Protection Ratio Calculation Methods for Fixed Radiocommunications Links

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Abstract

This paper describes three methods of calculating required interference protection ratios for Fixed Link radiocommunications receivers, using ITU-R prediction methods. The Initial Planning Method in common use in Australia can be used to predict the required fade margins for Fixed Links operating at frequencies where the dominant fade mechanism is multipath. The Detailed Link Planning Method can be used to determine more rigorous fade margin requirements for specific Fixed Links with known system and path parameters. The updated ITU-R Method for Small Percentages of Time has the potential to be implemented in a semi-automated way, without reference to topographic information or path profiles. Input of averaged parameters is replaced with specific known parameters at Fixed Link path locations.

1. Introduction

The calculation methods used to determine required levels of protection from noise and interference for microwave fixed services in Australia are given in the Australian Communications and Media Authority (ACMA) document Radiocommunications Assignment and Licensing Instruction No.FX-3 (RALI FX3), Microwave Fixed Services: Frequency Coordination [1, 2]. The methodology and assumptions that underpin the RALI FX-3 Protection Ratios and Correction Factor curves are not well described and have not been updated in accordance with ITU recommendations for a significant period. Anecdotal evidence suggests that in many cases, the protection criteria afforded to Fixed Links are well in excess of that required for their efficient operation. A need also exists for a review and clarification of the calculation methodology.

This paper describes three calculation methods which can be used to determine the required fade margins and levels of protection from noise and interference for point-to-point fixed service receivers (Fixed Links) in the 1.5 GHz band. While the 1.5 GHz band was chosen for this study, the methods are of general application and may be used for interference coordination of Fixed Links for which the dominant fade mechanism is multipath fading. Calculations of protection criteria for links with rain fade as the dominant mechanism are not considered in this paper.

1.1 The commonly used method of Protection Ratio calculation.

Initially, the protection ratios currently defined in RALI FX-3 are described in the context of their derivation from the Initial Planning Method (IPM) as presented in ITU Recommendations and Reports [3]. This method provides a way to determine interference protection ratios for all fixed links operating at frequencies where the dominant fade mechanism is multipath fading. The principal advantage is that protection ratios are simply and easily determined from a graphical perspective over a range of path lengths. The approach does not require complex calculations to be performed and is considered adequate for Fixed Link paths over flat terrain, however it can be shown that, for all other path types the protection ratio allowed is overly conservative for the protection of Fixed Links.

1.2 A more accurate method of Protection Ratio calculation.

The Detailed Link Planning Method (DLPM) as presented in ITU Recommendations and Reports [3] is implemented to determine more rigorous protection ratio requirements for specific Fixed Links, given known path and equipment parameters. Reference to printed topographic maps to calculate an *average grazing angle* along the radio path is required for each Fixed Link calculation. The advantage over the simple (IPM) graphical method is that the resulting protection ratio is typically less conservative for a given Fixed Link. This method has the potential to allow more efficient use of the available radiofrequency spectrum by increasing the number of possible Fixed Link assignments in a particular band and geographical area. The primary drawback of this method is the time and effort required to determine terrain heights and undertake complex calculations.

1.3 A method for future software implementation

The approach to determining protection ratios as presented in updated ITU Recommendations [4] is investigated with regard to its possible future use as a method of Protection Ratio calculation which can be implemented using software. Such an approach has the potential to significantly reduce the labour-intensive nature of using the DLPM, by using excisions and manipulations of data from a Digital Elevation Model (DEM) to calculate an *area surface roughness factor* for the relevant path in preference to calculating an *average grazing angle*, along with the use of a *refractivity gradient* dataset covering the Australian continent. This updated method allows the input of specific known data in preference to using 'averaged' factors for calculating climate and terrain effects.

2. Initial Planning Method for fixed link receivers

The Initial Planning Method can be used to calculate a value of required fade margin for Fixed Links. The fade margin represents the predicted maximum fade depth exceeded for a specified percentage of time due to anomalous atmospheric attenuation of the signal received at a Fixed Link radiocommunications receiver. It is dependant on the required threshold Bit Error Ratio (BER) in the case of digital receivers, as well as frequency, path length and profile, occupied bandwidth, required time percentage availability and the variability of the refractivity gradient in the lowest section of the troposphere. The algorithms used to calculate fade margin were developed by researchers in a semi-empirical way utilising measurements of received signal degradation due to fading on existing Fixed Links at various locations.

Protection ratios include a fixed margin for noise and interference. This fixed margin is the difference in power level between a wanted minimum signal arriving at a receiver and any unwanted received signals which constitute interference. The reception of a wanted signal at an acceptably high power level allows the receiver to operate at a defined minimum BER which is required for a minimum standard of operation. The level of acceptable interference is normally set at 6dB or 10dB below the calculated noise floor of a given Fixed Link receiver [7]. The calculated fade margin and the fixed margin for noise and interference constitute the required protection ratio for a particular Fixed Link receiver with known path length and profile type.

In this study based on the 1.5 GHz band, the parameters of an AWA RMD1500 receiver [8] were adopted. This receiver type is widely deployed in Australia and can be considered representative in the band. A required BER of 10^{-3} was assumed, requiring a minimum received level of -95 dBm.

Figure 1 is a reproduction of the Protection Ratio Correction Factor curve as presented in RALI FX3 for the 1.5 GHz band. The curve was produced using an adaptation of the semi-empirical algorithm for calculating necessary Fade Margin as presented in ITU Report 338-5 (1986) [3] *equation (1),*

$$FM = 10\log\left[\,K\ f^{0.89}\,d^{3.6}\left(1+\left|\varepsilon_p\right|\right)^{-1.4}\right] - 10\log P \quad \textbf{\textit{(1)}}$$

using a conservative ***K*** factor for climate and terrain effects (*overland paths not in mountainous regions*).

$$K = 10^{-6.5} * \ P_L^{1.5}, \quad \left(P_L = 20\right)$$

Where,

$$f = frequency\ in\,GHz$$

$$d = Path\,Length\ in\ km$$

$$\varepsilon_p = path\ inclination\ in\ milliRadians$$

and taking into account the calculated noise floor of a receiver with 4MHz Bandwidth,

$$kTB\,(dBm) = 10\log\left(1.38^{-23} * 288 * 4 * 10^{6}\right) + 30 = -108\ dBm$$

The acceptable interference level is set to 6dB below the calculated noise floor in order to reproduce the RALI FX3 curve in Figure 1. This setting allows the Protection Ratio Correction Factor (PRCF) to be zero at a nominal path length of 60 km in the 1.5 GHz band. The protection ratio for the nominal path length (10 log *P*) is therefore 60 dB.

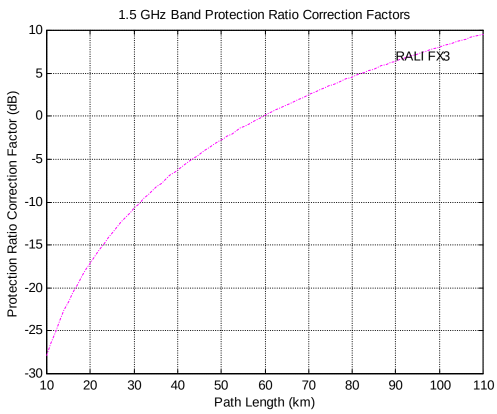

Figure 1. RALI FX3 Protection Ratio Correction Factors for the 1.5 GHz band.

3. Detailed Link Planning Method for selected fixed link receivers

The Detailed Link Planning Method (DLPM) is detailed in Recommendations and Reports of the CCIR Report 338-5 of 1986 [3] and in a modified form in RALI FX-3 of October 1992. [2]

The method can be applied to any fixed link where terrain heights along the path at regular intervals are known. Such data can be obtained from printed topographic maps or from digital elevation models (DEM) such as the Auslig 1:250000 raster. The terrain heights are used to calculate Average Grazing Angle[1] using the method of least squares. Protection Ratios are calculated for a number of apparatus licensed Fixed Links in Australia which are considered to be representative of links operating over 'flat', 'average' and 'mountainous' terrain.[2]

Figure 2 shows a Protection Ratio curve similar to that presented in RALI FX3 for the 1.5 GHz band. The curve was produced using the Initial Planning Method as above.

Specific protection ratios for selected Fixed Links were calculated using the semi-empirical algorithm for Detailed Link Planning Method for calculating necessary Fade Margin *equation (2),*

$$FM = 10\log\left[K f^{0.93} d^{3.3}\left(1+\left|\varepsilon_p\right|\right)^{-1.1} \phi^{-1.2}\right] \qquad \textbf{\textit{(2)}}$$

using a conservative ***K*** factor for 'Flat' or 'Average' terrain;

$$K = 10^{-6.5} * P_L^{1.5}, \quad (P_L = 20)$$

for climate and terrain effects (*overland paths not in mountainous regions*).

Or using another ***K*** factor for 'Mountainous' terrain;

$$K = 10^{-7.1} * P_L^{1.5}, \quad (P_L = 20)$$

for climate and terrain effects (*overland paths in mountainous regions*).

Where,

$$f = frequency\ in\, GHz$$
$$d = path\, length\ in\ km$$
$$\varepsilon_p = path\ inclination\ in\ milliRadians$$
$$\phi = average\ \ grazing\ \ angle$$

[1] Average Grazing Angle is calculated at a reflection point along the path, taking into account antenna heights and the terrain profile.

[2] 'Flat' or 'Average' terrain is defined here as analogous to *overland paths not in mountainous regions.*

'Mountainous' terrain is defined here as analogous to *overland paths in mountainous regions.*

and taking into account the calculated noise floor of a receiver with 4MHz Bandwidth.

Figure 2 also depicts the calculated Protection Ratios of various existing Fixed Links over almost 'flat' terrain. In this representation, Protection Ratios can be read directly from the graph for both the Initial Planning Method, (equivalent to the RALI FX3 curve) and the Detailed Link Planning Method. (*ie* no adjustment for Correction Factor is required). The level of acceptable interference into Fixed Link receivers is set at a more conservative level of 10dB below the calculated noise floor of the representative receiver. A control calculation referred to as Hypothetical Flat is used to depict a theoretical fixed link path of 60 km length operating over perfectly flat terrain, with transmit and receive antenna heights both set at 100m above ground level. The calculation result indicates that such a hypothetical link would be under-protected by the provisions of RALI FX3 by approximately 3dB. In practical situations, terrain paths are not perfectly flat and advantage is taken of transmit and receive antenna height differences to decrease the likelihood of fading due to anomalous propagation.

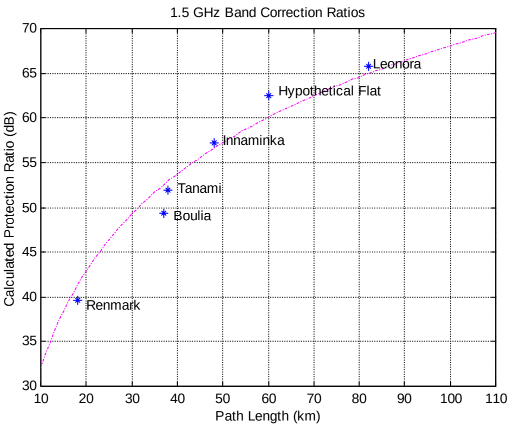

Figure 2. Protection Ratios for Fixed Links over 'Flat' terrain

There is a close correlation between the calculated protection ratios for existing Fixed Links operating over nearly flat terrain using the Detailed Link Planning Method, and the protection afforded to all fixed links by RALI FX3 using the Initial Planning Method. This result indicates that adequate protection is currently provided to fixed links operating over 'flat' terrain. The average level of overprotection afforded to the selected Fixed Links by RALI FX3 is 0.8 dB.

Figure 3 depicts the calculated Protection Ratios of various Fixed Links over 'average' terrain. Average terrain is defined here as terrain which is neither flat nor mountainous. These links normally have one or both masts and antennas located on a hilltop. The intervening terrain along the path (*the path profile*) may vary from partially flat to undulating.

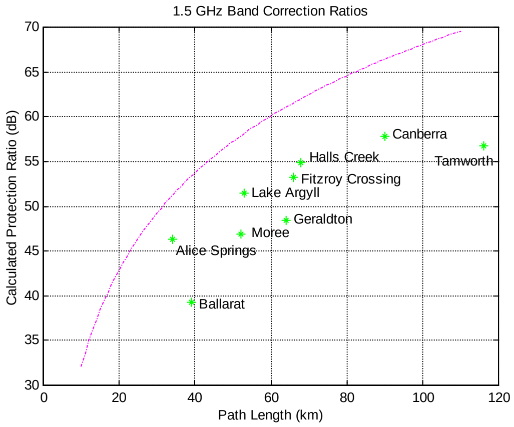

Figure 3. Protection Ratios for Fixed Links over 'Average' terrain

Reference to Figure 3 indicates that Fixed Links operating over 'average' terrain are generally afforded a higher level of protection from interference by the Initial Planning Method than is necessary for their reliable operation. The Fixed Links studied are representative of those operating over average terrain with a range of path lengths and situated in various locations on the Australian continent. The calculated level of over-protection varies between 5dB and 14dB over the range of Fixed Links selected, with an average of 9.25 dB.

Figure 4 depicts the calculated Protection Ratios for various Fixed Links over 'Mountainous' terrain. In all links depicted there is a significant difference in antenna heights above sea level and large variation in terrain height over the path profile.

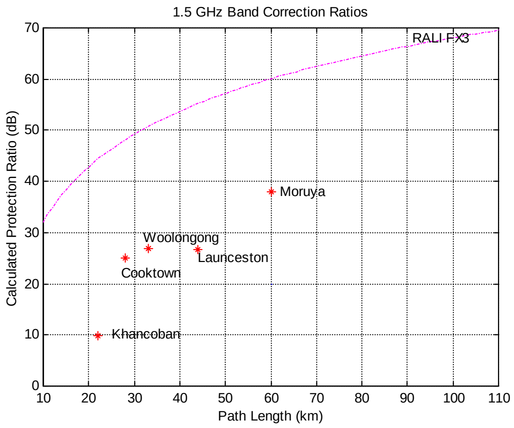

Figure 4. Protection Ratios for Fixed Links over 'Mountainous' terrain

Reference to Figure 4 indicates that Fixed Links over 'Mountainous' terrain are generally afforded a significantly higher level of protection from interference by the Initial Planning Method than is necessary for their reliable operation. The Fixed Links studied are representative of those operating over 'mountainous' terrain with a range of path lengths and situated in various locations on the Australian continent. The calculated level of over-protection varies between 21dB and 28dB over the range of existing fixed links selected, with an average of 24dB. It should be noted that the result for Khancoban at -35 dB is not considered reliable as the path length is very short and the calculated grazing angle due to significant antenna height difference and path profile variation is large, however the grouping of Cooktown, Wollongong , Launceston and Moruya suggests a more realistic outcome.

4. Alternative Protection Ratio Calculation Method

An alternative empirically derived Protection Ratio calculation method, reproduced from ITU-R 530/9 of 2001 (*Fading and enhancement due to multipath and related mechanisms: Method for small percentages of time*) [4] and presented below can be used to determine protection ratios for individual Fixed Links, taking into account their path profiles and point refractivity gradients.

For detailed link design applications, calculate the percentage of time p_W that fade depth A (dB) is exceeded in the average worst month from
equation (3)

$$p_w = K\ d^{3.2}\left(1+\left|\varepsilon_p\right|\right)^{-0.97} 10^{0.032 f - 0.00085 h_L - A/10}\quad \% \qquad \textbf{(3)}$$

where,

$$f = frequency\ in\, GHz$$
$$d = Path\ Length\ in\ km$$
$$\varepsilon_p = path\ inclination\ in\ milliRadians$$
$$h_L = altitude\ of\ the\ lower\ antenna$$

*and the geoclimatic factor **K** is obtained from equation (4).*

Extract from ITU-R 530.9

*equation (4) for the geoclimatic factor K, was derived from multiple regressions on fading data for 251 links in various geoclimatic regions of the world with path lengths **d** in the range of 7.5 to 185 km, frequencies **f** in the range of 450 MHz to 37 GHz, path inclinations ε_p up to 37 mrad, lower antenna altitudes h_L in the range of 17 to 2 300 m,* *refractivity gradients* $\boldsymbol{dN_1}$ *in the range of –860 to –150 N-unit/km, and area surface roughnesses* $\boldsymbol{s_a}$ *in the range of 6 to 850 m (for* $s_a < 1$ *m, use a lower limit of 1 m).*

$$K = 10^{-3.9 - 0.003\, dN_1}\, s_a^{-0.42} \qquad \textbf{(4)}$$

*s_a (area surface roughness) is defined as the standard deviation of terrain heights (m) within a 110 km * 110 km area with a 30 s resolution.*

The algorithm used to find p_w *(equation 3)* determines the *time percentage that fade depth is exceeded in the average worst month*, given a required fade depth.

Equation 3 can be manipulated to determine the *fade depth*, given a required time percentage that fade depth is exceeded in the average worst month, as follows; *(equation 5)*

$$let \quad a = Pwx \,/\, \left(K\, d^{3.2}\left(1+\varepsilon_p\right)^{-0.97}\right) \qquad \textit{where } Pwx = 0.01\%$$

$$let \quad y = \log_{10}(a) \,/\, \log_{10}(10)$$

$$then, \quad A = \left(y - 0.032\, f + 0.00085 h_L\right) * -10 \qquad \textbf{(5)}$$

Given a required time percentage of 0.01%, the resulting fade margin (***A***) can be calculated for a range of path lengths. The standard deviation of terrain height data extracted from a Digital Elevation Model (the *area surface roughness*) is required for this implementation.

Protection Ratios depicted in Figure 5 are calculated using the updated and modified algorithm, *(equation 5)* with no change in the noise floor calculation or BER = 10^{-3} receive level applicable to 1.5 GHz Fixed Links using AWA RMD1500 receivers. The maximum allowable level of Interference is set to 6 dB below the noise floor of the receiver. The resulting curve is plotted along with a Protection Ratio curve derived from the Initial Planning Method. *(equation 1).*

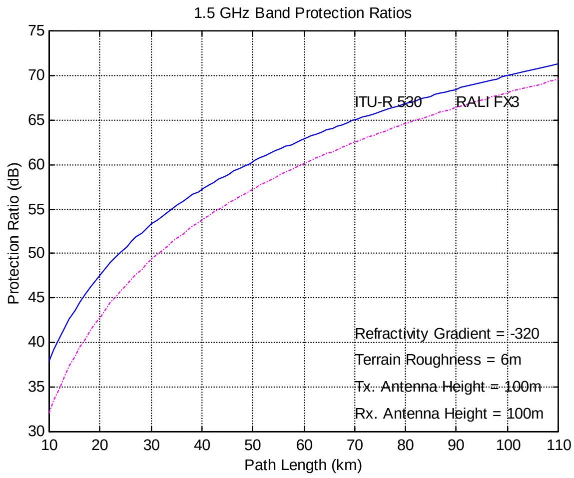

Figure 5. Comparison of ‘Flat’ Terrain Protection Ratios

Using the modified ITU-R P530 method (*equation 5*) provides an opportunity to enter known parameters specific to terrain roughness, antenna height, and refractivity gradient. It can be seen from figure 5 that using terrain roughness, transmit and receive antenna heights and refractivity gradient as noted on figure 5, the modified ITU-R P530 method produces a similar result to the existing RALI FX3 curve, and passes through the point previously calculated for ‘Flat’ terrain (Hypothetical Flat) using the Detailed Link Planning Method.

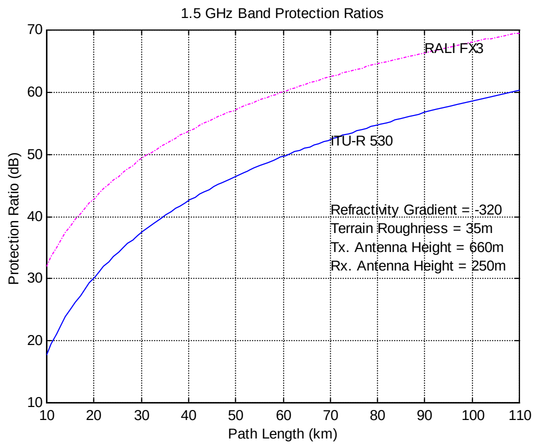

Figure 6. Comparison of ‘Average’ Terrain Protection Ratios

Figure 6 depicts a Protection Ratio curve specific to ‘average’ terrain by varying the terrain roughness and antenna elevation parameters to similar values applicable to links over ‘average’ terrain. (*equation 5*). This curve passes through the region previously calculated for ‘average’ terrain using the Detailed Link Planning Method.

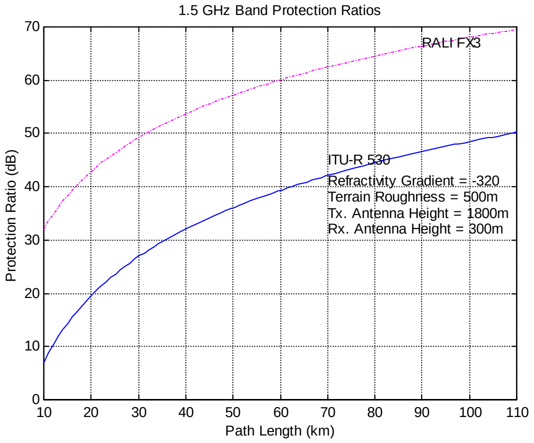

Figure 7. Comparison of 'Mountainous' Terrain Protection Ratios

Figure 7 depicts a Protection Ratio curve specific to 'mountainous' terrain by varying the terrain roughness and antenna elevation parameters to similar values applicable to 'mountainous' terrain links. This curve passes through the region previously calculated for 'mountainous' terrain using the Detailed Link Planning Method. It should be noted that this method is not reliable for very short path lengths with significant antenna height differences.

5. Conclusions

Three significant conclusions have been reached after implementing and comparing the methods of protection ratio calculation for Fixed Links as detailed in this paper.

5.1 The Protection Ratio Correction Factor curves presented in RALI FX3 are derived from the *Initial Planning Method* as presented in Recommendations and Reports of the CCIR, XVI Plenary Assembly, Dubrovnik, 1986, Report 338-5. [3] The curves as currently implemented provide a method to determine an adequate and often conservative protection ratio for all Fixed Links where the dominant fade mechanism is multipath fading.

5.2 The *Detailed Link Planning Method* as presented in Recommendations and Reports of the CCIR, XVI Plenary Assembly, Dubrovnik, 1986, Report 338-5 [3] can be used to calculate protection ratios for Fixed Links with known path and equipment parameters. Use of this method often results in a significantly less conservative protection ratio required for a given Fixed Link. A link that may otherwise fail coordination can often be successfully coordinated using the Detailed Link Planning Method, allowing for the efficient use of the radiofrequency spectrum by Fixed Links.

5.3 The *modified Method for Small Percentages of Time* (*equation 5*), referenced from ITU-R P530/9 of 2001 [4] and detailed in this document can be used to calculate protection ratios for all Fixed Links where the dominant fade mechanism is multipath fading. Algorithms were developed and improved for this semi-empirical method by researchers at multiple locations, taking into account fade measurement statistics on operating Fixed Links. The calculated results are comparable to those produced by the Detailed Link Planning Method. The *modified Method for Small Percentages of Time* has the potential to be implemented in a semi-automated way, without reference to physical topographic maps or charts. It uses data extracted from a *Digital Elevation Model* and takes into account the known values of *Refractivity Gradient* at the location of a Fixed Link.

6. References

[1] **RALI FX3 Microwave Fixed Services: Frequency Coordination** 1992 Sequence No. 12
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[2] **RALI FX3 Microwave Fixed Services: Frequency Coordination** 1998 Sequence No. 137
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[3] **REPORTS OF THE CCIR**
XVI Plenary Assembly, Dubrovnik Report 338-5 1986
Propagation Data and Prediction Methods Required for Line-of-Sight Radio-Relay Systems

[4] **RECOMMENDATION ITU-R P.530-9** 2001
Propagation data and prediction methods required for the design of terrestrial line-of-sight systems

[5] **RECOMMENDATION ITU-R P.453-8** 2001
The radio refractive index: its formula and refractivity data

[6] **RECOMMENDATION ITU-R P.452-11** 2003
Prediction procedure for the evaluation of microwave interference between stations on the surface of the Earth at frequencies above about 0.7 GHz

[7] **RECOMMENDATION ITU-R F.758-2** 2000
Considerations in the development of criteria for sharing between the terrestrial fixed service and other services

[8] **AWA RMD1500**
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