Interaction between offshore wind farms and maritime navigation
PIANC WG 161

Chapter 4
Interaction with communication (VHF), radar, AIS, D/F... and navigation systems

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Chapter 4

4 Interaction with communication (VHF), radar, AIS, D/F... and navigation systems

4.1 General introduction to electromagnetic radiation

4.1.1 What is electromagnetic radiation?

Electromagnetic radiation (EMR) is a wavelike pattern of electric and magnetic energy moving together. Types of EMR include X-rays, ultraviolet, visible light, infrared and radio waves. As a natural phenomenon, EMR is emitted by natural sources like the Sun, the Earth and the ionosphere. Radio frequency (RF) EMR is commonly used for a wide variety of communications applications from the broadcast of television and radio, through to radars and mobile phones. It is important that wind farms do not impact the quality of this communications.

4.1.2 What do wind farms have to do with electromagnetic radiation?

From a wind resource perspective, high and exposed sites are attractive. So it is not unusual for any of a range of telecommunications installations; radio and television masts, mobile phone base stations or emergency service radio masts, to be located nearby. Care must be taken to ensure that wind turbines do not passively interfere with these facilities by directly obstructing, reflecting or refracting the RF EMR signals from these facilities. There is also potential for a wind turbine to actively interfere by producing its own low energy RF signal.

4.1.3 What is electromagnetic radiation interferences?

Unwanted radio and background noise can impair effective telecommunications which rely on a strong signal to noise ratio. An appropriate transmitting antenna can dramatically improve this signal to noise ratio. A transmitting antenna can also increase the signal strength in a particular direction (i.e. toward a receiver).The directionality of a receiving antenna can also be enhanced, thus reducing the amount of unwanted noise.

4.1.4 How can wind farm electromagnetic radiation issues managed?

- **Point to Point Communications:** Careful siting and directional antenna can eliminate any impact on point to point links.

- **Mobile Radio Services:** Interference can be overcome by moving the mobile unit a short distance away as per normal practice for avoiding any other structure. Any interference to mobile radio services is usually negligible and limited to mobile communications within the wind farm site itself.

- **Television:** Interference to television signals in the wind farm area can be caused by either the reflection or obstruction of the signal by the turbine blades. With glass reinforced plastic blades, modern wind turbine generators will cause minimal television interference. It cannot however, be completely discounted for houses within a few kilometres of turbines. If interference does become apparent after construction, the possible mitigation techniques include:

• the installation of a better quality antenna or more directional antenna,
• directing the antenna toward an alternative broadcast transmitter,
• installation of an amplifier,
• relocation of the antennae to achieve better signal to noise ratio,
• installation of a terrestrial, digital set top box for digital TV,
• installation of satellite or cable TV, or
• if a wide area is affected then the construction of a new repeater station may be considered.

Active interference is minimised or completely avoided by ensuring that all equipment complies with relevant electromagnetic compatibility standards, as all wind farm equipment does. In the unlikely event that a problem arises over time at a particular site, the wind farm operator will usually be able to rectify it using one of the aforementioned solutions. In the focus of Interaction between offshore wind farms and maritime navigation, we will study the different equipments: radar (in particular VTS radar and ship borne radar), radio communications (in particular maritime radio communications in line with the GMDSS), Automatic Identification System (AIS), direction finder (D/F), global navigation satellite systems (GNSS) and others navigation systems.

4.2 Radar

The wind farm developers are urged to seek the advice of radar operators before submitting their application for building permit. This phase should allow the developer to obtain elements to guide the project and avoid rejection on the occasion of its possible application for a building permit. This pre-consultation also allows the following radar operators to make as soon as possible to the competent Authority their opinions during the investigation of the building permit.

At the end of the instruction as define by the competent Authority, radar operators transmit to wind farm developers an opinion which may be favorable, favorable with restrictions or unfavorable. In the latter two cases, the notice may include information specifying the location of favorable wind areas. This preliminary view assumes no radar operators, such a response does not prejudge the result may be reserved in fine to a request for building permission. Indeed, they do not necessarily have at this stage all the parameters of the wind project. Moreover, it should be noted that a positive opinion does not constitute a reservation on the proposed location of the wind farm.

4.2.1 Radar operators

Given the impact on air, sea and river safety, land protection, and the prevention of natural disasters, radar operators opinion should be considered in a decision making process on the application for a building permit to a wind farm developer. We have considered the principal radar operators: civil aviation, national defense, weather office and vessels traffic services.

a) civil aviation radars and systems

To protect paths approaches, Civil Aviation operat vessels in reporting, course and speed according to their size, their cargoes, seaworthiness and services that the state is supposed to provide. The IALA VTS committee has developed technical recommendations for VTS specifying in detail the IMO Res. A.857(20).

In this context, the objectives of radar monitoring have been set according to the type of ships, navigation areas they frequent, the necessary characteristics of precision and separation.

The coverage areas of VTS radar are:

- Call zones where ships must report and VTS personal control them. In practice, the limit of these areas is defined by means of radar performance. These areas include the Traffic Separation Scheme (TSS) and areas located adjacent to the TSS;
- others coastal areas, some channels or passes specified in the local regulations, access to ports where SOLAS vessels will approach;
- so-called passive surveillance areas that respond to a general navigation monitoring function. Are particularly targeted areas between TSS and all areas within 50 miles of the coast where ships may be damaged.

The VTS radar transmitter-receiver equipments are doubled frequency diversity mode to achieve high availability as close as possible to 100% per annum on all sites.

As the harbour radar, their main function is to monitor water access and port operations.

4.2.2 principles to avoid disruption of radar

4.2.2.1 Radar operator constraints

Radar operators deciding on the risk of disruption of their equipment especially in view:
- security issues such as the need to monitor the national airspace for defense,
- radio, land and aviation restricted area,
- constraints related to air and sea traffic,
- forecasting of weather disasters.

The mere fact that an aircraft proceeding or a portion of space is affected by a wind project is not sufficient to establish the unfavorable opinion.

4.2.2.2 Restricted areas

Aeronautical constraints of release shall be imposed to protect the evolution of aircraft in the vicinity of aerodromes, the visibility of visual aids and operation of weather stations or facilities of aerodromes.

Radio Electrical easements define areas and sectors clearance vis-à-vis the obstacles and electromagnetic interference, radio stations around.

No wind farm shall be located in an area subject to such regulatory easements.

4.2.2.3 Analysis of co-visibility of a wind turbine with radar

In the absence of co-visibility radar with wind the risk of disruption of radar is zero.

If co-visibility of radar with a wind turbine, the following method is suggested in order to organize space around a wind farm: it is important to determine whether the electrical machine is located in a protected area or coordination area. In the case of a protected area, the risk of disruption is too high to allow the installation of the machine. In the case of a coordination area, it is important to conduct a special study to assess the risk in coordination between the different services concerned by the wind farm.

Radar operators should study co-visibility conducting a simulation with a scanning field.

The extent of the scope of protected area and coordination area depends on the technology of radar equipment. It is specified in the following points.

a) Civil aviation radars

1) Primary radars

<table>
<tr><th></th><th colspan="4">Distance between a wind generator and a primary radar in co-visibility (d)</th></tr>
<tr><td>elevation angle originating home to the radar antenna (α)</td><td>d < 5 km</td><td>5 km ≤ d < 20 km</td><td>20 km ≤ d < 30 km</td><td>d ≥ 30 km</td></tr>
<tr><td>α ≤ 0.5°</td><td rowspan="2">Protected area</td><td colspan="2">Area subject to authorization</td><td rowspan="2">Area subject to authorization</td></tr>
<tr><td>α > 0.5°</td><td>Coordination area</td><td>Coordination area in case of important wind farm</td></tr>
</table>

The elevation angle α is the elevation angle in the vertical plane having to focus the radar antenna and passing through the tip of the blade of the wind turbine in the highest position.

2) secondary radar

Distance between a wind generator and a secondary radar in co-visibility (d)		
d < 5 km	5 km ≤ d < 30 km	d ≥ 30 km
Protected area	Coordination area in case of important wind farm	Area subject to authorization

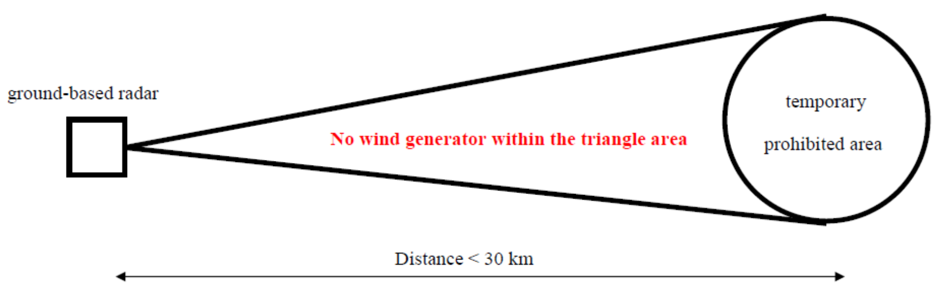
3) VOR

A study by the Civil Aviation showed that wind generator within a radius of less than 10 km from a VOR is likely to cause deviations from 1.5° to 2°. In fact, under the precautionary principle, a closed area to installing wind turbines in a 2 km radius around a VOR is established. Area, known as coordination, 10 km around VOR is created to study case by case the risk of interference between a wind turbine and a VOR.

There are two types of VOR: conventional VOR and Doppler VOR. Given the greater immunity to interference Doppler VOR reflections on the obstacles, it could be considered in some cases, the change of a conventional VOR into a Doppler VOR. In this case, the contribution of wind energy developers will be an agreement with the civil aviation.

b) National Defense radars

Following the attacks of 11 September 2001, in many countries no wind turbine can be installed in a temporary prohibited area mentioned in the aeronautical publications or the triangular surface(s) joining ground-based radar to a temporary prohibited area distant of less than 30 km from the radar.



Besides these features, the authorization to establish a wind turbine depends on the type of radar:

1) high and medium altitude radar (HMA)

<table>
<tr><th></th><th colspan="4">Distance between a wind generator and a radar in co-visibility (d)</th></tr>
<tr><td>elevation angle originating home to the radar antenna (α)</td><td>d < 5 km</td><td>5 km ≤ d < 20 km</td><td>20 km ≤ d < 30 km</td><td>d ≥ 30 km</td></tr>
<tr><td>α ≤ 0.5°</td><td rowspan="2">Protected area</td><td>Coordination area</td><td>Area subject to authorization</td><td rowspan="2">Area subject to authorization</td></tr>
<tr><td>α > 0.5°</td><td>Protected area</td><td>Coordination area</td></tr>
</table>

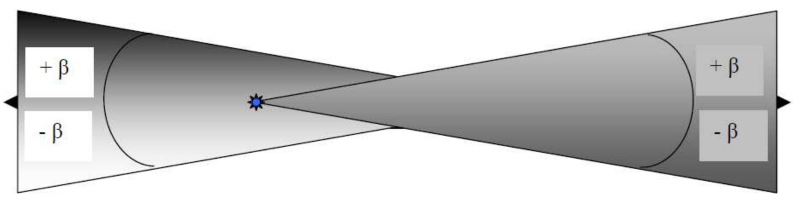
2) low level altitude radar

<table>
<tr><th></th><th colspan="4">Distance between a wind generator and a radar in co-visibility (d)</th></tr>
<tr><td>elevation angle originating home to the radar antenna (α)</td><td>d < 5 km</td><td>5 km ≤ d < 20 km</td><td>20 km ≤ d < 30 km</td><td>d ≥ 30 km</td></tr>
<tr><td>α ≤ 0°</td><td rowspan="2">Protected area</td><td>Coordination area</td><td>Area subject to authorization</td><td rowspan="2">Area subject to authorization</td></tr>
<tr><td>α > 0°</td><td>Protected area</td><td>Coordination area</td></tr>
</table>

3) precision landing radar

<table>
<tr><th></th><th colspan="3">Distance between a wind generator and a radar in co-visibility (d)</th></tr>
<tr><td>angle on either side of the axis of the track, whatever its direction. The apex being the end of the runway. (β)</td><td>d < 5 km</td><td>5 km ≤ d < 20 km</td><td>d ≥ 20 km</td></tr>
<tr><td>β < 20°</td><td rowspan="2">Protected area</td><td>Protected area</td><td rowspan="2">Area subject to authorization</td></tr>
<tr><td>β ≥ 20°</td><td>Area subject to authorization</td></tr>
</table>

Definition of angle β:



β = 20°

c) Weather radars

	Distance between a wind generator and a radar in co-visibility (d)				
frequency band of the radar	d < 5 km	5 km ≤ d < 10 km	10 km ≤ d < 20 km	20 km ≤ d < 30 km	d ≥ 30 km
Band C	Protected area	Coordination area		Area subject to authorization	
Band S	Protected area		Coordination area		Area subject to authorization

1) A project is authorized if all the following conditions are met:

- no wind turbines is within the protected area of the radar;
- concealment of the radar beam by any group of wind generators is less than 10%;
- wind turbines are not aligned in the direction of prevailing winds;
- the size of the Doppler area of the wind farm does not exceed 10 km in its largest dimension.

2) Sensitive sites cases:

A sensitive site is a geographic area defined by the competent Authority:

- which is responsive to the meteorological risk, including particularly exposed to risks of strong wind,
- which has an important socio-economic issues, such as industrial area or an area with high urban concentration,
- and whose time responsiveness requested to the weather office is compatible with warning capabilities for nowcasting.

Thus, companies for which a special contingency plan is developed and aerodromes are considered sensitive sites.

The Doppler area of a wind farm must be distant 10 km at least from a sensitive si

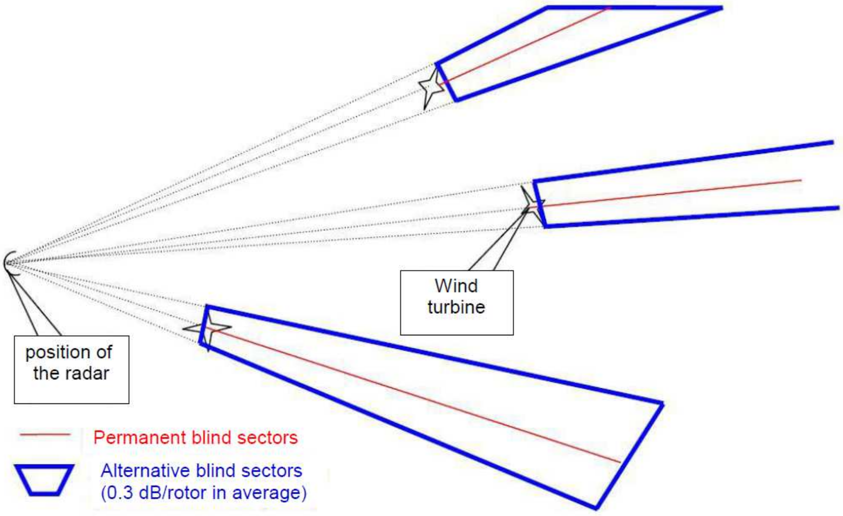
d) VTS radars

Effect of the presence of a wind farm on VTS radar:
- The angle referred imperatively near horizontal makes inevitable confusion between the target position (ships) and windmills;
- No Doppler analysis and no Moving Target Indicator (MTI) in signal processing make the rotation of the rotor causes no interference;
- The fineness of the azimuth angle of the radar beam is that the effects of a wind turbine (or row) are taken into account separately.

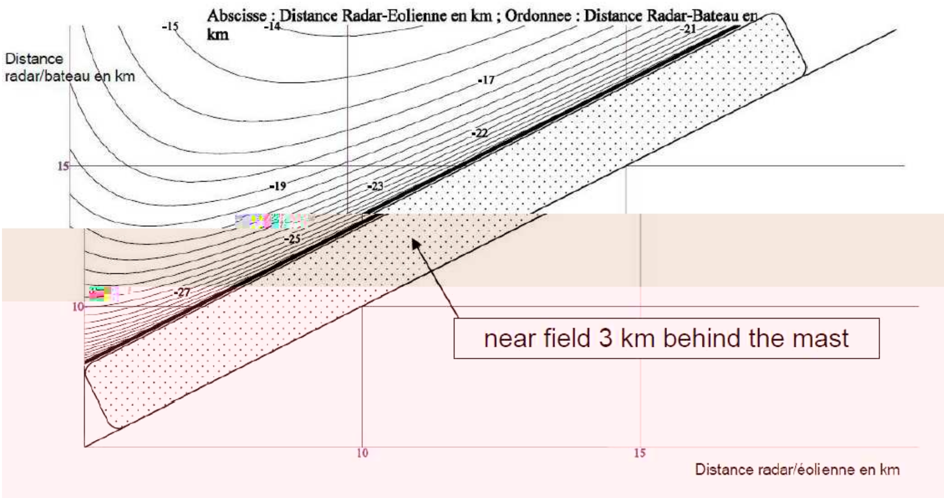
Radar Saturation:
Radars can be rendered inoperative if the power level of the received signal is too large compared to its operating range

Blind sectors behind wind generators
There are 2 types of blind sectors:

1) The most important is the blind sector generated by the mast of the wind generator



Blind sectors generated by wind turbines



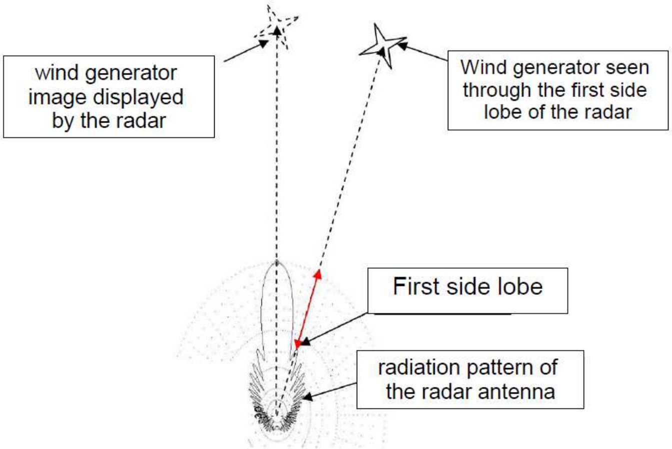
Blind sector generated by the mast of wind turbine

Nota: Maximum dB attenuation of the radar signal return behind a pole 7m diameter (radar frequency = 9.2 GHz - Iso mitigation: 1 dB)

2) The masking blades whose attenuation is low. This average attenuation is about 0.3 dB on a round trip.

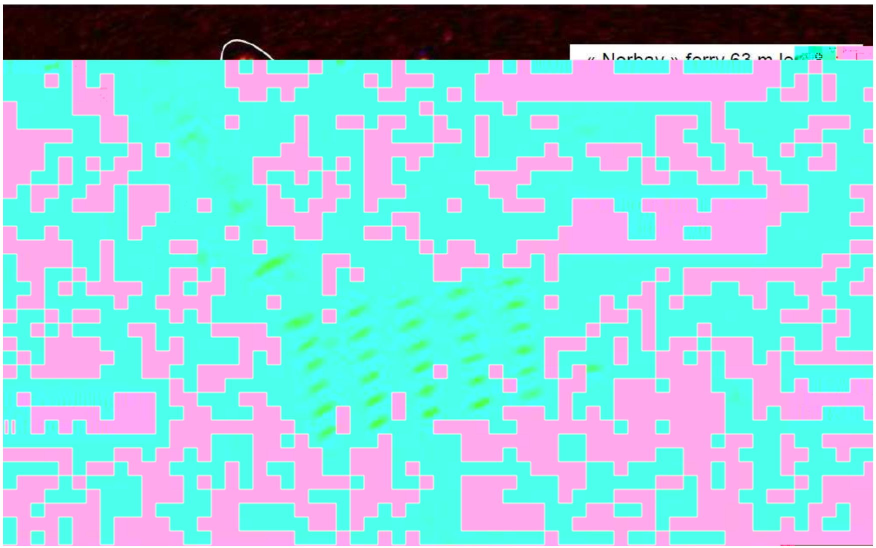
The appearance of false targets

- Because of their strong radar signature wind turbines generate a false echo from the side lobes of the radar antenna. These echoes appear with an angular offset relative to the clutter



False target phenomena

- The multipath reflection of the radar signal to or from the desired target



Example of false targets by multipath signal

In consequences these disturbances significantly degrade the capabilities of detection, localization, identification of radar around wind turbine.

1) coastal VTS radars

	Distance between a wind generator and a radar in co-visibility (d)		
frequency band of the radar	d < 5 km	5 km ≤ d < 20 km	d ≥ 20 km
Band X	Protected area	Coordination area	Area subject to authorization

2) harbour VTS radars

Compared to coastal VTS radar, the protected area is amended as follows:

- protected distance is 10 km,
- the protected area is restricted to ± 6 ° on either side of the operating area radar

Recommendation for harbour radar

e) Analysis when co-visibility in an area of coordination

If co-visibility in an area of coordination, radar cross section (RCS) is used in the impact analysis between radar and wind generator. It characterizes the ability of an element to return the electromagnetic energy of the radar to the same radar. It is the expression of a relationship between the energy re-emitted on the received energy density per unit area and is expressed in m² or dBm².

RCS depends in particular on:

- the polarization of the wave,
- the wavelength of the radar,
- the shape of the wind generator,
- the geometry and the materials forming the wind generator.

The highest of the RCS of the wind generator and its wind rotor can be either calculated or measured and that from all angles from 0° to 360°. They can be given by the manufacturer of wind generators or a specialized study office, failing the radar operators instruct impact with RCS values of 200 m².

4.3 Radiocommunications

In addition to their potential impact on radar systems, offshore wind farm structure may also affect communications systems operating in the marine environment. This includes vessel-to-vessel, vessel-to-shore and vessel-to-space links. Examples of systems that potentially may be affected include satellite links such as GPS (global positioning system, 1.6GHz) for navigation and Iridium (1.6GHz) and GOES (400MHz) for data relay by various ocean monitoring sensors, VHF (160MHz) radio for marine communications, and AIS (160MHz, automatic identification system) for vessel tracking.

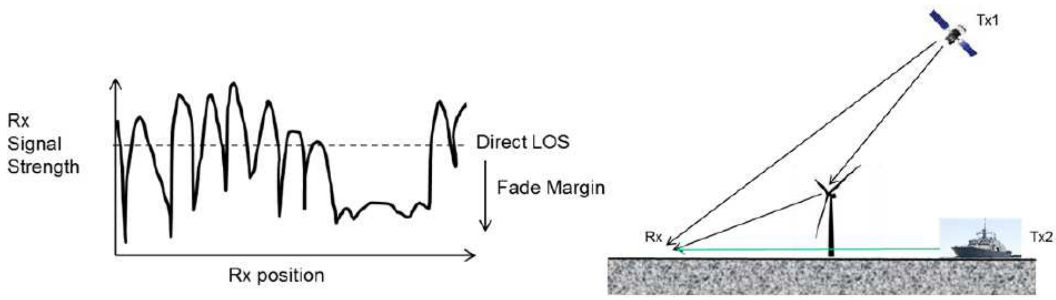
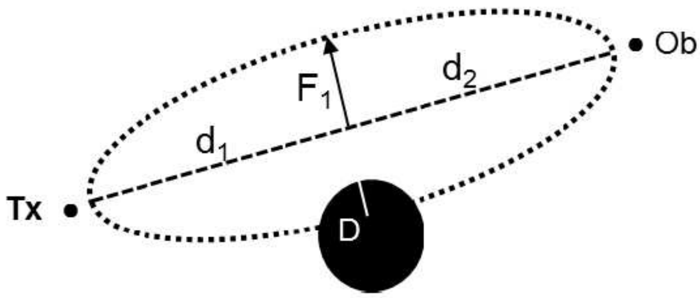


Illustration of communications channels encountered in the marine environment

A number of analytical and numerical approaches have been applied to model the wind farm blockage problem. A simple, approximate geometrical blockage estimate can be derived based on the Fresnel zone argument. This is the standard methodology used to estimate the shadowing effect due to wind turbine structures by the Federal Aviation Administration (USA) obstruction evaluation process.



$$F_1 = \sqrt{\frac{\lambda d_1 d_2}{d_1 + d_2}}$$

$$\frac{E^{tot}}{E^{i}} = 1 - \frac{D}{F_1}$$

Fresnel zone blockage calculation for assessing wind turbine blockage.

Base on different studies in the world, we can summarize the effect of wind farms on marine communications are as follows:

1) A distinct shadow region is observed behind the tower. Multi-path interference is observed outside the shadow region.
2) The shadow becomes more optical-like as frequency is increased, leading to longer, narrower and deeper shadows. However, the signal fade is still less than 6dB relative to the direct line of sight (LOS) signal up into the GHz range.
3) The vessel-to-vessel link and the vessel-to-shore station link are worst-cases estimate of the vessel-to-satellite link.
4) The shadow becomes deeper when more than one turbine is lined up with respect to the transceiver (Tx) line of sight (LOS) and then the fading risk is elevated.
5) Most communications systems have built-in link margins to combat signal fading. For example, typical GPS receivers have a fade margin of 15dB or greater.

4.3.1 The Global Maritime Distress and Safety System (GMDSS)

The Global Maritime Distress and Safety System (GMDSS) is an internationally agreed-upon set of safety procedures, types of equipment, and communication protocols used to increase safety and make it easier to rescue distressed ships, boats and aircraft. The GMDSS has been internationally regulated in the ITU Radio Regulation and within IMO in chapter IV of the Safety Of Life At Sea (SOLAS) convention.

GMDSS consists of several systems, some of which are new, but many of which have been in operation for many years. The system is intended to perform the following functions: alerting (including position determination of the unit in distress), search and rescue coordination, locating (homing), maritime safety information broadcasts, general communications, and bridge-to-bridge communications. Specific radio carriage requirements depend upon the ship's area of operation, rather than its tonnage. The system also provides redundant means of distress alerting, and emergency sources of power.

Recreational vessels do not need to comply with GMDSS radio carriage requirements, but will increasingly use the Digital Selective Calling (DSC) VHF radios. Offshore vessels may elect to equip themselves further. Vessels under 300 Gross Tonnage (GT) are not subject to GMDSS requirements. Nevertheless VHF channel

4.3.2 GMDSS area

GMDSS sea areas serve two purposes: to describe areas where GMDSS services are available, and to define what radio equipment GMDSS ships must carry (carriage requirements). Prior to the GMDSS, the number and type of radio safety equipment ships had to carry depended upon its tonnage. With GMDSS, the number and type of radio safety equipment ships have to carry depends upon the GMDSS areas in which they travel.

In addition to equipment listed below, all GMDSS-regulated ships must carry a satellite EPIRB, a NAVTEX receiver (if they travel in any areas served by NAVTEX), an Inmarsat-C SafetyNet receiver (if they travel in any areas not served by NAVTEX), a DSC-equipped VHF radiotelephone, two (if between 300 and less than 500 GRT) or three VHF handhelds (if 500 GRT or more), and two 9 GHz search and rescue radar transponders (SART).

Sea Area A1: An area within the radiotelephone coverage of at least one VHF coast station in which continuous digital selective calling (Ch.70/156.525 MHz) alerting and radiotelephony services are available. Such an area could extend typically 30 nautical miles (56 km) to 40 nautical miles (74 km) from the Coast Station (depending mainly of the hight of the antenna).

Sea Area A2: An area, excluding Sea Area A1, within the radiotelephone coverage of at least one MF coast station in which continuous DSC (2187.5 kHz) alerting and radiotelephony services are available. For planning purposes, this area typically extends to up to 180 nautical miles (330 km) offshore during daylight hours, but would exclude any A1 designated areas. In practice, satisfactory coverage may often be achieved out to around 150 nautical miles (280 km) offshore during night time.

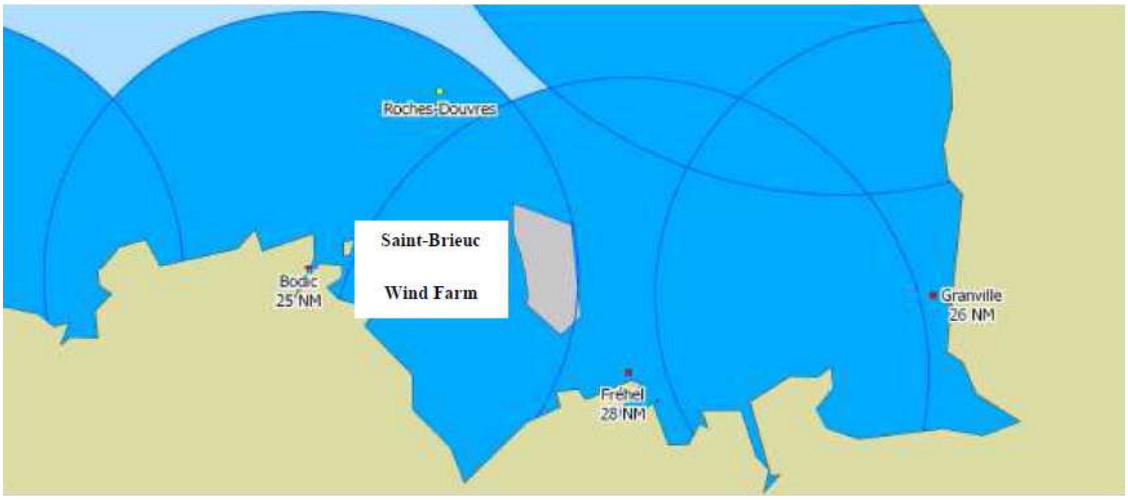
Sea Area A3: An area, excluding sea areas A1 and A2, within the coverage of an Inmarsat geostationary satellite. This area lies between about latitude 76 Degrees North and South, but excludes A1 and/or A2 designated areas. Inmarsat guarantees their system will work between 70 South and 70 North though it will often work to 76 degrees South or North.

Sea Area A4: An area outside Sea Areas A1, A2 and A3 is called Sea Area A4.

IMO Res. A. 801(19) adopted on 23 November 1995, on provisions for radio services for the GMDSS, is the reference document to basic principles to establish the different GMDSS sea Areas. In particular, the formula to determine the coverage of a Coastal radio Station (CRS) has been defined and helps Coastal States to declare their GMDSS infrastructure to IMO as requested in SOLAS IV R5.

The collection of all GMDSS sea area is consolidated by the secretary of the IMO into the GMDSS master plan. This plan helps to define the radio equipment to be carried on board ships depending of the radio communication infrastructures declared ashore.

Wind farms at sea are generally located in an oceanic area A1 covered by VHF CRS. The Doppler area generated by the wind farms may affect the reception, in particular the reception of distress calls on channel 16 or digit selecting calls on channel 70. It is suggested that a study on the potential impact on radio transmissions and coverage be considered during the planning process for a wind farm.



Saint-Brieuc (France) Wind Farm project
and the different VHF coverages (GMDSS sea area A1)

In any case, it is considered best practice to establish what the implications could be for radio systems operating in the area around a wind farm, and to carry out to the extent possible.

4.4 Automatic Identification System (AIS)

Automated Identification Systems (AIS): this is a tracking system, which involves radio communication from ship to ship and also from ships to AIS stations ashore. The system integrates VHF transmissions with a positioning system such as a GPS. The purpose of AIS is first to identify ships in the vicinity carrying an AIS. In that respect AIS assist in collision avoidance, but it should be keep in mind AIS is not mandatory on all ships.

AIS are transceiver and receptor on the VHF. They are subject to the Doppler area of the wind farm as the VHF radio as indicated in paragraph 4.3 above.

It is suggested that a study on the potential impact on AIS transmissions and coverage be considered during the planning process for a wind farm.

4.5 Direction finder (D/F)

The disruption on phase due to wind farms may cause some concerns on those applications where phase information is used, such as direction finding and precise GPS relative and absolute positioning techniques based on carrier phase measurements. These should be further examined.

In the case of the use of a direction finder (D/F) station ashore, whether for the purpose of a VTS or SAR, the D/F will be inoperative because of the Doppler area of the wind farm.

It is suggested to study an alternative solution for the D/F shore based station.

4.6 GNSS & others navigation systems

Depending from the importance of the information provided by GNSS or local radio navigation system available, it is suggested that a study on the potential impact on GNSS and radio navigation transmissions and coverage be considered during the planning process for a wind farm. Last but not least the electromagnetic field generated by wind generator hampered magnetic compass.

4.6.1 GNSS

Multi-path disturbance effects of the satellite communication already exist on a merchant ship. These effects are generated by cranes and mast of the ships. It is possible to minimize the disturbance on the GNSS receptor by dedicated setting. The problem on ship is the regular change of the physical parameters with the loading condition. The high of the antenna, mast and crane are then changing with the loading condition because of the draft.

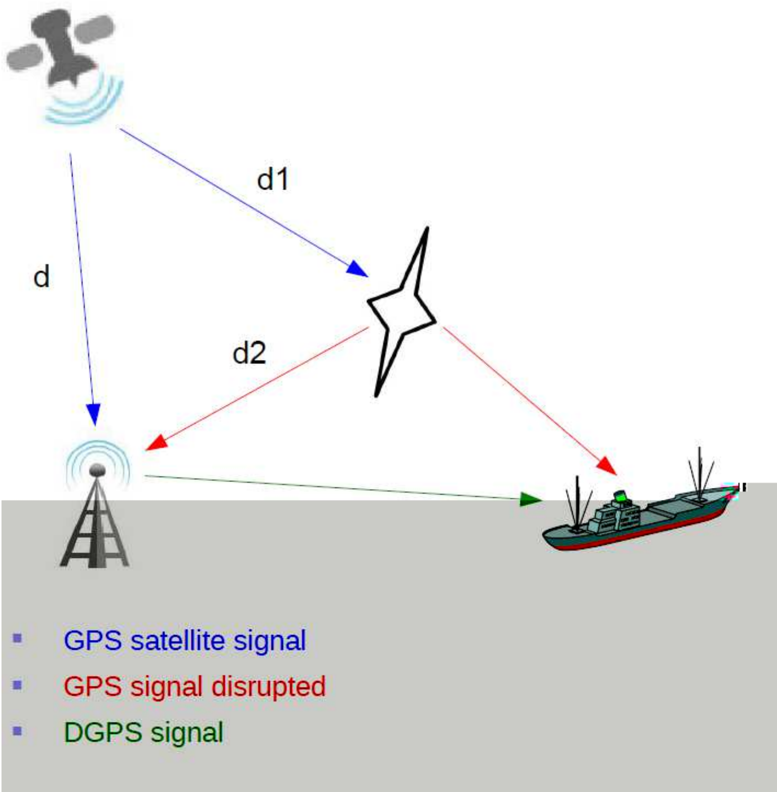
Studies have been focus on the DGPS:

1) The risk of disruption affects only the GPS signal from the reference station;

2) The reference station uses signals from satellites positioned more than10 ° above the horizon.

3) The consequences are respect a minimum distance:
    - Between the reference station and wind turbine and
    - Between the ship and the wind turbine.

4) A distance greater than 1200 m for a wind turbine of 160 m and an angle of 8 ° distance above the horizon overcomes the potential impact of multi-path between satellite, boat, wind turbines and DGPS reference station.



Disruption of DGPS

To maintain the accuracy of DGPS, it is necessary to ensure a distance of 1.2km between wind turbines and ships, and between wind turbines and the DGPS reference station.

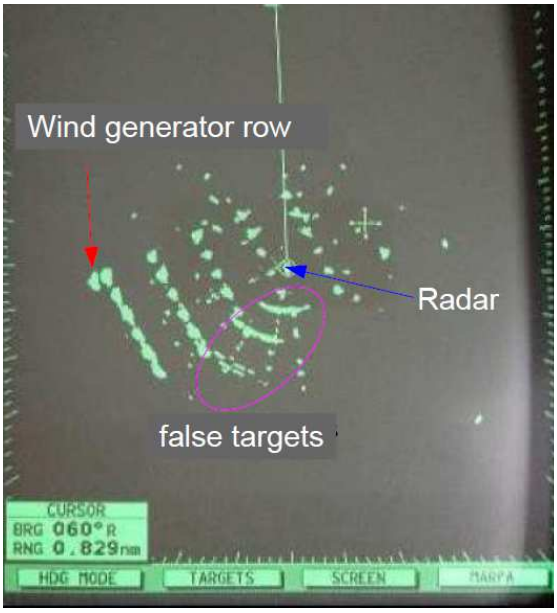
4.6.2 Radar

Ships are using two types of radar:

1) band X radar on 9.6 GHz frequency with a short wave length of 3 cm. This type of radar is mainly used for accurate navigation and to detect targets around the ship.

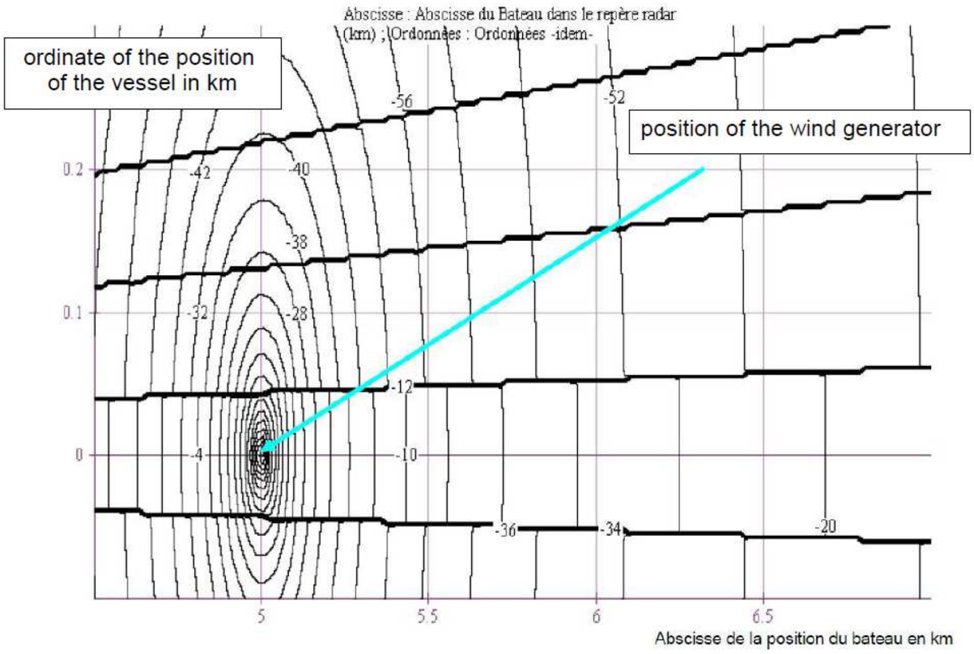
2) band S radar on 3 GHz frequency with a longer wave length of 10 cm. This type of radar is used for long distance detection and fix, but it is more sensitive to sea and rain cluting.

Depending of their size, some merchant ships should carry both type of radar in compliance to SOLAS. Band X radar is also used by VTS and band S radar is also use by weather services (see above). In consequence ship radar are disturbed the same way as explain above for VTS.



Example of false target generated on a ship radar screen

Interaction wind turbine/ship radar generates false targets by the side lobes of the antenna. Clutter of the wind turbine is located at the same distance as the latter.



Quantifying the multi-path effect of order 1 compared to the level of the direct path depending on the position of the ship relative to the wind generator (ship radar / wind generator distance of 5 Km)

The table below gives an interpolation based on the limits of VTS radar and weather using radar vessels near a wind farm.

	Distance between a wind generator and a radar in co-visibility (d)				
frequency band of the radar	d < 5 km	5 km ≤ d < 10 km	10 km ≤ d < 20 km	20 km ≤ d < 30 km	d ≥ 30 km
Coastal VTS radar **Band X** 8 – 12 GHz	Protected area	Coordination area		Area subject to authorization	
Weather radar **Band S** 2 – 4 GHz	Protected area		Coordination area		Area subject to authorization
Ship radars **Band X & S**	Protected area		To be checked		