GIBSON QUAI·AAS CONSULTING

18 October 2007 61859

WestWind Pty Ltd
505 Warrenheip Rd
Buninyong VIC 3357

Attention: Mr Grant Flynn

Dear Grant

RESPONSE TO COUNTRY FIRE AUTHORITY CONCERNS

1. INTRODUCTION

WestWind Energy Pty Ltd (WestWind) is an Australian based company established to develop, build and operate wind farms. WestWind have recently started development work on their second project – the Lal Lal Wind Farm near Ballarat in Victoria.

WestWind commissioned an assessment of the potential for interference from the proposed wind farm to radiocommunications services in the area. A report was prepared by Garrad Hassan Pacific Pty Ltd (GH) (Reference 1), detailing interference issues for point to point (fixed link) and point to multipoint radiocommunications services.

GH recommended that licensees of radiocommunications services near the proposed wind farm area be contacted, and this was carried out by WestWind. As a result, a response was received from the Country Fire Authority of Victoria (CFA) that expressed concern about interference to the CFA's fixed links and mobile radio services and requested wide clearances (250 m) between wind turbines and the paths of the fixed link services.

GQ-AAS was commissioned to undertake a review of the GH report (Reference 2), and make recommendations on the exclusion zones required to ensure wind turbines will not interfere with fixed link services.

GQ-AAS was also commissioned to respond to the concerns of the CFA (this document), including an explanation of the methodology used to determine recommended exclusion zones for wind turbines.

2. WIND TURBINES AND INTERFERENCE TO FIXED LINKS

Wind turbines can cause interference to point to point links and point to multipoint services by one of three interference mechanisms – near field effects, diffraction and reflection/scattering.

2.1 Near Field Effects

Antennas radiate electromagnetic waves which propagate away from the source, and decrease in field intensity as distance R, away from the antenna, increases (proportional to 1/R). At large distances from the antenna, the wavefront can be approximated as a plane wave. This is known as the far field (or Fraunhofer) region. In the near field of an antenna this approximation does not fit, and field intensity includes factors proportional to $1/R^2$, $1/R^3$, etc.

When an obstruction exists within the near field zone of a transmitting or receiving antenna, signal degradation can occur which is complex to predict.

The near field zone can be estimated using the following formula:

$$D_{nf} = \frac{N_{nf}\eta D_a{}^2}{\lambda} \qquad \text{Equation (1)}$$

Where D_a is the diameter of the antenna physical aperture, η is antenna efficiency (in the range 0 to 1) and N_{nf} is a constant. Bacon (Reference 3) recommends a conservative estimate of 3 for N_{nf}.

The following approximation is given by Bacon, where the antenna aperture is unknown:

$$D_{nf} = \frac{N_{nf}\lambda 10^{0.1G}}{\pi^2} \qquad \text{Equation (2)}$$

Where G is the isotropic antenna gain (dBi).

The near field distances are approximately 5 m for the 400 MHz and 850 MHz point to point services.

2.2 Diffraction

When an electromagnetic wave encounters an obstruction, some energy is diffracted around the obstruction, causing an additional loss above free space loss for the radio path due to some of the energy of the wave being diffracted away from the direct path between the transmitter and receiver.

The effects of diffraction are bounded by two cases – smooth earth and knife edge diffraction.

When the terrain along a radio path is considered smooth (irregularities are of the order, or less than, 10% of the first Fresnel zone radius[1]), the smooth earth prediction model applies. This model predicts diffraction loss for smooth earth obstructions of the radio path (where the obstruction is created by the curvature of the earth).

The knife edge diffraction model predicts diffraction loss using an ideal isolated obstruction with negligible thickness (a knife edge). Diffraction over real terrain obstructions is modelled with more complicated algorithms. For predicting diffraction from a wind turbine, GQ-AAS has assumed the knife edge diffraction model applies.

2.2.1 Knife edge diffraction

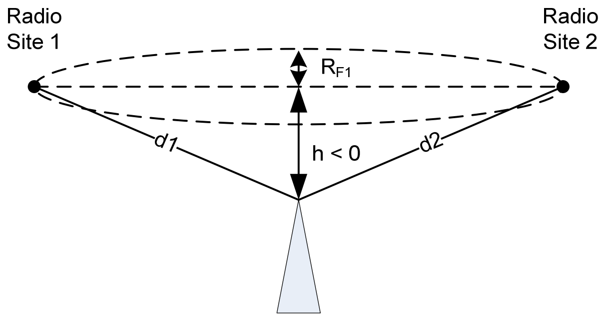


Figure 2.1 – Knife edge diffraction over an obstruction (adapted from ITU-R P.526-10)

The parameter v is defined in ITU-R P.526-10 as follows:

[1] As defined in ITU-R Recommendation P.526-10.

$$v = h\sqrt{\frac{2}{\lambda}\left(\frac{1}{d_1}+\frac{1}{d_2}\right)}$$ Equation (3)

This equation can be rewritten using the first Fresnel zone radius as:

$$v = \frac{h\sqrt{2}}{R_{F1}} = \frac{-\sqrt{2}\times R_{F1\%}}{100}$$ Equation (4)

Where $R_{F1\%}$ is the percentage of the first Fresnel zone clear of obstruction, and R_{F1} is the first Fresnel zone radius given by:

$$R_{F1} = \sqrt{\frac{\lambda d_1 d_2}{d_1 + d_2}}$$ Equation (5)

The following graph shows that for knife edge diffraction loss to begin to become significant, v must be greater than approximately -0.8. This corresponds to 57% (or less) of the first Fresnel zone clear of obstructions.

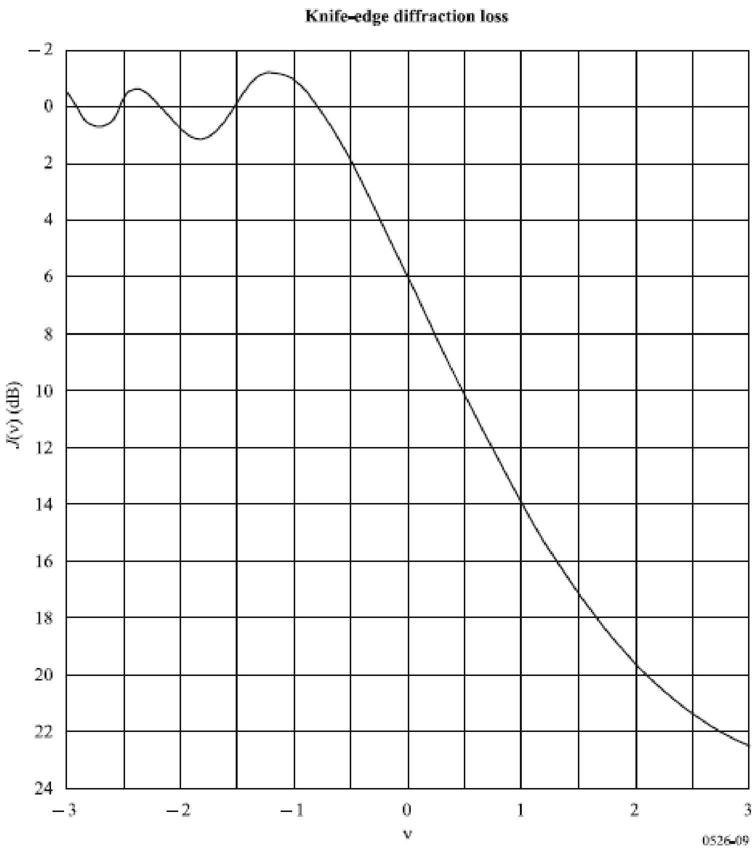


Figure 2.2 – Knife edge diffraction loss from ITU-R P.526-10

GQ-AAS therefore concludes that if there is more than 57% of the first Fresnel zone clear of knife edge obstructions, loss due to diffraction is not significant.

2.3 Reflection/Scattering

When an electromagnetic wave encounters an obstruction, some energy is re-radiated (reflected or scattered) in other directions. The amount and direction of re-radiated energy depends on the properties of the obstruction.

Reflection (specular reflection) refers to the case where the incident electromagnetic wave is reflected in a single outgoing direction (i.e. similar to a mirror for visible light).

Diffuse reflection (scattering) occurs when energy is reflected in a range of directions, not just the specular direction.

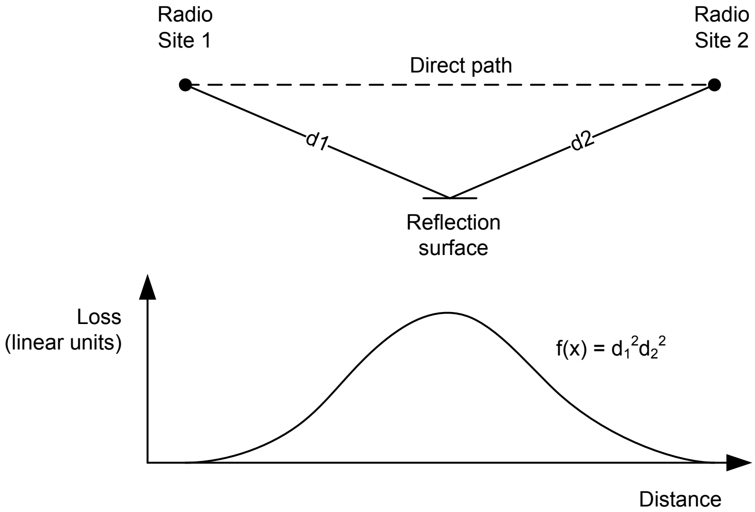


Figure 2.3 – Transmission over an indirect path

According to Bacon, the free space transmission loss between a transmitter and receiver over an indirect path (refer to Figure 2.3) is given by:

$$l = \frac{(4\pi)^3 d_1^{\ 2} d_2^{\ 2}}{\sigma \lambda^2 g_1(\theta_1) g_2(\theta_2)} \qquad \text{Equation (6)}$$

Where σ is the Radar Cross Section of the reflecting surface, $g_1(\theta_1)$ and $g_2(\theta_2)$ are the antenna gains in the off-boresight directions. This equation shows that the loss over the reflected path is determined by the $d_1^2 d_2^2$ factor, which is a maximum when $d_1 = d_2$.

The critical parameter is the ratio of the amplitude of the direct and reflected signals, defined by Bacon as the carrier to interference ratio, Rci.

Rci = 71 - S + 20 log ($s_1 s_2$) - 20 log (Dp) + $G_1(0)$ + $G_2(0)$ - $G_1(\theta_1)$ - $G_2(\theta_2)$ (dB)

where:

- $s_{1,2} = \sqrt{d_{1,2}^{\ 2} + D_s^{\ 2}}$ (km);
- Ds = perpendicular distance for bore sight to the reflection point
- S = 10 log(σ) (dB) and σ = Worst-case radar cross section of turbine (m^2)
- Dp = bore sight path length
- $G_{1,2}$ (0) = Antenna bore sight gains (dBi)
- $G_{1,2}$ ($\theta_{1,2}$) = Antenna gain at off-bore sight angles θ (dBi)
- $\theta_{1,2}$ = angle (Ds , $d_{1,2}$)

Simplifying to take the worst case where $G_{1,2}$ (0) = $G_{1,2}$ ($\theta_{1,2}$) and Ds = 0, we have

Rci = 71 - S + 20 log ($d_1 d_2$) - 20 log (Dp) (dB)

The level of Rci that will ensure no interference to the wanted signal depends on the modulation scheme and performance of the receiver. However an Rci of 50 dB will generally be sufficient.

The equation is independent of frequency and in the simplified form, antenna gains. The variables are the path length and the radar cross section of the wind turbine. The radar cross section of the wind turbine is estimated as 30 m^2 by Bacon. In one example, for a 20 km 7 GHz link, Bacon calculates losses due to reflections are only significant within 1 km of each end of the link, that is, the 50 dB Rci is achieved at that distance.

GQ-AAS calculated the Rci using a path length of 42 km with a wind turbine radar cross section of 120 m^2 and found the 50 dB Rci was achieved at a distance of 1 km from the transmitter site.

Reflections from multiple wind turbines are possible, but the path losses on the reflection path are such that the combined effect is still negligible at 1 km and further from the transmitter site.

This indicates that interference due to reflections is only significant close to each end of the radio link.

3. EXCLUSION ZONE CALCULATIONS

GQ-AAS has calculated recommended exclusion zones based on the principles outlined in Section 2 above, and also the methodology outlined in Reference 2.

3.1 Diffraction Exclusion Zone

GQ-AAS recommends a diffraction exclusion zone based on clearance of the first Fresnel zone by the whole wind turbine (tower and blades) to overcome the degradation of the link due to diffraction.

The diffraction exclusion zone is calculated as double the distance from the bore sight line of the radio path to the centre line of the wind turbine. This equals the maximum first Fresnel zone radius of the fixed link service + the length of the turbine blade, as shown in the figure below.

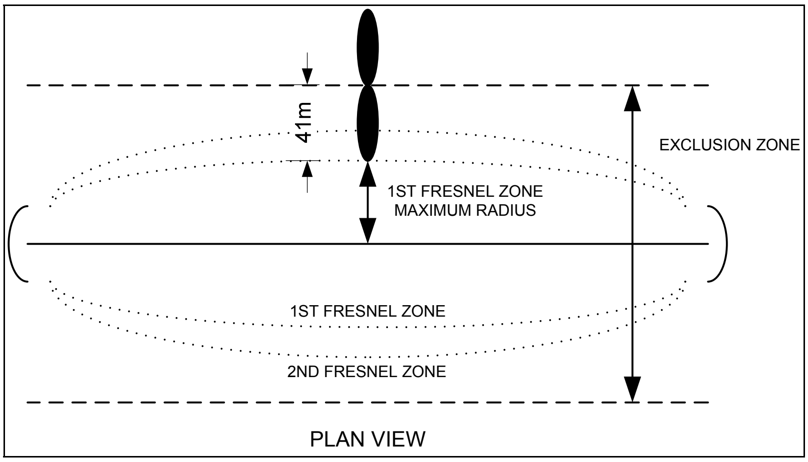


Figure 3.2 – Exclusion zone width

Reference 2 recommends clearance of the complete 2nd Fresnel zone, but GQ-AAS believe this is overly conservative.

In the report prepared by Garrad Hassan, a clearance zone of the 1st Fresnel zone is recommended.

3.1.1 Wind Turbine Dimensions

The following Figure provides wind turbine dimensions. A maximum tip height of 130 m was used for modelling path profile obstructions.

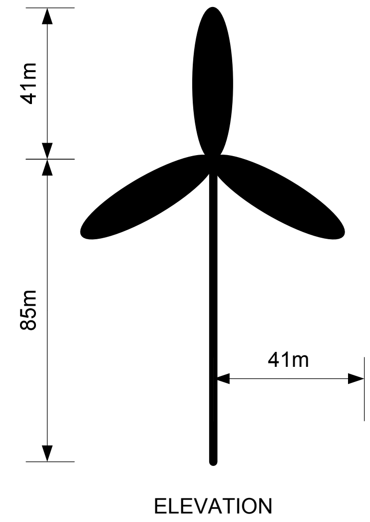


Figure 3.3 – Wind turbine dimensions

3.2 Reflection Exclusion Zone

GQ-AAS recommends a reflection exclusion zone for radio services at 400 and 800 MHz of approximately 1 km, based on achieving a wanted to unwanted signal level ratio of 50 dB.

3.3 Near Field Exclusion Zone

The near field exclusion zone for radio services at 400 and 800 MHz is very small – less than 10 m and therefore is made irrelevant by the reflection exclusion zone.

4. CFA LINK ANALYSIS

4.1 CFA Links

From the ACMA Register of Radio communications Licences (RRL) GQ-AAS identified four fixed links licensed to the CFA that cross the proposed Yendon wind farm area. From the data in the ACMA RRL, these links appear to be single channel UHF links carrying mobile radio voice traffic between the CFA's mobile radio repeater sites.

Path ID	From (ACMA Site ID)	To (ACMA Site ID)	Frequency (MHz)	Path Length (km)
1	11716 (Mt Buninyong)	41712 (Blue Mountain)	852.3875 928.3875	41.2
8	46299 (Ballan)	11716 (Mt Buninyong)	852.2375 928.2375	27.06
12	302624 CFA Site Moorabool Rd West	11716 Mt Buninyong	450.9 460.4	23.48
13	45962 CFA Site Fiskville	46209 Sidbury Ave Ballarat	460.15 450.65	37.59

Table 4.1 – CFA fixed links crossing the wind farm zones

These links are shown with the Lal Lal wind farms in the following figure.

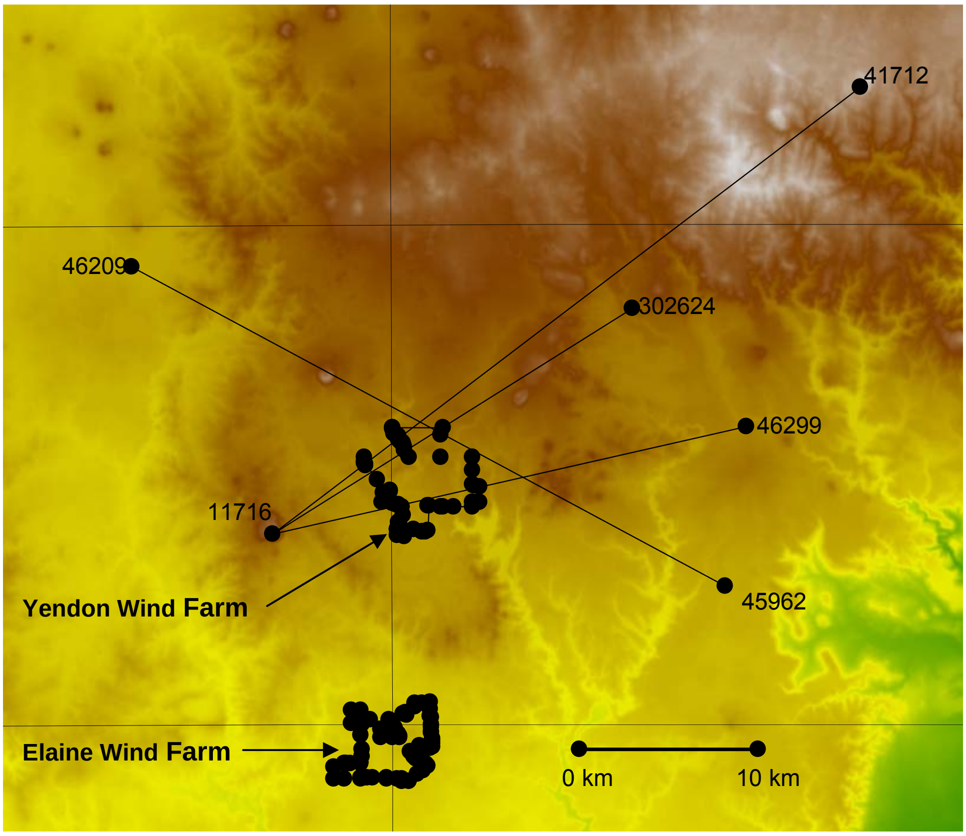


Figure 4.1– CFA Links and the Lal Lal Wind Farms

4.2 Path Profiles

Path profiles for each link are included in Appendix A, along with a brief description of the path and recommended exclusion zone (if required).

4.3 Exclusion Zones for the CFA Links

GQ-AAS determined that no exclusion zone is required for one of the four links. A diffraction exclusion zone of 240 m is recommended for one of the remaining three links, and a partial exclusion zone is recommended for the remaining two links.

GQ-AAS has also calculated the reflection exclusion zones for the links. These results are summarised below.

Path ID	1st Fresnel Zone Maximum Radius	Diffraction Exclusion Zone Width	Reflection Exclusion Zone Distance
1	60 m	Not required, adequate path clearance	1 m
8	49 m	180 m, between 15 km and 18 km along the link path from the Fisken St Fire Station site.	1.1 km
12	62 m	206 m, between 10 km and 11 km along the link path from the Mt Buninyong site.	1.1 km
13	79 m	240 m	1 km

Table 4.2 – Exclusion zones for CFA links

5. WIND TURBINES AND INTERFERENCE TO MOBILE RADIO SERVICES

5.1 From Fixed Repeater Sites

Mobile radio fixed repeater sites are generally established to provide wide area mobile radio coverage. The range of a fixed repeater depends on the elevation of the repeater site, the antenna height on the mast, the operating frequency and the terrain and vegetation in the coverage area. Typically, the coverage radius is 25 to 40 km from the repeater site.

Unlike the case of the transportable repeaters covered in the next section, the locations of the fixed repeater sites in relation to the wind farms are known and predictions of the general effect of the wind farms on mobile radio coverage can be estimated.

While mobile radio coverage from fixed repeater sites can be expected to be affected by wind turbines in a similar way to fixed link services, most locations in the mobile radio coverage area will not be affected, as the wind farm is likely to occupy only a small segment of the coverage area.

In addition, mobile radio services typically provide coverage to a combination of line of sight and non line of sight locations, where diffraction over hills, reflections from buildings and hills and foreground clutter are often common. In general, mobile radio is capable of operating adequately in less than ideal propagation conditions, much more so than fixed services.

The other factor concerning the effects of wind farms is that while there may be some localised effects from the wind turbines, the general effect is minor. For example if there is poor coverage when standing close to a wind turbine and directly behind it in relation to the repeater site, moving to one side of the wind turbine will improve the signal level from the repeater significantly. Whether it will provide an increase sufficient to give suitable coverage will depend on the general signal level in the wind farm, which will in turn depend on the distance from the repeater and path losses between repeater site and the wind farm.

There is substantial anecdotal evidence that mobile radio services and mobile phone services can operate successfully within the wind farm site.

GQ-AAS expects that there may be some effects from the wind farm on mobile radio coverage in areas behind the wind farm in relation to the repeater site. The extent of these effects is difficult to quantify, but GQ-AAS expects that, at most, the reduction in signal level would be of the order of 6 dB in some locations close to the wind farm. In areas behind the wind farm, the effect of the wind farm on signal level will decrease with distance away from the wind farm.

As with the signal levels within the wind farm, whether this potential reduction in signal level will cause the mobile radio coverage to become inadequate will depend on the general signal level in the area. If the repeater lies within an area of strong signals, a reduction of 6 dB will not be noticeable. If the wind farm is on the fringe of coverage from the repeater, a reduction in signal level is likely to be noticeable.

5.2 From Transportable Repeater Sites

Transportable radio repeater sites are established to deal with incidents where there is inadequate coverage from the fixed repeaters and/or to provide a channel or channels for an additional traffic associated with the incident. The repeater provides coverage to the incident area, much more than the coverage achieved by mobile to mobile or handheld to handheld communications.

There are two general possibilities for the way transportable repeater sites are established:

1. As an independent repeater that is not connected to the main radio network.
2. As part of the main radio network with a link back to the main control centre directly or via an existing repeater site.

In either case the repeater may be situated on a hill to maximise the coverage area or it may be located at the field control centre.

The very nature of the transportable repeaters means that they can be located almost anywhere, so it is very difficult to predict the effects, if any, of the wind farm on the operation of the repeater. In the case where the repeater is linked back to the network, the wind farm location needs to be considered for both the link to the network and the coverage area.

The potential effects of the wind farm on the transportable repeater are the same as those for fixed link services and fixed repeater sites, with the added complication of the variable location of the transportable repeater site.

6. CFA MOBILE RADIO REPEATER ANALYSIS

6.1 CFA Fixed Mobile Radio Repeater Sites

From the sites with CFA fixed links that are located in the vicinity of the Yendon Section of the wind farm, GQ-AAS identified five sites (listed in the table below) where the CFA has mobile radio repeaters operating in the 160 MHz band (VHF high band).

ACMA Site ID	Site Name
11716	Police & Ambulance Site Mt Buninyong
302624	CFA Site Bunding
41712	Fire Watch Tower Blue Mountain
45962	CFA Site Fiskville
46299	Fire Station Ballan

Table 6.1 – CFA mobile radio repeater sites near the Yendon wind farm

This list does not identify all the sites with CFA repeaters in the area surrounding the Yendon Section, (these are shown in Figure 6.1 below with the ACMA site ID) but other than the site at Blue Mountain (site 41712), the repeater sites listed are within 15 km of the Yendon Section of the wind farm.

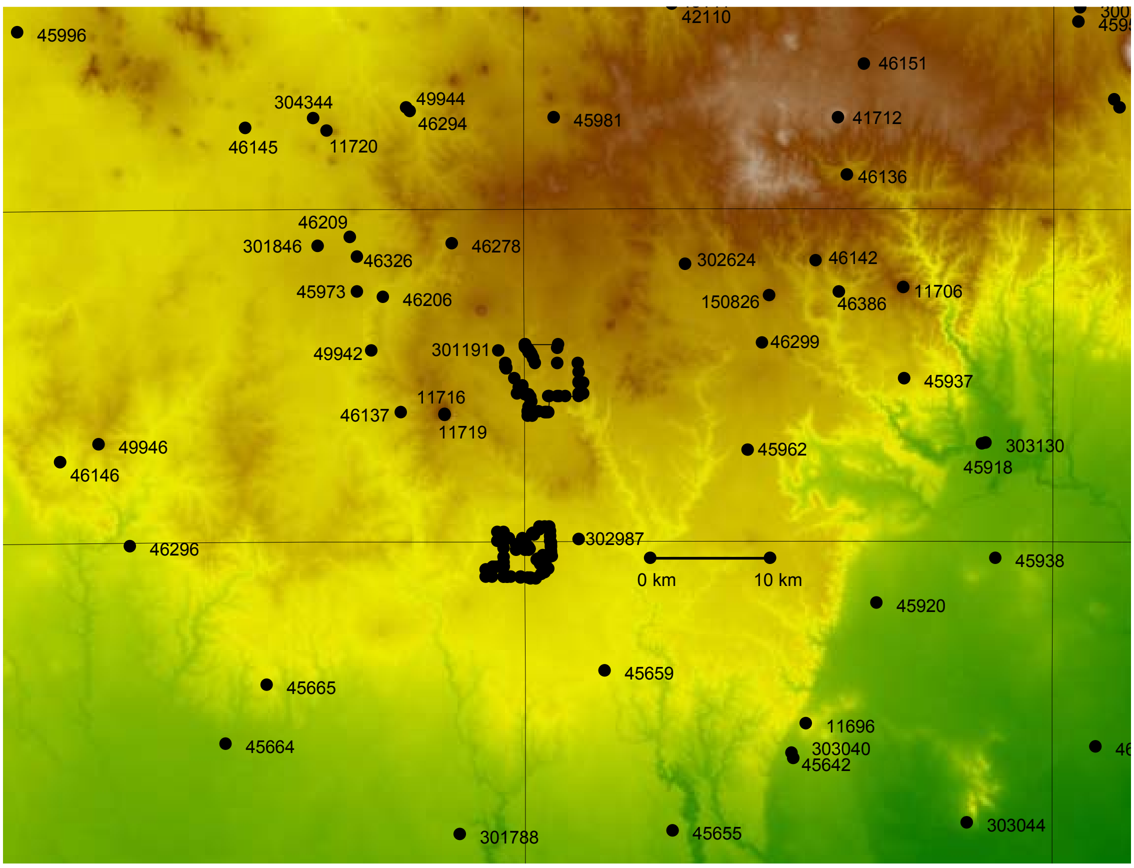


Figure 6.1– CFA mobile radio repeater sites and the Lal Lal Wind Farm

6.2 Analysis

GQ-AAS does not have detailed information on the CFA mobile radio network – the numbers of channels and how they are configured, overlapping coverage areas, etc, but we expect that the four sites close to the Yendon Section will have moderate to strong signal levels in the vicinity of the wind farm. GQ-AAS therefore expects that there will be significant margin for the signal levels from these repeaters in the wind farm area and in the areas where there is potential interference due to the wind farm.

The Blue Mountain site will have lower signal levels near the wind farms, but it may be designed to provide coverage to another area. If this is the case, GQ-AAS does not expect that the Yendon Section of the wind farm will cause any significant degradation of the coverage of the identified CFA fixed mobile radio repeaters.

A complete analysis of the CFA repeater sites is beyond the scope of this study.

7. CONCLUSIONS

From the study GQ-AAS concludes the following:

Fixed Links

1. Near field effects are restricted to locations very close to the transmitters.
2. If there is more than 57% of the first Fresnel zone clear of knife edge obstructions, wanted signal loss due to diffraction is not significant.
3. Diffraction exclusion zones are required for three of the four CFA links that have paths that cross the wind farm sites.
4. The interference due to reflections is only significant close to each end of the radio link (within 1 km).
5. The end points of all four CFA links that have paths that cross the wind farm sites are at a minimum distance of 6 km from the wind farms and therefore reflections from the wind turbines are extremely unlikely to have any effect on the CFA fixed link services.

Mobile Radio Services

6. Mobile radio services have the potential to be affected by wind turbines in a similar way to fixed link services.
7. The degree to which the mobile radio services are affected by wind turbines is mitigated by:
   - mobile radio being capable of operating adequately in less than ideal propagation conditions;
   - most locations in the mobile radio coverage area will not be affected, as the wind farm is likely to occupy only a small portion of the coverage area;
   - the effects are likely to be localised and moving a short distance may mean the effect is removed;
   - the effect is only likely to be noticed at the edge of coverage, where the signal level is low.
8. There is substantial anecdotal evidence is that mobile radio services and mobile phone services can operate successfully within the wind farm site.
9. There are a large number of CFA mobile radio repeater sites near the wind farms, implying that the wind farm area is well covered by CFA mobile radio services.

8. REFERENCES

The following reference documents were used to conduct this work:

1. Garrad Hassan report Revision B (Final), document number 2635/PR/001.
2. "Peer Review of Garrad Hassan Report – Lal Lal Wind Farm", 28 September 2007.
3. "Fixed-link wind-turbine exclusion zone method", D. F. Bacon, Version 1.1, 2002.
4. WestWind Energy Pty Ltd, Lal Lal Wind Farm Project Update 3, August 2007.
5. ITU-R Recommendation P.526-10 "Propagation by Diffraction"
6. ACMA Register of Radiocommunications Licences http://web.acma.gov.au/pls/radcom/register_search.main_page

Gibson Quai-AAS trusts that this paper meets WestWind requirements.

Yours sincerely

GIBSON QUAI – AAS PTY LTD

Tony Bower
Associate

Attachment: **Appendix A – CFA Path Profiles and Calculations**

A. APPENDIX A: PATH PROFILES AND CALCULATIONS

A.1 General

In each path profile:

- The red line represents the ray line between the transmitting and receiving antennas.
- The first and second Fresnel zones for the link are shown in blue.
- The flat plane earth is shown as the diagonally hatched area.
- The curvature of the earth is shown in orange (above the hatched area).
- The area of the wind farm is shown as the grey area with vertical lines.
- The k factor is 1.33.

A.2 Path ID 1 (ACMA Site ID) 11716 to (ACMA Site ID) 41712

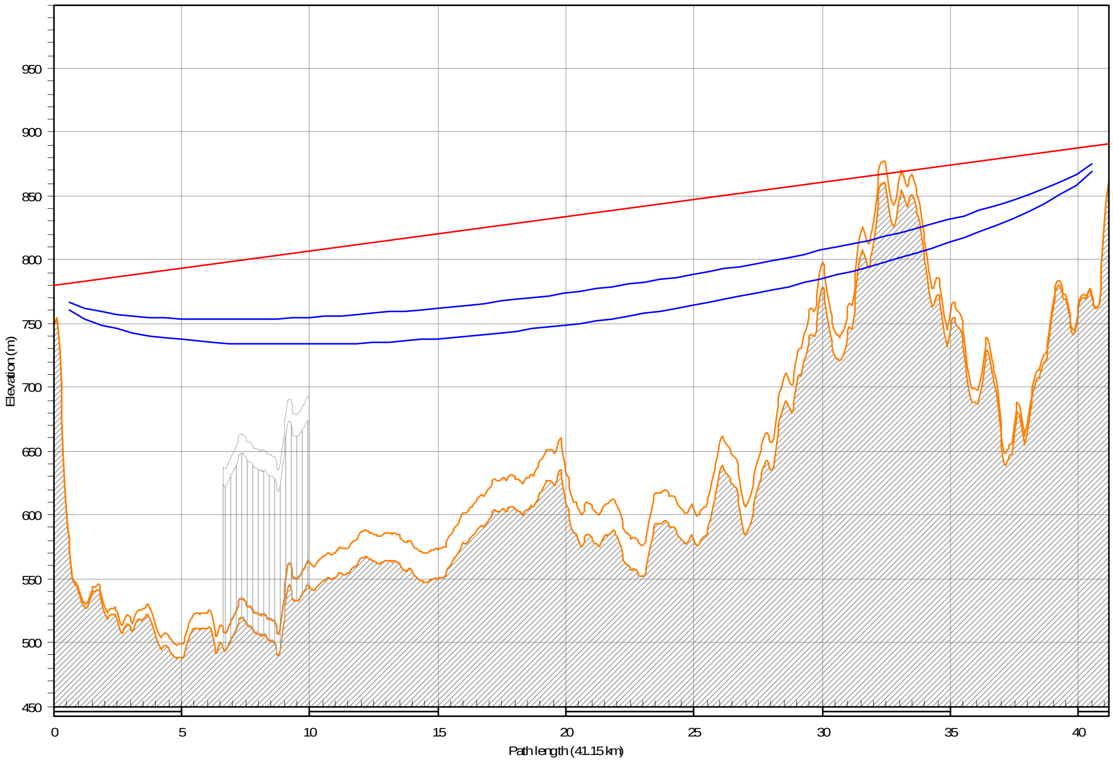
This link passes through the Yendon Section.

ACMA Site ID	Frequency	Wavelength	Gain	Near Field Distance (approximation)
11716	852.3875 MHz	0.352 m	16.2 dBi	4.9 m
41712	852.3875 MHz	0.352 m	16.2 dBi	4.9 m

Frequency	First Fresnel Zone (Maximum radius, m)	Second Fresnel Zone (Maximum radius, m)
852.3875 MHz	60	85
928.3875 MHz	58	82

The path profile for the link in the figure below shows the 1^{st} Fresnel zone is approximately 60 m above the maximum blade tip height (130 m AGL) of the proposed wind turbines.

No exclusion zone is required for this link.



11716	
Latitude	37 39 16.73 S
Longitude	143 55 29.78 E
Azimuth	53.10°
Elevation	749 m ASL
Antenna CL	30.0 m AGL

Frequency (MHz) = 852.0
K = 1.33
Fn = 1.00, 2.00

41712	
Latitude	37 25 53.29 S
Longitude	144 17 48.11 E
Azimuth	232.87°
Elevation	861 m ASL
Antenna CL	30.0 m AGL

	Sep 25 07	

A.2.1 Path ID 8 46299 to 11716

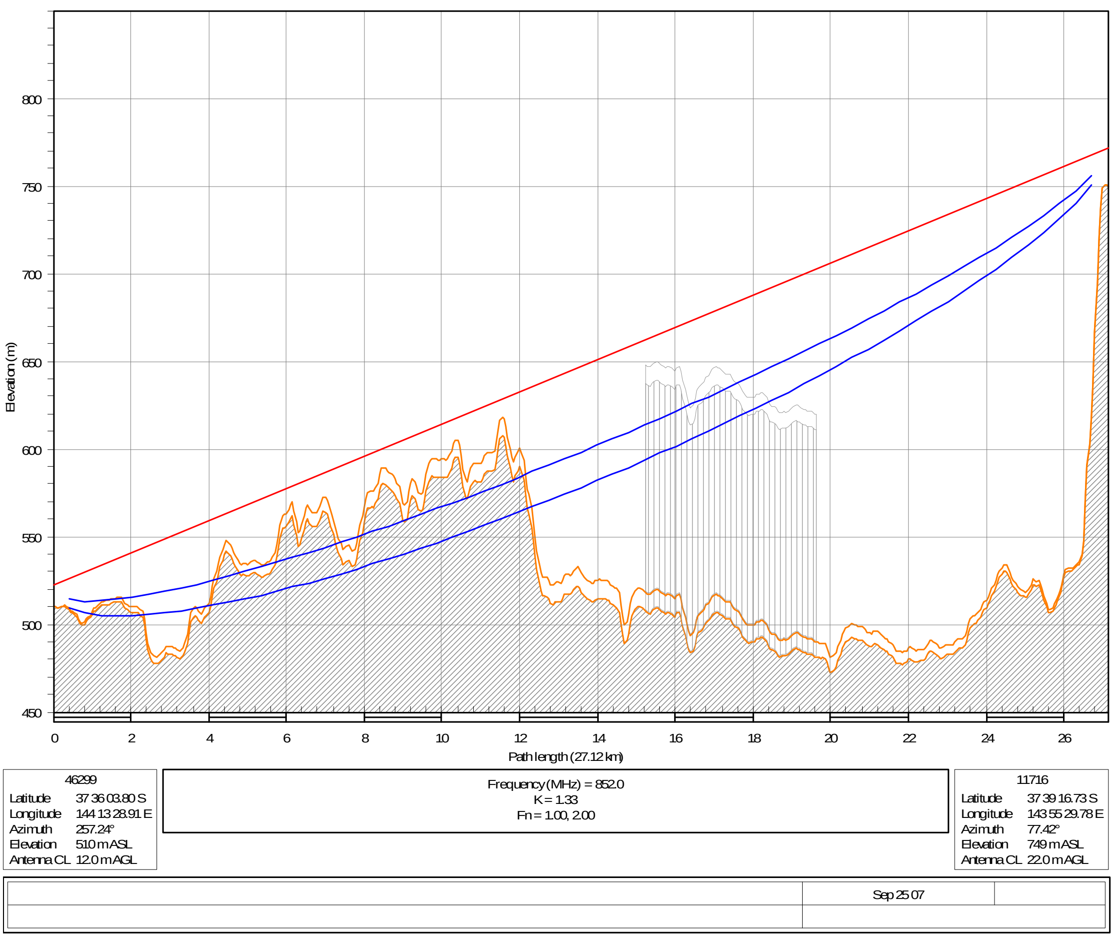
This link crosses above the Yendon Section.

ACMA Site ID	Frequency	Wavelength	Gain	Near Field Distance (approximation)
46299	852.2375 MHz	0.352 m	16.2 dBi	4.9 m
11716	852.2375 MHz	0.352 m	16.2 dBi	4.9 m

The path profile for the link in the figure below shows wind turbines placed in the path of the link (between 15 km and 18 km from the Fisken St Fire Station end, ACMA site ID 46299) will obstruct the 1st Fresnel zone.

Frequency	First Fresnel Zone (Maximum radius, m)	Second Fresnel Zone (Maximum radius, m)
852.2375 MHz	49	69
852.2375 MHz	49	69

An exclusion zone of 180 m is recommended for half of the Yendon Section along the path of this link.



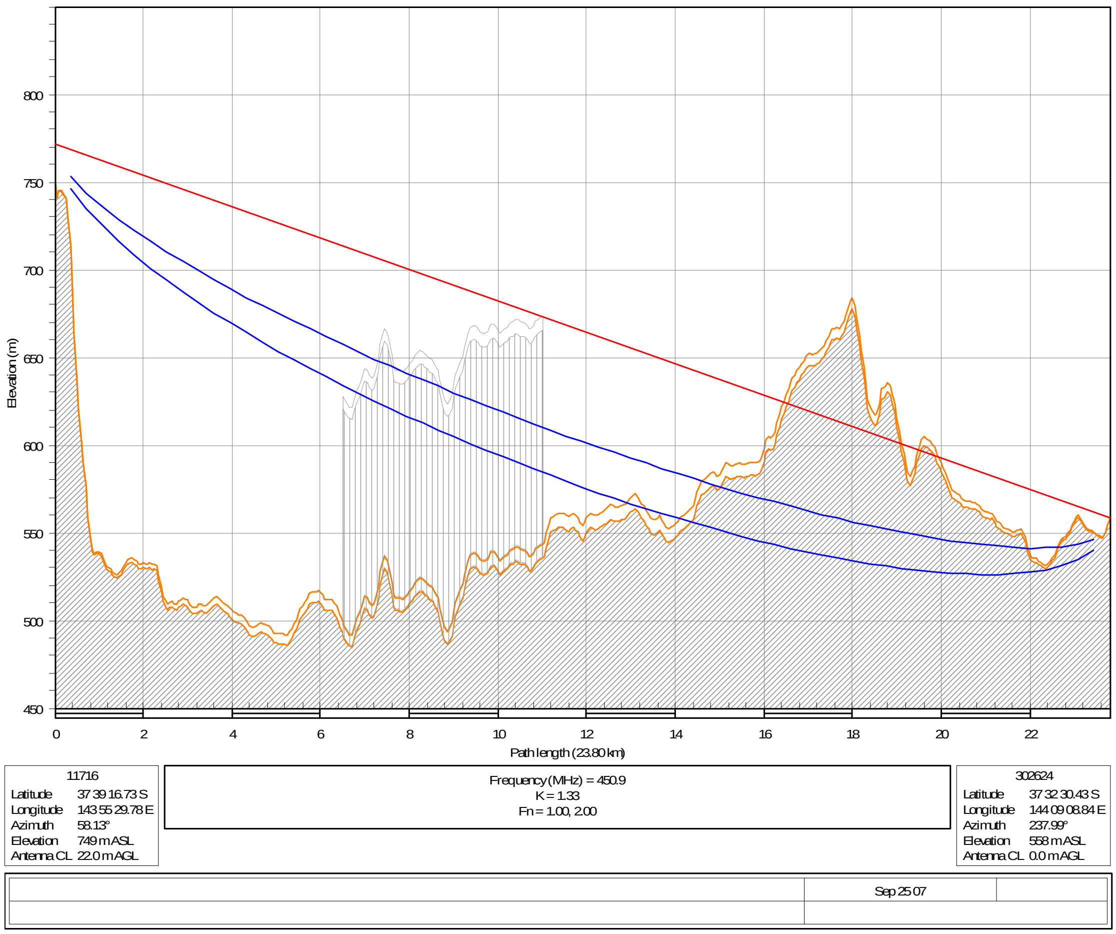
A.3 Yendon – GQ Paths

A.3.1 Path ID 12 302624 to 11716

This link passes through the Yendon Section.

ACMA Site ID	Frequency	Wavelength	Gain	Near Field Distance (approximation)
302624	450.9 MHz	0.665 m	13.1 dBi	4.53 m
11716	450.9 MHz	0.665 m	13.1 dBi	4.53 m

The path profile for the link in the figure below shows the operation of the path appears to rely on knife edge diffraction over the terrain obstruction 18 km from the Mt Buninyong end of the link.



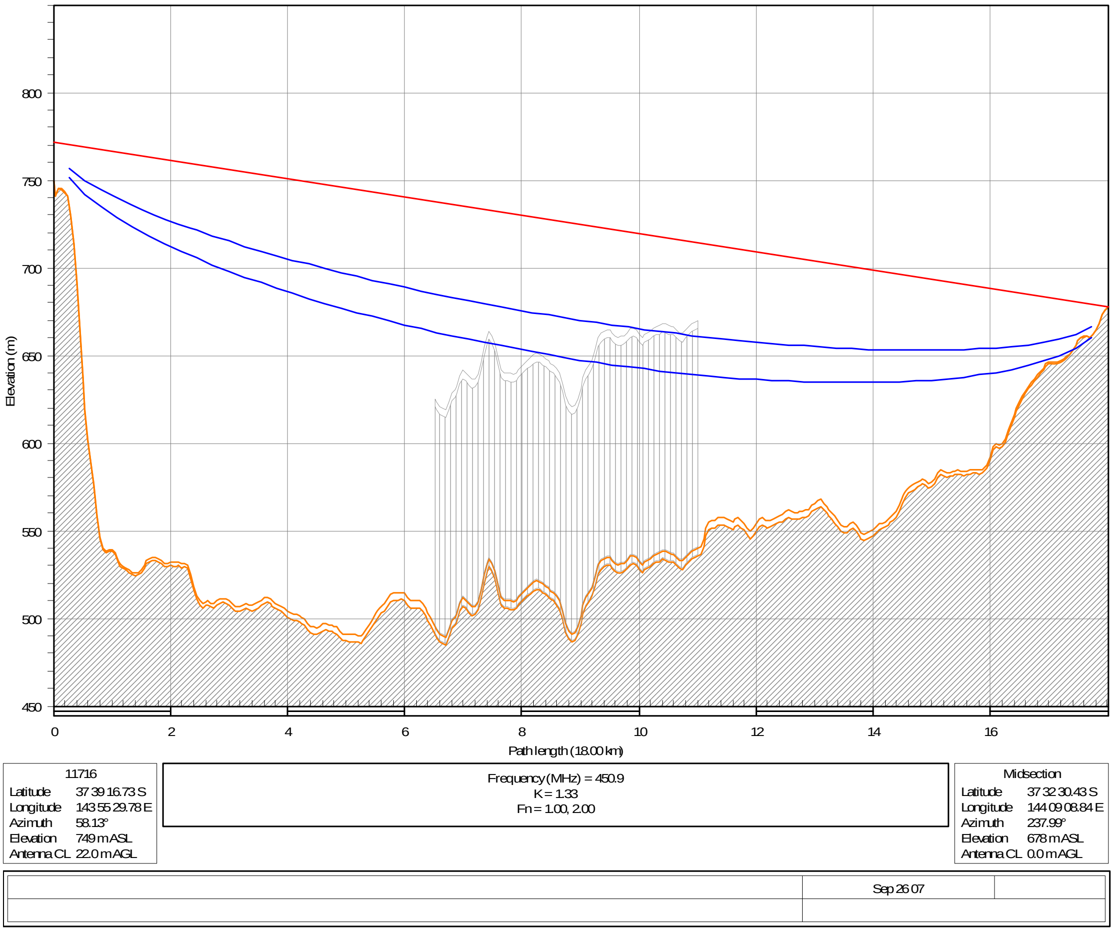
The Fresnel zone of interest is along the path from the Mt Buninyong site to the knife edge obstruction. This section of the path is shown in the following Figure. The first Fresnel zone of this path is smaller, as the path length is shorter.

A.3.2 Path ID 12 Midsection

The path profile for the midsection of the link in the figure below shows wind turbines along the path of the link will only provide an obstruction for the section of the Yendon Section between 10 and 11 km from the Mt Buninyong site.

Frequency	First Fresnel Zone (Maximum radius, m)	Second Fresnel Zone (Maximum radius, m)
450.9 MHz	62	88
450.9 MHz	62	88

An exclusion zone width of 206 m is recommended for this link.



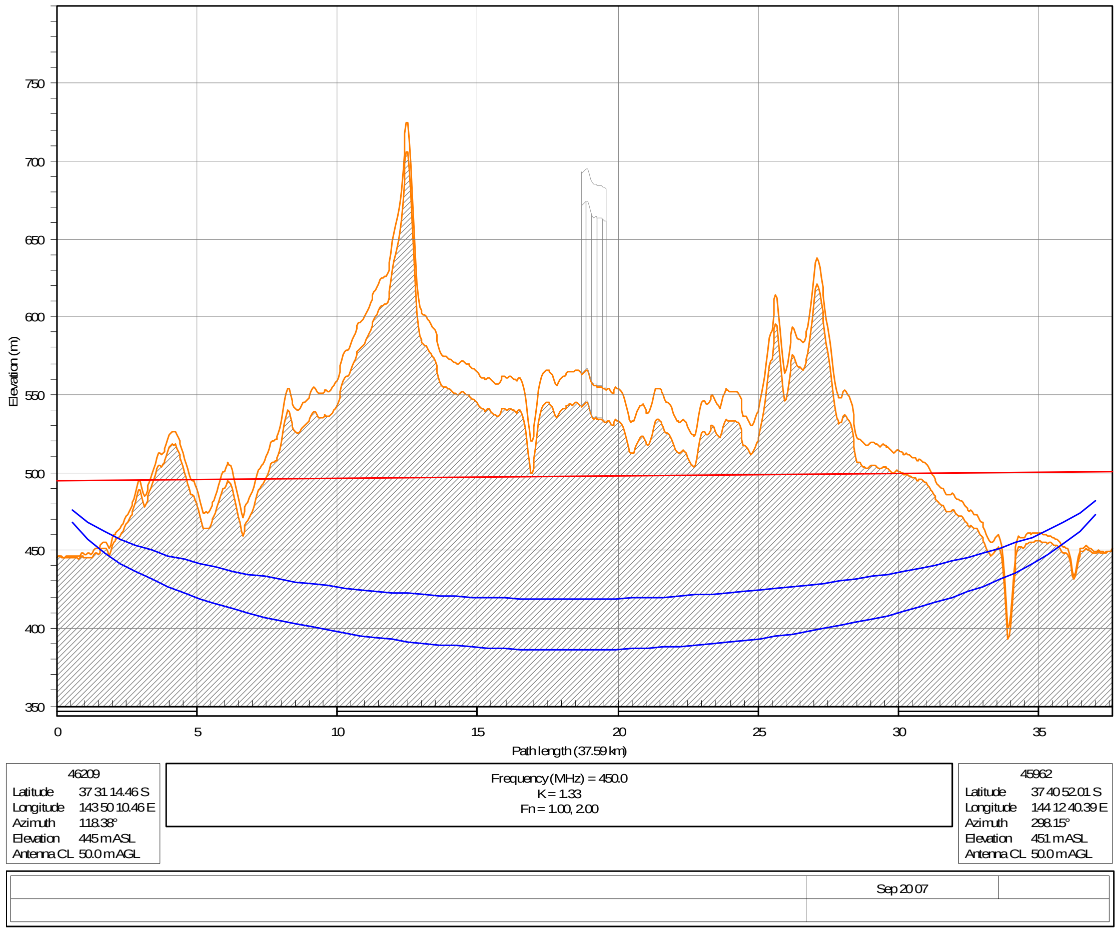
A.3.3 Path ID 13 45962 – 46209

This link passes through the Yendon Section.

ACMA Site ID	Frequency	Wavelength	Gain	Near Field Distance (approximation)
45962	450.65 MHz	0.666 m	13.1 dBi	3.3 m
46209	450.65 MHz	0.666 m	11.7 dBi	4.5 m

The path profile for the link in the figure below shows the operation of the path appears to rely on knife edge diffraction over two terrain obstructions 12.5 km and 27 km from the Ballarat end of the link (Mt Warrenheip and Mt Egerton respectively).

The first obstruction is Mt Warrenheip. In reality the radio path may diffract around the side of this obstruction, and this may not be indicated in the path profile due to small inaccuracies in the location of the two end sites.



The Fresnel zone of interest is along the path between the two diffraction points. This segment of the path is shown in the following Figure.

A.3.4 Path ID 13 Midsection

The path profile for the link in the figure below shows wind turbines along this segment of the path will obstruct the 1st Fresnel zone of the link.

Frequency	First Fresnel Zone (Maximum radius, m)	Second Fresnel Zone (Maximum radius, m)
450.65 MHz	79	112
450.65 MHz	79	112

An exclusion zone width of 240 m is recommended for this link.