Beatrice Offshore Wind Farm Consent Plan

Television and Radio Reception Mitigation Plan

October 2015

Beatrice
Offshore Windfarm Ltd

Project Title/ Location	Beatrice Offshore Wind Farm
Project Reference Number	LF0000005
Date:	28th October 2015

Beatrice Offshore Wind Farm
Television and Radio Reception Mitigation Plan

Rev	Prepared By	Sign Off	Checked By	Sign Off	Approved By	Sign Off	Date of Issue
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List of Abbreviations and Definitions

Term	Description
BOWL	Beatrice Offshore Wind Farm Ltd.
CIR	Carrier to Interference Ratio
Commencement of the Development	The date on which construction begins on the site of the Development in accordance with the s36 Consent.
Consent Conditions	The terms that are imposed on BOWL under the S.36 or Marine Licence Consent.
dB	Decibel
The Development	Means the Beatrice Offshore Wind Farm.
Electricity Act	Means the Electricity Act 1989 (as amended).
ETSU	Energy Technology Support Unit
ES	Environmental Statement
Final Commissioning of the Development	The date on which all wind turbine generators forming the Development have supplied electricity on a commercial basis to the National Grid, or such earlier date as the Scottish Ministers deem the Development to be complete.
FSPL	Free Space Path Loss
ITU	International Telecommunications Union
MS-LOT	Marine Scotland Licensing Operations Team
RCS	Radar Cross Section
S.36 Consent	The written Consent granted by the Scottish Ministers under Section 36 of the Electricity Act 1989, on 19 March 2014.
SEIS	Supplementary Environmental Impact Statement
THC	The Highland Council
TRRMP	Television and Radio Reception Mitigation Plan
TV	Television
UHF	Ultra-High Frequency

Term	Description
UKHO	United Kingdom Hydrographic Office
Wind Farm	The Beatrice Offshore Wind Farm in the outer Moray Firth as assessed in the ES including wind turbines, their foundations and inter-array cabling
WTG	Wind Turbine Generator

1 Introduction

The Beatrice Offshore Wind Farm (the Wind Farm) received consent under Section 36 of the Electricity Act 1989 from the Scottish Ministers on 19th March 2014 (the S.36 Consent) and was issued two Marine Licences from the Scottish Ministers, for the Wind Farm and for the Offshore Transmission Works (OfTW) respectively, on 2nd September 2014 (the Marine Licence Consents).

This TRRMP is prepared to enable Condition 24 of the S.36 Consent to be discharged. The Marine Licence Consents contain no equivalent conditions relating to television and radio reception interference. Table 1.1 details Condition 24 of the S.36 Consent.

This TRRMP has been prepared by BOWL with input from Pager Power and Arcus Consultancy Services Ltd (Arcus).

Table 1.1: Consent Condition

Consent Document	Condition Reference	Condition Text	Reference to relevant Section of TRRMP
Section 36	Condition 24	The Company must, no later than 6 months prior to the Commencement of the [Wind Farm], submit a Television and Radio Reception Mitigation Plan ("TRRMP"), in writing, to the Scottish Ministers for their written approval.	This TRRMP.
		Such approval may only be granted following consultation by the Scottish Ministers with the Highland Council.	To be undertaken by the Scottish Ministers, but supported by consultations detailed in Section 5.
		The TRRMP must provide for a baseline television reception survey to be carried out at a location(s) to be agreed by the Scottish Ministers in consultation with the Highland Council, paid for by the Company, prior to the commencement of any WTG installation.	Section 6.3
		The results of which must be submitted by the Company, in writing, to the Highland Council within the time limit set in the TRRMP.	Section 6.3

Consent Document	Condition Reference	Condition Text	Reference to relevant Section of TRRMP
		From Commencement of the [Wind Farm] until the date occurring 12 months after the Final Commissioning of the [Wind Farm], any reasonable claim by any individual person regarding television picture loss or interference at their house, business premises or other building, which they claim is attributable to the [Wind Farm] and which is notified to the Company, must be investigated by a qualified engineer approved by the Scottish Ministers in consultation with the Highland Council.	Section 6.4
		The Company is liable for any costs incurred by any such investigation.	Section 7
		The results of any investigation must be submitted by the Company to the Scottish Ministers and the Highland Council within 2 months of completion of the investigation.	Sections 6.4 and 7
		Any impairment to the television signal shall be remedied by the Company, at its own expense, as soon as practicable to provide that the standard of reception at any affected property is equivalent to the baseline television and radio reception as existing at that property before the operation of the [Wind Farm].	Sections 6.5 and 7

2 BOWL Commitments

The Environmental Statement (ES) and Supplementary Environmental Information Statement (SEIS) set out a number of commitments in relation to various aspects of the Wind Farm (design, monitoring, mitigation etc). No commitments relating to TV and radio reception were made within the ES or SEIS which are relevant to this TRRMP.

3 Policy and Guidance

There is no single guidance for the assessment of TV and radio interference, but the following documents have informed the proposed methodology:

- International Telecommunications Union, Assessment of impairment caused to television reception by a wind turbine, Recommendation ITU-R BT805, 1992;
- Bacon, D.F., A proposed method for establishing an exclusion zone around a terrestrial fixed radio link outside of which a wind turbine will cause negligible degradation of the radio link performance, Radio Communications Agency, 2002;
- Hall, S.H., The assessment and avoidance of electromagnetic interference due to windfarms, Wind Engineering Vol 16 No 6, 1992;
- Dabis, H.S., The provision of guidelines for the installation of wind turbines near aeronautical radio stations, Civil Aviation Authority, CAA Paper 99002, 1999;
- ETSU, Feasibility of mitigating the effects of windfarms on primary radar, ETSU W/14/00623/REP, 2003;
- Dabis, H.S., The establishment of guidelines for the installation of wind turbines near radio systems, Proceedings of the eighteenth BWEA Wind Energy Conference, 1996;
- FES, Wind farms impact on aviation interests – final report, FES W/16/00614/00/REP, 2003;
- S Vila-Moreno, A Methodology to Assess Interference to TV Reception due to Wind Farms, RES, 2005; and
- BBC, The impact of large buildings and structures (including wind farms) on terrestrial televisions reception.

4 Scope of the Television and Radio Reception Mitigation Plan

4.1 Purpose of the TRRMP

The purpose of this TRRMP is to set out the methodology which will be implemented to ensure that the Wind Farm complies with the relevant Consent Condition to enable Marine Scotland, on behalf of Scottish Ministers, to discharge Section 36 condition 24. The provisions of this TRRMP will be valid from Commencement of the Development until the date occurring 12 months after the Final Commissioning of the Development.

As with any large structure, wind turbine generators (WTGs) have the potential to directly obstruct a signal, and also to reflect electromagnetic waves. These reflections can also cause interference, leading to areas of poor reception. Where impacts occur, TV and broadcast radio reception interference can cause inconvenience, however these impacts can be mitigated. For the purposes of this TRRMP, radio reception is defined as broadcast radio received at properties, covering DAB, AM and FM bands.

In the unlikely event that interference occurs as a result of the Wind Farm, this TRRMP sets out the procedures which would be implemented by BOWL to remedy the issue.

This TRRMP sets out the recommended procedure for:

- Quantifying the interference effect;
- Determining whether the interference is due to the Wind Farm; and
- A schedule of mitigation options.

An overview of the process for satisfying the Consent Condition is outlined below:

A. Detailed modelling has been undertaken to predict the areas where TV reception could be impacted by the Wind Farm in the terrestrial area within 20 km of the outermost turbines, and in coastal areas to the south of the Wind Farm (see section 6.2 and Appendix B for further information);

B. A baseline TV reception survey will be undertaken (in line with the Consent Condition) in the areas where the modelling has indicated impacts are possible and/or common interference locations based on Pager Power's experience (see section 6.3);

C. From Commencement of the Development until the date occurring 12 months after the Final Commissioning of the Development, an investigation of any reasonable claim by an individual in relation to TV reception being affected by the Wind Farm will be undertaken (in line with the Consent Condition) (see section 6.4); and

D. Mitigation will be implemented if it is determined any significant impairment to the television signal is attributable to the presence of the Wind Farm (see section 6.5).

Section 6 describes the modelling method employed by Pager Power and the recommended approach for measuring TV reception quality. A schedule of mitigation options which could be employed in the event of interference being experienced is provided within this TRRMP (section 6.5).

4.2 Physical Extent of this TRRMP

The standard distance for assessing TV interference arising from WTGs on land is 20 km from the turbines. As such this TRRMP applies to the terrestrial area within 20 km of the outermost turbines, as shown in the Drawing BEA-MAP-SSER-463, provided in Appendix A (referred to as the '20 km Potential Interference Zone').

The modelling carried out to predict the areas where TV reception could be impacted identified that signals from one of the main transmitters may also be received at a small number of dwellings along the coast to the south of the Wind Farm, approximately 55 km across the Moray Firth. Although the distance is greater than 20 km, interference was considered possible as there are no topographical (land) obstacles in the path of the signals through the Wind Farm and to these dwellings to the south. Therefore, for completeness, this TRRMP also applies to the coastal area to the south of the Wind Farm.

The areas modelled, and the 20 km Potential interference Zone are shown on Drawing BEA-MAP-SSER-463, provided in Appendix A.

This TRRMP is restricted to impacts on reception at properties i.e. fixed receptors.

5 Consultation

During the Environmental Impact Assessment (EIA) process, potential effects on television reception from the Wind Farm were considered unlikely to occur given the distance between the Wind Farm and the closest receptors. As such, these were not considered in the ES or SEIS. However, through the post-submission process, The Highland Council (THC) requested that a condition be applied to any consent which protected against adverse effects on television reception.

This TRRMP will be issued to Marine Scotland Licensing Operations Team (MS-LOT), who, on behalf of Scottish Ministers, will consult with THC prior to the methodology being implemented and the condition being discharged.

Section 6.4 details the procedure that will be followed in the event that a reasonable claim is notified to BOWL regarding television picture loss or interference at a property from Commencement of the Development until the date occurring 12 months after the Final Commissioning of the Development.

6 Methodology

This section details the methodology to be undertaken at each stage of this TRRMP, as set out in steps A – D in section 4.1.

6.1 Background

6.1.1 TV Signals

Terrestrial television signals propagate from transmitters to receiving aerials which in turn are connected to television receiving equipment. The main TV transmitters serving the coastal areas around the Moray Firth are Knockmore, Rosemarkie and Rumster Forest and all of these transmitters broadcast digital services. The transmitters most likely to be affected by the Wind Farm are Knockmore and Rumster Forest. The location of these transmitters is presented in Drawing BEA-MAP-SSER-463, provided in Appendix A.

When considering interference from wind farms it is usual to consider direct signals – those that pass from transmitter to receiver in a straight line and reflected, or indirect, signals. The reflected signal goes from the transmitter to a turbine and then on to the receiver.

Standard receiving aerials are directional meaning that signals from the direction of the transmitter are amplified and signals from other angles are attenuated.

6.1.2 Radio Signals

Generally speaking radio signals are more tolerant to wind farm interference than TV signals. The interference mechanisms are largely the same for radio signals and TV signals.

6.2 Step A – Modelling

Pager Power, on behalf of BOWL, has completed baseline modelling to predict where TV and radio reception could be impacted by the Wind Farm. The detailed report is available in Appendix B of this TRRMP.

6.2.1 Relevant Parameters

The parameters considered within the model are set out below. Interference effects have been modelled within the following areas;

- A 60 km by 60 km area to incorporate the land areas to the north and west of the Wind Farm. The model requires a square area to be assessed, however in terms of informing the baseline television reception survey (Step B), only areas within 20 km of the outermost turbines within this 60 km by 60 km area have been assessed further (see Drawing BEA-MAP-SSER-463 provided in Appendix A). This is because interference is highly unlikely beyond 20 km distance of a terrestrial wind farm.
- Notwithstanding the above, as this is an offshore wind farm, and as the intervening surface between the Wind Farm to the transmitter and receivers is relatively flat (sea) to the south, Pager Power decided to model interference effects in a 20 km by 60 km

area to the south of the Wind Farm (see Drawing BEA-MAP-SSER-463 provided in Appendix A). This 20 km by 60 km area was chosen as it encompasses any dwellings that may receive a signal from the Rumster Forest transmitter based on Pager Power's review.

The areas where modelling has been carried out, and the '20 km Potential Interference Zone' are presented on Drawing BEA-MAP-SSER-463, provided in Appendix A .

6.2.1.1 Carrier to Interference Ratio

The likelihood of television interference is determined by considering the strength of the direct, or carrier, signal in comparison to the reflected, or interfering, signal. The Carrier to Interference Ratio (CIR) quantifies the relative strength of the direct and reflected signals.

A high CIR means interference is less likely. A low CIR means that interference is more likely. The CIR is normally expressed in decibels (dB).

6.2.1.2 Free Space Path Loss

Television signals weaken over distance. The closer a receiver is to a transmitter the stronger its received signal will be. This reduction in signal strength due to separation distance is referred to as Free Space Path Loss (FSPL).

6.2.1.3 Electromagnetic Propagation by Diffraction

An electromagnetic signal may travel between two points, even when no direct line of sight exists between those two points. This is because transmission travels as a series of waves rather than as a direct ray. When no direct line of sight exists between the two points the signal is considerably weakened. This weakening is known as a diffraction loss.

International Telecommunications Union (ITU) Recommendation ITU-R P526-7 describes a method for calculating diffraction losses over regular terrain.

Total path loss for a specific path is determined by adding FSPL to Diffraction Loss.

6.2.1.4 Radar Cross Section

The size of the interfering signal is dependent on the amount of energy that is reflected from the WTG. This reflective quality is known as the Radar Cross Section (RCS) and can be expressed in metres squared or in dBm^2.

A lot of work has been carried out to help determine wind turbine RCS by various parties although little work has been carried out at UHF frequencies. Values cited typically vary between 25 and 300 m^2 with instantaneous peaks reaching 3000 m^2 for a single WTG.

The moving and static parts of the turbine are often considered separately.

6.2.2 Pager Power's Approach to Modelling

This section describes the key elements of the model used by Pager Power to predict the areas where TV reception could be impacted by the Wind Farm. Full detail is provided in Appendix B. Having reviewed the published works listed in section 3, Pager Power has arrived at a compound methodology i.e. incorporating the best elements of the various methodologies set out in the publications, which include factors such as:

- Triplicate calculations accounting for blade tip, hub and blade bottom;

- Accounting for actual field strength;
- Calculating interference in accordance with the Dabis Method (see reference in section 3 – Policy and Guidance); and
- Calculating interference in accordance with the ITU method (see reference in section 3 – Policy and Guidance).

The following conclusions have been drawn:

- Although it is true that wind farm interference appears more likely when the received signal is weak there is no direct relationship between direct signal strength and observed picture interference;
- Observed picture interference is directly related to the CIR;
- The ITU-R BT805 method appears to be significantly more accurate than the Dabis method for assessing observed interference;
- Summing of unwanted signals from each turbine to determine a total unwanted signal level appears to be reasonably accurate;
- The CIR threshold of 10 dB cited by RES appears to be reasonable – it is certainly true that the threshold of 28-34 cited by BT805 appears too high. Observations on a 32 wind turbine development suggest that a threshold of 15 dB may be more reasonable in this case as interference is considered possible between 5-15 dB (RES 2005);
- Pager Power's basis for concluding that the threshold in BT805 is too high comes from experience of existing wind farms where interference effects have been modelled and recorded. This has shown that predicted CIR values below 28 dB have not resulted in actual interference; and
- Carrying out an assessment based on the hub height appears to be fairly representative - however there can be significant variation in CIR over the blade span. In an example with no direct line of sight between transmitter and receiver the CIR varied by 31 dB between the top and bottom of the rotor. This is a large variation and should be considered or accounted for.

It was concluded therefore that triplicate calculations at tip, hub and rotor base should be considered. The principles of this calculation are as follows:

- The interference signal calculation should be carried out three times for each turbine – at tip, hub and rotor base;
- A weighted average of the three unwanted interference signal levels should be made (of absolute levels not decibel levels);
- A signal passing through the turbine at hub height is clearly going to be affected much more than one passing through the tip or rotor base so an increased weighting should be applied to the hub signal;
- The weighting applied to rotor tip and rotor base should be identical as the proportion of the signal passing through the rotor is identical at both heights; and
- A geometric calculation suggested that the weightings in Tables 6.1 and 6.2 should be used for averaging.

Table 6.1: Weightings used for averaging

Turbine Part	Weighting (%)
Blade Tip	19.55
Hub	60.9
Rotor Bottom	19.55

Table 6.2: Rounded weighting values used for calculation purposes when modelling

Turbine Part	Weighting (%)
Blade Tip	20
Hub	60
Rotor Bottom	20

6.2.2.1 Digital TV Interference Mechanisms

The interference mechanisms for digital transmissions are the same as those for analogue transmission. The main difference is the manner in which the interference is manifested on the TV screen.

Analogue signals may suffer degradation that reduces the signal quality by causing various effects such as ghosting or flickering. Digital transmissions tend to be robust to small amounts of interference, but are drastically affected by more severe interference. However, the modelling methodology is applicable to digital transmissions.

The assessment has focussed on potential issues pertaining to digital transmissions only, as the digital switchover is complete in the UK.

6.2.3 Modelling Results

The detailed results from the modelling undertaken by Pager Power are presented in Appendix B to this TRRMP.

In summary, no impacts are expected upon TV or DAB radio signals from the Wind Farm.

6.3 Step B - Baseline Television Reception Survey

A baseline survey will be undertaken prior to the commencement of construction of the Wind Farm in locations to be agreed by the Scottish Ministers in consultation with THC. It is anticipated that the baseline survey would be completed in Q2 2017, approximately 1 year prior to commencement of WTG installation in Q2 2018. Where the modelling has indicated interference is possible, or in common interference locations, survey locations will be chosen within 20 km of the outermost turbines (area to the north and west) and at properties on the coastline to the south. Survey locations will be chosen where two criteria have been met, these are:

- Interference has been predicted for a transmitter in an area; and
- The affected transmitter may have coverage in the area.

See Table 11 in Appendix B for likely survey locations. Survey locations will be confirmed with

MS-LOT and THC before the survey is undertaken.

The purpose of a baseline survey is to:

- Increase the certainty of the modelling results;
- Establish which TV transmitters are serving the relevant areas; and
- Quantify the current reception quality for comparison purposes in the event that a complaint is received following construction of the Wind Farm.

The baseline TV survey, undertaken at locations informed by the modelling, will determine the following at each location:

- The TV transmitter serving the area;
- The strength of the signal; and
- Subjective assessment of the picture and sound quality.

A report containing the results of the baseline survey will then be submitted to MS-LOT and THC within 2 months of its completion which will identify the areas where interference is considered likely. BOWL would visit each property identified within these areas of likely interference and issue residents with a brochure notifying residents of the existence of this TRRMP (including the mitigation procedure), where a copy of the TRRMP is available from (e.g. Project website), an overview of the construction programme and contact details for BOWL. If residents are out when the visit is made then a brochure will be left for the residents.

As the WTGs will be installed in two phases, each phase comprising of approximately half of the WTGs, it is proposed to undertake two further rounds of surveys as phase I and phase II of the WTG installation are completed. These surveys would be carried out after the WTGs have been installed in each phase in order to assess the effect installing the WTGs has had on the baseline results originally recorded. It is currently anticipated that the post phase I survey would be completed in Q4 2018 and the post phase II survey would be completed in Q4 2019.

The residents visited following the baseline survey would be re-visited following completion of each phase of WTG installation in order to provide an update of the surveys. This communication with residents would also re-iterate the procedure to be followed should they experience interference to their TV or radio reception following the installation of the WTGs (as set out in Section 6.4 below), and would include contact details for BOWL. If residents are out when the visit is made then a brochure will be left for the residents.

6.3.1 Baseline Television Reception Survey Procedure

Measurements will be taken using a wideband UHF TV aerial, extended to 10 metres above ground level in order to simulate a typical household aerial. Measurements will be taken using an advanced TV analyser that records the required data. The baseline survey will be carried out prior to the construction of the Wind Farm. This ensures that the existing environment prior to the presence of the Wind Farm is recorded. The number of measurements required for this survey may vary with the particular circumstances of the location(s) being measured, although a sufficient number of locations will be used to establish the baseline conditions. This survey would then be repeated after the installation of the phase I WTGs and then again once all the WTGs have been installed after phase II, and results compared against the pre-construction baseline survey.

6.4 Step C - Procedures for Investigating Reasonable Claims

Provision of a protocol for dealing with complaints relating to interference is a requirement of the S.36 Consent Condition 24. Protocol for complaints regarding TV interference will be limited to reasonable claims within the scope of this TRRMP by any individual person regarding television picture loss or interference at their house, business premises or other building. Claims must be made to BOWL within a timeframe extending from Commencement of the Development until the date occurring 12 months after the Final Commissioning of the Development. If it is found that the interference is attributable to the Wind Farm following an investigation, appropriate mitigation will be put in place.

6.4.1 Protocol

The recommended process for dealing with reasonable claims can be summarised in the following six steps.

Step 1 - Commission an investigation into the reasonable claim of TV interference;

Step 2 - Consider the location of the reported interference with reference to the desk based modelling or locations where interference is most likely;

Step 3 - Commission a qualified engineer that has been approved by the Scottish Ministers, in consultation with the Highland Council, to investigate the claim;

Step 4 - Carry out measurements at relevant locations (where complaints have been received). Characterise interference and compare to the results of the baseline survey to determine the cause. Investigate receiving equipment where appropriate;

Step 5 - Determine whether the interference is attributable to the Beatrice Offshore Wind Farm based on steps 2 and 3. Determination of a legitimate interference complaint is done by reviewing the location of the complaint relative to the Wind Farm and transmitters, modelling (if undertaken- or complete retrospective modelling) and comparing the difference between the baseline reading and post-construction reading (if no baseline reading was undertaken at that location then this can be based solely on the result of the post-construction survey). The timescales for completing this will be dependent upon the number of complaints received. If only a small number of complaints are received then an investigation would be initiated and completed within approximately 2 weeks of a complaint being made. However, if large numbers of complaints are received then the investigation would take longer but would be completed in any case within 6 weeks at any one property; and

Step 6 - Apply mitigation if required in order to provide a standard of reception at the affected property equivalent to the baseline television and radio reception existing at that property before the operation of the Wind Farm, based on the measurements taken in step 3. The requirement for the implementation of such measures will be addressed on a case-by-case basis. If mitigation is found to be necessary it would be provided by BOWL within approximately 2 weeks of the investigation being completed, dependent upon the number of properties requiring mitigation. If mitigation is required at a large number of properties this could take up to 6 weeks. Thus the total number of weeks from when a claim is made, and until mitigation is provided at any one property, would be approximately 4 weeks, but up to 12 weeks if a large number of complaints are received which require mitigation.

The results of any investigation must be submitted by BOWL to MS-LOT, acting on behalf of the Scottish Ministers, and THC within 2 months of completion of the investigation.

6.5 Step D - Mitigation Options and Procedures for Implementation

No mitigation requirement has been identified as a result of the modelling exercise for the Wind Farm. However, for completeness, this section outlines the mitigation options that may be available, and how the appropriate mitigation will be selected and implemented if required.

6.5.1 Schedule of Mitigation Options - TV

Below is a list of standard potential actions to mitigate TV reception issues caused by wind energy developments. Should mitigation be required, one or more of these solutions may be explored to investigate the most suitable form of mitigation:

1. Repositioning the existing receiving aerial so that its received signal is stronger;
2. Directing the existing receiving aerial to an alternative transmitter that covers the area and retuning the television accordingly;
3. Replacement of receiving aerial with a more directional, or high gain, aerial;
4. Upgrading antenna cabling and connections;
5. Installation of signal amplifiers;
6. Development of a bespoke local solution using a receiving aerial some distance from the dwelling;
7. A combination of the above; and
8. Replacing terrestrial reception with satellite or cable reception equipment.

Actions 1-5 are unlikely to occur as individual solutions and are likely to be deployed in combination. Table 6.3 details how actions 1-8 are most likely to be implemented.

Table 6.3: Potential TV Reception Mitigation Implementation

Actions	**Basis**
Combination of # 1-5 aerial system upgrade	Per residence
# 6 bespoke reception system	Per residence / per area
# 7 combination of 1-6	Per residence / per area
# 8 satellite installation	Per residence

6.5.2 Schedule of Mitigation Options - Radio

Below is a list of potential actions to mitigate radio reception issues caused by wind developments. One or more of these solutions may be explored to investigate the most suitable form of mitigation (if any):

1. Retuning of the radio;
2. Relocation of the radio;
3. Upgrading the aerial or the radio itself;
4. Provision of an external aerial for receiving radio services; and
5. Development of a bespoke reception system.

Table 6.4 details how actions 1-5 would be most likely to be implemented.

Table 6.4: Potential Radio Reception Mitigation Implementation

Actions	**Basis**
# 1 – 4	Per residence
# 5	Per residence / per area

The requirement for the implementation of any measures will be addressed on a case-by-case basis.

7 Responsibilities and Timescales

BOWL will manage the implementation of this TRRMP, although it will use appropriately qualified personnel to implement the methods proposed.

As detailed in section 6.3 it is anticipated that the baseline television reception survey will be undertaken in Q2 2017, approximately 1 year prior to commencement of WTG installation in Q2 2018. As the WTGs will be installed in two phases, further surveys will be completed after each of these phases (i.e. Q4 2018 and Q4 2019). The results of these surveys will be provided to the Scottish Ministers and THC within 2 months of the survey being completed.

As detailed in section 6.4, and as specified by the condition, reasonable claims made from the Commencement of the Development until the date occurring 12 months after the Final Commissioning of the Development will be investigated following the procedure set out in section 6.4. The results of such an investigation will be submitted by BOWL to MS-LOT, acting on behalf of the Scottish Ministers, and THC within 2 months of completion of the investigation. Depending upon the number of complaints BOWL will endeavour to investigate any reasonable complaint within approximately 2 to 6 weeks.

As detailed in section 6.5, should any investigations demonstrate that reception is impaired by the Wind Farm, BOWL will endeavour to remedy the interference at the property within approximately 2 to 6 weeks of the completion of the investigation into a complaint, dependent upon the number of properties requiring mitigation.

Investigations and any remediation as required by the terms of the condition will be undertaken at BOWL's expense within the time periods set out in this TRRMP.

8 References

Bacon, D.F., A proposed method for establishing an exclusion zone around a terrestrial fixed radio link outside of which a wind turbine will cause negligible degradation of the radio link performance, Radio Communications Agency, 2002

BBC, The impact of large buildings and structures (including wind farms) on terrestrial televisions reception

Dabis, H.S., The establishment of guidelines for the installation of wind turbines near radio systems, Proceedings of the eighteenth BWEA Wind Energy Conference, 1996

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FES, Wind farms impact on aviation interests – final report, FES W/16/00614/00/REP, 2003

Hall, S.H., The assessment and avoidance of electromagnetic interference due to windfarms, Wind Engineering Vol 16 No 6, 1992

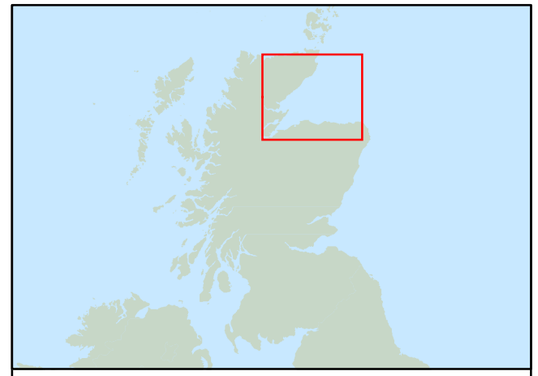
International Telecommunications Union, Assessment of impairment caused to television reception by a wind turbine, Recommendation ITU-R BT805*, 1992

S Vila-Moreno, A Methodology to Assess Interference to TV Reception due to Wind Farms, RES, 2005

Appendix A

Drawings

4°0'0"W
3°30'0"W
3°0'0"W
2°30'0"W
2°0'0"W
58°30'0"N
58°0'0"N
57°30'0"N
N
Rumster Forest
Knockmore
MORAY FIRTH
Helmsdale
DORNOCH
INVERGORDON
NAIRN
FORRES
ELGIN
BUCKIE
BANFF
FRASERBURGH
INVERNESS
KEITH
ALNESS
CROMARTY
LOSSIEMOUTH
ROSS
BLACK ISLE



Legend

- Beatrice Offshore Wind Farm Site
- Developable Boundary
- Developable Boundary 20 km Potential Interference Zone
- Potential Turbine Locations
- Television Transmitter Location
- FM Radio Transmitter Location
- DAB Radio Transmitter
- Modelled Area for North and West
- Modelled Area for South

0 4 8 16 km 0 2 4 8 nm

UK Offshore Development

Beatrice Offshore Wind Farm
Potential TV & Radio Interference Area

Drawn: MM	Checked: LR	Approved: LR
Date: 16/07/2015	Scale: 1:500,000 @ A3	
Drawing Number: BEA-MAP-SSER-463		Version: 04
Datum: WGS84	Projection: UTM30N	

Beatrice Offshore Windfarm Ltd

File ref: E:\Beatrice_GIS\FormalDrawings\Marine\MXD\08_SocioEconomic\TRRMP\BEA_MAP_SSER_463_PotentialTVandRadioInterferenceArea_v04.mxd

Appendix B

Pager Power Television and Radio Desk Study Assessment

PAGERPOWER

Television & Radio Desk Study

Prepared for:

Arcus Consultancy Services Ltd

Beatrice Offshore Wind Farm

July, 2015

www.pagerpower.com

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ADMINISTRATION PAGE

Job Reference:	8312B
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EXECUTIVE SUMMARY

Report Objective

Beatrice Offshore Wind Farm Ltd (BOWL) is developing the Beatrice Offshore Wind Farm (the Wind Farm) in the Outer Moray Firth on the north-western point of the Smith Bank, approximately 13.5 km from the Caithness coastline, in Scotland.

The Wind Farm comprises 84 wind turbines with a maximum tip height of 186.7 m at lowest astronomical tide (LAT). Wind Farm infrastructure may be installed at up to 88 locations; two of these locations are dedicated to Offshore Substation Platforms, and a further two locations are spare locations in case BOWL experiences pile refusal at any one of the 84 locations dedicated to wind turbines. However, for the purposes of this report and to ensure the worst case scenario is modelled, it has been assumed that wind turbines would be installed at each of the 88 locations.

This report has assessed the potential impact of the Wind Farm on terrestrial television and radio services in the surrounding area. The analysis has been undertaken using Pager Power's custom software and has considered a 20km radius of the outermost row of turbines, which includes the coastal area to the north and west of the Wind Farm and an additional 20 x 60km area on the coastal region to the south of the Wind Farm (because the intervening surface between the Wind Farm to the transmitter and receivers is relatively flat (sea)).

Report Findings – TV

Coastal area to the north and west of the Wind Farm

- The analysis has included desk based modelling of a 60 x 60km area for the Rumster Forest and Knockmore main transmitters.
- The majority of the potential interference areas for both assessed transmitters extends over the sea where impacts would be immaterial.
- Interference to Knockmore signals has been mainly predicted to the northwest of the assessed area. However, Knockmore signals are unlikely to be used in these areas because the Rumster Forest transmitter is likely to provide coverage at these locations. **No impacts are expected.**
- Interference to Rumster Forest signals has been mainly predicted to the coastal area located to the northwest of the Wind Farm. However, this is in the backscatter region where effects are unlikely to occur because television aerials are designed to ignore signals arriving from a significantly different bearing and because television systems are designed to ignore delayed weaker signals as a result of backscatter. **No impacts are expected.**
- No other TV transmitter signals are expected to be affected in this area.

Coastal area to the south of the Wind Farm

- Through this desk based modelling assessment it was identified that the Rumster Forest Transmitter may be providing TV coverage for a small number of dwellings along the coast approximately 55 km to the south of the Wind Farm. In Pager Power's experience, effects from wind farms on TV signals are unlikely beyond a distance of 20km for onshore wind developments however, as the intervening surface between the Wind Farm to the transmitter and receivers is relatively flat (sea), it was decided to include the coastal areas to the south. The closest receptors are 55km to the south of the Wind Farm.
- Therefore, for completeness, further analysis was undertaken for an area of 20 x 60km covering the northern part of the coastal area to the south of the Wind Farm.

- Interference to Rumster Forest signals has been predicted either where there are no homes or where interference is likely to be attributed to poor signals and not because of the Wind Farm, which is located more than 50km to the north. **No impacts are expected.**

Overall Impact

- Any homes receiving television signals via satellite or cable are not expected to be affected by the Wind Farm.
- The overall expected impact with regard to TV interference is considered **Low.**
- No mitigation requirement has been identified.

Report Findings – Radio

- Interference to DAB radio services due to wind turbine developments is considered unlikely because such services are more robust to interference than TV signals.
- The analysis has considered transmissions from the Rumster Forest DAB radio transmitter for the same area as per TV interference.
- If interference was to occur, it would be most likely for mobile radios in the immediate vicinity of the Wind Farm. Effects would be similar to those experienced in close proximity to large buildings.
- Interference to Rumster Forest DAB signals has been mainly predicted to the coastal area located to the north and west of the Wind Farm. However, this is in the backscatter region where effects are unlikely to occur because radio systems are designed to ignore delayed, weaker signals arriving as a result of backscatter. **No impacts are expected**.
- Cumulative impacts due to other wind turbine developments in the assessed area are considered highly unlikely.
- The overall risk with regard to Radio interference is considered **Low.**
- No mitigation requirement has been identified.

Next Steps

- A written scheme to address the consent condition with regard to TV and radio has been prepared in parallel with this study (LF000005-PLN-118 Beatrice Television and Radio Reception Mitigation Plan).
- A TV baseline reception survey is recommended to be undertaken prior to the construction of the Wind Farm to the northern coastal area in order to confirm that homes are receiving signals from the Rumster Forest transmitter, and to identify any other transmitters which are unlikely to be affected by the Wind Farm.

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1 INTRODUCTION

1.1 Background

BOWL is developing the Beatrice Offshore Wind Farm (the Wind Farm) in the Outer Moray Firth on the north-western point of the Smith Bank, approximately 13.5 km from the Caithness coastline, in Scotland.

The Wind Farm comprises 84 wind turbines with a maximum tip height of 186.7 m above mean sea level (amsl). Wind Farm infrastructure will be installed at 88 locations; two of these locations are dedicated to Offshore Substation Platforms, and a further two locations are spare locations in case BOWL experiences pile refusal at any one of the 84 locations dedicated to wind turbines. However, for the purposes of this report and to ensure the worst case scenario is modelled, it has been assumed that wind turbines would be installed at each of the 88 locations.

The Wind Farm received consent under Section 36 of the Electricity Act 1989 from the Scottish Ministers on 19th March 2014 and is scheduled to commence construction in 2017. Under the Section 36 consent, a condition has been set with regard to TV and radio interference. To discharge the consent a Television and Radio Reception Mitigation Plan has been produced as a separate document[1], to which this report is appended.

This report assesses the potential impact of the Wind Farm on terrestrial television and radio services in the area.

Terrestrial television signals propagate from transmitters to receiving aerials which, in turn, are connected to television receiving equipment. Transmissions are broadcast in the UHF frequency range and are digital. It is known that wind turbines can interfere with TV and other radio broadcast systems.

Using specialised software, Pager Power has modelled the effects of the Wind Farm on the quality of TV reception in key areas surrounding the Wind Farm from the identified transmitters. The analysis has considered a large area in order to be conservative and consider the nearest residential locations that could be in interference zones. The assessed areas are discussed in Section 5.2 of this report.

Modelling has also been undertaken for radio services.

Information about the methodology used is attached in Appendix A of this report.

All coordinates used within this report are in British National Grid (OSGB36 datum).

[1] LF000005-PLN-118 Beatrice Television and Radio Reception Mitigation Plan.

1.2 Wind Farm Details

The following table lists the turbine details that were used in this modelling exercise. This list is correct at the time of publication, but may be refined as design progresses on the Development. However, the details presented are proposed to represent a worst case scenario for the Development.

WTG	Easting	Northing	Hub height (m LAT)	Rotor Diameter (m)	Tip Height (m LAT)
1	341336.30	924765.64	109.7	154	186.7
2	342442.17	925150.26	109.7	154	186.7
3	342663.24	926299.23	109.7	154	186.7
4	342883.39	927449.12	109.7	154	186.7
5	343548.05	925533.97	109.7	154	186.7
6	343768.14	926683.90	109.7	154	186.7
7	343989.22	927832.71	109.7	154	186.7
8	344209.32	928982.66	109.7	154	186.7
9	344429.40	930131.63	109.7	154	186.7
10	344433.84	924768.67	109.7	154	186.7
11	344653.93	925917.64	109.7	154	186.7
12	344874.04	927067.51	109.7	154	186.7
13	345094.08	928216.40	109.7	154	186.7
14	345098.56	922853.48	109.7	154	186.7
15	345315.18	929366.28	109.7	154	186.7
16	345318.61	924002.48	109.7	154	186.7
17	345535.29	930516.19	109.7	154	186.7
18	345539.73	925152.37	109.7	154	186.7
19	345755.38	931665.11	109.7	154	186.7
20	345759.79	926302.29	109.7	154	186.7
21	345975.49	932815.04	109.7	154	186.7
22	345979.89	927451.21	109.7	154	186.7
23	346199.95	928601.04	109.7	154	186.7
24	346204.38	923237.15	109.7	154	186.7
25	346420.06	929749.99	109.7	154	186.7
26	346424.51	924387.10	109.7	154	186.7
27	346641.17	930899.83	109.7	154	186.7
28	346644.57	925536.06	109.7	154	186.7
29	346861.29	932049.81	109.7	154	186.7
30	346865.64	926685.90	109.7	154	186.7
31	347081.34	933198.68	109.7	154	186.7
32	347085.75	927834.77	109.7	154	186.7

WTG	Easting	Northing	Hub height (m LAT)	Rotor Diameter (m)	Tip Height (m LAT)
33	347301.45	934348.57	109.7	154	186.7
34	347305.83	928984.77	109.7	154	186.7
35	347525.95	930134.67	109.7	154	186.7
36	347747.01	931283.56	109.7	154	186.7
37	347750.43	925920.70	109.7	154	186.7
38	347967.14	932433.48	109.7	154	186.7
39	347970.50	927069.62	109.7	154	186.7
40	348187.21	933583.30	109.7	154	186.7
41	348191.64	928219.42	109.7	154	186.7
42	348407.32	934732.25	109.7	154	186.7
43	348411.71	929368.36	109.7	154	186.7
44	348627.45	935882.20	109.7	154	186.7
45	348631.79	930518.31	109.7	154	186.7
46	348851.87	931668.16	109.7	154	186.7
47	348856.29	926304.31	109.7	154	186.7
48	349072.00	932817.13	109.7	154	186.7
49	349076.37	927453.17	109.7	154	186.7
50	349293.08	933967.00	109.7	154	186.7
51	349296.47	928603.16	109.7	154	186.7
52	349513.20	935115.89	109.7	154	186.7
53	349517.56	929753.03	109.7	154	186.7
54	349733.28	936265.79	109.7	154	186.7
55	349737.64	930901.93	109.7	154	186.7
56	349954.41	937415.69	109.7	154	186.7
57	349957.73	932051.84	109.7	154	186.7
58	350177.88	933201.76	109.7	154	186.7
59	350182.27	927837.81	109.7	154	186.7
60	350398.96	934350.56	109.7	154	186.7
61	350402.31	928986.74	109.7	154	186.7
62	350619.04	935500.51	109.7	154	186.7
63	350622.41	930136.68	109.7	154	186.7
64	350839.18	936649.46	109.7	154	186.7
65	350843.51	931286.51	109.7	154	186.7
66	351063.60	932435.48	109.7	154	186.7
67	351283.70	933585.34	109.7	154	186.7
68	351503.79	934734.22	109.7	154	186.7

WTG	Easting	Northing	Hub height (m LAT)	Rotor Diameter (m)	Tip Height (m LAT)
69	351508.23	929371.41	109.7	154	186.7
70	351724.94	935884.10	109.7	154	186.7
71	351728.27	930520.30	109.7	154	186.7
72	351945.04	937034.00	109.7	154	186.7
73	351949.39	931670.18	109.7	154	186.7
74	352169.50	932820.09	109.7	154	186.7
75	352389.60	933969.02	109.7	154	186.7
76	352609.71	935118.95	109.7	154	186.7
77	352829.80	936267.78	109.7	154	186.7
78	352834.16	930904.00	109.7	154	186.7
79	353054.27	932053.84	109.7	154	186.7
80	353275.33	933203.79	109.7	154	186.7
81	353495.44	934352.66	109.7	154	186.7
82	353715.56	935502.54	109.7	154	186.7
83	354380.19	933587.36	109.7	154	186.7
84	354601.31	934737.28	109.7	154	186.7
85	343337.23	924432.36	109.7	154	186.7
86	344256.24	923839.93	109.7	154	186.7
87	344958.39	921797.13	109.7	154	186.7
88	347478.34	924815.47	109.7	154	186.7

Table 1 Wind Farm details[2]

[2] Coordinates were converted from Longitude and Latitude (WGS84) to Eastings and Northings (British National Grid).

1.3 Wind Farm Map

Figure 1 shows the location of the Wind Farm.

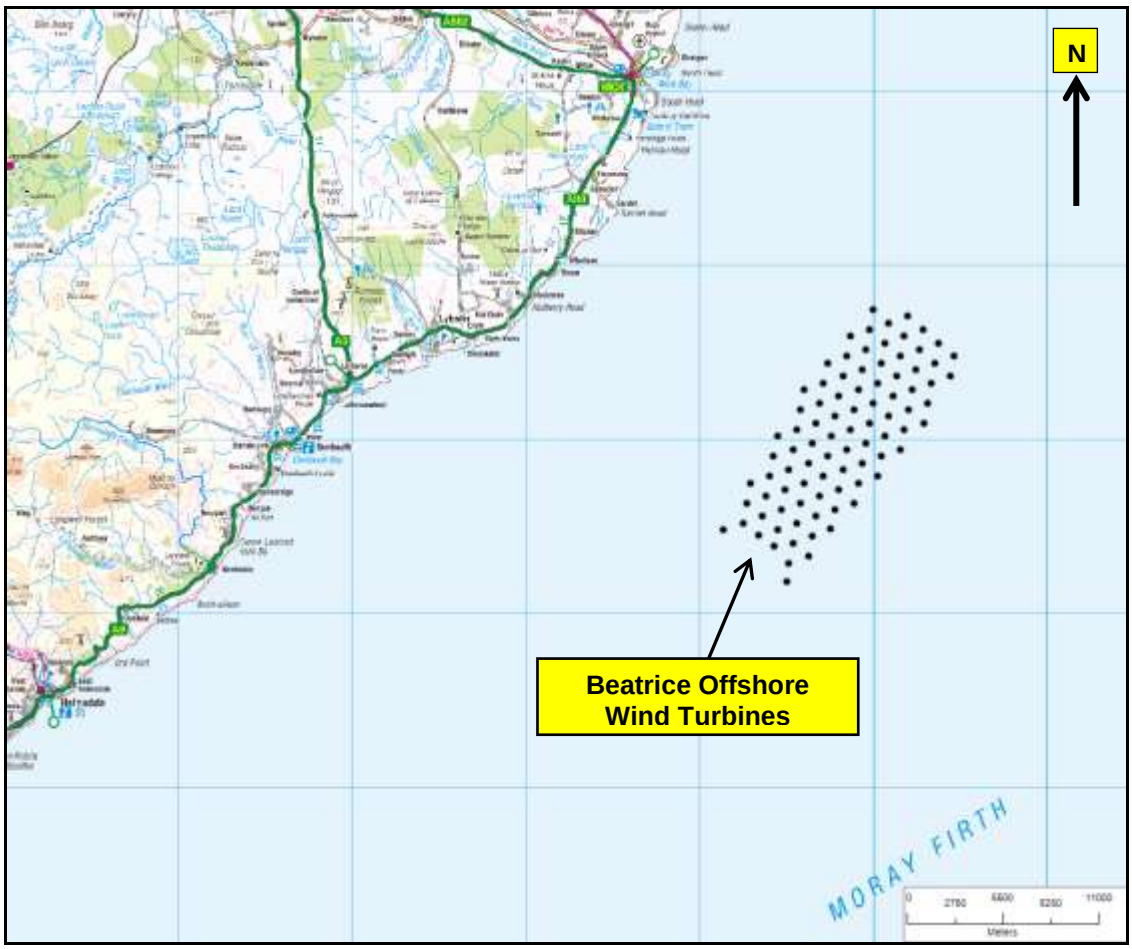

Figure 1 Wind Farm location – Ordnance Survey map

2 TV TRANSMITTER DETAILS

2.1 Relevant Transmitters

The transmitter that requires assessment has been determined based on:

- Coverage maps for the area;
- Digital UK[3]; and
- A cross-check based on street-level photography.

The relevant transmitter information is presented in the section below.

2.2 Rumster Forest Main Transmitter

This is one of the UK's main TV transmitters located approximately 30 km northwest of the Wind Farm's site centre. The digital services broadcast from Rumster Forest are shown below:

	Public (PSB)			Commercial (COM)		
Service	BBC A	Digital 3&4	BBC B	SDN	Arqiva A	Arqiva B
Channel	27	24	21+	30-	59	55
Power	20 kilo-Watts (kW)			10 kilo-Watts (kW)		

Table 2 Rumster Forest Transmissions

2.3 Knockmore Main Transmitter

This is one of the UK's main TV transmitters located approximately 82 km south of the Wind Farm's site centre. The digital services broadcast from Knockmore are shown below:

	Public (PSB)			Commercial (COM)		
Service	BBC A	Digital 3&4	BBC B	SDN	Arqiva A	Arqiva B
Channel	26	23	29	53	57	60-
Power	20 kilo-Watts (kW)			10 kilo-Watts (kW)		

Table 3 Knockmore Transmissions

2.4 Keelylang Hill Main Transmitter

This is one of the UK's main TV transmitters located approximately 81 km north of the Wind Farm's site centre. However, due to its location its signals are unlikely to be affected by the Wind Farm and have not been considered further.

[3] http://www.digitaluk.co.uk/mytvregion. (Last accessed 29.06.15).

2.5 TV Transmitter Locations

Figure 2 shows the locations of the Wind Farm and the two TV transmitters which have been assessed in this report.

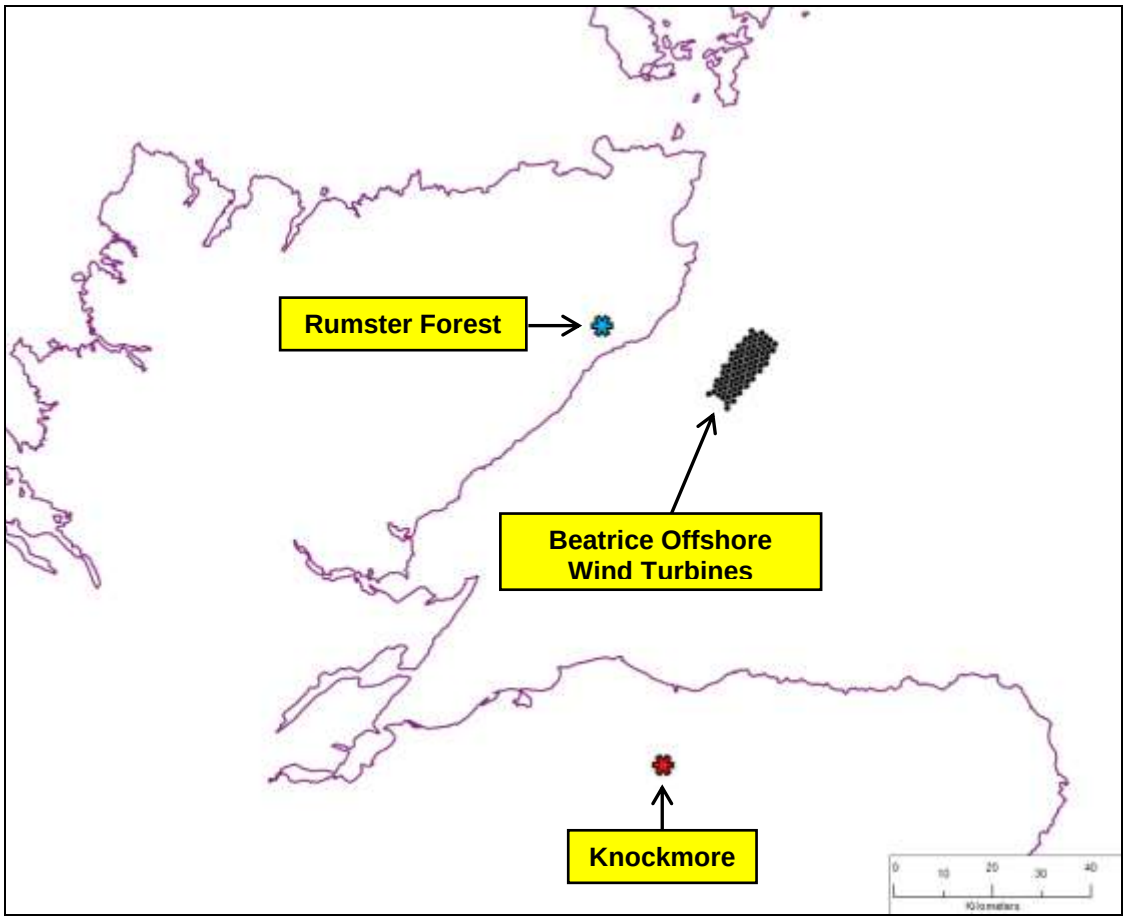

Figure 2 The Wind Farm and the two TV transmitters assessed in this report

3 RADIO TRANSMITTER DETAILS

3.1 Radio Coverage

There are numerous masts providing radio coverage throughout the country. Some of these broadcast local services within a small radius, while others are more powerful and cover a wider area. Different transmitters also provide different services, some national and some local. In order to determine the transmitters that require assessment, coverage charts for the nearest transmitters were considered.

3.2 Assessed Transmitter

In Pager Power's experience interference to radio signals below the base frequency of DAB radio (approximately 175 MHz in the UK) has not occurred. This is likely to be due to the difference between the wavelength of the radio signal when compared to the diameter of a turbine blade. Thus, only effects to DAB transmitters have been considered.

There are various sources of DAB radio signals provided by various transmitters in the coastal area in the vicinity of the Wind Farm. The nearest radio DAB transmitter that provides coverage in the vicinity of the wind turbines is likely to be Rumster Forest. Details of this transmitter are shown in the table below.

Transmitter	Location	Power (kW)	Services	Assessed Frequency (MHz)
Rumster Forest	Approx. 30 km northwest of the development	10	Digital Radio - (12B)	225.6

Table 4 Modelled Rumster Forest DAB radio transmitter

3.3 Radio Transmitter Location

Figure 3 shows the location of the Rumster Forest DAB radio transmitter and the Wind Farm.

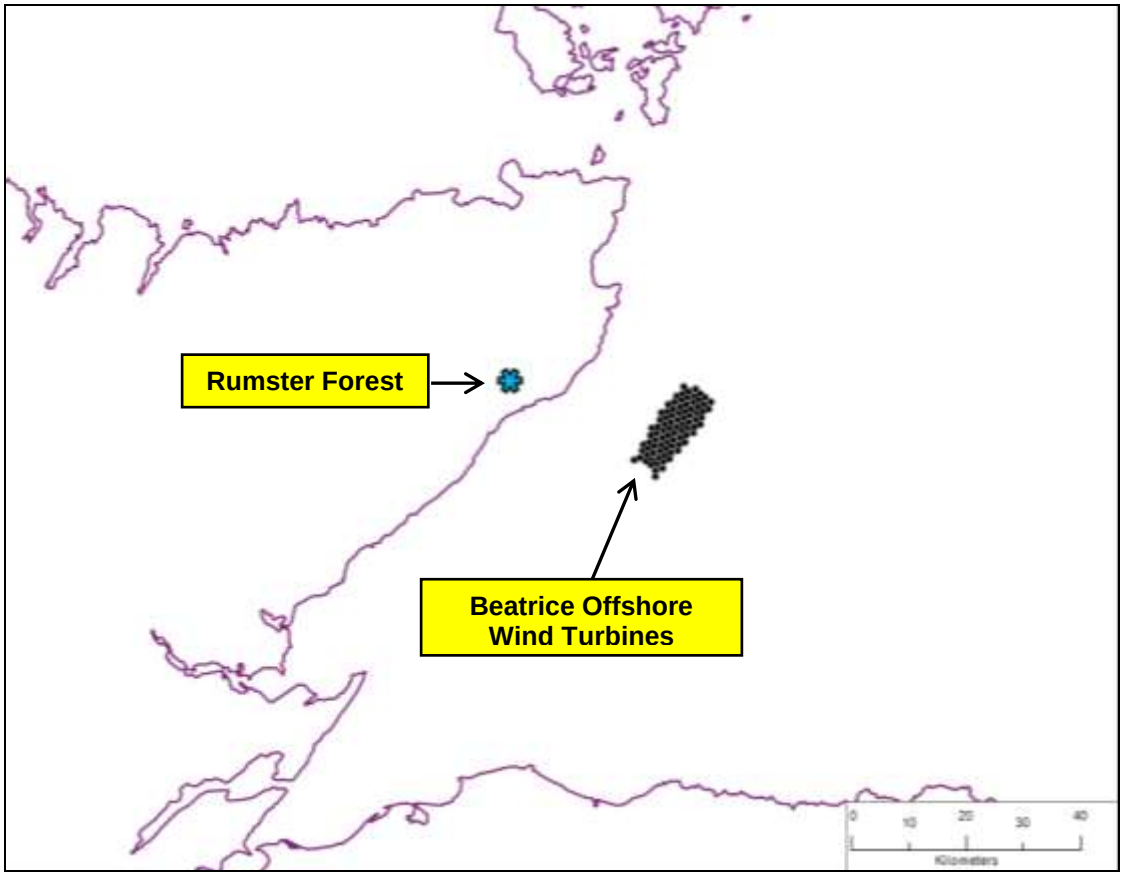

Figure 3 Rumster Forest DAB Radio transmitter and the Wind Farm

4 GUIDANCE

4.1 Overview

There is little in the way of official guidance with regard to managing TV interference issues. However, there are some publications that warrant consideration when evaluating potential impacts. There is no formal guidance with regard to an assessment process for DAB radio signals. However, the principles regarding signal propagation for radio services are the same as those for TV services.

4.2 Guidance used for Modelling

Appendix A of this report lists an overview of published works that have informed the modelling approach used within this report.

4.3 Guidance for Evaluating Potential Interference

Further to the publications shown in Appendix A, the most relevant advice for considering potential interference for digital TV signals can be found[4] in ITU-R BT.2142-1. Key points within this publication are:

- Small interference signals can be dealt with by a standard antenna whilst larger ones can typically be mitigated by a more directional antenna;
- In the backscatter region (the area in between the transmitter and the wind turbines) there is little effect from scattering from wind turbines on the performance of digital television, but in the forward scattering region, if there is significant blockage of the direct signal, significant interference to the reception of the digital television signal is possible.

The above is not an extensive review of the ITU publication; however these two points are particularly relevant with regard to quantifying potential interference (see Section 6).

4.4 Practical Experience

The results of Pager Power's model also compares well with real-world cases. Cases of interference that have been reported post-construction are almost[5] always in areas where potential impacts have been predicted by the model. In Pager Power's experience effects from wind farms on TV signals are unlikely beyond distances of 20km.

[4] Published in 2010 by the International Telecommunications Union.

[5] The author does not know of any occasions when interference has occurred outside a modelled zone of interference.

5 TV INTERFERENCE ANALYSIS

5.1 Technical Overview

Terrestrial television services are provided by means of UHF Radio waves which propagate from transmitters to receiving aerials which then relay the signal to a TV set.

The quality of the image and sound on a TV set is dependent on both the strength of the signal received directly from the transmitter (Carrier signal) and the strength of Interference signals from other sources. In this case the interference signals are modelled as reflections of the Carrier signal by a wind turbine as detailed in Appendix A. To achieve good quality reception an aerial must receive a strong Carrier signal but weak Interference signals.

Pager Power's methodology for assessment of interference effects was developed based on evaluation of the predicted Carrier to Interference Ratio (CIR). Whilst this parameter is related to analogue services, the interference mechanisms for digital transmissions are similar to those for analogue transmissions. The main difference is the manner in which the interference is manifested on the TV screen. Analogue signals may suffer degradation that reduces the signal quality by causing various effects such as ghosting or flickering. Digital transmissions tend to be robust to small amounts of interference, but are drastically affected by more severe interference. The interference zones modelled here are applicable to digital transmissions.

The CIR is interpreted as follows:

Colour	CIR (dB)	Interference Level	Likelihood of Interference
Red	<5	High	Likely
Yellow	5 – 15	Medium	Possible
None	>15	Low	Unlikely

Table 5 Interpreting the CIR

The CIR is evaluated by taking the ratio of the predicted signal strength (provided directly from the transmitter) to the predicted interference signal strength (reflections from the turbine). More detail on the calculation method can be found in Appendix A of this report.

It should be noted that the TV interference model used for the analysis is considered to be conservative as detailed in Section 4 of this report.

5.2 TV Interference Modelling

Two separate areas were considered to model the effects of the Wind Farm. These are further discussed below.

5.2.1 Coastal area to the north and west of the Wind Farm

Interference effects were assessed out to a distance of 20km from the outermost turbines as interference is considered to be very unlikely beyond this distance. Transmitter coverage in this area appears to be provided by Rumster Forest (discussed further in Section 7). The assessed area (yellow) can be seen in Figure 4.

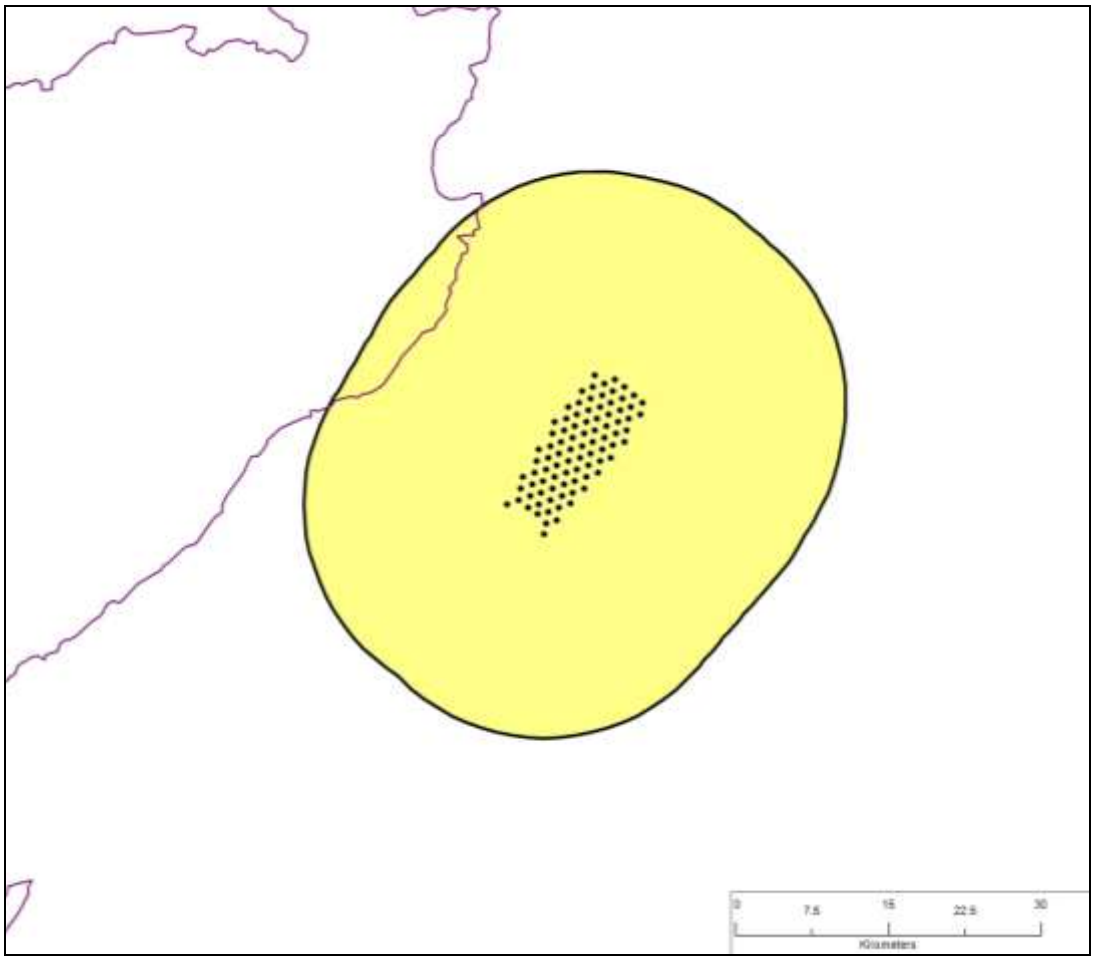

Figure 4 Assessed Area

Modelling of a 60 x 60km area encompassing the assessed area (Figure 5) has been undertaken at 1,000 metres resolution. This area has been used because Pager Power's model considers a square formula however any interference predicted outside the 20 km radius of the outermost turbines has not been considered. This 60 x 60km area is defined by the coordinates in Table 6 below.

Boundary Point	Coordinates	
	Easting	Northing
Top Right	380000	960000
Bottom Left	320000	900000

Table 6 Boundary coordinates (TV) – 1,000m resolution

Figure 5 shows the modelled area for TV reception.

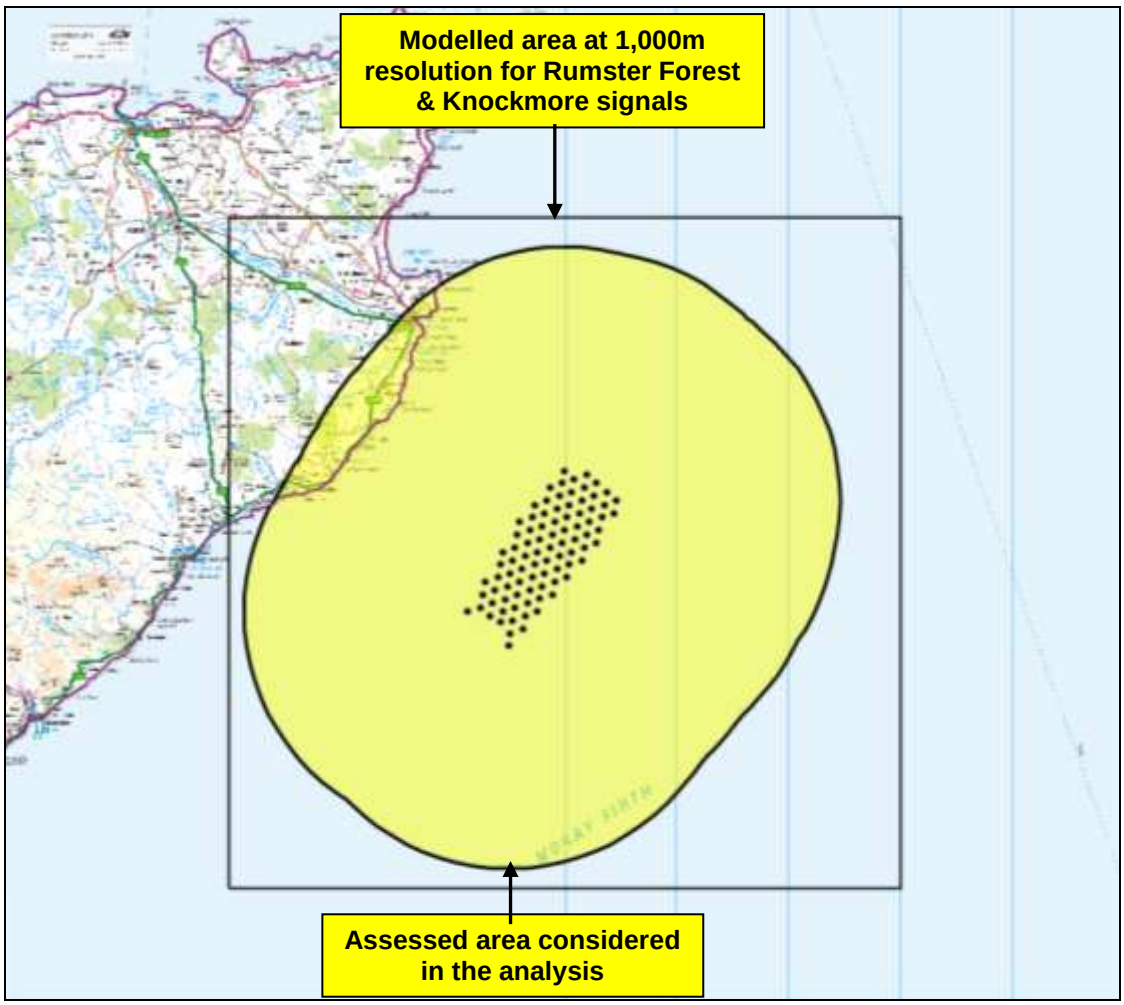

Figure 5 Modelled TV area – north and west of the Wind Farm

5.2.2 Coastal area to the south of the Wind Farm

A review of Google Street View imagery and coverage maps carried out as part of this desk based modelling assessment has revealed that signals from the Rumster Forest transmitter may be received by a small number of dwellings along the coast approximately 55 km to the south of the Wind Farm, across the Moray Firth i.e. across the sea. Therefore, it is a possibility that the Wind Farm could interfere with signals as they travel over the Moray Firth.

In Pager Power's experience, effects from wind farms on TV signals are unlikely beyond a distance of 20km for onshore wind developments however, as the intervening surface between the Wind Farm to the transmitter and receivers is relatively flat (sea), it was decided to include the coastal areas to the south.

The modelling was undertaken at 250m resolution for 3 areas shown in Figure 6 and which are defined by the coordinates provided in Tables 7 – 9. A 20 x 60km area was chosen because, based on a review of coverage maps and street view imagery, this area encompasses all dwellings that may receive a signal from the Rumster Forest transmitter.

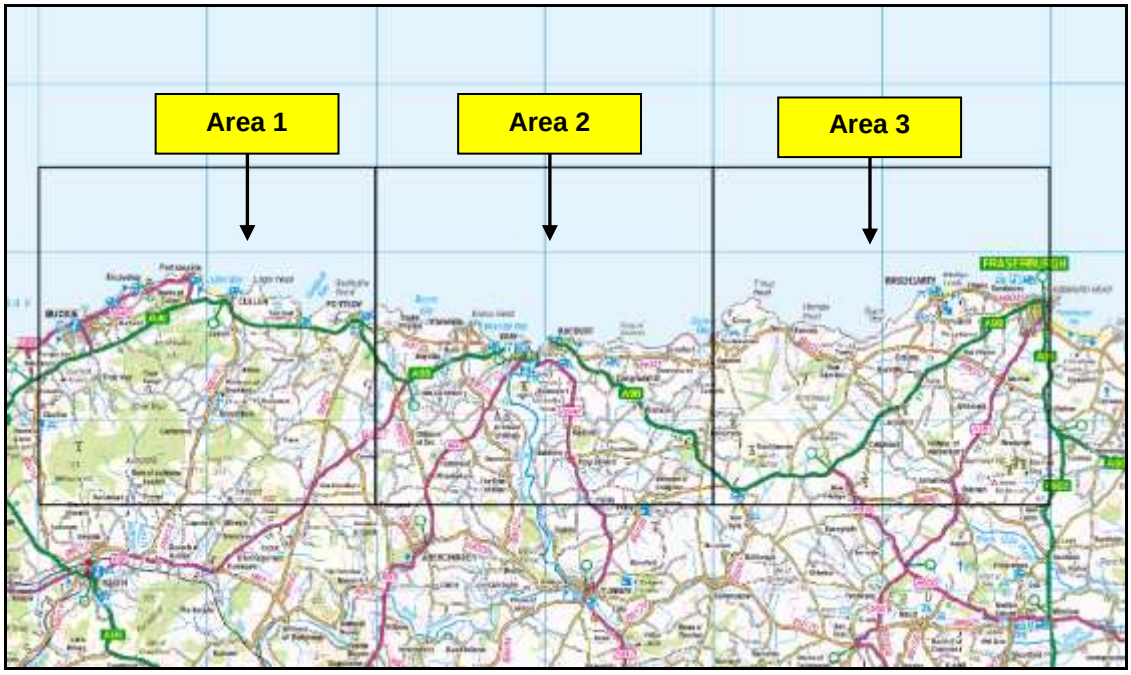

Figure 6 Assessed TV areas – Coastal area south of the Wind Farm

Area 1 - Boundary Point	Coordinates	
	Easting	Northing
Top Right	360000	875000
Bottom Left	340000	855000

Table 7 Boundary coordinates (TV) – 250m resolution (Area 1)

Area 2 - Boundary Point	Coordinates	
	Easting	Northing
Top Right	380000	875000
Bottom Left	360000	855000

Table 8 Boundary coordinates (TV) – 250m resolution (Area 2)

Area 3 - Boundary Point	Coordinates	
	Easting	Northing
Top Right	400000	875000
Bottom Left	380000	855000

Table 9 Boundary coordinates (TV) – 250m resolution (Area 3)

The following section of the report shows the interference chart and map for the Rumster Forest and Knockmore transmitters. The only difference between the 'interference chart' and 'interference map' in each case is the background. The results are presented with no background in order to clearly show the pattern and with a map of the area in order to put the results in context. The assessed area to the north and west of the Wind Farm (20km radius beyond the outermost turbines) is also shown on Figures 7 - 10.

5.3 Interference Chart - Rumster Forest Transmitter - 1,000m resolution

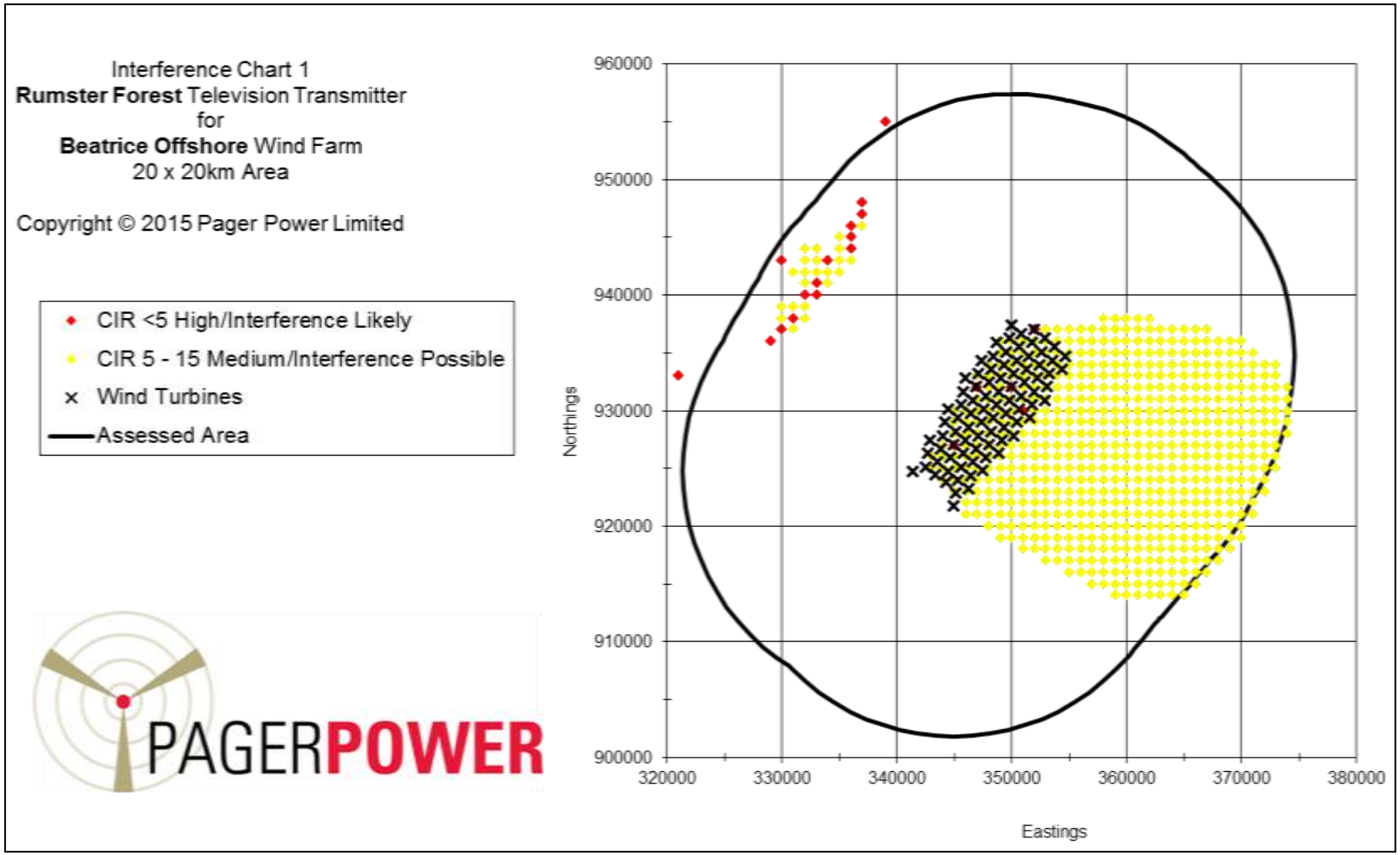

Figure 7 Interference chart for the Rumster Forest TV Transmitter – 1,000m resolution

5.4 Interference Map - Rumster Forest Transmitter - 1,000m resolution

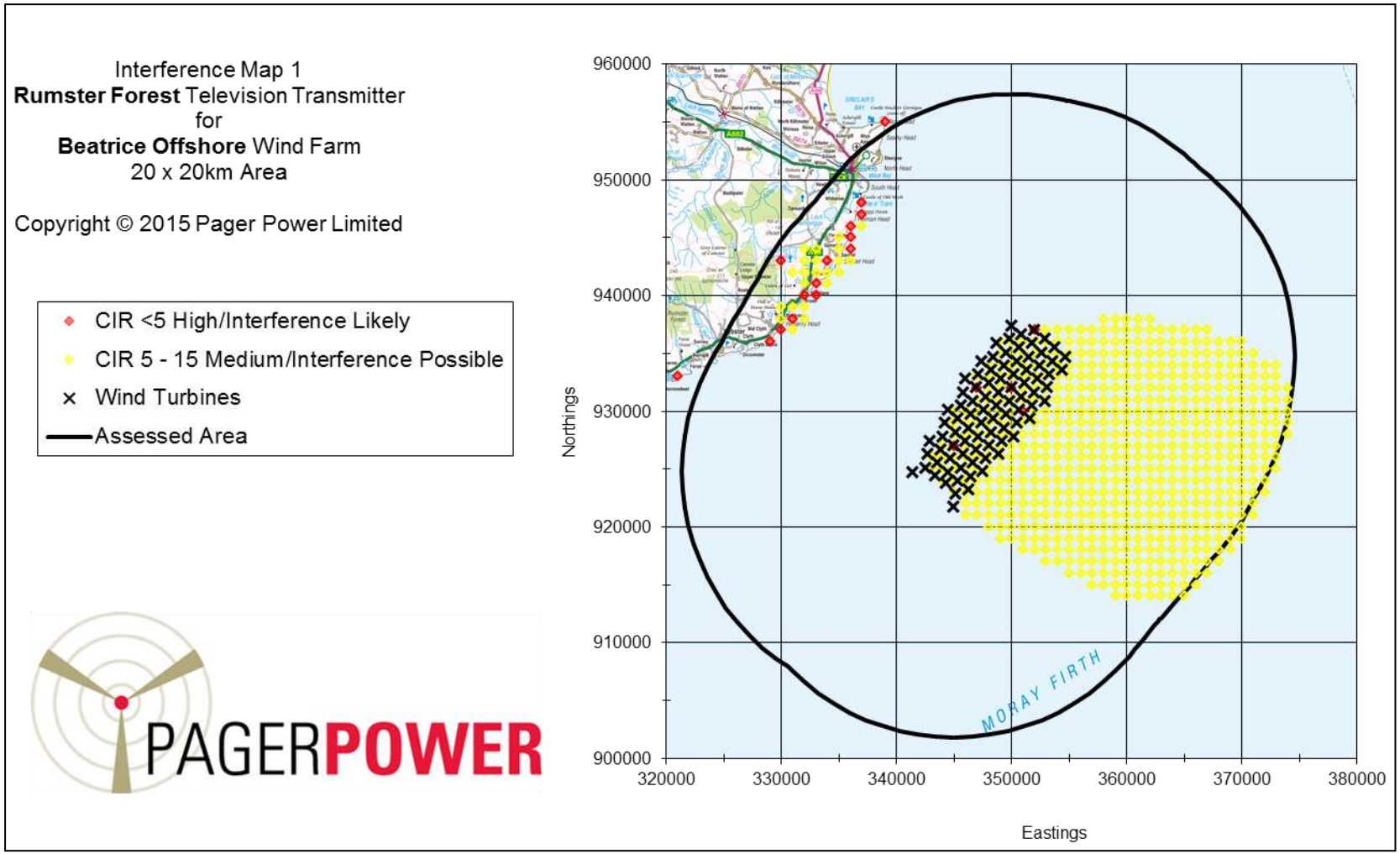

Figure 8 Interference map for the Rumster Forest TV Transmitter – 1,000m resolution

5.5 Interference Chart - Knockmore Transmitter - 1,000m resolution

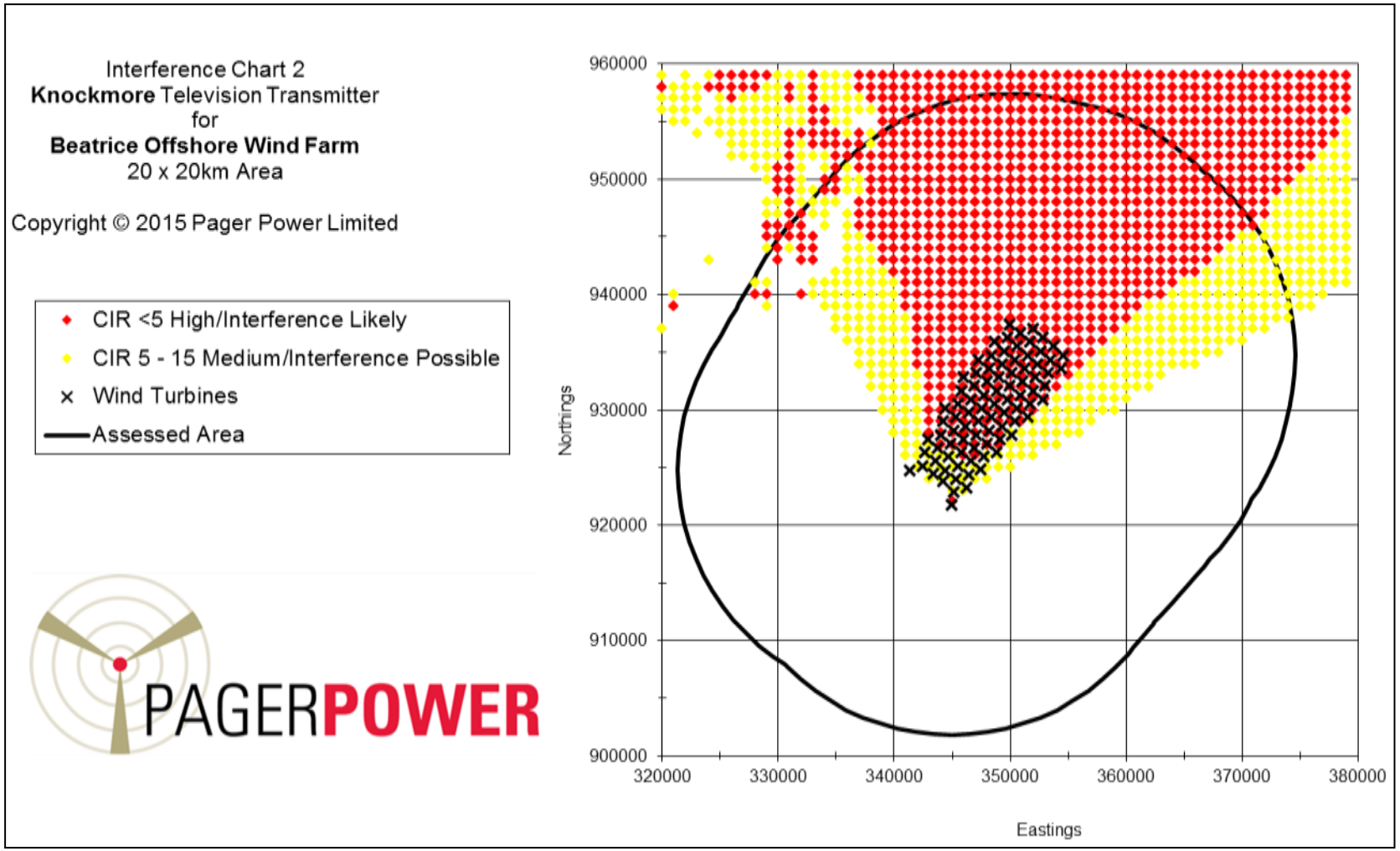

Figure 9 Interference chart for the Knockmore TV Transmitter – 1,000m resolution

5.6 Interference Map - Knockmore Transmitter - 1,000m resolution

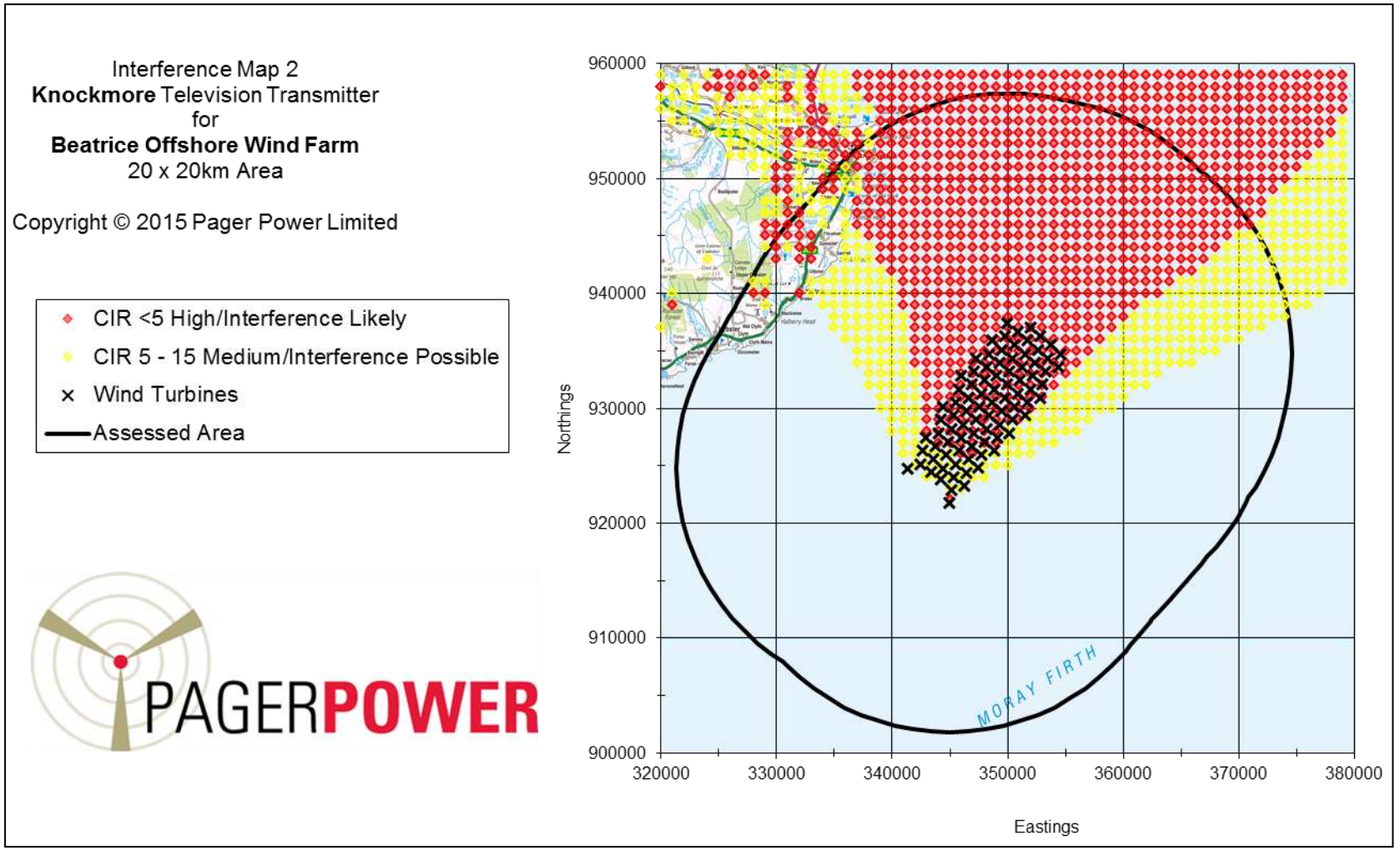

Figure 10 Interference map for the Knockmore TV Transmitter – 1,000m resolution

5.7 Interference Chart - Rumster Forest Transmitter-250m resolution – Area 1

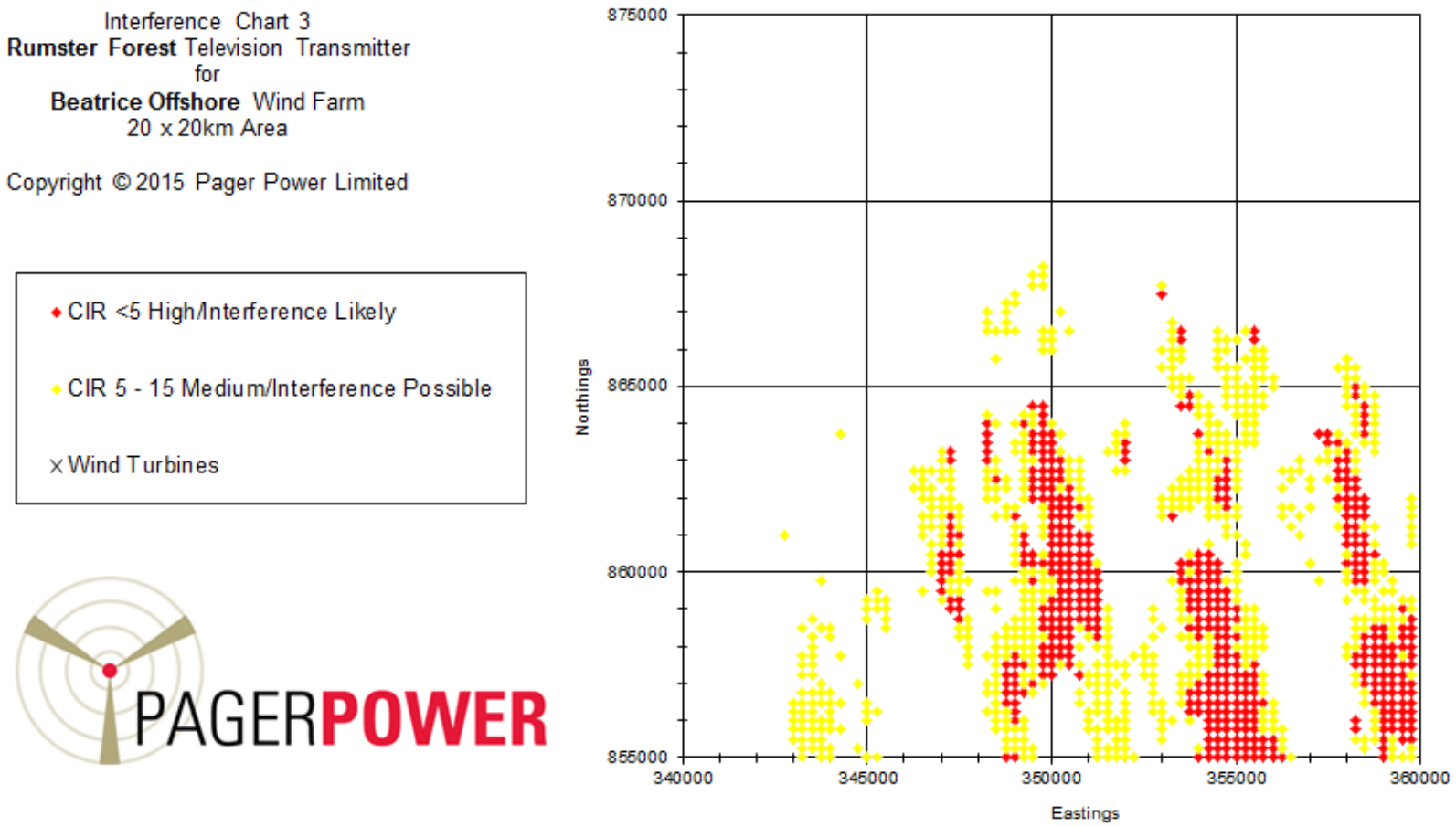

Figure 11 Interference chart for the Rumster Forest TV Transmitter – 250m resolution – Area 1

5.8 Interference Map - Rumster Forest Transmitter - 250m resolution – Area 1

Interference Map 3
Rumster Forest Television Transmitter
for
Beatrice Offshore Wind Farm
20 x 20km Area

- CIR <5 High/Interference Likely
- CIR 5 - 15 Medium/Interference Possible
- × Wind Turbines

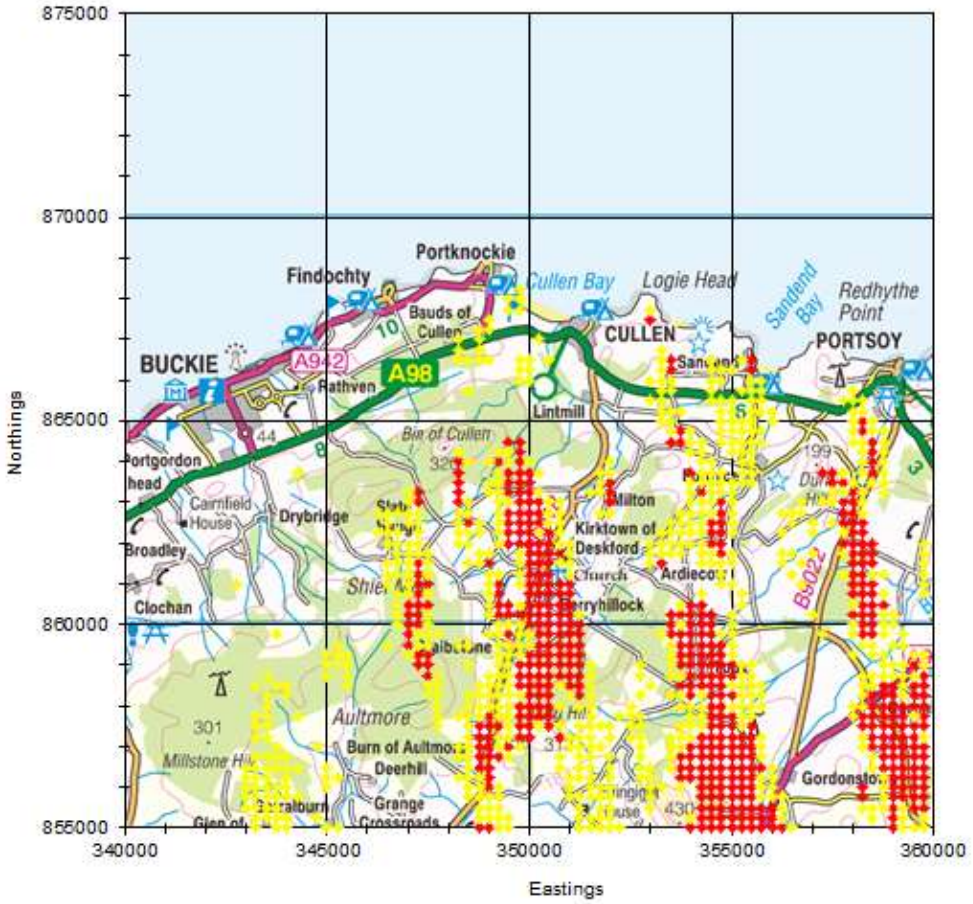

Figure 12 Interference map for the Rumster Forest TV Transmitter – 250m resolution – Area 1

5.9 Interference Chart - Rumster Forest Transmitter - 250m resolution – Area 2

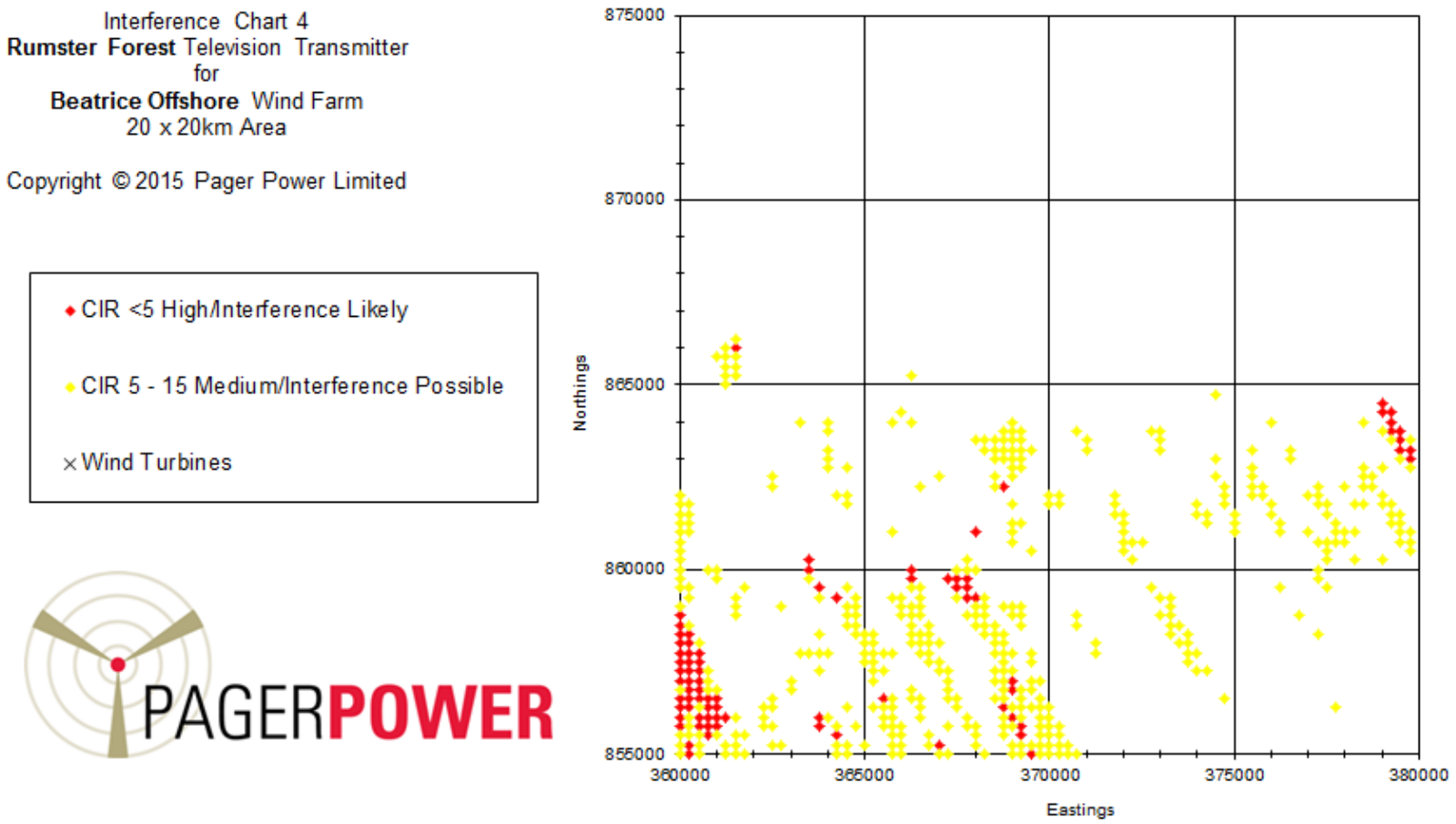

Figure 13 Interference chart for the Rumster Forest TV Transmitter – 250m resolution – Area 2

5.10 Interference Map - Rumster Forest Transmitter - 250m resolution – Area 2

Interference Map 4
Rumster Forest Television Transmitter
for
Beatrice Offshore Wind Farm
20 x 20km Area

- CIR <5 High/Interference Likely
- CIR 5 - 15 Medium/Interference Possible
- × Wind Turbines

Figure 14 Interference map for the Rumster Forest TV Transmitter – 250m resolution – Area 2

5.11 Interference Chart - Rumster Forest Transmitter - 250m resolution – Area 3

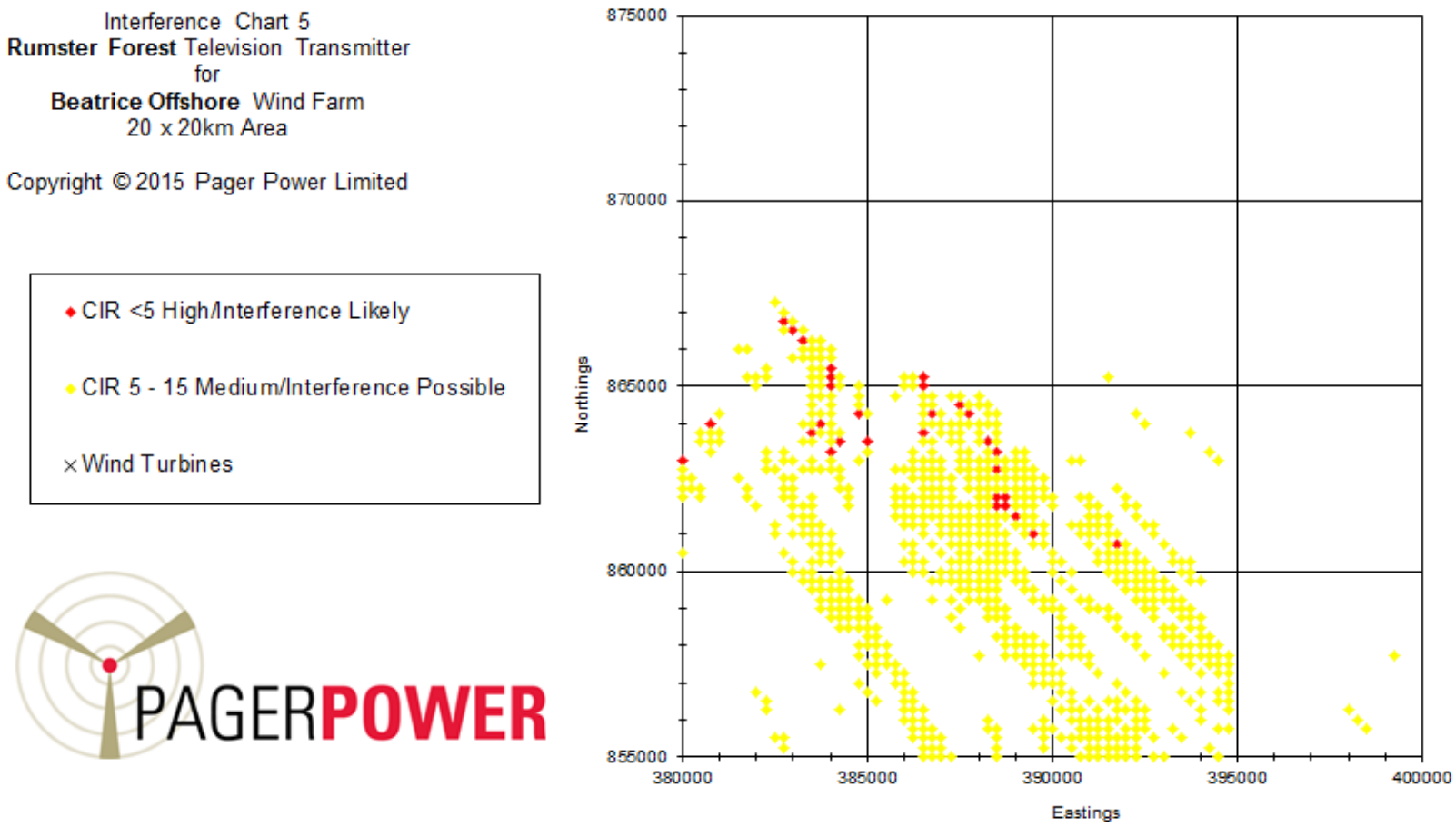

Figure 15 Interference chart for the Rumster Forest TV Transmitter – 250m resolution – Area 3

5.12 Interference Map - Rumster Forest Transmitter - 250m resolution – Area 3

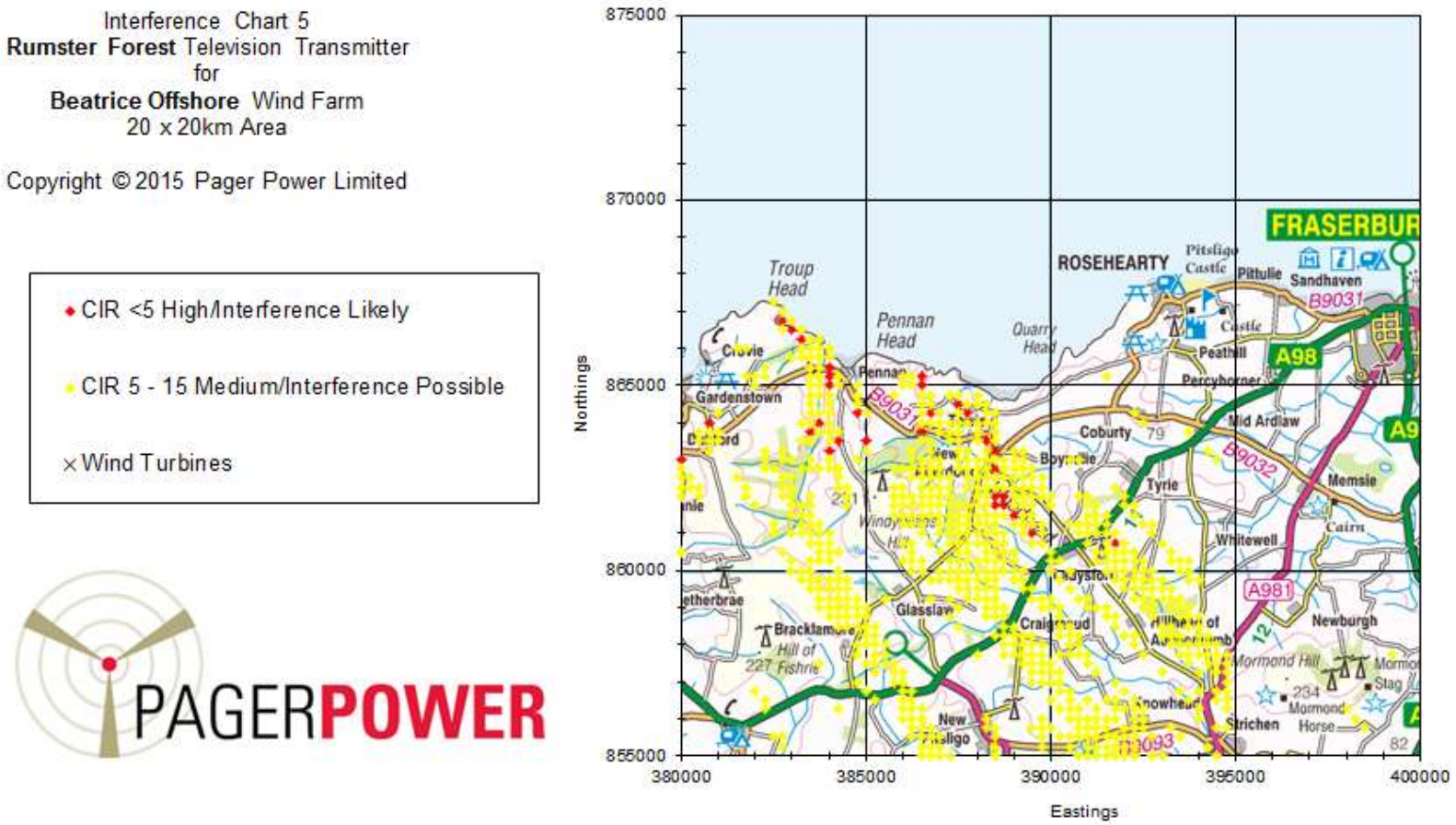

Figure 16 Interference map for the Rumster Forest TV Transmitter – 250m resolution – Area 3

6 RADIO INTERFERENCE ANALYSIS

6.1 Overview

The interference mechanisms for radio signals are similar to those for television signals. However, radio services are generally more robust to interference than TV signals. This is partly because there is no picture information to be transmitted. Radio signals are designed to operate in a dynamic environment with various sources of interference including buildings and terrain. Moving receivers of radio signals, such as cars or mobile devices encounter many variable sources of interference based on their location relative to the transmitter.

Potential radio interference has been considered in this report for completeness.

6.2 Modelling Approach

The following approach has been taken in order to quantify the potential interference effects to radio transmissions caused by the turbines.

- Carrier to Interference ratio modelling based on the TV tool for an area similar to that for TV (very conservative approach);
- Define a minimum CIR for radio services;
- Consideration of locations within the forward scatter region.

6.3 Radio Interference Modelling

Modelling of a 60 x 60km area (Figure 5) has been undertaken at 1,000 metres resolution. This area has been used because Pager Power's model considers a square formula however any interference predicted outside the 20 km radius of the outermost turbines has not been considered. This area is defined by the coordinates in Table 10 below.

Boundary Point	Coordinates	
	Easting	Northing
Top Right	380000	960000
Bottom Left	320000	900000

Table 10 Boundary coordinates (Radio) – 1,000m resolution

Figure 17 shows the modelled area for radio reception.

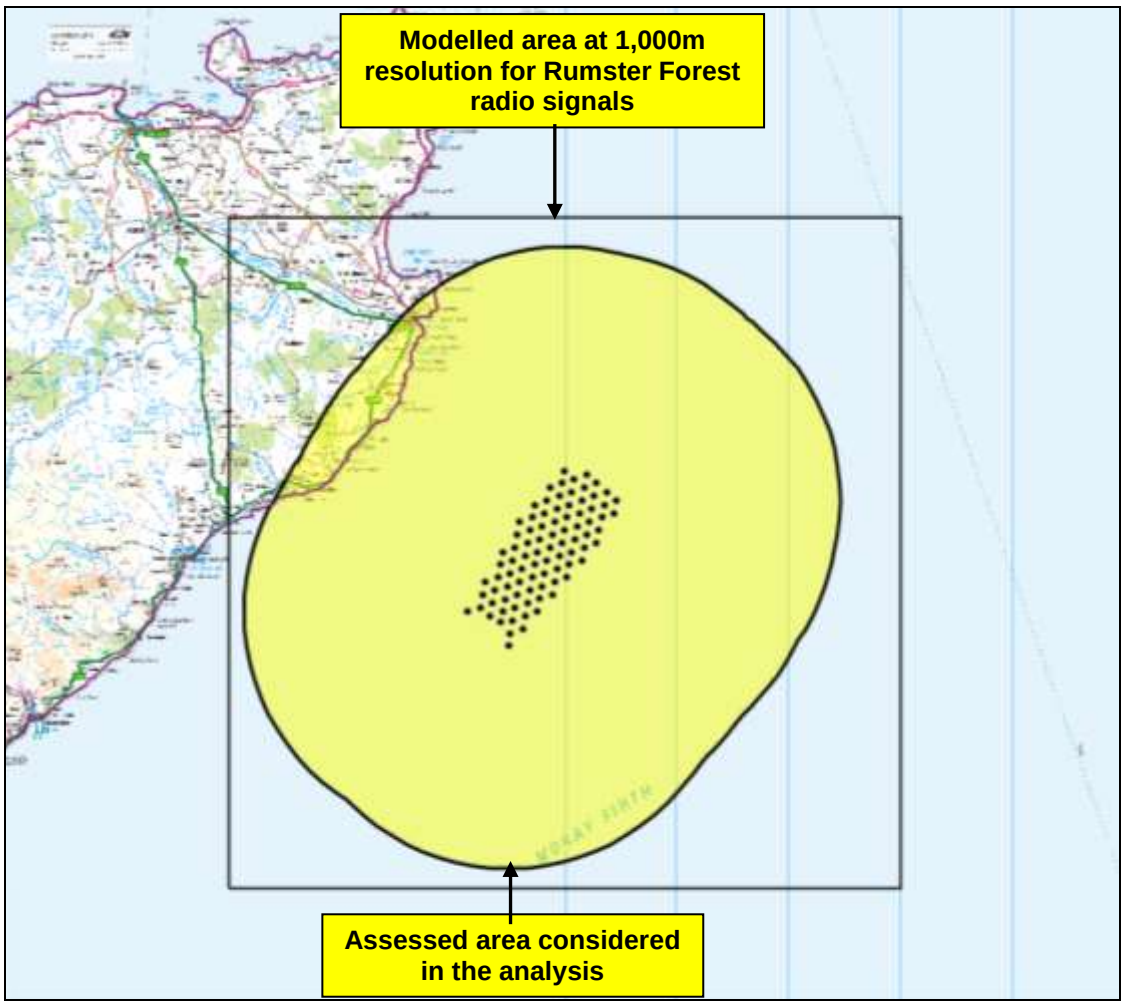

Figure 17 Assessed radio area

The figures on the following pages show the interference modelling for the Rumster Forest DAB transmitter. The modelling tool was designed for television issues and the results should be considered indicative only. However, since the interference mechanism is the same for radio signals and TV signals, there is merit to considering the results of the model.

The minimum CIR for radio services has been defined as 10 dB[6]. This is considered an appropriate threshold value for modelling purposes.

[6] There is no published guidance on CIR for radio services. This figure is based on Pager Power's experience and has been accepted as an acceptable threshold by stakeholders previously.

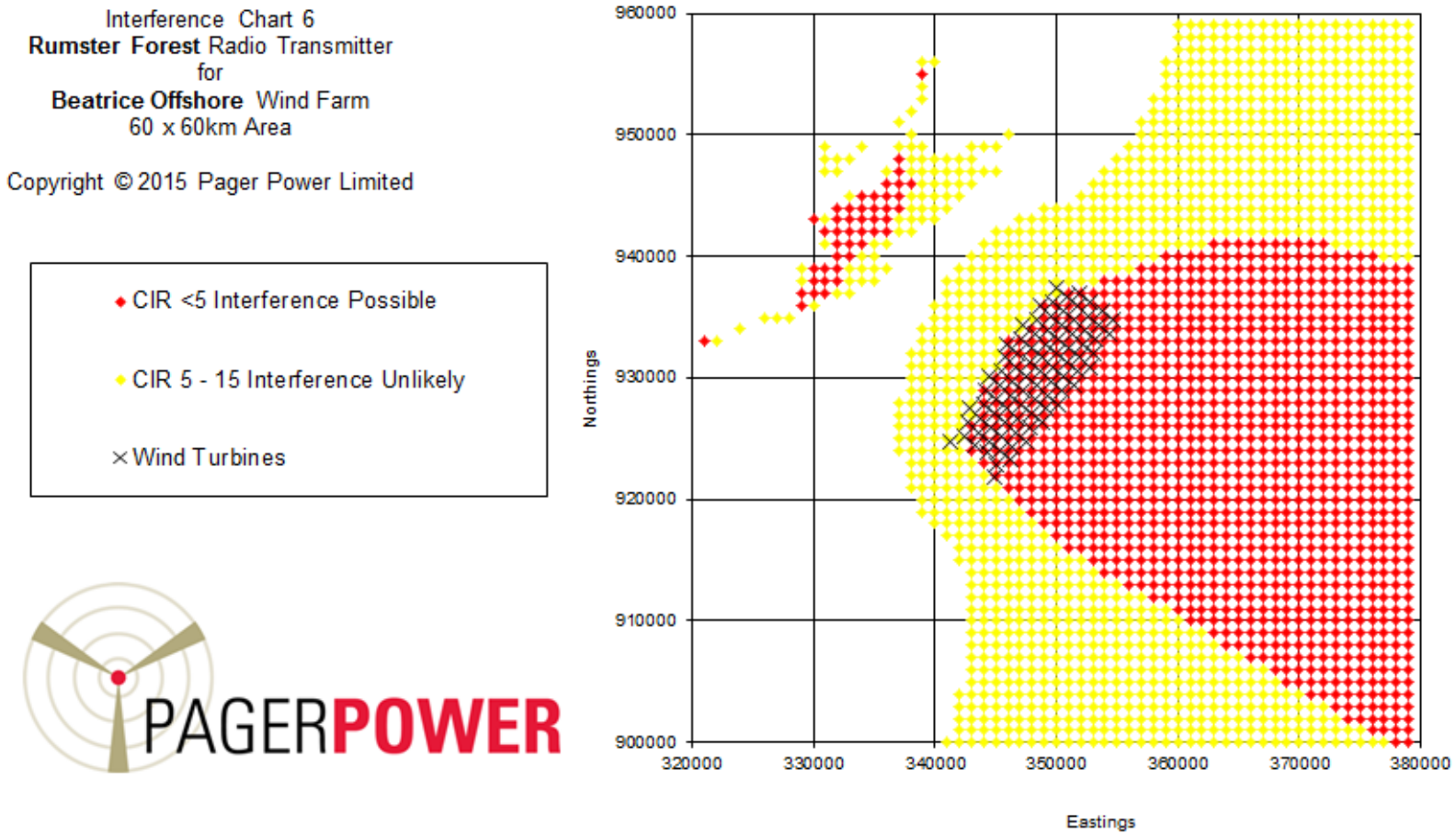

Figure 18 Interference chart for Rumster Forest transmitter – DAB Radio

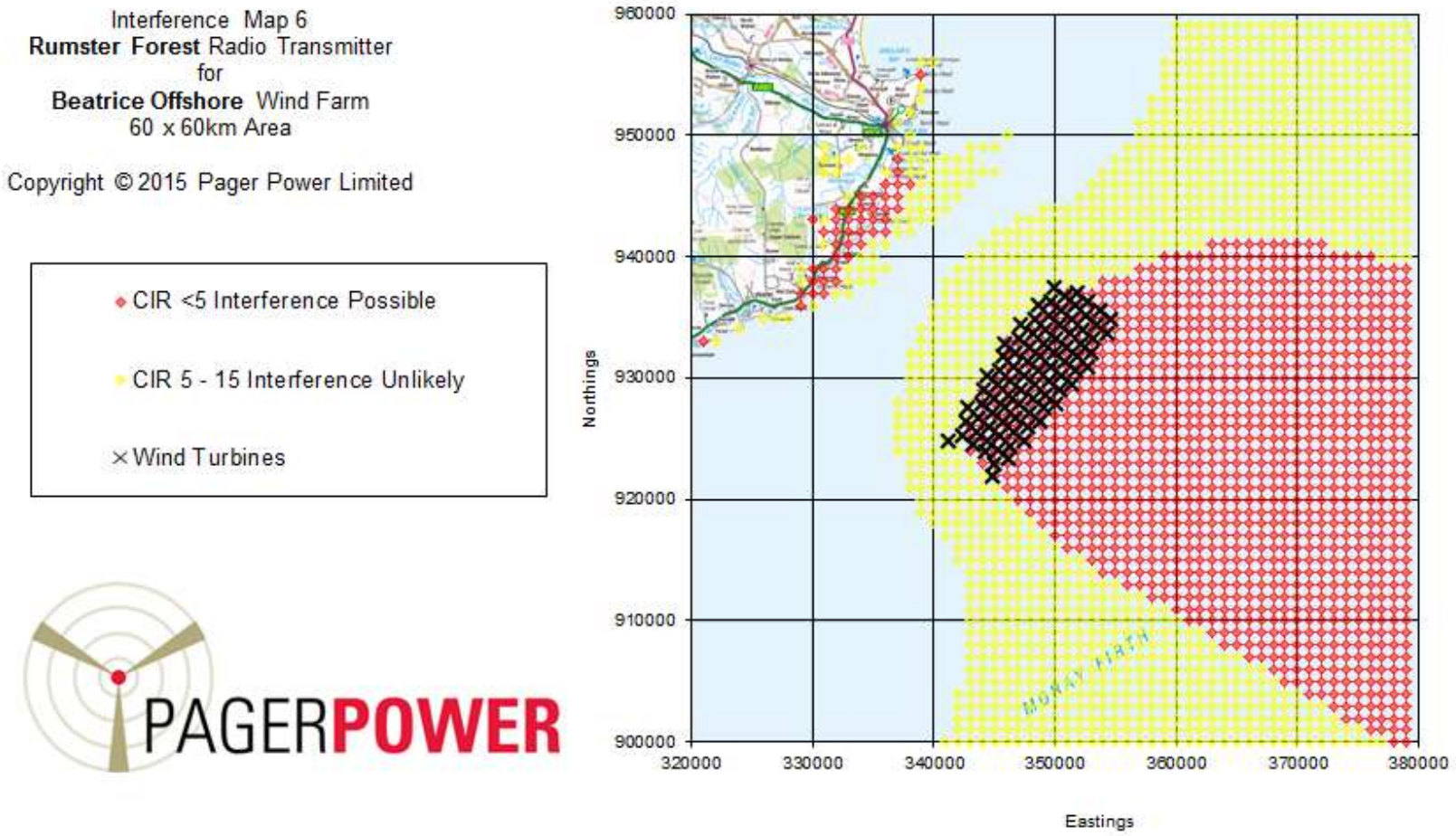

Figure 19 Interference map for Rumster Forest transmitter – DAB Radio

7 TV INTERFERENCE QUANTIFICATION ASSESSMENT

7.1 Background

The following should be noted when interpreting the modelling results:

- The worst case scenario for interference to occur is when the direct signal between the transmitter and the receivers (i.e. homes) is obstructed or is weak and the indirect signal coming through the wind turbines has a clear path and is strong.
- Based on Pager Power's previous experience of comparing modelling and actual effects, interference usually occurs in the forward scatter region. This is the area in the shadow of the turbines in relation to the transmitter. Furthermore, especially following the digital switchover interference, complaints have been received mainly in areas where predicted interference (CIR) is high. Where CIR is 5 to 15, significant interference warranting a complaint is possible but uncommon.
- Actual interference depends on the quality of the TV signal already being received.
- Interference predicted often could be a result of terrain between the TV transmitter and the receiver and not a result of the wind turbines.

7.2 Desk Based Investigation

High and medium interference produced by the presence of the Wind Farm can cause significant problems if it occurs in populated areas. Thus, it is important to determine where the interference may occur, what level of interference has been predicted, what transmitter signals are likely to be used and whether interference is likely to occur.

Using aerial photography, available Google Street View Imagery, OS mapping, the interference patterns produced by the model and Pager Power's experience of electromagnetic propagation, an initial assessment has been made regarding the potential TV interference effects caused by the Wind Farm.

Overall, based on the interference modelling results of the 20km radius beyond the outermost turbines and the 20 x 60km area to the south of the Wind Farm (presented in Figures 7-16), the following observations can be made:

Coastal area to the north and west of the Wind Farm

- The majority of the potential interference areas for both of the assessed transmitters extends over the sea where impacts would be immaterial as there are no properties in those areas.
- Interference to Knockmore signals has been mainly predicted to the northwest of the assessed area. However, Knockmore signals are unlikely to be used in these areas because coverage maps aerial orientation suggests that the Rumster Forest transmitter is likely to provide coverage at these locations.
- Interference to Rumster Forest signals has been mainly predicted to the coastal area located to the northwest of the Wind Farm. Other areas predicted to experience interference are all located over the sea.

Coastal area to the south of the Wind Farm

- Interference to Rumster Forest signals has been also predicted for the coastal area south of the Wind Farm, although the majority of the interference is either medium (interference unlikely) or is located over non populated areas.
- No other TV transmitter signals are expected to be affected.

Further discussion of the potential effects is presented in Table 11.

Location	Transmitter likely to be used	Interference (CIR)	Assessment
Broadhaven, Wick	Rumster Forest / Possible Keelylang Hill	Rumster Forest: CIR>15	No interference predicted for Rumster Forest signals. Keelylang Hill signals are not expected to be affected. **Interference effects are unlikely.**
Staxigoe, Papigoe, Northfield, Newton, Whiterow, Hempriggs House, Toftcarl, Thrumster	Rumster Forest or Keelylang Hill	Rumster Forest: CIR>15	No interference predicted for Rumster Forest signals. Keelylang Hill signals are not expected to be affected. **Interference effects are unlikely.**
Corbiegoe, Sarclet, Whiteleen	Rumster Forest or Keelylang Hill	Rumster Forest: 5<CIR<15	Interference is possible for Rumster Forest signals but unlikely as it is predicted in the backscatter region where effects are unlikely. Keelylang Hill signals are not expected to be affected. **Interference effects are unlikely.**
Ulbster	Rumster Forest or Keelylang Hill	Rumster Forest: 5<CIR<15 and CIR<5	Interference is possible for Rumster Forest signals but unlikely as it is predicted in the backscatter region where effects are unlikely. Keelylang Hill signals are not expected to be affected. **Interference effects are unlikely.**
Whaligoe, Bruan, East Clyth	Rumster Forest	Rumster Forest: 5<CIR<15	Interference is possible for Rumster Forest signals but unlikely as it is predicted in the backscatter region where effects are unlikely. **Interference effects are unlikely.**
Mid Clyth	Rumster Forest	Rumster Forest: CIR>15	No interference predicted. **Interference effects are unlikely.**

Location	Transmitter likely to be used	Interference (CIR)	Assessment
Blackness	Rumster Forest	Rumster Forest: 5<CIR<15 & CIR<5	Interference is possible for Rumster Forest signals but unlikely as it is predicted in the backscatter region where effects are unlikely. **Interference effects are unlikely.**
Occumster, Invershore, Lybster and other coastal areas to the north and west of the Wind Farm	Rumster Forest	Rumster Forest: CIR>15	No interference predicted. **Interference effects are unlikely.**
Coastal areas to the south of the Wind Farm	Rumster Forest or other transmitters (the latter are unlikely to be affected)	Rumster Forest: 5<CIR<15 & CIR<5	No significant interference predicted on populated areas. Based on the distance and the spatial relationship between the transmitter, the wind turbines, the populated areas and the interference pattern predicted effects are unlikely. **Interference effects are unlikely.**

Table 11 Possible locations of TV interference

All predicted interference on land is located in the backscatter region where effects are unlikely to occur.

Overall, the risk of interference is considered **Low.**

8 RADIO INTERFERENCE QUANTIFICATION ASSESSMENT

8.1 Potential Impacts – Radio (Rumster Forest)

The model shows areas where the CIR is below 10 for a small part of the coastal area to the north and west of the Wind Farm. Areas included within the potential interference area are Thrumster, Corbiegoe, Sarclet, Whiteleen, Ulbster, and Blackness. However, the predicted interference area is within the backscatter region and not within the forward scatter region[7] where interference is most likely to occur. Overall no interference to land-based terrestrial radio signals is expected as a result of the Wind Farm.

It should be noted that users of mobile terrestrial radios could be affected at locations in the forward scatter zones in close proximity to the turbines.

8.2 General Comments – Radio Interference

It should be noted that radio is designed to operate in a dynamic environment and that intermittent interference to mobile radio or car radio is not uncommon.

It is unlikely that interference to radio signals will occur due to the Wind Farm for receptors on land.

Any other radio transmitters located to the west and south of the Wind Farm are unlikely to be affected.

Overall, the risk is considered **Low**.

[7] The area in the turbines' 'shadow' from the transmitter's point of view.

9 MITIGATION

9.1 Overview

No mitigation requirement has been identified.

10 CONCLUSIONS

10.1 Report Findings – Television

Coastal area to the north and west of the Wind Farm

- The analysis has included desk based modelling of a 20 km radius of the outermost row of turbines for the Rumster Forest and Knockmore main transmitters.
- The majority of the potential interference areas for both assessed transmitters extends over the sea where impacts would be immaterial.
- Interference to Knockmore signals has been mainly predicted to the northwest of the assessed area. However, Knockmore signals are unlikely to be used in these areas because the Rumster Forest transmitter is likely to provide coverage at these locations . **No impacts are expected.**
- Interference to Rumster Forest signals has been mainly predicted to the coastal area located to the northwest of the Wind Farm. However, this is in the backscatter region where effects are unlikely. **No impacts are expected.**
- No other TV transmitter signals are expected to be affected in this area.

Coastal area to the south of the Wind Farm

- It was identified that the Rumster Forest Transmitter may be providing TV coverage for a small number of dwellings on the coastal area to the south of the Wind Farm. In Pager Power's experience, effects from wind farms on TV signals are unlikely beyond a distance of 20km for onshore wind developments however, this is a large offshore wind farm with many more wind turbines than a typical onshore development. The wind turbines are much larger than typical onshore turbines and the intervening surface between the Wind Farm the transmitter and receivers is relatively flat (ocean). The closest receptors to the south of the Wind Farm are 55km.
- Therefore, for completeness, further analysis was undertaken for an area of 20 x 60km covering the northern part of the coastal area to the south of the Wind Farm.
- Interference to Rumster Forest signals has been mainly predicted where there are no homes or it is likely to be attributed to poor signals and not because of the Wind Farm which is located more than 50km to the north. **No impacts are expected.**

Overall Impact

- Any homes receiving television signals via satellite or cable are not expected to be affected by the presence of the Wind Farm.
- The overall expected impact with regard to TV interference is considered **Low.**
- No mitigation requirement has been identified.

10.2 Report Findings – Radio

- Interference to terrestrial radio services due to wind turbine developments is considered unlikely because such services are more robust to interference than TV signals.
- The analysis has considered transmissions from the Rumster Forest DAB radio transmitter for the same area as per TV interference.
- If interference was to occur, it would be most likely for mobile radios in the immediate vicinity of the turbines. Effects would be similar to those experienced in close proximity to large buildings.
- Interference to Rumster Forest DAB signals has been mainly predicted to the coastal area located to the north and west of the Wind Farm. However, this is in the backscatter region

where effects are unlikely to occur because radio systems are designed to ignore delayed, weaker signals arriving as a result of backscatter. **No impacts are expected**.

- Cumulative impacts due to other wind developments in the assessed area are considered highly unlikely.
- The overall risk with regard to Radio interference is considered **Low.**
- No mitigation requirement has been identified.

APPENDIX A – TELEVISION INTERFERENCE

Television Interference

Introduction

Terrestrial television signals propagate from transmitters to receiving aerials which in turn are connected to television receiving equipment. Transmissions are in the UHF frequency range and may be either analogue or digital. Television channels have a bandwidth of 8 MHz

When considering interference from buildings or wind farms it is usual to consider direct signals – those that pass from transmitter to receiver in a straight line and reflected, or indirect, signals. The reflected signal goes from transmitter to turbine (or building) to receiver.

Standard receiving aerials are directional meaning that signals from the transmitter direction are amplified and signals from the sides and rear of the aerial are attenuated.

Carrier to Interference Ratio

The likelihood of television interference is determined by considering the strength of the direct, or carrier, signal in comparison to the reflected, or interfering, signal. The Carrier to Interference Ratio (CI Ratio) quantifies the relative strength of the direct and reflected signals.

A high Carrier to Interference ratio means interference is less likely. A low Carrier to Interference ratio means that interference is more likely. The CI Ratio is normally expressed in decibels (dB).

Free Space Path Loss

Television signals weaken over distance. The closer a receiver is to a transmitter the stronger its received signal will be. This reduction in signal strength due to separation distance is referred to a Free Space Path Loss (FSPL).

Electromagnetic Propagation by Diffraction

An electromagnetic signal may travel between two points, even when no direct line of sight exists between those two points. This is because transmission travels as a series of waves rather than as a direct ray. When no direct line of sight exists between the two points the signal is considerably weakened. This weakening is known as a diffraction loss.

International Telecommunications Union (ITU) Recommendation ITU-R P526-7 describes a method for calculating diffraction losses over regular terrain.

Total path loss for a specific path is determined by adding Free Space Path Loss to Diffraction Loss.

Radar Cross Section

The size of the interfering signal is dependent on the amount of energy that is reflected from the wind turbine. This reflective quality is known as the Radar Cross Section (RCS) and can be expressed in metres squared or in dBm^2.

A lot of work has been carried out to help determine wind turbine RCS by various parties although little work has been carried out at UHF frequencies. Values cited typically vary between 25 and 300 m^2 with instantaneous peaks reaching 3000 m^2 for a single wind turbine.

The moving and static parts of the turbine are often considered separately.

Nature of Television Interference from Wind Turbines

Determining whether a television picture is impaired by wind turbines or whether the impairment is significant enough to cause picture quality to become unacceptable is considered a subjective matter. The level of effect is determined by looking at the picture when the turbine is operating.

There is a subjective system for grading television picture impairment with grades from 5 down to 1 described in ITU-R 500. The impairments are shown in the table below:

Impairment Grade	Description
5	Imperceptible
4	Perceptible, but not annoying
3	Slightly annoying
2	Annoying
1	Very Annoying

Grading Table

Where interference is marked it is generally clear that it is being caused by wind turbines. The picture regularly distorts with a time base matching the passing of turbine blades. This means that it is fairly easy to determine whether a viewer's interference problem is related to a wind turbine.

Conditions for Wind Turbine Interference

Simplistically the television picture is likely to be unacceptably affected by wind turbine interference when the CI Ratio is low. In practice interference is most noticeable when some or all of the following conditions are satisfied:

1. The received signal strength is weak.
2. The direct signal path between transmitter and receiver is physically obscured.
3. There is a clear signal path between transmitter and wind turbine.
4. There is a clear signal path between wind turbine and receiver.
5. The wind turbine lies directly between the transmitter and receiver.

Pager Power Approach

Having reviewed many relevant published works, a synopsis of which is included at the end of this text, Pager Power has arrived at a compound methodology including some additional factors such as:

- Triplicate calculations accounting for tip, hub and rotor bottom.
- Accounting for actual field strength
- Calculating interference in accordance with the Dabis Method
- Calculating interference in accordance with the ITU method

Following assessment by these various methods the following conclusions have been drawn:

- Although it is true that wind farm interference appears more likely when the received signal is weak there is no direct relationship between direct signal strength and observed picture interference.
- Observed picture interference is directly related to the CI Ratio.
- The ITU-R BT805 method appears to be significantly more accurate than the Dabis method for assessing observed interference.
- Summing of unwanted signals from each turbine to determine a total unwanted signal level appears to be reasonably accurate.
- The CIR threshold of 10dB cited by RES appears to be reasonable – it is certainly true that the threshold of 28-34 cited by BT805 is too high when using this method. Observations on a 32 wind turbine development suggest that a threshold of 15dB may be more reasonable in this case.
- Carrying out an assessment based on the hub height appears to be fairly representative – however there can be significant variation in CI Ratio over the blade span. In an example with no direct line of sight between transmitter and receiver the CI Ratio varies by 31dB between the top and bottom of the rotor. This is a large variation and should be considered or accounted for.

It was concluded therefore that triplicate calculations at tip, hub and rotor base should be considered. The principals of this calculation are as follows:

- The interference signal calculation should be carried out three times for each turbine – at tip, hub and rotor base.
- A weighted average of the three unwanted interference signal levels should be made (of absolute levels not decibel levels).
- A signal passing through the turbine at hub height is clearly going to be affected much more than one passing through the tip or rotor base so an increased weighting should be applied to the hub signal.
- The weighting applied to rotor tip and rotor base should be identical as the proportion of the signal passing through the rotor is identical at both heights.
- A geometric calculation suggested that following weightings be used for averaging:

Turbine Part	Weighting (%)
Tip	19.55
Hub	60.9
Rotor Bottom	19.55

- The following rounded values have therefore been used for calculation purposes.

Turbine Part	Weighting (%)
Tip	20
Hub	60
Rotor Bottom	20

Weighting for Calculation

Pager Power Assessment Methodology

Having considered the various published works, exploring knowledge of real interference caused by wind farms, and modelling interference in various ways Pager Power has developed an effective modelling method for mapping likely television interference from wind farms. The process involves the following stages:

1. Acquire terrain data in digital format.
2. Determine the following for modelling:
   a. Transmitter location and height.
   b. Turbine locations and hub heights.
   c. Single Blade Area.
   d. Blade Width for modelling purposes.
   e. Television signal wavelength for modelling purposes.
   f. Area of interest for interference modelling – this will be a rectangular area defined by top-right and bottom-left coordinate pair.
   g. Determine the sample point spacing for modelling purposes – this is currently a fixed value for the entire area.
   h. Determine the receiver aerial height for modelling purposes.
3. Calculate coordinates of each Receiver Sample Point in the area of interest.
4. Calculate Free Space Path Losses for the following paths:
   a. Transmitter to each Wind Turbine FSPL_TW.
   b. Transmitter to each Receiver Sample Point FSPL_TR.
   c. Each Wind Turbine to each Receiver Sample Point FSPL_WR.
5. Build electronic terrain profile for each of the above paths. The number of points in the profile is determined dynamically based on the source terrain data resolution and the particular path length.
6. Determine additional diffraction losses for each of the above paths using ITU-R 526 method. These losses are DL_TW, DL_TR and DL_WR respectively. These calculations are carried out for the turbine tip, turbine hub and turbine rotor.
7. Calculate a Wind Turbine Reflection Factor (RF) in accordance with ITU-R BT805.
8. Calculate an adjustment factor (ADJ) to compensate for the 1km free space path loss built into the Relative Amplitude (RA) calculation defined in ITU-R BT805. This is 88.662dB.
9. Determine the following for each wind turbine – sample point pair:
   a. Horizontal Angle (alpha) at the turbine between extended path from transmitter and path to sample point.
   b. Horizontal Angle (beta) at sample point between turbine and transmitter.
   c. Calculate Relative Amplitude (RA) based in accordance with ITU-R BT805. If RA is calculated to be smaller than -10 it is changed to -10 (as described in BT805).
   d. Calculate Loss due to Antenna Directivity (AL) based on angle beta and the curves in ITU-R BT419.
10. Calculate Interference Signal Magnitude for each Turbine Receiver Sample Point Pair at turbine tip, hub and rotor base by summing the following:
    a. - FSPL_TW
    b. - DL_TW
    c. - FSPL_WR

d. - DL_WR
e. - RF
f. - RA
g. - ADJ
h. - AL

11. The above absolute values are summed for each turbine sample point and converted back into decibel values and saved as Summed Interference Values (I). Summing occurs with a 20/60/20 respective weighting split for tip, hub and rotor base.
12. Carrier Signal Magnitude (C) is then determined for each Receiver Sample Point by summing:
    a. – FSPL_TR
    b. – DL_TR
13. CI Ratio is then calculated for each point by subtracting I from C.
14. CI Ratio for each sample point is then recorded on an interference map.

Formulae

Term	Unit	Description
A	m^2	Blade Area
AL	dB	Antenna Loss due to angle between signal source and antenna direction
Ave aC	dB	Carrier signal strength (based on inverse of losses)
CIR	dB	Carrier to Interference Ratio
d	m	Length of signal path
dkm	km	Length of signal path
DL	dB	Diffraction Loss
FSPL	dB	Free Space Path Loss
FSWT	dBV/m	Field Strength at Wind Turbine
I	dB	Interference signal strength
Iabs	-	Interference signal strength (absolute)
Ih	dB	Interference signal strength due to a single turbine calculated at hub height
Ir	dB	Interference signal strength due to a single turbine calculated at bottom of rotor
It	dB	Interference signal strength due to a single turbine calculated at tip height
Iw	dB	Interference due to a single wind turbine
Iwf	dB	Interference due to a wind farm

Term	Unit	Description
RA	dB	Relative Amplitude in forward scatter region
RF	dB	Reflection factor for a wind turbine including free space path loss for 1km
TW	suffix	Denotes path from transmitter to Wind Turbine
TR	suffix	Denotes path from transmitter to receiver
TXFIELD	dBV/m	Transmitter field strength at 1 metre
v	-	Diffraction Parameter
W	m	Width of blade
WR	suffix	Denotes path from wind turbine to receiver
α	Radians	Horizontal angle at turbine between extended path from transmitter and path to receiver
β	Degrees	Horizontal angle between path to signal source and direction receiving antenna is pointing
λ	m	Wavelength

1 Antenna Loss

AL = 0 when β<20
AL = (β-20) x 0.4 when β between 20 and 60
AL = 16 when β>60
From Figure 1 of ITU-R BT419 Bands IV and V (UHF)

2 Reflection Factor

RF = 20log(A/λ)-60 (From Annex 1 of ITU-R BT805).

3 Relative Amplitude

RA=20log sin(π×W/λ×sinα)/(π×W/λ×sinα) (From Annex 1 of ITU-R BT805).

4 Carrier to Interference Ratio

CIR = C – I (From first principles by definition when values expressed in dB)

5 Free Space Path Loss

FSPL = 20log(4πd/λ) (From Dabis paper and by definition)

6 Interference – Single Turbine – Hub Height

Formulae for a single path at hub height:

Ih = FSWT + RF + max(-10,RA) - 20log(dkm) [**a**]

From ITU-R BT805 for an unobscured path from Wind Turbine to transmitter

FSWT = TXFIELD - FSPL_TW - DL_TW [**b**]

From first principles

Ih = TXFIELD - FSPL_TW - DL_TW + RF + max(-10,RA) - 20log(dkm) [**c**]

Combining [**b**] and [**a**]

Ih = TXFIELD-FSPL_TW-DL_TW+RF+max(-10,RA)-20log(dkm)-DL_WR [**d**]

Accounts for additional diffraction losses between Wind Turbine and receiver

20log(dkm) = 20log(d/1000) = 20log(d) - 60 [**e**]

From first principles

FSPL = 20log(4π/λ) + 20log(d)

20log(d) = FSPL - 20log(4π/λ) [**f**]

From [**e**] and first principles

20log(dkm) = FSPL - 20log(4π/λ) - 60 [**g**]

Combining [**f**] and [**e**]

Ih = TXFIELD - FSPL_TW - DL_TW + RF + max(-10,RA) - FSPL_WR + 60 + 20log(4π/λ) - DL_WR [**h**]

Combining [**d**] and [**g**]

7 Interference Single Turbine

Interference for a single turbine is calculated by taking a weighted average of interferences at tip, hub and rotor base.

It, Ih and Ir are all calculated as detailed in 6 above. These values will differ due to diffraction loss differences.

Iw = 20log((0.2*10^(It/20))+(0.6*10^(Ih/20))+(0.2*10^(Ir/20)))
Absolute averaging of signals with a 20/60/20 weighting – Pager Power Methodology

8 Interference Multiple Turbines

Multiple Turbines based on calculations at hub height.

Interference signals from multiple sources are calculated by summing absolute values. The following formulae apply:

Iw = 20log(Iabs)

Iabs =10^(Iw/20)
By definition Iwf=20log(Σ(10^(Iw/20)))

Direct summing of absolute values – Pager Power and RES methodologies

9 Diffraction – Single Knife Edge

DL = 6.9 + 20log(sqrt(((v-0.1)^2)+1)+v-0.1) when v > -0.7
DL = 0 when v <= -0.7

Equation 17 of ITU-R P526 (DL ≈ 0 when v<= -0.7 from the graph at Figure 7)

10 Diffraction – Path over Irregular Terrain

The general method is described in Section 4.5 of ITU-R P526.

Up to three peaks are considered as specified by the method.
An effective Earth Radius (to account for atmospheric refraction) of 8,494,678 metres is used for calculation purposes.

Review of Published Works

A number of documents relate to the interference effects of wind turbines on television and radio systems. These include:

1. BBC, The impact of large buildings and structures (including wind farms) on terrestrial televisions reception
2. International Telecommunications Union, **Assessment of impairment caused to television reception by a wind turbine**, Recommendation ITU-R BT805*, 1992
3. Bacon, DF, **A proposed method for establishing an exclusion zone around a terrestrial fixed radio link outside of which a wind turbine will cause negligible degradation of the radio link performance**, Radio Communications Agency, 2002
4. Hall, SH, **The assessment and avoidance of electromagnetic interference due to wind farms**, Wind Engineering Vol 16 No 6, 1992
5. Dabis, HS, **The provision of guidelines for the installation of wind turbines near aeronautical radio stations**, Civil Aviation Authority, CAA Paper 99002, 1999
6. ETSU, **Feasibility of mitigating the effects of wind farms on primary radar**, ETSU W/14/00623/REP, 2003
7. Dabis, HS, **The establishment of guidelines for the installation of wind turbines near radio systems**, Proceedings of the eighteenth BWEA Wind Energy Conference, 1996
8. FES, **Wind farms impact on aviation interests – final report**, FES W/16/00614/00/REP, 2003
9. S Vila-Moreno, **A Methodology to Assess Interference to TV Reception due to Wind Farms**, RES, 2005

The two Dabis papers describe a method for determining the likely interference from a wind turbine based on it behaving like a reflector. This methodology is generally used for interference predictions. The methodology in these papers does not address the significant increase in the level of interference observed when the wind turbine is on the direct path between transmitter and receiver and in addition a method for accounting for multiple wind turbines is not provided.

The ITU-R BT805 paper is quite useful and applies to a single wind turbine. It suggests:

- A CIR in excess of 28-34 dB is required to attain a good analogue picture quality having impairment grade 4 or above.
- Interference levels directly behind the turbine are 10dB higher than interference levels to the side of the turbine.
- Interference levels in flat terrain are unlikely at distances of more than 500m from the wind turbine site.
- Investigation of interference levels is not required at distances of more than 5km from the site.
- The paper refers to the ratio of the wanted signal to the unwanted signal which the Dabis papers refer to as CI Ratio. This document uses the term CI Ratio or CIR.

Radar studies have shown that reflected or scattered signals are much stronger immediately beyond the turbine. This is normally accounted for in interference calculations by using a higher RCS for scenarios where the turbine lies between transmitter and receiver.

The RES document describes a similar approach but includes a method for accounting for the effects of multiple wind turbines by summing the unwanted reflected signals (absolute not decibel). The RES document also suggests:

- a study area of 20km x 20km centred on the wind farm
- allowing for a standard receiving antenna characteristic
- summing unwanted signals directly
- a CIR threshold of 10db – Interference being likely when CIR is less than 10dB

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