Subject	Radiated RF emissions from wind farms		
Society	**RSGB**	Country:	**United Kingdom**
Committee:	**C7**	Paper number:	**LA17_C7_04**
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1 Background

This paper shows that some modern wind farms can cause harmful interference to amateur radio reception, particularly in the 1,81 - 2 MHz band at a distance of 10 km or more. It considers shortcomings in the applicable EMC standards and makes a recommendation to influence applicable EMC standards and report cases of interference.

2 Introduction

In 2013, the RSGB received reports that a newly installed wind farm was causing severe interference to amateur radio reception in the 1,81 - 2,0 MHz band.

In 2014, RSGB made measurements of the disturbance field strength in vicinity of a three wind farms in Northern England and submitted a paper to IEC CISPR H Committee Working Group on Generic Standards. Further information was requested including Quasi-Peak (QP measurements. The RSGB has made QP measurements, which are summarised in this paper.

3. Key points and proposal

Radio frequency interference radiated by a wind farm in the range 1,81 – 2,0 MHz is causing harmful interference to amateur radio reception. A radio amateur who lives approx. 4,5 km from the centre of the wind farm reports that before the wind farm was built, the typical background noise level from his elevated wire antenna at 1,9 MHz was S2. When the wind farm first started, the disturbance level increased to S9 + 40 dB. The operating company reduced this to S9 + 20 dB but it still causes harmful interference to amateur radio reception over a wide area. The UK Regulator does not consider that the wind farm is causing harmful interference and is unwilling to take any action.

Measurements by RSGB using a loop antenna 1,5 m above ground level show that at a distance of 4,5 km from the apparent source, the disturbance raises the background noise level by at least 25 dB compared to a relatively quiet area. At a distance of 13 km, the disturbance still raises the background noise level by at least 9 dB and it remains significant beyond 20 km distance, covering an area of at least 1v250 km^2. Further details of the measurements are in Annex A.

The EMC standard for wind turbines references the Generic Standard, which does not specify any enclosure port radiated emission limits below 30 MHz. This is based on the assumption that the equipment under test is small compared with a wavelength so that it does not radiate significantly and only conducted emissions need to be considered. In the case of large structures such as wind turbines, the rotor tips may be 125 - 140 m above ground level so these are clearly not small compared to a wavelength. It is also not feasible to make conducted emissions on a large wind turbine such as 2 MW output.

4 Recommendations

This paper shows that there is clearly a need for enclosure port radiated emission limits below 30 MHz in EMC standards that apply to large structures such only wind turbines. It is recommended that member societies should influence their standards organisations and report any wind farm interference issues into the IARU EMC Chairman.

Annex A. Details of measurements

A.1 Measurement locations

Measurements were made at three different wind farms in England. These consisted of 22, 36 and 8 wind turbines respectively. Each turbine is rated at 2 MW maximum output. The locations of Wind Farms 1 and 2 are shown on the map in Figure 5 below. All three wind farms are on low-lying land near sea level in Yorkshire or Lincolnshire and wind farm 1 is only 2 metres above mean sea level (OSGB36 datum). The foundations of the wind turbines extend below sea level and ground conductivity is high. This increases the efficiency of the wind turbines as unintentional antennas for radiating electromagnetic disturbances. Figure 1 shows measurements at Wind Farm 1, Location 'A'.

Figure 1: Radiated field strength measurements at Location "A" on the map below.

A.2 Characteristics of disturbance

It was observed that the disturbance is present whether the turbines are rotating or stationary but a local radio amateur reports that it disappeared when the wind farm was switched off for a short time for maintenance. The level of disturbance fluctuates and it has been observed that when the turbines are rotating, the variation in level is synchronised to the rotation. This indicates that the wind turbines and their rotors are acting as unintentional radiating antennas with variable height. A possible source of disturbance is the Doubly-Fed Induction Generators (DFIG) that are used in modern wind turbines. These use electronic variable speed drive techniques. Some wind turbines appear to radiate significantly more than other identical turbines in the same wind farm but the reason for this is not clear. The output from the wind farm to the electricity grid is via underground cables and it is not known whether High Voltage Direct Current (HVDC) converter stations are used. There is no direct connection to the overhead power cables shown in Figure 1 or Figure 6.

A.3 Measurements

A.3.1 Equipment used

- Rohde & Schwarz FSH8, 8 GHz portable spectrum analyser with pre-amplifier, QP detection and GPS
- Rohde & Schwarz FSC3, 3 GHz spectrum analyser with external battery pack
- HP 8447F pre-amplifier, 9 kHz - 50 MHz, Nominal 29 dB gain (used with FSC3)
- Schaffner-Chase HLA6120 Active Loop measuring antenna
- Prototype tuned loop antennas type HTL1000-1A and HTL1000-4A, 1 metre diameter

A.3.2 Measuring antennas and measurement system noise floor

The Schaffner-Chase HLA6120 is an active EMC measuring loop antenna that is designed for H-Field measurements from 9 kHz - 30 MHz. It has similar performance to the Rohde and Schwarz HFH-Z2 active loop. The HLA6120 antenna used has an E-field antenna factor of 19,7 dB(1/m) at 1,9 MHz.

This type of measuring antenna gives a relatively high measuring system noise floor equivalent to an E-field strength of approximately 26 dB(μV/m) average or 31 dB(μV/m) Quasi Peak (QP) in 9 kHz bandwidth. This is approximately 22 dB higher than the daytime background atmospheric noise levels at a quiet rural location at 1,9 MHz. This means that to allow a 6 dB margin above the measuring system noise floor, this antenna is only suitable for measuring field strengths of at least 31 dB(μV/m) average or 37 dB(μV/m) QP in 9 kHz bandwidth.

The HLA6120 has been used as a reference antenna to perform far field calibration of other antennas including a prototype tuned loop antenna type HTL1000-4A and two different models of Wellbrook ALA1530 active loop antenna. An on-site antenna calibration check was also performed at Location 'A' on the map below. The emission from the wind farm measured on the HLA6120 was 42,9 dB(μV/m) QP in 9 kHz and this was used as a far-field reference signal to check the calibration of other loop antennas. The spectrum analyser was set to average 10 traces.

The HTL1000-4A antenna is passive and achieves an equivalent E-field antenna factor of 21,6 dB(1/m) into a 50 Ω load without a built-in pre-amplifier. When used with an R&S FSH8 spectrum analyser with built-in pre-amplifier, the measuring system noise floor is equivalent to an E-field strength of approximately 2 dB(μV/m) average or 7 dB(μV/m) QP in 9 kHz bandwidth.

The HTL1000-4A antenna allows measurements to be made from 1,8 MHz to 10 MHz down to the typical day time background atmospheric noise levels that are found at a relatively quiet rural location. Background noise levels in the same area on 12 March 2017 were also measured at a distance of 13 km from the wind farm with the loop antenna oriented for minimum signal. A minimum field strength of 13 dB(μV/m) (QP) in 9 kHz bandwidth was measured although this may still include some emissions from Wind Farm 1 or 2. This level is approximately 4 dB higher than levels that have been measured at a quiet rural location in England without excess man-made noise sources. Natural background atmospheric noise levels also vary according to time of day, season and latitude.

A3.3 Analysis of results

Tests were performed at a centre frequency of 1,9 MHz with 200 kHz or 500 kHz span. Other tests were performed in the 3,5 MHz and 5,2 MHz amateur bands where the levels of disturbance were lower than in the 1,8 MHz Amateur Band but these were still significant. If a 500 kHz sweep width is used with a tuned loop antenna, there is a reduction in sensitivity towards the edges of the sweep.

The trace in Figure 2 below was measured on 01 June 2014 in conditions of low wind when the turbines were stationary or rotating very slowly. The measurement location was 4,5 km from the nearest turbine of Wind Farm 1 and 5 km or more from other wind turbines in that wind farm. All the peaks on the trace appear to be emissions from the wind farm rather than ambient signals.

The amplitude units are dBm and these can be converted to equivalent E-field strength in dB(µV/m) in 9 kHz as follows. Add 106,9 dB to convert dBm to dB(µV/m) in 50 Ω. Subtract the gain of the external pre-amplifier gain (29,1 dB), add the E-field antenna factor (Type HTL1000-1A, 17.7 dB(1/m)) and scale the bandwidth from 10 kHz to 9 kHz (-0,46 dB). The overall conversion factor is +95,04 dB. Hence the peak level of -60 dBm on the trace is equivalent to 35,04 dB(µV/m) peak envelope voltage (PEV). The operators of the wind farm may have made some changes since 01 June 2014 that would affect this level.

The trace in Figure 2 was taken with an R&S FSC3 with 10 kHz RBW and Max Peak detection. The sweep time is 50 ms and there is a periodic structure caused by amplitude modulation with a 10 ms period, i.e. 100 Hz.

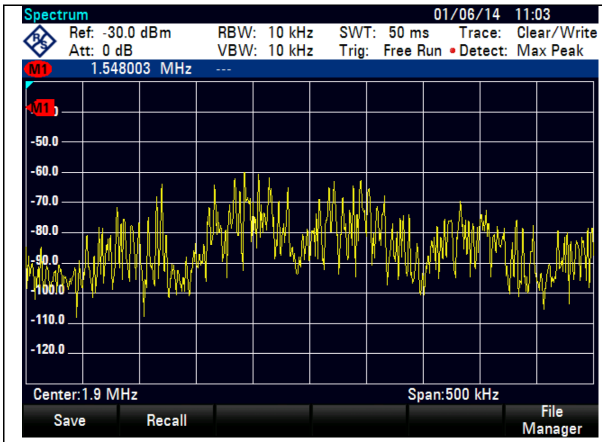


Figure 2: Peak measurement at an amateur radio station 4,5 km from Wind Farm 1

Figure 3: QP measurement (10 trace avg.) at Location "A" on the map below

The trace in Figure 3 above was measured on 12 March 2017 when the turbines were not rotating. An R&S FSH8 portable spectrum analyser was used in receiver mode with 50 kHz steps, 9 kHz RBW, QP detection and averaging of 10 traces. The disturbance field strength was high enough to allow the HLA6120 active loop antenna to be used. For Marker 1, adding the E-field antenna factor of 19,7 dB(1/m) to the amplitude of 24,0 dB(µV) gives 43,74 dB(µV/m) QP. The altitude shown by the GPS data is -5,8 m but land at Location 'A' is 2 - 3 m above Ordnance Survey GB sea level datum.

Figure 4 below shows the disturbance at Location 'A'. An IQ file was recorded using an SDRplay

RSP1 and SDR Uno software. A tuned loop was used to avoid overloading due to local MF AM broadcasts.

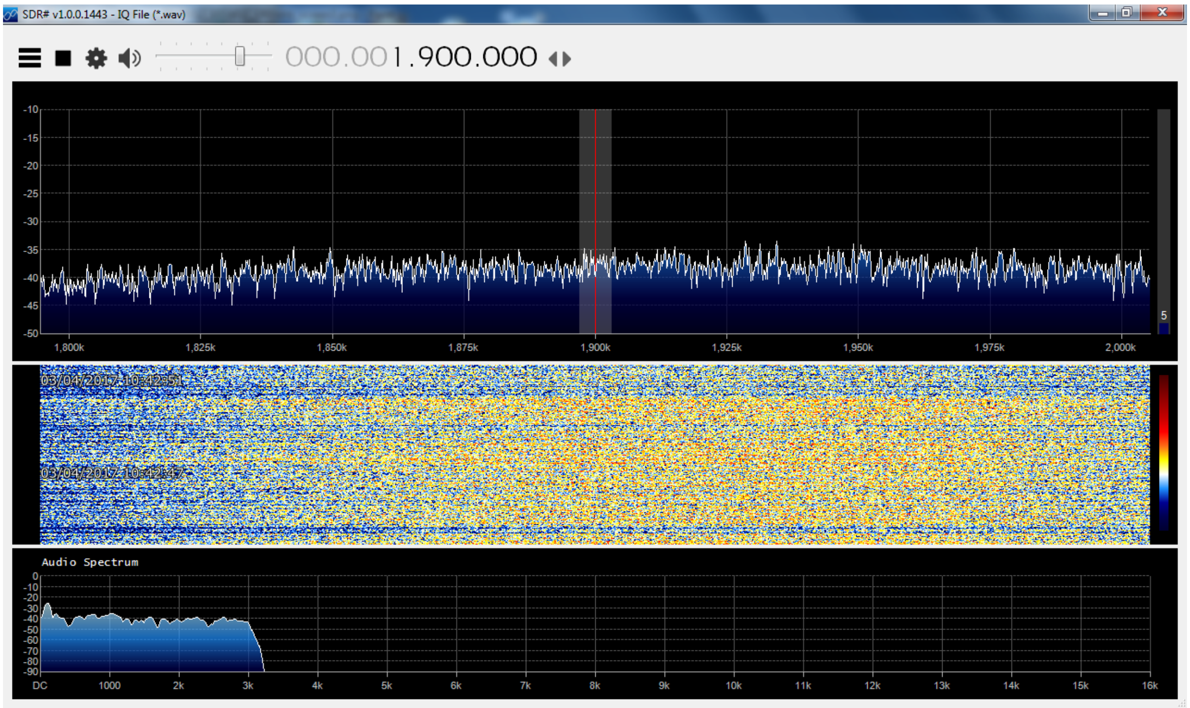
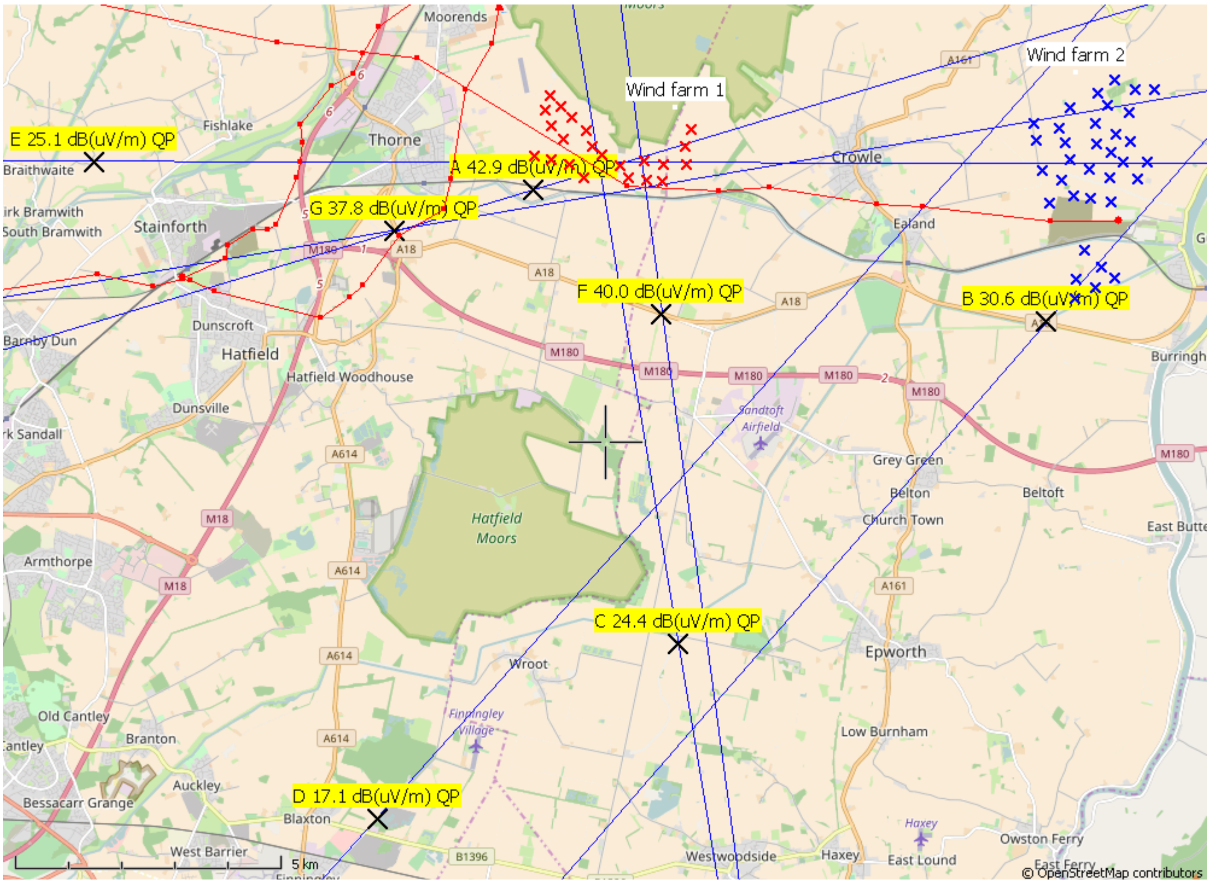


Figure 4: SDR plot of disturbance at Location "A" on the map below

The recorded IQ .wav file was played back using SDR Sharp software. The IF bandwidth is 6 kHz and the detector type is AM. The spectrum of the demodulated audio shows a peak at 100 Hz.

The time markers on the 'waterfall' display are at 3 second intervals and it can be seen that the amplitude fluctuates with an irregular pattern over a period of a few seconds. There is also a pattern of horizontal lines that indicate amplitude modulation at a frequency of approximately 10 Hz.

Figure 5 below shows a map of disturbance field strength measurements around two wind farms. The underlying map was created from OpenStreetMap maps using Viking GPS software.



Map © OpenStreetMap contributors, licensed as CC BY-SA, see this copyright page.
Figure 5: Map of disturbance field strength measurements around two wind farms

Red lines have been added to the map to show high voltage overhead power lines. Measurement points A - G have also been added. The blue lines show the direction of maximum field strength at the measurement points. These were obtained by finding the minimum and adding 90°.

At Point 'A', (see also Figure 1) the direction of maximum signal does not point to the nearest wind turbines and it does not point towards the nearest part of the overhead power line.

At Point 'B', the direction of maximum signal points towards the nearest wind turbines or Wind Farm 2.

At Points C, D and E the directional bearings were less accurate, e.g. +/- 15°. This is due to the weaker disturbance signal and/or the presence of emissions from two different wind farms, 1 and 2.

At Points A, F and G the directional bearings are the most accurate and these all suggest that the predominant source in Wind Farm 1 may be towards the southwest corner.