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| Radar and IMT Adjacent Band Sharing at 2700 MHz |
| Spectrum Planning Paper SPP 07/2011 |
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Contents

[Contents iii](#_Toc292291667)

[Figures iv](#_Toc292291668)

[Tables v](#_Toc292291669)

[List of Acronyms and Abbreviations vi](#_Toc292291670)

[Executive Summary 8](#_Toc292291671)

[1. Literature Review 10](#_Toc292291672)

[1.1. The Previous ACMA Sharing Study 10](#_Toc292291673)

[1.2. Ericsson submission to WP8F 615 12](#_Toc292291674)

[1.2.1. Theoretical Analysis 12](#_Toc292291675)

[1.2.2. Simulation 14](#_Toc292291676)

[1.3. Ericsson submission to WP8F 696 17](#_Toc292291677)

[1.4. Report ITU-R M.2112 19](#_Toc292291678)

[1.5. Recommendation ITU-R M. 1464 20](#_Toc292291679)

[1.6. ERA Technology Practical Experiment 21](#_Toc292291680)

[1.7. Ofcom submission to WG5B 24](#_Toc292291681)

[1.8. SELEX report on Watchman Radars 26](#_Toc292291682)

[2. Radars around Australia 28](#_Toc292291683)

[3. Mathematical Analysis of Radar and OFDM LTE receivers 30](#_Toc292291684)

[4. IMT Blocking Analysis 34](#_Toc292291685)

[4.1. Radar Antenna and Emission masks 34](#_Toc292291686)

[4.2. Radar and IMT parameters 34](#_Toc292291687)

[4.3. Methodology 35](#_Toc292291688)

[4.4. Results 36](#_Toc292291689)

[4.5. Further Analysis 36](#_Toc292291690)

[4.6. Conclusion 37](#_Toc292291691)

[5. Radar Blocking and Interference 38](#_Toc292291692)

[5.1. Selectivity Masks 39](#_Toc292291693)

[5.2. Radar and IMT parameters 40](#_Toc292291694)

[5.3. Method 41](#_Toc292291695)

[5.4. Interference and Blocking Standard Situation 44](#_Toc292291696)

[5.4.1. Meteorological Radar Results 44](#_Toc292291697)

[5.4.2. Aeronautical Radar Results 45](#_Toc292291698)

[5.5. Interference and Blocking Restricted Situation 45](#_Toc292291699)

[5.5.1. Meteorological Radar Results 46](#_Toc292291700)

[5.5.2. Aeronautical Radar Results 46](#_Toc292291701)

[5.6. Blocking situation with Ofcom mask 47](#_Toc292291702)

[5.7. Discussion of Results 47](#_Toc292291703)

[5.7.1. Sensitivity to Selectivity 48](#_Toc292291704)

[5.7.2. Ofcom Blocking Mask 49](#_Toc292291705)

[5.7.3. Heights and Antenna Discrimination 50](#_Toc292291706)

[5.7.4. Category B Radars 52](#_Toc292291707)

[6. Conclusions 53](#_Toc292291708)

[References 55](#_Toc292291709)

Figures

[Figure 1: Calculated radar emission mask (1) 11](#_Toc289847968)

[Figure 2: Calculated radar selectivity mask (1) 11](#_Toc289847969)

[Figure 3: Theoretical Effect of radar cochannel interference to a linear IMT/WCDMA receiver. Raw BER vs SRR (2) 13](#_Toc289847970)

[Figure 4: Raw BER versus SRR for co-channel interference and WCDMA spreading factor 8 (2) 14](#_Toc289847971)

[Figure 5: Envelope of filtered pulses of radar E (long) with different frequency offsets (2) 16](#_Toc289847972)

[Figure 6: Raw BER versus SRR for 20 MHz frequency offset and WCDMA spreading factor 8 (2) 16](#_Toc289847973)

[Figure 7: Model of antenna pattern for meteorological radar (Radar E) (6). 17](#_Toc289847974)

[Figure 8: Model of antenna pattern for aeronautical radar (Radar C) (6). 18](#_Toc289847975)

[Figure 9: Time variation of raw BER due to radar antenna rotation with a period of 6 seconds. Parameters: Co-channel operation of radar E; Spreading factor 128; without radar interference the raw BER is 5% (5). 18](#_Toc289847976)

[Figure 10: Time variation of raw BER due to radar antenna rotation with a period of 6 seconds. Parameters: Co-channel operation of radar C; Spreading factor 128; without radar interference the raw BER is assumed to be 5% (5). 19](#_Toc289847977)

[Figure 11: Measured selectivity mask for Radar B 21](#_Toc289847978)

[Figure 12: Conducted measurement setup for radar interference into UMTS(8) 22](#_Toc289847979)

[Figure 13: Airport A radar’s measured emissions and calculated mask (8) 23](#_Toc289847980)

[Figure 14: Airport B radar’s measured emissions and calculated mask (8) 23](#_Toc289847981)

[Figure 15: Airport C radar’s measured emissions and calculated mask (8) 24](#_Toc289847982)

[Figure 16: Airport D radar’s measured emissions and calculated mask (8) 24](#_Toc289847983)

[Figure 17: Watchman Radar blocking levels 25](#_Toc289847984)

[Figure 18: Watchman Radar receiver architecture (10) 26](#_Toc289847985)

[Figure 19: Location of 2.7 – 3.1 GHz radar sites around Australia 28](#_Toc289847986)

[Figure 21: Sample signal with radar interference before A/D (2) 31](#_Toc289847987)

[Figure 22: Indicative OFDM symbol power with radar interference 32](#_Toc289847988)

[Figure 23: Relationship between emission and selectivity masks 38](#_Toc289847989)

[Figure 24: Abstraction of a receiver chain showing where blocking and interference occur 39](#_Toc289847990)

[Figure 25: Antenna discrimination due to common placement of radars and base stations 51](#_Toc289847991)

Tables

[Table 1: Coordination and Restriction Zones 9](#_Toc289847992)

[Table 3: IMT mobile characteristics 35](#_Toc289847993)

[Table 4: Received power with 15 MHz separation 36](#_Toc289847994)

[Table 5: Received power with 40 MHz separation 36](#_Toc289847995)

[Table 6: Meteorological radar parameters 40](#_Toc289847996)

[Table 7: Aeronautical radar parameters 41](#_Toc289847997)

[Table 8: IMT parameters 41](#_Toc289847998)

[Table 9: Propagation loss (dB) at various separation distances 43](#_Toc289847999)

[Table 10: Meteorological radar, ‘standard situation’, 15 MHz separation interference and blocking results (received power in dBm) 44](#_Toc289848000)

[Table 11: Meteorological radar, ‘standard’ situation, 40 MHz separation interference and blocking results (received power in dBm) 44](#_Toc289848001)

[Table 12: Aeronautical radar, ‘standard’ situation, 15 MHz separation interference and blocking results (received power in dBm) 45](#_Toc289848002)

[Table 13: Aeronautical radar, ‘standard’ situation, 40 MHz separation interference and blocking results (received power in dBm) 45](#_Toc289848003)

[Table 14: Meteorological radar, ‘restricted’ situation, 15 MHz separation interference and blocking results (received power in dBm) 46](#_Toc289848004)

[Table 15: Meteorological radar, ‘restricted’ situation, 40 MHz separation interference and blocking results (received power in dBm) 46](#_Toc289848005)

[Table 16: Aeronautical radar, ‘restricted’ situation, 15 MHz separation interference and blocking results (received power in dBm) 46](#_Toc289848006)

[Table 17: Aeronautical radar, ‘restricted’ situation, 40 MHz separation interference and blocking results (received power in dBm) 47](#_Toc289848007)

[Table 19: Aeronautical radar blocking performance with Ofcom's mask (received power in dBm) 47](#_Toc289848008)

[Table 20: Blocking from other services with Ofcom's Mask (received power in dBm) 50](#_Toc289848009)

[Table 21: Coordination and Restriction Zones 53](#_Toc289848010)

List of Acronyms and Abbreviations

3GPP 3rd Generation (3G) Partnership Project

ACLR Adjacent Channel Leakage Ratio

ACS Adjacent Channel Selectivity

A/D Analogue to Digital

ACS Adjacent Channel Selectivity

AGC Automatic Gain Control

AMS – Gematronik Now called SELEX or SELEX – Gematronik. See SELEX entry

AMSA Australian Maritime Safety Association

ASA Air Services Australia

BER Bit Error Rate

BoM Bureau of Meteorology

CDMA Code-Division Multiple Access

Cobham Cobham Technical Services - New name for ERA Technologies. A consultancy and design company located in the UK and commissioned by Ofcom.

CW Continuous Wave

DoD Department of Defence

DTCH Dedicated Traffic Channel

EIRP Effective Isotropic Radiated Power

ENG Electronic News Gathering

ERA ERA Technologies, now called Cobham Technical Services. See Cobham entry

F/B Front to back. As in Front to back gain ratio of an antenna.

FDR Frequency Dependent Rejection

FEC Forward Error Correction

FFT Fast Fourier Transform

ICAO International Civil Aviation Organisation

IF Intermediate Frequency

IMT International Mobile Telecommunications

ISM Industrial, Scientific and Medical

ITU International Telecommunications Union

LIPD Low Interference Potential Device

LNA Low Noise Amplifier - Typically used early in receiver chains.

LPF Low Pass Filter

LTE Long Term Evolution - An emerging mobile technology.

MCL Minimum Coupling Loss - A method of calculating interference potential that compares the received power to the acceptable interference limit.

OFDM Orthogonal Frequency Division Multiplexing

OFDMA Orthogonal Frequency Division Multiple Access

PEP Pulse Envelope Power

PRF Pulse Repetition Frequency

PRP Pulse Repetition Period

PSR Primary Surveillance Radar

SARPs Standards and Recommended Practices (ICAO)

SELEX A Radar manufacturer commission by Ofcom that made Watchman Aeronautical Radars and Australian used Meteor 1500S Meteorological Radars.

SF Spreading Factor in a CDMA system

SNR Signal to Noise Ratio

SRR Signal to Radar peak power Ratio

QAM Quadrature Amplitude Modulation

ULNA Ultra Low Noise Amplifier

UMTS Universal Mobile Telecommunication System

WCDMA Wideband Code-Division Multiple Access

WiMAX Worldwide Interoperability for Microwave Access

Executive Summary

This study builds on a number of previous internal ACMA radar studies: “Adjacent Band Sharing Study between IMT2000 Stations in the 2500-2690 MHz Band”; “ASR and Meteorological Radar Systems in the 2700-2900 MHz Band”; and “Radiodetermination Operations in the 2700-3100 MHz band”. It aims to provide an analysis of the potential for adjacent band sharing between radar systems operating in the 2.7 – 3.1 GHz band and International Mobile Telecommunications (IMT) services proposed for the 2.5 – 2.69 GHz band.

The study includes a review of existing published studies into radar – IMT sharing in Section 1. This review established the issues that needed further analysis in this work, such as the effect of pulsed radar emissions on the reception of OFDM signals, and the parameters that have been recommended or used, such as emission and selectivity masks.

The studies in Sections and 3 found that due to the pulsed nature of radar emissions there would not be any significant interference into IMT systems from radar, provided there is at least a 5 MHz separation and blocking does not occur. A blocking analysis for IMT receivers was performed in Section 4. It found that blocking would not occur to IMT provided there is at least: 1 km separation at 15 MHz or 500 m at 40 MHz. The current proposed arrangements for new IMT systems mean that there is at least 15 MHz separation between the centre frequency of the highest planned 10 MHz IMT channel and the edge of the radar band, and 40 MHz between the edge of the IMT band and the centre frequency of the lowest currently licensed radar in Australia.

Interference and blocking from IMT into radar is then evaluated in Section 5. The results of this section are highly dependent on the selectivity performance of radar equipment. When selectivity masks specified in ITU recommendations are used for this analysis, blocking does not occur until the separation distance between IMT and radar sites is well below 100 m. It was found that by taking into account the likely antenna elevations of the two services and their deployment, it will be possible with appropriate coordination to operate IMT base stations as near as 1 km to a radar site without causing interference.

It must be noted that radar systems can be highly individual set ups and each radar model is likely to have differing selectivity performance. If the ITU-specified representative parameters are used, the following limits on IMT transmissions and restricted/coordination zones detailed in Table 1 will be needed.

|  |  |  |  |
| --- | --- | --- | --- |
| IMT Out-of-Band Emission Limit | Frequency Separation | Coordination zone | Restricted Zone |
| None | 40 MHz | 7.5 km for Aeronautical  20 km for Meteorological | 1 km for Aeronautical  500 m for Meteorological |
| -36 dBm | 15 MHz | 7.5 km for Aeronautical  15 km for Meteorological | 1 km for Aeronautical  500 m for Meteorological |
| -36 dBm | 40 MHz | 5 km for Aeronautical  15 km for Meteorological | 1 km for Aeronautical  500 m for Meteorological |
| -45 dBm | 15 MHz | 7.5 km for Aeronautical  10 km for Meteorological | 1 km for Aeronautical 100 m for Meteorological |
| -45 dBm | 40 MHz | 2 km for Aeronautical  7.5 km for Meteorological | 500 m for Aeronautical  <100 for Meteorological |

Table 1: Coordination and Restriction Zones

It can therefore be concluded that through application of antenna coordination and specification of out-of-band emission limits on IMT transmissions, adjacent band sharing between IMT and radar is possible.

1. Literature Review
   1. The Previous ACMA Sharing Study

*Adjacent Band Sharing Study between IMT2000 Stations in the 2500-2690 MHz Band and ASR and Meteorological Radar Systems in the 2700-2900 MHz Band*(1)

The first ACMA sharing study produced focused on protecting both IMT and radar systems to the noise floor. It examined the likelihood of interference using a deterministic minimum coupling loss method. Effects like the rotational or pulsed nature of radar were not taken into account in the study. This study used the ITU radar models A, C, and G from ITU-R M.1464 and IMT parameters from ITU-R M.2039.

Since this study was produced there has been considerable overseas work into radar and IMT interoperability, including studies into the affect of pulsed interference into IMT. Furthermore planning for the 2.5 GHz band in Australia now specifies a base transmit ‘high’, ie. the uppermost channels in the band (nearest the radar band) will be base transmit. Many parameters in this study have been refined, and some of the situations examined are no longer relevant. For these reasons many of the results of this study are no longer valid or have changed significantly.

Relevant to this study however are the emission and spectral masks that were calculated from M.1461 and Rec. M.1541. These are shown in and respectively. According to M.1541, radars are expected to meet a 20 dB/decade roll off while new radars designed (as of 2001) should meet a 40 dB/decade roll off. M.1461 specifies a selectivity roll off of 80 dB/decade, outside the necessary bandwidth. reproduces the necessary roll off for radar type G.

However the study points out that there is likely to be significant variation in the parameters of individual radars and cites a US study that shows that many radar stations in that country do not even meet the 20 dB/decade requirement. Radar selectivity is revisited later in an Ofcom-commissioned study by ERA Technology Ltd., which was done after the ACMA sharing study was complete.



Figure 1: Calculated radar emission mask (1)



Figure 2: Calculated radar selectivity mask (1)

The study went on to show that, based on the previously detailed assumptions, a separation distance of between 230 km and 150 km at 40 MHz separation was required to avoid radar interference into IMT, depending on the type of radar. These distances were reduced to between 90 km and 10 km by using F/B instead of main beam gain. The radars in this band are often located in areas where IMT could be heavily used, making these zones are unacceptably large. Interference from IMT into radar was calculated as requiring slightly smaller separations, ranging from 135 km to 67 km for main beam gain.

The receiver blocking results were based on -40 dBm as the highest acceptable level of interference to avoid 1 dB compression in the IMT receiver. The results showed that there needed to be between 3 km and 36 km at 40 MHz separation between radar and IMT Base Stations to avoid blocking of the IMT receiver. In contrast, type G radars would not experience saturation from IMT until there was less than 270 m separation. Receiver blocking performance was not available for other radar types at the time of this report and the report did not consider blocking of IMT handsets.

* 1. Ericsson submission to WP8F 615

*Proposed Report or Recommendation on Radar Interference to IMT-2000/WCDMA in the band 2700-2900 MHz*(2)

This document has been included and published in ITU-R Recommendation M.2112

This document was written by Ericsson to investigate the effects of pulsed radar emissions on IMT services. The Ericsson report consisted of two stages;

1. a theoretical mathematical analysis of the effect of radar interference; and
2. a simulation of a WCDMA receiver injected with high power radar interference.
   * 1. Theoretical Analysis

IMT is based upon spread spectrum technologies with a chip rate of 3.84 Mchips/s. Depending on a spreading factor that ranges from 4 to 512 in powers of 2, symbol lengths can range from 1.04 µs to 133 µs. Radar sends short pulses that reflect from the objects they are designed to detect. Those pulses vary from 0.6 – 89 µs (3). The higher the radar pulse length to symbol length, the more WCDMA symbols will be affected by interference.

IMT-2000 (WCDMA) receivers use a Rake structure. The quantity of interest in determining the effect of interference is the decision variable, as errors in the decision cause errors in the bit stream. Ericsson derived for the raw BER in terms of signal-to-radar interference ratio (*SRR*) at Rake input (referred to as SRR0 in the Ericsson report). The raw BER is the bit error rate before any channel decoding has taken place, *SF* is the spreading factor, *TPRP* the pulse repetition period (usually around 1 ms), and *Tchip* the period of one WCDMA chip .



Equation 1: Theoretical raw BER (2)

With the variables of spreading factor and SRR was produced showing the theoretical limits of interference.



Figure 3: Theoretical Effect of radar cochannel interference to a linear IMT/WCDMA receiver. Raw BER vs SRR (2)

After deriving this expression, Ericsson went on to qualify the physical effects of elements in the receiver chain and how they affect or are affected by the BER and high power radar pulse. Ericsson draws attention to the two A/D converters (I and Q), which act to hard limit the incoming radar pulse.

That is, ADCs have a particular range of operation, when an analogue input exceeds that range the output is limited to the top of the range. No matter how far the input exceeds the range the output cannot exceed the maximum output. This means that the SRR is limited to the ADCs load factor, about -15 dB at most. When a maximum SRR of -15 dB is entered into (see ) the BER is well below 0.1%.

The automatic gain control (AGC) of the receiver however needs to be constructed with radar pulses in mind. When the power estimation is conducted from the hard limited output of the ADCs and when the averaging time of the estimation is 60 µs or greater, the effect of radar pulses is negligible. Ericsson state that both design decisions are reasonable, and conclude that “*It should be no problem to design the AGC such that the effect of radar pulses is negligible.*”

Ericsson state that under normal operating conditions, a WCDMA system can be expected to have a raw BER of about 5%. Interference begins to be noticeable in voice services when the BER reaches 8%, and that data services are designed to be able to cope with a block error rate of 10%, that is at least an 8% raw BER encountered for 10% of the time[[1]](#footnote-1). As a result, an extra raw BER of less than 0.1% caused by short pulse radar interference is negligible.

Ericsson concluded that “***radar pulse interference has no significant effect on radio link quality in a IMT-2000/WCDMA receiver****, thanks to the limiting effect from the A/D-converter and the strong forward error correcting scheme.*” This is true for co-channel operation with short pulse radars. The only limiting effect is receiver burn out, which Ericsson state would occur at powers greater than 10 dBm at the receiver input.

* + 1. Simulation

Ericsson continued their study by creating a simulation model for a WCDMA receiver that matched 3GPP specifications. A trapezoidal pulse generator was assumed to simulate the radar interference. Ericsson found that long pulse radars with a relatively high pulse repetition frequency (PRF) can cause higher interference than their theoretical analysis might suggest (see ). However, due to the unexpected effects of the IF filter this was only true for co-channel operation.

rber_co_sf8

Figure 4: Raw BER versus SRR for co-channel interference and WCDMA spreading factor 8 (2)

Ericsson went on to investigate the effects of frequency separations of 5, 10 and 20 MHz (20 MHz is the more useful case for the ACMA’s work). They showed that the WCDMA IF filter had a differentiating effect on the envelope of incoming out-of-band pulses. As seen in this meant that long pulses that had travelled through the IF filter are primarily represented only by spikes during their rise and fall time. A long pulse effectively becomes a short pulse. This means that there is no significant difference between long pulses and short pulses given the available frequency separation.

On the other hand, the filter also spreads the bases of high power pulses somewhat. This means that as the SRR increases the width of the pulse slightly increases before the hard limiting effect of the A/D converter comes into play. SRR does have a reduced effect after ‑15 dB. This affect is included in Figure 4 above.

Ericsson produced as a comparison to to show the effect of a 20 MHz separation on the BER. This figure was generated from simulation and includes the A/D converter and AGC effects mentioned above, as well as the IF-filter effects. The raw BER attributed to radar interference does not exceed 1%, and therefore Ericsson determined that the interference will not be detrimental to IMT operation.

Ericsson conclude that for short pulse radars there is no fundamental limit in the ability of a WCDMA receiver to reject interference, apart from the receiver overload limit (which is therefore the overall interference limit). The maximum recommended input to the receiver is 10 dBm. For long pulse radars a frequency separation of at least 5 MHz is required and it must be ensured that receiver blocking does not occur. Ericsson recommends that the 3GPP 3 dB compression blocking level is used. They further recommend:

*For the calculation of required isolation distances the following limits are recommended as long as the interference from radar to WCDMA is considered:*

* *Radar types A, B, D, F and G:* 
  + *No frequency separation required;*
  + *Maximum radar peak power at mobile antenna connector: 10 dBm; and*
* *Radar types C and E (long pulses):*
  + *Co-channel operation: SRR ≥ 10 dB[[2]](#footnote-2);*
  + *Carrier frequency offset 5…15 MHz   
    Maximum radar peak power at mobile antenna connector -56 dBm (given by the blocking level);*
  + *Carrier frequency offset >15 MHz   
    Maximum radar peak power at mobile antenna connector: -44 dBm (given by the blocking level).*

pulse2

Figure 5: Envelope of filtered pulses of radar E (long) with different frequency offsets (2)

rber_adj20_sf8

Figure 6: Raw BER versus SRR for 20 MHz frequency offset and WCDMA spreading factor 8 (2)

* 1. Ericsson submission to WP8F 696

*Effect of the Antenna Rotation of Radar Systems on an IMT-2000/WCDMA Receiver*(5)

This document is supplementary to the document described in Section 1.2 (). It addresses the effect of antenna rotation on radar interference to IMT and recovery time concerns.

Ericsson state that Lab tests have shown that the IMT LNA needs no time to recover even after high overloads with up to 10 dBm of power. The only practical limit imposed by the LNA is the burn out level which Ericsson recommends as no higher than 10 dBm. Ericsson states that in other contributions it was claimed that a significant recovery time was needed for some RF components after an overload.

However, Ericsson is confident that there are simple cost effect solutions to prevent this problem that can easily be incorporated into mobile or base station receivers. Ericsson consider that these solutions would be implemented on any receiver designed for the 2.7 – 2.9 GHz band (these Ericsson papers were looking at co-channel operation in the 2.8 GHz band rather than adjacent channel operation in 2.5 – 2.69 GHz band) .

In this submission, Ericsson takes into account the additional loss from boresight that antenna rotation causes. That means that the results in Section 1.2 are treated as results with maximum antenna gain, and that antenna discrimination causes a decrease in the SRR. This submission focuses on Radar C and E, as these were the two types that were shown to encounter problems in the previous studies. Ericsson use antenna patterns ( and ) taken from which have served as a basis for ITU interference analysis.

Figure 7: Model of antenna pattern for meteorological radar (Radar E) (6).

Figure 8: Model of antenna pattern for aeronautical radar (Radar C) (6).

The radar antennas are assumed to rotate at a constant rate, the angle axis mapping directly onto a time axis and similarly the gain axis maps onto received pulse peak envelope power (PEP). When these antenna patterns are combined with the results presented in Section 1.2, they produce the results shown in and . Note that in these figures there is an assumed background raw BER of 5%. Ericsson state that for the radar E results an error level of 8% is only exceeded for 3.5% of a rotation scan. Radar C because it has a longer pulse length and a lower peak to off-peak antenna gain ratio has a higher raw BER.

Figure 9: Time variation of raw BER due to radar antenna rotation with a period of 6 seconds. Parameters: Co-channel operation of radar E; Spreading factor 128; without radar interference the raw BER is 5% (5).

Figure 10: Time variation of raw BER due to radar antenna rotation with a period of 6 seconds. Parameters: Co-channel operation of radar C; Spreading factor 128; without radar interference the raw BER is assumed to be 5% (5).

Given that voice transmissions may start to experience degradation at a raw BER of 8% and data transmissions won’t experience degradation until a raw BER of 8% over 10% of the time, Ericsson have concluded that *“co-channel operation with radars of type C and E would be possible as long as the received peak power of a radar pulse in the main beam of the radar antenna is less than 45 dB above the signal level”, i*n other words a .

This level replaces and supersedes the co-channel level of mentioned in the preceding Ericsson paper for C and E type radars. Ericsson expect that the adjacent channel tolerable interference level will be significantly higher than the blocking level, and therefore blocking will be the dominant out of band effect.

The results from the two Ericsson submissions render many of the results derived in the ACMA’s previous study (on radar into IMT interference) obsolete. These studies show that noise floor MCL methods are not appropriate for determining out-of-band interference, and recommend that a coordination threshold based on the 3 dB compression blocking level is used instead.

* 1. Report ITU-R M.2112

*Compatibility/sharing of airport surveillance radars and meteorological radar with IMT systems within the 2700 – 2900 MHz band* (7)

This report is an ITU publication of multiple submissions on co-channel operation between IMT and radar in the 2700 – 2900 MHz band. The studies use differing methods to determine interference potential, and go into varying levels of depth in their studies. This report also includes Ericsson’s submission no. 615 to ITU-R WP 8F (as described in Section 1.2).

Based on these studies the report concludes that co-channel operation between IMT and radar is not possible without separation distances of several hundred kilometres – some studies suggesting over 500 km. However, the ACMA is specifically interested in adjacent band sharing, rather than co-channel sharing, so this result is not directly relevant. In addition, many of the studies in this report were written in parallel, and refer to one another’s results – i.e. a variation of one set of results may impact on others.

Annex 2 includes a brief analysis of the effect of pulsed radar emissions on WCDMA and OFDM. The WCDMA analysis is not as detailed as Ericsson’s (as described in Section 1.2) and does not relate SRR to BER. This analysis suggests that short pulse radar emissions will cause increase BER by 0.4% while long pulse will increase BER by up to 10%. This is similar to Ericsson’s findings. For OFDM (and therefore LTE) they have assumed a 50 µs symbol time and (roughly) 20 kHz carrier spacing. They assumed that a 1 µs radar pulse would knock out the entire symbol, and that as the radar pulse will repeat roughly every 20 symbols, the resultant BER will be 5%.

This analysis is not necessarily correct, and a better understanding of how the LTE receiver front end responds is needed to properly determine the effect of burst interference on a LTE system. The analysis does not consider that radar pulses may affect multiple sub-carriers, nor does it relate the results to SRR. The assumption used in the analysis is that any interference to a symbol, regardless of how short, will destroy the entire symbol appears to be an extreme worst case and instead depends on how the decision metric is configured in an LTE receiver.

* 1. Recommendation ITU-R M. 1464

*Characteristics of radiolocation radars and characteristics and protection criteria for sharing studies for aeronautical radionavigation and meteorological radars in the radiodetermination service operating in the frequency band 2700 – 2900 MHz*(3)

This recommendation not only provides the definitive radar characteristics used in sharing studies by the ACMA, the ITU and other international organisations, but also provides a detailed analysis of protection requirements for aeronautical and meteorological radars. Annex 1 includes the definitions and parameters for radar types A through L.

Annex 2 is a report on the results of tests on aeronautical radionavigation radars. This report investigated I/N protection criteria, blocking performance, selectivity masks, and the effects of interference on the performance of Radar B. The report outlines the methods in which this was done and provides discussion of the results. Only the results and conclusions are included in this summary.

The blocking performance and selectivity mask of an aeronautical radar (Radar B) were measured by injecting a CW signal into the radar receiver and measuring the output at the IF stage output. The resultant selectivity mask is shown in . Note the measurement was made at the output of the IF stage and this is reflected in the x‑axis of the graph. The roll off at 2.8 GHz however should be identical.

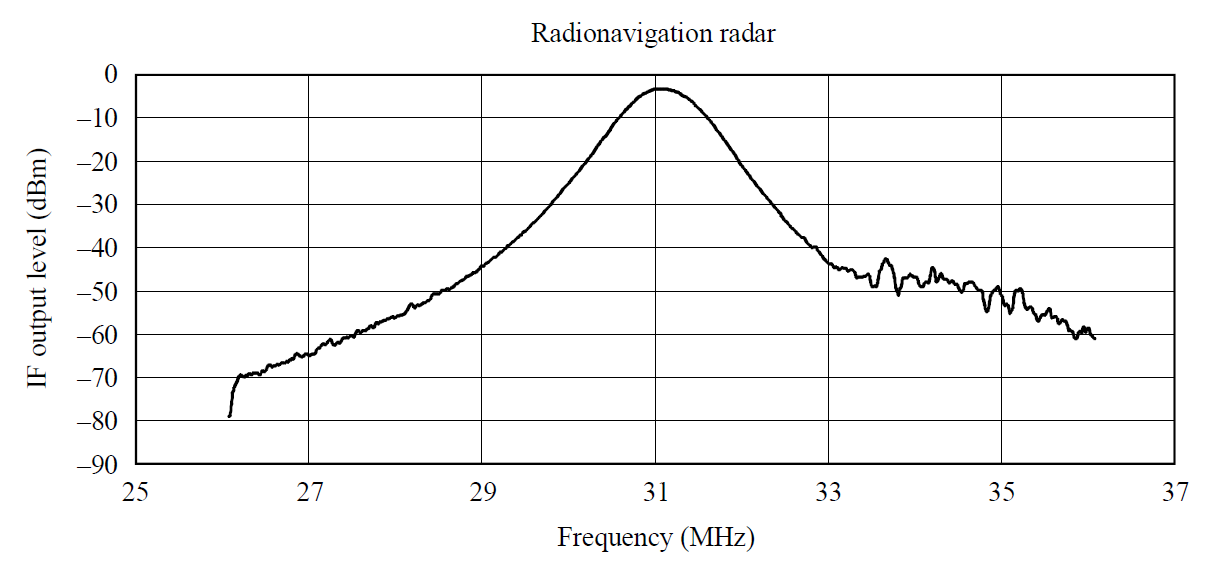


Figure 11: Measured selectivity mask for Radar B

The compression point occurred at an input power level of -43 dBm. The report concludes that a -10 dB I/N criteria is required to protect the radar receiver from interference. As the minimum discernible received signal power for Radar B is given as -108 dBm, this would mean the interference threshold is at -118 dBm.

Annex 3 is a report on an investigation into the protection requirements for meteorological radars, particularly in the presence of interference from WCDMA and CDMA-2000 3x systems. The study was performed on a particular radar system that has been operating for 11 years. Annex 3 calculates that processing improvements made to newer radars would not reduce the actual noise floor.

The study concluded that the test results “support the requirement for a protection value that could be as low as -9 dB I/N”. They note that some functions of the radar only support a I/N of -10 dB, and that therefore the protection requirement for meteorological radars should be -10 dB.

* 1. ERA Technology Practical Experiment

*Interference from Radars into Adjacent Band UMTS and WiMAX Systems*(8)

Ofcom commissioned in 2007 a study by ERA Technologies[[3]](#footnote-3) into the effects of radar interference into IMT systems from adjacent band radars. ERA performed both laboratory and field tests on both WCDMA and WiMAX equipment. In laboratory tests, ERA used a programmable signal generator to simulate a rotating antenna. In the field tests, they setup their equipment 600 m from an operating radar.

There were four such trials at four different airports, and included solid state, TWT, and magnetron radars. Typical radar characteristics, that included both long and short pulse, were used to program the signal generator, but it is not stated what the operating parameters or pulse length of the airport radars were. The test setup they used is shown in however no explanation or justification for the use of this setup has been provided by ERA, nor has the effect of the band pass filter or signal generator on the overall results been considered in the report.

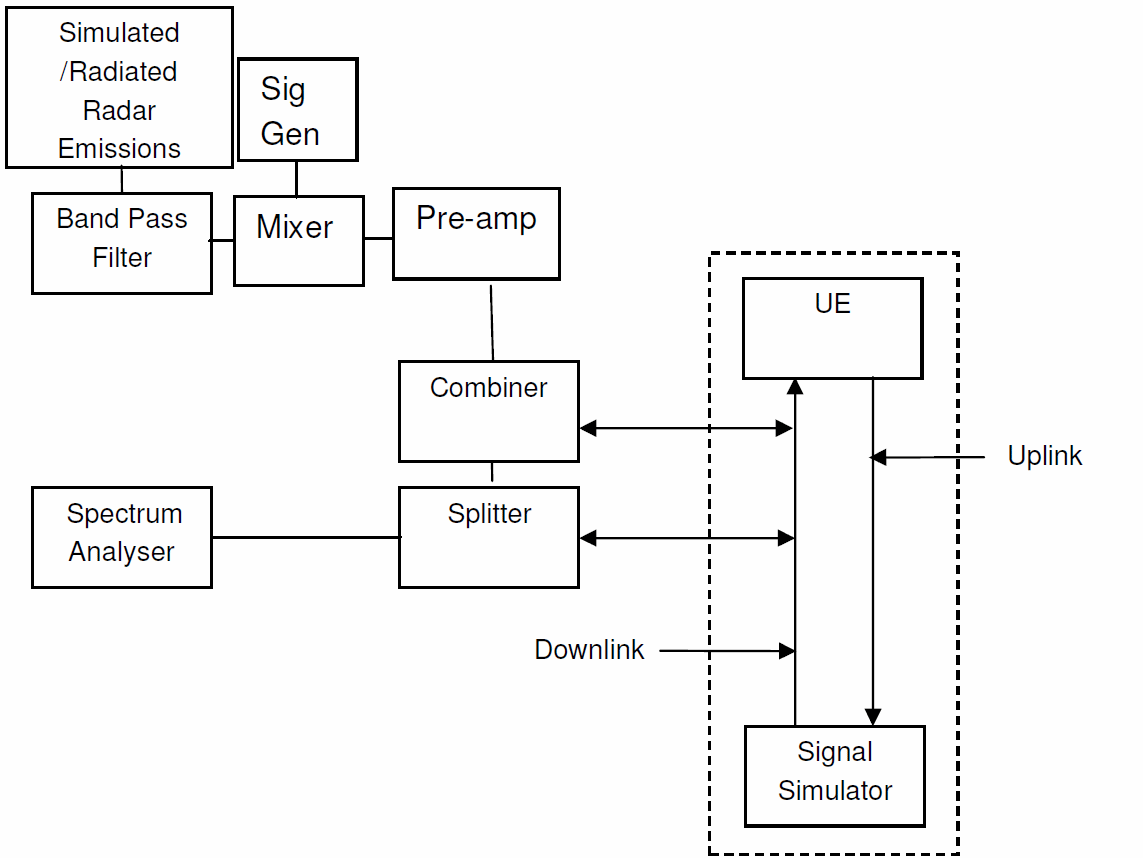
**

Figure 12: Conducted measurement setup for radar interference into UMTS(8)

ERA configured the UE in loopback mode and conducted their measurements on a standard reference measurement channel, as defined in (4), with a bit rate of 12.2 kb/s. They transmitted a 15 bit pseudo-random sequence on the DTCH channel, received the looped back data, and then compared the transport blocks to determine the BER. As the transport blocks follow the channel coding and FEC, the measurements that ERA have conducted are not raw BER measurements, but post correction BER.

ERA concluded from the airport trials that the BER in the presence of measured radar interference was less than 10-3 to either the UMTS or WiMAX test equipment at 600 m separation distance. ERA assumed that the acceptable interference criteria was a BER of 10-3, and as such did not consider that interference to be significant. It is not clear why they assumed this BER level and it is explicitly stated that the impact of this BER on services was not considered.

It should also be noted that as these are errors in transport blocks they are not comparable to Ericsson and the ITU studies, nor are the antenna patterns used in simulation in this study the same as the antenna patterns the ITU recommends. ERA also state that the degradation that UMTS and WiMAX systems experience is dominated by the average power received from antenna side lobes, rather than the, main beam. This would seem to confirm Ericsson’s findings in (5).

ERA included measured radar emission spectrum from the four radars used for field tests. These are shown in Figure 13, Figure 14, Figure 15 and Figure 16. They show both the max peak, max hold method that ERA state is recommended in ITU-R SM.1541, and the max peak, average method that time averages the received power over some period. The mask value shown in the figures is presumably calculated from ITU-R SM.1541 adjusted for free space path loss and maximum radar EIRP.

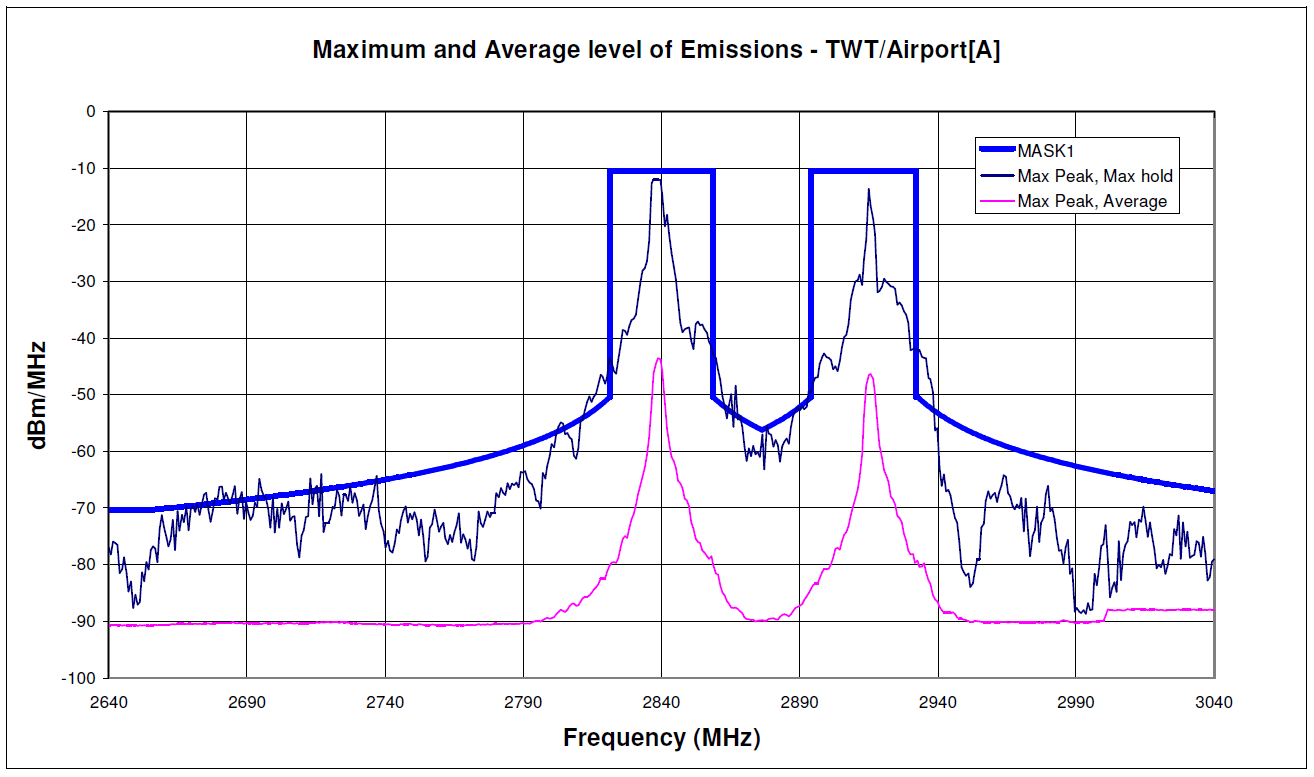


Figure 13: Airport A radar’s measured emissions and calculated mask (8)

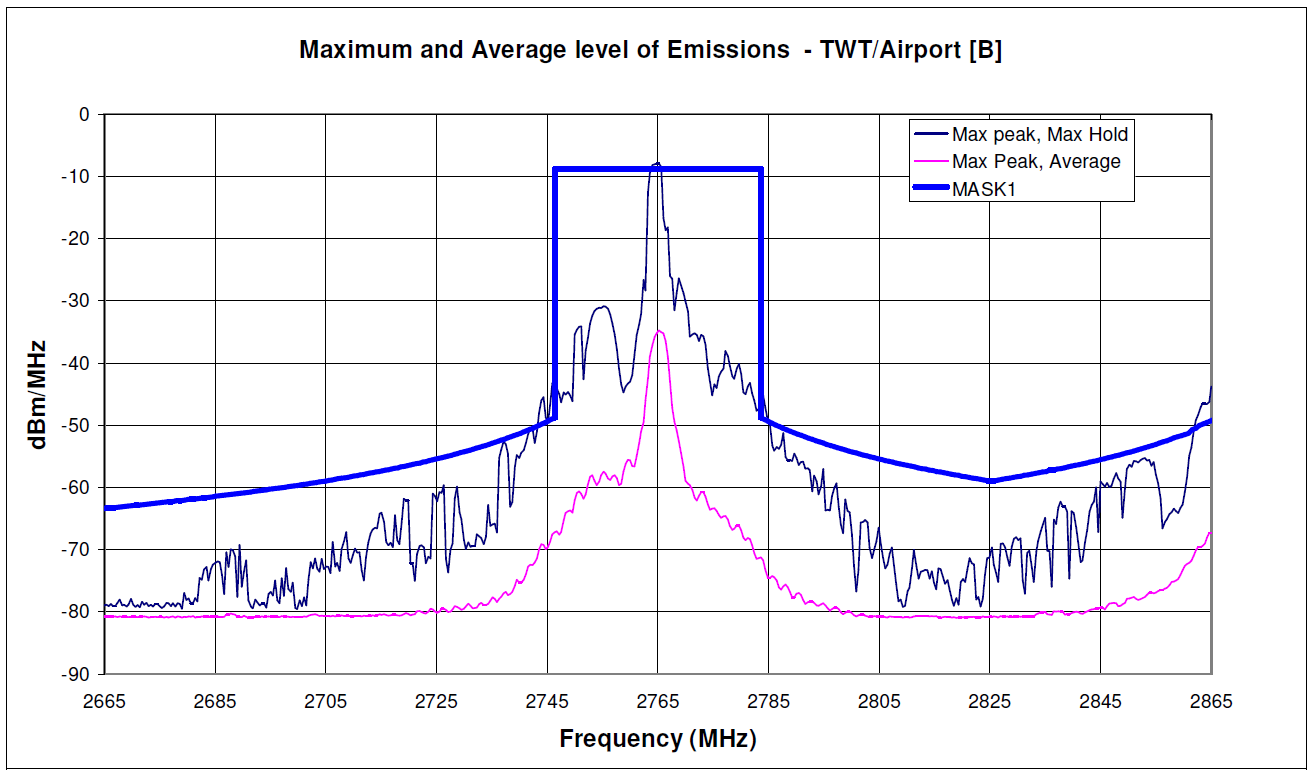


Figure 14: Airport B radar’s measured emissions and calculated mask (8)

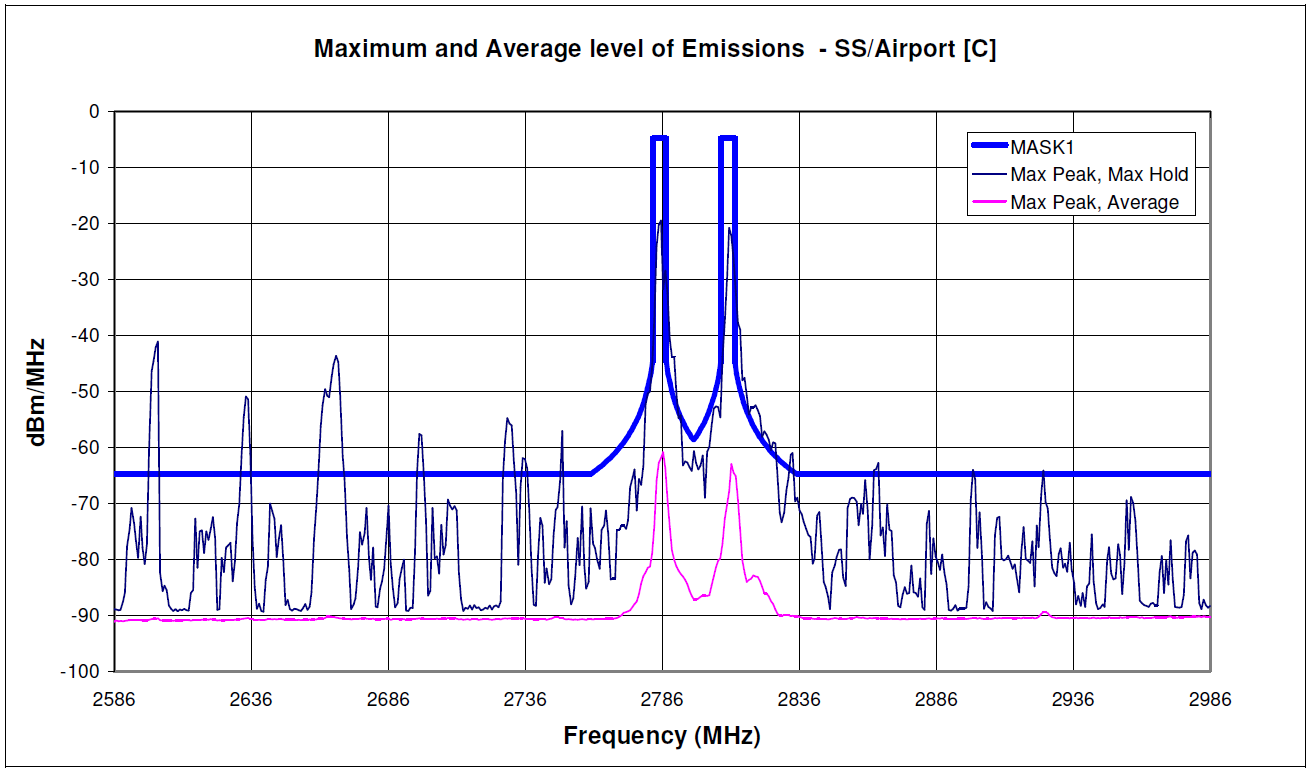


Figure 15: Airport C radar’s measured emissions and calculated mask (8)

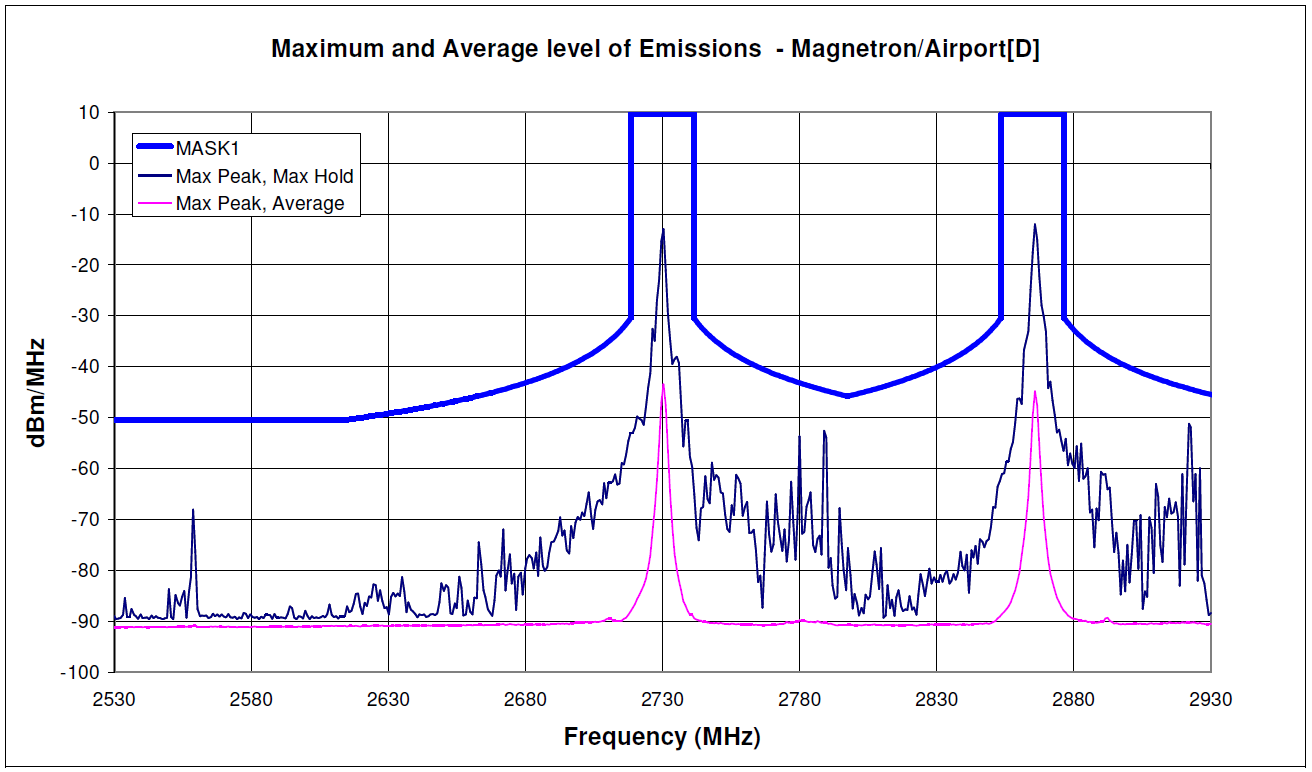


Figure 16: Airport D radar’s measured emissions and calculated mask (8)

* 1. Ofcom submission to WG5B

*Radar Adjacent Band Selectivity*(9)

This submission is a collation and summary of the results of a number of studies commissioned by the Ofcom and performed by various UK Engineering companies. Most of the important information found in these studies is summarised in this paper, while the other reports focus on method and data, however only this report and one by the design authority for Watchman radars (SELEX) will be reviewed in this document.

Ofcom have identified that at least one of the aeronautical and maritime radars in use around the UK has selectivity properties that are significantly worse than the parameters determined in ITU-R M.1464. Watchman radars have been modelled by Ofcom and the companies they have commissioned as having extremely poor blocking performance at out of band frequencies due to inadequate selectivity.

A theoretical blocking level mask for the Watchman Radar was developed, and ERA Technologies were commissioned to confirm that mask in injected tests and flight trials (denoted as phase 1 trials). The injected tests showed slightly better performance than the initial mask. The Watchman Design Authority, SELEX, modelled a second mask which matched the injected tests as shown in .

Note that what is shown in this figure is the level at which blocking occurred, at a particular frequency. For example, a ‑45 dBm signal injected to the radar antenna connector at a frequency 100 MHz lower than the radar’s centre frequency caused receiver blocking. This measurement has already taken into account any affects from selectivity filters.

Flight trials were performed to determine whether interference would occur to radar in normal operating conditions. The trials clearly showed that emissions in the 2.5 GHz band had significant detrimental affects to the tested radar. Ofcom considered that the results of these trials correlated within measurement accuracy with those obtained in the earlier tests.

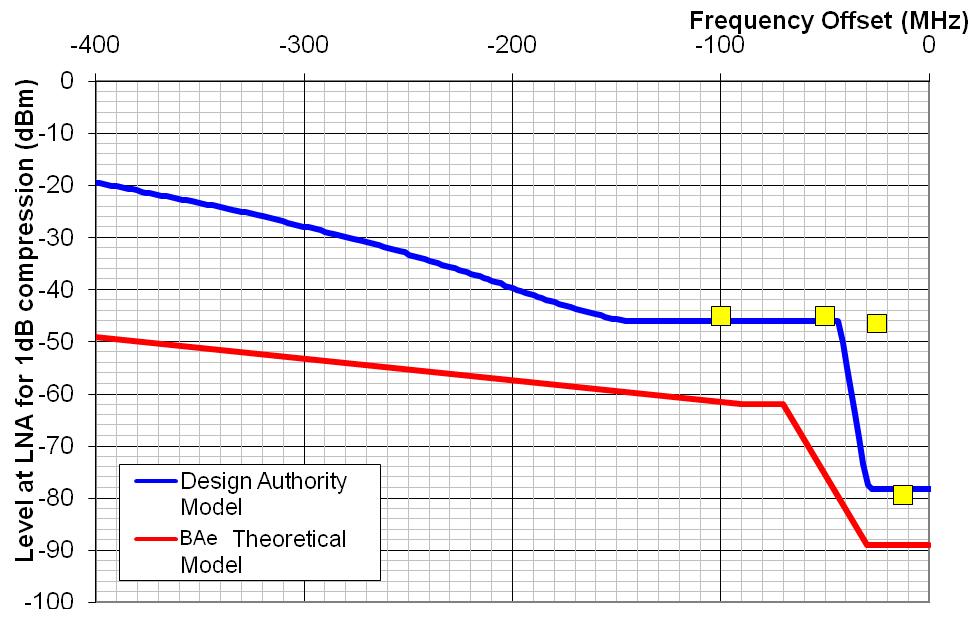


Figure 17: Watchman Radar blocking levels

* 1. SELEX report on Watchman Radars

*Watchman Radar: Receiver selectivity improvements in the 2700-3100 MHz band*(10)

SELEX Systems Integration is the design authority commissioned by Ofcom to perform two tasks: to confirm the mask of blocking levels previously developed; and to determine a solution to improve performance of the Watchman radar s by 40 to 60 dB. SELEX produced the Design Authority Mask shown in as an accurate representation of the current Watchman radar blocking performance. They identified five components of the receiver chain (shown in ) that could be contributing to the poor selectivity:

* The Transmit Receiver (TR) cells;
* Main Beam LNA;
* Aux/High Beam LNA;
* 1st IF Amplifier; and
* 2nd IF Limiting Amplifier X14.

In order to solve the selectivity problem, SELEX identified 3 separate improvements:

* Replace 1st generation TR cells with later ones that are up-to-date with current specifications;
* Perform a minor reconfiguration and modification of existing front end receiver components to bring earlier Watchman radars in line with the most recent installations; and
* Replace the old (RF) LNA with a pre LNA filter and a new Ultra Low Noise Amplifier (ULNA) which has a better noise figure than the old LNA.

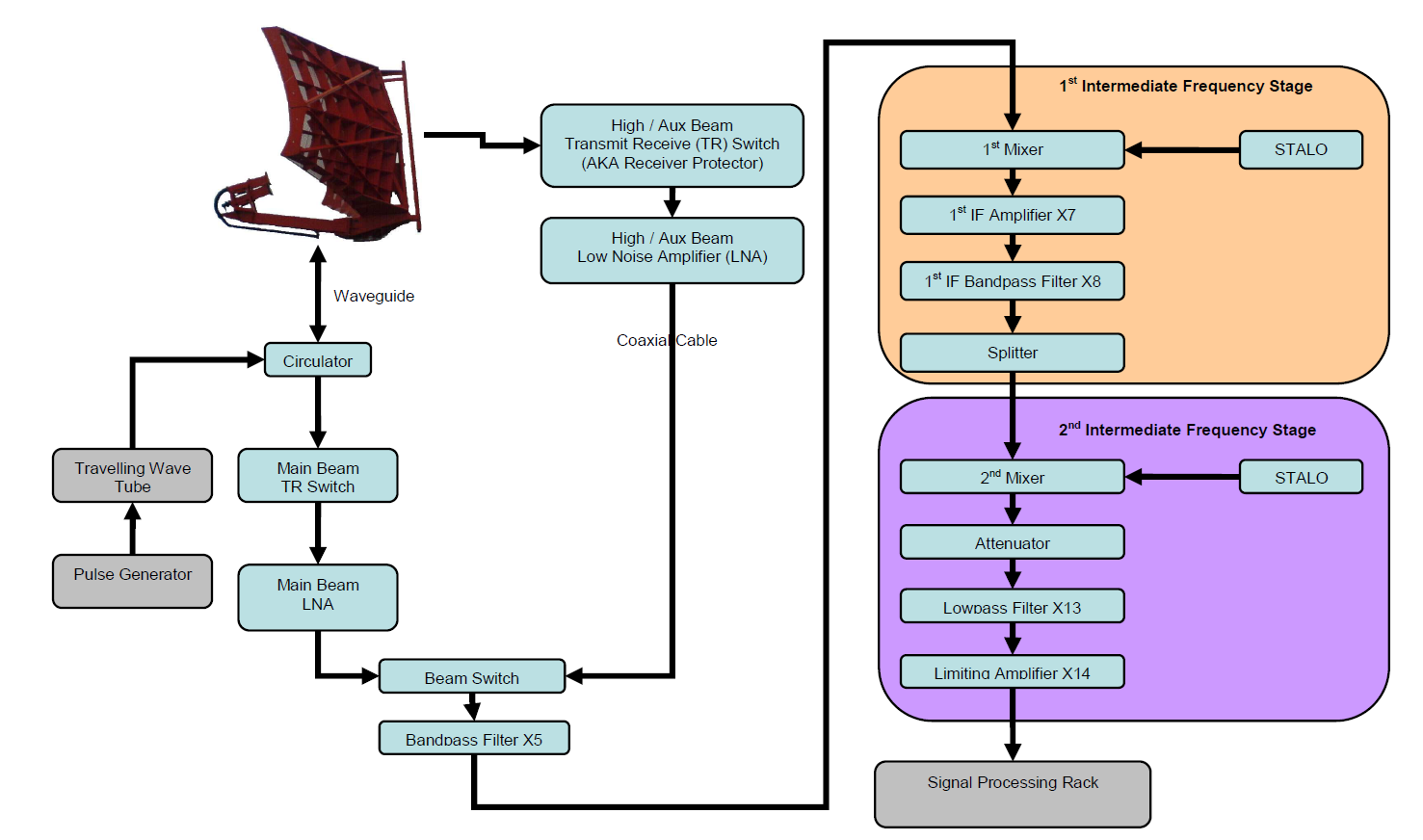


Figure 18: Watchman Radar receiver architecture (10)

Ofcom also mentions in the report that swapping the order of the 1st IF Amplifier and the 1st IF band-pass Filter was part of the solution. Possibly this modification is included in the minor reconfiguration mentioned by SELEX.

These modifications were tested in phase 2 of the flight trials commissioned by Ofcom. SELEX believe that these modifications had the effect of preventing the Watchman radar receiver from going into compression. However there were other identified interference issues that are still being investigated as per latest publications (29/3/2010) on the Ofcom website.

1. Radars around Australia

There are nine operators with radiodetermination licenses operating in the 2700 – 3100 MHz band namely: Air Services Australia (ASA); the Australian Maritime Safety Association (AMSA); the Bureau of Meteorology (BoM); Chevron; the Department of Defence (DoD); ENI; ESSO; Port of Melbourne and Sydney Ports. Nearly half of these licences are for low powered transponder equipment operating in the band above 2900 MHz. Excluding these devices leaves only ASA, BoM, Chevron, DoD, and ESSO operating radar equipment in the band 2700-2900 MHz.

The map shown in Figure 19 shows that the Chevron radar is located well off the coast of the Pilbara and the ESSO equipment is in the Bass Strait. It is highly unlikely the Chevron equipment will cause any problem to IMT given its location. The ESSO equipment is about 100 km off the Gippsland coast and is therefore unlikely to suffer or cause a major problem either. That leaves the federal government agencies (ASA, BoM, and DoD) as the primary radar operators that need to be considered.

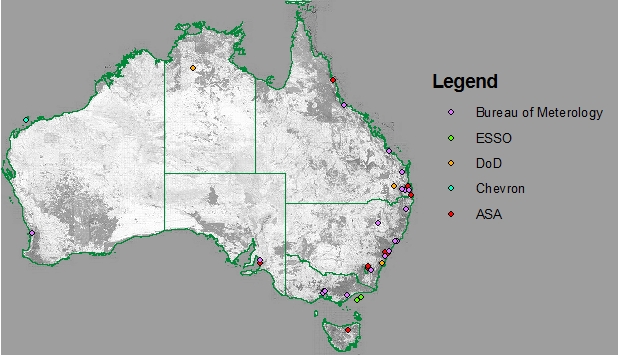


Figure 19: Location of 2.7 – 3.1 GHz radar sites around Australia

ASA operates radars at 16 locations around Australia, but most of those locations have licenses for multiple frequencies in the 2700 – 2900 MHz band. BoM has 19 sites each with a single frequency. DoD has three sites, two of which are using two frequencies. Note however that the use of multiple frequencies at a site could indicate a radar using multiple frequencies or multiple co-located single frequency radars.

The RADCOM data used in this study shows that the lowest frequency radar licence operates at 2730 MHz, with a bandwidth of 3 MHz (ie. lower limit of 2728.5 MHz). There are no licensed radars with emissions below 2728.5 MHz in the band. This means that there is a 38.5 MHz gap between the edge of potential IMT emissions at 2690 MHz and existing radar emissions. There is little information regarding the model designations for the radar systems in use, stored in the RADCOM data.

It is however it is known that the Meteor 1500 is in use and a datasheet for the Meteor 1500 radar is available (13). Parameters from the datasheet are listed in . Further information on the particular Meteor 1500 radar located at Terrey Hills, Sydney has been gleamed from a feature article in a magazine (*Silicon Chip)* (14). Parameters given in the article are shown alongside the values from the datasheet in Table 3 for comparison. The datasheet gives a range for the physical operating characteristics of the radar while the magazine article gives parameters specific for the Terrey Hills site.

Note: AMS – Gematronik is now **SELEX – Gematronik**. The same company that manufactures the Watchman radars and that has been commissioned by Ofcom to design and test a filtering solution.

|  |  |  |
| --- | --- | --- |
| **Parameter** | **Value (Silicon Chip)** | **Value (Datasheet)** |
| Model | Meteor 1500S | Meteor 1500S |
| Manufacturer | AMS-Gematronik | AMS-Gematronik |
| Type | VKS 8387 Klystron tube | VKS 8387 or equivalent |
| Frequency | 2.8 GHz band[[4]](#footnote-4) | 2.7 – 2.9 GHz |
| Transmit Power | 750 kW | 750 kW |
| Antenna Gain | 45 dB | 45 dB |
| Side lobe suppression | 26 dB | 25 dB |
| Polarisation | Linear – horizontal | Linear – horizontal |
| Half power beamwidth | 1⁰ | 1⁰ |
| Scan rate | 0.2 – 6 rpm, normally 3 rpm | 0.2 – 6 rpm |
| Minimum elevation | 0.5⁰ | Not Specified |
| RF Pulse Width | Not Specified | 0.4 – 3.3 µs |
| Pulse Repetition Frequency | Not Specified | 250 – 2000 Hz |
| Minimum Detectable Signal | Not Specified | -109 dBm (Short Pulse) -113 dBm (Long Pulse) |
| Height above ground | 20 m | N/A |

Table 2: Meteor 1500S and Terrey Hills radar parameters

1. Mathematical Analysis of Radar and OFDM LTE receivers

The Ericsson papers  reviewed in Sections 1.2 and 1.3 showed that, radar emissions should not cause significant interference to WCDMA receivers, as long as there is a frequency separation of at least 5 MHz. This frequency separation allows the receiver to turn potentially interfering long pulses into safer short pulses, owing to the differentiating effect on the pulse envelope in the stopband of the IF filter.

Short pulses do not cause interference due to the manner in which the short pulse interference interacts with the spreading factor (SF) and an implicitly hard limiting A/D converter, which prevents radar pulse power from exceeding roughly 15 dB above signal power.

The formula for the bit error rate becomes a function of SRR and SF. This analysis is therefore not applicable to OFDM (incl. LTE) systems, which do not use CDMA and have a different receiver structure. The OFDM analysis reviewed in Section 1.4 did not take into account the method in which signals are decoded, or how a short burst of interference affects a much longer OFDM symbol.

This section theoretically analyses the effect of radar pulses on OFDM, by building on Ericsson’s WCDMA study where possible. In order to do this the following assumptions have been made:

* An LTE OFDM symbol is approximately 66 µs long;
* Sub-carrier spacing is therefore 15 kHz;
* 12 subcarriers make one 180 kHz resource block. There are a minimum of 6 resource blocks in 1.4 MHz of contiguous spectrum;
* Upper bound of LTE transmissions is 2690 MHz, lower bound of radar transmissions is 2700 MHz;
* LTE filters have the same differentiating effect on the incoming pulse envelope as WCDMA filters in the stopband. (It is sufficient for this analysis to assume that the differentiating effect occurs at < 10 MHz from the upper -3dB point of filter – 10 MHz being the frequency separation between the lower end of the radar band and the upper edge of the highest IMT channel[[5]](#footnote-5));
* The hard limiting effect of the LTE A/D converter is the same as the WCDMA A/D converter. That is an A/D converter will limit the received radar pulse to about 15 dB above the LTE signal;
* The rise time of a radar pulse is between 0.1 and 1 µs ; and
* The design requirements that allow the AGC and RF components to work in the presence of high powered pulse interference into WCDMA equipment (as mentioned in the Ericsson submission) are also implemented in any LTE equipment operating in the 2.6 GHz band.



Figure 20: OFDM receiver architecture. Figure adapted from Goldsmith (15)

Goldsmith describes an OFDM transmitter and receiver with an IFFT/FFT implementation like a LTE receiver (shown in ). It consists of a normal downconverter, LPF and A/D converter. The digital circuitry then removes the cyclic prefix, performs the FFT and demodulates the QAM signal. Without any noise, the r(t) will be samples of the multicarrier OFDM signal. That is, each sample in time contains information about all subcarriers in an OFDM signal. Therefore a spike of radar interference that occurs in a narrow time window will be present over all subcarriers. The incoming signal would look equivalent to , which is taken from the Ericsson report.

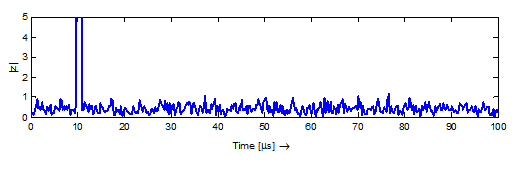


Figure 21: Sample signal with radar interference before A/D (2)

The Ericsson report mentions that the IF filter has a differentiating effect on incoming out of band emissions. Assuming filters in LTE handsets have a similar differentiating effect, the width of the pulse shown in would be related to the width of the rise time, not the hold time, of the radar pulse. This effect was shown in . It is assumed that the pulses[[6]](#footnote-6) present at the A/D are high power, approximately square pulses like that shown in , however if the filters had the effect of making the pulses distinctly triangular in shape this analysis would still hold (this will be shown below).

The analogue to digital converter will have the same limiting effect as described by Ericsson as this is an implicit limiting factor in all A/D converters. The assumption has been made that the A/D converter input limit is the same as that of a WCDMA receiver, ie. about 15 dB higher than the wanted signal. Because the peak to average power ratio of an OFDM signal is sensitive to the number of subcarriers it is possible that LTE designers have chosen A/D converters with a higher dynamic range.

Lacking any better information it is assumed in this study that a limit of 15 dB above the wanted signal is accurate for LTE A/D converters. The serial-to-parallel converter reassembles the OFDM symbols from the samples taken from the serial input. Each is an OFDM symbol that is a time domain representation of a frequency domain QAM symbol. If is the transmitted OFDM symbol then the received symbol is given by;

Where is the channel response, is the radar pulse interference, and is ordinary additive noise. For the purposes of this analysis ordinary noise can be ignored as it does not affect our understanding of the effect of the radar interference. At this point it is presumed that the power of the OFDM symbol and interference looks similar to .



Figure 22: Indicative OFDM symbol power with radar interference

The symbols are then passed to the FFT block in the OFDM receiver, the output Y is given by:

In the QAM demodulation process the inverse of the channel estimate is multiplied with the received QAM symbol Y. It should be noted that as the multiplication is linear, so the signal, noise and interfering radar signal are affected equally. There is no change in SNR or SRR. If the reasonable assumption is made that the channel is estimated perfectly is made, then the expression that gets fed into the decision variable is:

It can be seen that it is not the radar pulse that will affect the decision variable of the QAM demodulator in an OFDM receiver rather it is the Fourier transform of that radar pulse. The important question is therefore what does the power density of look like in comparison to ?

As previously stated, the pulse is assumed to be a rectangular pulse of between 0.1 and 1 µs in duration, corresponding to the rise time of radars in ITU-R M. 1464 . Therefore the relationship between the pulse and its Fourier transform is given by:

The transform of a rectangular pulse is a *sinc* wave with amplitude τ, where τ is the width of the pulse in the time domain. The total power in the time and frequency domains is the same, however while the power of the interfering pulse is concentrated over a small timeframe, in the frequency domain the power is spread over a large bandwidth. Therefore a short pulse of noise becomes a wide underlay of noise in the frequency domain. A high power radar pulse has the effect of raising the noise floor.

As the radar pulse is hard limited by the A/D converter, it is possible to calculate the maximum amount of power added to the noise floor by the radar. The pulse power is limited to 15 dB above the signal regardless of pulse length; therefore the longer 1 µs pulse will be of higher overall power (when integrated over time). When transformed into the frequency domain, the signal will be represented as:

The amplitude of the *sinc* wave will be reduced by a factor of as compared to the amplitude *A* of the pulse. This equates to a 120 dB reduction in power. Assuming that there is no significant reduction in the amplitude of the wanted signal – the FFT of a sine wave has the same amplitude as the time domain wave – then the interfering signal is now 105 dB below the wanted signal. The post FFT SSR is 105 dB.

In any digital representation of an analogue signal, the quantum separation of amplitude levels that can be represented are finite, and limited by the total number of bits assigned to that signal (and influenced by the input range). When the A/D converter limits the radar signal, it will limit it at its maximum value. In order for there to be a reduction in amplitude and the signal still exist afterwards there must be a minimum of 20 bits in the signal.

This is not an unreasonable number, so it cannot be claimed that the radar interference will simply disappear after the FFT. There is a very high probability however that the radar interference will be below the noise floor and SNR requirements.

If the radar pulse turned out to be more triangular than rectangular, then the Fourier relationship would be given by:

This means that the amplitude will be reduced by a factor of , rather than . This is an even better scenario than a rectangular pulse.

From this analysis, it is expected that adjacent band radar emissions will not cause any significant interference to LTE systems. The FFT function of LTE receivers should limit the effect of any pulse interference. These results however are yet to be confirmed through either simulation or experimentation.

1. IMT Blocking Analysis

This section aims to determine whether radar is likely to cause receiver blocking in IMT systems. As reviewed in Section 1.2, and analysed in Section 3, interference to IMT systems would probably be mitigated by the properties of the modulation scheme. However, it still must be ensured that the receiver will not be blocked by the high powered radars.

* 1. Radar Antenna and Emission masks

In the previous ACMA sharing study, aeronautical and meteorological radar antenna masks were calculated indirectly from then current ITU recommendations. ITU studies published since then use the masks shown in and . For this analysis the assumed radar antenna masks used are those depicted in and , as these are consistent with ITU studies and reports.

There are also a number of radar emission masks used in previous studies. shows an emission mask calculated from ITU recommendations. through to show the emission spectra of four radars around the UK, as measured by ERA. By carefully comparing the measured emission masks against the calculated mask in , it can be seen that the airport A, B and D type radars approximately meet the 20 dB/decade calculated filter.

Airport C’s radar’s emission rolloff is initially sharper however high power spikes at frequencies distant from the centre frequency mean the emission mask flattens off quickly. Therefore it was decided that the 20 dB/decade mask shown in should be used, as it best represents three out of the four measured masks. In addition, Recommendation M. 1541-2 states that emission spectra for existing radars in this band should adhere to a roll-off of 20 dB/decade, with new radars achieving 40 dB/decade.

* 1. Radar and IMT parameters

Parameters used in this study are shown in . The IMT parameters used are in accordance with ITU recommendations and previous ACMA sharing studies. Note that the upper portion of the 2500 – 2690 MHz band is intended for use as the mobile station receive band. The receivers that a radar is most likely to affect are mobile receivers. The radar parameters are taken from those given for radar type G (3), as this is the worst case radar for this analysis.

|  |  |  |
| --- | --- | --- |
| **Parameter** | **Value** | **Source** |
| IMT Receiver Blocking Performance |  | 3GPP TS.25-101 |
| IMT ACS 15 MHz | 49 dB |  |
| IMT ACS > 35 MHz | < 60 dB | Assumed |
| IMT Bandwidth | 5 MHz |  |
| IMT Antenna Gain | 0 dBi |  |
| Radar EIRP (max gain) | 132.7 dBm | (3) |
| Radar Antenna Gain | 45.7 dBi | (3) |
| Radar Emission Mask |  | See above |
| Radar Antenna Pattern |  | See above |
| Radar Height | 20 m | Terrey Hills radar site (14) |

Table 3: IMT mobile characteristics

* 1. Methodology

Power levels at the receiver are given by;

The radar band begins at 2700 MHz, meaning the centre of the first theoretical radar service would be approximately 15 MHz away from the centre of the top IMT channel. Of currently active radars, the lowest frequency service operating in Australia is 38.5 MHz above the 2690 boundary.

This would correspond to a centre frequency separation of 41 MHz. In this analysis, frequency separations of both 15 and 40 MHz have been used. In the 40 MHz case, given that IMT selectivity is not available for this separation, it has been assumed that the radar emissions are the limiting case – ie. that the selectivity is far better than the radar’s emission mask.

From , the frequency separation-dependant attenuation has been estimated as:

* -50 dB for 15 MHz
* -60 dB for 40 MHz

That gives FDRs of;

Four propagation models were used to determine the path loss, free space, Indoor-Outdoor Pedestrian, Indoor-Outdoor Vehicular and COST-231 Hata.

* 1. Results

The power received was calculated for both the 15 and 40 MHz cases and are show in and respectively. The results are colour coded green if the received power is less than the blocking performance or red if the power is greater.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Received Power (dBm)** | 100 m | 500 m | 1 km | 5 km | 10 km |
| *Free Space* | 5.1 | -8.9 | -14.9 | -28.9 | -34.9 |
| *Pedestrian 1225* | -25.7 | -53.7 | -65.7 | -93.7 | -105.7 |
| *Vehicular 1225* | -7.0 | -33.3 | -44.6 | -70.9 | -82.2 |
| *COST-231 Hata* | -11.6 | -36.2 | -46.8 | -71.4 | -82.0 |

Table 4: Received power with 15 MHz separation

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Received Power (dBm)** | 100 m | 500 m | 1 km | 5 km | 10 km |
| *Free Space* | -8.4 | -22.4 | -28.4 | -42.4 | -48.4 |
| *Pedestrian 1225* | -39.2 | -67.2 | -79.2 | -107.2 | -119.2 |
| *Vehicular 1225* | -20.5 | -46.8 | -58.1 | -84.4 | -95.7 |
| *COST-231 Hata* | -25.1 | -49.7 | -60.3 | -84.9 | -95.5 |

Table 5: Received power with 40 MHz separation

Based on these results, blocking will not occur to any IMT terminal potentially deployed in the 2.5 GHz band unless that terminal is less than 500 m away from a radar antenna. This analysis used worst case radar EIRP, emission masks, and assumed no pointing discrimination. Real world situations are likely be better than indicated here.

* 1. Further Analysis

The results in Section 4.4 above are based on the worst case radar in ITU-R.1464 and a location directly in the main beam antenna gain. In an ERA study, it was found experimentally that UMTS and WiMAX degradation is primarily a result of the antenna side lobes and not the main beam gain. Therefore it is probable that the results in Table 4 and Table 5 are unnecessarily pessimistic, as the effect of the antenna gain will be much lower.

The gain of the interfering antenna used in the analysis is the maximum 45.7 dB (as shown in Figure 7), and given the narrow beamwidth of this radiation pattern and the antenna’s rotating nature, this peak gain in the direction of a fixed IMT site will only occur with a very low duty cycle. In fact, with only a small angular rotation off-axis, the gain drops 35 dB to about 10 dBi, and the actual gain during rotation is approximately ‑8 dBi for the majority of the time (ie. the theoretical gain floor).

Even at only 10 dBi of gain, it can be seen from the results in Tables 5 and 6 that blocking may occur at up to only 100 m of separation. With the extra 18 dB of mitigation at the gain floor, all the results fall below -44 dBm. In combination with this, the radar antenna is unlikely to be pointing directly at the IMT station, as IMT stations are ground based and radars are typically designed not to point at ground locations within a few hundred meters. This is likely to significantly further reduce the antenna gain in practice and this is explored in Section 5.7.3.

The Meteor 1500S meteorological radar used in Australia has approximately the same EIRP as the radar type G model. The most powerful radar licensed in Australia is a 1.2 MW meteorological radar with 45 dB antenna gain near Brisbane.

This is only 3 dB more powerful than the radar type G model, and therefore does not significantly alter the above results. More than half of the radars in Australia have a power of less than 50 kW, 10 dB better than the results above. In addition, the aeronautical radars have main beam gains of around 34 dBi in Australia, another 11 dB better than the results shown in Tables 5 and 6.

As is explained in detail in Section 5.7.3, the placement, height and antenna pointing of IMT and radar stations is likely to provide significant further mitigation. Radar stations are aiming to observe airborne objects and avoid ground reflections. In contrast IMT mobile stations are ground based receivers usually beneath clutter.

The main beam of a radar antenna is highly unlikely to point directly at a mobile receiver as that would entail pointing at the ground. The extra mitigation from antenna discrimination could provide 30 dB or more based on the reasoning in Section 5.7.3, which would be sufficient to prevent blocking in nearly all cases.

In addition, high powered meteorological radars are typically placed on open land or hill tops away from high levels of development to avoid reflections from clutter and to minimise high levels of RF exposure to the public. Thus, there are unlikely to be many IMT users in close proximity to radars, minimising the risk of blocking.

* 1. Conclusion

The worst case scenario for receiver blocking is that mobiles may experience blocking within 500 m of a handful of high powered radars around Australia. However there are significant mitigating factors due to the rotational nature of the radar antenna, the placement and power of radars. Typically the radars in this band will not have their main beam aimed at ground based objects such as IMT mobile stations and this will provide significant additional antenna discrimination. Therefore it is considered unlikely that significant mobile receiver blocking will occur.

1. Radar Blocking and Interference

Whilst robustness of the modulation techniques used by IMT provide some mitigation against interference from radar emissions, this is not true the other way around. The analysis presented in the following sections protects radar services to below the noise floor. It uses the minimum coupling loss method determine the potential for interference. In addition, it must be ensured that, even if interference does not occur, blocking will not occur either. The two results are related to one another, but there are subtle differences.

Interference occurs when unwanted received power (interfering power) causes the decision variable at the end of the receiver chain to mistake one symbol for another (in IMT) or falsely detect a target (in a radar). The interfering power is made up of two equally important sources of power – on tune interference, and off tune interference. That is, the intended IMT signal operating within its licensed bandwidth is picked up due to imperfect radar selectivity and unintended IMT (out-of-band) signals within the radar’s bandwidth that exist due to imperfect IMT emission masks.

This is shown in Figure 23, where the green area is the power that is causing interference to the radar. Interference occurs at the decision variable at the end of the receiver chain.



Figure 23: Relationship between emission and selectivity masks

Blocking, on the other hand, is caused by the saturation of components in the receiver chain. ie. Blocking affects components earlier in the receiver chain than interference does such as is shown in Figure 24: Abstraction of a receiver chain showing where blocking and interference occur. The total green interfering power in Figure 23 causes the saturation of a component before the end of the receiver chain. It is possible that unwanted signals that won’t saturate components will affect the decision variable – as is the case with ordinary interference.

Another point to note is that the selectivity masks are not necessarily the same. The selectivity mask for interference is the cumulative result of all the filters in the receiver chain. In the Watchman receiver chain of there are three filters which contribute to interference selectivity. The blocking mask is a result of the overload levels of each component combined with any filters before that component. If the amplifier in overloads it doesn’t matter if the filter after it can remove all unwanted power as the received has already failed.



Figure 24: Abstraction of a receiver chain showing where blocking and interference occur

* 1. Selectivity Masks

In the literature reviewed for this study, three different masks were identified for radars. The mask shown in was calculated for the last ACMA sharing study, from ITU-R M.1464 illustrates the measured response from an operating aeronautical radar, and is the mask of blocking levels on a Watchman radar produced by Ofcom.

For the latter mask, at each point in the mask Ofcom have identified which component in the Watchman radar overloads. This mask is not an interference selectivity mask – there are filters that follow the components in the chain (see ) that overload and alter the unwanted power received at the decision variable. Therefore this mask is suitable for determining blocking, but not for determining interference. Furthermore, it must be noted that this mask includes both the blocking level and the frequency selectivity – it states that -43 dBm at 25 MHz off centre frequency will cause blocking.

from M.1464 is a measured response mask. Depending on the exact method of measurement – which is not stated in detail in the Recommendation – this mask is valid for both the blocking and interference masks for that radar. The problem with this mask is that it extends for only MHz, and therefore is insufficient to meet the requirements for testing 15 and 40 MHz frequency separations without extrapolation.

Upon comparison however, this mask is very close to the calculated mask in . For the first MHz, the masks are very close, with the measured mask performing slightly better at lower frequencies than at higher frequencies. The calculated mask rolls of at a rate of 80 dB/decade, a value taken from ITU R. M.1461.

Based on the available selectivity masks the following decisions on the study were made:

* Interference will be evaluated based on the mask shown in . This mask will be henceforth known as ‘the ITU mask’, as it was calculated from ITU-R M.1464 and M.1461. As specified in M.1461 this mask varies depending on the bandwidth of the receiver; and
* Two blocking cases will be examined, one using as a selectivity mask and the other using as a blocking level mask.
  1. Radar and IMT parameters

The IMT parameters used are in accordance to ITU recommendations, 3GPP TS.25-104, and previous ACMA sharing studies. Note however that the band 2620 – 2690 MHz band is intended for base station transmit, therefore it will be the transmission from the base stations, not the mobile stations, that affects the radars.

The radar parameters for both aeronautical and meteorological radars are shown below. They are taken from Radar A, Radar G models and the Meteor1500S Datasheet . Parameters used in this study are shown in Table 6, and .

|  |  |  |
| --- | --- | --- |
| **Radar Parameter** | **Value** | **Source** |
| Antenna Gain | 45.7 dBi | (3) |
| Bandwidth | 600 kHz | (3) |
| Selectivity at 15 MHz (ITU Mask) | 96 dB | *calculations* |
| Selectivity at 40 MHz (ITU Mask) | 131 dB | *calculations* |
| Height | 20 m | *Terrey Hills radar site* (14) |
| Blocking Level | -43 dBm/Ofcom Mask | (3) */*(9) |
| Interference Level | -123 dBm | (13)*,* (3) |

Table 6: Meteorological radar parameters

|  |  |  |
| --- | --- | --- |
| **Radar Parameter** | **Value** | **Source** |
| Antenna Gain | 33.5 dBi | (3) |
| Bandwidth | 5000 kHz | (3) |
| Selectivity at 15 MHz (ITU Mask) | 91 dB | *calculations* |
| Selectivity at 40 MHz (ITU Mask) | 129 dB | *calculations* |
| Height | 20 m | *Terrey Hills radar site* (14) |
| Blocking Level | -43 dBm (on frequency)  / Ofcom Mask | (3) */*(9) |
| Interference Level | -120 dBm | (3) |

Table 7: Aeronautical radar parameters

|  |  |
| --- | --- |
| **IMT Station Parameters** | **Value** |
| Antenna Gain | 17 dBi |
| Bandwidth | 5 MHz |
| Tx Power | 43 dBm |
| Standard 15 MHz ACLR | 67 dB |
| Standard Spurious Emissions (40 MHz) | -30 dBm |
| Proposed Emission limit A | -36 dBm |
| Proposed Emission limit B | -45 dBm |
| Height | 30 m |

Table 8: IMT parameters

Note that four emission limits have been specified for IMT in Table 9. The first two (15 MHz ACLR and 40 MHz spurious emission limit) are the default parameters for an IMT base station, without any extra restrictions placed upon them. The two proposed emission limits are extra limits that are being considered for the 2.5 GHz band. These limits have been investigated in previous ACMA sharing studies .

* 1. Method

The results of this study shall evaluate three cases:

* Interference and Blocking based on the ITU selectivity mask and standard emissions. This is the ‘standard situation’ and shown in Section 5.4;
* Interference and Blocking based on the ITU selectivity mask and proposed emission limits. This is referred to as the ‘restricted situation’ and shown in Section 5.5; and
* Blocking based on the Ofcom mask as shown in Section 5.6. The extra restrictions do not have any effect using this mask, as it is the on-channel IMT power that dominates the results.

The results were calculated based on the parameters above using the MCL method. For the standard situation this was done as follows:

In the spurious domain of the standard situation and in the restricted situation where emission limits were specified, the emission limit took the place of the value. This leads to the following formula:

Note that there are two mechanisms at work, in band interference given by IMT EIRP less radar selectivity, and out of band interference given either by the proposed emission limit, or IMT EIRP minus IMT ACLR. The formulas for *FDR* and are shown below. In all formulas, EIRP was normalised for radar receiver bandwidth.

This means that *FDR* is the total resultant loss and is the total interfering power as seen in Figure 23.

Three path loss models were used, Free Space, Longley Rice, and ITU-R P.1546. Longley Rice and P.1546 were calculated in the WRAP software package using a 20 m high transmitter and 30 m high receiver over flat terrain (in accordance with Tables 7, 8 and 9). P.1546 was configured for 1% time and a suburban environment.

These models default to Free Space loss condition at short distances. The modelling does not include the effects of antenna height on vertical antenna pattern discrimination, which is discussed later in Section 5.7.3.

|  |  |  |  |
| --- | --- | --- | --- |
| Distance | Free Space Loss | Longley Rice Loss | 1546 Loss |
| 100 m | 81.1 | 81.6 | 81.1 |
| 500 m | 95.1 | 95.1 | 95.1 |
| 1 km | 101.1 | 101.1 | 106.7 |
| 2 km | 107.1 | 107.1 | 115.7 |
| 3 km | 110.7 | 110.7 | 121.3 |
| 5 km | 115.1 | 116.3 | 129.5 |
| 7.5 km | 118.6 | 121.6 | 137 |
| 10 km | 121.1 | 125.9 | 143 |

Table 9: Propagation loss (dB) at various separation distances

An example calculation of the results in Table 10 follows (for meteorological radar, standard situation, 40 MHz, 100m separation):

|  |  |
| --- | --- |
|  |  |
|  | = |
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For the third situation (blocking based on the Ofcom mask), the mask provided by Ofcom includes both the blocking level and the frequency rejection information. If the on-channel power exceeds the blocking level specified by the mask at that frequency, then blocking will occur. Power present at the input of the receiver is therefore given as;

* 1. Interference and Blocking Standard Situation

This situation uses the ITU selectivity mask and standard IMT emission limits. Values in Tables 11, 12, 13 and 14 can be interpreted as follows:

* Red font indicates that the received power exceeds both blocking and interference thresholds (above -43 dBm);
* Yellow font indicates that the received power exceeds the interference threshold but would not cause blocking (above -120 dBm for meteorological or -117 dBm for aeronautical);
* Olive Green font indicates that the received power value is within 3 dB of the interference threshold (above -123 dBm for meteorological or -120 dBm for aeronautical);
* Green font indicates that neither blocking nor interference would occur (equal to or below -123 dBm for meteorological or -120 dBm for aeronautical).
  + 1. Meteorological Radar Results

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Standard Situation - 15 MHz** | | |  |  |  |  |  |  |
| *Distance* | *100m* | *500m* | *1 km* | *2 km* | *3 km* | *5 km* | *7.5 km* | *10 km* |
| *Free Space* | -51.6 | -65.6 | -71.6 | -77.7 | -81.2 | -85.6 | -89.1 | -91.6 |
| *Longley-Rice* | -52.1 | -65.6 | -71.6 | -77.6 | -81.2 | -86.8 | -92.1 | -96.4 |
| *P.1546* | -51.6 | -65.6 | -77.2 | -86.2 | -91.8 | -100.0 | -107.5 | -113.5 |

Table 10: Meteorological radar, ‘standard situation’, 15 MHz separation interference and blocking results (received power in dBm)

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Standard Situation - 40 MHz** | | |  |  |  |  |  |  |
| *Distance* | *100m* | *500m* | *1 km* | *2 km* | *3 km* | *5 km* | *7.5 km* | *10 km* |
| *Free Space* | -65.4 | -79.4 | -85.4 | -91.4 | -95.0 | -99.4 | -102.9 | -105.4 |
| *Longley-Rice* | -65.9 | -79.4 | -85.4 | -91.4 | -95.0 | -100.6 | -105.9 | -110.2 |
| *P.1546* | -65.4 | -79.4 | -91.0 | -100.0 | -105.6 | -113.8 | -121.3 | -127.3 |

Table 11: Meteorological radar, ‘standard’ situation, 40 MHz separation interference and blocking results (received power in dBm)

* + 1. Aeronautical Radar Results

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Standard Situation - 15 MHz** | | |  |  |  |  |  |  |
| *Distance* | *100m* | *500m* | *1 km* | *2 km* | *3 km* | *5 km* | *7.5 km* | *10 km* |
| *Free Space* | -54.6 | -68.6 | -74.6 | -80.6 | -84.2 | -88.6 | -92.1 | -94.6 |
| *Longley-Rice* | -55.1 | -68.6 | -74.6 | -80.6 | -84.2 | -89.8 | -95.1 | -99.4 |
| *P.1546* | -54.6 | -68.6 | -80.2 | -89.2 | -94.8 | -103.0 | -110.5 | -116.5 |

Table 12: Aeronautical radar, ‘standard’ situation, 15 MHz separation interference and blocking results (received power in dBm)

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Standard Situation - 40 MHz** | | |  |  |  |  |  |  |
| *Distance* | *100m* | *500m* | *1 km* | *2 km* | *3 km* | *5 km* | *7.5 km* | *10 km* |
| *Free Space* | -77.6 | -91.6 | -97.6 | -103.6 | -107.2 | -111.6 | -115.1 | -117.6 |
| *Longley-Rice* | -78.1 | -91.6 | -97.6 | -103.6 | -107.2 | -112.8 | -118.1 | -122.4 |
| *P.1546* | -77.6 | -91.6 | -103.2 | -112.2 | -117.8 | -126.0 | -133.5 | -139.5 |

Table 13: Aeronautical radar, ‘standard’ situation, 40 MHz separation interference and blocking results (received power in dBm)

* 1. Interference and Blocking Restricted Situation

This situation uses the ITU selectivity mask and the proposed emission limits. Values in Tables 15, 16, 17 and 18 can be interpreted as follows:

* Red font indicates that the received power exceeds both blocking and interference thresholds (above -43 dBm);
* Yellow font indicates that the received power exceeds the interference threshold but would not cause blocking (above -120 dBm for meteorological or -117 dBm for aeronautical);
* Olive Green font indicates that the received power value is within 3 dB of the interference threshold (above -123 dBm for meteorological or -120 dBm for aeronautical); and
* Green font indicates that neither blocking nor interference would occur (equal to or below -123 dBm for meteorological or -120 dBm for aeronautical).

The results in this section assumed the following out-of-band emission limit:

* With 15 MHz offset an IMT out-of-band emission limit of -36 dBm was used;
* With 40 MHz offset an IMT out-of-band emission limit of -45 dBm was used.

Other combinations only produce minor variations from these results. The complete list of combinations and their variation is as follows:

-36 dBm limit and 15 MHz: see and ;

-36 dBm limit and 40 MHz: 0.5 dB better (less interfering power received) for meteorological or 6 dB better for aeronautical as compared with and respectively;

-45 dBm limit and 40 MHz: see and ; and

-45 dBm limit and 15 MHz: 7 dB better (less interfering power received) for meteorological or 1 dB better for aeronautical as compared with and respectively.

This means that a -45 dBm limit at 15 MHz would allow meteorological radars to operate at 10 km separation, and a -36 dBm limit at 40 MHz would allow aeronautical radars to operate without interference at 5 km separation.

* + 1. Meteorological Radar Results

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Restricted Situation - 15 MHz, Limit A** | | | |  |  |  |  |  |
| *Distance* | *100m* | *500m* | *1 km* | *2 km* | *3 km* | *5 km* | *7.5 km* | *10 km* |
| *Free Space* | -70.9 | -84.9 | -90.9 | -97.0 | -100.5 | -104.9 | -108.4 | -110.9 |
| *Longley-Rice* | -71.4 | -84.9 | -90.9 | -96.9 | -100.5 | -106.1 | -111.4 | -115.7 |
| *P.1546* | -70.9 | -84.9 | -96.5 | -105.5 | -111.1 | -119.3 | -126.8 | -132.8 |

Table 14: Meteorological radar, ‘restricted’ situation, 15 MHz separation interference and blocking results (received power in dBm)

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Restricted Situation - 40 MHz, Limit B** | | | |  |  |  |  |  |
| *Distance* | *100m* | *500m* | *1 km* | *2 km* | *3 km* | *5 km* | *7.5 km* | *10 km* |
| *Free Space* | -80.4 | -94.4 | -100.4 | -106.4 | -110.0 | -114.4 | -117.9 | -120.4 |
| *Longley-Rice* | -80.9 | -94.4 | -100.4 | -106.4 | -110.0 | -115.6 | -120.9 | -125.2 |
| *P.1546* | -80.4 | -94.4 | -106.0 | -115.0 | -120.6 | -128.8 | -136.3 | -142.3 |

Table 15: Meteorological radar, ‘restricted’ situation, 40 MHz separation interference and blocking results (received power in dBm)

* + 1. Aeronautical Radar Results

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Restricted Situation - 15 MHz, Limit A** | | | |  |  |  |  |  |
| *Distance* | *100m* | *500m* | *1 km* | *2 km* | *3 km* | *5 km* | *7.5 km* | *10 km* |
| *Free Space* | -77.4 | -91.4 | -97.4 | -103.5 | -107.0 | -111.4 | -114.9 | -117.4 |
| *Longley-Rice* | -77.9 | -91.4 | -97.4 | -103.4 | -107.0 | -112.6 | -117.9 | -122.2 |
| *P.1546* | -77.4 | -91.4 | -103.0 | -112.0 | -117.6 | -125.8 | -133.3 | -139.3 |

Table 16: Aeronautical radar, ‘restricted’ situation, 15 MHz separation interference and blocking results (received power in dBm)

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Restricted Situation - 40 MHz, Limit B** | | | |  |  |  |  |  |
| *Distance* | *100m* | *500m* | *1 km* | *2 km* | *3 km* | *5 km* | *7.5 km* | *10 km* |
| *Free Space* | -92.6 | -106.6 | -112.6 | -118.6 | -122.2 | -126.6 | -130.1 | -132.6 |
| *Longley-Rice* | -93.1 | -106.6 | -112.6 | -118.6 | -122.2 | -127.8 | -133.1 | -137.4 |
| *P.1546* | -92.6 | -106.6 | -118.2 | -127.2 | -132.8 | -141.0 | -148.5 | -154.5 |

Table 17: Aeronautical radar, ‘restricted’ situation, 40 MHz separation interference and blocking results (received power in dBm)

* 1. Blocking situation with Ofcom mask

This situation uses the same radar parameters used above but using the Design Authority model mask () which specifies blocking limits at particular frequencies. The blocking limit for 40 MHz separation specified by Ofcom is -45 dBm. Results that exceeded this value are coloured red, indicating potential blocking, and results that were less than this value are green, indicating blocking should not occur. Note that a result of no blocking with this mask does not imply no interference, and vice versa.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Ofcom Blocking** | |  |  |  |  |  |  |  |
| *Distance* | *100m* | *500m* | *1 km* | *2 km* | *3 km* | *5 km* | *7.5 km* | *10 km* |
| *Free Space* | 14.7 | 0.7 | -5.3 | -11.4 | -14.9 | -19.3 | -22.8 | -25.3 |
| *Longley-Rice* | 14.2 | 0.7 | -5.3 | -11.3 | -14.9 | -20.5 | -25.8 | -30.1 |
| *P.1546* | 14.7 | 0.7 | -10.9 | -19.9 | -25.5 | -33.7 | -41.2 | -47.2 |

Table 18: Meteorological radar blocking performance with Ofcom’s mask (received power in dBm)

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Ofcom Blocking** | |  |  |  |  |  |  |  |
| *Distance* | *100m* | *500m* | *1 km* | *2 km* | *3 km* | *5 km* | *7.5 km* | *10 km* |
| *Free Space* | 12.4 | -1.6 | -7.6 | -13.6 | -17.2 | -21.6 | -25.1 | -27.6 |
| *Longley-Rice* | 11.9 | -1.6 | -7.6 | -13.6 | -17.2 | -22.8 | -28.1 | -32.4 |
| *P.1546* | 12.4 | -1.6 | -13.2 | -22.2 | -27.8 | -36.0 | -43.5 | -49.5 |

Table 19: Aeronautical radar blocking performance with Ofcom's mask (received power in dBm)

* 1. Discussion of Results

This section has shown that without accounting for the assumptions made in obtaining the results Tables 18 and 19, and temporarily ignoring the results obtained using the Ofcom mask, radar can function in the presence of IMT when appropriate restrictions are placed on IMT services. These restrictions could include a -45 dBm emission limit in combination with a distance separation of:

* Aeronautical radars: 2 km at 40 MHz separation or 7.5 km at 15 MHz separation;
* Meteorological radars: 7.5 km at 40 MHz separation or 10 km at 15 MHz separation.

These distances were chosen based on results using P. 1546 being below the threshold, and results using Longley Rice being at least within 3 dB of the threshold.

Restricting IMT emissions further will improve the results. A -55 dBm limit would reduce the distance to 3 km for meteorological radar with 40 MHz separation and 7.5 km with 15 MHz separation; and would reduce the distance to less than 1 km for aeronautical radar with 40 MHz separation. The separation distance for aeronautical radar with 15 MHz separation would remain unchanged, due to the selectivity limitation.

For cases where potential interference could occur at distances exceeding the maximum distance in the tables in sections 5.4 and 5.5, the required separation distance has been calculated and is shown in Table 21 below. This table only covers results that exceed 10 km, distances in all other cases can be read from the tables in sections 5.4 and 5.5.

|  |  |  |
| --- | --- | --- |
| **Limit/Service** | **15 MHz** | **40 MHz** |
| Standard/Aeronautical | 12.5 km | N/A |
| Standard/Meteorological | 60 km | 20 km |
| Limit A/Meteorological | 15 km | 15 km |

Table : Required separation distances greater than 10 km

* + 1. Sensitivity to Selectivity

Improving the selectivity of the radar would not significantly decrease the unwanted signal power into the radar, unless IMT out-of-band emission performance is improved. An ideal radar selectivity mask (ie. a rectangular mask giving total out-of-band attenuation) would:

* Decrease unwanted received signal power by up to 6 dB assuming emission limit A (-36 dBm), and 15 MHz separation or up to 15 dB using emission limit B (-45 dBm) for aeronautical radar; and
* Have no effect on any other case (including the standard situations).

The above mentioned 15 dB improvement (assuming emission limit B) that could be achieved if a receiver with ideal selectivity was used would reduce the separation distance to within 2 km for aeronautical radar with 15 MHz separation. A 6 dB improvement (assuming emission limit A) would reduce the distance to 5 km.

If radar selectivity was worse than assumed in this study it would:

* Need to be degraded by over 20 dB before results would be affected for 40 MHz separation (restricted situation);
* Immediately affect all restricted situation results for 15 MHz separation; and
* Need to be degraded by 20 – 30 dB to affect the results for the standard situation.

This can be interpreted as meaning that the radar selectivity of at least 90 dB at the desired frequency separation would be required for the ‑30 or ‑36 dBm IMT emission limits to be effective. For -45 dBm limits to be fully effective a radar selectivity of at least 110 dB would be required at the desired frequency.

* + 1. Ofcom Blocking Mask

When using the Ofcom mask which specifies blocking levels on Watchman radars, it is likely that blocking would occur for separation distances of well over 10 km, depending on terrain. The interference rejection performance of the Watchman radar is not known, so it has been assumed that the interference selectivity mask is similar to the ITU mask. IMT services and radars which have Ofcom’s measured blocking performance would need to be subjected to a strict coordination regime, along with significant system improvements, if they were to operate in adjacent bands without interference.

By reconfiguring the Watchman’s front end, Ofcom are hoping to have improved the blocking selectivity by between 40 and 60 dB by the first IMT channel. If this adjustment was made, then the results in and would be amended to indicate that blocking would not occur for separation distances down to less than 1 km.

The Watchman radar is typically used at airports for traffic control, and is specified for safety and regularity of flight in accordance with ICAO SARPS. It is important that new IMT services should not cause interference to these radars. However, considering the poor performance of the blocking mask of the Watchman radar, it’s worth asking: if these radars are not already receiving interference from existing services?

Both the 2.4 GHz band (used by ISM devices and used in part for WiFi (IEEE 802.11) systems) and the 2.5 GHz band (presently used by ENG services in Australia) are two bands that could potentially cause blocking to radars of such poor performance right now. Furthermore, at some airports, there are multiple, co-site, primary radars registered in the 2.7 – 2.9 GHz band. These radars could potentially interfere with one another if the radars had blocking performance as poor as described for the Watchman radars.

shows radar receiver power levels due to transmissions from ENG, other aeronautical radar and WiFi services. Free Space propagation was used for ENG helicopters and ENG vans and radars were evaluated with the P.1546 model. WiFi was evaluated with the vehicular model, though the higher loss pedestrian model could also be appropriate for this simulation.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Other service** |  | **Ofcom Blocking Distance** | | |  |  |
|  | *100m* | *500m* | *1 km* | *2 km* | *3 km* | *5 km* |
| *WiFi (Vehicular)* | -29.8 | -56.1 | -67.4 | -78.7 | -85.3 | -93.7 |
| *ENG Van (P. 1546)* | 6.9 | -7.1 | -18.7 | -27.7 | -33.3 | -41.5 |
| *ENG Helicopter (Free Space)* | -12.1 | -26.1 | -32.1 | -38.1 | -41.6 | -46.1 |
| *Aeronautical Radar (P. 1546)* | 77.3 | 63.4 | 51.8 | 42.8 | 37.2 | 29.0 |

Table 21: Blocking from other services with Ofcom's Mask (received power in dBm)

shows that the operation of both ENG and radar within 5 km of a radar site that has a receiver with the Watchman radar’s selectivity could potentially result in blocking. The high power of an interfering aeronautical radar means that the required separation distance need to increase significantly, probably out to hundreds of kilometres.

While ENG is an itinerate service, airports are often places that attract news crews. It is likely that if Australian radars had blocking performances as bad as described for the English Watchman radars then ENG would already be causing intermittent blocking of aeronautical radars.

In the case of other aeronautical radars synchronisation could minimise such interference. Nevertheless, coordinating against the Watchman mask would be difficult. This would suggest that Australian radars have better blocking performances than those used in the above analysis.

* + 1. Heights and Antenna Discrimination

One important assumption that has been made thus far is that both radar and IMT base station antennas are pointing directly at each other. This is unlikely to be the case (see discussion in Section 4.5). IMT base stations are aiming to service devices at ground level, and usually have an antenna downtilt of 3⁰. IMT base stations need to coordinate with each other and it is not advantageous to have antennas pointing towards the horizon.

While the horizontal antenna pattern of a UMTS antenna is quite wide, the vertical pattern is surprisingly sharp. Calculations done using ITU R F.1336 indicate that the loss from antenna discrimination at 3⁰ above the horizon would be 14 dB. The antenna patterns shown in and (18) indicate that a discrimination value of 14 dB (3 dBi gain) could be achieved at roughly 5-6⁰ off axis (2-3⁰ above the horizon with 3⁰ downtilt).

Aeronautical and metrological radars antennas are typically not pointing directly at IMT stations. The radars in question are interested in observing objects in the sky such as weather or aircraft. Ground reflections, especially at close range, are not only undesirable but potentially compromise the radar’s ability to detect targets. The locations of meteorological radars around Australia have been chosen considering field of view, in order to achieve a distant radio horizon/observation range.

All the locations around capital cities are located on peaks where possible, or in flat terrain with minimal clutter. Only the Grafton radar appears to be in a slight valley. The Terrey Hills radar is located on a peak, and is known not to point below 0.5⁰ (with a 1⁰ beamwidth – so they are not aiming to look below 0⁰). This means that the Terrey Hills radar never points at the surface, always into the atmosphere.

Aeronautical radars are either located at airports, or on nearby hills. As airports sites are not chosen based on the radio horizon, no deductions can be made from the locations of these radars. Aeronautical primary radars are generally specified for up to 200 nm coverage for route surveillances and 80 nm for approach monitoring. Obviously, low local clutter is also a factor in site selection. A typical deployment situation for IMT and radars is shown in Figure 25.



Figure 25: Antenna discrimination due to common placement of radars and base stations

Given this typical scenario, the off-axis discrimination afforded by the narrow beam of the radar antenna pattern should also be considered. The main beam gain of meteorological radar antennas is 45 dBi, but this drops to roughly 14 dBi at 2⁰ off-axis (Figure 7).

The previous results were obtained under the assumption that the main beam of the IMT base station antenna would be pointing directly at the main beam of radar – within a distance of 10 km. In practice, the IMT station would have to be elevated at 3⁰ higher than the radar station for this worst case to be realised, as the IMT antenna is tilted down by 3⁰, which is clearly not likely (as the Grafton radar is in a slight depression if it occurs anywhere is may occur there).

It is much more likely that IMT stations are at least 2⁰ below the horizon within 10 km, with 3⁰ downtilted antennas, resulting in 2⁰ of separation from the radar main beam, and 5⁰ from the IMT base station main beam. This would give an extra 45 dB of extra discrimination between meteorological radars and IMT. Furthermore, this still assumes that the radar antenna is stationary, whereas in fact, they generally rotate. The figure of 45 dB antenna discrimination would therefore be a worst case figure.

As aeronautical radars are generally situated on lower terrain and closer to urban areas, the situation is not as clear cut as with meteorological radars – they are more likely to be pointing towards an IMT station. There is a 20 dB drop in 2⁰ for aeronautical radar antenna patterns according to Figure 8, however, Helios in (19) state that the drop would be more like 5-10 dB. It would be a safe assumption that at least 20 dB of extra mitigation could be achieved with proper IMT placement around radar sites. This could be as high as 34 dB with the careful placement of IMT stations (especially if making use of local terrain shielding), however 20 dB is a reasonable conservative estimate.

When taking into account the extra 45 dB mitigation for meteorological radars and 20 dB for aeronautical radars derived from collective antenna discrimination, and comparing to previous results, it can be concluded that IMT base stations could be deployed within 500 m of a meteorological radar site, or within 1 km of an aeronautical radar site without additional IMT emission filtering.

* + 1. Category B Radars

Ofcom classified all the aeronautical radars in the UK into two categories, distinguished by their characteristics. The Watchman radar is classified as a Category A radar. Ofcom have not examined other Category A radars to determine whether they have similar selectivity.

Ofcom classified four other types of radar including the Star2000, as Category B. While no detailed analysis of Category B radars has been undertaken, Ofcom in consultation with Defence and the Civil Aviation Authority, have estimated that they are likely to block at -27 dBm input power. This is 16 dB above the blocking level used in this report. The selectivity mask of Category B radars has not been investigated by Ofcom.

If these selectivity masks are in accordance with ITU recommendations, then the resultant change in blocking level will not alter the results in Section 5.5. If the value of -27 dBm applies at the relevant frequency separation, then the results shown in Section 5.6 are correct if the threshold is adjusted to -27 dBm instead of -45 dBm. For aeronautical radars this means that the required separation distance would be reduced to 7.5 km. If an extra 20 dB of antenna discrimination is added, the separation distance would be reduced to 1 km.

1. Conclusions

This report aimed to determine the potential for compatibility between IMT services in the 2.5 – 2.69 GHz band and radar services in the 2.7 – 2.9 GHz band. Section 1 examined the previous work by ACMA on this issue and reports published by international organisations. Of particular note was the Ericsson submission reviewed in Section 1.3, examining in detail the effect of pulsed radar transmissions on WCDMA receivers.

The Ericsson study was expanded on to determine the effect on OFDMA LTE receivers in Section 3. In accordance with the Ericsson study a blocking analysis from radar to IMT was performed in Section 4. This completed the analysis of interference from radar to IMT. Effects in the other direction were explored in Section 5 based on selectivity masks identified in Sections 1.1, 1.5 and 1.7.

Based on the information and calculations contained in this report, it can be concluded that it is possible to operate radar and IMT equipment with a combination of restricted zones, antenna coordination, and restrictions on IMT emissions, provided that radar equipment meets ITU specifications.

The relationship between IMT out-of-band emission limits and separation distances are detailed in Section 5.7. They can be summarised as:

|  |  |  |  |
| --- | --- | --- | --- |
| IMT Emission Limit | Frequency Separation | Coordination zone | Restricted Zone |
| None | 40 MHz | 7.5 km for Aeronautical  20 km for Meteorological | 1 km for Aeronautical  500 m for Meteorological |
| -36 dBm | 15 MHz | 7.5 km for Aeronautical  15 km for Meteorological | 1 km for Aeronautical  500 m for Meteorological |
| -36 dBm | 40 MHz | 5 km for Aeronautical  15 km for Meteorological | 1 km for Aeronautical  500 m for Meteorological |
| -45 dBm | 15 MHz | 7.5 km for Aeronautical  10 km for Meteorological | 1 km for Aeronautical 100 m for Meteorological |
| -45 dBm | 40 MHz | 2 km for Aeronautical  7.5 km for Meteorological | 500 m for Aeronautical  <100 m for Meteorological |

Table 22: Coordination and Restriction Zones

In addition, at least 1 km separation is required at 15 MHz of frequency separation, or 500 m at 40 MHz separation, to prevent blocking to IMT services. These are the minimum restricted zones for IMT macro cell base stations using only the coordination techniques examined in this report.

For this to be valid the radar must meet minimum selectivity performance of 90 dB at 15 MHz and 110 dB at 40 MHz. This selectivity criteria is in accordance with ITU recommendations, however it is known from Section 1.8 that some aeronautical radars in the UK do not meet this requirement. It is considered unlikely that Australian radars have the same blocking performance as these, as they would currently be suffering interference from existing services operating in the band.

It is noted that radar systems are highly individual and parameters differ from radar to radar. The two key radar parameters that affect the required separation distance are antenna gain and selectivity. Specific coordination requirements should be determined for each radar site prior to IMT deployment.

Radar and IMT equipment can operate in adjacent bands with appropriate site planning and coordination.

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1. Some of this is stated in the following Ericsson paper rather than this one. [↑](#footnote-ref-1)
2. The following Ericsson paper adjusts this SRR limit to greater than -45 dB [↑](#footnote-ref-2)
3. Now Cobham Technical Services [↑](#footnote-ref-3)
4. It is known from the RADCOM database that Terrey Hills is operating at 2.86 GHz [↑](#footnote-ref-4)
5. As the first radar service in Australia is 38.5 MHz from the edge of the IMT band this could potentially be relaxed even further. [↑](#footnote-ref-5)
6. There will be two pulses, one for the rise time and one for the fall time. [↑](#footnote-ref-6)