Beaw Field Wind Farm Radar Assessment

Peel Wind Farms (Yell) Ltd

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Produced under contract	PO 43087 & 43088
Version	Issue 1.0
Copy Number	1 of 2
Date of release	26 October 2015
Document reference	CL-5152-RPT-003 Issue 1.0

Change History Record

Issue	Change Reference	Date	Details
Draft A		20 October 2015	For internal review
1.0		26 October 2015	Initial issue

Controlled Copy Distribution

Copy Number	Ownership
1.	Peel Energy Limited
2.	Cyrrus Limited

Document Release

Organisation	Name and signature	Position	Date
Cyrrus Limited	Simon McPherson	Safeguarding Officer	26 October 2015
Cyrrus Limited	Martyn Wills	Director	26 October 2015

Executive Summary

Cyrrus Limited has been engaged by Peel Energy Limited to re-investigate the potential impact of a proposed wind farm development at Beaw Field on the Sumburgh Primary Surveillance Radar (PSR) and Fitful Head Secondary Surveillance Radar (SSR). This follows a revision to the wind farm layout and reduction in the number of turbines.

The investigation takes the form of radar propagation analysis comprising Line of Sight (LoS), Path Loss and Probability of Detection (PD) calculations, and evaluation of the results.

The main findings are:

- Sumburgh PSR does not have LoS to the proposed turbines at Beaw Field and it is highly unlikely to detect reflections from these turbines.
- Fitful Head SSR has LoS to the proposed turbines, however aircraft would need to be within 306m of a turbine in order to detect a reflected signal from the radar.
- Fitful Head is a Mode S SSR which uses selective and predictive tracking to make it relatively immune to multipath effects.
- SSR track jitter may be experienced in the area shadowed by the turbines. In this case, the shadowed area is confined to the sector 013.3° - 015.2° from Fitful Head (relative to True North), extending approximately 1.3NM beyond the turbines, and may theoretically affect aircraft flying at altitudes below 1750ft AMSL within a small portion of the Scatsta Final Approach Vectoring Area.
- Beaw Field is approximately 38NM from Fitful Head SSR and the Civil Aviation Authority advises that the possibility for effects on SSR only exists for turbines up to 13NM from the radar site.
- No mitigations are recommended or required for either radar.

Full details of the assessment are contained within the body of this report.

Abbreviations

AGL	Above Ground Level
AIP	Aeronautical Information Publication
AMSL	Above Mean Sea Level
ATC	Air Traffic Control
CAA	Civil Aviation Authority
CAP	Civil Aviation Publication
DTM	Digital Terrain Model
EGPM	Location Indicator for Scatsta Aerodrome
FAVA	Final Approach Vectoring Area
ICAO	International Civil Aviation Organisation
LoS	Line of Sight
MIP	Mode Interlace Pattern
MSSR	Monopulse Secondary Surveillance Radar
NM	Nautical Miles
PD	Probability of Detection
PSR	Primary Surveillance Radar
RCS	Radar Cross Section
SSR	Secondary Surveillance Radar

References

[1] CAP764 – CAA Policy and Guidelines on Wind Turbines

[2] Scatsta ATC Surveillance Minimum Altitude Chart - ICAO, UK AIP AD 2-EGPM-5-1 (9 Jan 14)

[3] EUROCONTROL Guidelines on How to Assess the Potential Impact of Turbines on Surveillance Sensors, EUROCONTROL-GUID-0130, Ed. 1.1

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1. Introduction

1.1. Background

1.1.1. Peel Energy Limited is proposing a wind farm development known as Beaw Field, located in the Shetland Isles. The site of the proposed development lies approximately 8.5NM northeast of Scatsta Airport.

1.1.2. In 2014 Cyrrus Limited was commissioned by Peel Energy to undertake an aeronautical assessment of the proposal, originally planned to comprise 21 wind turbines. Following this study the proposed layout of the wind farm has been revised and the number of wind turbines reduced to 17, each with a maximum tip height of 145m AGL.

1.1.3. The purpose of this report is to assess the possible impact the revised wind farm layout may have on the radar sensors at Sumburgh and Fitful Head. The Sumburgh sensor is a Primary Surveillance Radar (PSR) situated 40NM to the south of Beaw Field, while the sensor at Fitful Head is a Monopulse Secondary Surveillance Radar (MSSR) 4NM to the northwest of Sumburgh PSR.

1.2. Effects of wind turbines on PSR

1.2.1. PSR transmits pulses of energy that are reflected back to the radar's receiver by objects that are within radar Line of Sight (LoS).

1.2.2. The principle effects that wind turbines can have on PSR systems are as follows:

- Each turbine structure can act as a large reflector with the potential to swamp aircraft returns in the same area.
- The rotating blades of a wind turbine can appear on a radar display as primary radar returns, presenting air traffic controllers with false aircraft targets.

1.3. Effects of wind turbines on MSSR

1.3.1. Unlike PSR, MSSR is an 'active' system. It operates by the radar transmitting a coded pulse sequence which is received and decoded by suitably equipped aircraft. The aircraft responds with a coded pulse sequence on a different frequency which is received by the MSSR. Range and azimuth information is derived in the same way as PSR, but additional information in the coded reply allows the identification of a particular aircraft and its height. Other data may also be made available dependant on the mode of operation.

1.3.2. MSSR is immune to direct reflections (monostatic back scatter) from large objects such as wind turbines because the transmitted and received frequencies differ and the message structure is different for transmit and receive paths.

1.3.3. Bistatic reflection is where the signal transmitted by the radar is 'forward' reflected to an aircraft, and the aircraft reply is also reflected back to the radar. The effect of this is best understood by considering the following diagrams.

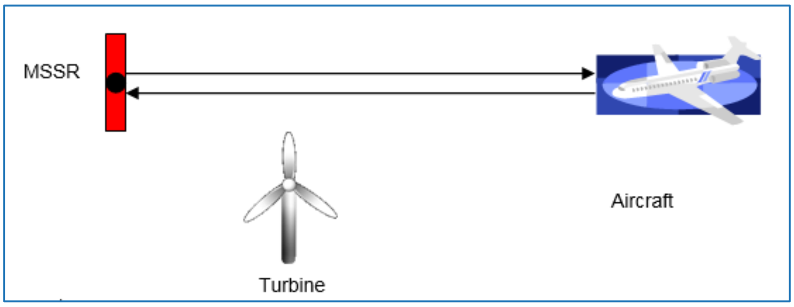

Figure 1: Direct interrogation and reply pulses

1.3.4. In Figure 1, the MSSR transmits an interrogation pulse sequence and the aircraft, on receiving the interrogation sequence, replies with a coded pulse sequence. The time delay between interrogation and receipt of reply is proportional to the distance of the aircraft from the radar. The bearing of the aircraft is the physical bearing of the radar antenna.

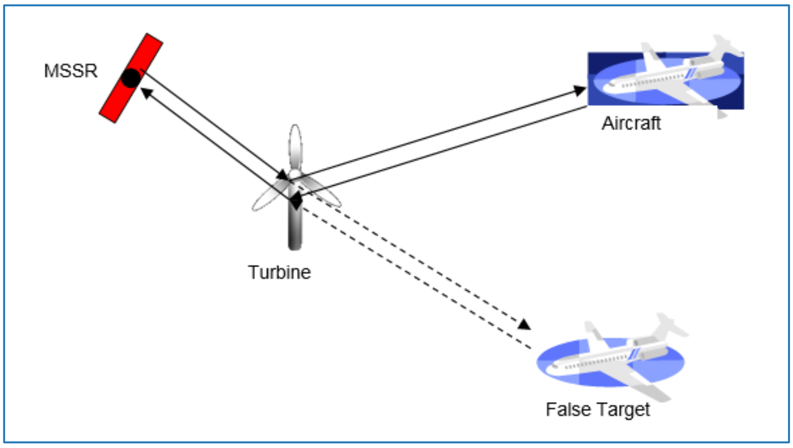

Figure 2: Reflected interrogation and reply pulses

1.3.5. In Figure 2, the MSSR beam illuminates a wind turbine which reflects the interrogation to the aircraft on a different bearing. The aircraft transponder replies and this is received by the radar. The radar processes this as a false target on the bearing of the wind turbine and at a distance proportional to the path length, which is slightly longer than the direct path length.

1.3.6. Objects can and do produce a radar shadow in the area behind the object. As a wind turbine is narrow compared to the radar beamwidth, assuming the turbine is >2km from the radar, the shadow will be relatively small, and will reduce with increasing distance behind the turbine. The shadowing effects are therefore likely to be insignificant. Due to diffraction however, when the turbine is not central within the radar beam, small azimuth angular errors may be introduced.

1.3.7. To summarise, wind turbines can potentially have 2 adverse effects on SSR systems:

- Multipath, or bistatic, reflections from turbine towers in both the uplink and downlink directions can potentially give rise to false targets or ‘ghosts’. Effectively, aircraft reply through the reflector, tricking the radar into seeing a false target in the direction of the obstruction.

- Wind turbines may form an obstruction to the SSR that creates a shadowed area behind the turbines. Returns from aircraft targets in this area can potentially be subject to track jitter causing the returns to meander from side to side. This can only occur where the turbine is in the direct LoS between the radar and its target.

1.4. Turbine data

1.4.1. The details of the proposed turbines, supplied by Peel Energy Limited, are presented in Table 1.

Turbine No	Easting	Northing	Hub height AGL (m)	Blade length (m)	Maximum tip height AGL (m)
T1	450453.69	1183369.10	91-100	45-54	145
T2	450654.42	1183104.98	91-100	45-54	145
T3	451093.67	1183089.33	91-100	45-54	145
T4	450670.28	1182757.12	91-100	45-54	145
T5	451343.25	1182860.49	91-100	45-54	145
T6	450909.81	1182524.89	91-100	45-54	145
T7	451627.07	1182659.15	91-100	45-54	145
T8	451079.42	1182242.65	91-100	45-54	145
T9	451997.87	1182487.59	91-100	45-54	145
T10	451678.47	1182109.19	91-100	45-54	145
T11	451232.63	1181946.14	91-100	45-54	145
T12	452190.06	1182208.27	91-100	45-54	145
T13	451965.88	1181817.7	91-100	45-54	145
T14	451476.66	1181722.76	91-100	45-54	145
T15	452111.28	1181525.19	91-100	45-54	145
T16	451602.47	1181432.53	91-100	45-54	145
T17	452357.61	1181254.07	91-100	45-54	145

Table 1: Details of the proposed turbines

1.4.2. For the PSR assessment a blade length of 54m and a hub height of 91m is assumed.

1.4.3. The size of the turbine tower is more critical for the SSR assessment so a hub height of 100m is assumed for worst-case.

1.5. Radar data

1.5.1. Radar data is taken from data held on file by Cyrrus Limited and from OFCOM document 'Annex 3: Protected radar list', updated 18th September 2014.

1.6. Locations of turbines and radars

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1.6.1. Figure 3 shows the layout of the 17 proposed turbines at Beaw Field.

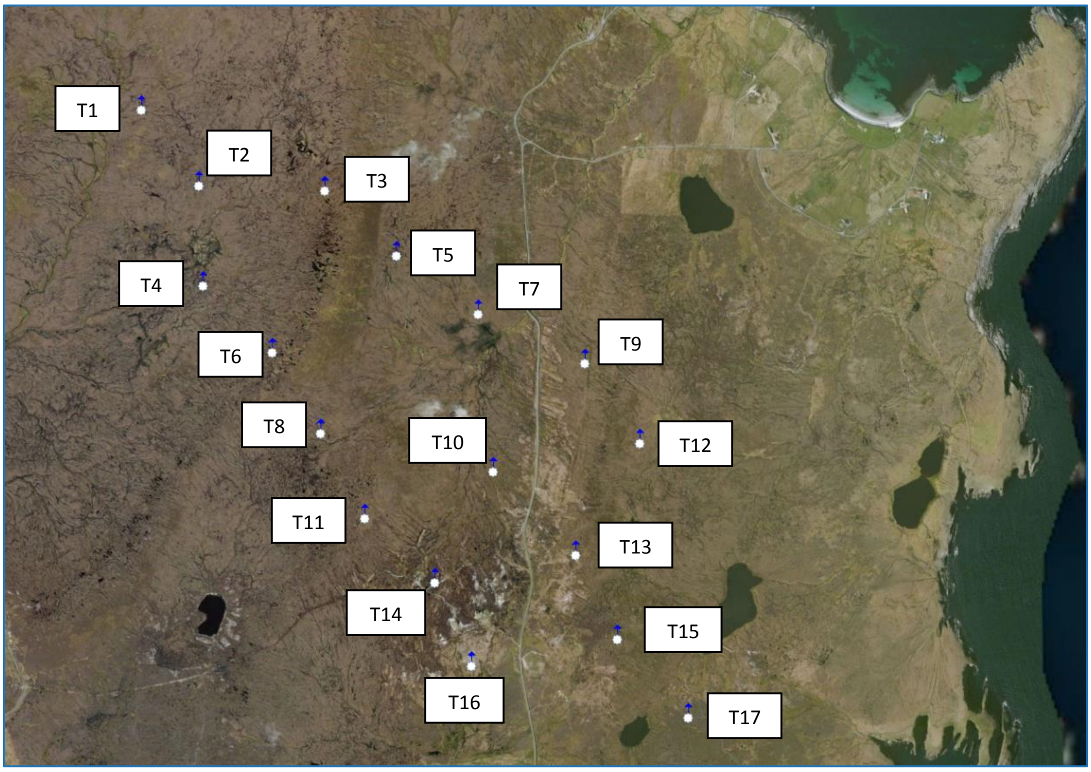

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Figure 3: Beaw Field wind farm layout

1.6.2. The relative locations of the proposed turbines and the radar sensors are depicted in Figure 4.

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Figure 4: Location of radars and proposed wind farm

2. Radar Assessment

2.1. Methodology

2.1.1. The initial stage of the assessment is to determine if LoS exists between the subject radar and the proposed turbines.

2.1.2. LoS is determined from a radar propagation model (ATDI ICS Designer v3.4.1) using 3D NEXTMap Digital Terrain Model (DTM) data with 25m horizontal resolution. Radar data is entered into the model and LoS to the turbines from the radar is calculated.

2.1.3. For PSR, the principal source of adverse effects are the turbine blades, so LoS is calculated for the maximum tip height of the turbines.

2.1.4. In the case of SSR, adverse effects are generated by turbine towers, so LoS is calculated for the maximum hub height of the turbines.

2.1.5. Next, detailed models of the actual radar configurations are constructed to establish the Probability of Detection (PD) of each turbine using processes outlined in CAA Publication CAP764 [1].

2.1.6. Analysis of PD calculations enables an assessment of the probability of each turbine being detected by the radar and creating unwanted clutter on the radar display.

2.1.7. In the event that a particular turbine is expected to produce unwanted clutter, options are investigated for mitigation, either technical changes to the radar or modifications to the size or location of the turbine.

3. Line of Sight assessment

3.1. Sumburgh PSR

3.1.1. The proposed wind farm lies 40NM to the north of Sumburgh PSR. The magenta shading in Figure 5 illustrates the LoS coverage from Sumburgh PSR to turbines with a blade tip height of 145m AGL.

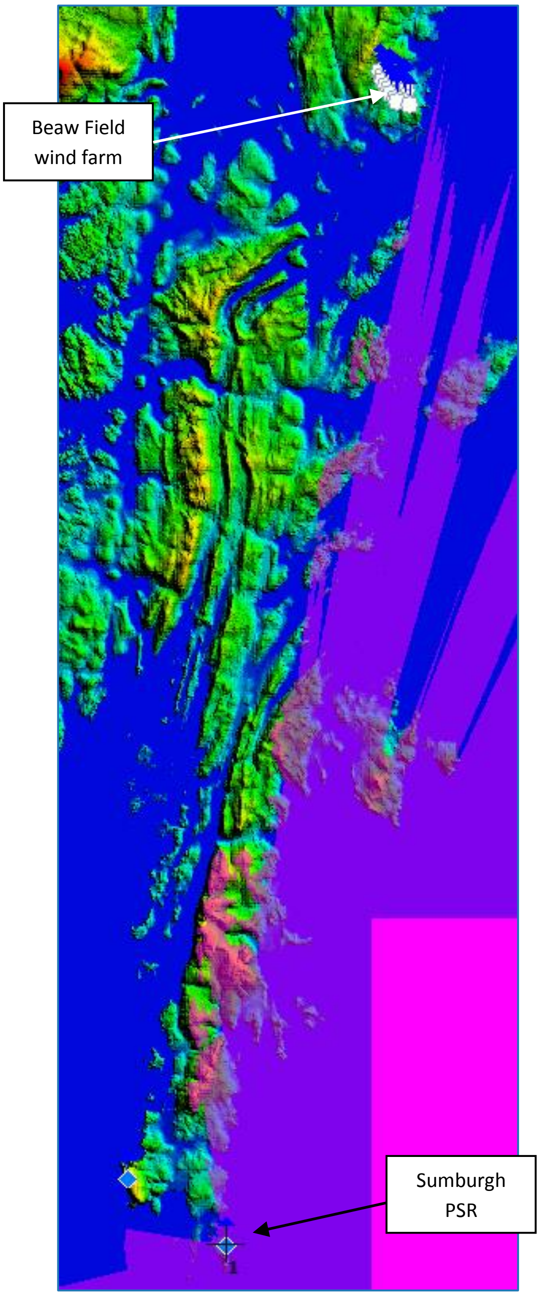

Figure 5: Sumburgh PSR LoS to 145m AGL

3.1.2. Figure 6 confirms that LoS does not exist between Sumburgh PSR and the proposed turbines at Beaw Field.

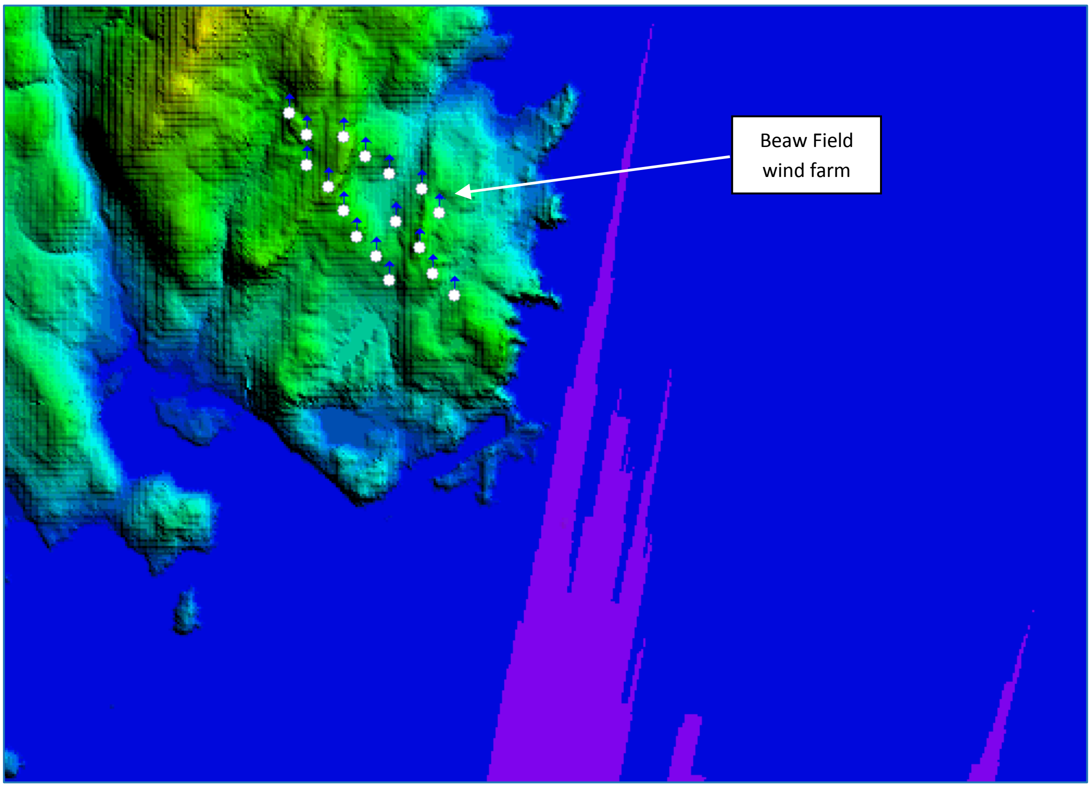

Figure 6: Sumburgh PSR LoS to 145m AGL zoomed

3.2. Fitful Head SSR

3.2.1. The proposed wind farm lies 38NM to the north of Fitful Head SSR. The magenta shading in Figure 7 illustrates the LoS coverage from Fitful Head SSR to turbines with a tower height of 100m AGL.

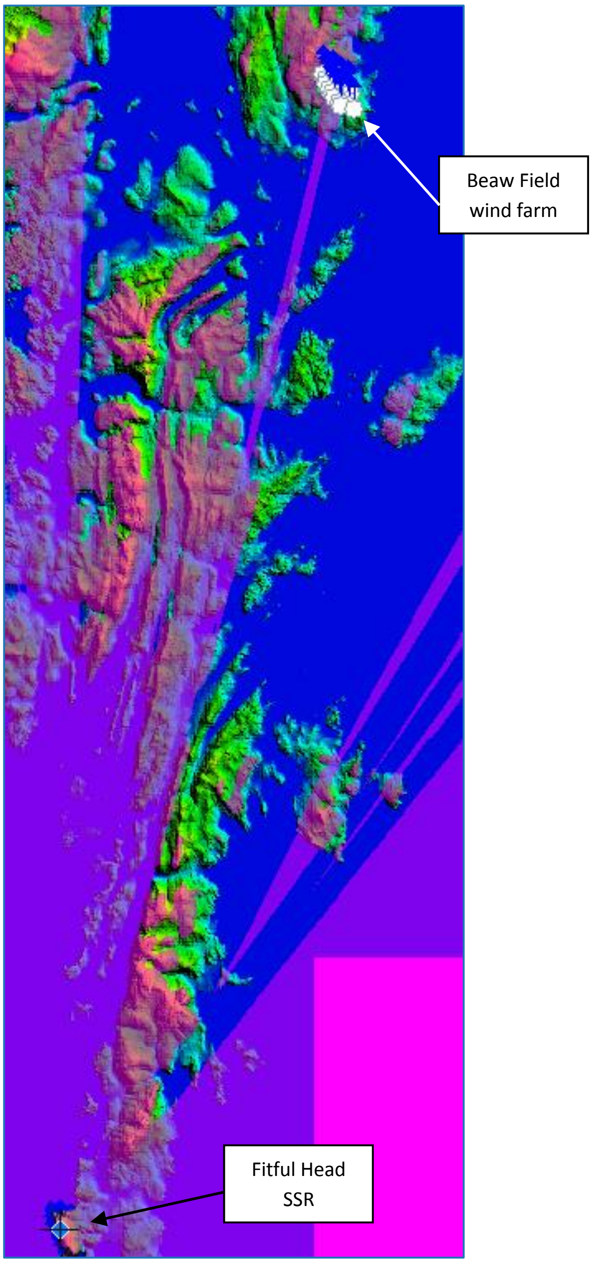

Figure 7: Fitful Head SSR LoS to 100m AGL

3.2.2. Figure 8 shows the LoS coverage from Fitful Head SSR to Beaw Field in more detail.

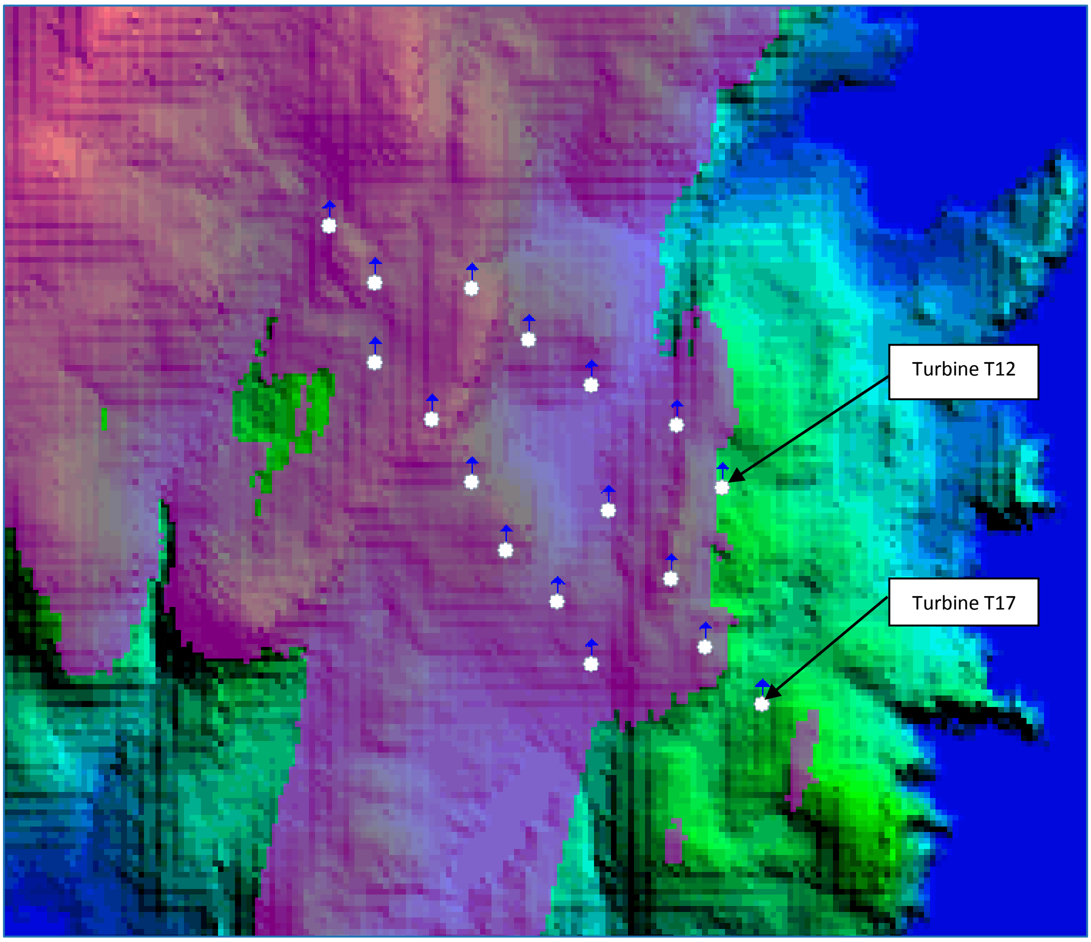

Figure 8: Fitful Head SSR LoS to 100m AGL zoomed

3.2.3. As can be seen, LoS exists at 100m AGL from Fitful Head SSR to all but the two easternmost turbines, T12 and T17.

4. Sumburgh PSR path loss and PD

4.1. Methodology

4.1.1. Using a radar propagation model the actual path loss between the PSR and various parts of the turbine can be determined.

4.1.2. An illustration of a path loss profile between Sumburgh PSR and a Beaw Field turbine is shown in Figure 9.

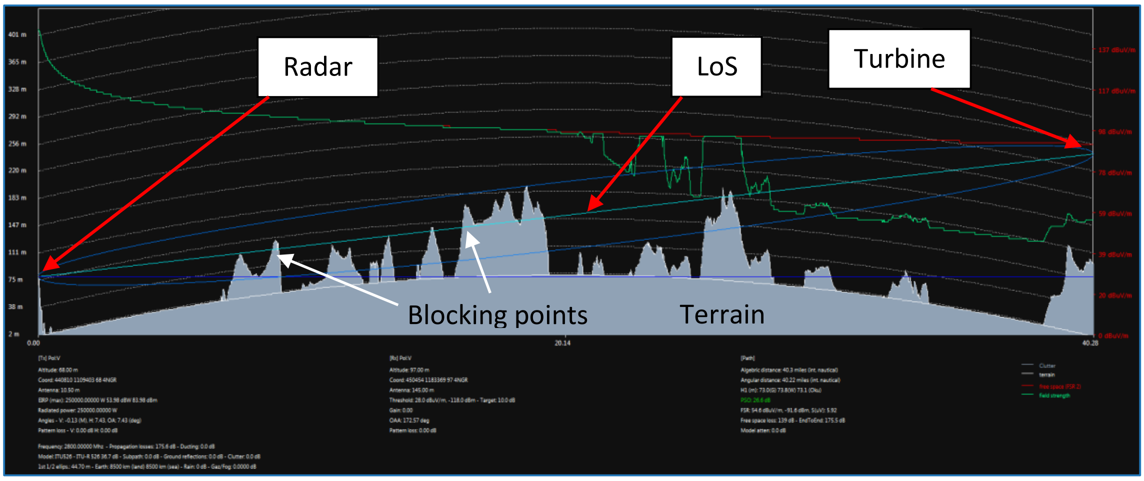

Figure 9: Example path loss profile between Sumburgh PSR and tip of turbine T1

4.1.3. By knowing the PSR transmitter power, antenna gain, 2-way path loss, receiver sensitivity and the turbine Radar Cross Section (RCS) gain, the probability of the radar detecting the target (PD) can be determined.

4.1.4. The static parts of the turbine (tower structure) are ignored in the calculation as these will be rejected by the radar Moving Target filter. In this refined model, 3 parts of the turbine blade are considered: the hub; the blade tip; and a point midway along the turbine blade. Each part of the turbine blade is assigned an RCS of 30m^2 based on a blade length of 54m in accordance with the recommendations in CAP764 [1]. Path loss calculations are made to all turbines. The received signal at the radar from each component part of the turbine is then summed to determine the total signal level.

4.1.5. The path loss calculation carried out for each turbine component is as follows:

	Tx Power	dBm
+	Antenna Gain	dB
-	Path Loss	dB
+	RCS Gain	dB (30m^2 ~ +45dB)
-	Path Loss	dB
+	Antenna Gain	dB
=	Received Signal	dBm

4.1.6. The received signal is then compared with the radar receiver Minimum Detectable Signal level.

4.1.7. An example of the calculation from Sumburgh PSR to turbine T1 is shown in Figure 10.

Radar 2-Way Path Loss Calculator

Data		
Tx Frequency	2800	MHz
Tx Power	58000	Watts
Antenna Gain	30	dBi
Rx Sensitivity	-123	dBm
Target		
RCS	30	m^2
Path Loss (1-way)	175.5	dB
Calculations		
Tx Wavelength	0.11	m
Tx power	77.63428	dBm
EIRP	107.6343	dBm
Power at Target	-67.8657	dBm
RCS Gain	45.17	dB
Power at Rx	-168.19	dBm
dB over Rx Threshold	-45.19	dB

Figure 10: Example path loss calculation

4.1.8. The two-way path losses to each part of each turbine are tabulated and combined in a further spreadsheet. The results are colour-coded to indicate the likelihood of detection by the subject radar. Radar returns >3dB above the detection threshold are coloured green as these values show a high probability of detection. Those between +3dB and -3dB are coloured yellow and indicate a possibility of detection. Between -3dB and -6dB, figures are coloured orange to show only a small possibility of detection. Signals >6dB below the threshold of detection are shaded red as these values show that detection is unlikely.

4.1.9. Using this representation provides a ready visual comparison of different scenarios. The final result is shown in the final column (TOTAL) of each colour-coded chart.

4.2. Sumburgh PSR results

4.2.1. The results of the PD calculations for Sumburgh PSR are shown in Figure 11.

Initial data from '2-Way'			KEY:	Unlikely to be detected
A	175.5	Path Loss		Small possibility of detection
B	-45.19	dB over Rx Thr		Possibility of detection
C	30.00	RCS (m^2)		High probability of detection

Turbine	Turbine Nacelle Path Loss dB	Blade mid-point Path Loss dB	Blade Tip Path Loss dB	TOTAL dB over RX threshold
1	180.2	177.9	175.5	-43.59
2	181.4	178.6	175.2	-43.57
3	173.8	169.6	166.9	-26.75
4	182.3	179.7	177.1	-46.95
5	184.7	179.0	176.4	-45.77
6	176.5	174.3	171.6	-35.95
7	195.7	189.5	182.3	-58.63
8	174.9	170.5	168.1	-29.01
9	183.0	178.6	176.9	-46.18
10	187.7	181.5	175.5	-44.91
11	180.5	174.3	169.4	-32.54
12	180.0	174.7	171.0	-35.41
13	178.6	177.0	175.1	-42.31
14	188.7	181.6	176.0	-45.86
15	176.0	170.8	169.1	-30.64
16	186.1	179.3	175.5	-44.47
17	181.8	179.3	177.0	-46.56

Figure 11: Sumburgh PSR PD results

4.2.2. From Figure 11, it would appear that Sumburgh PSR is very unlikely to detect any of the turbines at Beaw Field.

4.2.3. Note also that the calculation is based on the optimum performance of the radar. The maximum gain of the radar antenna usually occurs at an elevation angle of approximately 3° above the horizontal and falls off rapidly at lower elevation angles.

4.2.4. The vertical angle from Sumburgh PSR to the tips of the turbines varies between -0.1° and -0.2°. The antenna gain at 3° below the peak of the beam will be approximately 10dB below the peak gain. A further -20dB can therefore be added to the 'Total dB over RX Threshold' values in Figure 11. This means that even for Turbine No.3 any reflected energy will be more than 46dB below the RX threshold.

4.2.5. It can be concluded that it is extremely unlikely that Sumburgh PSR will detect any of the turbines at Beaw Field.

5. Fitful Head SSR path loss

5.1. Methodology

5.1.1. Multipath, or bistatic, reflections from turbine towers can potentially cause 'ghost' targets on SSR. This occurs when an aircraft replies through a signal reflected from an obstruction; the radar attributes the response to the original signal and outputs a false target in the direction of the obstruction.

5.1.2. 'Ghost' targets may lead air traffic controllers to deconflict real traffic from targets that do not physically exist.

5.1.3. Using a radar propagation model the actual path loss between the SSR and various parts of the turbine can be determined.

5.1.4. An illustration of a path loss profile between Fitful Head SSR and a Beaw Field turbine is shown in Figure 12.

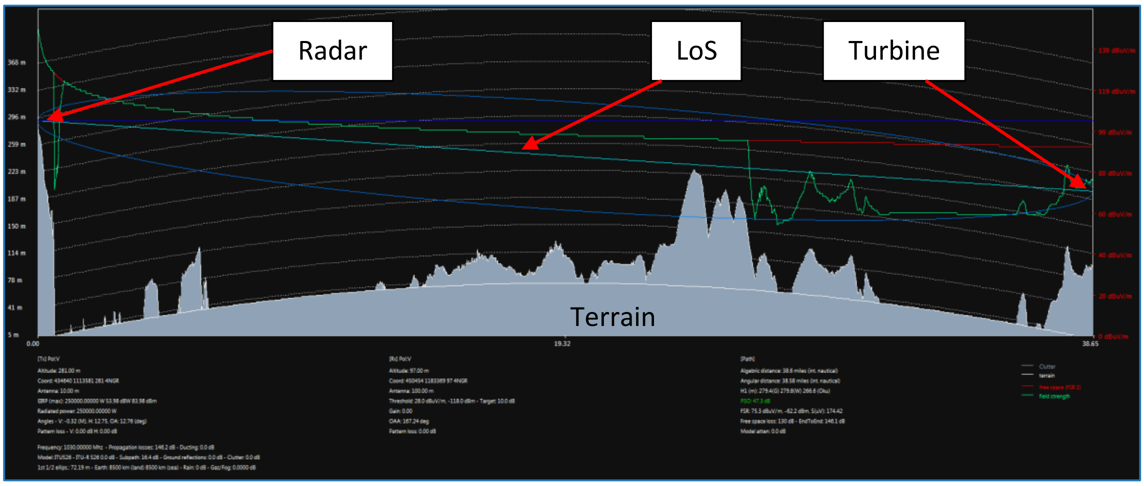

Figure 12: Example path loss profile between Fitful Head SSR and hub of turbine T1

5.1.5. The likelihood of bistatic reflections can be determined by knowing the SSR transmitter power, antenna gain, and path loss to the turbine tower, aircraft receiver sensitivity and RCS gain.

5.1.6. The amount of signal reflected by a turbine tower is a function of the tower's RCS. A typical value of RCS for a 100m steel tower of 8m diameter is 3,000,000m^2. However, a 0.5° taper of the tower can reduce this figure from millions to hundreds of square metres.

5.1.7. If we assume an area of 1000m^2 for a turbine tower this equates to an RCS gain of 52dB.

5.1.8. The following calculation can be used to determine the power of a radar signal reflected by a wind turbine tower:

	Tx Power	dBm
+	Antenna Gain	dB
-	Path Loss	dB

+	RCS Gain	dB (1000m^2 ~ +52dB)
=	Reflected Power	dBm

5.1.9. Free Space Path Loss can be can be used to calculate the maximum distance from the reflecting obstacle an aircraft needs to be in order for the reflected signal to trigger a response from its transponder.

5.2. Fitful Head SSR results

5.2.1. The path loss results between Fitful Head SSR and the turbine nacelles at Beaw Field are shown in Figure 13.

Turbine	Turbine Nacelle Path Loss dB
1	146.1
2	138.5
3	129.8
4	138.2
5	129.7
6	129.7
7	136.5
8	129.7
9	144.2
10	142.5
11	129.6
12	151.3
13	137.3
14	130.1
15	142.1
16	141.4
17	152.9

Figure 13: Fitful Head SSR path loss results

5.2.2. The turbine nacelle is at the hub, i.e. at the top of the static part of the turbine.

5.2.3. Looking at Figure 13, the worst-case or smallest path loss is 129.6dB to the hub of turbine T12. Using the calculation outlined in paragraph 5.1.8 results in a reflected power of 11.4dBm.

5.2.4. If we assume an aircraft receiver sensitivity of -71dBm then, if the Free Space Path Loss from the obstacle to the aircraft is more than 82.4dB, the signal will not trigger a response.

5.2.5. The Free Space Path Length for an SSR frequency of 1030MHz and path loss of 82.4dB is 306m. This means that aircraft beyond this distance from the turbine will not detect a reflected signal.

5.2.6. 306m is very close to the distance a pulse propagates in 1µs [$3x10^8$ ms^{-1}]. This is only slightly larger than the 0.8µs pulse width used in the interrogation messages. It does mean that the direct and reflected incident interrogation messages received at the transponder will have a high degree of overlap. Such small differences in range and azimuth do have the potential to cause either split plots or minor bearing errors. The beamwidth of the SSR sum antenna is 2.4°, which is greater than the azimuth occupied by the wind farm. Any aircraft within 306m of the turbines is going to be within the beam as it illuminates the turbines.

5.2.7. Aircraft on final approach to Scatsta will be overflying the turbines at 1700ft. The tips of the turbines are at about 875ft, giving a space of approximately 250m. This increases to a minimum of 295m to the nearest turbine nacelle, where SSR reflections are more probable. As this is only marginally less than 306m there is a slight possibility for the incidence of multipath errors arising from overlap of direct and reflected paths. These could manifest themselves either as split plots or as small errors in azimuth. Split plots are multiple target reports with small range and azimuth separation arising from code corruption of overlapping pulses.

5.2.8. The EUROCONTROL Guidelines [3] show that multiple target reports, i.e. reflections where there is a large angle between the direct and reflected paths, are not expected to occur when the turbines are greater than 10NM from an interrogator. Additionally, the SSR at Fitful Head is a Mode S interrogator operating in a Mixed Mode Interlace Pattern (MIP), a mixture of Mode S interrogations and Mode A/C interrogations. The Mode S processing has very effective rejection of reflections due to the unique Mode S address of each aircraft. There is also effective rejection of reflections from Mode A/C interrogations, especially where unique Mode A codes are assigned. Reflections are more likely to result in multiple target reports for general aviation (GA) traffic using a common Mode A code. However, this is very unlikely to be attributable to the turbines when they are 38NM from the interrogator.

5.2.9. An array of turbines can create a radar shadow in the space beyond it from the radar. The EUROCONTROL Guidelines [3] provides a means of calculating the dimensions of this shadow region.

$$Dwr = Dtw/[\lambda.\frac{Dtw}{S^2}\left(1-\sqrt{PL}\right)^2 - 1]$$

- *Dwr* = depth of the shadow region.
- *Dtw* = distance of turbines (38NM)
- λ = wavelength (0.3m)
- S = diameter of support structures (8m)
- PL = acceptable power loss (0.5 per guidelines)

5.2.10. From the above, *Dwr* = 2,453m. This is the depth of the region beyond the direct LoS of the turbines from the radar.

5.2.11. The vertical angle between Fitful Head SSR and the tips of the turbines varies between -0.30° and -0.36°. Fitful Head SSR is at an elevation of 950ft AMSL. If it is assumed that the potential shadowing zone extends a further 0.5°above the vertical angle between the SSR and the turbines then aircraft will need to be flying below an altitude of approximately 1750ft AMSL within the shadow region for minor positional errors (track jitter) to occur.

5.2.12. The lateral extents of the wind farm indicate that the potential shadowed area is confined to the sector 013.3° - 015.2° from Fitful Head relative to True North. This is shown as the hatched area in Figure 14.

5.3. Operational impact

5.3.1. There are no Lower or Upper Air Traffic Service (ATS) Routes in the area potentially shadowed by the Beaw Field wind farm.

5.3.2. The Scatsta ATC Surveillance Minimum Altitude Chart [2], an extract of which is presented in Figure 14, shows the minimum initial altitude to be allocated by the approach surveillance controller at Scatsta Aerodrome. The red hatching shows the area of potential shadowing.

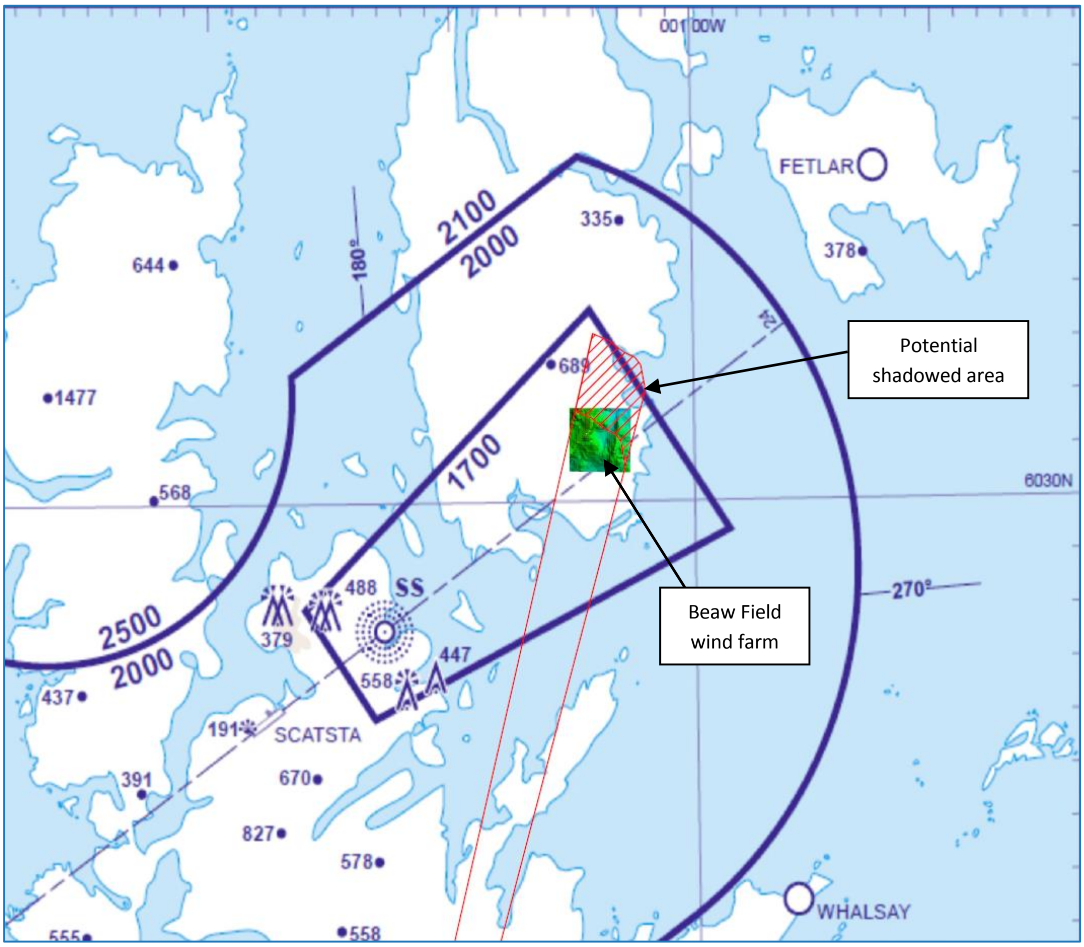

Figure 14: Scatsta ATC Surveillance Minimum Altitude Chart extract

5.3.3. The Final Approach Vectoring Area (FAVA) altitude is 1700ft AMSL. Paragraph 5.2.11 warns of the potential for track jitter at altitudes up to 1750ft AMSL in the vicinity of the wind farm, so there is the possibility, albeit very slight, of this occurring in the red hatched area of the FAVA. However, with the imminent removal from service of the Scatsta PSR this area will no longer be applicable.

5.3.4. Notwithstanding the above, CAP764 [1] indicates that turbines beyond 24km (approximately 13NM) from an SSR radar are unlikely to have any impact on SSR performance and in fact the majority of effects are likely to be within 10km.

6. Summary

6.1. Sumburgh PSR

6.1.1. The proposed wind farm development at Beaw Field is highly unlikely to have any impact on the Sumburgh PSR. LoS does not exist between the PSR and the turbines, and PD calculations confirm that there is little chance of the turbines being detected.

6.2. Fitful Head SSR

6.2.1. There is LoS between Fitful Head SSR and the majority of the turbines at Beaw Field. However, the extent of the Free Space Path Loss over the 38NM separating the turbines from the SSR indicates that in the worst-case aircraft need to be within 306m of a turbine for there to be the potential for multipath reflections.

6.2.2. The SSR at Fitful Head is a Mode S radar which uses selective and predictive tracking to make it relatively immune to the effects of multipath.

6.2.3. SSR track jitter may be experienced in the area shadowed by the turbines. This area is confined to a sector between 13.3° and 15.2° from Fitful Head relative to True North, and may theoretically affect aircraft flying at altitudes below 1750ft AMSL within a small portion of the Scatsta FAVA.

6.2.4. It should be borne in mind that CAP764 [1] indicates that wind farms more than 13NM from an SSR are unlikely to have an impact on SSR performance. Beaw Field is approximately 38NM from Fitful Head.

6.3. Mitigation

6.3.1. No mitigations are recommended or required for either radar.