International Telecommunication Union

ITU-R

Radiocommunication Sector of ITU

Report ITU-R M.2443-0

(11/2018)

NAVDAT Guidelines

M Series

Mobile, radiodetermination, amateur and related satellite services

International Telecommunication Union

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REPORT ITU-R M.2443-0

NAVDAT Guidelines

(2018)

Scope

This Report describes the use of the NAVDAT system operating in the mobile maritime service to provide digital broadcasting of safety and security related information from shore to ships. This Report gives information on the implementation of the radio parts of the NAVDAT system and on its overall understanding. These guidelines will be supplemented by the results of future installations of the NAVDAT system.

Keywords

Maritime, NAVDAT, digital, broadcasting

Abbreviations/glossary

BER	Bit error rate
CDU	Control and display unit
COMSAR	Subcommittee of IMO on communications, search and rescue
DRM	Digital radio mondiale
EMC	Electromagnetic compatibility
GNSS	Global navigation satellite system
HF	High frequency
IMO	International Maritime Organization
LF	Low frequency
MF	Medium frequency
MUF	Maximum usable frequency
NAVDAT	Navigational data (the system name)
NAVTEX	Navigational telex (the system name)
NM	nautical mile = 1 852 metres
NVIS	Near vertical incidence skywave
OFDM	Orthogonal frequency division multiplexing
PEP	Peak envelope power
QAM	Quadrature amplitude modulation
RF	Radio frequency
RSSI	Received signal strength indication
SNR	Signal to noise ratio
SOLAS	Safety of life at sea
SWR	Standing wave ratio

Related ITU Recommendations and Reports

Recommendation ITU-R P.368 – Ground-wave propagation curves for frequencies between 10 kHz and 30 MHz

Recommendation ITU-R P.372 – Radio noise

Recommendation ITU-R P.1147 – Prediction of sky-wave field strength at frequencies between about 150 and 1 700 kHz

Recommendation ITU-R P.1321 – Propagation factors affecting systems using digital modulation techniques at LF and MF

Recommendation ITU-R M.1467 – Prediction of sea area A2 and NAVTEX ranges and protection of the A2 global maritime distress and safety system distress watch channel

Recommendation ITU-R M.2010 – Characteristics of a digital system, named Navigational Data for broadcasting maritime safety and security related information from shore-to-ship in the 500 kHz band

Recommendation ITU-R M.2058 – Characteristics of a digital system, named navigational data for broadcasting maritime safety and security related information from shore-to-ship in the maritime HF frequency band

Report ITU-R M 1032 – Radio noise environment on board vessels (withdrawn)

Report ITU-R BS.2144 – Planning parameters and coverage for Digital Radio Mondiale (DRM) broadcasting at frequencies below 30 MHz

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 Introduction

This Report describes the use of NAVDAT system operating in the mobile maritime service to provide digital broadcasting of safety and security related information from shore to ships.

This Report gives information on the implementation of the radio parts of NAVDAT system and on its overall understanding. These guidelines will be supplemented by the results of future installations of the NAVDAT system.

Two NAVDAT frequency bands are used for this purpose:

– Medium frequency (MF) frequency band (500 kHz);

– High frequency (HF) frequency bands (frequencies of RR Appendix **17**).

This Report describes the electrical radio components of the system as well as the parameters used for the coverage calculations.

It does not address digital modulation, coding parts or server system.

2 General principle

Basic rule: Transmit USEFUL information on an APPROPRIATE area.

Broadcast of digital files from shore to ships:

– General for all ships

– Selective

  • By geographical area

  • By group of ships

  • For a specific ship

There is the possibility of encryption for confidential information.

EXAMPLES OF TYPE OF MESSAGES

PRIORITY messages

This kind of text messages can be broadcast at reduced rate (4 quadrature amplitude modulation (QAM) or 16 QUAM) to ensure high signal to noise ratio (SNR) signal strength with large coverage.

Navigational warning

Meteorological warning

Search and rescue

Piracy warning

Ices warning

Distress and emergency

INFORMATIONS for navigation

Meteorological forecast

Local meteorological information

Tides and currents

VTS traffic information

Cartography for ices and icebergs

Aids to navigation states

WIDE services (for example)

Cartography updates

Information for fisherman

3 Usable frequency bands

The WRC-12 allocated the MF frequency of 500 kHz with a 10 kHz radio frequency (RF) channel for the exclusive use of NAVDAT.

However, any frequency in the maritime frequency band 479-526.5 kHz could be used after validation by the administrations concerned in the future.

Recommendation ITU-R M.2010 and Report ITU-R M.2201 describe the MF NAVDAT system.

Recommendation ITU-R M.2058 describes the NAVDAT system in HF and proposes the use of the following frequencies in RR Appendix **17** with a 10 kHz RF channel.

TABLE 1

Channel	Maritime frequency band	Central frequency	Limits
C1	4 MHz	4 226 kHz	4 221 to 4 231 kHz
C2	6 MHz	6 337.5 kHz	6 332.5 to 6 342.5 kHz
C3	8 MHz	8 443 kHz	8 438 to 8 448 kHz
C4	12 MHz	12 663.5 kHz	12 656.5 to 12 668.5 kHz
C5	16 MHz	16 909.5 kHz	16 904.5 to 16 914.5 kHz
C6	22 MHz	22 450.5 kHz	22 445.5 to 22 455.5 kHz

4 The NAVDAT system

The NAVDAT system is a digital file broadcasting system for ships at sea, for navigation, safety and security.

The modulation is orthogonal frequency division multiplexing (OFDM) multi-carriers in a 10 kHz channel maximum.

The subcarriers are orthogonal and modulated in amplitude and phase (QAM). This modulation can be 4 QAM, 16 QAM or 64 QAM with a bandwidth from 1 to 10 kHz.

4.1 Orthogonal frequency division multiplexing parameters

OFDM parameter values are listed in Table 2.

TABLE 2

Orthogonal frequency division multiplexing parameter values

Tu	**1/*Tu***	***Td***	***Ts=Tu+Td***	***Ns***	***Tf***
24 ms	$41^{2/3}$ Hz	2.66 ms	26.66 ms	15	400 ms

Tu: duration of the useful part of an OFDM symbol

1/*Tu*: carrier spacing

Td: duration of the guard interval

Ts: duration of an OFDM symbol

Ns: the number of symbols per frame

Tf: duration of the transmission frame.

4.2 Channel bandwidth

NAVDAT digital broadcast defines different channel bandwidths and determines subcarrier numbers corresponding to different spectrum occupancy rates. Table 3 presented the channel bandwidth value and subcarrier numbers.

TABLE 3

Relationship between channel bandwidth and orthogonal frequency division multiplexing sub-carrier numbers

	Spectrum occupancy			
	1	**2**	**3**	**4**
Channel bandwidth (kHz)	1	3	5	10
Number of subcarriers	23	69	115	229
Subcarrier number k	k = −11 to 11	k = −34 to 34	k = −57 to 57	k = −114 to 114

4.3 Modulation

Every subcarrier is modulated in amplitude and phase (QAM: Quadrature amplitude modulation).

Modulation patterns can be either 64 states (6 bits, 64-QAM), 16 states (4 bits, 16-QAM), or 4 states (2 bits, 4-QAM).

The modulation pattern depends on the desired robustness of the signal.

Pilot signals are integrated into each transmitted symbol allowing:

– to synchronize the receiver;

– to estimate the frequency offset;

– to assess the quality of the transmission channel.

The final data rate depends on the number of sub-carriers modulated by the data. The higher the protection of the channels, and therefore the robustness of the signal, (multipath protection, fading, delay and Doppler effects), there will be less useful sub-carriers.

The error correction coding must then be applied to the raw data rate to obtain the useful bit rate. With a coding efficiency of 0.5 to 0.75, the useful flow rate will be then between 7 to 16/18 kbit/s according to the modulation used (4 to 64 QAM) and only if the required SNR at the receiver's demodulator is reached.

5 Components of the NAVDAT System

Transmitting site with:

– 1 Digital modulator

– 1 Transmitter with RF amplifier

– 1 Antenna Impedance Adapter

– 1 Antenna system with artificial ground plane

– 1 Monitoring equipment

Radio propagation channel

Reception system with:

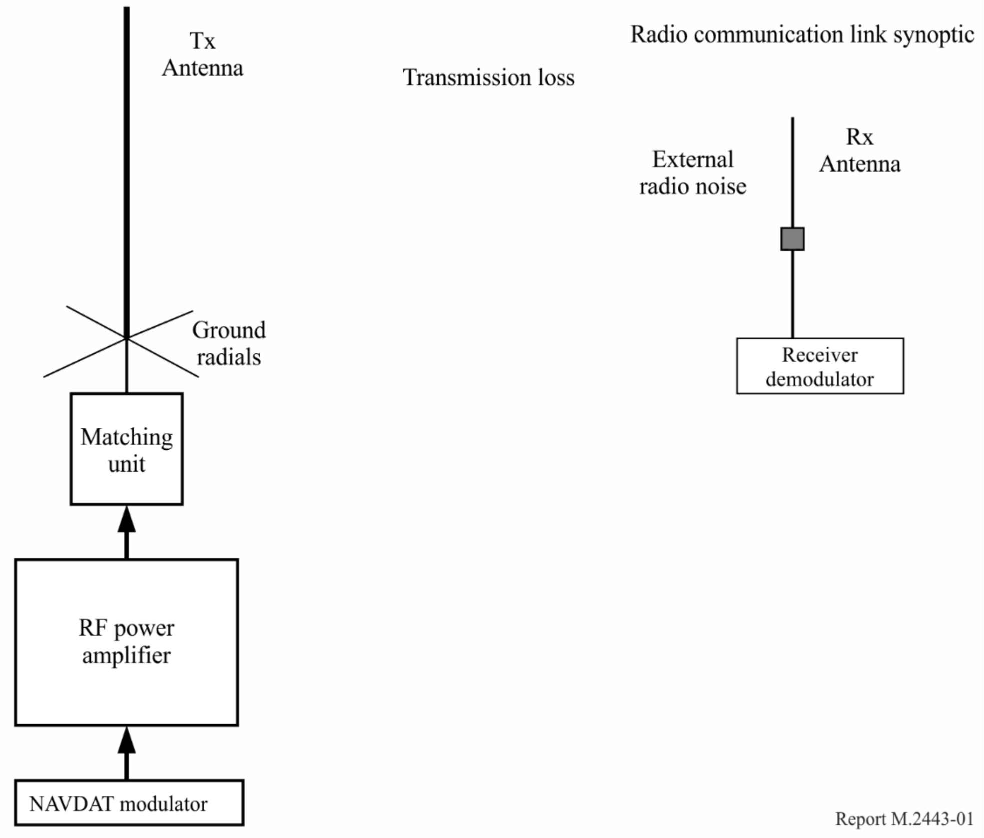
– 1 Receiving antenna

– 1 Receiver

– 1 Global navigation satellite system (GNSS) receiver (or a Lat Long position, time and 1 pps source network).

FIGURE 1

Radio communication link synoptic



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6 Propagation channel

The propagation channel depends on the propagation mode and the frequency used.

Report ITU-R BS.2144 which describes the broadcast DRM with an OFDM modulation defines 4 categories of basic transmission modes that can be used for our analysis:

TABLE 4

Mode	Robustness	Typical propagation condition	Usable frequency band
A	Surface wave channels with minor fading	Surface Wave	MF (500 kHz)
B	Time and frequency selective channel with longer delay spread	Sky Wave	MF and HF
C	As B but with higher Doppler spread	Sky Wave	only HF long range
D	As B but with severe delay and Doppler spread	Sky Wave	only HF long range

For all robustness mode (A to D) 3 different modulations scheme (4, 16 or 64 QAM) can be used with some protection level ratio (0.5 to 0.78).

Due to all these parameters, the NAVDAT system thus offers a high degree of digital broadcasting flexibility.

It is possible to vary the It is possible to vary the type of modulation (4 to 64 QAM), the number of pilot and modulated carriers, the error correction rate as well as the frequency used to adapt to changes in propagation conditions of the radio channel (Seasonal, daily and local time, radio noise) for obtain the right SNR for the right data rate with required bit error rate (BER).

TABLE 5

Summary of expected data rate versus parameters (on 10 kHz as example)

Mode required	Modulation scheme	Protection level	Average code rate	Expect useful data rate (kbit/s)	SNR For BER 10^{-5}
A	4 QAM	0	0.5	6.4	14 dB
		1	0.75	9.6	14 dB
	16 QAM	0	0.5	13	16 dB
		1	0.75	19	18 dB
	64 QAM	0	0.5	19	22 dB
		1	0.62	23	22 dB
		2	0.75	29	24 dB
		3	0.78	30	26 dB
B (for reference only)	4 QAM	0	0.5	6	14 dB
		1	0.62	9.5	14 dB
	16 QAM	0	0.5	10	16 dB
		1	0.62	12.5	16 dB
	64 QAM	0	0.5	15	23 dB
		1	0.62	18	24 dB
		2	0.71	20	25 dB
		3	0.78	23	25 dB
C (given for information only)	4 QAM	0	0.5	5	16 dB
		1	0.62	6.5	16 dB
	16 QAM	0	0.5	7.8	20 dB
		1	0.62	9.8	20 dB
	64 QAM	0	0.5	12	26 dB
		1	0.62	14	26 dB
		2	0.71	16	26 dB
		3	0.78	18	26 dB

6.1 Mode of propagation for MF frequency band

In the MF frequency band, for the 500 kHz frequency, two propagation modes must be considered:

– Surface wave propagation (mainly);

– Propagation by sky wave.

6.1.1 Surface wave propagation

Surface wave signal propagate along the surface of the sea well beyond the optical horizon.

This model of propagation is not dependent upon the ionosphere layers and is very stable on day time.

The polarization of the transmitting and receiving antenna must be vertical.

Recommendation ITU-R P.368 give propagation curves for frequencies between 10 kHz and 30 MHz. Calculations of path loss and field level at any distances can be made with GRWAVE software or equivalent.

Recommendation ITU-R ITU-R P.1321 gives interesting explanation on multipath environment.

In general, shore stations are located near the sea with negligible land / sea distance. In this situation, the following parameters will be taken into consideration:

Sea water: average salinity

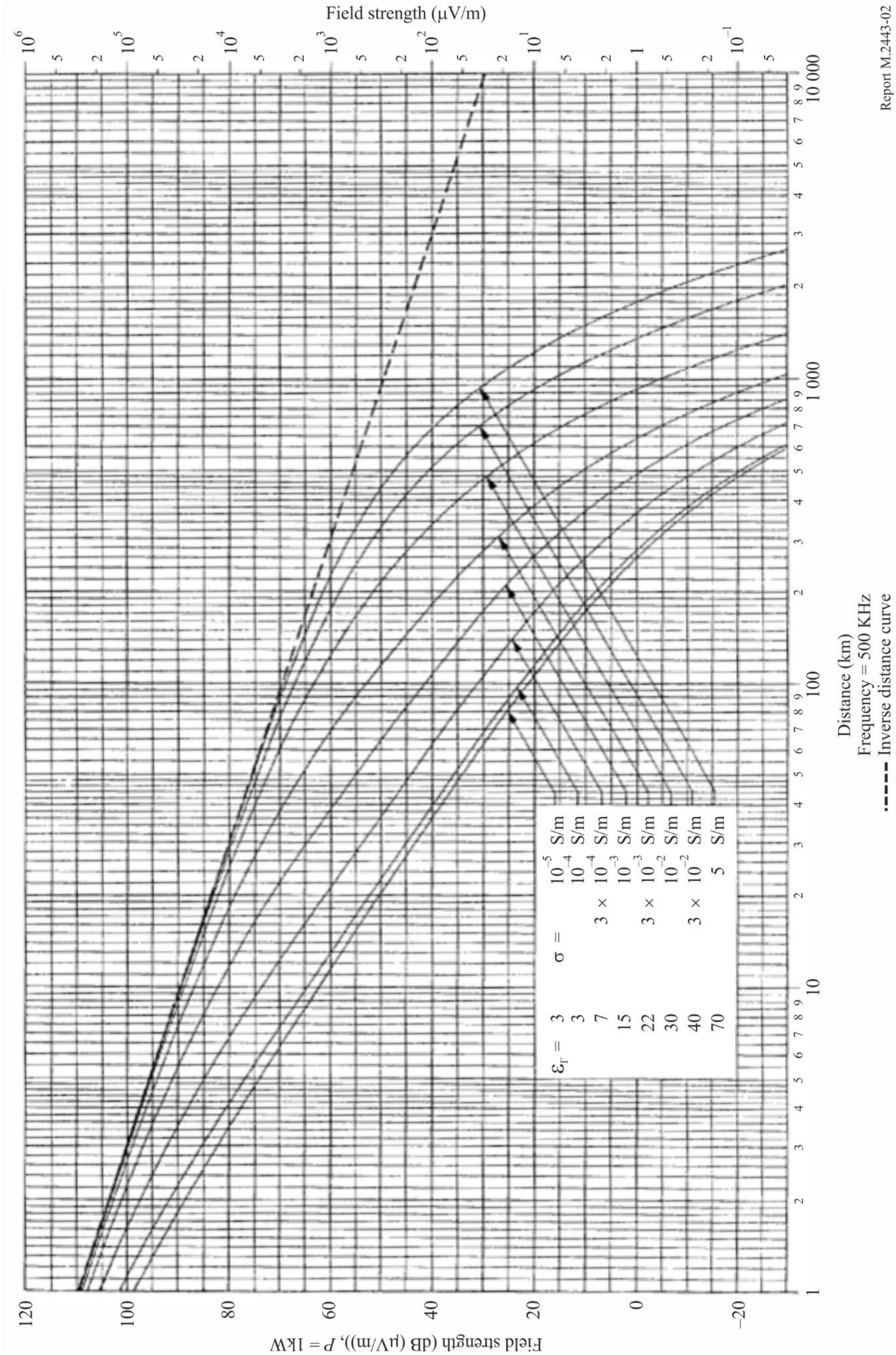
– Permittivity $\varepsilon = 80$

– Conductivity $\sigma = 5$ S/m

For example, with 1 kW e.r.p., for 500 kHz at 500 km, path lost = 88.5 dB

FIGURE 2

Curves example of 500 kHz surface wave propagation



6.1.2 Ionospheric or sky wave propagation

In this mode the radio waves are reflected on different layers of the ionosphere thus allowing long distance links.

However, there is a silent zone (skip zone) between the surface wave coverage and that obtained by reflection on the ionospheric layers. This area is directly related to the radiation pattern of the transmitting antenna (vertical diagram angle may vary from a few degrees to 45 degrees).

FIGURE 3

Ionospheric propagation

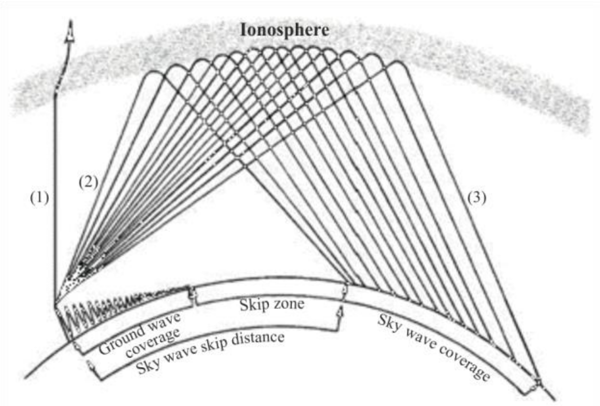


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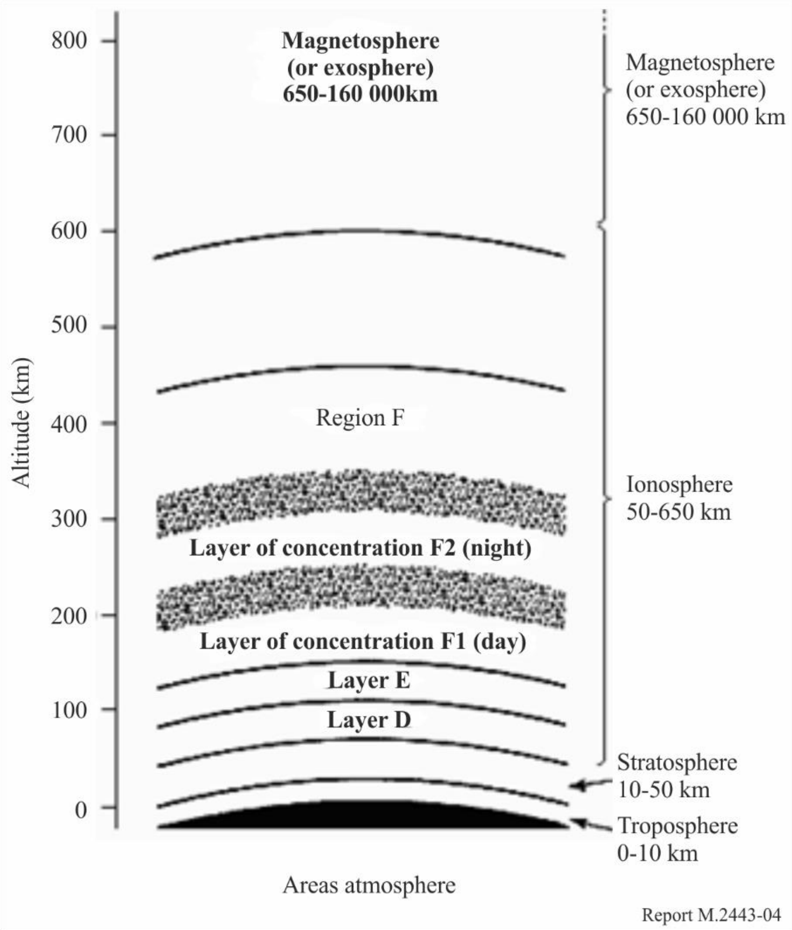
FIGURE 4

Atmosphere zones



Four ionospheric layers are considered

The **D-LAYER** at an average altitude of 80 km; it's permeable to high-frequency waves. Its ionization is proportional to the solar flux. It forms at daybreak and disappears with the sunset. The absorption is inversely proportional to the frequency. Signals up to about 3.5 MHz are completely absorbed during the day time.

The **E-LAYER** from 95 to 150 km; it is a reflective layer. It appears at dawn and disappears at sunset.

The **F-LAYER** from 150 to 400 km; this is the ionized region used for long distance communication. It ionizes at sunrise reaches it's maximum rapidly to gradually decrease at sunset.

During the day the region F is divided in two:

– The layer F1, 150 to 200 km who disappears at night;

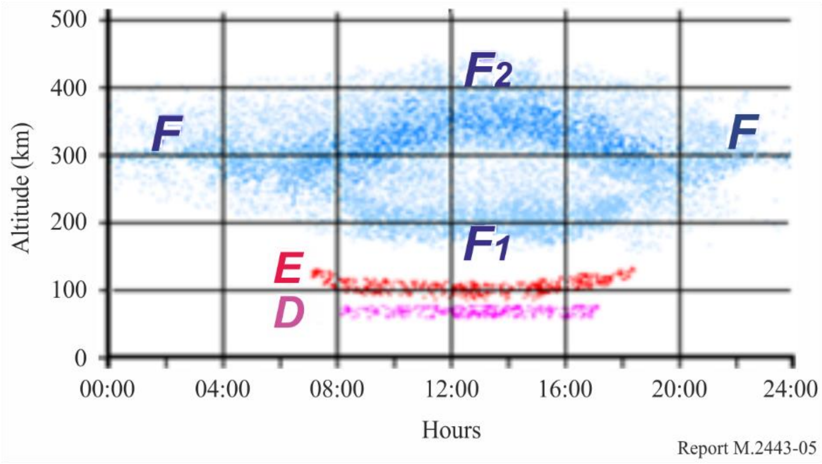
– The layer F2 of 250 to 400 km who is the most interesting layer for HF link.

The**F-LAYER** from 150 to 400 km; this isthe ionized region used for long distance communications. It ionizes at sunrise reaches its maximum rapidly to gradually decrease at sunset. During the day the region F is divided in two:

The layer **F1**, 150 to 200 km disappears at night.

FIGURE 5

Presence of layers according to time of day



Various parameters influence the ionization of the ionospheric layers:

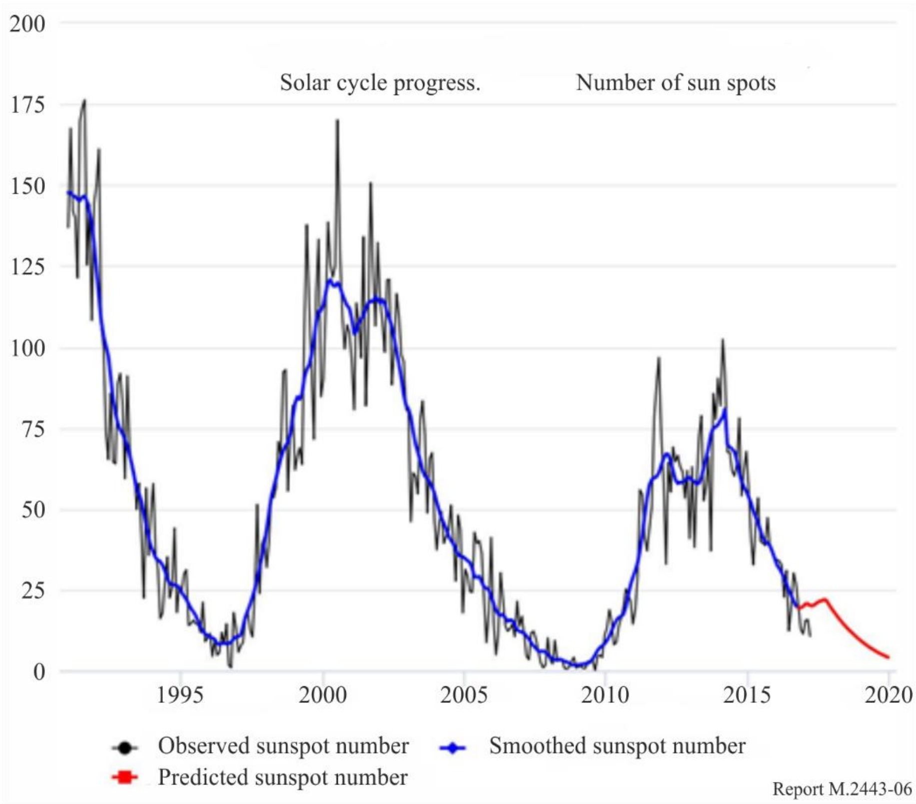
– The intensity of the solar radiation (seasons and hours of the day);

– The number of solar tasks (sunspots over a cycle of about 11 years);

– The geomagnetic activity.

FIGURE 6

Average number of sunspots



At maximum peaks, frequencies up to 30 MHz can be used in ionospheric mode.

At the dip of the peaks these frequencies are less than 20 MHz.

It is therefore necessary to calculate permanently the maximum usable frequency (MUF) (knowing that the frequencies located above the MUF penetrate the ionosphere and continue their paths through space).

Similarly, one calculates the minimum usable frequency or lowest useable frequency below which the signals are totally absorbed.

From the MUF the optimum operating frequency is calculated, which is about 85% of the MUF.

To carry out these calculations, communication prediction software is used.

Recommendation ITU-R P.1147-4, and the Handbook ITU-R "*Ionosphere and its effects on radio wave propagation*", both provide details on sky wave propagation parameters and propose several prediction methods for this mode.

The following parameter combinations are recommended in order to define ionospheric mode propagation channels for HF frequency bands:

1 Good propagation conditions. Differential time 0.5 ms

Frequency spreading 0.1 Hz

2 Mean propagation conditions, Differential delay 1 ms

Frequency spreading 0.5 Hz

3 Poor propagation conditions. Differential delay 2 ms

1 Hz frequency spreading

4 Significant fading through fluctuations

Significant Doppler effect, multiple pathways;

Delay time 0.5 ms

Frequency spreading 1 to 10 Hz.

NOTE – The ionospheric propagation (sky wave) should not normally be sought for the NAVDAT system at 500 kHz. This spread can interfere at long distance (after the skip zone) with other NAVDAT coast stations.

This ionospheric propagation will be directly linked to the radiation pattern (angle of the site) of the transmitting antenna which should be kept as low as possible (see § 8). RF power can also be reduced during this period.

6.2 Mode of propagation in HF frequency band

In the HF frequency band 4 to 30 MHz, two propagation modes can be also considered.

– Surface wave

– Skywave.

6.2.1 Surface wave propagation

As for the 500 kHz we can use the surface wave propagation as a main mode of propagation with the advantage of good signal stability. The radio noise in HF frequency band is considerably lower than that existing in the MF frequency band.

The antennas, transmitting and receiving, must be in vertical polarization.

The selected surface parameters are the same:

Sea water:	average salinity
Permittivity	$\varepsilon = 70$
Conductivity	$\sigma = 5$ S/m

TABLE 6

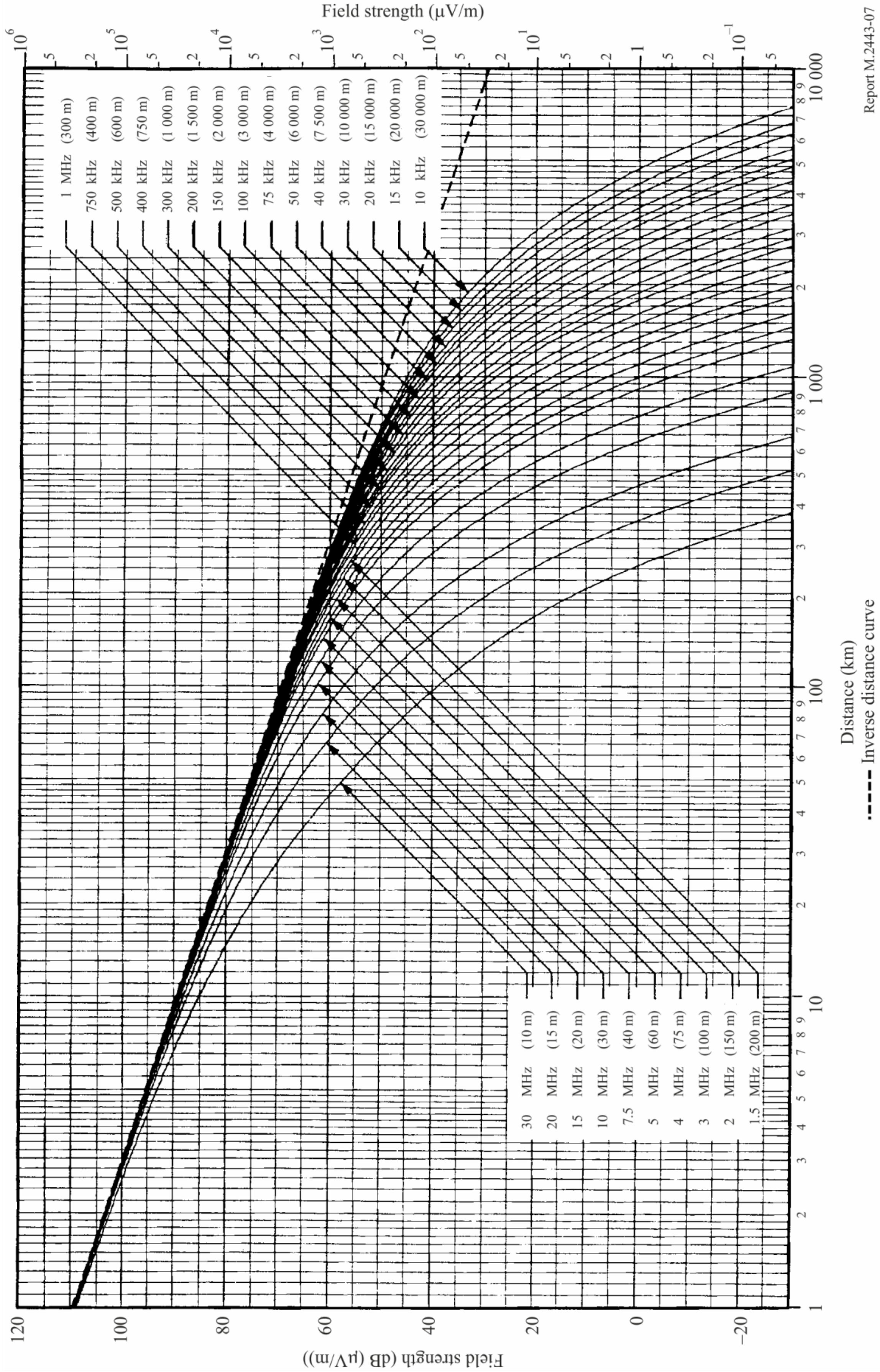
Usable distance is inversely proportional to the frequency

Frequency (kHz)	Distance for 100 dB loss (km)	Distance for 110 dB loss (km)
4 200	272	400
6 340	200	300
8 500	150	230
12 660	100	160
16 900	72	115
22 500	50	75

In tropical areas, where radio noise is high, the frequency of 4 200 and 6 340 kHz are interesting.Other frequencies can be used for regional or local coverage.

FIGURE 7

Example of propagation curves from Recommendation ITU-R P.368-9



6.2.2 Sky wave propagation

This propagation mode corresponds to the same rules described in the 500 kHz sky wave analysis.

Except for the voluntary target for wide range coverage, this mode is not very suitable for the NAVDAT system. To broadcast NAVDAT messages at thousands of km does not really make sense. However, we can also consider the near vertical incidence sky wave (NVIS).

6.2.3 Near vertical incidence sky wave propagation

NVIS in HF frequency band is regularly used for broadcasting to large areas in tropical regions where the LF and the MF frequency bands are heavily attenuated and noisily. It is also used to fill the skip zone which is the area of silence or a zone of no reception extending from outer limit of ground wave communication to the inner limit of sky wave communication (first hop) It is possible to obtain a coverage of approximately 200 km centred on the transmitter.

NVIS utilizes the same principles of ordinary sky wave transmissions. The key factor in this operation is the antenna. For effective HF communication using this NVIS mode, the antenna must radiate its main beam energy at a very high angle, near vertical. The objective is to launch a wave nearly directly upward from the antenna to the ionospheric layer. The transmit antenna will be in horizontal polarization. This implies that the receiving antenna should also be preferably in horizontal polarization. Otherwise we will have a loss of polarization.

The best performance for this type of operation is to use frequencies from 3 to 6 MHz; NVIS circuits also suffer the same impairments as long distance sky wave circuits, but in this specific case the delay spread and the Doppler spread are more severe.

At certain times of day, such as dawn and dusk, these reflections can have similar energy and be spread over a period of several milliseconds. In order to prevent destructive interference it is important to ensure that these reflections arrive inside the guard interval of the OFDM frame otherwise the system will fail. At the same time as these multiple impulses are observed they can also be subject to high values of Doppler spread. This is due to the constant movement of the reflecting layers and is more significant compared to long path reflections, due to the fact that for NVIS the movement represents a greater proportion of the ground to ionospheric distance. The result of the conjunction of these two phenomena is simultaneously the high values of delay and Doppler spread. This can only be overcome by the use of a long guard interval in conjunction with wider frequency spacing for the OFDM carriers. However, because the signal strength can be quite high due to the short paths, signal to noise ratio is often not the limiting factor in NVIS.

FIGURE 8

Near vertical incidence skywave propagation

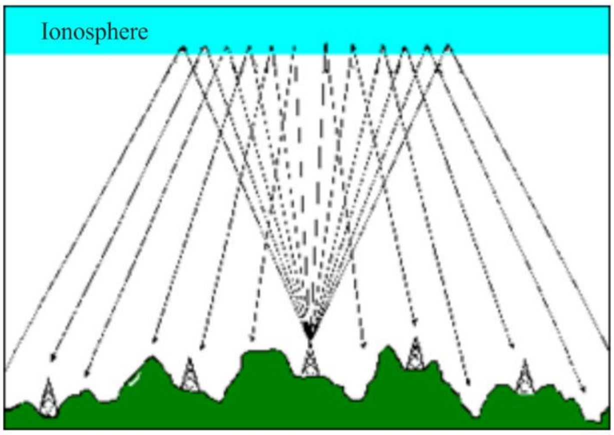


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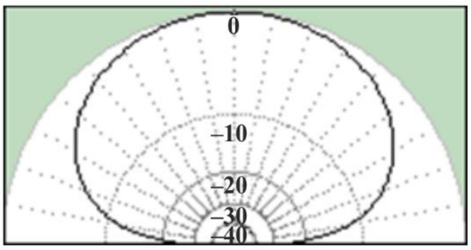
FIGURE 9

Horizontal dipole antenna at 0.12 λ



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7 Transmitter

To ensure transmission without distortion of an OFDM multicarrier modulation, the transmitter must be linear and have a high dynamic range.

The spectral occupation must respect the template to avoid interferences in adjacent channels or splash caused by saturations.

Because OFDM uses a big number of carriers, transmitters must produce only minimal intermodulation distortion products. Signal OFDM is a complex digital signal represented by I (inphase) and Q (quadrature phase) components. Resultant composite signal has simultaneous amplitude and phase modulation with a peak-to-average ratio (crest factor) about 8/10 dB.

7.1 Crest factor

Usually a crest factor of at least 8/10 dB is applied for keep low distortion. That is to say that the RF powers of given peak envelope power (PEP) given one will obtain average RF power (for 8 dB crest factor):

TABLE 7

Radiated RF power versus transmitter peak envelope power

TX PEP RF power	1 kW	3 kW	5 kW	10 kW	15 kW	20 kW
dBm	60	64.8	67	70	71.8	73
Crest Factor	*−8 dB*	*−8 dB*	*−8 dB*	*−8 dB*	*−8 dB*	*−8 dB*
RF power **Rms dBm** **kW**	*52* *0.16*	*56.8* *0.480*	*59* *0.795*	*62* *1.6*	*63.8* *2.4*	*65* *3.16*
Antenna Efficiency 35% (−4.6 dB)	*−4.6 dB*	*−4.6 dB*	*−4.6 dB*	*−4.6 dB*	*−4.6 dB*	*−4.6 dB*
Radiated RF power dBm **kW**	*47.4* *0.055*	*52.2* *0.166*	*54.4* *0.276*	*57.4* *0.550*	*59.2* *0.832*	*60.4* *1.10*
Antenna Efficiency 25% (−6.0 dB)	*−6.0 dB*	*−6.0 dB*	*−6.0 dB*	*−6.0 dB*	*−6.0 dB*	*−6.0 dB*
Radiated RF power dBm **kW**	*46.0* *0.040*	*50.8* *0.120*	*53.0* *0.199*	*56.0* *0.400*	*57.8* *0.600*	*59.0* *0.790*

7.2 Pre-correction

It is of course possible to manufacture linear amplifiers, but their efficiency is very poor, typically 20 to 30%, with a high operating cost. In addition, they require large cooling systems.

The fundamental requirement for the NAVDAT OFDM signal is to keep without distortion all I/Q components of modulation.

If the signal is distorted, errors will be introduced and the BER may fall to unacceptable level and the NAVDAT signal become unusable and/or out-of-band radiation are excessive. To avoid distortion, the RF power amplifier must therefore have a linear transfer function such that the output signal is an exact replica of the input but at a higher power level.

The development of new modulation technologies for broadcasting digital transmitters has led to several pre-correction processes.

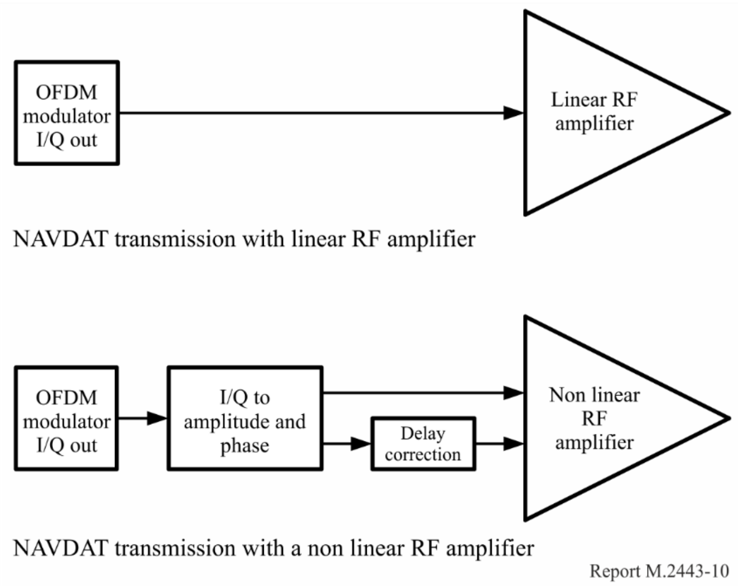
Non-linear amplification:

The OFDM signal is a complex digital signal represented by (I) for the in-phase and (Q) for the quadrature phase component. The optimum solution is “non-linear” high efficiency amplifiers which are capable of transmitting on all digital signals. In order to operate with a high efficiency amplifier, it is necessary to use envelope elimination and restoration or equivalent. To carry out this approach, it is necessary to convert the (I) and (Q) waveform into an amplitude (r) and phase (φ) component. This conversion allows a “non-linear” transmitter to amplify the Amplitude (r) and Phase (φ) signals separately, and to then reconstructed the (i) and (q) waveform in the modulation process.

This type of process greatly increases the overall efficiency of the amplifier (AC to RF), which can reach more than 75% with a significant reduction in cost.

FIGURE 10

Linear and non-linear RF amplifier



7.3 NAVDAT transmitter performances and minimal specifications

Frequency band	455 to 550 kHz for MF frequency band
	4 to 23 MHz for HF frequency band
Spectrum occupation	See Fig. 11.
Carrier frequency error	±2.5 Hz (The 1 pps signal received from a GNSS system can be used for the calibration of RF generators).

Spurious emissions ≥ 50 dBc, without exceeding the absolute mean power of 50 mW (+17 dBm).

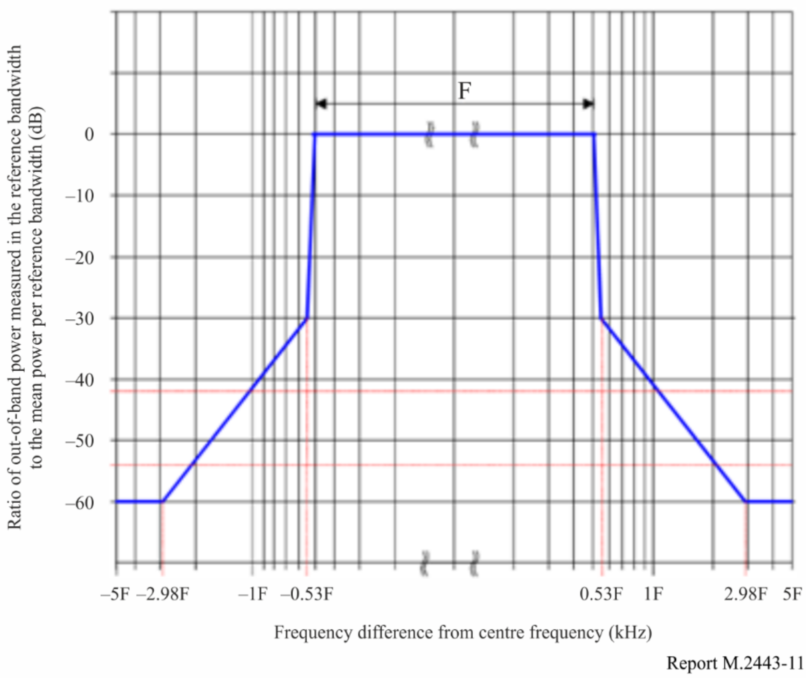
Modulation Error Ratio ≥ 30 dB for 10 kHz bandwidth.

RF power output, in accordance with the expected coverage and the antenna efficiency.

7.3.1 Spectral occupancy of RF signal

FIGURE 11

Spectral occupation of NAVDAT RF signal with bandwidth F = 10 kHz



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8 Transmitting antennas

Surface wave propagation requires antennas in vertical polarization.

8.1.1 MF antenna 500 kHz

Reminder: For the frequency of 500 kHz the wavelength is 600 m. A quarter wave antenna would therefore have a height of 150 m! This type of antenna will rarely be used because of the cost of installation and maintenance. More realistically, shortened vertical antennas with terminal capacity are generally used.

These antennas, called ***T ANTENNA***, require, like any vertical antenna, a very good quality for the artificial ground plane to ensure the lowest possible radiation angle and reduce soil losses.

The overall efficiency of these antennas depends on several factors:

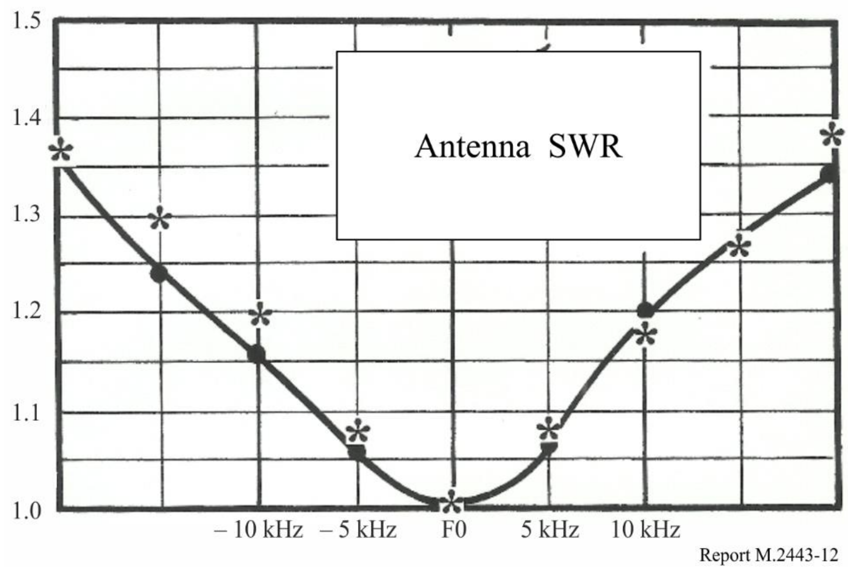
– The height of the monopole (0.07 λ or more);
– The size of the top capacity;
– The quality of the artificial ground plane;
– The quality of the matching unit;
– The adequacy between the Q coefficient of the matching coil and the antenna bandwidth.

Moreover, it may show a standing wave ratio (SWR) lower than 1.2:1 in a total band of 14 kHz centred to 500 kHz this to ensure a good transmission of OFDM signals.

From these various elements, the overall efficiency of such a transmitting antenna can vary between 10 to 35%.

FIGURE 12

Antenna standing wave ratio typical curve



8.1.2 Top-loaded antenna

– Efficiency could be very high when the antenna height is higher than 0.07 λ and with an artificial ground plane of 0.25 λ of radius (150 m) and 120 radials in medium frequency band. Field strength will be close to a quarter-wave monopole case.

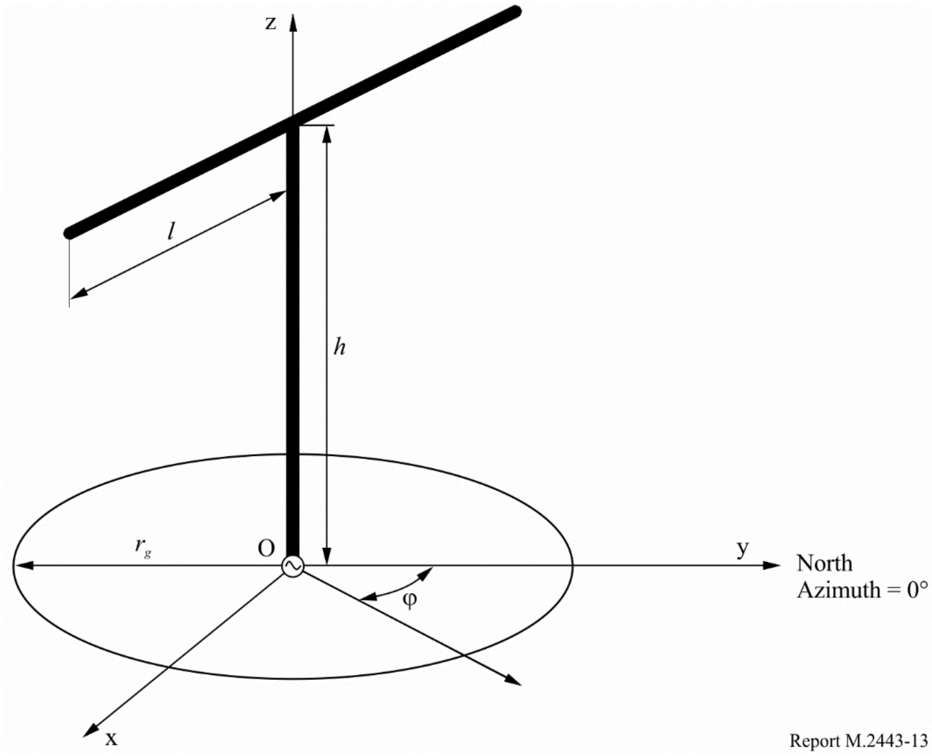
– Radiation resistance is not only a function of the antenna height, but also a function of the RF current relationship at the top and the base of the monopole.

It is often difficult, if not impossible, to realize a ground plane of 0.25 λ. In general, ground plane made up of 36 / 72 radians with a length at minimum equal to the vertical monopole are more realistic.

This has the consequence of increasing the ground plane resistance Rg and therefore the losses in this ground plane reducing the overall efficiency of the antenna. This loss, however, has the advantage of increasing the bandwidth of the antenna.

FIGURE 13

T-antenna



Capacitive top antenna system requires support at either end from 2 towers. The radiator section is the center vertical wire fed via high voltage insulators and corona shield

FIGURE 14

T antenna configuration

The horizontal parts, constituting the top capacity, must be symmetrical to avoid any sky wave radiation. (For symmetrical strands the currents in the two horizontal parts cancel each other out).

Indeed any radiation of this horizontal part would give a NVIS propagation mode that would interfere with the surface wave.

The top capacity will preferably be horizontal and not in the form of an umbrella, in order to maintain a linear RF current in the vertical monopole.

FIGURE 15

Vertical monopole current distribution

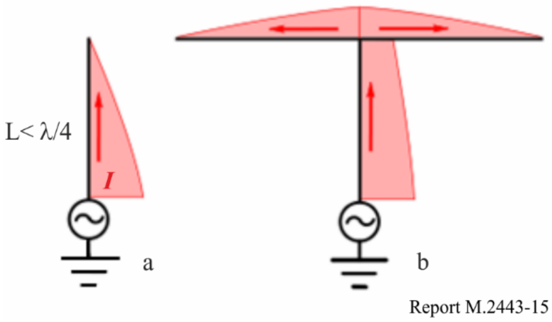


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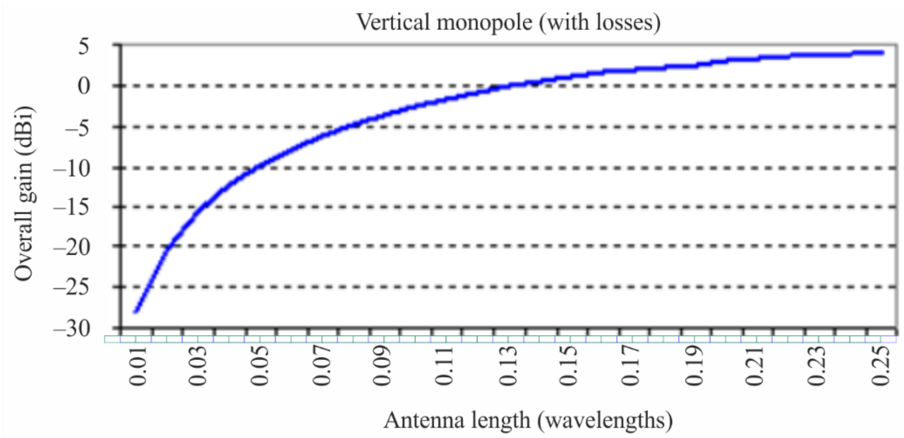
FIGURE 16



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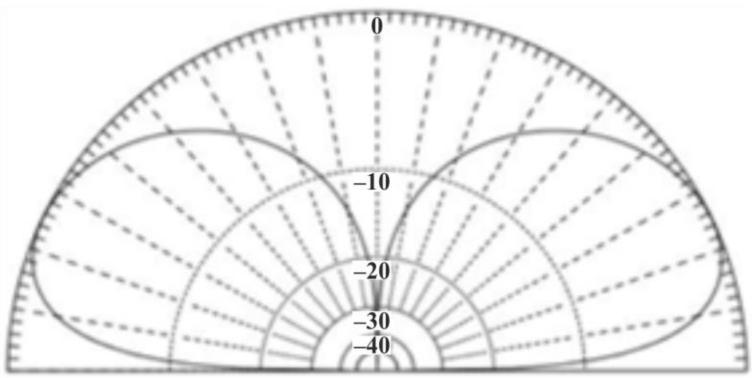
The diagram above gives the relative gain of the shortened vertical part related to its physical length compared to the wavelength of the frequency used (for example, F = 500 kHz λ = 600 m if the vertical part is equal to 30 m, ratio in wavelengths is: 0.05. In this case the relative gain is: −10 dB).

FIGURE 17

The site angle is directly related to the quality of the ground plane



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8.1.3 Theoretical calculations

TABLE 8

Theoretical calculations

Vertical monopole height	**Units**	**45 m (0.075 λ)**	**36 m (0.06 λ)**	**30 m (0.058 λ)**
Horizontal wires length (top capacity): 3X	m	50	36	30
Estimate Rg (ground)	Ω	3	3	3
He	m	38	32	25
Rr	Ω	6.5	4.5	3
Xc (-j)	Ω	208	282	336
IA	A	7.5	7.9	8
Loss in L matching	W	236	350	425
Loss in ground	W	170	186	189
Loss in material	W	27	27	27
RF TX output	W	1 000	1 000	1 000
e.r.p.	W	406	277	196
Total efficiency of antenna system	%	40	28	15
Bandwidth (x)	kHz	36	25	19

(x) Is the total bandwidth of the antenna for SWR < 2:1.

8.1.4 Environmental resistance

Since NAVDAT antennas are by definition installed on the coast, near the sea, they must be able to withstand the climatic conditions linked to this situation.

– Wind: Resistance to winds of 160 km/h without ice;
– Rain: Precipitation should not affect the insulation of the radiating parts;
– Atmospheric discharges: Atmospheric discharge systems will be installed and re-connected to the earth network;
– Anti-corona systems will be placed on the insulators;
– Gas or air spark gaps will be installed on the antenna lines and / or on the coaxial cables;
– A complete lightning protection for electrical network and building with good ground reference.

FIGURE 18

Base isolator with air gap

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FIGURE 19

Anticorona coupole

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8.1.5 Impedance matching unit

To compensate the capacitive reactance of the antenna, an adjustable coil is used which can be completed by a variometer.

It is a significant loss vector. The coil must be made of high-quality materials and must not have any significant coupling with its protective case. It must be large enough to minimize losses.

FIGURE 20

Matching coils

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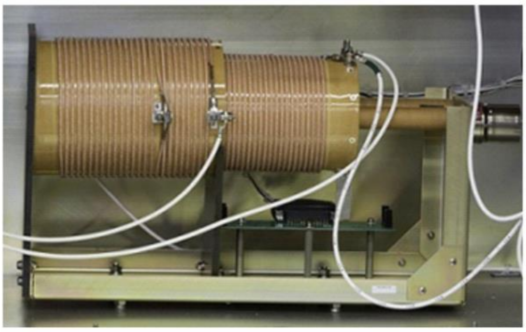
FIGURE 21

Variometer



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Some industrial realization from well-known Canadian manufacturer

8.1.6 Artificial ground plane

As mentioned before the antenna current "returns" via the soil to the feeding point of the antenna. By adding a radial system and/or ground rod(s) the ground loss can be reduced. The radial system contains several wires on or in the soil. Generally buried radials of bare wire are superior to radials on the ground or buried isolated radials. Buried radials should be at least 15 cm deep in the soil. Although blank copper radials can be used, galvanized iron radials are cheaper and will be less affected by corrosion. Regarding the number of radials and their length the rule is simple: the more and the longer, the better. But there are some practical limits, once you have put a certain length of radials in the soils further extension of the radial system will only result in a marginal reduction of the ground loss.

In general, the efficiency of a radial system is based on:

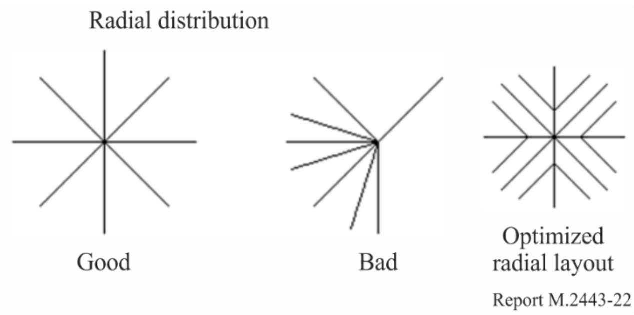
– The total length of the radial system: Within reasonable limits a smaller number of long radials will give the same result as a larger number of short radials (e.g. 10 radials of 30 m each will roughly equal to 20 radials of 15 m each).

– The soil conductivity: The lower the soil conductivity is, the less efficient the radial system.

– Other environmental losses: The higher eventual other environmental losses are, the less efficient the radial system.

FIGURE 22

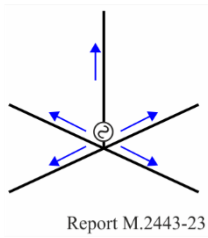
Radials



Best results are achieved when the radials are equally distributed over the area below the antenna (see left picture). Placing two radials too close is not very effective and will hardly bring any improvement over a single radial. Depending on the soil conductivity, radials need to be spaced at least 2 m to 10 m for optimal effect. When using many radials an optimized layout can reduce the amount of wire needed (and the work to bury the radials) without losing efficiency (see right picture).In addition to radials, ground rods can reduce the ground loss. These rods can be located at the feeding point of the antenna or at the end of the radials.

FIGURE 23

Current distribution in monopole and ground plane



8.2 HF transmitting antenna

Three modes of operation for HF frequencies can be considered:

– Surface wave propagation;

– Propagation by sky wave;

– NVIS propagation even though the use of this mode is not really recommended for the NAVDAT system due to multipaths thus created.

8.2.1 Surface wave propagation

The antenna polarization will be vertical.

The antenna will consist of a vertical monopole above a ground plane.

The physical height recommended for the vertical monopole is equal to the quarter wave.

TABLE 9

Frequency	**λ**	**λ/4**	**Minimal artificial ground plane**
4 200 kHz	71.42 m	17.86 m	36 × 20 m
6 340 kHz	47.32 m	11.83 m	36 × 12 m
8 500 kHz	35.30 m	8.83 m	36 × 10 m
12 660 kHz	23.70 m	5.93 m	36 × 6 m
16 900 kHz	17.75 m	4.44 m	36 × 5 m
22 500 kHz	13.33 m	3.33 m	36 × 4 m

As for the MF antenna, the quality of the ground plane will be decisive for the elevation angle value of the antenna radiation pattern which must be kept as low as possible to minimize the sky wave propagation. In contrast to the antenna 500 kHz the dimensions of the antennas HF facilitate their installations. The efficiency of these antennas is also high, making it possible to use lower transmitter RF power. The use of frequencies 4 MHz and 6 MHz can be very advantageous for the tropical regions or the atmospheric noise is very high. Regional or local coverage such as for some critical maritime routes or large harbour as example are in fact very easy to implement.

The usable distance is inversely proportional to the frequency.

TABLE 10

Theoretical losses on sea surface propagation for HF frequencies

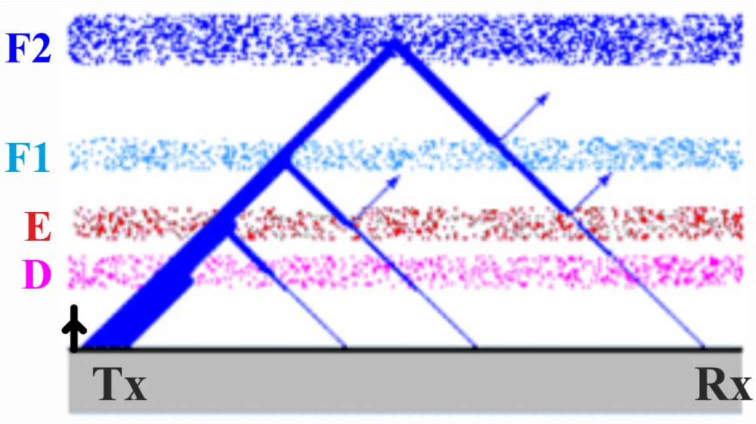
Frequency (kHz)	**Distance for 100 dB loss (km)**	**Distance for 110 dB loss (km)**
4 200	272	400
6 340	200	300
8 500	150	230
12 660	100	160
16 900	72	115
22 500	50	75

8.2.2 Sky wave propagation

This mode of propagation makes it possible to cover an important zone at great distance, beyond the skip zone, via a reflection on the ionospheric layers. Remember that this type of propagation creates a skip zone.

FIGURE 24

Distance and coverage with ionospheric layers



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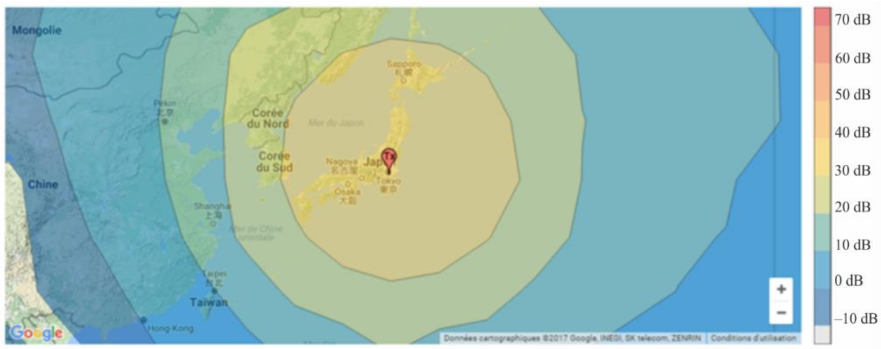
The distance and coverage area will depend on the frequency and the layer used (see § 6.1.2).

FIGURE 25

Sky wave propagation



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Example of 8 MHz sky wave propagation for TOKYO area.

8.2.3 Near vertical incident sky wave

NVIS mode is also possible with horizontal antenna for obtain vertical beam with the advantage to suppress the skip zone but with important multipath and Doppler.

Again, it is recalled that the broadcast of NAVDAT messages to thousands of km is not consistent.

Basic rule: Transmit USEFUL information on an APPROPRIATE area.

9 Radio noise

FIGURE 26

Determination of required carrier-to-noise-ratio

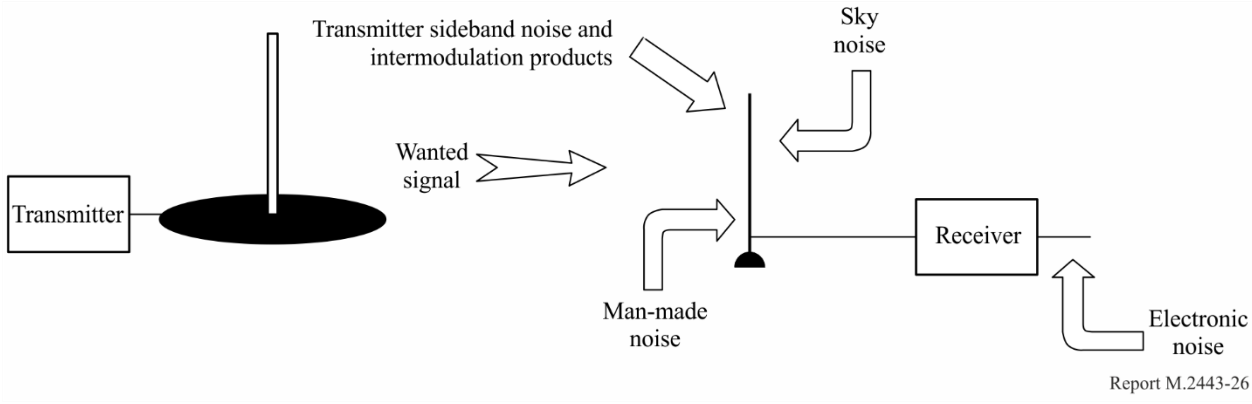
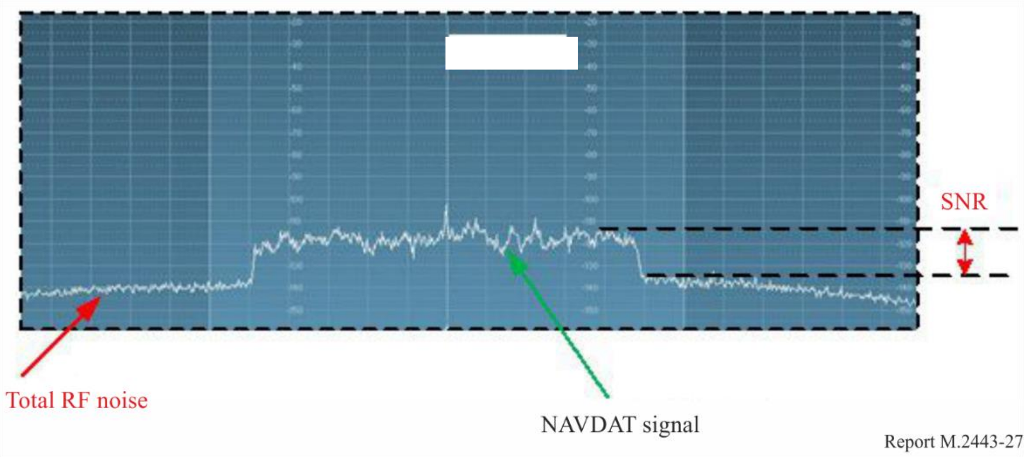


FIGURE 27

RF signal at the receiving antenna



9.1 Noise contribution

The signal coming to the antenna contains many other components in addition to the received power from the transmitter. Most of these are from undesired radio transmissions which we will call interferences. Some of these are from other man-made sources such as electric power distribution, electric sparks in rotating equipment such as electric motors and spark plugs. Some noise is from natural sources such as lightning and solar flares.

The external noise decreased with the increase of the frequency. NAVDAT MF use the 500 kHz that is medium frequency and NAVDAT HF can use frequencies from 4 to 22.5 MHz.

Atmospheric noise is the result of natural electrical activity (thunderstorms) in the earth's atmosphere, propagated over very long distance.

The level of this noise is strongly dependent on the season of the year as well as on the time of the day and also the geographical location of the receiver, especially in tropical areas (See Recommendation ITU-R P.372).

The ***Fa*** (noise factor) defined in Recommendation ITU-R P.372 accounts for three types of noises: Sky noise, man-made noise, and galactic noise.

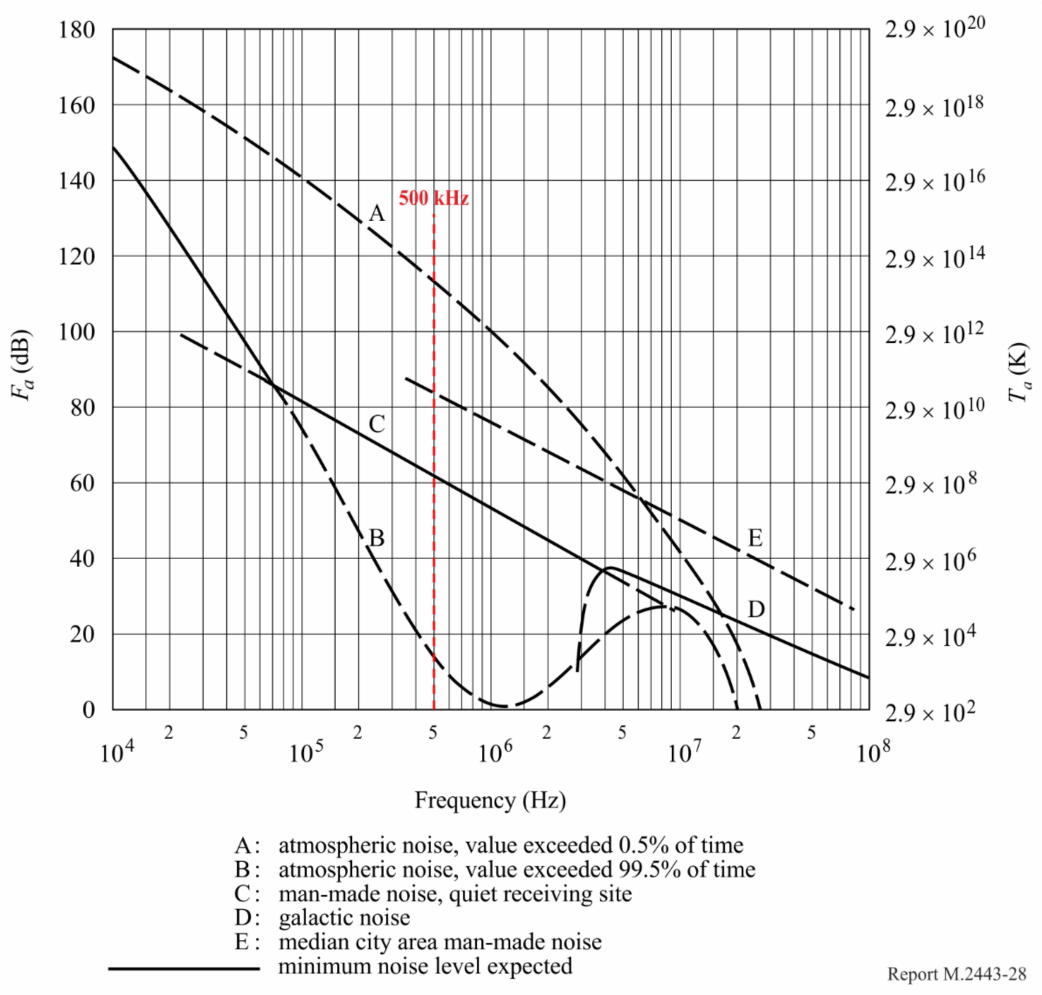
We can expect noises levels with NOISEDAT software for medium value of ***Fam***.

Man-made noise on board a vessel is mainly from electrical sources.

It is therefore necessary to install the receiving antenna as far as possible from sources of electrical interference or to use antenna less sensitive to electrical noise.

FIGURE 28

Total radio noise from Recommendation ITU-R P.372



9.1.1 Estimated man-made noise

Accounting for ships topside noise

There are multiple sources of radio electric noise on board vessels:

– Propulsion Motors

– Power Supplies and electrical networks

– Navigational equipment

– Radio communication equipment

– Leisure facilities.

The first studies on this subject date from 1986/1990 (Report ITU-R M.1032-1).

Since that time, the problem of electromagnetic compatibility (EMC) has been seriously taken into account in order to ensure the proper functioning of equipment in a given environment.

Specific standards have been developed for the testing of each type of equipment which will be installed on board vessels: standard IEC 60945. Then a standard concerning the whole of a steel vessel shell became applicable: standard IEC 60533.

IEC 60533:2015(E) specifies minimum requirements for emission, immunity, and performance criteria regarding EMC of electrical and electronic equipment for ships with metallic hull. This International Standard assist in meeting the relevant EMC requirements as stated in SOLAS 74, Chapter IV, Regulation 6 and Chapter V, Regulation 17. Reference to this International Standard is made in International Maritime Organization (IMO) Resolution A.813 (19).

The IMO Circular COMSAR / circ 32 recall the prevention of interference to radio reception on board ships. Since Recommendation ITU-R M.1467-1 ambient radio noise on board ships has been taken into account. This noise captured by the antenna was subdivided into several categories:

TABLE 11

Rec. ITU-R M.1467-1 (Table 2), Naval environmental categories for top-side noise

Environmental category	dB below 1 W ref. 3 MHz
DOD Cat 1 mobile platform	−137.0
IPS ship (ASAPS and GWPS)	−142.0
AGARD ship	−148.0
Quasi-minimum noise	−156.7
Noise galactic (Rec. ITU-R P.372)	−163.6

ASAPS: Advanced stand-alone prediction system

GWPS: Groundwave prediction system

Table 11 shows a number of published figures, and for reference purposes including galactic and quasi-minimal noise levels, which are accepted as representing the best achievable noise floor.

The levels of noise to be expected on commercial vessels were estimated between these figures. The level of −142 dBW had been accepted as representing the noise level encountered on container vessels, pleasure cruisers, and utility ships.

The application of EMC standards in recent years for equipment and ships suggests that this reference of −142 dBW can be revised.

Despite the increase in equipments installed on board the ships, the EMC protections have improved considerably, resulting in a reduction in the radio noise at the antennas. It would be interesting to conduct an updated measurement campaign on this subject.

A gain of 3 dB appears realistic or a reference of -145 dBW, which corresponds to the RESIDENTIAL category in Recommendation ITU-R P.372-13.

This figure is required for entry into NOISEDAT and other programs.

The Recommendation ITU-R P.372-13 gives the relationships between the levels of manmade noise in four environments:

– Quiet rural
– Rural
– Residential
– Business.

But in tropical areas the atmospheric noise levels are higher than other sources of noise.

9.1.2 NOISEDAT OUTPUT 500 kHz examples

LAT = 1.20, LONG = 103.59, **SINGAPORE**

WINTER, FMHZ = 0.500, 3 MHZ MANMADE NOISE = -142 DBW

--MEDIAN NOISE VALUES, FA(DB)-- STATISTICAL VALUES IN DB

					OVERALL NOISE				
TIME BLOCK	ATMO	GAL	MANMADE	OVERALL	DL	DU	SL	SM	SU
0000-0400	90.7	58.9	83.6	91.7	8.2	10.6	2.1	4.0	2.9
0400-0800	81.8	58.9	83.6	83.5	12.1	14.2	5.2	6.3	4.7
0800-1200	65.7	58.9	83.6	83.7	5.9	9.6	1.5	5.2	1.5
1200-1600	76.0	58.9	83.6	85.1	5.5	9.2	1.4	3.8	1.6
1600-2000	86.0	58.9	83.6	86.7	11.0	14.2	4.3	5.0	4.1
2000-2400	92.3	58.9	83.6	93.1	7.6	10.4	2.1	4.8	3.1

LAT = 1.20, LONG = 103.59, SINGAPORE

SPRING, FMHZ = 0.500, 3 MHZ MANMADE NOISE = -142 DBW

--MEDIAN NOISE VALUES, FA(DB)-- STATISTICAL VALUES IN DB

					OVERALL NOISE				
TIME BLOCK	ATMO	GAL	MANMADE	OVERALL	DL	DU	SL	SM	SU
0000-0400	97.4	58.9	83.6	97.6	9.8	10.6	2.8	3.7	2.7
0400-0800	88.5	58.9	83.6	88.7	13.6	16.0	3.9	5.6	5.2
0800-1200	78.6	58.9	83.6	81.4	9.5	14.3	7.1	9.6	7.2
1200-1600	93.3	58.9	83.6	93.3	13.8	18.1	7.6	7.3	6.8
1600-2000	92.3	58.9	83.6	92.3	15.6	18.8	5.7	5.3	5.7
2000-2400	98.6	58.9	83.6	98.8	9.2	10.3	3.1	3.9	2.9

LAT = 1.20, LONG = 103.59, SINGAPORE

SUMMER, FMHZ = 0.500, 3 MHZ MANMADE NOISE = -142 DBW

--MEDIAN NOISE VALUES, FA(DB)-- STATISTICAL VALUES IN DB

					OVERALL NOISE				
TIME BLOCK	ATMO	GAL	MANMADE	OVERALL	DL	DU	SL	SM	SU
0000-0400	94.5	58.9	83.6	95.1	9.7	9.9	2.7	5.1	2.7
0400-0800	87.5	58.9	83.6	87.7	14.0	16.5	4.8	7.8	5.2
0800-1200	75.3	58.9	83.6	77.4	10.6	16.6	15.6	22.8	18.1
1200-1600	87.8	58.9	83.6	87.8	16.3	18.5	6.4	9.3	6.0
1600-2000	96.1	58.9	83.6	96.1	15.9	16.8	4.8	6.6	5.7
2000-2400	93.9	58.9	83.6	94.8	7.5	8.7	1.8	3.9	2.7

LAT = 1.20, LONG = 103.59, SINGAPORE

AUTUMN, FMHZ = 0.500, 3 MHZ MANMADE NOISE = -142 DBW

--MEDIAN NOISE VALUES, FA(DB)-- STATISTICAL VALUES IN DB

					OVERALL NOISE				
TIME BLOCK	ATMO	GAL	MANMADE	OVERALL	DL	DU	SL	SM	SU
0000-0400	99.3	58.9	83.6	99.5	9.7	10.1	2.4	4.3	2.8
0400-0800	89.7	58.9	83.6	89.8	14.6	16.7	3.8	5.1	4.7

0800-1200	81.4	58.9	83.6	82.3	8.1	15.9	7.3	8.5	7.3
1200-1600	90.8	58.9	83.6	90.8	11.7	17.4	5.8	6.7	5.9
1600-2000	95.1	58.9	83.6	95.1	15.3	17.8	4.0	5.2	4.8
2000-2400	99.8	58.9	83.6	100.0	8.2	9.9	2.5	4.4	2.8

9.1.3 NOISEDAT OUTPUT 4.2 MHz

LAT = 1.20, LONG = 103.59, **SINGAPORE**

WINTER, FMHZ = 4.200, 3 MHZ MANMADE NOISE = -142 DBW

--MEDIAN NOISE VALUES, FA(DB)-- STATISTICAL VALUES IN DB

					OVERALL NOISE				
TIME BLOCK	ATMO	GAL	MANMADE	OVERALL	DL	DU	SL	SM	SU
0000-0400	59.0	37.7	58.0	62.2	4.9	8.2	1.8	2.6	1.5
0400-0800	56.1	37.7	58.0	61.5	7.0	8.8	1.5	2.6	1.4
0800-1200	27.2	37.7	58.0	58.0	6.0	9.7	1.5	5.4	1.5
1200-1600	33.0	37.7	58.0	58.0	6.0	9.7	1.5	5.4	1.5
1600-2000	53.7	37.7	58.0	60.6	7.4	9.1	1.6	3.0	1.4
2000-2400	59.5	37.7	58.0	63.0	5.8	8.1	1.8	2.4	1.7

LAT = 1.20, LONG = 103.59, SINGAPORE

SPRING, FMHZ = 4.200, 3 MHZ MANMADE NOISE = -142 DBW

--MEDIAN NOISE VALUES, FA(DB)-- STATISTICAL VALUES IN DB

					OVERALL NOISE				
TIME BLOCK	ATMO	GAL	MANMADE	OVERALL	DL	DU	SL	SM	SU
0000-0400	65.9	37.7	58.0	67.4	7.1	7.3	1.9	2.5	1.8
0400-0800	59.7	37.7	58.0	62.0	11.0	11.2	2.3	2.8	2.0
0800-1200	33.8	37.7	58.0	58.0	6.0	9.7	1.5	5.3	1.5
1200-1600	40.3	37.7	58.0	58.4	5.9	9.6	1.4	4.9	1.4
1600-2000	56.8	37.7	58.0	58.7	11.7	13.5	4.1	5.1	3.8
2000-2400	65.6	37.7	58.0	67.1	6.4	6.8	1.6	2.7	1.7

LAT = 1.20, LONG = 103.59, SINGAPORE

SUMMER, FMHZ = 4.200, 3 MHZ MANMADE NOISE = -142 DBW

--MEDIAN NOISE VALUES, FA(DB)-- STATISTICAL VALUES IN DB

					OVERALL NOISE				
TIME BLOCK	ATMO	GAL	MANMADE	OVERALL	DL	DU	SL	SM	SU
0000-0400	64.2	37.7	58.0	65.9	6.4	7.0	1.8	3.1	1.6
0400-0800	56.5	37.7	58.0	61.2	9.8	9.8	2.0	2.8	1.6
0800-1200	34.7	37.7	58.0	58.0	6.0	9.7	1.5	5.3	1.5
1200-1600	41.1	37.7	58.0	56.3	5.9	11.4	2.3	8.0	3.0
1600-2000	59.2	37.7	58.0	60.6	11.9	13.1	3.5	4.3	3.4
2000-2400	62.5	37.7	58.0	63.4	4.6	7.6	1.9	3.7	2.0

LAT = 1.20, LONG = 103.59, SINGAPORE

AUTUMN, FMHZ = 4.200, 3 MHZ MANMADE NOISE = -142 DBW

--MEDIAN NOISE VALUES, FA(DB)-- STATISTICAL VALUES IN DB

					OVERALL NOISE				
TIME BLOCK	ATMO	GAL	MANMADE	OVERALL	DL	DU	SL	SM	SU

0000-0400	65.1	37.7	58.0	66.9	7.1	7.5	1.7	2.2	1.7
0400-0800	60.4	37.7	58.0	62.9	10.1	10.3	2.0	2.8	1.9
0800-1200	35.8	37.7	58.0	58.0	6.0	9.7	1.5	5.3	1.5
1200-1600	41.2	37.7	58.0	58.3	5.9	9.6	1.4	5.0	1.4
1600-2000	59.3	37.7	58.0	61.9	10.1	11.0	2.3	2.9	2.1
2000-2400	64.9	37.7	58.0	66.6	6.4	7.0	1.5	2.5	1.7

9.1.4 NOISEDAT OUTPUT 500 kHz

LAT = 35.14, LONG = 139.55, TOKYO

WINTER, FMHZ = 0.500, 3 MHZ MANMADE NOISE = -145 DBW

	--MEDIAN NOISE VALUES, FA(DB)--				STATISTICAL VALUES IN DB OVERALL NOISE				
TIME BLOCK	ATMO	GAL	MANMADE	OVERALL	DL	DU	SL	SM	SU
0000-0400	88.0	58.9	80.6	89.0	8.2	10.7	2.1	4.1	2.9
0400-0800	80.0	58.9	80.6	81.3	12.2	14.3	4.8	5.7	4.5
0800-1200	53.4	58.9	80.6	80.6	6.0	9.7	1.5	5.4	1.5
1200-1600	57.3	58.9	80.6	80.6	6.0	9.7	1.5	5.3	1.5
1600-2000	83.0	58.9	80.6	83.8	11.0	14.2	4.3	5.0	4.1
2000-2400	91.4	58.9	80.6	91.9	7.7	10.5	2.2	5.1	3.3

LAT = 35.14, LONG = 139.55, TOKYO

SPRING, FMHZ = 0.500, 3 MHZ MANMADE NOISE = -145 DBW

	--MEDIAN NOISE VALUES, FA(DB)--				STATISTICAL VALUES IN DB OVERALL NOISE				
TIME BLOCK	ATMO	GAL	MANMADE	OVERALL	DL	DU	SL	SM	SU
0000-0400	85.9	58.9	80.6	87.5	9.6	10.1	2.2	2.9	2.2
0400-0800	70.0	58.9	80.6	75.3	12.0	14.8	13.9	18.4	12.9
0800-1200	57.2	58.9	80.6	80.7	5.9	9.7	1.5	5.3	1.5
1200-1600	58.7	58.9	80.6	71.8	7.2	15.3	13.3	40.5	29.5
1600-2000	75.1	58.9	80.6	75.5	15.4	18.7	16.1	17.8	15.9
2000-2400	85.7	58.9	80.6	87.5	8.8	9.7	2.4	2.9	2.3

LAT = 35.14, LONG = 139.55, TOKYO

SUMMER, FMHZ = 0.500, 3 MHZ MANMADE NOISE = -145 DBW

	--MEDIAN NOISE VALUES, FA(DB)--				STATISTICAL VALUES IN DB OVERALL NOISE				
TIME BLOCK	ATMO	GAL	MANMADE	OVERALL	DL	DU	SL	SM	SU
0000-0400	91.6	58.9	80.6	92.1	9.7	9.9	2.7	5.1	2.7
0400-0800	70.6	58.9	80.6	74.5	12.7	15.6	17.6	22.3	16.7
0800-1200	61.3	58.9	80.6	74.3	6.3	14.1	6.4	23.1	14.9
1200-1600	72.0	58.9	80.6	73.1	16.0	18.3	27.6	30.9	26.4
1600-2000	80.8	58.9	80.6	81.2	15.8	16.7	6.2	7.6	6.5
2000-2400	92.1	58.9	80.6	92.8	7.5	8.8	1.9	4.0	2.8

LAT = 35.14, LONG = 139.55, TOKYO

AUTUMN, FMHZ = 0.500, 3 MHZ MANMADE NOISE = -145 DBW

--MEDIAN NOISE VALUES, FA(DB)-- STATISTICAL VALUES IN DB
OVERALL NOISE

TIME BLOCK	ATMO	GAL	MANMADE	OVERALL	DL	DU	SL	SM	SU
0000-0400	90.9	58.9	80.6	91.5	9.6	9.9	2.2	3.9	2.6
0400-0800	75.6	58.9	80.6	76.8	14.3	16.5	11.2	13.2	10.7
0800-1200	59.1	58.9	80.6	78.8	5.9	11.2	2.3	8.1	2.9
1200-1600	62.0	58.9	80.6	72.7	6.1	15.1	9.3	32.8	23.5
1600-2000	83.3	58.9	80.6	83.4	15.3	17.8	4.6	5.8	5.3
2000-2400	92.1	58.9	80.6	92.6	8.1	9.8	2.4	4.1	2.7

9.1.5 NOISEDAT OUTPUT 4.2 MHz

LAT = 35.14, LONG = 139.55, TOKYO

WINTER, FMHZ = 4.200, 3 MHZ MANMADE NOISE = -145 DBW

--MEDIAN NOISE VALUES, FA(DB)-- STATISTICAL VALUES IN DB
OVERALL NOISE

TIME BLOCK	ATMO	GAL	MANMADE	OVERALL	DL	DU	SL	SM	SU
0000-0400	57.6	37.7	55.0	60.4	5.0	7.8	1.7	2.4	1.6
0400-0800	54.9	37.7	55.0	59.3	7.4	8.8	1.6	2.3	1.4
0800-1200	23.6	37.7	55.0	55.0	6.0	9.7	1.5	5.3	1.5
1200-1600	25.5	37.7	55.0	55.0	6.0	9.7	1.5	5.3	1.5
1600-2000	52.2	37.7	55.0	58.1	7.9	9.1	1.7	2.8	1.4
2000-2400	59.0	37.7	55.0	61.7	6.2	7.9	1.9	2.4	1.9

LAT = 35.14, LONG = 139.55, TOKYO

SPRING, FMHZ = 4.200, 3 MHZ MANMADE NOISE = -145 DBW

--MEDIAN NOISE VALUES, FA(DB)-- STATISTICAL VALUES IN DB
OVERALL NOISE

TIME BLOCK	ATMO	GAL	MANMADE	OVERALL	DL	DU	SL	SM	SU
0000-0400	58.7	37.7	55.0	61.2	6.6	7.6	1.7	2.3	1.6
0400-0800	47.0	37.7	55.0	56.6	9.0	9.5	2.0	3.8	1.3
0800-1200	25.2	37.7	55.0	55.0	6.0	9.7	1.5	5.3	1.5
1200-1600	24.8	37.7	55.0	55.0	6.0	9.7	1.5	5.3	1.5
1600-2000	46.4	37.7	55.0	53.8	10.1	12.1	4.5	7.1	3.4
2000-2400	57.9	37.7	55.0	60.1	5.7	7.8	1.7	2.7	1.6

LAT = 35.14, LONG = 139.55, TOKYO

SUMMER, FMHZ = 4.200, 3 MHZ MANMADE NOISE = -145 DBW

--MEDIAN NOISE VALUES, FA(DB)-- STATISTICAL VALUES IN DB
OVERALL NOISE

TIME BLOCK	ATMO	GAL	MANMADE	OVERALL	DL	DU	SL	SM	SU
0000-0400	62.4	37.7	55.0	63.9	6.5	6.8	1.8	3.2	1.7
0400-0800	46.1	37.7	55.0	56.4	7.5	9.3	1.6	3.9	1.3
0800-1200	27.2	37.7	55.0	55.0	6.0	9.7	1.5	5.3	1.5
1200-1600	32.9	37.7	55.0	54.9	5.9	9.9	1.6	5.5	1.5
1600-2000	49.2	37.7	55.0	54.7	10.9	12.0	4.2	5.8	3.0
2000-2400	61.3	37.7	55.0	62.1	4.8	6.9	1.8	3.7	1.8

LAT = 35.14, LONG = 139.55, TOKYO

AUTUMN, FMHZ = 4.200, 3 MHZ MANMADE NOISE = -145 DBW

--MEDIAN NOISE VALUES, FA(DB)-- STATISTICAL VALUES IN DB

TIME BLOCK	ATMO	GAL	MANMADE	OVERALL	DL	DU	SL	SM	SU
					OVERALL NOISE				
0000-0400	59.9	37.7	55.0	62.2	6.9	7.5	1.6	2.1	1.6
0400-0800	50.9	37.7	55.0	57.7	8.9	9.3	1.7	3.0	1.4
0800-1200	26.7	37.7	55.0	55.0	6.0	9.7	1.5	5.3	1.5
1200-1600	27.9	37.7	55.0	55.0	5.9	9.7	1.5	5.3	1.5
1600-2000	52.4	37.7	55.0	57.5	9.4	10.2	2.1	3.2	1.6
2000-2400	60.4	37.7	55.0	62.4	6.2	7.2	1.5	2.5	1.7

The NOISEDAT calculation outputs for the frequency of 500 kHz and 4.2 MHz demonstrate the significant variations in noise values (*Fam*) and the advantage of the use of HF frequencies in the tropics area or very noisy areas.

9.2 *Fa* and *En* calculations

The ITU NOISEDAT software can be used to estimate the average noise levels for defined geographical areas (according to Recommendation ITU-R P.372-13).

The NOISEDAT output data, lists the atmospheric, galactic, man-made and overall noise value ***Fam*** for all time block and seasons for the selected geographical area.

The ***Fa*** calculation is carried out from the following equation:

$$\textbf{\textit{Noise factor}}\ F_a\ (dB\ above\ kT_0B) = F_{am} + \sqrt{{D_u}^2 + {D_s}^2}$$

The value of ***Ds*** is given at = 3 dB.

From the values of ***Fa*** we can edit the noise level graphs in dBμV / m in a bandwidth of 10 kHz.

From this factor ***Fa*** we can now calculate the noise field strength ***En*** with:

En = *Fa* + 20 log F (MHz) + 10log B – 95.5

where:

F = Frequency in MHz = 0.5 MHz for MF NAVDAT

B = Receiver bandwidth in Hz = 10 000 for 10 kHz NAVDAT receiver.

Significant variations can be seen in total noise levels according to the seasons and periods of the day. It is appropriate to adapt the periods of broadcast to the times when this total noise level is the lowest.

The calculations and predictions given hereunder used average parameters and can be refined with some local measurement.

Example of Fa and En calculation from the outputs of NOISEDAT for the SINGAPORE zone and the 500 kHz frequency (10 kHz bandwidth)

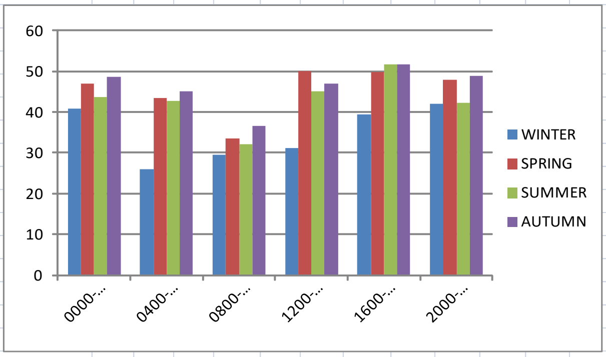
Bandwidth Hz	Fa and En calculations from NOISEDAT outputs	Site: SINGAPORE	1°21 N	103°59 E	RFNAV V1
10000	Ship noise -145 dBW	F= 0.5 MHz		Ds = 3	

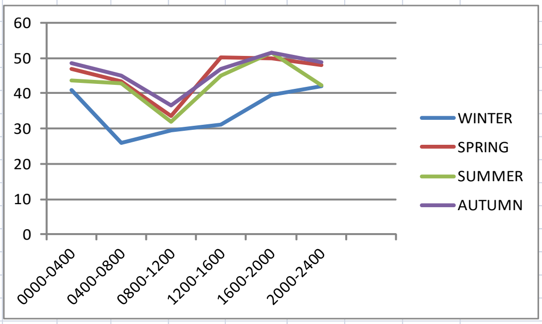
TIME BLOCK	WINTER Fam	WINTER Dl	WINTER Du	SPRING Fam	SPRING Dl	SPRING Du	SUMMER Fam	SUMMER Dl	SUMMER Du	AUTUMN Fam	AUTUMN Dl	AUTUMN Du	WINTER FA	WINTER En	SPRING Fa	SPRING En	SUMMER Fa	SUMMER En	AUTUMN Fa	AUTUMN En
0000-0400	91.2	8.4	10.8	97.5	9.8	10.6	94.8	9.7	10	99.5	9.7	10.1	102.4	40.89	108.5	47	105.24	43.72	110	48.52
0400-0800	82.7	12.3	14.4	88.6	13.6	16	87.6	14	16.5	89.7	14.6	16.7	87.54	26.02	104.9	43.36	104.37	42.85	106.7	45.15
0800-1200	80.9	5.9	9.6	80.1	10.2	14.7	76.4	11.4	16.9	81.9	8.7	16	90.96	29.44	95.1	33.58	93.564	32.04	98.18	36.66
1200-1600	83.1	5.1	9	93.3	13.8	18.1	87.8	16.3	18.5	90.8	11.7	17.4	92.59	31.07	111.6	50.13	106.54	45.02	108.5	46.94
1600-2000	86.4	11.1	14.3	92.3	15.7	18.8	96.1	15.9	16.8	95.1	15.3	17.8	101	39.49	111.3	49.82	113.17	51.65	113.2	51.63
2000-2400	92.7	7.7	10.5	98.7	9.2	10.3	94.4	7.6	8.8	99.9	8.2	10	103.6	42.1	109.4	47.91	103.7	42.18	110.3	48.82

Calculations for Fa and En

Noise factor Fa (dB above $k T_0 B$) = $Fam + \sqrt{Du^2 + Ds^2}$

$En = Fa + 20\log F + 10 \log B - 95.5$ in dBµV/m

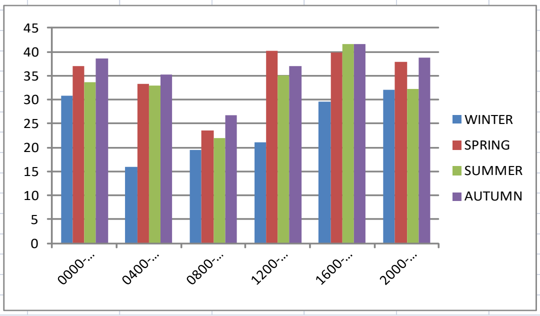


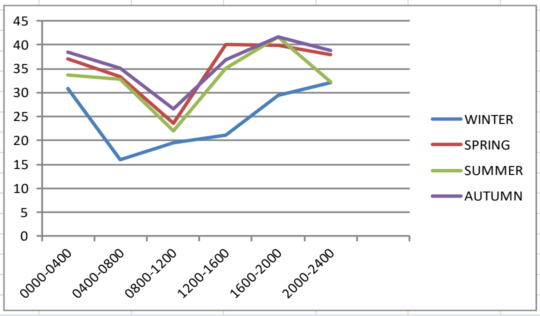


EVOLUTION OF NOISE LEVEL IN dBµV/m

Example of Fa and En calculation from the outputs of NOISEDAT for the SINGAPORE zone and the 500 kHz frequency (1 kHz bandwidth)

	WINTER	SPRING	SUMMER	AUTUMN
0000-0400	30.89	37	33.72	38.52
0400-0800	16.02	33.36	32.85	35.15
0800-1200	19.44	23.58	22.04	26.66
1200-1600	21.07	40.13	35.02	36.94
1600-2000	29.49	39.82	41.65	41.63
2000-2400	32.1	37.91	32.18	38.82





Example of Fa and En calculation from the outputs of NOISEDAT for the SINGAPORE zone and the 4.2 MHz frequency (10 kHz bandwidth)

Bandwidth Hz: 10000 — Fa and En calculations from NOISEDAT outputs — Site: SINGAPORE 1°21 N 103°59 E — *RFNAV V1*

Ship noise -145 dBW — F= 4.2 MHz

	WINTER			SPRING			SUMMER			AUTUMN		
TIME BLOCK	*Fam*	*Dl*	*Du*	*Fam*	*Dl*	*Du*	*Fam*	*Dl*	*Du*	*Fam*	*Dl*	*Du*
0000-0400	61.4	5.2	7.6	66.8	7.3	7.4	65.5	6.6	6.6	66.2	7.4	7.6
0400-0800	59.9	7.7	8.9	61	11.2	11.5	59.4	10.3	10.4	61.8	10.3	10.6
0800-1200	55	6	9.7	55.1	5.9	9.7	55.1	5.9	9.6	55.1	5.9	9.6
1200-1600	55	5.9	9.7	55.5	5.8	9.7	52	6.1	12.5	55.6	5.8	9.5
1600-2000	58.6	8.3	9.3	57.8	11.9	13.8	60	12.1	13.3	60.7	10.3	11.3
2000-2400	62	6.3	7.8	66.6	6.6	6.6	63.3	4.9	6.5	66.1	6.6	6.9

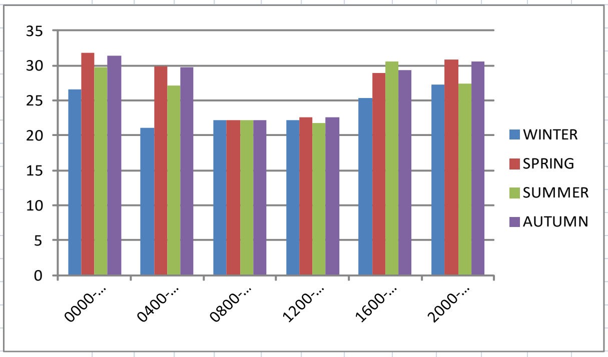
Ds = 3

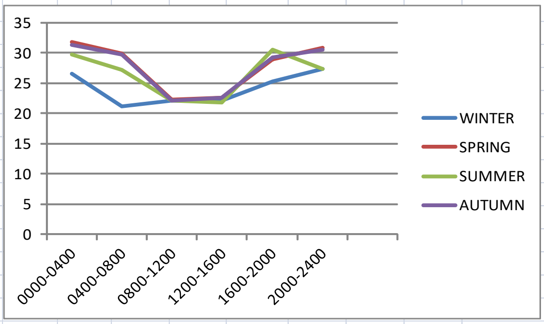
	WINTER		SPRING		SUMMER		AUTUMN	
TIME BLOCK	*FA*	*En*	*Fa*	*En*	*Fa*	*En*	*Fa*	*En*
0000-0400	69.57	26.54	74.78	31.75	72.75	29.71	74.37	31.34
0400-0800	64.13	21.1	72.88	29.85	70.224	27.19	72.82	29.78
0800-1200	65.15	22.12	65.25	22.22	65.158	22.12	65.16	22.12
1200-1600	65.15	22.12	65.65	22.62	64.855	21.82	65.56	22.53
1600-2000	68.37	25.34	71.92	28.89	73.634	30.6	72.39	29.36
2000-2400	70.36	27.32	73.85	30.81	70.459	27.42	73.62	30.59

Calculations for Fa and En

Noise factor Fa (dB above k T_o B) = Fam + $\sqrt{Du^2 + Ds^2}$

En = Fa + 20log F + 10 log B - 95.5 in dBµV/m





EVOLUTION OF NOISE LEVEL IN dBµV/m

Example of Fa and En calculation from the outputs of NOISEDAT for the TOKYO zone and the 500 kHz frequency and 10 kHz bandwidth

Bandwidth Hz: 10000 — Fa and En calculations from NOISEDAT outputs — Site: TOKYO Lat: 35.14 N Long: 139.55 E — *RFNAV V1*

Ship noise - 142 dBW — F= 0.5 MHz

	WINTER			SPRING			SUMMER			AUTUMN		
TIME BLOCK	*Fam*	*Dl*	*Du*	*Fam*	*Dl*	*Du*	*Fam*	*Dl*	*Du*	*Fam*	*Dl*	*Du*
0000-0400	89.8	8	10.4	88.8	9.3	9.8	92.6	9.6	9.8	92.1	9.5	9.7
0400-0800	82.5	11.8	14	78.5	10.9	14	77.1	11.9	15	77.9	14	16.2
0800-1200	83.6	6	9.7	83.7	6	9.7	79.1	6	12.9	83	6	10.3
1200-1600	83.6	6	9.7	76.7	6.4	14.1	74	15.8	18.1	77.3	6	14
1600-2000	84.4	10.7	14.1	76	15.2	18.6	81.6	15.8	16.6	83.5	15.2	17.8
2000-2400	92.4	7.5	10.3	88.8	8.4	9.3	93.3	7.4	8.6	93.1	8	9.6

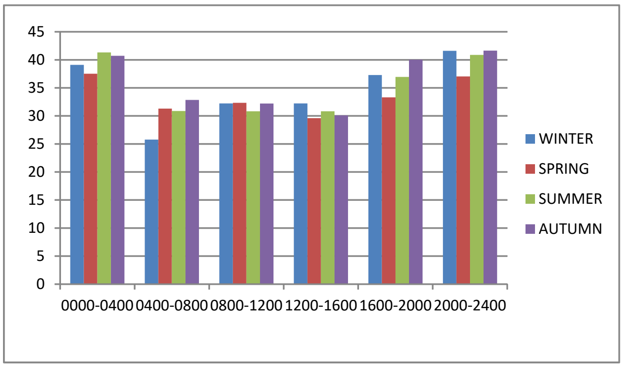
Ds = 3

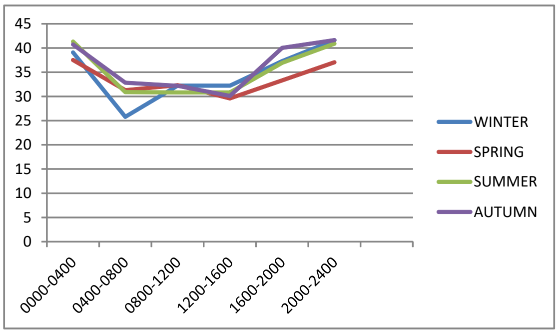
	WINTER		SPRING		SUMMER		AUTUMN	
TIME BLOCK	*FA*	*En*	*Fa*	*En*	*Fa*	*En*	*Fa*	*En*
0000-0400	100.6	39.1	99.05	37.53	102.85	41.33	102.3	40.73
0400-0800	87.3	25.78	92.82	31.3	92.397	30.88	94.38	32.85
0800-1200	93.75	32.23	93.85	32.33	92.344	30.82	93.73	32.21
1200-1600	93.75	32.23	91.12	29.6	92.347	30.83	91.62	30.1
1600-2000	98.82	37.3	94.84	33.32	98.469	36.95	101.6	40.03
2000-2400	103.1	41.61	98.57	37.05	102.41	40.89	103.2	41.64

Calculations for Fa and En

Noise factor Fa (dB above k T_o B) = Fam + $\sqrt{Du^2 + Ds^2}$

En = Fa + 20log F + 10 log B - 95.5 in dBµV/m





EVOLUTION OF NOISE LEVEL IN dBµV/m

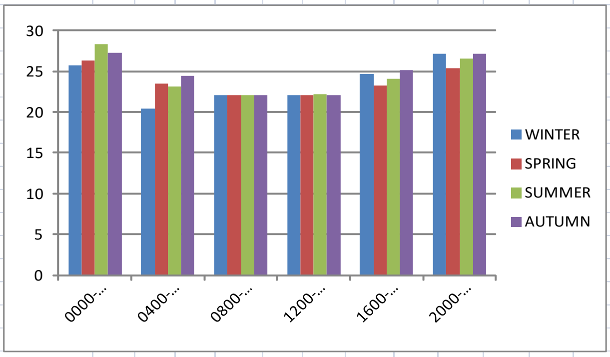
Example of Fa and En calculation from the outputs of NOISEDAT for the TOKYO zone and the 4.2 MHz frequency (10 kHz bandwidth)

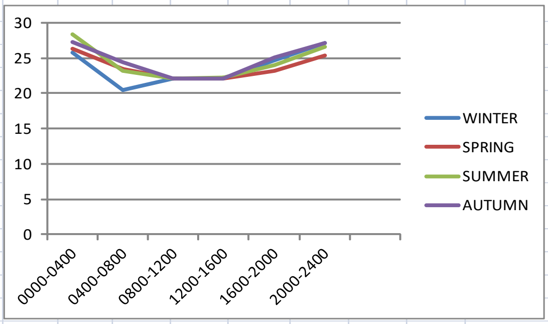
Bandwidth Hz	Fa and En calculations from NOISEDAT outputs								Site:	TOKYO			35°14 N		139°55 E				RFNAV V1	
10000			Ship noise	-145	dBW			F=	4.2	MHz										
														Ds =	3					
	WINTER			SPRING			SUMMER			AUTUMN			WINTER		SPRING		SUMMER		AUTUMN	
TIME BLOCK	Fam	Dl	Du	Fam	Dl	Du	Fam	Dl	Du	Fam	Dl	Du	FA	En	Fa	En	Fa	En	Fa	En
0000-0400	60.4	5	7.8	61.2	7.6	7.6	63.9	6.5	6.8	62.2	6.9	7.5	68.76	25.72	69.37	26.34	71.332	28.3	70.28	27.24
0400-0800	59.3	7.4	8.8	56.6	9.5	9.5	56.4	7.5	9.3	57.7	8.9	9.3	63.52	20.48	66.56	23.53	66.172	23.14	67.47	24.44
0800-1200	55	6	9.7	55	9.7	9.7	55	6	9.7	55	6	9.7	65.15	22.12	65.15	22.12	65.153	22.12	65.15	22.12
1200-1600	55	6	9.7	55	9.7	9.7	54.9	5.9	9.9	55	5.9	9.7	65.15	22.12	65.15	22.12	65.245	22.21	65.15	22.12
1600-2000	58.1	7.9	9.1	53.8	12.1	12.1	54.7	10.9	12	57.5	9.4	10.2	67.68	24.65	66.27	23.23	67.069	24.03	68.13	25.1
2000-2400	61.7	6.2	7.9	60.1	7.8	7.8	62.1	4.8	6.9	62.4	6.2	7.2	70.15	27.12	68.46	25.42	69.624	26.59	70.2	27.16

Calculations for Fa and En

Noise factor Fa (dB above $k\,T_o\,B$) = Fam + $\sqrt{Du^2 + Ds^2}$

En = Fa + 20log F + 10 log B - 95.5 in dBµV/m





EVOLUTION OF NOISE LEVEL IN dBµV/m

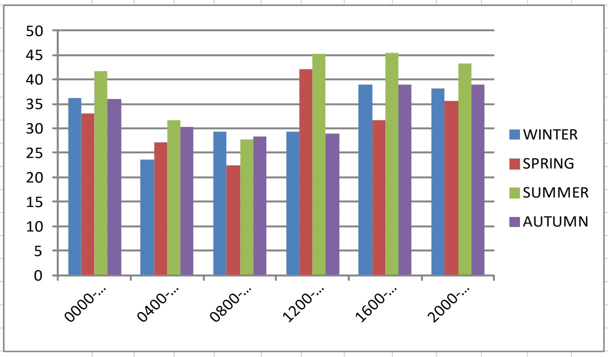
Example of Fa and En calculation from the outputs of NOISEDAT for the SHANGAI zone and the 500 kHz frequency and 10 kHz bandwidth

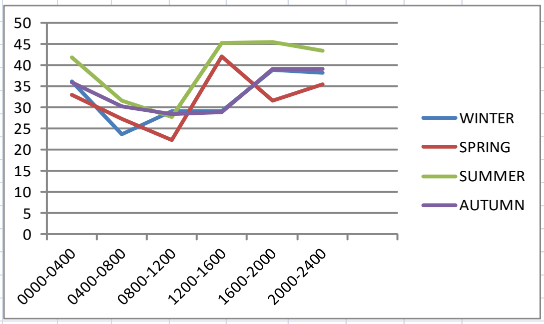
Bandwidth Hz	Fa and En calculations from NOISEDAT outputs								Site:	SHANGAI			31°36' N		121° 32' E				RFNAV V1	
10000			Ship noise	-145	dBW			F=	0.5	MHz										
														Ds =	3					
	WINTER			SPRING			SUMMER			AUTUMN			WINTER		SPRING		SUMMER		AUTUMN	
TIME BLOCK	Fam	Dl	Du	Fam	Dl	Du	Fam	Dl	Du	Fam	Dl	Du	FA	En	Fa	En	Fa	En	Fa	En
0000-0400	86.9	8	10.4	90.6	9.7	2.6	92.8	9.7	10	87.6	9.4	9.5	97.72	36.2	94.57	33.05	103.24	41.72	97.56	36.04
0400-0800	80.4	12	14.2	75.9	12.6	12.5	76.7	13.5	16.2	75.2	14	16.3	85.22	23.7	88.75	27.23	93.175	31.65	91.77	30.25
0800-1200	80.6	6	9.7	80.5	5.9	1.6	72.9	9.1	16.1	76.8	5.9	12.7	90.75	29.23	83.9	22.38	89.277	27.76	89.85	28.33
1200-1600	80.7	6	9.7	71.8	12.2	31.7	88.1	16.3	18.5	73.3	8.9	16.9	90.85	29.33	103.6	42.12	106.84	45.32	90.46	28.94
1600-2000	85.8	11.1	14.3	86.6	15.6	5.8	89.8	15.9	16.8	82.5	15.3	17.8	100.4	38.89	93.13	31.61	106.87	45.35	100.6	39.03
2000-2400	89	7.5	10.3	92.8	9.1	3	95.5	7.6	8.9	90.4	8	9.7	99.73	38.21	97.04	35.52	104.89	43.37	100.6	39.03

Calculations for Fa and En

Noise factor Fa (dB above $k\,T_o\,B$) = Fam + $\sqrt{Du^2 + Ds^2}$

En = Fa + 20log F + 10 log B - 95.5 in dBµV/m





EVOLUTION OF NOISE LEVEL IN dBµV/m

Example of Fa and En calculation from the outputs of NOISEDAT for the SHANGAI zone and the 4.2 MHz frequency (10 kHz bandwidth)

Bandwidth Hz	Fa and En calculations from NOISEDAT outputs	Site:	SHANGAI	31°36' N	121° 32' E	RFNAV V1
10000	Ship noise -145 dBW	F=	4.2 MHz		Ds =	3

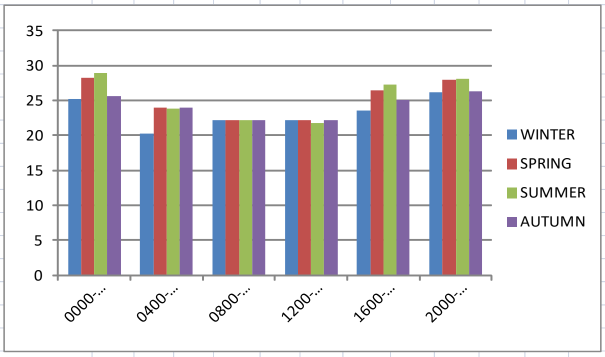
	WINTER			SPRING			SUMMER			AUTUMN		
TIME BLOCK	*Fam*	*Dl*	*Du*	*Fam*	*Dl*	*Du*	*Fam*	*Dl*	*Du*	*Fam*	*Dl*	*Du*
0000-0400	59.6	4.9	8.1	63.4	7	7.3	64.6	6.6	6.7	60.1	6.4	8
0400-0800	59.1	7.3	8.7	56.9	9.7	9.7	57.1	8.7	9.3	57.3	8.5	9.2
0800-1200	55	6	9.7	55	6	9.7	55.1	5.9	9.7	55	5.9	9.7
1200-1600	55	6	9.7	55.1	5.9	9.7	51.8	6.1	12.7	55.1	5.9	9.7
1600-2000	58.6	8.3	9.3	55.6	11.6	13.5	57	11.8	13	57.5	9.4	10.2
2000-2400	60.8	6	7.9	63.7	6.3	6.8	64.4	5	6.1	61.3	6	7.5

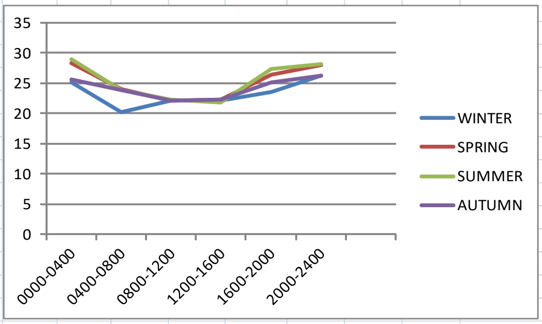
	WINTER		SPRING		SUMMER		AUTUMN	
TIME BLOCK	*FA*	*En*	*Fa*	*En*	*Fa*	*En*	*Fa*	*En*
0000-0400	68.24	25.2	71.29	28.26	71.941	28.91	68.64	25.61
0400-0800	63.31	20.27	67.05	24.02	66.872	23.84	66.98	23.94
0800-1200	65.15	22.12	65.15	22.12	65.253	22.22	65.15	22.12
1200-1600	65.15	22.12	65.25	22.22	64.85	21.81	65.25	22.22
1600-2000	68.37	25.34	69.43	26.39	70.342	27.31	68.13	25.1
2000-2400	69.25	26.22	71.13	28.1	71.198	28.16	69.38	26.34

Calculations for Fa and En

Noise factor Fa (dB above kT_0B*)* $= Fam + \sqrt{Du^2 + Ds^2}$

$En = Fa + 20\log F + 10\log B - 95.5$ *in dBµV/m*





EVOLUTION OF NOISE LEVEL IN dBµV/m

Example of Fa and En calculation from the outputs of NOISEDAT for the GISLOVSHAMMAR zone and the 500 kHz frequency and 10 kHz bandwidth

Bandwidth Hz	Fa and En calculations from NOISEDAT outputs	Site:	GISLOVSHAMMAR	55°29' N	14°19 E	RFNAV V1
10000	Ship noise -145 dBW	F=	0.5 MHz		Ds =	3

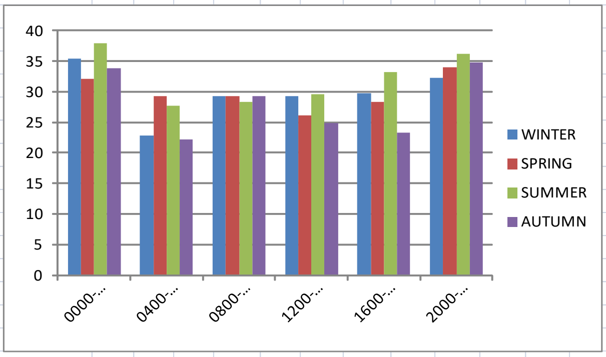
	WINTER			SPRING			SUMMER			AUTUMN		
TIME BLOCK	*Fam*	*Dl*	*Du*	*Fam*	*Dl*	*Du*	*Fam*	*Dl*	*Du*	*Fam*	*Dl*	*Du*
0000-0400	86.2	7.8	10.3	84	8.5	9.2	89.3	9.6	9.7	86.6	9.2	8.2
0400-0800	79.5	11.8	14	80.2	6.3	10.1	74.2	11.5	14.8	74.1	13.7	9.2
0800-1200	80.6	6	9.7	80.6	6	9.7	77.6	6	11.9	80.6	6	9.7
1200-1600	80.6	6	9.7	72.3	6.9	15	72.6	16	18.3	76.3	5.9	9.7
1600-2000	78.9	7.5	12	71.1	14.9	18.5	77.8	15.8	16.6	74.9	15	9.4
2000-2400	84.1	6	9.2	85.7	8.4	9.3	88.8	7.2	8.4	87.6	7.7	8.1

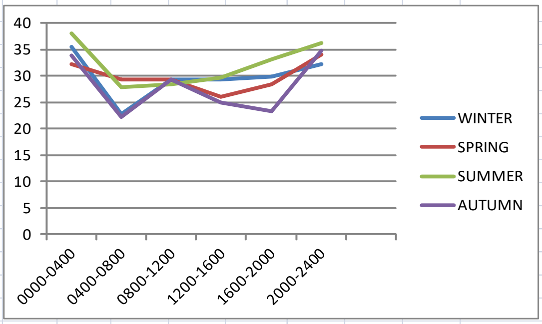
	WINTER		SPRING		SUMMER		AUTUMN	
TIME BLOCK	*FA*	*En*	*Fa*	*En*	*Fa*	*En*	*Fa*	*En*
0000-0400	96.93	35.41	93.68	32.16	99.453	37.93	95.33	33.81
0400-0800	84.3	22.78	90.74	29.22	89.301	27.78	83.78	22.26
0800-1200	90.75	29.23	90.75	29.23	89.872	28.35	90.75	29.23
1200-1600	90.75	29.23	87.6	26.08	91.144	29.62	86.45	24.93
1600-2000	91.27	29.75	89.84	28.32	94.669	33.15	84.77	23.25
2000-2400	93.78	32.26	95.47	33.95	97.72	36.2	96.24	34.72

Calculations for Fa and En

Noise factor Fa (dB above kT_0B*)* $= Fam + \sqrt{Du^2 + Ds^2}$

$En = Fa + 20\log F + 10\log B - 95.5$ *in dBµV/m*





EVOLUTION OF NOISE LEVEL IN dBµV/m

Example of Fa and En calculation from the outputs of NOISEDAT for the GISLOVSHAMMAR zone and the 4.2 MHz frequency (10 kHz bandwidth)

Bandwidth Hz — Fa and En calculations from NOISEDAT outputs — Site: GISLOVSHAMMAR — 55°29' N — 14°19 E — *RFNAV V1*

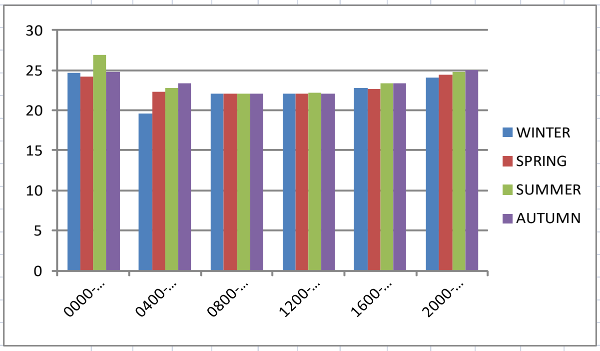
10000 — Ship noise -145 dBW — F= 4.2 MHz — *Ds =* 3

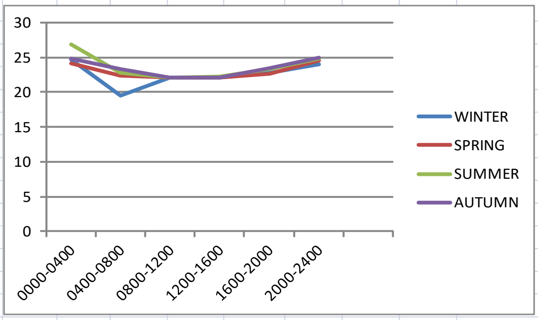
TIME BLOCK	WINTER *Fam*	*Dl*	*Du*	SPRING *Fam*	*Dl*	*Du*	SUMMER *Fam*	*Dl*	*Du*	AUTUMN *Fam*	*Dl*	*Du*	WINTER *FA*	*En*	SPRING *Fa*	*En*	SUMMER *Fa*	*En*	AUTUMN *Fa*	*En*
0000-0400	58.9	4.8	8.3	58.1	5.8	8.6	62.1	6.2	7.2	59.1	6.1	8.2	67.73	24.69	67.21	24.17	69.9	26.86	67.83	24.8
0400-0800	58.4	6.9	8.8	55.3	6	9.6	55.9	6.7	9.4	56.7	7.7	9.2	62.62	19.58	65.36	22.32	65.767	22.73	66.38	23.34
0800-1200	55	6	9.7	55	6	9.7	55	6	9.7	55	6	9.7	65.15	22.12	65.15	22.12	65.153	22.12	65.15	22.12
1200-1600	55	6	9.7	55	6	9.7	54.9	5.9	9.9	55	6	9.7	65.15	22.12	65.15	22.12	65.245	22.21	65.15	22.12
1600-2000	56.1	6	9.3	54.4	8.7	10.9	54.7	10.2	11.3	56.6	7.6	9.4	65.87	22.84	65.71	22.67	66.391	23.36	66.47	23.43
2000-2400	57.9	5.3	8.7	58.7	5.4	8.3	59.2	4.5	8.1	59.4	5.6	8.1	67.1	24.07	67.53	24.49	67.838	24.8	68.04	25

Calculations for Fa and En

Noise factor Fa (dB above k T_0 B) = Fam + $\sqrt{Du^2 + Ds^2}$

En = Fa + 20log F + 10 log B - 95.5 in dBµV/m





EVOLUTION OF NOISE LEVEL IN dBµV/m

Example of Fa and En calculation from the outputs of NOISEDAT for the OUESSANT island zone and the 500 kHz frequency and 10 kHz bandwidth

Bandwidth Hz — Fa and En calculations from NOISEDAT outputs — Site: OUESSANT — 48°28' N — 05°03' W — *RFNAV V1*

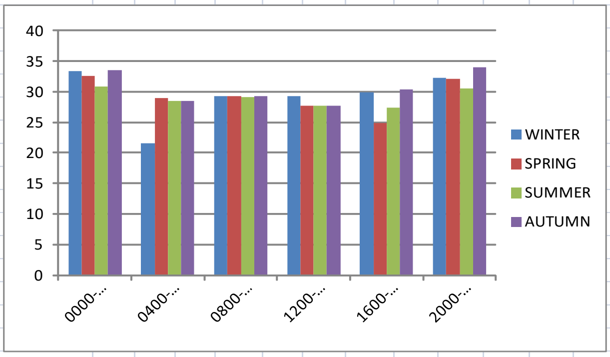
10000 — Ship noise -145 dBW — F= 0.5 MHz — *Ds =* 3

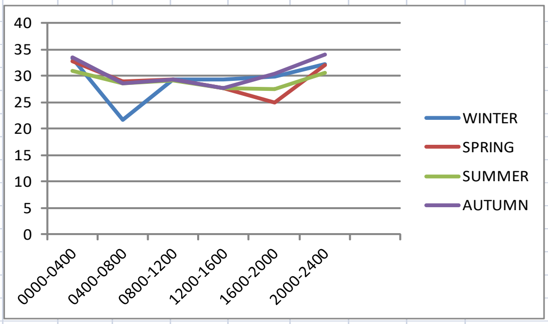
TIME BLOCK	WINTER *Fam*	*Dl*	*Du*	SPRING *Fam*	*Dl*	*Du*	SUMMER *Fam*	*Dl*	*Du*	AUTUMN *Fam*	*Dl*	*Du*	WINTER *FA*	*En*	SPRING *Fa*	*En*	SUMMER *Fa*	*En*	AUTUMN *Fa*	*En*
0000-0400	84.6	7.2	9.8	84.4	8.7	9.3	82.9	7.4	9	85.5	9	9	94.85	33.33	94.17	32.65	92.387	30.87	94.99	33.47
0400-0800	78.4	11.2	13.5	79.1	7.1	11	78.1	7.5	11.6	73.9	13.6	15.9	83.14	21.62	90.5	28.98	90.082	28.56	90.08	28.56
0800-1200	80.6	6	9.7	80.6	6	9.7	80.3	6	9.9	80.5	6	9.8	90.75	29.23	90.75	29.23	90.645	29.12	90.75	29.23
1200-1600	80.6	6	9.7	76.1	6.1	12.8	76.5	8.3	12.4	75.9	5.9	13	90.75	29.23	89.25	27.73	89.258	27.74	89.24	27.72
1600-2000	78.6	8.1	12.4	68.5	13.4	17.7	74.4	13.8	14.2	74	14.9	17.6	91.36	29.84	86.45	24.93	88.913	27.39	91.85	30.33
2000-2400	84.1	5.9	9.2	84.2	7.6	8.9	82.7	5.5	8.9	86	7.3	9	93.78	32.26	93.59	32.07	92.092	30.57	95.49	33.97

Calculations for Fa and En

Noise factor Fa (dB above k T_0 B) = Fam + $\sqrt{Du^2 + Ds^2}$

En = Fa + 20log F + 10 log B - 95.5 in dBµV/m





EVOLUTION OF NOISE LEVEL IN dBµV/m

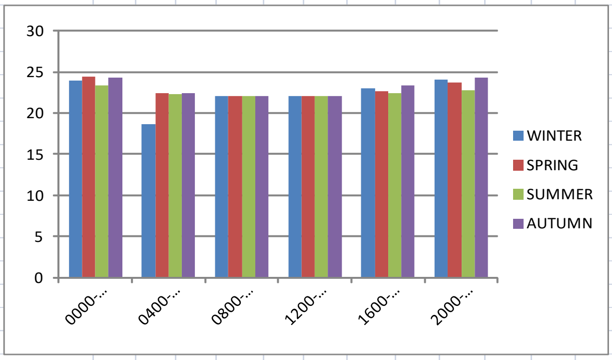
Example of Fa and En calculation from the outputs of NOISEDAT for the OUESSANT island zone and the 4.2 MHz frequency (10 kHz bandwidth)

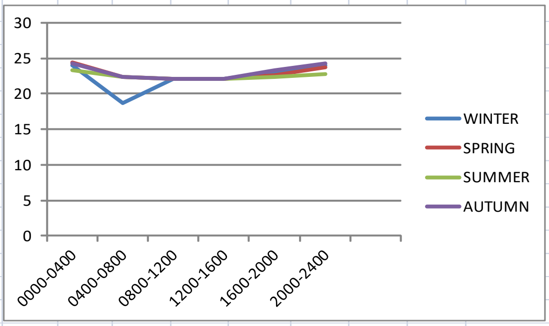
Bandwidth Hz	Fa and En calculations from NOISEDAT outputs								Site:	OUESSANT		48°28' N		05°03' W				RFNAV V1		
10000			Ship noise	-145	dBW			F=	4.2	MHz										
													Ds =	3						
	WINTER			SPRING			SUMMER			AUTUMN			WINTER		SPRING		SUMMER		AUTUMN	
TIME BLOCK	Fam	Dl	Du	Fam	Dl	Du	Fam	Dl	Du	Fam	Dl	Du	FA	En	Fa	En	Fa	En	Fa	En
0000-0400	57.9	4.8	8.6	58.5	5.9	8.4	56.9	5.2	9	58.3	5.9	8.5	67.01	23.97	67.42	24.38	66.387	23.35	67.31	24.28
0400-0800	57.5	6.3	8.9	55.5	6.3	9.5	55.3	5.9	9.6	56.7	7.6	8.2	61.73	18.7	65.46	22.43	65.358	22.32	65.43	22.4
0800-1200	55	6	9.7	55	6	9.7	55	6	9.7	55	6	9.7	65.15	22.12	65.15	22.12	65.153	22.12	65.15	22.12
1200-1600	55	6	9.7	55	6	9.7	55	6	9.7	55	6	9.7	65.15	22.12	65.15	22.12	65.153	22.12	65.15	22.12
1600-2000	56.3	6.1	9.3	55.2	7	10	55.4	6.5	9.6	56.5	7.4	9.4	66.07	23.04	65.64	22.61	65.458	22.42	66.37	23.33
2000-2400	57.9	5.3	8.7	57.5	5.2	8.8	56.1	5	9.3	58.3	5.4	8.5	67.1	24.07	66.8	23.76	65.872	22.84	67.31	24.28

Calculations for Fa and En

Noise factor Fa (dB above k T_o B) = Fam + $\sqrt{Du^2 + Ds^2}$

En = Fa + 20log F + 10 log B - 95.5 in dBµV/m





EVOLUTION OF NOISE LEVEL IN dBµV/m

9.3 Necessary RF field level at the receive antenna

Hence to achieve the target SNR of 14 to 26 dB (according digital mode and demodulator using in receiver) the required *rms* signal level is given by:

En + SNR in dBµV/m (or En + SNR in dBW after conversion)

This highlights the significant impact of radio noise on the quality of reception and therefore the coverage, as for any radio system.

IMO Resolution A.801(19) states "Administrations should determine time-periods and seasons appropriate to their geographic area based on prevailing noise levels".

9.4 Example of observation in field test

9.4.1 Operation of the test system

A NAVDAT test system was deployed in Shanghai and Zhoushan (China) in 2015 and began operation in 2016. The transmitter broadcasts about five file messages respectively at different time during the day and the same file message is again broadcast three times in six different transmission modes (refer to Table 12). The information and management subsystem of the test system All received data records give a large number of real-time feedback from the remote monitoring receivers, as well as the FER (frame error rate) and SNR (signal to noise ratio). Long term record data shows that the test system works well.

TABLE 12

Transmission modes of the test system

Transmission mode	Modulation, code rate
1	4-QAM, 0.5
2	4-QAM, 0.75
3	16-QAM, 0.5
4	16-QAM, 0.75
5	64-QAM, 0.5
6	64-QAM, 0.75

9.4.2 Analysis of monitoring data

Huaniao monitoring station, which is farther from the coastline compared to the other monitoring stations and is surrounded by the sea, is located in Huaniao island of Zhoushan, about 70 nautical miles from the shore transmitter. As the Huaniao monitoring station is relatively closest to the ship's environment, data provided by this monitoring station are typical for analysis.

Here is an example of the relationship between SNR and received signal strength indication (RSSI). The statistical data of SNR and RSSI of Huaniaoisland in June were recorded in the following table.

TABLE 13

SNR vs RSSI

Time(hour)	9h00	11h00	15h00	17h00	21h00
SNR(dB)	18.39	17.00	14.95	15	22.5
RSSI(dBm)	−71.79	−71.86	−72.37	−71.85	−72

It shows that the RSSI is relatively stable, but the SNR increased at 21h00, due to the reduction of the RF noise at night.

10 Receiving system on ships

It consists of the following elements:

A: Receiving antenna:

B: Receiver and demodulator.

10.1 The receiving antenna

We can distinguish 2 main categories of reception antennas:

A Antenna receiving the electric field E.

These antenna models have the advantage of simplicity of installation but are, by definition, sensitive to electric fields and therefore to atmospheric radio noise.

B Antenna receiving the magnetic field H.

10.1.1 Field Antenna E

To be compatible with the majority of ships, these antennas are often of the type:

10.1.1.1 4/8 m passive vertical whip antenna with wide band impedance matching for connection to coaxial cable. The main difficulty for this type of antenna is to maintain good impedance matching over the entire frequency band (400 kHz to 30 MHz);

or,

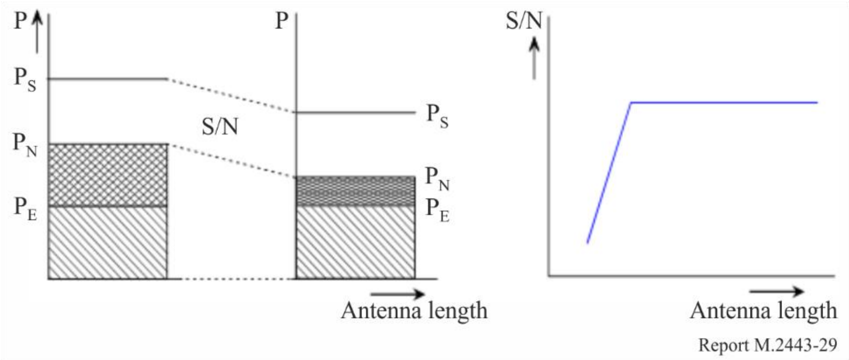
10.1.1.2 Active vertical antenna with vertical whip from 1 to 1.5 m.

An active antenna comprises a very short vertical monopole connected to an impedance adapter followed by an amplifier.

The quality of reception of wanted signal is not determined by the signal voltage at the receiver, but predominantly by the ratio of the wanted signal level compared to the noise level present at the output of the receiver: it is the SNR.

FIGURE 29

Fundamental working principle of signal to noise versus antenna length



Obviously the active antenna cannot differentiate the wanted signal and the radio noise that arrives at the antenna simultaneously.

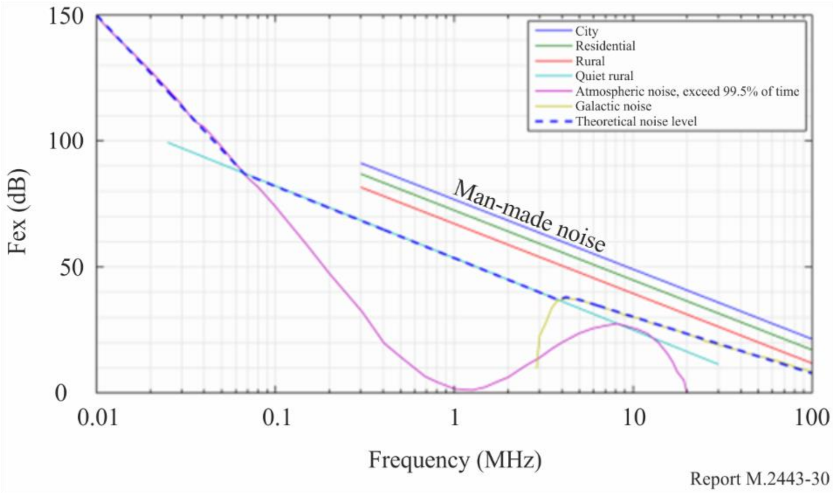
If the antenna length is reduced, the wanted signal (*Ps*) and the noise signal (*Pn*) picked up from the ship environment are reduced by the same amount. This leads to a constant SNR so the quality of reception does not suffer.

The optimum length of a radiator is depending of the noise figure of the receiver (which will give the threshold of reception) as well as on the environmental total noise present at the antenna location on the ship.

Figure 30 gives different contributions to the environmental noise. For MF frequency band atmospheric noise is preponderant but in HF the man-made noise is higher.

FIGURE 30

Different sources of environmental noise versus frequency compared to the theoretical minimum noise



10.1.2 Field antenna H

These antennas can be of three types:

– Loop antenna;

– Passive Ferrite Antenna;

– Active Ferrite Antenna.

10.1.2.1 Loop antenna

It consist of two crossed loops with a diameter of 0.5 m to 1 m, making it possible to obtain a quasi-omnidirectional diagram.

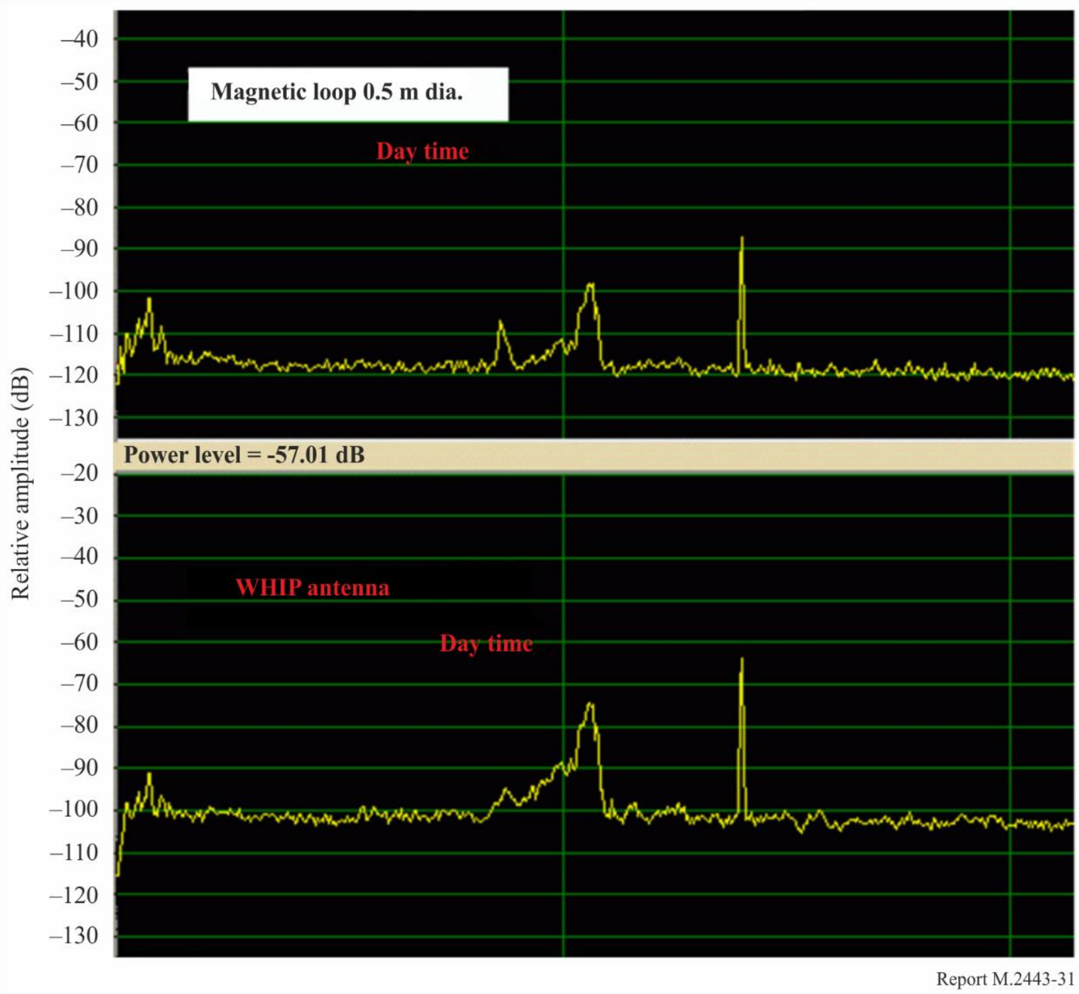
The preamplifier must meet the same specifications as for the active antenna E.

The dimensions of this type of antenna can some time pose a problem of resistance to the weather, in particular wind, and requires a relatively larger space for its installation than whip antennas.

But the level reduction of electrical noise remains the most important factor for the use of this type of antenna.

FIGURE 31

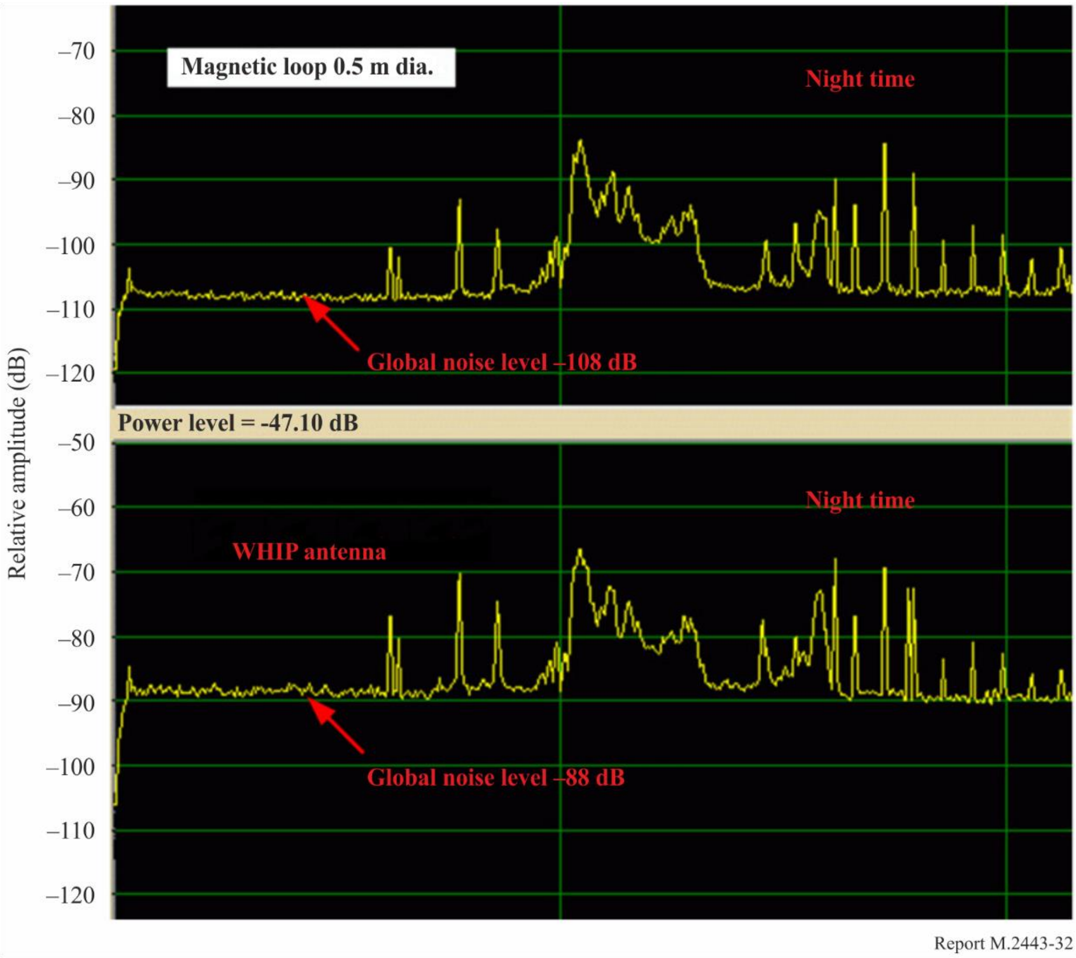
Magnetic loop versus whip antenna at day time



Example of reception on day time with loop and whip antenna.

FIGURE 32

Magnetic loop versus whip antenna at night time



Example of reception on night time with loop and whip antenna.

10.1.2.2 Passive ferrite antenna

It consists of two crossed wound ferrites with a low impedance output.

The advantage of this type of antenna is its immunity to atmospheric noise and strong fields.

On the other hand its capacities of capture are very weak.

Efficiency at high frequencies (> 4 MHz) is too low.

10.1.2.3 Active ferrite antenna

Similar to the cross frame but using wound ferrites coupled to a preamplifier. Better sensitivity that passive ferrite antenna but very low efficiency at high frequencies > 4 MHz.

There are two models:

Antenna ferrite untuned:

– Advantage: better resistance to strong fields.
– Disadvantage: Low sensitivity.

Tuned ferrite antenna:

– Advantage: better sensitivity.
– Disadvantage: more sensitivity to transmodulation.

– Sensitive to temperature variations.

– Complexity of realization.

FIGURE 33

Passive whip antenna

Report M.2443-33

FIGURE 34

Active whip antenna

Report M.2443-34

FIGURE 35

Cross loop antenna

Report M.2443-35

FIGURE 36

Cross loop ferrite antenna Passive or active

Report M.2443-36

10.2 Environmental performances of receiving antenna (refer to IEC standard 60945)

Wind rating:	160 km/h without ice deposit
Temperature range:	−55°C to + 55°C
	Dry heat and damp heat tests
Relative humidity:	100%
Water proofing:	IP 67 / EN 60945 rain test
Shock:	50 g / 10 ms
Vibration:	2 to 12.5 Hz amplitude 1.5mm
	12.5 to 90 Hz acceleration 10 m/s²
Corrosion	Test shall be carried out 4 times with a storage of 7 days at 40°
	(90/95% humidity)
Lighting protection:	500 kV/m/µs.

10.3 Technical specifications of a typical receiving antenna

Frequency range:	300 kHz to 30 MHz
Polarization:	Vertical

Radiation pattern: Omni-directional

Impedance output: 50 Ω

Antenna factor: 10/15 dB

Internal noise: Fa ≤ 60 at 500 kHz

IP²: ≥ 50 dB

IP³: ≥ 30 dB

Cross modulation: ≥ 10 V/m

Minimal RF field sensitivity: 10 µV/m for *S*/*N* 20 dB

Power supply: As receiver

EMC according EN (IEC) 60945

Radiated emission:	150 kHz to 300 kHz	80 dBµV/m to 52 dBµV/m
For active antenna	300 kHz to 30 MHz	52 dbµV/m to 34 dBµV/m
	30 MHz to 2 GHz	54 dBµV/m exept for VHF frequency band
	156 MHz – 165 MHz	24 dBµV/m
Conducted emission:	10 kHz – 150 kHz	96 to 50 dBµV quasi peak
For active antenna	150 kHz to 350 kHz	60 dBµV to 50 dBµV quasi peak
	350 kHz to 30 MHz	50 dBµV quasi peak

Immunity

ESD 6 kV/ 8 kV contact / air

RF radiated field 10 V/m

Conducted RF 3 V rms to 10 V rms

Burst 1 kV

Surge 1 kV

Power supply variation and failure: 10.8 V dc to 32 V dc or manufacturer specified voltage.

10.4 Connection to receiver

If this connection is made by coaxial cable it is recommended to use double shield cable type RG214 or equivalent for long distance.

RG58 or equivalent must be used only for short links.

TABLE 14

Loss for 100 m at various frequencies depending on coaxial model

Frequency	**Coaxial model**		
	RG 214	**RG 213**	**RG 58**
500 kHz	0.10 dB	0.10 dB	0.30 dB
5 MHz	1.4 dB	1.4 dB	3.6 dB
10 MHz	2 dB	2 dB	5 dB
20 MHz	3.2 dB	3.3 dB	7.5 dB
30 MHZ	4.5 dB	4.6 dB	12 dB

Some new active antennas use standard four pairs SFTP data cable.

11 Receiver

Its role is to:

– Filter the received frequencies;

– Amplify received signals;

– Demodulate received signals.

It can be divided into four parts:

– The RF part

– The digital part and decoding

– The man-machine interface with control and display unit (CDU)

– The data interface for connection to peripheral equipments.

Power supply

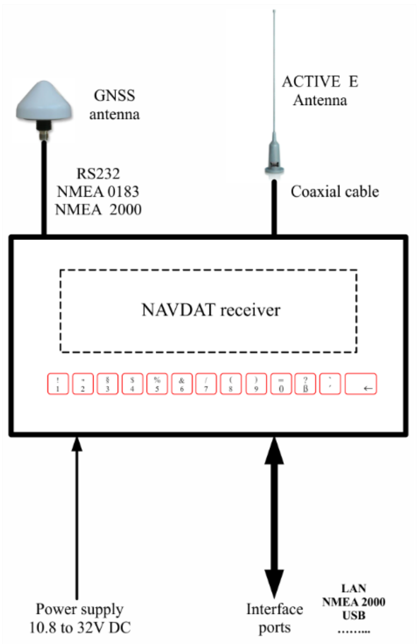
– The power supply must be adapted to the ship:

  • DC voltage from 10.8 V to 32 V

  • AC voltage (from converter for example)

FIGURE 37

Receiver synoptic



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NOTE – The internal GNSS receiver can be replaced by an external receiver or a GNSS dataset (geographical position, time and 1pps clock) connected on an interface port.

11.1 RF part

The signals picked up by the receiving antenna are applied to filters corresponding to each operating frequency of the NAVDAT in MF and HF. This makes it possible to ensure a high rejection of the interfering out-of-band signals. (This principle is also valid for A/D conversion receivers).

The receiver operates on the preprogrammed frequencies of the NAVDAT system.

The frequency of 500 kHz has priority. HF channels can be deselected by the operator (except the 4 and 6 MHz) that it is preferable to watch constantly. Other MF and HF channels can be selected by operator.

The selected frequencies are automatically watched to detect the presence of NAVDAT signals with sufficient SNR for good decoding.

The OFDM signals of the NAVDAT system can be varied according to:

– The propagation channel used (MF or HF).
– Surface wave or surface wave + sky wave with variable delay and Doppler.

The choice of modulation:

– It is possible to use 3 types of modulation depending on the objective (type of message), and propagation conditions.
– 4 QAM, 16 QAM or 64 QAM with variable bandwidth.

The receiver must be able to automatically determine the type of modulation and corrections factor received on its digital part.

11.2 Digital part

It is responsible for demodulating received OFDM signals and converting them into usable files for operator and peripheral equipment.

A GNSS receiver (or GNSS standard signals network) is connected to the receiver to obtain:

– The position of the vessel (required for the selective message mode)
– Time
– The 1 pps (which can be used to calibrate the internal frequencies clocks of the receiver)

The exchanges with the peripherals are done by different data link like:

ETHERNET, NMEA2000, USB, etc. comply with the requirement of the IEC61162 series.

11.3 Man – machine interface

The receiver has a keypad and a simplified display for parameterization by operator (CDU).

11.4 Sensitivity

The sensitivity of a digital radio receiver is the minimum received signal power required in order to achieve a specified bit error rate after demodulation.

The required signal power depends on the amount of noise present at the input, and on the minimum signal to noise ratio (SNR) needed by the decoder.

SNR_{min} depends on the specified error rate, the modulation used, the algorithm used for demodulation and decoding, and the quality of the implementation of that algorithm.

Using DSP and powerful mathematical algorithms it is now possible to decode frames with lower SNR. Gain of 4 to 6 dB is often obtained from theoretical value.

11.5 Calculations

Thermal noise at 290 K:	−174 dBm/Hz
Bandwidth factor for 10000 Hz:	40 dB

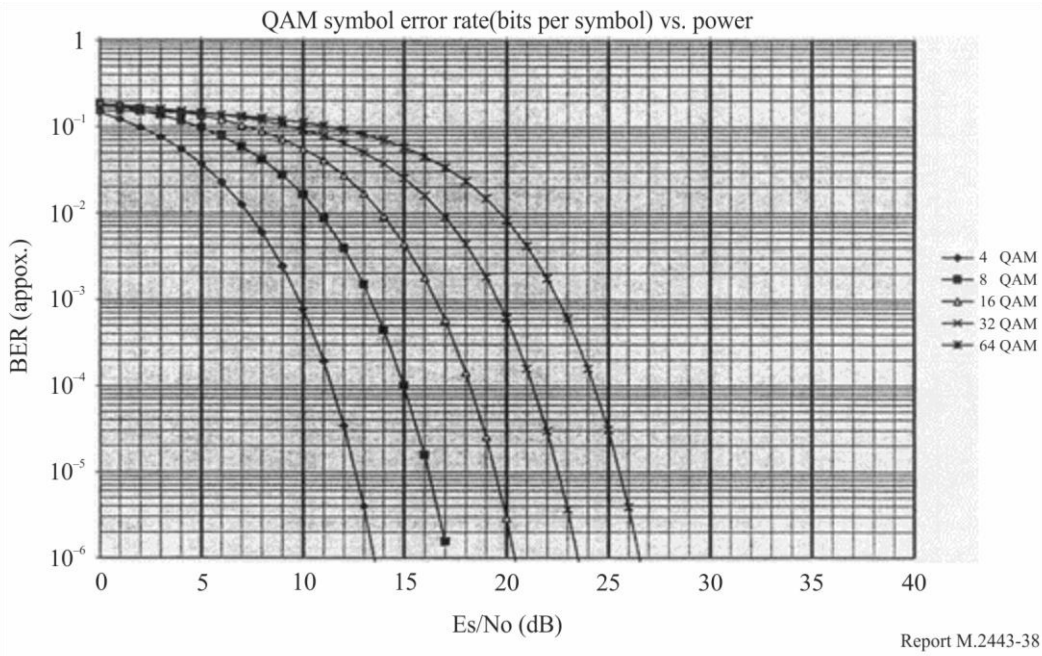
Receiver noise figure:	10 dB
Noise power in 10 kHz:	−124 dBm
Required CNR for a BER = 10^{-5}:	≥ 26 dB (Theoretical value)
Fading provision:	2 dB
Input signal requirement:	−96 dBm
Convert into voltage in 50 Ω	3.6 µV / 11 dBµV.

11.6 Necessary signal to noise ratio

Figure 38 gives the SNR theoretical values necessary to obtain a BER of 10^{-4} to 10^{-6}.

FIGURE 38

Theoretical signal to noise value for some quadrature amplitude modulated modulation scheme



11.7 Signal to noise ratio values used for calculations

TABLE 15

Modulation	**Code rate**	**SNR (dB)**	
		Propagation channel	
		A	**B**
For 4 QAM	0.5	14	14
For 4 QAM	0.75	14	14
For 16 QAM	0.5	16	16
For 16 QAM	0.75	18	18
For 64 QAM	0.5	22	23
For 64 QAM	0.75	24	25

11.8 Technical specifications

By definition, the NAVDAT receiver will be installed in a multiple interference source environment. It must therefore meet appropriate technical specifications.

TABLE 16

Technical specifications of the NAVDAT receiver

Received frequencies / band:	500 kHz
	479 to 526.5 kHz
	4200 kHz
	6340 kHz
	8500 kHz
	12660 kHz
	16900 kHz
	22500 kHz
Bandwidth:	max: 10 kHz (1, 3, 5 or 10 kHz)
Modulation type:	OFDM
Demodulation mode:	4 QAM, 16 QAM and 64 QAM
Forward Error Correction Codes:	0.5 / 0.62 / 0.75 / 0.78
Antenna input impedance:	50 Ω
Minimum sensitivity for BER 10^{-4}:	11 dBμV (3.6 μV)
Dynamic range:	for 500 kHz = 90 dB
	For HF frequencies = 85 dB
Adjacent channel selectivity:	At +/−10 kHz 25 dB
For BER 10^{-4}	At +/−20 kHz 35 dB
	At +/−30 kHz 45 dB
	At more than +/−30 kHz 50 dB
Blocking:	Wanted signal = 20 dBμV Unwanted signal = 90 dBμV
For BER 10^{-4}	Range +/−10 kHz to +/−100 kHz
Intermodulation:	Wanted signal = 20 dBμV
For BER 10^{-4}	Unwanted signal = 70 dBμV at normal conditions
	64 dBμV at extreme conditions
Co channel rejection:	≥ −6 dB
Spurious response rejection:	≥ 60 dB

AGC efficiency: The receiver may perform AGC and adjust its gain so that strong signals are attenuated to avoid clipping of an analogue-to-digital converter (ADC) in the receiver. Weak signals are amplified to occupy the full ADC range. By using the proper receiver gain control, clipping of the ADC and degradation due to ADC clipping may both be avoided. It is thus desirable to effectively perform AGC at the receiver for all the dynamic range. The AGC system must be managed by the digital part of the receiver.

TABLE 17

EMC

Radiated emission	150 kHz to 300 kHz 300 kHz to 30 MHz 30 MHz to 2 GHz 156 MHz – 165 MHz	80 dBµV/m to 52 dBµV/m 52 dBµV/m to 34 dBµV/m 54 dBµV/m except for VHF frequency band 24 dBµV/m
Conducted emission	10 kHz – 150 kHz 150 kHz to 350 kHz 350 kHz to 30 MHz	96 to 50 dBµV quasi peak 60 dBµV to 50 dBµV quasi peak 50 dBµV quasi peak

TABLE 18

Immunity according IEC 60945

ESD	6 kV/8 kV contact / air
RF radiated field	10 V/m
Conducted RF	3 V rms to 10 V rms
Burst	1 kV
Surge	1 kV
Power supply variation and failure:	10.8 to 32 V DC

Electrical Safety

The receiver shall comply with the safety requirements as defined in IEC 60950-1. or equivalent international standards.

12 NAVDAT coverage calculations

12.1 Parameters

The coverage of the NAVDAT system depends on the following parameters:

Radiated RF power (see § 7.1).

Transmitter average RF power of OFDM signal.

Global efficiency of the antenna system

Propagation channel (in surface wave mode)

Attenuation that depends on Frequency used

Atmospheric noise level dependent on:

– The frequency used
– The Geographical Zone
– The season
– Time of the day

Reception on the ship

– Man made noise
– Quality of the antenna and the receiver
– Quality of the digital demodulator

12.2 Factors affecting bit error rate

BER can be affected by a number of factors. By manipulating the variables that can be controlled it is possible to optimize the system to provide the performance levels that are required.

Interference: The interference levels present in a system are set by external factors and cannot be changed by the system design. However it is possible to use H antenna less sensitive to electric noise fields.

Increase transmitter power: It is also possible to increase the radiated power level of the system so that the power per bit is increased. The limit is in general linked to the overall cost of the transmitter and antenna assembly.

Lower order modulation: Lower order modulation schemes can be used, but this is at the expense of data throughput with reduced bandwidth:

> **Reduce bandwidth:** Another approach that can be adopted to reduce the bit error rate is to reduce the bandwidth. Lower levels of noise will be received and therefore the signal to noise ratio will improve. Again this results in a reduction of the data throughput attainable. For example:
>
> – With a bandwidth of 1 kHz the gain is of 10 dB compare to 10 kHz
>
> – With a bandwidth of 3 kHz the gain is 5 dB
>
> – With a bandwidth of 5 kHz the gain is 3 dB.

It is necessary to balance all the available factors to achieve a satisfactory bit error rate. The NAVDAT system is very flexible and its parameters can be adapted to each situation and type of broadcast message within the limits of any radio communication system:

Frequency, Bandwidth, Modulation, Error code according to the objectives to be achieved.

12.3 Predictions coverage methods

Two methods are described for coverage calculations.

The first one use the Recommendation ITU-R M.1467-1 (see § 12.3.1).

The second one use prediction software for obtain the SNR coverage or RF field coverage (see § 12.3.2).

12.3.1 Coverage calculation according ITU-R M.1467-1

According to Recommendation ITU-R M.1467-1, the prediction of NAVDAT coverage range includes the following steps:

1) Achieving the required quality of signal;

2) Determination of external noise factor, F_a, for the required availability;

3) Accounting for filed strength;

4) Determination of the coverage ranges.

Achieving the required quality of signal

As the NAVDAT system operates in the mid-wave (MF) band, the two typical MF channels (refer to Table 2, according to ESTI standard "Digital Radio Mondiale (DRM) System Specification") in the DRM system are used as simulation channels. The specific parameters are shown in Table 19.

TABLE 19

Channel parameters for simulation

(a) Channel 1

Channel no 1: AWGN		good typical/moderate bad		LF, MF,HF LF, var.SNR
	path 1	path 2	path 3	path 4
Delay (Δ_k)	0			
Path gain, rms (ρ_k)	1			
Doppler shift (D_{sh})	0			
Doppler spread (D_{sp})	0			

(b) Channel 2

Channel no 2: Rice with delay		good typical/moderate bad		MF, HF
	path 1	path 2	path 3	path 4
Delay (Δ_k)	0	1 ms		
Path gain, rms (ρ_k)	1	0,5		
Doppler shift (D_{sh})	0	0		
Doppler spread (D_{sp})	0	0,1 Hz		

The simulation of bit error rate (BER) performance was carried out under the two channel conditions respectively for the three transmission modes (4/16/64-QAM, 0.5) of NAVDAT. The results were recorded in Table 20.

TABLE 20

SNR performance (10 kHz bandwidth)

Modulation/code rate	SNR (dB) (Channel 1, BER (after error correction)=10^{-5})	SNR (dB) (Channel 2, BER (after error correction)=10^{-5})
4-QAM/0.5	4.6	6.1
16-QAM/0.5	9.8	12.3
64-QAM/0.5	14.4	19.4

Determination of external noise factor, F_a, for the required availability

According to Recommendation ITU-R P.372-13, the median external noise factor (F_{am}) and the upper decile value D_u were calculate by ITU NOISEDAT software. The coordinate parameters from Table 21 were used in the calculation.

TABLE 21

Coordinate parameters

Area	Latitude	Longitude
Copenhagen	55.7N	12.6E
Huaniao island	30.85N	122.68E
Singapore	1.3N	103.6E

According to Recommendation ITU-R M.1467-1, an upper value F_a for the external noise factor which corresponds to the required availability is calculated by equation (1).

$$F_a \text{ (dB above } kT_0) = F_{am} + \sqrt{{D_t}^2 + {D_s}^2} \quad (1)$$

where:

F_{am}: median external noise factor

D_s : variation in signal level expected for the required time percentage, is equal to 3 dB fading margin as specified by IMO

D_t : variation in noise level expected for the required percentage of time.

Assuming that the availability required for NAVDAT is 90%, then the upper decile value D_u should be substituted for D_t in equation (1). F_{am} and D_u are calculated using NOISEDAT software by inputting relevant parameters (refer to Table 22).

TABLE 22

Input parameters of NOISEDAT

Lat	30.85
Long	122.68
Frequency	500 kHz
Noise characteristics	−145 dB

Huaniao Island was taken as an example, and the calculation results of $\mathbf{F_a}$ are shown in the following table. It shows that $\mathbf{F_a}$ ranges from 75.5 to 107.4 Nm (140 km to 200 km).

TABLE 23

F_a of Huaniao island (Lat = 30.85, Long = 122.68)

Season	Time block	F_{am}	$D_t = D_u$	$F_a = F_{am} + \sqrt{D_t^2 + D_s^2}$
Winter	0000-0400	88.4	10.6	99.4
	0400-0800	81.5	14.3	96.1
	0800-1200	80.7	9.7	90.9
	1200-1600	80.7	9.7	90.9
	1600-2000	87.8	14.4	102.5
	2000-2400	91	10.4	101.8

TABLE 23 (*end*)

Season	**Time block**	***Fam***	$D_t = D_u$	$F_a = F_{am} + \sqrt{D_t^2 + D_s^2}$
Spring	0000-0400	91.5	10.5	102.4
	0400-0800	76.4	15.4	92.1
	0800-1200	80.3	10.1	90.8
	1200-1600	72.1	17.7	90.1
	1600-2000	87	18.8	106.0
	2000-2400	93.8	10.2	104.4
Summer	0000-0400	94.2	10	104.6
	0400-0800	77.2	16.2	93.7
	0800-1200	73.2	16.3	89.8
	1200-1600	88.7	18.5	107.4
	1600-2000	90.3	16.8	107.4
	2000-2400	96.7	8.9	106.1
Autumn	0000-0400	88.8	9.7	99.0
	0400-0800	76.1	16.4	92.8
	0800-1200	76.1	13.2	89.6
	1200-1600	73.8	17	91.1
	1600-2000	84.3	17.8	102.4
	2000-2400	91.7	9.8	101.9

The following figures show the trend of F_a over season and time.

FIGURE 39

Fa vs season (time)

Huaniao island (Lat = 30.85N, Long = 122.68E)

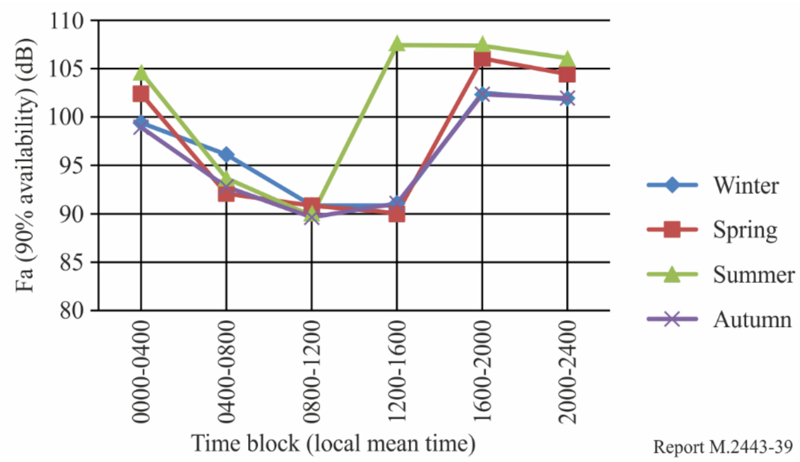


FIGURE 40

Fa of Copenhagen (Lat = 55.7N, Long = 12.6E)

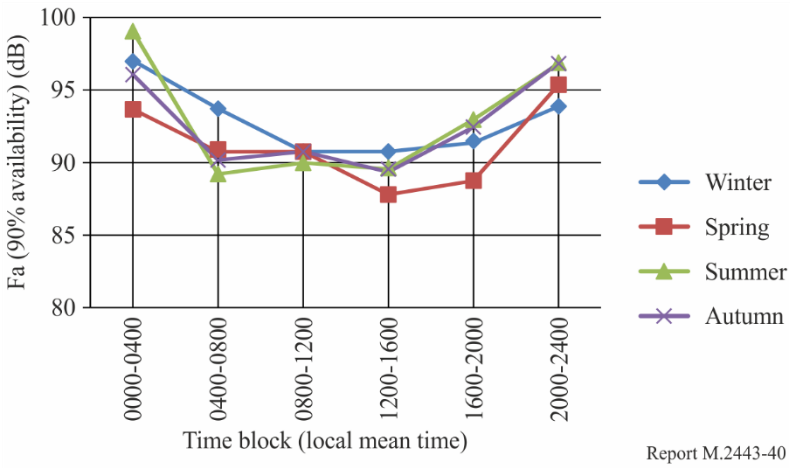
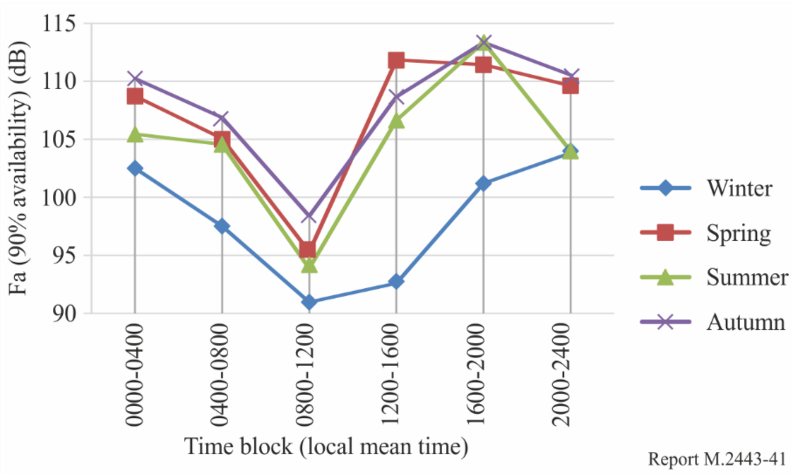


FIGURE 41

Fa of Singapore (Lat = 1.30N, Long = 103.90E)



Accounting for field strength

According to Recommendation ITU-R P.368, the field strength of propagation by groundwave was calculated using GRWAVE software. The parameters used for calculation are as follows:

TABLE 24

Input parameters of GRWAVE

σ (electrical conductivity)	5 S/m
ε (permittivity)	70
Transmitting antenna height	30 m
Receiving antenna height	10 m

The relationship between range and field strength calculated by GRWAVE is shown in Fig. 42.

FIGURE 42

GRWAVE OUPUT vertical polarization 1 kW radiated power

Permittivity = 70 Conductivity = 5S/m

Frequency = .500 MHz

Transmitter height = 30.0 meters
Receiver height = 10.0 meters

Distance km	Field strength dB (UV/m)	Basic transmission loss dB	
			(F)
1. 20	107. 89	27. 98	
50. 00	75. 23	60. 64	
			(R)
50. 00	75. 29	60. 58	
100. 00	68. 78	67. 09	
150. 00	64. 61	71. 25	
200. 00	61. 36	74. 51	
250. 00	58. 56	77. 31	
300. 00	56. 03	79. 83	
350. 00	53. 68	82. 19	
400. 00	51. 44	84. 43	
450. 00	49. 28	86. 59	
500. 00	47. 18	88. 69	
550. 00	45. 13	90. 74	
600. 00	43. 12	92. 75	
650. 00	41. 13	94. 74	
700. 00	39. 17	96. 70	
750. 00	37. 23	98. 63	
800. 00	35. 32	100. 55	
850. 00	33. 42	102. 45	
900. 00	31. 53	104. 34	
950. 00	29. 65	106. 21	
1 000. 00	27. 79	108. 07	
1 050. 00	25. 94	109. 93	
1 100. 00	24. 10	111. 77	
1 150. 00	22. 27	113. 60	
1 200. 00	20. 45	115. 42	
1 250. 00	18. 63	117. 24	
1 300. 00	16. 82	119. 04	
1 350. 00	15. 02	120. 85	
1 400. 00	13. 23	122. 64	
1 450. 00	11. 44	124. 43	
1 500. 00	9. 65	126. 22	
1 550. 00	7. 87	128. 00	
1 600. 00	6. 09	129. 77	
1 650. 00	4. 32	131. 55	
1 700. 00	2. 56	133. 31	
1 750. 00	. 79	135. 08	
1 800. 00	–. 97	136. 84	
1 850. 00	–2. 72	138. 59	
1 900. 00	–4. 48	140. 34	
1 950. 00	–6. 23	142. 09	
2 000. 00	–7. 97	143. 84	

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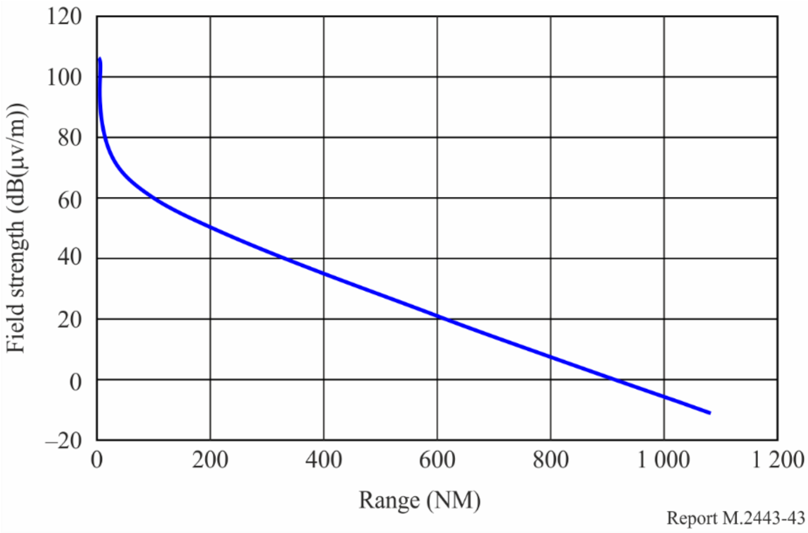
FIGURE 43

Range vs field strength

(Radiated RF power: 550 W)



The receiver input power P_{rx} (W) can be converted to field strength with equation (2):

$$P_{rx} = \frac{G_r \times \lambda^2}{4\pi} \times \frac{E^2}{Z_0} \tag{2}$$

where:

- G_r: receiving antenna efficiency
- λ: Wavelength (m)
- E: Field strength (v/m)
- Z_0: Characteristic impedance of free space = 120 π.

Considering the influence of external noise and other factors, the receiver input power P_{rx} (dBm) satisfying the reception requirement is:

$$P_{rx} = -174 + 10\log(BW) + SNR + NF \tag{3}$$

where：

- −174 dBm/Hz: Thermal noise at 290 K
- BW: Receiver bandwidth (Hz)
- SNR: Signal to noise ratio meeting the requirements of bit error rate
- NF: It consists of F_a and receiver noise figure. F_a is the main consideration here.

NOTE – The receiving antenna efficiency has been considered in equation (2).

By substituting equation (3) into equation (2), the relation between field strength E and F_a can be obtained.

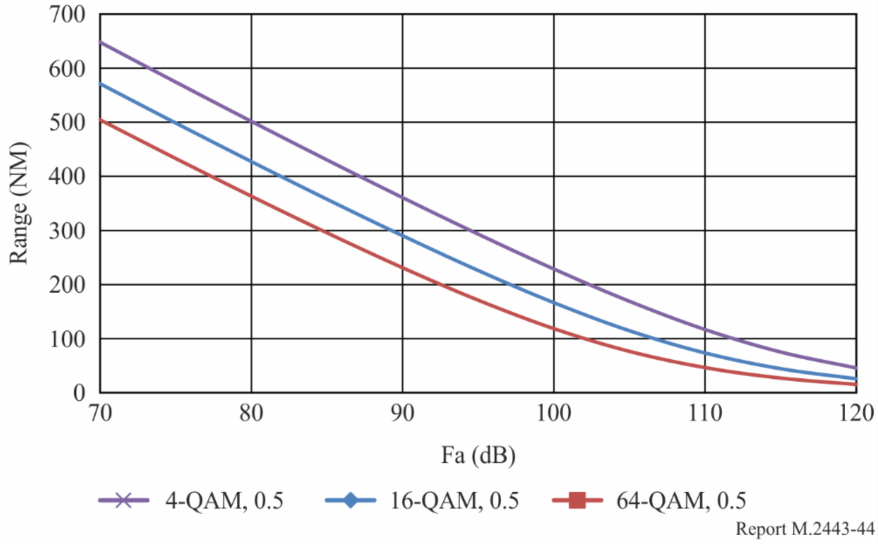
Determination of the coverage ranges

Combining the above results, we can get the relationship between range and F_a (refer to Fig. 44).

FIGURE 44

Range vs F_a

(Radiated RF power: 550 W, bandwidth: 10 kHz)



By substituting the F_a of Fig. 39 into Fig. 44, we can get the calculation results of coverage range in Huaniao island. The coverage ranges of Copenhagen and Singapore were also calculated in the same way. The results were recorded in Table 25.

TABLE 25

NAVDAT ranges

(Radiated RF power: 550 W, bandwidth: 10 kHz)

Area	Fa (dB)	Range (NM)	Modulation(code rate)
Huaniao island (Shanghai)	89.6 ~ 107.4	142.3 ~ 365.6	4-QAM(0.5)
		93.3 ~ 295.3	16-QAM(0.5)
		60.5 ~ 235.8	64-QAM(0.5)
Copenhagen	87.8 ~ 99.1	240.6 ~ 391.0	4-QAM(0.5)
		177.5 ~ 319.8	16-QAM(0.5)
		128.0 ~ 259.1	64-QAM(0.5)
Singapore	91.0 ~ 113.4	87.5 ~ 347.5	4-QAM(0.5)
		53.0 ~ 277.9	16-QAM(0.5)
		32.6 ~ 219.3	64-QAM(0.5)

The conclusion of the example calculation:

1) Based on the calculation of NAVDAT ranges, the results (refer to Table 25) show that the NAVDAT can well cover the sea area A2 in the middle and high latitudes.

2) In order to meet the requirements of coverage of sea area A2 at all latitudes, the broadcast periods, modulation mode, bandwidth and transmitting power must be chosen taking into account for the noise levels Fa variation during the day. The broadcast can also be ensured according the noise level.

12.3.2 GRWAVE OUPUT vertical polarization 1 kW radiated power

Permittivity = 80 Conductivity = 5 S/m

```
FREQUENCY =    0.500 MHZ

TRANSMITTER HEIGHT =    40.0  METRES
RECEIVER HEIGHT    =    10.0  METRES

DISTANCE      FIELD STRENGTH     BASIC TRANSMISSION LOSS
  KM            DB(UV/M)               DB           (F)
                                                     (R)
    50.00         75.30                60.51
    75.00         71.55                64.25
   100.00         68.79                67.01
   125.00         66.55                69.25
   150.00         64.63                71.17
   175.00         62.93                72.87
   200.00         61.39                74.42
   225.00         59.95                75.86
   250.00         58.59                77.21
   275.00         57.31                78.49
   300.00         56.08                79.72
   325.00         54.89                80.92
   350.00         53.73                82.07
   375.00         52.60                83.20
   400.00         51.50                84.30
   425.00         50.42                85.39
   450.00         49.35                86.45
   475.00         48.30                87.50
   500.00         47.26                88.54
   525.00         46.24                89.57
   550.00         45.22                90.58
   575.00         44.21                91.59
   600.00         43.21                92.59
   625.00         42.22                93.58
   650.00         41.24                94.56
   675.00         40.26                95.54
   700.00         39.29                96.51
   725.00         38.32                97.48
   750.00         37.36                98.44
   775.00         36.41                99.40
   800.00         35.45               100.35
```

12.3.2.1 Coverage predictions

The following charts are edited as an example for a given season (autumn) and time (UTC + 02).

Each implementation of a NAVDAT coast station should be the subject of a specific study which falls outside the scope of this Report.

FIGURE 45

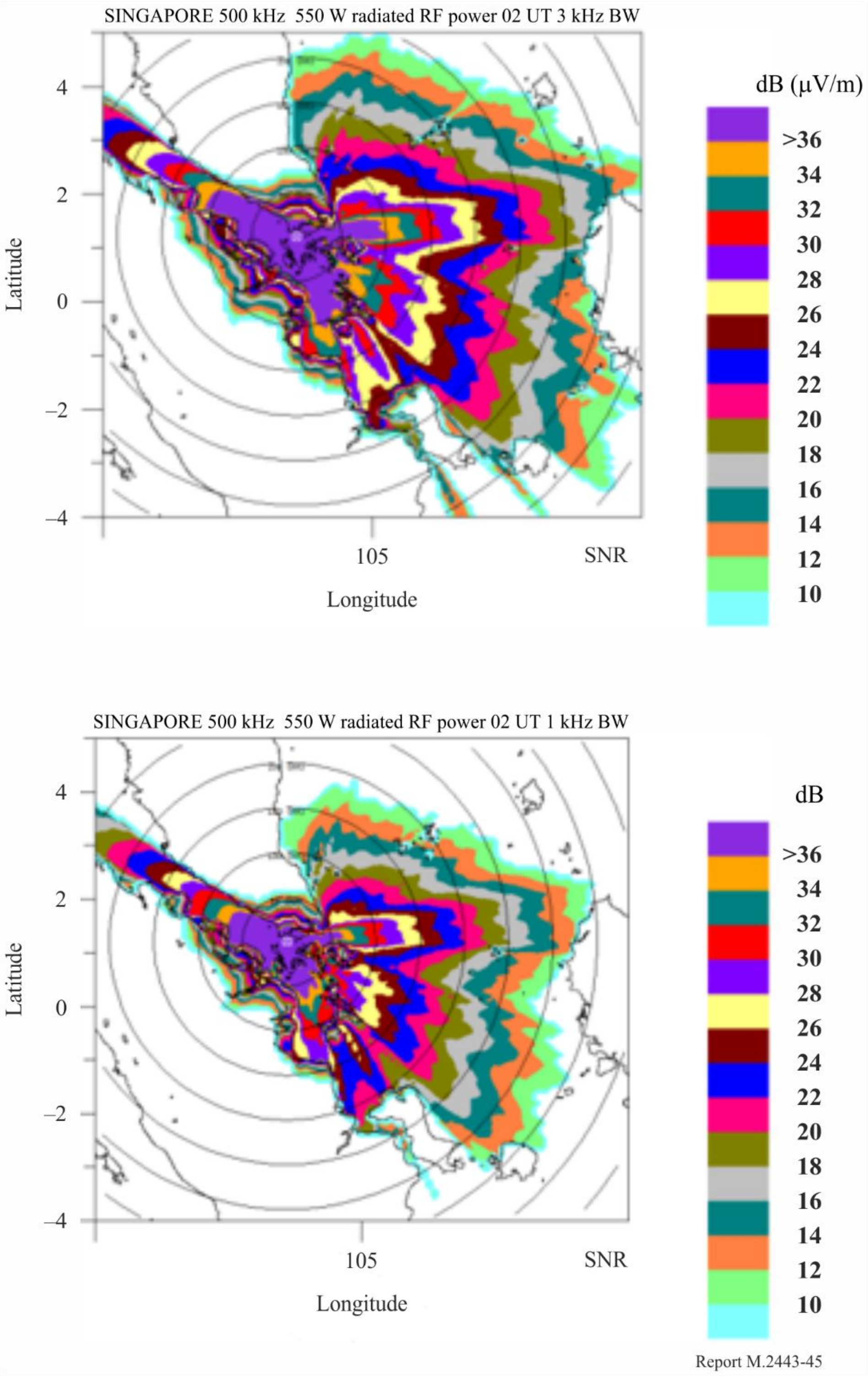

SINGAPORE 500 kHz 550 W radiated RF power 02 UT 3 kHz BW
Latitude
Longitude
105
SNR
dB (µV/m)
>36
34
32
30
28
26
24
22
20
18
16
14
12
10
SINGAPORE 500 kHz 550 W radiated RF power 02 UT 1 kHz BW
Latitude
Longitude
105
SNR
dB
>36
34
32
30
28
26
24
22
20
18
16
14
12
10
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FIGURE 46

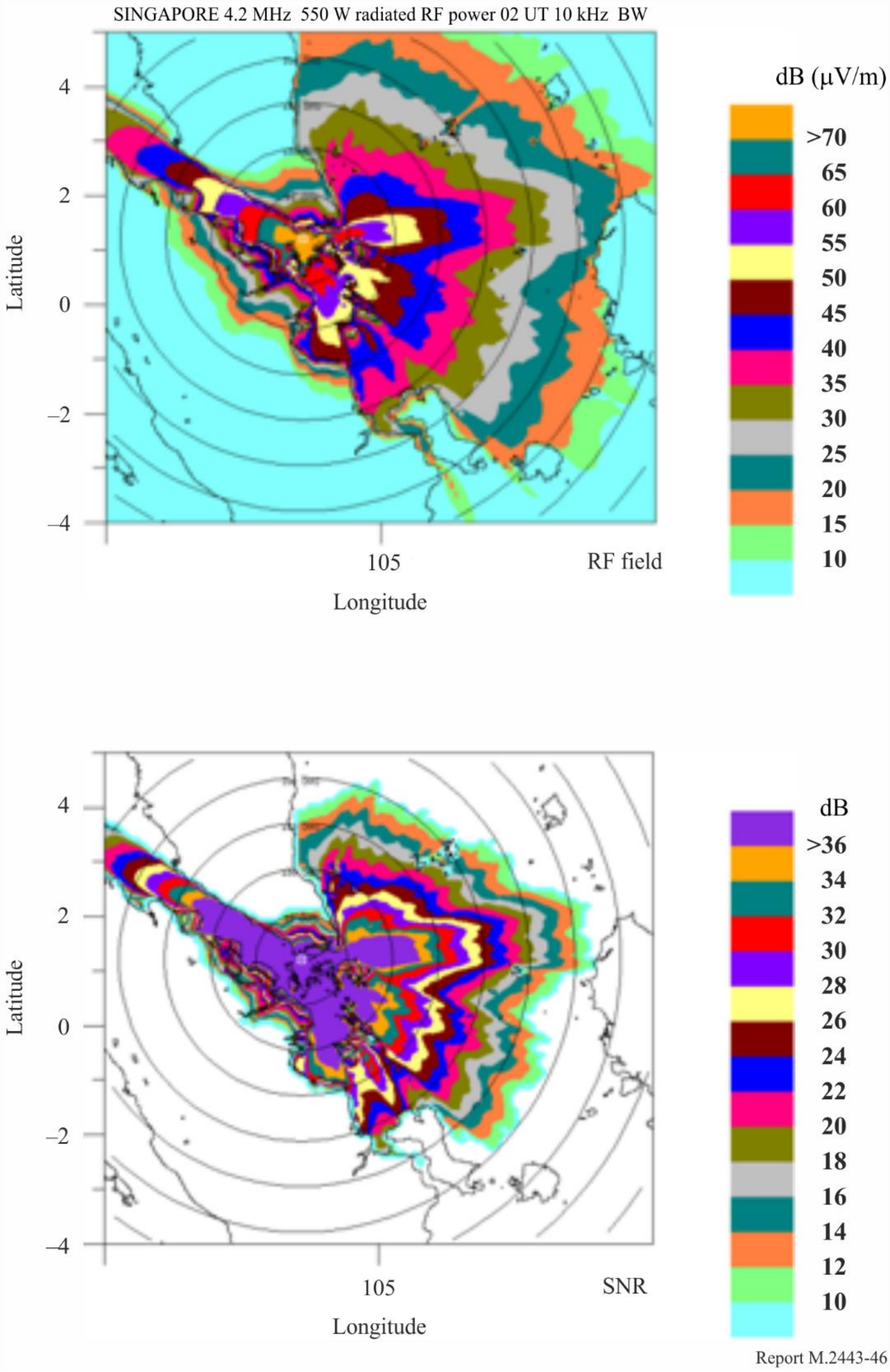

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FIGURE 47

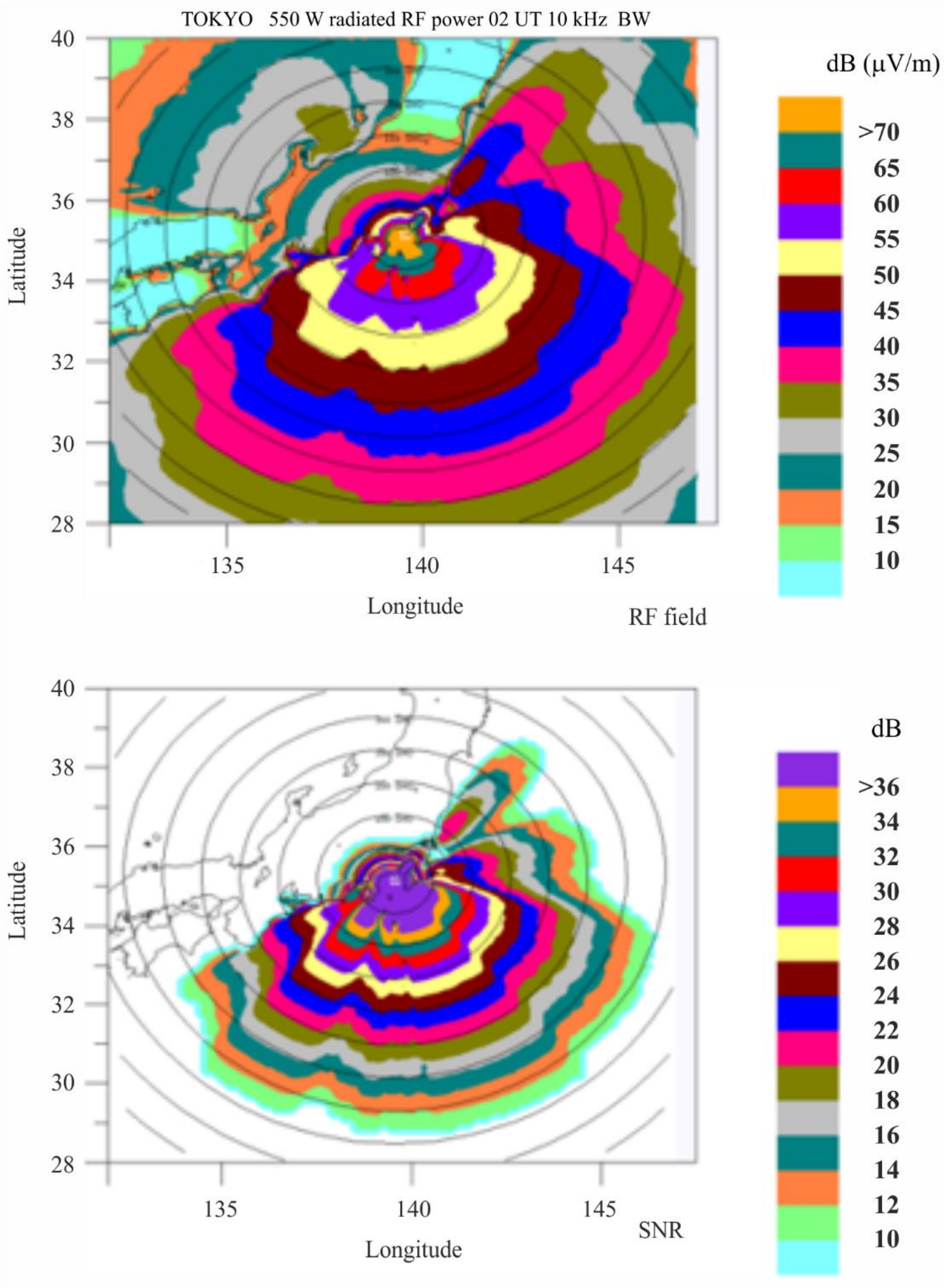

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FIGURE 48

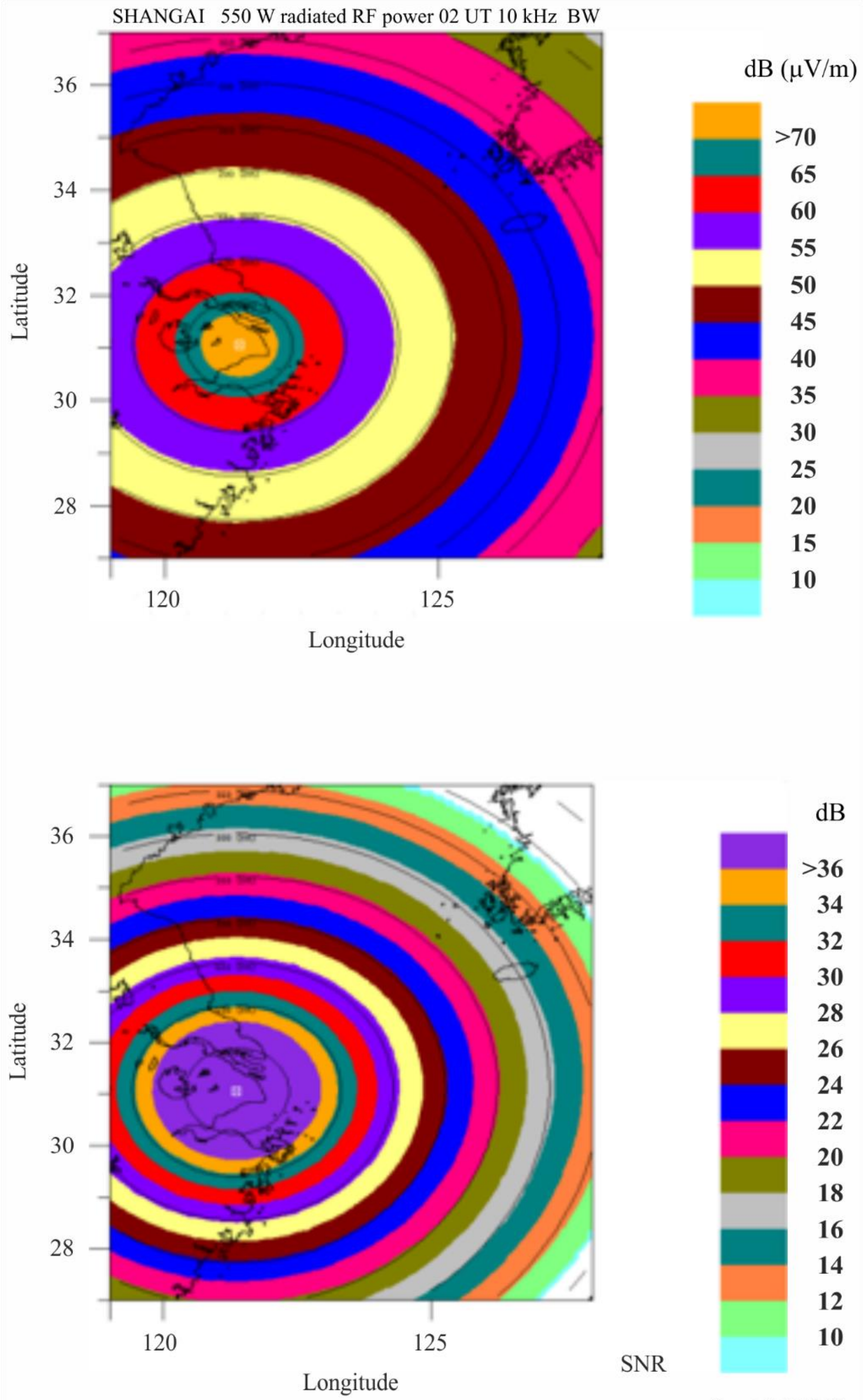

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FIGURE 49

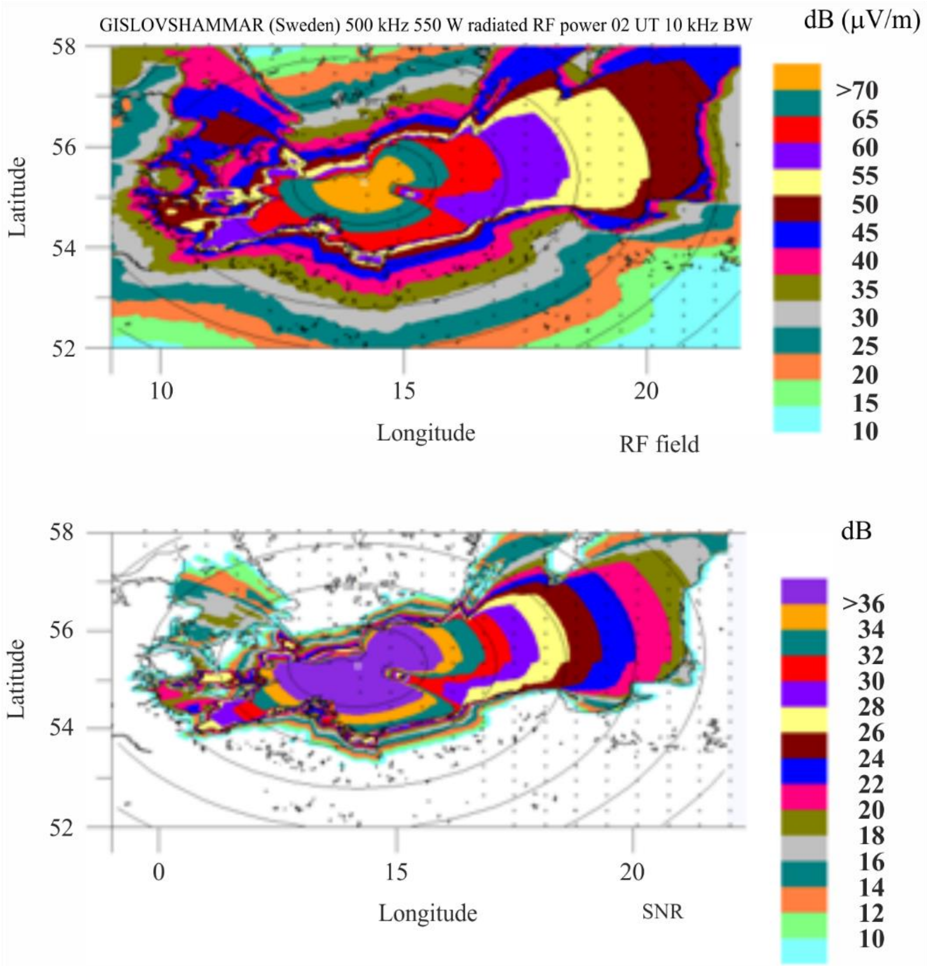

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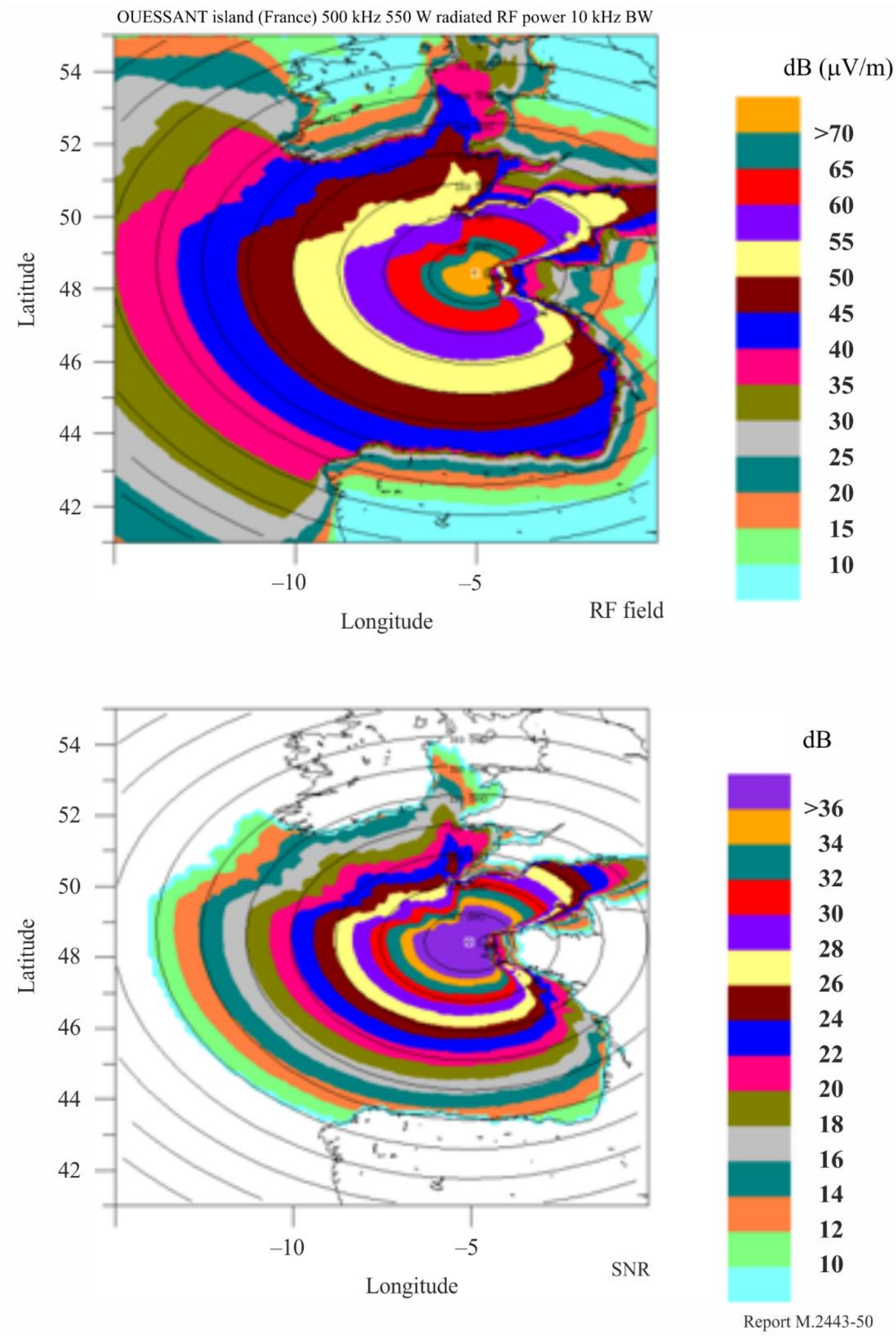
FIGURE 50



13 Conclusion

The information that has been presented in this document may be used by any people in charge to design a NAVDAT coast station in order to achieve the best performance of the system.

It is primarily a tool for understanding the overall NAVDAT system in order to manage all parameters. The NAVDAT system is open to any technological evolution.