REPORT ITU-R M.2123*

Long range detection of automatic identification system (AIS) messages under various tropospheric propagation conditions

(2007)

1 Introduction

In the 1990s, the International Maritime Organization (IMO), the International Telecommunications Union (ITU) and the International Electrotechnical Commission (IEC) adopted a new navigation aid known as the Automatic Identification System (AIS) to help improve safety-of-navigation, maritime traffic control and efficiency of maritime commerce. The primary purpose of the AIS is to facilitate the efficient exchange of navigation and voyage data between ships, and between ships and shore stations. The technical characteristics of the AIS using time division multiple access (TDMA) techniques in the VHF maritime mobile band are described in Recommendation ITU-R M.1371.

Like most VHF terrestrial systems, the maximum range of AIS communications is normally governed by line-of-sight and diffraction mode propagation mechanisms. Assuming typical technical parameters of AIS equipment, maximum reliable ship-to-ship radiocommunications over sea water is in the range of 20-25 NM. Shore stations, with high antennas, can reliably receive AIS messages from ships at distances of up to 20 to 35 NM, depending on antenna heights above sea level. The safety-of-navigation and traffic control functions provided by the AIS dictate a requirement for high communications reliability in which a high percentage of the AIS messages are detected and corrected decoded.

Because of the continued growing importance of the AIS traffic, a need has arisen to monitor shipping at distances from shore greater than can be achieved via these conventional propagation mechanisms. Recommendation ITU-R M.1371 introduces the concept of long range detection of AIS data but does not define a specific communications mechanism to accomplish long range AIS detection. As contrasted with normal AIS safety-of-navigation functions, this long range AIS capability does not necessarily need the same high degree of communications reliability. This lower reliability requirement follows from the fact that it is necessary to only detect a fraction of the AIS messages sent from a given ship to accomplish the goal of updating ship locations on a regular basis.

This Report addresses long range monitoring of ship locations at sea through detection of AIS messages. Section 2 focuses on concepts that may enhance long range detection of ships at sea by AIS coast stations. Section 3 assesses whether long range detection has similar spectrum sharing characteristics with other co-channel mobile systems as that of normal AIS safety-of-navigation functions. Section 4 provides an overall summary.

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* This Report should be brought to the attention of Radiocommunication Study Group 3, the International Maritime Organization (IMO), the International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA) and the Comité International Radio Maritime (CIRM).

2 Concepts to enhance the long range detection capabilities of AIS coast stations

2.1 Off-shore platforms

One mechanism to effectively supplement the shore-based reception range of AIS ship messages is through the installation of AIS receivers on off-shore platforms. Two cases are considered herein – off-shore oil platforms and off-shore weather buoys.

2.2 Oil platforms

In some parts of the world, off-shore oil platforms are extensively deployed along coastal areas. These platforms are typically very large, as illustrated in Fig. 1, and have extensive radiocommunications capability with the nearby mainland. Consequently, in such areas, oil platforms can provide a very useful base on which to locate AIS receiving equipment to enhance shore-based coverage.

FIGURE 1

Typical offshore oil platform

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The first step in evaluating the range enhancements possible with the use of offshore oil platforms is the development of a baseline capability for conventional shore-based reception. Table 1 gives representative technical parameters applicable for the AIS ship to shore link. Using these parameters and a radio propagation model as described in Appendix 3, Fig. 2 was developed which shows the median predicted received power for AIS ship to shore radiocommunications as a function of shore station antenna height.

The results from Fig. 2 indicate a median radiocommunication range of about 38 to 60 km (20 to 32 NM) for the antenna heights shown.

Offshore oil platforms have tower heights considerable higher than the coast station heights used above and consequently have larger communications range with ships at sea.

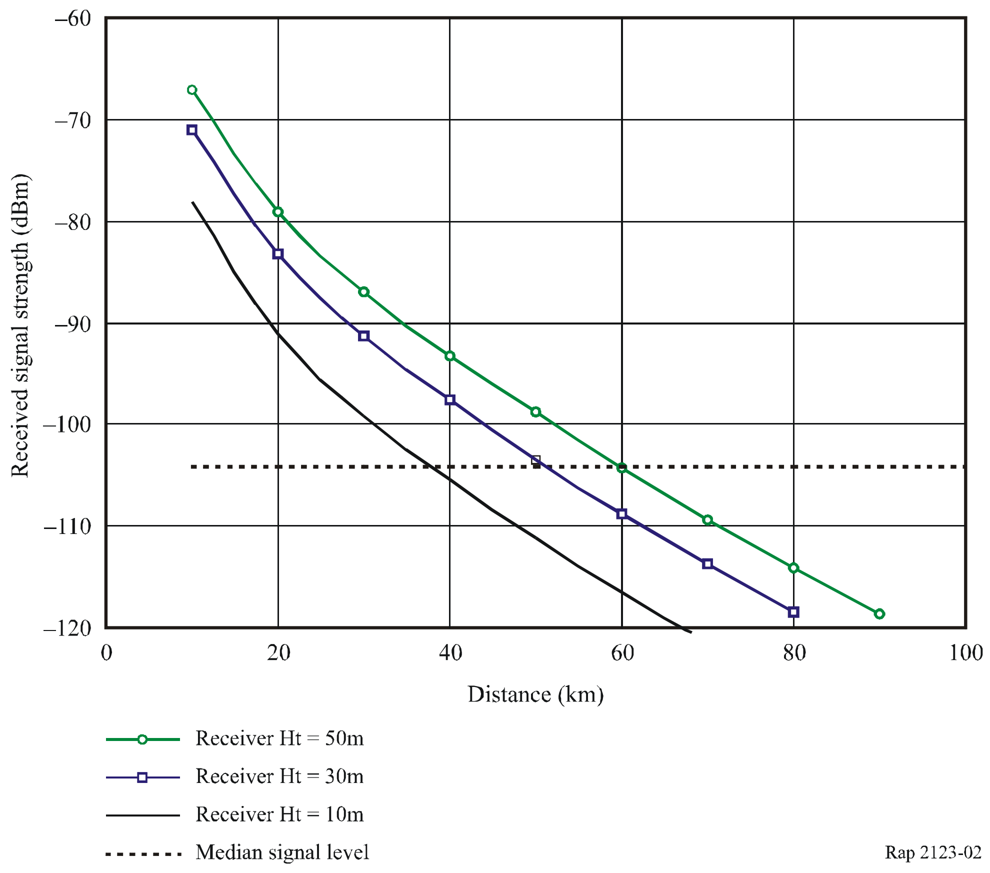
TABLE 1

Representative technical parameters for AIS ship-to-shore communications

Technical parameter	Typical value
Ship	
Transmit power	41 dBm
Antenna line losses	3 dB
Antenna gain	2 dB
Antenna height	~10 M
Shore station	
Antenna gain	5 dBi (omnidirectional)
Antenna line losses	3 dB
Receiver sensitivity	–107 dBm for 20% per (minimum) –109 dBm for 20% per (typical)
Median received signal level from edge of service range	–104 dBm
Antenna height	10 to 50 m

FIGURE 2

Predicted AIS median received power at shore station

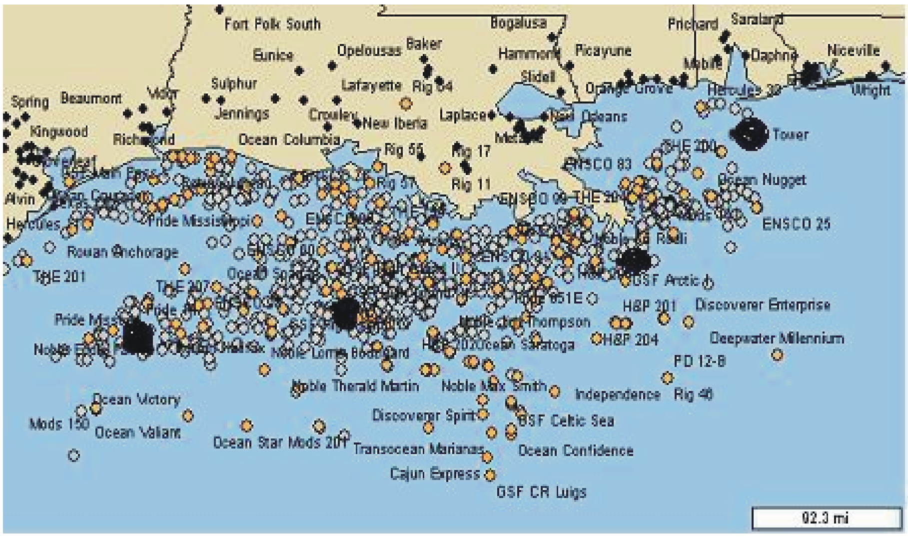


In those cases where there are sufficient numbers of such oil platforms, a line of AIS-equipped oil platforms appropriately located surrounding a key port can provide reliable AIS reception coverage at up to triple the distance from coast stations alone. Because of the extensive communications equipment already installed on most oil platforms, backhaul of the received AIS data to shore, either via satellite or undersea cable, generally presents no problems.

One such location is the Gulf of Mexico on the Southern Border of the United States of America. Figure 3 gives an overview of the oil platforms deployed in this area. Also shown as dark circles on the figure is one possible arrangement of AIS-equipped platforms. This arrangement of platforms extends reliable AIS reception coverage for ships to at least 120 NM from two major port areas, Houston, Texas and New Orleans, Louisiana in the United States of America.

FIGURE 3

Example of off shore oil platform deployment near New Orleans LA, United States of America



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The communication range enhancement as a result of anomalous propagation modes, primarily atmospheric ducting, discussed later in this section would also be applicable for AIS receivers installed on off-shore platforms. Consequently, on an intermittent basis, AIS reception coverage would extend further out to sea. For the Gulf of Mexico example described here, climatic conditions are often conducive to atmospheric ducting.

It is concluded that in areas where off-shore oil drilling occurs, installation of AIS receivers on these platforms can increase the coverage range of shore-based AIS detection by a factor of up to three. A line of well-placed platforms can provide complete extended-range coverage around key port facilities.

2.3 Weather buoys

As in the case of oil platforms, off-shore weather buoys are also used along coastal areas. Figure 4 illustrates a typical 10 m buoy. While the density of deployment is typically much lower than the example described above for oil platforms, their use is much more widespread in many coastal areas.

FIGURE 4

Typical offshore weather buoy

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These platforms offer an additional opportunity for the installation of AIS receivers to supplement shore-based AIS detection. However, use of off-shore weather buoys presents several additional challenges. The much smaller size of the weather buoys significantly limits the possible height for placement of the antennas; consequently the detection range is smaller than normal shore based reception. Table 2 presents representative technical parameters for a ship-to-weather buoy link.

TABLE 2

Representative link parameters for AIS weather buoy communications

Technical parameter	Typical value
Ship parameters	
Transmit power	41 dBm
Antenna line losses	3 dB
Antenna gain	2 dB
Antenna height	10 m
Weather buoy	
Antenna gain	2 dBi
Antenna line losses	1 dB
Antenna height	~3 m
Median signal level from edge of service area	–104 dBm
Receiver sensitivity	–107 dBm for 20% per (minimum) –109 dBm for 20% per (typical)

Using analysis methods as described earlier, the reliable communication range of weather buoy AIS detection is estimated to be approximately 33 km (18 NM).

FIGURE 5

AIS communication range from typical weather buoys

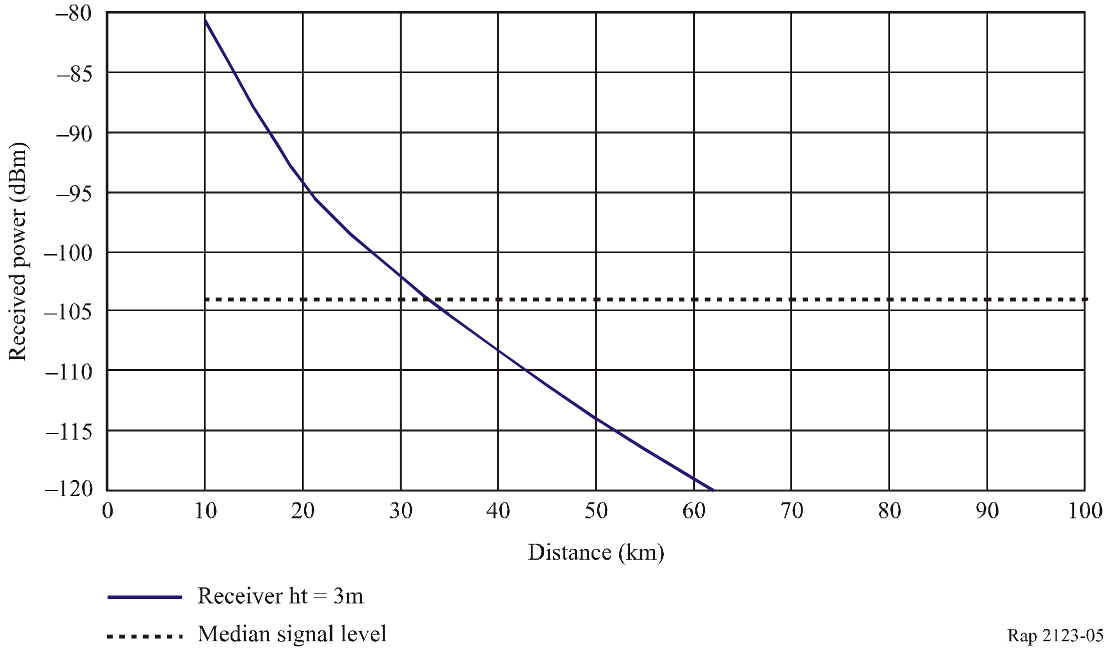

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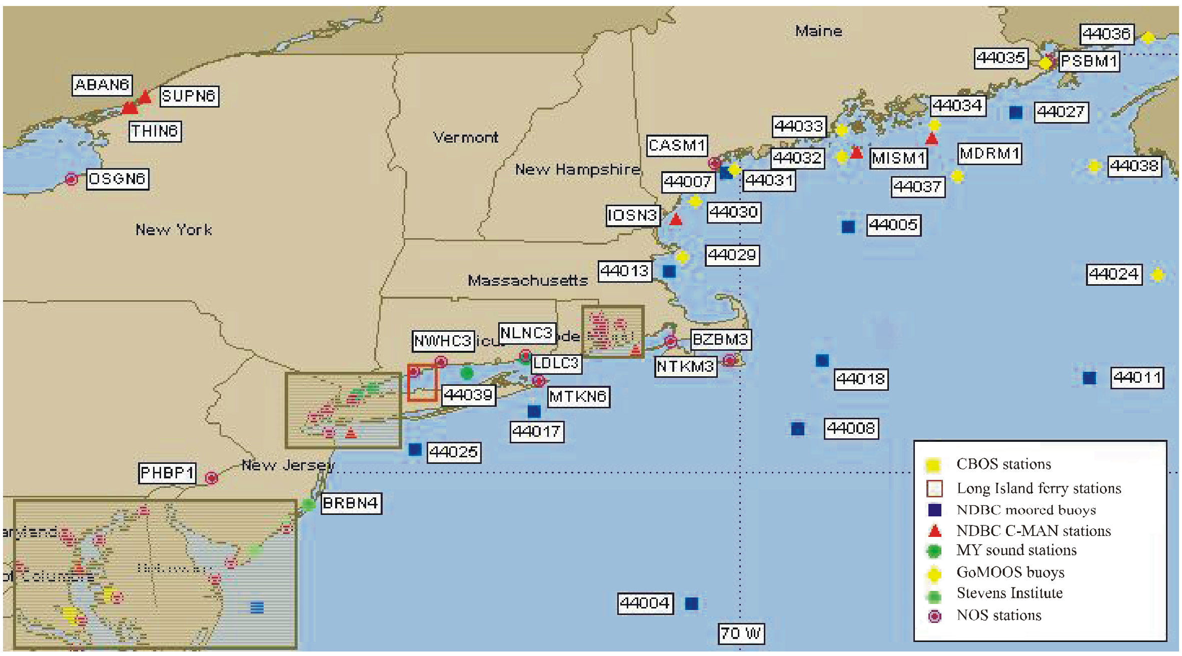
Figure 6 shows one example of the distribution of off-shore weather buoys along the East Coast of the United States of America. As contrasted with the use of oil platforms, the lower density and shorter communication range of AIS-equipped weather buoys typically could not provide enhanced AIS coverage in all directions from a key port area. For this example, installation of AIS receivers on several weather buoys could provide limited enhanced AIS coverage along major shipping lanes approaching the port of New York but not full umbrella coverage.

FIGURE 6

Example of off shore weather buoy deployment



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One significant limitation on the use of weather buoys to enhance AIS range is the mechanism to backhaul the data to shore. While the use of undersea cables is impractical, communication to shore via satellite communications is possible. However, the reliance on solar energy as the source of power limits satellite communications to intermittent, low data rate communications. This limitation, in turn, would require the use of on-board signal processing with the AIS receiver so that only significant new or updated ship information would be sent and all unnecessary repetitive AIS data eliminated.

One option to add the backhaul AIS data to the existing weather data channel via LEO and geostationary earth orbiting (GEO) weather satellite links was investigated. The weather data transmitters installed on the weather buoys typically operate on an intermittent, low-duty-cycle, basis at a data rate of 300 to 1 200 bit/s on a channel shared by many other weather buoys. The sharing of a single uplink channel among many buoys generally limits the transmissions from a given buoy to about once per hour. In order to not significantly impact the primary weather functions, any added AIS data must be limited to some small fraction of the existing weather traffic. With these combined limitations, the use of the existing satellite weather communication channel for AIS derived data on an operational basis appears impractical.

The alternative is to include a separate transmitter on the weather buoy capable of communicating with an existing LEO satellite communications network. The communications requirements of such a link can be estimated as follows:

a) Assume that the on-board AIS signal processing limits the data forwarded via the satellite link to only a single message when a ship enters its AIS communications zone and one message when a ship leaves the zone.

b) Assume that the average ship traffic along the associated shipping lane is X inbound ships and Y outbound ships per hour.

Under these assumptions, the net number of AIS messages forwarded via the satellite link would then be $2 \cdot X + 2 \cdot Y$ per hour. Under any reasonable estimate of ship traffic, the transmitted AIS message rate via the satellite link would be quite low.

In summary, the installation of AIS receivers on off-shore weather buoys can provide useful extended range coverage along key shipping routes, although full umbrella coverage will typically not be possible.

2.4 Anomalous propagation

Another concept to take advantage of the lower reliability requirement for long range AIS detection is to supplement normal coverage via line-of-sight and diffraction propagation modes by placing additional reliance on anomalous propagation mechanisms. Several ITU-R Recommendations address the characteristics of a number of these mechanisms including:

Tropospheric scatter	Atmospheric ducting
Meteor burst	Rain scatter
Sporadic-E	

Two of these mechanisms, tropospheric scatter and atmospheric ducting, are investigated in the following paragraphs.

2.4.1 Tropospheric scatter

Tropospheric scatter (hereinafter called troposcatter) is a mode of transhorizon radio wave propagation that results from the random reflections and scattering from irregularities in the dielectric gradient density of the troposphere. This propagation mode is applicable from below 100 MHz to above 8 000 MHz and may extend for distances of several hundred kilometres.

Although it is included herein under the general category of anomalous propagation, the propagation loss resulting from this effect, although quite large, can be sufficiently steady and predictable to support reliable long range communications. Because of the typically large propagation losses involved, it is clear at the outset of this study that reliable reception of AIS messages from ships at sea via troposcatter propagation will not be possible using current AIS coast station designs.

The discussion herein focuses on design factors that may allow reliance on tropospheric scatter for long range AIS detection. Since the characteristics of ship-borne AIS equipment is fixed and cannot be modified in the near term, the key factors are the propagation loss, coast station receiver sensitivity, receiver antenna gain, receiver signal processing, and radio noise.

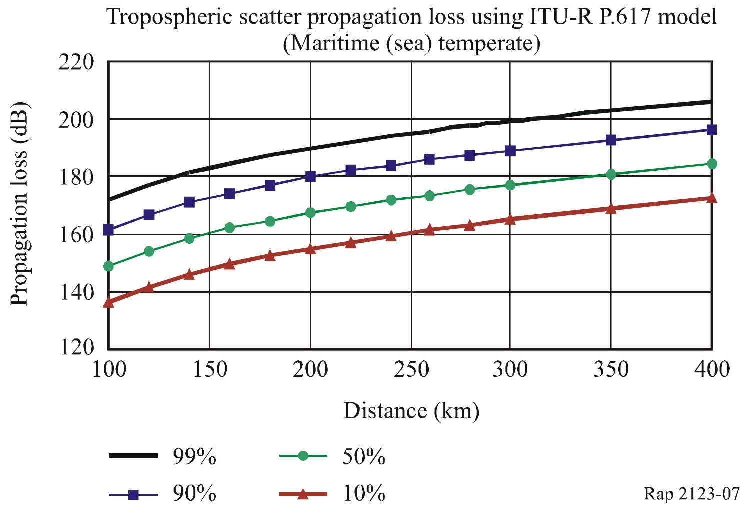
a) *Propagation loss*

Appendix 1 describes in detail two ITU-R Recommendations that address the characteristics of troposcatter propagation. Recommendation ITU-R P.617 addresses propagation loss from the standpoint of the design of transhorizon communications systems in the frequency range 200 MHz to 5 GHz. Recommendation ITU-R P.452 addresses the evaluation of interference via various propagation mechanisms, including tropospheric scatter, for the frequency range 100 MHz to 50 GHz.[1] Although the latter recommendation is not directly applicable to the present subject, consideration of the recommendation is useful here in that it demonstrates that propagation trends continue smoothly, free from unexpected results, as low as 100 MHz. A third propagation model was examined which similarly showed consistent trends as low as 20 MHz. Consequently, for purposes of this report, the propagation methodologies described in Recommendation ITU-R P.617 are assumed applicable when extrapolated to 162 MHz.

Figure 7, drawn from Appendix 1, describes troposcatter loss as a function of distance and reliability statistics. The curves were developed based on a ship height of 10 m and a receiving antenna height above average terrain of 50 m. However, since troposcatter propagation losses over water are relatively insensitive to antenna heights, the curves will be generally applicable at most practical shore station heights.

FIGURE 7

Tropospheric propagation loss at 162 MHz



[1] The subject recommendation is focused on interference considerations above 700 MHz. However, the recommendation states that the propagation calculation methods described therein are believed to be reliable at frequencies down to 100 MHz, except for the ducting model.

b) *Receiver sensitivity*

The specifications in Recommendation ITU-R M.1371 for receiver sensitivity of ship-borne AIS equipment call for a sensitivity of –107 dBm for a 20% PER or better. Commercial equipment currently on the market typically have a sensitivity of –109 dBm. To successfully communicate via troposcatter, custom designed receivers would be necessary having a significantly higher sensitivity. Textbooks describing optimum receiver performance of differential GMSK modulation indicate that performance at a carrier-to-noise ratio of 13 dB for a bit error ratio (BER) of 10^{-5} is possible, including reasonable implementation losses. This BER approximately corresponds to a PER of 1%. With an assumed receiver noise figure of 3 dB and optimum receiver design, a sensitivity for reception of 9 600 bit/s GMSK modulation of –118 dBm for a 1% PER appears feasible. Relaxing the criteria to 20% PER would further increase sensitivity to approximately –120 dBm.

c) *Receiving antenna*

Similar to the above discussion, current AIS antenna designs with gains of 2 to 5 dBi would be impractical for effective AIS reception via troposcatter. Antennas using a four element collinear vertical array are commercially available for operation at 162 MHz with a peak gain of 8 dBi. The gain can be further increased using offset dipole elements resulting in a cardioid pattern with a peak gain of 11 dBi. Higher gain will likely require custom designs – for example constructing a horizontal array of 2 to 4 elements, where each element is as described above. Using this approach, an antenna main beam gain of up to 17 dBi may be feasible.

d) *Receiver correlation processing*

A much more uncertain improvement factor would take advantage of the repetitive nature of AIS messages. For example, during a 10 min period, a given ship will transmit about 86 AIS messages. During this period, approximately 60% of the bits in each of these AIS ship messages are repeated identically. The MMSI ship identification code is, in particular, repeated with each message. Given the moderately low data rates of AIS transmissions, use of parallel correlation processing techniques may permit an effective increase in receiver sensitivity in a manner somewhat analogous to spread spectrum.

Further study would be required to determine the degree of correlation gain, if any, that may be achievable using this technique. For purposes herein, correlation gains of 0, 5 and 10 dB are considered.

e) *Radio noise environment*

In the VHF band, the environment radio noise can be a significant factor that limits the achievable receiver sensitivity. This would be especially true for the very high receiver sensitivity that would be required for AIS reception via troposcatter propagation. The ambient noise environment results from a combination of natural and manmade sources. At 162 MHz, galactic noise is the predominate natural radio source. Manmade sources of radio noise include vehicular ignitions, power lines and industrial machinery. Recommendation ITU-R P.372 presents typical values of ambient radio noise for galactic radio noise and three generic environments; business, suburban, and rural. The noise density values as a function of frequency are described relative to –204 dB(W/Hz) based on an ambient temperature of 290 K. For 162 MHz, the values are as follows:

Quiet rural	~0 dB (limited by galactic noise)
Rural	+ 2 dB
Residential	+5 dB
Business	+12 dB.

To realize the very high receiver sensitivity values described earlier, it is clear that the location of the receiving antenna in a very quiet rural environment is necessary to avoid degrading the achievable sensitivity.

f) *Results*

Combining the factors described above, a simple link calculation shows the potentially achievable AIS detection range via troposcatter propagation as follows:

$$P_{rec} = EIRP - L_p + G_r + G_{corr} - L_{misc} > Sens$$

where:

P_{rec}: received power (dBm)

$EIRP$: ship-borne AIS equivalent isotropic radiated power (dBm)

L_p: troposcatter propagation loss (dB)

G_r: receiver antenna gain (dBi)

G_{corr}: receiver correction gain (dB)

L_{misc}: miscellaneous cable losses (assumed to be ≤ 1 dB)

$Sens$: receiver sensitivity (dBm).

Rearranging terms yields:

$$L_p < EIRP + G_r + G_{corr} - L_{misc} - Sens$$

Substitution of values for various assumed parameters yields the results shown in Table 3.

TABLE 3

Calculated AIS detection range via troposcatter

(Based on EIRP = 40 dBm; Sensitivity = –120 dBm; 90% Reliability))

Antenna gain (dBi)	**Correlation gain (dB)**	**Maximum propagation loss (dB)**	**Detection distance (km)**
11	0	170	93
11	5	175	180
11	10	180	157
17	0	176	124
17	5	181	168
17	10	186	230

These results show that with optimized receiver and antenna design, enhanced detection range would be possible using the troposcatter mode of propagation to distances on the order of 100 to 200 km.

2.4.2 Atmospheric ducting

Atmospheric ducting is a propagation phenomenon that occurs predominately when the atmosphere stratifies into layers of differing temperatures and humidity. This layering results in varying index of refraction at different heights above ground. This situation, in turn, can lead to a condition where radio waves are effectively “trapped” between the layers somewhat similar to a waveguide. The trapping can occur between the Earth’s surface and a ducting layer, called a surface duct, or between two upper atmosphere ducting layers, called an elevated duct.

The key features of this propagation mode are generally low propagation loss values but sporadic and intermittent occurrence. In some instances, the propagation loss values can approach free space values, but more typically is 5 to 30 dB higher than free space for distances in the range of about 50 to 200 km (see "Atmospheric ducting" in Appendix 5). For propagation over sea water, the rate of occurrence is very dependent on the general climatic and current weather conditions. Considerable diurnal and seasonal variations also exist. Conditions to the occurrence of atmospheric ducting may sometimes persist for hours or even days while at other times not occur for many consecutive days. On a long term average, conditions for atmospheric ducting occur less than 20% of the time and in most cases less than 5 to 10% of the time. Geographic areas where atmospheric ducting is most prevalent are humid climates and warm seas. One such area is the Gulf of Mexico and surrounding areas; conditions for atmospheric ducting with higher percentages have been recognized in other areas.

Because of its intermittent nature, reliance on atmospheric ducting propagation conditions for long range AIS detection on a regular basis, such as every four hours, is generally not practical. However, the long range detection capability that does occur can be a useful supplement to normal shore-based AIS detection.

Figure 8 is based on measurements in the Gulf of Mexico and describe the percent of time that AIS equipped ships were detected at an AIS receiver site on two days in April 2005. This represented normal non-ducting conditions. Figure 9 shows the same data collected on two other days when much greater detection distances were achieved from the same site. Only atmospheric ducting can account for these statistical results.

FIGURE 8

Measured AIS detection range under normal atmospheric conditions

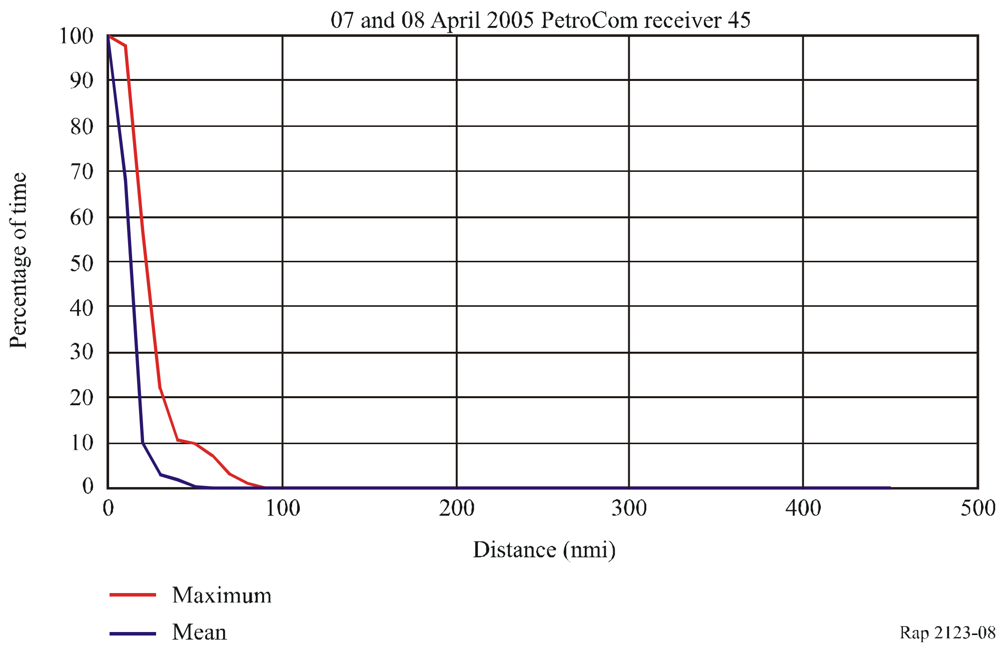
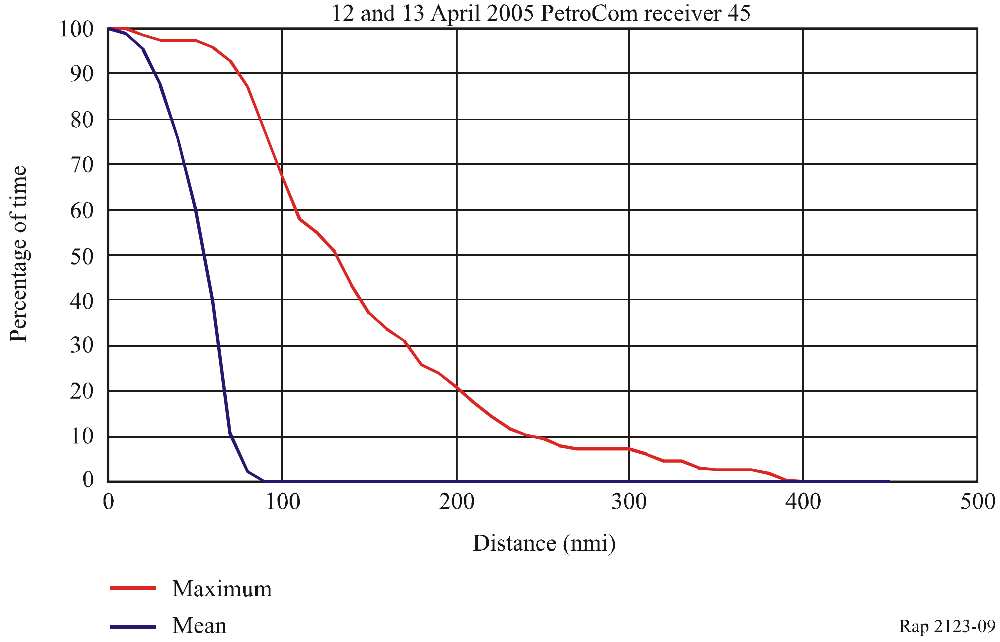


FIGURE 9

Measured AIS detection range under atmospheric ducting conditions



These limited measurements show that AIS detection ranges can expand many-fold during periods of atmospheric ducting.

As described in Appendix 2, Recommendation ITU-R P.452 examines the long term statistical characteristics of atmospheric ducting. However, as stated in the recommendation the prediction methods described have not been tested below the frequency of 700 MHz. Consequently, any extrapolation of the methods in that recommendation to 162 MHz must be viewed cautiously. Noting this limitation, statistic curves, shown here in Fig. 10, are developed in the Appendix in the same manner as done earlier for troposcatter propagation.

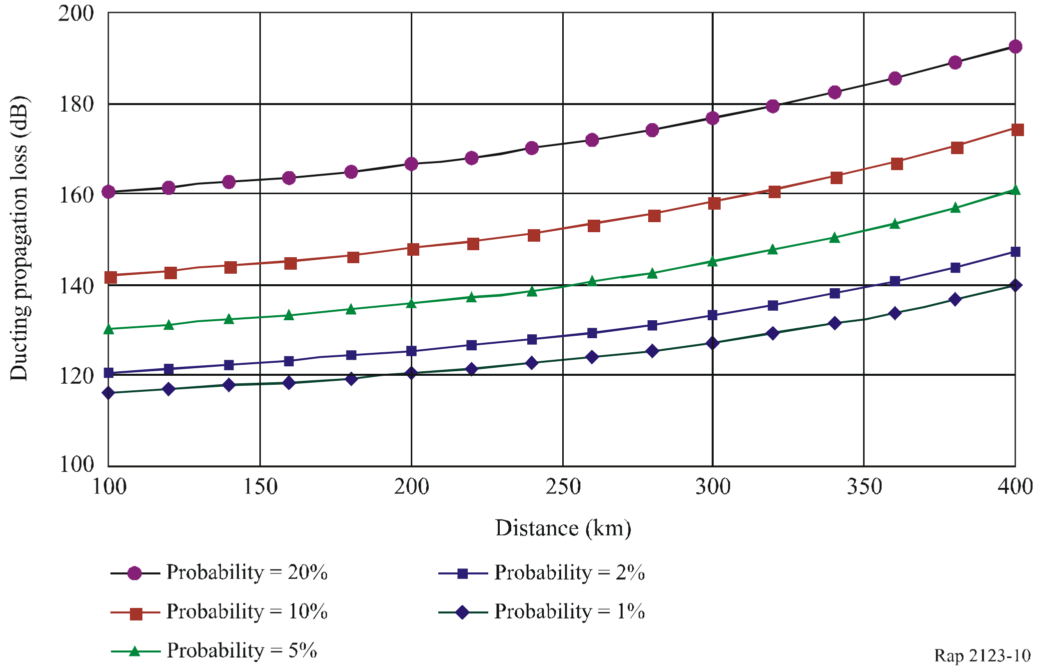
As characterized in the Fig. 10 quite low values of propagation loss can occur over extended distances for very low percentages of time and conversely for high percentages of time, the predicted loss values are much higher – about 40 to 45 dB higher for 20% versus 1% occurrence. However, limited measurements suggest that in certain geographic areas, such as the Gulf of Mexico, the atmospheric ducting probability of occurrence predicted by Recommendation ITU-R P.452 may be lower than that actually experienced.

As described earlier regarding troposcatter propagation, with significant upgrades to the AIS receiver and antenna, reliable communications may be achievable at distances exceeding 100 km. In contrast, with atmospheric ducting radio equipment upgrade will only provide marginally improved performance.

In summary, atmospheric ducting propagation can provide useful enhanced AIS detection range, sometimes at distances of several hundred kilometres, on an intermittent basis but cannot approach the potential communication reliability described earlier for troposcatter propagation.

FIGURE 10

Ducting propagation loss at 162 MHz using the ITU-R P.452 model (smooth terrain)



3 Spectrum sharing of AIS long range detection with other co-channel mobile service systems

The two frequencies that have been designated as channels within the maritime mobile service for the terrestrial AIS function are not allocated on an exclusive basis. Rather, these channels and adjacent channels are allocated and used throughout various regions of the world for other mobile service applications including VHF public correspondence stations (VPCS) in the maritime mobile service and land mobile radio (LMR) systems. Long range AIS must be able to successfully operate in the interference environment resulting from existing services. Since long range detection of AIS is a new and evolving concept, it would be beneficial to examine the sharing of long range AIS operating with existing services, such as co-channel mobile systems and determine whether long range AIS presents sharing issues.

Current spectrum sharing arrangements between existing AIS operation and co-channel mobiles systems have evolved and have been implemented in various ways by administrations. This section compares sharing between AIS operating in a long range detection mode (hereinafter long range AIS) and other co-channel mobile systems to that of normal AIS with the same mobile systems. Four steps are addressed in the following paragraphs:

– characterization of technical parameters of systems involved,
– designation of assumed sharing conditions
– determining an appropriate radio propagation model, and
– combination of these factors to determine whether long range AIS presents additional sharing issues.

3.1 Technical parameters

The following paragraphs describe the basic technical parameters used in this study of sharing between long range AIS and the other co-channel mobile systems.

3.1.1 Mobile systems

The first step in investigating long range AIS sharing with mobile systems is identification of technical parameters of LMR and VPCS systems. Table 4 lists representative technical parameters for VPCS and LMR systems. As seen in this table, both the VPCS and LMR systems typically employ an effective radiated power (ERP) 10 dB (or more) higher than the ship AIS transmitters sharing these frequencies.

TABLE 4

Typical VPCS and LMR technical parameters

Parameter	Land mobile base station (wideband)	Land mobile base station (narrow-band)	VHF public correspondence coast station
Transmit ERP	37-56 dBm (54 dBm typical)	37-56 dBm (54 dBm typical)	50-61 dBm
Modulation	16F3E	11F3E	16F3E
Channelling	25 kHz	12.5 kHz	25 kHz
Typical antenna height	10-150 m (60 m typical)	10-150 m (60 m typical)	10-150 m
Transmit duty cycle	See Table 5	See Table 5	See Table 5

One of the important factors in evaluating sharing between AIS and other mobile systems is the mobile system transmit duty cycle. Most mobile communications systems operate at less than a 100% transmit duty cycle. A series of over-the-air spectrum measurements were completed in the United States in selected portions of the 138-174 MHz band that included the percent of time that a given channel was found to be in use.[2] Based on these and other data sources, it is possible to broadly categorize mobile service transmitters into high (30-100%), medium (10-30%) and low (<10%) duty cycle categories. Although it is not practical to generate a complete list, examples for each category are given in Table 5.

3.1.2 AIS coast stations

Recommendation ITU-R M.1371 describes in detail the characteristics of AIS systems as they are used for their primary purpose – improving safety-of-navigation. It is this safety aspect of AIS operation that dictates the requirement for a high level of reliability. For purposes herein, reliability refers to the ability to receive and correctly decode a high percentage of the transmitted ship AIS messages within its communications range. For the long range detection and tracking function described in this Report, a somewhat lower level of reliability is adequate. Table 6 summarizes key technical parameters for AIS coast station receivers used in this study for these two functions along with typical parameters for the associated ship transmitters.

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[2] See for example: SANDERS, F.H., HAND, G.R. and LAWRENCE, V.S. [September 1998] Land mobile radio channel usage measurements at the 1996 Summer Olympic Games. NTIA Report 98-357 (available at www.its.bldrdoc.gov/pub/ntia-rpt/98-357/.

TABLE 5

Examples of mobile system transmit duty cycle

High duty cycle (30-100%)	Medium duty cycle (10-30%)	Low duty cycle (<10%)
Paging systems	Multiple user LMR business/industrial repeaters (i.e. community repeaters)	Most single-user private LMR systems
Trunking system control channel	Public safety dispatch	Most administrative government LMR systems
Broadcast type systems (such as weather broadcasts)	Trunking system communication channels	Some types of LMR fixed control links
Some transportable telemetry (such as seismic sensors)	VHF maritime mobile working channels	
VHF public correspondence coast stations		
Some types of LMR fixed control links		

TABLE 6

Typical parameters for an AIS ship-to-shore link

Parameter	Safety-of navigation mission	Long range tracking (via troposcatter)
AIS ship transmitter		
Transmit power	41 dBm	
Transmit antenna gain	2 dBi	
Transmit miscellaneous losses	3 dB	
Transmit EIRP	40 dBm	
Antenna height	~ 10 M	
Modulation	9 600 bit/s GMSK	
Message rate	6 to 15 messages per minute (~8.5 average)	
AIS coast receiver		
Sensitivity	–109 dBm for 1% per	–120 dBm for 20% (Note 1))
Median signal level from edge of service area	–104 dBm	–115 dBm
Antenna type	Two element stacked dipole	Multi-element array
Antenna main beam gain	5 dBi (omnidirectional)	11-17 dBi (Note 2))
Antenna backlobe gain	5 dBi	Estimated average ~ 0 dBi
Antenna height	10-50 m (30 m typical)	10-50 m (30 m assumed)
Miscellaneous losses	3 dB (assumed)	1 dB (assumed)

NOTE 1 – The sensitivity specified for the long range function is considerable higher than the minimum value specified in Recommendation ITU-R M.1371 for ship-borne AIS receivers. In order to maximize the detection range for long range tracking, an optimized receiver is needed, with –120 dBm expected to be an achievable value.

NOTE 2 – In order to maximize detection range, higher gain directional antennas are assumed.

3.1.3 Sharing factors

The next step in evaluating sharing is designating sharing conditions and assumptions for this analysis. Within ITU-R Recommendations, a number of different methodologies are used to define sharing criteria for various radiocommunication service categories, most of which are performance based. One method is to define the sharing criteria in terms of a percent reduction in the performance of the victim system, with a 10% reduction in performance being a commonly used value.

For AIS receivers, the principal measure of system performance is the packet error rate (PER). This is the percent of AIS message packets that are received and correctly decoded without error.

Measurements completed on typical shipborne AIS receiver show that they are capable of achieving a PER of 20% with a desired-to undesired ratio (D/U) of 10 dB or more.[3] This D/U ratio is assumed to be adequate for the long range tracking function. Performance levels have not been established for regular AIS coast station receivers. Because of their safety-of-navigation functions a higher D/U of 15 dB is assumed for this study.

Taking the preceding factors into account, the following AIS sharing criteria is assumed for the analysis contained in this document:

a) D/U < 10 dB for no more than 50% of the locations and 10% of the time for the long range tracking function.

b) D/U < 15 dB for no more than 50% of the locations and 10% of the time for the primary safety-of-navigation function.

These criteria only apply when the co-channel operating signal is present 100% of the time. When the type of mobile system is of the type where the transmit duty cycle is less than 100%, the D/U criteria may be relaxed. An assumed relaxation of 5 dB is proposed for a transmit duty cycle of 10% or less.

3.1.4 Radio propagation

Appendices 1, 2 and 3 provide a detailed review of available ITU-R recommended models describing various radio propagation models appropriate for certain VHF communication in temperate climates. Sharing considerations using conventional diffraction mode propagation as described in Appendix 3 is used for the study described here.

3.1.5 Sharing analysis

There is no existing ITU-R Recommendation establishing sharing criteria for AIS operation. It is common practice within many administrations to assign the frequencies used by AIS exclusively for that purpose only to land mobile stations far enough inland from navigable waterways and coastlines to ensure adequate performance.

With the information presented in the preceding subsections, an analysis can be undertaken to compare distance separations for sharing between AIS coast stations and other co-channel mobile stations. The calculation is performed as follows:

$$D/U = D_{median} - [EIRP - L_p(d,\%) + G_r - L_{misc}] > D/U_{Criteria}$$

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[3] Performance requirements established in IEC 61993-2 require AIS receivers to operate at a C/I ratio of 10 dB with a PER of 20% or less. Tests show that this co-channel interference test results vary little with the type of modulation used in the interfering signal. For example, results for GMSK and FM voice modulation are generally the same.

where:

D/U :	desired to undesired ratio (dB)
D_{median} :	median desired signal level from the edge of the service area (dBm)
$EIRP$:	mobile transmitter equivalent radiated power (dBm)
$L_p(d,\%)$:	propagation loss as a function of distance and percent occurrence (dB)
G_r :	receiver antenna gain (dBi)
L_{misc} :	miscellaneous receiving system losses (dB) (assumed 3 dB)
$D/U_{Criteria}$:	applicable D/U protection criteria.

Rearranging terms yields:

$$L_p(d,\%) > D/U_{Criteria} - D_{median} + EIRP + G_r - L_{misc}$$

Using this equation and the propagation model described in Appendix 3, sharing conditions based on the nominal sharing criteria can be tabulated, shown in Table 7, and compared for the AIS safety-of-navigation and long range detection functions.

TABLE 7

Comparison of the calculated distance separation from co-channel LMR base stations to meet the assumed sharing AIS criteria

AIS function	Propagation mode	$D/U_{criteria}$ (dB)	D_{median} (dBm)	LMR ERP (dBm)	LMR antenna height (m)	Propagation statistics	Calculated propaga-tion loss (dB)	Calculated distance (km)
Safety-of navigation	Diffraction	15	–104	50	15	50% locations 10% time	171	117
Safety-of navigation	Diffraction	15	–104	56	60	50% locations 10% time	177	127
Long range tracking	Diffraction	10	–115	50	15	50% locations 10% time	169	115
Long range tracking	Diffraction	10	–115	56	60	50% locations 10% time	175	125

As a result of varying site-specific considerations, it is not practical to identify a generic separation distance which could be appropriate for any sharing scenario. The calculated distances shown in Table 8 apply only for low lying inland coastal plain areas. No terrain features were considered. In many cases, coastal plain terrain does not extend inland for the distances calculated in this table; consequently additional factors need to be considered. Where mountainous areas are present additional diffraction losses significantly reduce these calculated distance values.

The analysis results presented in this section indicate that, under conditions of diffraction mode propagation, similar distance separations would suffice irregardless of whether the AIS coast stations were operating in a safety-of-navigation function or long range detection function.

In certain geographic and climatic regions additional propagation factors may be applicable. In Appendix 4, a comparison of the sharing for long range AIS and normal AIS is provided considering other propagation methods.

4 Summary

This Report examined four options to enhance the detection range of shore-based AIS coast stations:

– installation of AIS receivers on off-shore oil platforms;

– installation of AIS receivers on off-shore weather buoys;

– use of tropospheric scatter propagation (part-time enhancements); and

– use of atmospheric ducting propagation (part-time enhancements).

As summarized below, each option discussed entailed one or more limitations, as described in more detail in the text. However, each option was found to provide some degree of enhanced AIS detection range.

Installation of AIS receivers on off-shore oil drilling platforms can greatly enhance shore AIS detection in an umbrella fashion around key ports areas but their use has very limited geographic applicability. Off-shore weather buoys are widely but sparsely distributed along many coast lines. Installation of AIS receivers on weather buoys offers limited range enhancement but may be useful in enhance detection capabilities along major shipping routes. Reliance on troposcatter propagation can increase AIS detection range from shore to 100 to 200 km but requires significant advances over current AIS receiver and antenna designs. Atmospheric ducting is also a propagation mode that can provide intermittent detection range enhancement to 100 to 200 km or more.

Because long range detection of AIS is a new and evolving concept, the report also examined operations with other co-channel mobile systems whether long range AIS presents sharing issues beyond that for normal AIS functions. Based on conventional diffraction mode propagation, preliminary results developed herein show that similar distance separations would be sufficient irregardless of whether the AIS coast stations were operating in a safety-of-navigation function or long range detection function.

This Report is an initial study that addresses possible implementation concepts and spectrum sharing issues relative to long range AIS detection. Further contributions are invited to provide measurements and/or analyses to supplement or update the results derived herein.

Appendix 1

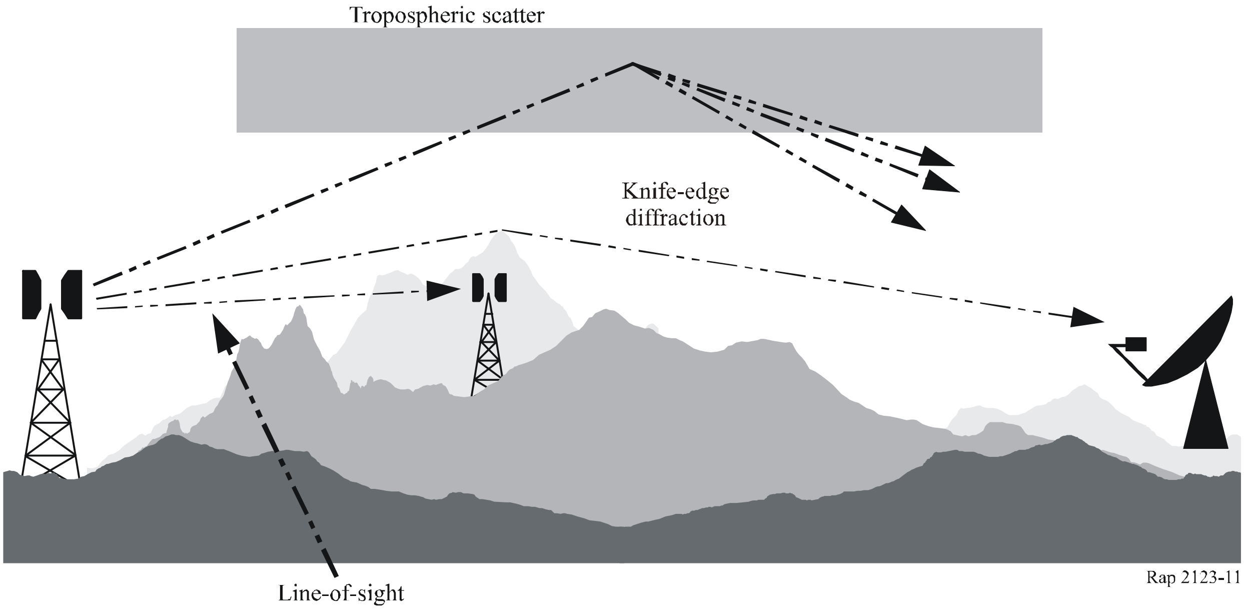
Tropospheric scatter propagation

1 Introduction

Tropospheric scatter is a mode of transhorizon radio wave propagation that results from the random reflections and scattering from irregularities in the dielectric gradient density of the troposphere. This propagation mode is applicable from below 100 MHz to above 8 000 MHz and extends for distances of several hundred kilometres. Although it is included herein under the general category of anomalous propagation, the propagation loss resulting from this effect, although quite large, can be sufficiently steady and predictable to support reliable long range communications. In contrast, somewhat lower propagation loss values occur on a more intermittent basis that sometimes leads to radio interference conditions. Figure 11 below illustrates this mode as compared with line-of-sight and diffraction knife-edge propagation modes.

FIGURE 11

Long-term interference propagation mechanisms



Two Recommendations of the ITU-R, Recommendations ITU-R P.452 and ITU-R P.617, provide long term statistical equations for predicting the tropospheric scatter propagation loss under various conditions. Because of some frequency limitations on these models, a third model was also investigated. The results of the investigation of these three models are discussed below.

1.1 Recommendation ITU-R P.617-1 model

Recommendation ITU-R P.617-1 describes propagation prediction techniques and data required for the design of trans-horizon radio-relay systems. Since the propagation model described in this recommendation is for the design of radio systems, the focus is on moderate to high path reliability conditions where the propagation loss is not exceeded greater than about 20% of the time. Although the focus of this Recommendation is on the design of fixed radio-relay systems, the physics of the propagation mode is not limited to just the fixed service but is driven primarily by factors such as frequency, path geometry, terrain, and climate. The characteristics of this model are extrapolated to 162 MHz and summarized in the paragraphs below for purposes of this study for temperate climates.

The applicable frequency limits stated for the propagation model described in Recommendation ITU-R P.617-1 is 200 MHz to 4 GHz. Since the frequency of interest is slightly outside of this range some uncertainty exists as to it's validity at the lower frequency. However, other models described later in this Annex show consistent loss trends down to frequencies as low as 20 MHz. Consequently, it is assumed that any errors introduced by extrapolation of the methodology to 162 MHz are expected to be minor.

The Recommendation divides the climatic regions of the world into nine zones:

1) Equatorial

2) Continental sub-tropical

3) Maritime sub-tropical

4) Desert

5) Mediterranean

6) Continental temperate

7a) Maritime temperate, overland

7b) Maritime temperate, oversea

8) Polar

The focus of this study is on the temperate regions of the world defined as follows:

Continental Temperate corresponds to regions between 30° and 60° latitude. Such a climate in a large land mass shows extremes of temperature and pronounced diurnal and seasonal changes in propagation conditions may be expected to occur. The western parts of continents are influenced strongly by oceans, so that temperatures here vary more moderately and rain may fall at any time during the year. In areas progressively towards the east, temperature variations increase and winter rain decreases. Propagation conditions are most favorable in the summer and there is a fairly high annual variation in these conditions.

Maritime Temperate, Overland also corresponds to regions between latitudes of about 30° and 60° where prevailing winds, unobstructed by mountains, carry moist maritime air inland. Typical of such regions are the United Kingdom, the west coast of North America and of Europe and the north-western areas of Africa. Although the islands of Japan lie within this region, climate 6 is considered more appropriate.

Maritime Temperate, Overseas corresponds to coastal and oversea areas in regions similar to those for climate 7a. The distinction is that a radio propagation path having both horizons on the sea is considered to be an oversea path (even though the terminals may be inland); otherwise climate 7a is considered to apply.

From this Recommendation the average tropospheric scatter propagation loss can be described by a series of equations as follows:[4]

$$L(q) = M + 30 \log f + 10 \log d + 30 \log \theta + L_N - Y(q)$$

$$\theta = \theta_e + \theta_t + \theta_r$$

$$\theta_e = d \cdot 10^3/(k \cdot a)$$

$$L_N = 20 \log(5 + \gamma \cdot H) + 4.34\, \gamma \cdot h$$

$$H = 10^{-3}\, \theta \cdot d/4$$

$$h = 10^{-6}\, \theta^2 \cdot k \cdot a/8$$

$$Y(q) = C(q) \cdot Y(90)$$

$$Y(90) = 2.2 - (8.1 - 2.3 \cdot 10^{-4} \cdot f) \cdot e^{(-0.137\,h)} \quad \text{for climate regions 6 and 7a}$$

$$= -9.5 - 3 \cdot e^{(-0.137\,h)} \quad \text{for climate region 7b}$$

where:

- M : meteorological factor defined by the climatic region (dB) = 29.73, 33.20, 26.00 for climate regions 6, 7a, and 7b, respectively
- f : frequency (MHz)
- d : transmitter-to-receiver distance (km)

[4] The equation defined in the recommendation is for transmission loss that includes the antenna gain factors. Since the present study addresses relatively low gain antennas, the aperture-to-medium coupling loss factor described in the recommendation is effectively zero. Consequently, the equation can be described herein for propagation loss without the antenna gain factors with insignificant error.

θ : effective scatter angle (mrad)

θ_e : geocentric angle between transmitter and receiver (mrad)

$\theta_{t,r}$: transmitter and receiver horizon angles (mrad) (assumed to be 0)

L_N : propagation loss dependence on the height of the common volume

$Y(q)$: conversion factor for percentage of time other than 50% (dB)

k : effective Earth radius factor (assumed to be 4/3)

a : mean Earth radius (6 370 km)

γ : atmospheric structure parameter (0.27 for temperate climate regions 6, 7a, and 7b)

H, h : height factors (km)

$C(q)$: probability factor (dB) (defined in Table8)

W : factor to convert average annual loss to worst month loss (see Fig. 11).

TABLE 8

Values of $C(q)$ of interest

q	20*	50	80*	90	99	99.9	99.99
$C(q)$	–0.66	0	0.66	1.00	1.82	2.41	2.90

* Interpolated values added.

Using the equations as described above, Figs. 12 through 14 give example calculations for transmit and receive antenna heights of 10 m and 50 m, respectively.

FIGURE 12

Tropospheric scatter propagation loss using ITU-R P.617 model
(Continental temperate)

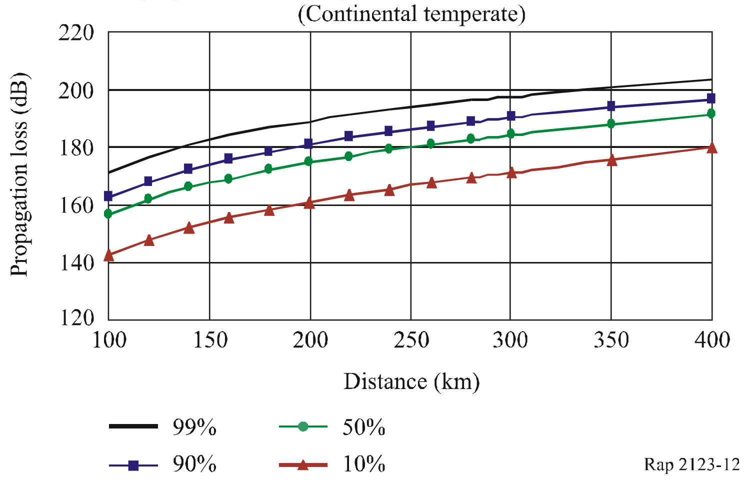


FIGURE 13

Tropospheric scatter propagation loss using ITU-R P.617 model (Maritime (land) temperate)

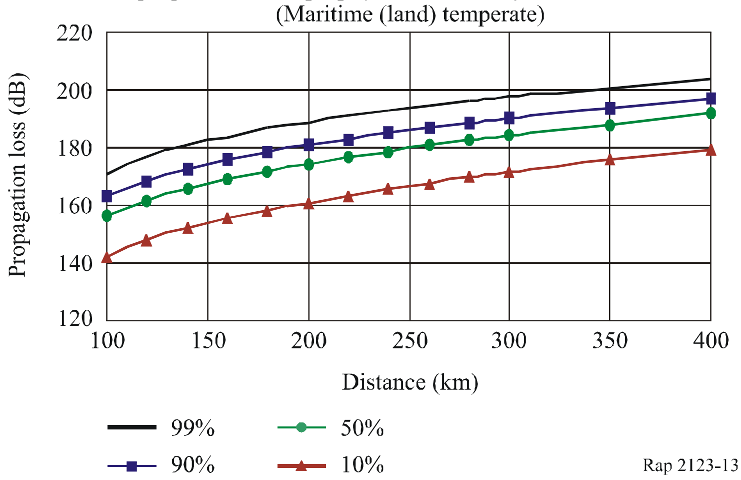
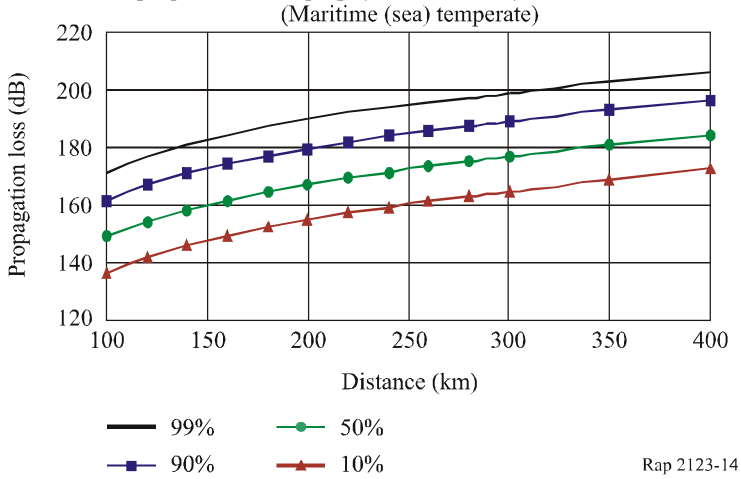


FIGURE 14

Tropospheric scatter propagation loss using ITU-R P.617 model (Maritime (sea) temperate)



1.2 Recommendation ITU-R P.452-12 model

Recommendation ITU-R P.452-12 provides a prediction procedure for the evaluation of microwave interference between stations on the surface of the Earth at frequencies above 0.7 GHz. However, the recommendation states that the propagation models are believed valid down to 100 MHz. Since this recommendation addresses interference paths, the focus is on propagation statistics below 50% and is not appropriate for time percentages above 50%. The recommendation notes that for time percentages much below 50%, it is difficult to separate true tropospheric scatter mode propagation from other secondary phenomena. The model is an empirical generalization to include these other secondary effects as well.

From this Recommendation the tropospheric scatter propagation loss for any defined percentage of time, p, can be described by a series of equations as follows:

$$L(p) = 190 + L_f + 20 \log d + 0.573\,\theta - 0.15\,N_0 - 10.1\,[-\log (p / 50)]^{0.7}$$

$$L_f = 25 \log(f) - 2.5\,[\log(f / 2)]^2$$

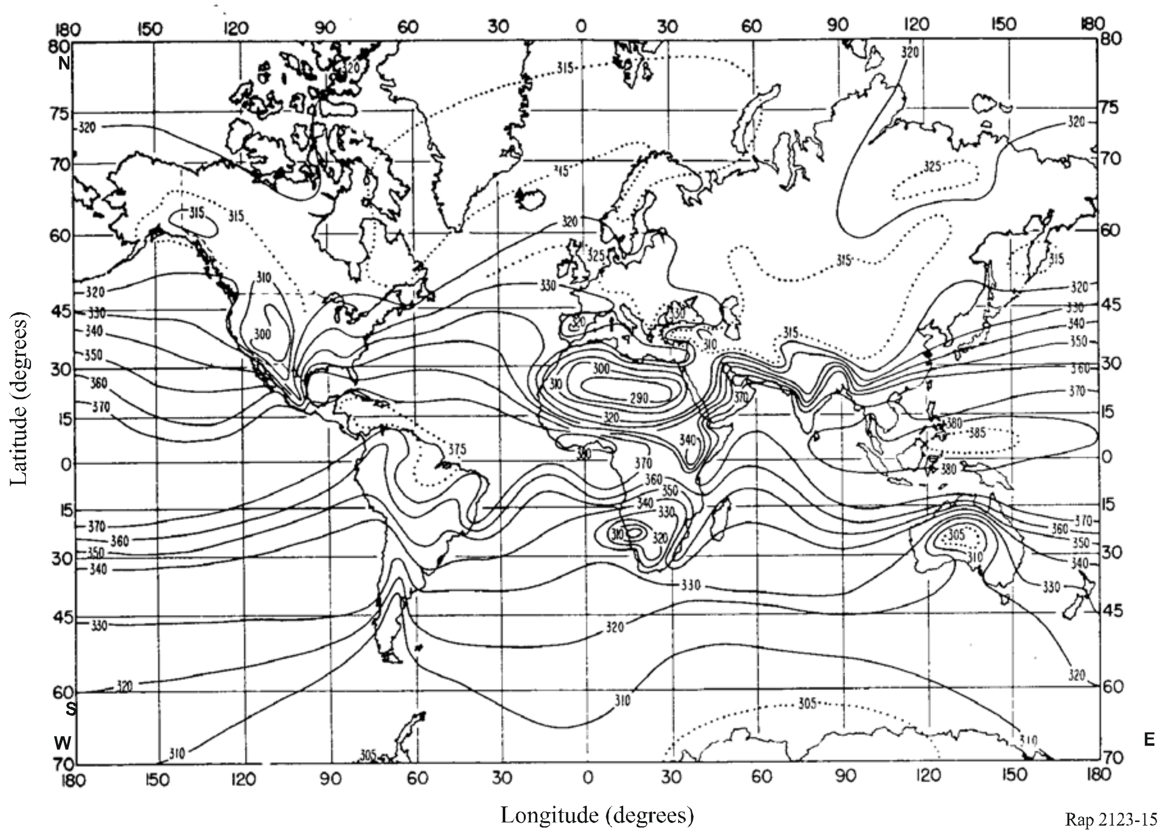
$$\theta = \theta_e + \theta_t + \theta_r$$

$$\theta_e = d \cdot 10^3 / (k \cdot a)$$

where:

- L_f : frequency loss factor (dB)
- N_0 : sea-level surface refractivity (see Fig. 15)
- θ : path angular distance (mrad)
- θ_e : defined as above
- θ_t, θ_r : defined as above (assumed to be zero)
- f : frequency (GHz)
- p : time percentage (%).

FIGURE 15



Examples from this model are shown in Figs. 16 and 17.

FIGURE 16

Tropospheric scatter propagation loss using ITU-R P.452 model
(Continental temperate)

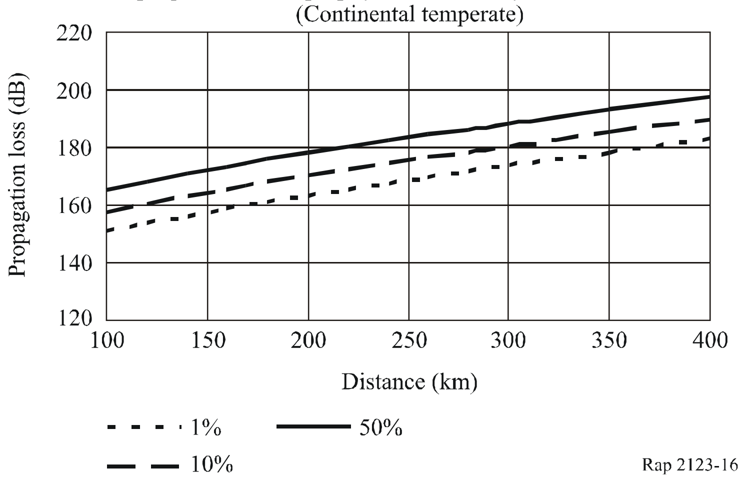
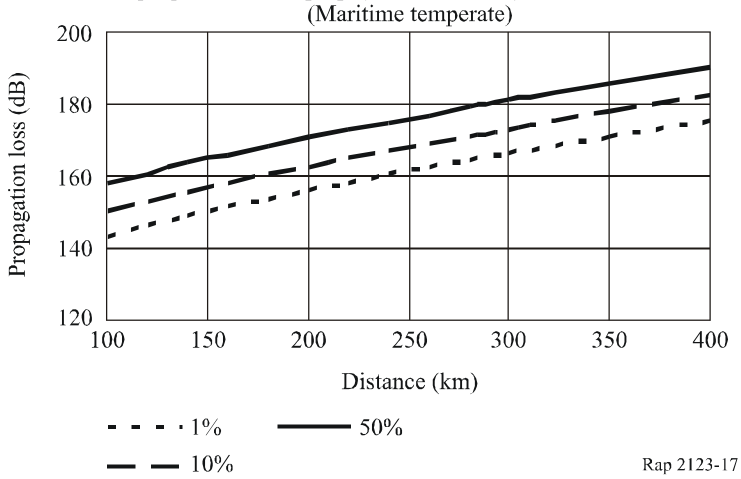


FIGURE 17

Tropospheric scatter propagation loss using ITU-R P.452 model
(Maritime temperate)



2 Irregular terrain model

The irregular terrain model (ITM) estimates radio propagation losses for frequencies between 20 MHz and 20 GHz as a function of distance and the variability of the signal in time and space. It is an improved version of the Longley-Rice Model, which gives an algorithm developed for computer applications.[5] The model is based on electromagnetic theory and signal loss variability expressions derived from extensive sets of measurements. The ITM algorithm works in two modes:

– point-to-area prediction mode – used when an exact terrain description is not available, and

– point-to-point prediction mode – used when the terrain profile between the terminals is available.

[5] See http://flattop.its.bldrdoc.gov/itm/itm_alg.pdf.

The “point” is where a broadcast station or a base station for mobile service may be located and “area” refers to the service area locations of broadcast receivers or mobile stations. The model considers several propagation modes, one of which is tropospheric scatter, and is applicable for frequencies 20 MHz through 20 GHz.

This model was developed using similar principles to those described in the two ITU-R Recommendations discussed above. In order to supplement the tropospheric scatter propagation data derived earlier from relevant ITU-R Recommendations, especially for frequencies below 200 MHz, the ITM model was exercised for the frequency 162 MHz for distances greater than 100 km where the tropospheric scatter mode predominates. Figures 18 and 19 plot the resulting tropospheric scatter propagation loss for continental temperate and maritime temperate over water for probability statistics ranging from 1 to 99%.

FIGURE 18

Tropospheric scatter loss using the ITM model

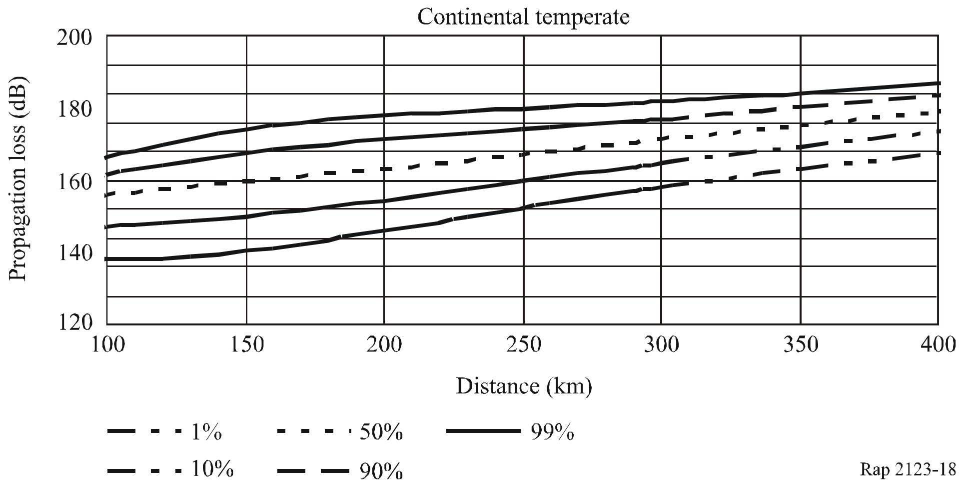
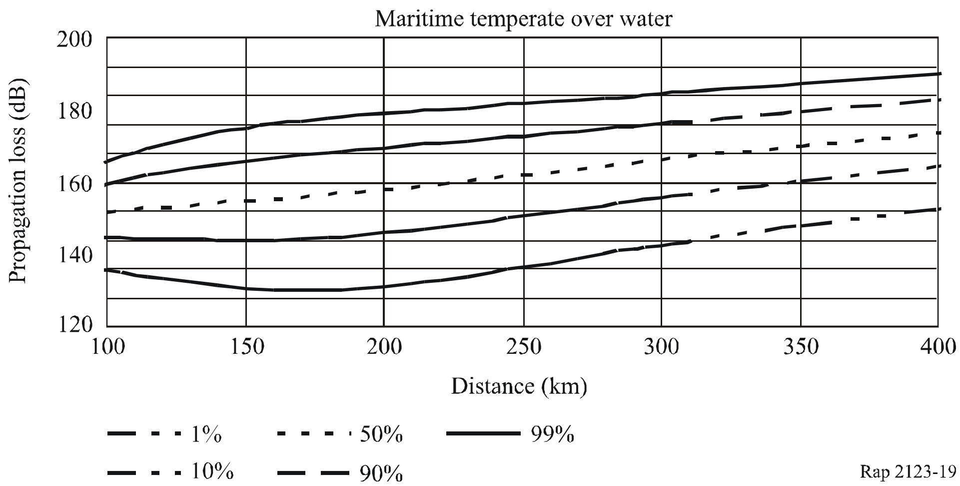


FIGURE 19



3 Summary

Although the three tropospheric scatter models described above gave different values for median propagation loss, the differences in most cases were no more than 3 dB. The consistent results among the models suggest that extrapolating the model defined in Recommendation ITU-R P.617 beyond its stated limits may be suitable.

Consequently, for purposes of this study only it is assumed that the two models defined by Recommendations ITU-R P.617 and ITU-R P.452 can be used for design and interference calculations of VHF AIS systems, respectively.

Appendix 2

Atmospheric ducting propagation

1 Introduction

Atmospheric ducting is a propagation phenomena that been known and studied in some detail since before the 1980s.[6] The condition occurs predominately when the atmosphere stratifies into layers of differing temperatures and humidity. This layering results in varying index of refraction at different heights above ground. This condition, in turn, can lead to a condition where the varying indices of fraction can effectively be "trapped" between the layers somewhat similar to a waveguide. The trapping can occur between the Earth's surface and a ducting layer, called a surface duct, or between to upper atmosphere ducting layers, called an elevated duct. Figure 20 compares atmospheric ducting with other short term propagation phenomena.

Recommendation ITU-R P.452 is the only ITU-R text that addresses atmospheric ducting. However the recommendation states that the ducting model has not been tested to frequencies lower than about 0.7 GHz. Noting this uncertainty, it is assumed for purposes of this study to be applicable at 162 MHz. The key features of this model are summarized in the following paragraphs based on an extrapolation to the VHF band. Other methodologies are also discussed.

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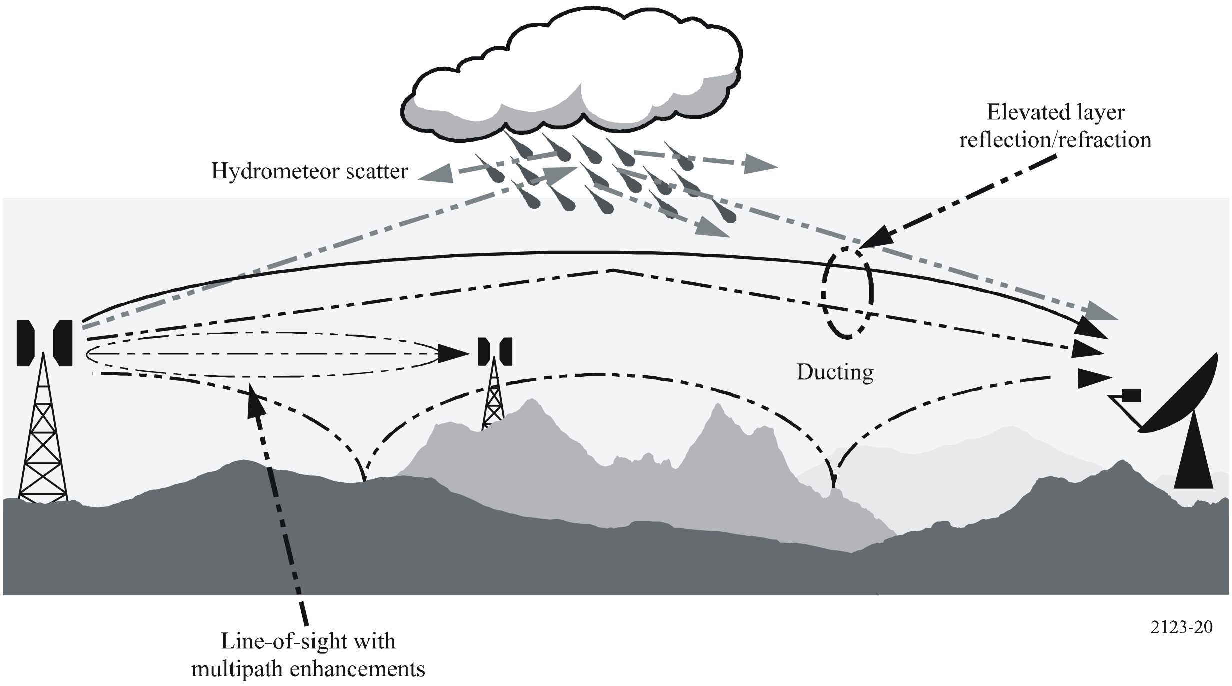
[6] See for example: DOUGHERTY, H.T. and DUTTON, E.J. [1980] The Role of Elevated Ducting for Radio Service and Interference Fields. National Telecommunications and Information Administration.

FIGURE 20

Anomalous (short-term) interference propagation mechanisms



2 Recommendation ITU-R P.452

This Recommendation is intended for the evaluation of microwave interference between stations on the surface of the Earth at frequencies above about 0.7 GHz. The recommendation states that surface ducting is the most important short-term interference mechanism over water and in flat coastal land areas, and can give rise to high signal levels over long distances. Signals received under these conditions can exceed the equivalent free space values under certain conditions.

The calculated ducting propagation loss calculated by this model for a given percent of time is a complex function of frequency, latitude, path geometry and climatic region. The climatic regions are defined as:

– coastal land,

– other inland areas and

– sea. A simplification of the basic equations describing the model is as follows:

$$L_{ba}(p) = 102.45 + 20 \log f + 20 \log (d_{lt} + d_{lr}) + A_d(p)$$

$$A_d(p) = \gamma_d \cdot \theta' + A(p)$$

$$\gamma_d = 5 \times 10^{-5} \, a_e \cdot f^{1/3}$$

$$\theta' = \text{Same as } \theta \text{ defined in Appendix 1}$$

where:

d_{lt}, d_{lr} : distances to the optical horizon from the transmitter and receiver antennas, respectively

a_e : effective Earth radius

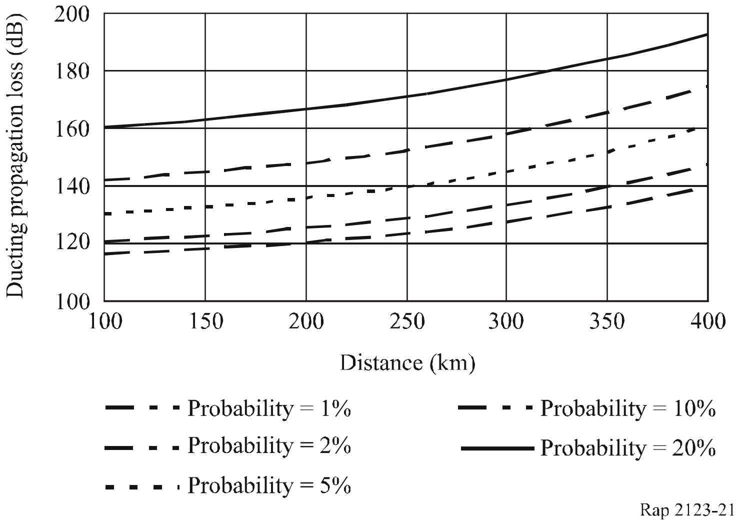
f : frequency (GHz)

$A(p)$: complex function of geometry, latitude and climatic region.

Figure 21 evaluates these equations extrapolated to the frequency 162 MHz over smooth terrain with no intervening obstacles with transmitter and receiver antenna heights of 10 m and 50 m, respectively.

FIGURE 21

Ducting propagation loss at 162 MHz using the ITU-R P.452 model (Smooth terrain)



3 Hepburn predictions

The Hepburn predictions are a service provided to the radio amateur community for those interested in long distance communications via atmospheric ducting.[7] These predictions take into account terrain, weather conditions and other factors to provide qualitative atmospheric ducting predictions. The qualitative predictions range from "marginal" to "extremely intense opening" for ducting communications paths. No propagation loss values are provided. Consequently, these predictions are of limited value when specific quantitative results are required. Copyright restrictions also constrain widespread use.

However, these predictions do provide a useful visualization of the effects of terrain and local climate conditions on atmospheric ducting.

[7] See http://www.dxinfocentre.com/tropo.html.

Appendix 3

Diffraction propagation

1 Introduction

Diffraction propagation loss is the principal propagation mode applicable for most desired and interfering paths among terrestrial radiocommunication systems. A number of factors influence diffraction mode propagation including frequency, distance, transmitter and receiver antenna heights, surface admittance and conductivity, and polarization. However, at 162 MHz, the latter three factors generally do not play a major role. Recommendation ITU-R P.526 describes in detail the methodology for calculation of diffraction mode propagation losses.

2 Recommendation ITU-R P.526

Recommendation ITU-R P.526 describes the calculation of propagation loss over diffraction paths including a spherical earth surface or over irregular terrain. For purposes herein only the smooth spherical earth is considered. At 162 MHz, the smooth earth diffraction propagation loss can be described by the following equations:

$$L_{Diff} = L_{FS} + F(X) + G(Y_1) + G(Y_2)$$

$$F(X) = 11 + 10 \log (X) - 17.6 \cdot X$$

$$X = 0.029 \cdot D$$

$$G(Y) = 20 \log (Y + 0.1 \cdot Y^3)$$

(NOTE – Different equations apply for very low and very high antennas)

$$Y = 0.014\, H$$

where:

L_{Diff} : smooth Earth diffraction loss (dB)

L_{FS} : free space propagation loss (dB)

$F(X)$: distance factor (dB)

$G(Y_{1,2})$: height gain factors (dB)

D : distance separation

H : transmitter, receiver antenna height (m).

Implementation of the methods described above yields the following results for several example cases.

FIGURE 22

Calculated diffraction propagation loss over smooth terrain using ITU-R P.526 model
(162 MHz; Receiver height = 30 m; 50% of locations; 50% of time)

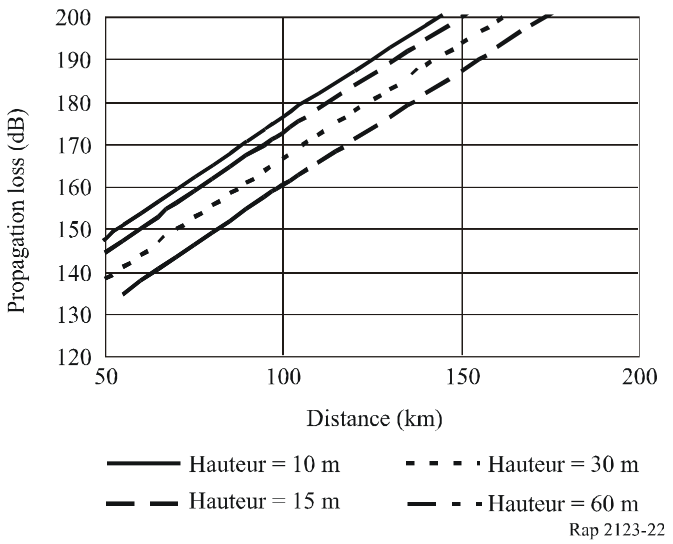
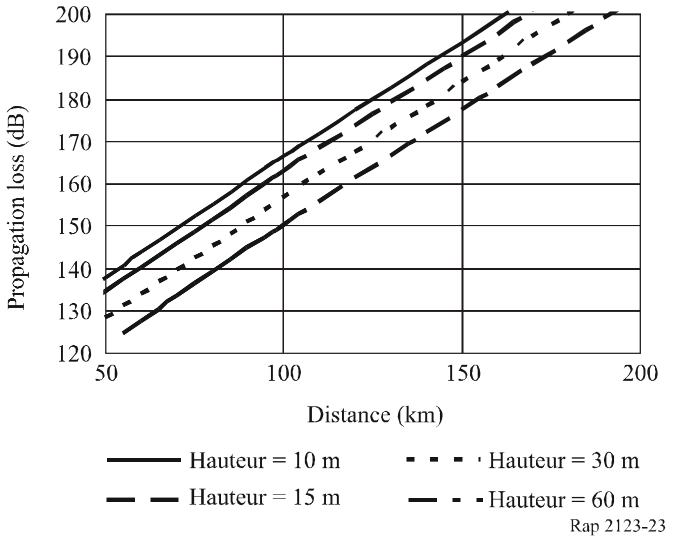


FIGURE 23

Calculated diffraction propagation loss over smooth terrain using ITU-R P.526 model
(162 MHz; Receiver height = 30 m; 50% of locations; 10% of time)



Appendix 4

Additional spectrum sharing considerations

Section 3 of the Report addresses spectrum sharing between AIS systems and other co-channel mobile systems. The results were derived assuming normal diffraction mode propagation mechanisms. This appendix addresses additional sharing factors taking into account anomalous propagation modes, specifically tropospheric scatter and atmospheric ducting.

Following the procedures described in § 3, the nominal distance separation for long range AIS and normal AIS under conditions of anomalous propagation can be estimated and compared using the following:

$$D/U = D_{median} - [EIRP - L_p(d,\%) + G_r - L_{misc}] > D/U_{Criteria}$$

where:

D/U :	desired to undesired ratio (dB)
D_{median} :	median desired signal level from the edge of the service area (dBm)
$EIRP$:	mobile transmitter equivalent radiated power (dBm)
$L_p(d,\%)$:	propagation loss as a function of distance and percent occurrence (dB)
G_r :	receiver antenna gain (dBi)
L_{misc} :	miscellaneous receiving system losses (dB) (assumed 3 dB)
$D/U_{Criteria}$:	applicable D/U protection criteria.

Rearranging terms yields:

$$L_p(d,\%) > D/U_{Criteria} - D_{median} + EIRP + G_r - L_{misc}$$

Using this equation and the extrapolated propagation models described in Appendices 1 and 2, the nominal distance separation can be tabulated, shown in Table9, and compared for the AIS safety-of-navigation and long range detection functions.

The calculated distances shown in Table 9 apply only for low lying inland coastal plain areas. No terrain features were considered. In many cases, coastal plain terrain does not extend inland for the distances calculated in this table; consequently additional factors need to be considered. As a result of these varying site-specific considerations, it is not practical to identify a generic separation distance which could be appropriate for any sharing scenario.

The nominal distance separations calculated above using anomalous propagation modes are significantly larger, as expected, than those calculated under normal diffraction mode propagation. The analysis results presented in this section indicates that, comparable to the case of diffraction mode propagation, similar distance separations would suffice irregardless of whether the AIS coast stations were operating in a safety-of-navigation function or long range detection function.

TABLE 9

Calculated distance separation from co-channel mobile systems to meet the assumed sharing AIS criteria

AIS function	Propagation mode	$D/u_{criteria}$ (dB)	D_{median} (dBm)	Mobile ERP (dBm)	Mobile antenna height (m)	Propagation statistics	Calcula-ted propaga-tion loss (dB)	Calculated distance (km)
Safety-of navigation	Tropo-scatter	15	–104	50	15	50% locations 10% time	171	200
Safety-of navigation	Tropo-scatter	15	–104	56	60	50% locations 10% time	177	220
Long range tracking	Tropo-scatter	10	–115	50	15	50% locations 10% time	169	190
Long range tracking	Tropo-scatter	10	–115	56	60	50% locations 10% time	175	210
Safety-of navigation	Ducting	15	–104	50	15	50% locations 10% time	171	375
Safety-of navigation	Ducting	15	–104	56	60	50% locations 10% time	177	400
Long range tracking	Ducting	10	–115	50	15	50% locations 10% time	169	370
Long range tracking	Ducting	10	–115	56	60	50% locations 10% time	175	395

Appendix 5

AIS propagation observations – Ducting

1 Introduction

Techniques and methods to improve AIS signal detection at shore facilities are the subject of field trials. Observations made during these trials provide practical examples that generally support the material presented in this paper.

2 Atmospheric ducting

The impact of ducting can be viewed two ways.

– Ducting enhances the performance of a system intended for long range tracking.

– Ducting introduces interference sources to signals from AIS stations within the nominal AIS reception range. This can result in a reduction of the performance of AIS both ashore and on vessels.

Figures 24 and 25 plot data collected during 24 h of a 48 h ducting event during 7-9 October 2006. The figures provide actual signal level information from a high performance receiver installation. The plots show all the AIS signals received during 8 October 2006.

The signal measurements are displayed based upon the distance separation of the transmitting AIS unit from the AIS receiver installation. The "message color bar" at the right of the figures indicates the number of messages (by colour) that are involved with each calculation.

Figure 24 plot shows the peak, average, and minimum signal measurements for each nautical mile from 1 to 200 nautical miles. The level indicated by the black triangles show the strength of the weakest received AIS messages. This level is directly affected by "local radio noise" conditions. Figure 25 shows the number of messages received at each dB level for each mile of the 1 to 200 nautical miles. The figure consists of color cells that show the number of received messages. The color cells dimensions are 1 nautical mile by 1 dB.

The plots can be used to show how atmospheric ducting is useful for long range detection of ships. The plots can also be used to show that during ducting events, the strength of signals received from distant ships can be greater than signals from nearby ships. This is not a problem since the AIS technology was designed to operate properly under these conditions. The logic built into every AIS unit would enable the AIS units to organize their broadcasts in a manner to avoid causing co-channel AIS interference.

FIGURE 24

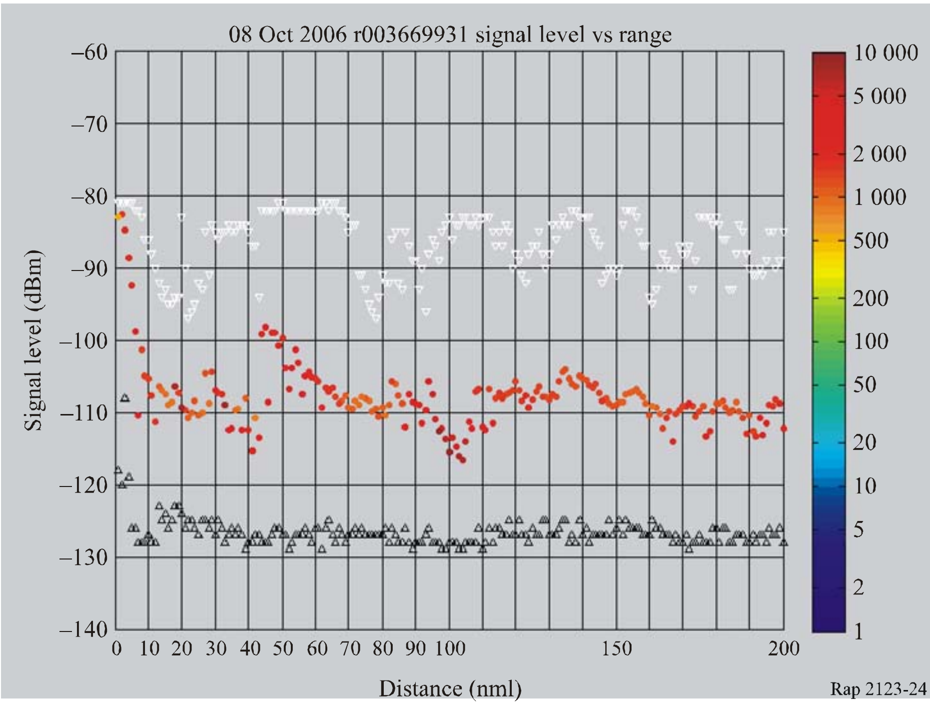
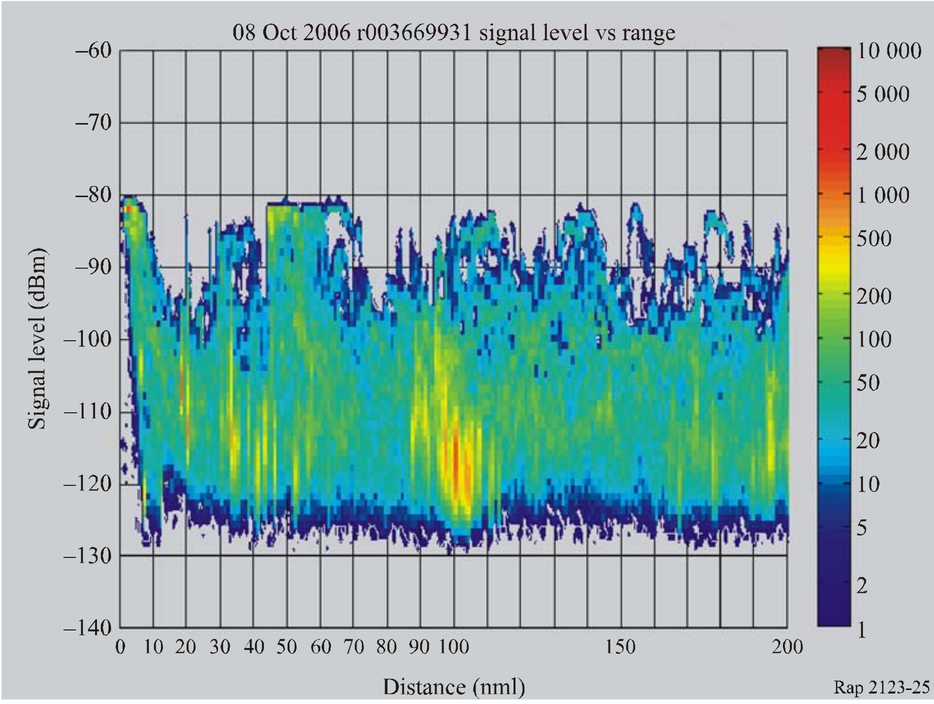


FIGURE 25

Observed AIS signal levels during 8 October 2006 "ducting event."



The plots could also be used to illustrate how ducting could allow other types of emissions to affect local AIS signals on an intermittent basis. Under the ducting conditions shown in the plots, it is possible that a non-AIS continuous signal from 150 to 200 miles away could affect reception of an AIS signal from a AIS unit less than 10 miles away. The distances in the plots considered reception of signals from ships at sea; for land based transmissions, other factors such as terrain features or attenuation from manmade structures would need to be taken into account. These signals could be co-channel signals from non-AIS services using the AIS channels or spurious emissions from non-AIS transmitters. They could effectively raise the "local radio noise," as viewed from the perspective of the AIS technology. To be reliably detected, an AIS signal needs to be 10 dB stronger (the AIS test standard for receiver co-channel rejection) than the "local radio noise". The conditions shown in the plots could result in degraded AIS performance for the duration of the ducting event. However, given its sporadic and intermittent occurrence, ducting should not be used as a basis for determining compatibility between VHF systems. Ducting is an anomalous propagation occurrence that can occur for days or weeks at a time. It is dependant on geographical location and electromagnetic atmospheric effects.