C59-8.2.3-2

Radiocommunication Study Groups

Received:

Source: Annex 24 to document 5B/475

Document 5B/ -E
2014
English only

International Association of Marine Aids to Navigation and Lighthouse Authorities

LIAISON NOTE TO ITU-R WP 5B

REGARDING A WORKING DOCUMENT TOWARD A PRELIMINARY DRAFT NEW RECOMMENDATION ITU-R M.[VDES]

1 1 Background

IALA thanks ITU-R WP 5B for the opportunity to contribute to studies and the work for WRC-15 agenda item 1.16. This liaison note provides a contribution on the Working Document Toward a Preliminary Draft New Recommendation ITU-R M. [VDES].

2 2 Discussion

IALA has further developed the Working Document Toward a Preliminary Draft New Recommendation ITU-R M. [VDES]. Due to the complexity of the changes, IALA is submitting the changes in its entirety as a new document to replace the existing ITU-R WP5B Annex 24 to document 5B/475.

3 3 Action requested

IALA plans to further develop the Working Document Toward a Preliminary Draft New Recommendation ITU-R M. [VDES] and submit a contribution to the May 2015 ITU-R WP5B meeting.

IALA requests ITU-R WP 5B to consider this information in the future development of the Working Document Toward a Preliminary Draft New Recommendation ITU-R M. [VDES] and provide comments to IALA to continue work on the VDES Recommendation.

Ref: Document 5B/475 Annex 24 (9 January 2014)
Document 5B/636 Annex 5 (30 June 2014)
Document 5B/636 Annex 28 (9 July 2014)
Document 5B/636 Annex 29 (9 July 2014)
Document 5B/636 Annex 30 (9 July 2014)

WORKING DOCUMENT TOWARD A PRELIMINARY DRAFT NEW RECOMMENDATION ITU-R M.[VDES]*

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

Scope

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

Keywords:

[TBD]

Glossary:

ACPR	Adjacent channel power ratio
AIS	Automatic identification system
AMSL	Above mean sea level
ASM	application specific messages
CIRM	Comité International Radio Maritime
DA	Doherty Amplifier
DPD	Digital Pre-Distortion

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

DSC	digital selective calling
ET	Envelope Tracking
FATDMA	fixed access time-division multiple access
FEC	Forward error correction
HAAT	Height above average terrain
IALA	International Association of Marine Aids to Navigation and Lighthouse Authorities
ICAO	International Civil Aviation Organization
IEC	International Electrotechnical Commission
IMO	International Maritime Organization
ITDMA	incremental time division multiple access
LEO	low-earth orbiting
MEO	medium-earth orbiting
MMSI	maritime mobile service identity
OFDM	orthogonal frequency division multiple access
PAPR	peak to average power ratio
PFD	power flux-density
QoS	Quality of Service
RR	radio regulations
SOLAS	safety of life at sea convention
SOTDMA	self-organized time division multiple access
VDES	VHF data exchange system
VDL	AIS VHF data link
VTS	vessel traffic services

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) 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 (VTS) applications, a growing need for other maritime safety related communications has developed;

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

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

recognizing

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

noting

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

recommends

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

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

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

ANNEX 1

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

4 General

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

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

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

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

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

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

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

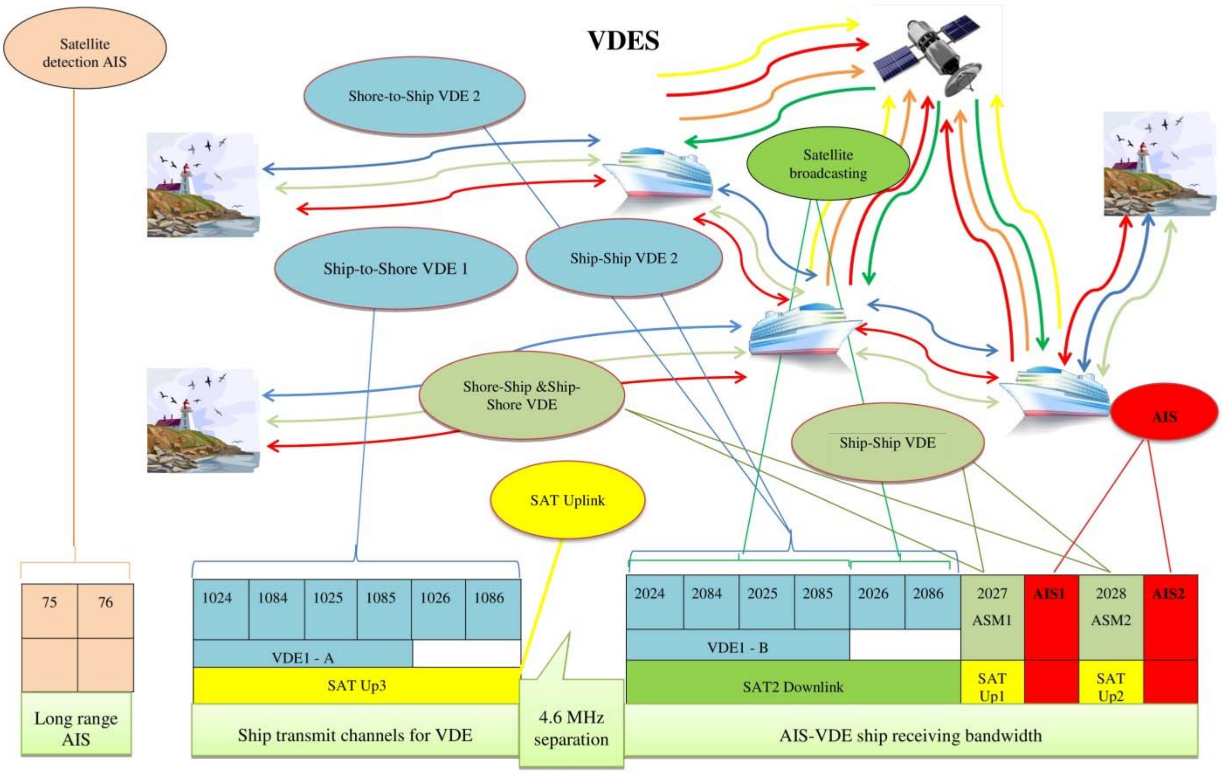
1.8 The system should address the use cases identified in the report ITU-R M.[VDES-SELECT].

5 VHF data exchange system functions and frequency usage

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

Figure 1

VDES functions and frequency usage



NOTE – SAT Up is receive-only by satellite.

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

5.1.1 VHF data exchange system data exchange between terrestrial stations

- AIS 1 (channel 2087) and AIS 2 (channel 2088) are AIS channels, in accordance with Recommendation ITU-R M.1371;
- ASM 1 (channel 2027) and ASM 2 (channel 2028) are the channels used for application specific messages (ASM);
- VDE1-A lower legs (channels 1024, 1084, 1025, 1085) are ship-to-shore VDE;
- VDE1-B upper legs (channels 2024, 2084, 2025, 2085) are shore-to-ship and ship-to-ship VDE.

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

- AIS 1 (channel 2087) and AIS 2 (channel 2088) are terrestrial AIS channels that are also used as uplinks for receiving AIS messages by satellite;
- Long Range AIS using channel 75 and channel 76 are specified channels to be used as uplinks for receiving AIS messages by satellite. SAT Up1 (channel 2027) and SAT Up 2 (channel 2028) are used for receiving ASM by satellite;
- SAT Up3 (channels 1024, 1084, 1025, 1085,1026 and 1086) are used for ship-satellite VDE uplinks;
- SAT Downlink (channels 2024, 2084, 2025, 2085, 2026 and 2086) are used for satellite-ship VDE downlinks.

5.1.3 Technical characteristics

5.1.3.1 Shipborne VHF data exchange system receivers are protected

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

5.1.3.2 SAT Downlink

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

5.1.3.3 VDE1 uses both legs of the duplex channels

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

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

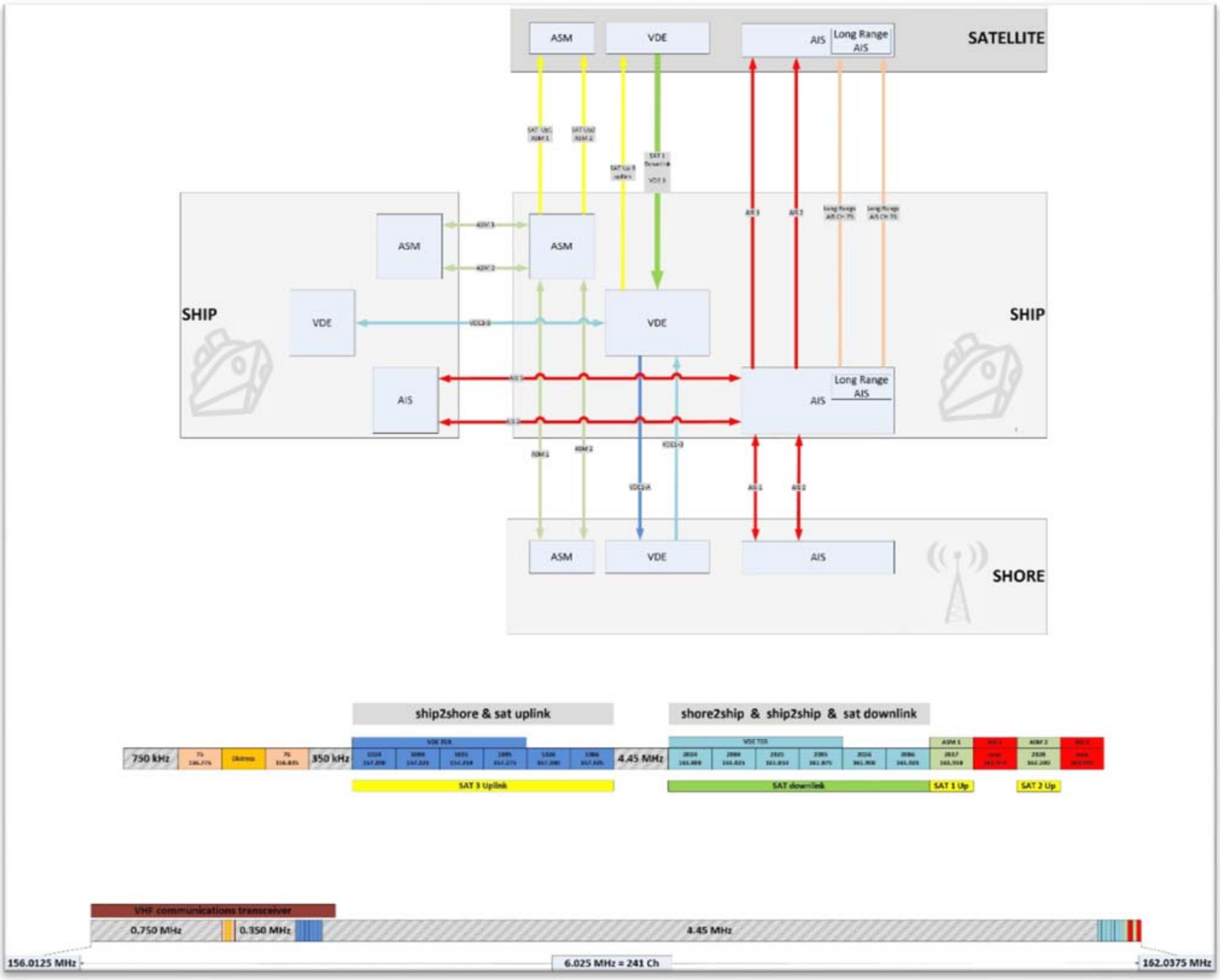
Table 1

RR Appendix 18 channels for VDES applications: AIS, ASM, VDE

RR Appendix 18 channel number		**Transmitting frequencies (MHz)**	
		Ship stations (ship-to-shore) **(long range AIS)** **Ship stations (ship-to-satellite)**	**Coast stations** **Ship stations (ship-to-ship)** **Satellite-to-ship**
AIS 1		161.975	161.975
AIS 2		162.025	162.025
75 (long range AIS)		156.775 (ships are Tx only)	N/A
76 (long range AIS)		156.825 (ships are Tx only)	N/A
2027 (ASM 1)		161.950 (2027)	161.950 (2027)
2028 (ASM 2)		162.000 (2028)	162.000 (2028)
24/84/25/85 (VDE 1)	24/84/25/85/26/86 (Ship-satellite, satellite-ship)	100/150 kHz channel (24/84/25/85, lower legs (VDE1-A) merged) Ship-to-shore (24/84/25/85/26/86,) Ship-to-satellite	100/150 kHz channel (24/84/25/85, upper legs (VDE1-B) merged) Ship-to-ship, Shore-to-ship (24/84/25/85/26/86,) Satellite-to-ship
24	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 2

VDES functions and frequency usage engineer's perspective



6 Identification

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

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

6.1 Automatic identification system VHF data link non-controlling stations

6.1.1 Automatic identification system shipborne station

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

6.2 Automatic identification system VHF data link controlling stations

6.2.1 Automatic identification system shore base station

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

7 Application specific messages

For the VDES, to mitigate AIS VDL loading effects, application specific messages (ASM) should conform to the data structure specified in Recommendation ITU-R M.1371 and may use the two channels designated for ASM in Table 1 (ASM 1 and ASM 2) instead of AIS 1 and AIS 2. Transmission method should be according to Section 10.1.

8 Protocol layer overview

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

Figure 3

OSI layers 1-4.

<table>
<tr><td>Layer 4:</td><td colspan="2">Transport</td><td rowspan="4">ITU-R M.1371</td></tr>
<tr><td>Layer 3:</td><td colspan="2">Network</td></tr>
<tr><td>Layer 2:</td><td colspan="2">Data Link</td></tr>
<tr><td>Layer 1:</td><td colspan="2">Access</td></tr>
<tr><td>Channels</td><td>VDE</td><td>ASM</td><td>AIS</td></tr>
</table>

9 Technical considerations for VDES Access Schemes

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

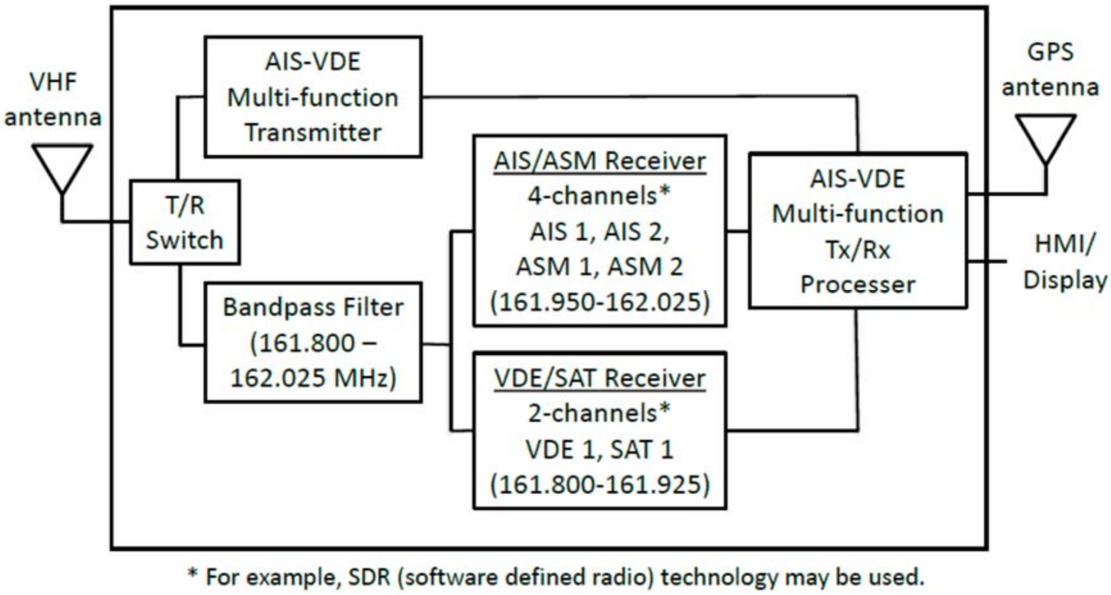
From Figure 1, the satellite downlink shares the spectrum with the terrestrial ship-ship and shore-ship links, and the satellite uplink shares the spectrum with the terrestrial ship-shore link. Thus, access schemes should be considered to mitigate potential conflicts between the links.

9.1 TDMA access scheme for the VDE terrestrial service

The VDES terrestrial service is comprised of ASM, VDE ship-shore, VDE shore-ship and VDE ship-ship. An example shipborne VDES transceiver implementation is illustrated in Figure 4 below. Note that in this implementation example all receivers, including the AIS receivers, are protected from blocking from the shipborne VHF radio by the band-pass filter that attenuates signals from the lower side of the Appendix 18 band. The AIS receiver blocking issue, along with the fact that the AIS can share the same antenna with the other VDES functions, is incentive for manufacturers to consider this implementation for their VDES system designs.

Figure 4

Example VDES transceiver implementation



9.1.1 TDMA access scheme for the VDES ASM channels

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

9.1.2 TDMA access scheme for the VDES ship-shore link

The TDMA access scheme for the VDE1-A ship-shore link could be by reservation through ITDMA (Incremental TDMA) from an ASM (Application Specific Message) on either one of the ASM channels, as described in 9.2.2.2. A VDE1-A ship-shore transmission should not exceed five contiguous slots.

9.1.3 TDMA access scheme for the VDES ship-ship link

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

9.1.4 TDMA access scheme for the VDES shore-ship link

The TDMA access scheme for the VDE1-B shore-ship link could be the same as for the VDE1 ship-shore link, i.e., by reservation through ITDMA (Incremental TDMA) from an ASM

(Application Specific Message) on either one of the ASM channels. This is necessary because the shore station has a very wide coverage area compared to ships, and it needs to have priority access to the VDE1 channel in its coverage area. A VDE1-B shore-ship transmission should not exceed five contiguous slots.

9.2 Sharing options for the VDE terrestrial and VDE satellite services

9.2.1 VDE Terrestrial links on the upper legs (VDE1-B) and VDE Satellite Downlink

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

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

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

9.2.1.1 Frequency division multiple access (FDMA)

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

9.2.1.2 Time division multiple access (TDMA)

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

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

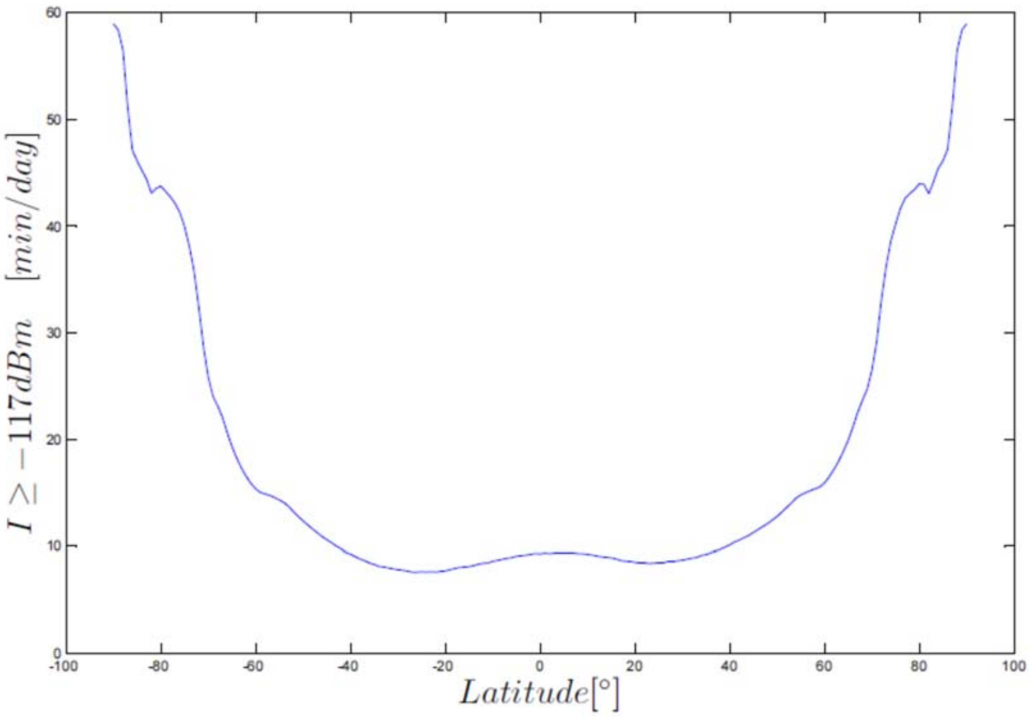
9.2.1.3 Full Frequency reuse (superposition)

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

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

Figure 5

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



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

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

9.2.2.1 Frequency Division Multiple Access (FDMA)

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

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

9.2.2.2 Time Division Multiple Access (TDMA)

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

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

9.2.2.3 Full Frequency reuse

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

10 Transmission waveforms for VDES Terrestrial Links

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

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

Table 2

ITU-standard transmission waveforms for AIS, ASM and VDE terrestrial links

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

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

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

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

10.1 Transmission waveform for the 25 kHz ASM channels

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

- It is generated by phase modulation with an inter-symbol rotation of π/4 radians. This produces an amplitude envelope with very moderate peak to average power ratio (PAPR);
- It has excellent characteristics for detection by satellites as required by the channel plan.

10.2 Transmission waveform for the 100 kHz VDE channels

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

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

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

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

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

11 Antenna options for VDES terrestrial stations

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

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

Figure 6

Antenna options for shipborne VDES stations

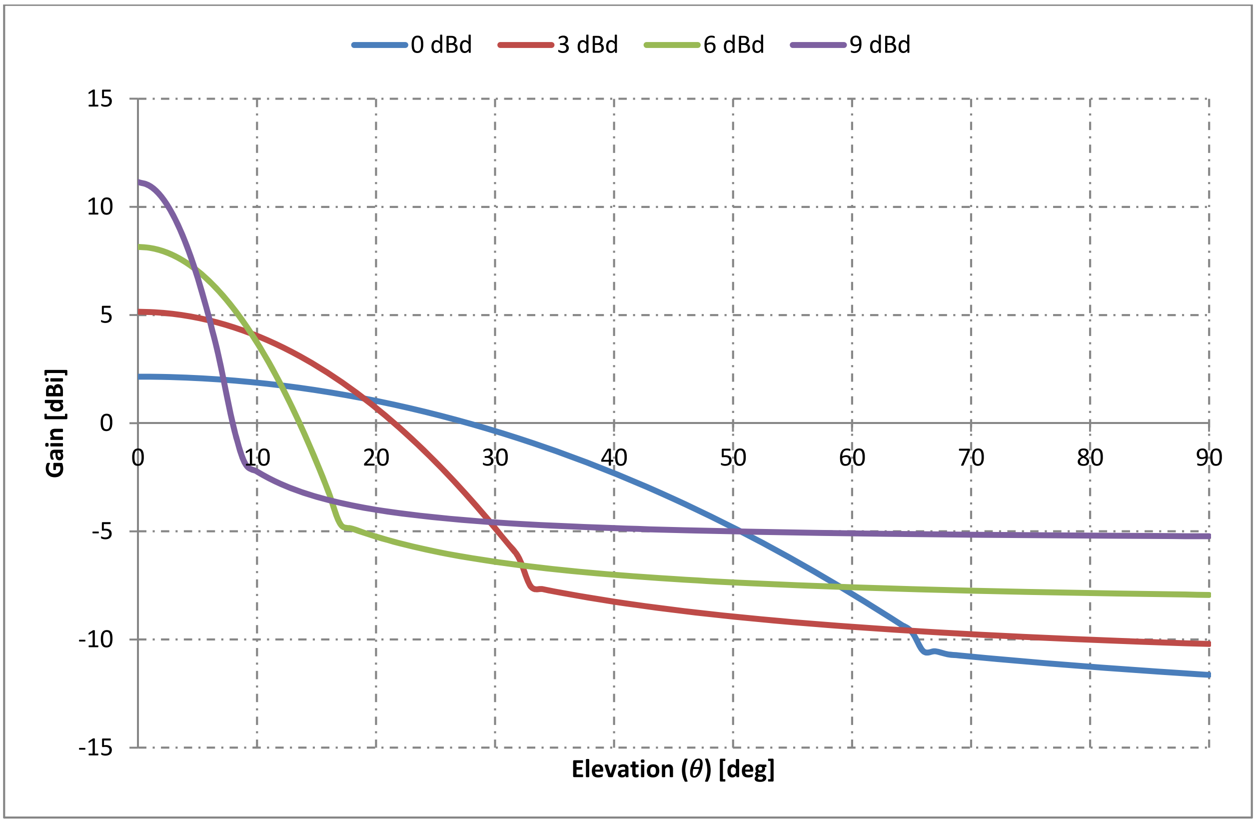
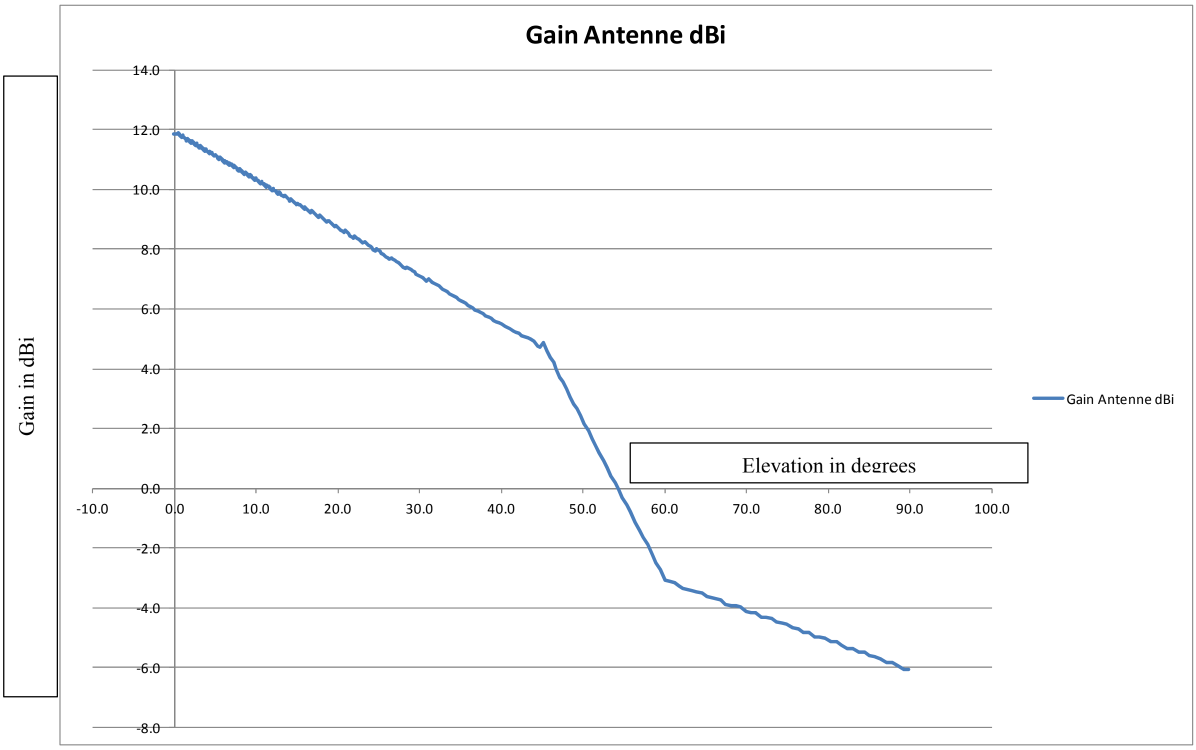


Figure 7

Mask for 'Ideal' Antenna



12 Presentation interface protocol

For VDES transceivers:

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

13 VHF data exchange by satellite

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

13.1 General

13.1.1 VHF data exchange system satellite component

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

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

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

13.1.2 Applications

Continuous exchanges with the maritime community will provide further insight into the priorities, Quality of Service (QoS), security, integrity and other requirements of future VDES services.

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

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

13.2 Overall architecture, operational characteristics and assumptions

13.2.1 Architecture

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

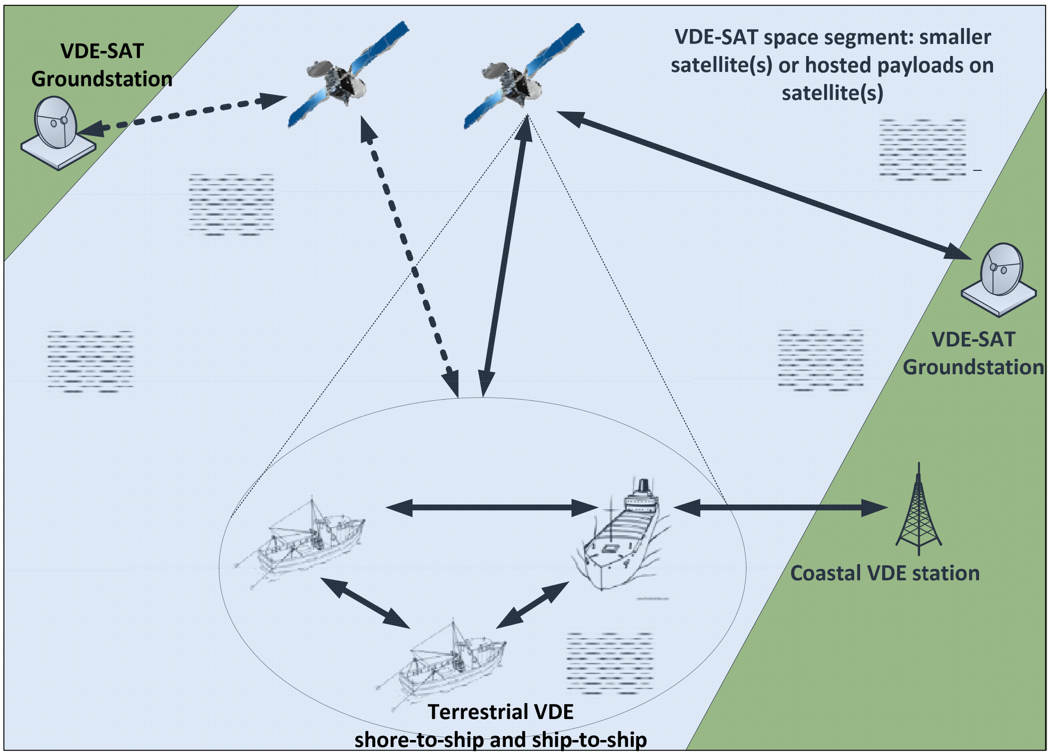
Due to the frequencies used, it is likely that VDE-SAT will consist of low-earth orbiting (LEO) or medium-earth orbiting (MEO) satellites. VDE-SAT could also consist of hosted payload on spacecraft in such orbits.

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

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

Figure 8

VHF data exchange-satellite component architecture



13.2.2 Operational characteristics

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

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

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

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

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

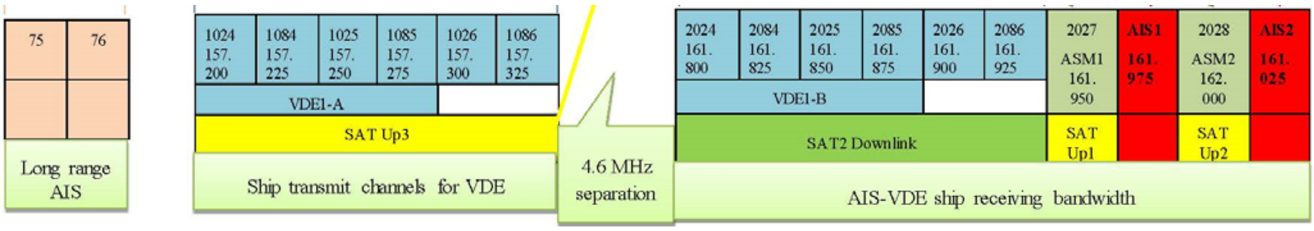
13.3 Technical characteristics

13.3.1 VHF data exchange-satellite channels and spectrum

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

Figure 9

VHF data exchange system channel allocation



13.3.1.1 SAT Downlink

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

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

The VDE-SAT downlink signal also includes repeated known symbols (e.g. pilots, preamble, post-amble) to facilitate signal detection and synchronization as well as possible interference mitigation and channel estimation. In order to avoid unwanted in-band spectral lines, the data symbols are scrambled with a known sequence. The example in section 13.4.2 concludes that a downlink data rate of 240 kbps is possible.

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

Table 3

Power flux-density (PFD) mask

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

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

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).

13.3.1.2 SAT 3 Uplink

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

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

13.3.2 Rationale of channel allocation for VHF data exchange-satellite

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

- The requirements for VDES concentrate the reception frequencies on board of the ship to a limited range of 250 kHz at the upper maritime VHF band. This provides an efficient implementation of VDES on-board receivers by narrowing the input filter bandwidth, reducing potential impairments due to other activities within the maritime VHF band.
- The VDE-SAT downlink shares the same frequency range as the terrestrial VDE and AIS. This allows sharing the same antenna as well as the receiver front-end design.
- Satellite and shore reception frequencies of shipborne VDE signals occupy the lower end of the VHF maritime band. This allows for a complementary service close to the shore and at the high sea while sharing the same spectrum. The frequency separation between the upper and lower spectra (with 4.6 MHz separation) provides an acceptable level of isolation between VDES receiving chain and the VDE ship-borne transmitters.
- The frequency separation between the uplink and downlink allows hosting VDE-SAT transmitter and receiver on the same satellite which allows for a more cost-effective satellite mission concepts (i.e. reduce number of satellites, improved efficiency and possible interactivity).

13.4 Example VDES satellite implementation

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

13.4.1 Determine the VDES satellite orbital characteristics

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

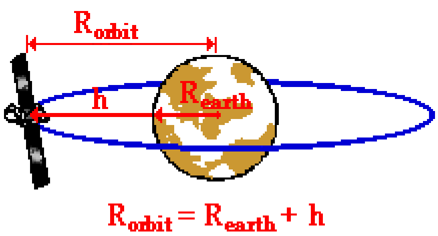
13.4.1.1 Determine the satellite's orbit

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

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

Figure 10

Satellite orbital characteristics



Given/Known:	Unknown:
$R = R_{earth} + \text{height} = 6.92 \times 10^{6}$ m	v = ???
$M_{earth} = 5.98 \times 10^{24}$ kg	a = ???
$G = 6.673 \times 10^{-11}$ N m^2/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 Figure 10, the radius of orbit for a satellite is equal to the sum of the earth's radius and the height above the earth. These two quantities are added to yield the orbital radius. The 550 km altitude is first converted to 0.550×10^{6} m and then added to the radius of the earth.

Determine the velocity of the satellite

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

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

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

Determine the acceleration of the satellite

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

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

$a = 8.333$ m/s^2

Determine the orbital period of the satellite

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

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

$T = 5725.7$ s = 1.59 hrs

13.4.2 VDES satellite antenna and downlink characteristics

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

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

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

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

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

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

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

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

13.4.2.4 Determine the width of the antenna coverage path:

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

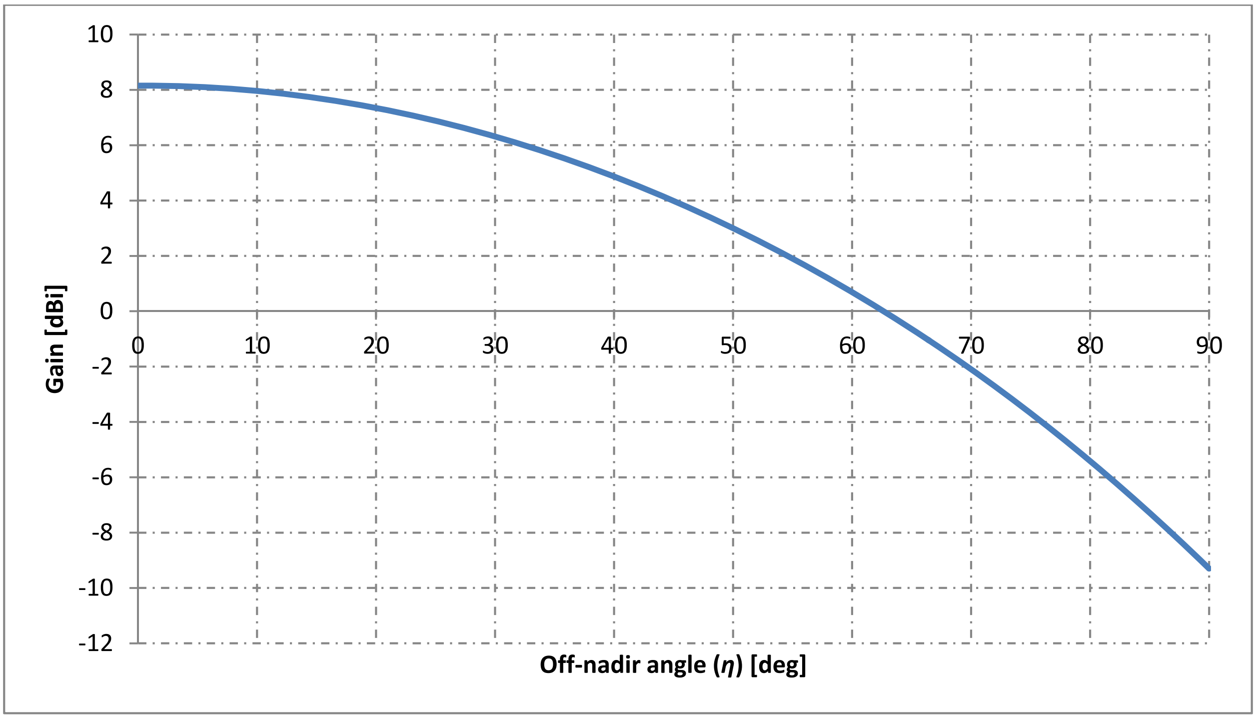
$\mathbf{W_c} = 2(\mathbf{D_s} \cos (90^0-\mathbf{\theta_a}/2))$

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

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

Figure 11

Example VDES satellite antenna pattern



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

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

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

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

13.4.2.6 Consideration of the angular power flux-density(PFD) mask limits for transmission by the VDES satellite

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

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

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

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

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

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

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

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

13.4.2.9 Determine the PFD level for the elevation angle of 0^0

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

13.4.2.10 Determine the PFD level for the elevation angle of 10^0

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

13.4.2.11 Determine the PFD level for the elevation angle of 30^0

The slant range at 30^0 elevation is 993.5 km, the satellite relative angle to the horizon is -23^0, the satellite antenna relative angle with a 35^0 down-tilt is (35^0-30^0) = 5^0 the gain, from Figure 7, is 8 dB (the same as the reference), the relative range loss is 20 log (748.3/993.5) = -2.5 dB and thus the

PFD at 30^0 is (-142 – 2.5) = **-144.5 dB(W/(m2*4kHz))** which is 0.3 dB below the 10^0 mask limit of -144.2 dB(W/(m2*4kHz)).

13.4.2.12 Determine the PFD level for the elevation angle of 60^0

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

13.4.2.13 Determine the PFD level for the elevation angle of 90^0

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

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

Table 4

PFD for various elevation angels

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

Notes for Table 4:

1. *When the PFD level is set to the mask limit of -142dB(W/(m2*4kHz))) at 45^0 elevation angle, the PFD levels at all other elevation angles are below the mask.*
2. *The maximum PFD level is -141dB(W/(m2*4kHz)) at 60^0 elevation angle, which is 7 dB below the mask limit level of -134dB(W/(m2*4kHz)).*

13.4.2.14 Consider the shipborne VDES antenna and receiver characteristics

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

13.4.2.15 Specify the shipborne VDES antenna characteristics

The available shipborne antenna options are comprised of stacked vertical dipole elements of various lengths and gain values, were previously shown in Figure 6 in section 11. This analysis considers the 0 dBd antenna because it has the best performance for the elevation angles required for satellite detection.

13.4.2.16 Determine the shipborne VDES receiver characteristics

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

Table 5

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

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

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

G = gain of a half-wavelength ($\lambda/2$) dipole antenna = 1.64

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

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

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

λ = 1.852 meters (at 161.9 MHz)

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

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

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

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

F = frequency in MHz = 161.9

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

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

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

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

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

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

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

Applying adjustments for cable loss (2dB) and Rx noise figure (4dB), the C/N calculation follows:

C/N (150 kHz bandwidth): C/N_{ref} = (-129.4-2) – (-152.2 +4) = **16.8dB** (Rx 0dBd antenna, 0^0 elevation)

NOTE: These calculations serve to confirm the applicability of the metrics and reference levels.

13.4.2.17 Determine the values of C/N vs. elevation angle for the shipborne VDES receiver

Based on the C/N reference level (C/N_{ref}) from Table 5, determine the C/N for the PFD values and elevation angles in Table 4, taking into account the shipborne antenna angular gain values for the 0 dBd antenna in Figure 6. For this antenna, G_a = 2.1 dBi at 0^0 elevation angle.

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

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

The C/N values for elevation angles from 0^0 to 90^0 are shown in Table 6 below.

Table 6

C/N and PFD for various elevation angels

Orbital angle (degrees)	Elapsed time from horizon (sec)	Slant range (km)	Elevation angle (degrees)	PFD (actual/mask/margin, in dB(W/(m2*4kHz)))	C/N ship receiver (dB)
23	0	2703.6	0	-153.2/-149/4.2	5.6
22	15.9	2592.7	0.5	-152.8/-148.9/3.9	6
21	31.8	2481.6	1.0	-152.4/-148.8/3.6	6.4
20	47.7	2370.5	3.2	-152/-148.5/3.5	6.8
19	63.6	2259.6	4.4	-151.6/-148.3/3.3	7.2
18	79.5	2148.8	5.6	-151.2/-148.1/3.1	7.6
17	95.4	2038.3	7.0	-150.7/-147.9/2.8	8
16	111.3	1928.1	8.4	-150.2/-147.7/2.5	8.5
15	127.2	1818.4	10.0	-149.7/-147.4/2.3	8.9
14	143.1	1709.2	11.6	-149.2/-147.1/2.1	9.4
13	159.0	1600.6	13.5	-148.6/-146.8/1.8	9.7
12	175.0	1493.0	15.5	-148/-146.5/1.5	10.2
11	190.9	1386.5	17.8	-147.4/-146.1/1.3	10.8
10	206.8	1281.4	20.3	-146.7/-145.8/0.9	10.9
9	222.7	1178.1	23.2	-145.9/-145.3/0.6	11.5
8	238.6	1077.3	26.6	-145.2/-144.7/0.5	11.8
7.145	252.2	993.5	30.0	-144.5/-144.2/0.3	11.9
7	254.5	979.6	30.6	-144.3/-144.1/0.2	11.9
6	270.4	886.3	35.3	-143.5/143.35/0.15	11.9
5	286.3	798.7	41.0	-142.5/-142.4/0.1	11.7
4.38	296.1	748.3	45.0	-142/-142/0 *(reference)*	11.2
4	302.2	719.2	47.8	-141.7/-140.5/1.2	11.0
3	318.1	650.6	56.2	-141.5/-136.1/5.4	8.6
2.7	322.9	632.7	60.0	-141/-134/7	8.1
2	334.0	596.8	66.1	-141.8/-133.4/8.4	4.4
1	349.9	562.1	77.6	-143.1/-132.2/10.9	2.4
0	365.8	550.0	90	-145.3/-131/14.3	-0.2

13.4.2.18 Determine the data rate for elevation angles 0^0 to 60^0 using the DVB-S standards

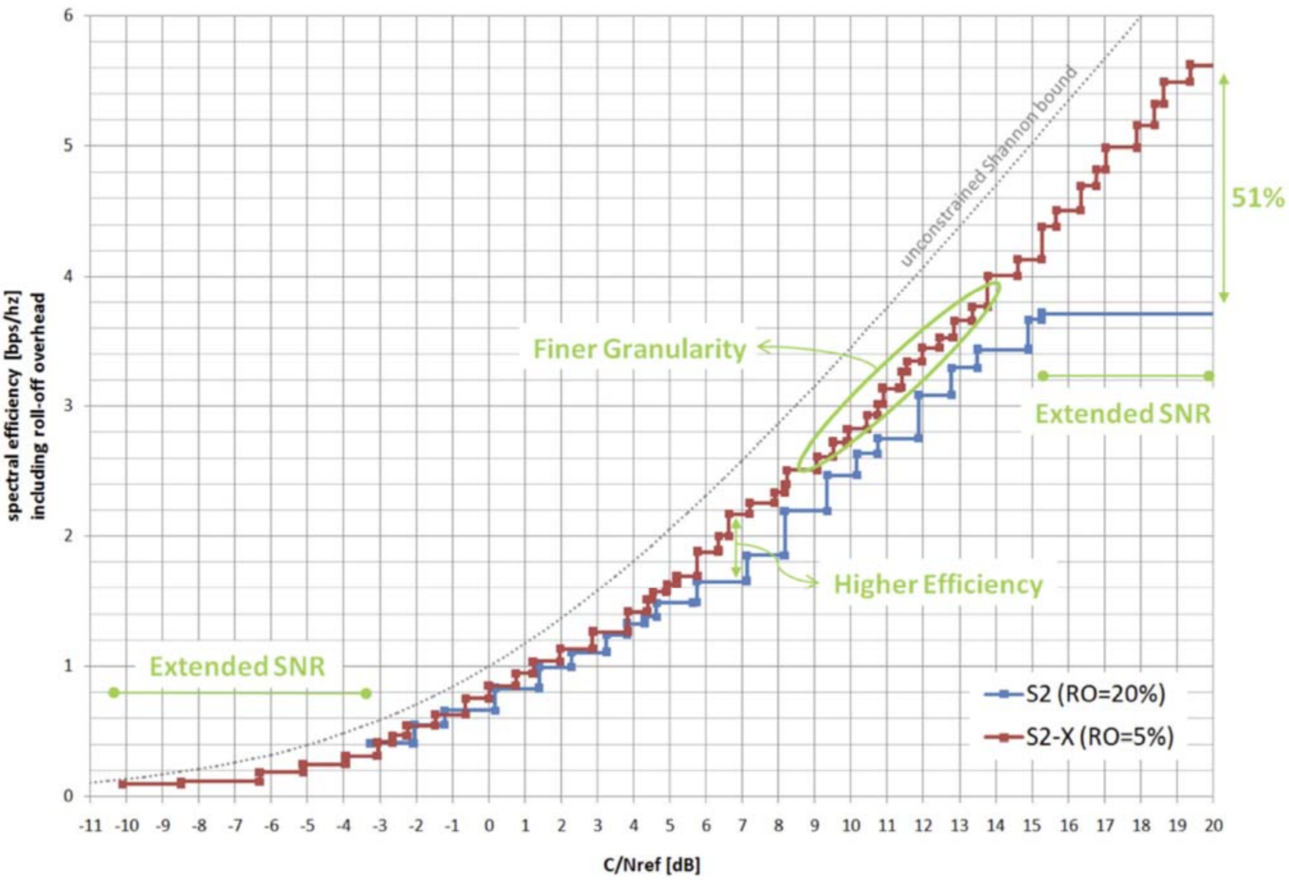
The DVB-S (digital video broadcast by satellite) standards are designed to provide the maximum utilization of the available bandwidth in a low-to-moderate C/N ratio. The spectral efficiencies for DVB-S2X and DVB-S2 are shown in Figure 12 below.

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

- Smaller roll-off options of 5% and 10% (plus 20%, 25% and 35% in DVB-S2)
- A finer gradation and extension of number of modulation and coding modes
- New constellation options for linear and non-linear channels
- Additional scrambling options for critical co-channel interference situations
- Channel bonding of up to 3 channels
- Very Low SNR operation support down to -10 dB SNR
- Super-frame option

Figure 12

Performance of DVB-S2X and DVB-S2



13.4.2.19 Performance conclusion

From Figure 12 above, it is concluded that the DVB-S2X standard transmission applied to the VDES satellite downlink provides spectral efficiency of 1.6bps/Hz and a date-rate of **240 kbps** in a 150 kHz bandwidth for C/N ≥ 5 dB, which, from Table 6, includes **elevation angles from 0^0 to 60^0**.

14 Summary of operational capability and performance

This Recommendation provides the following operational capability and performance:

- Protection of AIS
- Relief of AIS VDL congestion
- Raw ASM data transfer at 28.8 kbps
- Raw VDE data transfer ship-to-ship, ship-to-shore and shore-to-ship at 307.2 kbps
- Raw VDE satellite data transfer up to 240 kbps
- VDE satellite downlink that satisfies the PFD mask requirements
- VDE shore-to-ship and ship-to-shore service to 85km (46NM)
- Channel access and sharing schemes that organize the links and mitigate conflicts
- Full VDES satellite and terrestrial functionality from a single shipborne antenna

ANNEX 2

Propagation range predictions for VDES terrestrial links

1 Introduction

This is an informative annex. The excellent propagation characteristics of AIS are well established and appreciated. It is expected that the ASM will have similar performance to AIS. The propagation range predictions for the 100 kHz VDE ship-to-shore and shore-to-ship links follow below.

2 Ship-to-shore application

2.1 Basis for the coverage assessment

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

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

Transmitter power for ships: 12.5 Watts

Tx ships antenna gain: 2dBi (0dBd)

Rx shore antenna gain: 8dBi (6dBd)

P_r: -103dBm (VDE shore station sensitivity)

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

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

2.3 Determination of transmitting/base antenna height, h_1

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

2.4 Determination of the minimum field strength (sensitivity threshold) at the VDE Base receiving site

For ship-to-shore:

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

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

E_r = field strength in volts/meter

G_r = gain of receiving antenna = 6.3 = 8dBi

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

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

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

Thus,

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

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

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

G = antenna gain in dBi = 8dBi

F = frequency in MHz = 157

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

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

Calculate the effective radiated power:

$P_s = P_t + G$

P_t = 10 log 12.5 – 30 = -19dBk (19dB below 1 kW)

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

Thus P_s = -19 +0 = -19dBk ERP

$F_e = F - P_s$ (vertical scale reference for the propagation graph in Figure 4 of Recommendation ITU-R P.1546-4, Figure 13 of this Annex)

F = +10.1dBu

P_s = -19dBk

Thus F_e = 10.1 – (-19) = +29.1dB

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

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

2.7 Determine the RSSI values for various other ranges

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

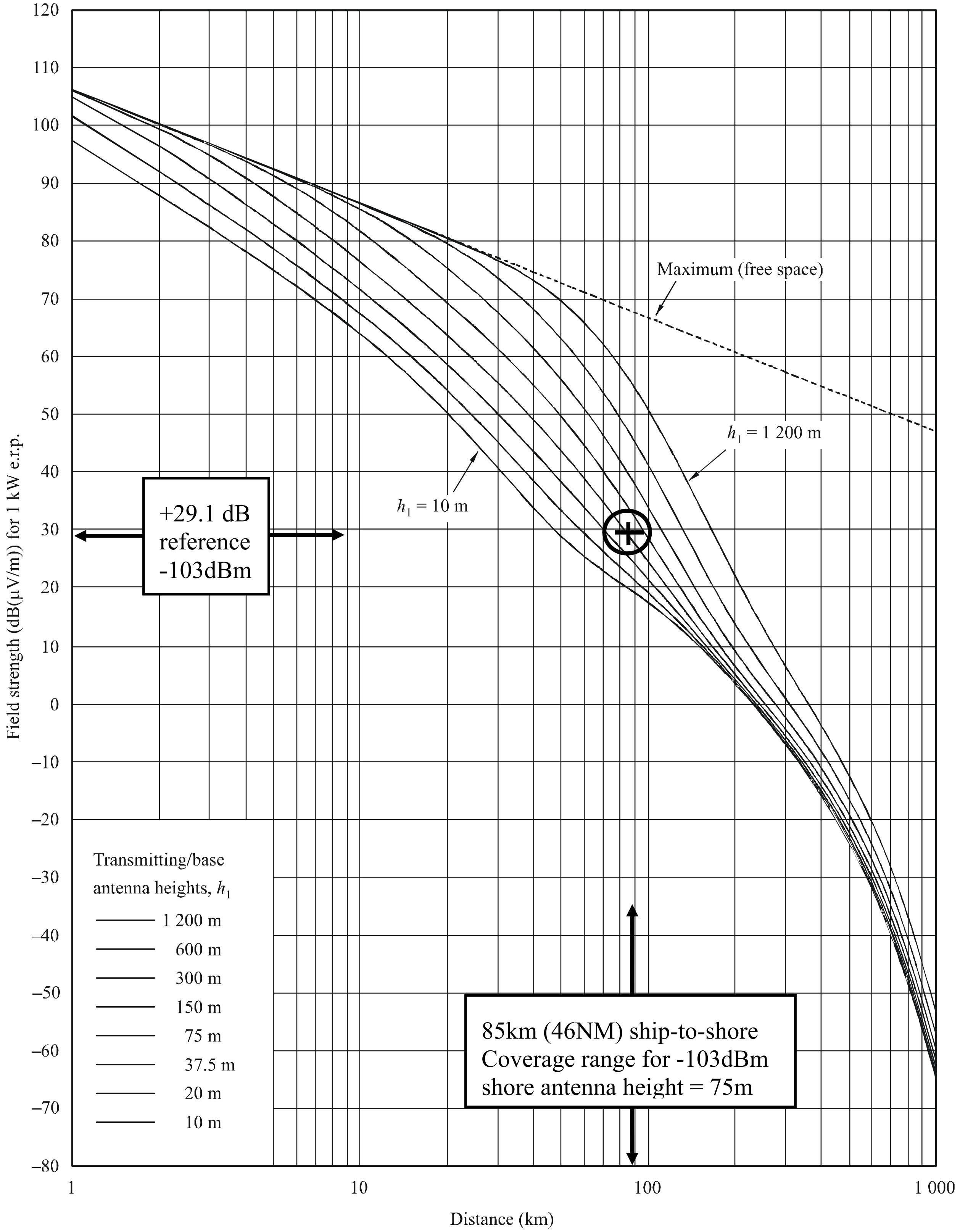
Table 7

VDE base station RSSI value vs. distance ship-to-shore

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

Figure 13

100 MHz, sea path, 50% time



50% of locations

h_2 = 10 m

1546-04

3 Shore-to-Ship Application

3.1 Basis for the coverage assessment

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

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

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

Tx shore antenna gain: 8dBi (6dBd)

Rx ships antenna gain: 2dBi (0dBd)

P_r: -98dBm (VDE ship station sensitivity)

3.1.1 Determination of the minimum field strength (sensitivity threshold) at the VDE ship receiving site

For shore-to-ship:

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

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

E_r = field strength in volts/meter

G_r = gain of receiving antenna = 1.62 = 2.1dBi

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

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

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

Thus,

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

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

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

G = antenna gain in dBi = 2.1dBi

F = frequency in MHz = 162

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

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

Calculate the effective radiated power:

$P_s = P_t + G$

P_t = 10 log 50 – 30 = -13dBk (13dB below 1 kW)

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

Thus P_s = -13 +6 = -7dBk ERP

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

F = +21.3dBu

P_s = -7dBk

Thus F_e = 21.3 – (-7) = +28.3dB

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

3.1.3 Determine the seaward shore-to-ship coverage range from Figure14:

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

3.1.4 Determine the RSSI values for various other ranges

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

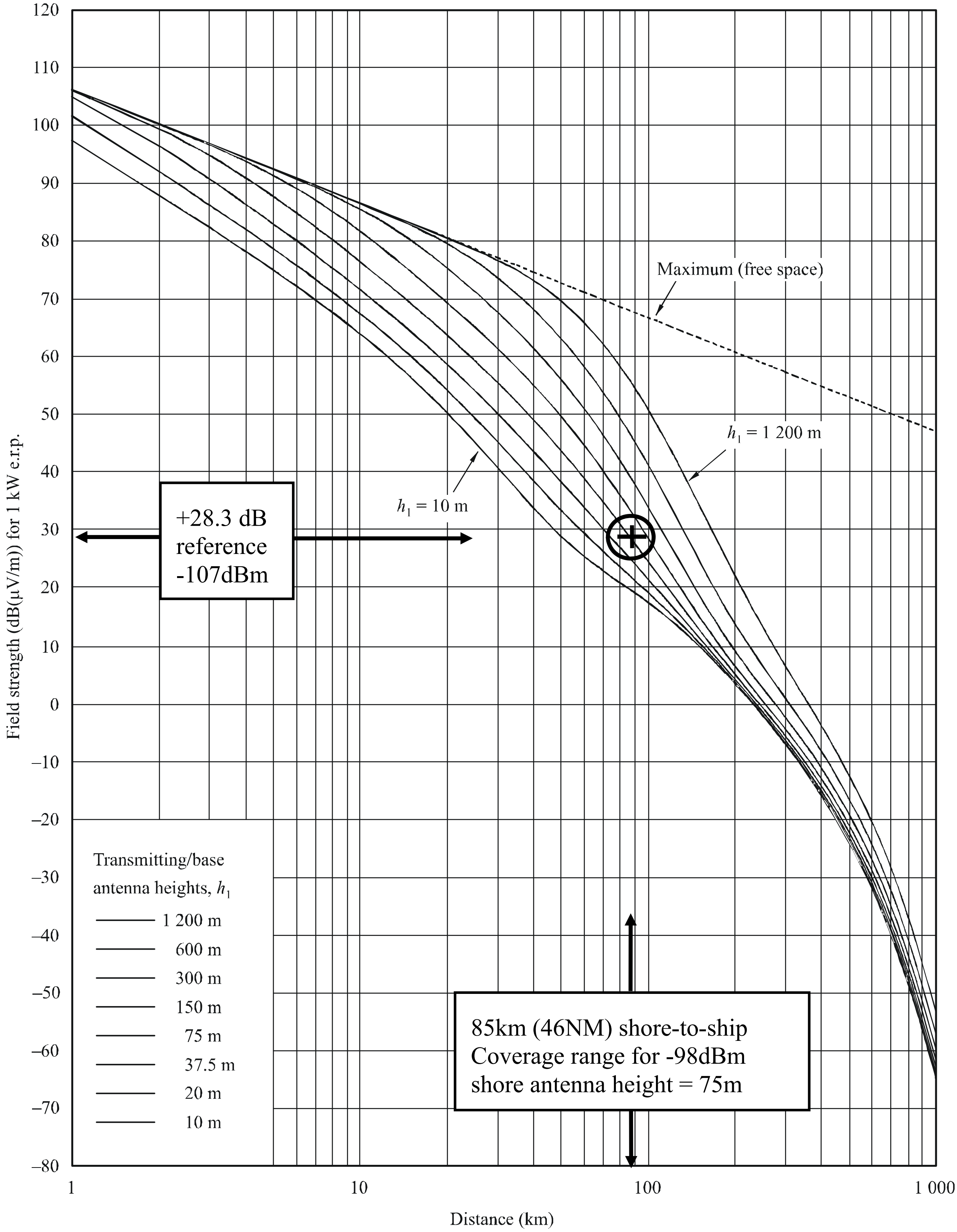
Table 8

VDE ship station RSSI value vs. distance shore-to-ship

-118dBm	170km
-108dBm	130km
-98dBm	85km (46NM)
-88dBm	60km
-78dBm	40km

Figure 14

100 MHz, sea path, 50% time



50% of locations

h_2 = 10 m

1546-04

ANNEX 3

Example of VDE-SAT Downlink Implementation and Analysis

1 Introduction

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

2 VDE Satellite Orbital Characteristics

The spacecraft flies in a circular orbit of 600km and 68° inclination compliant with orbital debris regulations and safe de-orbiting of the spacecraft after its lifetime. The satellite counts with attitude control mechanisms to guarantee a stable antenna pointing in the nadir direction (i.e. satellite to Earth).

Under these assumptions Figure 155 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 15.

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

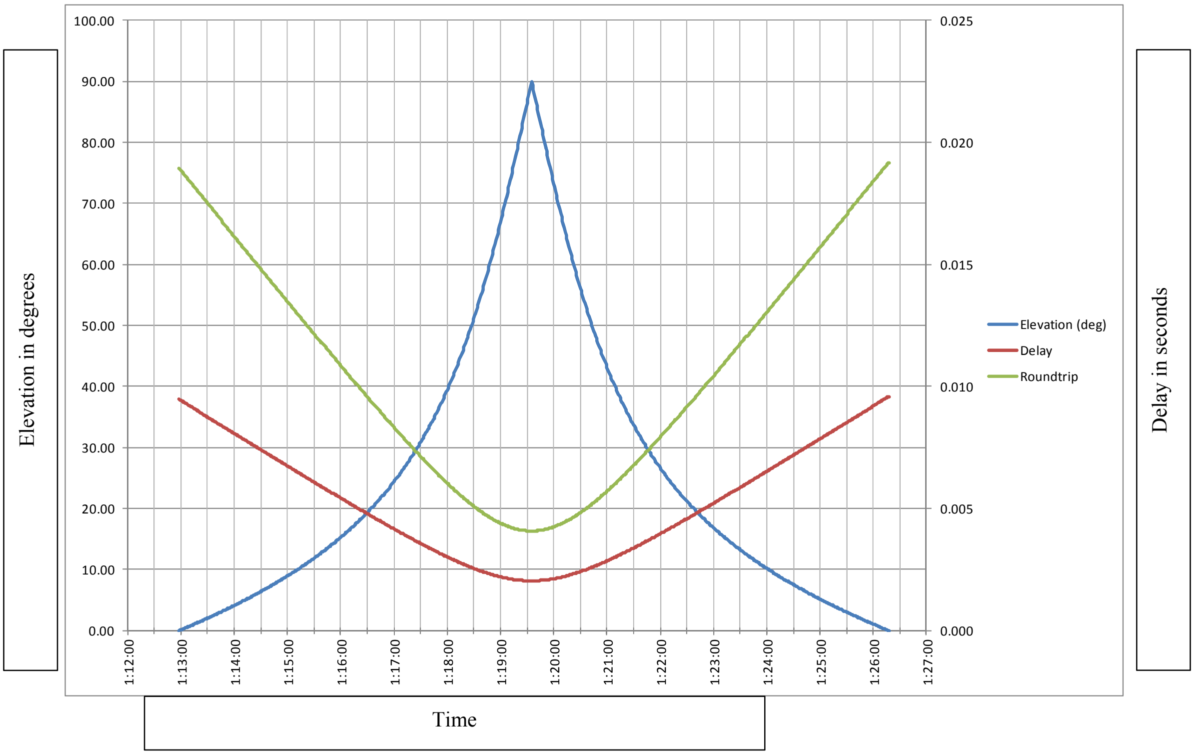


Figure 15 shows that the satellite is just over 4 minutes above 30° elevation, thus 9 minutes under 30° elevation from acquisition-of-signal (AOS) to loss-of-signal (LOS) for a pass duration of about 13 minutes. The roundtrip delay varies from 19 ms at AOS down to 4ms at Zenith (i.e. 90° elevation). During that pass the Doppler shift varies from -3.73kHz to +3.73kHz and the Doppler rate reaches 47Hz/s at Zenith.

Figure 16

Pass elevation scheme for selected orbit over 24 hours.

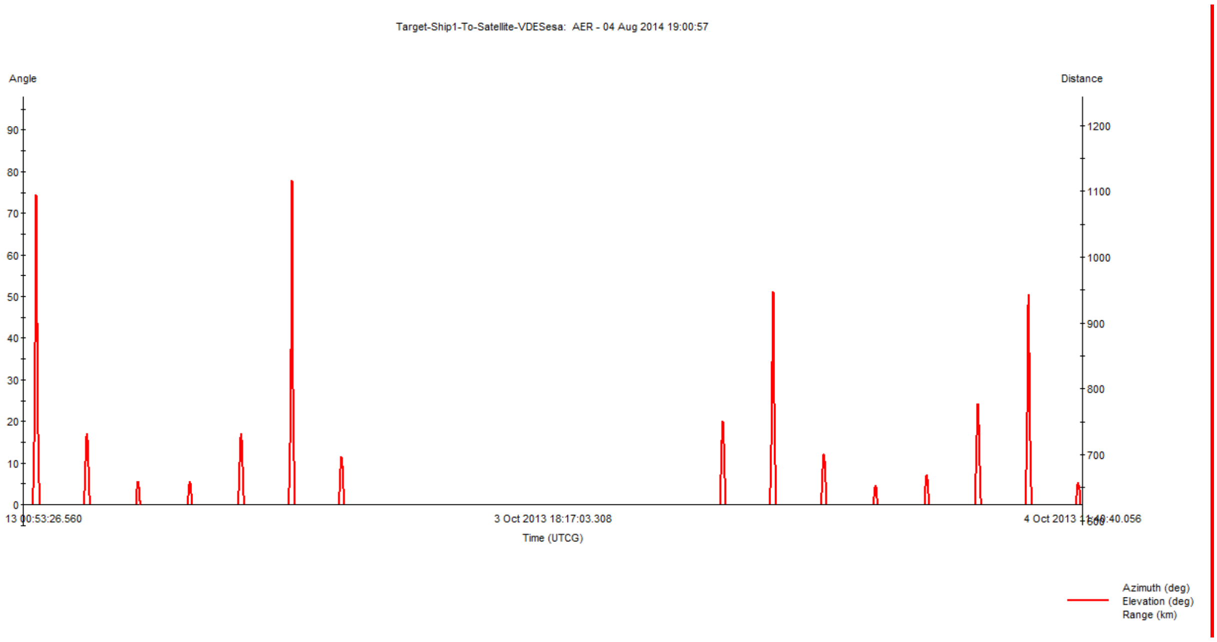


Figure 16 illustrates the satellite elevation as a function of time, as seen by a ground terminal at a fixed location in a 24 hour period. As shown the contact periods are short and low. Depending on the latitude, the duration and the number of contact periods will vary. *(distance is provided in km)*

Figure 17

Satellite Field of View

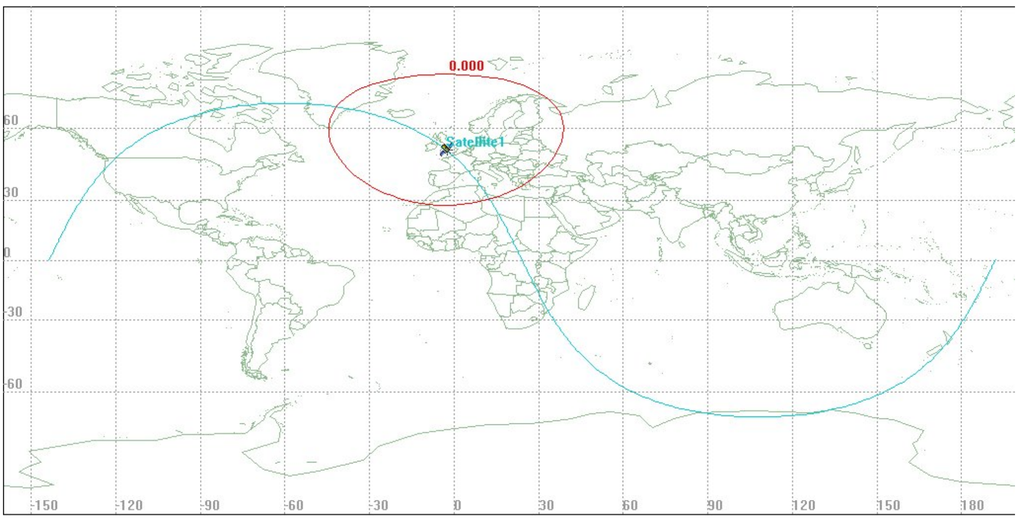


Figure 17 presents the satellite field of view. A wide geographical area is covered by the satellite field of view at any given point of the orbit. For this area, the average instantaneous ship count is 22000 respectively as shown in Figure 18. The ship count is based on combined received terrestrial and satellite data for AIS class A.

Figure 18

Field of view case for ship instantaneous number

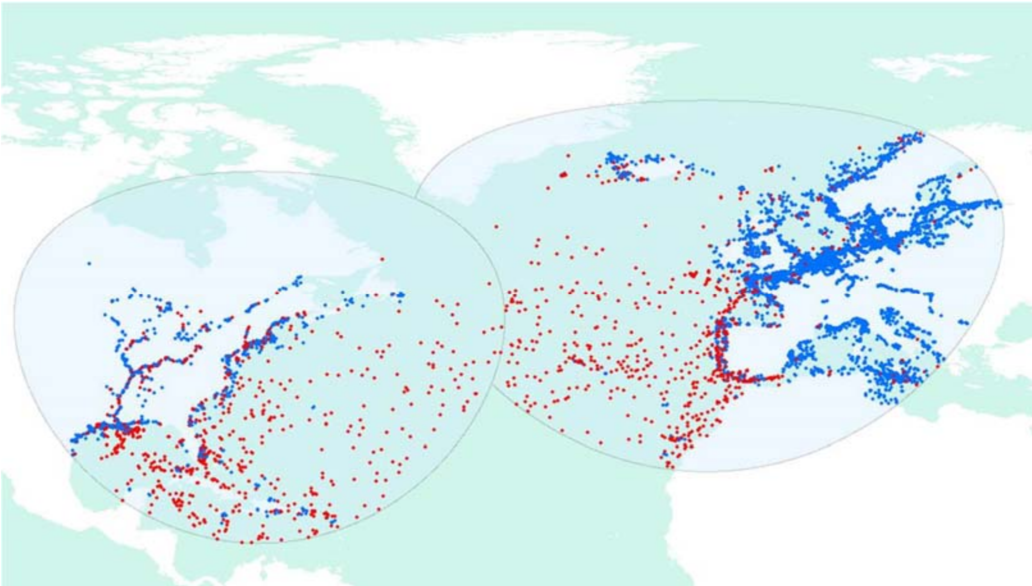


Figure 18 is indicative of the AIS received by terrestrial stations is displayed in blue while AIS received by satellite is displayed in red.

2.1 VDE Satellite Downlink Characteristics

The power flux density mask to be respected is (as also presented in Table 3 of Annex 1).

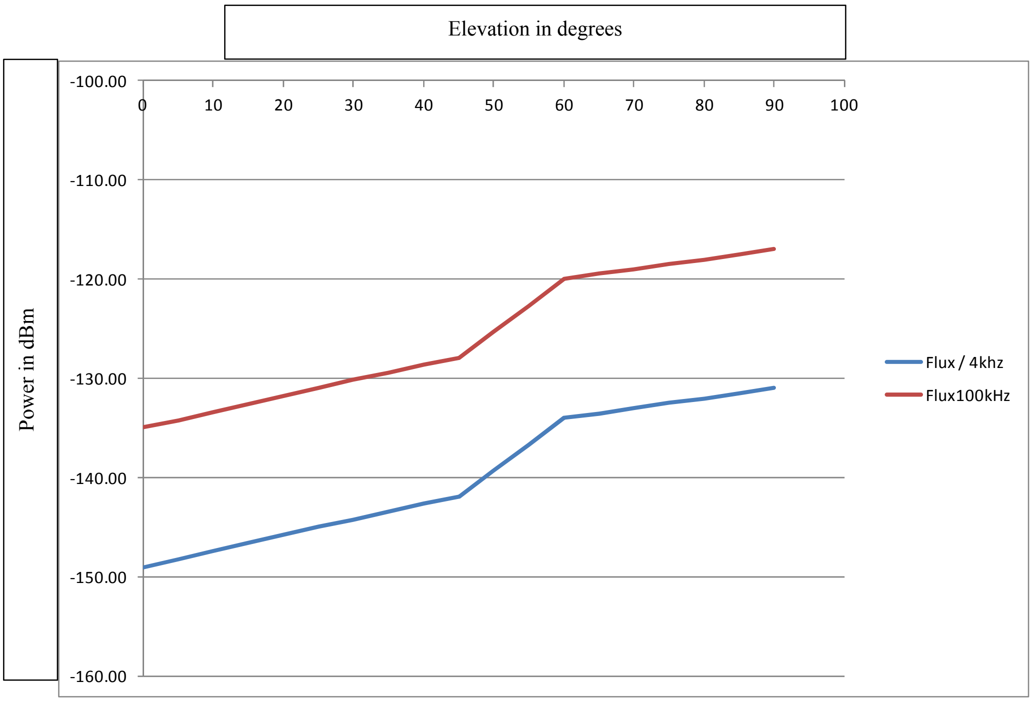
$$PFD(\theta°)_{(dBW/(m^2*4\,kHz))} = \begin{cases} -149 + 0.16 * \theta° & 0° \leq \theta < 45°; \\ -142 + 0.53 * (\theta° - 45°) & 45° \leq \theta < 60°; \\ -134 + 0.1 * (\theta° - 60°) & 60° \leq \theta \leq 90°. \end{cases}$$

which translates to:

	dBW	14.0	10Log10(100/
Theta	Flux / 4khz	Flux / 1Hz	Flux100kHz
0	-149.00	-185.00	-135.00
5	-148.20	-184.20	-134.20
10	-147.40	-183.40	-133.40
15	-146.60	-182.60	-132.60
20	-145.80	-181.80	-131.80
25	-145.00	-181.00	-131.00
30	-144.20	-180.20	-130.20
35	-143.40	-179.40	-129.40
40	-142.60	-178.60	-128.60
45	-142.00	-178.00	-128.00
50	-139.35	-175.35	-125.35
55	-136.70	-172.70	-122.70
60	-134.00	-170.00	-120.00
65	-133.50	-169.50	-119.50
70	-133.00	-169.00	-119.00
75	-132.50	-168.50	-118.50
80	-132.00	-168.00	-118.00
85	-131.50	-167.50	-117.50
90	-131.00	-167.00	-117.00

Figure 19

Power flux density mask.

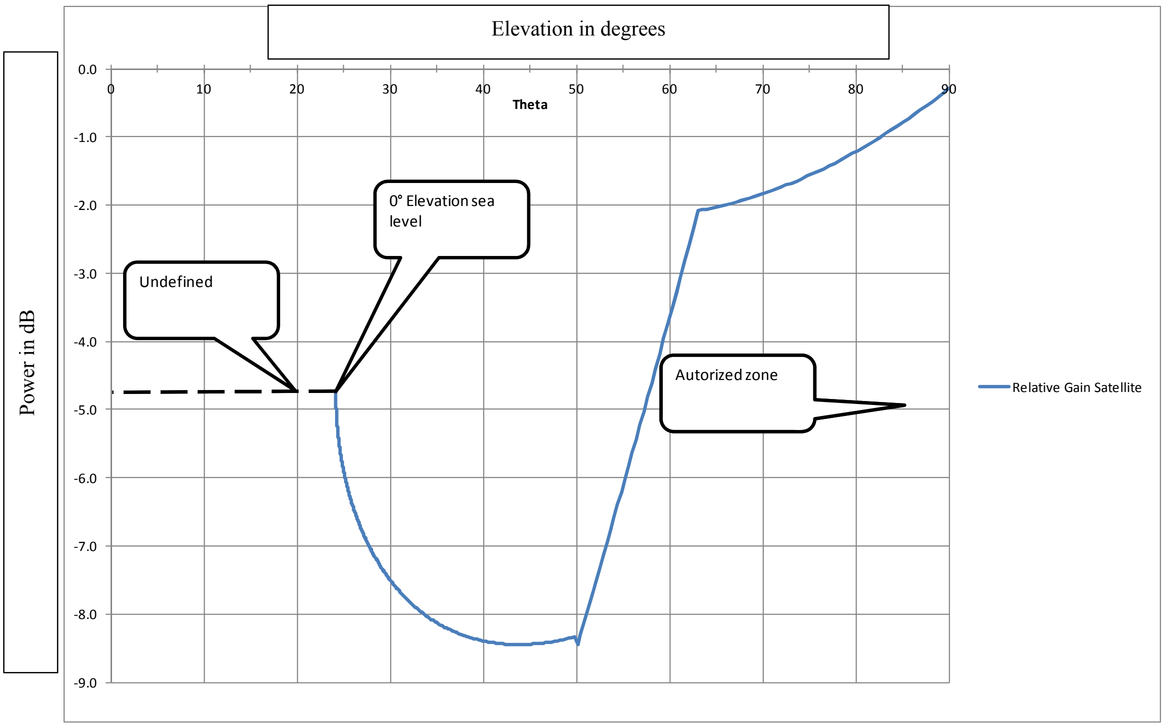


Erreur ! Source du renvoi introuvable. depicts the PFD mask in dBm as a function of elevation in a reference bandwidth of 4 kHz and in 100 kHz bandwidth.

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

Figure 20

Satellite EIRP mask.

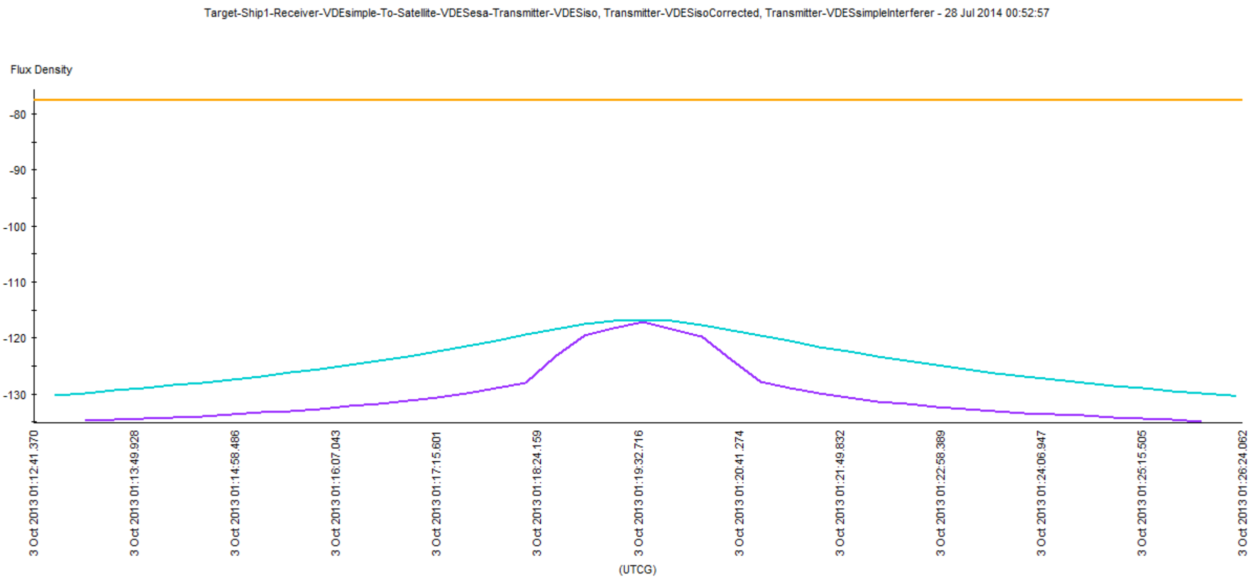


Assuming a circularly polarized downlink signal from the satellite meeting the e.i.r.p. mask in Figure 20, then the PFD in 100 kHz seen in an overhead pass by a ground terminal is shown as a violet curve in

Figure 21. In this figure the signal power of a nearby ship (shown in yellow) is also presented as a benchmark reference. The green line represents the realization of an antenna on the satellite compliant with the e.i.r.p. mask.

Figure 21

Rx carrier input for a 0 dB gain antenna. Iso and compensated sat TX antenna + nearby ship (for the sake of completeness, not relevant for this example)



2.2 VDE Satellite Receiver Characteristics

On the receiver side, the ship's system temperature is considered to be between 630°K (noise figure of 3dB and 2dB of cable loss) and 1500°K. Variations can occur, but it is not expected that the system temperature falls below roughly 900°K in a standard installation. The system temperature accounts for the noise source integrated in the antenna patterns. Some onboard 'industrial' noise is yet to be added, but will be ignored for the remainder of the document.

2.3 'Ideal' Receiving antenna

For the sake of completeness, the receiver antenna mask that would allow the received signal to be at constant power level at the receiver input is calculated and shown as a function of elevation angle in Figure 22.

Figure 22

"Ideal" RX antenna mask, Zenith is 90°

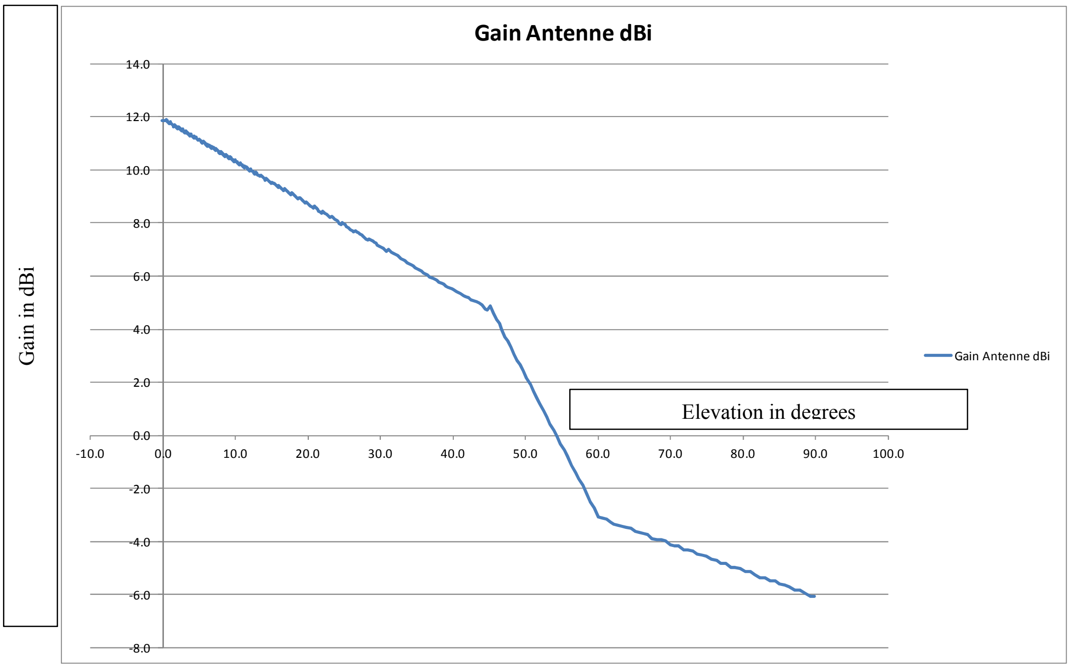


Figure 23

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

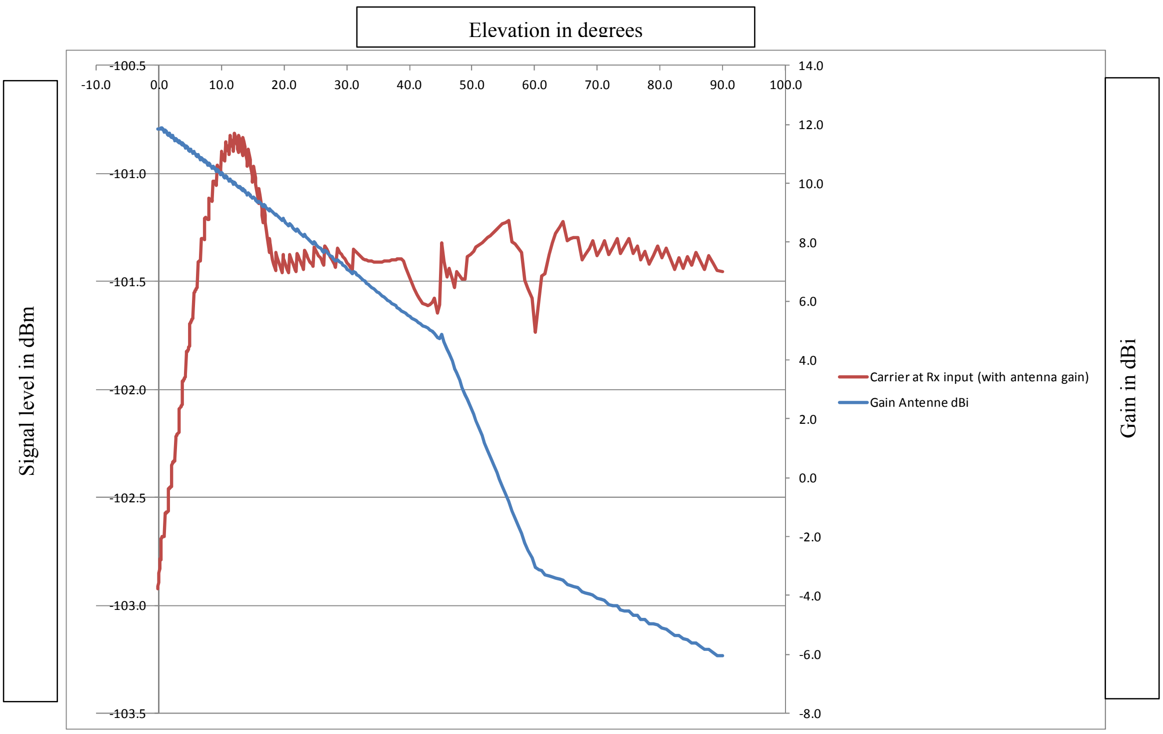


Figure 23 shows the received signal power in dBm at the input of a receiver with the “ideal” receiving antenna as a function of elevation. The link analysis is computed using professional commercial software tools for satellite communications that account for the signal propagation impairments. The software tool however, does not account for possible loss of power strength at very low elevation (<1°). The power loss could be as high as 6 dB due to reflecting surface of seawater, mainly in circular or horizontal polarizations. It is worth noting that the signal power at the receiver input is around -101dBm, and this is 3dB lower than the ITU-R M.1842 recommended sensitivity for 16-QAM for ship stations.

Figure 24

Eb/N0 compensated patterns for ‘ideal’ antenna

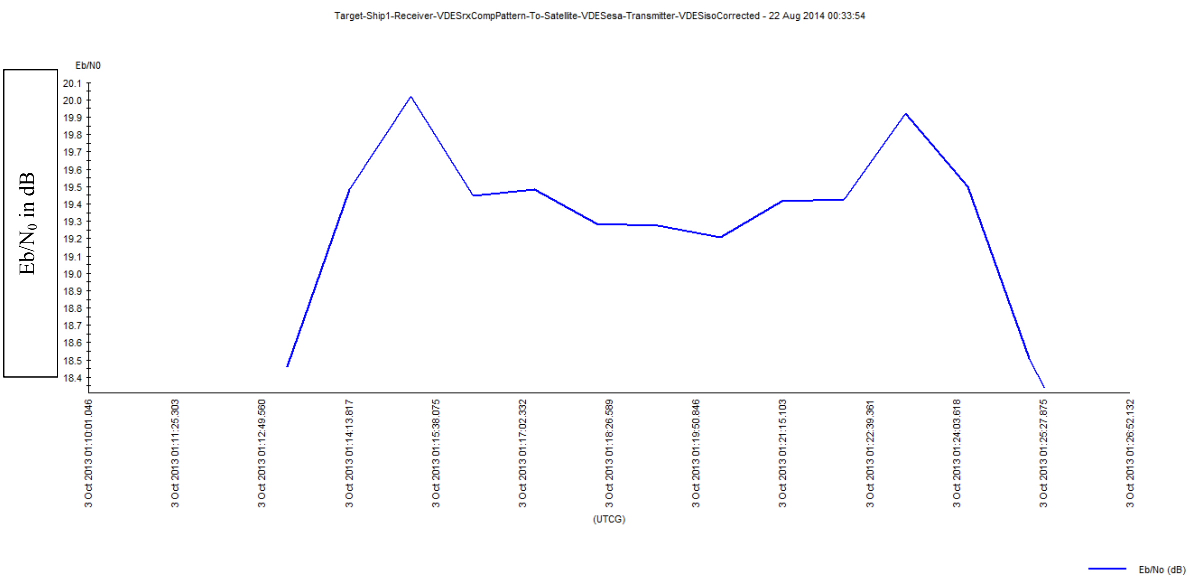


Figure 24 shows the corresponding Eb/N0 observed for the 100 kHz carrier in an overhead pass for the ‘ideal’ antenna.

2.4 Realistic Receiving antenna

Four different antennas are considered:

- The 0dBd ITU-R 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, with Right Hand Circular Polarization (RHCP) (antenna 3)
- A hemispherical 0dBi gain antenna, vertical polarization (antenna 4).

Using professional software tools for satellite communications, simulations have been carried out to determine the carrier power level at the receiver input and to determine the Eb/N0 in the following cases:

- Overhead pass
- Side pass
- Very low pass

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

3.1.5 Overhead pass

Figure 25

Overhead pass, Carrier level at receiver input

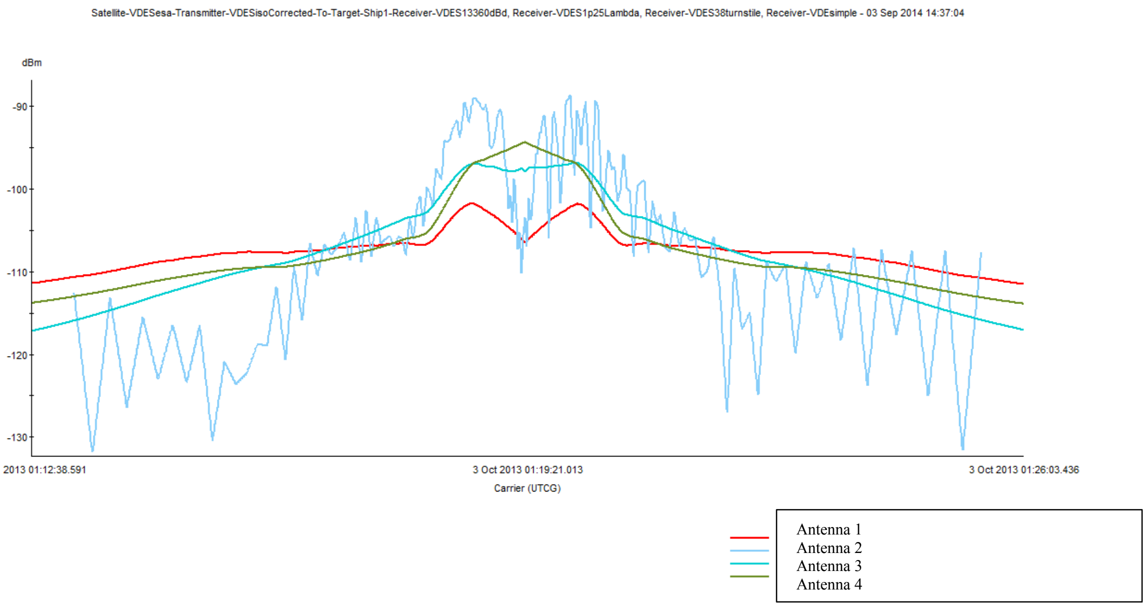
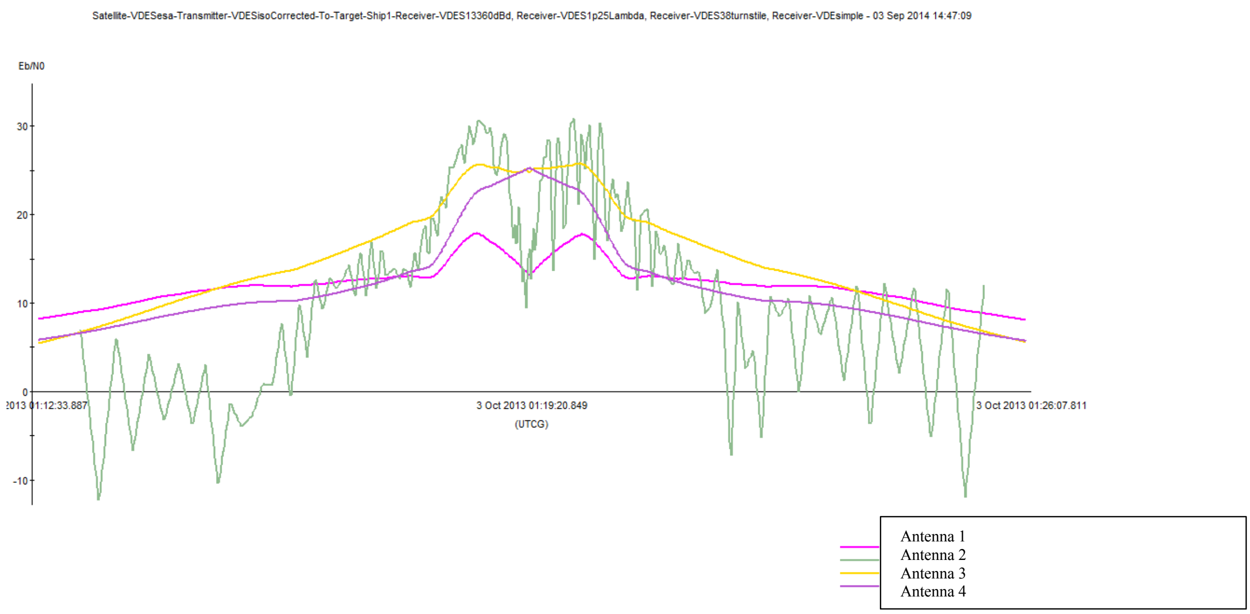


Figure 26

Overhead pass, Eb/N0 at demodulator input



3.1.6 Side pass

Consider a 16° elevation pass, the signal power and corresponding signal quality measured in 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 27

Carrier level at receiver input, Side pass

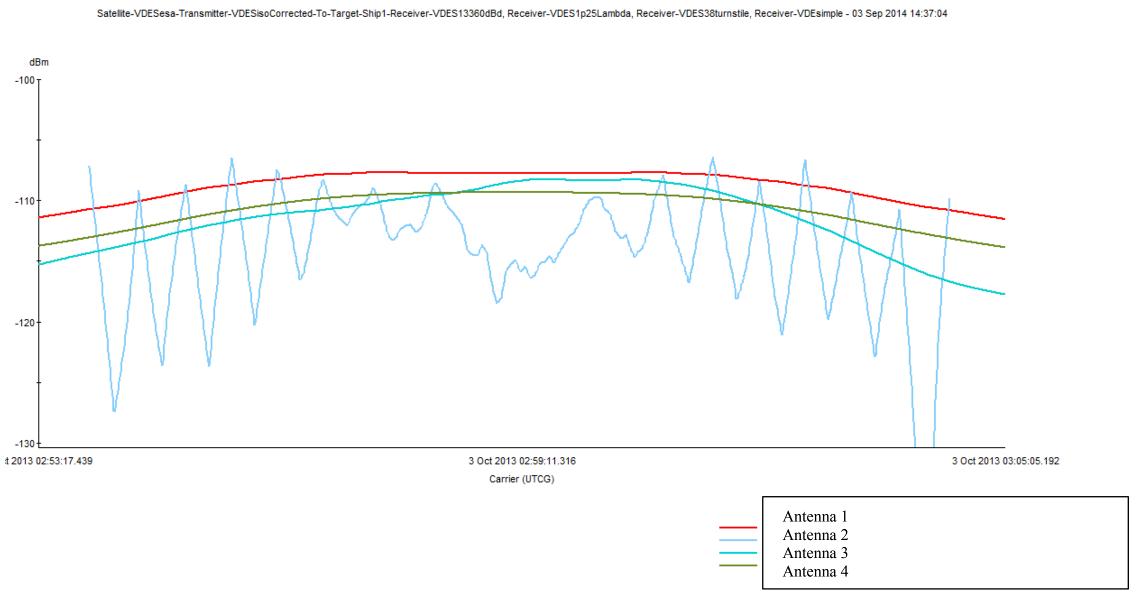
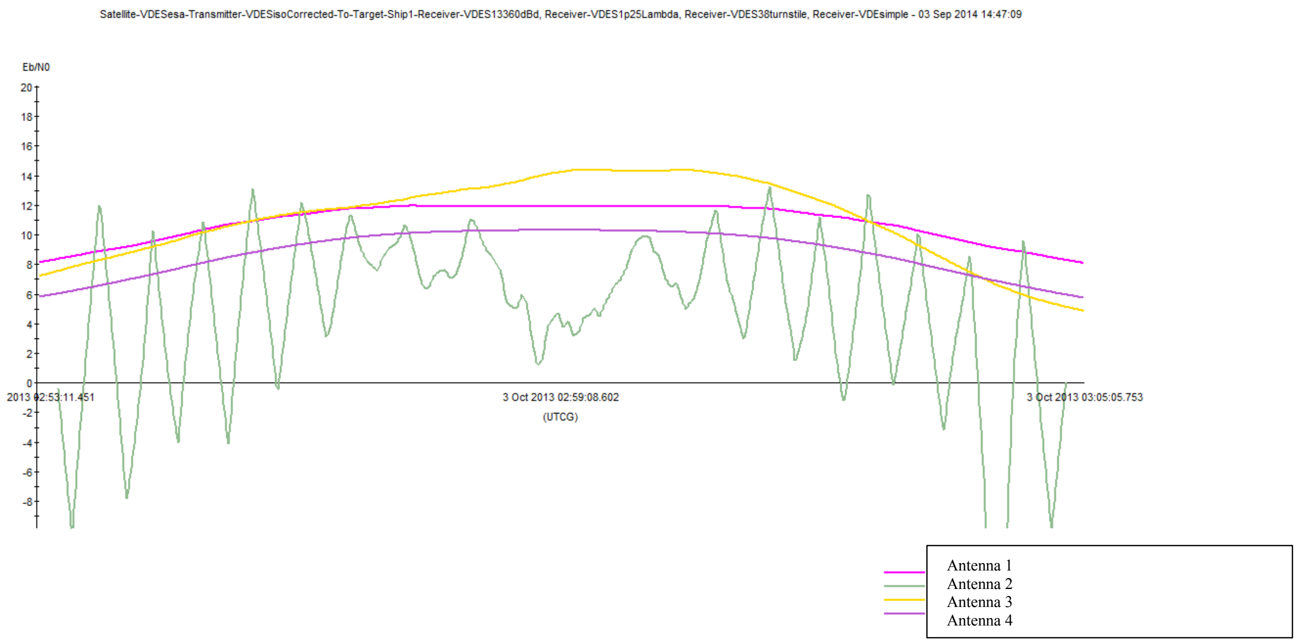


Figure 28

Eb/N_0 at demodulator input, side pass



3.1.7 Very Low side pass

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

Figure 29

Carrier input at receiver input, very low side pass

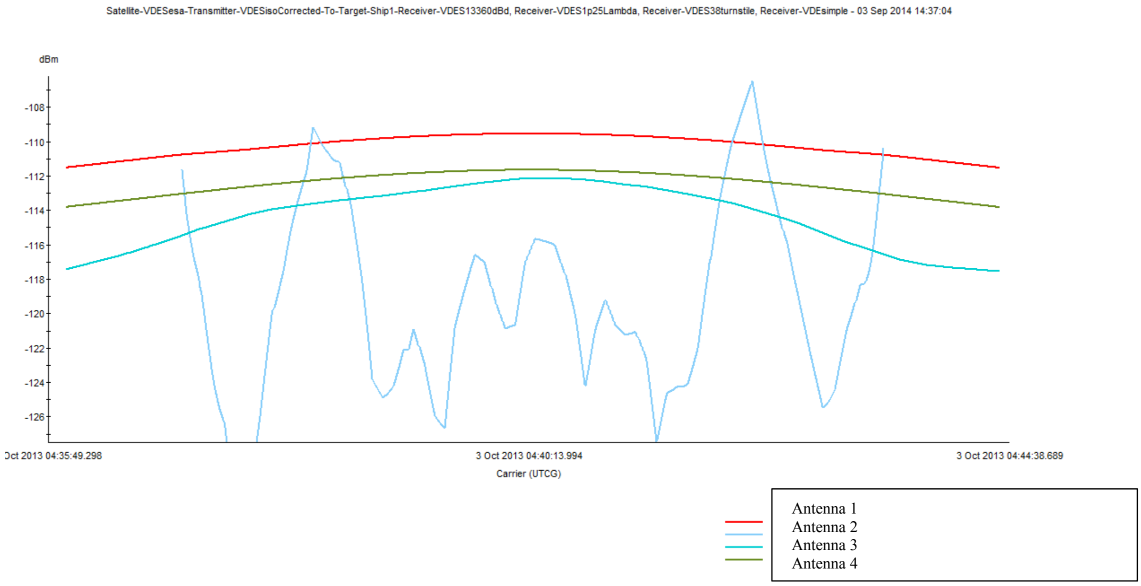
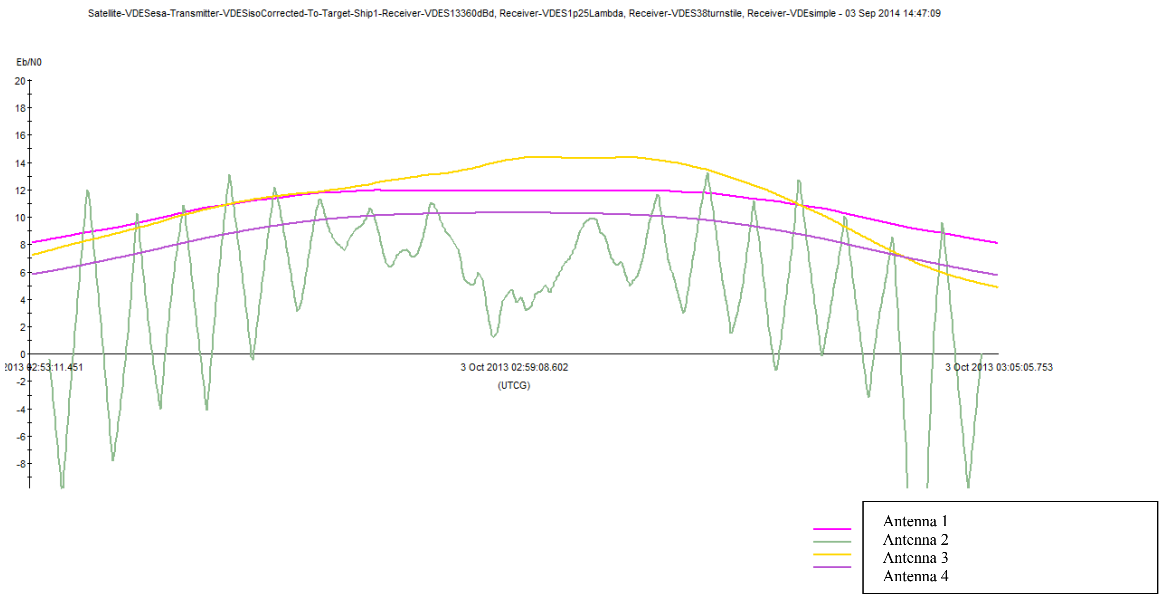


Figure 30

Eb/N$_0$ at demodulator input, very low elevation side pass.



2.5 Waveform choice

As shown in previous sections, for a realistic antenna the signal to noise ratio at the input of the receiver can vary considerably as a function of elevation angle. The choice of the waveform modulation, coding and frame structure has a significant impact on the link throughput and its availability.

The decision on continuous versus intermittent transmission of the signal will impact the acquisition, tracking and the overall performance (bit rate, probability of error, etc.) of the VDE satellite broadcasting. At the system level, a time slot-based transmission (time division) may increase the complexity of the satellite-terrestrial system interactions and reduce the overall efficiency. However, the coexistence of VDE broadcasting and terrestrial shore-to-ship or ship-to-ship may also impact the detection performance of the terrestrial signal.

The choice of modulation scheme has an impact on the efficiency of the power amplifier on board of the satellite. The use of (quasi-) constant envelope reduces the peak to average power ratio and allows the transmitter to operate at a more power efficient mode with less signal distortion.

In order to facilitate synchronisation and signal detection at the receiver, the use of known symbols (as pilot or preamble) is essential as part of the air interface definition.

The use of data sequence randomisation (scrambling) facilitates the synchronisation and mitigates spectral abnormality.

A system capability to allow more than one coding rate (and modulation scheme) may provide more flexibility in the system dimensioning and service availability.

There are a number of existing open standards with air interface specifications, such as Digital Video Broadcasting via satellite DVB-S2x , DVB-SH and DVB-RCS2, that offer mature technical solutions as a starting point for such design trade-offs. The performance characteristics of DVB-RCS2 waveforms are reported in Table 1. Figure 31 presents the spectral efficiency (information bits/symbol) as a function of E_s/N_0 for these waveforms.

Note - DVB-RCS2 reference: ETSI TS 101 545-1 V1.2.1 (2014-04) available at:
http://www.etsi.org/deliver/etsi_ts/101500_101599/10154501/01.02.01_60/ts_10154501v010201p.pdf

Table 9

Waveform Efficiency in AWGN Channel

Frame Size (symbols)	Guard (symbols)	Payload (bits)	Efficiency (Bits/Symbol)	E_s/N_0 @ PER=10^{-5}
266	4	408	1.51	7.3
266	4	440	1.63	8.71
266	4	496	1.84	10.04
266	4	552	2.04	11.59
266	4	672	2.49	11.73
266	4	744	2.76	13.18
536	4	304	0.56	0.22
536	4	472	0.87	2.34
536	4	680	1.26	4.29
536	4	768	1.42	5.36
536	4	864	1.60	6.68
536	4	920	1.70	8.08
536	4	1040	1.93	9.31
536	4	1152	2.13	10.85
536	4	1400	2.59	11.17
536	4	1552	2.87	12.56
1616	4	984	0.61	-0.51
1616	4	1504	0.93	1.71
1616	4	2112	1.30	3.69
1616	4	2384	1.47	4.73
1616	4	2664	1.64	5.94
1616	4	2840	1.75	7.49
1616	4	3200	1.98	8.77
1616	4	3552	2.19	10.23
1616	4	4312	2.66	10.72
1616	4	4792	2.96	12.04
3236	4	984	0.30	-3.52
3236	4	1504	0.46	-1.3

Figure 31

Spectral efficiency of DVB-RCS2 waveform