International Telecommunication Union

ITU-R

Radiocommunication Sector of ITU

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(11/2010)

Utilization of the 495-505 kHz band by the maritime mobile service for the digital broadcasting of safety and security related information from shore-to-ships

M Series

Mobile, radiodetermination, amateur and related satellites services

International Telecommunication Union

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***Note**: This ITU-R Report was approved in English by the Study Group under the procedure detailed in Resolution ITU-R 1.*

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REPORT ITU-R M.2201

Utilization of the 495-505 kHz band by the maritime mobile service for the digital broadcasting of safety and security related information from shore-to-ships[1]

(2010)

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[1] This Report should be brought to the attention of the International Maritime Organization (IMO) (NAV Sub-Committee and COMSAR Sub-Committee (International NAVTEX Coordinating Panel)), the International Electrotechnical Commission (IEC), International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA), the World Meteorological Organization (WMO), the International Hydrographic Organization (IHO), and the Comité International Radio-Maritime (CIRM).

1 Background information

This Report describes a technical approach allowing the reuse of the 500 kHz band for digital broadcasting of maritime safety and security related information for the benefit of ships at sea. Systems based on this technical approach can coexist with the worldwide NAVTEX system that operates on 490 kHz, 518 kHz, and in some cases 424 kHz.

The system will provide an improved means for an automated broadcast. It will coexist with existing services (NAVTEX, satellite, MF, HF, VHF).

Since the early 1900s, the frequency 500 kHz had been the international maritime calling and distress frequency. It was used in telegraphy mode for distress and safety communications for ships at sea. This functionality has been replaced by the Global Maritime Distress and Safety System (GMDSS). The International Maritime Organization’s (IMO) Convention for the Safety of Life at Sea (SOLAS) required certain ships to be equipped with GMDSS equipment since 1999.

Since the adoption of GMDSS, the band 495-505 kHz has no longer been globally used for maritime calling and distress and the designation of this band for calling and distress was suppressed at WRC-07. In accordance with provision RR Edition of 2008 Nos. 5.79 and 5.82A, maritime mobile operations are presently limited to radiotelegraphy. Accordingly, use of the band has diminished.

This frequency band 415 kHz to 526.5 kHz is ideally suited to broadcast from shore to ship. The surface wave propagation of a coast station using this band can provide a coverage area from the coast to 400 nautical miles (~741 km) off shore. This is the same coverage area that the current NAVTEX system provides at 490 kHz, 518 kHz and in some cases 424 kHz.

2 Identification of the usable band

The band 415 kHz to 526.5 kHz is accessible for the maritime mobile service; however, some sharing conditions apply. The band 495 kHz to 505 kHz is an excellent candidate for introduction of new technology to the maritime mobile service. It is ideally suited for this purpose due to:

- its ground-wave propagation characteristics;
- the current frequency bands of NAVTEX transmissions;
- the under-utilization of 495-505 kHz due to the cessation of the 500 kHz distress frequency requirement with the adoption of GMDSS.

3 Overview of the system

This system may operate in one of two modes, a mode similar to the current NAVTEX system, which is a "sequential mode" based on timing, or possibly a "permanent mode" on another basis. The coast stations will be spaced along the coast approximately 500 nautical miles (~926 km) apart. In the "sequential mode", all the transmitters on a coast will share the 10 kHz channel by transmitting in a specific time slot. Some time slots will remain free for unforeseen broadcasts. Table 1 is an example of time slot allocations for a network of 500 kHz broadcast transmitters for the Atlantic coast of Europe. It is based on 3-minute slots of a 60-minute cycle.

The current NAVTEX system has a data rate of 100 bit/s with a 300 Hz channel. This system would have a data rate of up to 47 400 bit/s with a 10 kHz channel.

TABLE 1

Example of allocations of 500 kHz broadcast transmitters for the West Atlantic
(Base: 60 min)

Stations	**T0**	**T1 +3**	**T2 +6**	**T3 +9**	**T4 +12**	**T5 +15**	**T6 +18**	**T7 +21**	**T8 +24**	**T9 +27**	**T10 +30**	**T11 +33**	**T12 +36**	**T13 +39**	**T14 +42**	**T15 +45**	**T16 +48**	**T17 +51**	**T18 +54**	**T19 +57**
Niton (UK)	X										X									
Corsen (France)		X										X								
Monsanto (Lisbon, Portugal)			X										X							
W				X										X						
X					X										X					
Y						X										X				
Z							X										X			

4 Specifications for the 500 kHz coastal transmitters

The radiated power from the regional coast station transmitter should be what is sufficient to cover the intended service area of that coast station. The power would be decreased at night during periods of better RF propagation. A conservative estimate of the coverage area from shore is approximately 320 nautical miles (~593 km) with a radiated power of 1 kW and 400 nautical miles (~741 km) with a radiated power of 5 kW.

The modulation is OFDM with N-QAM. Section 13 illustrates an example of 64-QAM @ 47.4 kbit/s that is capable of reaching 400 nautical miles (~741 km) with an appropriate antenna effecctive height and a sufficient transmitter power. Where antenna effective height and/or transmitter power are limited, 16-QAM is preferrable.

This type of modulation, OFDM with N-QAM, works very well in DRM system (sound broadcasting). The modulation scheme is similar to that described in Recommendation ITU-R M.1798-1, Annex 4, which uses both 16-QAM and 64-QAM. 16-QAM has the advantage of 6 dB more energy per bit, and therefore it is more robust and more commonly used in radio systems with power and antenna effective height limitations, but it has only half the data-rate of 64-QAM.

5 Local transmitters

Local transmitters can be used to fill in coverage gaps if needed, especially in significant harbour areas. Local transmitters would have simplified antenna systems and less radiated power then the regional coast stations. An example implementation of this was used for field tests described in § 15.

6 Network

The static allocation of the broadcasting slots allows the installation of a simplified broadcasting network (refer to Fig. 1).

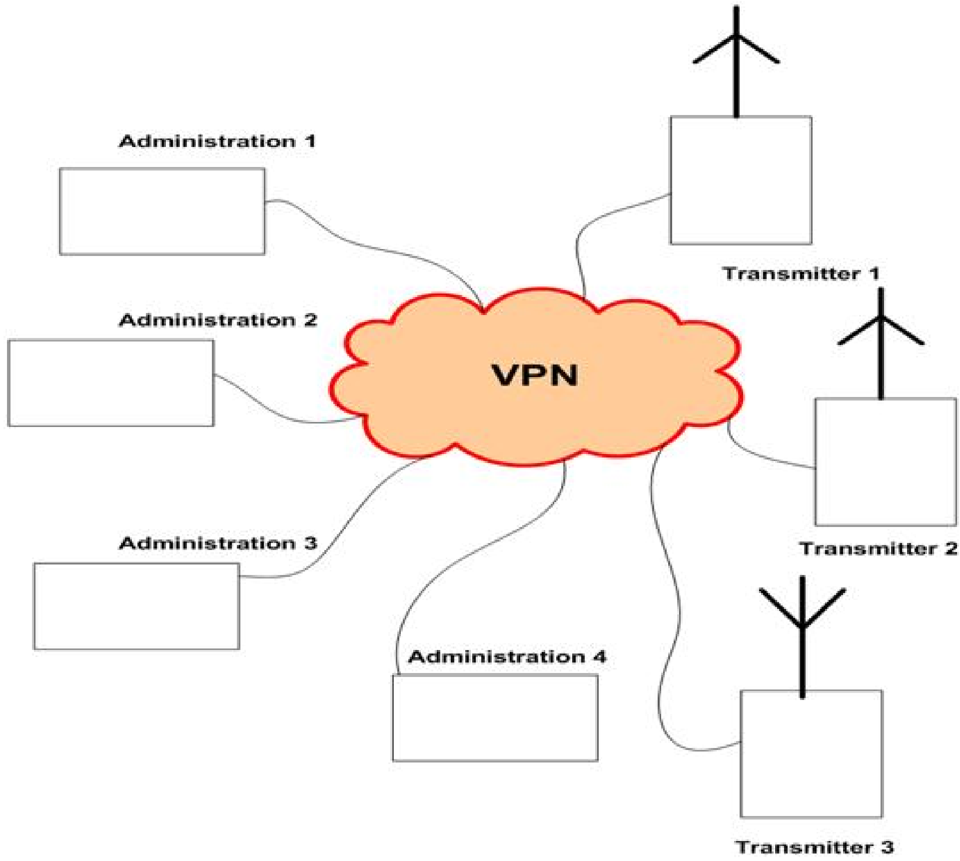
Each national authority would have a certain number of coastal stations connected to a standard Ethernet virtual private network (VPN) controlled by the national authority.

It is not essential to establish a national server because each station will collect on the VPN network the messages meant for them and will broadcast them within the timing of the allocated slot.

The exchange of files among various countries for broadcasting by transmitters outside their national boundary is feasible. It would be managed by an identified national coordination centre, as used currently for some automatic identification system (AIS) and GMDSS networks.

FIGURE 1

National digital 500 kHz network



7 Type of messages

It is appropriate that any emission of messages is controlled perfectly and from a secure originating source.

Several possible origins:

- safety of navigation messages;
- meteorological messages;
- safety and security messages;
- search and rescue information and pirate attack warnings;
- pilotage service messages;
- harbour messages;
- file transfer, e.g.: harbour VTS display;
- cartographic update.

8 Type of information broadcasts

Three types of broadcast messages are included:

- **General broadcast** – These messages are broadcast for the attention of all ships.
- **Selective broadcast** – These messages are broadcast for the attention of the ships located in a given area.
- **Dedicated messages** – These messages are addressed to one or more specific ships.

9 Encryption

It is completely possible to envisage the encryption of certain files transmitted in agreement with the administration concerned and with evolutionary keys.

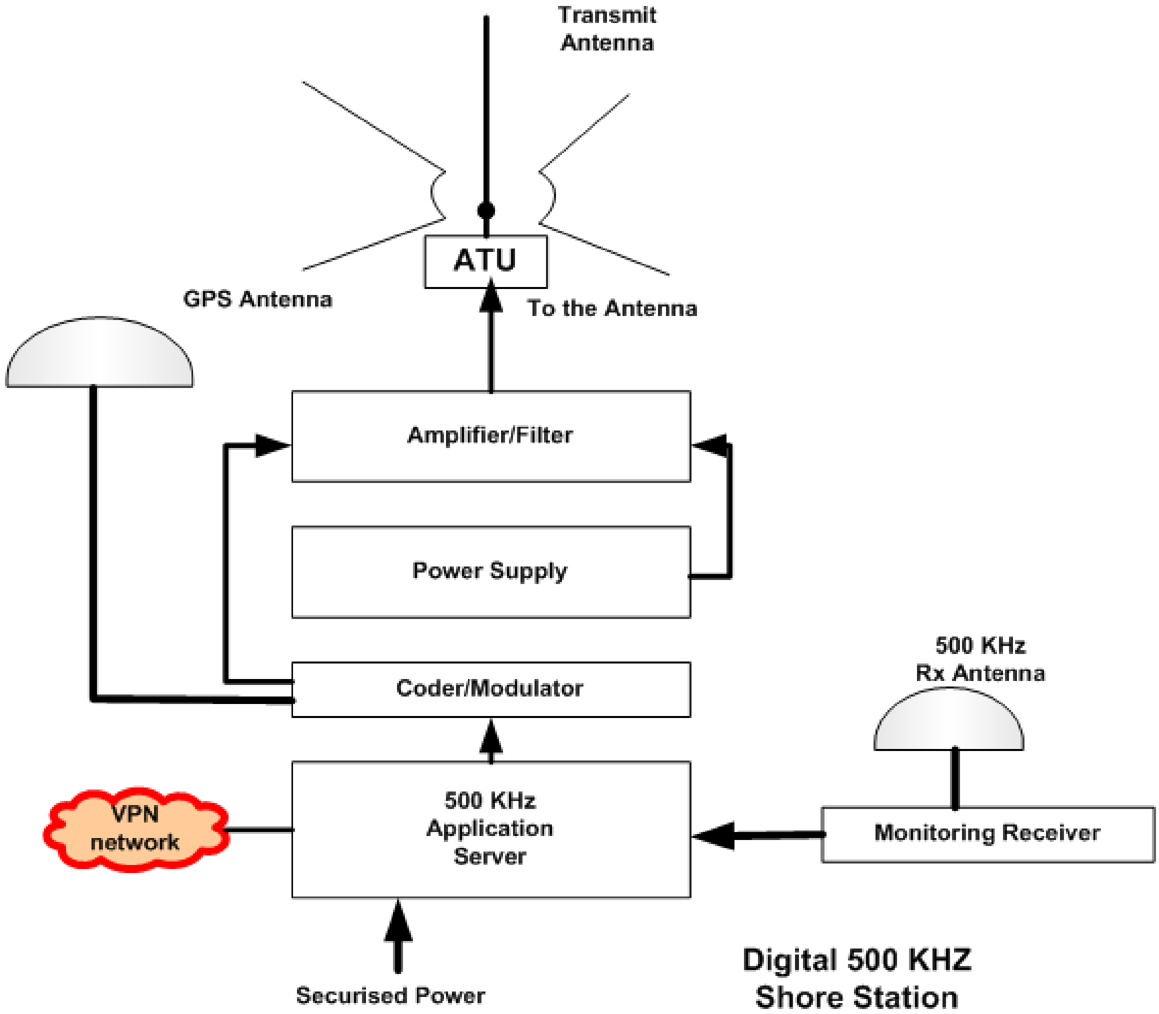
10 Description of a coastal transmitting station

A coastal transmitting station would consist of (refer to Fig. 2):

- 1 local server connected to a protected VPN network;
- 1 modulator coder charged to transpose the files in modulation OFDM/N-QAM on frequency 500 kHz;
- 1 RF power amplifier with its power supply and filtering;
- 1 antenna matching unit;
- 1 transmitting antenna with ground radials;
- 1 GPS antenna with clock output for the synchronization of slots and frequencies;
- 1 monitoring receiver in order to check that the frequency is free.

FIGURE 2

Coastal transmitting station



11 Equipment for ship

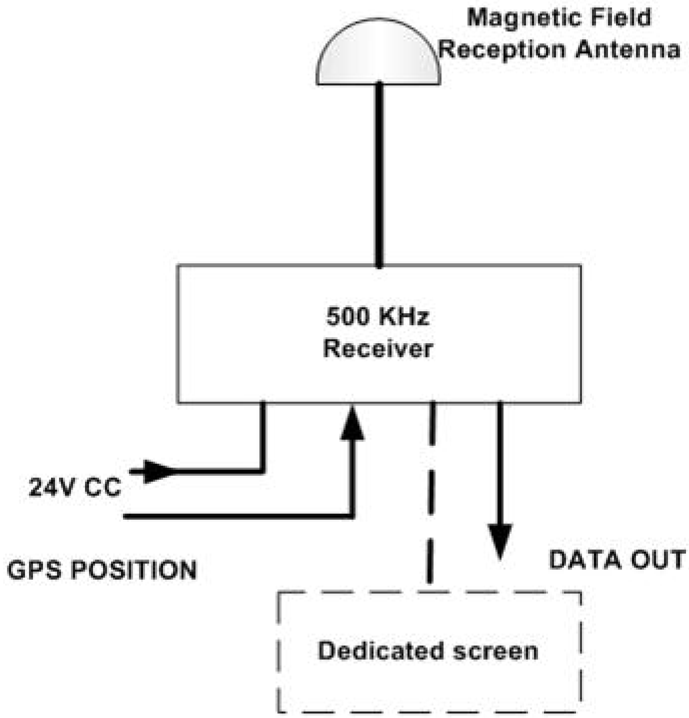
This equipment would be like a "black box" which can be connected on the existing on-board equipment or a dedicated display (computer) as shown in Fig. 3.

The 500 kHz receiver would be connected to a 500 kHz magnetic receiving antenna of very small dimension and to an existing GPS receiver for the selection of messages according to the position of the ship.

Its consumption in energy would be about 10 W.

FIGURE 3

Synoptic 500 kHz reception ship station



12 Protection for broadcasting of NAVTEX on 490 kHz and 518 kHz

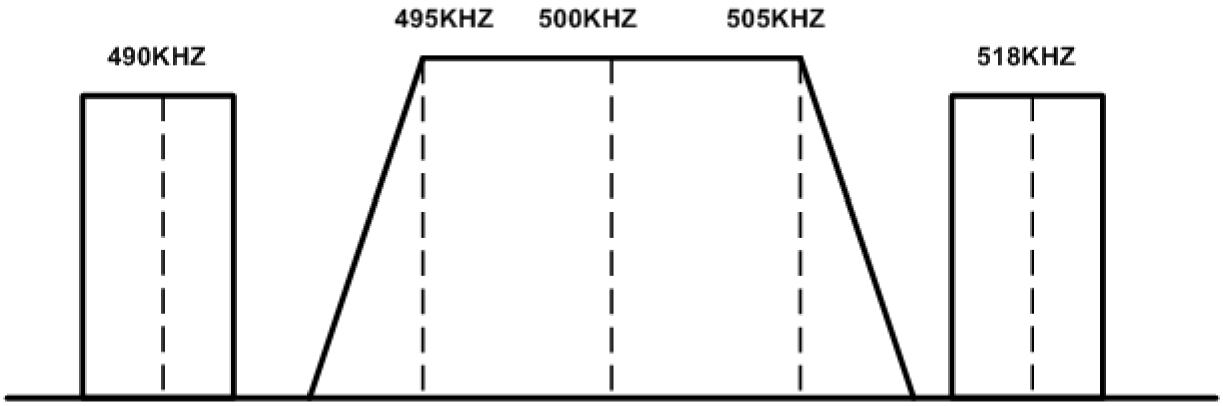
NAVTEX transmitter emissions are narrow-band at 490 kHz and 518 kHz using a modulating centre frequency of 1 700 Hz and a deviation of ±85 Hz.

The bandwidth of the receivers is about 300 Hz.

The 500 kHz transmitter notional emission mask must be fitted to protect the NAVTEX transmissions as shown in Fig. 4.

FIGURE 4

Notional emission mask



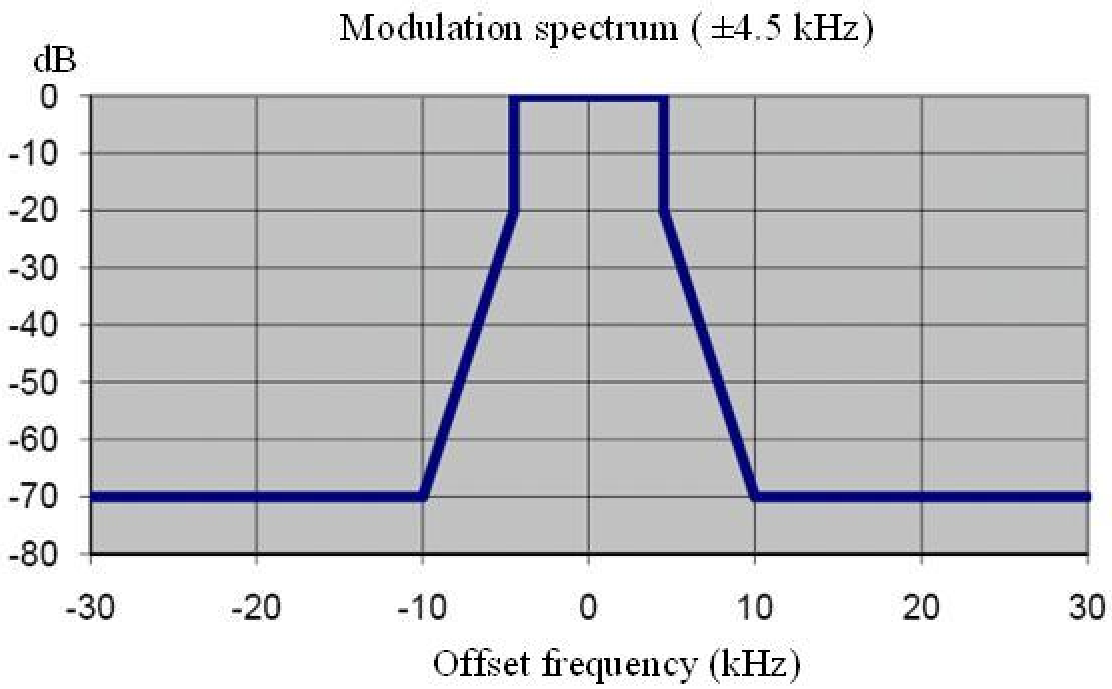
12.1 Transmitter emissions mask

For transmitters designed to operate on this 10 kHz channel, any emission must be attenuated below the peak envelope power (P) of the transmitter as follows (refer to Fig. 5):

1. On any frequency from the centre of the authorized bandwidth f_0 to 4.5 kHz removed from f_0 : 0 dB.
2. On any frequency removed from the centre of the authorized bandwidth by a displacement frequency (f_d in kHz) of more than 4.5 kHz but no more than 10 kHz: at least $5.82(f_d - 2.30$ kHz) dB.
3. On any frequency removed from the centre of the authorized bandwidth by a displacement frequency (f_d in kHz) of more than 10 kHz: at least 50 + 10 log (P) dB or 70 dB, whichever is the lesser attenuation.

FIGURE 5

10 kHz channel emissions mask (N-QAM modulation)



13 Selection of 64-QAM modulation parameters

For the prospective 495 kHz to 505 kHz digital broadcast channel, a 64-QAM modulation at 47.4 kbit/s would meet these requirements and would fit the transmitter emissions mask in § 12.1.

64-QAM modulation is customarily used in high-performance digital RF systems to provide a maximum data transmission rate in a limited channel bandwidth. The characteristics in Table 2 are taken from the high data-rate ISDB (Integrated Services Digital Broadcasting) standard for 64-QAM modulation. These characteristics were scaled in Table 3 to fit the 10 kHz channel mask.

TABLE 2

High data-rate ISDB (Integrated Services Digital Broadcasting) standard for 64-QAM transmission

Specification of 64-QAM transmission system	
Input signal	MPEG2-TS packets
Frame synchronization	Sync byte inversion for every 8 packets
Randomization	PRBS (polynomial $1 + X^{14} + X^{15}$)
FEC	Reed-Solomon (204,188)
Interleave	Byte unit convolutional (depth: 12)
Modulation	64-QAM
Mapping	Given in Fig. 6
Roll-off	13% as shown in Fig. 7
Bandwidth	6 MHz
Symbol rate	5.274 M baud
Transmission rate	31.644 Mbit/s
Information rate	29.162 Mbit/s

TABLE 3

ISDB standard scaled for 64-QAM transmission in a 10 kHz channel

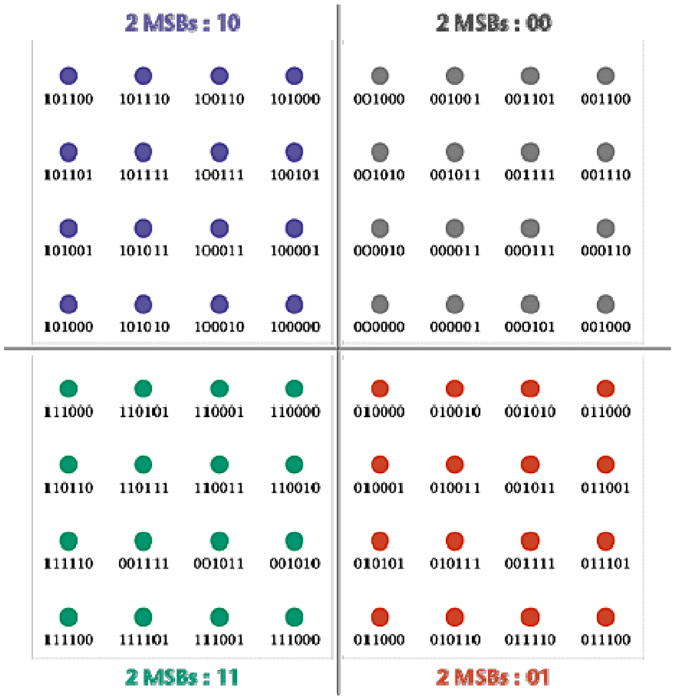
Specification of 64-QAM transmission system	
Input signal	MPEG2-TS packets
Frame synchronization	Sync byte inversion for every 8 packets
Randomization	PRBS (polynomial $1 + X^{14} + X^{15}$)
FEC	Reed-Solomon (204,188)
Interleave	Byte unit convolutional (depth: 12)
Modulation	64-QAM
Mapping	Given in Fig. 6
Filter roll-off	13% as shown in Fig. 7
Bandwidth	9 kHz (10 kHz channel mask)
Symbol rate	7.9 k baud
Transmission rate	47.4 kbit/s
Information rate	43.7 kbit/s

13.1 Differential coding and mapping

After the two Most Significant Bits (MSB) of each symbol are differentially coded, the symbols are mapped into the 64-QAM constellation as shown in Fig. 6. In this mapping, rotation-invariant constellation is adopted in which four Least Significant Bits (LSB) become the same values even when the signal point is turned 90°, 180° or 270°.

FIGURE 6

Constellation chart for 64-QAM

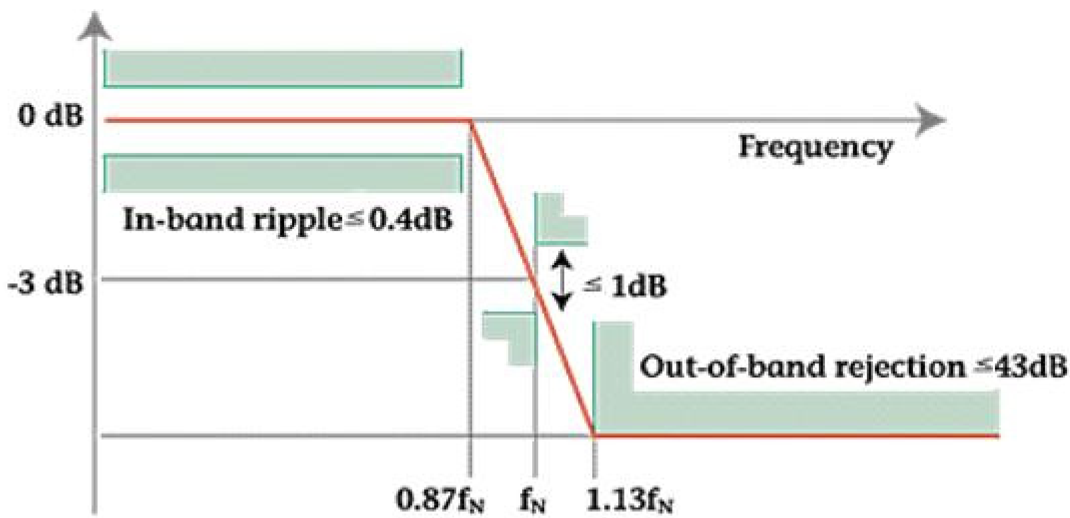


13.2 Filter roll-off factor

As seen in Fig. 7, the bandwidth is limited with a filter that has a 13% roll-off factor. As the symbol rate is 7.9 k baud as shown in Table 3, the bandwidth becomes approximately 8.83 kHz after modulation so that the signal can be transmitted within a 9 kHz bandwidth.

FIGURE 7

Baseband filter characteristics

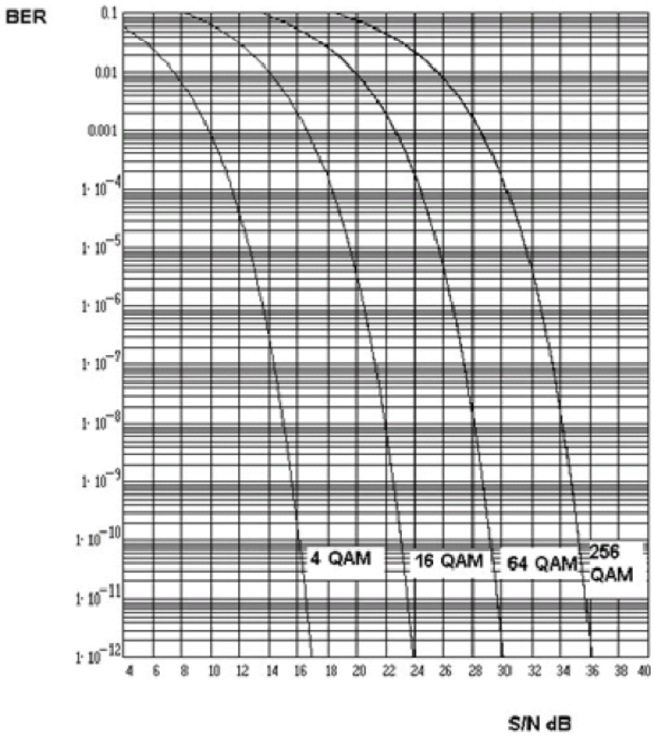


13.3 Bit error rate versus signal-to-noise ratio for 64-QAM

The bit error rate (BER) performance for QAM modulation is shown in Fig. 8. For 64-QAM modulation signal-to-noise (*S*/*N*) ratio is specified conservatively at 26 dB or more (noise bandwidth of 9 kHz), where BER is 10^{-5} or less without error correction and 10^{-9} or less with error correction.

FIGURE 8

Bit error rate (BER) versus signal-to-noise (*S*/*N*) ratio for QAM transmission



14 Candidate 500 kHz digital broadcast antennas

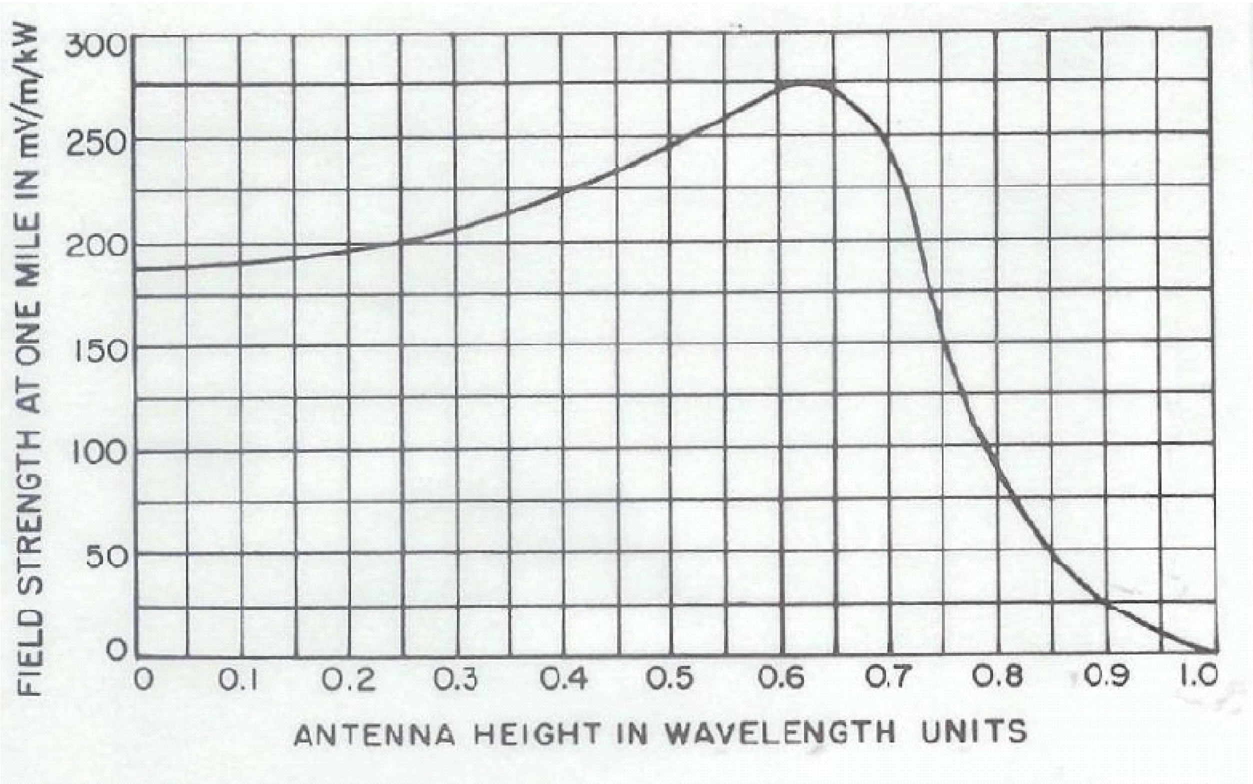
Generally speaking, vertical tower antennas are considered ideal radiators at a quarter-wavelength, but antennas of lesser or greater heights are useful when provided with appropriate matching networks and/or top loading elements. Other antenna configurations such as the inverted-L and the "T" antenna (refer to Fig. 15 of § 16.3) are useful when limited antenna height is available.

14.1 Practical vertical-tower antennas

The field strength from a single vertical tower insulated from ground and either of self-supporting or guyed construction, such as is commonly used for medium-frequency broadcasting, is shown in Fig. 9. With the modernization of the global navigation satellite systems (GNSSs), some antenna tower assets may become available that have been previously used to provide a legacy differential global navigation satellite systems (DGNSSs) in the 300 kHz frequency band. Also, since Loran-C (100 kHz band) is being phased out in some parts of the world, those assets may also become available. Since these assets are of this configuration, it is convenient to characterize their impedance and radiation efficiency. For the high data rate proposed for this new 500 kHz broadcast data service, it is also very important that the antenna towers have an adequate bandwidth to support the fidelity of the transmitted signal. Thus the Q of the antenna (the ratio of the reactive and resistive components of impedance) must be kept as low as possible. Figure 10 may be used to assess the Q of the antenna tower, with the understanding that capacitive top loading of the tower by means of the guy wires should also be considered.

FIGURE 9*

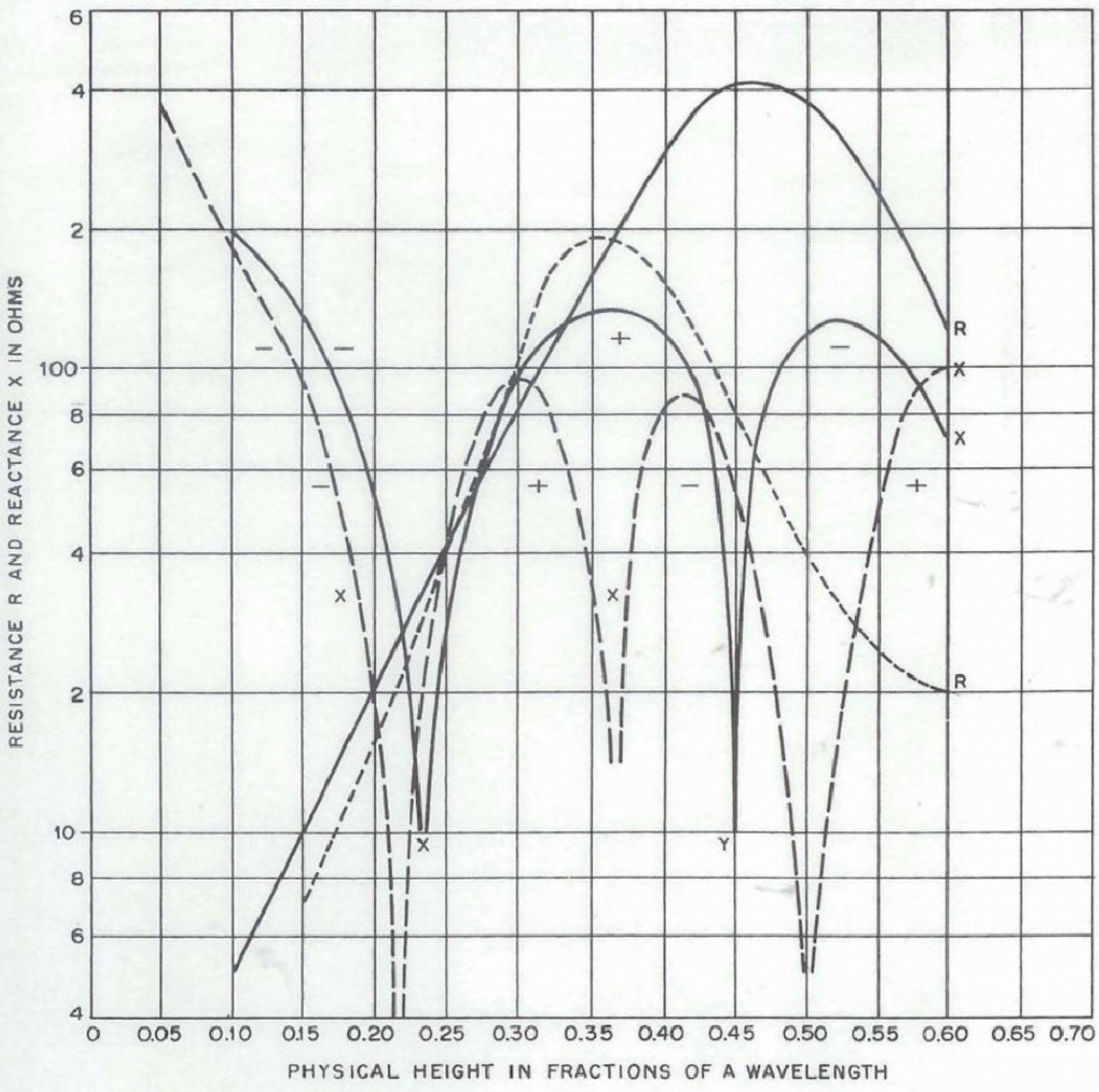
Field strength along the horizontal as a function of antenna height for a vertical grounded radiator with 1 kW of radiated power



* taken from "Reference Data For Radio Engineers", Fifth Edition, Third Printing: March, 1970, Section 25-6, Fig. 5 of that reference Section

FIGURE 10*

Resistance and reactance components of impedance between tower base and ground of vertical radiators



* same reference as Fig. 9, Section 25-8, Fig. 6 of that reference Section

Note 1 – Solid lines show average results for five guyed towers. Dashed lines show average results for 3 self-supporting towers.

14.2 Potentially available antenna assets from retiring legacy systems

It is interesting to consider that some antenna tower assets are now available and more may become available in the near future due to the retirement and planned future retirement of legacy radionavigation and other radio systems. Based on a minimum Q of ten, which is needed to support the proposed 64-QAM modulation, the minimum height for a vertical-tower broadcast antenna, based on Fig. 10, would need to be slightly over 100 m, and there are a substantial number of these potentially available legacy assets (DGNSS and Loran-C towers) in this range.

15 Determination of the coverage range for the broadcast data service

The coverage range that is determined for the digital broadcast system is shown in Table 4.

TABLE 4

Range propagation for 64-QAM transmission in a 10 kHz channel

Parameter	Value	Comment
Transmitter power	1 000 or 5 000 W	Fig. 14
Antenna effective height (ASL) Polarization Bandwidth Efficiency	30 m	Example: Vertical monopole with capacitive toploading. – Vertical – 15 kHz – 4 to 8%
Channel bandwidth	10 kHz	10 kHz
Background noise level	F_a = 62 dB	Figs 12, 13
Target BER (no FEC/FEC)	$10^{-5}/10^{-9}$	Fig. 8
Target *S*/*N* ratio	26 dB	Fig. 8
Range for 5 kW transmitter	400 nautical miles (~741 km)	Fig. 14
Range for 1 kW transmitter	320 nautical miles (~593 km)	Fig. 14

15.1 Radio-frequency propagation and noise

For predicting radio-frequency propagation, the technical approach set out in Recommendation ITU-R P.368-9 is used (refer to Fig. 11). Radio noise and man-made noise characteristics are provided in Recommendation ITU-R P.372-10 (refer to Figs 12 and 13).

FIGURE 11

Propagation characteristics for 500 kHz radio transmission
(Fig. 2 of Recommendation ITU-R P.368-9, Annex 1)

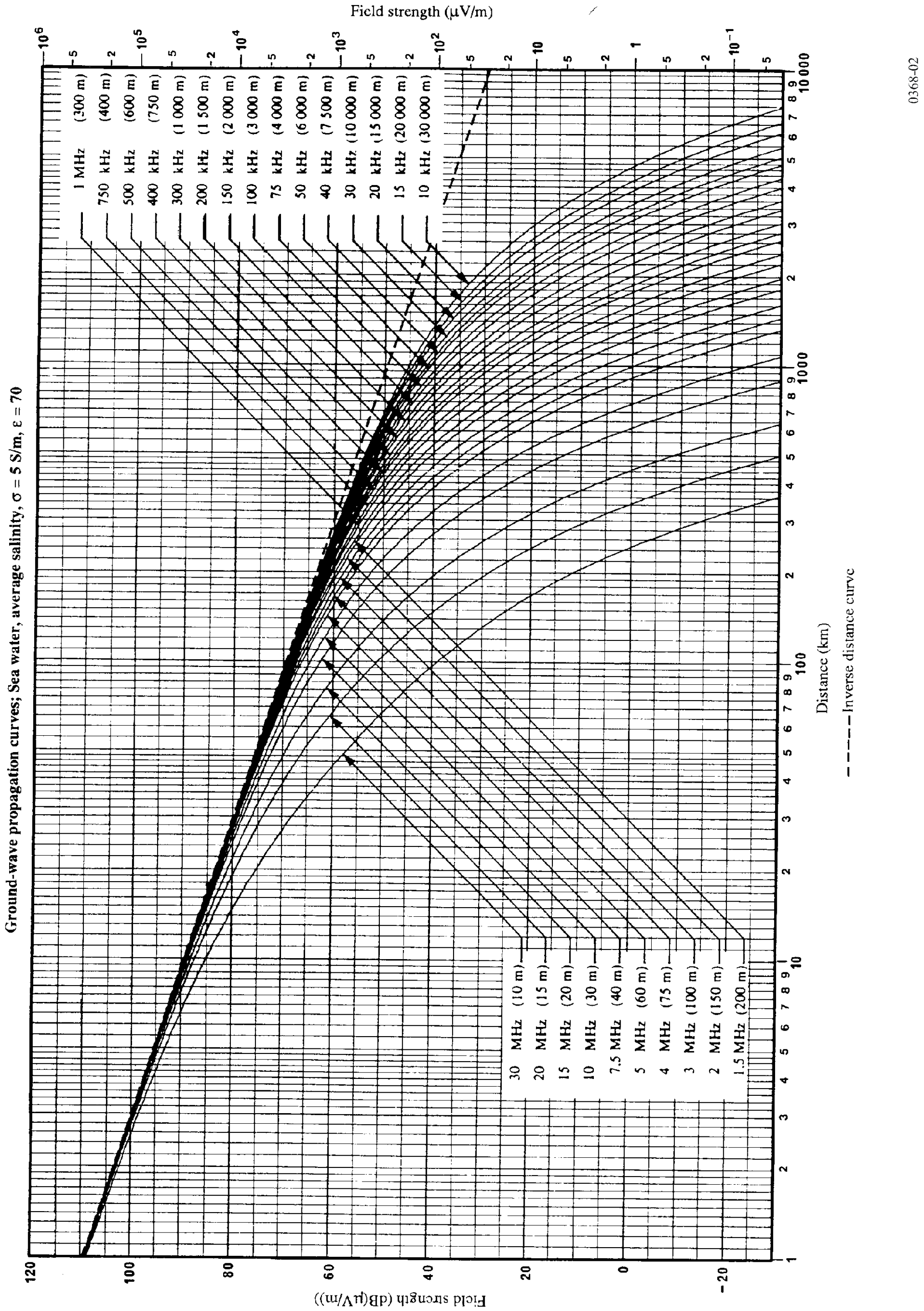
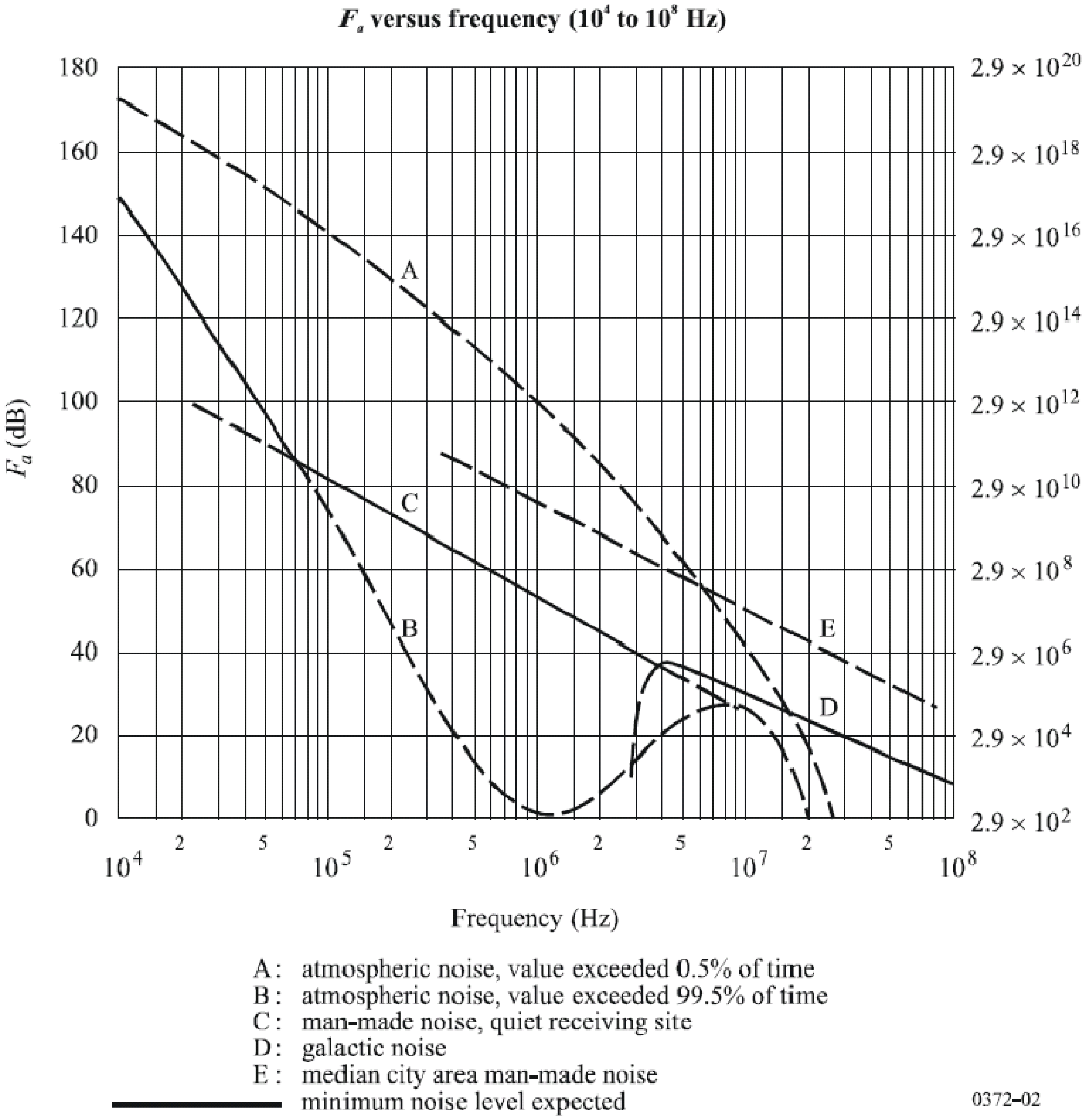


FIGURE 12

Radio noise characteristics (Fig. 2 of Recommendation ITU-R P.372-10): Noise in the frequency range 10 kHz to 100 MHz



For a short ($h << \lambda$) vertical monopole above a perfect ground plane, the vertical component of the root mean squared field strength is given by:

$$E_n = F_a + 20 \log f_{MHz} + B - 95.5 \qquad \text{dB}(\mu\text{V/m})$$

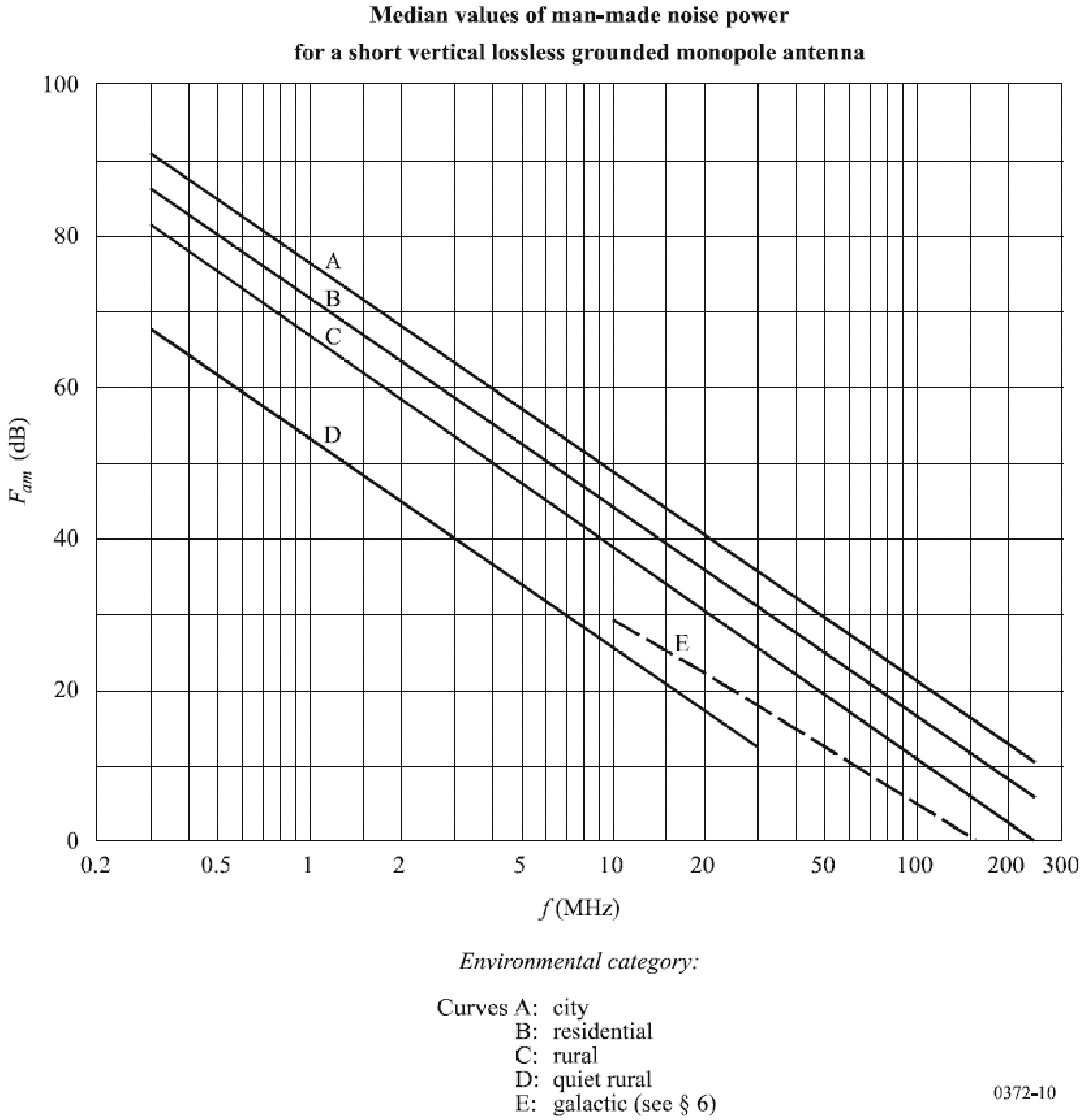
where:

E_n: field strength in bandwidth b

f_{MHz}: centre frequency (MHz).

FIGURE 13

Man-made noise in the frequency range 200 kHz to 300 MHz
(Fig. 10 of Recommendation ITU-R P.372-10)



15.2 Determination of the range achieved using NAVTEX operation

According to Recommendation ITU-R M.1467-1, the range achieved by a given NAVTEX transmitter depends upon the efficiency of the transmit antenna, and the external noise factor on board the ship, as shown in Fig. 14. The antenna efficiency depends upon the quality of the Earth system provided, and once the required cymomotive force has been determined, it should be measured as described in § 2.5.2 of Recommendation ITU-R M.1467-1, and the efficiency determined. Cymomotive force (CMF) is the product formed by multiplying the electric field strength at a given point in space, due to a transmitting station, by the distance of the point from the antenna. CMF can only be calculated if the distance from the transmitting antenna is sufficient for reactive effects to be negligible; moreover, the finite conductivity of the ground is presumed to have no effect on propagation. CMF is expressed in volts and corresponds numerically to the field strength, in mV/m, at a distance of 1 km.

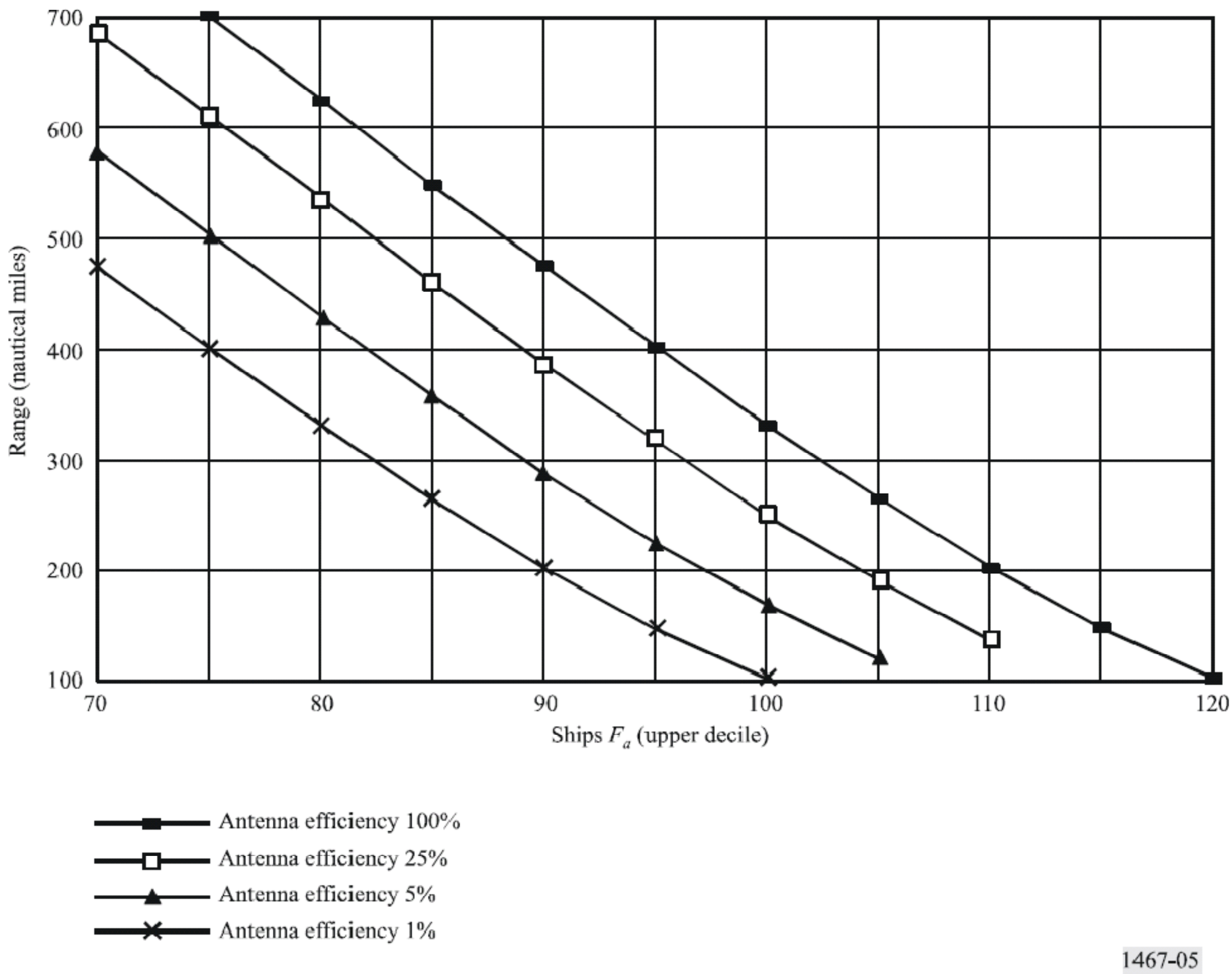
IMO Resolution A.801(19) specifies 90% availability, and so the upper decile value for F_a should be calculated using the statistical data produced by NOISEDAT.

FIGURE 14

(Fig. 5 of Recommendation ITU-R M.1467-1)

NAVTEX range for a 1 kW transmitter, versus ships F_a

(For 5 kW transmitter, reduce F_a by 7 dB)



15.3 Prediction of A2 and NAVTEX ranges (IMO performance criteria)

The criteria developed by the IMO for determination of A2 and NAVTEX ranges are reproduced in Table 5 and should be used in the determination of ranges for A2 and NAVTEX services.

TABLE 5

Performance criteria for A2 and NAVTEX transmissions

Distress channel	Radiotelephony	DSC	ARQ NBDP	NAVTEX
Frequency (kHz)	2 182	2 187.5	2 174.50	490 and 518
Bandwidth (Hz)	3 000	300	300	300
Propagation	Groundwave	Groundwave	Groundwave	Groundwave
Ship's power (W)	60	60	60	
Ship's antenna efficiency (%)	25	25	25	
RF full bandwidth signal/noise ratio (S/N) (dB)	9	12	18 min(1)	8
Mean Tx power below peak (dB)	8	0	0	0
Fading margin (dB)	3	Not stated		3
IMO reference for above	Resolution A.801(19)	Resolution A.804(19)	Recommendation ITU-R F.339	Resolution A.801(19)
Availability required (%)	95(2)	Not stated	Not stated	90

DSC: digital selective calling

NBDP: narrow-band direct printing

(1) Stated as 43 dB(Hz) under stable and 52 dB(Hz) under fading conditions with 90% traffic efficiency.

(2) Availability can be relaxed to 90% in cases where the noise data used or performance achieved can be proven by measurement.

15.4 C/N required for NAVTEX broadcasts

The transmit range for NAVTEX broadcasts should be calculated assuming an RF C/N density figure of 35 dB(Hz) at the ship's antenna. This will ensure that the NAVTEX receiver is provided with an RF S/N of 8 dB in a 300 Hz bandwidth.

15.5 Prediction of 64-QAM broadcast transmission range

Adjustment (horizontal scale, Fig. 14) of NAVTEX requirements for 64-QAM broadcast transmission:

– Scale C/N requirements from 8 dB to 26 dB (Fig. 8 @ 10^{-5} BER): +18 dB
– Scale bandwidth from 300 Hz to 9 kHz: +15 dB
– Allowance for 5 kW transmitter (Fig. 14): −7 dB
– Assumed baseline value of ship's F_a (Figs 12 and 13): 62 dB
– Net adjusted value for ship's F_a (Fig. 14, (18 + 15 − 7 + 62 = 88 dB)): 88 dB
– Net adjusted value for a 1 kW transmitter (add 7 dB to 88 dB above): 95 dB
– Antenna efficiency: 25%
– Adjusted range for 64-QAM (5 kW Tx) from Fig. 14: 400 NM (~741 km)
– Adjusted range for 64-QAM (1 kW Tx) from Fig. 14: 320 NM (~593 km)

15.6 Ship receiver performance specifications

The assumed ship receiver specifications are set out below. To achieve the desired bit error rate (BER) at the extreme range, the data rate may be adjusted and 16-QAM to 64-QAM may be used.

Ship receiver specifications:

–	Frequency band:	495 to 505 kHz.
–	Noise factor:	< 20 dB.
–	Usable sensitivity for 10^{-5} BER:	< 100 dBm.
–	Dynamic range:	> 80 dB.
–	Reference noise:	see Figs 12 and 13.

16 Field tests

The feasibility of the local transmitter system referenced in § 5 was assessed through a field test in France. Note that this system has utilized one of the alternative antenna configurations mentioned in § 14, the "T" antenna for use where available antenna height is limited.

16.1 Generalities

Within the framework of § 5, it was decided to carry out tests of digital broadcasting at 500 kHz with a transmitting shore station and a receiving ship along the coast of France. Two components were used for these tests:

– A shore transmitting station near to Brest.

– A test receiver installed on the ship "PONT AVEN".

16.2 Transmitting shore station

It consists of:

– a digital modulator;

– a 500 kHz transmitter;

– a transmit antenna.

The authorization to use the frequency was granted by ARCEP (French authority).

16.3 Broadcast emissions

The digital modulator can deliver an OFDM modulation into 4 or 16-QAM. In a band of 4.5 kHz or 10 kHz with the choice for 102 to 210 subcarriers according to selected encoding.

The message transmitted in loop was composed of the logo of Kenta Electronic in normal or reversed version (6 kB files).

I/Q outputs of the modulator were used to modulate the exciter centred on 500 kHz. The signal from the exciter is amplified to deliver approximately 180 W after the low pass filter.

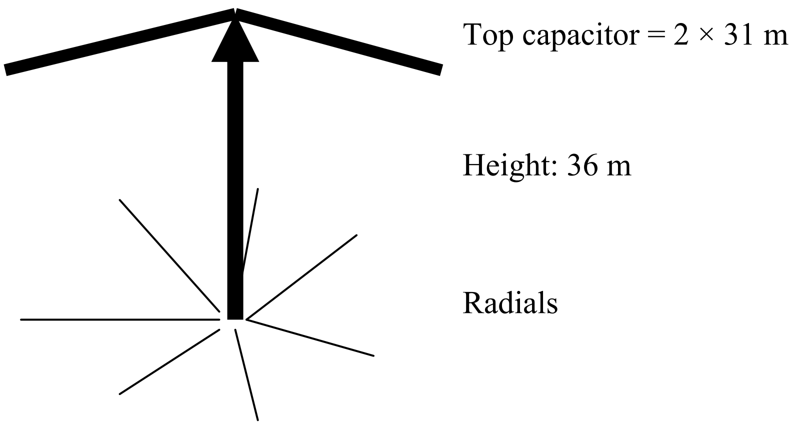
The transmit antenna is a "T" antenna with top capacity and 10 ground radials (refer to Fig. 15).

The matching was carried out to optimize the necessary bandwidth.

The estimate of the RF radiated power is approximately 10 W.

FIGURE 15

Tx antenna synoptic



16.4 Reception by the test ship station

It consists of:

– 500 kHz antenna sensitive to the H field;

– GPS antenna;

– receiver;

– reception display system.

The reception system was installed on the Pont-Aven ship from Brittany Ferries.

This ship was retained because of its regular trips between Brittany (France)/Plymouth (United Kingdom), Cork (Ireland) and Santander (Spain), refer to Fig. 16. Outside the territory of France operation was under provision RR No. 4.4.

FIGURE 16

Trip of the Pont-Aven

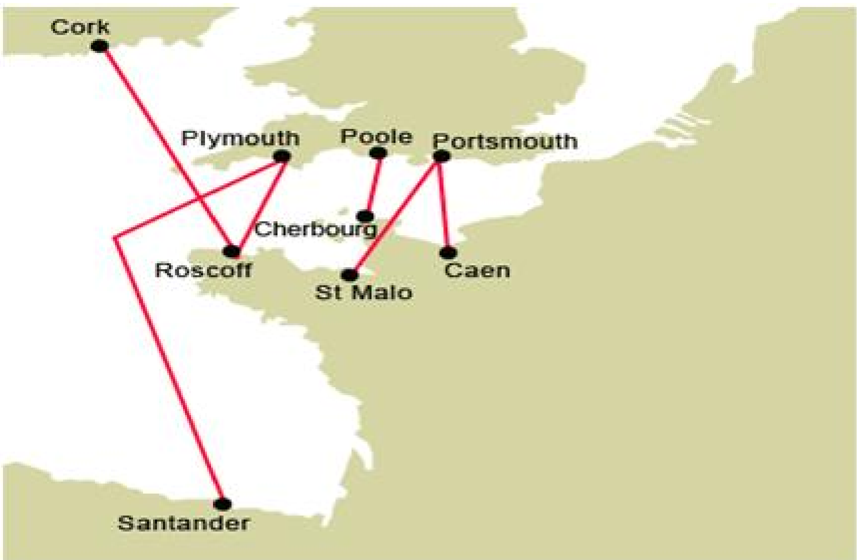


FIGURE 17
ANTENNA POSITIONING

The antennas were installed on the bridge.

FIGURE 18
Reception display system

The received data were recorded permanently during the trip, recovered at each transit and sent for analysis and treatment.

The 10 W RF radiated power of the transmitter was voluntarily limited to better analyze:

– the influence of the atmospheric noises on the SNR;
– variations of day/night propagation;
– limits of the system with weak SNR.

16.5 Results

Figures 19 to 21 show the measures of signal strength, signal-to-noise ratio and decoding quality level along a sample trip of the Pont-Aven.

FIGURE 19

RSSI (received signal strength indicated) results

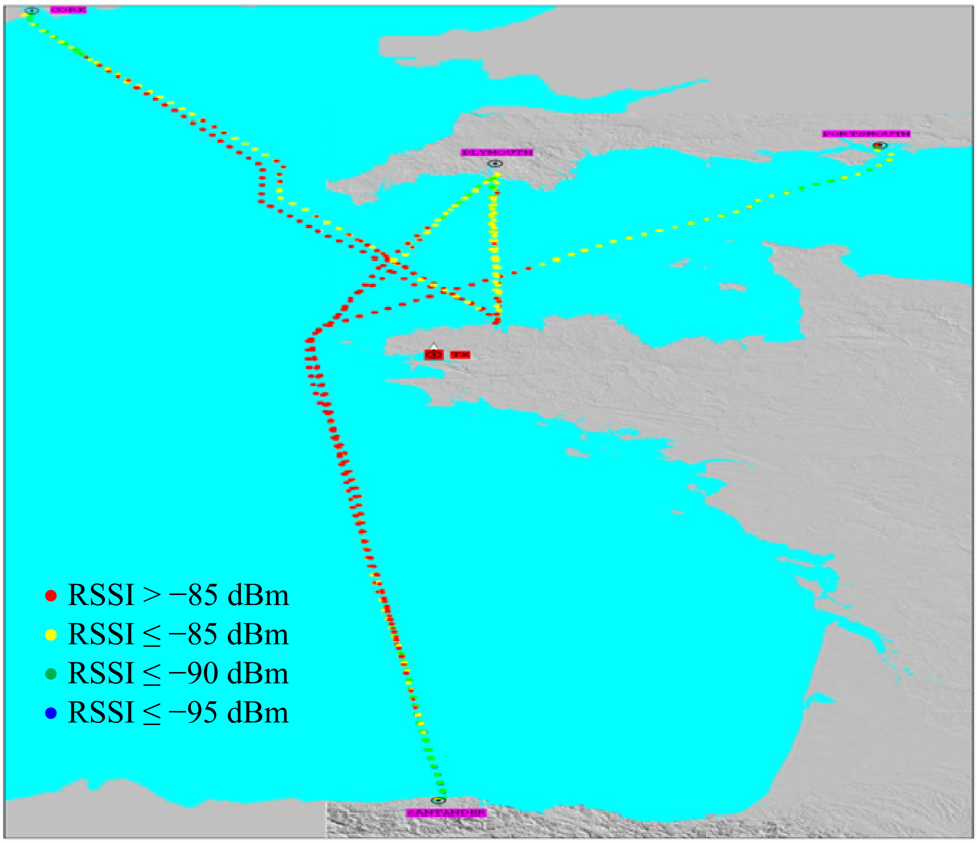


FIGURE 20

SNR (signal to noise ratio) results

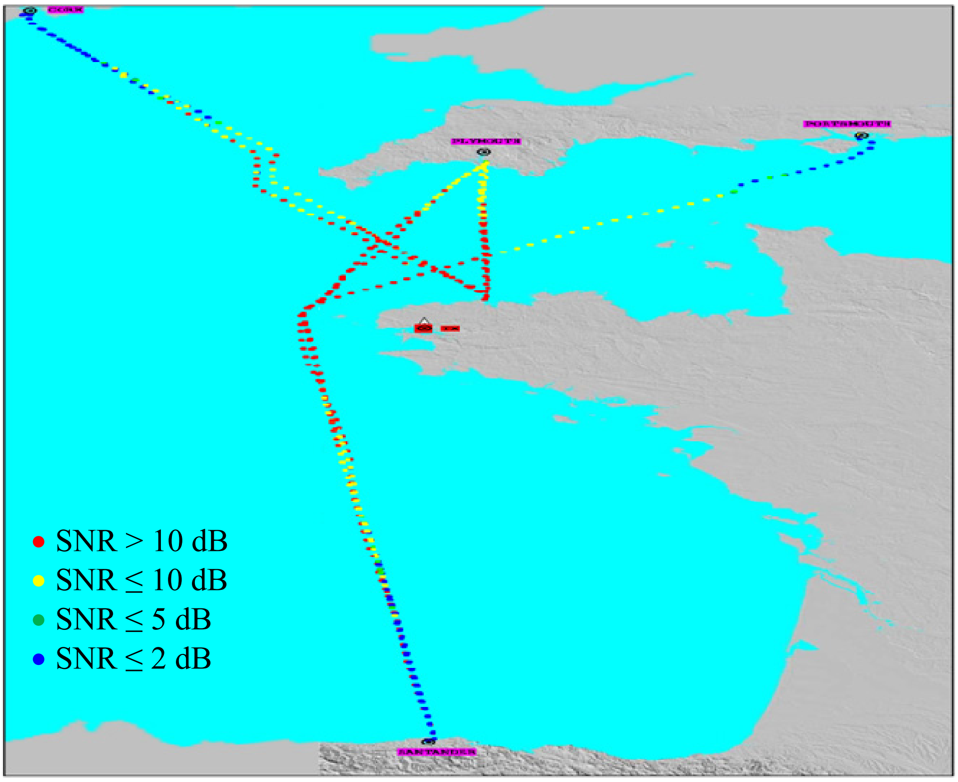
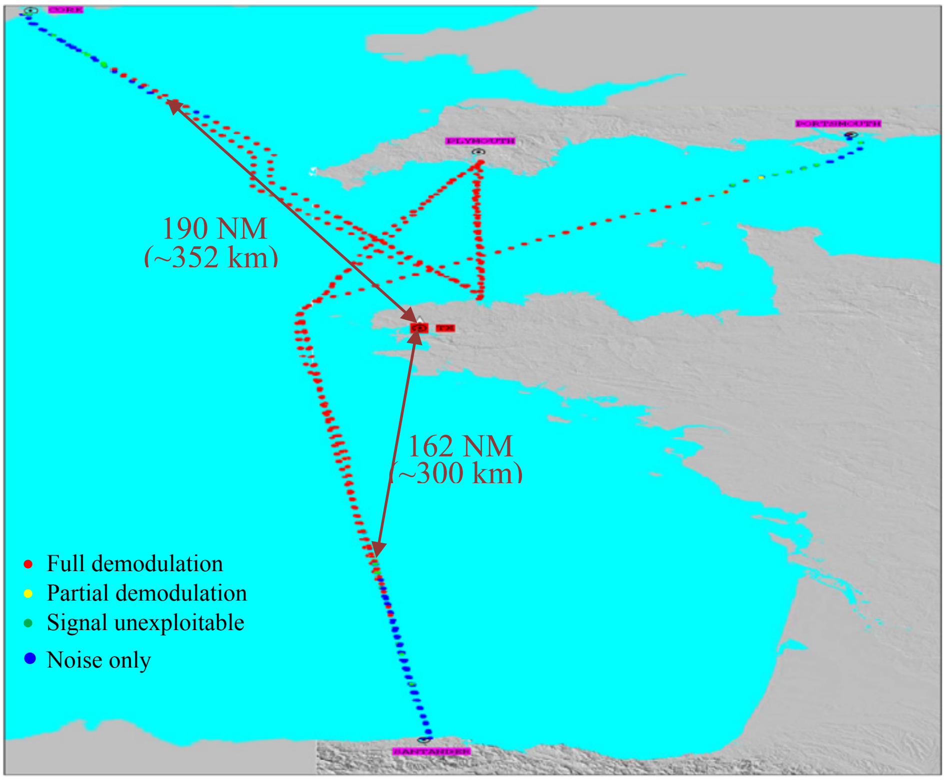


FIGURE 21

Demodulation results



Applying calculations consistent with § 15 to the situation (10 W e.r.p.) with 12 dB attenuation for ground path (around 10 to 25 km from transmitter to the sea), coverage of 165 nautical miles (~306 km) was expected. This is consistent with the field test results.

17 Conclusions

The 495 kHz to 505 kHz band is available for the new system, and the coverage range is sufficient to match the coverage provided by the current NAVTEX system. The new system provides protection to the incumbent NAVTEX system operating at 490 kHz and 518 kHz. New digital technology provides a greatly improved data throughput from that currently provided by the current NAVTEX system.

Further studies on ship-to-shore radiocommunications may be required.