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Selection of the channel plan for a VHF data exchange system

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REPORT ITU-R M.2371-0

Selection of the channel plan for a VHF data exchange system

(2015)

Scope

This Report provides an evaluation of four channel plan options for the VHF data exchange system (VDES) concept. The channel plans are evaluated against a set of implementation, operational and technical factors and six particular use cases.

1 Introduction

Four channel plans for the VHF data exchange system (VDES) concept have been considered, taking into account input contributions from the International Association of Marine aids to Navigation and Lighthouse Authorities (IALA), a multi-country European group, Canada, China and Russian Federation. The channel plans are similar in that they use the same group of VHF maritime Radio Regulations Appendix **18** channels; however they are different in the exact way that the channels are used. Each plan has its unique merits and limitations, and is compared against a number of implementation, operational, and technical factors in Table 1 of § 4.

2 Channel plans under consideration

2.1 Overall considerations and common elements to all channel plans

– Automatic identification system (AIS), AIS 1 (161.975 MHz) and AIS 2 (162.025 MHz) are AIS channels, in accordance with Recommendation ITU-R M.1371;

– AIS 1 (161.975 MHz) and AIS 2 (162.025 MHz) are used as uplinks for receiving AIS messages by satellite;

– Application specific message (ASM), ASM 1 (161.950 MHz) and ASM 2 (162.000 MHz) are non-navigation application specific messages (ASM);

– SAT up1 (161.950 MHz) and SAT up2 (162.000 MHz) are used for receiving ASM by satellite.

2.2 Channel plan A

1024 157.200	1084 157.225	1025 157.250	1085 157.275	1026 157.300	1086 157.325	2024 161.800	2084 161.825	2025 161.850	2085 161.875	2026 161.900	2086 161.925	2027 161.950	AIS1 161.975	2028 162.000	AIS2 162.025
VDE1 Ship-to-shore						VDE1 Shore-to-ship, ship-to-ship						ASM1		ASM2	
SAT up3						SAT downlink						SAT up1	AIS1 uplink	SAT up2	AIS2 uplink

2.2.1 VHF data exchange system channel usage for channel plan A

2.2.1.1 VHF data exchange system between terrestrial stations

– Automatic identification System (AIS) use channels AIS 1 (161.975 MHz) and AIS 2 (162.025 MHz), in accordance with Recommendation ITU-R M.1371;

– Application Specific Messages (ASM) use channels ASM 1 (channel 2027) and ASM 2 (channel 2028) are non-navigation ASMs;

– VDE1 lower legs (channels 1024, 1084, 1025 and 1085) are ship-to-shore VHF data exchange (VDE);

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

2.2.1.2 VHF data exchange system between satellites and terrestrial stations

– AIS 1 (161.975 MHz) and AIS 2 (162.025 MHz) are used as uplinks for receiving AIS messages by satellite;

– SAT up1 (channel 2027) and SAT up2 (channel 2028) are used for receiving ASM by satellite;

– SAT up3 (channels 1024, 1084, 1025, 1085, 1026 and 1086) is a ship-to-satellite VDE uplink;

– SAT Downlink (channels 2024, 2084, 2025, 2085, 2026 and 2086) is the satellite-to-ship VDE downlink.

2.2.2 Technical characteristics

2.2.2.1 ShipborneVHF date exchange system receivers are protected

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

2.2.2.2 Satellite downlink is optimized

The satellite downlink power is spread over 6 channels to minimize interference to terrestrial services and to maximize reception by ship VDES stations.

2.2.2.3 VDE1 uses both legs of the duplex channels

Full channel capacity is utilized for the duplex channels in VDE1 by using the lower legs for ship-to-shore and the upper legs for shore-to-ship and ship-to-ship digital messaging.

2.3 Channel plan B

1024 157.200	1084 157.225	1025 157.250	1085 157.275	1026 157.300	1086 157.325
	VDE1 Ship-to-ship, ship-to-shore, shore-to-ship				
	SAT up3 extension			SAT up3	

2024 161.800	2084 161.825	2025 161.850	2085 161.875	2026 161.900	2086 161.925	2027 161.950	AIS1 161.975	2028 162.000	AIS2 162.025
VDE1 Shore-to-ship				Innovative applications		ASM1		ASM2	
SAT downlink						SAT up1	AIS1 uplink	SAT up2	AIS2 uplink

2.3.1 VHF data exchange system channel usage for channel plan B

2.3.1.1 Overall considerations:

– to maximize effective use of the channel resources;

– to retain the frequencies AIS 1 and AIS 2, and minimize interference;

– to use channels 2027 and 2028 for ASM (data vs. Navigation) reducing the loading on the AIS channels;

– to focus the AIS sat uplink on channels 75 and 76 which are already allocated for satellite detection;

– to keep all other ship borne transmissions (VDE and voice) in the low band, enabling protection of the AIS system on existing frequencies;

– to use channels 2026 and 2086 for low power innovative AIS applications not on board ships which will reduce the load on AIS 1 and AIS 2, and to create a guard band for coast stations and satellites, to enable protection of their AIS and ASM receivers from the VDE transmitters;

– the large footprint of the satellite.

2.3.1.2 VHF data exchange system between terrestrial stations

Ship transmissions for point-to-point communication ship-to-ship and ship-to-shore are in the channels 1024, 1084, 1025 and 1085. Ship-to-ship will be in simplex mode, and ship-to-shore can be in simplex mode in the channels and/or semi duplex mode in combination with the shore station transmitting in the channels 2024, 2084, 2025 and 2085.

Shore-to-ship transmissions will be in both the channels 2024, 2084, 2015, 2085, and the channels 1024, 1084, 1025 and 1085. These transmissions will be either in broadcast, multicast or point-to-point mode.

2.3.1.3 VHF data exchange system between terrestrial stations and satellite

Taking the large footprint of the satellite into consideration, and the subsequent risk of the satellite receiving many ships' transmissions simultaneously, the channels 1026 and 1086 are dedicated to ship-to-satellite uplink. This would avoid terrestrial VDE communications reducing the probability of satellite detection of ships. The SAT up3 extension channels 1024, 1084, 1025 and 1085 are utilised for increased data speed in the uplink.

The SAT downlink channels 2024, 2084, 2025 and 2085 are shared with the terrestrial VDE shore-to-ship transmissions. On these channels SAT transmission will have priority.

The SAT downlink channels are used both for broadcast and for satellite-to-ship point-to-point.

2.4 Channel plan C

1024	**1084**	**1025**	**1085**	**1026**	**1086**
157.200	**157.225**	**157.250**	**157.270**	**157.300**	**157.325**
SAT3 uplink		VDE-simplex Ship-to-ship, ship-to-shore, shore-to-ship			

4. 6 MHz

2024	**2084**	**2025**	**2085**	**2026**	**2086**	**2027**	**AIS 1**	**2028**	**AIS 2**
161.800	**161.825**	**161.850**	**161.875**	**161.900**	**161.925**	**161.950**	**161.975**	**162.000**	**162.025**
SAT downlink						ASM1 SAT1 uplink	Collision avoidance	ASM2 SAT2 uplink	Collision avoidance

2.4.1 VHF data exchange system channel usage for channel plan C

It is highly desirable for shore authorities to preserve AIS receiver sensitivity especially in areas of high traffic density where VDE is targeted to be used the most to communicate marine safety information (MSI). High traffic volume areas are often associated with the greatest AIS loading and it would not be desirable, from a shore authority perspective, to have a diminished VDE capacity in these circumstances. In high traffic areas, shore authorities are more likely to need all of the VDE capacity. As such, this proposal aims to provide as much separation as possible (given the available spectrum) between AIS and Terrestrial VDE in order to:

– preserve AIS receiver sensitivity;
– isolate the two systems so that the load on AIS does not affect VDE performance and available bandwidth.

2.4.1.1 VHF data exchange system between terrestrial stations

A simplex, 100 kHz wide-band channel consisting of the 4 following contiguous channels: 1025, 1085, 1026 and 1086 for terrestrial VDE communications. Using Recommendation ITU-R M.1842-1 based modulation; these channels may be able to reach data transfer speed of up to 307.2 kbit/s. The access scheme would be self-organised time division multiple access (SOTDMA) as with AIS.

2.4.1.2 VHF data exchange system between terrestrial stations and satellite

A 150 kHz wide-band channel consisting of the six following contiguous channels: 2024, 2084, 2025, 2085, 2026 and 2086 for VDE satellite downlink. A 50 kHz wide-band channel consisting of the two following contiguous channels: 1024 and 1084 for VDE satellite uplink from ships.

2.5 Channel plan D

1023 157.150	1083 157.175	1024 157.200	1084 157.225	1025 157.250	1085 157.275	1026 157.300	1086 157.325	1027 157.350	87 157.375	1028 157.400	88 157.425
Regional or national VDE Ship-to-shore				Global VDE1 Ship-to-shore				Voice	Voice	Voice	Voice
		SAT up3									

2023 161.750	2083 161.775	2024 161.800	2084 161.825	2025 161.850	2085 161.875	2026 161.900	2086 161.925	2027 161.950	AIS1 161.975	2028 162.000	AIS2 162.025
Regional or national VDE Shore-to-ship and ship-to-ship				Global VDE1 Shore-to-ship and ship-to-ship				ASM1	AIS1	ASM2	AIS2
		SAT downlink						SAT up1	AIS up1	SAT up2	AIS up2

2.5.1 VHF data exchange system channel usage for channel plan D

2.5.1.1 VHF data exchange system between terrestrial stations

– According to the result of compatibility studies between VDE and voice application, and between VDEs, the channels 1025, 1085, 1026 and 1086 will be used for the ship-to-shore transmission of the global harmonized VDES terrestrial component. The channels 1023, 1083, 1024 and 1084 could be used for ship-to-shore transmission of regional or national VDE, by means of one 100 kHz wide-band system, two 50 kHz wide-band systems, or four 25 kHz narrow-band systems.
– According to the result of compatibility studies between VDE and ASM application, and between VDEs, the channels 2025, 2085, 2026 and 2086 will be used for shore-to-ship or ship-to-ship transmission of the global harmonised VDES terrestrial component. The channels 2023, 2083, 2024 and 2084 could be used for shore-to-ship or ship-to-ship transmission of regional or national VDE, by means of one 100 kHz wide-band system, two 50 kHz wide-band systems, or four 25 kHz narrow-band systems.
– AIS 1 (161.975 MHz) and AIS 2 (162.025 MHz) are AIS channels, in accordance with Recommendation ITU-R M.1371; ASM 1 (channel 2027) and ASM 2 (channel 2028) are non-navigation application-specific messages (ASM).

2.5.1.2 VHF data exchange system between terrestrial stations and satellite

– AIS 1 (161.975 MHz) and AIS 2 (162.025 MHz) are used as uplinks for receiving AIS messages by satellite; SAT up1 (channel 2027) and SAT up2 (channel 2028) are used for receiving ASM by satellite.

– SAT up3 (channels 1024, 1084, 1025, 1085, 1026, and 1086) is a ship-to-satellite VDE uplink; SAT Downlink (channels 2024, 2084, 2025, 2085, 2026, and2086) is the satellite-to-ship VDE downlink.

3 Comparison of the channel plans

The four proposed channel plans A, B, C and D described above were evaluated:

– against an agreed set of important criteria which were developed by considering the different aspects of the VDES (Table 1), and

– for channel plan performance in supporting an agreed set of six use cases (Table 2).

The use cases took into account potential implementation and variations and realistic variations in data volume. Operational priorities were considered to enable design of VDES to support a future modernized GMDSS if so desired. The primary considerations relate to the protection and integrity of the function of AIS 1 and AIS 2, as well as the potential effects on other services, including other maritime services such as VHF voice communications.

Voice VHF communications would have significant effects on the effectiveness of the VDES as well as the existing AIS if not addressed. This concern became the primary factor in selecting the preferred channel plan. The use cases and the results of the evaluations can be found in Table 2.

While each channel plan has merits, the group agreed that Channel Plans B and C are unacceptably susceptible to interference from VHF voice communications.

Compare with channel plan A, channel plan D required:

– more isolation between antennas for shore stations instead of using 50 kHz frequency band gap between VDE and ASM and an alternative to the co-site interference mitigation technique;

– another method to mitigate the potential conflicts between regional channel use and part of the satellite link;

– methodology to mitigate the complexity of channel management (switching between global and regional channels).

4 Results

The proposed VDES channel plans were assessed against factors arising from discussion in IALA technical forum with wide representation from the maritime community.

Table 1 lists the assessment criteria used for the proposed VDES channel plans, along with observation of certain aspects of each criterion.

TABLE 1

Criteria for comparing the VHF data exchange system channel plans

System Aspects		
Criteria	**Description**	**Observation**
AIS ←→ VDE dependency. The overall dependency of the existing AIS system with VDES. This includes AIS 1, AIS 2, ASM 1, ASM 2 and LR-AIS.	Could a high AIS load take VDES capacity away?	No impact for all proposed channel plans
	Could a high VDES load take AIS capacity away?	No impact for all proposed channel plans
	Does VDE need to be coordinated with AIS? If so, must they be interfaced?	This is not a function of the channel plan. A protocol must be defined taking into account the ability to maximize AIS reception on board ship. A ship receiver will be desensitised when transmitting. However, care must be taken to ensure that the collision avoidance aspects of AIS are maintained (near ships must be heard). Care must be taken to ensure that the Sat downlink does not interfere with ASM channels. Yes – coordination is required, especially between ASM channels and AIS. This is true for all four channel plans.
	What would happen in case of an AIS failure/overload? Would the VDE stop working? And vice versa?	Failure is defined as over a 50% load on AIS channels. The VDE would not be impacted with all four channel plans.
VDE-Terrestrial → SAT-AIS interference	Interference level caused by VDE terrestrial transmissions to SAT-AIS reception. This includes reception of LR-AIS, ASM 1/2, AIS 1 and AIS 2.	Channel plans A, B and D would be impacted for the channels shared between satellite and terrestrial. Sharing studies must be conducted. For plans A, B the dedicated satellite channels mitigate this. Channel plan C would not be impacted.
VDE-SAT → SAT-AIS interference	Interference level caused by VDE satellite transmissions to SAT-AIS reception. This includes reception of LR-AIS, ASM 1, ASM 2, AIS 1 and AIS 2.	VDES transmissions will affect reception for AIS/ASM for all proposed channel plans; LR-AIS will not be impacted. There are available channels for satellite uplink.
VDE-SAT → VDE-Terrestrial interference	Interference level caused by VDE satellite transmissions to VDE terrestrial communications. This includes ship-to-ship, ship-to-shore and shore-to-ship.	Channel plans A, B and D would be impacted. Sharing studies must be conducted. Channel plan C would not be impacted.

TABLE 1 (*continued*)

System Aspects		
Criteria	**Description**	**Observation**
Capacity	Throughput (at system level) achieved by the proposed channel plans.	Channel plan C is simplex for terrestrial VDE, ship and shore must share but satellite is dedicated. Channel plans A and B are half-duplex and ship and shore may have to share with satellite. Channel plan D has a reduced throughput compared to the other channel plans.
Shore Aspects		
Criteria	**Description**	**Observation**
Shore-VDE ←→ Shore-AIS interference	Co-site interference between AIS and VDE. Ease and cost of taking countermeasures and adapting shore equipment.	Co-site interference is an issue with all four channel plans and impact is dictated by installation considerations. Channel plan C simplifies these issues. Channel plan A allows for the Co-site interference issue to be resolved with the use of Co-site Interference Mitigation Systems (CIMS). Channel plan D does not provide the 50 kHz separation needed for CIMS; Channel plan D requires a mitigation method including more isolation between antennas.
Ship Aspects		
Criteria	**Description**	**Observation**
VDE resilience to VHF voice communications	Can the VDE withstand VHF voice interference?	Channel plans A and B provide adequate protection; Channel plan C is subject to heavy impact on the VDE from voice; As long as the duty cycle is kept to a minimum VDE communications should not impact voice. Channel plan D is a duplex channel allotment for VDE, and the studies show that compatibility between the lower leg of these four channels being used for ship-to-shore transmitting and channel 1027 being used for simplex voice could be achieved.
AIS → VDE interference	VDE resilience to AIS transmissions.	All channel plans must coordinate between AIS and VDE.
VDE ship-to-ship / ship-to-shore → AIS interference	Impact of VDE communications to the AIS probability of detection and capacity.	No impact for all proposed channel plans.

TABLE 1 (*continued*)

Ship Aspects		
Criteria	**Description**	**Observation**
VDE ship-to-ship → VDE-SAT downlink interference	Amount of VDE-SAT downlink capacity that is taken away by VDE ship-to-ship communications.	Channel plans A and D may not accommodate satellite downlink during ship-to-ship communications. Channel plans B and C satellite downlink do not impact ship-to-ship communications. Regional channel used of plan D conflicts with part of satellite link.
VDE-SAT uplink impact on AIS	Impact of VDE-SAT uplink to AIS probability of detection and capacity.	Satellite uplink and AIS probability of detection may only be affected by VDE-SAT downlink on channel plans A, B and D.
VDES box complexity	Design, testing and certification.	Channel plans A, B and D may require sharing with satellite – if required, this will drive complexity.
Satellite Aspects		
Criteria	**Description**	**Observation**
Combining SAT-AIS and VDE on the same satellite?	Is it possible to combine SAT-AIS and VDE in the same satellite?	None of the channel plans support simultaneous operation with AIS 1 and AIS 2. However, it would be possible for LR-AIS.
Commercial Aspects		
Criteria	**Description**	**Observation**
Ease of migration from existing shipboard equipment	Is it necessary to interface the VDE box and the AIS box?	All four channel plans require an interface between VDE and AIS/ASM.
	Is it necessary to replace the existing AIS box?	This is not required for any of the four channel plans.
Modularity	Does the proposed channel plan/system allow product diversity? Is it possible to produce a VDE unit separately from an AIS unit? Is it possible to produce a VDES receive only unit?	All four channel plans support diversity.

The four channel plans described in § 2 were also considered against six different use cases. These scenarios include search and rescue communications, broadcast of notices to mariners, automated ship reporting, vessel traffic service portfolio, download of digital publications and route exchange. The details of these scenarios may be found in Annex 1. Table 2 provides a summary overview of the performance of each channel plan for each scenario.

TABLE 2

Channel plan performance against use cases

No	Scenario	Priority Distress	Priority Urgency	Priority Safety	Priority Routine	AIS / ASM	VDE	ship-ship	ship-short (Terr.)	Ship-Shore (SAT)	Shore-Ship (Terr.)	Shore-Ship (SAT)	Channel Plan A	Channel Plan B	Channel Plan C	Channel Plan D
1A	SAR communication (terrestrial)	x				x	x		x		x		Acceptable	Good	Poor	Acceptable
1B	SAR communication (satellite)	x				x	x			x		x	Good	Good	Good	Poor
2A	MSN / NM (T-& P-) (terr., small)		x	x		x	x				x		Good	Good	Poor	Good
2B	MSN / NM (T-& P-) (terr., medium)		x	x			x				x		Good	Good	Poor	Good
2C	MSN / NM (T-& P-) (sat., small)		x	x			x					x	Good	Good	Good	Poor
2D	MSN / NM (T-& P-) (sat., medium)		x	x			x					x	Fair	Fair	Acceptable	Poor
3A	Automated reporting (terr. medium)				x		x		x				Good	Good	Good	Good
3B	Automated reporting (terr. large)				x		x		x				Good	Good	Good	Good
3C	Automated reporting (sat medium)				x		x			x			Acceptable	Acceptable	Acceptable	Poor
3D	Automated reporting (sat large)				x		x			x			Fair	Fair	Fair	Poor
4A	VTS services (small)			x		x	x		x		x		Good	Good	Poor	Good
4B	VTS services (medium)			x		x	x		x		x		Good	Good	Poor	Good
4C	VTS services (sat - small)			x			x					x	Good	Good	Good	Poor
4D	VTS services (sat - medium)			x			x					x	Acceptable	Acceptable	Good	Poor
5A	Download large publication (terr.)				x		x				x		Good	Good	Poor	Good
5B	Download large publication (sat)				x		x					x	Fair	Acceptable	Good	Poor
6A	route exchange (ASM)			x		x		x					Good	Good	Good	Good
6B	route exchange (VDE)			x			x	x					Good	Poor	Poor	Good

	Good	Channel plan supports use case well;
	Acceptable	Channel plan supports use case with design considerations;
	Fair	Channel plan has limited support for the use case;
	Poor	Channel plan support may compromise use case;

Annex 1

Use case scenarios

Scenario 1				
SAR communication				
Description				
A ship sends a distress alert via VHF DSC, MF DSC, Inmarsat C or other appropriate means. The responsible MRCC wishes to use VDES to send out a Mayday Relay and request ships nearby to report their SAR capabilities, using a standardized data format or clear text, depending on onboard system capabilities.				
Priority				
Distress				
Variants				
A) In coastal waters near terrestrial shore station				
B) In remote area outside terrestrial coverage				
Assumed solution				
VDE is used to first broadcast a mayday relay, using A) shore station B) Satellite				
VDE is used to multicast a request for SAR capabilities to specific ships in the SAR area using A) shore station B) Satellite				
Ships use VDE to send SAR capability report to MRCC				
Channel plan A	**Ship-to-shore**	**Shore-to-ship**		**Total**
A) Reception of shore station broadcast is competing with ship-to-ship communications, satellite transmissions and own ships AIS transmissions, but can be protected by slot reservations and from ships own voice communications through filtering. Repetition of broadcasts should be considered.	Good	Acceptable		Acceptable
B) Satellite broadcast should be in dedicated satellite part of downlink channel; otherwise likely to be missed due to ship-to-ship (or shore-to-ship) transmissions, own ships AIS transmissions from preventing reception. Repetition of the broadcast should be considered. Reception can be protected from ships own voice transmissions.	Good	Good		Good
Channel plan B				
A) Reception of shore station broadcast is competing with satellite transmissions and own ships AIS transmissions, can be protected from ships own voice communication through filtering. Repetition of broadcasts should be considered.	Good	Good		Good
B) Satellite broadcast could be affected by own ships AIS transmissions could prevent reception. Repetition of the broadcast should be considered. Reception can be protected from ships own voice transmissions.	Good	Good		Good
Channel plan C				
A) Reception of shore station broadcast is competing with ship-to-ship communications, other shore-to-ship transmissions and VHF voice. Repetition of broadcasts must be applied, and even so, reception may be totally blocked for long periods of VHF voice.	Fair	Poor		Poor
B) Satellite reception may be affected by own ships AIS transmissions, but repetition of the broadcast may solve this. Reception can be protected from ships own voice transmissions.	Good	Good		Good

Channel plan D				
A) Reception of shore station broadcast is competing with ship-to-ship communications, satellite transmissions and own ships AIS transmissions, but can be protected by slot reservations and from ships own voice communication through filtering. Repetition of broadcasts should be considered.	Good	Acceptable		Acceptable
B) Satellite broadcast does not have a dedicated satellite downlink channel and will be interfered with from ship-to-ship (or shore-to-ship) transmissions, own ships AIS transmissions from preventing reception. Repetition of the broadcast should be considered. Reception can be protected from ships own voice transmissions. There is a potential conflict with ship-to-ship regional channel use.	Poor	Acceptable		Poor

Scenario 2	
Broadcast of MSI and Temporary & Preliminary Notices to Mariners	
Description	
Broadcast of Maritime Safety Information (Navigational warnings, Weather warnings, …)	
Broadcast of Temporary and Preliminary Notices to Mariners	
Could also cover broadcasting 'virtual Aids to Navigation' type of information	
Priority	
Safety (or Urgency)	
Variants	
A) In coastal waters near terrestrial shore station, small data packages (<10 kB)	
B) In coastal waters near terrestrial shore station, medium data packages (10-100 kB)	
C) In remote area outside terrestrial coverage, small data packages (<10 kB)	
D) In remote area outside terrestrial coverage, medium data packages (10-100 kB)	
Assumed solution	
VDE is used to broadcast data using S-100 data structures presentable on graphical displays	
(ASM could be used in variant A)	
Channel plan A	**shore ship**
A) Reception of shore station broadcast is competing with ship-to-ship communications, satellite transmissions and own ships AIS transmissions, may to some degree be protected by slot reservations and from ships own voice communication through filtering. Repetition of broadcasts/request for acknowledges could be considered.	Good
B) Data transfer may take some time - repetition of broadcasts / request for acknowledge could be considered.	Good
C) Satellite broadcast should be dedicated satellite part of downlink channel; otherwise likely to be missed due to ship-to-ship (or shore-to-ship) transmissions, own ships AIS transmissions from preventing reception. Repetition of the broadcast should be considered. Reception can be protected from ships own voice transmissions.	Good
D) Large bandwidth needed. Broadcast should be on dedicated satellite part of downlink to avoid conflict with ship-to-ship, due to size likely to be affected by own ships AIS transmissions - thus repetition needed, and due to satellite movement data transfer may not be completed before loss of signal occurs.	Fair
Channel plan B	
A) Reception of shore station broadcast is competing with satellite transmissions and own ships AIS transmissions, but can be protected from ships own voice communication through filtering. Repetition of broadcasts/request for acknowledges could be considered.	Good
B) Data transfer may take some time repetition of broadcasts / request for acknowledge could be considered.	Good
C) Could be missed due to own ships AIS transmissions. Repetition of the broadcast should be considered. Reception can be protected from ships own voice transmissions or VDE transmissions.	Good
D) Large bandwidth needed but available, however affected by own ships AIS transmission. Repetition/request for acknowledge should be considered	Fair

Channel plan C	
A) Reception of shore station broadcast is competing with ship-to-ship transmissions and VHF voice. Repetition of broadcasts / request for acknowledges must be considered.	Poor
B) Data transfer may take some time repetition of broadcasts / request for acknowledge could be considered.	Poor
C) Could be missed due to own ships AIS transmissions. Repetition of the broadcast should be considered. Reception can be protected from ships own voice transmissions or VDE transmissions.	Good
D) Large bandwidth needed and available, however affected by own ships AIS transmissions. Repetition/request for acknowledge should be considered	Acceptable
Channel plan D	
A) Reception of shore station broadcast is competing with ship-to-ship communications, satellite transmissions and own ships AIS transmissions, may to some degree be protected by slot reservations and from ships own voice communication through filtering. Repetition of broadcasts / request for acknowledges could be considered.	Good
B) Data transfer may take some time repetition of broadcasts / request for acknowledge could be considered.	Good
C) Satellite broadcast does not have a dedicated satellite downlink channel and will possibly be interfered with from ship-to-ship (or shore-to-ship) transmissions, own ships AIS transmissions from preventing reception. Repetition of the broadcast should be considered. Reception can be protected from ships own voice transmissions. There is a potential conflict with ship-to-ship regional channel use.	Poor
D) Large bandwidth needed. Satellite broadcast does not have a dedicated downlink channel and will possibly be interfered with from ship-to-ship, due to size likely to be affected by own ships AIS transmissions - thus repetition needed, due to satellite movement may not be completed until out of sight. There is a potential conflict with ship–to-ship regional channel use.	Poor

Scenario 3	
Automated reporting (IMO FAL forms)	
Description	
Ship pushes information package to National Single Window system, port or similar	
Encryption may be applied to protect sensitive information	
May be packaged into sequence of packages requiring acknowledge or retransmission for each packet	
Not time critical - may take time.	
Priority	
Routine	
Variants	
A) In coastal waters near terrestrial shore station, medium data packages (10-100 kB)	
B) In coastal waters near terrestrial shore station, large data package (<100 kB)	
C) In remote area outside terrestrial coverage, medium data package (10-100 kB)	
D) In remote area outside terrestrial coverage, large data packages (>100 kB)	
Assumed solution	
VDE is used to transfer data based on IMO FAL form implemented in standard data structure	
Channel plan A	**ship shore**
A) Extended time of VDE broadcast may affect AIS reception - limit to duty cycle must be observed	Good
B) Extended time of VDE broadcast will affect AIS reception over a longer period - limit to duty cycle must be observed	Good
C) Large bandwidth available, but many ships in footprint. Extended time of VDE broadcast may affect VHF voice reception - limit to duty cycle must be observed	Acceptable
D) Large bandwidth available, but many ships in footprint. Extended time for large size transfers may not be completed until satellite out of sight - but may be continued when next satellite passes, VDE broadcast may affect VHF voice reception - limit to duty cycle must be observed.	Fair

Channel plan B	
A) Extended time of VDE broadcast affects VHF voice reception - limit to duty cycle must be observed	Good
B) Ship-to-ship bandwidth may be affected. Extended time of VDE broadcast will affect VHF voice reception over a longer period - limit to duty cycle must be observed	Good
C) Sharing bandwidth with ship-to-ship, and many ships in footprint. Extended time of VDE broadcast may affect VHF voice reception - limit to duty cycle must be observed	Acceptable
D) Sharing bandwidth with ship-to-ship, and many ships in footprint. Extended time for large size transfers may not be completed until satellite out of sight - but may be continued when next satellite passes, VDE broadcast may affect VHF voice reception - limit to duty cycle must be observed.	Fair
Channel plan C	
A) Extended time of VDE broadcast affects VHF voice reception - limit to duty cycle must be observed	Good
B) Ship-to-ship bandwidth may be affected. Extended time of VDE broadcast will affect VHF voice reception over a longer period - limit to duty cycle must be observed	Good
C) Sharing bandwidth with ship-to-ship, and many ships in footprint. Extended time of VDE broadcast may affect VHF voice reception - limit to duty cycle must be observed	Acceptable
D) Sharing bandwidth with ship-to-ship, and many ships in footprint. Extended time for large size transfers may not be completed until satellite out of sight - but may be continued when next satellite passes, VDE broadcast may affect VHF voice reception - limit to duty cycle must be observed.	Fair
Channel plan D	
A) Extended time of VDE broadcast may affect AIS reception - limit to duty cycle must be observed	Good
B) Extended time of VDE broadcast will affect AIS reception over a longer period - limit to duty cycle must be observed	Good
C) Large bandwidth available, but many ships in footprint. Extended time of VDE broadcast may affect VHF voice reception - limit to duty cycle must be observed. There is a potential conflict with ship-to-ship regional channel use.	Poor
D) Large bandwidth available, but many ships in footprint. Extended time for large size transfers may not be completed until satellite out of sight - but may be continued when next satellite passes, VDE broadcast may affect VHF voice reception - limit to duty cycle must be observed. There is a potential conflict with ship to ship regional channel use.	Poor

Scenario 4	
VTS service Portfolio	
Description	
Ship sending reporting line information to VTS	
VTS requesting ship to send reporting line information	
Ship requesting VTS information service (dynamic no-go areas, information on route, METOCEAN information, etc.) and receiving reply	
Priority	
Safety	
Variants	
A) In coastal waters near terrestrial shore station, small data packages (<10 kB)	
B) In coastal waters near terrestrial shore station, medium data packages (10-100 kB)	
C) In remote area outside terrestrial coverage, small data packages (<10 kB)	
D) In remote area outside terrestrial coverage, medium data packages (10-100 kB)	
Assumed solution	
VDE or ASM is used	
Channel plan A	**shore ship**
A) Link likely to be busy, can be protected from VHF voice	Good

B) Link likely to be busy, can be protected from VHF voice	Good
C) Link likely to be busy, can be protected from VHF voice	Good
D) Link likely to be busy, can be protected from VHF voice	Acceptable
Channel plan B	
A) Link likely to be busy, can be protected from VHF voice	Good
B) Link likely to be busy, can be protected from VHF voice	Good
C) Link likely to be busy, can be protected from VHF voice	Good
D) Link likely to be busy, can be protected from VHF voice	Acceptable
Channel plan C	
A) Link likely to be busy, ships reception can NOT be protected from VHF voice	poor
B) Link likely to be busy, ships reception can NOT be protected from VHF voice	poor
C) Link likely to be busy, can be protected from VHF voice	Good
D) Link likely to be busy, can be protected from VHF voice	Good
Channel plan D	
A) Link likely to be busy, can be protected from VHF voice	Good
B) Link likely to be busy, can be protected from VHF voice	Good
C) Link likely to be busy can be protected from VHF voice. There is a potential conflict with ship to ship regional channel use.	Poor
D) Link likely to be busy, can be protected from VHF voice. There is a potential conflict with ship to ship regional channel use.	Poor

Scenario 5	
Download of updated digital publication	
Description	
Ship requests download of an updated digital publication (large size, <100 kB)	
GMDSS Master Plan, the Almanac, ENC update, …	
Data is serialized into packages, and each package acknowledged or repeated	
Priority	
Safety (or Urgency)	
Variants	
A) In coastal waters near terrestrial shore station	
B) In deep sea, outside terrestrial coverage	
Assumed solution	
VDE is used to download	
Channel plan A	**shore ship**
A) Ships reception is competing with ship-to-ship communications, satellite transmissions and own ships AIS transmissions, may to some degree be protected by slot reservations and from ships own voice communication through filtering.	Good
B) Ships reception competing with ship-to-ship and own AIS transmissions. Will be slow.	Fair
Channel plan B	
A) Ships reception is competing with satellite transmissions, own ships AIS transmissions, may be protected from ships own voice communication through filtering.	Good
B) Ships reception competing own AIS transmissions.	Acceptable

Channel plan C	
A) Reception of shore station broadcast is competing with ship-to-ship transmissions and VHF voice.	Poor
B) Full bandwidth available only affected by own AIS transmissions, may be protected from Voice transmissions	Good
Channel plan D	
A) Ships reception is competing with ship-to-ship communications, satellite transmissions and own ships AIS transmissions, may to some degree be protected by slot reservations and from ships own voice communication through filtering.	Good
B) Ships reception competing with ship-to-ship and own AIS transmissions. Will be slow. There is a potential conflict with ship-to-ship regional channel use.	Poor

Scenario 6	
Route exchange (ship-to-ship)	
Description	
Ship broadcasts waypoints related to next 30 minutes of planned, active route every 10 min, or when changed	
Ships may request update of other ships route intention	
Priority	
Safety	
Variants	
A) ASM is used	
B) VDE is used	
Assumed solution	
Channel plan A	**ship-ship**
A) Affected by own ships AIS transmissions, but may be protected from ships own voice communication through filtering.	Good
B) Affected by own ships AIS transmissions, but may be protected from ships own voice communication through filtering.	Good
Channel plan B	
A) Affected by own ships AIS transmissions, but may be protected from ships own voice communication through filtering.	Good
B) Affected by own ships AIS transmissions, and may be blocked by ships own voice communication	Poor
Channel plan C	
A) Affected by own ships AIS transmissions, but may be protected from ships own voice communication through filtering.	Good
B) Affected by own ships AIS transmissions, and may be blocked by ships own voice communication	Poor
Channel plan D	
A) Affected by own ships AIS transmissions, but may be protected from ships own voice communication through filtering.	Good
B) Affected by own ships AIS transmissions, but may be protected from ships own voice communication through filtering.	Good

Annex 2

Study from China for channel plan D

1 Task goal

The goals of the task are as follows:

– Compatibility analysis between VDE and ASM, between VDE and voice, and between different VDE systems.

– Calculation and simulation of needed isolation space between antennas of VDE and ASM or voice applications subject to implement of compatibility.

2 Task condition

The main condition and input parameter of the task is as following:

1) VDE channel: be consistent with Recommendation ITU-R M.1842-1 Annex 3, or Annex 4:
   - The class of emission: 50K0F1DDN (Annex 3), or 100K0F1DDN (Annex 4).
   - Modulation: 16 × 16-QAM (Annex 3), or 32 × 16-QAM (Annex 4).
   - The carrier power: 50 W (coast station transmitters), 25 W (ship station transmitters).
   - The adjacent channel selectivity: at least 70 dB.
   - The spurious response rejection ratio: at least 70 dB.
   - The radio-frequency intermodulation rejection ratio: at least 70 dB.
   - The receiver sensitivity levels: better than −103 dBm for shore stations, and better than −98 dBm for ship stations.
   - The power of any conducted spurious emissions at the antenna terminals is not to exceed 2.0 nW.

2) ASM channel: be consistent with Recommendation ITU-R M.1842-1 Annex 1:
   - The class of emission: 16K0F1DDN.
   - Modulation: π/4 DQPSK, or π/8 D8-PSK.
   - The carrier power: 50 W (coast station transmitters), 25 W (ship station transmitters).
   - The adjacent channel selectivity: at least 70 dB.
   - The spurious response rejection ratio: at least 70 dB.
   - The radio-frequency intermodulation rejection ratio: at least 70 dB.
   - The receiver sensitivity levels: better than −107 dBm.
   - The power of any conducted spurious emissions at the antenna terminals is not to exceed 2.0 nW.

3) Voice channel: be consistent with Recommendation ITU-R M.489-2:
   - The class of emission: F3E/G3E, with 16 kHz of necessary bandwidth.
   - Modulation: phase modulation (frequency modulation with a pre-emphasis characteristic of 6 dB/octave).
   - The carrier power: 50 W (coast station transmitters), 25 W (ship station transmitters).
   - The adjacent channel selectivity: at least 70 dB.
   - The spurious response rejection ratio: at least 70 dB.

– The radio-frequency intermodulation rejection ratio: at least 65 dB.
– The power of any conducted spurious emission at the antenna terminals is not to exceed 2.0 nW.

4) Antenna used by the coastal station:
– Type: 4-loop array.
– Frequency bands: 134 MHz~173 MHz.
– Bandwidth: 8 MHz.
– Length: 6.7 m.
– Gain: omnidirectional 9 dBi.
– Standing wave ratio: ≤.5.
– Type of polarization: vertical.

5) Ship antenna used by the ship station:
– Length: 1.2 m.
– Gain: omnidirectional 3 dBi.
– Standing-wave ratio (SWR): ≤ 1.5.

3 Theoretical analysis

Inter-symbol interference (ISI) is the key factor which brings bit error in digital communication system. It is needed to design the spectrum mask to implement proper adjacent channel rejection ratio value by eliminating ISI. The characteristics of digital communication are related to some key parameters:

– R_b (bit/s or bps): bit transmitting rate in a certain channel.
– R_B (baud): symbol transmitting rate in M-ary system, or the transmitting number of symbol per second.
– T (s): the symbol transmitting period, $T = 1/R_B$.

If every symbol of information source is equal probability independent, the relationship of R_b and R_B would be:

$$R_\mathrm{b}= R_\mathrm{B}\log_2 M$$

When multi sub-carrier transmission is adopted, the frequency band of a single sub-carrier would be B/N, in which B is the whole band of the channel, and N is the number of sub-carriers. When the whole bit transmitting rate is R_b kbps, the bit rate of a single sub-carrier would be R_b/N.

The inverse Fourier transform of a square root raised-cosine spectrum is defined as following:

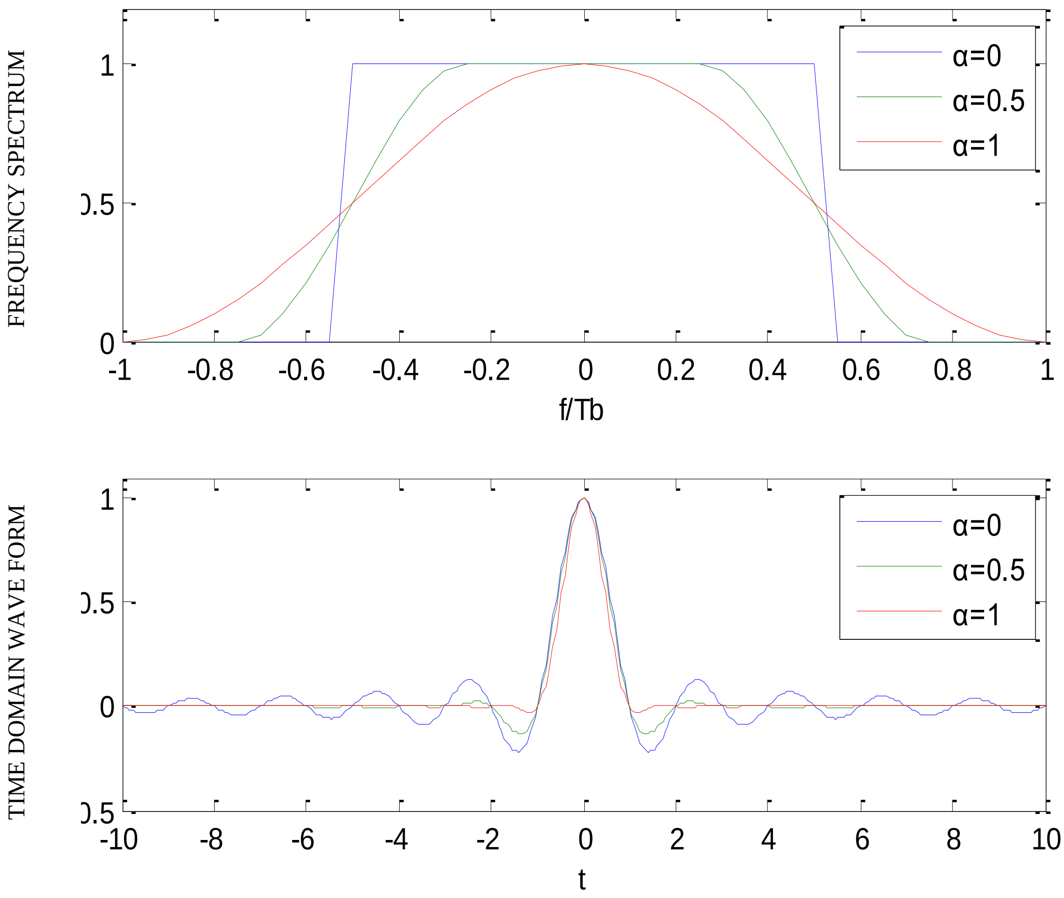
$$P_\mathrm{r}(f) = \begin{cases} T_b & 0 \le |f| < (1-\alpha)B_\mathrm{N} \\ T_b\left\{1-\sin\left[\dfrac{\pi(|f|-B_\mathrm{N})}{2\alpha B_\mathrm{N}}\right]\right\} & (1-\alpha)B_\mathrm{N} \le |f| < (1+\alpha)B_\mathrm{N} \\ 0 & |f| \ge (1+\alpha)B_\mathrm{N} \end{cases}$$

Where α is the roll-off factor, which determines the width of the transmission band at a given symbol rate.

The frequency and time domain characteristics of α is typically shown as in Figure A2-1.

FIGURE A2-1

The frequency and time domain characteristics with different roll-off values



Subject to no ISI, there would be a relationship expressed as following:

$$B = (1 + \alpha)R_B$$

in which *B* is the system required frequency band B.

4 Simulation result

4.1 Spectrum characteristics of single sub-carrier of VHF data exchange

The spectrum characteristics of a single sub-carrier of VHF data exchange in different configurations of data transmitting rates and filter performance are respectively shown in Figs. A2-2, A2-3 and A2-4. The filter order is set to 100, which is comparatively the optimistic practical value.

FIGURE A2-2

The spectrum of a single sub-carrier of VHF data exchange with 307.2 kbps data transmission rate

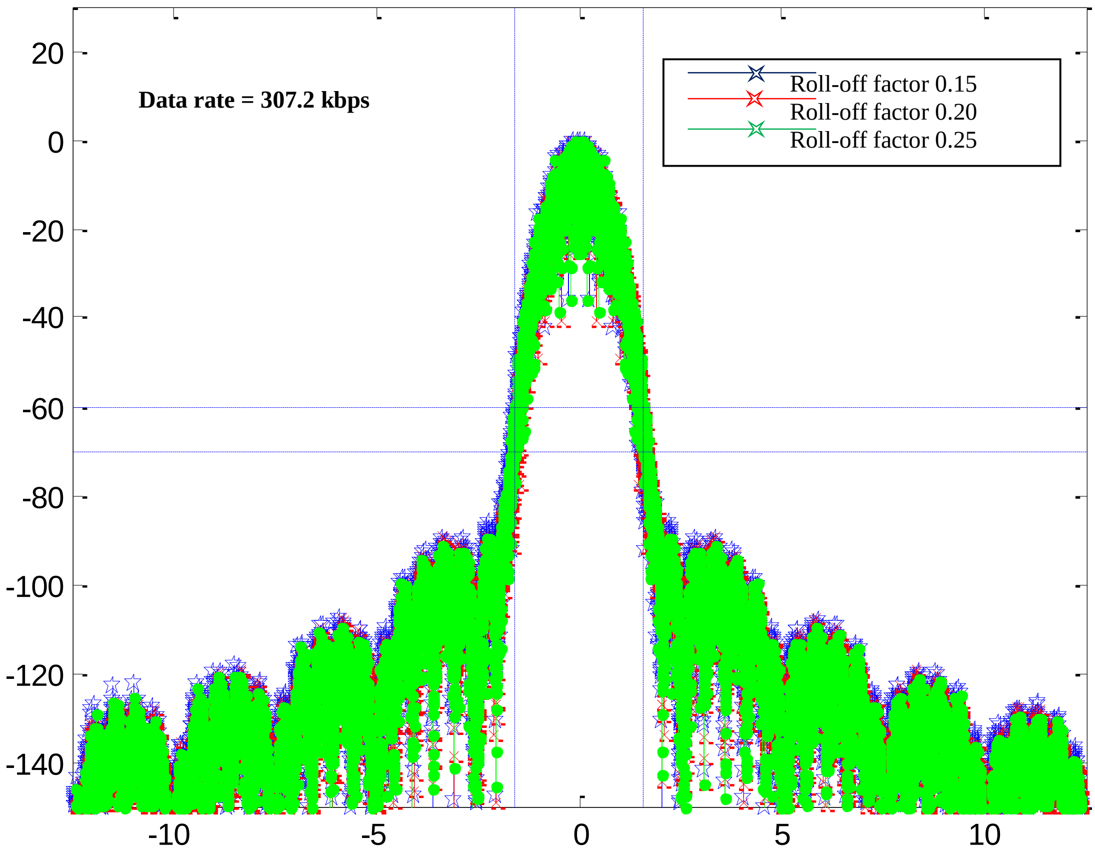


FIGURE A2-3

The spectrum of a single sub-carrier of VHF data exchange with 288 kbps data transmission rate

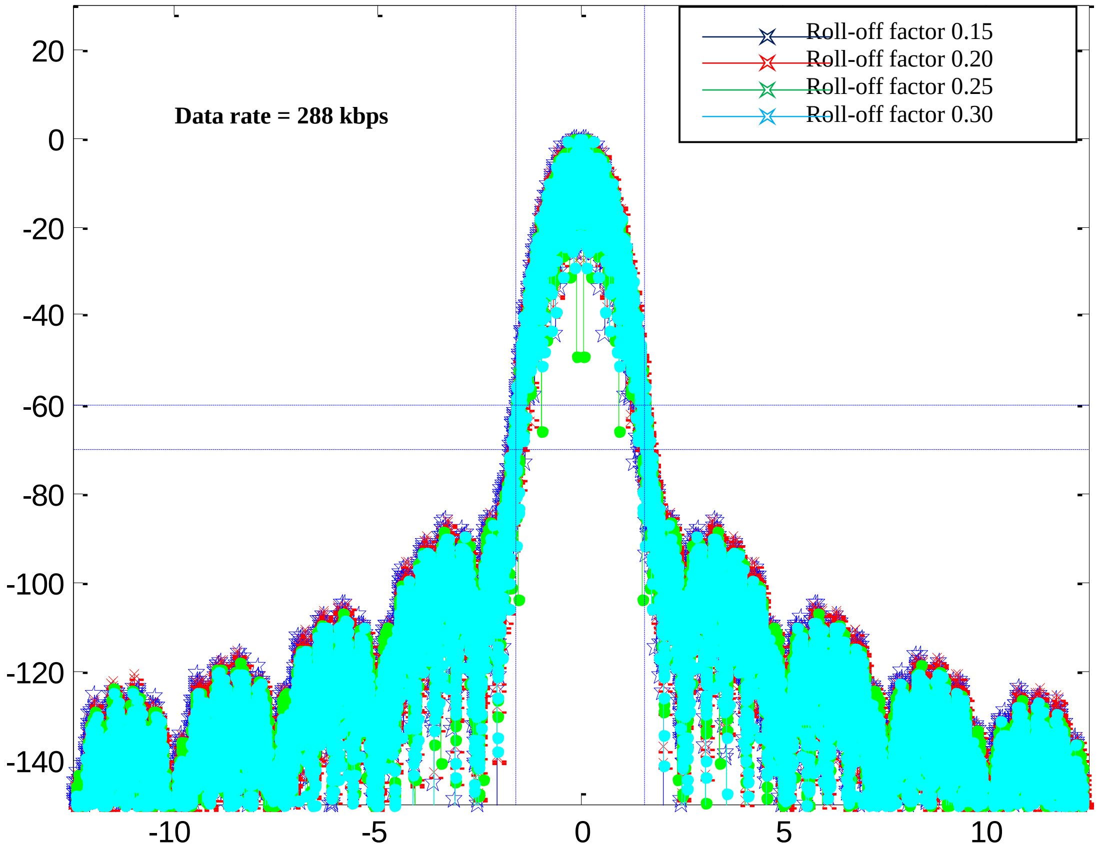
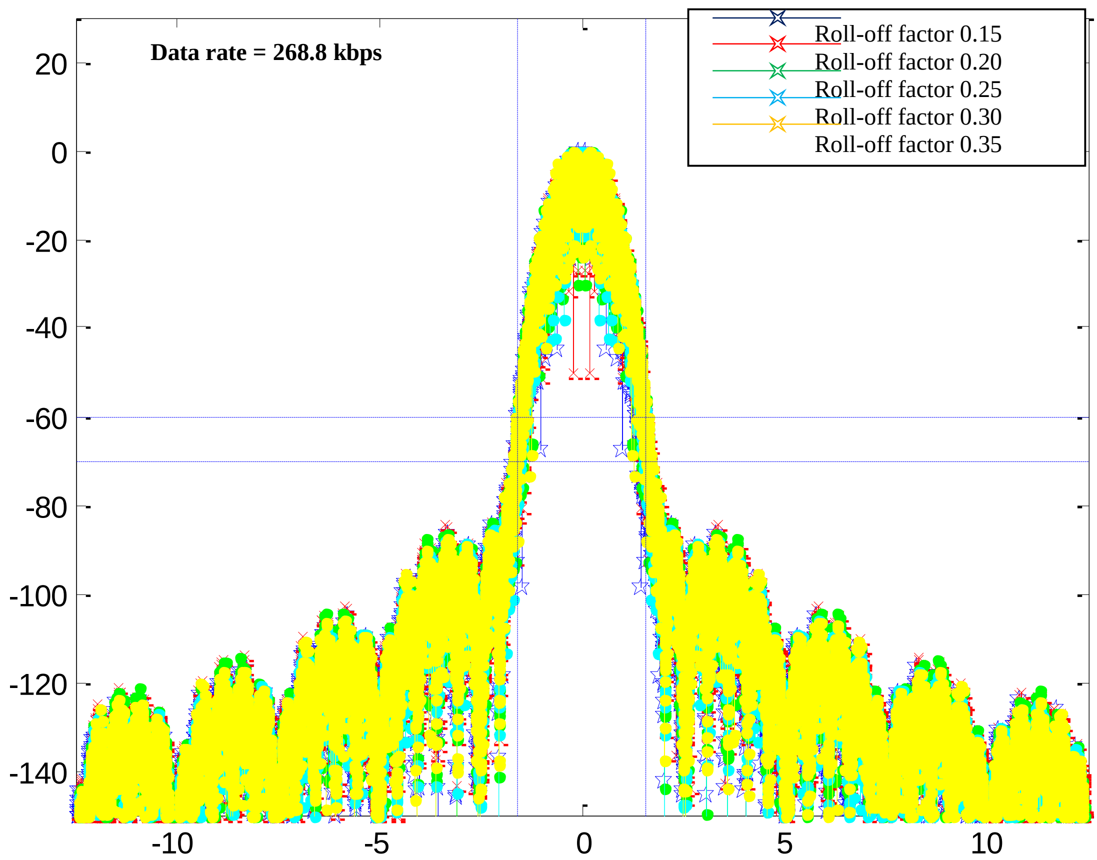


FIGURE A2-4

The spectrum of a single sub-carrier of VHF data exchange with 268.8 kbps data transmission rate



4.2 Spectrum characteristics of VHF data exchange adjacent to voice channel

Figures A2-5, A2-6 and A2-7 show the spectrum characteristics of VHF data exchange adjacent to voice channel respectively with data rate of 307.2 kbps, 288 kbps and 268.8 kbps. The filter order is set to 100, and the roll-off factor equals to 0.20, which is comparatively the optimistic practical value.

4.3 Spectrum characteristics of VHF data exchange adjacent to application specific message channel

Figures A2-8, A2-9 and A2-10 show the spectrum characteristics of a VHF data exchange channel adjacent to the ASM channel respectively, with data rates of 307.2 kbps, 288 kbps and 268.8 kbps. The filter order is set to 100, and the roll-off factor equals 0.20, which is comparatively the optimistic practical value.

FIGURE A2-5

The spectrum of VHF data exchange adjacent to voice channel respectively with 307.2 kbps data transmission rate

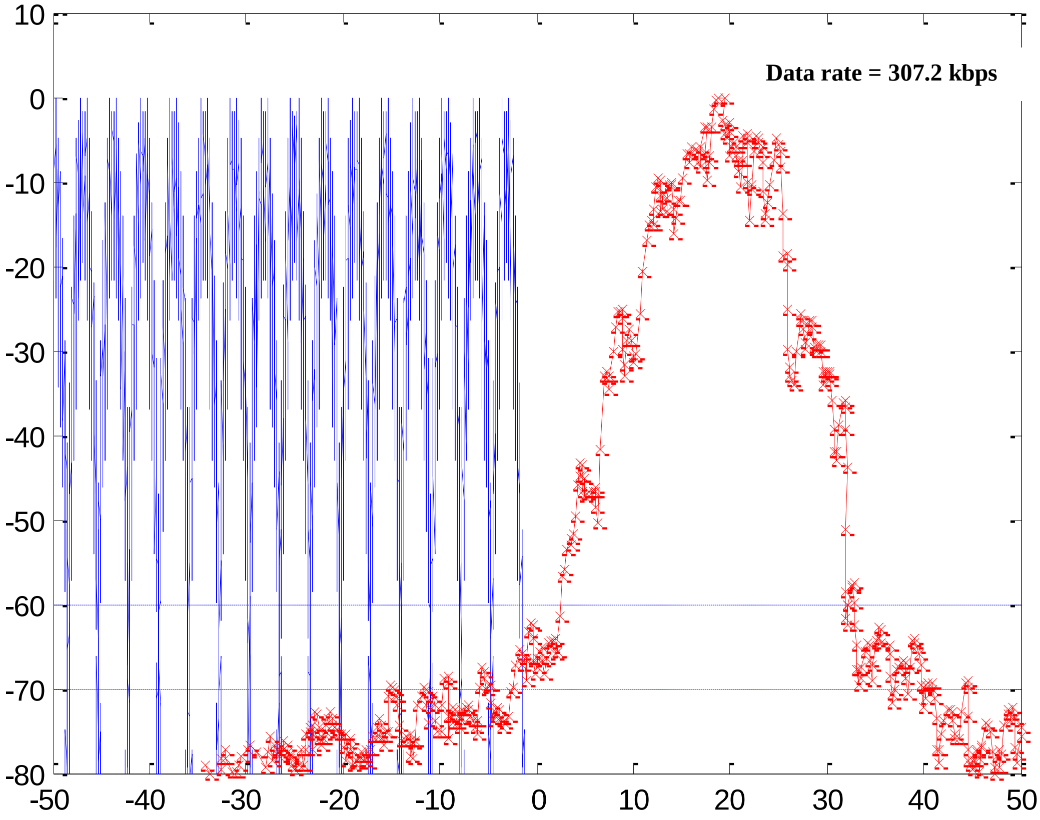


FIGURE A2-6

The spectrum of VHF data exchange adjacent to voice channel respectively with 288 kbps data transmission rate

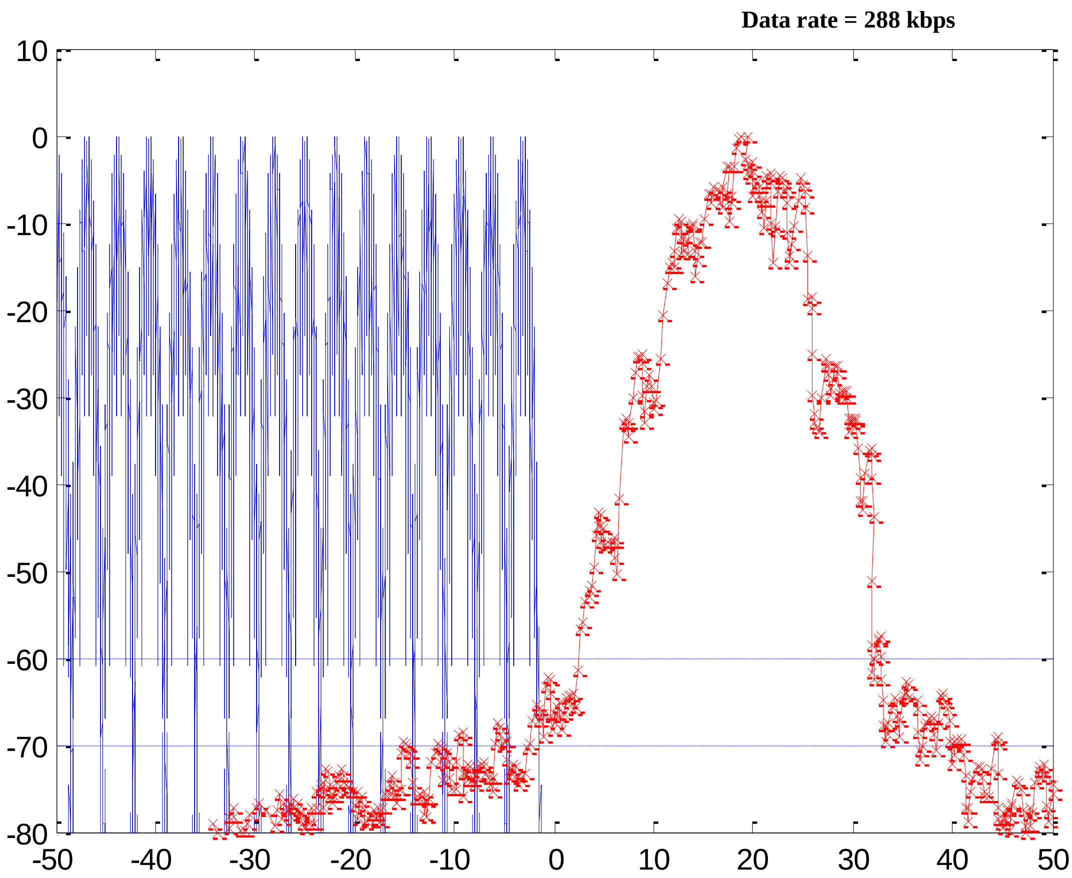


FIGURE A2-7

The spectrum of VHF data exchange adjacent to voice channel respectively with 268.8 kbps data transmission rate

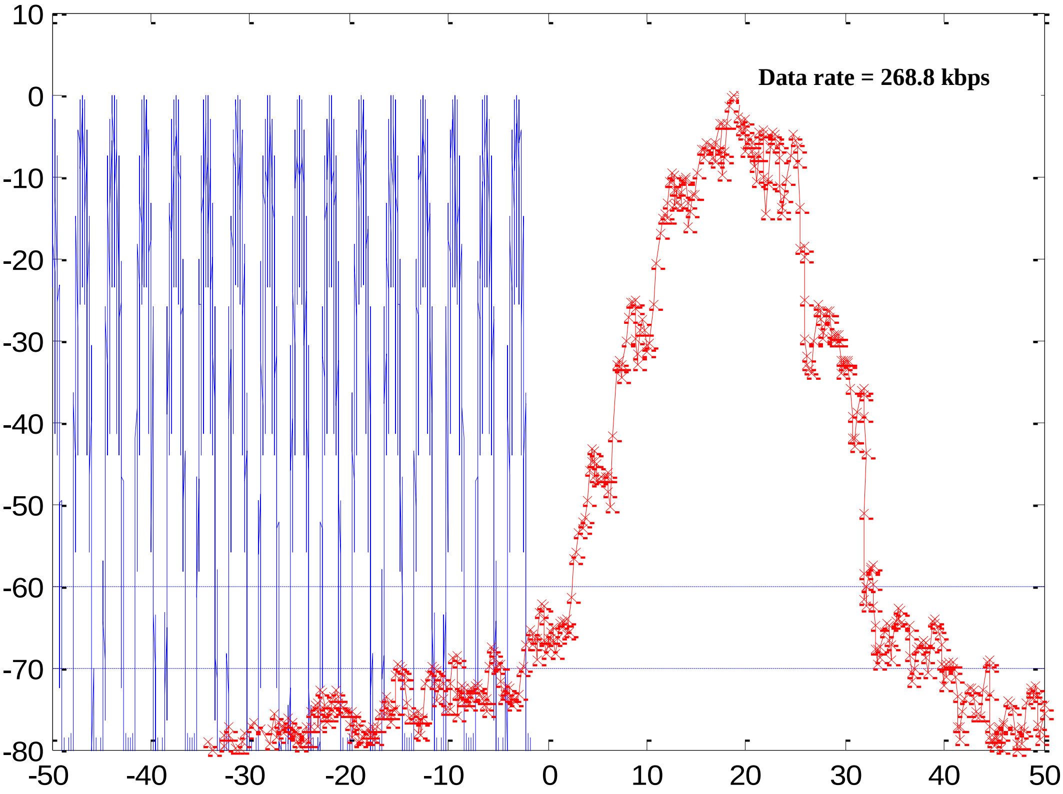


FIGURE A2-8

The spectrum of VHF data exchange adjacent to ASM channel respectively with 307.2 kbps data transmission rate

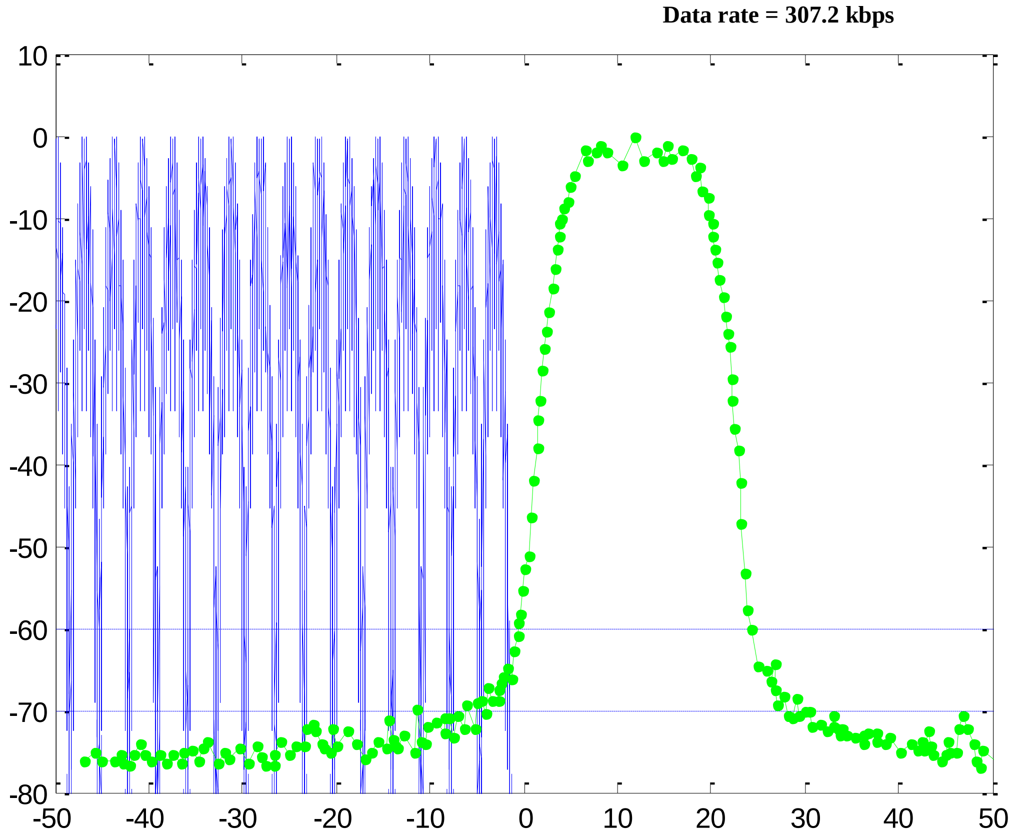


FIGURE A2-9

The spectrum of VHF data exchange adjacent to ASM channel respectively with 288 kbps data transmission rate

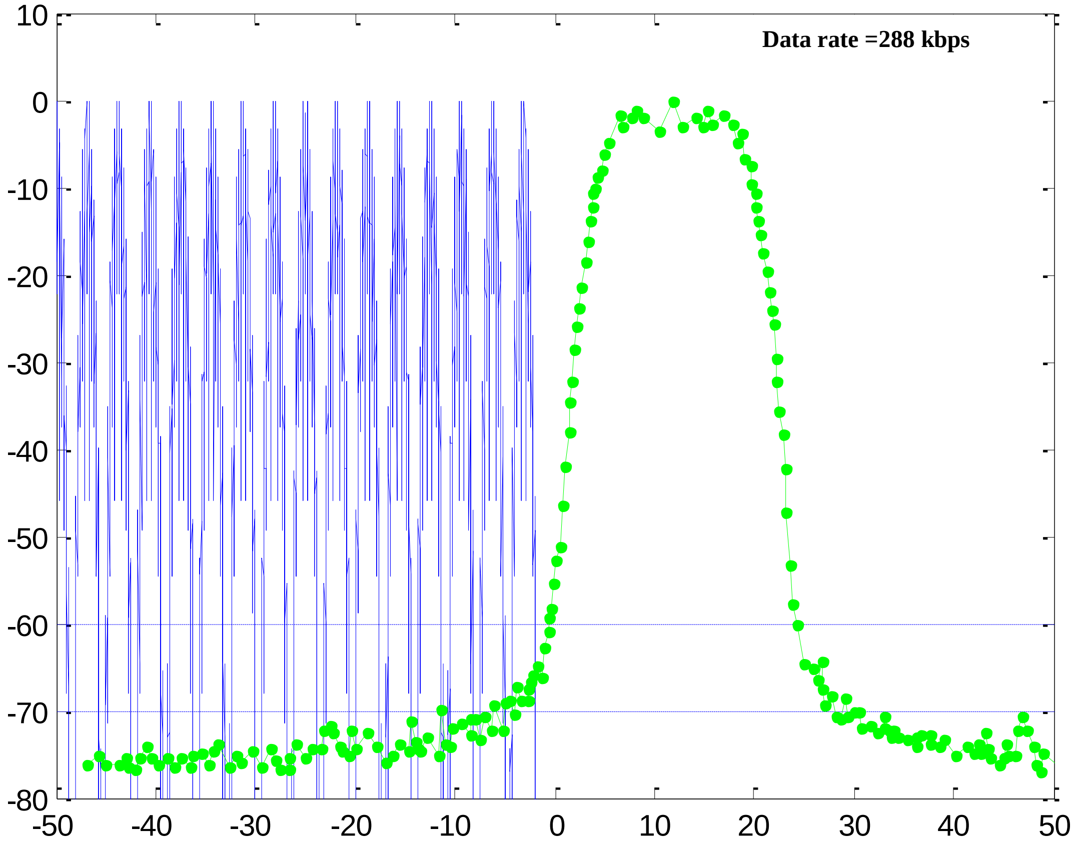
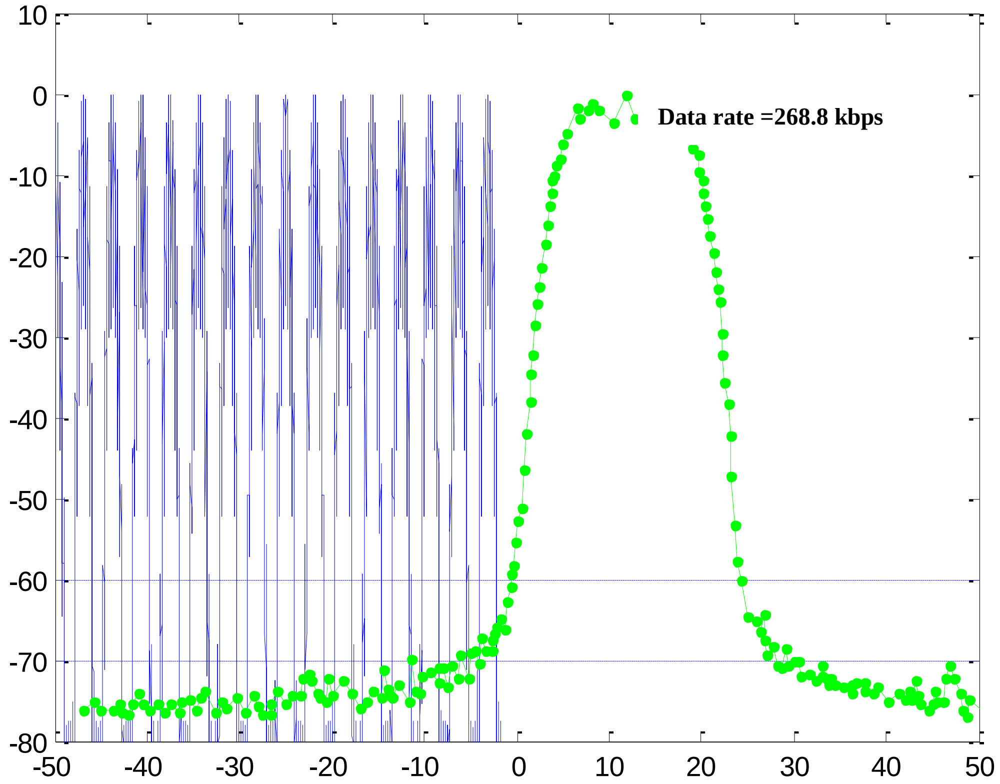


FIGURE A2-10

The spectrum of VHF data exchange adjacent to ASM channel respectively with 268.8 kbps data transmission rate



4.4 Frequency requirements for VHF data exchange system in different conditions

Table A1-1 gives some channel parameters and filter performance requirements in different conditions of data transmitting rate and adjacent channel rejection.

TABLE A1-1

Data rate in the channel (kbps)	Data rate of a single sub-carrier (kbps)	Symbol rate (Bd)	Roll-off factor	Band subject to no ISI	Adjacent channel rejection (dB)	Filter shape factor
307.2	9.6	2.4	0.25	3.00	70.00	1.00
				3.00	65.00	1.00
				3.00	60.00	1.00
			0.20	2.88	70.00	1.05
				2.88	65.00	1.05
				2.88	60.00	1.05
			0.15	2.76	70.00	1.07
				2.76	65.00	1.08
				2.76	60.00	1.08
			0.12	2.69	70.00	1.09
				2.69	65.00	1.10
				2.69	60.00	1.10

TABLE A1-1 (*end*)

Data rate in the channel (kbps)	Data rate of a single sub-carrier (kbps)	Symbol rate (Bd)	Roll-off factor	Band subject to no ISI	Adjacent channel rejection (dB)	Filter shape factor
288.00	9.00	2.25	0.35	3.04	70.00	1.04
				3.04	65.00	1.04
				3.04	60.00	1.04
			0.30	2.93	70.00	1.06
				2.93	65.00	1.06
				2.93	60.00	1.06
			0.20	2.70	70.00	1.09
				2.70	65.00	1.09
				2.70	60.00	1.09
			0.15	2.59	70.00	1.12
				2.59	65.00	1.13
				2.59	60.00	1.13
			0.12	2.52	70.00	1.15
				2.52	65.00	1.15
				2.52	60.00	1.15
268.80	8.40	2.10	0.45	3.05	70.00	1.00
				3.05	65.00	1.00
				3.05	60.00	1.00
			0.40	2.94	70.00	1.00
				2.94	65.00	1.00
				2.94	60.00	1.00
			0.35	2.84	70.00	1.06
				2.84	65.00	1.06
				2.84	60.00	1.06
			0.30	2.73	70.00	1.08
				2.73	65.00	1.08
				2.73	60.00	1.09
			0.25	2.63	70.00	1.11
				2.63	65.00	1.11
				2.63	60.00	1.12
			0.20	2.52	70.00	1.15
				2.52	65.00	1.15
				2.52	60.00	1.15
			0.15	2.42	70.00	1.19
				2.42	65.00	1.19
				2.42	60.00	1.20
			0.12	2.35	70.00	1.21
				2.35	65.00	1.22
				2.35	60.00	1.23

5 Conclusion

The real world sounding campaign (see Report ITU-R M.2317) and the above analysis could bring the following conclusions:

1) Channel 25, 26, 85 and 86 of RR Appendix **18** are suitable for a maritime VHF data exchange system. The compatibility between the lower leg of these four channels being used for ship-to-shore transmission and channel 1027 being used for simplex voice, and the upper leg of the four channels being used for shore-to-ship and ship-to-ship transmitting and channel 2027 being used for ASM could be achieved.

2) The data rate of 307.2 kbps using 100 kHz frequency bands with16-QAM modulation will hardly be achieved subject to adjacent channel power ratio being at least 70 dB, for the reason of practical manufacturing art. Two options are proposed with the reasonable conditions of practical manufacture:

   – To reduce the practical system data rate to 268.8 kbps (see Figure 2 of Recommendation ITU-R M.1842-1 Annex 1). This means the efficiency of the channel usage has to be lost to ensure the high quality of spectrum, and consequent high quality of data transmitting and receiving. This is crucial to a safety and security-related system.

   – To reduce the requirement for the adjacent channel power ratio down to 65 dB or 60 dB (see Table 6.14 in provision 6.4.9.2.1 of ETSI 300 392-2 V3.4.1). This option costs the quality of data transmission and reception to ensure the ideal system data rate, and obviously stronger coding and error correction are needed. This might be proper for applications for commercial purposes.

3) Further studies and tests are needed for the physical systems and prototypes in the real world.

6 Antenna spacing

The antenna isolation I_{Req} (dB) could be calculated with the formula:

$$I_{\mathrm{Re}q} = 137 + 10\lg P_t + S - I_n$$

P_t: transmitting power (W)

S: receiver sensitivity level (dBμV); or $S = P_{min}$(dB) + 113

I_n: receiver interference rejection index (dB). According to the standard of China, I_n should be more than 100 dB.

The vertical isolation I_{AV} (dB) of two VHF antennas could be calculated with the formula:

$$I_{AV} = 39.557\lg H + 22.263$$

H: vertical distance from the top of the lower antenna to the bottom of the upper antenna (m).

The horizontal isolation I_{AH} (dB) of two VHF antennas could be calculated with the formula:

$$I_{AH} = 20\lg d + 12.956$$

d: horizontal distance between two VHF antennas (m).

The following conditions should be implemented for ensuring the isolation of VHF antennas:

$$I_{AV} \geq I_{\mathrm{Re}q}$$

$$I_{AH} \geq I_{\mathrm{Re}q}$$

The model and gain simulating scheme of an omnidirectional antenna for a coastal station is shown as Figs. A2-11 and A2-12.

Figures A2-13 and A2-14 give the horizontal gain scheme and the vertical gain scheme respectively.

FIGURE A2-11

The model of an omni-directional antenna for a coastal station

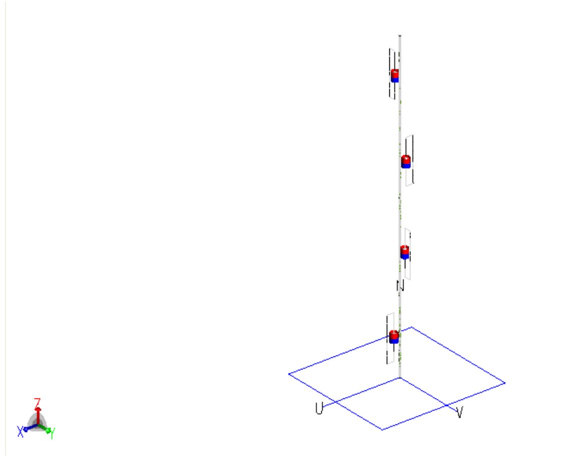


FIGURE A2-12

The gain simulating of an omni-directional antenna for a coastal station

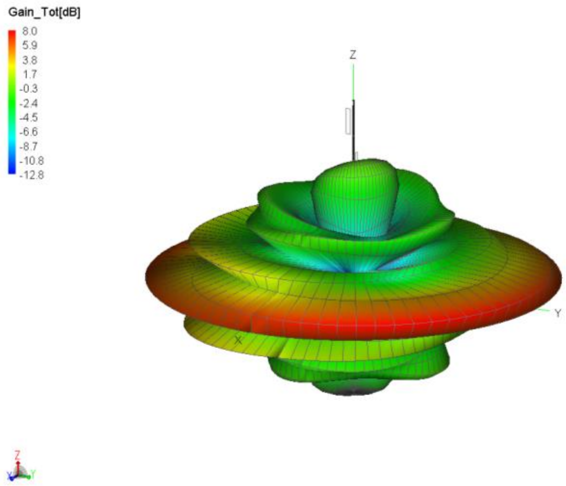


FIGURE A2-13

The horizontal gain simulating scheme

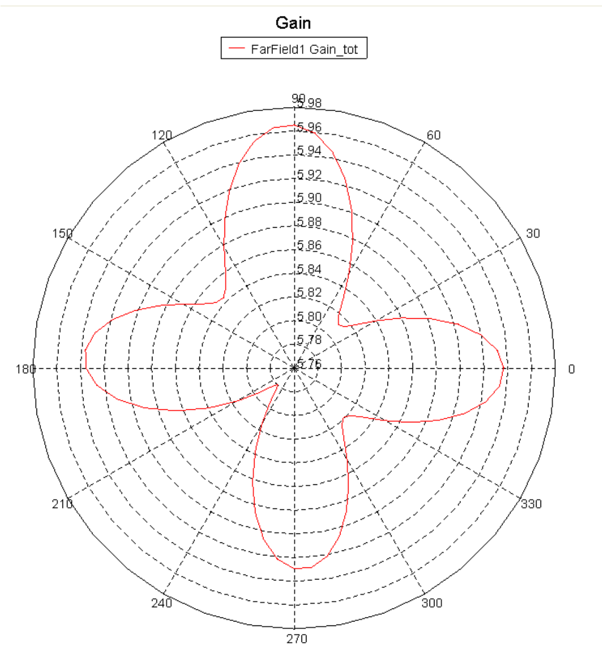


FIGURE A2-14

The vertical gain simulating scheme

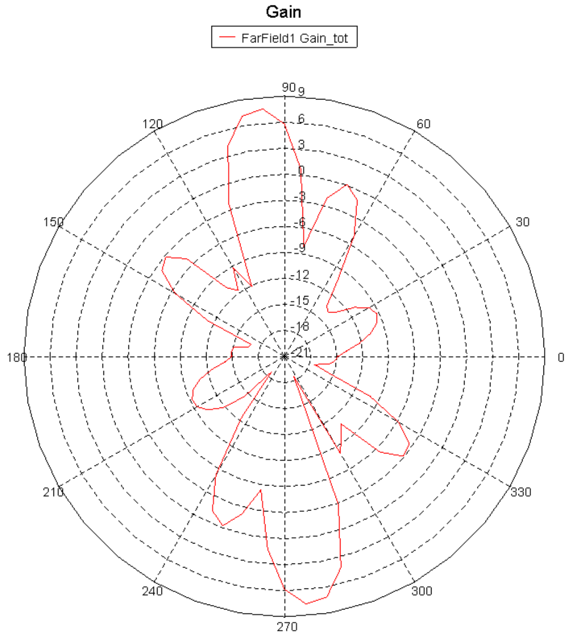


Table A2-2 gives the antenna isolation space for VHF applications.

TABLE A2-2

Radiant power (W)	Receiving sensitivity (dBm)	Interference rejection index (dB)	Isolation (dB)	Horizontal space (m)	Vertical space (m)
25	−98	100	51	79.18	5.30
	−107	100	42	28.09	3.14
50	−103	100	49	62.97	4.72
	−107	100	45	39.73	3.74

Annex 3

Study from Canada for channel plan A, B and C

The attachment is a study on impacts relating to plans A, B and C for VDE and AIS systems as well as the differences between each plan. Channel plan D was not developed when this study was completed; therefore plan D was not considered.

This study discusses options on various technologies to mitigate interference and provides scenarios on specific communications under the proposed plans A, B and C. It provides recommendations in the attempt to optimize frequency allocation for maritime communications in the VHF band.

It was determined that, for each channel plan, compromises are required in terms of, but not limited to, integration of VDES and AIS communications, antenna separation and filtering and site selection.

Study from Canada

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