

REPORT ITU-R M.2122

**EMC assessment of shore-based electronic navigation (eNAV)*
infrastructure and new draft Standards for data exchange
in the VHF maritime mobile band (156-174 MHz)**

(2007)

1 The emergence of modern shore-based eNAV infrastructure

The 1997 ITU World Radio Conference (WRC-97), by request from International Maritime Organization (IMO) (NAV 43; 1997), designated two upper legs of the duplex VHF public correspondence (VPC) channels, channels 87B and 88B, for the AIS globally. Following that frequency designation and the request for a technical standard for the AIS from IMO/NAV43, the ITU-R commenced drafting the AIS technical standard ITU-R M.1371 which also designated the Appendix 18 of the Radio Regulations (RR) channels 87B and 88B as the global ship-to-ship default channels for use on the high seas and globally unless otherwise designated by administrations within their territorial waters. The AIS designation by IMO and ITU affects the VPC, because the globally-designated AIS simplex frequencies were interleaved at the upper end of the block of duplex channels designated for the VPC. Consequentially, administrations should consider the needs of both the Marine Safety Authority (MSA) and the VPC provider to insure the safe and efficient operation of both the VPC and the AIS. An EMC (electro-magnetic compatibility) analysis should be considered to support the development of the eNAV that accounts for the technical characteristics of the radiocommunications systems that are used by the eNAV to ensure compatible operations.

The Reference Example of a 225 kHz wideband system based on the European Technical Standards Institute (ETSI) Standard in Section 3¹ requires a new channel usage plan in which digital VPC services would use a contiguous 225 kHz block of VPC channels, excluding channels 27 and 28. Channels 27 and 28 are adjacent to, and interleaved with, the AIS channels. This system poses potential compatibility issues amongst the maritime services in RR Appendix 18. A technical analysis of the prospective shore-based eNAV infrastructure is needed in order to insure the safe interoperability of the eNAV and SOLAS. This assessment should consider the need to protect all maritime systems.

2 Rationale for the EMC assessment of eNAV infrastructure**2.1 Compatibility of various eNAV infrastructure on adjacent RR Appendix 18 channels**

It is particularly important to address the possibility of interference from other maritime stations that use the channels adjacent to AIS for VPC voice radiocommunications, since this system could raise a constant CW carrier transmitter for the entire duration of the transmission. For example, VPC stations receive on the A-side of the duplex channels (e.g. channel 27A = 157.350 MHz, and

* eNAV – “E-Navigation is the harmonised creation, collection, integration, exchange and presentation of maritime information onboard and ashore by electronic means to enhance berth to berth navigation and related services, for safety and security at sea and protection of the marine environment”.

¹ The Reference Example in § 3 is based on Standard ETSI ETS300113-1v.1.5.1.

channel 28A = 157.400 MHz) and transmit on the B-side (e.g. channel 27B = 161.950 MHz, and channel 28B = 162.000 MHz), while the AIS both transmits and receives on the B-side (channel 87B = 161.975 MHz, and channel 88B = 162.025 MHz). Because of the frequency separation (± 0.025 MHz), these VPC voice shore transmitters could potentially interfere with AIS shore station receivers if they are located in close geographical proximity to each other, but the AIS transmitters have a large frequency separation (+4.625 MHz) from the VPC voice receivers and thus pose little interference threat to those stations. Additional study is required.

2.2 Compatibility of the transmitter emissions used for the eNAV

Transmitter emissions should be evaluated to assess the EMC between the shore-based eNAV:

- Voice radiocommunications,
- Data exchange, and
- AIS.

Transmitter emissions for AIS base stations are now defined by International Standard IEC 62320-1 Ed.1. The IEC also has emissions mask requirements for radio transmitters operating in RR Appendix 18, and these requirements have been considered for the AIS. Presumably, voice radiocommunications also consider the IEC emissions mask requirements, but the Reference Example for a 225 kHz wideband VHF data exchange system based on ETS300113-1v.1.5.1 does not consider the need to meet these requirements.

3 Maritime radiocommunications in Appendix 18 with the eNAV and the AIS requires EMC assessment

3.1 Channels for voice and data exchange

The interleaved adjacent channels within RR Appendix 18 present concerns to all maritime systems applications (voice, data exchange and AIS). A comprehensive EMC analysis based on the technical characteristics of the systems has not been performed within ITU-R and is required.

There may be some question whether a digital VPC application could be impaired on the ship station side by the ship-borne AIS on the internationally-designated AIS channels. No suitable off-the-shelf solution has been identified that solves this interference problem, although technology is currently available to develop a solution.

Thus, it may seem logical to conclude that VPC voice communications could be introduced on channels 27 and 28 (the VPC channels adjacent to and interleaved with AIS) in order to provide an immediate commercial application that was invulnerable to AIS and to reserve the channels farther removed from the AIS (and therefore less vulnerable to degradation from the AIS) for the new digital application. This argument may be supported by the rationale that a multi-channel bandwidth may be needed for the data exchange application that would necessitate combining contiguous VPC channels that could not include those interleaved and adjacent to the AIS. The Reference Example for a 225 kHz wideband data exchange system accommodates this rationale for multi-channel bandwidth; however, it does not clearly address the potential EMC issues to the VHF maritime mobile, including the AIS.

3.2 The impact of providing for a 225 kHz wideband VHF data system in RR Appendix 18

The Reference Example would necessarily be implemented in two parts. The first part concerns the consequential impacts on RR Appendix 18 in order to support the wideband 225 kHz VHF data system Reference Example and the second part describes the maritime application of the

ETS300113-1v.1.5.1 standard (the Reference Example) for a VHF data network. The second part describes the technical details of the digital radiocommunications system and the characteristics of the system.

A condensed summary of the wideband Reference Example follows:

- a) The consequential impact to RR Appendix 18:
RR Appendix 18 could require revision to provide more capacity to meet the increasing spectrum demand and in particular respond to the needs of data communications if the Reference Example were implemented. A possible digital maritime VHF technology to replace the existing analogue voice communications should be accepted only after completion of a full study. Such commonly acceptable technology for data is not likely to be available in the immediate future. For digital data in the VHF bands, such technology is being evaluated on an experimental basis by some administrations.
- b) Summary of technical and operational studies and relevant ITU-R Recommendations:
The diminished demand for public correspondence coast stations is apparent. The further introduction of digital radio telephony systems into this band could adopt suitably modified land mobile technology into a worldwide interoperable standard. When such radio telephony technology is available, RR Appendix 18 could consequentially be impacted be needed in the future if technologies such as the Reference Example were implemented. Concerning new digital data systems in the maritime VHF band, such technology is now available. A draft new ITU-R Recommendation will need to be prepared to support this application. This technology would introduce the use of a continuous band, i.e. up to 225 kHz bandwidth.

3.2.1 Inter-system EMC issues with the 225 kHz bandwidth VHF data exchange system

This Reference Example system has potential harmful effects on RR Appendix 18 and the other important services it supports, including the AIS which is now an IMO global carriage requirement for SOLAS vessels. Administrations are obligated to support the AIS, and many administrations are in the process of implementing AIS shore infrastructure that could prospectively be negatively impacted if the proposed wideband VHF data system is implemented with its shore infrastructure. Careful consideration should be given to technologies that can more efficiently provide this much-needed VHF data exchange that do not consequentially impact RR Appendix 18 and that have better EMC with the other existing systems.

Alternative technologies are available that could more efficiently provide a more efficient “VHF radio system and equipment for the exchange of data and e-mail on maritime RR Appendix 18 channels” without harmful interference to the VTS radiocommunications and the AIS and disruption to RR Appendix 18 and the applications it supports, including the International Convention for the Safety of Life at Sea (SOLAS).

The Reference Example would occupy a 225 kHz block of duplex spectrum (just below channels 27 and 28) by consolidating nine contiguous 25 kHz channels designated for VPC. This was to support a prospective wideband digital maritime VPC data exchange system. Concerns about this Reference Example are as follows:

- a) There is not an agreed need for a data rate as high as the proposed data rate of 133 kbit/s.
- b) Technology is available that is more spectrum-efficient that can also provide a high data rate on 25 kHz channels (e.g. ETSI TETRA-TEDS) provides up to 54 kbit/s in a 25 kHz channel bandwidth, and Radio Technical Commission for Maritime Services Special Committee 123 (RTCM SC123) is considering this for a new marine VHF digital small messaging service.
 - This would not require consolidating the 25 kHz marine VHF channels.

- This would provide 3.65 times more data throughput ($9 \times 54 \text{ kbit/s} = 486 \text{ kbit/s}$ vs. 133 kbit/s) in the same spectrum.
 - This would provide a means to simultaneously serve multiple customers rather than one at a time, which further increases the efficiency of service.
- c) The 225 kHz transmitter spectral mask for the system (see Fig. 1) is so wide that it is an interference source for the adjacent 25 kHz channels, extending as far as the AIS channels.
- d) Since some administrations do not have all of the proposed nine (9) contiguous channels available in the maritime VPC, this poses an international interoperability problem for the new system.

An alternative approach could analyse the notion of having each channel independently available for any functional use, which would not require the upper interleaved VPC channels to be the only channels designated for voice radiocommunications in order to keep the lower VPC channels available as one contiguous block for the proposed new digital service. This could allow the voice services to be implemented on any of the channels currently available in RR Appendix 18 for VPC voice service thus alleviating the pressure on channels 27 and 28 to accommodate all voice traffic.

Note also that the ETSI TETRA-TEDS 54 kbit/s^2 system would provide a generous data rate allotment for forward error correction (FEC) and interleaving to mitigate any potential co-site interference problems imposed by the ship-borne AIS and still provide a high data throughput for the data exchange system.

3.2.2 Technical assessment of the 225 kHz bandwidth Reference Example

3.2.2.1 Technical assessment by the IALA eNAV Committee

The International Association of Maritime Aids to Navigation and Lighthouse Authorities (IALA) AIS Technical Working Group of the IALA eNAV Committee considered the Reference Example system at their 15-19 January 2007 meeting and drafted a liaison paper based on their expert assessment of this for submittal to ITU-R. IALA requested that ITU-R consider the potential impact on the systems operating in RR Appendix 18, especially the AIS.

3.2.2.2 Detailed technical analysis of the effects of the Reference Example on RR Appendix 18

3.2.2.2.1 The consequential impact of the Reference Example on RR Appendix 18

The consequential impact of the Reference Example on RR Appendix 18 is shown in Tables 1a) and 1b). Note that this calls for the consolidation of the 9 duplex (shore-ship) channels in the Upper Part (Table 1b)) designated for VHF Public Correspondence with footnote o), channels 23-26 and 82-86, into one 225 kHz wideband duplex (shore-ship) channel. Note also that the remaining VPC channels, including the adjacent channels to the AIS, channels 27 and 28, are proposed to be designated for VPC voice radiocommunications.

² ETSI – European Technical Standards Institute

TETRA – Terrestrial Trunked Radio

TEDS – TETRA Enhanced Data Service

TABLE 1

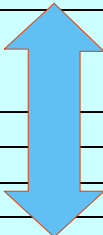
Consequential Impact of the Reference Example on RR Appendix 18

a) Lower part of RR Appendix 18

Channel designator	Notes	Transmitting frequencies (MHz)		Intership	Port operations and ship movement		Public correspondence
		Ship stations	Coast stations		Single frequency	Two frequency	
60	<i>m), o)</i>	156.025	160.625			x	x
01	<i>m), o)</i>	156.050	160.650			x	x
61	<i>m), o)</i>	156.075	160.675		x	x	x
02	<i>m), o)</i>	156.100	160.700		x	x	x
62	<i>m), o)</i>	156.125	160.725		x	x	x
03	<i>m), o)</i>	156.150	160.750		x	x	x
63	<i>m), o)</i>	156.175	160.775		x	x	x
04	<i>m), o)</i>	156.200	160.800		x	x	x
64	<i>m), o)</i>	156.225	160.825		x	x	x
05	<i>m), o)</i>	156.250	160.850		x	x	x
65	<i>m), o)</i>	156.275	160.875		x	x	x
06	<i>f)</i>	156.300	160.900	x			
66	<i>m), o)</i>	156.325	160.925				x
07	<i>m), o)</i>	156.350	160.950				x
67	<i>h)</i>	156.375	156.375	x	x	x	
08		156.400		x			
68		156.425	156.425		x	x	
09	<i>i)</i>	156.450	156.450	x	x	x	
69		156.475	156.475	x	x	x	
10	<i>h)</i>	156.500	156.500	x	x	x	
70	<i>j)</i>	156.525	156.525	Digital selective calling for distress, safety and calling			
11		156.550	156.550		x	x	
71		156.575	156.575		x	x	
12		156.600	156.600		x	x	
72	<i>i)</i>	156.625		x			
13	<i>k)</i>	156.650	156.650	x	x	x	
73	<i>h), i)</i>	156.675	156.675	x	x	x	
14		156.700	156.700		x	x	
74		156.725	156.725		x	x	
15	<i>g)</i>	156.750	156.750	x	x	x	
75	<i>n)</i>	156.775			x	x	

TABLE 1 (end)

b) Upper part of RR Appendix 18

Channel designator	Notes	Transmitting frequencies (MHz)		Intership	Port operations and ship movement		Public correspondence
		Ship stations	Coast stations		Single frequency	Two frequency	
16		156.800	156.800	DISTRESS, SAFETY AND CALLING			
76	n)	156.825			x		
17	g)	156.850	156.850	x	x		
77		156.875		x			
18	m)	156.900	161.500		x	x	x
78	m)	156.925	161.525			x	x
19	m)	156.950	161.550			x	x
79	m)	156.975	161.575			x	x
20	m)	157.000	161.600			x	x
80	m)	157.025	161.625			x	x
21	m)	157.050	161.650			x	x
81	m)	157.075	161.675			x	x
22	m)	157.100	161.700		x	x	x
82	m), o)	157.125	161.725		x	x	x
23	m), o)	157.150	161.750		x	x	x
83	m), o)	157.175	161.775		x	x	x
24	m), o)	157.200	161.800		x	x	x
84	m), o)	157.225	161.825		x	x	x
25	m), o)	157.250	161.850		x	x	x
85	m), o)	157.275	161.875		x	x	x
26	m), o)	157.300	161.900		x	x	x
86	m), o)	157.325	161.925		x	x	x
27		157.350	161.950			x	x
87		157.375			x		
28		157.400	162.000			x	x
88		157.425			x		
AIS 1	l)	161.975	161.975				
AIS 2	l)	162.025	162.025				

	Public correspondence (Voice)
	VHF Data
	Ship to ship communication
	VTS, harbor and pilots
	AIS

An EMC analysis is needed to assess the impact of the Reference Example on the other applications provided by RR Appendix 18. The impact assessment should include:

- The characteristics of the wideband transmitter; and
- EMC analysis of the effects of the designation of channels 27 and 28 for VPC voice radiocommunications.

3.2.2.2.2 Analysis of the transmitter characteristics (based on ETSI Standard ETS300113)

Types of radios

The system operates in full duplex mode where bursts of data are transmitted over the RF channel. All data radios used are required to be capable of full-duplex operation.

Though base and mobile data radios are used in the system, the RF performance of both types shall meet the same requirements. For the purpose of this document only one wideband data radio type is assumed. Whenever a referred standard defines different parameter limits for different radio types, the limit value pertinent to base stations shall be applied.

Channel spacing

The wideband system is assumed to operate in a pair of 225 kHz channels created by joining 9 standard 25 kHz channel. The duplex spacing is assumed to be 4.6 MHz.

Emission designator

200KF1DAN

Modulation symbol rate

The modulation symbol rate shall be 133 000 symbols/s, which corresponds to raw data bit-rate of 133 kbit/s.

Test conditions, power sources and ambient temperatures

For definition of normal and extreme test conditions and for requirements on the test power sources see ETS300113-1 v.1.5.1 clause 6.

Transmitter frequency error

The frequency error of the transmitter is the difference between the measured carrier frequency in the absence of modulation (or with modulation, provided that the presence of modulation allows sufficiently accurate measurement of the carrier frequency) and the nominal frequency of the transmitter.

The transmitter frequency error shall not exceed 3 kHz under any combination of allowable operating conditions. For method of measurement see ETS300113-1 v 1.5.1., clause 8.1.2.

Transmitter carrier power

The transmitter carrier power is the mean power delivered to the artificial antenna during a radio frequency cycle.

The rated output power is the carrier power (conducted) of the equipment declared by the manufacturer.

The transmitter carrier power shall stay within +2.0 dB and –3.0 dB from the rated power under any combination of allowable operating conditions. For method of measurement see ETS300113-1 v 1.5.1., clause 8.2.2.1.

Transmitter spectral mask based on the 225 kHz data channel (refer to Fig. 1)

The emissions spectrum for the 225 kHz wideband data channel is measured by a spectrum analyser using 10 kHz read bandwidth, the zero reference level equals to the unmodulated carrier power.

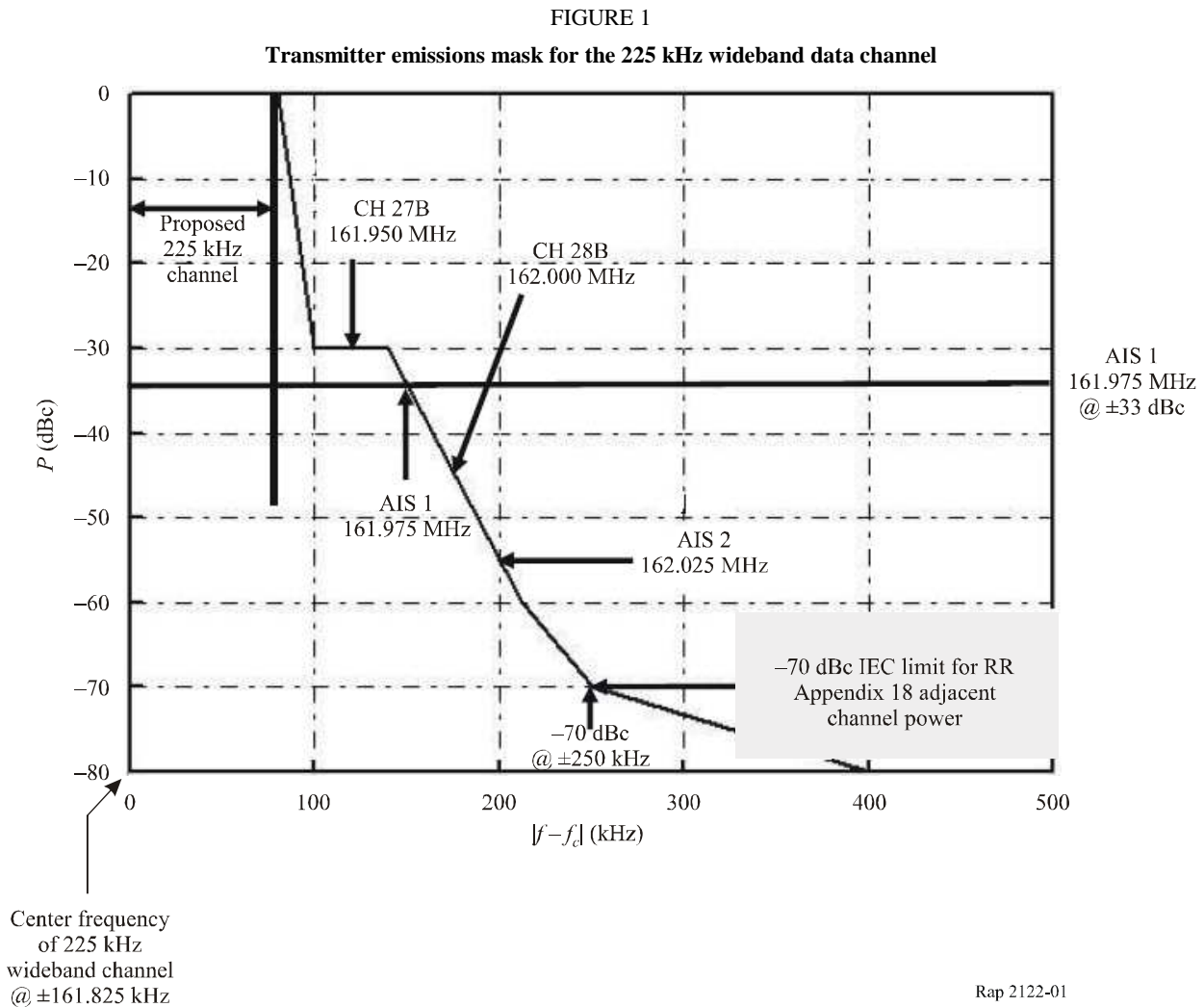
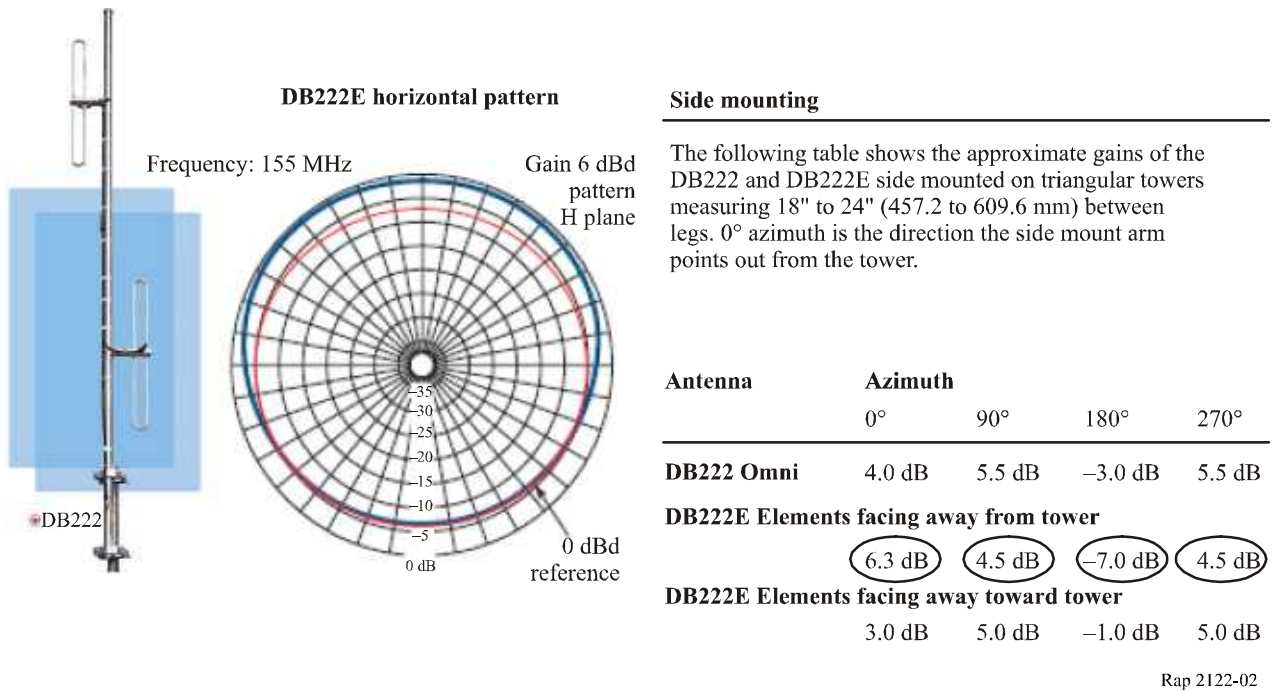


Figure 1 shows that the transmitter spectral emissions mask for the 225 kHz wideband data channel is not compatible with the 25 kHz channel structure of RR Appendix 18 in that it does not meet the adjacent channel power limit of $-70 \text{ dBc} \pm 25 \text{ kHz}$ specified by International Electrotechnical Commission (IEC) until $\pm 250 \text{ kHz}$ offset from the carrier. Thus the proposed 225 kHz data channel will adversely restrict the other essential eNAV communications and safety systems operating in RR Appendix 18, including the AIS.

3.2.2.2.3 Example EMC analysis of channels 27 and 28 for VPC voice radiocommunications

The following EMC example is based on an AIS receiver sensitivity of -107 dBm (optionally, -115 dBm), VPC transmitter emissions with an ACPR (adjacent channel power ratio) = 70 dB (in accordance with IEC 62320-1 Ed.1, the AIS base station standard) and an assumed base station antenna selection (the DB 222E, a popular typical marine VHF base station antenna shown in Fig. 2 for both the AIS and the VPC). The distance separation (D) between the two shore stations (the VPC voice station and the AIS station) is derived based on free-space propagation between the stations, assuming that the antennas are situated on high-sites. For lower antenna elevations, propagation models such as ITU-R P.525 can be used to more accurately assess the separation distance.

FIGURE 2
VHF marine base station antenna



$$20 \log D = P_t - P_s - 36.6 - 20 \log F - ACPR + 10 \log N + NA + CCRR + Gr - L + G_t$$

where:

- D : distance separation between AIS and VPC voice stations in land (statute) miles
- P_t : VPC transmitter carrier power (50 W at antenna base) = +47 dBm
- P_s : AIS minimum receiver sensitivity specification level (for a 20% PER) = -107 dBm
- $20 \log F$: 44.18 dB, where F = frequency (MHz) = 161.975 MHz (AIS1)
- $ACPR$: adjacent channel power ratio of VPC transmitters, channels 27 and 28 = 70 dB
- $10 \log N$: $10 \log 2$ (N : number of VPC adjacent channels = 2 for AIS1) = 3 dB
- NA : noise level allowance = 3 dB
- $CCRR$: AIS receiver co-channel rejection ratio = 10 dB
- Gr : gain of the AIS base station antenna in the VPC direction (at broadside) = 6.5 dBi
- L : total loss of feed-line, connectors, lightning arrestors and filters = 4 dB, and
- G_t : gain of the VPC antenna in the AIS direction (at broadside) = 6.5 dBi.

Thus, for $P_s = -107$ dBm:

$$20 \log D = 47 - (-107) - 36.6 - 44.18 - 70 + 3 + 3 + 10 + 6.5 - 4 + 6.5 = 28.22 \text{ dB}$$

$$D = 10^{(28.22/20)} = 25.8 \text{ miles}$$

This example shows that installation of two base stations on shore with adjacent 25 kHz RR Appendix 18 channels should have a geographical separation of greater than 25.8 miles. If the Reference Example is implemented, AIS shore stations should be separated from the proposed voice VPC base stations by a greater distance than this, especially if the AIS receiver has better

sensitivity than the IEC standard minimum value. As a result of site/scenario specific considerations, it is not practical to identify a generic separation distance which would be appropriate for any sharing situation. Separation distances should be analysed on a case-by-case basis. Separation distances may be reduced by taking into account additional factors of the specific sharing situation being considered or applying mitigation techniques.

Typically, AIS base stations are capable of receiver sensitivity of -115 dBm or better.

If this receiver sensitivity value is used and needed to be protected, the required distance separation is raised. Note that this may actually be beyond the free-space propagation range, depending on antenna height, but the distance is still very large.

Then, for $P_s = -115$ dBm:

$$20 \log D = 47 - (-115) - 36.6 - 44.18 - 70 + 3 + 3 + 10 + 6.5 - 4 + 6.5 = 36.22 \text{ dB}$$

$$D = 10^{(36.22/20)} = \mathbf{64.7 \text{ miles}}$$

TABLE 2

**Distance between AIS base stations and VPC stations
on adjacent 25 kHz channels**

AIS base station receiver sensitivity	VPC voice channels	Distance to AIS base station
-107 dBm	27 & 28	25.8 miles
-115 dBm	27 & 28	64.7 miles

VPC voice radiocommunications on the lower VPC channels far below the AIS channels, and where cavity filters were used to reduce the transmitter noise floor, would reduce this sharing problem. The advantage of the alternate method shown below is that it allows the individual channels to be used separately and thus the VPC voice radiocommunications could be implemented on any VPC channel(s) available within the administrations' designations and not solely aggregated on channels 27 and 28.

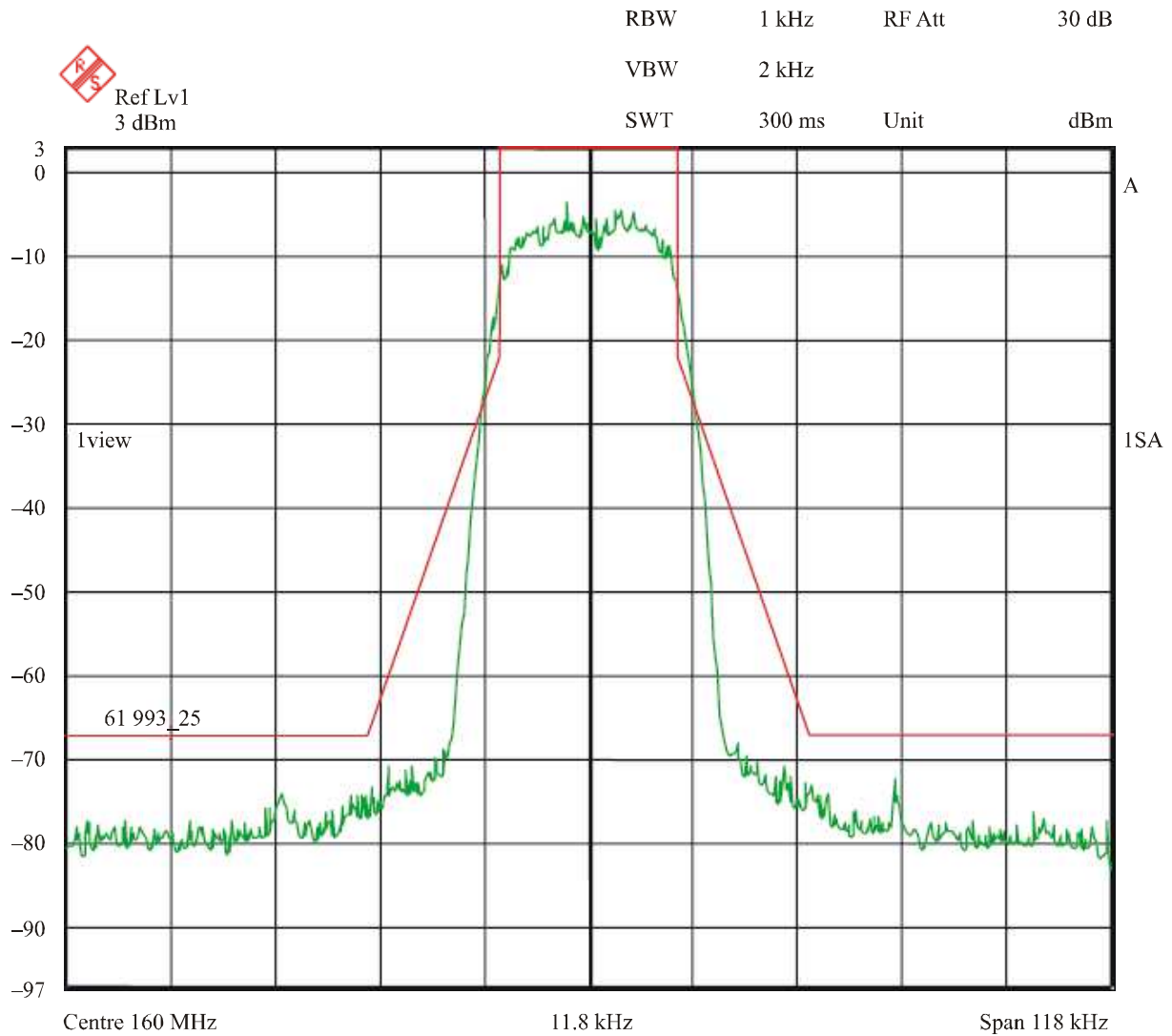
4 An alternative method for data transmission based on the ETSI TETRA Standard

ETSI has implemented a standard for radio data transmission for the Trans-European Trunked Radio Association (TETRA) in the land mobile radio on 25 kHz channels. The standard includes two modulation types for use on 25 kHz channels, $\pi/4$ DQPSK at 36 kbit/s and $\pi/8$ D8-PSK at 54 kbit/s. The higher data rate (54 kbit/s) standard is the most recent one, and it is used for TEDS (TETRA Enhanced Data Service). This is proven technology, and both base station and mobile equipment is currently in widespread use. RTCM (the Radio Technical Commission for Maritime Services) has formed a Special Committee (RTCM SC 123) to assess this and other technologies for use in the VHF marine band (RR Appendix 18) for a prospective new VSMS (VHF small messaging service). Figures 3 to 5 illustrate RTCM SC 123 test results of the TETRA-TEDS transmission methods.

Figure 3 presents the spectra for TETRA modulation at the normal 36/54 kbit/s data rates, along with the IEC mask for RR Appendix 18. It is apparent that these data rates slightly fail to meet the mask limit of -25 dBc at ± 10 kHz offset from the carrier.

FIGURE 3
Transmitter emissions mask

RTCM SC123 test results: TETRA modulation at 36/54 kbit/s



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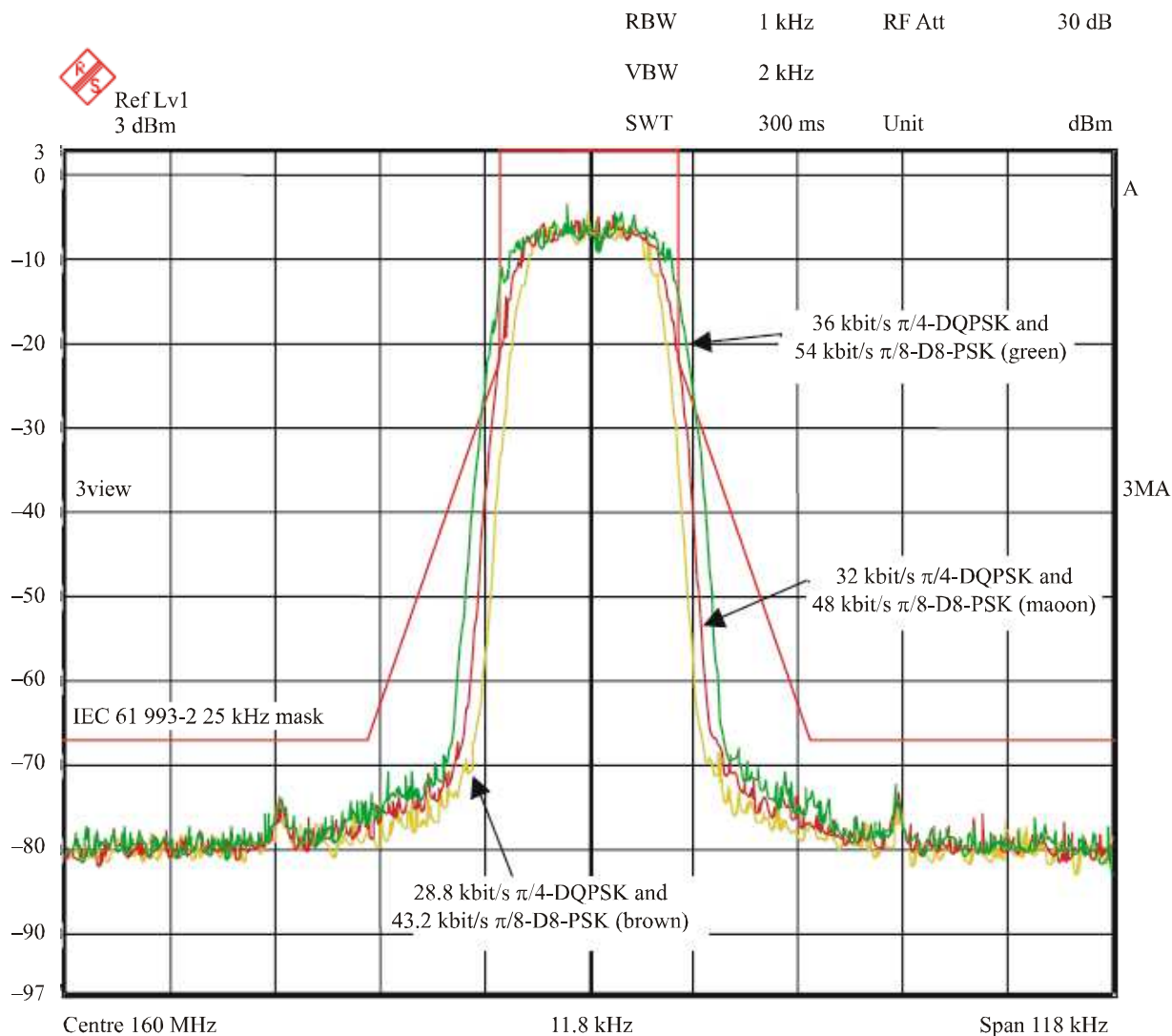
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Somewhat lower data rates (32/48.8 kbit/s and 28.8/43.2 kbit/s) were then tested. Figure 4 overlays these test results with those of Fig. 3. It is evident that both 28.8 kbit/s $\pi/4$ -DQPSK modulation and 43.2 kbit/s $\pi/8$ -D8-PSK modulation comfortably fit the IEC mask for RR Appendix 18.

FIGURE 4

Transmitter emissions mask

RTCM test results: Slightly reduced data rates to fit IEC emissions mask

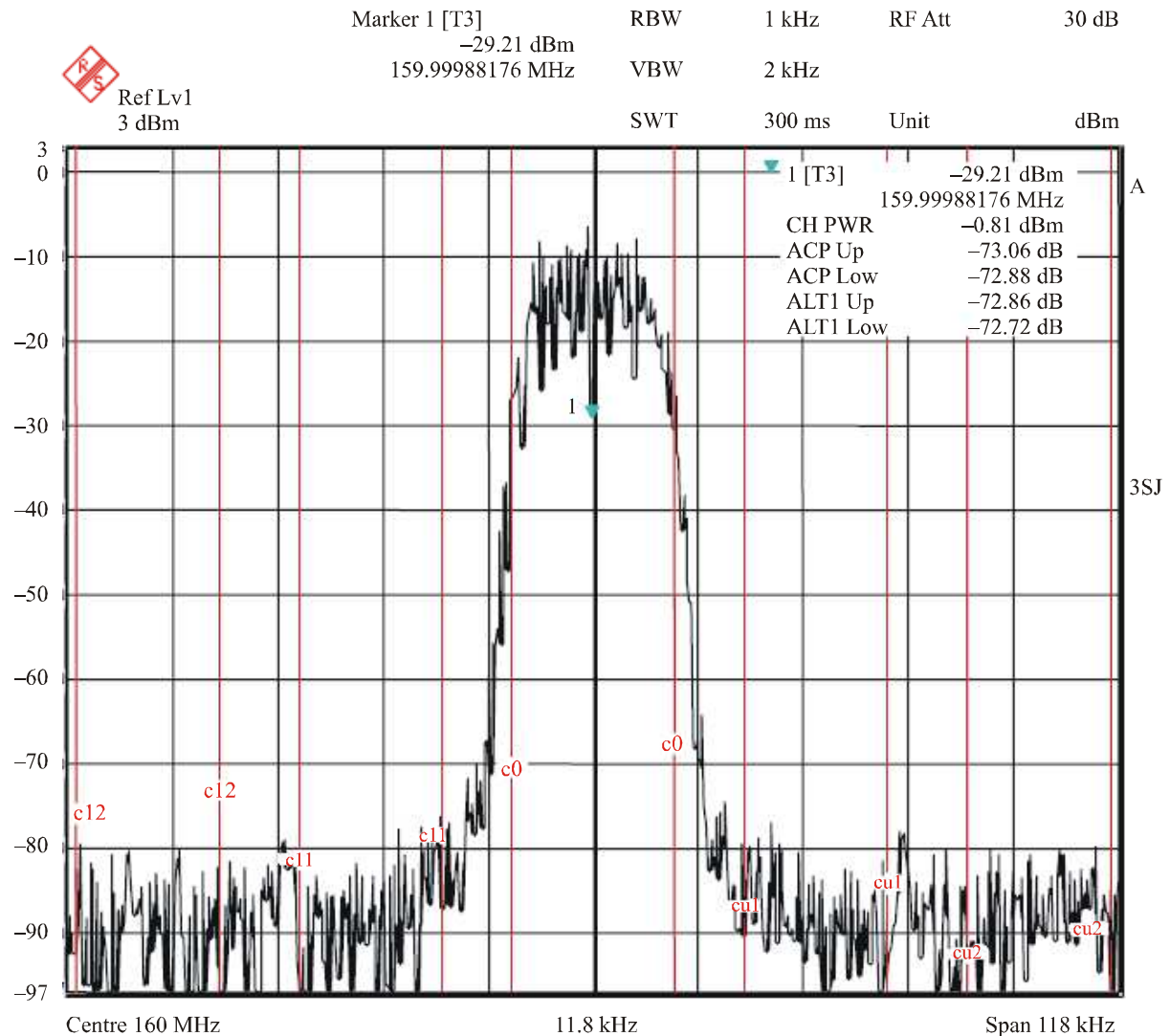


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Another important consideration in addition to the transmitter emissions mask is the adjacent channel power. This determines the net amount of power received by separate systems on adjacent 25 kHz channels. The adjacent channel power (a.k.a. adjacent channel power ratio, ACPR) was measured for the 28.8 kbit/s $\pi/4$ -DQPSK and 43.2 kbit/s $\pi/8$ -D8PSK modulations using the ETSI EN 300 113 16 kHz bandwidth criterion. The results are shown in Fig. 5, which indicates compliance with the IEC maritime requirement of -70 dB ACPR for operation in RR Appendix 18.

FIGURE 5

Adjacent channel power ratio (ACPR) performance**RTCM test results: 28.8 kbit/s $\pi/4$ -DQPSK and 43.2 kbit/s $\pi/8$ -D8-PSK modulation**

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The conclusions of RTCM SC123 are:

- ETSI TETRA modulations at 28.8 kbit/s $\pi/4$ -DQPSK and 43.2 kbit/s $\pi/8$ -D8-PSK are efficient methods for transmitting data in the marine VHF band, and
- These methods are compatible with the 25 kHz channels in RR Appendix 18.

5 Comparison of the two ETSI Standards (ETS300113 and TETRA-TEDS)

The two ETSI Standards (the ETS300113-based Reference Example and the TETRA-TEDS example by RTCM SC123) are compared for their suitability for the VHF Data Exchange System operating in RR Appendix 18.

5.1 Impact on ITU RR Appendix 18

The Reference Example would consolidate 9 contiguous RR Appendix 18 duplex channels of 25 kHz each, specifically the channels 82, 23, 83, 24, 84, 25, 85, 26 and 86. Furthermore, it would designate channels 27 and 28 for VPC voice radiocommunications.

Alternatively, the approach by RTCM SC 123 preserves the 25 kHz channel structure of RR Appendix 18 by using the IEC emissions mask to allow the channels to be used separately (independently) by administrations.

5.2 Spectrum efficiency (bits/s/Hz of bandwidth)

The ETSI Standard ETS300113-1v.1.5.1 Reference Example achieves 133 kbit/s in a 225 kHz channel (a combination of 9 contiguous duplex channels of 25 kHz each, specifically the RR Appendix 18 channels 82, 23, 83, 24, 84, 25, 85, 26 and 86).

Alternatively, the test results shown in Fig. 2 above where the ETSI standard for TETRA is slightly reduced to fit for RR Appendix 18 achieves 43.2 kbit/s in a single 25 kHz channel without consolidating multiple channels. The performance advantage (spectral efficiency) of the TETRA-TEDS method is $43.2/25 = 1.73$ vs. $133/225 = 0.59$ or $1.73/0.59 = 2.93$, a factor of almost 3:1.

5.3 EMC (electromagnetic compatibility)

The ETSI Standard ETS300113-1v.1.5.1 Reference Example violates the IEC adjacent channel power limit of -70 dBc for the adjacent ± 5 RR Appendix 18 channels, which compromises the performance and usefulness of these channels, including the AIS channels AIS 1 and AIS 2. The problem for the AIS is of global impact due to its use for maritime safety.

Alternatively, the test results shown in Fig. 2 above indicate that the IEC adjacent channel power limit of -70 dBc is met with a data rate as high as 43.2 kbit/s on a 25 kHz channel. This, along with the IEC requirement for 70 dB adjacent channel rejection ratio for receivers operating in RR Appendix 18, insures EMC between the channels. Thus, the ETSI TETRA method is demonstrated to be compatible with all existing systems in RR Appendix 18, voice, data and AIS.

5.4 Service effectiveness

International standards enhance safety, global interoperability, and maritime operational efficiency. Administrations vary in their use of RR Appendix 18 channels, e.g. at least one administration has assigned some of these channels to the land mobile radio. Any proposed new standard for VHF data exchange should consider that using the channels one at a time is preferred because it allows flexibility amongst the various administrations. There is also a practical advantage to keeping the channels separated in that multiple users can access the services simultaneously on different channels rather than having to be multiplexed into one consolidated channel.

5.5 EMC of the VPC with the AIS

Traditionally, assignment of channels in the land mobile radio considers that geographical separation is needed between uses of the same channel (channel reuse) and also the adjacent channel. This is because base stations are situated on high elevations to achieve coverage of the service area. For shore-based VHF marine radio, specifically the VPC, this tradition has been followed. There has always been avoidance of the use of adjacent VPC channels in the same area because of the potential for interference between the base stations.

The Reference Example designates VPC voice services to channels 27 and 28 which are interleaved and adjacent to AIS 1 and AIS 2. This could raise potential issues with respect to the AIS, when VPC base stations operate in close proximity to AIS base stations. Additional studies are needed.

5.6 Summary and conclusion concerning the Reference Example and alternatives

The Reference Example has potential harmful effects on RR Appendix 18 and the other important applications it supports, including VTS radiocommunications and the AIS which is now a global mandate for SOLAS. Administrations are obligated to support the AIS in the context of SOLAS Convention agreements. Administrations are in the process of implementing AIS shore infrastructure that could prospectively be negatively impacted if the proposed wideband VHF data system is implemented with its shore infrastructure.

This report provides an electromagnetic compatibility (EMC) analysis of the harmful effects of the prospective Reference Example. It also provides an example of an alternative technology that provides more efficient data exchange. The alternative technology does not consequentially impact RR Appendix 18 since it can be tailored to fit the emissions mask for the 25 kHz channels. Thus it does not pose incompatibility with the other services that also use the RR Appendix 18 channels.

6 EMC assessment of the eNAV and advanced technologies

In developing an “eNAV systems and technologies assessment,” administrations should consider information such as that shown below describing the base station locations:

- Antenna tower address, latitude and longitude
- Antenna height above ground and above sea level
- Antenna make and model
- Antenna gain, radiation pattern and EIRP
- Antenna orientation
- Transmitter characteristics (applicable standards)
- Transmitter make and model
- Transmitter output power
- Transmitter emissions spectrum
- Any equipment/operations to limit interference

This information should be processed (in an EMC analysis similar to that provided in this report) to determine if the EMC scenario is likely to cause interference. If there is a probability of interference, then recommendations should be made (based on the EMC analysis) on how to minimize/alleviate the interference.

6.1 EMC assessment of site-based eNAV infrastructure

The following example illustrates EMC assessment of site-based licensees with coverage area contours. It also states the signal level received by a mobile station (in this case a shipboard receiver) in the service area contour. Following this convention, geographically adjacent VPC stations (with only enough coverage overlap to insure continuous coverage) have customarily been licensed with frequencies that were at least ± 50 kHz but preferably even ± 100 kHz removed from each other. VPC channels in the series 24, 25, 26, 27 and 28 (alternatively, channels in the series 84, 85, 86 and 87) were assigned in even numbers or odd numbers at a site or at closely-spaced adjacent sites to provide this spacing between channels in order to minimize the potential for co-site or adjacent-site interference. This reference example has the value of relating the received signal

strength in a receiver, e.g. a ship-borne AIS receiver or an AIS base station receiver, to the radiated field strength emanating from a transmitting station, e.g. an AIS base station or a VPC station operating on the frequencies adjacent to the designated AIS frequencies. When data is unavailable from the VPC, this example can be used with field strength measurements that can be made to form the basis of an EMC analysis.

Signal strength at the service area contour:

- a) The requirements for reception by a marine VHF shipboard receiver are satisfied if the field strength from the coast station is at least +17 dBu above one microvolt.
- b) These field strengths, voltages and powers at the receiver input are equivalent:
 - (1) -132 dBW (decibels referred to 1 W).
 - (2) 1.8 μ V across 50 Ω .
 - (3) +17 dBu (decibels referred to 1 μ V/m).
 - (4) 7 μ V/m.

Rx power to a ship's receiver in the coverage area:

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

where:

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

E : field strength = 7×10^{-6} V/m (7 μ V/m = +17 dBu)

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

f : lowest marine VHF frequency = 156×10^6 (156 MHz)

λ = 1.923 m (at 156 MHz)

$Pr = 62.732 \times 10^{-15}$ W = -132 dBW = -102 dBm

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

Pr (dBm) = $42.8 - 20 \log F + 20 \log E + G$

where:

G : antenna gain (dBi) = 2.1 dBi

F : frequency (MHz) = 156

Pr (dBm) = $42.8 - 43.8 - 103.1 + 2.1 = -102$ dBm

6.2 EMC assessment of area-based eNAV infrastructure

Assessment of eNAV infrastructure should also consider that the VPC and/or the AIS may have administration-wide authorization. In that case, the EMC assessment should consider the different technical characteristics of the two systems, e.g. simplex packet data operation (as in the AIS service) vs. duplex FM-CW voice operation (as in the VPC voice radiotelephony services). Technical details of the radio systems should include receiver sensitivity, adjacent channel power ratio, adjacent channel rejection ratio, co-channel rejection ratio, any data packet error correcting scheme (e.g. interleaving/FEC) and the coverage requirements of the VPC and AIS base stations.

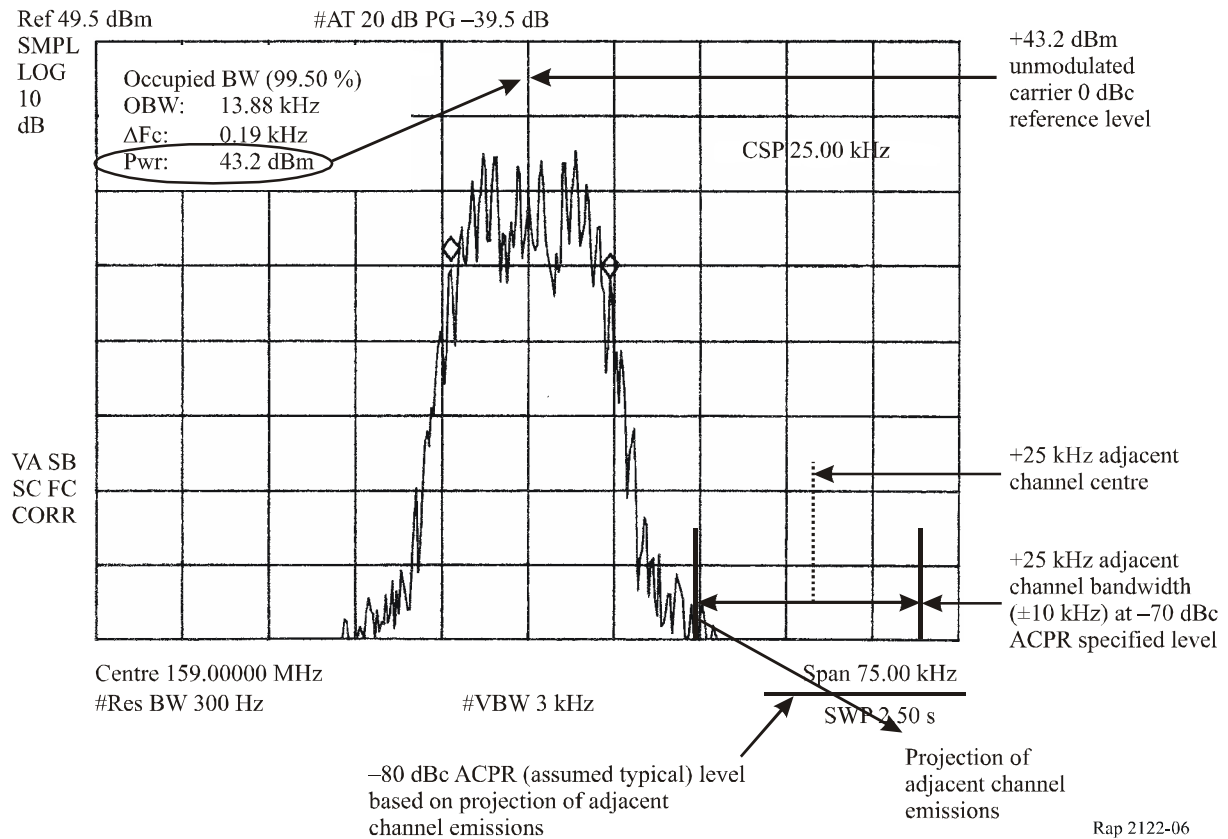
6.3 Assessing technical advances in AIS receiver sensitivity and VPC transmitter emissions

Manufacturers have developed super-sensitive AIS receivers that are being evaluated by administrations at selected locations. This initiative was to determine whether AIS base stations may have extended over-the-horizon (100-200 miles) detection capability if technology were developed to significantly improve receiver sensitivity beyond the minimum level specified by the internationally-adopted AIS standard. Although the results of this work have not yet been officially published, an AIS base station receiver was developed that has receiver sensitivity on the default AIS channels of -121 dBm (based on a 20% packet error rate) and a detection range of over 150 miles on several receiving sites. This receiver sensitivity places an extraordinary burden on the eNAV Services because it requires the adjacent channel power emissions from the VPC operations on the adjacent channels to the AIS to be extremely low. Fortunately, advances in transmitter technology, e.g. DSP-based Cartesian vector feedback, provide significantly improved VPC transmitter emissions such as that shown in Fig. 6.

FIGURE 6

Example of a VPC transmitter emissions spectrum from a DSP-based Cartesian vector feedback system

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This is a good example showing the need for an **eNAV infrastructure EMC assessment** because these assessments are customarily designed around coverage areas with defined coverage contours where base station transmitter signal field strength levels are significantly above the receiver sensitivity thresholds of the mobile receiving equipment. For this technical assessment, all of the technical characteristics of the VPC transmitters and the VPC sites along with the receivers and the sites must be considered to achieve acceptable EMC levels.

6.4 EMC analysis of technically advanced AIS and VPC systems

Administrations have acquired AIS receivers with a receiver sensitivity performance of up to -121 dBm. These receivers have adjacent channel rejection ratio of 70 dB and intermodulation rejection ratio of 74 dB as specified in the IEC AIS Base Station standard and the IEC AIS Class A standard. Although site designs often include a triple-cavity filter for protection from the land-mobile radio services, the selectivity of this filter is insufficient to improve the adjacent channel rejection ratio beyond the IEC specified level.

A typical AIS base station antenna is the DB222E previously shown in Fig. 5 which has 6.3 dBd (8.3 dBi) gain in the forward direction (at 0°, toward the sea) and 4.5 dBd (6.5 dBi) to the sides (at 90° and 270°, presumably in the general directions of VPC base stations).

The following EMC analysis example considers using the best available AIS base station receiver sensitivity, the best available VPC transmitter technology, and the optimization of the antenna placement to provide maximum inter-system isolation. Free-space distance calculations are used,

but computer propagation model simulations, e.g. ITU-R P.525 and NTIA ITM³, can be applied to further refine these calculations and to adjust to irregular terrain. The AIS receiver has a sensitivity of -121 dBm and co-channel rejection ratio of 10 dB. In the co-channel performance test, a 3 dB allowance for noise is made such that the interfering co-channel signal and the noise are assumed to be at equal levels. Thus, to insure the AIS sensitivity of -121 dBm, the maximum tolerable co-channel interference from the VPC transmitter adjacent channel power is $(-121 \text{ dBm}) - 3 \text{ dB} - 10 \text{ dB} = -134 \text{ dBm}$. The AIS receiver adjacent channel rejection ratio (ACRR) is 70 dB, and this is referenced to a PER (packet error rate) of 20% which is the PER specified for receiver sensitivity. If we take the same 3 dB allowance for noise in this case, then the maximum allowable VPC transmitter power (on the VPC adjacent channel frequency) received by the AIS site is $(-121 \text{ dBm}) - 3 \text{ dB} + 70 \text{ dB} = -54 \text{ dBm}$. Note that these levels are 80 dB apart and that these are two separate candidate contributors to the degradation of AIS sensitivity performance. If both ACPR and ACRR were at the 70 dB specification thresholds set by the IEC standards, then the predominant contributor of these two independent contributions would be the ACPR of the VPC transmitter. However, if the ACPR of the VPC transmitter were 80 dB (referring to Fig. 6), then the two contributions would be equal and the EMC analysis could be made based on either parameter (ACPR or ACRR) with an additional 3 dB allowance for the other parameter. For example, the ACRR case analysis which indicates a maximum level of -54 dBm would be decreased to -57 dBm to account for both of these effects.

An EMC analysis (in free space) based on the AIS receiver sensitivity of -121 dBm, VPC transmitter selected with ACPR = 80 dB and the DB222E AIS base station antenna is as follows:

$$20 \log D = P_t - P_s - 36.6 - 20 \log F - ACPR + 10 \log N + NA + CCRR + Gr - L + Gt$$

where:

- D : distance separation between AIS and VPC stations in land (statute) miles
- P_t : VPC transmitter carrier power (50 W at antenna base) = +47 dBm
- P_s : AIS minimum receiver sensitivity specification (for a 20% PER) = -121 dBm
- $20 \log F$ = 44.18 dB, where F : Frequency (MHz) = 161.975 MHz (AIS1)
- $ACPR$: adjacent channel power ratio of the VPC transmitter = 80 dB
- $10 \log N$ = $10 \log 2$ (N = number of VPC adjacent channels = 2 for AIS1) = 3 dB
- NA : noise level allowance = 3 dB
- $CCRR$: AIS receiver co-channel rejection ratio = 10 dB
- Gr : gain of the AIS antenna in the VPC direction (broadside) = 6.5 dBi
- L : loss of AIS feed-line, connectors, lightning arrestor and filters = 4 dB, and
- Gt : gain of the VPC antenna in the AIS direction (at broadside) = 7 dBi.

Thus, for **ACPR = 80 dB**:

$$20 \log D = 47 - (-121) - 36.6 - 44.18 - 80 + 3 + 3 + 10 + 6.5 - 4 + 7 = 32.72 \text{ dB}$$

$$D = 10^{(32.72/20)} = \mathbf{43.3 \text{ miles}}$$

Further consideration of the two sites (VPC and AIS) by **reorientating the AIS antenna** on a side of its tower facing away from the direction of the VPC tower may possibly reduce the antenna gain in the adverse direction by as much as 11.5 dB (refer to Fig. 2, “Side Mounting” details). This is *precarious* and may be considered *only as a last resort* and only when only one VPC site is close to

³ Refer to § 6.5 for an example of how these two models (ITU-R P.525 and NTIA ITM) are used to further refine the EMC analysis.

the AIS site because the necessary distance separation to another VPC site could be consequentially increased. In this case, the distance separation may possibly be reduced to:

$$20 \log D = 32.72 \text{ dB} - 11.5 \text{ dB} = 20.22 \text{ dB}$$

$$D = 10^{(20.22/20)} = \mathbf{11.5 \text{ miles}^4}$$

NOTES OF CAUTION (this illustrative example makes some assumptions that are not applicable in the general case based on the approved minimum standards):

- a) This EMC analysis assumes that the ACPR of the VPC transmitter is equal to or better than 80 dB (from test data) which is not the general case, when ACPR is specified at only 70 dB.
- b) A standard convention in VHF FM radio broadcasting is to reduce ACPR emissions by controlling the modulation, i.e. automatically adjusting the “loudness” with ALC (automatic level control). In the VPC service, the peak FM deviation should be controlled to a maximum of ± 3 kHz peak deviation. This technique has a point of diminishing returns when the VPC transmitter emissions level reaches its minimum based on the noise sidebands of the transmitter’s fundamental RF oscillator.
- c) Reducing the ACPR beyond 80 dB can potentially yield a maximum improvement of only about 3 dB (a distance reduction of about 30%). Further ACPR reduction beyond about 85 dB will not significantly reduce the minimum safe distance because the ACRR (70 dB) of the AIS receiver will become the predominant factor.

6.5 Computer propagation models could be used to enhance EMC analysis

Propagation models have been used to improve the accuracy of this EMC analysis. The following example demonstrates the use of the two computer propagation models referenced in § 6.4 (ITU-R P.525 and NTIA ITM). Section 6.5.1 provides the baseline parameters and the calculation of minimum safe distance based on free-space propagation, and § 6.5.2 provides the enhanced results based on the two propagation models.

6.5.1 Estimates for distance separation (free-space propagation)

The effects on the AIS base station receivers using AIS1 and AIS2 from the adjacent channel power EIRP from the VPC operations are as follows:

For AIS1, the VPC signal appears as two adjacent channel signals (one on each side, lower and upper) with sidebands that are co-channel at -70 dBc each (-67 dBc total with respect to each adjacent channel). For AIS2, only one VPC signal appears at -70 dBc (on the lower side).

The AIS receiver co-channel signal rejection ratio specified by IEC 62320-1 Ed.1, the International Standard for AIS base stations, is -10 dB for a 20%PER. The AIS receiver sensitivity specified by IEC 62320-1 Ed.1 is -107 dBm. Thus, for an AIS base station to meet its specified performance on both the AIS-designated channels (AIS1 and AIS2), the maximum signal levels that are co-channel to AIS that appear from the VPC system on the VPC channels 27 and 28 must be below -120 dBm (13 dB below -107 dBm, two equal signals, each 10 dB below -107 dBm for a 20%PER).

Since the AIS base stations are expected to cover the coastline as well as the offshore, the selection of the antenna by VPC is consistent with what would be typical for the AIS base stations. The reference level for AIS detection is at the AIS receiver input at the base of the antenna feed-line

⁴ **This may be difficult or impractical to achieve.** There is also the question as to whether rotating the VPC antenna to the opposite side of its tower facing away from the AIS tower would also further reduce the minimum safe distance, since this would probably move the problem to the other direction (assuming there is also AIS coverage there).

(allowing for an antenna gain of 11 dBi and a feed-line loss factor of 2 dB). The geographical distance separations (in free space between) between the VPC sites and the AIS base station sites can be calculated from the free space radio range equations as follows.

$$20 \log D = Pt - Pr - 36.6 - 20 \log F - ACPR + Gt + Gr - L$$

where:

- D*: distance separation (in free-space) between AIS and VPC sites in statute miles
- P_t*: VPC transmitter carrier power at antenna base = +47 dBm (50 W)
- P_r*: power at AIS receiver input (dBm) = -120 dBm (for a 20% PER at -107 dBm)
- F*: frequency (MHz) = 161.975 MHz (AIS1)
- ACPR*: adjacent channel power ratio of assumed VPC transmitter = 70 dBc
- G_t*: antenna gain of the assumed VPC antenna = 11 dBi
- G_r*: antenna gain of the assumed AIS base station antenna = 11 dBi
- L*: feed-line loss of the assumed AIS base station antenna feed-line = 2 dB.

Then:

$$20 \log D = 47 + 120 - 36.6 - 44.18 - 70 + 11 + 11 - 2 = 36.22, \text{ and}$$

$$D = 10^{((20 \log D)/20)} = 64.7 \text{ miles}$$

But the radio horizon (the limit for free-space propagation) for these sites must be considered. This is determined as follows:

- D*: radio horizon distance in statute miles = $\sqrt{(3KH1/2)} + \sqrt{(3KH2/2)}$, where:
 - K*: diffraction factor of the Earth's atmosphere = 1.33 (the "4/3 Earth model"), and
 - H1*: VPC antenna elevation (in feet) ASL (above sea level) = 150 m = 492 ft, and
 - H2*: AIS antenna elevation (in feet) ASL (above sea level) = 50 m = 164 ft

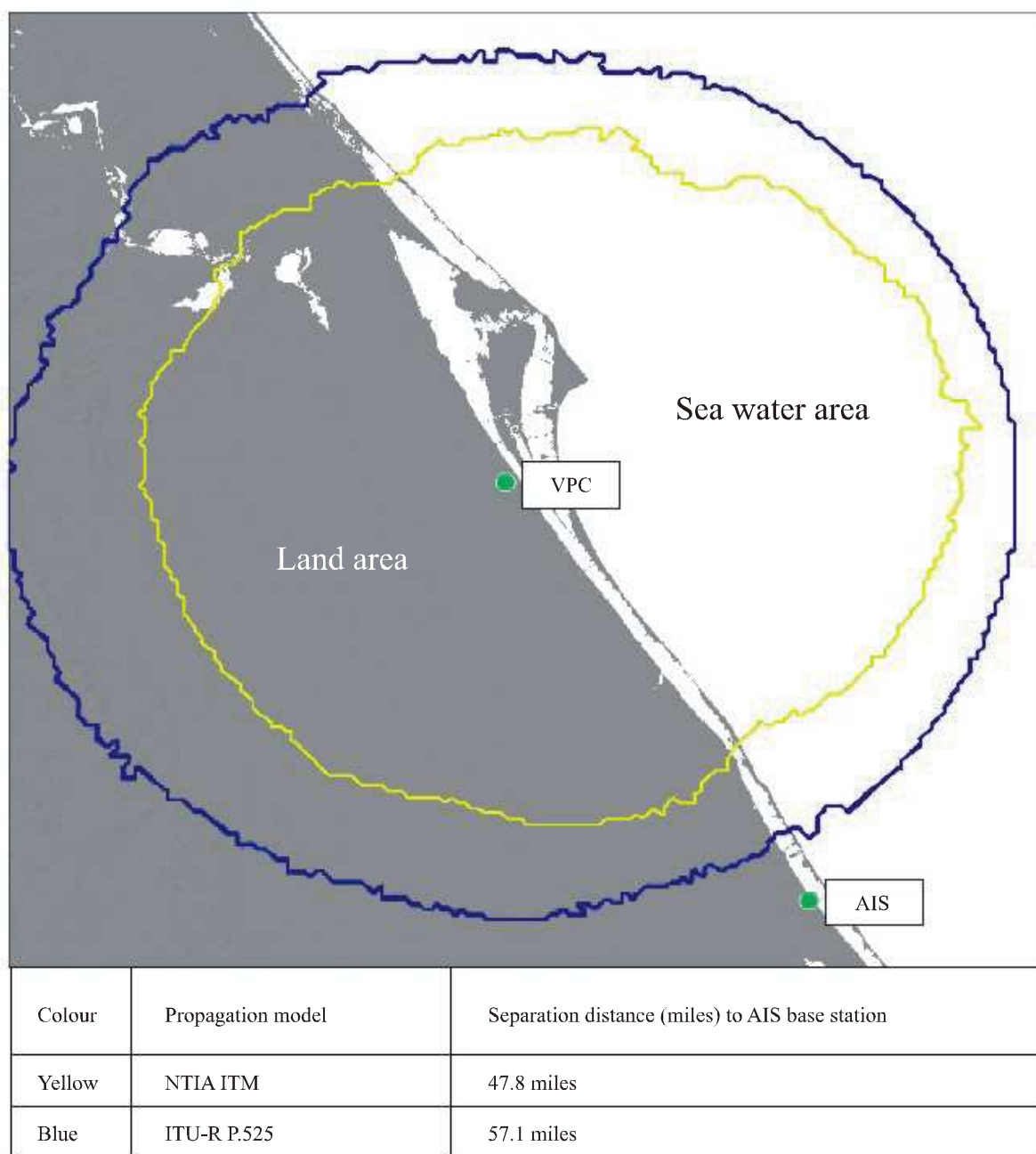
$$D = 31.3 + 18.1 = 49.4 \text{ miles}$$

The estimated distance separation is obviously the lesser of these two values, in this case, **49.4 miles**, but computerized Earth propagation models can be used to more precisely determine this separation as shown below. This is a general example and additional study is necessary. Separation distances may be reduced by taking into account additional factors of the specific sharing situation being considered, or applying mitigation techniques.

6.5.2 Distance separation from computer propagation models (ITU-R P.525 model and NTIA ITM (irregular terrain model))

Sample propagation model simulations (NTIA ITM and ITU-R P.525) of these effects are shown in Fig. 7. Both models predict distance separations on the order of the value estimated in § 6.5.1. Because of their different treatment of geographic and atmospheric variables, i.e. the *K*-factor in § 6.5.1, the assumed gradient of the index of refraction in Earth's atmosphere, these predictions differ slightly, but they both confirm that large geographical separations are necessary for this specific case.

FIGURE 7
Computer propagation model simulations



Rap 2122-07

6.6 Technical possibilities for interference mitigation

This notional example EMC analysis illustrates that operating VPC voice radiocommunications on channels 27B and 28B with AIS1 and AIS2 may be difficult. Further study into mitigation techniques is needed, such as signal discrimination or antenna pattern discrimination.

Advanced technology may provide new ways to mitigate any potential coexistence issues in the VHF maritime mobile service band. For example, preliminary studies within one administration have demonstrated actual recorded signal graphs taken from a coastal area where they had applied their signal discrimination techniques to mitigate potential interference issues between VPC signals and the AIS signals that were being received by the area VTIS. The conclusions of these studies indicate that this technology is “a practical and affordable means” to addressing any VHF maritime

mobile band issues. Antenna pattern discrimination techniques may also provide a practical and affordable solution to potential VPC-AIS adjacent channel issues. For example, if a highly directional antenna, e.g. a yaggi-type antenna, were amplitude/phase matched and combined with the main VPC and/or AIS base station antenna, a sharply focused antenna pattern null could be directed toward the susceptible and/or the interfering site without significant degradation to the main antenna's coverage pattern.

6.7 The benefit of automatic continuous interference detection capability in the AIS

Some AIS receivers have the inherent capability to detect and record the RSSI (received signal strength indication) levels for each AIS time period (typically referred to as a time slot) on both AIS frequencies and to report the value of the RSSI level on the serial input/output port. This inherent capability needs to be further exploited by the development and integration of special software that can be installed in the AIS receivers and the connected on-site AIS computers that can continuously monitor the "background noise level" on the AIS VDL (VHF data link) on the AIS-designated frequencies AIS1 and AIS2. For this proposed special capability, in a time period when no signal is present, the RSSI level reported by the AIS receiving system should be approximately:

$$NF + KTB + I$$

where :

NF: noise figure of the AIS receiver

KTB: value of thermal noise in the AIS receiver bandwidth

I: value of on-channel interference received on the AIS frequency.

This proposed special software also has the benefit of determining AIS VDL loading and detecting slot reuse. Base stations otherwise see "reused" slots as unused due to the fact that multiple simultaneous AIS messages can not be detected by base stations whenever (which is usually the case) the difference in received signals is not much higher than 10 dB, the AIS co-channel signal detection minimum threshold. While VDL management may be beyond the scope of administrations' requirements, this capability is urgently needed to enable this proposed maritime ENAV systems EMC assessment.
