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|  | **Radiocommunication Study Groups** | |  |
| **INTERNATIONAL TELECOMMUNICATION UNION** | |  | |
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| Annex 26 to the Working Party 5B Chairman’s Report | | | |
| Working document towards A PRELIMINARY DRAFT NEW  REPORT ITU-R M.[VDES-SAT] | | | |
| Technical characteristics and feasibility assessment of the satellite component for the VHF data exchange system in the VHF maritime mobile band | | | |

# 1 Introduction

ENAV20-11.16

At the WRC-15, ITU-R Resolution **360** was revised and updated to invite the WRC-19 to consider, based on the results of ITU-R studies, modifications of the Radio Regulations, including new spectrum allocations to the maritime mobile-satellite service (MMSS) (Earth-to-space and space-to-Earth), preferably within the frequency bands 156.0125-157.4375 MHz and 160.6125‑162.0375 MHz of RR Appendix **18**, to enable a new VHF data exchange system (VDES) satellite component, while ensuring that this component will not degrade the current terrestrial VDES components, ASM and automatic identification system (AIS) operations and not impose any additional constraints on existing services in these and adjacent frequency bands as stated in *recognizing d)* and *e)* of ITU-R Resolution **360**.

Furthermore, in preparation for WRC-19, ITU-R was invited to conduct, as a matter of urgency, and in time for WRC-19, sharing and compatibility studies between VDES satellite components and incumbent services in the same and adjacent frequency bands specified in *recognizing d)* and *e)* of ITU-R Resolution **360** to determine potential regulatory actions, including spectrum allocations to the MMSS (Earth-to-space and space-to-Earth) for VDES applications. This report is the response from ITU-R to that invitation, and it provides a summary of why a VDES satellite component is needed, spectrum requirements, technical description and the appropriate sharing and compatibility studies.

# 2 VHF data exchange-satellite, the essential supplement to coastal VHF data exchange system

## 2.1 Practical aspects of deploying coastal coverage

Analysis of ship density at global scale shows that coastal areas play a key role in ship traffic and safety management and the VDES terrestrial (VDE-TER) will always remain a key component a successful implementation of VDES for a competent authority. However, the current state of AIS-TER deployment shows that while some areas like Europe, the US and Japan are largely covered, others like the West of Africa or the South West of Asia have much sparser coverage Figure 2-1 illustrates this well.

Figure 2-1

Automatic identification system costal station locations (green points) and automatic identification  
 service data coverage (red points)



Many countries with long coastlines are currently not able to ensure adequate terrestrial infrastructure to cover their coastlines. There are numerous challenges, but one of the main difficulties is to find appropriate hosting sites, especially with a reliable power supply. Figure 2-2 represents a 10-minute distribution of terrestrial AIS data over three consecutive days in the Gulf of Guinea illustrating critical gaps in routine operations.

Figure 2-2

Representation of the 10 minute distribution of terrestrial automatic identification system data   
over 3 consecutive days in the Gulf of Guinea



Figure 2-3 exemplifies the high variability observed on the temporal distribution of AIS messages collected from coastal stations. Such high variability indicates severe disruption to ship tracking and, given that AIS is a component of VDES we can assume these same sites will be used, thus VDES will suffer the same issues. These problems of infrastructure distribution, reliability and maintenance in remote and difficult to access areas, or operators with insufficient budget for technical support, are difficult to solve and affects many maritime zones.

Figure 2-3

High variability observed on the distribution of automatic identification system messages collected from coastal stations in the Gulf of Guinea. The grey line corresponds to sunrise when power generators possibly are activated on some sites



VDE-SAT will provide an opportunity to fill the gaps in the coverage of coastal areas. VDE-SAT can also provide redundancy in operations in a situation where parts of the terrestrial infrastructure experience outages. VDE-SAT technical characteristics provide a flexible mode of operation, allowing VDE-SAT services to dynamically adapt to changes in the terrestrial VDE coverage.

### 2.2 To expand the VHF data exchange system from the coastal area to global coverage

The implementation of the SAT-AIS has already demonstrated how the capabilities of the terrestrial AIS can be extended to global coverage, this is illustrated in Figure 2-4. Like SAT-AIS, VDE-SAT, will enable the extension of terrestrial VDE capabilities to long-range communications on a global scale. With polar orbiting satellites the Arctic and Antarctic will also be covered. However, the VDE-SAT is designed specifically for satellite services and thus it is not subject to some of the limitations experienced with SAT-AIS.

Figure 2-4

Comparison of one day of terrestrial automatic identification system data (green dots) to one day of   
satellite automatic identification system data (blue dots) - April 2015 [Source CLS]



## 2.3 Use case descriptions

The VDES is a complementary service to the AIS and is not a safety of life or safety of navigation service.

### 2.3.1 Distribution of maritime safety information

The maritime safety information (MSI) consists of navigational and meteorological warnings, meteorological forecasts, and other urgent safety-related messages broadcasted to ships. VDE-SAT, as the only standard (non-proprietary) global communications link for the maritime community would provide for the global distribution of MSIs extending existing terrestrial coverage and providing coverage where a terrestrial infrastructure isn’t practical such as the Arctic Sea. Maritime Safety Information may concern the following topics:

– warnings of severe live or forecasted weather conditions to make the trip as safe and comfortable (passengers’ trip) as possible;

– warnings of navigation hazards like dangers at sea (floating objects like containers, offshore structures, drifting buoys or ships...) (Figure 2-5);

– route information, protected marine environment areas, restricted navigation zones, under keel clearance (Figure 2-6);

– piracy or armed robbery at sea information including scene identification, warnings, procedures for example with the schedule plans for convoys with security resources (to be discussed).

Figure 2-5

Example of danger at sea caused when a ship capsizes in the Pacific Ocean



Figure 2-6

Ex. AMSA/Torres Strait where under keel clearance information is essential for safe navigation



### 2.3.2 Automated or on event ship reporting

In addition to supporting shore side services, VDE-SAT will also support ship services. Ship reporting may be mandatory, collaborative or of specific interest. For example, IMO has published guidelines for setting up a single window system in maritime transport with the aim to reduce the administrative burden and facilitate coordination between stakeholders. In particular, it includes reporting requirements for ships visiting foreign ports, the 96 hours pre-entry (IMO Fal forms). Before entering into the terrestrial VDES coverage, a ship can push its report via the VDE-SAT to the relevant authority Similar procedures can also be used for mandatory reporting of fish catching.

Another ship reporting case relevant for VDE-SAT is the Voluntary Observing Ship (VOS) program in which ships regularly report weather. The record and data transmission is completely automatic without any manual operation. This data is critical for accurate weather forecasting and modelling.

### 2.3.3 VHF data exchange-satellite opportunity for small vessels fleet or developing areas

The VDE-SAT is designed for satellite communications and so will support a simplified low cost transceiver. This low cost highly robust option will provide significant value for a large number of fishermen in developing areas. They will be able to receive weather warnings and alerts, allowing them to seek a safe harbour. In addition, the fishermen will be able to send a message to call for technical assistance to address incidents like an engine failure or a problem on the helm control.

The VDE-SAT may also be the solution for developing countries to manage their EEZ where a terrestrial infrastructure is cost prohibitive or where the necessary power infrastructure just doesn’t exist.

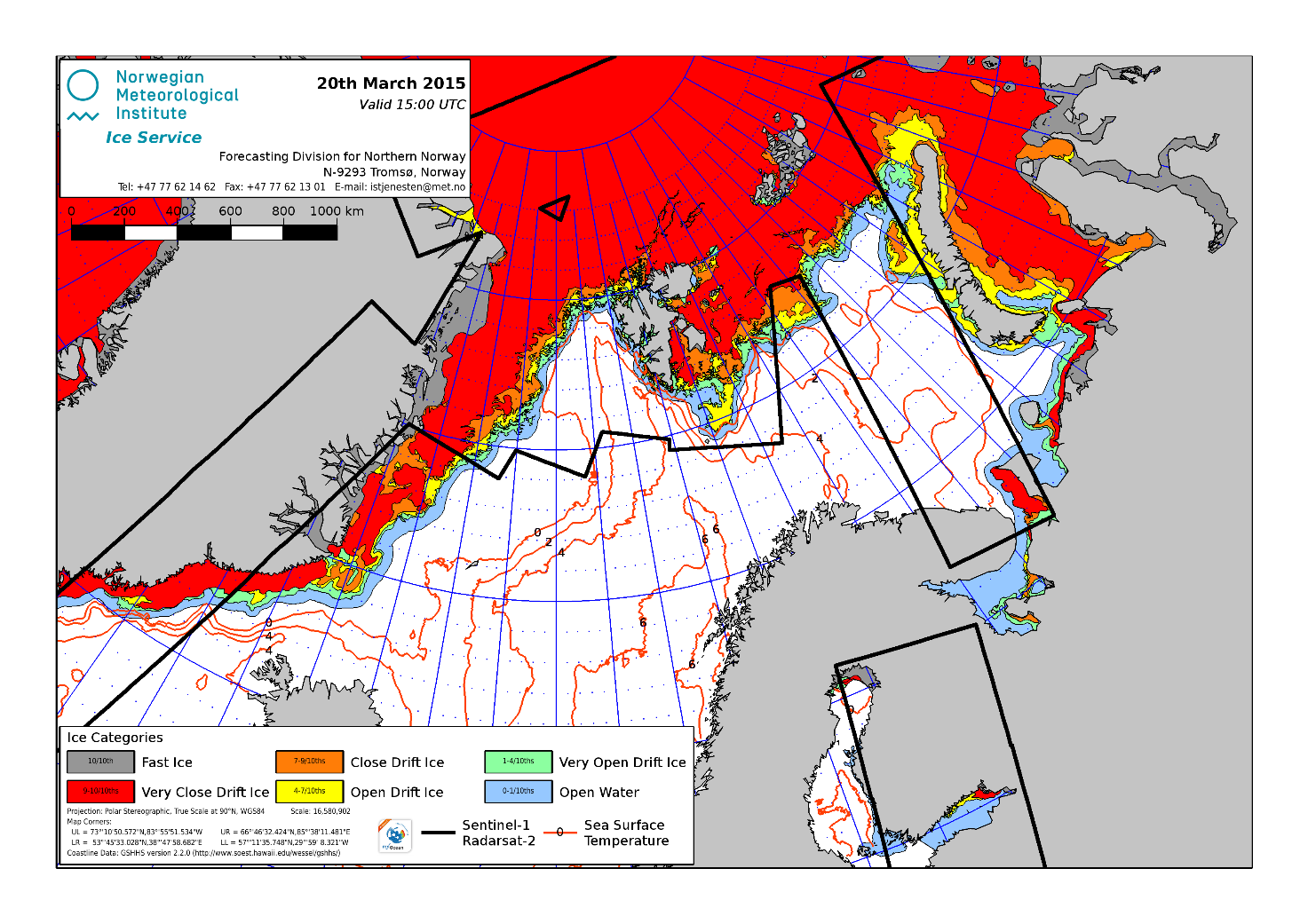
### 2.3.4 Ice chart distribution

Information on sea ice conditions is important to help ensure safe passage at sea. Knowledge of areas with sea ice along a ship’s planned route allows ships to find the most efficient route. Together with prognoses for expected ice movements, ice charts allow mariners to plan ahead and significantly reduce the risk of vessels becoming ice locked.

The Norwegian Meteorological Institute produces ice charts for the European part of the Arctic. Today ice charts and prognoses for the next 24 hours are generated on a daily basis. The ice charts are available as graphic files from the website of the Norwegian Meteorological Institute for free. An example ice chart showing the European part of the Arctic is provided in Figure 2-7.

Figure 2-7

Example ice chart graphics showing the european part of the arctic, available online from the Norwegian Meteorological Institute



The ice information should also become available as a grid of geographical positions, both the current ice situation and prognoses. It could then be formatted in a way suitable for distribution to electronic chart plotters. The amount of data to transfer depends on the size of the area and the geographical resolution of the ice information.

A future ice chart service should be expected to produce updated ice charts and prognoses every 6 hours. The distribution systems currently in use are unnecessarily manual. With VDE-SAT the distribution systems should become more automated and user friendly. Ships should get access to the updated ice charts and prognoses as soon as possible, as well as upon request when needed by the navigator on-board.

# 3 Identification of spectrum requirements and rationale for the use of the frequency bands of RR Appendix 18

## 3.1 Spectrum requirement for the VHF data exchange-satellite

The VDE-SAT communications functions (ship-to-satellite and satellite-to-ship) are intended to be fully integrated with the VDE-TER communications functions (AIS, ASM, ship-to-ship, ship-to-shore and shore-to-ship) in the shipborne VDES equipment, which preferably would utilize one combined transmitting/receiving VDES antenna system. For this reason, it is desirable to utilize frequencies that are within the range of RR Appendix **18** (156.025 MHz to 162.025 MHz), as shown in Figure 3-1. The bandwidth allocated to each function should be as much as possible, considering the large number of ships globally that carry AIS and may decide to upgrade to VDES.

## 3.2 Potential use of the frequency band 160.975-161.475 MHz versus channels 2024/2084/2025/2085/2026/2086 for the satellite downlink

Note the organization and frequency use of RR Appendix **18**, channelized in two sections of 25 kHz channels, a lower section with center frequencies at 156.025 MHz to 157.425 MHz and an upper section with center frequencies at 160.625 MHz to 162.026 MHz, spaced 4.6 MHz apart. The channels are numbered in two groups, 60 numbers apart, 01 to 28 and 60 to 88. Some of the channels are duplex channels with paired frequencies that are 4.6 MHz apart, for example, channel 60 (156.025 MHz and 160.625 MHz) is followed by channel 01 (156.050 MHz and 160.650 MHz), then by channel 61 (156.075 MHz and 160.675 MHz), then by channel 02 (156.100 MHz and 160.700 MHz), etc., and this sequence continues to channel 07 (156.350 MHz and 160.950 MHz). But then the channels 67 to 77 are implemented as simplex channels, where only the lower side (156.375 MHz to 156.875 MHz) is used. The unused upper side of these 25 kHz channels with center frequencies at 160.975 MHz to 161.475 MHz comprises a 525 kHz bandwidth that may be considered as an alternative for the VDES satellite downlink, since it poses no conflict to incumbent maritime services and could be constrained with an appropriate pfd mask to protect incumbent terrestrial services. Utilization of this band could provide a very robust satellite-to-ship service.

### 3.3 Frequency plan alternatives

The channels 24, 84, 25, 85, 26 and 86 are allocated for VDE after WRC-15, with the lower leg frequencies used for ship-to-shore and the upper leg frequencies used for shore-to-ship and ship-to-ship. The channels 2027 (ASM 1) and 2028 (ASM 2) are allocated for ASM. Currently, 2 alternative frequency utilization plans for VDES are under consideration. They describe how resources are allocated and shared between VDE-TER, VDE-SAT and ASM. These 2 alternative frequency utilization plans are illustrated in Figure 3-1, and described further below.

Figure 3-1

RR Appendix 18 and VHF data exchange system frequency utilization plans



### 3.3.1 Frequency plan alternative 1

Frequency plan alternative 1 allow for utilization of the channels 24, 84, 25, 85, 26 and 86 in a shared manner between VDE-TER and VDE-SAT.

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

– The two channels 1026 and 1086 are exclusively reserved for ship-to-satellite (VDE-SAT uplink) services

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

– The two channels 2026 and 2086 are exclusively reserved for satellite-to-ship (VDE-SAT downlink) services.

– Two channels 2027(ASM 1) and 2028 (ASM 2) are shared between ship-to-shore, ship-to-ship, shore-to-ship and ship-to-satellite services

### 3.3.2 Frequency plan alternative 2

Frequency plan alternative 2 allow for utilization of channels 24, 84, 25 and 85 primarily for VDE‑TER, while channels 26 and 86 exclusively reserved for VDE-SAT uplink. VDE-SAT uplink is also possible in channels 24, 84, 25 and 85, but the VDE-SAT uplink in these channels do not impose constraints on VDE-TER. Frequencies are exclusively reserved for VDE-SAT downlink within the frequency range 160.9625 MHz to 161.4875 MHz, which is not channelized in RR Appendix **18**.

– The four channels 1024, 1084, 1025 and 1085 are reserved for ship-to-shore services, but ship-to-satellite (VDE-SAT uplink) services are possible without imposing constraints on ship-to-shore services.

– The four channels 2024, 2084, 2025 and 2085 are reserved for shore-to-ship and ship-to-ship services, but ship-to-satellite (VDE-SAT uplink) services are possible without imposing constraints on shore-to-ship and ship-to-ship services.

– The four channels 1026, 1086, 2026 and 2086 are exclusively reserved for ship-to-satellite (VDE-SAT uplink) services.

– Frequencies are exclusively reserved for satellite-to-ship (VDE-SAT downlink) services within the frequency range 160.9625 MHz to 161.4875 MHz, which is not channelized in RR Appendix **18**.

– Two channels 2027(ASM 1) and 2028 (ASM 2) are shared between ship-to-shore, ship-to-ship, shore-to-ship and ship-to-satellite services.

# 4 Technical description of the VHF data exchange-satellite

### 4.1 VDE-SAT key parameters

This section outlines key parameters regarding the VDE-SAT system that are used in the various studies throughout this report and are common for uplink and downlink.

### 4.1.1 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 Figure 4-1 and Figure 4-2.

For the VDE-SAT downlink, in addition to the relative propagation delays between signal receptions at a vessel from different satellites, there could be delays due to other factors such as signal processing delay. The satellite service provider should pre-compensate for the minimum propagation delay.

Figure 4-1

VDE-SAT downlink timing



Figure 4-2

VDE-SAT Uplink timing



### 4.1.2 Satellite transmission carrier frequency error

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 shift of ±4 kHz at VHF.

### 4.1.3 Ship station antenna gain and transmitter requirements

Ship station antenna gain and transmitter requirements are defined in Annex 1 of Recommendation ITU-R M.2092. From that definition it is expected that a ship transmitter will have linear output power of at least 6 W.

The assumed ship antenna gain and minimum ship e.i.r.p. versus elevation angle is shown in Table 4-1. There are no minimum e.i.r.p. requirements above 80 degrees elevation. Table 4-1 is based on a linear transmitter that meets the maximum Adjacent Channel Interference levels defined in Annex 1 of Recommendation ITU-R M.2092, which is expected to provide an output power of at least 6 W. For saturated operation the e.i.r.p. shall be 3 dB higher.

TABLE 4-1

Ship antenna gain and minimum ship e.i.r.p. versus 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 |

### 4.1.4 Satellite antenna gain

The following two satellite antennas have been analysed and provide acceptable performance for VDE-SAT:

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. Assuming a peak antenna gain of 8 dBi, satellite antenna gain versus ship elevation angle and nadir offset angle are shown in Table 4‑2.

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, satellite antenna gain versus ship elevation and nadir offset angle are shown in Table 4-3.

TABLE 4-2

Satellite Yagi-antenna gain vs. nadir offset angle

|  |  |  |
| --- | --- | --- |
| Ship elevation angle | Nadir offset angle | Satellite antenna gain |
| degrees | degrees | dBi |
| 0 | 66.1 | 8 |
| 10 | 64.2 | 8 |
| 20 | 59.2 | 8 |
| 30 | 52.3 | 7.8 |
| 40 | 44.4 | 6.9 |
| 50 | 36 | 5.5 |
| 60 | 27.2 | 3.6 |
| 70 | 18.2 | 0.7 |
| 80 | 9.1 | –2.2 |
| 90 | 0 | –5.5 |

TABLE 4-3

Satellite Isoflux-antenna gain vs. nadir offset angle

|  |  |  |
| --- | --- | --- |
| Ship elevation angle | Nadir offset angle | Satellite antenna gain |
| degrees | degrees | dBi |
| 0 | 66.1 | 2 |
| 10 | 64.2 | 1.5 |
| 20 | 59.2 | 1 |
| 30 | 52.3 | –0.5 |
| 40 | 44.4 | –2 |
| 50 | 36 | –4 |
| 60 | 27.2 | –5 |
| 70 | 18.2 | –7 |
| 80 | 9.1 | –8 |
| 90 | 0 | –8.5 |

### 4.2 Technical characteristics of the VHF date exchange-satellite downlink in the VHF maritime mobile frequency band

This section outlines key parameters and link budgets for the VDE-SAT system that are used in the various studies of the downlink throughout this report.

### 4.2.1 Satellite downlink e.i.r.p

The VDE-SAT downlink has been imposed a pfd mask, as specified in Recommendation ITU-R M.2092-0. This pfd mask ensures that VDE-SAT downlink will not cause harmful interference to fixed and mobile services. The pfd mask was coordinated and agreed between WP5A, WP5B and WP5C ahead of WRC-15. In a Liaison Statement to WP5B (Doc 5B/199), WP5A confirmed that the Recommendation ITU-R M.1808 has not been revised since and as such the mask is still valid. The pfd mask is presented in Table 4-4.

TABLE 4-4

Proposed power spectral and power flux density mask

From the mask given in Table 4-4 a theoretical maximum satellite e.i.r.p can be calculated as a function of ship elevation angle. The result is provided in Table 4-5.

TABLE 4-5

Satellite maximum e.i.r.p. versus 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 |

The maximum achievable satellite e.i.r.p depends on the antenna on-board the satellite, and how well the antenna pattern can be made to fit the theoretical maximum satellite e.i.r.p mask. 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 two satellite antenna types given in Section 4.1.4 have been analysed to calculate the maximum possible satellite e.i.r.p that meets the pfd mask:

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. 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 mask. Satellite e.i.r.p. versus ship elevation angle and resulting margin to the pfd mask are shown in Table 4‑6.

TABLE 4-6

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 |
| 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 mask. Satellite e.i.r.p. vs. ship elevation and resulting margin to the pfd mask are shown in Table 4-7.

TABLE 4-7

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/m2/4 kHz | dBW/m2/4 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 |

### 4.2.2 Ship station noise and interference level

The noise floor for a ship receiver is a function of many sources such as vessel electronics, other radio equipment, power supplies, etc. Sensitivity is also reduced by RF cabling losses and the LNA noise figure. Table 4-8 presents representative values for the receiver noise figure.

TABLE 4-8

Ship receiver noise figure calculations

|  |  |  |
| --- | --- | --- |
| Parameter | Value | Unit |
| 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 according to Recommendation ITU-R P.372. | | |

A typical ship station receiver is expected to observe an interference level of -116 dBm per 25 kHz at the antenna input.

### 4.2.3 VDE-SAT downlink link budget

The nominal signal level, *C*/(*N*0+*I*0) and the link budget versus elevation for a 25 kHz channel are provided in Table 4‑9 for a Yagi antenna and Table 4-10 for an Isoflux antenna. The assumed maximum ship antenna gain is 3 dBi and the system noise temperature is 30.2 dBK as shown in Table 4-2 in Section 4.1.4.

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 dB and 6 dB respectively. Limiting the service area to ship elevation angles between 10 and 55 degrees also improves the link margin 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.

TABLE 4-9

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

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Ship elevation angle | Satellite e.i.r.p. in circular polarization | Satellite range | Path loss | Polarization loss | Ship antenna gain | Antenna signal level | *C*/*N*0 | Ship on-board interference level in 25 kHz | *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 4-10

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

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Ship elevation angle | Satellite e.i.r.p in circular polarization | Satellite range | Path loss | Polarization loss | Ship antenna gain | Antenna signal level | *C/N0* | Ship on-board interference level in 25 kHz | *C/(N0+I0)* |
| deg | dBW | (km) | dB | dB | dBi | dBm | dBHz | dBm | dBHz |
| 0 | −3.0 | 2 830 | 145.6 | 3 | 3 | −118.6 | 49.8 | −116 | 41.4 |
| 10 | −3.5 | 1 932 | 142.2 | 3 | 3 | −115.7 | 52.7 | −116 | 44.2 |
| 20 | −4.0 | 1 392 | 139.4 | 3 | 2.5 | −113.9 | 54.5 | −116 | 46.1 |
| 30 | −5.5 | 1 075 | 137.2 | 3 | 1 | −114.7 | 53.7 | −116 | 45.3 |
| 40 | −7.0 | 882 | 135.4 | 3 | 0 | −115.4 | 53.0 | −116 | 44.5 |
| 50 | −9.0 | 761 | 134.2 | 3 | −1.5 | −117.7 | 50.7 | −116 | 42.3 |
| 60 | −10.0 | 683 | 133.2 | 3 | −3 | −119.2 | 49.2 | −116 | 40.8 |
| 70 | −12.0 | 635 | 132.6 | 3 | −4 | −121.6 | 46.8 | −116 | 38.4 |
| 80 | −13.0 | 608 | 132.2 | 3 | −10 | −128.2 | 40.2 | −116 | 31.8 |
| 90 | −13.5 | 600 | 132.1 | 3 | −20 | −138.6 | 29.8 | −116 | 21.4 |

### 4.3 Technical characteristics of the VHF data exchange-satellite uplink in the VHF maritime mobile frequency band

This section outlines key parameters and link budgets for the VDE-SAT system that are used in the various studies of the downlink throughout this report.

### 4.3.1 VDE-SAT uplink receiver thresholds

The VDES maximizes frequency efficiency by using adaptive coding and modulation based on the actual link quality. Initial system access is done using a combination of spread spectrum, low bitrate and powerful FEC. The VDE-SAT defined in Recommendation [ITU-R M.2092-0](http://www.itu.int/rec/R-REC-M.2092/en), uses the waveforms defined in Table 4-11 for uplink. The thresholds *C/N*0 and *C/(N+I)* on a Gaussian channel have been estimated.

TABLE 4-11

Estimated thresholds for the VHF data exchange-satellite uplink waveforms

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Physical Layer Frame Format # | 1 | 2 | 3 | 4 | 5 |
| Channel bandwidth (kHz) | 50 | 50 | 50 | 50 | 50 |
| Occupied bandwidth (kHz) | 42 | 42 | 42 | 42 | 42 |
| CDMA chip rate (kcps) | 33.6 | 33.6 | NA | NA | NA |
| Symbol rate (ksps) | 2.4 | 2.4 | 33.6 | 33.6 | 33.6 |
| Packet size (ms) | 133.3 | 133.3 | 26.7 | 26.7 | 800 |
| Modulation | BPSK | CPM/QPSK | QPSK | 16APSK | 16APSK |
| FEC rate | 1/2 | 1/4 | 3/4 | 3/4 | 3/4 |
| Information rate (kbps) | 2.1 | 2.1 | 50.4 | 100.8 | 100.8 |
| Estimated threshold Es/N0 for a Gaussian channel (dB) (BER=1E-5) | 0.1 | 0.1 | 4.4 | 11.4 | 11.4 |
| Symbol error rate at threshold (%) | 30 | 30 | 10 | 2 | 2 |
| Estimated required C/N0 (dBHz) | 34.2 | 33.9 | 51.4 | 61.4 | 61.4 |
| Estimated required C/(N+I) (dB) | -12.0 | -12.3 | 5.2 | 15.2 | 15.2 |

*[Editorial note: Table needs to be verified, especially the values for C/N and C/(N+I)]*

### 4.3.2 VDE-SAT uplink receiver characteristics

Satellite noise levels at the receiver front end are presented in Table 4-12. The system noise temperature is taken to be 25.7 dBK assuming no external interference. The required *C*/(*N+I*) listed in Table 4-12 is for the most robust waveform, as given in Table 4-11. Adaptive coding and modulation allow the usage waveforms with higher throughput when the necessary link quality is available.

TABLE 4-12

Characteristics of VHF data exchange system satellite receiver

|  |  |  |
| --- | --- | --- |
| Parameter | Value | Unit |
| Antenna noise temperature | 200.0 | K |
| Feed losses | 1.0 | dB |
| LNA noise figure | 2.0 | dB |
| LNA noise temperature | 159.7 | K |
| Feed loss noise temperature at LNA | 56.1 | K |
| Antenna noise temperature at LNA | 158.9 | K |
| System noise temperature at LNA | 374.7 | K |
| System noise temperature at LNA | 25.7 | dBK |
| Intrinsic noise power density | -202.9 | dBW/Hz |
| Intrinsic noise power in 42 kHz bandwidth | -156.6 | dBW |
| Required carrier-to-noise-plus-interference ratio (C/(N+I)) | -12.3 | dB |

### 4.3.3 VDE-SAT uplink link budget

Tables 4-13 and 4-14 present link budgets for VDES up-link with a satellite receiver in a 600 km altitude orbit using Isoflux and Yagi antennas. A 6 W ship station transmitter is assumed. For the most robust waveform, the link margin is high for all elevation angles and both satellite antenna types. Furthermore, in an interference free environment all five waveforms given in Table 4-11 will be usable up to 70 degrees elevation angle for the isoflux antenna and up to 80 degrees elevation angle for the Yagi-antenna.

TABLE 4-13

Worst-case link budget for VHF data exchange-satellite uplink with 6 W ship transmitter, Isoflux satellite receiving antenna without interference.

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Ship elevation angle | Ship antenna gain | Ship e.i.r.p. | Polarization loss | Path length | Path loss | Satellite antenna gain | Carrier level at LNA, including feed loss | *C/N*0 | *C/N* | Link margin for waveform 1 |
| deg | dBi | dBW | dB | km | dB | dBi | dBW | dBHz | dB | dB |
| 0.0 | 3.0 | 10.8 | 3.0 | 2 830 | 145.4 | 2.0 | –136.6 | 66.2 | 20.0 | 32.3 |
| 10.0 | 3.0 | 10.8 | 3.0 | 1 932 | 142.1 | 1.5 | –133.8 | 69.0 | 22.8 | 35.1 |
| 20.0 | 2.5 | 10.3 | 3.0 | 1 392 | 139.3 | 1.0 | –132.0 | 70.9 | 24.7 | 37.0 |
| 30.0 | 1.0 | 8.8 | 3.0 | 1 075 | 137.0 | –0.5 | –132.7 | 70.1 | 23.9 | 36.2 |
| 40.0 | 0.0 | 7.8 | 3.0 | 882 | 135.3 | –2.0 | –133.5 | 69.4 | 23.1 | 35.4 |
| 50.0 | –1.5 | 6.3 | 3.0 | 761 | 134.0 | –4.0 | –135.7 | 67.1 | 20.9 | 33.2 |
| 60.0 | –3.0 | 4.8 | 3.0 | 683 | 133.1 | –5.0 | –137.3 | 65.6 | 19.3 | 31.6 |
| 70.0 | –4.0 | 3.8 | 3.0 | 635 | 132.4 | –7.0 | –139.7 | 63.2 | 17.0 | 29.3 |
| 80.0 | –10.0 | –2.2 | 3.0 | 608 | 132.1 | –8.0 | –146.3 | 56.6 | 10.4 | 22.7 |
| 90.0 | –20.0 | –12.2 | 3.0 | 600 | 131.9 | –8.5 | –156.7 | 46.2 | 0.0 | 12.3 |

TABLE 4-14

Worst-case link budget for VHF data exchange-satellite uplink with 6 W ship transmitter, Yagi satellite receiving antenna without interference.

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Ship elevation angle | Ship antenna gain | Ship e.i.r.p. | Polarization loss | Path length | Path loss | Satellite antenna gain | Carrier level at LNA, including feed loss | *C*/*N*0 | *C/N* | Link margin for waveform 1 |
| deg | dBi | dBW | dB | km | dB | dBi | dBW | dBHz | dB | dB |
| 0.0 | 3.0 | 10.8 | 3.0 | 2 830 | 145.4 | 8.0 | –130.6 | 72.2 | 26.0 | 38.3 |
| 10.0 | 3.0 | 10.8 | 3.0 | 1 932 | 142.1 | 8.0 | –127.3 | 75.5 | 29.3 | 41.6 |
| 20.0 | 2.5 | 10.3 | 3.0 | 1 392 | 139.3 | 8.0 | –125.0 | 77.7 | 31.7 | 44.0 |
| 30.0 | 1.0 | 8.8 | 3.0 | 1 075 | 137.0 | 7.8 | –124.4 | 78.4 | 32.2 | 44.5 |
| 40.0 | 0.0 | 7.8 | 3.0 | 882 | 135.3 | 6.9 | –124.6 | 78.3 | 31.2 | 44.3 |
| 50.0 | –1.5 | 6.3 | 3.0 | 761 | 134.0 | 5.5 | –126.2 | 76.6 | 30.4 | 42.7 |
| 60.0 | –3.0 | 4.8 | 3.0 | 683 | 133.1 | 3.6 | –128.7 | 74.2 | 27.9 | 40.2 |
| 70.0 | –4.0 | 3.8 | 3.0 | 635 | 132.4 | 0.7 | –132.0 | 70.9 | 24.7 | 37.0 |
| 80.0 | –10.0 | –2.2 | 3.0 | 608 | 132.1 | –2.2 | –140.5 | 62.4 | 16.2 | 28.5 |
| 90.0 | –20.0 | –12.2 | 3.0 | 600 | 131.9 | –5.5 | –153.7 | 49.2 | 3.0 | 15.3 |

# 5 Interoperability and resource sharing with VDE-TER and between VDE-SAT systems

### 5.1 Resource sharing method for VDE-TER and VDE-SAT services

The VDES resource assignment between the VDE-TER and the VDE-SAT services is outlined in the following sections. In particular the signalling and control mechanisms envisaged to coordinate the use of each time slot either for terrestrial or satellite communication.

Shore stations utilize the terrestrial bulletin board (TBB) and the announcement signalling channels (ASC) to coordinate the resource assignment within the control area. Shore stations may provide information regarding VDE-SAT communications and availability as part of their information service. VDE-SAT information may be acquired by shore stations, either directly from the satellite bulletin board (SBB) and the ASC or through 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.

Each satellite system will use satellite bulletin board (SSB) and announcement signalling channels (ASC), as described in Annex 1 and 4., to communicate the VDE-SAT resource assignments, for both downlink and uplink, to vessels in the coverage area. There are dedicated slots and frequency bands for the SBB and ASC 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.

How and to which extent resources are shared between VDE-TER and VDE-SAT are closely linked to the frequency utilization plan selected for VDES. Section 3 currently discuss two alternative frequency plans and their implications on resource sharing between VDE-TER and VDE-SAT. Methods for resource sharing are discussed in the following sections.

Methods for resource sharing between VDE-TER and VDE-SAT depend on the frequency plan and the resource sharing methods are different for VDE-SAT uplink and downlink.

### 5.2 VDE-TER and VDE-SAT downlink resource sharing

### 5.2.1 Resource sharing with frequency plan alternative 1

With frequency plan alternative 1, the channels 2026 and 2086 are dedicated to VDE-SAT downlink. Within these exclusive VDE-SAT channels, there are dedicated time slots that are assigned to the satellite bulletin board and announcement signalling channels as described in Annex 1 and 4. 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-TER. 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 described in Annex 1 and 3. These slots should not be used by the VDE-SAT downlink when a VDE shore station is within the satellite coverage area.

A shore station may assign the full resources of channels 2024, 2084, 2025 and 2085 for terrestrial services when there is no transmitting VDE satellite in the field of view.

When a transmitting VDE satellite is in the field of view the resource sharing between VDE-SAT downlink and VDE shore-to-ship and ship-to-ship must be coordinated between the shore operator and the satellite operator. This coordination can be done either directly between the operators or rely 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.

– Channels 2024 and 2084 are exclusively used for terrestrial VDE, maintaining the original signalling assignment that was described above

– Channels 2026 and 2086 are exclusively used for VDE-SAT downlink, maintaining the original signalling assignment that was described above

– 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 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.

Coordination of resource sharing between VDE ship-to-ship and VDE-SAT downlink for areas not controlled by a VDE shore station is managed by the VDE-SAT bulletin board, as described in Annex 4. As a starting point for this resource sharing or in the absence of any VDE-SAT bulletin board, the resource sharing method described above should be used.

### 5.2.2 Resource sharing with frequency plan alternative 2

With frequency plan alternative 2, the frequency band from 160.9625 MHz to 161.4875 MHz is dedicated to VDE-SAT downlink. The frequencies in this band are not channelized in RR APPENDIX 18. Within this exclusive VDE-SAT band, there are dedicated channels and time slots that are assigned to the satellite bulletin board and announcement signalling channels as described in Annex 1 and 4. Other slot assignments in this exclusive VDE-SAT frequency band 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).

### 5.3 VDE-TER and VDE-SAT uplink resource sharing

### 5.3.1 Resource sharing with frequency plan alternative 1

With frequency plan alternative 1, the lower frequency bands, channel 1026 and 1086 are dedicated to VDE-SAT uplink while channels 1024, 1084, 1025 and 1085 are shared between VDE-TER and VDE-SAT.

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.).

Through the bulletin board, a shore station may assign the full resources of channels 1024, 1084, 1025 and 1085 for terrestrial services when there is no receiving VDE satellite in the field of view.

When a transmitting VDE satellite is in the field of view the resource sharing between VDE-SAT uplink and VDE-TER ship-to-shore must be coordinated between the shore operator and the satellite operator. This coordination can be done either directly between the operators or rely 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.

– Channels 1024 and 1084 are exclusively used for VDE-TER ship-to-shore

– Channels 1026 and 1086 are exclusively used for VDE-SAT uplink (ship-to-satellite)

– Channels 1025 and 1085 are time-shared between the VDE-SAT uplink and VDE-TER services. The time-sharing is based on time intervals of 1 hexslot (6 slots) that are assigned alternately to VDE-SAT and VDE-TER services

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.

### 5.3.2 Resource sharing with frequency plan alternative 2

With frequency plan alternative 2, the utilization of channels 24, 84, 25 and 85 is primarily for VDE-TER. VDE-SAT uplink is also possible in channels 24, 84, 25 and 85, but the VDE-SAT uplink in these channels does not impose constraints on VDE-TER and should only use resources not reserved by VDE-TER.

Channels 26 and 86 are exclusively reserved for VDE-SAT uplink. Therefore, on these channels no resources are shared and no sharing scheme is required.

### 5.4 Resource sharing between multiple satellite VHF data exchange systems

The sharing between two or more satellite systems is coordinated between the satellite operators and organized through the bulletin board, delivered by satellites in the VDE-SAT downlink band, as described in Annex 1 and 4. Ships use the satellite bulletin boards for channel and resource configuration.

The waveform 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 allows for detection of up to 8 overlapping satellite signals.

# 6 Interference to incumbent services and those in adjacent frequency bands

### 6.1 In-band interference

### 6.1.1 Fixed services in-band

The VDE-SAT uplink has common characteristics with VDE terrestrial ship-to-shore. Therefore, it will not create any additional interference to land and aeronautical mobile services.

The VDE-SAT downlink has been imposed a pfd mask, as specified in Recommendation ITU-R M.2092-0 and provided in Section 4.2.1. This pfd mask ensures that VDE-SAT downlink will not cause harmful interference to fixed services. The pfd mask was coordinated and agreed between WP5A, WP5B and WP5C ahead of WRC-15. In a Liaison Statement to WP5B (Doc 5B/199), WP5A confirmed that the Recommendation ITU-R M.1808 has not been revised since and as such the mask is still valid. The pfd mask is presented in Table 4-4.

### 6.1.2 Land and aeronautical mobile services in-band

The VDE-SAT uplink has common characteristics with VDE terrestrial ship-to-shore. Therefore, it will not create any additional interference to land and aeronautical mobile services.

The VDE-SAT downlink has been imposed a pfd mask, as specified in Recommendation ITU-R M.2092-0 and provided in Section 4.2.1. This pfd mask ensures that VDE-SAT downlink will not cause harmful interference to land and aeronautical mobile services. The pfd mask was coordinated and agreed between WP5A, WP5B and WP5C ahead of WRC-15. In a Liaison Statement to WP5B (Doc 5B/199), WP5A confirmed that the Recommendation ITU-R M.1808 has not been revised since and as such the mask is still valid. The pfd mask is presented in Table 4-4.

### 6.2 Out-of-band interference

### 6.2.1 Maritime distress and voice services

The impact of introducing VDE-SAT services into channels 24, 84, 25, 85, 26 and 86 of RR Appendix **18** was addressed in Report [ITU-R M.2371](http://www.itu.int/pub/R-REP-M.2371), along with introduction of terrestrial VDES in channel 24, 84, 25 and 85 of RR Appendix **18**.

The VDE-SAT uplink has common characteristics with VDE terrestrial ship-to-shore. Therefore, VDE-SAT uplink will not create any additional interference to maritime distress and voice services.

The VDE-SAT downlink is located in the upper leg channels of RR Appendix **18**, while maritime distress services and ship-to-ship and ship-to-shore voice is located in the lower leg channels. The 4.6 MHz frequency separation between VDE-SAT downlink and these services ensure that they can be protected from harmful interference.

### 6.2.2 Satellite automatic identification system

The impact of introducing VDE-SAT services into channels 24, 84, 25, 85, 26 and 86 of RR Appendix **18** was addressed in Report [ITU-R M.2371](http://www.itu.int/pub/R-REP-M.2371), along with introduction of terrestrial VDES in channel 24, 84, 25 and 85 of RR Appendix **18**.

The VDE-SAT uplink has common characteristics with VDE terrestrial ship-to-shore. Therefore, VDE-SAT uplink will not create any additional interference to satellite AIS.

The impact of the VDE-SAT transmission on the AIS1, AIS2, ASM1, ASM2 and LR-AIS reception by satellite has been highlighted in Report ITU-R M.2371. Due to a large frequency separation between VDE-SAT transmission frequencies and LR-AIS frequencies, there is no impact on the satellite detection of LR-AIS is expected. The impact of VDE-SAT transmission on the reception of AIS1, AIS2 and ASM1 and ASM2 depends on the system scenarios.

In a system scenario where the VDE-SAT transmission and SAT-AIS reception are hosted on different satellites the space separation between the satellite orbits and their coverage will reduce the impact. In this case, when the two satellites are close together, the use of bulletin boards and the announcement channels as specified in section 4, provides a practical solution to coordinate and control the duty cycle of the VDE-SAT transmission. Using this mechanism, system operators can schedule the VDE-SAT transmission on a dynamic manner (with a repetitive control as frequent as every minute) to avoid the interference of the VDE-SAT on the detection of SAT-AIS. The high repetition rate for AIS transmissions from ships also increase the detection of ships by SAT-AIS even if some AIS messages are lost to interference from VDE-SAT transmissions*.* The time that a VDE-SAT satellite is within interference range of a SAT-AIS satellite will not be continuous, and in most circumstances limited to only a few minutes.

The co-location of SAT-AIS receiver and VDE-SAT transmission may require a more sophisticated solution on board of the satellite. One such solution can be a full-duplex radio design that would allow for the cancellation of interference caused by the transmitted signal. This may impact the complexity of the on-board transceivers. However, also in this case, the high repetition rate for AIS transmissions from ships also increase the detection of ships by SAT-AIS even if some AIS messages are lost to interference from VDE-SAT transmissions*.*

### 6.2.2.1 SAT-AIS receiver blocking analysis

Reception of a strong signal on a nearby channel will result in compression in the SAT-AIS receiver, which can result in blocking of the SAT-AIS receiver. The blocking performance of a radio receiver is typically described as the input level of the unwanted signal where it will generate a 1 dB compression of the wanted signal. A 1 dB compression level result in an insignificant impact on the receiver performance.

SAT-AIS receivers, commercially available, typically have a 1 dB compression level of -48 dBm, for the most sensitive receiver setting. To ensure that the VDE-SAT downlink is operating within the mask defined in Recommendation ITU-R M.2092-0 and provided in Section 4.2.1, the maximum output power of a VDE-SAT transceiver is 22.0 dBm in a 50 kHz channel. This also assumes Yagi antenna case. With frequency plan alternative 1, up to 150 kHz will be available for the VDE-SAT downlink, while with frequency plan alternative 2 up to 525 kHz will be available for the VDE-SAT downlink. If the full VDE-SAT downlink band is used by a satellite, either as single or multi-carrier, the total output power of the VDE-SAT transceiver will be then be either 26.8 dBm or 32.2 dBm. These two output power levels are the basis for the analysis of required separation distance presented in Table 6-1.

TABLE 6-1

SAT-AIS receiver blocking analysis

|  | Units | Frequency plan alternative 1 | Frequency plan alternative 2 |
| --- | --- | --- | --- |
| VDE-SAT tx output power | dBm | 26.8 | 32.2 |
| Feed loss | dB | 1.1 | 1.1 |
| Max VDE-SAT tx antenna gain (RHCP) | dBi | 8.0 | 8.0 |
| SAT-AIS rx antenna gain (LP) | dBi | 0.0 | 0.0 |
| Polarization loss | dB | 3.0 | 3.0 |
| Max acceptable SAT-AIS rx input level | dBm | -48 | -48 |
| Required free space loss | dB | 78.7 | 84.1 |
| Required separation distance | km | 1.3 | 2.4 |

From Table 6-1 it can be observed that even in the worst case situation, with full output power from the VDE-SAT transceiver using frequency plan alternative 2, the required separation distance to avoid blocking of a SAT-AIS receiver on another satellite is only 2.4 km. Such proximity between two satellites occurs very rarely. Furthermore, given that satellites travel at a speed of about 7.5 km/s, if such proximity between two satellites occurs it will only last for a fraction of a second. Thus, it can be concluded that AIS receiver blocking on other satellites by a VDE-SAT transceiver is not a problem, and no mitigation measures are needed.

### 6.2.2.2 SAT-AIS receiver front end burnout analysis

Reception of a very strong signal within the operating frequency range of a SAT-AIS receiver may cause receiver front end burnout. A burn out protection level typically defines the receiver front end input level that can be sustained over a longer period of time without damaging the receiver front end. SAT-AIS receivers, commercially available, typically have front end burnout protection level of 8 dBm. This value is used in the nominal case analysis of required separation distance for avoiding SAT-AIS receiver front end burnout. Assuming there are SAT-AIS receivers on the commercial market of lower quality, a worst case analysis using a front end burnout protection level of 0 dBm has also been performed. The two analysis cases also assume the same two VDE-SAT transceiver output power levels as those used in the AIS receiver blocking analysis discussed in Section 6.2.2.1. Table 6-2 presents the analysis of the separation distance required for avoiding SAT-AIS receiver front end burnout.

TABLE 6-2

SAT-AIS receiver front end burnout analysis

|  | Units | Worst case | Nominal case |
| --- | --- | --- | --- |
| VDE-SAT tx output power | dBm | 32.2 | 26.8 |
| Feed loss | dB | 1.1 | 1.1 |
| Max VDE-SAT tx antenna gain (RHCP) | dBi | 8.0 | 8.0 |
| SAT-AIS rx antenna gain (LP) | dBi | 0.0 | 0.0 |
| Polarization loss | dB | 3.0 | 3.0 |
| Max acceptable SAT-AIS rx input level | dBm | 0.0 | 8.0 |
| Required free space loss | dB | 36.1 | 22.7 |
| Required separation distance | km | 0.009 | 0.002 |

From Table 6-2 it can be observed that even in the worst case situation, with full output power from the VDE-SAT transceiver using frequency plan alternative 2 and a very sensitive AIS receiver, the required separation distance to avoid AIS receiver front end burnout on another satellite is only 0.009 km. Such proximity between two satellites occurs extremely rarely. Furthermore, given that satellites travel at a speed of about 7,5 km/s, if such proximity between two satellites occurs it will only last for a fraction of a second. Also, such proximity events do not happen without ample warning, allowing a planned shutdown of the VDE-SAT transceiver if so deemed necessary. Thus it can be concluded that SAT-AIS receiver front end burnout on other satellites by a VDE-SAT transceiver is not a problem, and no mitigation measures are needed.

### 6.2.3 Radiolocation service in the frequency band 154-156 MHz

### 6.2.3.1 Introduction

Radio regulations (RR) No. **5.225A** specifies that in certain countries of Region 1 the frequency band 154-156 MHz is allocated to the radiolocation service on the primary basis. Application of the radiolocation service in those frequency bands is limited to the space surveillance radars. Study results reflected in Report [ITU-R M.2172-1](http://www.itu.int/pub/R-REP-M.2172) show that the mentioned radars could operate in a shared manner with the maritime mobile service (MMS) ground systems operating in the adjacent frequency band 156-174 MHz.

A sharing study has been performed to ascertain if the potential VDE-SAT downlink service will generate harmful interference into the radiolocation service.

### 6.2.3.2 Transmitter and receiver characteristics of the radiolocation service used for the sharing study

Table 6-3 presents characteristics of the space surveillance radars operating in the frequency band 154-156 MHz. The characteristics were taken from Report [ITU-R M.2172-1](http://www.itu.int/pub/R-REP-M.2172) and were used in the compatibility studies.

TABLE 6-3

Radiolocation service systems characteristics

|  | Units | Radar А (narrow-band radar) | Radar В (wideband radar) |
| --- | --- | --- | --- |
| Frequency band | MHz | 154-156 | |
| Output pulse power (min/max) | dBW | 27/46 | 40/46 |
| Mean output power (min/max) | dBW | 22/41 | 35/41 |
| Polarization |  | Linear | |
| Pulse duration | μs | 13 000 | 3 200 |
| Duty cycle |  | 0.322 | |
| Modulation type |  | pulse | |
| Altitude above the ground level | m | 19 | |
| Antenna type |  | Phased array | |
| Maximum antenna gain  – transmitter – receiver | dB | 25 30 | |
| Maximum antenna gain on the horizon | dB | 9 | |
| Antenna pattern |  | See § 1.1 in Appendix 1 of Report ITU-R M.2172-1 | |
| Main beam pattern,  – horizontal plane (Rx/Tx) – vertical plane (Rx/Tx) | degrees | 2.6/5.2 2.6/2.6 | |
| Receiver noise temperature | K | 800 | |
| Operational receiver passband (−3 dB level) | kHz | 0.132 | 625 |
| Receiver thermal noise | dBW | −178.4 | −141.6 |

In Recommendation [ITU-R M.1802-1](http://www.itu.int/rec/R-REC-M.1801/en) the protection criteria for the radiolocation service is given as *I/N*=-6 for both radar types. When converting the receiver thermal noise level stated for Radar A and Radar B in Table 6-3 to receiver thermal noise density, they both end up with a receiver thermal noise density level of -199.6 dBW/Hz. To ensure the protection of the radiolocation service, any interference must be at least 6 dB below that noise level. That corresponds to an I0 of  
 -205.6 dBW/Hz.

According to the technical characteristics of the radiolocation service as presented in Table 6-3, the maximum receiver gain is 30 dB. It is assumed this is the gain at 156 MHz. The effective aperture area of the receiver antenna is then Aeff = (G\*c2)/(f2\*4**π**) = 24.7 dBm2. Thus, to ensure protection of the radiolocation service, the interference power flux density in the 154-156 MHz band must be less than -230.3 dBW/(Hz\*m2)

### 6.2.3.3 VHF data exchange-satellite downlink proposed power spectral and power flux density mask

The VDE-SAT downlink has been imposed a pfd mask, as specified in Recommendation ITU-R M.2092-0 and provided in Section 4.2.1 for the in band signal. This mask is presented in Table 4-4 and again here in Table 6-4.

TABLE 6-4

Proposed power spectral and power flux density mask

### 6.2.3.4 VDE-SAT downlink out of band noise

Without additional filtering of the spectral side lobes, the noise generated by a VDE-SAT transmitter in the frequency band 154-156 MHz be will more than 50 dB below that of the in-band signal. Appropriate filtering can ensure an additional 15 dB of reduction of the out of band noise. Table 6-5 presents the resulting interference pfd mask for the 154-156 MHz frequency band.

TABLE 6-5

Proposed interference pfd mask for the frequency band 154-156 MHz

The significant frequency separation between the radiolocation service in the frequency band 154-156 MHz and the upper leg of the RR Appendix **18** frequencies starting at 160.625 MHz ensures that this interference pfd mask will be the worst case interference level in the frequency band 154-156 MHz.

### 6.2.3.5 Conclusions

According to section 7.2.5, the radiolocation service in the frequency band 154-156 MHz operates in an elevation span from 2-70 degrees. The proposed interference pfd mask presented in Table 6-5 provides a maximum interference pfd at 70 degrees of -239.0 dBW/(Hz\*m2). This is 3.7 dB below the protection criteria level calculated in section 6.2.3.2.

The VDE-SAT downlink uses circular polarisation, while the radiolocation service uses linear polarisation. This results in a 3 dB reduction in interference from the VDE-SAT downlink to the radiolocation service due to polarisation loss. The additional 3 dB of margin ensure an *I/N* of less than -12.7 dB.

Based on these calculations it is concluded that the VDE-SAT downlink, in compliance with the proposed interference mask, will not cause harmful interference to stations operating in the radiolocation service in the 154-156 MHz frequency band according to Report ITU-R M.2172-1 and Recommendation ITU-R M.1802-1.

### 6.2.4 Broadcasting service in the frequency band 162-164 MHz

*[Editorial note: See RR No*.***5.229****]*

*[Editorial note: In the Chairman’s report from the last WP6A meeting held in October 2016, the Liaison Statement from WP5B asking for information on this subject is listed as noted. Can this be interpreted as this is not any issue for VDE-SAT, or is a more specific Liaison Statement referring to RR Nos. 5.229 required?]*

Nos. 5.229 of the Radio Regulations (Volume I, page 84), stipulate an alternative allocation in Morocco in the band 162-174 MHz to the broadcasting service on a primary basis. The use of this band for this allocation shall be subject to agreement with administrations having services, operating or planned, in accordance with the Table of Frequency Allocations in Article 5 of the Radio Regulations which are likely to be affected. Thus, outside of Morocco, any changes to the VDE-SAT downlink to avoid interference to the broadcasting service in this band requires agreement between relevant administrations.

### 6.2.5 Space operation service (space-to-Earth) in the frequency band 162-164 MHz

*[Editorial note: See No*.***5.230****]*

Nos. 5.230 of the Radio Regulations (Volume I, page 84), stipulate an alternative allocation in China in the band 163-167 MHz to the space operation service (space-to-Earth) on a primary basis, subject to agreement obtained under RR Nos. 9.21. RR Nos. 9.21 stipulates the requirement to seek agreement of other administrations to use this service. Thus, outside of China, any changes to the VDE-SAT downlink to avoid interference to the space operations service (space-to-Earth) in this band requires agreement between relevant administrations.

### 6.2.6 Land and aeronautical mobile services in adjacent frequency bands

*[Editorial note: Relevant frequency band as specified in ITU-R Resolution* ***360*** *is 154-164 MHz]*

The VDE-SAT uplink has common characteristics with VDE terrestrial ship-to-shore. Therefore, it will not create any additional interference to land and aeronautical mobile services.

The VDE-SAT downlink has been imposed a pfd mask, as specified Recommendation ITU-R M.2092-0 and provided in Section 4.2.1. This pfd mask ensures that VDE-SAT downlink will not cause harmful interference to land and aeronautical mobile services. The pfd mask was coordinated and agreed between WP5A, WP5B and WP5C ahead of WRC-15. In a Liaison Statement to WP5B (Doc. 5B/199), WP5A confirmed that the Recommendation ITU-R M.1808 has not been revised since and as such the mask is still valid. The pfd mask is presented in Table 4-4. In addition, as discussed in Section 6.2.3.4, the out of band emissions from the VDE-SAT downlink will be at least 65 dB below the in-band emissions when more than 500 kHz out from the VDE-SAT downlink.

### 6.2.7 Radio astronomy out of band power flux density mask

Ahead of the WRC-15 studies were performed and a power flux density mask was defined for the satellite downlink emissions and for the protection of the RAS operating in the nearby band 150.05-153.00 MHz. This mask is included and described in Recommendation ITU-R M.2092-0, and it specifies that the VDE-SAT downlink emissions not to exceed -238 dBW/m2 in a 2.95 MHz bandwidth centered around 152 MHz. Application of this pfd mask will ensure the protection of the RAS band 150.05-153.00 MHz. In a Liaison Statement to WP5B (Doc. 5B/177), WP7D confirmed that this mask still is sufficient and valid for protection of the RAS, also after WRC-15.

# 7 Satellite receiver resilience to harmful interference from incumbent services and those in adjacent frequency band

*[Editorial note: Address the mitigation of interference from terrestrial services to the VDE-SAT uplink]*

### 7.1 Impact assessment of systems operating in the frequency band 156-162 MHz in the mobile service on the VDE-SAT uplink

### 7.2 Compatibility of a new VHF data exchange system satellite component with radars operating in the frequency band 154-156 MHz

### 7.2.1 Introduction

Radio regulations (RR) No. **5.225A** specifies that in certain countries of Region 1 the frequency band 154-156 MHz is allocated to the radiolocation service on the primary basis. Application of the radiolocation service in those frequency bands is limited to the space surveillance radars. Study results reflected in Report ITU-R M.2172-1 show that the mentioned radars could operate in a shared manner with the maritime mobile service (MMS) ground systems operating in the adjacent frequency band 156-174 MHz. At the same time to provide protection for the MMS stations in the frequency bands 156.5125-156.5375 MHz, 156.7625-156.8375 MHz, 161.9625-161.9875 MHz and 162.0125-162.0375 MHz additional constrains specifying that e.i.r.p. of out-of-band emissions produced by the space surveillance radars should not exceed the level of –16 dBW was imposed by RR No. **5.225A**. The mentioned requirement is met by integrating additional notch filters into radar transmitting circuits for the mentioned frequency bands. The rest frequency bands related to provisions of RR Appendix **18** contain no constrains imposed on operation of the space surveillance systems and no specific measures are applied to reduce out-of-band emissions.

Recommendation ITU-R M.2092-0 specifies that the VDES up-link should be established in the frequency band 157.1875-157.3375 MHz by combining channels 1024, 1084, 1025, 1085, 1026, 1086 of RR Appendix **18** into a single channel of 150 kHz.

This Report presents results of studies in compatibility of a new VHF data exchange system (VDES) satellite component up-link in the frequency band 156.0125-157.4375 MHz with space surveillance radars operating in the frequency band 154-156 MHz.

### 7.2.2 Characteristics of space surveillance radars operating in the frequency band 154‑156 MHz

Table 7-1 presents characteristics of the space surveillance radars operating in the frequency band 154-156 MHz. The characteristics were taken from Recommendation [ITU-R M.1802-1](http://www.itu.int/rec/R-REC-M.1802/en) and were used in the compatibility studies.

TABLE 7-1

**Characteristics of radars operating in the frequency band 154-156 MHz**

|  |  |  |  |
| --- | --- | --- | --- |
| **Parameter** | **Units** | **Value** | |
| **Radar А** | **Radar В** |
| Radar type |  | Primary ranging radar | |
| Radar function |  | Space objects recognition and trackingе | |
| Frequency band | MHz | 154−156 | |
| Relative frequency instability |  | 10–11 | |
| Output pulse power (min/max) | dBW | 27/46 | 40/46 |
| Mean output power (min/max) | dBW | 22/41 | 35/41 |
| Polarization |  | Linear | |
| Pulse length | µs | 13 000 | 3 200 |
| Duty cycle |  | 0.322 | |
| Modulation type |  | Pulse | |
| Altitude above the ground level | m | 19 | |
| Antenna type |  | Phased array | |
| Maximum antenna gain: – transmitter – receiver | dB | 25 30 | |
| Max antenna gain into horizon | dB | 9 | 12 |
| Main beam pattern – horizontal plane (Rx/Tx) – vertical plane (Rx/Tx) | degrees | 2.6/5.2  2.6/2.6 | |
| Scan angle ranges: – horizontal plane – vertical plane | degrees | 0−360  2−70 | |
| Receiver noise temperature | K | 800 | |
| Operation receiver passband | kHz | 0.132 | 625 |
| Required frequency band | kHz | 0.132 | 625 |
| Emission class |  | P0N | MXN |
| *I*/*N* protection ratio | dB | −6 | |
| Level of unwanted emissions |  | Complies with provisions of RR Appendix **3**[[1]](#footnote-1) | |

### 7.2.3 Characteristics of VHF data exchange system satellite link (ship-to-satellite)

*[Editorial note: All the information in this section is now available in Sections 4.1 and 4.3, so this section should be rewritten to reference those sections instead of repeating the information]*

VDES system ship-to-satellite link is described in Recommendation [ITU-R M.2092-0](http://www.itu.int/rec/R-REC-M.2092/en) which assumes a low-Earth orbit (LEO) satellite system with altitude of 600 km[[2]](#footnote-2). It is also assumed that such satellite system could use antennas of two types, i.e. Yagi antenna and Isoflux isotropic antenna. Technical characteristics of VDES system up-link taken from Recommendation [ITU-R M.2092-0](http://www.itu.int/rec/R-REC-M.2092/en) are described below.

Table 7-2 depicts minimum transmitting ship station e.i.r.p. as a function of elevation angle. Patterns for Yagi-antenna and Isoflux antenna are shown in Tables 7-3 and 7-4 accordingly.

TABLE 7-2

**Minimum ship station effective isotropic radiated power vs. elevation angle**

|  |  |  |
| --- | --- | --- |
| Ship elevation angle | Ship antenna gain | Minimum ship e.i.r.p. with 6 W transmitter\* |
| degree | 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 |

\* Note: Multilevel and filtered modulation is used, and 3 dB back-off from saturation is assumed. Transmit average power shall be at least 1.0 watts and not exceed 25 watts as declared by the manufacturer. The ship stations may be equipped with antennas having patterns different from that shown in Table 2 (see Recommendation [ITU-R M.2092-0](http://www.itu.int/rec/R-REC-M.2092/en) § 3.7.1).

TABLE 7-3

Satellite Yagi-antenna gain vs. nadir offset angle

|  |  |  |
| --- | --- | --- |
| Satellite elevation angle | Nadir offset angle | Satellite antenna gain |
| degrees | degrees | dBi |
| 0 | 66.1 | 8 |
| 10 | 64.2 | 8 |
| 20 | 59.2 | 8 |
| 30 | 52.3 | 7.8 |
| 40 | 44.4 | 6.9 |
| 50 | 36 | 5.5 |
| 60 | 27.2 | 3.6 |
| 70 | 18.2 | 0.7 |
| 80 | 9.1 | –2.2 |
| 90 | 0 | –5.5 |

TABLE 7-4

Satellite Isoflex-antenna gain vs. nadir offset angle

|  |  |  |
| --- | --- | --- |
| Satellite elevation angle | Nadir offset angle | Satellite antenna gain |
| degrees | degrees | dBi |
| 0 | 66.1 | 2 |
| 10 | 64.2 | 1.5 |
| 20 | 59.2 | 1 |
| 30 | 52.3 | –0.5 |
| 40 | 44.4 | –2 |
| 50 | 36 | –4 |
| 60 | 27.2 | –5 |
| 70 | 18.2 | –7 |
| 80 | 9.1 | –8 |
| 90 | 0 | –8.5 |

The VDES maximizes frequency efficiency by using adaptive coding and modulation based on the actual link quality. Initial system access is done using a combination of spread spectrum, low bitrate and powerful FEC. The VDE-SAT defined in Recommendation [ITU-R M.2092-0](http://www.itu.int/rec/R-REC-M.2092/en), uses the waveforms defined in Table 7-5 for uplink. The thresholds *C/N*0 and *C/(N+I)* on a Gaussian channel have been estimated.

TABLE 7-5

Estimated thresholds for the VHF data exchange-satellite uplink waveforms

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Physical Layer Frame Format # | 1 | 2 | 3 | 4 | 5 |
| Channel bandwidth (kHz) | 50 | 50 | 50 | 50 | 50 |
| Occupied bandwidth (kHz) | 42 | 42 | 42 | 42 | 42 |
| CDMA chip rate (kcps) | 33.6 | 33.6 | NA | NA | NA |
| Symbol rate (ksps) | 2.4 | 2.4 | 33.6 | 33.6 | 33.6 |
| Packet size (ms) | 133.3 | 133.3 | 26.7 | 26.7 | 800 |
| Modulation | BPSK | CPM/QPSK | QPSK | 16APSK | 16APSK |
| FEC rate | 1/2 | 1/4 | 3/4 | 3/4 | 3/4 |
| Information rate (kbps) | 2.1 | 2.1 | 50.4 | 100.8 | 100.8 |
| Estimated threshold Es/N0 for a Gaussian channel (dB) (BER=1E-5) | 0.1 | 0.1 | 4.4 | 11.4 | 11.4 |
| Symbol error rate at threshold (%) | 30 | 30 | 10 | 2 | 2 |
| Estimated required C/N0 (dBHz) | 34.2 | 33.9 | 51.4 | 61.4 | 61.4 |
| Estimated required C/(N+I) (dB) | -12.0 | -12.3 | 5.2 | 15.2 | 15.2 |

*[Editorial note: Table needs to be verified, especially the values for C/N and C/(N+I)]*

Satellite noise levels at the receiver front end are presented in Table 7-6. The system noise temperature is taken to be 25.7 dBK assuming no external interference. The required *C*/(*N+I*) listed in Table 7-6 is for the most robust waveform. Adaptive coding and modulation allow the usage waveforms with higher throughput when the necessary link quality is available.

TABLE 7-6

Characteristics of VHF data exchange system satellite receiver

|  |  |  |
| --- | --- | --- |
| Antenna noise temperature | 200.0 | K |
| Feed losses | 1.0 | dB |
| LNA noise figure | 2.0 | dB |
| LNA noise temperature | 159.7 | K |
| Feed loss noise temperature at LNA | 56.1 | K |
| Antenna noise temperature at LNA | 158.9 | K |
| System noise temperature at LNA | 374.7 | K |
| System noise temperature at LNA | 25.7 | dBK |
| Intrinsic noise power density | -202.9 | dBW/Hz |
| Intrinsic noise power in 42 [50] kHz bandwidth | -156.6 | dBW |
| Required carrier-to-noise-plus-interference ratio (C/(N+I)) | -12.3 | dB |

### 7.2.4 Scenario of interference from unwanted emissions by radars operating in the frequency band 154-156 MHz on VHF date exchange system satellite receiver

Subject to Recommendation [ITU-R M.2029-0](http://www.itu.int/rec/R-REC-M.2029/en) the VDES up-link should be established in the frequency band 157.1875–157.3375 MHz by combining channels 1024, 1084, 1025, 1085, 1026, 1086 of RR Appendix **18** into a single channel of 150 kHz.

FIGURE 7-1

Scenario of radar unwanted emission interference effect on CHF data exchange system satellite receiver

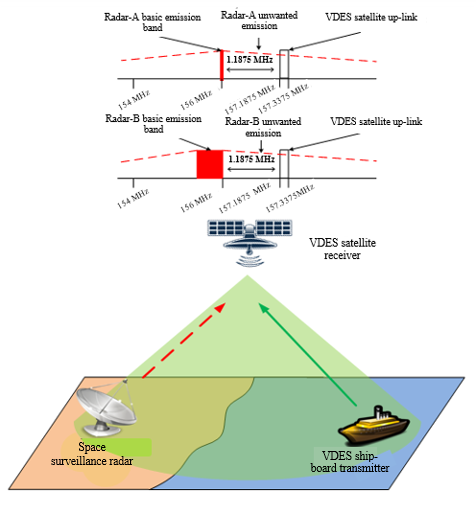


Figure 7-1 depicts scenario of effect caused by interference from space surveillance radar emissions on the VDES satellite receivers. A wanted signal from the ship transmitter is shown as a solid green arrow whereas interference from the space surveillance radar is reflected as a dashed red arrow.

### 7.2.5 Estimation of interference level from unwanted emissions by radars operating in the frequency band 154-156 MHz on VHF data exchange system satellite receiver

Methodology described in Report [ITU-R M.2172-1](http://www.itu.int/pub/R-REP-M.2172) was used for estimating the levels of unwanted emissions from Radar A in the band of the VDES satellite receiver. Assuming frequency separation of 1.2 MHz it was found that the unwanted emission power at the radar antenna front end in 25 kHz bandwidth would be minus 30.7 dBW and that in 150 kHz bandwidth would be minus 22.9 dBW. Given the 25 dB transmit gain of the radar, this is equal to a peak e.i.r.p. in 42 kHz of -3.4 dBW

The obtained result meet the RR Appendix **3** provisions for spurious emissions as specifying that for radars of the given type the level power delivered to the antenna feed shall not exceed minus 21.3 dBW in 77 Hz reference band.

Radar B unwanted emissions level is a function of modulation parameters. Therefore, for Radar B in accordance with requirements of RR Appendix **3** the value of its unwanted emissions at the radar antenna front end would be minus 33 dBW in the bandwidth of 25 kHz and minus 25.2 dBW in the bandwidth of 150 kHz. This radar is less of a contributor to interference than radar A, so the worst case condition of radar A is used to assess feasibility in this report.

A satellite with a VDES on-board receiver is in a circular orbit of 600 km in altitude. Carrier-to-interference (*C/I*) ratios are estimated using satellite elevation angle steps of 10 degrees for the angles of satellite visibility by the ship station from 0 to 90 degrees corresponding to appropriate angles of satellite visibility by the radar. Since space surveillance radar scans in vertical plane within angle sector of 2-70 degrees the estimation assumes that a receiving antenna onboard a satellite be aligned with the space surveillance radar main lobe. Table 7-7 and Table 7-8 show the resulting received interference power using the satellite isoflux antenna and the 8 dBi Yagi antenna as defined in M.2092-0. These calculations are worst case in that they assume that the radar and satellite antenna boresigths are aligned, a rare occurrence. It can be seen that the worst-case interference level is -144.7 dBW for the isoflux case. The worst case interference level for the Yagi is -135.8 dBW for a radar elevation angle to the satellite of 40 degrees.

TABLE 7-7

Radar emissions into a 600 km low earth orbit satellite using isoflux antenna

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Radar elevation angle | Radar peak e.i.r.p. in  42 kHz at  157 MHz | Polarisation loss | Path length | Path loss | Satellite antenna gain | Interference level at LNA, including feed loss |
| deg | dBW | dB | Km | dB | dBi | dBW |
| 0.0 | -3.4 | 3.0 | 2 830 | 145.4 | 2.0 | -150.9 |
| 10.0 | -3.4 | 3.0 | 1 932 | 142.1 | 1.5 | -148.0 |
| 20.0 | -3.4 | 3.0 | 1 392 | 139.3 | 1.0 | -145.7 |
| 30.0 | -3.4 | 3.0 | 1 075 | 137.0 | -0.5 | -145.0 |
| 40.0 | -3.4 | 3.0 | 882 | 135.3 | -2.0 | -144.7 |
| 50.0 | -3.4 | 3.0 | 761 | 134.0 | -4.0 | -145.5 |
| 60.0 | -3.4 | 3.0 | 683 | 133.1 | -5.0 | -145.5 |
| 70.0 | -3.4 | 3.0 | 635 | 132.4 | -7.0 | -146.9 |
| 80.0 | -3.4 | 3.0 | 608 | 132.1 | -8.0 | -147.5 |
| 90.0 | -3.4 | 3.0 | 600 | 131.9 | -8.5 | -147.9 |

TABLE 7-8

Radar emissions into a 600 km low earth orbit satellite using 8 dBi Yagi antenna

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Radar elevation angle | Radar peak e.i.r.p. in  42 kHz at  157 MHz | Polarisation loss | Path length | Path loss | Satellite antenna gain | Interference level at LNA, including feed loss |
| deg | dBW | dB | km | dB | dBi | dBW |
| 0.0 | -3.4 | 3.0 | 2 830.0 | 145.4 | 8.0 | -144.9 |
| 10.0 | -3.4 | 3.0 | 1 932.0 | 142.1 | 8.0 | -141.5 |
| 20.0 | -3.4 | 3.0 | 1 392.0 | 139.3 | 8.0 | -138.7 |
| 30.0 | -3.4 | 3.0 | 1 075.0 | 137.0 | 7.8 | -136.7 |
| 40.0 | -3.4 | 3.0 | 882.0 | 135.3 | 6.9 | -135.8 |
| 50.0 | -3.4 | 3.0 | 761.0 | 134.0 | 5.5 | -136.0 |
| 60.0 | -3.4 | 3.0 | 683.0 | 133.1 | 3.6 | -136.9 |
| 70.0 | -3.4 | 3.0 | 635.0 | 132.4 | 0.7 | -139.2 |
| 80.0 | -3.4 | 3.0 | 608.0 | 132.1 | -2.2 | -141.7 |
| 90.0 | -3.4 | 3.0 | 600.0 | 131.9 | -5.5 | -144.9 |

### 7.2.6 Estimation of link budget for VHF data exchange system up-link with a satellite receiver in a 600 km altitude orbit

Tables 7-9 and 7-10 present link budgets for VDES up-link with a satellite receiver in a 600 km altitude orbit using Isoflux and Yagi antennas. A 6 W ship station transmitter is assumed. The link margin is high for all elevation angles. Tables 7-11 and 7-12 present the resulting worst case C/N and C/(N+I) when the interference level from unwanted emissions by radars operating in the frequency band 154-156 MHz as calculated in Table 7-7 and Table 7-8 is included.

Table 7-11 and Table 7-12 show that formats 1 and 2 will ensure link availability with substantial margins under the worst case radar interference condition for ship elevation angles up to 80 degrees, Format 3 will be available for ship elevation angles up to 60 degrees and Formats 4 and 5 will require additional discrimination or mitigation techniques. Table 7-13 summaries a few potential discrimination factors and mitigation techniques.

TABLE 7-9

Worst-case link budget for VHD data exchange-satellite uplink with 6 W ship transmitter, Isoflux satellite receiving antenna without interference.

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Ship elevation angle | Ship antenna gain | Ship e.i.r.p. | Polarization loss | Path length | Path loss | Satellite antenna gain | Carrier level at LNA, including feed loss | *C/N*0 | *C/N* | Link margin for waveform 1 |
| deg | dBi | dBW | dB | km | dB | dBi | dBW | dBHz | dB | dB |
| 0.0 | 3.0 | 10.8 | 3.0 | 2 830 | 145.4 | 2.0 | –136.6 | 66.2 | 20.0 | 32.3 |
| 10.0 | 3.0 | 10.8 | 3.0 | 1 932 | 142.1 | 1.5 | –133.8 | 69.0 | 22.8 | 35.1 |
| 20.0 | 2.5 | 10.3 | 3.0 | 1 392 | 139.3 | 1.0 | –132.0 | 70.9 | 24.7 | 37.0 |
| 30.0 | 1.0 | 8.8 | 3.0 | 1 075 | 137.0 | –0.5 | –132.7 | 70.1 | 23.9 | 36.2 |
| 40.0 | 0.0 | 7.8 | 3.0 | 882 | 135.3 | –2.0 | –133.5 | 69.4 | 23.1 | 35.4 |
| 50.0 | –1.5 | 6.3 | 3.0 | 761 | 134.0 | –4.0 | –135.7 | 67.1 | 20.9 | 33.2 |
| 60.0 | –3.0 | 4.8 | 3.0 | 683 | 133.1 | –5.0 | –137.3 | 65.6 | 19.3 | 31.6 |
| 70.0 | –4.0 | 3.8 | 3.0 | 635 | 132.4 | –7.0 | –139.7 | 63.2 | 17.0 | 29.3 |
| 80.0 | –10.0 | –2.2 | 3.0 | 608 | 132.1 | –8.0 | –146.3 | 56.6 | 10.4 | 22.7 |
| 90.0 | –20.0 | –12.2 | 3.0 | 600 | 131.9 | –8.5 | –156.7 | 46.2 | 0.0 | 12.3 |

TABLE 7-10

Worst-case link budget for VHF data exchange-satellite uplink with 6 w ship transmitter, Yagi satellite receiving antenna without interference.

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Ship elevation angle | Ship antenna gain | Ship e.i.r.p. | Polarization loss | Path length | Path loss | Satellite antenna gain | Carrier level at LNA, including feed loss | *C*/*N*0 | *C/N* | Link margin for waveform 1 |
| deg | dBi | dBW | dB | km | dB | dBi | dBW | dBHz | dB | dB |
| 0.0 | 3.0 | 10.8 | 3.0 | 2 830 | 145.4 | 8.0 | –130.6 | 72.2 | 26.0 | 38.3 |
| 10.0 | 3.0 | 10.8 | 3.0 | 1 932 | 142.1 | 8.0 | –127.3 | 75.5 | 29.3 | 41.6 |
| 20.0 | 2.5 | 10.3 | 3.0 | 1 392 | 139.3 | 8.0 | –125.0 | 77.7 | 31.7 | 44.0 |
| 30.0 | 1.0 | 8.8 | 3.0 | 1 075 | 137.0 | 7.8 | –124.4 | 78.4 | 32.2 | 44.5 |
| 40.0 | 0.0 | 7.8 | 3.0 | 882 | 135.3 | 6.9 | –124.6 | 78.3 | 31.2 | 44.3 |
| 50.0 | –1.5 | 6.3 | 3.0 | 761 | 134.0 | 5.5 | –126.2 | 76.6 | 30.4 | 42.7 |
| 60.0 | –3.0 | 4.8 | 3.0 | 683 | 133.1 | 3.6 | –128.7 | 74.2 | 27.9 | 40.2 |
| 70.0 | –4.0 | 3.8 | 3.0 | 635 | 132.4 | 0.7 | –132.0 | 70.9 | 24.7 | 37.0 |
| 80.0 | –10.0 | –2.2 | 3.0 | 608 | 132.1 | –2.2 | –140.5 | 62.4 | 16.2 | 28.5 |
| 90.0 | –20.0 | –12.2 | 3.0 | 600 | 131.9 | –5.5 | –153.7 | 49.2 | 3.0 | 15.3 |

TABLE 7-11

Worst-case link budget for VHF data exchange-satellite uplink with 6 W ship transmitter, Isoflux satellite receiving antenna with interference radar type A.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Ship elevation angle | Carrier level at LNA, including feed loss | *C/N*0 | *C/N* | Interference level at LNA, including feed loss | C/I | C/(N+I) | Link margin for waveform 1 |
| deg | dBW | dBHz | dB | dBW | dB | dB | dB |
| 0.0 | –136.6 | 66.2 | 20.0 | -144.7 | 8.1 | 7.8 | 20.1 |
| 10.0 | –133.8 | 69.0 | 22.8 | -144.7 | 10.9 | 10.6 | 22.9 |
| 20.0 | –132.0 | 70.9 | 24.7 | -144.7 | 12.7 | 12.5 | 24.8 |
| 30.0 | –132.7 | 70.1 | 23.9 | -144.7 | 12.0 | 11.7 | 24.0 |
| 40.0 | –133.5 | 69.4 | 23.1 | -144.7 | 11.2 | 11.0 | 23.3 |
| 50.0 | –135.7 | 67.1 | 20.9 | -144.7 | 9.0 | 8.7 | 21.0 |
| 60.0 | –137.3 | 65.6 | 19.3 | -144.7 | 7.4 | 7.2 | 19.5 |
| 70.0 | –139.7 | 63.2 | 17.0 | -144.7 | 5.0 | 4.8 | 17.1 |
| 80.0 | –146.3 | 56.6 | 10.4 | -144.7 | -1.6 | -1.8 | 10.5 |
| 90.0 | –156.7 | 46.2 | 0.0 | -144.7 | -12.0 | -12.2 | 0.1 |

TABLE 7-12

Worst-case link budget for VHF data exchange-satellite uplink with 6 w ship transmitter, Yagi satellite receiving antenna with interference radar type A.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Ship elevation angle | Carrier level at LNA, including feed loss | *C*/*N*0 | *C/N* | Interference level at LNA, including feed loss | C/I | C/(N+I) | Link margin for waveform 1 |
| deg | dBW | dBHz | dB | dBW | dB | dB | dB |
| 0.0 | –130.6 | 72.2 | 26.0 | -135.8 | 5.2 | 5.2 | 17.5 |
| 10.0 | –127.3 | 75.5 | 29.3 | -135.8 | 8.5 | 8.5 | 20.8 |
| 20.0 | –125.0 | 77.7 | 31.7 | -135.8 | 10.8 | 10.8 | 23.1 |
| 30.0 | –124.4 | 78.4 | 32.2 | -135.8 | 11.4 | 11.4 | 23.7 |
| 40.0 | –124.6 | 78.3 | 31.2 | -135.8 | 11.2 | 11.2 | 23.5 |
| 50.0 | –126.2 | 76.6 | 30.4 | -135.8 | 9.6 | 9.6 | 21.9 |
| 60.0 | –128.7 | 74.2 | 27.9 | -135.8 | 7.1 | 7.1 | 19.4 |
| 70.0 | –132.0 | 70.9 | 24.7 | -135.8 | 3.8 | 3.8 | 16.1 |
| 80.0 | –140.5 | 62.4 | 16.2 | -135.8 | -4.7 | -4.7 | 7.6 |
| 90.0 | –153.7 | 49.2 | 3.0 | -135.8 | -17.9 | -17.9 | -5.6 |

TABLE 7-13

Summary of a few potential discrimination factors and mitigation techniques for VHF data exchange-satellite uplink against interference from unwanted emissions by radars

|  |  |  |
| --- | --- | --- |
| Factor | Description | Effect |
| Range | Radars that are below horizon | No interference |
| Radar operating mode | When the radar is operating in a scan mode, it will only affect the satellite for the short time it points directly at it. | There are approximately 69 horizontal beam positions and 27 vertical beam positions, or a total of 1 863 beam positions. Assuming a beam offset of 2 beamwidths provides sufficient discrimination, the probability that transmission in one of the seven possible beams is 0,4 %. This level of interference blocking can be handled by FEC and/or ARQ |
| Radar scan loss | Planar phased array radars have a scan loss when not pointing orthogonal to the flat surface. | The scan loss depends on the number of planar arrays used. A horizontal scan of 60 degrees will cause a 3 dB loss, a vertical scan of 35 degrees will cause a scan loss of 0.9 dB.  The worst case condition when the main beam is orthogonal to the array is considered. |
| Yagi antenna isolation | The Yagi antenna provides better spatial selectivity than the isoflux antenna when pointed away from the radar | The Yagi antenna provides discrimination when pointed away from the radar.  Figure 7-2 shows typical Yagi isolation of 10 dB,  60 degrees off boresight and 20 dB 75 degrees off boresight. |

FIGURE 7-2

Typical Yagi gain pattern as a function of boresight offset angle



### 7.2.7 Potential for burnout and blocking of the VHF data exchange-satellite receiver caused by unwanted emissions from the radar

Table 7-14 and Table 7-15 show the radar levels at the antenna for both the isoflux and Yagi antennas, with peak output e.i.r.p. from the radar of 71 dBW at 156 MHz. It can be seen that the maximum level is less than -61 dBW. This is more than 30 dB below expected burnout levels. Thus, the VDE-SAT receiver will not be exposed to an interference level from the radar that potentially can be capable of destroying the satellite receiver.

The presence radar signal between 154 and 156 MHz will add a blocking performance requirement for the VDE-SAT receiver. This requirement is not expected to be a concern.

TABLE 7-14

Maximum signal level of unwanted emissions from radar with Isoflux antenna onboard the satellite

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Elevation angle | Radar e.i.r.p. | Polarisation loss | Range | Pathloss | Satellite antenna gain | Received signal level |
| Degrees | dBW | dB | km | dB | dBi | dBW |
| 0 | 71.0 | 3.0 | 2 830.0 | –145.3 | 2.0 | –76.3 |
| 10 | 71.0 | 3.0 | 1 932.0 | –142.0 | 1.5 | –73.5 |
| 20 | 71.0 | 3.0 | 1 392.0 | –139.2 | 1.0 | –71.2 |
| 30 | 71.0 | 3.0 | 1 075.0 | –136.9 | –0.5 | –70.4 |
| 40 | 71.0 | 3.0 | 882.0 | –135.2 | –2.0 | –70.2 |
| 50 | 71.0 | 3.0 | 761.0 | –133.9 | –4.0 | –70.9 |
| 60 | 71.0 | 3.0 | 683.0 | –133.0 | –5.0 | –71.0 |
| 70 | 71.0 | 3.0 | 635.0 | –132.4 | –7.0 | –72.4 |
| 80 | 71.0 | 3.0 | 608.0 | –132.0 | –8.0 | –73.0 |
| 90 | 71.0 | 3.0 | 600.0 | –131.9 | –8.5 | –73.4 |

TABLE 7-15

Maximum signal level of unwanted emissions from radar with Yagi antenna onboard the satellite

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Elevation angle | Radar e.i.r.p. | Polarization loss | Range | Pathloss | Satellite antenna gain | Received signal level |
| deg | dBW | dB | km | dB | dBi | dBW |
| 0.0 | 71.0 | 3.0 | 2 830.0 | –145.3 | 8.0 | –70.3 |
| 10.0 | 71.0 | 3.0 | 1 932.0 | –142.0 | 8.0 | –67.0 |
| 20.0 | 71.0 | 3.0 | 1 392.0 | –139.2 | 8.0 | –64.2 |
| 30.0 | 71.0 | 3.0 | 1 075.0 | –136.9 | 7.8 | –62.1 |
| 40.0 | 71.0 | 3.0 | 882.0 | –135.2 | 6.9 | –61.3 |
| 50.0 | 71.0 | 3.0 | 761.0 | –133.9 | 5.5 | –61.4 |
| 60.0 | 71.0 | 3.0 | 683.0 | –133.0 | 3.6 | –62.4 |
| 70.0 | 71.0 | 3.0 | 635.0 | –132.4 | 0.7 | –64.7 |
| 80.0 | 71.0 | 3.0 | 608.0 | –132.0 | –2.2 | –67.2 |
| 90.0 | 71.0 | 3.0 | 600.0 | –131.9 | –5.5 | –70.4 |

### 7.2.8 Conclusions

*[Editorial note: The conclusion is reserved for finalization of the contents of this report and for confirmation in liaison exchanges with appropriate working parties.]*

[Based on the calculations and estimations presented above it is clear that most robust waveforms defined for the VDE-SAT uplink is resilient to harmful interference from radars operating in the frequency band 154-156 MHz for all elevation angles up to 60-80 degrees, depending on waveform used, without any additional interference discrimination or mitigation techniques. Allowing for potential discrimination factors and mitigation techniques discussed above, also the less robust waveforms are expected to perform as stipulated in section 4. The adaptive modulation and coding scheme defined for VDE-SAT can be utilized to ensure the link is closed.

These calculations and estimations also show that the VDE-SAT receiver will not be exposed to an interference level from the radar that potentially can be capable of destroying the satellite receiver.]

# 8 Testing, demonstrations and measurements

# 9 Future demonstrations and measurements

*[Editorial note: This section is intended only as information on planned and on-going demonstration and measurement projects, and should be removed from the final report. As results from these projects are available they should be summarised and moved to section 8.*

*[Editorial note: Additional demonstration and measurement projects/activities should be included as they become public.]*

### 9.1 NORSAT-2 (European Space Agency VHF data exchange-satellite downlink verification planned H1 2017)

The objective of the ESA VDE-SAT Downlink Verification is to demonstrate the feasibility of the VHF data exchange via satellite in a real operating environment. The feasibility of VDE-SAT will be demonstrated by a test campaign as well as a VDE-SAT service demonstration.

The main purpose of the test campaign is to assess the performance of the waveforms considered, enabling standardisation of a suitable set of waveforms and corresponding parameters. Based on these results, recommendations regarding the downlink physical layer will be given.

Two test receivers, one on-board a Norwegian Coast Guard vessel and a reference receiver at FFI premises at Kjeller (Norway) will be used during the test campaign. The Coast Guard vessel will receive VDE-SAT transmissions at sea. The terminal at the FFI premises will be used as reference, for transmitter (Tx) and ship terminal receiver (Rx) verification, and debugging if necessary.

The specification and performance figures are derived from the Recommendation ITU-R M.2092-0. The activity shall demonstrate the functionality and performance of VDE-SAT Downlink waveforms and data link protocols that are currently being consolidated by international working groups in IALA and ITU for data exchange via satellite in VHF maritime bands.

### 9.2 Efficiensea 2 coordination

EfficienSea2 is a European Community project for a safer and more efficient waterborne operation through new technologies and smarter traffic management. This project, which is planned for a 3-year period from mid-2015 to mid-2018, is in the scope of the Horizon 2020, the biggest EU Research and Innovation programme. Lead by the DMA, 33 entities are contributors. One of activities is dedicated to novel maritime communications and among them the VDES. Taking into account the radio technical standards and specifications under construction at IALA and the resolution adopted in November 2015 by ITU during the WRC-15, the first initiative to develop VDES hardware prototypes in a lab environment will be lead. In addition, live sea trials are planned for testing exchanges of ship-to-ship and ship-to-shore data with real-life e-navigation scenarios. EfficienSea 2 also intends to coordinate the terrestrial VDES activities with satellite VDES activities that are fortunately also envisaged during the same period of time. They are lead by ESA under the ARTES program dedicated to research on the telecommunications systems. One of these activities is focussed on the VDE-SAT user needs and requirements to derive the system design. Another is aimed at the realisation of a test satellite with a flight demonstration within the EfficienSea 2 timeframe (Figure 6). A liaison between ESA, the main actors of the VDE-SAT activities and the EfficienSea 2 terrestrial VDES actors will permit to include the satellite VDES downlink component into the testbed.

1. Values of unwanted emissions in the VDES receiver frequency band are described in section 6 herein. [↑](#footnote-ref-1)
2. Due to unavailability of relevant data for the VDES satellite receiver characteristics the low-Earth orbit system described in Recommendation [ITU-R M.2092-0](http://www.itu.int/rec/R-REC-M.2092/en) is used herein. But it is to note that Report [ITU-R M.2084](http://www.itu.int/pub/R-REP-M.2084) deals with different characteristics of AIS satellite receivers. [↑](#footnote-ref-2)