCS	X, X, X, X	Placeholder for future MCS			

* An assumption: 19.2 ksym/s in 25 kHz bandwidth (Roll-off factor: 0.3)

** An assumption: 38.4 ksym/s in 50 kHz bandwidth (Roll-off factor: 0.3)

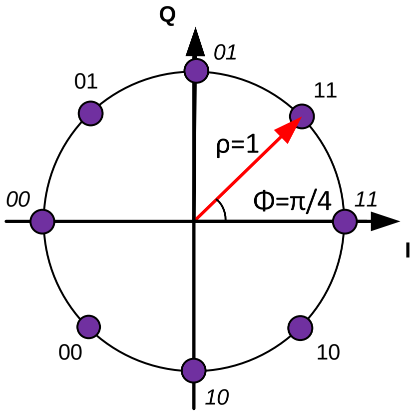
*** An assumption: 76.8 ksym/s in 100 kHz bandwidth (Roll-off factor: 0.3)

3.4.2 Bit Mapping

The bit mapping is shown in figures Figs. A3-1, A3-2 and A3-3.

FIGURE A3-1

Bit Mapping for π/4 QPSK



NOTE – Each subsequent transmission is phase-rotated by π/4.

FIGURE A3-2

Bit Mapping for 8PSK

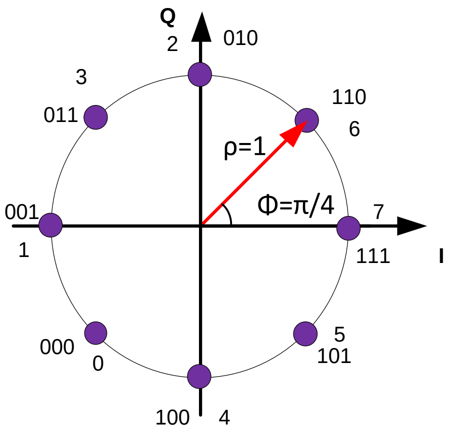
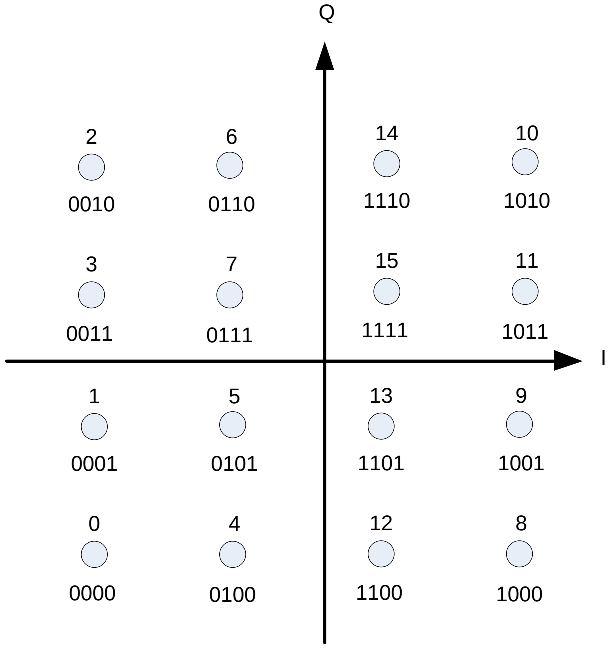


FIGURE A3-3

Bit Mapping for 16QAM



3.5 Sensitivity and Interference

VDE uses adaptive modulation and coding to maximise spectral efficiency and throughput. Sensitivity and interference levels for the supported modulation methods are given in Table A3-3.

TABLE A3-3

Sensitivity and Carrier to Interference Ratios

Modulation Coding Scheme	25 kHz		50 kHz		100 kHz	
	Sensitivity (dBm)	CIR (dB)	Sensitivity (dBm)	CIR (dB)	Sensitivity (dBm)	CIR (dB)
MCS-1*	−110	8	−107	8	−104	8
MCS-3*	−104	14	−101	14	−98	14
MCS-5*	−102	16	−99	16	−96	16

* Modulation Coding Schemes, see Table A3-2.

3.6 Symbol timing accuracy

Symbol timing accuracy is less than 5 parts per million (ppm).

3.7 Transmitter timing jitter

Less than 5% symbol interval (peak).

3.8 Slot transmission accuracy at the output

Less than 100 µs peak relative to UTC reference time for the ship station.

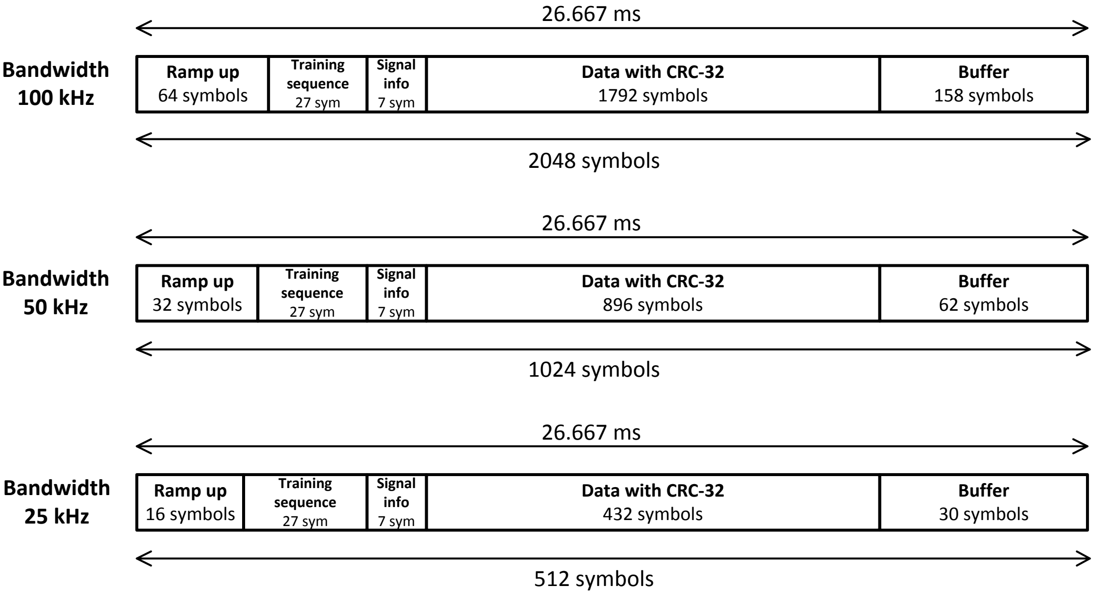
Less than 50 µs peak relative to UTC reference time for the shore station.

3.9 Slot structure

The VDES frame structure is identical and synchronized in time to UTC (as in AIS). The slot structure is shown in Fig. A3-4. Each element is described in the subsequent sections.

FIGURE A3-4

Slot structure



3.9.1 Ramp up

The ramp up time from −50 dBc to −1.5 dBc of the power shall occur in less than or equal to 832 µs. This is a means to maintain compliancy with the adjacent channel interference requirements.

3.9.2 Training sequence

The training sequence is 1111110011010100000011001010.

3.9.3 Signal information

The signal information carries the MCS id for the receiver.

The signal information should follow the training sequence for transmissions, see Table A3-2.

The signal information consists of 4 bits (D0, D1, D2, D3) encoded into a sequence of 7 bits using Hamming (7,4) code.

3.9.4 Bit mapping for training sequence and signal information

For training and signal information, following mapping applies:

– 1 maps to QPSK symbol 3 (1, 1) (see Fig. A3-1)

– 0 maps to QPSK symbol 0 (0, 0).

For QPSK bit mapping, see § 3.4.2.

3.9.5 Data with CRC-32

The data payload with its appended CRC-32 is interleaved, encoded and then scrambled and bit mapped.

3.9.6 Forward error correction

Refer to Annex 1.

3.9.7 Bit scrambling

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

3.9.8 Buffer

The buffer consists of the ramp down time from full power to −50 dBc of less than or equal to 832 µs. The remaining time is for delay and jitter.

4 Link layer

4.1 Access Schemes

The VDE terrestrial system should support the following TDMA access schemes:

– FATDMA;

– RATDMA;

– ITDMA.

4.2 Data encapsulation

The data field consists of multiple variable length datagrams and these are encapsulated. Each datagram contains the following encapsulation fields:

- Datagram type;
- Datagram size;
- Destination (optional);
- Transaction ID (optional);
- Datagram sequence number (for multi-segment datagrams);
- Source ID;
- Datagram payload (variable);
- Data padding;
- CRC (4 bytes).

4.3 Cyclic redundancy check

Refer to Annex 1.

4.4 Automatic repeat request (ARQ)

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

4.5 Acknowledgement (ACK)

Unicast datagrams without CRC errors that are acknowledged over the VDE link should be sent with a receive signal channel quality indicator (CQI).

4.6 End delivery notification (EDN)

All datagrams requiring delivery notifications that are successfully delivered to the destination should be notified to the source.

4.7 End delivery failure (EDF)

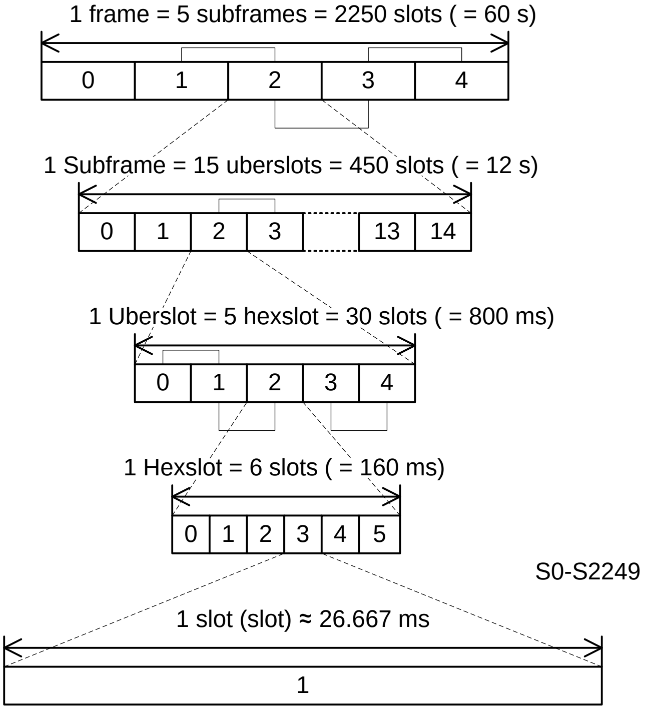
All datagrams requiring delivery notifications that are not successfully delivered within the timeout or retry limit should be notified to the source.

4.8 Frame hierarchy

Refer to Annex 6.

FIGURE A3-5

Frame hierarchy



4.9 Channel resource and media access control for VDE terrestrial

VDE spectrum (and logical channel) resources are allocated by the reception of shore (or satellite-based) media access control messaging (for example, shore stations perform this operation using the bulletin board service). In the event of vessel reception of, both satellite and shore-based stations, the shore-based resource allocations should take precedence.

Duplexing modes are a function of the resource allocation above, as well as the operational mode.

4.9.1 Simplex modes

– Ship-to-ship

Same channel resource is used for both directions of communications.

4.9.2 Duplex modes

– Shore-to-ship

– Ship-to-shore

Upper and lower spectrum are used for ship to shore or shore to ship respectively, only one side transmits at one time.

Refer to Annex 1 for details of frequency allocations.

4.10 Physical and logical channels

VDES uses several channels to carry data. These channels are separated into Physical and Logical channels. Shore-based stations should transmit a channel terrestrial bulletin board (TBB) message that defines the configuration of the VDE channels.

Lacking bulletin board information, ship borne stations should employ a default channel configuration of 50 kHz channels on the terrestrial VDES (channel 2024, and 2084 combined) operating in a simplex ad-hoc access scheme. The simplex ad-hoc access scheme for ship-to-ship communications should be ITDMA (when possible) or RATDMA.

4.11 Physical channels

The physical channels (PC) are determined by the centre frequency and bandwidth.

4.12 Logical channels

The logical channels (LC) are divided into signalling and traffic channels. These are described below. Logical channel definitions can be defined based on the physical channel and message time information (frame hierarchy, start time, etc.).

Signalling channels:

- Terrestrial Bulletin Board (TBB), see § 4.12.1
- Announcement, see § 4.12.2
- Random access, see § 4.12.5.

All signalling channels use the most robust modulation and coding scheme.

Traffic channels:

- Multicast, see § 4.12.3
- Unicast, see § 4.12.4
- Random access, see § 4.12.5.

Traffic channels may use a combination of robust and higher bitrate modulation and coding schemes.

4.12.1 Terrestrial bulletin board (TBB) signalling channel

Each VDE shore station should employ a fixed logical channel for the TBB. All TBB logical channels will be based on one of a number of predefined structures of the frame hierarchy 50 kHz shore to ship physical channel (2024 and 2084 combined). These are defined to occupy only a portion of the frame (60 seconds, 2 250 slots) to permit possible spectrum and temporal sharing with satellites, see Annex 6.

The TBB defines the network configuration parameters such as signalling channels (control channels) and data channel(s), protocol versions and future network configuration. The TBB takes precedence in the allocation of spectrum (logical channel) resources. This may be co-ordinated with the satellite bulletin board signalling channel to facilitate sharing of mutual spectrum resources.

The logical channels are normally repeated based on the VDES frame hierarchy.

The VDE terrestrial channel usage for the service area of VDE shore station is defined by the TBB, see Annex 1.

The TBB information includes the area of applicability. The TBB does not change often and should be transmitted in regular intervals.

4.12.2 Announcement signalling channel (ASC)

This channel(s) will normally carry announcements, MAC information, VDE forward and return resource allocation, CQIs, ARQs, and ACKs. Announcements also include the co-ordination of uni-cast and multi-cast (broadcast) datagrams.

The MAC information includes changes to network version, congestion control (randomization interval (hold-off) and minimum priority level). Some of these parameters will be reflected in the TBB on periodic basis.

The ASC logical channels will be assigned in the TBB and consist of a number of defined structures of the frame hierarchy 50 kHz shore to ship physical channel (2024 and 2084 combined). These are defined to occupy only a portion of the frame (60 seconds, 2 250 slots) to permit possible spectrum and temporal sharing with satellites, see Annex 6.

The ASC defines the physical channel usage (logical channel, i.e. frequency and slot) to an individual ship following a resource request. The VDE shore station uses CQI information from the ship terminal to select the highest throughput format with adequate link margin.

4.12.3 Multicast data channel (MDC)

This traffic channel(s) is utilized to send messages to be received by a large number of ships. By default multicast messages are addressed to all stations (i.e. broadcast).

4.12.4 Unicast data channel (UDC)

This traffic 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 channel quality information (CQI) allowing the shore station to maximise throughput.

4.12.5 Random access channel (RAC)

This channel has the characteristics of a slotted Aloha channel, uses a random access scheme and will be selected from a predefined list of logical channels.

4.12.5.1 For ship-to-shore, and shore-to-ship communications

A ship station uses this channel to access the network or send a short message.

4.12.5.2 For ship-to-ship when ships are within control area of a VDE shore station

A ship station uses this channel to communicate directly with other ships. This logical channel is allocated by shore station via TBB or ASC.

4.12.5.3 For ship-to-ship when outside the control area of a shore VDE station

A ship station uses these channels to communicate with other ship stations directly via short message, and will also use these random access channels to co-ordinate communication with other ships for larger messages. These logical channels will be based on a number of predefined structures of the frame hierarchy of the ship-to-ship physical channels (2024 and 2084 combined). Ship-to-ship random access channels should have fixed physical channel assignments and use the most robust modulation and coding scheme. These logic channels are distinct from the TBB logical channels.

5 Network layer

5.1 Terrestrial data transfer protocols

The following types of transmissions should be supported:

- – Bulletin Board transmission from shore station (network configuration)
- – Multicast from shore station (e.g. icemaps, weather info, notices to mariners)
- – Unicast from shore station (e.g. shore-to-ship file transfer)
- – Multicast from ship-to-ship (e.g. icemaps, weather info, notices to mariners)
- – Unicast from ship-to-shore (e.g. ship-to-shore file transfer)
- – Unicast from ship-to-ship (e.g. ship-to-ship file transfer)

– Shore originated polling (e.g. shore-to-ship-to-shore).

Figures A3-6 to A3-9 show message sequence charts for the shore originated cases. In order to manage logical channel congestion on the ASC, as shown in message sequence charts, functions such as ARQ or ACK may be inhibited at source through setting of a status bit. This may be beneficial in the case of multicast (or broadcast) messages transmitted to a large population of vessels, some of which may be beyond the nominal coverage area of the shore-originated multicast as shown in Fig. A3-7.

FIGURE A3-6

Terrestrial bulletin board with network version change

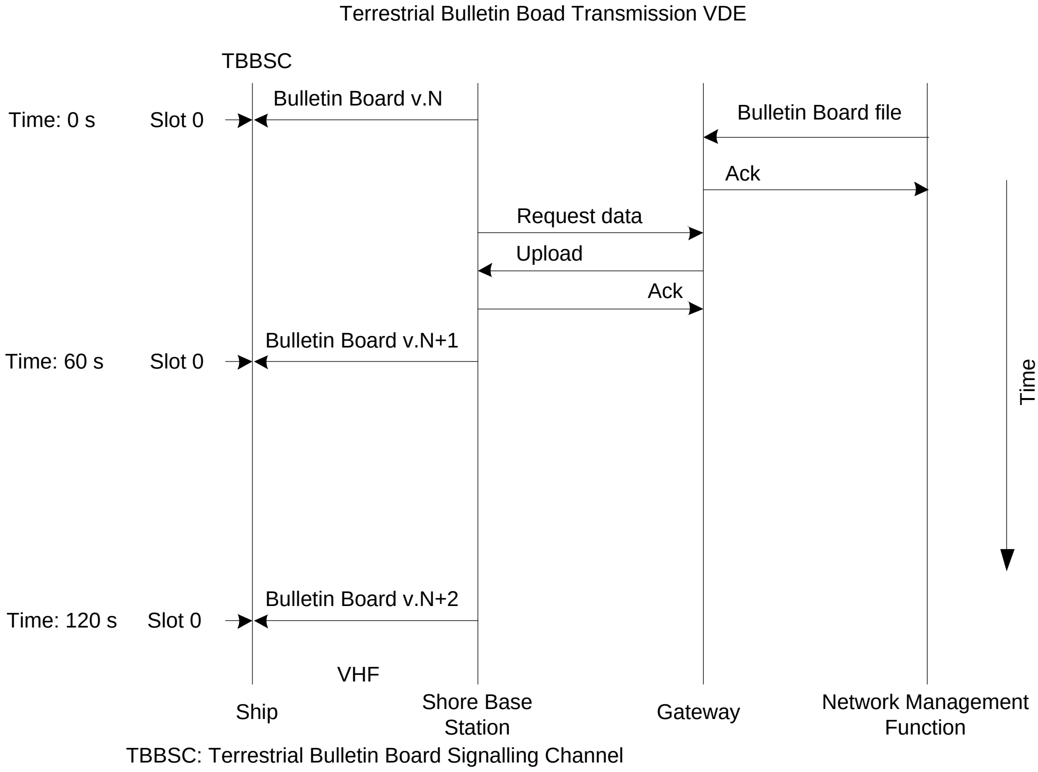


FIGURE A3-7

Shore originated multicast

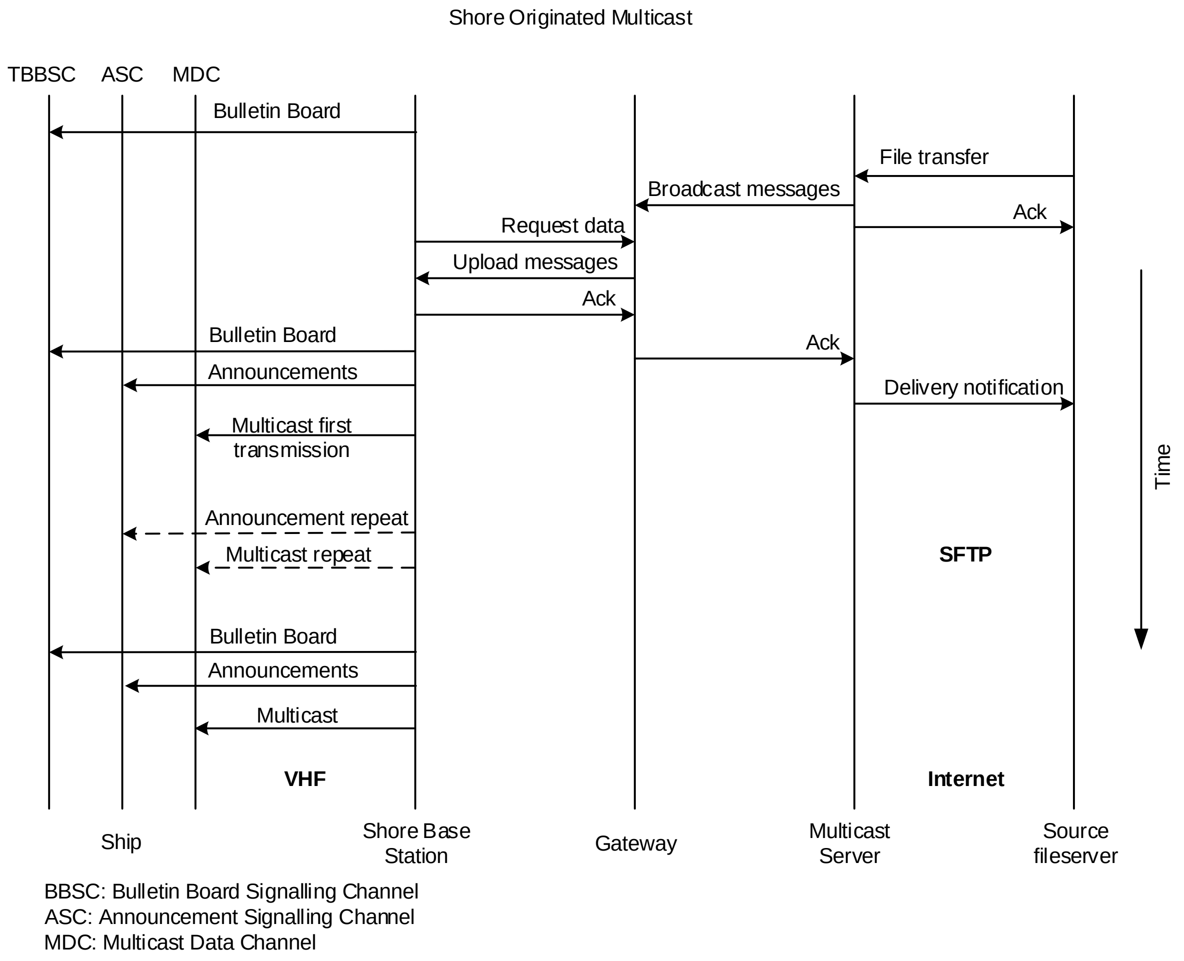
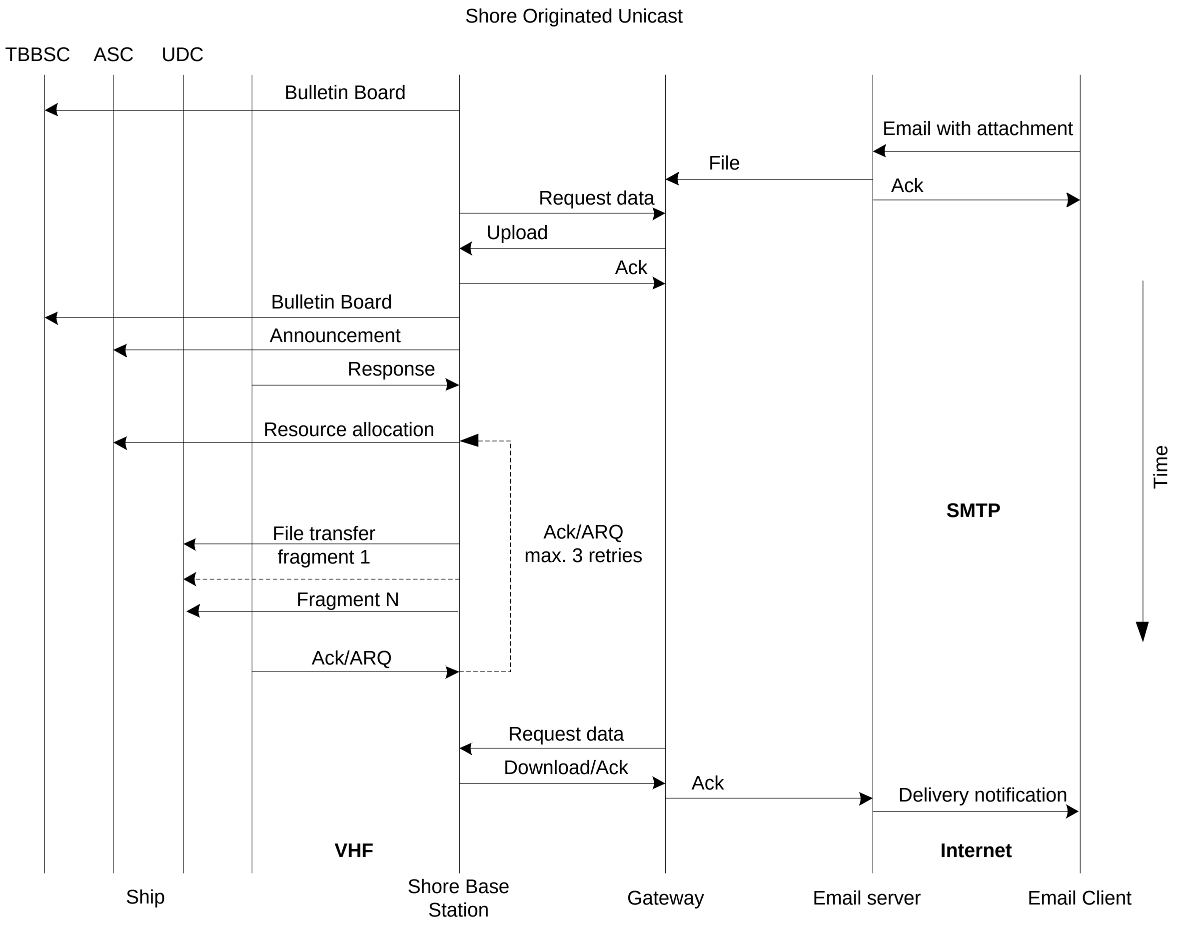


FIGURE A3-8

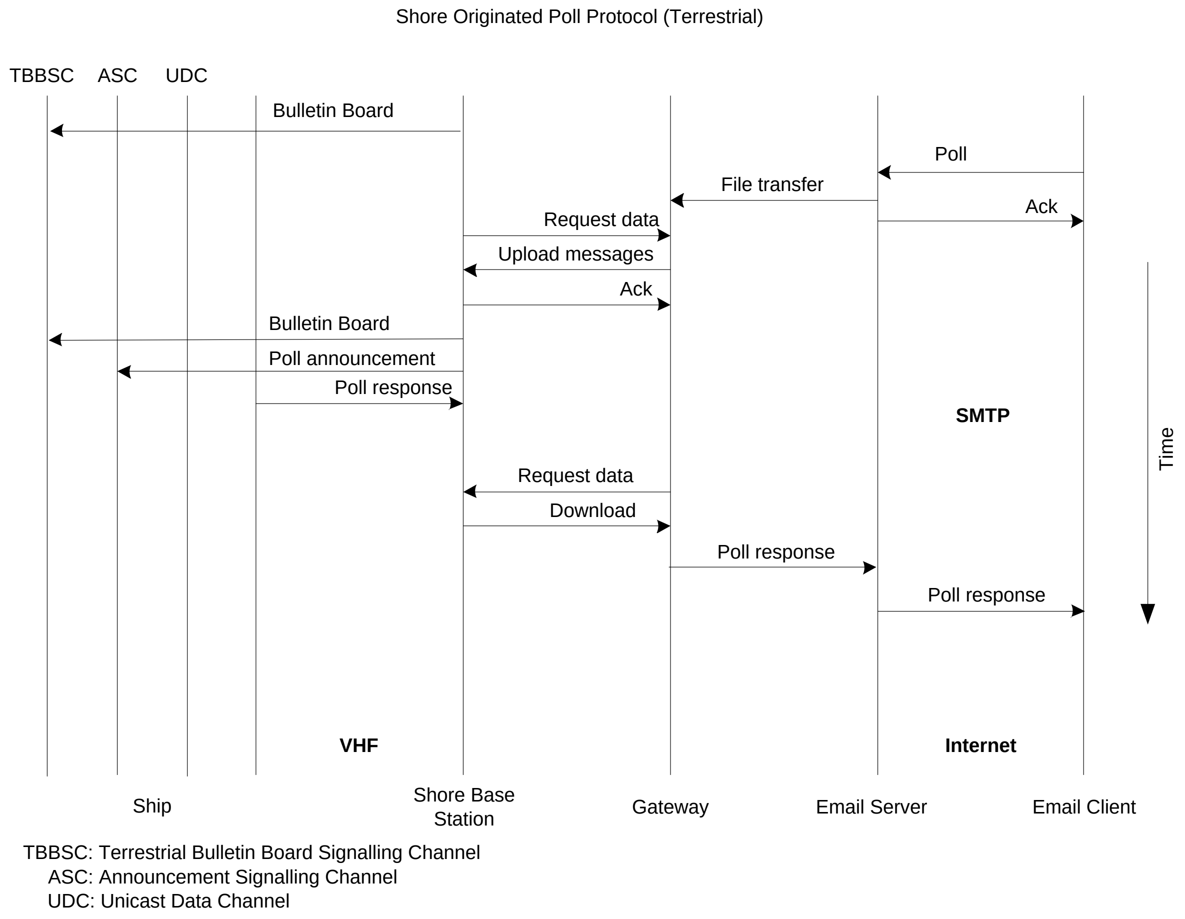
Shore originated unicast (file transfer) protocol



TBBSC: Terrestrial Bulletin Board SignallingCchannel
ASC: Announcement Signalling Channel
UDC: Unicast Data Channel

FIGURE A3-9

Shore originated poll protocol



6 Transport layer

Existing Internet protocols including TCP, UDP, SNMP, Secure File Transfer Protocol (SFTP), Simple Mail Transfer Protocol (SMTP) as shown in Figs. A3-6 to A3-9 should be supported.

Terrestrial IP protocols are terminated at the terrestrial network gateway.

Annex 4

Technical characteristics of VDE satellite downlink in the VHF 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.

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.

The focus of this Annex is to describe the four lower layers of the OSI model (as defined in Annex 1): the physical, the link, the network and the transport layers.

2 VDE-SAT downlink physical layer

2.1 VDE-SAT downlink key parameters

This section outlines assumptions regarding the VDE-SAT downlink system parameters that are used as representative examples in this Annex.

2.1.1 Satellite to surface distance range

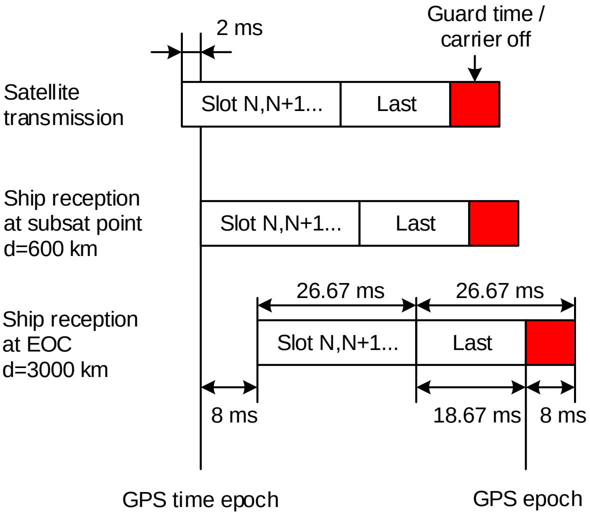
The orbit height determines the satellite range variations. For example, for a 600 km LEO the maximum range is 2 830 km. For timing purposes a maximum range of 3 000 km will be used.

The minimum range is equal to the orbit height. For a LEO satellite at 600 km altitude the minimum range will be 600 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 2 ms, a variation of 8 ms as shown in Fig. A4-1.

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

FIGURE A4-1

Downlink guard timing



2.1.2 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, i.e. ±160 Hz.

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

2.1.3 Downlink link budget analyses

The link C/N_0 is determined by the satellite e.i.r.p. path losses, propagation losses, receiver sensitivity/figure of merit and local interference levels. Examples of link budget analyses are provided in the following sections.

2.1.4 Satellite downlink e.i.r.p.

The e.i.r.p. can be derived from PFD mask given in Table A4-1.

TABLE A4-1

Proposed power spectral and PFD mask

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

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

Table A4-2 shows the theoretical maximum satellite e.i.r.p. as a function of elevation angles for this mask.

TABLE A4-2

Satellite maximum e.i.r.p. vs. elevation angle

Ship Elevation angle θ	Powerflux density on ground	Satellite range	Maximum downlink satellite e.i.r.p.
(degrees)	(dBW/m²/4 kHz)	(km)	(dBW in 25 kHz)
0	−149.0	2 831	−1.0
10	−147.4	1 932	−2.7
20	−145.8	1 392	−4.0
30	−144.2	1 075	−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

2.1.5 Satellite e.i.r.p. 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 following two satellite antennas have been analysed and are acceptable.

1) Yagi Antenna: For this antenna the link budget is optimised for 0 degrees ship elevation angle using a three element Yagi antenna with the satellite pointed at the horizon is given in Table A4-3. 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. Satellite e.i.r.p. vs. ship elevation is shown in Table A4-3.

TABLE A4-3

Satellite e.i.r.p. vs. elevation using a Yagi antenna

Ship elevation angle	Nadir offset angle	Boresight offset	Satellite antenna gain	Satellite e.i.r.p. in circular polarization	Satellite range	PFD	Table A4-1 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	2 830	−152.4	−149.0	3.4
10	64.2	1.9	8	−4.4	1 932	−149.1	−147.4	1.7
20	59.2	6.9	8	−4.4	1 392	−146.2	−145.8	0.4
30	52.3	13.8	7.8	−4.6	1 075	−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

TABLE A4-3 (*end*)

Ship elevation angle	**Nadir offset angle**	**Boresight offset**	**Satellite antenna gain**	**Satellite e.i.r.p. in circular polarization**	**Satellite range**	**PFD**	**Table A4-1 PFD limit**	**PFD margin**
degrees	**degrees**	**degrees**	**dBi**	**dBW**	**km**	**dBW/m^2/ 4 kHz**	**dBW/m^2/ 4 kHz**	**dB**
60	27.2	38.9	3.6	−8.8	683	−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

2) Isoflux antenna: This antenna is designed to point at the nadir direction providing a symmetric radiation pattern around the pointing direction. Assuming a peak antenna gain of 2 dBi, a transmit RF power of −5 dBW in 25 kHz will ensure compliance with the PFD limit. Satellite e.i.r.p. vs. ship elevation is shown in Table A4-4.

TABLE A4-4

Satellite e.i.r.p vs. elevation using an isoflux antenna

Ship elevation angle	**Nadir offset angle**	**Boresight offset**	**Satellite antenna gain**	**Satellite e.i.r.p. in circular polarization**	**Satellite range**	**PFD**	**Table A4-1 PFD limit**	**PFD margin**
degrees	**degrees**	**degrees**	**dBi**	**dBW**	**km**	**dBW/m^2/ 4 kHz**	**dBW/m^2/4 kHz**	**dB**
0	66.1	0	2	−3.0	2 830	−151.0	−149.0	2.0
10	64.2	1.9	1.5	−3.5	1 932	−148.2	−147.4	0.8
20	59.2	6.9	1	−4.0	1 392	−145.8	−145.8	0.0
30	52.3	13.8	−0.5	−5.5	1 075	−145.1	−144.2	0.9
40	44.4	21.7	−2	−7.0	882	−144.9	−142.6	2.3
50	36	30.1	−4	−9.0	761	−145.6	−139.4	6.2
60	27.2	38.9	−5	−10.0	683	−145.7	−134.0	11.7
70	18.2	47.9	−7	−12.0	635	−147.0	−133.0	14.0
80	9.1	57	−8	−13.0	608	−147.6	−132.0	15.6
90	0	66.1	−8.5	−13.5	600	−148.0	−131.0	17.0

2.1.6 Protection of the radio astronomy service in the 150.05-153 MHz band

An appropriate protection limit for Radio Astronomy service in the 150.05-153.0 MHz band would be −238 dBW/m^2 in a 2.95 MHz bandwidth centred around 152 MHz. Accordingly the maximum VDE-SAT downlink emission in the 150.05-153 MHz band should be below values shown in Table A4-5.

TABLE A4-5

Maximum satellite unwanted emissions in the 150.05-153 MHz band

Ship elevation angle (deg)	RAS limit (W/m^2/ 2.95 MHz)	Range (km)	Sat. max. interference e.i.r.p.		
			(W)	(dBW)	(dBW/Hz)
0	1.58E-24	2830	1.60E-10	−97.97	−162.67
10	1.58E-24	1932	7.43E-11	−101.29	−165.99
20	1.58E-24	1392	3.86E-11	−104.14	−168.83
30	1.58E-24	1075	2.30E-11	−106.38	−171.08
40	1.58E-24	882	1.55E-11	−108.10	−172.80
50	1.58E-24	761	1.15E-11	−109.38	−174.08
60	1.58E-24	683	9.29E-12	−110.32	−175.02
70	1.58E-24	635	8.03E-12	−110.95	−175.65
80	1.58E-24	608	7.36E-12	−111.33	−176.03
90	1.58E-24	600	7.17E-12	−111.44	−176.14

2.1.7 Receive antenna gain

Refer to Annex 1.

2.1.8 Received signal to noise plus interference level

Refer to Annex 1.

2.1.9 Link $C/(N_0+I_0)$

The nominal signal level and $C/(N_0+I_0)$ vs. elevation for a 25 kHz channel are provided in Table A4-3 and Table A4-4 for Yagi and Isoflux on-board antennas. The assumed ship antenna gain is 3 dBi and the system noise temperature is 30.2 dBK as shown in Table A1-5 (Annex 1).

Because the downlink is PFD limited, increasing the channel bandwidth to 50 kHz or 100 kHz will increase the signal level and $C/(N_0+I_0)$ by 3 and 6 dB respectively. Limiting the service area to ship elevation angles between 10 and 55 degrees also improves the link by 3 dB.

The Isoflux antenna improves the link budget at low elevation angles and provides a wider symmetrical coverage area, but requires a 5 times larger transmitter power on the satellite.

The link budget results with a satellite Yagi antenna is shown in Table A4-6. Isoflux antenna is shown in Table A4-7A.

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

TABLE A4-6

Link budget with satellite Yagi antenna (transmit RF power = −12.4 dBW/25 kHz)

Ship elevation angle	**Satellite EIRP in circular polarization**	**Satellite range**	**Path loss**	**Polarization loss**	**Ship antenna gain**	**Antenna signal level**	***C*/*N*₀**	**Noise level in 25 kHz BW**	***C*/(*N*₀+*I*₀)**
(degrees)	**(dBW)**	**(km)**	**(dB)**	**(dB)**	**(dBi)**	**(dBm)**	**(dBHz)**	**(dBm)**	**(dBHz)**
0	−4.4	2 830	145.6	3	3	−120.0	48.4	−116	40.0
10	−4.4	1 932	142.2	3	3	−116.7	51.7	−116	43.3
20	−4.4	1 392	139.4	3	2.5	−114.3	54.1	−116	45.7
30	−4.6	1 075	137.2	3	1	−113.8	54.6	−116	46.2
40	−5.5	882	135.4	3	0	−114.0	54.4	−116	46.0
50	−6.9	761	134.2	3	−1.5	−115.6	52.8	−116	44.4
60	−8.8	683	133.2	3	−3	−118.0	50.4	−116	41.9
70	−11.7	635	132.6	3	−4	−121.3	47.1	−116	38.7
80	−14.6	608	132.2	3	−10	−129.8	38.6	−116	30.2
90	−17.9	600	132.1	3	−20	−143.0	25.4	−116	17.0

TABLE A4-7A

Link budget using Isoflux antenna (transmit RF power = −5.0 dBW/25 kHz)

Ship elevation angle	**Sat. EIRP**	**Path loss**	**Pol. loss**	**Ship antenna gain**	**Ship G/T**	***C*/*N*₀ no interference**	**Antenna level**	**Noise level in 25 kHz**	***C*/(*N*₀+*I*₀)**
deg	**dBW**	**dB**	**dB**	**dBi**	**dB/K**	**dBHz**	**dBm**	**dBm**	**dBHz**
0	−3.0	145.6	3	3	−27.2	49.8	−118.6	−116	41.4
10	−3.5	142.2	3	3	−27.2	52.7	−115.7	−116	44.2
20	−4.0	139.4	3	2.5	−27.7	54.5	−113.9	−116	46.1
30	−5.5	137.2	3	1	−29.2	53.7	−114.7	−116	45.3
40	−7.0	135.4	3	0	−30.2	53.0	−115.4	−116	44.5
50	−9.0	134.2	3	−1.5	−31.7	50.7	−117.7	−116	42.3
60	−10.0	133.2	3	−3	−33.2	49.2	−119.2	−116	40.8
70	−12.0	132.6	3	−4	−34.2	46.8	−121.6	−116	38.4
80	−13.0	132.2	3	−10	−40.2	40.2	−128.2	−116	31.8
90	−13.5	132.1	3	−20	−50.2	29.8	−138.6	−116	21.4

2.1.10 Propagation effects

The received signal level on-board a ship will vary due to a number of factors as shown in Table A4-7. A Rice distribution with a carrier to multipath (*C*/*M*) ratio of 10 dB and fading bandwidth of 3 Hz is assumed (see Fig. A4-2), however the system shall be adaptable to handle significantly worse and better propagation conditions. Mid-latitude fade depths due to ionospheric scintillation are shown in Table A4-8.

TABLE A4-7

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 1 018 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.

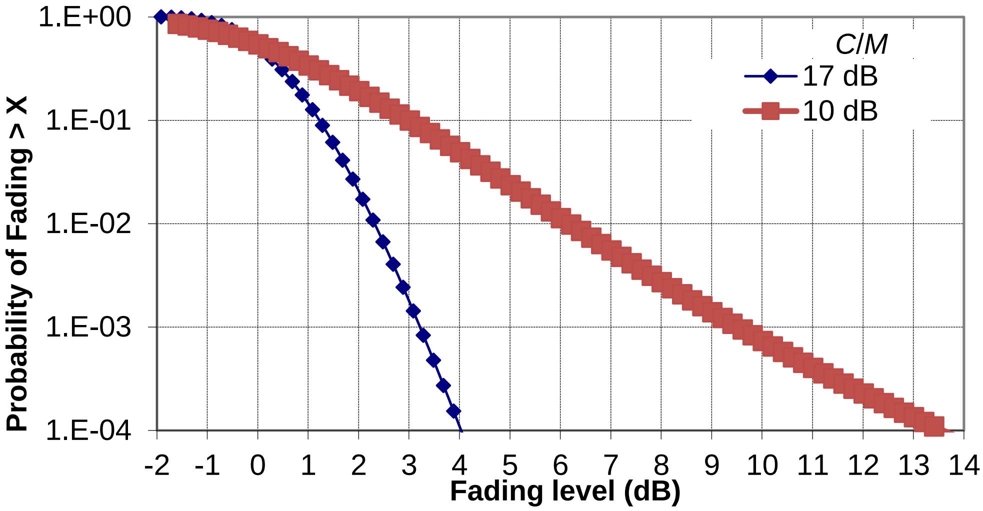
TABLE A4-8

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 A4-2

Ricean fade depth probability



2.2 Physical layer modulation schemes

VDE-SAT Downlink supports different modulation to maximise spectral efficiency and throughput. The supported modulation methods are given in Table A4-9.

TABLE A4-9

Downlink modulation methods

Index	Bits/symbol	Modulation type	Bit mapping
1	1	BPSK	–
2	2	Gray encoded QPSK	Figure A4-3
3	3	Gray encoded 8PSK	Figure A4-4
4	4	16APSK	Figure A4-5

FIGURE A4-3

QPSK symbol to bit mapping

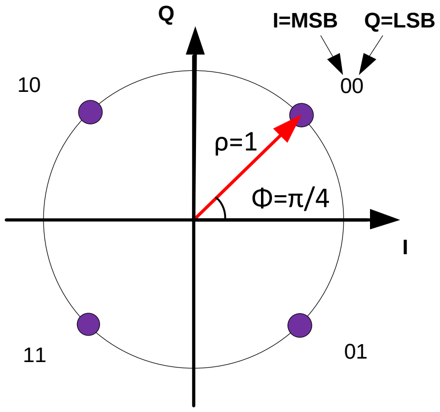


FIGURE A4-4

8PSK symbol to bit mapping

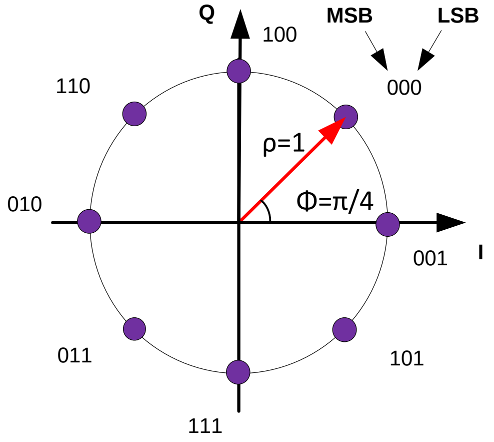
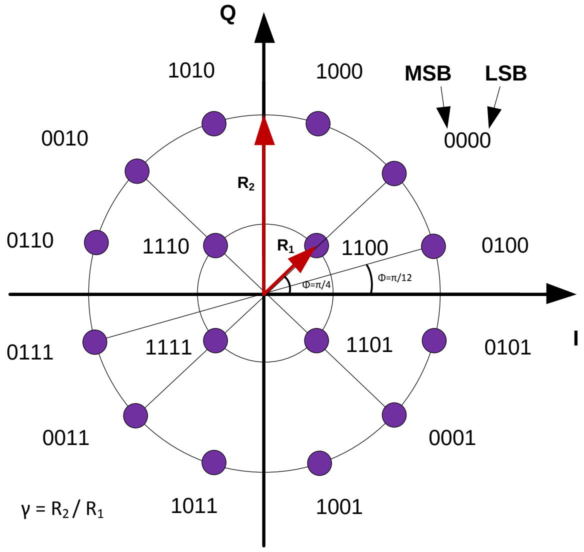


FIGURE A4-5

16APSK bit to symbol mapping



The 16 APSK modulation constellation is 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.

2.3 Baseband shaping and quadrature modulation

The baseband symbols shall be squared root raised cosine filtered. The roll-off factor should be = 0.25.

2.4 Transmission accuracy figures

2.4.1 Symbol timing accuracy (at the output of satellite)

The timing accuracy of the transmit signal at the satellite should be better than 5 ppm.

2.4.2 Transmitter timing jitter

The timing jitter should be better than 5% of the symbol interval (peak value).

2.4.3 Slot transmission accuracy at the satellite output

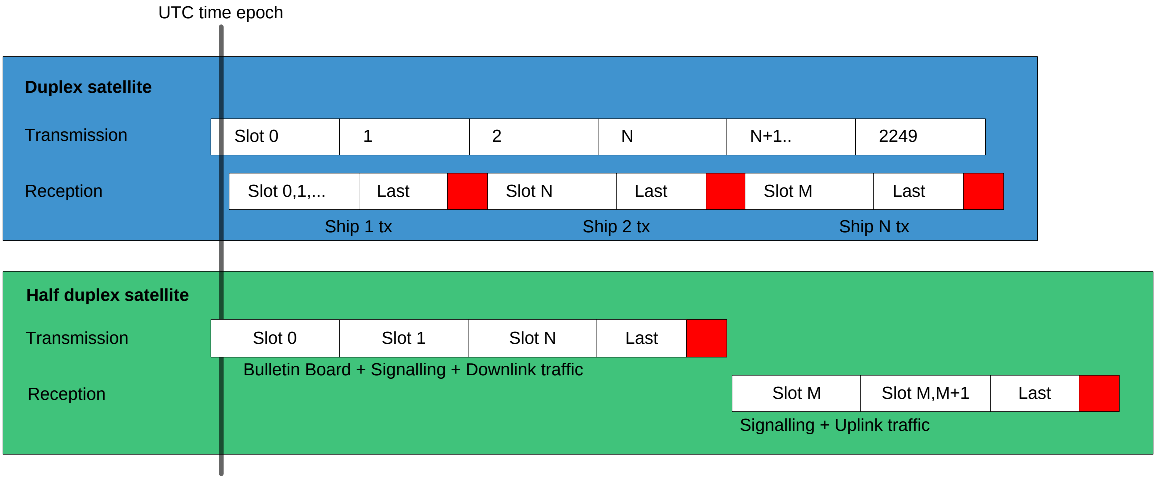
The slot transmission accuracy should be better than 50 µs (peak) relative for example to GNSS reference timing.

2.5 Half duplex and full duplex satellites

The system can be configured for both half and full duplex satellites as shown in Fig. A4-6.

FIGURE A4-6

Half-duplex and full duplex satellite operation



2.6 Frame hierarchy

The VDES frame structure is identical and synchronized in time on the Earth's surface to UTC (as in AIS). The frame hierarchy is shown in Fig. A4-7.

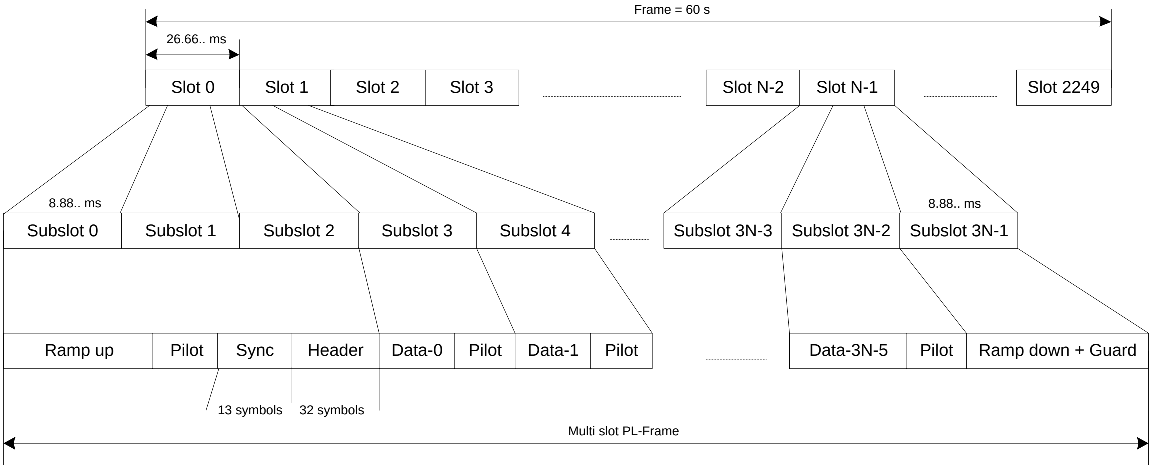
As shown in Fig. A4-7, each frame consists of 2 250 slots (similar to Recommendation ITU-R M.1371).

Frame 0 starts at 00:00:00 UTC, and there are 1 440 frames in a day. The impact of leap second adjustments should be accounted for to avoid any propagation of error.

The number of sub slots per PL-Frame is encoded within its header (as described in the following sections).

FIGURE A4-7

VDE-SAT downlink frame hierarchy



2.6.1 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 µs 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 PL-Frame may not be required, but has been provided to allow for future expansion of the pilot, synchronization word and the PL-Frame format header.

2.6.2 Synchronization pilot

Synchronization pilot is a set of known symbols before the synchronization word and at regular intervals during the data portion.

2.6.3 Synchronization (SYNC) word

The PL-Frame synchronization word and header format is fixed for all transmissions. The 13 bit Barker code unique word is defined in Table A4-10. It is modulated with BPSK at a symbol rate of 2.4 ksym/s. Bit 0 is transmitted first. The duration is 4.91 ms.

TABLE A4-10

Barker sequence unique word

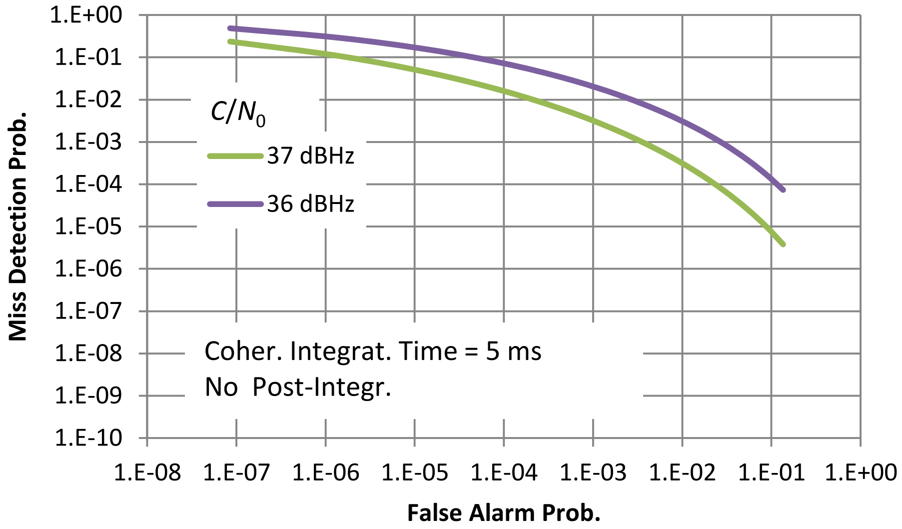
Bit number												
0	1	2	3	4	5	6	7	8	9	10	11	12
1	1	1	1	1	−1	−1	1	1	−1	1	−1	1

The missed detection and false detection probabilities are shown in Figure A4-8 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 10^{-4} will result in 2% of PL-Frame not detected during the fading events.

FIGURE A4-8

SYNC word loss and false detection probabilities



2.6.4 Direct sequence spreading

The spreading codes SS0 and SS1 are selected to minimize the maximum "undesired correlation" as defined below:

- Self-correlation of the code with its time delayed version
- Correlations of the code with other sequences.

The evaluation is carried out not only for frequency-aligned signals, but also for signals with Doppler difference.

The selected codes are SS0 and SS1 as shown in Table A4-11.

The first pilot and BPSK symbols are spread using an 8 bit sequence to a chip rate of 19.2 kchip/s to fit in a 50 kHz channel. Spreading sequence SS0 from Table A4-11 is used.

TABLE A4-11

Spreading sequences

Sequence name	Chip number							
	0	1	2	3	4	5	6	7
SS0 (0b1001010)	1	−1	−1	−1	1	−1	1	−1
SS1 (0b10100011)	1	−1	1	−1	−1	−1	1	1
SS2 (0b01101100)	−1	1	1	−1	1	1	−1	−1
SS3 (0b 01111001)	−1	1	1	1	1	−1	−1	1

2.6.5 PL-Frame header

The header is BPSK modulated and spread the same way as the synchronization word described above. This PL-Frame header defines the following parameter associated with the each PL-Frame:

PL-Frame duration (as an integer multiple of a sub slot duration)

Number of data sub slots (N) per PL-Frame:

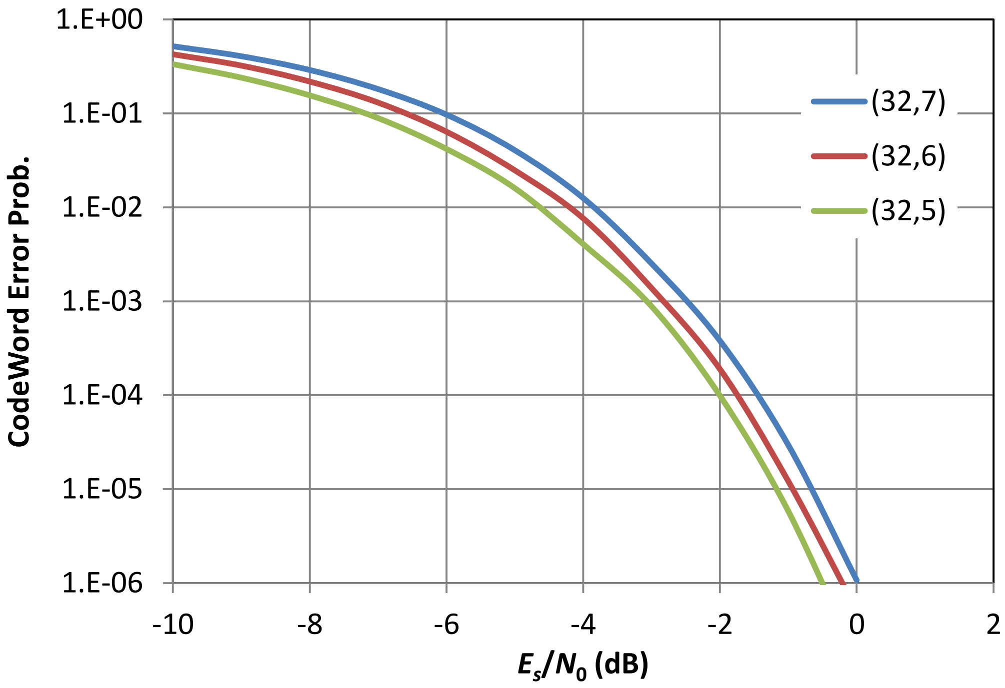
- Symbol rate

- Modulation type
- FEC type
- FEC rate
- Interleaver type
- Scrambler type
- Spreading Factor (1 or higher)
- Spreading sequence (1 or as defined).

The header provides 7 bits to define up to 128 PL-Frame formats. The PL-Frame header is encoded using (32,7) quad-orthogonal forward error correction coding. The performance of this FEC is shown in Fig. A4-9.

FIGURE A4-9

Header error probability



2.6.6 Data segment forward error correction coding

The FEC coding scheme applied to the data segment of PL-Frames is similar to the FEC code of the 3GPP standard. The definition of the FEC is Annex 1 since a common FEC scheme is applicable to VDE-SAT and VDE-terrestrial.

2.6.7 Data segments

As shown in the frame hierarchy, each PL-Frame includes one or several data segments. Data segments contain channel symbols that carry encoded information bits. In each PL-Frame, the encoded bits are mapped into segment of *N* of interleaved data.

2.6.8 Physical layer scrambling

Prior to modulation (and spreading if applicable), each PL-Frame samples, excluding the SYNC word, should be randomized for energy dispersal by multiplying the (I + jQ) samples by a complex randomization sequence ($C_I + jC_Q$):

– $I_{SCRAMBLED} = (I\,C_I - Q\,C_Q)$

– $Q_{SCRAMBLED} = (I\,C_Q + Q\,C_I)$.

The randomization sequence rate corresponds to the PL-Frame symbol rate, thus it has no impact on the occupied signal bandwidth. The randomization sequence shall be reinitialized at the end of each PL-Frame. The randomization sequence length should be truncated to the length of the PL-Frame (excluding the SYNC word).

The scrambling code sequence should be pre-defined according to the PL-Frame format.

2.6.9 Channel interleaver

A block channel interleaver is considered on the VDE-SAT downlink in order to reduce the impact of the channel short blockage (for example due to the AIS transmission from the vessel or fast fading events). The channel interleaver is applied to the code-words at the output of the encoder.

The interleaver can be applied on data blocks by column permutation (as long as the number of columns can be made as an integer power of 2). The interleaver memory in this case (from the point of view of the transmitter) is written by row and read by columns after having applied an inter-column permutation. The proposed column permutation is resulting from reading the column index in the reverse order (bit shuffling), i.e. the column with index i_5 i_4, i_3, i_2, i_1, i_0 become the column i_0, i_1, i_2, i_3, i_4, i_5, where i_0, i_1, i_2, i_3, i_4 and i_5 are the bits representing a given number.

In more general cases (where the number of columns is not an integer power of 2), the interleaver index can be made available as table-lookup.

2.6.10 Ramp down

The ramp down occurs in the last sub slot of each PL-Frame (as shown in Fig. A4-7) followed by the guard time. The overall duration of the ramp-down and guard time is 8.88 ms (one sub slot duration) while the ramp-down time from 90% to 10% of the power should occur in less than 300 µs.

2.6.11 Guard time

The guard time is added to the end of each PL-Frame to avoid overlapping with VDES terrestrial transmissions. The guard time duration is 8.88 ms corresponding to one sub-slot duration. This time is adequate to cover the differential delay between the shortest and the longest propagation time within the coverage area of a LEO satellite at 600 km altitude (or lower).

2.7 VDE-SAT downlink PL-Frame formats

As illustrated in Fig. A4-7, PL-Frames are the self-contained transmission units used for the VDE-SAT downlink and uplink. This section defines several PL-Frame formats that are used for signalling and data transmission on the VDE-SAT downlink channels. Based on the PL-Frame header, it is possible to define 128 distinct PL-Frame formats for the VDE-SAT downlink and uplink.

2.7.1 PL-Frame format 1

The PL-Frame format 1 is provided in Table A4-12.

TABLE A4-12

PL-Frame Format 1

Downlink format	1	
Function	Multiple access, reliable one way transmission	
Usage	Bulletin Board	
Header value	′01	hex
Channel bandwidth	50	kHz
Unfaded C/N_0	43.0	dBHz
Burst duration	90	slots
Burst duration	2 400	ms
Ramp down	0.3	ms
Guard time	8.0	ms
Channel rate	33.6	kchip/s
Spreading factor	8	
Spreading code	SS0	Table 29
Modulation	BPSK	
Channel bits/symbol	1	
FEC rate	0.50	
FEC type	3GPP	Annex 1
Information rate/user	2.10	kbits/s
Number of simultaneous users	8	
E_b/N_0	9.8	dB
Channel Rice factor (C/M)	10	dB
Channel fading bandwidth	3	Hz
Target frame error rate	1	%
Pilot and data duration of burst	2 371	ms
Pilot duration	237.1	ms
Data duration	2 133.9	ms
Number of info bits	4 480	bits
Number of coded bits	8 960	bits
Block interleaver width	128	bits
Block interleaver height	70	bits
Interleaver size	8 960	bits
Number of info bytes	560	bytes

2.7.2 PL-Frame format 2

The PL-Frame format 2 is provided in Table A4-13.

TABLE A4-13

PL-Frame format 2

Downlink format	2	
Function	Reliable one way transmission	
Usage	Multicast, announcements, ack	
Header value	′02	hex
Channel bandwidth	50	kHz
Unfaded C/N_0	43.0	dBHz
Burst duration	90	slots
Burst duration	2 400	ms
Ramp down	0.3	ms
Guard time	8.0	ms
Channel rate	19.2	kchip/s
Spreading factor	1	
Modulation	QPSK	
Channel bits/symbol	2	
FEC rate	0.25	
FEC type	3GPP	Annex 1
Information rate/user	9.60	kbits/s
Number of simultaneous users	1	
E_b/N_0	3.2	dB
Channel Rice factor (C/M)	10	dB
Channel fading bandwidth	3	Hz
Target frame error rate	1	%
Pilot and data duration of burst	2 371	ms
Pilot duration	237.1	ms
Data duration	2 133.9	ms
Number of info bits	20 480	bits
Number of coded bits	81 920	bits
Block interleaver width	256	bits
Block interleaver height	320	bits
Interleaver size	81 920	bits
Number of info bytes	2 560	bytes

2.7.3 PL-Frame format 3

The PL-Frame format 3 is provided in Table A4-14.

TABLE A4-14

PL-Frame format 3

Downlink format	3	
Function	High throughput TDM channel	
Usage	File segment transfer	
Header value	′03	hex
Channel bandwidth	50	kHz
Unfaded C/N_0	50.0	dBHz
Burst duration	90	slots
Burst duration	2 400	ms
Ramp down	0.3	ms
Guard time	8.0	ms
Channel rate	19.2	kchip/s
Spreading factor	1	
Modulation	8PSK	
Channel bits/symbol	3	
FEC rate	0.50	
FEC Type	3GPP	Annex 1
Information rate/user	28.80	kbits/s
Number of simultaneous users	1	
E_b/N_0	5.4	dB
Channel Rice factor (C/M)	10	dB
Channel fading bandwidth	3	Hz
Target frame error rate	1	%
Pilot and data duration of burst	2 371	ms
Pilot duration	237.1	ms
Data duration	2 133.9	ms
Number of info bits	61 448	bits
Number of coded bits	122 896	bits
Block interleaver width	512	bits
Block interleaver height	241	bits
Interleaver size	123 392	bits
Number of info bytes	7 681	bytes

3 VDE-SAT link layer

3.1 Data encapsulation

The data segments of each PL-Frame contain multiple variable length encapsulated datagrams. Each datagram contains the following encapsulation fields:

- Datagram type (1 byte)
- Datagram size (3 bytes)
- Ship ID (4 bytes)
- 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).

3.2 Cyclic redundancy check

Refer to Annex 1.

3.3 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.

3.4 Acknowledgement (ACK)

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

3.5 End delivery notification (EDN)

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

3.6 End delivery failure (EDF)

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

3.7 Physical and logical channels

VDE-SAT protocols use 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.

3.7.1 Physical channels

The physical channels (PC) are determined by the centre frequency and bandwidth.

3.7.2 Logical channels

The logical channels (LC) are divided into signalling and data channels as described below.

3.8 Signalling logical channels

The following downlink signalling channels are used:

- Bulletin board signalling channel (BBSC)
- Announcement signalling channel (ASC)
- Multicast data channel (MDC)
- Unicast data channel (UDC).

3.8.1 Bulletin board signalling channel

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, centre frequency, PL-Frame format and start of the first slot. The logical channels are normally repeated every frame, unless a network configuration change has taken place to optimise 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 PL-Frame format 1 defined in Table A4-12 and should be transmitted once every minute in the VDE satellite downlink exclusive channels (channel 2046 and 2086), starting at slot 0, the duration is 2.4 s (corresponding to 90 slots). A code division multiple access scheme is used to allow multiple satellites with overlapping coverage to transmit the Bulletin Board at the same time. The ship receiver should 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).

Bulletin Board content is shown in Table A4-15. All packets start with an 8 bit packet type, followed by an 8 bit field giving the length in bytes. Padding bits are used if the frame is not filled. The 4 last bytes are the 32 bit CRC applied to the whole PL-Frame.

TABLE A4-15

Bulletin board construction

Name	Description	Total size (bytes)	Repeat interval (frames)	Comment
Network ID	Network name, up to 16 ASCII characters	18	1	
Satellite ID	The ID of this satellite in a network. Up to 256 satellites per network.	3	1	
Bulletin board version	Version number of this Bulletin Board. Up to 256 frames active	3	1	

TABLE A4-15 (*end*)

Name	**Description**	**Total size (bytes)**	**Repeat interval (frames)**	**Comment**
Validity of this version	Lifetime of this version in number of 1 minute frames. 16 bits used.	4	1	
Future satellite status change	Packet providing information about planned future status change. From Julian day of year start, frame no, today and frame, new status.	13	1	
Back-up bulletin board frequency	Channel number above 156 MHz, 25 kHz resolution	3	1	
Satellite protocol capability	Index showing which protocols are supported by this satellite	3	1	
Downlink announcement/signalling channel configuration	Packet providing centre frequency, start slot, PL-Frame format no, logical channel number	6	1	8 bits are used for slots corresponding to actual slot number/10. A frame may contain multiple announcement channels to reduce protocol latency
Downlink data channel configuration	Packet providing centre frequency, start slot , PL-Frame format no, logical channel number	6	1	A frame may contain multiple data channels
Uplink random access/signalling channel configuration	Packet providing centre frequency, start slot , PL-Frame format no, logical channel number	6	1	A frame may contain multiple uplink signalling channels to reduce protocol latency
Uplink demand assign channel configuration	Packet providing centre frequency, start slot , PL-Frame format no, logical channel number	6	1	A frame may contain multiple data channels
This satellite ephemeris	Packet containing the ephemeris, validity	25	Flexible	GPS almanac format may be used.
Other satellite ephemeris	Packet containing network ID, satellite ID, status , ephemeris, validity	46	Flexible	GPS almanac format may be used.
Free text message	Containing up to 128 ASCII characters	9	Flexible	Network operator message to all ships, information only

The BBSC supports a classification of messages into logical categories of message types in the BBSC.

Different class of BBSC messages belong to one of the following categories:

1) Satellite system static configuration/status:

   The Satellite system static configuration and status includes parameters such as satellite number, assigned number in constellation (for satellite constellations), ephemeris data in stated format, firmware version, etc.

2) Satellite system dynamic configuration information

   a) BBSC management information:

      The satellite system dynamic configuration pertaining to usage of the BBSC, which includes information for the BBSC itself, for example if time division duplexed, slot and or time information for next message packet to be transmitted (similar to role of COMSTATE in AIS), physical channel allocation for next transmission (if channel is being changed, or the physical channel must change to permit self or inter-system channel resource sharing).

   b) Configuration of other physical and logical channels:

      Other dynamic configuration parameters for all other channels, including announcement signalling channel (ASC), multicast data channel (MDC), unicast data channel (UDC).

Note that assignments of the second category may change frequently, for example changing in the timeframe of a satellite pass (10-15 minutes).

For efficiency, and ease of processing information on BBSC, all message types have a configuration revision level, CRL, (or other numerical sequence number) that indicates relative freshness of the information, so that terrestrial receivers will be able to determine if there has been a change in the currently transmission, if so, the transceiver shall receive the entire data transmission, and make any required updates to dynamic parameters, such as logical channel definitions. If the configuration revision level is changed, however the remaining data packets are not received error free, the transceiver will cease any VDES transmission activities until updated dynamic configuration information is received error free.

In the event that the configuration revision level is unchanged from the state previously received, the receiver does not need to listen to the remainder of the BBSC transmission.

3.8.1.1 Note on configuration revision level parameter

A configuration revision level (CRL) should be very early in any single or multiple slot BBSC transmission. It is possible to also have more than one CRL in a long transmission, for example a CRL at the beginning of a BBSC transmission, reflecting the change level for all messages with the BBSC. Each of the categories of messages can also employ a CRL, reflecting their level of update.

In practice, every time any message is updated, its CRL is incremented, and if any message within a BBSC CRL is incremented, the top level CRL is also incremented.

The latter scheme allows a quick global view of changes, and then a lower level of granularity by message type as to changes. Such a scheme has benefits in low SNR and fading channels, allowing for reception of only partial messages, with the benefit of achieving high confidence knowledge of a change in the configuration.

3.8.2 Announcement signalling channel (ASC)

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

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

To reduce protocol latency the ASC may be repeated several times (different content) during a frame. Announcements include unicast and multicast (broadcast) datagrams.

The ASC uses PL-Frame format 1 or 2. The format the start slots are 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, the satellite makes a $C/(N_0+I_0)$ estimate which is used to select the highest throughput format with adequate link margin.

Table A4-16 to Table A4-20 provides several templates of ASC for different usage.

TABLE A4-16

Media access control (start of ASC)

Field name	Size (bytes)	Comment	Additional info
Packet type	1	Defines packet content. This packet is addressed to all ships, sub address 0.	
Packet size	1	Total size of this packet	The size may be implicit in most packet types, but some packet types may be of variable length.
Frame number	2	1 440 frames in 24 h	
Network version	1	Version defined on the Bulletin Board. Old versions are stored and retrieved as required.	
Satellite network status	1	Defines health of satellite, busy, reduced capacity, high latency	
Uplink access priority level	1	Ship messages have different levels of priority, distress is highest. Only messages with priority level equal to and higher than this number are accepted	
Retry interval	1	Wait time in slots before random access timeouts. Resolution is 10 slots	
Maximum message size	1	During congestion long messages may not be allowed. This field is an index to maximum discrete file sizes	

TABLE A4-17

Multicast announcement

Field name	Size (bytes)	Comment	Additional info
Packet type	1	Defines packet content. This packet is addressed to all ships, sub address 0.	Other multicast packets may address an area, class of terminals or types of ships
Packet size	1	Total size of this packet	The size may be implicit in most packet types, but some packet types may be of variable length.
Logical channel	1	Logical channels are defined in the BB, including centre frequency, start slot, number of slots and MODCOD	
Transaction ID	2	The satellite assigns a transaction ID for all uplink and downlink messages. This ID is used in ACKs, ARQ and End Delivery Notifications. Some messages may be repeated and this ID enables the terminal to discard already received messages.	

TABLE A4-18

Downlink assigned message announcement

Field name	Size (bytes)	Comment	Additional info
Packet type	1	Defines packet content	
Packet size	1	Total size of this packet	The size may be implicit in most packet types, but some packet types may be of variable length.
Ship ID	4	Physical MAC address of ship	
Ship sub address	2	Ship Gateway and M2M device IDs	
Logical channel	1	Logical channels are defined in the BB, including centre frequency, start slot, number of slots and MODCOD	
Transaction ID	2	The satellite assigns a transaction ID for all uplink and downlink messages. This ID is used in ACKs, ARQs, End Delivery Notifications. Some messages may be repeated and this ID enables the terminal to discard duplicate messages.	

TABLE A4-19

Uplink resource assignment

Field name	Size (bytes)	Comment	Additional info
Packet type	1	Defines packet content	
Packet size	1	Total size of this packet	The size may be implicit in most packet types, but some packet types may be of variable length.
Ship ID	4	Physical MAC address of ship	
Ship sub address	2	Ship gateway and M2M device ID	
Logical channel	1	Logical channels are defined in the BB, including centre frequency, start slot, number of slots and MODCOD	
Start slot	1	Start slot where ship starts transmission. Resolution 10 slots	
Transaction ID	2	The satellite assigns a transaction ID for all uplink and downlink messages. This ID is used in ACKs, ARQ and End Delivery Notifications. Some messages may be repeated and this ID enables the terminal to discard duplicate messages.	

TABLE A4-20

Uplink ACK

Field name	Size (bytes)	Comment	Additional info
Packet type	1	Defines packet content.	
Packet size	1	Total size of this packet	The size may be implicit in most packet types, but some packet types may be of variable length.
Ship ID	4	Physical MAC address of ship	
Ship sub address	2	Ship gateway and M2M device ID	
Logical channel	1	Used to point to a specific ship message. Transactions IDs are assigned by the satellite.	Enables ship to associate message with Transaction ID, used to determine if end delivery notification is received.
Receive slot	1	Slot where message was received also used to point to a specific message.	
Start slot	1	Start slot where ship starts transmission. Resolution 10 slots	
Transaction ID	2	The satellite assigns a transaction ID for all uplink and downlink messages. This ID is used in ACKs, End Delivery Notifications. Some messages may be repeated and this ID enables the terminal to discard duplicate messages.	

3.8.3 Multicast data channel (MDC)

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

3.8.4 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.

4 Network layer

4.1 Downlink data transfer protocols

The following downlink protocols shall be supported:

– Bulletin board transmission (network configuration).

- Multicast (one-way) (icemaps, weather info, notices to mariners)
- Unicast (shore to ship file transfer, up to 100 kBytes).

The protocols are shown in Fig. A4-10 – Fig. A4-13.

FIGURE A4-10

Bulletin board with network version change

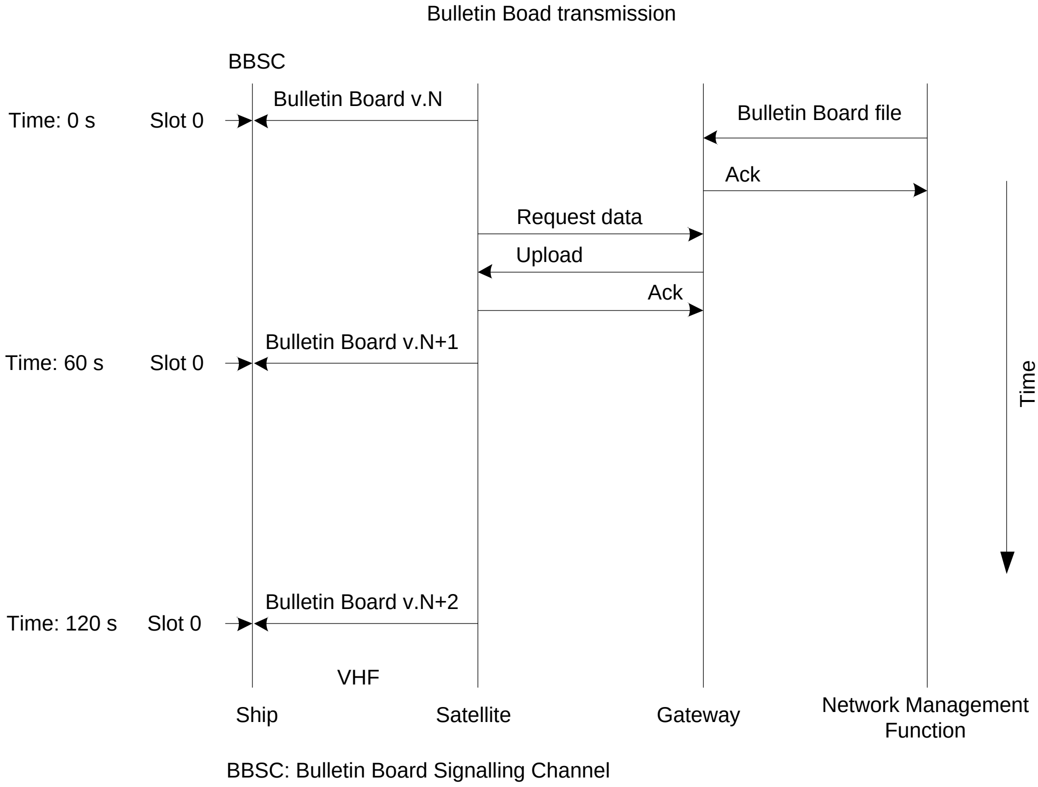


FIGURE A4-11

Multicast protocol (one-way)

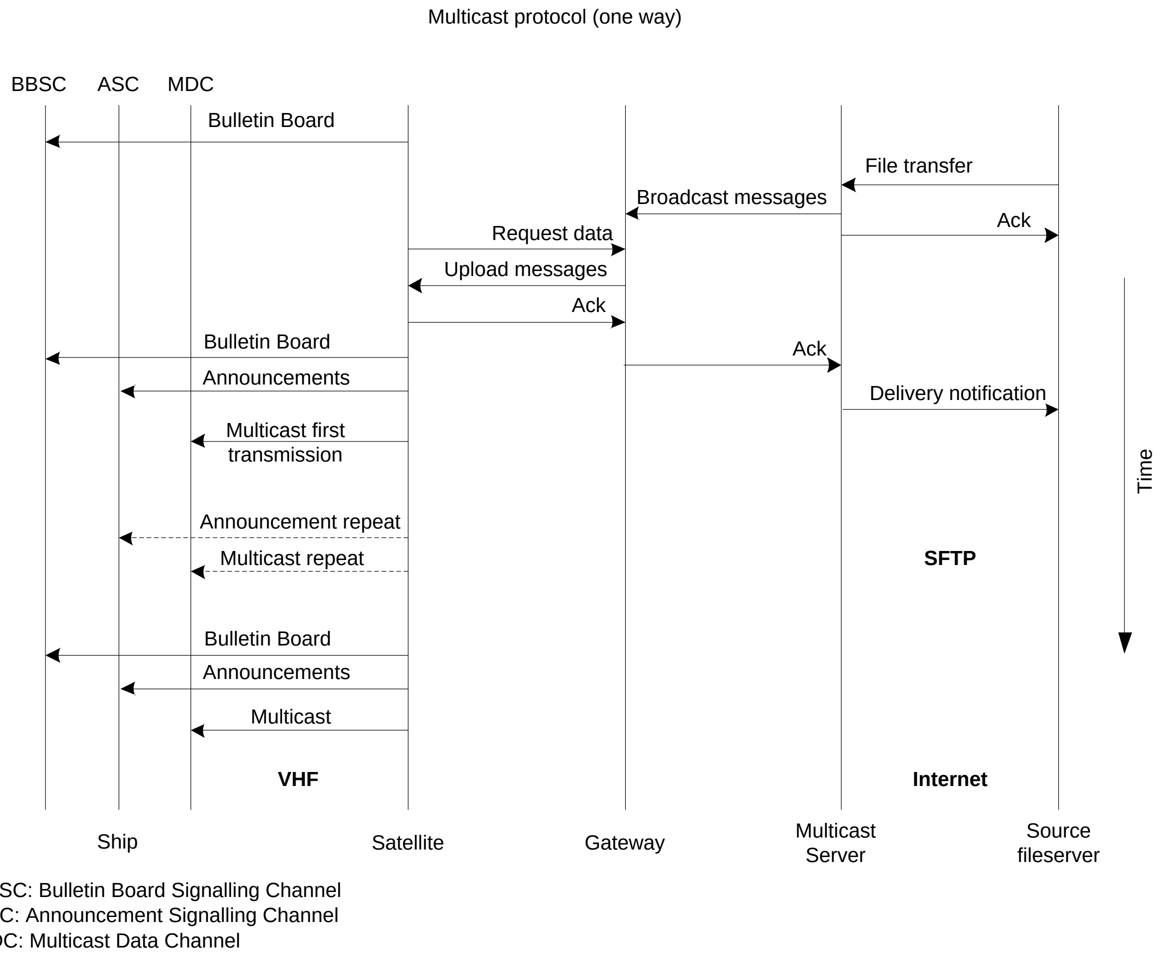
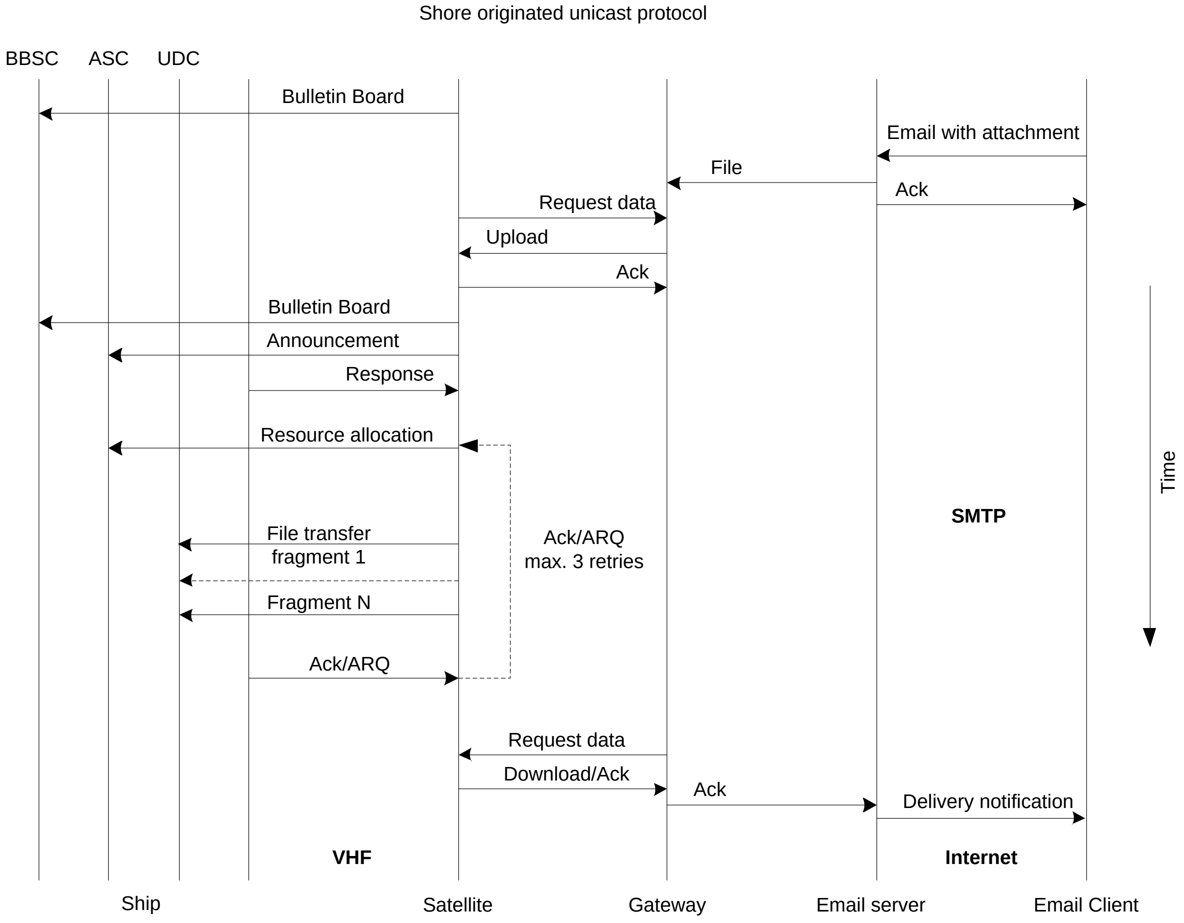


FIGURE A4-12

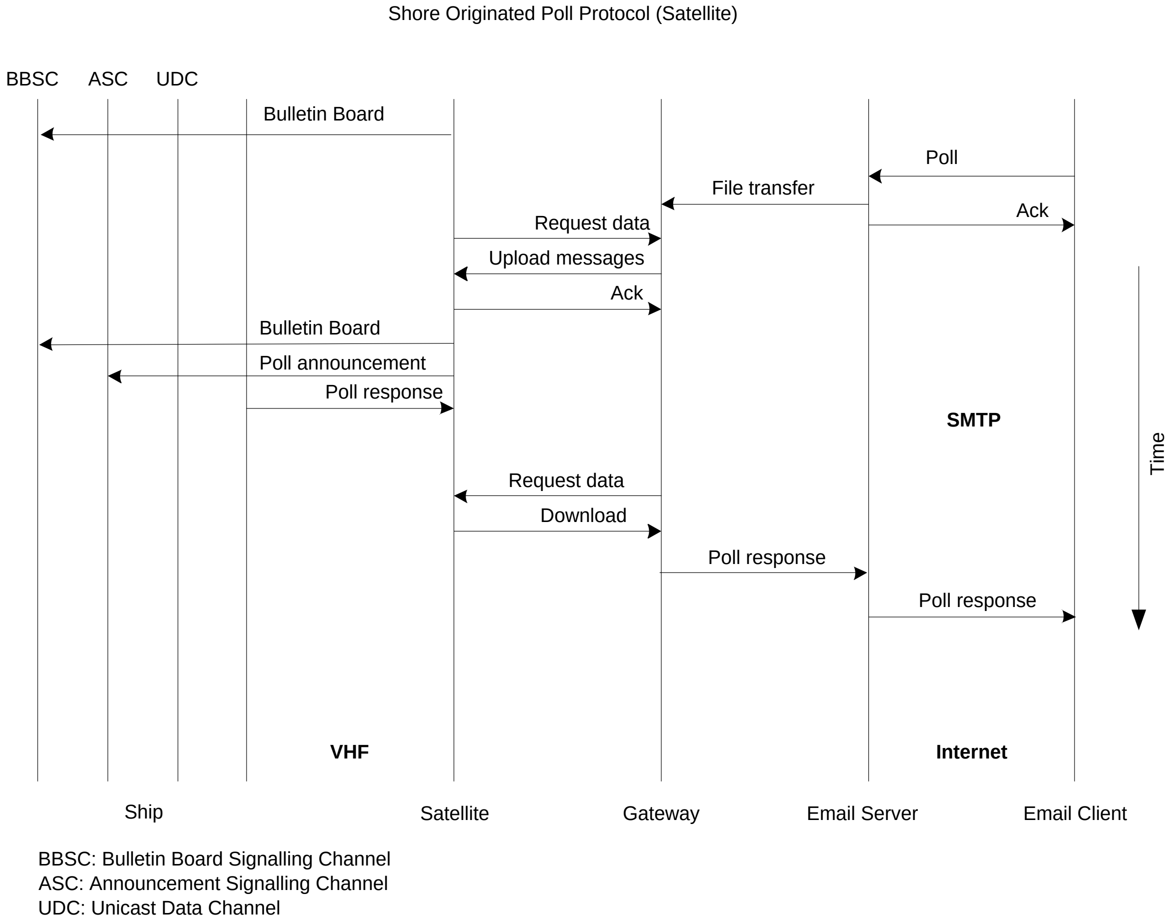
Shore originated unicast (file transfer) protocol



BBSC: Bulletin Board SignallingCchannel
ASC: Announcement Signalling Channel
UDC: Unicast Data Channel

FIGURE A4-13

Shore originated poll protocol



5 Transport layer

5.1 End to end protocols

Existing Internet protocols such as UDP, SNMP, secure file transfer protocol (SFTP), simple mail transfer protocol (SMTP) as shown in Figs. A4-10 to A4-13 are used.

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

5.2 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 4 byte VDES physical addressing field has 4.3×10^9 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 4 byte address field, a 2 byte sub addressing field has been added.

The ship, local gateway and device addressing are shown in Table A4-21. Unlike MMSI, there will be no dedicated field or segmentation in this addressing scheme.

TABLE A4-21

Ship, Gateway and Device addressing

Addressing field	Usage	Range
32 bit physical address (all messages)	Ship Terminal ID	4.3 Billion
16 bit sub addressing	To address local gateways and transducers	Flexible, e.g. 16 gateways each with 4 096 transducers

5.3 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.

Annex 5

Technical characteristics of VDE satellite uplink in the VHF maritime mobile band

1 Introduction

This annex describes the characteristics of the VDE satellite uplink. In this context, the following types of functionality are envisaged:

- Two-way communications:
  - 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. The time slot and frequency band for this service should be assigned by the bulletin board and announcement signalling channels.

In this annex low earth orbit (LEO) satellites with 600 km altitude are considered to present typical examples of VDE satellite solutions. It should be noted that other orbital selections are also possible according to the overall system design consideration.

The focus of this annex is to describe the physical layer and link layer of the OSI model as defined in Annex 1. The overall description of the network and the transport layers is provided in Annex 4.

2 VDE-SAT uplink physical layer

2.1 VDE-SAT uplink key parameters

This section outlines assumptions regarding the VDE-SAT uplink system parameters that are used as representative examples in this annex.

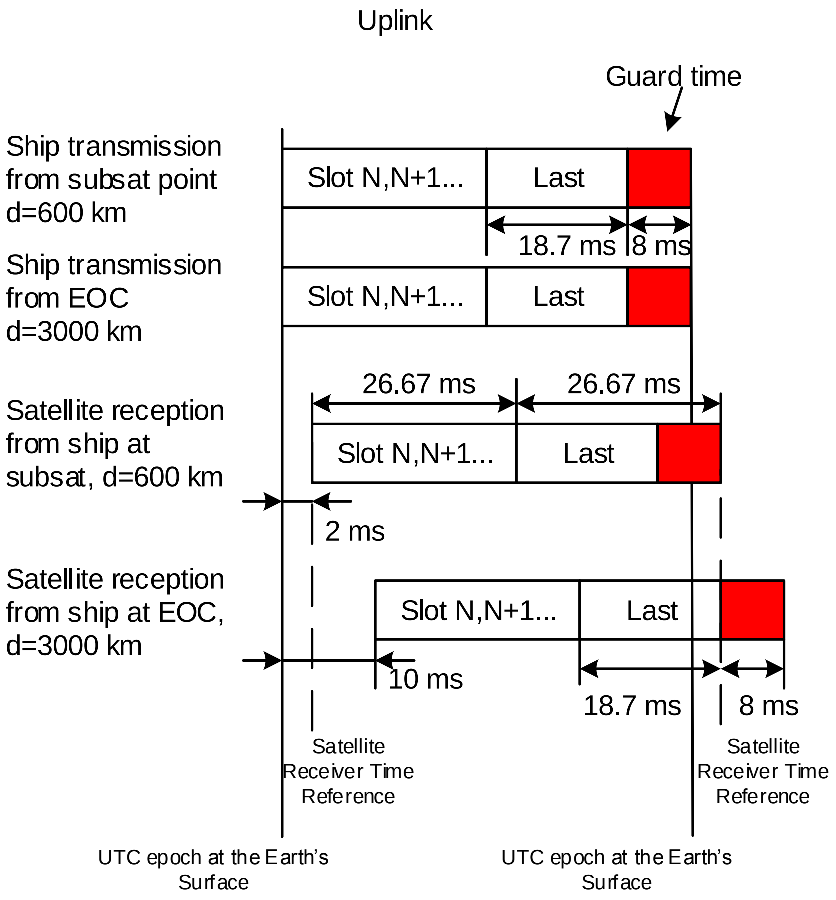
2.1.1 Satellite to surface distance range

The orbit height determines the satellite range variations. For example, for a 600 km LEO the maximum range is 2 830 km. For timing purposes a maximum range of 3 000 km will be used.

The minimum range is equal to the orbit height. For a LEO satellite at 600 km altitude the minimum range will be 600 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 2 ms to 10 ms, a variation of 8 ms as shown in Fig. A5-1.

FIGURE A5-1

VDE-SAT Uplink timing



2.1.2 Transmitter requirements for mobile station

Refer to Annex 1.

2.1.3 Mobile station transmit antenna gain

Refer to Annex 1.

2.1.4 Link budget analysis

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

2.1.5 Ship e.i.r.p. vs. elevation angle

Refer to Annex 1.

2.1.6 Satellite antenna gain

Table A5-1 presents the gain of a 3-element Yagi satellite antenna with a peak gain of 8 dBi as a functon of elevation angle.

TABLE A5-1

Satellite antenna gain vs. ship elevation angle

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

2.1.7 Satellite system noise temperature

The satellite noise level at the receiver input is shown in Table A5-2. Without external interference the system noise temperature is 25.7 dBK.

TABLE A5-2

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

2.1.8 Uplink C/N_0

The baseline uplink link budget is given in Table A5-3. It is optimised for 0 degree ship elevation angles.

It can be seen from Table A5-3 that the C/N_0 is better than 74 dBHz for ship elevation angles between 0 and 65 degrees.

TABLE A5-3

VDE-SAT Uplink link budget, 6 W ship transmit power

Ship elevation angle	**Ship antenna gain**	**Ship e.i.r.p.**	**Polarization loss**	**Range**	**Path loss**	**Satellite antenna gain**	**Satellite G/T**	**C/N$_0$**
deg	**dBi**	**dBW**	**dB**	**km**	**dB**	**dBi**	**dB/K**	**dBHz**
0	3	10.8	3	2 830	145.56	8	−17.6	73.2
10	3	10.8	3	1 932	142.25	8	−17.6	76.5
20	2.5	10.3	3	1 392	139.40	8	−17.6	78.9
30	1	8.8	3	1 075	137.16	7.8	−17.8	79.4
40	0	7.8	3	882	135.44	6.9	−18.7	79.2
50	−1.5	6.3	3	761	134.16	5.5	−20.1	77.6
60	−3	4.8	3	683	133.22	3.6	−22	75.2
70	−4	3.8	3	635	132.58	0.7	−24.9	71.9
80	−10	−2.2	3	608	132.21	-2.2	−27.8	63.4
90	−20	−12.2	3	600	132.09	-5.5	−31.1	50.2

2.1.9 Propagation effects

See § 2.1.10 of Annex 4.

2.2 Physical layer modulation schemes

VDE-SAT uplink supports different modulation to maximise spectral efficiency and throughput. The supported modulation methods are given in Table A5-4.

TABLE A5-4

Uplink modulation methods

Index	**Bits/symbol**	**Data Modulation type**	**Bit mapping**	**Maximum Adjacent Channel Interference level with worst case Doppler**
1	2	Gray encoded QPSK and OQPSK	Figure A5-2	Refer to Annex 1
2	3	Gray encoded 8PSK	Figure A5-3	
3	4	16APSK	Figure A5-4	
4	2	Spread Spectrum with Constant Envelope	See Section 2.2.1	

FIGURE A5-2

QPSK symbol to bit mapping

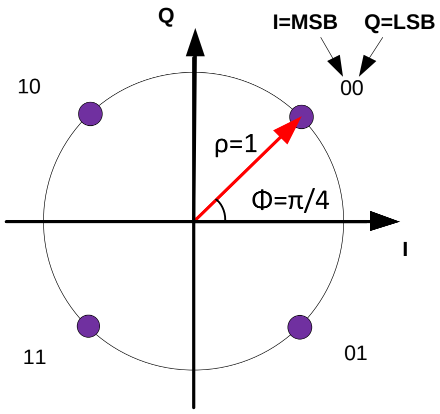


FIGURE A5-3

8PSK symbol to bit mapping

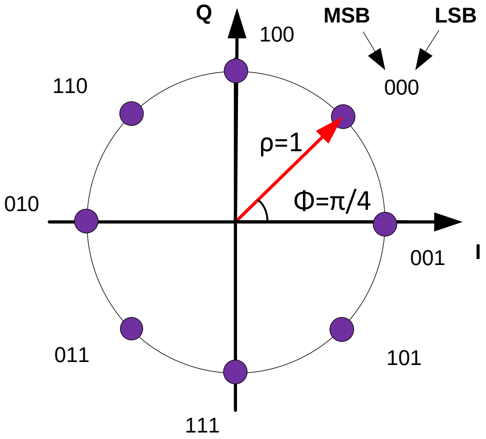
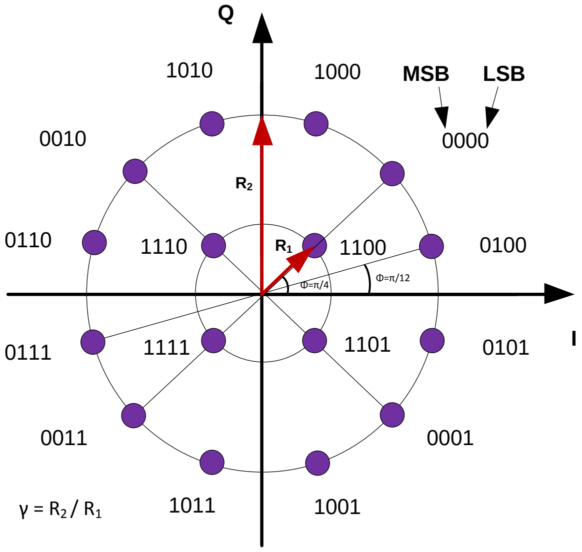


FIGURE A5-4

16APSK bit to symbol mapping



The 16 APSK modulation constellation is 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.

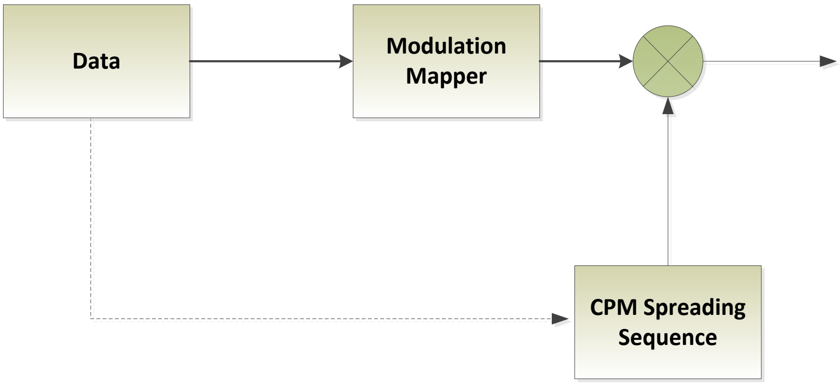
Similar to AIS, when data is output on the VHF data link it should be grouped in bytes of 8 bits from top to bottom of the table associated with each message in accordance with ISO/IEC 13239:2002. Each byte should be output with least significant bit first.

2.2.1 Spread spectrum with constant envelope

Direct sequence spreading with constant envelope can be implemented according to the spreading strategy {RD-3}. This provides a way to generate constant envelope signals whilst allowing the use of linear modulations (i.e. BPSK, or QPSK for data modulation). In this approach the CPM spreading sequences are selected such that the spread symbols maintain quasi continuous phase even at the transition from one symbol to the next. The CPM spreading principle is provided in Fig. A5-5.

FIGURE A5-5

CPM Spreading Principle



In order to avoid phase discontinuity at the data symbol transitions, the proposed solution is to adapt the spreading sequence to the modulation data. In other words, the CPM spreading sequence at the edge of each symbol is adapted according to the new input modulation symbol value to avoid any phase discontinuity. Such a solution produces a small loss at the receiver as the receiver does not know the edge symbol part of the used CPM spreading sequence. For a spreading factor of 16 or higher, the resulting correlation loss experienced by the receiver due to this issue is less than 0.25 dB. Performance losses with respect to conventional spreading is thus quite negligible provided that SF = 16 or larger is used.

The CPM spreading sequences are computed and optimized off-line and then stored in the memory of the terminals and receivers. A single spreading code is sufficient for all the users in the system. There is thus no need for storing multiple spreading sequences but just a single spreading sequence.

The stored spreading sequence is then applied starting from the preamble and continuing in the data part (as shown in Fig. A5-6). It should be noted that the actual spreading sequence is actually partly dependent on the modulation symbols in order to ensure continuity of the signal phase when the modulation symbol changes (Fig. A5-5). The spread samples are computed on the basis of the current modulation symbol and previous modulation symbol. For QPSK modulation there are 4 possible values for the phase difference of these two symbols. An index from 0 to 3 can point to the possible phase differences and is used to address which of 4 possible spreading sequences is actually used for computing the output signal. Figure A5-7 illustrates the power spectral properties of the proposed modulation scheme (with spreading factor 16). Due to its constant envelope properties, this modulation scheme can operate with a transmit power amplifier operating close to saturation while maintaining a low power leakage to adjacent channels.

FIGURE A5-6

Proposed Spreading in the CPM

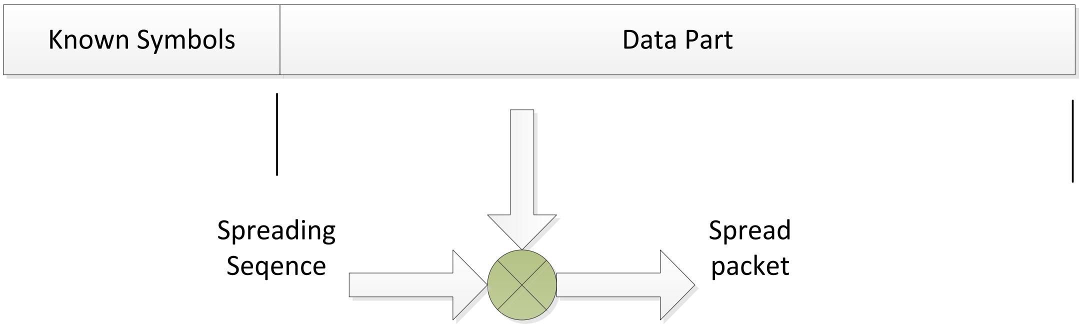
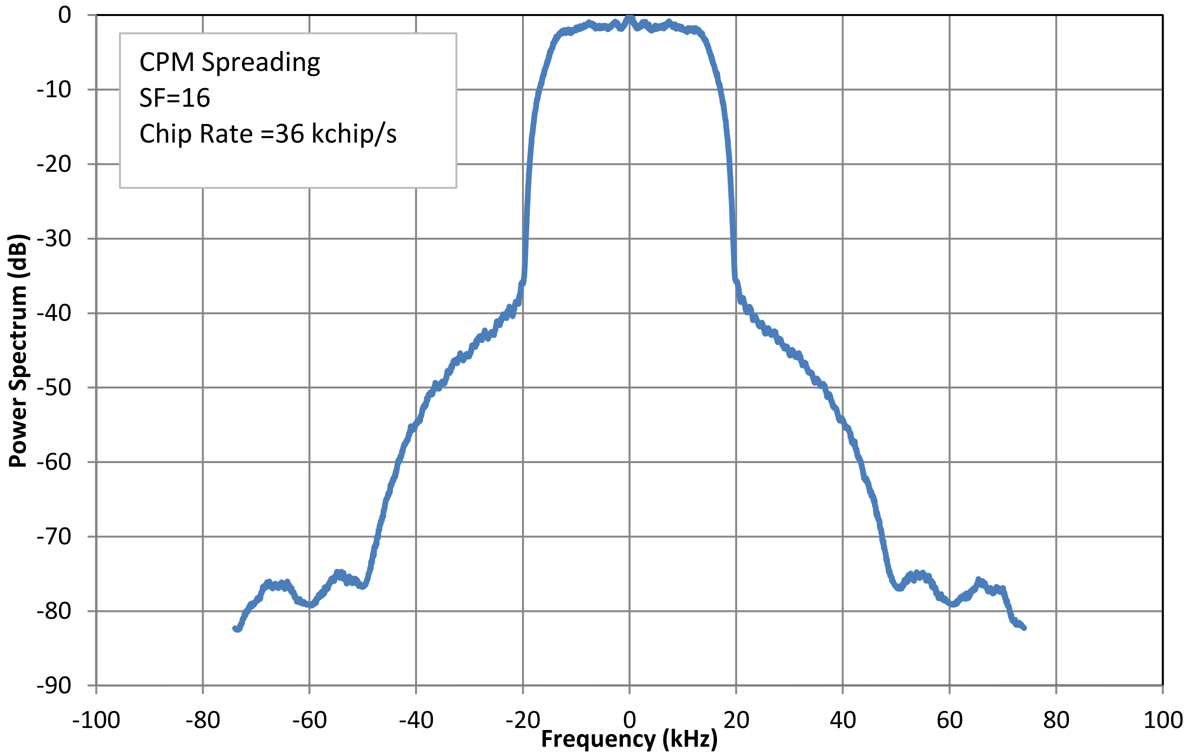


FIGURE A5-7

Power spectral properties of spread spectrum with constant envelope



2.3 Baseband shaping and quadrature modulation

The baseband symbols shall be squared root raised cosine filtered. The roll-off factor should be $\alpha = 0.25$ or $\alpha = 0.20$. It should be noted that the shaping is not applicable to CPM spreading.

2.4 Transmission timing accuracy

2.4.1 Symbol timing accuracy (at the output of satellite)

The timing accuracy of the transmit signal at the satellite should be better than 20 ppm.

2.4.2 Transmitter timing jitter

The timing jitter should be better than 5% of the symbol interval (peak value).

2.4.3 Slot transmission accuracy at the satellite output

The slot transmission accuracy should be better than 100 µs (peak) relative for example to GNSS reference timing.

2.5 Half duplex and full duplex satellites

See § 2.5 of Annex 4.

2.6 Frame hierarchy

The VDES frame structure is identical and synchronized in time on the Earth’s surface to UTC (as in AIS). The frame hierarchy is shown in Annex 6.

2.6.1 Uplink physical layer frame (PL-Frame)

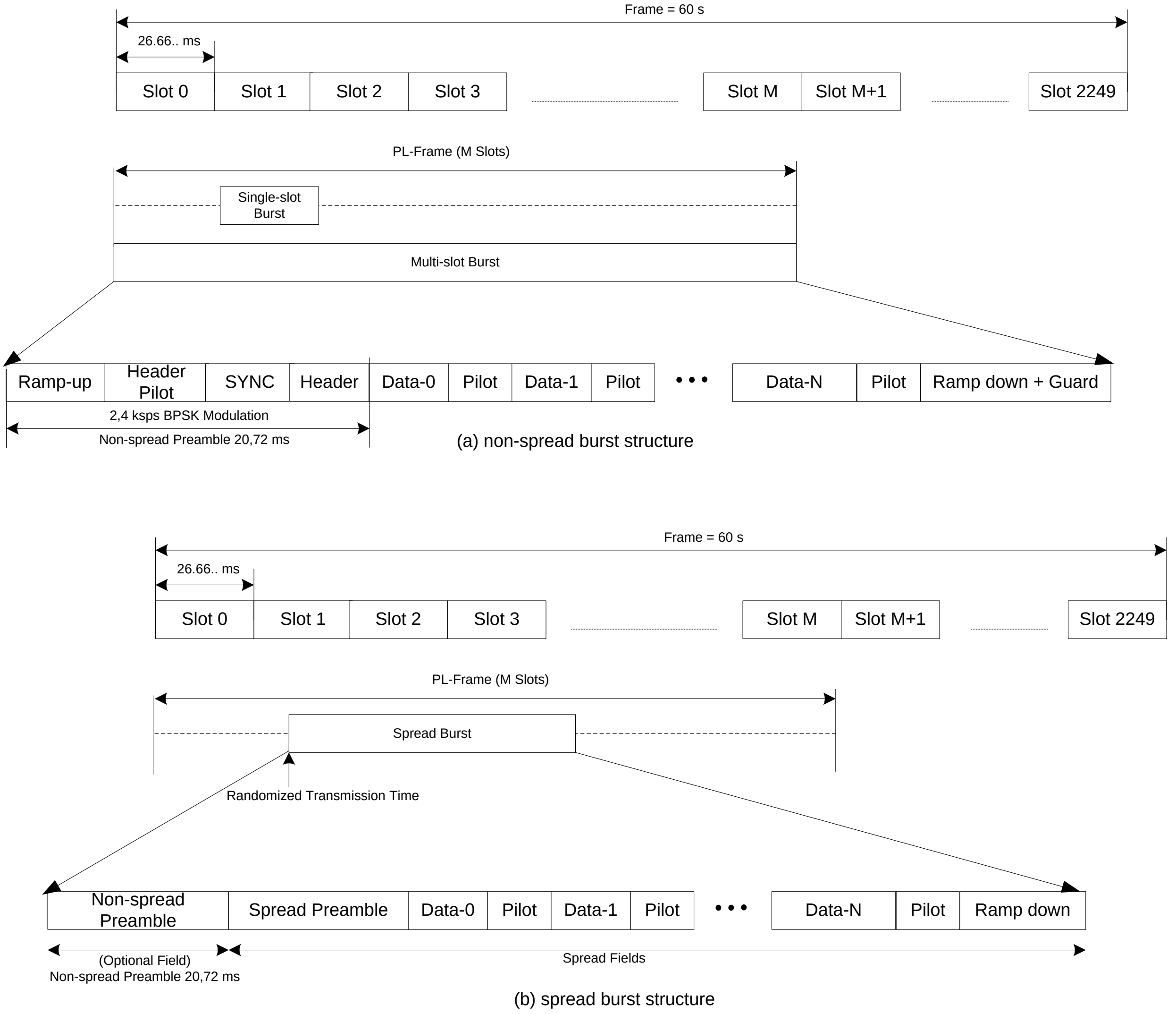
The uplink physical layer frame (PL-Frame) refers to a time window that the satellite expects to receive the VDE-SAT uplink signal. The PL-frame size is defined according to the PL-frame formats used for the VDE-SAT uplink. The current selected PL-frame intervals are 800 ms and 2.4 s.

2.6.2 Burst structure

For the VDE-SAT uplink, the active portion of PL-frame is referred to as a burst. Figure A5-8 illustrates the burst structure for non-spread and spread waveforms

FIGURE A5-8

VDE-SAT uplink burst structure (a) without spreading (b) with spreading



2.6.3 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 μs 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 burst may not be required, but has been provided to allow for future expansion of the pilot, synchronization word and the PL-Frame format header.

2.6.4 Preamble

A fixed format preamble as shown in Fig. A5-8 is used for non-spread burst and optionally for spread bursts. It consists of a CW (unmodulated carrier) pilot, a unique synchronization word and a format header. The preamble duration is shown in Table A5-5.

TABLE A5-5

Preamble Duration

Parameter	Value	Unit
Ramp up	0.30	ms
Symbol rate	2.4	ksym/s
Modulation	BPSK	
CW pilot duration	4	symbols
CW pilot duration	1.67	ms
(SYNC) UW size	13	bits
(SYNC) UW duration	5.42	ms
Header size	32	bits
Header duration	13.33	ms

2.6.5 Synchronization pilot

Pilot symbols (one or several) are inserted periodically among the data symbols. The number of known symbols per pilot field and the distance (in symbols) between two consecutive pilot fields are defined on case by case basis (per each PL-Frame format).

2.6.6 Synchronization (SYNC) unique word

The PL-Frame synchronization word and header format is fixed for all transmissions. (It is defined as part of non-spread preamble and considered optional field for spread burst as shown in Fig. A5-8). The 13 bit Barker code unique word, as defined in Annex 4 (Table A4-10) is modulated with BPSK at a symbol rate of 2.4 ksym/s.

2.6.7 PL-Frame header

The header is BPSK modulated and spread the same way as the synchronization word described above. This PL-Frame header defines the following parameter associated with the each PL-Frame:

- PL-Frame duration (as an integer multiple of a slot duration)
- Burst duration
- Number of data slots (M) per PL-Frame
- Symbol rate
- Modulation type
- FEC type
- FEC rate
- Interleaver type
- Scrambler type
- Spreading Factor (1 or higher)

– Spreading sequence (1 or as defined).

The header provides 7 bits to define up to 128 PL-Frame formats. The PL-Frame header is encoded to 32 bits. It is modulated with BPSK at a symbol rate of 2.4 ksym/s. Refer to Annex 4 for more details.

2.6.8 Direct sequence spreading

The VDE-SAT spread bursts are shown in Fig. A5-8 (b). The spread burst may contain optionally a non-spread field similar to that of a non-spread burst. This optional filed would contain known symbols, SYNC and PL-frame header all modulated as BPSK and at a symbol rate of 2.4 ksym/s.

A spread burst should carry a spread preamble allowing the detection of the burst as very low $C/(N_0+I_0)$ conditions. The data filed and pilot fields are spread as well.

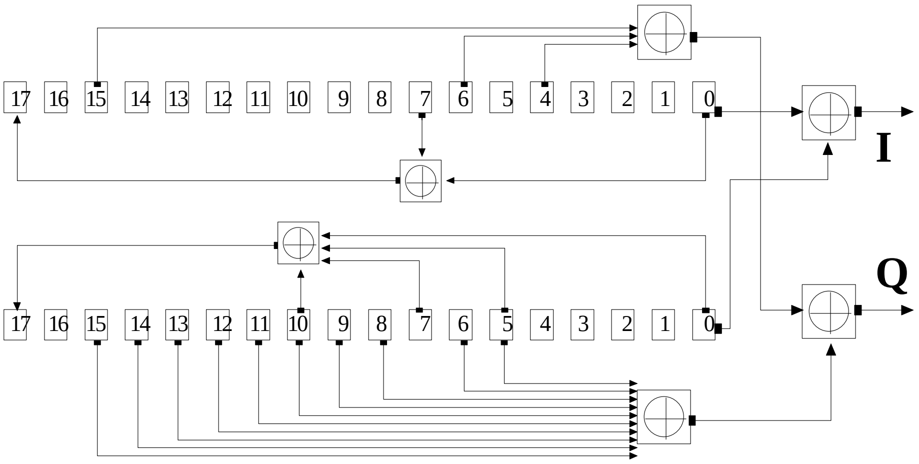
Each pilot filed contains one or several known QPSK symbols. The pilot field distances are defined per PL-Frame format.

The transmission time of a spread burst is randomly selected within the PL-Frame duration (keeping margin so that the full burst fits within the PL-Frame interval). The actual PL-frame size and the burst size are defined per PL-Frame format.

For the VDE-SAT uplink, the spreading codes should be selected from long Pseudo Noise (PN) Sequence. A spreading strategy similar to the one used in the down-link of the 3GPP standard is adopted recommended for VDE-SAT uplink. The complex spreading code is shown in Fig. A5-9 i.e. obtained through a long Gold code which is used to generate the I and Q scrambling sequences (with the Q sequence obtained by a different phase of the same Gold code).

FIGURE A5-9

Complex Scrambling code generation



2.6.9 Data segment forward error correction coding

The FEC coding scheme applied to the data segment of PL-Frames is similar to the FEC code of the 3GPP standard. The definition of the FEC is Annex 1 since a common FEC scheme is applicable to VDE-SAT and VDE-terrestrial.

2.6.10 Data segments

As shown in the frame hierarchy, each PL-Frame includes one or several data segments. Data segments contain channel symbols that carry encoded information bits. In each PL-Frame, the encoded bits are mapped into segment of *N* of interleaved data.

2.6.11 Physical layer scrambling

Prior to modulation (and spreading if applicable), each PL-Frame samples, excluding the SYNC word, should be randomized for energy dispersal by multiplying the (I + jQ) samples by a complex randomization sequence ($C_I + jC_Q$):

– $I_{SCRAMBLED} = (I\ C_I - Q\ C_Q)$

– $Q_{SCRAMBLED} = (I\ C_Q + Q\ C_I)$.

The randomization sequence rate corresponds to the PL-Frame symbol rate, thus it has no impact on the occupied signal bandwidth. The randomization sequence shall be reinitialized at the end of each burst. The randomization sequence length should be truncated to the length of the burst (excluding the SYNC word).

The scrambling code sequence should be pre-defined according to the PL-Frame format.

2.6.12 Channel interleaver

A block channel interleaver is considered on the VDE-SAT in order to reduce the impact of the channel short blockage (for example due to the AIS transmission from the vessel or fast fading events). The channel interleaver is applied to the code words at the output of the encoder.

The interleaver is a block interleaver composed by N_r rows and N_c columns. The interleaver memory in this case (from the point of view of the transmitter) is written by row and read by columns after having applied an inter-column permutation. The proposed column permutation is resulting from reading the column index in the reverse order (bit shuffling), i.e. the column with index $i_5, i_4, i_3, i_2, i_1, i_0$ become the column $i_0, i_1, i_2, i_3, i_4, i_5$, where i_0, i_1, i_2, i_3, i_4 and i_5 are the bits representing a given number.

In more general cases (where the number of columns is not an integer power of 2), the interleaver index can be made available as table-lookup.

2.6.13 Ramp down

The ramp down occurs at the end of each burst (as shown in Fig. A5-8) followed by the guard time. The overall duration of the ramp-down and guard time is 8.88 ms while the ramp-down time from 90% to 10% of the power should occur in less than 300 µs.

2.6.14 Guard time

The guard time is added to the end of each PL-Frame. The guard time duration is 8.88 ms. This time is adequate to cover the differential delay between the shortest and the longest propagation time within the coverage area of a LEO satellite at 600 km altitude (or lower).

2.7 VDE-SAT uplink PL-Frame formats

This section defines several PL-Frame formats that are used for signalling and data transmission on the VDE-SAT uplink channels. All formats consist of a fixed preamble and a data portion as shown in Fig. A5-8. The data portion is defined in the tables below. The pilot duration is one symbol after every 9 data symbols.

2.7.1 VDE-SAT Uplink PL-Frame format 1

The VDE-Sat uplink PL-Frame format 1 is provided in Table A5-6.

In the uplink PL-Frame format 2, the optional non-spread preamble field is used. Each pilot field consists of 1 symbol only. The distance between two consecutive pilot symbols is 9 data symbols. There are 24 pilot symbols in total in each burst. The spread preamble filed contains 14 known symbols.

TABLE A5-6

VDE-Sat uplink PL-Frame Format 1

Uplink format	1	
Function	Direct Sequence Spread random access	
Usage	Request, response, ACK and short message	
Header value	′41	hex
Channel bandwidth	50	kHz
Slots available for RA	30	slots
Unfaded C/N_0	73.0	dBHz
Burst duration	5	slots
Burst duration	133.33	ms
Ramp down	0.30	ms
Guard time	8.0	ms
Channel rate	19.2	kchip/s
Spreading factor	8	
Modulation	QPSK	
Channel bits/symbol	2	
FEC rate	1/3	
Information rate/user	1.60	kbits/s
Eb/N0	41.0	dB
Channel Rice factor (C/M)	10	dB
Channel fading bandwidth	3	Hz
Target frame error rate	1.00	%
Pilot duration	9	ms
(spread) Preamble duration	5.83	ms
Data duration	90	ms
Number of information bits	144	bits
Block interleaver width	16	bits
Block interleaver height	27	bits
Number of info bytes	18	bytes
Packet type field	1	bytes
Ship ID field	4	bytes
Destination short address	2	bytes

TABLE A5-6 (*end*)

Repeat transmission offset field	2	bytes
Received C/N_0 field	1	bytes
Packet sequence number	0	bytes
Transaction ID	0	bytes
CRC	4	bytes
Payload	4	bytes

2.7.2 VDE-SAT uplink PL-Frame format 2

The VDE-SAT uplink PL-Frame format 2 is provided in Table A5-7.

In the uplink PL-Frame format 2, the optional non-spread preamble field is not used. Each pilot field consists of 1 symbol only. The distance between two consecutive pilot symbols is 9 data symbols. There are 24 pilot symbols in total in each burst. The spread preamble filed contains 64 known symbols.

TABLE A5-7

VDE-SAT uplink PL-Frame format 2

Uplink format	2	
Function	Direct Sequence Spread random access with constant envelope	
Usage	Request, response, ACK and short message	
Header value	′42	hex
Channel bandwidth	50	kHz
Slots available for RA	30	slots
Unfaded C/N_0	73.0	dBHz
Burst duration	5	slots
Burst duration	133.33	ms
Ramp down	0.30	ms
Guard time	6.36	ms
Chip rate	38.4	kchip/s
Spreading factor	16	
Modulation	CPM/QPSK	
Channel bits/symbol	2	
FEC rate	1/3	
Information rate/user	1.60	kbits/s
E_b/N_0	41.0	dB
Channel Rice factor (C/M)	10	dB
Channel fading bandwidth	3	Hz
Target frame error rate	< 1.00	%
(spread) Preamble symbols	64	symbols

TABLE A5-7 (*end*)

(spread) Preamble duration	26.67	ms
Preamble, Pilot and data duration of burst	126.67	ms
Pilot duration	10	ms
Data duration	90	ms
Number of information bits	144	bits
Block interleaver width	16	bits
Block interleaver height	27	bits
Number of info bytes	18	bytes
Packet type field	1	bytes
Ship ID field	4	bytes
Destination short address	2	bytes
Repeat transmission offset field	2	bytes
Received C/N_0 field	1	bytes
Packet sequence number	0	bytes
Transaction ID	0	bytes
CRC	4	bytes
Payload	4	bytes

2.7.3 VDE-SAT uplink PL-Frame format 3

The VDE-SAT uplink PL-Frame format 3 is provided in Table A5-8.

TABLE A5-8

VDE-SAT uplink PL-Frame format 3

Uplink format	3	
Function	TDMA (non-spread) random access, high margin	
Usage	Request, response, ACK and short message	
Header value	′43	hex
Channel bandwidth	50	kHz
Slots available for RA	30	slots
Unfaded C/N_0	73.0	dBHz
Burst duration	1	slots
Burst duration	26.67	ms
Ramp down	0.30	ms
Guard time	0.0	ms
Channel rate	33.6	kchip/s
Spreading factor	1	
Modulation	OQPSK	

TABLE A5-8 (*end*)

Channel bits/symbol	2	
FEC rate	3/4	
Information rate/user	50.40	kbits/s
Number of simultaneous users	1	
E_b/N_0	26.0	dB
Channel rice factor (C/M)	10	dB
Channel fading bandwidth	3	Hz
Target frame error rate	1.00	%
Pilot and data duration of burst	5.65	ms
Pilot duration	0.57	ms
Data duration	5.09	ms
Number of information bits	256	bits
Block interleaver width	24	bits
Block interleaver height	15	bits
Number of info bytes	32	bytes
Packet type field	1	bytes
Ship ID field	4	bytes
Destination short address	2	bytes
Repeat transmission offset field	2	bytes
Received C/N_0 field	1	bytes
Packet sequence number	0	bytes
Transaction ID	0	bytes
CRC	4	bytes
Payload	18	bytes

2.7.4 VDE-SAT uplink PL-Frame format 4

The VDE-SAT uplink PL-Frame format 4 is provided in Table A5-9.

TABLE A5-9

VDE-SAT uplink PL-Frame Format 4

Uplink format	4	
Function	TDMA (non-spread) random access, high throughput	
Usage	Request, response, ACK and short message	
Header value	′44	hex
Channel bandwidth	50	kHz
Slots available for RA	30	slots
Unfaded C/N_0	73.0	dBHz
Burst duration	1	slots
Burst duration	26.67	ms
Ramp down	0.30	ms
Guard time	0.0	ms
Channel rate	33.6	kchip/s
Spreading factor	1	
Modulation	16APSK	
Channel bits/symbol	4	
FEC rate	3/4	
Information rate/user	100.80	kbits/s
Number of simultaneous users	1	
E_b/N_0	23.0	dB
Channel Rice factor (C/M)	10	dB
Channel fading bandwidth	3	Hz
Target frame error rate	1.00	%
Pilot and data duration of burst	5.65	ms
Pilot duration	0.57	ms
Data duration	5.09	ms
Number of information bits	512	bits
Block interleaver width	32	bits
Block interleaver height	22	bits
Number of info bytes	64	bytes
Packet type field	1	bytes
Ship ID field	4	bytes
Destination short address	2	bytes
Repeat transmission offset field	2	bytes
Received C/N_0 field	1	bytes
Packet sequence number	0	bytes
Transaction ID	0	bytes
CRC	4	bytes
Payload	50	bytes

2.7.5 VDE-SAT uplink PL-Frame format 5

The VDE-SAT uplink PL-Frame format 5 is provided in Table A5-10.

TABLE A5-10

VDE-SAT uplink PL-Frame format 5

Uplink format	5	
Function	TDM (non-spread) demand assign	
Usage	Long packet file fragments	
Header value	′45	hex
Channel bandwidth	50	kHz
Slots available for RA	Not applicable	s
Unfaded C/N_0	73.0	dBHz
Burst duration	30	slots
Burst duration	800	ms
Ramp down	0.30	ms
Guard time	8.0	ms
Channel rate	33.6	kchip/s
Spreading factor	1	
Modulation	16APSK	
Channel bits/symbol	4	
FEC rate	3/4	
Information rate/user	100.80	kbits/s
Number of simultaneous users	1	
E_b/N_0	23.0	dB
Channel Rice factor (C/M)	10	dB
Channel fading bandwidth	3	Hz
Target frame error rate	1.00	%
Pilot and data duration of burst	770.98	ms
Pilot duration	77.10	ms
Data duration	693.89	ms
Number of information bits	69 936	bits
Block interleaver width	360	bits
Block interleaver height	260	bits
Number of info bytes	8 742	bytes
Packet type field	1	bytes
Ship ID field	4	bytes
Destination short adress	0	bytes
Repeat transmission offset field	0	bytes
Received C/N_0 field	1	bytes
Packet sequence number	0	bytes
Transaction ID	4	bytes
CRC	4	bytes
Payload	8 728	bytes

3 VDE-SAT link layer

3.1 Data encapsulation

The data segments of each PL-Frame contain multiple variable length encapsulated datagrams. Each datagram contains the following encapsulation fields:

- Datagram type (1 byte)
- Datagram size (3 bytes)
- Destination (variable, up to 254 bytes, optional)
- Transaction ID (4 bytes, optional)
- Datagram sequence number (2 bytes, for multi segment datagrams)
- Source ID (6 bytes, optional)
- Datagram payload (variable)
- Data padding (variable, less than 8 bits)
- CRC (4 bytes).

3.2 Cyclic redundancy check

Refer to Annex 1.

3.3 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.

3.4 Acknowledgement (ACK)

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

3.5 End delivery notification (EDN)

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

3.6 End delivery failure (EDF)

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

3.7 Physical and logical channels

VDE-SAT protocols use 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.

3.8 Physical channels

The Physical channels (PC) are determined by the centre frequency and bandwidth.

3.8.1 Logical channels

The logical channels (LC) are divided into signalling and data channels as described below.

3.9 Signalling logical channels

The following uplink signalling channels are used:

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

3.9.1 Random access resource request (RQSC)

A ship uses this channel to access the network. A ship will randomly select the transmission time within the slots allocated for this channel on the Bulletin Board. The downlink Announcement Channel provides congestion control parameters such as retry interval and message priority.

The request includes a downlink C/N_0 estimate and message size.

3.9.2 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/N_0 estimate.

3.9.3 Acknowledgement (ACK)

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

3.9.4 Automatic repeat request signalling channel (ARQSC)

A ship uses this channel to inform the satellite that it has not received 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/N_0 estimate.

3.10 Data logical channels

The following data channels are used:

- Random access short messages
- Assigned (dedicated) data transfer.

3.10.1 Random access short messaging channel (RADC)

This channel is used for short messages that fit in a single transmission. Terrestrial addressing may require up to 254 bytes, and every ship uses therefore a 2 byte look-up table at the coast earth station for address translation.

3.10.2 Assigned data transfer channel (ADDC)

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

4 Network layer

4.1 Uplink data transfer protocols

The following protocols shall be supported:

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

The protocols are shown in Fig. A5-10 to Fig. A5-12.

FIGURE A5-10

Ship originated single packet data transfer

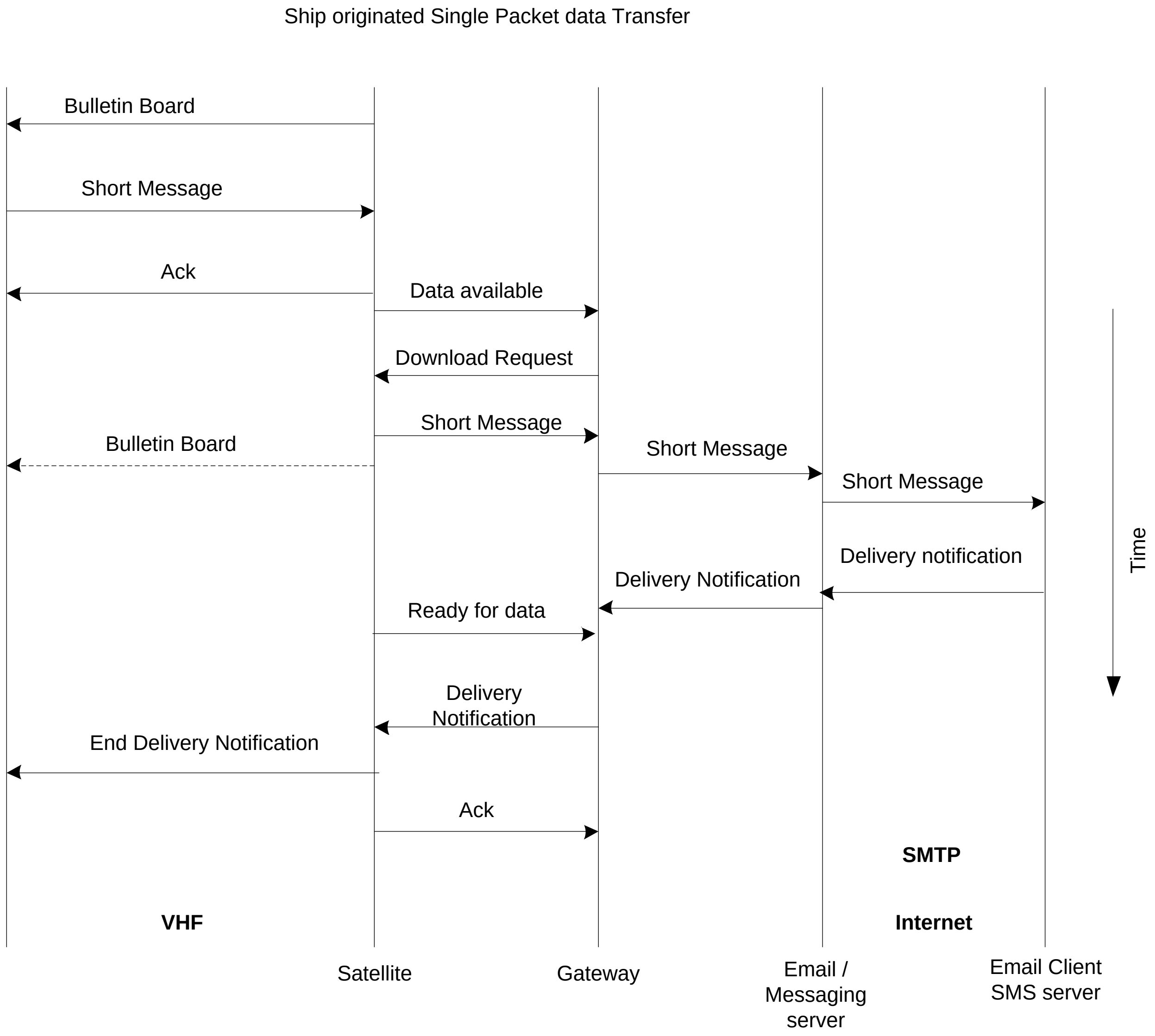


FIGURE A5-11

Ship originated multi-packet data transfer

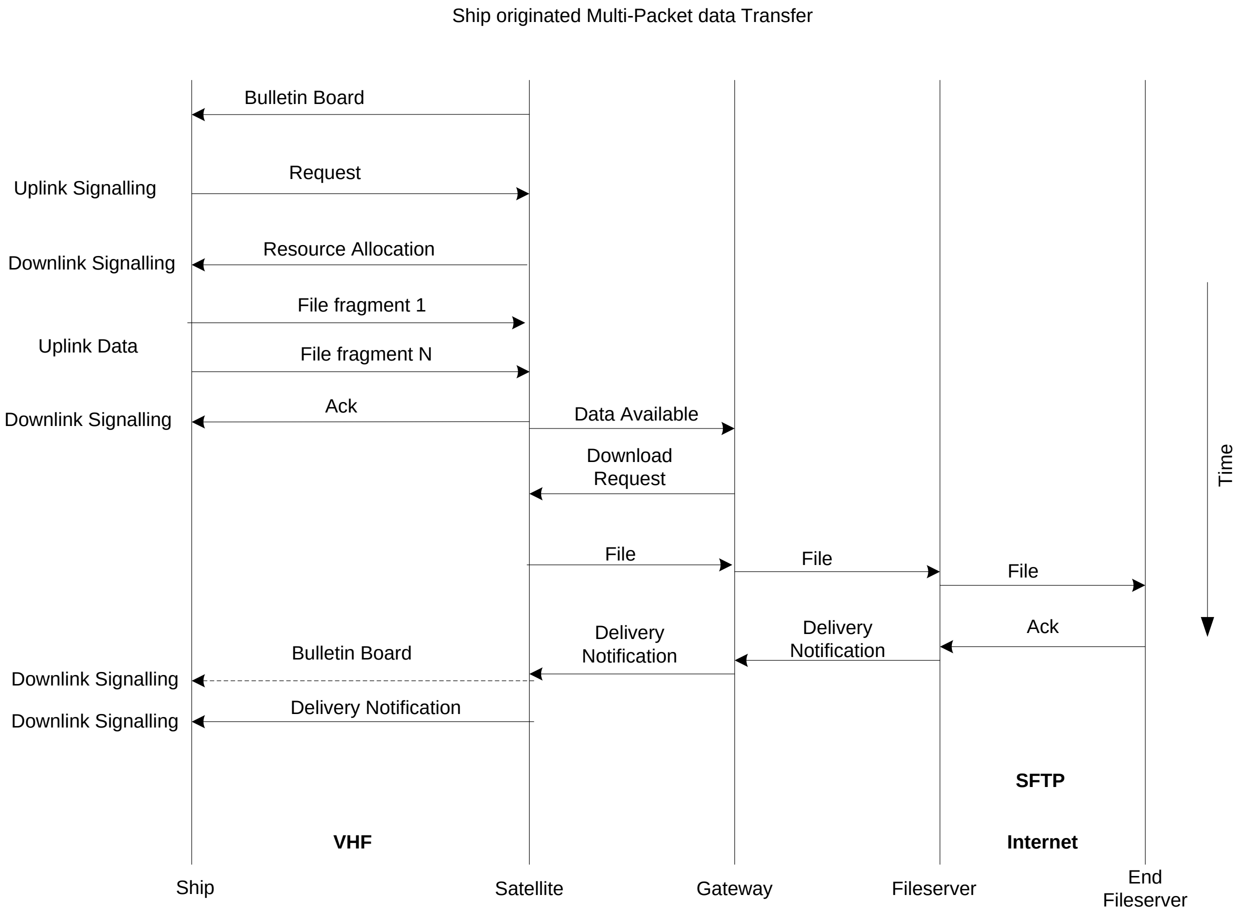
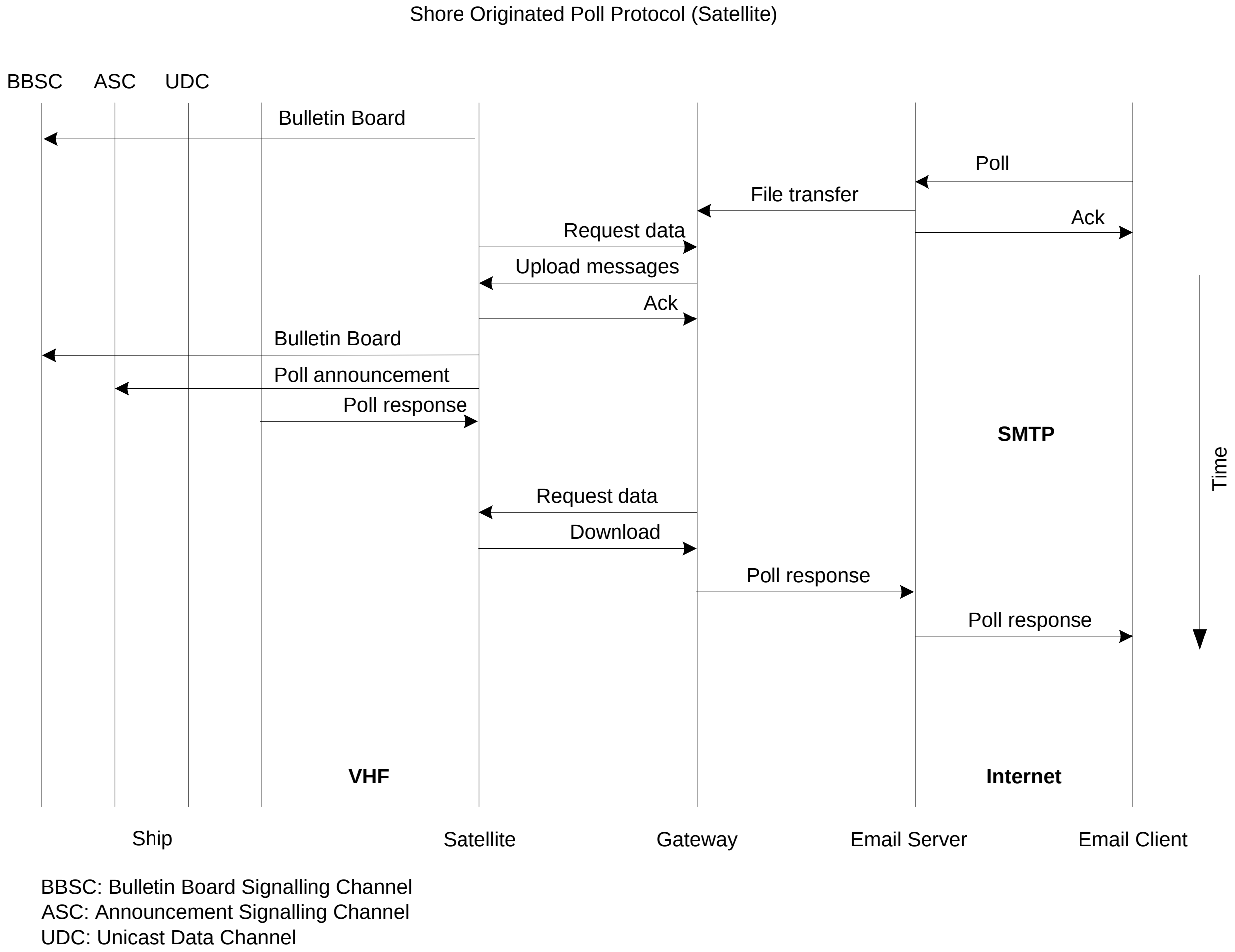


FIGURE A5-12

Shore oriented poll protocol



5 Transport layer

Refer to Annex 4.

Annex 6

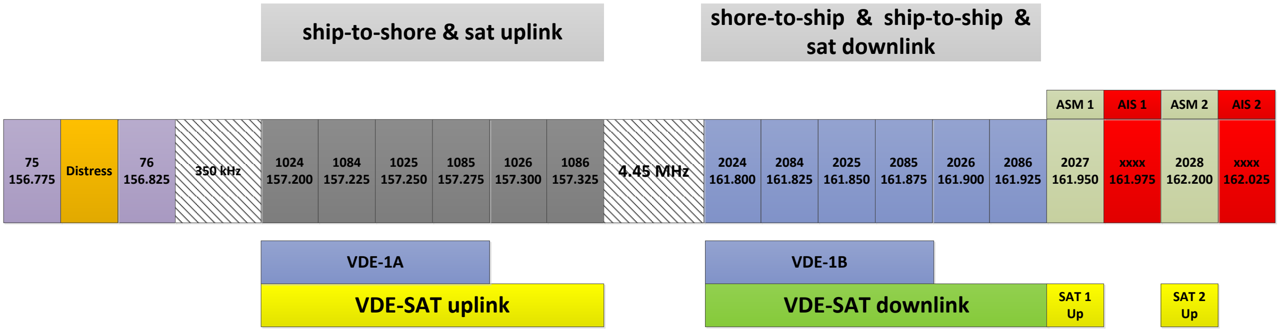
Resource sharing method for VDES Terrestrial and Satellite Services

1 Introduction

This Annex describes how resource sharing (i.e. in time and frequency) for utilizing the VHF spectrum available among different VDE terrestrial and satellite services should be accomplished. The baseline for VDES spectrum allocation is according to the frequency utilization plan illustrated in Fig. A6-1.

FIGURE A6-1

VDES spectrum allocation



where:

– Four channels 1024, 1084, 1025 and 1085 are shared between ship-to-shore and ship-to-satellite (VDE-SAT uplink) services

– Two channels 1026 and 1086 are exclusively reserved for ship-to-satellite communications

– Four channels 2024, 2084, 2025 and 2085 are shared among shore-to-ship, ship-to-ship and satellite-to-ship (VDE-SAT downlink) services

– Two channels 2026 and 2086 are exclusively reserved for satellite-to-ship communications services.

The VDE-SAT is an effective means to extend the VDES to areas outside of coastal VHF coverage. However, due to the large footprint of satellite, the VDE-SAT downlink signal may interfere with terrestrial VDE in the coastal areas when satellite is in visibility. Similarly, the terrestrial ship-to-shore VDE signals can interfere with the satellite reception of VDE-SAT uplink when a VDE Satellite is in the field of view.

The method described in this Annex for resource sharing is derived based on the characteristics of VDE terrestrial and VDE Satellite, particularly the use of bulletin board and announcement signalling channels, as defined in Annexes 3, 4 and 5.

2 VDES resource sharing principles

2.1 Common frequency-time frame structure

The transmission timing of all VDES components (i.e. AIS, ASM, VDE-SAT and VDE terrestrial), is defined based on a common frame structure that is synchronized in time on the Earth’s surface to the UTC.

The duration of each frame is 60 seconds. Each frame consists of 2 250 slots.

All VDES transmitters should be synchronized to this common frame structure and use a common addressing of frame constituents (i.e. sub frames and slots), so that each slot can be uniquely identified per frame. Frame 0 starts at 00:00:00 UTC, and there are 1 440 distinct frames in a day. The impact of leap second should be accounted for to avoid any propagation of error.

The frame and slot boundaries should respected independent of the frequency band to a VDE service.

Uncertainties due to the propagation delay or Doppler effect should be compensated, or accounted for (e.g. see Annexes 3 and 4 for guard time definition and Annex 4 for guard bands)

2.2 AIS priority

Understanding that when transmissions occurs a VDES mobile station with a single antenna will suffer decreased receiver sensitivity, care must be taken to respect the AIS transmission and reception as the highest priority.

2.3 Coordination with ASM

Similar to all VDES components, ASM transmission respects a common frame structure.

For the ASM channels and for VDE ship to ship communications on VDE-1B band, transmissions are accomplished through the use of candidate slot selection as described in Annex 2, § 3.3.1.2.

2.4 Shore station VDES control area

The VDES resource assignments in the proximity of a shore station is monitored and controlled by a shore station. Shore stations utilize terrestrial bulletin board (TBB) and announcement signalling channels (ASC) to coordinate the resource assignment within the control area. The shore station may incorporate information regarding VDE satellite communications within the TBB and ASC. The shore station may acquire the VDE satellite information directly from the VDE-Satellite downlink (the satellite bulletin board and ASC) or in coordination with the satellite service providers.

There are dedicated slots and frequency bands for TBB and ASC that are reserved to communicate the required information to each vessel in the control area of a shore station. The default (or initial) assignment are described in Section 4 of this Annex.

2.5 VDE-SAT resource assignment

Each satellite should use bulletin board and announcement channels (as defined in Annex 4) to communicate the VDE-SAT resource assignments (both downlink and uplink) to vessels in the coverage area.

There are dedicated slots and frequency bands for the satellite bulletin board and announcement channels that are reserved to communicate the required information to each vessel in the field of view of a satellite.

Since the satellite coverage may include several shore station control areas, the VDE-SAT resource assignment should respect all requirements of shore control areas that are within the field of view at any given time. Within each satellite orbit the information regarding the resource assignment should be updated according to the shore station control areas in the satellite field of view.

A default (or initial) VDE-SAT resource allocation is defined in § 4 below to serve as the starting point for the resource sharing.

3 Frame hierarchy definition

The frame hierarchy is shown in Fig. A7-2. The frame hierarchy definition is independent of the assigned bandwidth to the VDE channel

3.1 Time slot

The time slot is a time interval of approximately 26.667 ms (60 000 / 2 250 = 80/3 ≈ 26.667).

3.2 Hexslot

Six timeslots should form a Hexslot (HS). The HS has duration of 160 ms.

The HS should be numbered cyclically from 0 to 4. The HS should be incremented after every 6 time slots.

3.3 Timeslot numbering

The timeslots within a Hexslot should be numbered from 0 to 5 and a particular timeslot should be referenced by its timeslot number (TN).

3.4 Uberslot

Five Hexslots should form a Uberslot (US). The US should have duration of 800 ms.

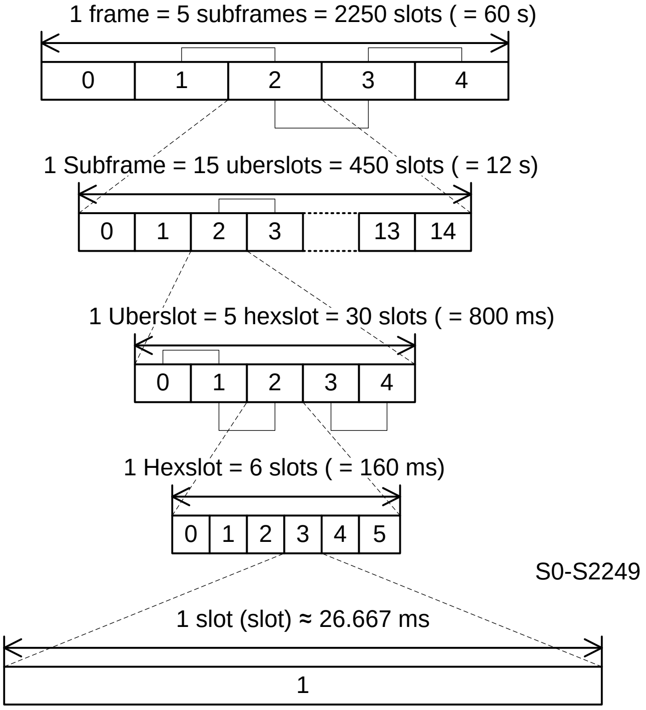
The US should be numbered by a US Number. The US should be cyclically numbered from 0 to 14. The US should be incremented whenever the Hexslot returns to 0.

3.5 Sub frame

Fifteen US should form a sub frame. The sub frame should have duration of 12 seconds. The sub frame should be numbered by a sub frame Number. The PL-Frame should be cyclically numbered from 0 to 4. The sub frame should be incremented whenever the US returns to 0.

FIGURE A6-2

Frame Hierarchy for shared frequency



4 VDE terrestrial and VDE-SAT downlink resource sharing

Figure A6-3 illustrates the method of frequency and time slot coordination among VDE shore-to-ship, ship-to-ship and satellite downlink systems.

According to the frequency utilization plan, channels 2026 and 2086 are dedicated to VDE Satellite downlink. Within these exclusive VDE-SAT bands, there are dedicated time slots that are assigned to the satellite bulletin board and announcement signalling channels. Figure A6-3 shows the location of these slots in each frame. There are 90 consecutive slots (1/5th of sub frame duration) that are assigned to the signalling channels and the bulletin board in each sub frame (the assignment is repeated 5 times in each frame). Other slot assignments in the exclusive VDE-SAT frequency bands are managed based on the content of the bulletin board and announcement signalling channels.

The assignment may change dynamically (according to the satellite coverage or temporal demands).

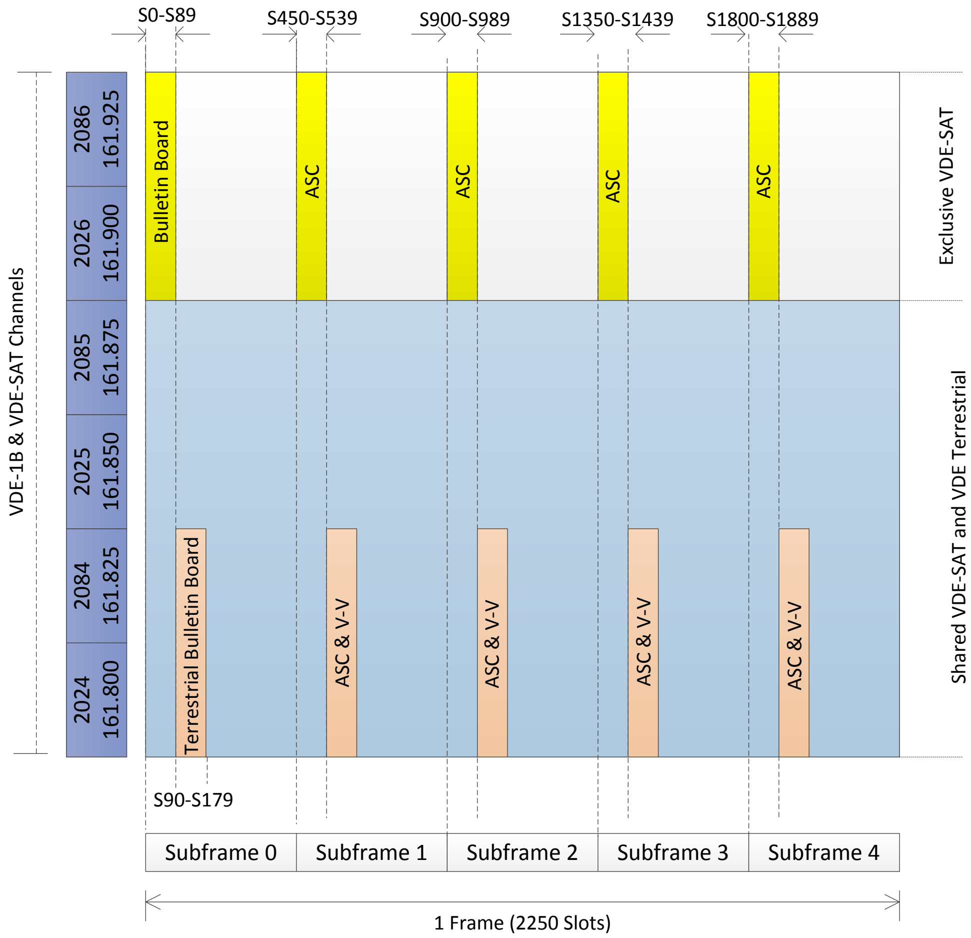
Channels 2024, 2084, 2025 and 2085 are shared between VDE-SAT Downlink and VDE terrestrial. Depending on the satellite coverage area and the shore control areas, the resource assignment may vary.

There are dedicated time slots in channel 2024 and 2084 that are assigned to the terrestrial signalling channel and terrestrial bulletin board, as shown in Fig. A6-3. These slots should not be used by VDE-SAT downlink. In each sub frame, 90 slots are assigned for the signalling. The same time slots are considered for ship-to-ship when ships are outside the control area of a shore VDE station.

A shore station may assign all the slots of VDE-1B for terrestrial services when there is no transmitting VDE satellite in the field of view.

FIGURE A6-3

Resource sharing between VDE-SAT downlink and VDE terrestrial



4.1 Initial resource sharing configuration

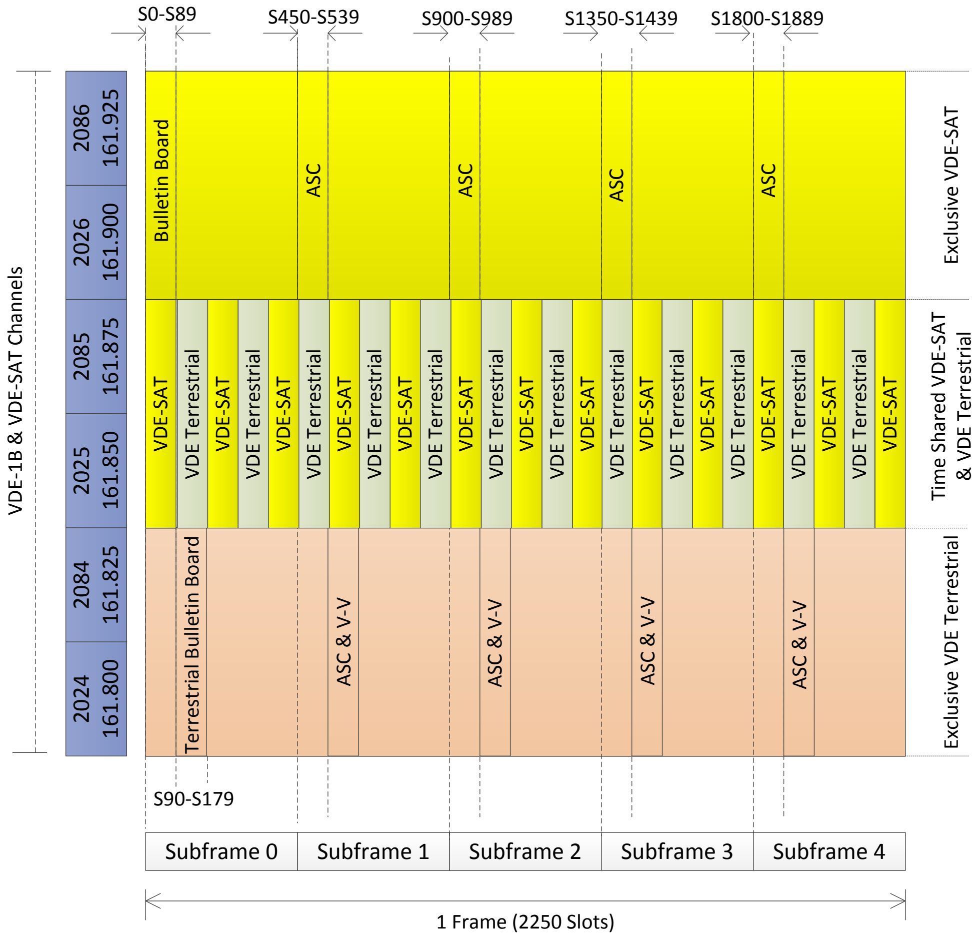
The resource sharing between VDE-SAT downlink and VDE shore-to-ship and ship-to-ship relies on the bulletin board and announcement channels of the satellite and shore stations. As an initial configuration for resource sharing, a static assignment in time and frequency should be adopted by the terrestrial and satellite entities. Figure A6-4 illustrates the initial configuration where:

- Channels 2024 and 2084 are exclusively used for terrestrial VDE, maintaining the original signalling assignment that was described above (as per Fig. A6-3).
- Channels 2026 and 2086 are exclusively used for VDE-SAT downlink, maintaining the original signalling assignment that was described above (as per Fig.e A6-3).
- Channels 2025 and 2085 are time-shared between VDE-SAT downlink and VDE terrestrial services. The time sharing is based on time intervals of 2.4 s (90 slots) that are assigned periodically to VDE-SAT and VDE terrestrial services (as shown in Fig. A6-4).

As the starting point of VDES resource sharing or in the absence of coordination between the shore and satellite operation, this resource sharing method should be used.

FIGURE A6-4

Initial resource sharing between VDE-SAT downlink and VDE terrestrial



5 Sharing between different VDE satellite systems

The sharing between two or more satellite system is organized by using the bulletin board, delivered by satellites in VDE-Sat downlink band (channels 2026 and 2086), as described in Annex 6.

The bulletin board provides as a minimum:

– Satellite and constellation ID

– Satellite ephemeris

– Downlink communication characteristics: spreading code (if any), time slots for broadcast, time slots for other communications, volume of data to downlink, and

– Uplink communication characteristics: spreading code (if any), available time slots for interrogation, available time slots for uplink, global communication channel load, etc.

By listening the bulletin board (transmitted every minute), ships can determine:

– When a satellite will be visible, and identify the satellite

– When a satellite will next be visible (based on ephemeris data)

– A satellite’s transmission characteristics (Doppler and delay, based on ephemeris data)

– Which data a ship shall receive (the security-related and safety-related broadcast downlink) and when they will be transmitted, and

– When it may initiate a communication for uplink or downlink of data, and globally in which part of the frame this initiated communication will take place.

The physical channel used for the bulletin board should allow for detection of overlapping signals received from multiple satellites. The use of direct sequence spreading as defined in Annex 4 (PL-Frame format 1) allows for detection of up to 8 overlapping signals.

6 VDE-1A terrestrial and VDE-SAT uplink resource sharing

At the lower frequency bands, channel 1026 and 1086 are dedicated to VDE-SAT uplink while channels 1024, 1084, 1025 and 1085 are shared for terrestrial and satellite communications.

The exclusive VDE-SAT uplink channels may be used for dedicated (demand assigned) or random access to satellite. Since there is no VDE terrestrial interference on these two channels, these channels should be used for higher priority message (safety, distress, acknowledgement, etc.).

The coordination between the VDE terrestrial (ship-to-shore) and VDE-SAT uplink is achieved using the bulletin board signalling channel as defined on the VDE-SAT downlink.

The use of direct sequence spreading for VDE-SAT uplink channel may provide a higher level of resilience in the presence of VDE ship-to-shore interfering signals.

Annex 7

Original design considerations to validate the VDES concept

1 Introduction

This annex provides additional information on the technical considerations of the VDES. It identifies aspects of both terrestrial and satellite VDE components, including access scheme options, antenna design and system sharing.

The annex reflects all original materials that were used to develop Annexes 2 through 6.

2 Summary of operational capability and performance

This Annex demonstrates the following operational capability and performance:

- Protection of GMDSS and AIS, i.e. recognizing that the implementation of VDES must ensure that the function of digital selective calling, AIS and voice distress, safety and calling communication (channel 16), are not impaired
- Relief of AIS VDL congestion
- Raw ASM data transfer at 28.8 kbits/s
- Raw VDE data transfer ship-to-ship, ship-to-shore and shore-to-ship at 307.2 kbits/s
- Raw VDE satellite data transfer up to 240 kbits/s
- VDE satellite downlink that satisfies the PFD mask requirements
- VDE shore-to-ship and ship-to-shore service to 85 km (46 NM)
- Channel access and sharing schemes that organize the links and mitigate conflicts
- Full VDES satellite and terrestrial functionality from a single shipborne antenna.

3 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.

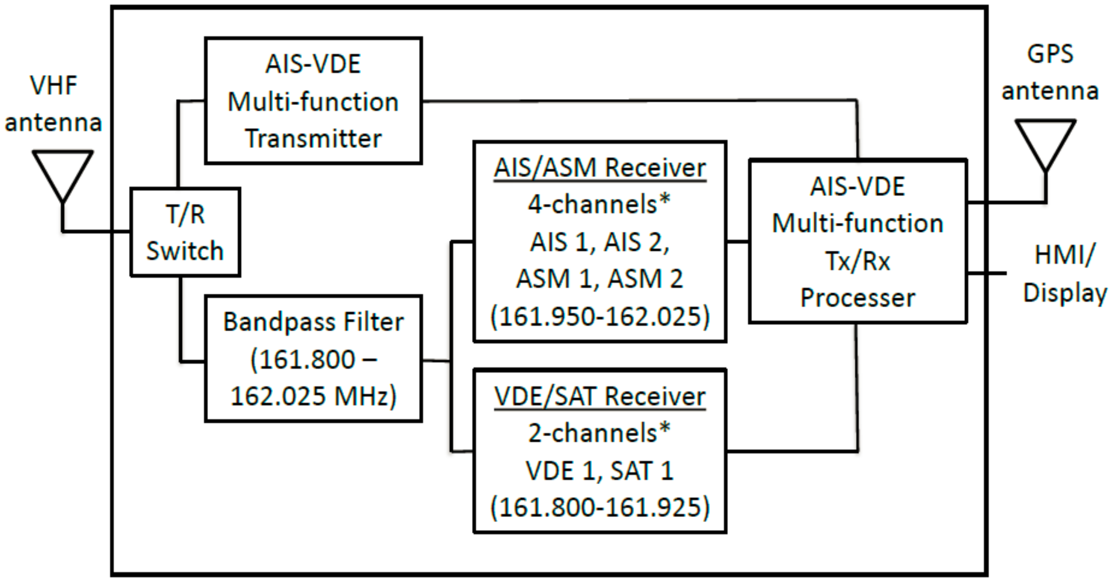
From Figure A1-1, the satellite downlink shares the spectrum with the terrestrial ship-to-ship and shore-to-ship links, and the satellite uplink shares the spectrum with the terrestrial ship-to-shore link. Thus, access schemes should be considered to mitigate potential conflicts between the links.

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

The VDES terrestrial service is comprised of ASM, VDE ship-to-shore, VDE shore-to-ship and VDE ship-to-ship. An example of a shipborne VDES transceiver implementation is illustrated in Fig. A7-1. 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 RR 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 A7-1

Example VHF data exchange system transceiver implementation



* For example, SDR (software defined radio) technology may be used.

4.1 Time division multiple access schemes

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

Note that Recommendation ITU-R M.1371 specifies the access schemes for the AIS messages, including ITDMA, on the AIS channels. It also specifies the structure for ASM and the content options for these messages. VDES provides dedicated ASM channels to relieve congestion on the AIS channels. Under VDES, the access scheme for using the ASM channels could initially be 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.

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

The TDMA access scheme for the VDE1-A, ship-to-shore link, could be by reservation through ITDMA from an ASM on either one of the ASM channels, as described in § 4.1.1. A VDE1-A ship-to-shore transmission should not exceed five contiguous slots.

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

The TDMA access scheme for the VDE1-B, ship-to-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-to-ship transmissions. A VDE1-B ship-to-ship transmission should not exceed five contiguous slots.

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

The TDMA access scheme for the VDE1-B, shore-to-ship link, could be the same as for the VDE1 ship-to-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 usually 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-to-ship transmission should not exceed five contiguous slots.

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

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

Table A4-1 provides the PFD at the Earth's surface from the satellite downlink at various elevation angles from 0° to 90°. 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.

4.2.1.1 Frequency division multiple access

Frequency division multiple access (FDMA) is accomplished by using only the upper 50 kHz for the VDE-SAT downlink, i.e. the two channels 2026 and 2086. The FDMA 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.

4.2.1.2 Time division multiple access

TDMA approach for shore-to-ship/ship-to-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 § 4.2.1 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 (2 250 slots/minute/frame) and access schemes (ITDMA, CSTDMA and FATDMA) that are used for VDES are defined in Recommendation ITU-R M.1371. This TDMA organization scheme protects the integrity of the AIS and is used to organize and synchronize the ASM and VDE transmissions.

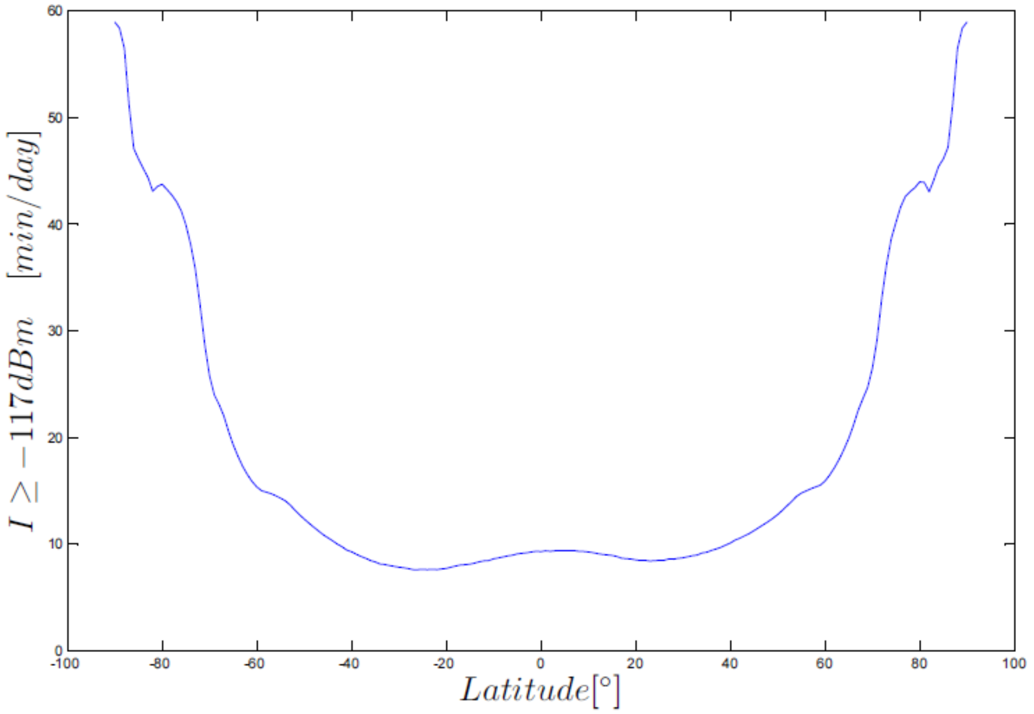
4.2.1.3 Full frequency reuse (simultaneous transmission)

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 Fig. A7-2.

FIGURE A7-2

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



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

4.2.2.1 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 channels 1026 and 1086 where no VDE terrestrial transmission is present.

4.2.2.2 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.

Recommendation ITU-R M.1371 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 provides 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.

4.2.2.3 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.

5 VHF data exchange – terrestrial

5.1 Waveforms for VHF data exchange

5.1.1 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. 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 A7-1 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.1546-5.

TABLE A7-1

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	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 kbits/s (1X)	28.8 kbits/s (3X)	307.2 kbits/s (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 (+9 dB) and range discrimination compared to AIS.	Provides much higher (32X) data transmission than AIS. Inferior CCR (+9 dB) 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.

5.1.2 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 Annex 1 of Recommendation ITU-R M.1842-1. 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 kbits/s 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.

5.1.3 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 kbits/s 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 2 400 symbols/s (2 400 symbols/s/carrier × 4 bits/symbol = 9 600 bits/s/carrier).

The long symbol duration (2 400 symbols/s = 416.7 µs/symbol) is designed to mitigate multi-path inter-symbol interference, since (ref: Report ITU-R M.2317) 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 4 800 symbols/s (9 600 bits/s) 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 analogue, 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-outphasing.

Note that the analogue 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 W) and VDES base stations (50 W).

5.2 Antenna options for VHF data exchange system terrestrial stations

Commercially available antenna options for the VDES terrestrial stations are characterized in Fig. A7-3 below. Since the shipborne antenna is required to receive the VDES satellite downlink at high elevation angles, the 0 dBd (2.1 dBi) 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 6 dBd (8 dBi) option is selected. These two antennas are used in the propagation range predictions in Annex 2.

Figure A7-4 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 A4-1 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 A7-3

Antenna options for shipborne VHF data exchange system stations

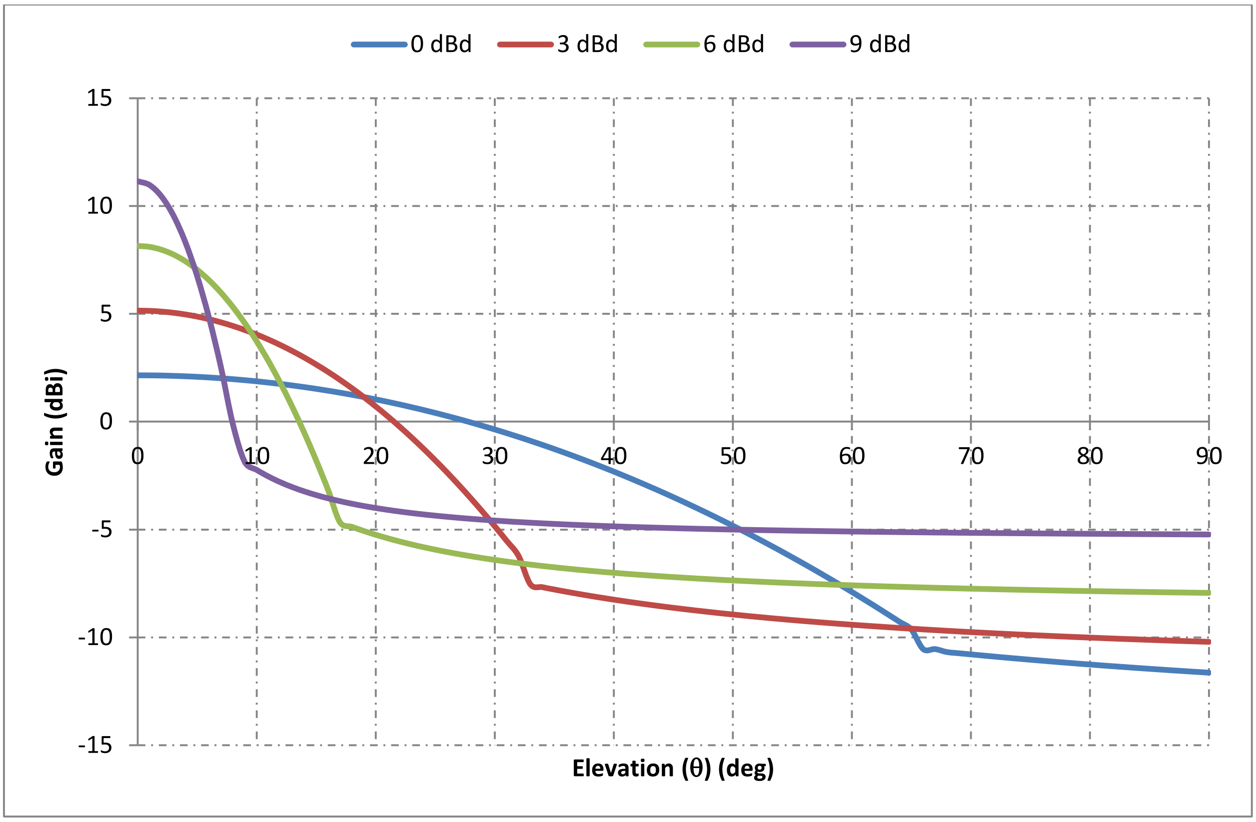
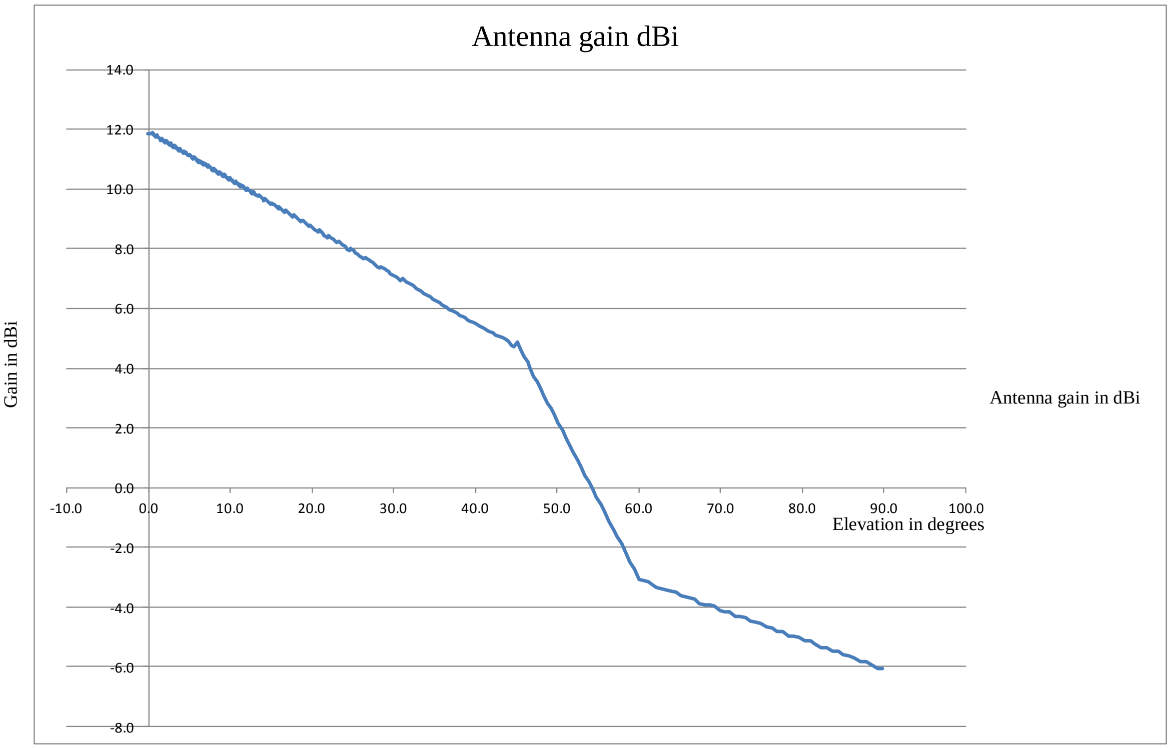


FIGURE A7-4

Mask for "Ideal" antenna



6 VHF data exchange by satellite

VHF data exchange by satellite should use the channels designated for satellite in Table A1-1 of Annex 1 and should be in accordance with this Recommendation. This is further described below.

6.1 General

6.1.1 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).

6.1.2 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 small vessels, fishing vessels and recreational vessels.

6.2 Overall architecture, operational characteristics and assumptions

6.2.1 Architecture

The VHF data exchange system architecture is shown in Fig. A7-5 below. The VDE-SAT is composed of one or more satellites transmitting and receiving in the maritime VHF bands this is the space segment.

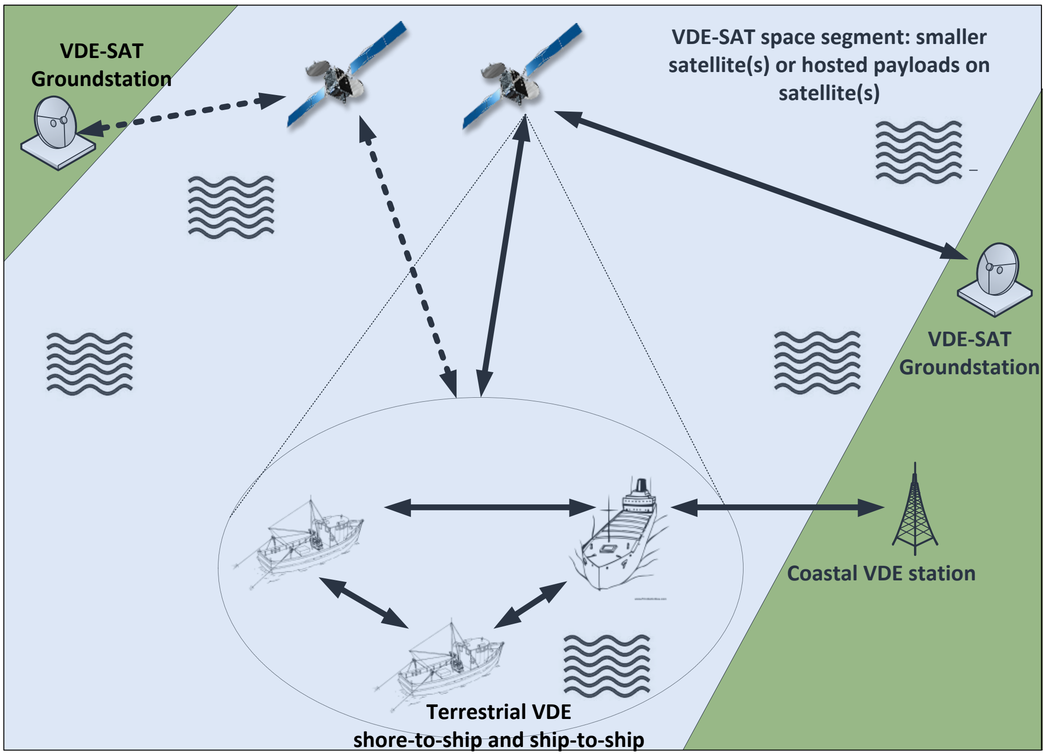
Due to the frequencies used, it is likely that VDE-SAT will consist of low-earth orbiting (LEO) or medium-earth orbiting (MEO) satellites. VDE-SAT could also consist of hosted payloads on spacecraft in such orbits.

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 A7-5

VHF data exchange-satellite component architecture



6.2.2 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.

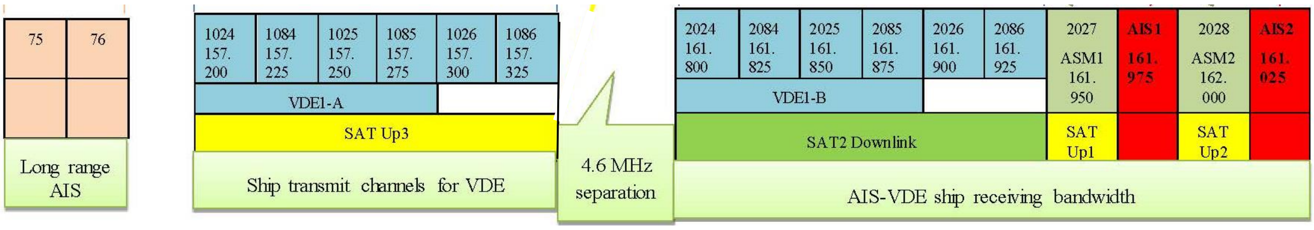
6.3 Technical characteristics

6.3.1 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 Fig. A7-6.

FIGURE A7-6

VHF data exchange system channel allocation



6.3.1.1 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 § 5.1.3).

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 § 6.4.2.19 concludes that a downlink data rate of 240 kbits/s 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 A7-2 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.

TABLE A7-2

Power flux-density mask

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

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

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).

6.3.1.2 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.

6.3.2 Rationale of channel allocation for VHF data exchange-satellite

The frequency plan for the entire VDES, as depicted in Fig. A7-6 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).

6.4 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.

6.4.1 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.

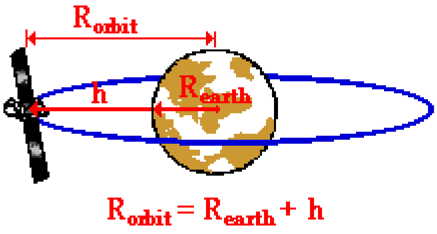
6.4.1.1 Determine the satellite's orbit

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: $M_{\text{earth}} = 5.98 \times 10^{24}$ kg, $R_{\text{earth}} = 6.37 \times 10^{6}$ m.

The satellite's orbit and the known and unknown parameters are shown in Fig. A7-7 below.

FIGURE A7-7

Satellite orbital characteristics



Known:	Unknown:
$R = R_{\text{earth}} + \text{height} = 6.92 \times 10^{6}$ m	v
$M_{\text{earth}} = 5.98 \times 10^{24}$ kg	a
$G = 6.673 \times 10^{-11}\ N\ \text{m}^2/\text{kg}^2$	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 Fig. A7-7, 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,

$v = \text{SQRT}((G \times M_{\text{central}}) / R)$

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

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

Determine the acceleration of the satellite,

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

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

$a = 8.333\ \text{m/s}^2$.

Determine the orbital period of the satellite,

$T = \text{SQRT}((4 \times \pi^2 \times R^3) / (G \times M_{\text{central}}))$

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

$T = 5725.7$ s = 1.59 h.

6.4.2 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.

6.4.2.1 Determine the Earth's rotation at the equator between each satellite orbit

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

6.4.2.2 Determine the slant distance to the Earth's horizon

The slant distance $\boldsymbol{D_s}$ from the satellite to the Earth's horizon is $\boldsymbol{D_s} = \text{SQRT}(\boldsymbol{R^2} - \boldsymbol{R_e^2}) = \text{SQRT}((6.92 \times 10^6\ \text{m})^2 - (6.37 \times 10^6\ \text{m})^2) = 2.7036 \times 10^6$ m = 2 703.6 km.

6.4.2.3 Determine the slant downward tilt angle to the Earth's horizon

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

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

6.4.2.4 Determine the width of the antenna coverage path

The example VDES satellite antenna pattern is shown in Fig. A7-8 below. The beam width (±3 dB) of the antenna is 80 degrees. The width of the satellite antenna's coverage path is:

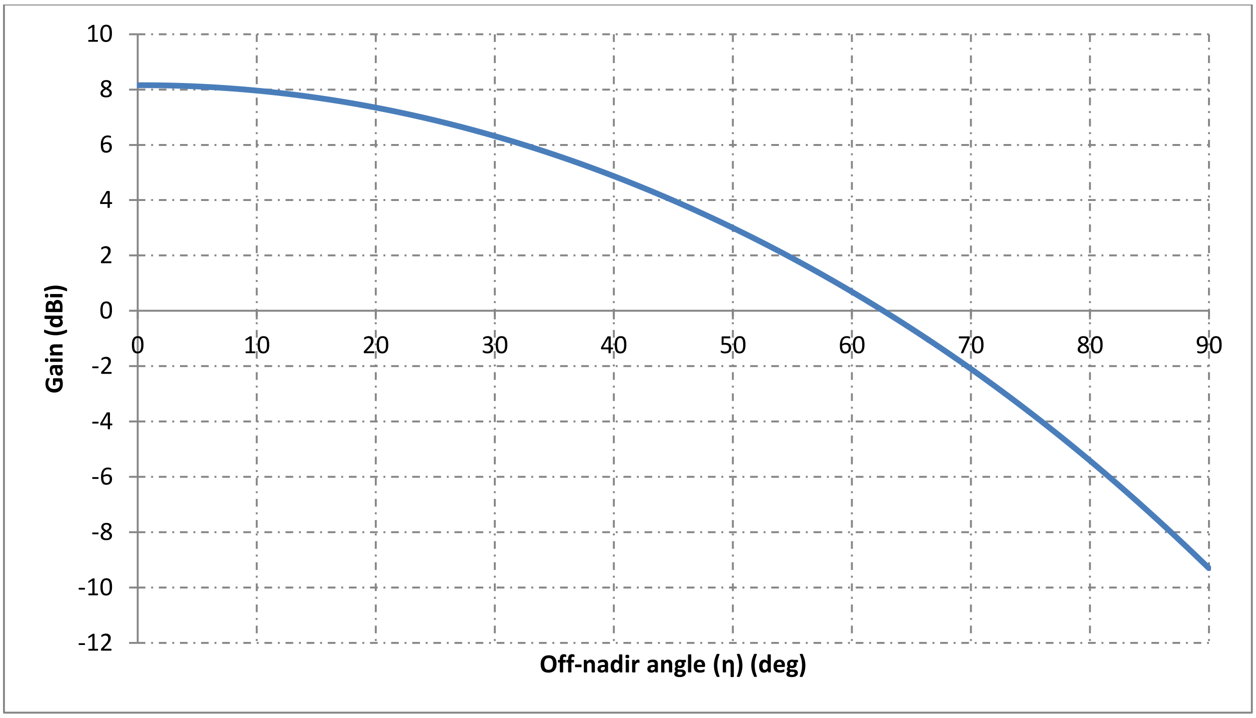
$W_c = 2\ (D_s \cos(90° - \theta_a/2))$

$W_c = 2 \times 2.7036 \times 10^6\ \text{m} \times \cos(90° - 80° / 2) = 3.4757 \times 10^6$ m = 3 475.6 km.

NOTE: From 4.2.1 that since ROT_{equator} = 2 652.4 km, this antenna beamwidth (θ_a = 80°) 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 A7-8

Example VDES satellite antenna pattern



6.4.2.5 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 f_d (max) = f_{VDES} (v/c) × cos θ_d = $162 \times 10^6 (7.594 \times 10^3)/(3 \times 10^8) \times \cos 23° = 3\,775$ Hz. The satellite transmitter frequency should be reduced by half of f_d (max) to provide a range of ±1 887.5 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 A7-8 above, note that the response is flat to approximately 12°. This supports an additional downward tilt of 12° below the horizon of 23° 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.

6.4.2.6 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/(m^2 × 4 kHz)) as a function of the elevation angle from the Earth), is shown in Table A7-2 of § 6.3.1. Note that the PFD mask at 0°

(horizon) is −149 dB(W/(m^2 × 4 kHz)), at 45° elevation is −142 dB(W/(m^2 × 4 kHz)), at 60° elevation is −134 dB(W/(m^2 × 4 kHz)) and at 90° (overhead) is −131 dB(W/(m^2 × 4 kHz)).

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° 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.

6.4.2.7 Determine the power flux density levels at elevations of 0°, 10°, 30°, 60° and 90° when the power flux density level at 45° elevation is set to −142 dB(W/(m^2 × 4 kHz))

This section confirms that the elevation angle of 45° 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 2 703.6 km. The results of these calculations are shown in Table A7-3 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° (the angle to the horizon) and proceed to C = 0° (the directly above/below position), shown in Table A7-3.

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 centre 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° from the reference angles, also shown in Table A7-3 below.

6.4.2.8 Determine reference levels based on the 45° elevation angle

From Table A7-2, the slant range to the satellite at 45° elevation is 748.3 km and the PFD at 45° elevation is set to the mask limit of −142 dB(W/(m^2 × 4 kHz)). Since the relative angle of the satellite antenna (down-tilted by 35°) in that direction is approximately (45° − 35°) = 10°, the gain of the satellite antenna in that direction, from Fig. A7-19, 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.

6.4.2.9 Determine the power flux density level for the elevation angle of 0°

The slant range at 0° (horizon) is 2 703.6 km, the satellite relative angle to the horizon is −23°, the satellite antenna relative angle with a 35° down-tilt is (35° − 23°) = 12° and the gain, from Figure A7-19, is 8 dB. Since the relative range loss is (20 log (748.3/2 703.6)) = −11.2 dB, the PFD at 0° is 11.2 dB below the 45° level (−142 − 11.2) = **−153.2 dB(W/(m^2 × 4 kHz))** which is (−149 − (−153.2)) = 4.2 dB below the 0° mask limit.

6.4.2.10 Determine the power flux density level for the elevation angle of 10°

The slant range at 10° elevation is 1 818.4 km, the satellite relative angle to the horizon is −23°, the satellite antenna relative angle with a 35° down-tilt is (35° − 23°− 10°) = 2° the gain, from Fig. A7-19, is 8 dB (the same as the reference), the relative range loss is 20 log (748.3/1 818.4) = −7.7 dB and thus the PFD at 10° is (−142 − 7.7) = **−149.7 dB(W/(m^2 × 4 kHz))** which is 2.3 dB below the 10° mask limit of −147.4 dB(W/(m^2 × 4 kHz)).

6.4.2.11 Determine the power flux density level for the elevation angle of 30°

The slant range at 30° elevation is 993.5 km, the satellite relative angle to the horizon is −23°, the satellite antenna relative angle with a 35° down-tilt is (35° − 30°) = 5° the gain, from Fig. A7-19, 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° is (−142 – 2.5) = **−144.5 dB(W/(m^2 × 4 kHz))** which is 0.3 dB below the 10° mask limit of −144.2 dB(W/(m^2 × 4 kHz)).

6.4.2.12 Determine the power flux density level for the elevation angle of 60°

The slant range at 60° elevation is 632.7 km, the satellite relative angle to the horizon is −23°, the satellite antenna relative angle with a 35° down-tilt is (35° − 60°) = −18° the gain, from Fig. A7-19, 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° is (−142 − 0.5 + 1.5) = **−141.0 dB(W/(m^2 × 4 kHz))** which is 7.0 dB below the 60° mask limit of −134.0 dB(W/(m^2 × 4 kHz)).

6.4.2.13 Determine the power flux density level for the elevation angle of 90°

The slant range at 90° (overhead) is the satellite altitude of 550 km, the gain of the satellite antenna in that direction, from Fig. A7-19, with a down-tilt of 35 degrees is the gain at (35° − 90°) = −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° is (−142 − 6 + 2.7) = **−145.3 dB(W/(m^2 × 4 kHz))** which is 14.3 dB below the 90° mask limit of −131 dB(W/(m^2 × 4 Hz)).

The PFD values for elevation angles from 0° to 90° are shown in Table A7-3 below.

TABLE A7-3

Power flux density for various elevation angles

Orbital angle (degrees)	Elapsed time from horizon (seconds)	Slant range (km)	Reference angle (degrees)	Elevation angle (degrees)	PFD (actual/mask/margin, in dB(W/(m^2 × 4 kHz)))
23	0	2 703.6	90	0	−153.2/−149/4.2
22	15.9	2 592.7	90.5	0.5	−152.8/−148.9/3.9
21	31.8	2 481.6	91.0	1.0	−152.4/−148.8/3.6
20	47.7	2 370.5	93.2	3.2	−152/−148.5/3.5
19	63.6	2 259.6	94.4	4.4	−151.6/−148.3/3.3
18	79.5	2 148.8	95.6	5.6	−151.2/−148.1/3.1
17	95.4	2 038.3	97.0	7.0	−150.7/−147.9/2.8
16	111.3	1 928.1	98.4	8.4	−150.2/−147.7/2.5
15	127.2	1 818.4	100.0	10.0	−149.7/−147.4/2.3
14	143.1	1 709.2	101.6	11.6	−149.2/−147.1/2.1
13	159.0	1 600.6	103.5	13.5	−148.6/−146.8/1.8
12	175.0	1 493.0	105.5	15.5	−148/−146.5/1.5
11	190.9	1 386.5	107.8	17.8	−147.4/−146.1/1.3
10	206.8	1 281.4	110.3	20.3	−146.7/−145.8/0.9
9	222.7	1 178.1	113.2	23.2	−145.9/−145.3/0.6

TABLE A7-3 (*end*)

Orbital angle (degrees)	**Elapsed time from horizon (seconds)**	**Slant range (km)**	**Reference angle (degrees)**	**Elevation angle (degrees)**	**PFD (actual/mask/margin, in dB(W/(m^2 × 4 kHz)))**
8	238.6	1 077.3	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 to Table A7-3:

1. When the PFD level is set to the mask limit of −142 dB (W/(m2 × 4 kHz)) at 45° elevation angle, the PFD levels at all other elevation angles are below the mask.
2. The maximum PFD level is −141 dB (W/(m2 × 4 kHz)) at 60° elevation angle, which is 7 dB below the mask limit level of −134 dB(W/(m2 × 4 kHz)).

6.4.2.14 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.

6.4.2.15 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 Fig. A7-3 in § 5.3. This analysis considers the 0 dBd antenna because it has the best performance for the elevation angles required for satellite detection.

6.4.2.16 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 A7-4 below are used to determine a reference value of C/N (carrier-to-noise ratio) for the example shipborne VDES receiver.

TABLE A7-4

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): $P_r = GE^2c^2/480\pi^2f^2$, where
G = gain of a half-wavelength (λ/2) dipole antenna = 1.64
E = field strength = 4×10^{-6} V/m (4 μV/m = +12 dBμ)
c = speed of light in free space = 3×10^8 m/s
f = VDES downlink frequency = 161.9×10^6 (161.9 MHz)
λ = 1.852 m (at 161.9 MHz)
$P_r = 19.02 \times 10^{-15}$ W = −137.2 dBW = −107.2 dBm
The logarithmic formula can also be used to calculate P_r (dBm):
P_r (dBm) = 42.8 − 20 log F + 20 log E + G, where
G = antenna gain in dBi = 2.1 dBi (2.1 dB over isotropic)
F = frequency in MHz = 161.9
P_r (dBm) = 42.8 – 44.1 – 108 + 2.1 = −107.2 dBm (−137.2 dBW)
PFD = dB(E) −153.72 = 12−153.72 = −141.72 dB(W/($\text{m}^2 \times 4$ kHz)) from a vertically-polarized source
A_e = effective area for a dipole antenna = $0.13\lambda^2 = 0.446\ \text{m}^2$
P_r (25 kHz channel) = PFD + 10 log A_e + 10 log (25/4) = −141.7 − 3.5 +8 = −137.2 dBW = −107.2 dBm
Power received by a shipboard VDES receiver (reference 150 kHz channel):
Noise floor in a 150 kHz bandwidth: kTB = 10 log ((1.38×10^{-23}) (290) (150×10^3))= −152.2 dBW
Rx carrier power (reference) in a 150 kHz bandwidth: C = 10 log ((19.02×10^{-15}) (150/25))= −129.4 dBW
Applying adjustments for cable loss (2dB) and Rx noise figure (4 dB), the C/N calculation follows:
C/N (150 kHz bandwidth): C/N_{ref} = (−129.4 − 2) − (−152.2 + 4) = 16.8 dB (Rx 0 dBd antenna, 0° elevation)
NOTE: These calculations serve to confirm the applicability of the metrics and reference levels.

6.4.2.17 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 A7-4, determine the C/N for the PFD values and elevation angles in Table A7-3, taking into account the shipborne antenna angular gain values for the 0 dBd antenna in Fig. A7-3. For this antenna, G_a = 2.1 dBi at 0° elevation angle.

$C/N = C/N_{ref} - (-142 - \text{PFD} - (2.1 - G_a))$, where G_a = shipborne antenna gain at the elevation angle.

- At 0° elevation, C/N = 16.8 − (−142 − (−153.2) − (2.1 − 2.1)) = 5.6 dB
- At 10° elevation, C/N = 16.8 − (−142 − (−149.7) − (2.1 − 1.9)) = 8.9 dB
- At 30° elevation, C/N = 16.8 − (−142 − (−144.5) − (2.1 − (−0.3)) = 11.9 dB
- At 45° elevation, C/N = 16.8 − (−142 − (−142) − (2.1 − (−3.5)) = 11.2 d.
- At 60° elevation, C/N = 16.8 − (−142 − (−141) − (2.1 − (−7.6)) = 8.1 dB
- At 90° elevation, C/N = 16.8 − (−142 − (−145.3) − (2.1 − (−11.6)) = −0.2 dB.

The C/N values for elevation angles from 0° to 90° are shown in Table A7-5 below.

TABLE A7-5

Carrier to noise and power flux density for various elevation angles

Orbital angle (degrees)	**Elapsed time from horizon (seconds)**	**Slant range (km)**	**Elevation angle (degrees)**	**PFD (actual/mask/margin, in dB(W/(m^2 × 4 kHz)))**	***C/N* ship receiver (dB)**
23	0	2 703.6	0	−153.2/−149/4.2	5.6
22	15.9	2 592.7	0.5	−152.8/−148.9/3.9	6
21	31.8	2 481.6	1.0	−152.4/−148.8/3.6	6.4
20	47.7	2 370.5	3.2	−152/−148.5/3.5	6.8
19	63.6	2 259.6	4.4	−151.6/−148.3/3.3	7.2
18	79.5	2 148.8	5.6	−151.2/−148.1/3.1	7.6
17	95.4	2 038.3	7.0	−150.7/−147.9/2.8	8
16	111.3	1 928.1	8.4	−150.2/−147.7/2.5	8.5
15	127.2	1 818.4	10.0	−149.7/−147.4/2.3	8.9
14	143.1	1 709.2	11.6	−149.2/−147.1/2.1	9.4
13	159.0	1 600.6	13.5	−148.6/−146.8/1.8	9.7
12	175.0	1 493.0	15.5	−148/−146.5/1.5	10.2
11	190.9	1 386.5	17.8	−147.4/−146.1/1.3	10.8
10	206.8	1 281.4	20.3	−146.7/−145.8/0.9	10.9
9	222.7	1 178.1	23.2	−145.9/−145.3/0.6	11.5
8	238.6	1 077.3	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
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

6.4.2.18 Determine the data rate for elevation angles 0^0 to 60^0 using the digital video broadcast by satellite standards

The digital video broadcast standards, by satellite (DVB-S), 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 Fig. A7-9 below.

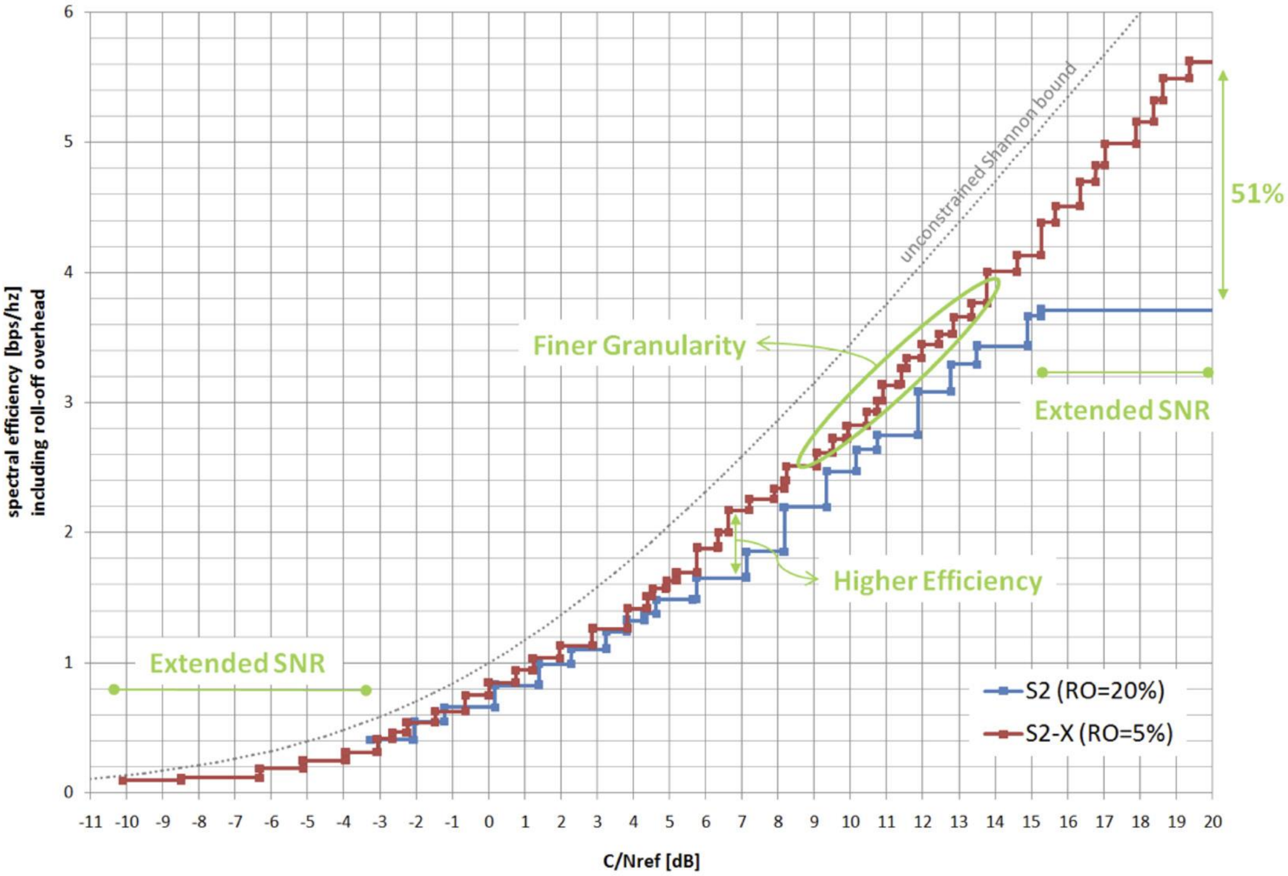
DVB-S2X is based on the well-established DVB-S2 specification. It uses the proven and powerful LDPC FEC scheme in combination with BCH FEC as outer code and introduces the following additional elements:

– 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; and
- Super-frame option.

FIGURE A7-9

Performance of DVB-S2X and DVB-S2



6.4.2.19 Performance conclusion

From Fig. A7-9 above, it is concluded that the DVB-S2X standard transmission applied to the VDES satellite downlink provides spectral efficiency of 1.6 bps/Hz and a date-rate of 240 kbits/s in a 150 kHz bandwidth for $C/N \geq 5$ dB, which, from Table A7-5, includes elevation angles from 0° to 60°.

7 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. 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.

7.1.1 Ship-to-shore application

7.1.1.1 Basis for the coverage assessment

This coverage assessment is based on Recommendation ITU-R P.1546-5 (assuming no ducting), taking into account the antenna height and the seawater propagation path:

Height of antenna (Base Station):	75 m (see graph for various heights)
Transmitter power for ship:	12.5 W
Tx ship antenna gain:	2 dBi (0 dBd)
Rx shore antenna gain:	8 dBi (6 dBd)
P_r:	−103 dBm (VDE shore station sensitivity)

7.1.1.2 Purpose for use of the Recommendation ITU-R P.1546-5 propagation curve

Recommendation ITU-R P.1546-5 prescribes the use of the propagation curves (§3 from Annex 5 and Fig. 4 from Annex 2 of ITU-R P.1546-5), see below Figs. A7-10 and A7-11 of this Annex, 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.

7.1.1.3 Determination of transmitting/base antenna height, h_1

Recommendation ITU-R P.1546-5 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.

NOTE: The reference antenna height for the ship's stations h_2 is 10 m.

7.1.1.4 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 V/m

G_r = gain of receiving antenna = 6.3 = 8 dBi

c = speed of light in free space = 3×10^8 m/s

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

$P_r = 5 \times 10^{-14}$ watts = −133 dBW = −103 dBm

Thus,

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

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

P_r (dBm) = 42.8 − 20 log F + 20 log E + G, where

G = antenna gain in dBi = 8 dBi

F = frequency in MHz = 157

P_r (dBm) = 42.8 − 43.9 − 109.9 + 8 = −103 dBm (−133 dBW)

7.1.1.5 Determine the range to the +10.1 dBµ (−103 dBm) coverage limit for a seawater propagation path

Calculate the effective radiated power:

$P_s = P_t + G$

$P_t = 10 \log 12.5 - 30 = -19$ dBkW (19 dB below 1 kW)

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

Thus $P_s = -19 + 0 = -19$ dBkW e.r.p.

$F_e = F - P_s$ (vertical scale reference for the propagation graph in Fig. A7-10)

$F = +10.1$ dBµ

$P_s = -19$ dBkW

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

7.1.1.6 Determine the seaward ship-to-shore coverage range from Fig. A7-10

The +10.1 dBµ (−103 dBm) range is 85 km, which is 46 NM (use $h_1 = 75$ m).

7.1.1.7 Determine the received signal strength indication values for various other ranges

The reference point received signal strength indication (RSSI) = −103 dBm at a range of 85 km (46 NM) is determined above. For other ranges, the RSSI value is determined from the propagation curve (Fig. A7-10) for the assumed antenna height of 75 m. RSSI values in 10 dB increments above the sensitivity threshold are shown in Table A7-6 below.

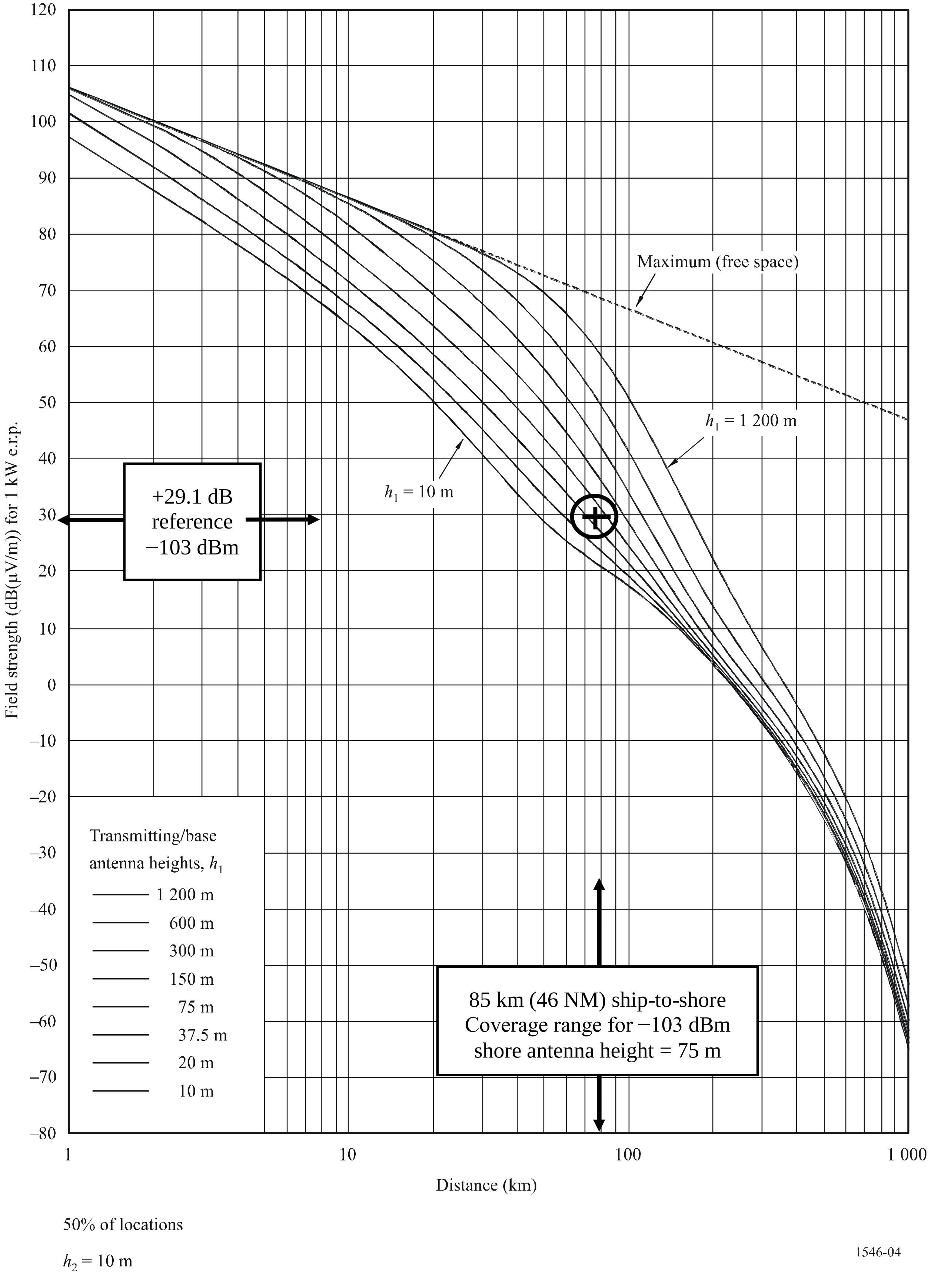
TABLE A7-6

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

−103 dBm	85 km (46 NM)
−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 A7-10

100 MHz, sea path, 50% time



7.1.2 Shore-to-ship application

7.1.2.1 Basis for the coverage assessment

Referring to § 2 above, we consider the reverse direction, shore-to-ship, signal levels at the ship receiving site, the shore transmitter power of 50 W and the shore-to-ship frequency of 162 MHz:

Height of antenna (VDES Base Station):	75 m (see graph for various heights)
Transmitter power of VDES on shore:	50 W (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)

7.1.2.2 Determination of 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 V/m

G_r = gain of receiving antenna = 1.62 = 2.1 dBi

c = speed of light in free space = 3×10^8 m/s

f = VDE shore-to-ship frequency = 1.62×10^8 (162 MHz)

$P_r = 1.58 \times 10^{-13}$ W = −128 dBW = −98 dBm

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

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

P_r (dBm) = 42.8 − 20 log F + 20 log E + G, where

G = antenna gain in dBi = 2.1 dBi

F = frequency in MHz = 162

P_r (dBm) = 42.8 − 44.1 − 98.7 + 2.1 = −98 dBm (−128 dBW).

7.1.2.3 Determine the range to the +21.3 dBµ (−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 = −13 dBkW (13 dB below 1 kW)

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

Thus P_s = −13 + 6 = −7 dBkW e.r.p.

$F_e = F - P_s$ (vertical scale reference for the propagation graph in Fig. A7-11)

F = +21.3 dBµ

P_s = −7 dBkW

Thus F_e = 21.3 − (−7) = +28.3 dB.

NOTE: that since this value of F_e is within 1 dB of the value calculated in § 7.1.1.5 because the reduced sensitivity of the ship station is compensated by the higher power and antenna gain of the shore base station.

7.1.2.4 Determine the seaward shore-to-ship coverage range from Fig. A7-11

The +28.3 dBµ (−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.

7.1.2.5 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 § 7.1.1.6 above. For other ranges, the RSSI value is determined from the propagation curve (Fig. A7-11) 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 A7-7 below.

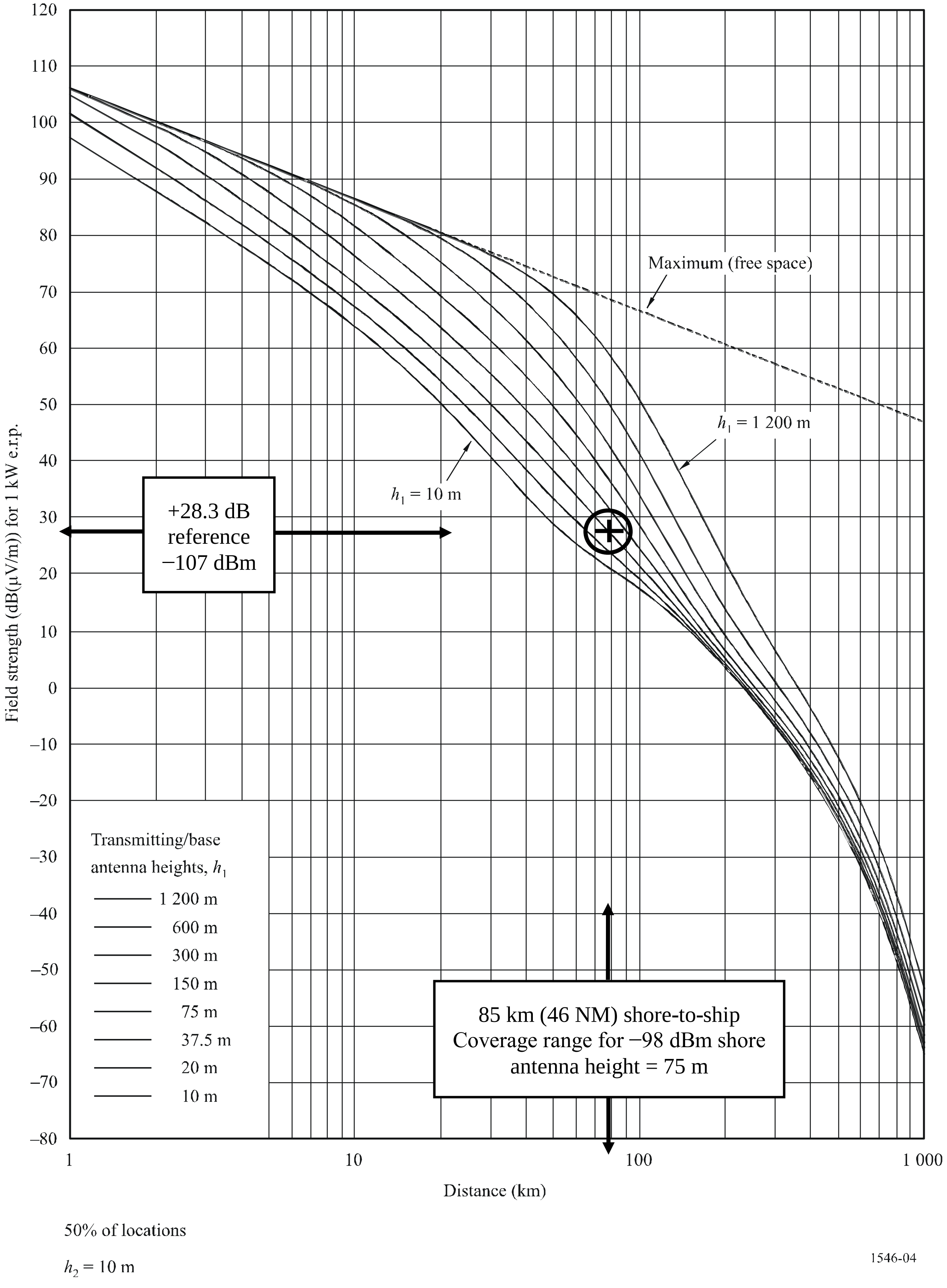
TABLE A7-7

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 (46 NM)
−88 dBm	60 km
−78 dBm	40 km

FIGURE A7-11

100 MHz, sea path, 50% time



8 Example of VHF data exchange satellite downlink implementation and analysis

8.1 Introduction

This is an informative annex providing an example of implementing the VDE-SAT downlink component and presenting performance results.

8.2 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 Fig. A7-12 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 A7-12

Satellite elevation and delay for the selected orbit as a function of time

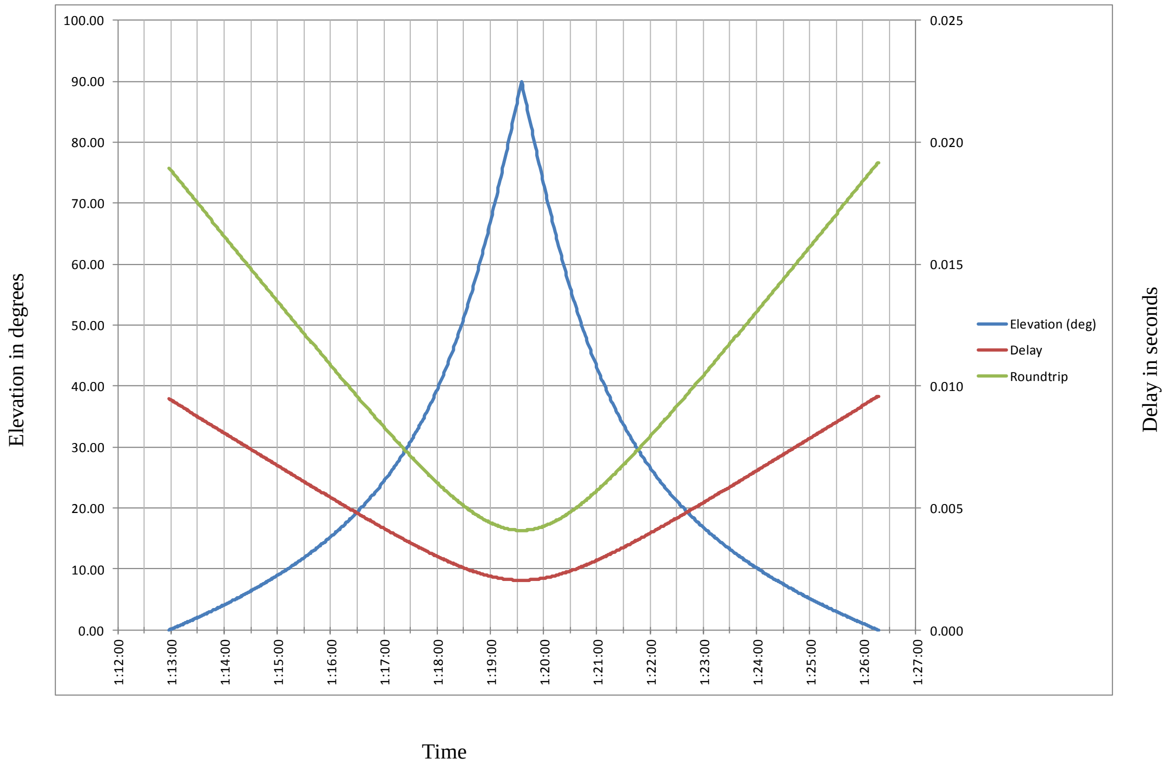


Figure A7-12 shows that the satellite is just over 4 minutes above 30° elevation, thus 9 minutes under 30° elevation from acquisition-of-signal (AOS) to loss-of-signal (LOS) for a pass duration of about 13 minutes. The roundtrip delay varies from 19 ms at AOS down to 4 ms at zenith (i.e. 90° elevation). 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 A7-13

Pass elevation scheme for selected orbit over 24 hours

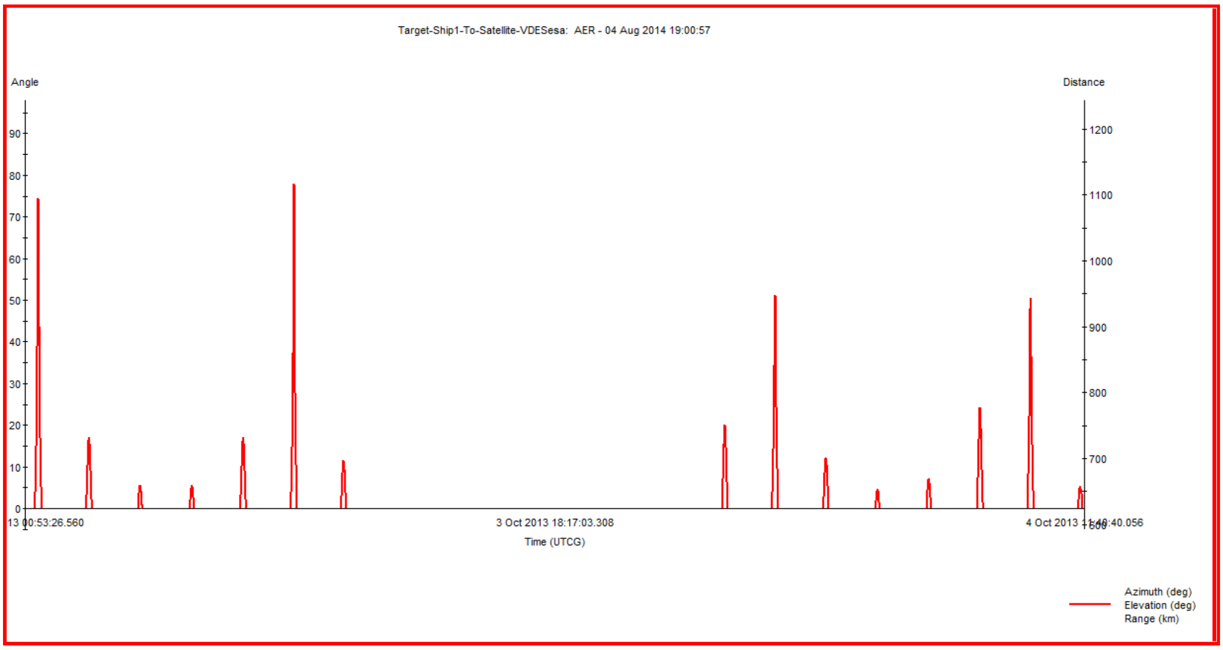


Figure A7-13 illustrates the satellite elevation as a function of time, as seen by a ground terminal at a fixed location in a 24 hour period. As shown the contact periods are short and low. Depending on the latitude, the duration and the number of contact periods will vary (distance is provided in km).

FIGURE A7-14

Satellite field of view

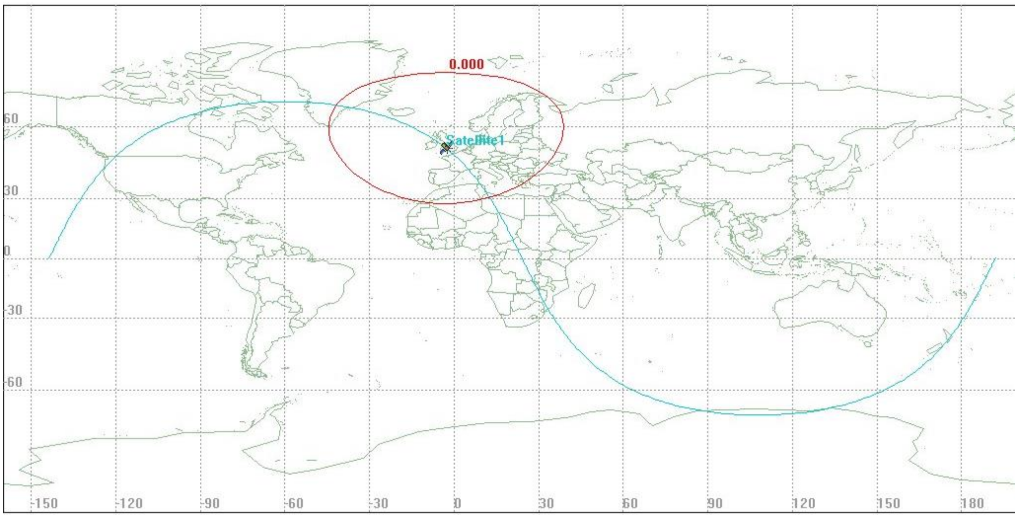


Figure A7-14 presents the satellite field of view. A wide geographical area is covered by the satellite field of view at any given point of the orbit. For this area, the average instantaneous ship count is 22 000 respectively as shown in Fig. A7-15. The ship count is based on combined received terrestrial and satellite data for AIS class A.

FIGURE A7-15

Field of view case for ship instantaneous number

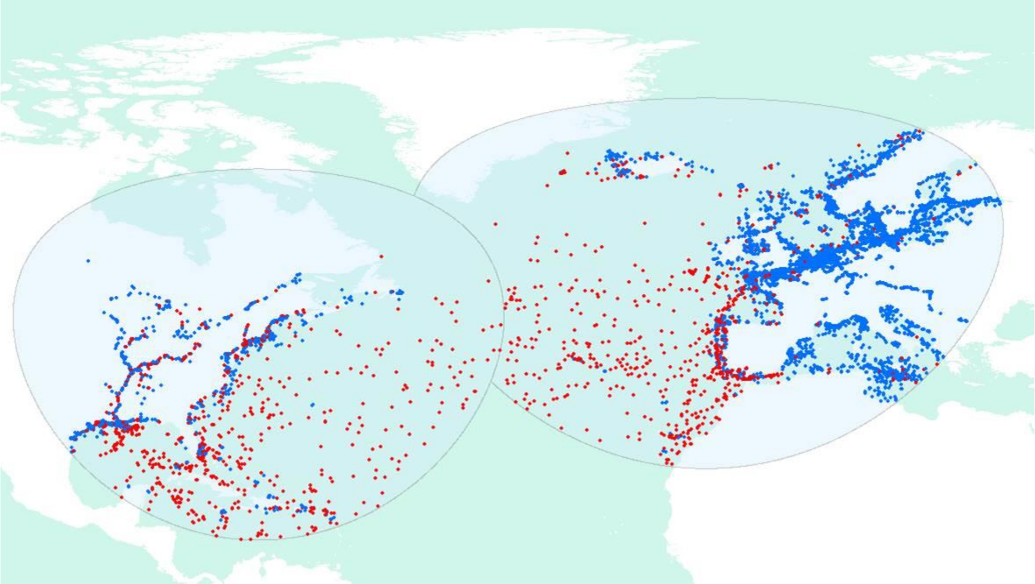


Figure A7-15 is indicative of the AIS received by terrestrial stations is displayed in blue while AIS received by satellite is displayed in red.

8.2.1 VHF data exchange satellite downlink characteristics

The power flux density mask to be respected is (as also presented in Table A4-1 of Annex 4).

$$\mathrm{PFD}(\theta°)_{\ (\mathrm{dBW}/(\mathrm{m}^2*4\ \mathrm{kHz}))} = \begin{cases} -149+0.16*\theta° & 0°\leq\theta<45°; \\ -142+0.53*(\theta°-45°) & 45°\leq\theta<60°; \\ -134+0.1*(\theta°-60°) & 60°\leq\theta\leq90°. \end{cases}$$

where θ is the angle of arrival of the incident wave above the horizontal plane, in degrees.

Which is tabulated as follows:

TABLE A7-8

Tabulation of pfd mask

	dBW	**Δ = −36.0 dB**	**Δ = +14.0 dB**
Theta	Flux/4 kHz	Flux/1 Hz	Flux 100 kHz
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

TABLE A7-8 (*end*)

	dBW	**Δ = −36.0 dB**	**Δ = +14.0 dB**
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 A7-16

Power flux density mask

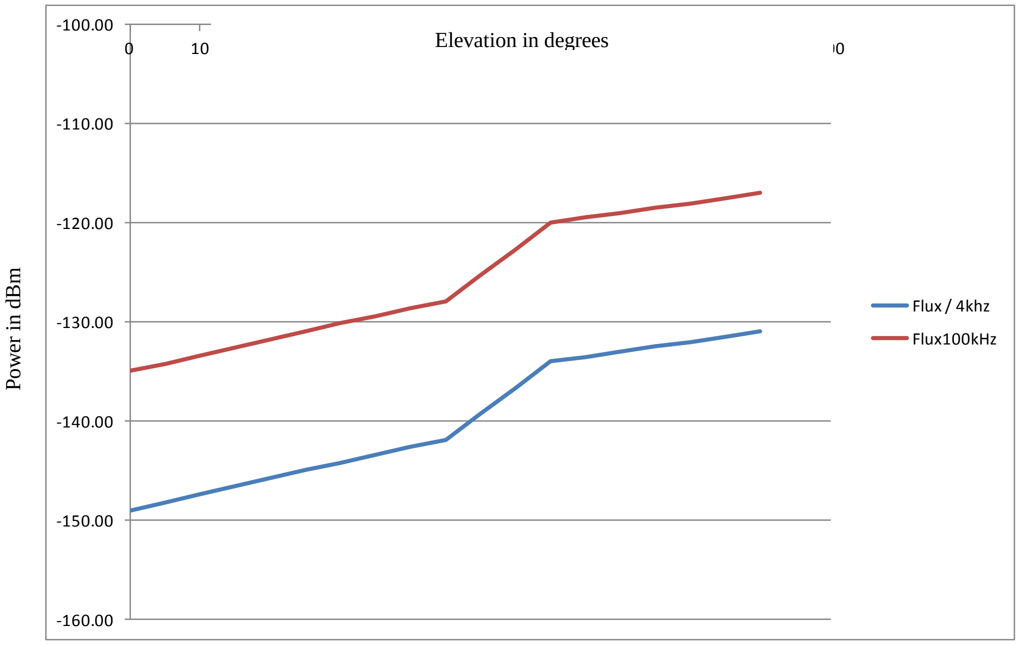


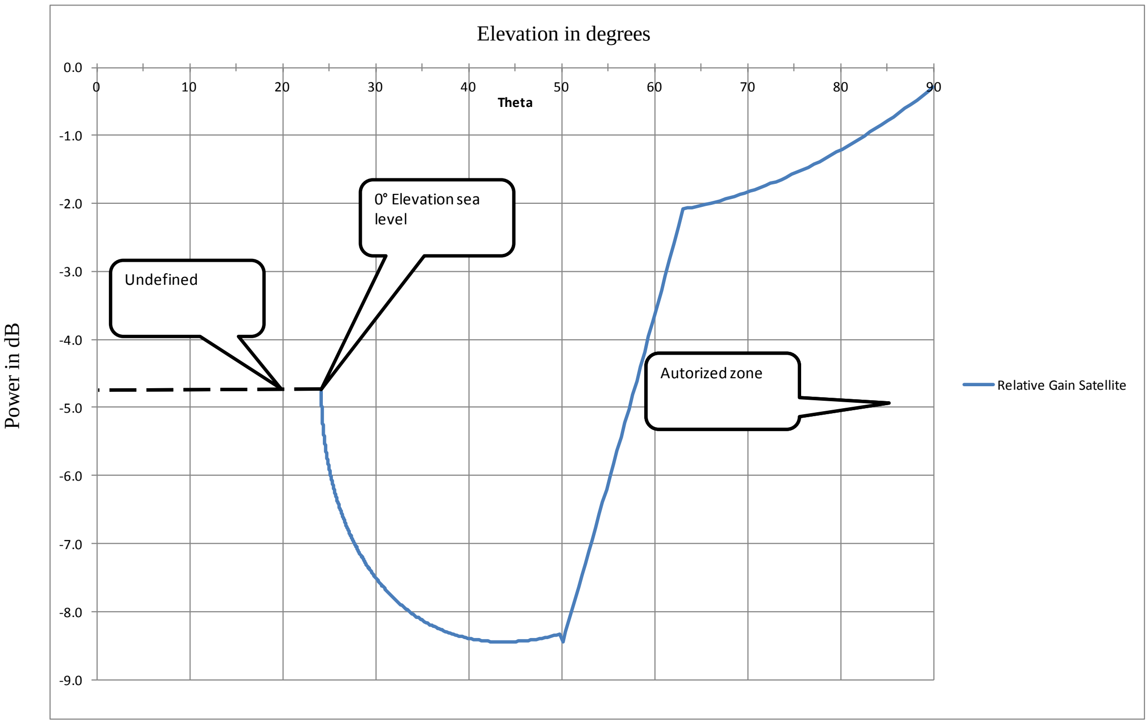
Figure A7-16 depicts the PFD mask in dBm as a function of elevation in a reference bandwidth of 4 kHz and in 100 kHz bandwidth.

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 A7-17 shows the e.i.r.p. mask which is symmetric around the nadir direction (90° angle in the figure).

FIGURE A7-17

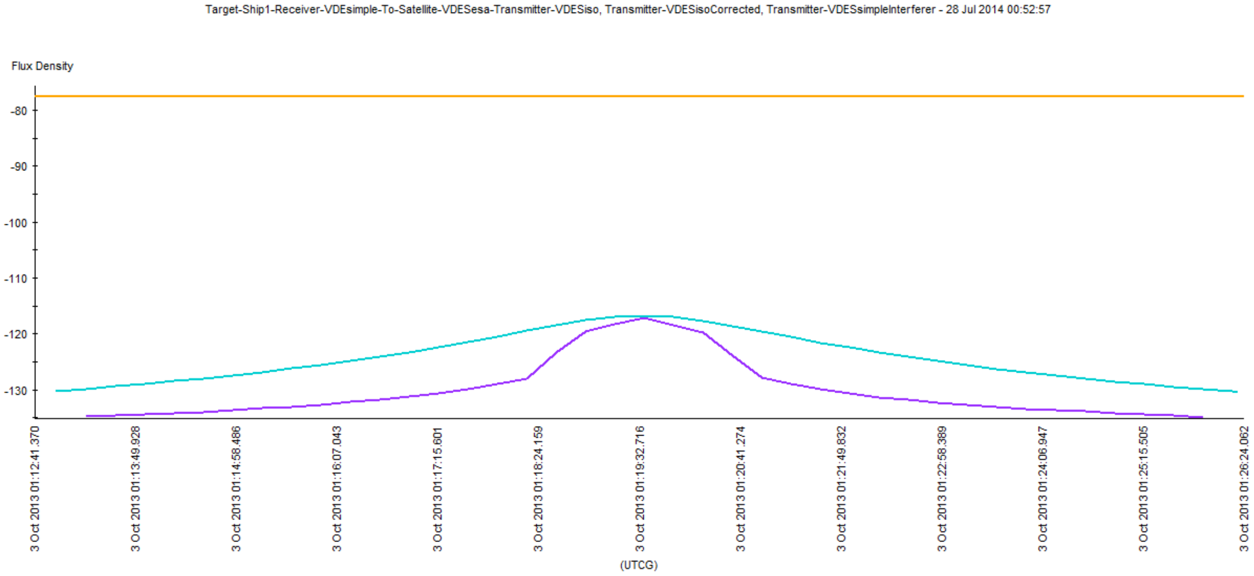
Satellite equivalent isotropic radiated power mask



Assuming a circularly polarized downlink signal from the satellite meeting the e.i.r.p. mask in Fig. A7-17, then the PFD in 100 kHz seen in an overhead pass by a ground terminal is shown as a violet curve in Fig. A7-18. 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 A7-18

Receiver carrier input for a 0 dB gain antenna.
Isoflux and compensated satellite transmitter antenna + nearby ship



8.2.2 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 on board 'industrial' noise is yet to be added, but will be ignored for the remainder of the document.

8.2.3 "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 Fig. A7-19.

FIGURE A7-19

"Ideal" receiver antenna mask, zenith is 90°

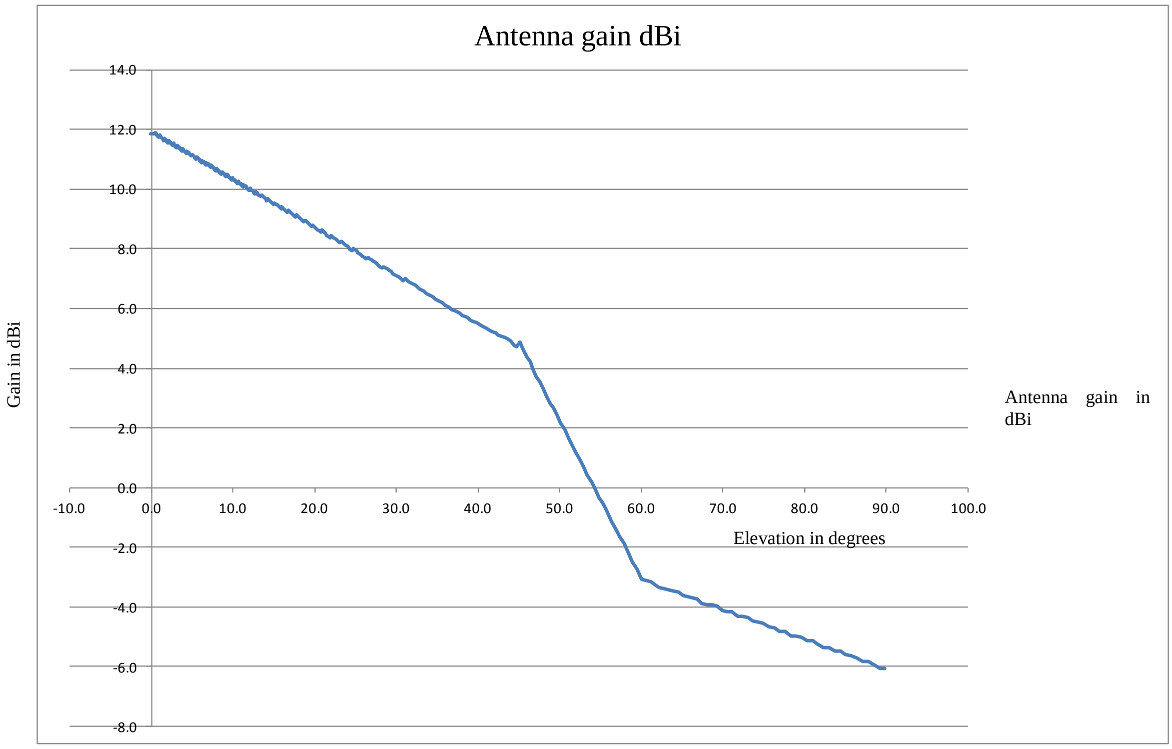


FIGURE A7-20

Received carrier power for a receiver with an "ideal" antenna

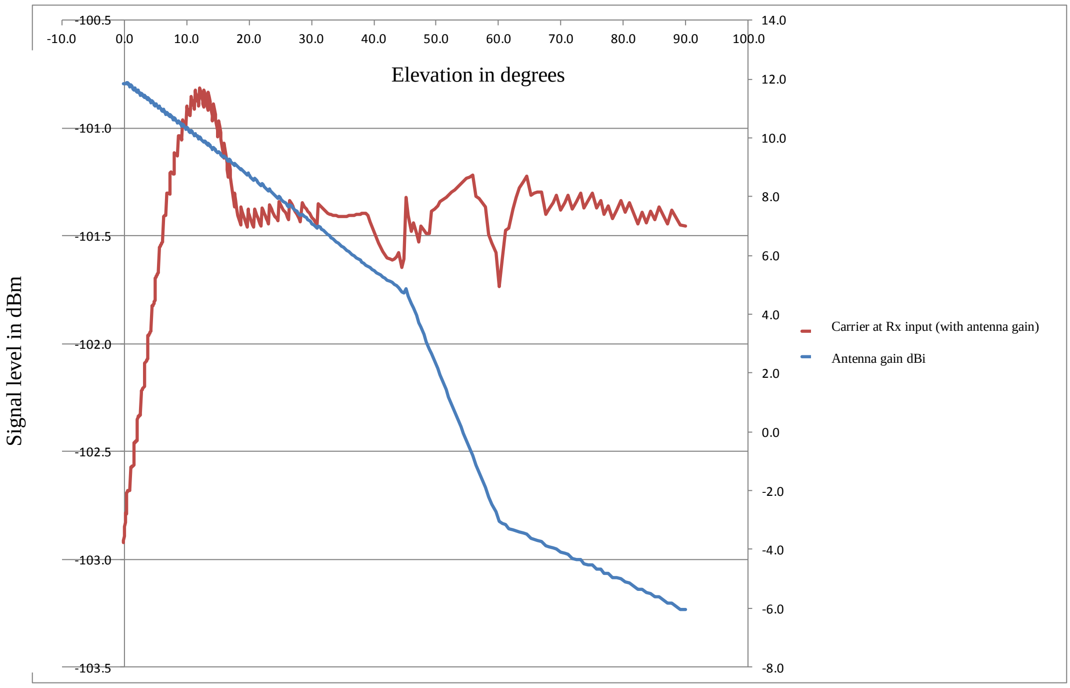


Figure A7-20 shows the received signal power in dBm at the input of a receiver with the "ideal" receiving antenna as a function of elevation. The link analysis is computed using professional commercial software tools for satellite communications that account for the signal propagation impairments.

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 Recommendation ITU-R M.1842 recommended sensitivity for 16-QAM for ship stations.

FIGURE A7-21

E_b/N_0 compensated patterns for "ideal" antenna

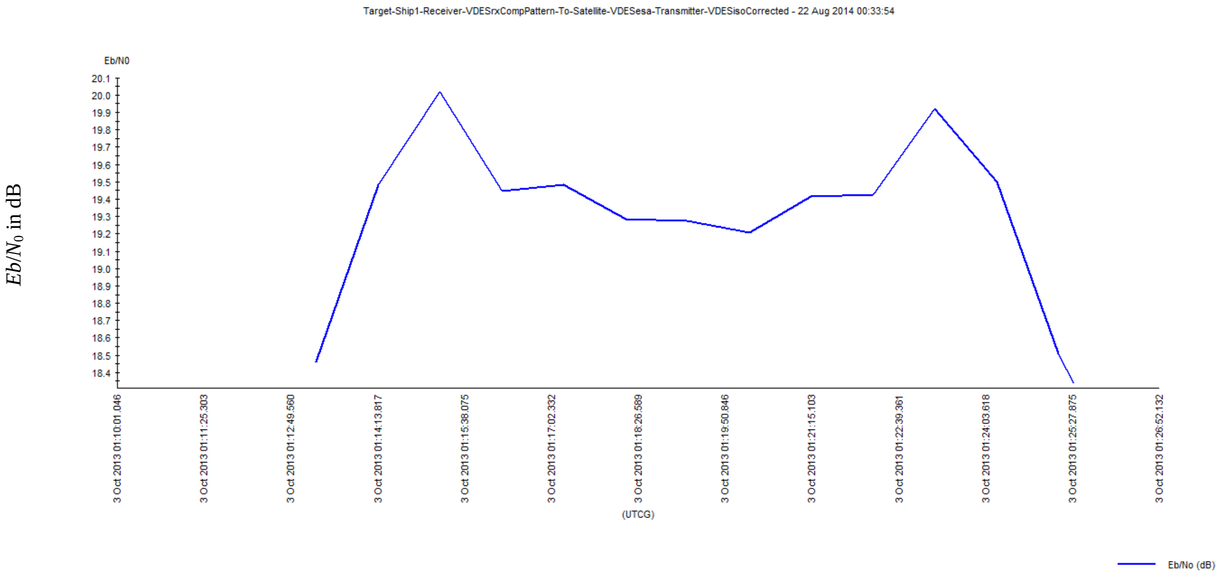


Figure A7-21 shows the corresponding E_b/N_0 observed for the 100 kHz carrier in an overhead pass for the "ideal" antenna.

8.2.4 Realistic receiving antenna

Four different antennas are considered:

- The 0 dBd point in the Recommendation ITU-R F.1336 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 antenna, with right hand circular polarization (RHCP) (antenna 3)
- A hemispherical 0 dBi 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 E_b/N_0 in the following cases:

- Overhead pass
- Side pass
- Very low pass.

Results corresponding to each scenario are reported in the following sections.

8.2.4.1 Overhead satellite pass

FIGURE A7-22

Overhead satellite pass, carrier level at receiver input

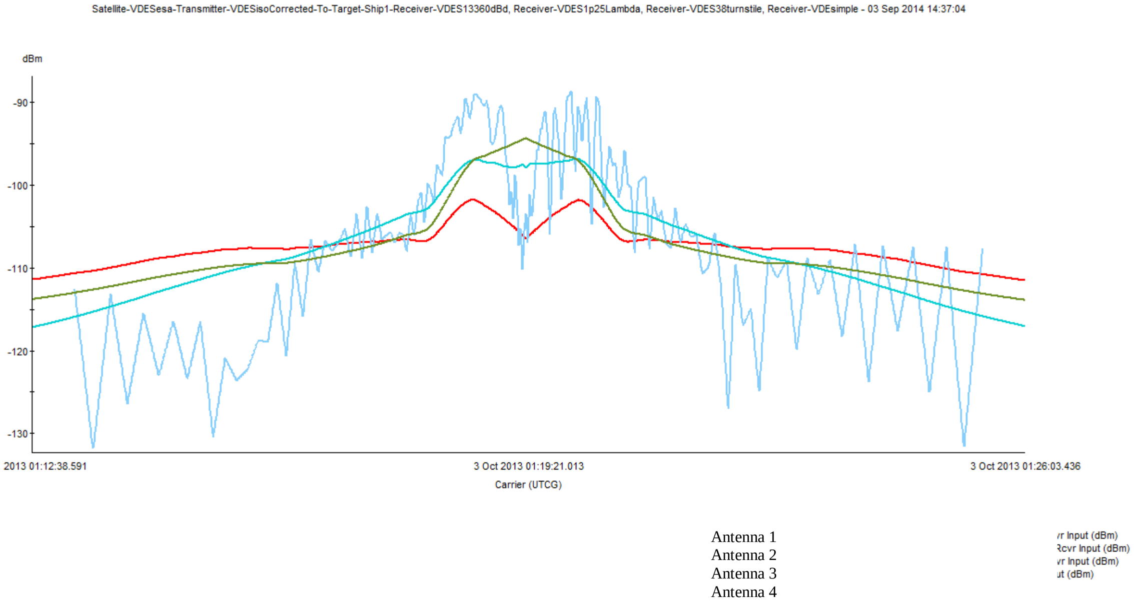
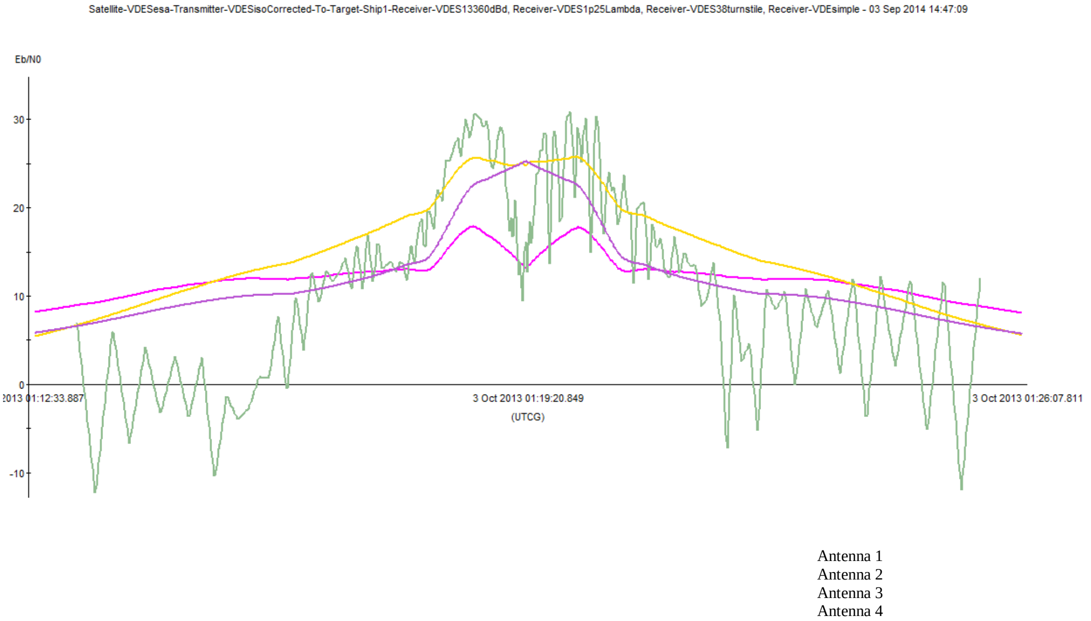


FIGURE A7-23

Overhead satellite pass, E_b/N_0 at demodulator input



8.2.4.2 Side satellite pass

Consider a 16° elevation pass, the signal power and corresponding signal quality measured in E_b/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 A7-24

Carrier level at receiver input, side satellite pass

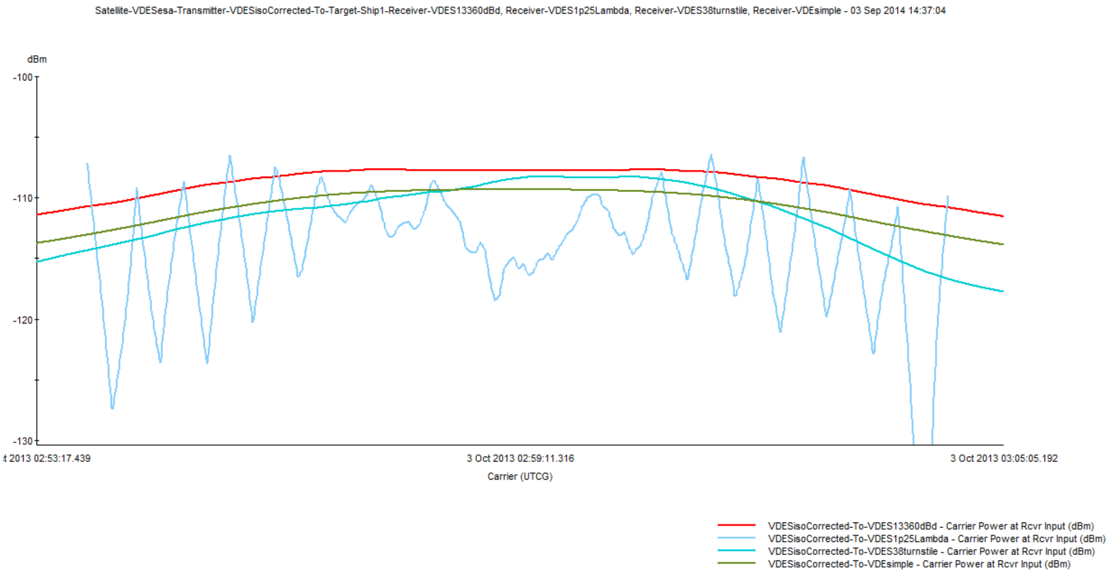
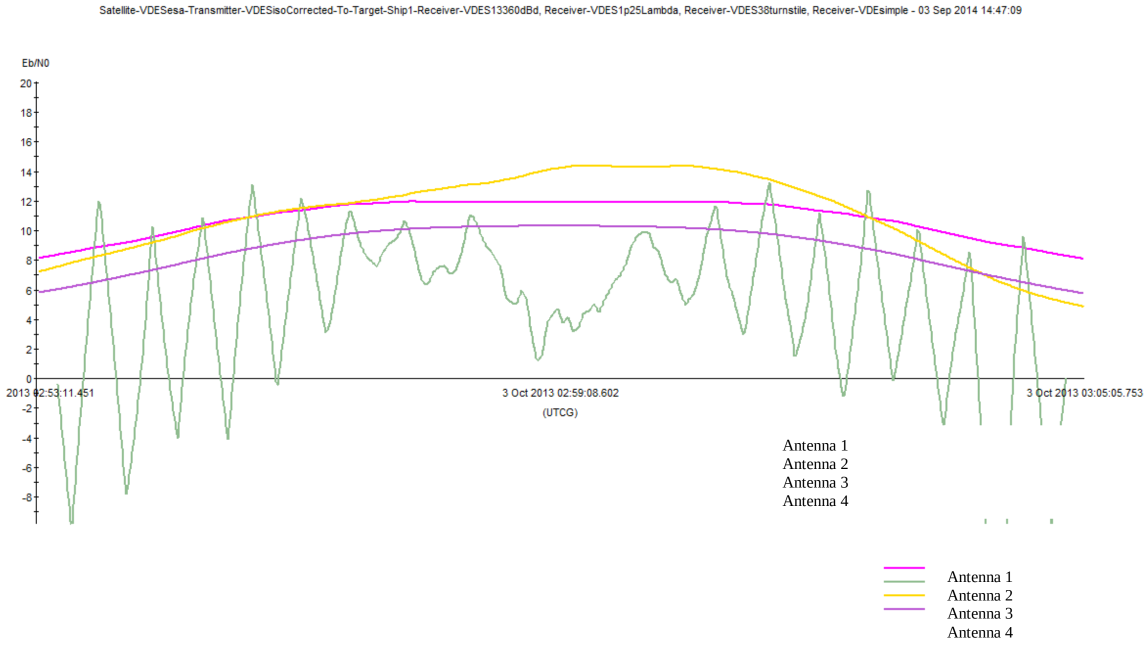


FIGURE A7-25

E_b/N_0 at demodulator input, side satellite pass



8.2.4.3 Very low side satellite pass

Results for a very low side pass (below 5° elevation) are presented in Figures below.

FIGURE A7-26

Carrier input at receiver input, very low side satellite pass

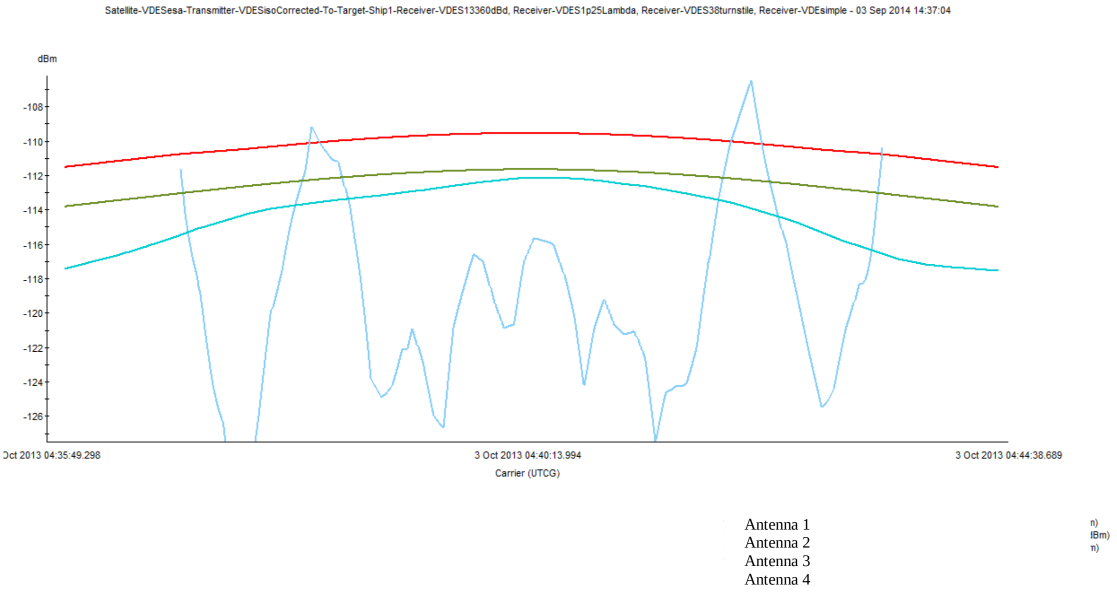
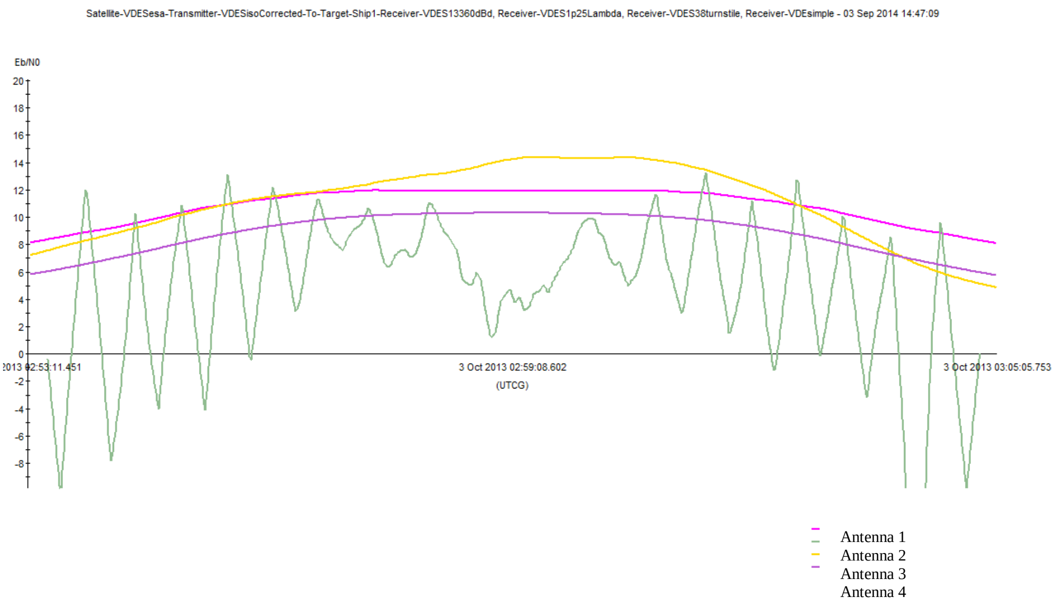


FIGURE A7-27

E_b/N_0 at demodulator input, very low elevation side satellite pass.



8.2.5 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 synchronization 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 randomization (scrambling) facilitates the synchronization 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 A7-8. Figure A7-28 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 A7-9

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	1 040	1.93	9.31
536	4	1 152	2.13	10.85
536	4	1 400	2.59	11.17
536	4	1 552	2.87	12.56
1 616	4	984	0.61	−0.51
1 616	4	1 504	0.93	1.71
1 616	4	2 112	1.30	3.69
1 616	4	2 384	1.47	4.73
1 616	4	2 664	1.64	5.94
1 616	4	2 840	1.75	7.49
1 616	4	3 200	1.98	8.77
1 616	4	3 552	2.19	10.23
1 616	4	4 312	2.66	10.72
1 616	4	4 792	2.96	12.04
3 236	4	984	0.30	−3.52
3 236	4	1 504	0.46	−1.3

FIGURE A7-28

Spectral efficiency of DVB-RCS2 waveform