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Annex 25 to Joint Task Group 4-5-6-7 Chairman's Report

WORKING DOCUMENT TOWARD A PRELIMINARY DRAFT NEW REPORT ITU-R M.[RADAR1300]

Studies on the impact of International Mobile Telecommunication use on radar systems in the frequency range 1 300-1 400 MHz

1 Overall consideration of results of studies

The attachments to this document represent submissions to JTG 4-5-6-7, and have not been reviewed in detail or agreed.

Several studies have been carried out with respect to the frequency range 1 300-1 400 MHz. All of the studies show, based on the parameters provided by the relevant working parties, that within the same geographical area co-frequency operation of mobile broadband systems and radar is not feasible. As a result, globally harmonised usage of the 1 300-1 400 MHz frequency range or a portion thereof by the mobile service (MS) for the implementation of International Mobile Telecommunication (IMT) may not be possible.

Local circumstances, such as; ubiquity of radar deployments and additional mitigation are, when taken together, the single most critical factor as to whether IMT can operate in particular geographic areas. The attachments to this document make no conclusion as to the complexity, practicability or achievability of the applied mitigations as discussed. Those decisions would have to be made at a national level under the current regulatory framework.

Based on the same parameters provided by the relevant working parties, compatibility also cannot be achieved in the same geographic area when operations including frequency offset are considered (i.e., when the occupied bandwidth of the IMT signal and the occupied bandwidth of the radar do not overlap). However several studies presented showed that compatibility may be achievable subject to a frequency offset and geographic separation if certain mitigation techniques can be implemented including the modification of mobile and radar parameters from those provided by the relevant expert groups within the ITU. This might offer possibilities for the introduction mobile service into the 1 300-1 400 MHz frequency range, with due consideration of the future deployment of radar. It should be noted that those mitigation techniques have not at this point been determined as practical by the expert working parties.

The size of the frequency offset and geographical separation depends on the mitigation technique assumptions made in the studies and the acceptability of those assumptions to an administration and its neighbouring administrations (i.e., those within several hundred kilometres, where no mitigation whatsoever, is employed). Coordination of IMT stations with the neighbouring administrations shall ensure protection of radars operating co-frequency and/or on adjacent frequencies to the proposed IMT stations.

It should also be noted that all of the studies which concluded it is feasible to introduce IMT systems in the 1 300-1 400 MHz frequency range require modification of the IMT and radar equipment. Such studies also suggest segmentation in accordance with Recommendation ITU-R SM.1132 which may involve replanning radar systems as necessary to remove radars from a portion of the range to provide sufficient spectrum to accommodate the IMT channel plus the frequency offset. Any consideration of radar replanning must take into account that some administrations make use of radars that operate across the range between 1 300-1 400 MHz.

Annex 1: Preliminary sharing/compatibility studies between radiolocation et IMT systems in 1 300-1 40 0MHz

Annex 2: “Sharing/compatibility studies of IMT systems with radiolocation systems in the frequency band 1 300-1 400 MHz”

Annex 3: “Working document on sharing/compatibility studies of IMT systems with radiolocation systems in the frequency band 1 300-1 400 MHz”

Annex 4: “Coexistence between radiolocation and IMT systems within 1 375-1 400 MHz band”

Annex 5: “Study into the co-existence of mobile broadband systems and radars in the frequency band 1 300-1 350 MHz”

Annex 6: “Spectrum sharing between radiolocation, and broadband wireless system using IMT in the band 1 350-1 525 MHz”

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Annex 11: “Analysis of required mitigation for IMT systems and radars to share the 1 300-1 400 MHz band”

ANNEX 1

Preliminary sharing/compatibility studies between radiolocation and IMT systems in 1 300-1 400 MHz

1 Introduction

The frequency range 1 300-1 400 MHz has been identified as a suitable frequency range and possible candidate band for IMT systems. The frequency bands 1 300-1 350 MHz and 1 350-1 400 MHz are allocated to the radiolocation service on a primary basis in all Regions. Because of these allocations it is necessary to study the impact from IMT systems into the radiolocation service.

Technical characteristics of radars operating in this frequency band and the technical characteristics of IMT systems have been provided by ITU-R. Having received these inputs it was possible to produce a study using approved technical characteristics of both radars and IMT systems.

The analysis and results of this preliminary deterministic study into co-channel and non-co-channel compatibility of IMT stations towards radars is presented in this document. The study considers interference from an IMT system in a suburban environment with macro base stations and associated user equipment into radars.

2 Background

WRC-15 agenda item 1.1 is considering additional spectrum allocations to the mobile service and identification of additional frequency bands for IMT, and JTG 4-5-6-7 is conducting compatibility/sharing studies in relation to this. The GSMA has proposed a number of suitable frequency ranges to be considered as potential candidate bands for IMT [(see Document 4-5_6-7/88)], including “L-band” frequencies between 1 300 and 1 527 MHz (excluding 1 400-1 427 MHz).

There are existing primary allocations to the radiolocation service in the frequency bands 1 300-1 350 MHz and 1 350-1 400 MHz in all Regions. This contribution contains preliminary studies into compatibility/sharing between IMT and the radiolocation service in frequencies between 1 300 and 1 400 MHz.

3 Technical characteristics

In this section the technical characteristics of radars and IMT systems are presented as provided by ITU-R.

3.1 Technical characteristics of radars in the frequency band 1 300-1 400 MHz

Recommendation ITU-R M.1463 defines the different types of radars operating in the frequency band 1 300-1 400 MHz.

TABLE 1

Technical characteristics of radars operating in the frequency band 1300-1400 MHz, given in Recommendation ITU-R M.1463

	System 1	System 2	System 3	System 4	System 5	System 6	System 7	System 8
Receiver gain Grec, dBi	33.5	38.9	38.2	32.5	38.5	34	35	34.5
Receiver Noise Figure NF, dB	2	2	4.7	3.5	2.6	4.25	9	3.2
Receiver Noise temperature Tn, K	171.4	171.4	571.7	362.9	240.2	486.6	2 034.4	319.2
Receiver bandwidth ΔF, kHz	780	690	6 400	1 200	1 250	880	330	1200
Protection criteria I/N, dB	-6							

3.2 Technical characteristics of IMT in the frequency band 1 300-1 400 MHz

The technical characteristics, as provided by ITU-R, for IMT operating in this frequency range are shown below.

TABLE 2

Deployment-related parameters of IMT for bands between 1 and 3 GHz

	Macro rural	**Macro suburban**	**Macro urban**	**Small cell outdoor / Micro urban**	**Small cell indoor / Indoor urban**
Base station characteristics / Cell structure					
Cell radius / Deployment density (for bands between 1 and 2 GHz)	> 3 km (typical figure to be used in sharing studies 5 km)	0.5-3 km (typical figure to be used in sharing studies 1 km)	0.25-1 km (typical figure to be used in sharing studies 0.5 km)	1-3 per urban macro cell[1] < 1 per suburban macro site	depending on indoor coverage/ capacity demand
Cell radius / Deployment density (for bands between 2 and 3 GHz)	> 2 km (typical figure to be used in sharing studies 4 km)	0.4-2.5 km (typical figure to be used in sharing studies 0.8 km)	0.2-0.8 km (typical figure to be used in sharing studies 0.4 km)	1-3 per urban macro cell[4] < 1 per suburban macro site	depending on indoor coverage/ capacity demand
Antenna height	30 m	30 m (1-2 GHz) 25 m (2-3 GHz)	25 m (1-2 GHz) 20 m 2-3 GHz)	6 m	3 m
Sectorization	3-sectors	3-sectors	3-sectors	single sector	single sector

[1] Outdoor small cells would typically be deployed in very limited areas in order to provide local capacity enhancement. Within these areas, the outdoor small cells would not need to provide Contiguous coverage since there would typically be an overlaying macro network present.

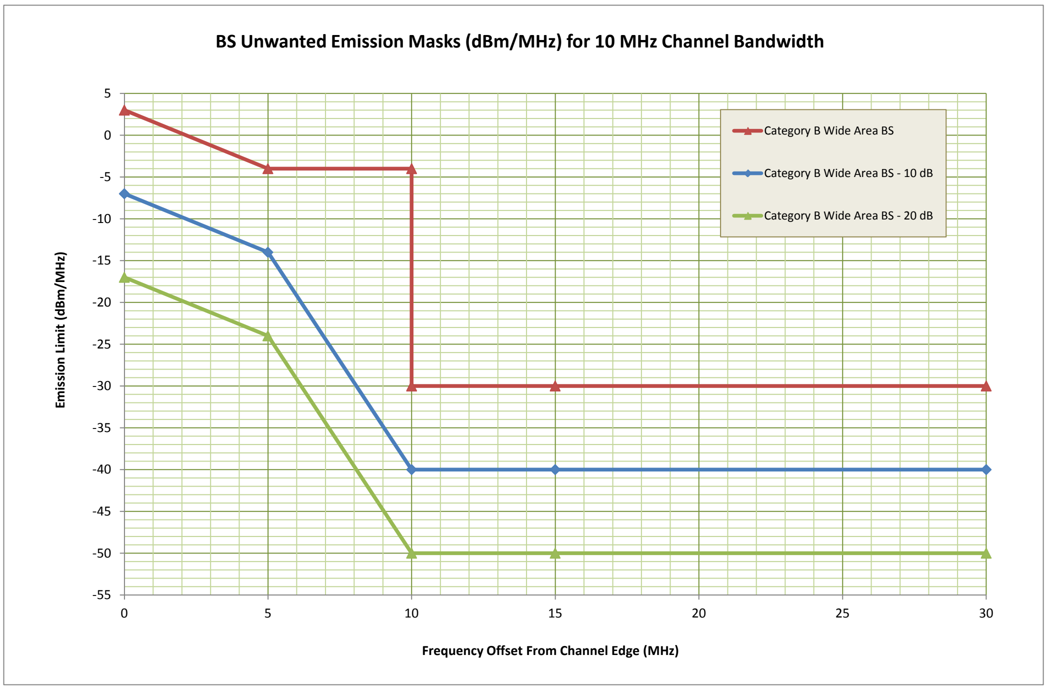
	Macro rural	**Macro suburban**	**Macro urban**	**Small cell outdoor / Micro urban**	**Small cell indoor / Indoor urban**
Downtilt	3 degrees	6 degrees	10 degrees	n.a.	n.a.
Frequency reuse[2]	1	1	1	1	1
Antenna pattern	Recommendation ITU-R F.1336 Annex 10 (see "Antenna Pattern" section) • k_a = 0.7 • k_p = 0.7 • k_h = 0.7 • k_v = 0.3 Horizontal 3 dB beamwidth: 65 degrees Vertical 3 dB beamwidth: determined from the horizontal beamwidth by equations in Recommendation ITU-R F.1336. Vertical beamwidths of actual antennas may also be used when available.			Recommendation ITU-R F.1336 omni	
Antenna polarization	linear / ±45 degrees	linear / ±45 degrees	linear / ±45 degrees	linear	linear
Indoor base station deployment	n.a.	n.a.	n.a.	n.a.	100%
Indoor base station penetration loss	n.a.	n.a.	n.a.	n.a.	20 dB (horizontal) P.1238, Table 3 (vertical)
Below rooftop base station antenna deployment	0%	0%	30% (1-2 GHz) 50% (2-3 GHz)	100%	n.a.
Feeder loss	3 dB	3 dB	3 dB	n.a	n.a
Maximum base station output power (5/10/20 MHz)	43/46/46 dBm	43/46/46 dBm	43/46/46 dBm	35 dBm	24 dBm
Maximum base station antenna gain	18 dBi	16 dBi	16 dBi	5 dBi	0 dBi
Maximum base station output power (e.i.r.p.)	58/61/61 dBm	56/59/59 dBm	56/59/59 dBm	40 dBm	24 dBm
Average base station activity	50%	50%	50%	50%	50%
Average base station power/sector	55/58/58 dBm	53/56/56 dBm	53/56/56 dBm	37 dBm	21 dBm
User terminal characteristics					
Indoor user	50%	70%	70%	70%	100%

[2] If the IMT network consists of three cell layers – macro cells, small outdoor cells and small indoor cells – they will not all use the same carrier. Two layers may use the same carrier, although separate carriers in the same or different bands are also possible.

	Macro rural	**Macro suburban**	**Macro urban**	**Small cell outdoor / Micro urban**	**Small cell indoor / Indoor urban**
terminal usage					
Indoor user terminal penetration loss	15 dB	20 dB	20 dB	20 dB	20 dB
User terminal density in active mode	0.17 / 5 MHz/km^2	2.16 / 5 MHz/km^2	3 / 5 MHz/km^2	3 / 5 MHz/km^2	depending on indoor coverage/ capacity demand
Maximum user terminal output power	23 dBm	23 dBm	23 dBm	23 dBm	23 dBm
Average user terminal output power[3]	2 dBm	−9 dBm	−9 dBm	−9 dBm	−9 dBm
Typical antenna gain for user terminals	−3 dBi	−3 dBi	−3 dBi	−3 dBi	−3 dBi
Body loss –	4 dB	4 dB	4 dB	4 dB	4 dB

Unwanted emissions for an IMT base station according to 3GPP TS 36.104 for a 10 MHz channel bandwidth (E-UTRA bands > 1 GHz) for Category B are shown in Figure 1.

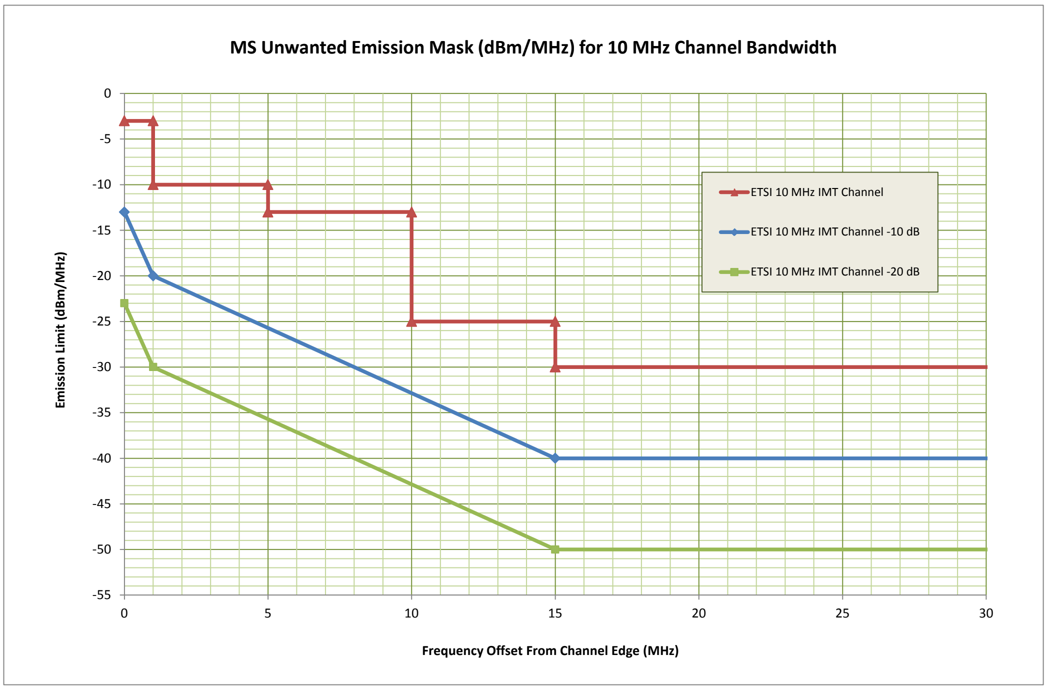
FIGURE 1



Unwanted emissions for IMT user equipment according to 3GPP TS 36.101 for 10 MHz channel bandwidth are shown in Figure 2.

3 According to JTG5-6/180 Annex 2 (except for small cell indoor scenario, which was not covered in that document).

FIGURE 2



4 Analysis

4.1 Assumptions

The study is performed under the following assumptions;

For both co-channel and non-co-channel analysis the assumed frequency is 1 350 MHz. For the non-co-channel analysis a 10 MHz frequency offset is assumed. The frequency offset is from the edge of the IMT band to the radar receiver's closest – 3dB point (half RX bandwidth from centre frequency).

The study analyses the required protection distances between IMT and radars for both IMT base stations and user equipment in order to consider the possibilities of both FDD and TDD operation in the band.

As an example, the study assumes a 10 MHz IMT system in a suburban environment typical of the area surrounding most airports.

The assessment of the required protection distances is for 10% of time and 50% of location for a suburban environment at antenna heights of 1.5 m for IMT UEs, 15 m for radars and 30 m for IMT base stations.

A sensitivity analysis is added to consider more typical values of unwanted emissions than the limits in the 3GPP specifications.

4.2 Methodology and formulas

The protection limit for the radar is calculated as power spectral density at the receiver input:

$$PSD_{\lim} = -174 + NF + (I/N) + Fl + 10\log(10^6)$$

where:

$PSD_{\lim}$: power spectral density protection limit in dBm/MHz

NF : receiver noise figure, dB

(I/N): interference/noise ratio, dB

Fl: feeder loss, dB.

The maximum power limit at the radar receiver is then derived from the above:

$$\mathrm{P}_{\mathrm{lim}} = PSD_{\mathrm{lim}} + 10\log(BW/1000)$$

where:

$\mathrm{P}_{\mathrm{lim}}$: power limit at the receiver in dBm

BW: receiver bandwidth in kHz.

The average power e.i.r.p. for the IMT base station is:

$$\mathrm{P}_{aveEIRP} = P_{out} + G - Fl + 10\log(Af/100)$$

where:

P_{out}: transmitter power in dBm.

G: antenna gain in dBi

Fl: feeder loss in dB

Af: activity factor in %.

The IMT base station average power spectral density, radiated, is derived from the above:

$$\mathrm{P}_{avePSD} = P_{aveEIRP} + 10\log(sigBW)$$

where:

$sigBW$: signal bandwidth in MHz

The average power e.i.r.p. for the IMT user equipment is:

$$\mathrm{P}_{aveEIRP} = P_{out} + G - Bl$$

where:

P_{out}: average transmitter power in dBm

G: antenna gain in dBi

Bl: feeder loss in dB.

The IMT user equipment average power spectral density, radiated, is derived from the above:

$$\mathrm{P}_{avePSD} = P_{aveEIRP} + 10\log(sigBW)$$

where:

$sigBW$: signal bandwidth in MHz.

To determine the necessary separation distance between IMT systems and radars the path loss requirement to meet the protection level of the radar receiver is calculated by deducting the calculated PSD levels of radars from the average PSD level of IMT base stations and user equipment taking account of the radar antenna gain and the additional loss for user equipment due to the height difference to the radar antenna.

The resulting path loss requirements are then calculated to determine a protection distance using Rec. ITU-R P.1546-4. The distances below 1 km are obtained by interpolation between

Recommendation ITU-R P.1546-4 at 1 km and free space propagation at 100 m and for distances below 100 m free space propagation is used. It is recognized there is a new revision of Recommendation ITU-R P.1546 that may provide a better solution, when available.

4.3 Radar calculations

In Table 3 the maximum acceptable interference level (PSD) at the radar receiver is calculated.

TABLE 3

Radar type		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Antenna height	m	15	15	15	15	15	15	15	15
Receiver gain	dBi	33.5	38.9	38.2	32.5	38.5	34	35	34.5
Feeder loss	dB	2	2	2	2	2	2	2	2
Receiver noise figure NF	dB	2	2	4.7	3.5	2.6	4.25	9	3.2
Receiver bandwidth	kHz	780	690	6 400	1 200	1250	880	330	1 200
Protection criterion (I/N)	dB	−6	−6	−6	−6	−6	−6	−6	−6
Maximum acceptable interference PSD at receiver	dBm/ MHz	−116	−116	−113.3	−114.5	−115.4	−113.8	−109	−114.8
Antenna gain reduction toward UEs because of height difference	dB	−10	−10	−10	−10	−10	−10	−10	−10

4.4 IMT base station calculations

In Table 4 the suburban macro base station average radiated power (PSD) is calculated.

TABLE 4

IMT base station parameter		
Antenna height	m	30
Antenna gain	dBi	16
Feeder loss	dB	3
Channel bandwidth	MHz	10
Maximum base station output power	dBm	46
Maximum base station output power (e.i.r.p.)	dBm	59
Average base station activity	%	50
Average base station output power (e.i.r.p.) / sector	dBm	55.99
Signal bandwidth	MHz	**9**
Average base station output radiated PSD	dBm/MHz	**46.46**

4.5 IMT user equipment calculations

In Table 5 the user equipment maximum radiated power (PSD) is calculated.

TABLE 5

IMT UE Parameter		
Antenna height	m	1.5
Antenna gain	dBi	−3
Body loss	dB	4
Maximum terminal output power	dBm	23
Signal Bandwidth	MHz	**9**
Max terminal in-band e.i.r.p./PSD	dBm/ MHz	**6.5**

4.6 Path loss calculations for the IMT base station

In Table 6 the path loss requirements are calculated for the suburban macro base station operating co-channel with a radar.

TABLE 6

Radar type		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Average base station output radiated PSD	dBm/ MHz	46.46	46.46	46.46	46.46	46.46	46.46	46.46	46.46
Radar receiver gain	dBi	33.5	38.9	38.2	32.5	38.5	34	35	34.5
Maximum acceptable interference PSD at radar receiver	dBm/ MHz	−116	−116	−113.3	−114.5	−115.4	−113.75	−109	−114.8
Path loss requirement (base station)	dB	**195.9**	**201.3**	**197.9**	**193.4**	**200.3**	**194.2**	**190.4**	**195.7**

4.7 Path loss calculations for the IMT user equipment

In Table 7 the path loss requirements are calculated for the user equipment operating co-channel with a radar. The result is calculated for a maximum power of 23 dBm.

TABLE 7

Radar type		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Max terminal in-band e.i.r.p./PSD	dBm/ MHz	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5
Radar receiver Gain	dBi	33.5	38.9	38.2	32.5	38.5	34	35	34.5
Maximum acceptable interference PSD at radar receiver	dBm/ MHz	−116	−116	−113.3	−114.5	−115.4	−113.8	−109	−114.8
Radar antenna gain reduction toward UEs because of height difference	dB	−10	−10	−10	−10	−10	−10	−10	−10
Path loss requirement (UE) Max power	dB	**146.0**	**151.4**	**148.0**	**143.5**	**150.4**	**144.2**	**140.5**	**145.8**

4.8 Path loss calculations for the IMT base station

In Table 8 the path loss requirements are calculated for the IMT suburban macro base station operating in the non-co-channel to a radar.

TABLE 8

Radar type		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Spurious Emissions (base station)	dBm/ MHz	−30	−30	−30	−30	−30	−30	−30	−30
Antenna gain	dBi	16	16	16	16	16	16	16	16
Feeder loss	dB	3	3	3	3	3	3	3	3
Spurious Emissions e.i.r.p. (base station)	dBm/ MHz	−17	−17	−17	−17	−17	−17	−17	−17
Maximum acceptable interference PSD at radar receiver	dBm/ MHz	−116	−116	−113.3	−114.5	−115.4	−113.8	−109	−114.8
Radar receiver Gain	dBi	33.5	38.9	38.2	32.5	38.5	34	35	34.5
Path loss requirement (base station)	dB	**132.5**	**137.9**	**134.5**	**130**	**136.9**	**130.8**	**127**	**132.3**

4.9 Path loss calculations for the IMT user equipment

In Table 9 the path loss requirements are calculated for the user equipment operating in the adjacent channel to a radar. The value used for spurious emissions is –27.5 dBm/MHz where the correct value at this frequency offset is –25 dBm/MHz.

TABLE 9

Radar type		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Spurious Emissions (UE)	dBm/ MHz	−25/−30	−25/−30	−25/−30	−25/−30	−25/−30	−25/−30	−25/−30	−25/−30
Antenna gain	dBi	−3	−3	−3	−3	−3	−3	−3	−3
Body loss	dB	4	4	4	4	4	4	4	4
Spurious Emissions e.i.r.p. (UE)	dBm/ MHz	−34.5	−34.5	−34.5	−34.5	−34.5	−34.5	−34.5	−34.5
Maximum acceptable interference PSD at radar receiver	dBm/ MHz	−116	−116	−113.3	−114.5	−115.4	−113.8	−109	−114.8
Radar receiver Gain	dBi	33.5	38.9	38.2	32.5	38.5	34	35	34.5
Radar antenna gain reduction toward UEs because of height difference	dB	−10	−10	−10	−10	−10	−10	−10	−10
Path loss requirement (UE)	dB	**105**	**110.4**	**107**	**102.5**	**109.4**	**103.25**	**99.5**	**104.8**

4.10 Results

The deterministic path loss requirements calculated above have been used to derive the resulting protection distances using Recommendation ITU-R P.1546-4 and are presented in Tables 10 to 12 below.

In Table 10 the required protection distances in km are shown separately for each radar type for the four cases; user equipment operating in non-co-channel with 10 MHz frequency offset to a radar, user equipment operating co-channel with a radar, suburban macro base station operating in non-co-channel with 10 MHz frequency offset to a radar, and suburban macro base station operating co-channel with a radar. The calculations have been made using the standard parameters given in section 3 of this document.

TABLE 10

Baseline protection distances (km)

	Radar	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
IMT									
Uplink	Non co-channel band	0.377	0.479	0.412	0.338	0.458	0.349	0.296	0.374
Uplink	Co-channel	3.154	4.180	3.505	2.746	3.976	2.866	2.312	3.121
Downlink	Non co-channel band	7.298	9.474	8.052	6.435	9.037	6.685	5.503	7.226
Downlink	Co-channel	187.560	231.831	191.417	167.190	223.672	173.286	142.900	185.913

Sensitivity analysis using more typical IMT UE unwanted emissions levels

In Table 11 required protection distances in km are shown for each radar type for the case where the IMT system is operating in non-co-channel with a 10 MHz frequency offset to a radar. The calculations have been made using the standard parameters apart from more typical unwanted emissions levels of –10 and –20 dB below the limits in the 3GPP specifications.

TABLE 11

Sensitivity analysis with different IMT UE unwanted emissions

Non co-channel band	Radar	1	2	3	4	5	6	7	8
IMT	Unwanted emissions								
Uplink	3GPP	0.377	0.479	0.412	0.338	0.458	0.349	0.296	0.374
Uplink	−10 dB	0.242	0.308	0.265	0.217	0.294	0.224	0.190	0.240
Uplink	−20 dB	0.155	0.197	0.170	0.139	0.189	0.144	0.122	0.154

Sensitivity analysis using more typical IMT base station unwanted emissions levels

In Table 12 required protection distances in km are shown for each radar type for the case where a suburban macro base station is operating in non-co-channel with a 10 MHz frequency offset to a radar. The calculations have been made using the standard parameters apart from more typical unwanted emissions levels of −10 and −20 dB below the limits in the 3GPP specifications.

TABLE 12

Sensitivity analysis with different base station unwanted emissions

Non co-channel band	Radar	1	2	3	4	5	6	7	8
IMT	Unwanted emissions								
Downlink	3GPP	7.298	9.474	8.052	6.435	9.037	6.685	5.503	7.226
Downlink	−10 dB	4.296	5.773	4.807	3.714	5.474	3.885	3.101	4.247
Downlink	−20 dB	2.327	3.274	2.646	1.980	3.082	2.079	1.615	2.297

5 Summary

This preliminary deterministic study has been focusing on interference into radars operating in the band 1 300 to 1 400 MHz to assess the feasibility of introducing IMT services into the band. The study has analysed cases of both co-channel operation and non-co-channel operation in the band assuming a 10 MHz frequency offset. The study has used worst-case deterministic analysis to calculate the required protection distances of a suburban macro IMT base station and user equipment for the standard parameters that have been provided to JTG 4-5-6-7. Sensitivity analysis has also been performed for more typical unwanted emissions levels of IMT user equipment and base station for the non-co-channel case. For the IMT user equipment the reduced unwanted emissions levels are a result of these levels typically being significantly below the limits in the standards, and lower typical transmit powers as a result of power control, and unwanted emissions levels will also be lower when not all of the resource blocks in the IMT channel are being utilised. For the base station the lower values reflect more realistic emissions levels that are achieved in practice, and which may be further reduced by site engineering / additional filtering in areas where this is required. The analysis has calculated the required protection for these cases using Recommendation ITU-R P.1546-4 to derive the associated protection distances.

The resulting protection distances calculated in this preliminary study using the inputs from ITU-R indicate that the band 1 300 to 1 400 MHz may be feasible for IMT uplink, in particular for the non-co-channel case and when the results of reduced unwanted emissions are considered. The results of the study also indicate that IMT uplink co-channel operation may be feasible, particularly with some mitigation such as exclusion zones and when the power of the user equipment in a real network is taken into account. The results further indicate that co-channel downlink operation may be very difficult within the same geographical area and that some coordination may be required in particular areas. It may however be feasible to operate downlink if frequency segmentation is introduced and some additional mitigation is applied to the IMT base station (for example additional filtering or use of microcells).

6 Recommendations

The results of this study indicate that the band may be feasible for IMT uplink operation, although further studies are required for the co-channel uplink case. Further studies for both uplink and downlink operation should evaluate the probabilistic nature of interference scenarios with a representative number of IMT user equipment and base stations. This may also include assessment of the effectiveness of different mitigation techniques, for example co-siting the base station with the radar, additional filtering, etc.

Whilst this preliminary study provides a good indication of the compatibilities involved it considers a single interferer only. At the distances calculated it may be unlikely to have more than one interferer within a single ‘snap shot’ of the radar due to the antenna discrimination. However for analysis of scenarios where a number of IMT user equipment or base stations are active in an area and how this relates to a radar at a location would appear to be better evaluated using Monte Carlo simulations, which will also deal better with the many variable power levels inherently involved in IMT systems.

ANNEX 2

Sharing/compatibility studies of IMT systems with radiolocation systems in the frequency band 1 300-1 400 MHz

1 Background

Some Administrations participating in the second JTG 4-5-6-7 meeting proposed to use the frequency band 1 300-1 400 MHz as a candidate one for conducting studies in compatibility with possible IMT systems (see Annex 8 to Doc. 4-5-6-7/113). Therefore it was necessary to conduct studies in that frequency band in relation to compatibility of possible IMT stations with radiodetermination radars operating in the frequency band 1 300-1 400 MHz.

Unfortunately technical characteristics of these IMT systems in the frequency band 1 300-1 400 MHz were not defined by ITU-R WP 5D at that time. Therefore the Communication Administration of the Russian Federation suggested to conduct the compatibility studies based on reasonable assumptions which presumed that technical characteristics of IMT systems in the frequency band 1 300-1 400 MHz would be similar to those associated with IMT systems operating in the frequency range 1 800 MHz that have characteristics specified in Report ITU-R M.2039.

Results of those studies [conducted by the Russian Federation were presented at the third JTG 4-5-6-7 meeting in Document 4-5-6-7/155] which contained preliminary results of analysis related to compatibility of possible IMT stations with radars operating in the radiolocation service in the frequency band 1 300-1 400 MHz. It was shown in that document that providing protection for radars operating in the frequency band 1 300-1 400 MHz would require separation distances exceeding 500 km. Based on those study results it was concluded that frequency sharing between possible IMT stations and relevant radars would be extremely difficult to implement and would prevent the IMT systems from effective operation in the frequency band concerned.

[Document 4-5-6-7/155 was discussed at the third JTG 4-5-6-7 meeting and]it was noted that the presented therein results required adjusting based on IMT system technical characteristics in the frequency band 1 300-1 400 MHz as provided by ITU-R.

The Russian Federation used those latest technical characteristics when conducting additional studies related to compatibility of possible IMT systems with radars operating in the frequency band 1 300-1 400 MHz. The obtained study results are discussed below herein.

2 Protection criteria for radiolocation stations in the frequency band 1 300-1 400 MHz

Subject to provisions of Recommendation ITU-R M.1463 the frequency band 1 300-1 400 MHz is used by different types of radars with even accommodation in the whole bandwidth. Table 1 below shows technical characteristics of 8 typical radar systems. The characteristics were used for estimating the effect from possible IMT systems on operation of the radars.

TABLE 1

Technical characteristics of radars operating in the frequency band 1 300-1 400 MHz (as specified in Recommendation ITU-R M.1463)

	System 1	**System 2**	**System 3**	**System 4**	**System 5**	**System 6**	**System 7**	**System 8**
Receiver gain, G_{Rx}, dBi	33.5	38.9	38.2	32.5	38.5	34	35	34.5
Receiver noise figure, NF, dB	2	2	4.7	3.5	2.6	4.25	9	3.2
Receiver noise temperature, Tn, K	171.4	171.4	571.7	362.9	240.2	486.6	2034.4	319.2
Receiver bandwidth, ΔF, kHz	780	690	6400	1200	1250	880	330	1200
Protection criterion, I/N, dB	–6							

Analysis of Recommendation ITU-R M.1463 also showed that wind profile radars operate in the frequency band 1 300-1 375 MHz. Table 2 reflects typical technical characteristics of those radars.

TABLE 2

Typical technical characteristics of wind profile radars in the frequency band 1 300-1 375 MHz

Parameter	**Unit of measure**	**Value**
Emission bandwidth	MHz	8
Antenna type		Parabolic-reflector
Antenna polarization		Horizontal
Maximum antenna gain	dBi	33.5
Vertical beam width	degrees	3.9
Horizontal beam width	degrees	3.9
Vertical scan		From –15° to +15°
Receiver IF passband	MHz	2.5
Noise figure	dB	1.5
Protection criterion I/N	dB	-6

3 Technical characteristics of envisioned mobile stations in the frequency band 1 300-1 400 MHz

Table 3 below shows IMT system technical characteristics as provided by ITU-R, which were used in the studies:

TABLE 3

Technical characteristics of IMT base stations between 1 GHz and 3 GHz

Cell type	**Rural macro cell**
Characteristics of base stations	
Antenna height	30 m
Number of sectors	3 sectors
Tilt	3 degrees
Feeder losses	3 dB
Maximum base station output power (BW*=5/10/20 MHz)	43/46/46 dBm
Maximum base station antenna gain	18 dBi
Maximum e.i.r.p.	58/61/61 dBm
Mean base station/sector e.i.r.p.	55/58/58 dBm

* BW – frequency bandwidth

4 Estimation of protection distances required for radar receivers in the frequency band 1 300-1 400 MHz

Radar receiver characteristics shown in Tables 1 and 2 were used for estimating an acceptable interference level at radar receiver front end. The interference level was calculated using the following equation::

$$I_{acc} = (I/N)_{acc} + kT_N \Delta F ,$$

where:

I_{acc} - acceptable level of noise at receiver front end, dBW;

$(I/N)_{acc}$ - acceptable interference-to-noise ratio, dB;

k - Boltzmann constant;

$T_N = 293(10^{\frac{NF}{10}} - 1)$ - receiver noise temperature, K;

NF – receiver noise figure, dB;

ΔF - receiver passband, Hz.

The obtained value of acceptable noise level was used for estimating acceptable interference field strength based on the following equation:

$$E_{acc} = I_{acc} - G_{rec} - 10\lg(\lambda^2 / 960\pi^2) + 120 ,$$

where

E_{acc} - acceptable level of interference field strength, dB(μV/m);

G_{rec} - radar antenna gain in a receiving mode, dB;

λ - operational wavelength, m.

Estimated values of acceptable interference power and associated values of acceptable interference field strength are shown in Table 4.

TABLE 4

Estimates of protection distances for radars operating in the frequency band 1 300-1 400 MHz accounting no tropospheric scattering

	System 1	**System 2**	**System 3**	**System 4**	**System 5**	**System 6**	**System 7**	**System 8**	**Wind profile radars**
Receiver thermal noise, dBW	–147,3	–147,9	–133,0	–142,2	–143,8	–142,3	–140,3	–142,8	–144
Acceptable interference power, dBW	–153,3	–153,9	–139,0	–148,2	–149,8	–148,3	–146,3	–148,8	–150
Acceptable interference field strength, dB(μV/m)	–14,1	–20	–4,4	–7,9	–15,5	–9,5	–8,5	–10,5	–10.5
Protection distances									
Interference bandwidth, MHz	5; 10								
$e.i.r.p._{eff}$, dBW	16.9	16.4	25.0	18.8	19.0	17.5	13.2	18.8	22
Land path, km	208	253	197	174	239	176	134	196	221
Sea path, km	436	495	417	390	474	388	342	417	450
Interference bandwidth, MHz	20								
$e..i.r.p._{eff}$, dBW	13.9	13.4	23.1	15.8	16.0	14.4	10.2	15.8	19
Land path, km	184	229	180	150	214	151	110	170	198
Sea path, km	401	459	395	360	440	360	312	383	420

The above technical characteristics of IMT stations were used for estimating the minimum separation distances required for protection of radar receivers from interference caused by base stations of possible IMT systems. The protection distances for the radars were estimated in relation to IMT systems operating with signals of 5 MHz, 10 MHz and 20 MHz bandwidth.

Therewith it was taken into consideration that operational passband of radar receivers related to al-most all typical radars reflected in Recommendation ITU-R M.1463 was narrower as compared with IMT base station frequency band. Therefore interference estimation used an effective IMT station e.i.r.p. value calculated on the basis of the following equation:

$$e.i.r.p._{eff} = P_{trans\ IMT} + G_{trans\ IMT} + 10\lg\left(\Delta F_{RLS} / \Delta F_{IMT}\right),$$

where:

$e.i.r.p._{eff}$ - effective interference e.i.r.p., dBW;

$P_{trans\ IMT}$ - IMT transmitter output power, dBW;

$G_{trans\ IMT}$ - IMT transmitter gain, dB;

ΔF_{RLS} - radar receiver operational passband, MHz;

ΔF_{IMT} - IMT transmitter operational bandwidth, MHz.

Estimated values for effective interference e.i.r.p. in the bandwidth of 5 MHz, 10 MHz and 20 MHz are shown in Table 4.

Estimation of interference to ground-based radar receivers used a radiowave propagation model reflected in Recommendation ITU-R P.1546. The required protection distances were estimated for 10% of time and for 50% of locations for land and sea paths. The estimation assumed that ground-based radar antenna altitude was 10 m. The results of protection distance estimation are shown in Table 4.

The results obtained show that the required protection distance related to interference of 5 MHz and 10 MHz bandwidth would vary from 134 kilometres to 253 kilometres for a land path and from 342 kilometres to 495 kilometres for a sea path. The values for interference of 20 MHz bandwidth would be less but even in that case the minimum protection distance would be 110 kilometres for a land path and 312 kilometres for a sea path.

It is worth mentioning that the protection distances shown in Table 4 were estimated without accounting for tropospheric scattering therefore they would not provide a complete protection for radar systems from the interference concerned. Table 5 below reflects the protection distance estimates accounting the tropospheric scattering.

TABLE 5

Estimates of protection distances for radars operating in the band 1 300-1 400 MHz accounting the tropospheric scattering

	System 1	**System 2**	**System 3**	**System 4**	**System 5**	**System 6**	**System 7**	**System 8**	**Wind profile radars**
Receiver thermal noise, dBW	–147.3	–147.9	–133.0	–142.2	–143.8	–142.3	–140.3	–142.8	–144
Acceptable interference power, dBW	–153.3	–153.9	–139.0	–148.2	–149.8	–148.3	–146.3	–148.8	–150
Acceptable interference field strength, dB(μV/m)	–14.1	–20	–4.4	–7.9	–15.5	–9.5	–8.5	–10.5	–10.5
Protection distances									
Interference band-width, MHz	5; 10								
$e.i.r.p._{eff}$, dBW	16.9	16.4	25.0	18.8	19.0	17.5	13.2	18.8	22
Land path, km	274	328	255	232	310	236	187	257	288
Sea path, km	455	515	435	410	493	414	362	438	472
Interference band-width, MHz	20								
$e.i.r.p._{eff}$, dBW	13.9	13.4	23.1	15.8	16.0	14.4	10.2	15.8	19
Land path, km	236	298	241	206	279	208	165	229	260
Sea path, km	424	482	419	381	461	383	337	407	440

Analysis of data reflected in Table 5 shows that accounting for the tropospheric scattering results in significant increasing the required protection distances. As for interference of 5 MHz and 10 MHz bandwidth the required protection distance would be from 187 kilometres to 328 kilometres for a land radio path and from 362 kilometres to 515 kilometres for a sea path. For interference of 20 MHz bandwidth the values of the distance would be reduced. However in that case the required protection distance would be of 165 kilometres for a land radio path and of 337 kilometres for a sea path.

The results shown in Table 5 were obtained assuming a cold sea radio path. Consideration of a warm sea radio path would result in increased protection distances.

The above presented results were obtained assuming single-source interference effect on a radar receiver. But since the beam width of radar antenna patterns features a finite value the pattern main lobe could be affected by emissions from several IMT interferers located at different distances from the radar receiver considered. In that case the effect of aggregate interference from IMT base stations would be defined by density of their deployment and would result in increasing the required protection distances.

5 Conclusions

Analysis of the obtained results shows that providing protection for radars operating in the frequency band 1 300-1 400 MHz would require separation distances exceeding 450 kilometres. Considering a global nature of radiolocation service allocations a conclusion could be drawn that sharing between IMT stations and the mentioned radars would be extremely hard to implement and would prevent from providing effective operation of IMT systems.

Estimation of feasibility for using the considered frequency band to implement IMT stations should take into account that the frequency band 1 300-1 350 MHz is also allocated to aeronautical radionavigation service (ARNS) on a global primary basis and that ARNS radars are actively used for navigation purposes. Recommendation ITU-R M.1463 points out that radionavigation radars operate in a wide range of technical characteristics variation as defined by their missions. The Recommendation also points out that RR No. **4.10** applies to those radars stating that no harmful interference shall be caused to them.

Considering a wide deployment of the mentioned radiolocation facilities and aeronautical navigation stations a conclusion may be drawn that IMT systems could not operate in the discussed frequency band on a global basis.

The conducted studies also show that compatibility of possible IMT systems and radiodetermination radars would be unfeasible in the frequency band 1 300-1 400 MHz.

Based on the above discussion it is proposed to exclude the frequency band 1 300-1 400 MHz from consideration as a candidate one for satisfying WRC-15 agenda item 1.1.

ANNEX 3

Study into the co-existence of mobile telecommunication systems and airborne radars in the 1 300-1 400 MHz frequency band

1 Introduction

The aim of this study is to investigate co-channel and non-co-channel compatibility between a high-density IMT system and an airborne radar receiver. An airborne radar has a significantly large radio horizon making it prone to interference from IMT systems at a distance. The following single interfering transmitters into single victim receiver scenarios are studied for both co-channel and non-co-channel emissions with respect to the radar receiver intermediate frequency (IF) bandwidth:

– single fixed IMT base station into an airborne radar receiver;

– single mobile station into an airborne radar receiver;

– single radar transmitter into a IMT base station receiver.

Radiolocation and radionavigation services require access to spectrum in a number of frequency bands to take advantage of the different propagation characteristics that suit different applications. The long-range detection capability provided by systems operating in the frequency band 1 215-1 400 MHz is complemented by mid-range systems operating in the frequency band 2 700-3 700 MHz and short-range systems operating in the frequency band 8.5-10.55 GHz. Collectively, radars in the above three bands provide radar operators the ability to conduct search, surveillance and tracking of long-range, mid-range and short-range objects. It is not possible to provide the long-range detection capability of radars operating in the 1 215-1 400 MHz frequency band in higher frequency bands.

2 Background

The following documents were used in this study:

A Recommendation ITU-R M. 1463-2 Characteristics of and protection criteria for radars operating in the radiodetermination service in the frequency band 1 215-1 400 MHz. Radar System 9 is found in the preliminary draft revision of this Recommendation (Annex 11 to Document 5B/475).

B Recommendation ITU-R M.1461-1 Procedures for determining the potential for interference between radars operating in the radiodetermination service and systems in other services.

C Report ITU-R M.2292, Characteristics of terrestrial IMT-Advanced systems for frequency sharing/interference analyses.

D 3GPP Document TS 36.104 V1.2.0.

E 3GPP Document TS 36.101 V11.2.0.

F Recommendation ITU-R P.528-3 Propagation curves for aeronautical mobile and radionavigation services using the VHF, UHF and SHF bands.

G Working document towards preliminary draft revision of Recommendation ITU-R F.1336-3 Reference radiation patterns of omnidirectional, sectoral and other antennas in point-to-multipoint systems for use in sharing studies in the frequency range from [X] MHz to about 70 GHz, Annex 12 to Document 5C/171.

H Working document towards preliminary draft new Report ITU-R M.[COM_RAD], Annex 30 to Chairman's Report on 12th meeting of WP 5B, Document 5B/475.

I Recommendation ITU-R M.1372-1, Efficient use of the radio spectrum by radar stations in the radiodetermination service.

3 Technical characteristics

3.1 Radiolocation system

Characteristics of the radar receiver used in this study are given in Table 1.

TABLE 1

Radar System 9 transmitter/receiver characteristics (Reference A)

Parameter	System 9
Receiver IF –3 dB bandwidth (MHz)	10
IF filter selectivity –20 dB (MHz) –60 dB (MHz)	Not given in Reference A, 80 dB/decade roll-off from 3 dB point is assumed (See Reference B) 16 50
Receiver Noise Figure (dB)	3
Antenna Gain (dBi)	30
Antenna Type	360° electronically steered array, 2° horizontal 3 dB beamwidth, vertical sinc pattern with 20° 3dB beamwidth
Antenna height (km)	10
Feeder Loss (dB)	0
Emission Bandwidth (MHz)	3
Peak Power (dBm/MHz)	77
Rec. ITU-R SM.329 Spurious Emission Limit (dBm/MHz)	17

3.2 Protection criteria for the radar systems in the frequency band 1 300-1 400 MHz

Recommendation ITU-R M.1463-2 “Characteristics of and protection criteria for radars operating in the radiodetermination service in the frequency band 1 215-1 400 MHz” contains in particular the interference criterion, I/N, that was used to protect Radar systems from other services. I/N = –6 dB value is recommended (see *recommends* 3 of Recommendation ITU-R M.1463-2).

However, as noted in Recommendation ITU-R M.1461-1, in some cases, a I/N ratio of -6 dB may not be appropriate, and further studies or compatibility measurements may be necessary to assess the interference in terms of the operational impact on the radar’s performance. Systems which use pulse compression have their IF bandwidth matched to the compressed pulse and act as a matched filter to maximise signal-to-noise ratio. Pulse compression filters may be partially matched to and hence increase the effect of interference which might otherwise be considered “noise-like” over longer integration times. In that case, an interference signal, which is 6 dB below the noise floor, can still lead to significant degradation of the radar performance. As an example, probability of detection performance of the Radar System 9 from revised Recommendation ITU-R M.1463-1 in the presence of an IMT signal is given in Table 5.

3.3 IMT System

Characteristics of the IMT base station transmitters used in this study are given in Table 2 and those of the IMT mobile station transmitters used in this study are given in Table 3.

TABLE 2

IMT base station transmitter/receiver characteristics

Parameter	IMT base station
Transmitter output power (dBm / 5 MHz)	43 (Reference C)
Emission bandwidth (MHz)	5 (Reference C)
Emission Mask	Reference D Table 6.6.3.1-6
Spurious emission (dBm / 100 kHz)	–96 (Reference D, Section 6.6.4 and Table 6.6.4.2-1)
Cable Loss (dB)	3
Antenna gain (dBi)	16.7 (Reference G)
Down Tilt (deg.)	10
Antenna Type	Sector Antenna (Reference G)
Antenna height (m)	30
Receiver Noise Figure (dB)	5

TABLE 3

IMT user equipment characteristics

Parameter	IMT user equipment
Terminal output power (dBm / 5 MHz)	23 (Reference C)
Emission bandwidth (MHz)	5 (Reference C)
Emission Mask	Reference E Table 6.6.2.1.1-1
Spurious Emissions (dBm / MHz)	–30 (Reference E Table 6.6.3.1-1 and Table 6.6.3.1-2)
Antenna gain (dBi)	–3 (Reference E)
Antenna type	Omni
Antenna height (m)	2
User terminal density (Stations / 5 MHz / km^2)	0.17
Body Loss (dB)	4

4 Analysis

4.1 Assumptions (NOTE 1)

– This analysis does not consider radar receiver front end saturation.

– Airborne receiver is located at its maximum altitude of 10 kilometres. Further analysis is conducted for 2.5 kilometres and 5 kilometres altitudes.

– Base station antenna height is 30 meters and user equipment (UE) antenna height is 1.5 meters.

– It is assumed that IMT transmitters are coupling into the main beam of the radar receiver.

– All antenna gain values are selected to be frequency independent. Hence no reduction of gain at off-tune frequencies.

– All transmitters are considered as operating at their peak power levels (NOTE 2)

– The 1% curves of Recommendation ITU-R P.528-3 are used in calculations. Clutter attenuation has not been considered in the path loss model (NOTE 3).

NOTE 1: These assumptions are based on worst case scenarios, which should guarantee the protection of radars as per protection criteria given in References A and B. The current protection criteria for radars in this frequency band is generic that maximum acceptable interference is 6 dB below the noise floor. For noise-like interference this corresponds to an approximate 1 dB increase in the noise floor and hence 1 dB reduction of the SNR. It must also be noted that this criteria has no temporal component. Therefore, only MCL calculations are meaningful with the protection criteria provided in references A and B.

NOTE 2: Reference C provides both peak and average power levels for base and mobile IMT transmitters. Average power of an IMT mobile can be defined in two ways:

1 time average for a single UE: UE is only transmitting during the data upload and uplink control signalling and it remains silent for majority of time. Hence the average transmit power over time is as low as -9 dBm for a UE in a macro urban cell. An example in the section 2.2.3.7 of the Report ITU-R M.2241 calculates this average power in conjunction with the activity factor;

2 spatial average for a single UE when transmitting: UE when transmitting is subject to power control mechanisms. The UE closer to base station transmit at lower power levels compared to those at the edge of the cell. Hence the transmit power during data uploads can be averaged as a variable of the location of the UE with respect to base station. The example in the section 2.2.3.7 of the Report ITU-R M.2241 has this value set to 15 dBm.

The relevant interference power for the radar is that of an active transmitter. Assuming 5 Mbps throughput during transmission and 2 Mbyte file upload, the duration of a transmission is around 3.4 seconds. For the radar considered in this study this is equal to 40 Coherent Processing Intervals (CPI). Any interference that occurs during this period may seriously affect the performance of the radar. For this reason at least spatial average power, (2) above, or for the worst case scenarios, as in this case, the peak power should be considered in compatibility studies.

NOTE 3: The protection criteria recommended for this radar does not include a temporal component. If the maximum interference level as per the protection criteria is exceeded at any point of time, the radar cannot be considered as protected and hence not compatible with the new service. However, the statistical nature of the propagation models requires percentage of time specified in calculations. Often for interference analysis the smallest percentage of time curves applicable to a propagation model used should be considered. The Recommendation ITU-R P.528 has the smallest available percentage of time at 1%, i.e., the path loss values used in this study are exceeded 99% of the time.

4.2 Methodology

The calculations are aimed at deriving MCL and the corresponding minimum separation distance using the Recommendation ITU-R P.528-3 propagation model between a single IMT base station/UE transmitter and an airborne radar receiver. Separation distance is the slant range between the IMT base/mobile station and the airborne receiver location.

Calculations are conducted for co-frequency, 5 MHz, 10 MHz, 12.5 MHz, 15 MHz, 20 MHz and 30 MHz carrier separation. Carrier separation is defined as the difference between the centre frequency of the IMT emission (fixed at 1 300 MHz in this case) and the centre frequency of the receiver IF filter. The IMT transmitter bandwidth is 5 MHz, however out-of-band and spurious emissions are applicable to other transmitter bandwidths with little or no adjustment to the emission masks.

Calculations are carried out to assess interference from a radar transmitter into the IMT base station receiver taking into account the IMT base station receiver blocking performance and radar spurious emissions. In this case carrier offset of at least 20 MHz is assumed.

The methodology used in determining radar performance degradation by an interfering IMT signal which is 6 dB below the noise floor is given in Reference H.

4.3 Calculations

Received interference at the victim receiver

The following formula applies for a single interference source and the victim radar receiver:

$$\mathrm{P_{RX} = P_{TX} - L_{TX} + G_{TX} - PL + G_{RX} - L_{RX} - FDR}$$

$\mathrm{P_{RX}}$ = Received Power (dBm)

$\mathrm{P_{TX}}$ = Transmitter power (dBm)

$\mathrm{L_{TX}}$ = Transmitter feeder loss (dB)

$\mathrm{G_{TX}}$ = Transmit antenna gain (dBi)

PL = Path loss as per ITU – R P.528 – 3 $L_b(0.01)$ *curves are used*

$\mathrm{G_{RX}}$ = Receiver Antenna Gain (dBi)

$\mathrm{L_{RX}}$ = Receiver feeder loss

FDR = Frequency Dependent Rejection (NOTE 1)

NOTE 1: frequency dependent rejection is produced by the radar receiver IF selectivity on the emissions from the IMT transmitters. The off tune rejection takes into account both the IF filter roll off and the transmitter emission mask.

Receiver inherent noise level

$$N = -144 + 10 \log \mathrm{B} + \mathrm{NF}$$

N = Receiver inherent noise level (dBm)

B = Receiver IF Bandwidth (kHz)

NF = Receiver Noise Figure (dB)

Minimum Coupling Loss

$$\mathrm{MCL = P_{TX} + G_{TX} + G_{RX}} - PC - N$$

MCL = Minimum Coupling Loss (dB)

PC = Protection criteria for the radar receiver (dB), I/N = −6dB

N = Receiver inherent noise level (dBm)

4.4 Results

TABLE 4

Minimum separation distance between an interfering IMT base station transmitter and the victim airborne radar receiver

	Minimum separation distance (km)						
Frequency offset (MHz)	0	5	10	12.5	15	20	30
Airborne antenna Height= 2.5 km	650	630	540	525	500	450	360
Airborne antenna Height= 5 km	720	670	630	600	560	500	440
Airborne antenna Height= 10 km	760	740	660	650	600	550	480

TABLE 5

Minimum separation distance between an interfering IMT UE transmitter and the victim airborne radar receiver

	Minimum separation distance (km)						
Frequency offset (MHz)	0	5	10	12.5	15	20	30
Airborne antenna Height= 2.5 km	155	150	140	130	120	60	0
Airborne antenna Height= 5 km	300	270	160	150	120	0	0
Airborne antenna Height= 10 km	405	400	380	300	180	0	0

TABLE 6

Minimum separation distance between a victim IMT base station receiver and the interfering airborne radar transmitter considering spurious emissions of the radar transmitter

Radiated spurious emissions of the radar (dBm/MHz) ($P_{TX} + G_{TX}$)	47
$P_{TX} + G_{TX} + G_{RX}$ (dBm/MHz)	63.7
Base receiver noise level (dBm/MHz)	-109
Maximum Interference level (dBm/MHz)	-115
MCL (dB)	178
Minimum Separation (km) (airborne antenna height 10 km, ITU-R P.528, 1% curves)	450

TABLE 7

Minimum separation distance between a victim IMT base station receiver and the interfering airborne radar transmitter considering receiver blocking characteristics of the IMT base station receiver

Radiated emissions of the radar (dBm) ($P_{TX} + G_{TX}$)	112
$P_{TX} + G_{TX} + G_{RX}$ (dBm)	128.7
Blocking level for base receiver (dBm)	-43 (Reference C)
MCL (dB)	172
Minimum Separation (km) (airborne antenna height 10 km, ITU-R P.528, 1% curves)	400

TABLE 8

Target SNR levels to achieve a detection probability of 50% in the presence of IMT interference for linear and non-linear FM radar waveforms. In all cases false alarm rate is set to 10^{-4} (Reference H)

	I/N = -∞ dB (radar receiver noise only)	**I/N = -6 dB (radar receiver noise +IMT interference)**
Linear FM radar waveform	10.6 dB	12.0 dB
Non-linear FM radar waveform	10.3 dB	11.6 dB

5 Summary

5.1 Discussion

Interference from a single IMT base station/UE transmitter into an airborne radar receiver is studied. Worst case coupling between the interferer and the victim receiver is assumed and minimum coupling loss (MCL) to meet protection criteria is calculated.

Calculations are repeated for co-channel and seven discrete carrier offsets. MCL values are translated into minimum separation distances using the Recommendation ITU-R P.528-3 propagation model.

IMT base into radar receiver

The results (Table 4) show that minimum separation for co-channel operation of radar and an IMT base station is more than 700 kilometres. Even for non-co-channel minimum separation is at or beyond line-of-sight. The coexistence of an airborne radar and an IMT base station (or a group of base stations) in the same geographic area is not possible.

IMT UE into radar receiver

At 30 MHz offset, it is possible that an airborne radar and the IMT UE transmitter can coexist in a same geographic area (Table 5). Implementing sharper filter roll-off at the transmitter is likely to further reduce the offset required for compatibility. This analysis is limited to a single IMT UE. In reality when high density deployment of IMT UE occurs, there should be additional separation between the radar and the IMT system.

Radar transmitter emission into IMT base receiver

Given the possibility of compatibility between the airborne radar receiver and the non-co-channel band IMT uplink it is necessary to also analyse the compatibility of the radar transmitter and the IMT base receiver. With at least 20 MHz guard band it is only necessary to consider the spurious emissions of the radar transmitter for the analysis as given in Table 6. An IMT base receiver blocking analysis is also conducted in Table 7. According to these two results minimum separation distance of 450 km will meet the IMT base receiver blocking and protection requirements. Although this is a distance beyond line-of-sight, improvements to spurious emissions and blocking performance that surpasses those in recommendations may achieve non-co-channel compatibility between radar and IMT systems.

Radar performance degradation due to IMT interference

Interference received by a radar receiver at 6 dB below the noise floor is considered generally acceptable in sharing studies. However, performance of the radar at this level is expected to be degraded to a certain level. This is calculated and presented in Table 5. Performance of a radar is compared between scenarios with respect to the reference probability of detection 50%. The radar receiver uses pulse compression with a constant false alarm rate (CFAR) (Reference I) set to 10^{-4}. The results show that the SNR is degraded by 1.3-1.4 dB below the level required to maintain the probability of detection at 50% in the presence of an IMT interferer. Note that for I/N=-6dB the SNR is expected to be degraded by only 1 dB. This difference should be taken into account when spectrum sharing between radars and IMT systems are planned.

5.2 Conclusion

The results of this study show that in order to meet the protection criteria for an airborne radar receiver large separation distances are required from any co-channel IMT system.

When an IMT mobile station is transmitting in the first or second adjacent channels of the radar receiver, further attenuation may allow coexistence within a reasonable distance of each other. Nevertheless such compatibility is unlikely with respect to an IMT base receiver operating in an non-co-channel band to the airborne radar.

6 Recommendations

According to the studies carried out between the airborne radar systems in the frequency band 1 300-1 400 MHz and IMT systems in the co-channel and non-co-channel:

– co-channel sharing between the airborne radar and an IMT system is not possible;

– non-co-channel sharing between the airborne radar receiver and the IMT system downlink is not viable;

– where there is sufficient guard band between allocations, non-co-channel sharing between the airborne radar receiver and the IMT system uplink may be possible, subject to stringent conditions on out-of-band/spurious emission levels and out-of-band rejection performance of the interfering and the victim systems;

– sharing between IMT base receivers and radar transmitters operating in non-co-channel spectrum is not possible without improvement to blocking performance of IMT base receivers above that specified in existing Recommendations.

ANNEX 4

Coexistence between radiolocation and IMT systems within 1 375-1 400 MHz band

1 Introduction

The WRC-15 agenda item 1.1 addresses additional spectrum allocations to the mobile service on a primary basis and identification of additional frequency bands for International Mobile Telecommunications (IMT) and related regulatory provisions, to facilitate the development of terrestrial mobile broadband applications, in accordance with Resolution **233 (WRC-12)**.

The band 1 300-1 400 MHz is currently allocated to the radiolocation service on a primary basis.

France has proposed to consider this band as a possible candidate band and further sharing studies are needed before being able to designate this band as candidate band.

2 Description and characteristics of the considered systems

a) Assumptions and methodology

A minimum coupling loss approach is used, modelling only a single interferer-victim pair (as to be base station-to-radar) and corresponding to the worst case scenario with main lobe (of the interferer transmitter antenna pattern) to main lobe (of the radar receiver antenna pattern) configuration.

The interference mechanism which is assumed in this document refers to:

– unwanted emissions of the interfering transmitter falling into the receiving bandwidth of the victim receiver for compatibility in non-co-channel band;

– Inband emissions of the interfering transmitter falling into the receiving bandwidth of the victim receiver for sharing in co-channel.

This study did not address the impact of blocking level onto radiolocation receivers. In practice, if the emission level of the IMT system exceeds the blocking level of radars systems, their performances could be seriously degraded and could even become inoperative from this method, we derive the required isolation to ensure the protection of the radar receiver:

$$\text{Isolation(dB)} \geq \text{e.i.r.p. (dBm/MHz)} - \text{FeederLoss}_R + G_R - \text{I/N} - \text{Noise(dBm/MHz)}$$

where

– Isolation=PathLoss[4]($d_{separation}$)

  – G_R is the antenna gain of the receiver depending on the elevation angle and tilt (dBi)

  – FeederLoss_R is the Receiver FeederLoss

Additional isolation is required when d< $d_{separation}$. In such a case, for example:

– in co-channel sharing, restricted inband level for base station could be required to ensure the protection of the radar;

– in non-co-channel band compatibility, Out-Of-Band (OOB) emissions limits of IMT systems could be required to ensure the protection of the radar.

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[4] With Recommendation ITU-R P.452-14 with p=50%, Path loss depends on distance d, frequency f, antenna heights of the interfering transmitter h_T and victim receiver h_R in dB.

The selected propagation model separating the radar receiver from the base station is terrestrial point-to-point propagation model extracted from the Recommendation ITU-R P.452-14. Recommendation ITU-R P.452-14 is suitable over any kind of areas since it accounts the digital terrain model featuring the relief of the location of both transmitter and receiver. Associated parameter to the propagation model is the time for which the pathloss assessment is higher or equal is time p= 50%. Furthermore when worst case scenario is assumed, flat terrain assumption is also covered by P.452 propagation model. In such a case, the digital terrain model is not required to derive the pathloss between the interfering IMT base station and the victim radar receiver.

Diversity of radar deployments as well as usage in rural area (hilly or flat environment) make antenna tilt being negative (when installed above hill) as well being positive, which justifies looping tilt in a negative and positive values range[5]. The studies performed in this paper assumed an 18 metre radar antenna height, corresponding to an average value for both ship born and ground radar situations. Radar antennas loop a 360° horizontal angular sector.

b) Radar systems

Recommendation ITU-R M.1463-2 “Characteristics of and protection criteria for radars operating in the radiodetermination service in the frequency band 1 215-1 400 MHz” contains in particular the interference criterion, I/N, that was used to protect Radar systems from other services. I/N = –6 dB value is recommended (see *recommends* 3 of Recommendation ITU-R M.1463-2).

Other parameters of the radar systems operating within 1 200-1 400 MHz band are taken from *recommends* 1 of Recommendation ITU-R M.1463-2 (see the Annex of this recommendation). Considered radar systems are depicted in Table . Note that the radar referred as No.9 is the radar wind profiler feature in Recommendation ITU-R M.1463-2.

TABLE 1

Radar systems characteristics

Radar Type	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Receiver gain, G_{Rx}, dBi	33.5	38.9	38.2	32.5	38.5	34	35	34.5	33.5
Receiver noise figure, NF, dB	2	2	4,7	3,5	2,6	4,25	9	3,2	1.5
Receiver bandwidth, ΔF, kHz	780	690	6400	1200	1250	880	330	1200	2500
Noise Power (dBm)	-113,1	-113,6	-101,2	-109,7	-110,4	-110,3	-109,8	-110,0	-108,5
Antenna azimuthal beamwidth 3dB (°)	1.2	1.4	3.2	3	2.2	1.2	1.3	1.2	3.9
I/N (dB)	-6	-6	-6	-6	-6	-6	-6	-6	-6
Imax (dBm/MHz)	-119,1	-119,6	-107,2	-115,7	-116,4	-116,3	-115,8	-116,0	-114,5
Feeder Loss (dB)	2	2	2	2	2	2	2	2	2

[5] –3° ;22°

c) IMT Systems

Macro base station characteristics are given in the following Table for the rural case[, extracted from Document 4-5-6-7/236,] as well as Out-of-Band (OoB) emission limits in non-co-channel band taken from 3GPP TS 37.104 for 5, 10 and 20MHz. The calculated interference level I, corresponds to the unwanted emissions level due to the leakage of the base station in its non-co-channels. Thus the impact of the base station Out-of-Band emissions (OoBe) levels on Radar receiver is investigated in this paper and appropriate separation distance is assessed in order to protect radar systems from the base station interference.

TABLE 2

Base Station characteristics

Parameters	Unit	Value
Transmitter bandwidth	MHz	5,10, 20
Maximum Base Station output power (5/10/20 MHz)	dBm	43/46/46
Feeder Loss	dB	3
Maximum Base Station antenna gain	dBi	18
Base Station antenna height	m	30
OoBemission level (immediately non-co-channel to the mobile band)	dBm/MHz	–8.7
Spurious emission level (10 MHz frequency separation)	dBm/MHz	–30
Transmitter frequency range	MHz	1 375-1 400

3 Results

a) Compatibility study (non-co-channel)

This section tackles the compatibility studies between IMT base station within 1 375-1 400 MHz and radar systems below 1 375 MHz with and without mitigation techniques.

1) Without mitigation technique (except separation distance)

The following Table3 depicts the separation distance for different radar systems operating within 1 375-1 400 MHz band with two assumptions on frequency separation: immediately adjacent and with 10 MHz frequency separation.

TABLE 3

Separation distance between IMT base station and Radar Receiver (km)

Radar type	1	2	3	4	5	6	7	8	9
Immediately adjacent	48.7	53.2	49.4	45.1	52	45.8	41.8	47.5	48.4
10MHz frequency separation	27.6	31.4	28.7	25.7	30.6	26.2	23.6	27.3	28

41 to 56 kilometres separation distance range is required according to radar systems to protect them from IMT base station Interference.

2) With mitigation techniques

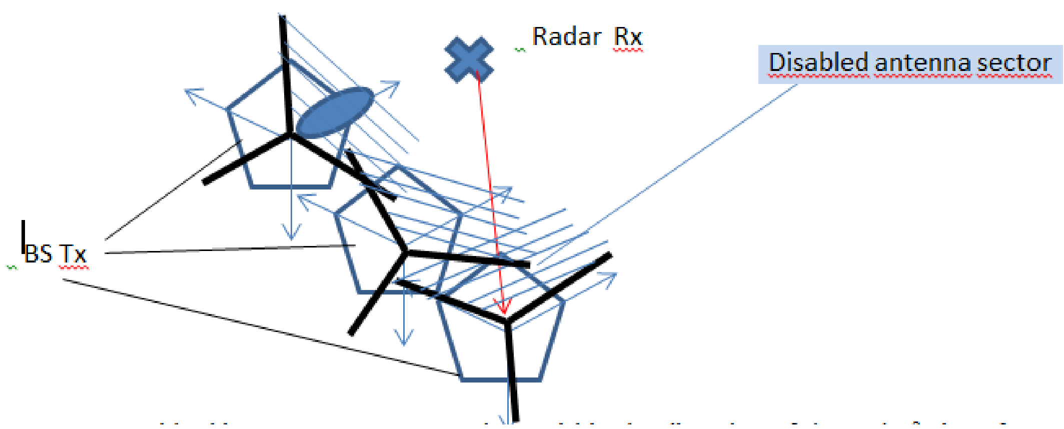
This section covers the techniques that would improve the compatibility between IMT-Advanced and Radiolocation. These mitigation techniques should be applied to radar systems whose applicability range makes the frequency separation with IMT base station very low. The use of these techniques result non-co-channel band operation of both systems and include for the base station:

– additional filtering: additional isolation to protect the radar receivers may be achieved by improvement of mobile equipment to reduce unwanted emissions in relation to regulatory requirements. This could be performed by reducing the inband power transmitted or with an additional filtering[6] to base stations transmission component at specific sites. Additional filtering would require frequency separation between radar and IMT base station edge bands to be applicable;

– sector disabling (for the base station): when disabling the base station sector antenna which faces the radar system, the 2 other ones (Figure) are the main interfering components onto the radiolocation system. The following figure depicts that any base station may face the radar main beam with the disabled antenna sector and thus the backlobes of the 2 active sectors facing the radar receiver lead to 20 dB antenna gain discrimination;

FIGURE 1

Overview on sector disabling



– antenna pattern nulling usage on base stations within the direction of the radar[7] : interference level could be reduced if the IMT-Advanced base station antennas can have blanking in the direction of the radar. Such blanking could be of the order of 20 dB antenna gain discrimination as depicted in the Figure within 5° small gap. Given that radar antenna has lower narrow horizontal beamwidth than 5°, this method may be applicable to reduce additional required isolation to protect the radar systems.

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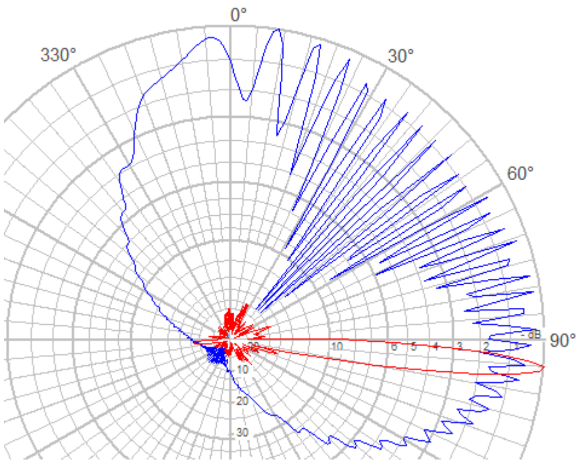
[6] Which may increase adjacent channel leakage ratio (ACLR).

[7] I.e. the direction to the radar position.

FIGURE 2

Antenna pattern in horizontal and vertical plans



For different mitigation techniques combinations, the compatibility results showed in Tables 4 and 5 highlight the separation distances reduction for various radar systems.

TABLE 4

Separation distance with different mitigation techniques (km)

Radar type	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Additional filtering 10 dB	38.2	41.9	38.6	35	40.9	35.6	32.1	37	37.8
Additional filtering 20 dB/Blanking	29.1	32.5	29.7	26.6	31.6	27.2	24.4	28.4	29
Additional filtering 20 dB+Blanking	9.2	14.6	10.1	6.4	13.1	6.9	4.5	8.2	8.9
Additional filtering 30 dB+Blanking	3.0	4.9	3.4	2.1	4.4	2.3	1.8	2.7	2.9

TABLE 5

Separation distance with different mitigation techniques (km) with 10MHz frequency separation

Radar type	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Additional filtering 10 dB	20.7	23.7	21.6	16.9	23.1	18.6	12	20.5	21
Additional filtering 20 dB/Blanking	7.3	12.7	8.7	5.5	11.4	6	3.9	7.1	7.7
Additional filtering 20 dB+Blanking	<1	1.4	1	<1	1.3	<1	<1	<1	<1

In addition, further isolation reduction could then be added when also applying mitigation techniques to the radar systems such as site shielding: natural or man-made shielding minimizes interference to the radar antennas or blanking.

b) Sharing study (co-channel)

When both IMT base station and radar systems share the band, the interfering impact of the IMT systems on the radiolocation service within 1 375-1 400 MHz band is depicted in the Table 6 below (with and without mitigation technique).

Note that:

– some mitigation techniques (additional filtering, frequency separation) are not applicable when both interferer and victim systems operate in co-channel;

– some mitigation techniques (additional downtilt+blanking, additional downtilt+sector antenna disabling) effects are not cumulative.

TABLE 6

Separation distance without/with different mitigation techniques (km)

Radar type	1	2	3	4	5	6	7	8	9
No Mitigation technique	>100	>100	>100	>100	>100	>100	>100	>100	>100
Additional downtilt (3°->6°)	>100	>100	95	>100	>100	>100	>100	>100	>100
Sector antenna disabling/Blanking	88	98	75	81	91	84	85	84	82
Additional downtilt (3°->6°)+ Sector antenna disabling	72	80	61	66	74	69	69	69	68

4 Conclusions

These studies addressed:

– the co-channel sharing between IMT base stations and radar systems within 1 375-1 400 MHz band and showed that large separation distances (over 100 kilometres) are required to protect the radio determination services in the band 1 300-1 400 MHz. When using feasible mitigation techniques, the separation distances are in the range of 61 km to more than 100 km depending on the type of radar which needs to be protected;

– the compatibility between radiolocation (below 1 375 MHz) and IMT systems (in 1 375-1 400 MHz). Based on these results, it is shown that compatibility requires a separation distance much lower than in sharing case and highly dependent on frequency separation and on unwanted emission levels. In addition, this separation distance can be considerably reduced using appropriate mitigation techniques: for example, with 10 MHz separation and additional filtering/blanking to the base station for a total of 20 dB the maximum separation distance is from 3.9 kilometres to 12.7 kilometres. The same approach would be applied for blocking radars protection criteria: additional filtering to (improve the selectivity of) the radar receiver would lead to similar separation distance.

The study has shown that co-channel sharing between the radiolocation service and the downlink of mobile service is not feasible while compatibility in non-co-channel band could be feasible for all radar types from Recommendation ITU-R R.1463 with appropriate mitigation techniques (frequency separation, distance separation, extra filtering for the base station and radars if necessary).

Recommendations

The study has shown that co-channel sharing between the radiolocation service and the transmission of a base station in the mobile service in the same geographical area would be difficult. On the other hand, cross-border coordination could be achieved taking into account appropriate mitigation techniques available

Compatibility in non-co-channel band between both services in the same geographical area would require a coordination process on national basis in order to protect each radar system from the interfering base stations within a country. This coordination may involve the use of mitigation techniques for the protection of radars operating close to the boundary between mobile service and radiolocation service.

ANNEX 5

Study into the co-existence of mobile broadband systems and radars in the frequency band 1 300-1 350 MHz

1 Introduction

World Radiocommunication Conference 2015, agenda item 1.1 seeks to identify additional spectrum that can be assigned to the mobile service in order to meet the expected increased demand for mobile broadband. One of the areas identified for study is the frequency band 1 300-1 350 MHz.

Currently the frequency band 1 300-1 350 MHz is used by air traffic control (ATC), defence and meteorological radars. ATC radars mainly for long range search, tracking and surveillance including wind profiling. Note that some of the defence radars being either transportable or located on-board aircraft.

This study investigates, based on the relevant ITU-R Recommendations where necessary supplemented by other freely available data, the potential for introducing mobile broadband systems into the frequency band 1 300-1 350 MHz.

The following single interferer/victim scenarios for both co and non-co-channel situations are studied:

– mobile base station impact on radar;
– mobile UE impact on radar;
– radar impact on mobile base station;
– radar impact on mobile UE;

This study does not consider aggregate interference however this issue may need to be considered in subsequent studies.

2 Background

The frequency band 1 300-1 350 MHz is allocated on a primary basis to the aeronautical radionavigation, radiolocation and the radionavigation satellite (Earth-to-space) services. This study only considers the impact of any mobile broadband deployment within the frequency band 1 300-1 350 MHz.

The aeronautical radionavigation service is restricted to ground based radar and associated transponders through RR No. **5.337**, and the radiolocation service on a secondary basis. The technical characteristics for these systems are taken from ITU-R Recommendations:

– Recommendation ITU-R SM.329-10 – Unwanted emissions in the spurious domain.
– Recommendation ITU-R M.1461-1 – Procedures for determining the potential for interference between radars operating in the radiodetermination service and systems in other services.
– Recommendation ITU-R M.1463-1 – Characteristics of and protection criteria for radars operating in the radiodetermination service in the frequency band 1 215-1 400 MHz.
– Recommendation ITU-R SM.1541-4 – Unwanted emissions in the out-of band domain.
– Recommendation ITU-R M.1849, – Technical and operational aspects of ground-based meteorological radars.

– Recommendation ITU-R M.1851, – Mathematical models for radiodetermination radar systems antenna patterns for use in interference analyses.

– Recommendation ITU-R V.573-4, – Radiocommunication vocabulary

Characteristics of the mobile broadband systems are based on those for IMT systems operating in the frequency range 1 300-1 350 MHz as contained in:

– Recommendation ITU-R SM.329-10 – Unwanted emissions in the spurious domain.

– Recommendation ITU-R SM.1541-4 – Unwanted emissions in the out-of band domain.

– Recommendation ITU-R F.1336-2 – Reference radiation patterns of omnidirectional, sectorial and other antennas in point-to-multipoint systems for use in sharing studies in the frequency range from 1 GHz to about 70 GHz.

– Report ITU-R M.2039-2 – Characteristics of terrestrial IMT-2000 systems for frequency sharing/interference analyses.

Propagation is modelled using:

– Recommendation ITU-R P.452-12 – Prediction procedure for the evaluation of microwave interference between stations on the surface of the Earth at frequencies above about 0.7 GHz.

– Recommendation ITU-R P.525-2 – Calculation of free-space attenuation.

3 Technical characteristics

3.1 Radar systems

The following radar system characteristics are based on those contained in Recommendation ITU-R M.1463.

TABLE 1

Radar characteristics

Transmitter		Units	Air Traffic Control		Defense				
			Radar 1	**Radar 2**	**Radar 3**	**Radar 4**	**Radar 5**	**Radar 6**	**Radar 7**
Power to the Antenna		dBW	67	50	46.5	43.9	66	63	48.8
		dBm/MHz	100	79.7	72.9	72.9	95.2	91.9	78
3 dB Emission Bandwidth			0.5	1.09	2.3	1.25	1.2	1.3	1.2
Rec. ITU-R SM.329/1541 Spurious emission limits	Roll off	dB/decade	30	30	30	30	30	40	30
	Limit	dBc	60	60	60	60	60	100	100
		dBm	37	20	16.5	13.9	36	33	18.8
		dBm/MHz	40	19.7	12.9	12.9	35.2	31.9	18
Receiver									
Noise Figure		dB	2	2	4.7	2.6	4.25	9	3.2
3 dB Bandwidth		MHz	0.78	0.69	4.4	1.25	1.32	0.88	1.2
Receiver thermal noise figure									
		dBm/MHz	–112	–112	–109	–111	–109	–105	–111
Required I/N		dB	–6	–6	–6	–6	–6	–6	–6
Antenna									
Gain		dBi	34.5	34.2	38.2	38.5	34	35	34.5
Feeder loss		dB	2	2	2	2	2	2	2
Azimuthal Beamwidth		degrees	1.2	1.4	3.2	2.2	1.2	1.3	1.2
Elevation Beamwidth		degrees	3.6	5.61	1.3	2	3.75	3.75	3.7
Rotation		rpm	5	5	6	5	6	5	5
Location			Fixed	Fixed	Transport	Fixed	Fixed	Fixed	Fixed
Nominal Height			15	15	10	15	15	15	15
Aeronautical Safety Factor[8]		dB	6	6	0	0	0	0	0

[8] The addition of a minimum 6 dB safety factor in theoretical studies is recommended by ICAO Doc. 9718.

3.2 Mobile broadband system

3.2.1 Base station

TABLE 2

Base station characteristics

Base Station		Units	LTE
Downlink frequency FDD		MHz	1325[9]
Bandwidth		MHz	5, 10 or 20
Maximum transmitter power	**BW=5 MHz**	dBm	43
	BW = 10 MHz		46
	BW = 20 MHz	dBm/MHz	46
	PeakPower density		36
Spurious emission limits	limit	dBm/MHz	–30
Max Antenna gain		dBi	18 (Rural),16 (Suburban/Urban)
Feeder loss		dB	3
Typical antenna height		m	30 (Rural/Suburban),25 (Urban)
Antenna down tilt		degrees	3 to 10
Antenna type			Sectoral (3 sectors)
Antenna Pattern			Rec. ITU-R F.1336
Polarization			± 45° cross-polarized

9 Assumed as the centre frequency for this study.

Representative air traffic control antenna polar diagram

FIGURE 1

Vertical pattern

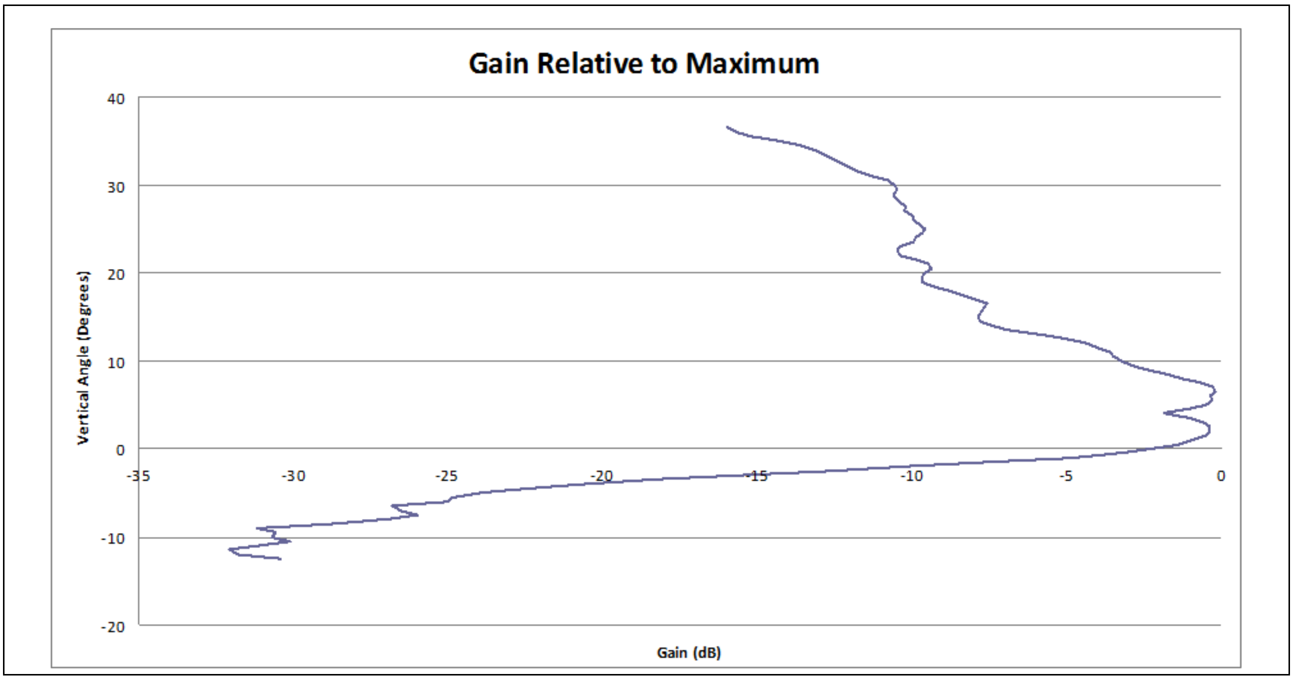


FIGURE 2

Horizontal Pattern

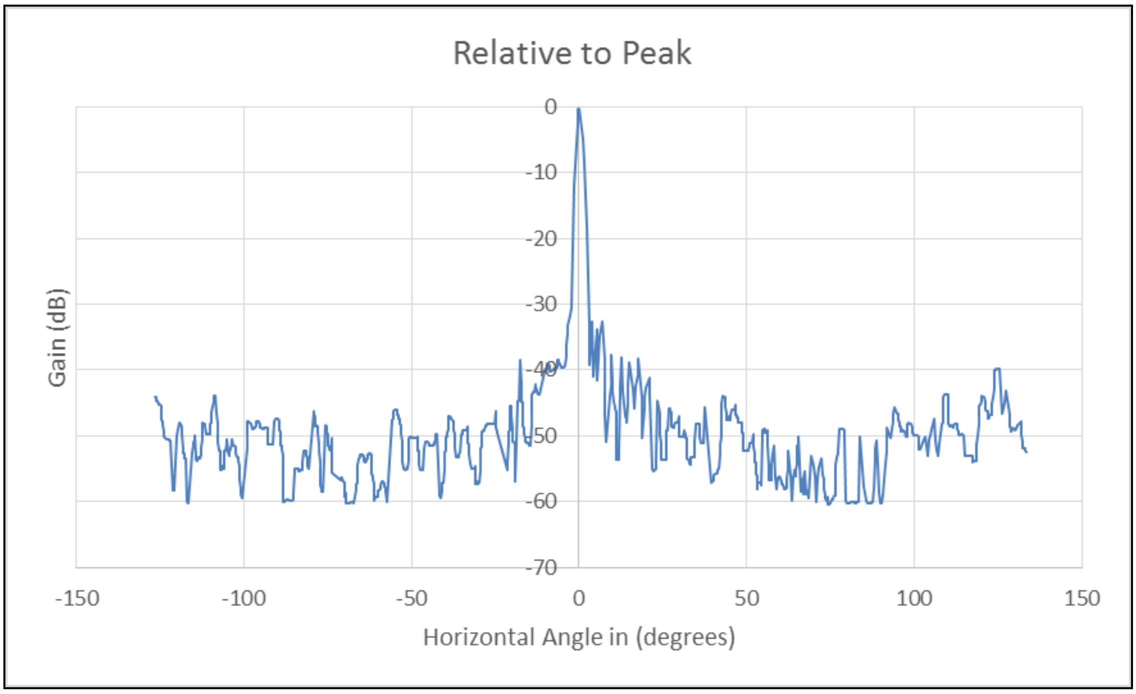


TABLE 3

Percentage of radar antenna relative gains falling within the following limits (dB below the peak of beam)

0 to –30 dB	1.42%
–30 to –50dB	45.8%
Greater than –50 dB	52.8%

3.2.2 User equipment

TABLE 4

User equipment characteristics

Base Station		**Units**	**LTE**
Downlink frequency FDD		MHz	1325
Bandwidth		MHz	5, 10 or 20
Access technique			SC-FDMA
Modulation type			QPSK/16-QAM/64-QAM
Maximum transmitter power		dBm	23
Antenna gain		dBi	-3.0
Antenna height		m	1.5
Antenna type			Omnidirectional
Polarization			Linear
Spectral mask	+10 to 20 MHz	dBm/MHz	–13
	+20 to 25 MHz	dBm/MHz	–25
Spurious emission limits		dBm/MHz	–30
Receiver Noise Figure (worst case)		dB	9
Receiver thermal noise level	BW = 5 MHz	dBm	–98
	BW = 10 MHz		–95
	Power density	dBm/MHz	–105
Required I/N		dB	–6
Maximum relative adjacent channel selectivity[10] for a 20 MHz channel	20 MHz	dB	27.0

[10] Based on blocking level commensurate with a noise figure of 9 dB.

4 Analysis

4.1 Assumptions

– Studies based on the impact of a single interferer on a single victim.

– Minimum separation:

  – base station = 1 km;

  – user equipment = 500 m.

– That peak transmission power used.

– That the mobile base station and radar will be in the main beam of the other.

– That typical mobile UE will be 3.5 degrees[11] below the main beam of the radar reducing the antenna gain by 10 dB in accordance with Figure 1.

– That cumulative effects can be ignore in all cases except when considering spurious emissions from mobile base stations on a single mast into the radar receiver[12]

– The cumulative interference from mobile base stations fitted to a single mask can be accounted on a case by case basis when determining, if any, the additional suppression required on the mobile signal in order to avoid interference into a radar.

4.2 Methodology

The following analysis is based on determining the interference margin, for a reference minimum separation distance, using free space path loss between mobile broadband and radar systems in the frequency band 1 300-1 350 MHz. The studies address both co-channel and non-co-channel issues.

4.2.1 Co-channel analysis

This analysis calculates the power at the victim receiver from the potential interference source for a given separation distance (1 km for a base station and 500 m for UE) assuming free space path loss and compares it against the receiver interference level. The difference between the receiver interference level and the power of the potential interferer at the victim receiver represents the interference margin where a negative number represents the additional suppression required to achieve compatibility.

Receiver interference level:

$$IL = TN + I/N - SM$$

Where:

IL = Receiver interference level;

TN = Receiver thermal noise level;

I/N = Required interference to noise protection level;

SM = Safety margin (only applicable for aeronautical safety systems).

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11 Based on the user equipment at 1.5 m the radar at 15 m and a separation of 500 m.

12 The rationale being:

– for a radar, given its directive antenna with good sidelobe suppression (>30 dB), the probability that more than one mobile base station is operating within the radar beamwidth on the same single frequency is not worth considering;

– for the mobile base station the probability that it will be illuminated by more than one radar at a time is also so low that it is not worth considering.

Power of the potential interferer at the victim receiver:

$$P_{RX} = P_{TX} - FL_{TX} + G_{TX} - PL + G_{RX} - FL_{RX}$$

Where:

P_{RX} = Power of the potential interferer at the victim receiver;

P_{TX} = Power of the potential interfering transmitter;

FL_{TX} = Transmit feeder loss;

G_{TX} = Transmit antenna gain;

PL = Path loss;

G_{RX} = Receive antenna gain;

FL_{RX} = Receive feeder loss.

Interference margin:

$$IM = IL - P_{RX}$$

Where:

IM = Interference margin;

IL = Receiver interference level;

P_{RX} = Power of the potential interferer at the victim receiver.

4.2.2 Non co-channel Analysis

This analysis calculates the power at the victim receiver from the spurious emissions of the potential interference source for a given separation distance (one kilometre for a base station and 500 metres for UE) assuming free space path loss and compares it against the receiver interference level. The difference between the receiver interference level and the power of the potential interferer at the victim receiver represents the interference margin where a negative number represents the additional suppression required to achieve compatibility.

Receiver interference level:

$$IL = TN + I/N - SM$$

Where:

IL = Receiver interference level;

TN = Receiver thermal noise level;

I/N = Required interference to noise protection level;

SM = Safety margin (only applicable for aeronautical services).

Spurious Power of the potential interferer at the victim receiver:

$$SP_{RX} = SP_{TX} - FL_{TX} + G_{TX} - PL + G_{RX} - FL_{RX}$$

Where:

SP_{RX} = Spurious power of the potential interferer at the victim receiver;

SP_{TX} = Spurious power of the potential interfering transmitter;

FL_{TX} = Transmit feeder loss;

G_{TX} = Transmit antenna gain;

PL = Path loss;

G_{RX} = Receive antenna gain;

FL_{RX} = Receive feeder loss.

Interference margin:

$$IM = IL - SP_{RX}$$

Where:

IM = Interference margin;

IL = Receiver interference level;

SP_{RX} = Spurious power of the potential interferer at the victim receiver.

4.3 Calculations

4.3.1 Co-channel

4.3.1.1 Mobile base station impact on radar

TABLE 5

Co-channel mobile base station on a radar receiver

	Units	**Radar 1**	**Radar 2**	**Radar 3**	**Radar 4**	**Radar 5**	**Radar 6**	**Radar 7**
Mobile base station transmit power	dBm/MHz	36.0	36.0	36.0	36.0	36.0	36.0	36.0
Mobile base station feeder loss	dB	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Mobile base station antenna gain	dBi	18.0/16	18.0/16	18.0/16	18.0/16	18.0/16	18.0/16	18.0/16
Free space path loss for 1 km	dB	95.0	95.0	95.0	95.0	95.0	95.0	95.0
Radar antenna gain	dBi	34.5	34.2	38.2	38.5	34	35	34.5
Radar feeder loss	dB	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Power at the receiver front-end	**dBm/MHz**	**–11.5/-13.5**	**–11.8/-13.8**	**–7.8/-9.8**	**–7.5/-9.5**	**–12.0/-14.0**	**–11.0/-13.0**	**–11.5/-13.5**
Minimum discernible signal	dBm/MHz	–112	–112	–109	–111	–109	–105	–111
Required I/N	dB	–6.0	–6.0	–6.0	–6.0	–6.0	–6.0	–6.0
Safety margin	dB	6.0	6.0	0.0	0.0	0.0	0.0	0.0
Interference level	**dBm/MHz**	**–124.0**	**–124.0**	**–115.0**	**–117.0**	**–115.0**	**–111.0**	**–117.0**
Level of compatibility Negative number indicates the amount of additional attenuation required	**dB**	**–112.5/-110.5**	**–112.2/-110.2**	**–117.2/-115.2**	**–109.5/-107.5**	**–103.0/-101.0**	**–100.0/-98.0**	**–105.5/-103.5**

4.3.1.2 Mobile user equipment impact on radar

TABLE 6

Co-channel mobile user equipment on a radar receiver

	Units	Radar 1	Radar 2	Radar 3	Radar 4	Radar 5	Radar 6	Radar 7
Mobile user equipment transmit power	dBm/MHz	23.0	23.0	23.0	23.0	23.0	23.0	23.0
Mobile user equipment feeder loss	dB	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mobile user equipment antenna gain	dBi	-3.0	-3.0	-3.0	-3.0	-3.0	-3.0	-3.0
Free space path loss for 500 m	dB	89.0	89.0	89.0	89.0	89.0	89.0	89.0
Radar antenna gain	dBi	34.5	34.2	38.2	38.5	34	35	34.5
Relative gain (3° below max)		–10.0	–10.0	–10.0	–10.0	–10.0	–10.0	–10.0
Radar feeder loss	dB	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Power at the receiver front-end	**dBm/MHz**	**–46.5**	**–46.8**	**–42.8**	**–42.5**	**–47.0**	**–46.0**	**–46.5**
Minimum discernible signal	dBm/MHz	–112	–112	–109	–111	–109	–105	–111
Required I/N	dB	–6.0	–6.0	–6.0	–6.0	–6.0	–6.0	–6.0
Safety margin	dB	6.0	6.0	0.0	0.0	0.0	0.0	0.0
Interference level	**dBm/MHz**	**–124.0**	**–124.0**	**–115.0**	**–117.0**	**–115.0**	**–111.0**	**–117.0**
Interference margin Negative number indicates the amount of additional attenuation required	**dB**	**–77.5**	**–77.5**	**–72.2**	**–74.5**	**–68.0**	**–65.0**	**–70.5**

4.3.1.3 Radar impact on mobile base station

TABLE 7

Co-channel radar on a mobile base station receiver

	Units	Radar 1	Radar 2	Radar 3	Radar 4	Radar 5	Radar 6	Radar 7
Radar power to the antenna	dBm/MHz	100	79.7	72.9	72.9	95.2	91.9	78
Radar feeder loss	dB	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Radar antenna gain	dBi	34.5	34.2	38.2	38.5	34	35	34.5
Free space path loss for 1 km	dB	95.0	95.0	95.0	95.0	95.0	95.0	95.0
Mobile base station antenna gain	dBi	18.0/16.0	18.0/16.0	18.0/16.0	18.0/16.0	18.0/16.0	18.0/16.0	18.0/16.0
Mobile base station feeder loss	dB	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Power at the receiver front-end	**dBm/MHz**	**52.5/50.5**	**31.9/29.9**	**29.1/27.1**	**29.4/27.4**	**47.2/45.2**	**44.9/42.9**	**30.5/28.5**
Minimum discernible signal	dBm/MHz	–109.0	–109.0	–109.0	–109.0	–109.0	–109.0	–109.0
Required I/N	dB	–6.0	–6.0	–6.0	–6.0	–6.0	–6.0	–6.0
Interference level	**dBm/MHz**	**–115.0**	**–115.0**	**–115.0**	**–115.0**	**–115.0**	**–115.0**	**–115.0**
Interference margin Negative number indicates the amount of additional attenuation required	**dB**	**–167.5/ -165.5**	**–146.9/ -144.9**	**–144.1/ -142.1**	**–144.4/ -142.4**	**–162.2/ -160.2**	**–159.9/ -157.9**	**–145.5/ -143.5**

4.3.1.4 Radar impact on mobile user equipment

TABLE 8

Co-frequency radar on a mobile user equipment receiver

	Units	Radar 1	Radar 2	Radar 3	Radar 4	Radar 5	Radar 6	Radar 7
Radar power to the antenna	dBm/MHz	67	50	46.5	43.9	66	63	48.8
Radar feeder loss	dB	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Radar antenna gain	dBi	34.5	34.2	38.2	38.5	34	35	34.5
Relative gain (3° below max)		–10.0	–10.0	–10.0	–10.0	–10.0	–10.0	–10.0
Free space path loss for 500 m	dB	89.0	89.0	89.0	89.0	89.0	89.0	89.0
Mobile base station antenna gain	dBi	-3.0	-3.0	-3.0	-3.0	-3.0	-3.0	-3.0
Mobile base station feeder loss	dB	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Power at the receiver front-end	**dBm/MHz**	**-2.5**	**–19.8**	**–19.3**	**–21.6**	**–4.0**	**–6.0**	**–20.7**
Minimum discernible signal	dBm/MHz	–109.0	–109.0	–109.0	–109.0	–109.0	–109.0	–109.0
Required I/N	dB	–6.0	–6.0	–6.0	–6.0	–6.0	–6.0	–6.0
Interference level	**dBm/MHz**	**–115.0**	**–115.0**	**–115.0**	**–115.0**	**–115.0**	**–115.0**	**–115.0**
Interference margin Negative number indicates the amount of additional attenuation required	**dB**	**–112.5**	**–95.2**	**–95.7**	**–93.4**	**–111.0**	**–109.0**	**–94.3**

4.3.2 Non co-channel

4.3.2.1 Mobile base station impact on radar

TABLE 9

Mobile base station spurious emissions falling in the pass-band of a radar receiver

	Units	**Radar 1**	**Radar 2**	**Radar 3**	**Radar 4**	**Radar 5**	**Radar 6**	**Radar 7**
Mobile base station spurious emission limit	dBm/MHz	–30.0	–30.0	–30.0	–30.0	–30.0	-30.0	-30.0
Mobile base station feeder loss	dB	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Mobile base station antenna gain	dBi	18.0/16.0	18.0/16.0	18.0/16.0	18.0/16.0	18.0/16.0	18.0/16.0	18.0/16.0
Free space path loss for 1 km	dB	95.0	95.0	95.0	95.0	95.0	95.0	95.0
Radar antenna gain	dBi	34.5	34.2	38.2	38.5	34	35	34.5
Radar feeder loss	dB	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Power at the receiver front-end	**dBm/MHz**	**–77.5/-79.5**	**–77.8/-79.8**	**–73.8/-75.8**	**–73.5/-75.5**	**–78.0/-80.0**	**–77.0/-79.0**	**–77.5/-79.5**
Minimum discernible signal	dBm/MHz	–112	–112	–109	–111	–109	–105	–111
Required I/N	dB	–6.0	–6.0	–6.0	–6.0	–6.0	–6.0	–6.0
Safety margin	dB	6.0	6.0	0.0	0.0	0.0	0.0	0.0
Interference level	**dBm/MHz**	**–124.0**	**–124.0**	**–115.0**	**–117.0**	**–115.0**	**–111.0**	**–117.0**
Level of compatibility Negative number indicates the amount of additional attenuation required	**dB**	**–46.5/-44.5**	**–46.5/-44.5**	**–41.2/-39.2**	**–43.5/-41.5**	**–37.0/-35.0**	**–34.0/-32.0**	**–39.5/-37.5**

4.3.2.2 Mobile user equipment impact on radar

TABLE 10

Mobile user equipment spurious emissions falling in the pass-band of a radar receiver

	Units	**Radar 1**	**Radar 2**	**Radar 3**	**Radar 4**	**Radar 5**	**Radar 6**	**Radar 7**
Mobile user equipment spurious emission limit	dBm/MHz	–30.0	–30.0	–30.0	–30.0	–30.0	–30.0	–30.0
Mobile user equipment feeder loss	dB	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mobile user equipment antenna gain	dBi	-3.0	-3.0	-3.0	-3.0	-3.0	-3.0	-3.0
Free space path loss for 500 m	dB	89.0	89.0	89.0	89.0	89.0	89.0	89.0
Radar antenna gain	dBi	34.5	34.2	38.2	38.5	34	35	34.5
Relative gain (3° below max)		–10.0	–10.0	–10.0	–10.0	–10.0	–10.0	–10.0
Radar feeder loss	dB	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Power at the receiver front-end	**dBm/MHz**	**-99.5**	**-99.8**	**-95.8**	**-95.5**	**-100.0**	**-99.0**	**-99.5**
Minimum discernible signal	dBm/MHz	–112	–112	–109	–111	–109	–105	–111
Required I/N	dB	–6.0	–6.0	–6.0	–6.0	–6.0	–6.0	–6.0
Safety margin	dB	6.0	6.0	0.0	0.0	0.0	0.0	0.0
Interference level	**dBm/MHz**	**–124.0**	**–124.0**	**–115.0**	**–117.0**	**–115.0**	**–111.0**	**–117.0**
Interference margin Negative number indicates the amount of additional attenuation required	**dB**	**-24.5**	**-24.5**	**-19.2**	**-21.5**	**-15.0**	**-12.0**	**-17.5**

4.3.2.3 Radar impact on mobile base station

TABLE 11

Radar spurious emissions falling in the pass-band of a mobile base station receiver

	Units	Radar 1	Radar 2	Radar 3	Radar 4	Radar 5	Radar 6	Radar 7
Radar spurious level	dBm/MHz	40	19.7	12.9	12.9	35.2	31.9	18
Radar feeder loss	dB	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Radar antenna gain	dBi	34.5	34.2	38.2	38.5	34	35	34.5
Free space path loss for 1 km	dB	95.0	95.0	95.0	95.0	95.0	95.0	95.0
Mobile base station antenna gain	dBi	18.0/16.0	18.0/16.0	18.0/16.0	18.0/16.0	18.0/16.0	18.0/16.0	18.0/16.0
Mobile base station feeder loss	dB	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Power at the receiver front-end	**dBm/MHz**	**–7.5/-9.5**	**–28.1 /-30.1**	**–30.9/ -32.9**	**–30.6/ -32.6**	**–12.8/ -14.8**	**–15.1/ -17.1**	**–29.5/ -31.5**
Minimum discernible signal	dBm/MHz	–102.0	–102.0	–102.0	–102.0	–102.0	–102.0	–102.0
Required I/N	dB	–6.0	–6.0	–6.0	–6.0	–6.0	–6.0	–6.0
Interference level	**dBm/MHz**	**–108.0**	**–108.0**	**–108.0**	**–108.0**	**–108.0**	**–108.0**	**–108.0**
Level of compatibility Negative number indicates the amount of additional attenuation required	**dB**	**–100.5/ -98.5**	**–79.9/ -77.9**	**–77.1/ -75.1**	**–77.4/ -75.4**	**–95.2/ -93.2**	**–92.9/ -90.9**	**–78.5/ -76.5**

4.3.2.4 Radar impact on mobile user equipment

TABLE 12

Radar spurious emissions falling in the pass-band of a mobile user equipment receiver

	Units	Radar 1	Radar 2	Radar 3	Radar 4	Radar 5	Radar 6	Radar 7
Radar spurious level	dBm/MHz	34.5	34.2	38.2	38.5	34	35	34.5
Radar feeder loss	dB	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Radar antenna gain	dBi	34.5	34.2	38.2	38.5	34	35	34.5
Relative gain (3° below max)		–10.0	–10.0	–10.0	–10.0	–10.0	–10.0	–10.0
Free space path loss for 500m	dB	89.0	89.0	89.0	89.0	89.0	89.0	89.0
Mobile base station antenna gain	dBi	-3.0	-3.0	-3.0	-3.0	-3.0	-3.0	-3.0
Mobile base station feeder loss	dB	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Power at the receiver front-end	**dBm/MHz**	**–35.0**	**–35.6**	**–27.6**	**–27.0**	**–36.0**	**–34.0**	**–35.0**
Minimum discernible signal	dBm/MHz	–102.0	–102.0	–102.0	–102.0	–102.0	–102.0	–102.0
Required I/N	dB	–6.0	–6.0	–6.0	–6.0	–6.0	–6.0	–6.0
Interference level	**dBm/MHz**	**–108.0**	**-–108.0**	**–108.0**	**–108.0**	**–108.0**	**–108.0**	**–108.0**
Interference margin Negative number indicates the amount of additional attenuation required	**dB**	**–73.0**	**–72.4**	**–80.4**	**–81.0**	**–72.0**	**–74.0**	**–73.0**

4.4 Results

4.4.1 Co-channel

TABLE 13

Interference margin for mobile systems into radar systems measured in dB

		Victim						
		Radar 1	**Radar 2**	**Radar 3**	**Radar 4**	**Radar 5**	**Radar 6**	**Radar 7**
Interferer	Mobile base station	**–112.5/ -110.5**	**–112.2/ -110.2**	**–117.2/ -115.2**	**–109.5/ -107.5**	**–103.0/ -101.0**	**–100.0/ -98.0**	**–-105.5/ -103.5**
	User equipment	**–77.5**	**–77.5**	**–72.2**	**–74.5**	**–68.0**	**–65.0**	**–70.5**

TABLE 14

Interference margin for radar systems into mobile systems measured in dB

		Victim	
		Mobile base station	**Mobile user equipment**
Interferer	Radar 1	**–167.5/-165.5**	**–112.5**
	Radar 2	**–146.9/-144.9**	**–95.2**
	Radar 3	**–144.1/-142.1**	**–95.7**
	Radar 4	**–144.4/-142.4**	**–93.4**
	Radar 5	**–162.2/-160.2**	**–111.0**
	Radar 6	**–159.9/-157.9**	**–109.0**
	Radar 7	**–145.5/-143.5**	**–94.3**

Non-co-channel

TABLE 15

Interference margin for mobile systems spurious into radar measured in dB

		Victim						
		Radar 1	**Radar 2**	**Radar 3**	**Radar 4**	**Radar 5**	**Radar 6**	**Radar 7**
Interferer	Mobile base Station	**–46.5/ -44.5**	**–46.5/ -44.5**	**–41.2/ -39.2**	**–43.5/ -41.5**	**–37.0/ -35.0**	**–34.0/ -32.0**	**–39.5/ -37.5**
	User equipment	**-24.5**	**-24.5**	**-19.2**	**-21.5**	**-15.0**	**-12.0**	**-17.5**

TABLE 16

Interference margin for radar systems spurious into mobile systems measured in dB

		Victim	
		Mobile base station	**Mobile user equipment**
Interferer	Radar 1	**–100.5/-98.5**	**–73.0**
	Radar 2	**–79.9/-77.9**	**–72.4**
	Radar 3	**–77.1/-75.1**	**–80.4**
	Radar 4	**–77.4/-75.4**	**–81.0**
	Radar 5	**–95.2/-93.2**	**–72.0**
	Radar 6	**–92.9/-90.9**	**–74.0**
	Radar 7	**–78.5/-76.5**	**–73.0**

4.4.2 Impact of pulsed signals on mobile systems

The interference margin shown in Tables 14 and 16 above relate to the peak power radiated by a radar. However if the statistics of the radar signal as well as the antenna pattern are taken into account then these levels will only be experienced for the following periods of time then these levels of interference margin may not be an issue however the ability of the communications receivers to operate correctly in the presence of the levels of peak power delivered by radar systems has yet to be established.

Thus the effects of pulsed interference, if successfully managed by the communications device will result in relatively short periods of loss of performance assuming no other detrimental effects have occurred subject to the peak power consideration above.

TABLE 17

Percentage time radar signal can be received at communications site in the radar main beam and sidelobes

	Solid state radar	TWT or magnetron radar
The duty cycle of the radar	9.34%	2% or less
Antenna gain and waveform	Peak radar transmission pmax to pmax –30 dB	
Percentage of time	0.14%	0.03%
	Sidelobe level wrt main beam gain-30 dB to –50 dB	
Percentage of time	4.58%	0.981%
	Sidelobe level wrt main beam gain Less than -50 dB	
Percentage of time	5.28%	1.131%
	Radar not transmitting	
Percentage of time	90.66%	98%

5 Summary

5.1 Discussion of findings

The results of the studies based purely on ITU Recommendations (Tables 11 and 12 above), indicate that there is a significant missing interference margin for both the co and non-co-channel scenarios. Additionally the studies do not account for the factors listed below and had these been taken into account then it is likely that the shortfall in interference budget would if anything have increased.

– peak to average power ratio;

– aggregation effects of multiple sources;

– impact of interference received through the antenna sidelobes.

An indication of the practical impact of the missing interference margin is given in the diagrams below that show the exclusion area that would apply to both the co and non-co-channel for mobile base station into radar and radar into mobile base station in order to protect the relevant system. The analysis is based on a representative en-route radar location using Recommendation ITU-R P.452 for 0.1% of time for interference from a rural mobile base station into the radar and 5% for the interference from the radar into the mobile base station[13].

[13] The percentage values were chosen for the purposes of this analysis although they may not necessarily be the appropriate value to use in this compatibility situation.

FIGURE 3

Area where an solid state radar (radar 2) would receive interference from a co-frequency mobile base station, 0.1% propagation model

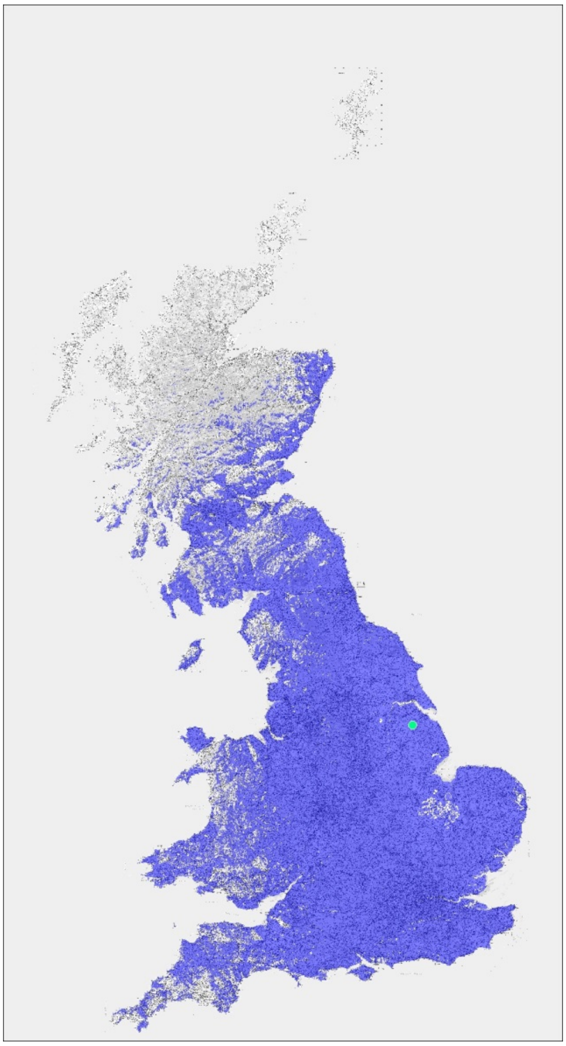
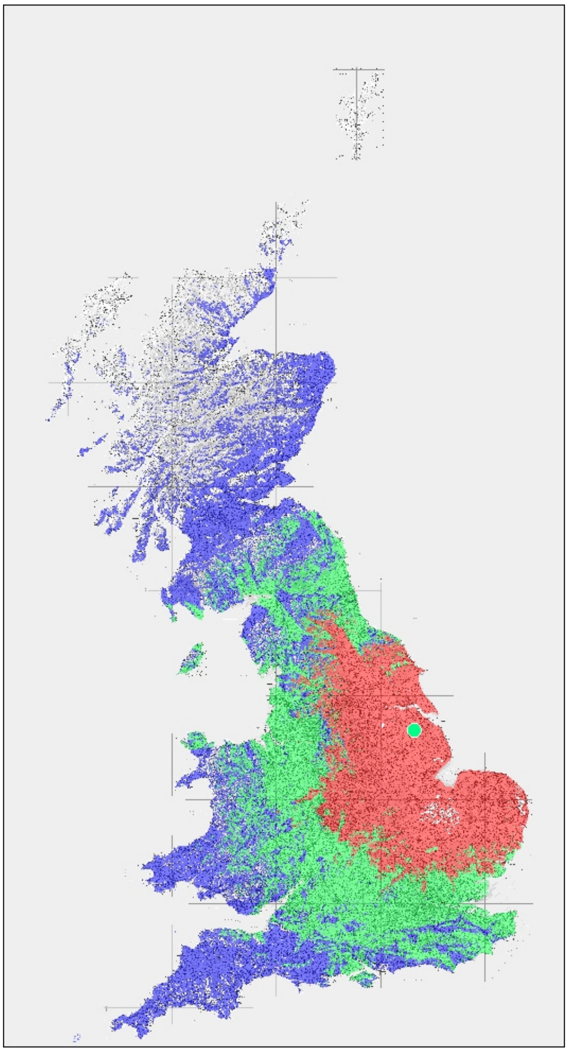


FIGURE 4

Area where a mobile base station would receive interference from a co-frequency solid state radar (radar 2), 5% propagation model



<0.14% of the time

<4.72% of the time

<9.34% of the time

FIGURE 5

Area where an solid state radar (radar 2) would receive interference from a co-frequency mobile base station, 0.1% propagation model

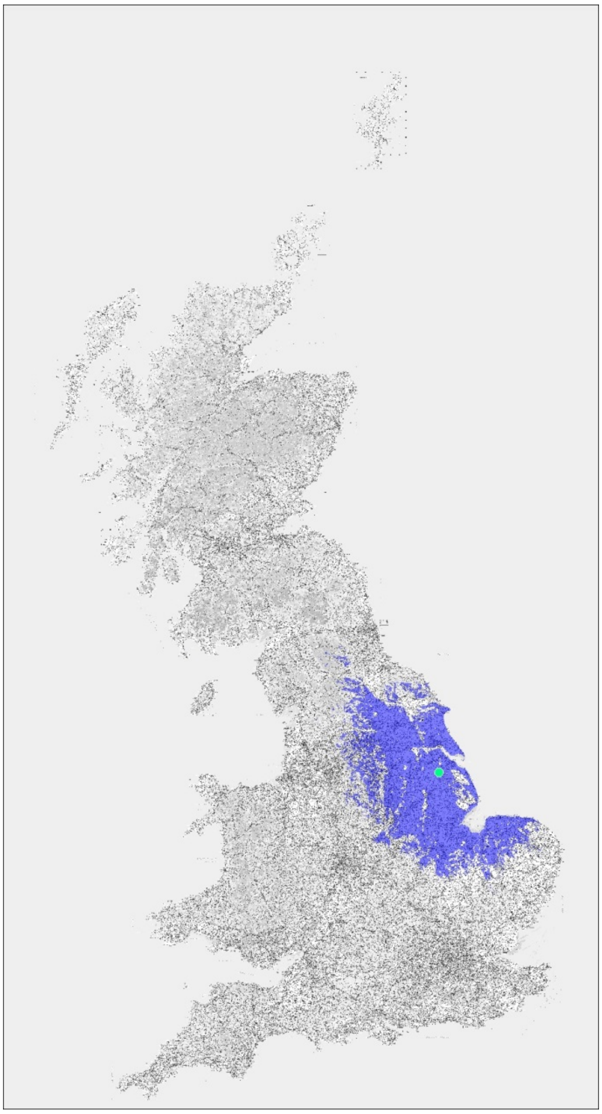
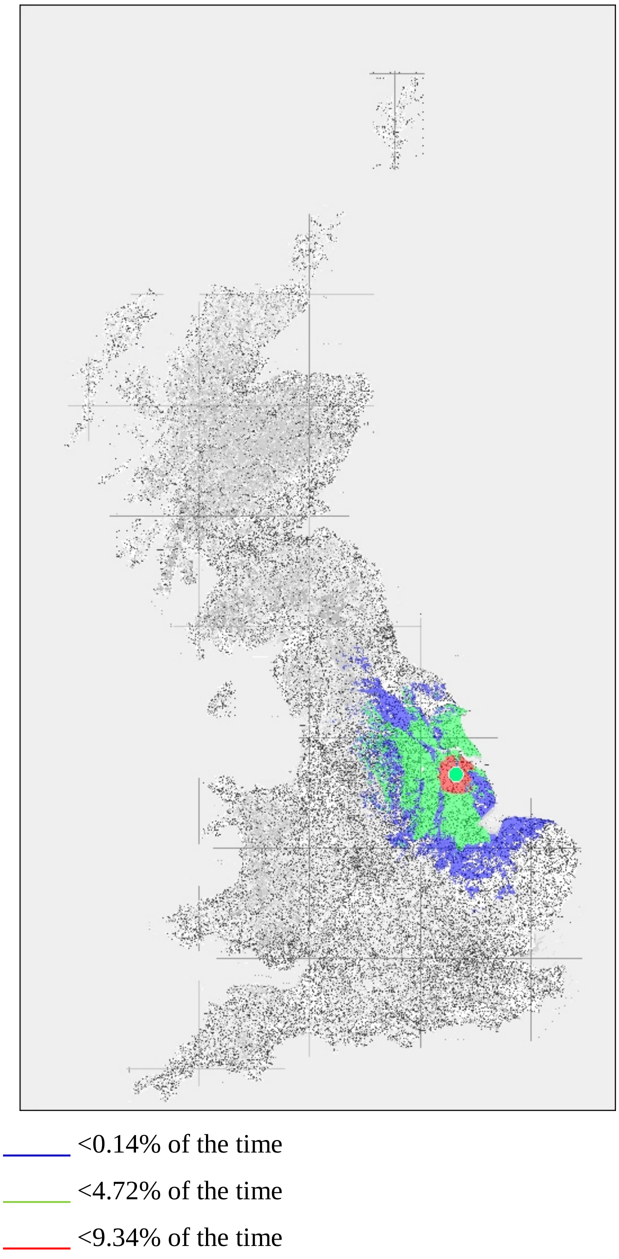


FIGURE 6

Area where a mobile base station would receive interference from a co-frequency solid state radar (radar 2), 5% propagation model



5.2 Conclusions

Based on this study the following conclusions can be drawn:

– That co-channel sharing is not feasible within the same geographical area.

ANNEX 6

Spectrum sharing between radiolocation, and broadband wireless system using IMT in the band 1 350-1 525 MHz

1 Introduction

This document presents studies performed in Brazil about suitable frequency ranges for IMT to be considered under WRC-15 agenda item 1.1. The Brazilian Administration supports sharing studies on non-co-channel operation between IMT and other systems operating in the band 1 350-1 525 MHz, with an aim to support the identification of one or more portions of bands in this frequency range to be used by IMT systems. It is necessary to guarantee enough spectrum for the operation of aeronautical mobile telemetry (AMT) and radiolocation, as well as to guarantee the operation of passive services in the band 1 400-1 427 MHz. Furthermore, there have been discussions on the definition of a band in 1 452-1 492 MHz for supplemental downlink (SDL), in order to address the traffic asymmetry between uplink and downlink of IMT-FDD systems.

Table 1 shows the communication services identified by the Brazilian Administration between the frequencies 1 300-1 525 MHz.

TABLE 1

Current frequency assignments in Brazil and IMT frequency sharing under consideration

Frequency	Services used in Brazil	Band for IMT under consideration
1 300-1 350 MHz	Radiolocation, Aeronautical Radionavigation and Radionavigation-Satellite Services	-
1 350-1 375 MHz	Radiolocation	IMT FDD Uplink frequency band L2
1 375-1 400 MHz	Radiolocation	IMT FDD Uplink frequency band L1
1 400-1 427 MHz	Earth Exploration Satellite, Space Research and Radio astronomy Services	-
1 427-1 452 MHz	Fixed service	IMT FDD Downlink frequency band L1
1 452-1 472 MHz	Aeronautical Mobile Telemetry (AMT)	Supplemental Downlink
1 472-1 492 MHz	Allocated to Fixed, Mobile services, Broadcasting (sound) and Broadcasting Satellite (sound) Services, but not regulated	
1 492-1 517 MHz	Fixed Service	IMT FDD Downlink frequency band L2
1 518-1 525 MHz	Allocated to Fixed and Mobile Services, but not regulated	-

FIGURE 1

IMT Frequency band for downlink (Radar, AMT and EESS)

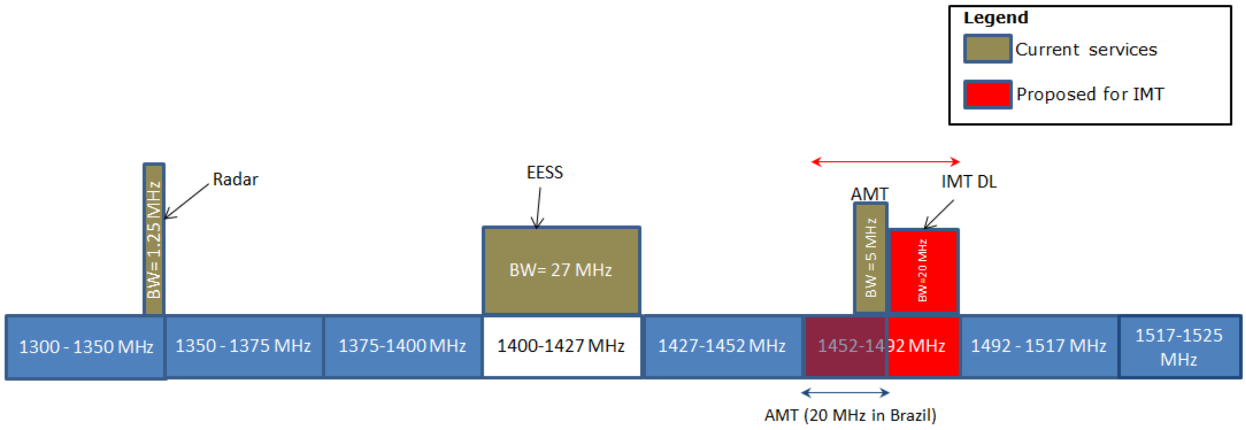


FIGURE 2

IMT FDD Frequency band L1 (Radar, AMT and EESS)

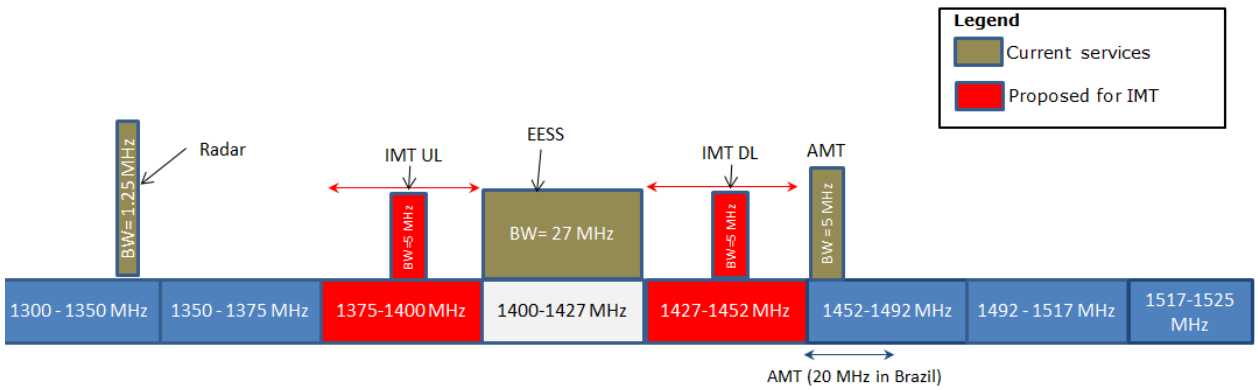
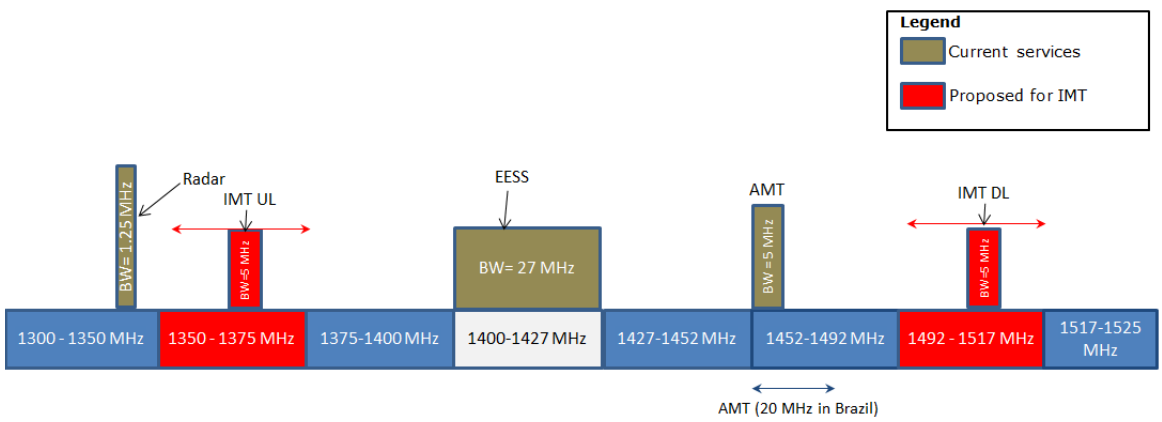


FIGURE 3

IMT FDD Frequency band L2 (Radar, AMT and EESS)



2 Background

The study considers technical characteristics and procedures of interference calculation from Recommendations of ITU-R.

For the radiolocation service the following Recommendations were used:

– for the radiolocation service in the frequency band of 1 300-1 350 MHz, the technical characteristics were obtained from Recommendation ITU-R M.1463-1 “Characteristics of and protection criteria for radars operating in the radiodetermination service in the frequency band 1 215-1 400 MHz”. In the case of Brazil, the antenna height is between 15 and 25 meters;

– for the transmission mask for the radiolocation service, a reference of the emission power was determined with the equation provided by a federal regulation 47 CFR article 27.53 Part (j). This expression is part of the Annex 8 of the Recommendation ITU-R SM.1541-4 “Unwanted emissions in the out-of band domain”;

– the antenna characteristics were modelled according Recommendation ITU-R M.1851 “Mathematical models for radiodetermination radar systems antenna patterns for use in interference analyses”;

– for the protection criteria I/N, the Recommendation ITU-R M.1461-1 “Procedures for determining the potential for interference between radars operating in the radiodetermination service and systems in other services”.

For the IMT the equipment characteristics of the LTE-Advanced radio access technology were selected. The documents used for IMT service are:

– LTE systems are described in detail in Report ITU-R M.2292, “Characteristics of terrestrial IMT Advanced systems for frequency sharing/interference analyses”;

– ITU-R Recommendation F.1336-2 “Reference radiation patterns of omnidirectional, sectorial and other antennas in point-to-multipoint systems for use in sharing studies in the frequency range from 1 GHz to about 70 GHz” provides antenna pattern information with respect to the effects of LTE base station antenna down-tilt.

– Report ITU-R M.2039-2 – Characteristics of terrestrial IMT-2000 systems for frequency sharing/interference analyses;

– The unwanted emission masks were obtained from the Appendix 1 to the Attachment 2 to the Annex 2 to the JTG 4-5-6-7 Chairman’s Report in the Document 4-5-6-7/584.

– The values for base station spurious emissions limits are from the Appendix 1 to the Attachment 2 to the Annex 2 to the JTG 4-5-6-7 Chairman’s Report in the Document 4-5-6-7/584.

– Category B definition and limits are given in Recommendation ITU-R SM.329-10 “Unwanted Emissions and Spurious Domain”, in Table 3.

For the propagation models and methodology the following Recommendations were used:

– For free space loss calculation the Recommendation ITU-R P.525-2 “Calculation of free-space attenuation”;

– For clear-air propagation models the Recommendation ITU-R P.452-15 “Prediction procedure for the evaluation of interference between stations on the surface of the Earth at frequencies above about 0.1 GHz”.– Okumura-Hata model.

For the simulation of interference, the worst cases will be considered with the IMT carriers adjacent with the other systems (radar). The results of the study will show the necessary guard band or distance of protection to IMT system coexists with actual operating telecommunication systems.

3 Technical characteristics

The systems considered for this document are the AMT, radar, EESS and IMT based on LTE-Advanced system characteristics.

3.1 IMT – LTE Advanced

The IMT system to be considered on the study will be the LTE base station for a rural area with the followings technical specifications:

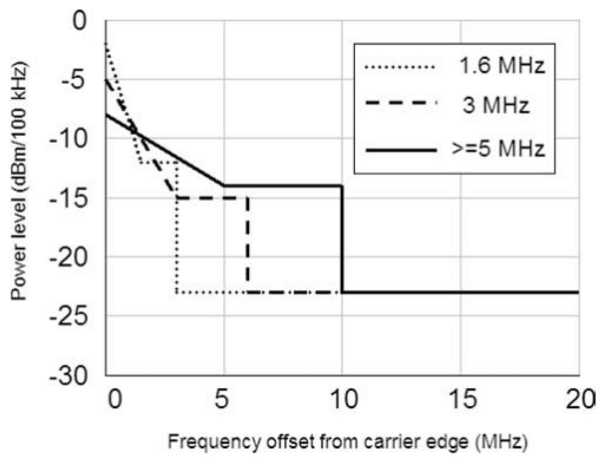
TABLE 2

LTE-Advanced base station characteristics used for simulations

Parameter	Unit	Value
Bandwidth	MHz	20
Antenna Gain	dBi	17
Transceiver Transmission Power	dBm	46
Interference Criterion	dB	–3
Antenna Height	m	15 – 30

For the worst case, no activity factor was considered, and the total power was assumed as continuous in time.

The emission mask for the base station is:



For the simulation purpose of the study, we can see that out-of-band emissions are the same for channel bandwidths above 5 MHz. The study use 20 MHz and 5 MHz of channel bandwidth.

The mobile station has the following technical parameters:

TABLE 3

LTE-Advanced UE characteristics used for simulations

Parameter	Unit	Value
Bandwidth	MHz	20
Antenna Gain	dBi	-3
Transmission Power	dBm	23
Interference Criterion	dB	-6
Antenna Height	m	1.5

The emission mask for the UE is:

TABLE 4

LTE-Advanced UE emission mask

Spectrum emission limit (dBm)/ Channel bandwidth							
Δf_{OOB} (MHz)	1.4 MHz	3.0 MHz	5 MHz	10 MHz	15 MHz	20 MHz	Measurement bandwidth
± 0-1	-10	-13	-15	-18	-20	-21	30 kHz
± 1-2.5	-10	-10	-10	-10	-10	-10	1 MHz
± 2.5-2.8	-25	-10	-10	-10	-10	-10	1 MHz
± 2.8-5		-10	-10	-10	-10	-10	1 MHz
± 5-6		-25	-13	-13	-13	-13	1 MHz
± 6-10			-25	-13	-13	-13	1 MHz
± 10-15				-25	-13	-13	1 MHz
± 15-20					-25	-13	1 MHz
± 20-25						-25	1 MHz

3.2 Radars

Radar refers to the radiolocation system used for air traffic control allowing the monitoring of all the aeronautical routes between the different airports in Brazil. The radars are operating in the 1 215-1 350 MHz. This study considers an equipment bandwidth of 1.25 MHz and I/N protection criteria of –6dB for the receiver. The radar antenna for the simulations is located at the height of 10 meters, as typical radar in Brazil, with electrical characteristics of the antenna with 38.5 dBi gain and 1.5° of HBW and VBW.

The used parameters are summarized on the Table 5.

TABLE 5

Radar characteristics used for simulations

Radar system 5	Unit	Value
Frequency range	MHz	1 300 -1 350
Frequency for analysis	MHz	1 349.375
Transmission Power	kW	40
Receiver Bandwidth	MHz	1.25
Reference Noise Temperature	K	290
Interference Criterion	dB	I/N=-6
Noise Figure	dB	2.6
Antenna Height	m	10
Antenna HBW	degrees	1.5
Radar antenna gain	dBi	38.5

4 Calculation methodology

The calculation methodology is based on the comparison between the maximum interfering e.i.r.p. allowed by victim system (e.i.r.p.max_OOB) employing the e.i.r.p. out of band (e.i.r.p.interferer) from the interfering system.

The calculation procedure is given by the following expressions:

– e.i.r.p.max_OOB [dBm/MHz] = kTB [dBm/MHz] + NF [dB] + PathLoss [dB] +Gant_rx_vi [dBi]

– e.i.r.p.interferer = PT_OOB [dBm] + Gant_int [dBi]

where:

Gant_rx_vi [dBi] : antenna gain of victim receiver

PT_OOB: transmitting power of interfering system in the operation frequency of victim system (ex., spurious emissions, adjacent channel leakage ratio (ACLR))

Gant_int [dBi] : antenna gain of interfering system.

5 Analysis

5.1 Non co-channel operations between radar and IMT FDD uplink and downlink

For the non-co-channel operation study, the methodology used established some scenarios of interference:

– For SDL frequency band of IMT FDD LTE:
  – LTE base station (20 MHz) interfering on radar;
  – LTE UE (20 MHz) interfered by radar.
– For IMT FDD Frequency band L1 and L2 (from table I):
  – LTE base station (5 MHz) interfering on radar;
  – LTE base station (5 MHz) interfered by radar;
  – LTE UE (5 MHz) interfering on radar;
  – LTE UE (5 MHz) interfered by radar.

The methodology used includes two kind of analyses, the first one is based on link budget and path loss calculations based from Recommendation ITU-R P.452 and Okumura Hata propagation models, and the main equipment characteristics are the I/N protection criteria and OOB emission masks of the interferers. The results consider the worst-case scenario with beam-to-beam interferer and interfered systems antenna configurations. The second part of the analysis corresponds to the Monte Carlo simulations to evaluate the possible combinations of distance and antenna pointing between interferer and interfered system. The resulting values are compared with the maximum OOB value permitted by the interfered receiver.

All the results are summarized in the following table:

TABLE 6

Simulation results

Scenario	e.i.r.p. $_{max\_OOB}$ Free Space Loss (1 km)	e.i.r.p. $_{max\_OOB}$ Okumura-Hata (1 km)	e.i.r.p. $_{max\_OOB}$ Monte Carlo Simulation	e.i.r.p. $_{interferer}$	Coordination conditions for interference suppression
SDL Band					
LTE base station (20 MHz) interfering on radar	–2.5 dBm/ MHz	18.75 dBm/ MHz	22.4 dBm/ MHz	4 dBm/MHz	No interference for Okumura-Hata model. For Rec. ITU-R P.452-15 the coordination distance is 2.12 km.
LTE UE(20 MHz) interfered by radar	52.81 dBm/ 20 MHz	73.94 dBm/ 20 MHz	59 dBm/ 20 MHz	100.55 dBm/ 20 MHz	For the Okumura Hata model, distance of 5 km is necessary to no interference condition
IMT FDD LTE Frequency band L1					
LTE base station (5 MHz) interfering on radar	–2.5 dBm/MHz	18.75 dBm/MHz	22.4 dBm/MHz	4 dBm/MHz	No interference for Okumura-Hata model. For Rec. ITU-R P.452-15 the coordination distance is 2.12 km.
LTE base station (5 MHz) interfered by radar	35.51 dBm/ 5 MHz	54.25 dBm/ 5 MHz	25 dBm/ 5 MHz	94.53 dBm/ 5 MHz	The coordination distance for Okumura-Hata is 12.1 km.
LTE UE (5 MHz) interfering on radar	-2.5 dBm/MHz	30.14 dBm/MHz	42.5 dBm/MHz	-21.01 dBm/MHz	
LTE UE (5 MHz) interfered by radar	52.2 dBm/ 5 MHz	73.43 dBm/ 5 MHz	56.25 dBm/ 5 MHz	98.05 dBm/ 5 MHz	The coordination distance for Okumura-Hata is 4.4 km.
IMT FDD LTE Frequency band L2					
LTE base station (5 MHz) interfering on radar	-2.5 dBm/MHz	18.75 dBm/MHz	22.4 dBm/MHz	4 dBm/MHz	No interference for Okumura-Hata model. For Rec. ITU-R P.452-15 the coordination distance is 2.12 km.
LTE base station (5 MHz) interfered by radar	35.51 dBm/ 5 MHz	54.25 dBm/ 5 MHz	25 dBm/ 5 MHz	94.53 dBm/ 5 MHz	The coordination distance for Okumura-Hata is 12.1 km.
LTE UE (5 MHz) interfering on radar	–2.5 dBm/ MHz	30.14 dBm/ MHz	42.5 dBm/ MHz	3.76 dBm/ MHz	
LTE UE (5 MHz) interfered by radar	52.89 dBm/5 MHz	74.09 dBm/5 MHz	56.55 dBm/MHz	98.05 dBm/5 MHz	The coordination distance for Okumura-Hata is 4.2 km.

6 Summary

A deterministic analysis (Okumura-Hata propagation model) and Monte Carlo simulations were performed in order to model in a more realistic way the impact of interference between IMT systems and existing services (Radiolocation, AMT and EESS).

Results were obtained in order to find a method to mitigate effects of interference on the three proposed bands for the IMT system (SDL, L1 and L2) as can be seen on Figures 1, 2 and 3.

Parameters of the systems were used form ITU-R recommendations and adapted from local use in Brazil (height of antenna and bandwidth).

7 Recommendations

Based upon the premises adopted in this study and the use of the Okumura-Hata model for the worst case distance calculation, the following results can be summarized concerning the sharing possibilities between Radar, AMT and EESS on non-co-channel coexistence with IMT FDD systems.

For the radiolocation systems, it was found the followings results for non-co-channel operation:

– for SDL band, L1 band and L2 band, no interference was found to radar systems from the base station for the propagation models used on simulation for non-co-channel operation for geographical distances above 2 kilometres without the use of additional mitigation technique, this calculation with the Recommendation ITU-R P.452-15, in the case of Okumura Hata no interference was found;
– the received non-co-channel interference from radar was high for the UE, resulting on a coordination distance between 4.2 to 5 kilometres for Okumura-Hata model on the three bands. This is a very hypothetical case with radar antennas pointing the UE;
– the received non-co-channel interference from radar was high for the base station, resulting on a coordination distance of 12.1 kilometres for Okumura-Hata model on the L1 and L2 bands. A method of reduction of interference is necessary in order to minimize the effects of interference and allows coexistence.

ANNEX 7

Co-existence of mobile broadband systems and radars in the frequency band 1 300-1 400 MHz

It should be noted that some of the studies in the attachments also reflect the inclusion of a notional safety margin. Due to the function performed by aeronautical safety-of-life systems, an additional safety margin added to the protection criteria for theoretical studies may be necessary as a means to maintain the high reliability requirements of this application.

The level of the safety margin, if any, to be applied to aeronautical radars operating in the band 1 300-1 400 MHz is to be established on the basis of further study within the ITU-R. As a result, conclusions based on the inclusion of a safety margin should be reviewed to determine if the same conclusion applies without that factor.

ANNEX 8

Study into the coexistence of IMT-advanced systems and radiolocation systems in the band 1 300-1 400 MHz

1 Introduction

This frequency range is of particular interest for IMT systems, not only because of its attractive propagation characteristics to address rural coverage scenarios, but also because the non-co-channel band 1 427-1 525 MHz is already allocated to the mobile service on a primary basis in all Regions. Specifically, the 1 427-1 525 MHz band could be considered a useful IMT 'downlink' companion to a new 'uplink' block within the range 1 300-1 400 MHz. Therefore, the co-existence of IMT 'uplink' usage with incumbent systems within (and non-co-channel to) the band 1 300-1 400 MHz have been the focus of sharing studies.

A study focused on preliminary analysis of the minimum coupling loss (MCL) requirements for co-existence due to emissions from a single mobile uplink (occupying 10 MHz of bandwidth) into typical radar systems using the band 1 300-1 400 MHz. These preliminary studies used the free space and Hata propagation models to assess worst-case separation distances based on the derived MCL values.

During the discussions it became apparent that the sharing studies should also take into account:

– interference from radar to mobile base-station receivers;

– interference to radar systems from multiple UE operating in a network environment; and

– the propagation model defined in Recommendation ITU-R P.1546, because it includes the impact of interference on signal availability for a given percentage of time and area.

This contribution therefore addresses these additional considerations, and derives revised MCL values and *worst-case* upper-bound separation distances using a deterministic approach to the analysis.

2 Back ground

The WRC-15 agenda item 1.1 is focused on consideration of *additional spectrum allocations to the Mobile Service on a primary basis and identification of additional frequency bands for International Mobile Telecommunications (IMT) and related regulatory provisions, to facilitate the development of terrestrial mobile broadband applications, in accordance with Resolution **233** **(WRC-12)***. The ITU-R established a Joint Task Group (JTG 4-5-6-7) to undertake relevant studies associated with this agenda item, and to include consideration of relevant information contributed by other interested Study Groups.

2.1 Proposed suitable frequency range: 1 300-1 525 MHz

A particularly attractive frequency range for future broadband IMT systems is the band 1 300-1 525 MHz or some portion thereof (as determined by sharing studies), because it exhibits:

– superior propagation range, to cover large regional/rural areas;

– good building penetration characteristics, for ubiquitous urban/suburban coverage; and

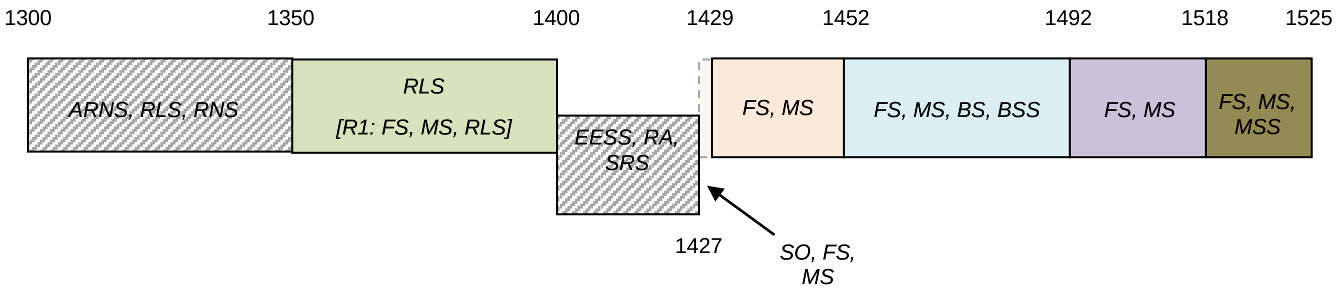
– possibility of wider IMT channel bandwidths, possibly up to 20 MHz (FDD and/or TDD).

The frequency band 1 300-1 525 MHz is also attractive due to its proximity to bands already identified for IMT (for example, 3GPP Bands #3, #11, #21, and others) which would simplify user terminal design (e.g. antenna and other radiofrequency components). Notably, however, the band 1 400-1 427 MHz is expected to be excluded from the wider proposed frequency range (along with suitable guard-bands in accordance with sharing studies) so as to protect existing Space Science allocations.

By way of overview of the frequency band 1 300-1 525 MHz, the Table of Allocations in Article **5** of the ITU-R Radio Regulations indicates the following allocations are currently in force:

FIGURE 1

Current frequency allocations



While a number of services are allocated in the lower band (below 1 400 MHz), it is the impact on aeronautical radio navigation service (ARNS) and radiolocation service (RLS) that is of particular relevance. Notably, these services are associated with safety-of-life services and must therefore be protected from unacceptable interference.

2.2 Scope of sharing studies

This contribution only considers the case of non-co-channel sharing between IMT and ARNS/RLS, based on possible further segmentation of the band. Further, while a number of sharing scenarios might be considered, covering both FDD and TDD technology variants of IMT, this contribution assumes that the band 1 300-1 400 MHz is only to be used for IMT ‘uplink’ purposes. Therefore, only two interference scenarios are investigated:

1) IMT UE transmitter emissions into ARNS/RLS receiver

2) ARNS/RLS transmitter emissions into IMT base-station receiver

It is further assumed that some guard-band may be needed between IMT systems and radars, and therefore the studies further investigate the sensitivity of the minimum coupling loss (MCL) results to the size of the guard-band.

2.3 Worst case deterministic versus Monte Carlo

While interference analysis may be undertaken using either a deterministic or Monte Carlo method, traditional ITU-R practice is to rely on deterministic analysis to establish co-ordination threshold (‘trigger’) values for indicating the need for international co-ordination procedures, and the Monte Carlo method is then used to determine efficient and equitable technical sharing conditions.

Moreover, when investigating interference arising from mobile emitters that exhibit varying location, orientation and emission power levels, usual practice is to adopt the Monte Carlo method to properly account for the statistical nature of the variables involved. Furthermore, in the special case of IMT-Advanced, where the channel resource (bandwidth) is simultaneously shared between multiple user devices, the instantaneous bandwidth assigned to a mobile emitter will also vary depending on the number of active user devices, the spectrum resources available, and capacity needs of users. For example, some simulations by 3GPP have assumed 10 users/sector to represent an efficiently ('fully') loaded system. Thus, in the case of a 10 MHz IMT-Advanced carrier, which provides fifty physical resource blocks (PRBs), a 'proportional-fair' resource algorithm would assign each user just five contiguous PRBs representing an occupied bandwidth of slightly less than 1 MHz averaged in time. The Monte Carlo method would again permit the variable nature of user-device emissions to be reasonably modelled.

However, in the study reported in this contribution, a *worst case* scenario is modelled where each IMT user device is assumed to occupy all available PRBs within a cell – and is transmitting at maximum power - for multiple users in a notional IMT network. It is also assumed that the requirements of the MCL are satisfied through the mean pathloss arising from a coordination distance between the IMT user device and a victim ARNS/RLS receiver.

3 System characteristics

This section summarises the technical characteristics of the relevant radar systems, IMT base-station receivers, IMT UE, and UE out-of-band and spurious emissions applicable to the studies.

3.1 Radar characteristics

The Recommendation ITU-R M.1463-2 provides the technical characteristics of the relevant types of radars operating within the frequency range 1 300-1 400 MHz – and the key technical parameters required for the studies are given below.

TABLE 1

Radar receiver characteristics 1 300-1 400 MHz Recommendation ITU-R M.1463

	System 1	System 2	System 3	System 4	System 5	System 6	System 7	System 8
Receiver gain Grec, dBi	33.5	38.9	38.2	32.5	38.5	34	35	34.5
Antenna Azi beamwidth	1.2	1.4	3.2	3.0	2.2	1.2	1.3	1.2
Antenna Ele beamwidth V	3.6	5.6	1.3	4-40	2.0	3.8	3.8	3.7-44
Receiver bandwidth ΔF, kHz	780	690	6400	1200	1250	880	330	1200
Receiver noise figure NF, dB	2	2	4.7	3.5	2.6	4.25	9	3.2
Protection criteria I/N, dB	–6	–6	–6	–6	–6	–6	–6	–6

Radar transmit characteristics 1 300-1 400 MHz Recommendation ITU-R M.1463

	System 1	System 2	System 3	System 4	System 5	System 6	System 7	System 8
Transmit gain Gtx, dBi	34.5	34.2	38.9	32.5	38.5	34	35	34.5
Antenna Azi beamwidth	1.2	1.4	3.2	3.0	2.2	1.2	1.3	1.2
Antenna Ele beamwidth V	3.6	5.6	1.3	4-40	2.0	3.8	3.8	3.7-44
Peak Power into Antenna dBm	97	80	76.5	80	73.9	96	93	78.8
Output device	Klystron	Transistor	Transistor	Cross-field amplifier	Transistor	Magnetron/ Amplitron	Klystron	Transistor

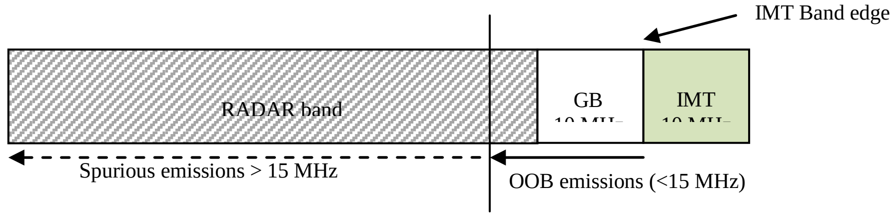
3.2 IMT UE characteristics

As this is non-co-channel band study we are primarily concerned with the UE out of band emissions and spurious emissions. These are shown in the table below for a 10 MHz LTE UE.

The specified maximum out-of-band and spurious domain emissions for IMT UE are:

Parameter	***Units***	***Value***	***Notes***
IMT User devices – for 10 MHz channel bandwidth (3GPP TS 36.101)			
OOB emissions	dBm/30kHz dBm/MHz dBm/MHz dBm/MHz	–18 –10 –13 –25	0-1 MHz separation from channel edge 1-5 MHz 5-10 MHz 10-15 MHz
Spurious emissions	dBm/MHz	–30	in the range 1-12.75 GHz (except OOB emission region noted above)

With a guard band of 10 MHz, the out-of-band limit of –25 dBm/MHz falls into this region and extends to 15 MHz from the IMT band edge. Radars operating in the lower part of the radar band would be afforded the spurious limit of –30 dBm/ MHz:



3.3 IMT base station receive characteristics

To investigate the case of interference from radars into IMT base-stations, the following receiver characteristics derived from 3GPP TS 36.104 are relevant:

Blocking –15 dBm

Receiver Noise figure 5 dB

Additional receiver system characteristics for feeder loss and antenna gain should also be considered. Typically these will be in the order of

Antenna Gain	18 dBi (rural)
Feeder losses	3 dB

4 Methodology and formulas

This section briefly outlines the methodology and formulae used to derive the worst-case minimum coupling losses and separation distances.

A three stage approach is taken:

1) Calculate the maximum allowable interfering level at the radar, based on the radar technical characteristics and minimum protection criteria of 6 dB below the noise floor:

$$P_{int} = -174 + NF + I/N + 10 \log_{10} 10^6 \text{ dBm / MHz}$$

where:

P_{int} = maximum allowable interference PSD;

NF = noise figure;

I/N = protection ratio.

2) Calculate the minimum coupling loss (MCL) required, by considering the UE emissions and radar system receive characteristics:

$$MCL = UE - P_{int} + G_{ant} - L_{feed}$$

where:

MCL = Minimum Coupling Loss;

UE = UE emissions;

G_{ant} = Radar receive antenna gain;

L_{feed} = Radar system feeder losses.

3) Finally, calculate required minimum separation distances using simple propagation models. The following alternative radio propagation models are considered.

a) Estimation of separation distance using the free space path loss model:

$$PL_{FS} = 32.4 + 20 \log10 (f) + 20 \log10 (d)$$

where:

PL_{FS} = free space path loss (dB);

MCL = minimum coupling loss (dB);

f = frequency (MHz);

d = distance (km).

Equating the PL_{FS} to MCL, and then re-arranging and solving for d gives:

$$d = 10\text{^}((MCL-32.4 - 20\log_{10} (f))/20)$$

b) Estimation of separation distance using the Hata path loss model

$$PL_{Hata} = 69.55 + 26.16 \log_{10}(f) - 13.82 \log_{10}(H_b) + [44.9 - 6.55 \log_{10}(H_b)] \log_{10} d$$

where:

PL_{Hata} = Hata path loss (dB);

f = frequency (MHz);

H_b = base station Height (Radar Height in this case = 15 m);

d = distance (km).

Equating the PL_{Hata} to MCL, and then re-arranging and solving for d gives:

d = 10^((MCL - 69.55 - 26.16 $\log_{10}(f)$ + 13.82 $\log_{10}(H_b)$) / (44.9 -6.55$\log_{10}(H_b)$)))/10

It is noted that the Hata model also incorporates a general clutter loss component, and may *over predict* the path loss (suggesting shorter separation distances). In contrast, the more simplistic free-space propagation model assumes clear line-of-sight and perfect propagation conditions, and will thus typically *under predict* path loss for low-elevation (terrain clearance) angles (suggesting unrealistically large separation distances).

However, neither of the above models consider the effect of interference on the desired signal availability for a particular percentage of time and area availability. This aspect can be incorporated by using the propagation model defined in Recommendation ITU-R P.1546. However, the free-space and Hata propagation models can usefully establish upper- and lower-bounds to the modelling and analysis of worst-case separation distances.

c) Estimation of separation distance using the Recommendation ITU-R P.1546-5 model

Recommendation ITU-R P.1546 -5 is intended as a point-to-area coverage prediction model. For the purposes of this study, the curves provided in figure 19 of that Recommendation are relevant. These curves represent estimates of land-based field strength exceeded for 1% of the time and 50% of locations at an operating frequency of 2 GHz.

To adjust these curves for applicability at 1 350 MHz, and extend them to cover the case of 1% of locations, a further margin must be included in accordance with Annex 5 (equation 34) of Recommendation ITU-R P.1546-5:

$$SD = 1.2 + 1.3 \log_{10}(1350)$$

$$= 5.3 \text{ dB}$$

$$\text{Margin for 1\% of locations} = \text{Inverse normal } (0.99) * SD$$

$$= 2.32 * 5.3$$

$$= 12.3 \text{ dB}$$

where SD = Standard deviation lognormal fading.

To further reduce either of these parameters to 1% bounds (to say 0.1%) in terms time and/or locations is outside of the validity of the Recommendation ITU-R P.1546 model. Therefore we have no agreed way to derive the additional margin

The Recommendation ITU-R P.1546 curves provide the expected field strength for a 1 kW e.r.p. transmitter, so conversion from field strength (E) to the effective path loss (Lb) is required. That conversion is achieved by use of equation 40 of Annex 5.

Thus, the conversion of MCL to Field strength (E) is given by the following Equation

$$E = 201.6 – MCL - Margin$$

$$= 201.6 - MCL – 12.3$$

$$= 189.3 - MCL$$

To derive field-strength values for the case of a transmitter antenna elevated 15 metres above ground, a linear interpolation is made between the 10 metre and 20 metre transmitter elevation values.

$$E_{15} = (E_{10} + E_{20}) / 2$$

Final separation distances are then obtained by linear interpolation of the tabulated E and D values above and below the E value corresponding to the required MCL:

$$D = D_1 + (E - E_1)/(E_2 - E_1) * (D_2 - D_1)$$

where $E1 < E < E2$.

5 Analysis

5.1 IMT User Equipment Interfering with Radar Receiver

The table below summarises the required minimum coupling losses and separation distances for a range of antenna types and UE emission limits.

TABLE 2

Upper Bound Separation Distances – single user case

Radar receive characteristics			*Type 1*	*Type 2*	*Type 3*	*Type 4*	*Type 5*	*Type 6*	*Type 7*	*Type 8*
Thermal	dBm/Hz	A	-174.0	-174.0	-174.0	-174.0	-174.0	-174.0	-174.0	-174.0
Noise figure	dB	B	2.0	2.0	4.7	3.5	2.6	4.3	9.0	3.2
Sensitivity	dBm/MHz	c= a+b+10log 1e6	-112.0	-112.0	-109.3	-110.5	-111.4	-109.8	-105.0	-110.8
Required I/N	dB	D	-6.0	-6.0	-6.0	-6.0	-6.0	-6.0	-6.0	-6.0
Max Interfering power	dBm/MHz	e=c-d	-118.0	-118.0	-115.3	-116.5	-117.4	-115.8	-111.0	-116.8
Antenna gain	dBi	F	33.5	38.9	38.2	32.5	38.5	34.0	35.0	34.5
Feeder loss	dB	G	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Maximum received power @antenna	**dBm/MHz**	**h=e-f+g**	**-149.5**	**-154.9**	**-151.5**	**-147.0**	**-153.9**	**-147.8**	**-144.0**	**-149.3**
UE transmit characteristics										
Emission limit	dBm/MHz	I	-25.0	-25.0	-25.0	-25.0	-25.0	-25.0	-25.0	-25.0

@ -25										
Emission limit @ -30	dBm/MHz	J	-30.0	-30.0	-30.0	-30.0	-30.0	-30.0	-30.0	-30.0
Minimum coupling loss										
MCL @ -25dBm/MHz	**dB**	**k=i-h**	**124.5**	**129.9**	**126.5**	**122.0**	**128.9**	**122.8**	**119.0**	**124.3**
MCL @ -30dBm/MHz	dB	l=j-h	119.5	124.9	121.5	117.0	123.9	117.8	114.0	119.3
Coordination distance by model										
UE emission limit		Prop model								
-25 dBm/MHz	**Km**	**m = dfspace(k)**	**32.86**	**31.75**	**36.87**	**21.96**	**48.61**	**23.94**	**15.55**	**28.62**
-25dBm/MHz	**Km**	**o = dhata(k)**	**0.56**	**0.79**	**0.64**	**0.74**	**0.50**	**0.40**	**0.55**	**0.56**
-25 dBm/MHz	**Km**	**q = d1546(k)**	**6.00**	**7.80**	**6.60**	**5.20**	**7.50**	**5.50**	**4.50**	**5.90**
-30 dBm/MHz	Km	n = dfspace(l)	18.48	17.85	20.73	12.35	27.33	13.46	8.74	16.10
-30 dBm/MHz	Km	p= dhata(l)	0.41	0.57	0.46	0.54	0.37	0.29	0.40	0.41
-30 dBm/MHz	Km	r = df1546(l)	4.60	6.10	5.10	4.00	5.80	4.20	3.40	4.60

Multiple IMT UE in surrounding cells

The MCL values calculated above represent the case of a single IMT UE device located within the antenna bore-sight of a radar receiver. To model the case of a 'network' hosting multiple UEs potentially causing interference to a victim radar receiver, it has been agreed to use a cluster of 19 cells each comprising a 3-sector base station - and placing UE at random within the cells, in accordance with applicable UE densities (urban/suburban/rural), enabling a Monte Carlo simulation to be undertaken to derive a CDF of interference to the victim receiver.

In practice, many of the UEs in such a 19-cell cluster will lie outside the main beam of the radar receiver antenna, and only those UEs located within the main-beam and in the nearest tier of cells will dominate the interference scenario. Previous modelling, and extensive IMT network drive-testing, has demonstrated that, typically, only 2 ~ 3 dominant interferers located with the first 'tier' sectors and directly within the victim receiver main beam contribute to the total aggregated interference (within < 2 dB).

To approximate the case of multiple IMT cells, it is noted that the 2~3 sectors falling within the radar antenna main beam (as it sweeps) will contribute a high proportion of the interfering emissions – while other cells beyond the main beam or more distant from the radar site will contribute a lesser proportion of interference. As for the single-entry analysis, it is assumed that in each IMT cell a single UE is transmitting on the entire 10 MHz bandwidth. This is clearly a *worst-case* scenario since, in practice, multiple UE share the 10 MHz available bandwidth and are thus each assigned fewer physical resource blocks (narrower bandwidth), and are randomly distributed throughout the host cell. The assumption of maximum bandwidth allocation to a single UE equates to *worst-case* out-of-band UE emissions. Furthermore, an inherent inference is that the interfering UE are all located at their respective cell-edge, since the UE are all assumed to be transmitting at maximum power.

From the discussion above, it might be assumed, for a worst-case deterministic analysis that the interference from multiple UE may be mostly coming from four full-bandwidth users: one in the bore-sight cell, and three from each of the surrounding cells. However, along with assuming all users occupy the full 10 MHz bandwidth, all are assumed to be transmitting at maximum power - and all located a similar distance away from the victim receiver.

On that basis, the equivalent impact of multiple users could t be roughly approximated by increasing the MCL by 10*log(4) or 6 dB. The table below provides the estimated upper-bound separation distances for each propagation model considered, and for each radar type.

TABLE 3

Upper Bound Separation Distances – multiple user case

Radar Type			*Type 1*	*Type 2*	*Type 3*	*Type 4*	*Type 5*	*Type 6*	*Type 7*	*Type 8*
Applicable UE Emission limit		Model								
-25 dBm/MHz	km	S = fspace(k+6)	65.72	63.5	73.74	43.92	97.22	47.88	31.1	57.24
-25dBm/MHz	km	U = hata(k+6)	0.82	1.15	0.93	1.08	0.73	0.58	0.81	0.82
-25 dBm/MHz	km	W = P1546(k+6)	8.1	10.5	8.9	7.1	10.0	7.4	6.1	8.0
-30 dBm/MHz	km	T = fspace(l+6)	36.96	35.7	41.46	24.7	54.66	26.92	17.48	32.2
-30 dBm/MHz	km	V= hata(l+6)	0.60	0.84	0.68	0.79	0.53	0.42	0.59	0.60
-30 dBm/MHz	km	X = P1546(l+6)	6.3	8.2	6.9	5.5	7.8	5.8	4.7	6.2

With a modest guard band of 10 MHz, and for a 10 MHz IMT UE uplink carrier bandwidth, the UE emissions are still in the out-of-band domain at –25 dBm/MHz. Extending the guard band a further 5 MHz reduces the UE emissions to –30 dBm/MHz, since these emissions now lie in the spurious domain. Based on the specified maximum out-of-band emission levels, the worst-case MCL requirement for 10 MHz guard band is about 119 dB for IMT UE emission limits of -25 dBm/MHz for a single UE.

In comparison, the aggregate interference due to multiple UE and with 10 MHz guard-band is roughly estimated as an equivalent 6 dB rise in interference level at the radar station - increasing the worst-case MCL requirement from 119 dB to about 125 dB.

For the case of multiple UE and -25 dBm emission limit, converting the worst-case MCL values to separation distance using the Hata propagation model results in values less than one kilometre.
A worst-case free space calculation results in a separation distance of between 31 - 97 kilometres.
A more realistic worst-case separation distance may therefore lie somewhere between the two cases.

Use of the Recommendation ITU-R P.1546 model suggests a worst-case separation distance of 6.1 - 10.5 kilometres.

These separation distances would be improved by considering several other issues, such as:

1) more detailed consideration of radar antenna elevation characteristics below horizontal;

2) more realistic values for OOB emissions of UEs, noting that 3GPP specifications are defined as minimum performance objectives. Actual OOB emissions of real devices are considerably better than 3GPP requirements (and UE antenna OOB efficiency may result in even lower values);

3) body loss will further attenuate UE radiated emissions.

5.2 Radar interfering with IMT base-station receiver

The second interference scenario to be considered is the case of radar emissions causing interference to the IMT base-station receiver. Two interference mechanisms need to be considered:

a) Blocking of the base-station receiver (ie. IMT out-of-band effects), and

b) Radar spurious emissions causing degradation of IMT receiver noise floor (ie. IMT in-band effects).

5.2.1 Base station blocking (out of band)

The first mechanism relies on a maximum out-of-band interference level of not more than –15 dBm. In 3GPP Recommendation ITU-R 36.104 the blocking characteristic is defined as a measure of the receiver's ability to receive a wanted signal in the presence of an unwanted interferer which is a CW signal for out of band blocking. The 1 300-1 525 MHz frequency band is closest to Band 3 and for this band for interferers lying between 1-20 MHz of the lowest uplink frequency, the blocking level is –15 dBm.

Using the typical e.i.r.p. of a high power radar (ref: Recommendation ITU-R M.1463 system 1), it can be seen:

Radar Tx Pwr	+97.0 dBm	
Radar Antenna gain	+34.5 dBi	
Base station gain	+18.0 dBi	
Feeder loss	- 3.0 dB	
	==========	
	146.5 dBm	
IMT Rx Blocking level	–15.0 dBm	
	=========	
Worst-case MCL	161.5 dB	
Nom. separation 1km	–95.0 dB	
	=========	
Shortfall =	66.5 dB	- requiring additional filtering.

This filtering requirement (67 dB) is relatively modest, and can be readily achieved via additional out-of-band filtering at the IMT base-station receiver - noting that the IMT base station will typically employ substantial filtering to protect its receivers from its own transmitters. For example, we would naturally assume that a real base-station will include a duplexer (at least) to protect the base-station receiver from its associated transmitter emissions.

Therefore, the assumption of a one kilometre minimum separation between the radar and IMT base-station receiver appears to be practical, since it seems likely that the IMT base-station receiver can be adequately protected from blocking effects with out-of-band filtering providing 67 dB or more of protection.

5.2.2 IMT base station degradation from radar spurious emission

The second mechanism to impact on IMT base-station performance is the radar system out-of-band emissions degrading IMT noise levels. The L-band radar systems are intended to achieve Category A limits of –60 dBc for out-of-band emissions[14]. Solid state radars can achieve this level within about 12 MHz of the main carrier. It is unlikely that legacy vacuum-tube based radar technologies can achieve Category A out-of-band emission limits within such a modest bandwidth. Therefore, future co-existence of IMT base station protection scenarios may suggest the need for retirement of klystron/magnetron systems, and deployment of solid-state radars only.

The maximum interfering level is determined by the interference level being 6dB below the IMT base station receive noise floor – and this level is –115 dBm/MHz assuming a receiver noise figure of 5 dB.

The highest powered solid-state radar is the System 2 shown in Table 2 above:

Transmit power	80.0 dBm
Tx Antenna gain	38.9 dBi
Cat A	–60.0 dBc
	==========
OOB Emission e.i.r.p.	58.9 dBm/1MHz
OOB Emission e.i.r.p.	68.9 dBm /10 MHz
IMT Rx Antenna gain	18.0 dBi
Feeder loss	–3.0 dB
Maximum level	–105 dBm/ 10 MHz
	=======
Worst-case MCL requirement =	188.9 dB

At first glance, this *worst-case* MCL requirement may seem a rather challenging objective.

However, in practice, there are a range of mitigation techniques available, including:

1) Co-ordinated placement of the IMT base station, to take advantage of natural or man-made obstructions – potentially offering at least 15 dB of isolation;

2) Orientation of the IMT base-station antenna to face directly away from the radar site – and use of a solid reflector to shield the IMT antenna – providing at least 20-40 dB of additional isolation;

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[14] Reference source: **ECC Report 174** – Category A out-of-band emissions limit for radar types 1-4 = –60 dBc, and for *modern* type 4 the limit is –75 to –90 dBc see table 5. Both these values apply in the spurious domain as the radar out-of-band emissions lie in the spurious domain. The 1 MHz emission bandwidth has been chosen in accordance with Recommendation ITU-R M.1177 and then converted to an equivalent 10 MHz bandwidth of the IMT service.

3) Further filtering of the radar OOB emissions - filter attenuations of 40-50dB are noted in Recommendation ITU R F.1097-1 as a possible mitigation option, (refer section 2.1 RF filters).

Obstructions	15	dB
Antenna orientation	20-40	dB
Radar OOB Filter	45	dB
	===========	
Resulting worst-case MCL	88.9 - 108.9	dB

For a separation distance of one kilometre, and assuming a free-space propagation model, only relatively minor additional isolation of between 0 - 13.9 dB is necessary to achieve the worst-case MCL of 88.9-108.9 to protect the IMT base-station.

If the worst-case MCL requirement were to be met by geographic separation alone, the above value of 108.9 dB equates to a distance of approximately 5km assuming worst-case free-space propagation. However, identification of additional isolation (mitigation) options, as noted above, is considered non-challenging – although this aspect may be location-specific.

Notably, only the free-space propagation model has been assumed – given that base station antennas are typically deployed at elevations relatively clear of local clutter. However, further improvement of these calculations may be observed if Recommendation ITU-R P.452 were to be used to derive worst-case co-ordination separation threshold values.

Moreover, observations have been presented to date indicating that contemporary radar out-of-band emission performance is considerably better than the values suggested in relevant ITU-R Recommendations. Therefore, if actual measurement results of radar out-of-band emissions were available, it is likely that worst-case values estimated above may be considerably improved.

Irrespective of the actual radar unwanted emission levels, the intermittent nature of the radar pulse and sweeping pattern, may well minimise its impact on IMT base-station performance. Studies of this aspect are not discussed in this paper.

6 Summary and conclusions

A simple deterministic analysis has been performed modelling the worst-case impact of UE into the radar receive band and the worst-case impact of radar transmissions to IMT base stations. For both of these interference scenarios, worst-case MCL values and thus worst-case separation distances have been determined.

The results of these studies clearly suggest that worst-case separation distances are not quite as challenging as previously envisaged.

More detailed studies should consider actual deployment situations - but that is a matter for national administrations to consider. In particular, the radio paths between IMT base-station and the radar transmitter may have benefit of natural and/or man-made obstructions which have only been generally characterised in this study.

In regard to IMT UE out-of-band emissions toward the radar: an upper bound for *worst-case* separation distances necessary to protect the radar receiver noise floor, for the case of multiple UE all operating at maximum power and 10 MHz guard-band for a 10 MHz IMT channel, have been shown to be in the range 6 – 98 km – using Recommendation ITU-R P.1546 and free-space propagation models. If the guard-band is expanded to 15 MHz, the upper bound for worst-case separation distances falls to 4.7 – 55 km, under the same conditions.

In contrast, the lower bound for *worst-case* separation distances necessary to protect the radar receiver noise floor, for the case of multiple UE all operating at maximum power and 10 MHz guard-band for a 10 MHz IMT channel, have been shown to be in the range 0.58 – 1.15 kilometres – using the Hata/Cost231 propagation model. For a 15 MHz guard-band, the lower bound falls to 0.42 – 0.84 kilometres.

A range of mitigation options should also be considered:

1) consider radar receive antenna elevation characteristics;

2) use more realistic values for radiated emissions of mobile devices, since 3GPP emission criteria are typically defined as minimum performance objectives, and confirmed by use of conducted measurements. The radiated emissions of real devices are usually considerably better than 3GPP requirements, and UE antenna efficiency will result in even lower values;

3) body loss will further attenuate UE radiated emissions.

However, these studies clearly indicate that worst-case separation/co-ordination distances between radar systems and IMT systems are considerably lower than previous studies have tended to suggest. In particular, when realistic distribution of UE emission levels are taken into consideration (along with random mobility of devices), a minimum separation of 1-2 kilometres may well prove to be feasible.

In regard to radar transmitter impact to IMT base-station (ie. receiver blocking and degradation of in-band receiver threshold): an upper bound for *worst-case* separation distance to protect the IMT base-station receiver, using a free-space propagation assumption and no specific mitigation measures, would appear to need very large isolation distances.

However, there are a number of practical mitigation measures available, including:

1) co-ordinated placement of the IMT base-station, to take account of natural or man-made obstructions;

2) orientation of the IMT base-station antenna to face directly away from the radar site – and use of a solid reflector to shield the IMT antenna; and

3) further filtering of the radar OOB emissions;

Moreover, it seems likely that where realistic radar out-of-band emissions are considered, along with implementation of mitigation measures, achieving separations that are realistic appears to be possible.

Additional support for the encouraging conclusions of these studies is provided by the conclusions of ECC Report 174, which states:

> *It should be noted that although the worst case analysis shown in this report suggests that there could be compatibility problems in certain circumstances between MS and radar, the actual situation in practice throughout CEPT will vary from country to country. In addition it is expected that by considering more realistic assumptions, including unwanted emissions levels for both services and using a combination of the mitigation techniques highlighted in the report, where appropriate, sufficient protection can be given to both services*

Finally, it should be noted that the studies reported in this document are based on worst-case modelling and assumptions - and actual scenarios will vary according to local circumstances/situation. It is expected by considering more realistic assumptions of unwanted emissions of both services, mitigation options such as deployment geometry, and other factors, will show that sufficient protection for separation distances of 1-2 kilometres and guard-bands of 10-15 MHz is likely to be achievable.

ANNEX 9

Sharing between IMT-advanced and radiodetermination systems in the band 1 300-1 400 MHz

1 Introduction

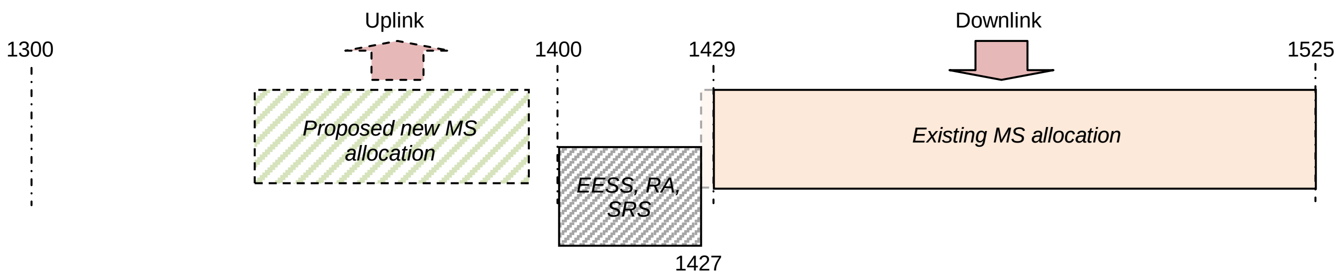
The World Radio Conference 2015 agenda item 1.1 seeks to identify additional spectrum for the mobile service to meet the forecast increase in capacity demand for mobile broadband systems to 2020 and beyond. One of the frequency bands of interest is the 1 300-1 400 MHz band, which is currently used for aeronautical radionavigation (ARNS), radiolocation (RLS), and radionavigation satellite services (RNSS) subject to RR No. **5.337A**.

In some countries, there is minimal or inefficient usage of the band 1 300-1 400 MHz by radiodetermination services - prompting some administrations to explore opportunities for other services such as wireless broadband systems to exploit the band (or some portion) toward further facilitating national economic growth and development.

The band 1 300-1 400 MHz offers notable advantages for future IMT systems, not only because of its favourable propagation characteristics, but also to potentially provide the frequency-division-duplex (FDD) ‘uplink’ companion to the band 1 427-1 525 MHz already allocated to the mobile service in all three Regions and which already seems destined to be used for ‘downlink’ signals:

FIGURE 1

Proposed IMT FDD structure



This Annex presents technical sharing studies that investigate the minimum necessary frequency and geographic separation necessary to protect ARNS and RLS systems from unacceptable interference caused by ‘uplink’ emissions of IMT-Advanced user devices.

These studies have used a Monte Carlo model, and focus on simulating non-co-channel-channel operating scenarios to illustrate the potential for either:

i) Local segmentation of the band (per Rec. ITU-R SM.1132) to accommodate IMT-Advanced systems and incumbent systems to occupy non-co-channel segments; or

ii) co-ordinated sharing of the band by IMT-Advanced systems and existing incumbent systems, through a combination of frequency and geographic separation.

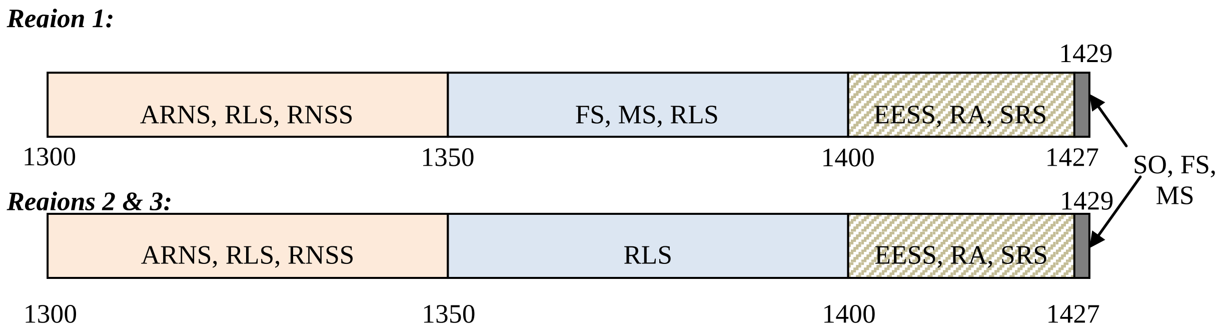
The results of these studies may also suggest possible threshold values for initiating cross-border co-ordination discussions enabling administrations to ensure both sufficient protection of incumbent systems and efficient usage of the radiofrequency spectrum resources.

2 Background

Under Article **5** of the International Radio Regulations (RR), the frequency band 1 300-1 400 MHz is currently allocated to the ARNS, RLS, and RNSS on a co-primary basis and restricted to ground-based radar and associated transponders through RR No. **5.337**:

FIGURE 2

ITU-R radiofrequency allocations in the band 1 300-1 400 MHz



In addition, reference was also made to relevant ITU-R Recommendations, including:

– Recommendation ITU-R SM.329-10 – Unwanted emissions in the spurious domain.
– Recommendation ITU-R M.1461-1 – Procedures for determining the potential for interference between radars operating in the radiodetermination service and systems in other services.
– Recommendation ITU-R M.1463-1 – Characteristics of and protection criteria for radars operating in the radiodetermination service in the frequency band 1 215-1 400 MHz.
– Recommendation ITU-R SM.1541-4 – Unwanted emissions in the out-of band domain.
– Recommendation ITU-R M.1851 – Mathematical models for radiodetermination radar systems antenna patterns for use in interference analyses.

Similar to other studies, and to explore the sensitivity of results to potential performance improvement of certain parameters, additional simulations were undertaken with selectively adjusted parameter values as noted in the results.

The radio propagation environments were modelled in accordance with relevant ITU-R documents and Recommendations:

– Recommendation ITU-R P.1546-5 - Method for point-to-area predictions for terrestrial services in the frequency range 30 MHz to 3 000 MHz
– Recommendation ITU-R P.452-15 – Prediction procedure for the evaluation of microwave interference between stations on the surface of the Earth at frequencies above about 0.7 GHz.
– Recommendation ITU-R P.525-2 – Calculation of free-space attenuation.

3 Technical characteristics

The technical characteristics of *System 3* and *System 5* in Table 1 of Recommendation ITU-R M.1463 are taken to represent solid-state ARNS and RLS systems with substantial future operational lifetime post-2018:

TABLE 1

Radar systems technical characteristics

Parameter	Units	ARNS	RLS
Transmitter			
RF Output Type	-	Solid State	Solid state
Peak Power into Antenna	dBm	76.5	73.9
3dB emission bandwidth	MHz	2.3	1.25
Unwanted emissions[15]	dB/dec	-40	-40
Receiver			
RF 3 dB Bandwidth	MHz	6.4	1.25
Noise Figure	dB	4.7	2.6
IF selectivity roll-off[16]	dB/dec	80	80
I/N criterion	dB	-6	-6
Antenna			
Pattern type		Phased array	Planar Array
Polarisation		Horizontal	Horizontal
Gain	dBi	38.9 Tx 38.2 Rx	38.5
Azimuth beamwidth	degrees	3.2	2.2
Nominal height	m (AGL)	15	15

NOTE: The antenna illumination pattern in the vertical plane is assumed to be consistent with a cosecant-squared envelope, as defined in Recommendation ITU-R M.1851 *Mathematical models for radiodetermination radar systems antenna patterns for use in interference analyses*.

[15] Consistent with the recommended design objective of Recommendation ITU-R SM.1541 - *Unwanted emissions in the out-of-band domain*.

[16] Consistent with suggested value in Recommendation ITU-R M.1461 - *Procedures for determining the potential for interference between radars operating in the radiodetermination service and other services*.

The following technical characteristics were adopted for IMT-Advanced systems:

TABLE 2

IMT-Advanced systems technical characteristics

Parameter	Units	Base station	User equipment
Antenna Type	-	65° sector	Compact omni
Antenna Gain	dBi	Rural: 18 Suburban: 16 Urban: 16	-3
Feeder Loss	dB	3	-
Antenna elevation	m (AGL)	Rural: 30 Suburban: 30 Urban: 25	1.5
Cell radius	km	Rural: 5 Suburban: 1 Urban: 0.5	-
Antenna down-tilt	degrees	Rural: 3 Suburban: 6 Urban: 10	-
Typical body loss	dB	-	4
User terminal density (in active mode)	Users/5MHz/km^2	-	Rural: 0.17 Suburban: 2.16 Urban: 3
Transmitter*			
Maximum Tx Power	dBm	NA	23
Dynamic Power Control	-		Yes
Max Tx e.i.r.p.	dBm		20
Channel bandwidth	MHz		10
Average activity factor	%		-
Average Tx e.i.r.p.	dBm		Rural: 2 Suburban: -9 Urban: -9
Noise figure	dB		9
Receiver*			
Ref sensitivity	dBm	-101.5	NA
Noise Figure	dB	5	
Blocking	dBm	-15	
Selectivity	dB@ΔMHz	[-58 dB @ 2.5 MHz offset]	

* Applicable to the case of 10 MHz IMT-Advanced channel.

The out-of-band (OOB) and spurious emission characteristics of IMT base-stations and UE are based on maximum mask specified in the 3GPP technical specification series 36 (TS 36). Commercial IMT products typically offer significantly better performance[17] than 3GPP requirements – noting that earliest practical date of launch of IMT services in this band is unlikely before end-2017. However, for the purposes of studies reported in this contribution, the following out-of-band (OOB) and spurious emission mask for IMT user equipment is assumed:

TABLE 3

IMT User equipment: OOB and spurious emission limits

Parameter	Units	Value	Notes
IMT User devices – for 10 MHz channel bandwidth (3GPP TS 36.101)			
OOB emissions	dBm/30 kHz dBm/MHz dBm/MHz dBm/MHz	-18 -10 -13 -25	0-1 MHz separation from channel edge 1-5 MHz 5-10 MHz 10-15 MHz
Spurious emissions	dBm/MHz	-30	in the range 1-12.75 GHz (except OOB emission region noted above)

NOTE: [In accordance with WP 5D advice[18] to the JTG 4-5-6-7: *Note: cannot be referred to like this in a DNR*] these unwanted emission limits are the upper limits defined in 3GPP specifications for laboratory testing while the user device is operating at maximum power (+23 dBm). When the in-band transmitting power of the device is reduced as a consequence of uplink power control function, the unwanted emission levels will also be reduced by an equivalent value (dB).

4 Analysis

As noted, these studies have focused on *non-co-channel* sharing, to support administrations reviewing the efficiency of current ARNS and RLS usage of the band 1 300-1 400 MHz in their own country. While the deployment of ARNS and RLS systems may be widespread in some countries, other countries have deployed few such systems (or none, in some cases) in this band – and, in that case, some administrations are exploring the possibility for better utilisation of the band 1 300-1 400 MHz (for example, by IMT-Advanced systems) to encourage further national economic growth and development.

In addition, as the band 1 427-1 525 MHz is already allocated on a primary basis to the mobile service in all Regions, and noting discussions within CEPT in regard to a possible IMT *downlink* arrangement for the band 1 452-1 492 MHz, it is proposed that the band 1 300-1 400 MHz (if identified for IMT) be assigned only for *uplink* usage (ie. UE emissions only are considered).

[17] Recent (2012) vendor contributions to CEPT have already indicated considerably better OOB and spurious emissions performance by UEs than is currently specified by 3GPP TS 36.101.

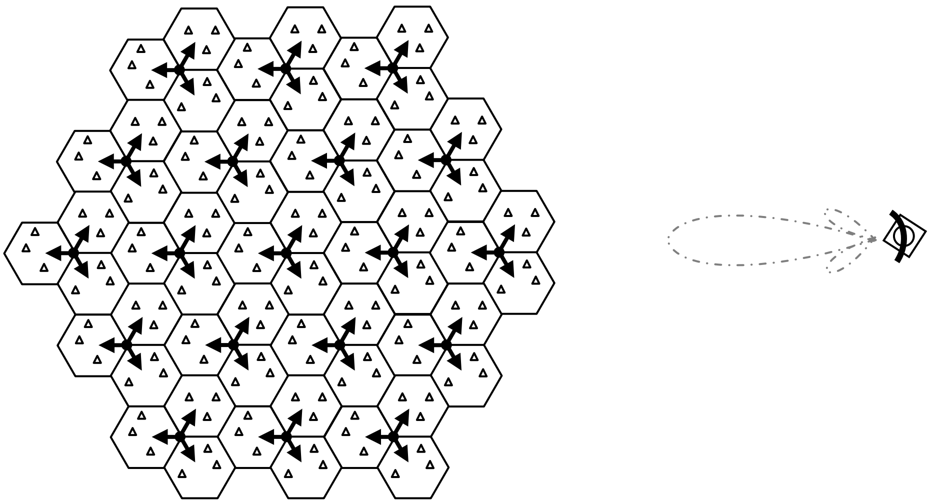
[18] Refer Note 17 in Section 2 of *Characteristics of terrestrial IMT-Advanced systems for frequency sharing/interference analyses*, 4-5-6-7/393 Annex 2, Annex 2, Appendix 1

4.1 Approach

To evaluate the implications of the uplink emissions of multiple UE, hosted by an IMT-Advanced network deployed in the vicinity of a radar site, a cluster of nineteen 3-sector cells is taken to represent the network[in accordance with agreement already established by a previous JTG 4-5-6-7 meeting]. Each sector is host to a number of active UE in accordance with its area, based on the applicable user-density and cell-radius for the relevant geographic environment (urban, suburban, or rural):

FIGURE 3

Network model for sharing analysis



The active UE are randomly located within each sector, reflecting the random mobility of users within the network coverage area. The emissions of active UE are variable subject to uplink power control, and the emissions from all UE incident on the radar antenna are aggregated to derive the effective interference level to the radar.

The nominal radar station is located at a fixed distance from the centre of the 19-cell cluster, and this distance is varied to determine the minimum separation required, for each frequency offset (guard-band) value, to ensure satisfactory I/N performance at the radar receiver. The radar antenna is oriented in azimuth directly toward the centre of the 19-cell cluster, and is *not* rotating, to reflect the worst-case interference scenario. Consideration of the impact of radar emissions on IMT base-station receivers is also included in this study.

No specific terrain topography was assumed. To reflect the low-elevation of IMT UE (1.5 metres AGL), and likelihood of surrounding pedestrians, vehicles, buildings and trees, clutter-loss appropriate to the particular geographic environment (urban, suburban, rural) was included.

4.2 Assumptions

As noted above, these studies assume that the band 1 300-1 400 MHz will *only* be used for IMT uplink – that is emissions from UE transmitters to base-station receivers. This assumption reflects a proposed frequency-division-duplex (FDD) arrangement, involving the band 1 427-1 518 MHz (or portion thereof) for purposes of IMT downlink emissions (that is, base station transmitters to UE receivers).

4.2.1 Radio wave propagation models

The conventional Hata/Cost231 propagation model is generally used to model IMT uplink paths between UE and the IMT base-station receiver, and to properly enable the power-control mechanism. However, in this study, and based on discussions [to date in preceding meetings of the JTG 4-5-6-7], two alternative propagation models are considered for modelling the interference paths between UEs and the radar receiver:

– **Recommendation ITU-R P.1546-5** (09/2013) - a point-to-area propagation model, [as recommended by WP 3K and WP 3M,] which provides an estimate of field strength including relevant adjustments for: operating frequency of 1 350 MHz; land path; field strength exceeded for 1% of time[19]; UE height above ground; radar height above ground; and smooth earth scenario. This model is used for evaluating the interference from low-elevation IMT UE transmitters into a radar receiver.

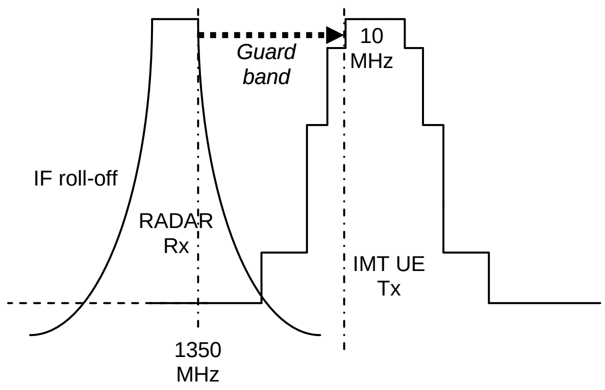
– **Recommendation ITU-R P.452-15** (09/2013) – for evaluating interference between stations on the surface of the earth at frequencies above about 0.1 GHz, which provides an estimate for the propagation loss not exceeded for time percentages over the range 0.001 ≤ p ≤ 50%. For distances less than about 5 km, propagation losses determined using Recommendation ITU-R P.452 approach free-space, and are considered unrealistic for the case of low-elevation IMT UE emissions especially in urban and suburban scenarios. However, this model is used for evaluating the interference from a radar transmitter into an IMT base-station receiver.

4.2.2 Guard-band

The guard-band is taken to be the frequency separation between the respective 3 dB-bandwidth boundaries of the radar and IMT carrier:

FIGURE 4

Illustration of assumed guard-band scenarios



[19] [Per advice of chairmen of WP 3K and WP 3M, noted in Document 4-5-6-7/393 Annex 2: ITU-R advised that '*for short distance scenarios, particularly with low antenna heights, the time variability of path loss is unlikely to be an important factor in interference estimation, so mean path loss values might also be used*'. Note cannot be referred to in such a manner in a DNR]

4.2.3 Localised clutter

For the case of interference by IMT UE into a radar receiver, Recommendation ITU-R P.1546 provides for an additional correction for clutter (*refer Annex 5 §10*). As a consequence of their low elevation above ground, UE are typically surrounded by clutter such as buildings, motor vehicles, pedestrians, and shrubs/tress when used outdoors in urban and suburban scenarios. In such scenarios, the clutter correction factor defined by Recommendation ITU-R P.1546 can vary over a wide range (3-25 dB or more) depending on the relative height and proximity of the clutter to the UE.

Since it is rare for UE in urban or suburban scenarios to be free of surrounding clutter, the clutter correction factor is included in field strength estimates derived using Recommendation ITU-R P.1546. Recommendation ITU-R P.1546 also provides a non-urban clutter correction factor applicable to low-elevation devices in rural areas.

4.2.4 Indoor versus outdoor UE

This study has assumed that all UE are located in outdoor locations.

Normal IMT network planning typically recognises that the UE ‘uplink’ signal budget effectively determines the nominal cell-radius – and a power-limited UE located indoors will suffer additional propagation loss due to building penetration attenuation. Consequently, if indoor operations are intended, normal IMT network planning procedures will include penetration losses when determining nominal cell-radius, to derive inter-site distance for base-station deployments.
This study assumes that the urban/suburban/rural cell-radii values recommended by ITU-R for use in sharing studies already account for indoor power-limited uplink emission constraints and building penetration loss.

4.2.5 IMT UE signal characteristics

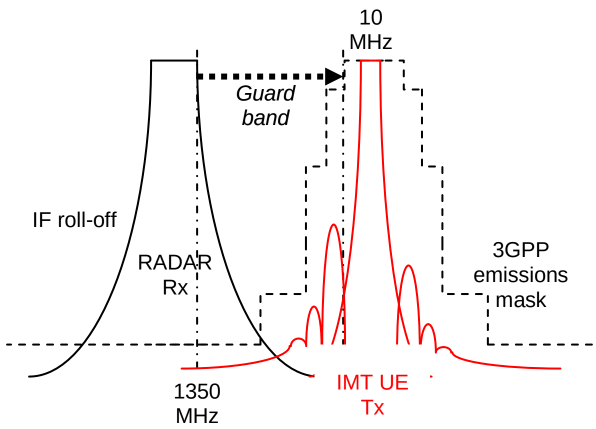
These studies have assumed that emissions of each UE occupy the full 10 MHz channel bandwidth – that is, each active UE is assigned all available channel resources (PRBs). This scenario is considered to be a worst-case model, because: although resource assignment is dependent on the particular scheduler algorithm implemented, such a large resource assignment to UEs is generally considered unlikely within a moderately-loaded IMT network.

Furthermore, in this study the UE emissions are always be located at band-edge, nearest to the radar channel. In a moderately-loaded network, UEs will typically be assigned some lesser portion of the available bandwidth, and the assigned resources may only sometimes be located at band-edge, and otherwise will be shifted spectrally further away from the radar.

Noting that 3GPP specifications of minimum OOB and spurious emissions performance also represent a *maximum* mask for UE emissions, the following figure illustrates how real interference situations will likely be considerably improved over the case modelled in these studies:

FIGURE 5

Example of real UE emissions



Therefore, the results presented in this study are considered to represent a ***worst-case*** scenario that overstates the likelihood of interference to radar receivers.

4.2.6 Radar interference threshold

The results of this study have been presented in graphical form to show a range of radar receiver I/N exceedance probability values, and the distribution of receiver I/N values versus associated exceedance probability. Two particular exceedance thresholds are observed:

– 0.1% I/N exceedance probability – since previous meetings have suggested this value as more appropriate (than 1%) for radiolocation systems in this band, and arising from a recent review by others of relevant ICAO flight safety and systems reliability recommendations[20].

– 0.01% I/N exceedance probability – to illustrate the rapid reduction of probability with only small change in I/N, and to provide an additional 10 dB ‘safety margin’ to the study results.

Noting contributions by others, these studies thus assume that a 0.1% I/N exceedance threshold represents the minimum level of protection for radar systems operating in this band.

[20] ICAO Document 9859 *Safety Management Manual* is the key reference for regional/national air traffic safety procedures – for example, the 4th part of Eurocontrol Safety Regulatory Requirement (ESARR4), and UKCAA Publication CAP760 which provides a useful matrix of risk classification/tolerability.

4.3 Results

To establish a baseline scenario for subsequent sensitivity analyses, the Monte Carlo simulation adopted the following initial values:

– Minimum separation between radar station and nearest IMT user device (UE) = 1 km

– Minimum guard-band between radar system (upper -3dB channel edge set at 1 350 MHz) and IMT user device emissions (lower -3dB emission mask edge, according to 3GPP) = 10 MHz

Analysis of the sensitivity of I/N exceedance probability to variations in these parameter values is also explored in subsequent stages of the studies.

4.3.1 IMT Interference to radar receivers

As noted, two representative radar systems taken from Table 1 of Recommendation ITU-R M.1463 are evaluated:

– ARNS systems - System 3 – solid state; widest receiver IF bandwidth (6.4 MHz)

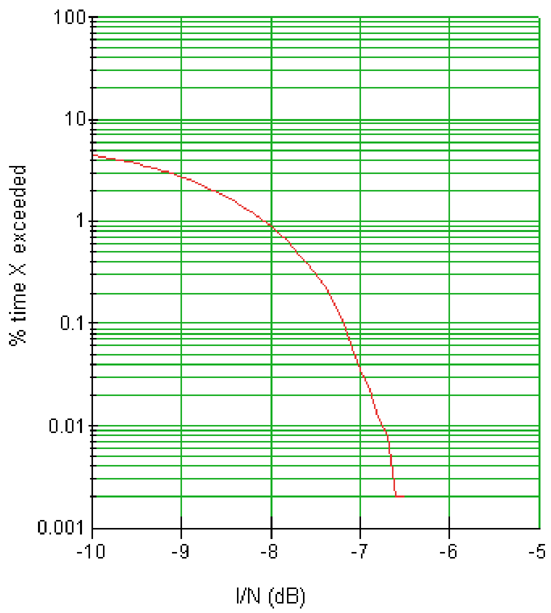
– RLS systems – System 5 – solid state; with lower Rx noise figure (2.6 dB)

4.3.1.1 Baseline I/N exceedance probability

The baseline results for each of the urban, suburban and rural geographic scenarios are shown in the following plots[21], and key values in Table 4 - see Appendix 1 for increased resolution plots of 0.1% and 0.01% threshold crossing values:

FIGURE 6

System 3 – urban environment – 1 km separation – 10 MHz guard-band



[21] Note that the Cumulative Distribution for each simulation case was derived via the aggregation of 50,000 randomised runs, to achieve the necessary resolution.

FIGURE 7

System 3 – suburban environment – 1 km separation – 10 MHz guard-band

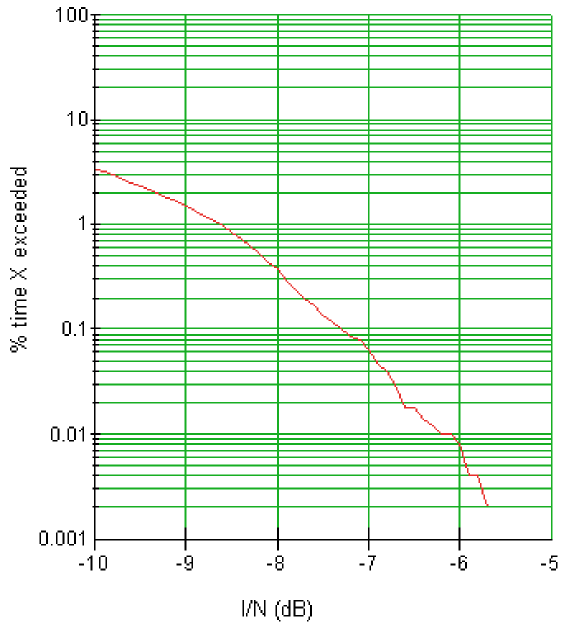
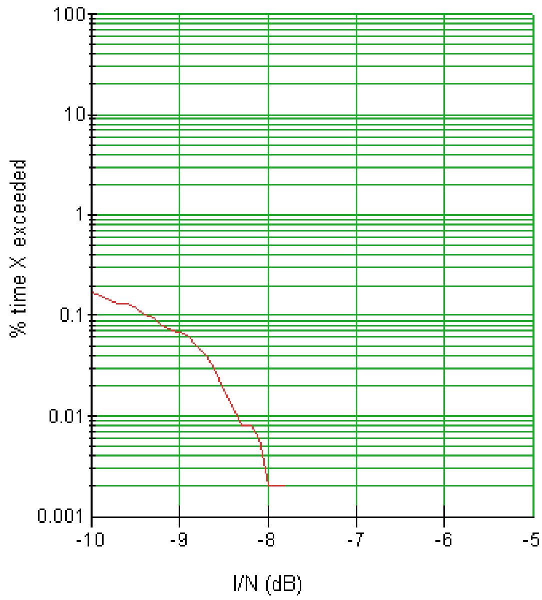


FIGURE 8

System 3 – rural environment – 1 km separation – 10 MHz guard-band



The equivalent baseline urban/suburban/rural Monte Carlo sharing study results for Radar System 5 are presented on the following page.

FIGURE 9

System 5 – urban environment – 1.2 km separation – 10 MHz guard-band

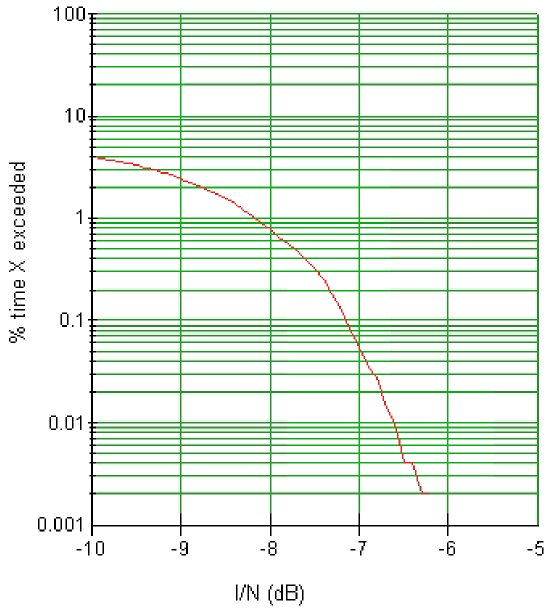


FIGURE 10

System 5 – suburban environment – 1.2 km separation – 10 MHz guard-band

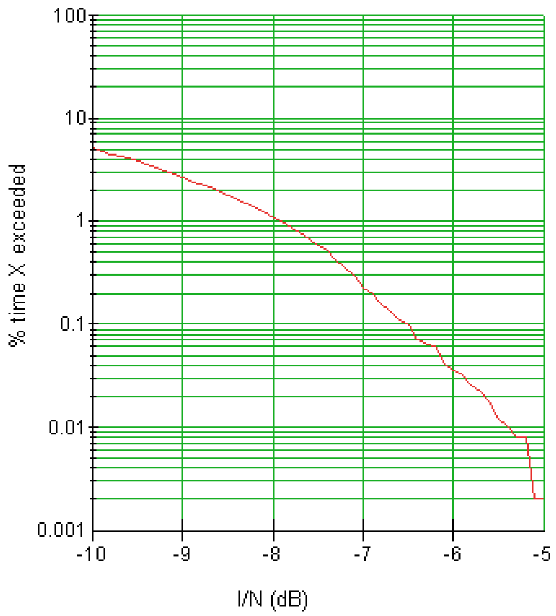
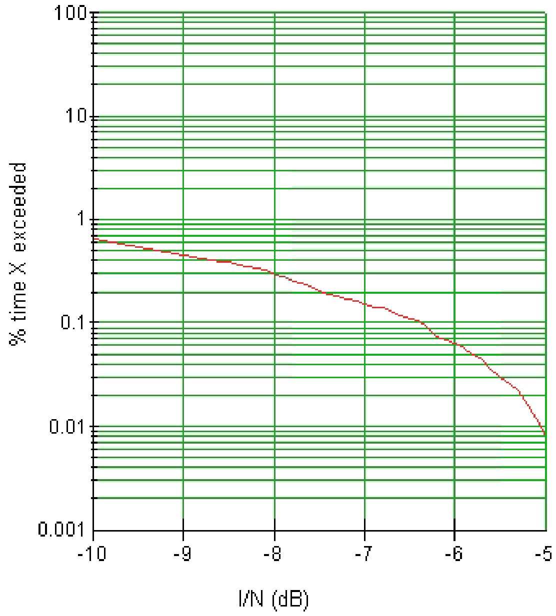


FIGURE 11

System 5 – rural environment – 1 km separation – 10 MHz guard-band



The urban and suburban scenarios clearly present higher interference impact on radar receivers than is the case for a rural environment – due to the higher-density of UEs, collectively located closer to the radar station. The summary of the baseline results for radar I/N is:

TABLE 4

Summary of baseline I/N results – 1 km separation – 10 MHz guard-band

$Pr_{exceedence}$	**Radar System 3**			**Radar System 5**		
	Urban	**Suburban**	**Rural**	**Urban**	**Suburban**	**Rural**
0.1%	**-7.2**	**-7.2**	**-9.4**	**-3.8**	**-4.4**	**-6.4**
0.01%	**-6.7**	**-6.1**	**-8.3**	**-3.4**	**-3.3**	**-5.1**

While Radar System 3 appears sufficiently protected by a one kilometre separation to the nearest IMT user-device with a 10 MHz guard-band, additional geographic/spectral separation is clearly required to protect Radar System 5. Separation values of 1.2 kilometres and 1.5 kilometres were therefore also explored – as well the trade-off between separation distance and guard-band, as shown in the following sensitivity analysis.

4.3.1.2 Sensitivity Analysis

To evaluate the sensitivity of the radar I/N to variations in geographic separation and size of the guard-band, additional analysis was undertaken of the urban case for the wider-bandwidth Radar System 3:

TABLE 5.1

Sensitivity Analysis – Urban scenario – Radar System 3

I/N (dB) for 0.1% time exceedance		Urban – geographic separation (km)		
		1.0	1.2	1.5
Frequency separation (MHz)	8	-2.5	-4.6	-7.4
	10	-7.2	-10.1	-12.9

TABLE 5.2

Sensitivity Analysis – Urban scenario – Radar System 3

I/N (dB) for 0.01% time exceedence		Urban – geographic separation (km)		
		1.0	1.2	1.5
Frequency separation (MHz)	8	-2.0	-4.7	-7.3
	10	-6.7	-9.6	-12.4

These results indicate that (for the wider bandwidth Radar System 3) a smaller guard-band could potentially be offset by a larger separation distance to the radar receiver. For example, an 8 MHz guard-band appears to require a separation distance of about 1.4 kilometres or more. However, larger separation distances may be difficult to enforce for aerodromes (Radars) located on the fringe of major urban centres. A separation distance of one kilometre (with 10 MHz guard-band) may be more readily implemented by virtue of the aerodrome perimeter fence, for example.

For the case of Radar System 5, similar sensitivity analysis reveals:

TABLE 5.3

Sensitivity analysis – Urban scenario – Radar System 5

I/N (dB) for 0.1% time exceedance		Urban – geographic separation (km)		
		1.0	1.2	1.5
Frequency separation (MHz)	8	+4.0	+1.5	-1.4
	10	-3.8	-7.2	-9.8

TABLE 5.4

Sensitivity analysis – Urban scenario – Radar System 5

I/N (dB) for 0.01% time exceedance		Urban – geographic separation (km)		
		1.0	1.2	1.5
Frequency separation (MHz)	8	+4.5	+2.2	-0.8
	10	-3.4	-6.6	-9.2

These results suggest that Radar System 5 (and other narrow-band radars, with low noise performance) will likely require a minimum guard-band of 10 MHz and a minimum geographic separation of 1.2 km. Therefore, the suggested minimum values to avoid interference by IMT UE into solid-state radar receivers in the 1 300-1 400 MHz band, are:

– Minimum guard-band = 10 MHz

– Minimum geographic separation[22] = 1.2 km

4.3.2 Radar interference to IMT base station receivers

To properly accommodate IMT ‘uplink’ systems within the band 1 300-1 400 MHz via segmentation, it is also appropriate to consider the impact of radar emissions on IMT base station receivers.

4.3.2.1 IMT base station blocking

The physical space available at an IMT base station site generally easily accommodates additional filtering (to address issues such as inter-modulation with other co-sited systems, blocking by non-co-channel systems, and other matters). Therefore, combating out-of-band interference into IMT base station receivers is typically resolved by filtering, to improve receiver selectivity:

TABLE 6

Radar blocking of IMT base station receiver

Parameter	***Values***			***Units***
	Urban	*Suburban*	*Rural*	
Radar R Tx power	+76.5			dBm
Radar antenna gain	+38.9			dBi
Radar signal e.i.r.p.	+115.4			dBm
IMT base-station antenna gain	16	16	18	dBi
IMT Rx blocking limit[23]	-15			dBm
Worst-case IMT Rx protection requirement	146.4	146.4	148.4	dB
Path loss (1 km free-space)	95			dB
Minimum additional filter OOB rejection	51.4	51.4	53.4	dB

According to 3GPP[24], minimum IMT base station receiver selectivity performance offers at least 57.9 dB of protection (for ≤ 1dB receiver degradation) from a non-co-channel wide-band (5 MHz) carrier (2.5075 MHz offset). To achieve an additional 51-55 dB of protection at 10 MHz offset using external filtering equipment is not a challenging out-of-band filtering objective.

[22] Minimum geographic separation is defined as the distance between the radar site and the nearest IMT cell edge (or nearest possible location of an active IMT user device).

[23] See 3GPP TS 36.104 V10, Table 7.6.2.1-1 for Bands 11 and 21. [Note: Is that the right table? Would it be 7.6.1.1-1?].

[24] See 3GPP TS 36.104 V10, Table 7.5.1-3.

4.3.2.2 IMT base station in-band interference

In-band interference to IMT receivers due to excessive levels of unwanted out-of-band emissions from an non-co-channel transmitter are often more challenging, and may therefore determine the potential for co-existence in this band.

Radar systems operating in the 1 300-1 525 MHz frequency band are generally expected to achieve Category A limits for out-of-band emissions[25] of at least –60 dBc. Solid-state radars can achieve this limit within 12 MHz of the main carrier[26]. Assuming that the radar antenna is directed at the victim IMT base station site (for each rotation, at least), analysis of the in-band noise degradation of IMT base station receivers can be estimated via a simple minimum coupling loss analysis:

TABLE 7

IMT base-station in-band interference from radar

Parameter	*Values*			*Units*
	Urban	*Suburban*	*Rural*	
Radar Tx power	+76.5			dBm
Radar antenna gain	+38.9			dBi
Radar emission bandwidth	2.3			MHz
Category A OOB emissions	-60.0			dBc
Radar OOB emissions	+51.8			dBm/MHz
IMT base-station antenna gain	16	16	18	dBi
IMT base-station Rx noise figure	5			dB
IMT Rx Interference threshold (*≤1dB Rx sensitivity degradation*)	-104.9			dBm
Worst-case IMT Rx protection requirement	182.7	182.7	184.7	dB

While the required protection may initially seem a somewhat challenging objective, there are several mitigation measures that may be readily implemented to resolve the unwanted radar emissions:

i) Co-ordinated placement of the IMT base-station, to take advantage of natural or man-made obstructions – potentially offering at least 20 dB of isolation;

ii) Orienting the IMT base-station antenna to face directly away from the radar site – and use of a solid reflector to shield the IMT antenna – providing at least 20-40 dB of additional isolation; and

iii) Further filtering of the radar OOB emissions – noting that filter attenuations of 40-50 dB are noted in Recommendation ITU-R F.1097-1 as a possible mitigation option (refer section 2.1 RF filters).

[25] Reference source: ECC Report 174 – Category A out-of-band emissions limit for radar types 1-4 = -60 dBc, and for *modern* type 4 the limit is -75 to -90 dBc.

[26] Legacy vacuum-tube radars may not meet the Category A emissions limit – so future IMT co-existence in the band 1 300-1 400 MHz may be subject to retirement of spectrally less-efficient klystron/magnetron systems, and systematic replacement by sold-state systems.

Including free-space path-loss for a separation of one kilometre, the following interference mitigation budget is therefore highlighted:

TABLE 8

IMT base-station in-band interference mitigation

Parameter	*Values*			*Units*
	Urban	*Suburban*	*Rural*	
Path loss – free space – 1 km	95			dB
Use of obstructions	15-20			dB
Antenna orientation	20-40			dB
RADAR OOB filtering[27]	45			dB
Nett additional protection requirement	**-17.3** ~ **7.7**	**-17.3** ~ **7.7**	**-15.3** ~ **9.7**	dB

Therefore, identification of appropriate and practical mitigation measures turns out to be not quite so challenging – although this aspect may be location-specific, and therefore subject to site-by-site co-ordination with nearby radar stations.

5 Conclusions

Results of Monte Carlo studies of the co-existence of IMT UE with solid-state radar systems in the band 1 300-1 400 MHz suggest that sharing is possible with at least a 1.2 kilometres geographic separation and 10 MHz guard-band. Furthermore, while the peak power of radar signals may appear to be a risk to IMT base-station receivers, minimum coupling loss analysis illustrates that mitigation is feasible if IMT antennas are pointed away from the radar, along with appropriate filtering and judicious co-ordination/location of IMT base-stations. There may also be a need for verification/remediation of radar out-of-band emissions performance.

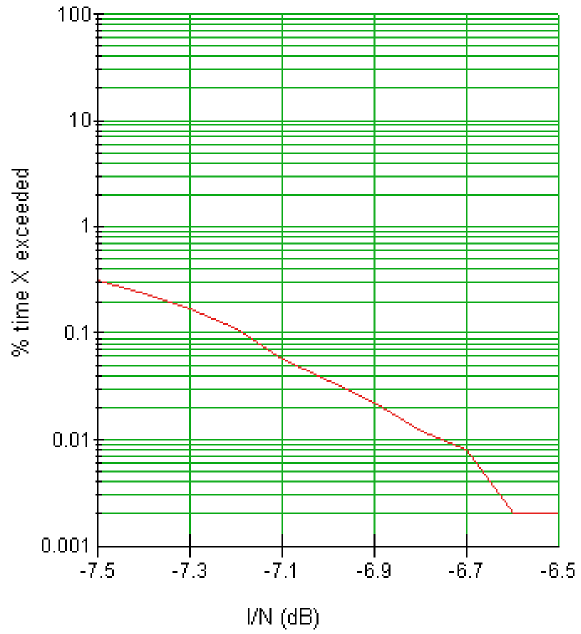
The working document on sharing/compatibility studies of IMT systems and radiolocation systems in the frequency band 1 300-1 400 MHz [(Annex 2 to Annex 6 of Document 4-5-6-7/393) *Note cannot be referred to like this in a DNR*] contains relevant studies contributed [to JTG 4-5-6-7]. Telstra proposes that the above updated study report and conclusions replace the preliminary text [(drawn from Document 4-5-6-7/278) currently included in Annex 2 of Annex 2 of the working document in Annex 6 of Document 4-5-6-7/393 *Note cannot be referred to like this in a DNR*].

[27] There have been some observations at prior ITU-R meetings that contemporary radar systems exhibit considerably lower out-of-band emissions that reported in ITU-R Recommendations. Thus, the need for additional filtering may be subject to verification of actual radar performance.

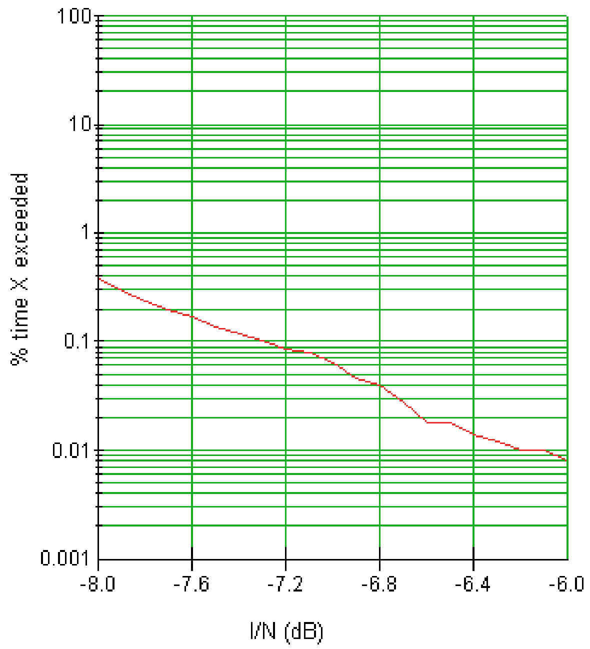
APPENDIX 1

Radar I/N exceedance thresholds – higher resolution plots

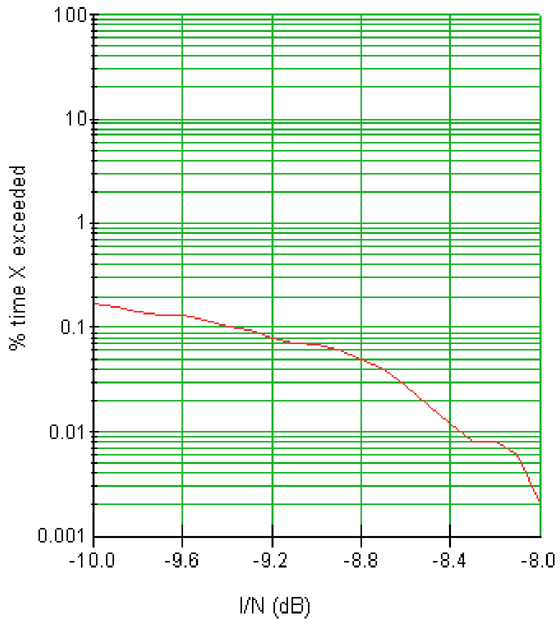
Case 1.1 – Urban scenario – 1 km separation – 10 MHz guard-band – System 3



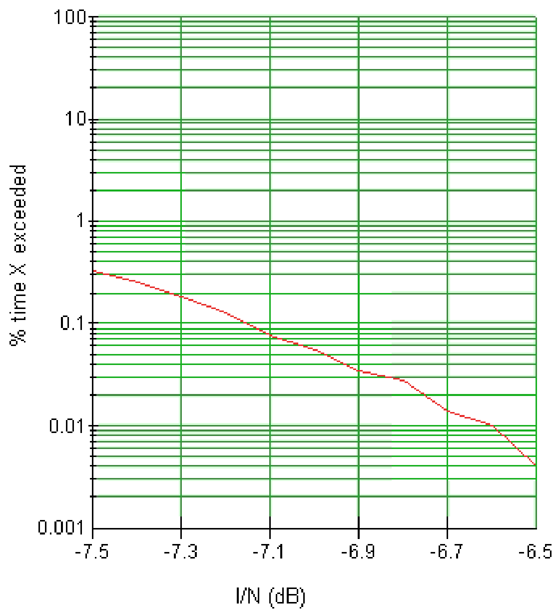
Case 1.2 - Suburban scenario – 1 km separation – 10 MHz guard-band – System 3



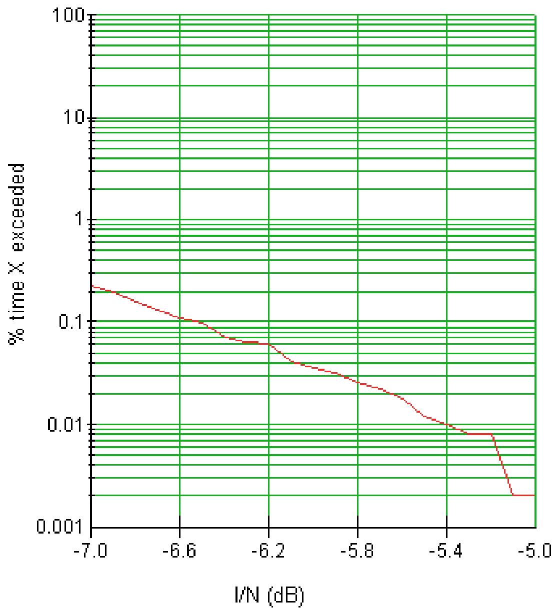
Case 1.3 - Rural scenario – 1 km separation – 10 MHz guard-band – System 3



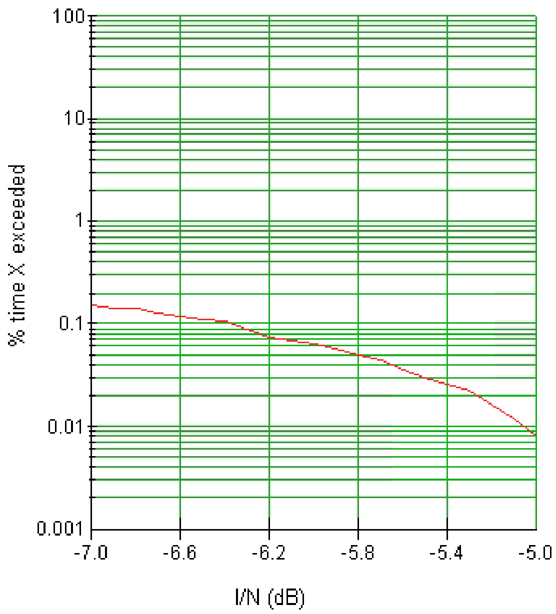
Case 2.1 – Urban scenario – 1.2 km separation – 10 MHz guard-band – System 5



Case 2.2 - Suburban scenario – 1.2 km separation – 10 MHz guard-band – System 5



Case 2.3 – Rural scenario – 1 km separation – 10 MHz guard-band – System 5



ANNEX 10

Sharing between IMT systems and radars in the 1 300-1 400 MHz band

1 Introduction

In this contribution, a deterministic study is presented building on the inputs [to the 4th JTG 4-5-6-7 meeting]. The study includes a baseline set of calculations[using the parameters from Working Parties 5B and 5D].

A number of mitigation techniques are discussed, and incorporated into the sensitivity analysis, with the aim of showing how interference to radar receivers may be reduced to acceptable levels.

Interference from radars to IMT systems is not addressed in this contribution.

2 Background

The 1 300-1 400 MHz band has been proposed as a candidate band for WRC-15 agenda item 1.1. Several of the studies received [at the 4th JTG 4-5-6-7 meeting] suggest that non-co-channel coexistence may be possible. This document contains a deterministic non-co-channel coexistence analysis, discusses some possible mitigation techniques and provides an analysis based on the mitigated performances.

3 Technical characteristics

The technical characteristics of the IMT and radar systems are described in this section. Firstly in Section 3.1 the ‘baseline’ characteristics are described. Secondly in Section 3.2, various potential mitigation techniques are described, and revised technical characteristics of the IMT and radar systems presented that include the sensitivity to these techniques.

3.1 Baseline

The baseline technical characteristics of radar and IMT systems are described in this section, without any mitigation assumed. Also characteristics are described that are based on the combined assumptions of both radar and IMT systems.

3.1.1 Radar system

The following radar system characteristics in Table 1 are those provided by ITU-R.

TABLE 1

Radar characteristics

Transmitter		**Units**	**ATC**		**Defence**				
			Radar 1	**Radar 2**	**Radar 3**	**Radar 4**	**Radar 5**	**Radar 6**	**Radar 7**
Power to the Antenna		dBW	67	50	46.5	43.9	66	63	48.8
		dBm/MHz	100	79.7	72.9	72.9	95.2	91.9	78
3 dB Emission Bandwidth			0.5	1.09	2.3	1.25	1.2	1.3	1.2
Rec. ITU-R SM.329/1541 Spurious emission limits	Roll off	dB/decade	30	30	30	30	30	30	30
	Limit	dBc	60	60	60	60	60	60	60
		dBm	37	20	16.5	13.9	36	33	18.8
		dBm/MHz	40	19.7	12.9	12.9	35.2	31.9	18
Receiver									
Noise Figure		dB	2	2	4.7	2.6	4.25	9	3.2
3 dB Bandwidth		MHz	0.78	0.69	4.4	1.25	1.32	0.88	1.2
Receiver thermal noise figure		dBm	-113.1	–113.6	–102.9	–110.4	–108.5	–105.6	-110.0
		dBm/MHz	–112	–112	–109.3	–111.4	–109.8	–105	-110.8
Required I/N		dB	–6	–6	–6	–6	–6	–6	–6
Antenna									
Gain		dBi	34.5	34.2	38.2	38.5	34	35	34.5
Feeder loss		dB	2	2	2	2	2	2	2
Azimuthal Beamwidth		degrees	1.2	1.4	3.2	2.2	1.2	1.3	1.2
Elevation Beamwidth		degrees	3.6	3.6	1.3	2	3.75	3.75	3.7
Rotation		rpm	5	5	6	5	6	5	5
Location			Fixed	Fixed	Transport	Fixed	Fixed	Fixed	Fixed
Nominal Height			15	15	10	15	15	15	15
Aeronautical Safety Factor[28]		dB	6	6	0	0	0	0	0

The radar IF selectivity parameters have been added to the above table. A selectivity roll-off of 80 dB per decade from the radar 3 dB bandwidth has been assumed as suggested by Recommendation ITU-R M.1461-1 (end of Section 3.2). Also a frequency offset of 10 MHz has been assumed between the radar and IMT system channel edges, and an IMT system bandwidth of 10 MHz.

Representative air traffic control antenna polar diagram

[28] The addition of a minimum 6 dB safety factor in theoretical studies is recommended by ICAO Doc. 9718.

FIGURE 1

Vertical pattern

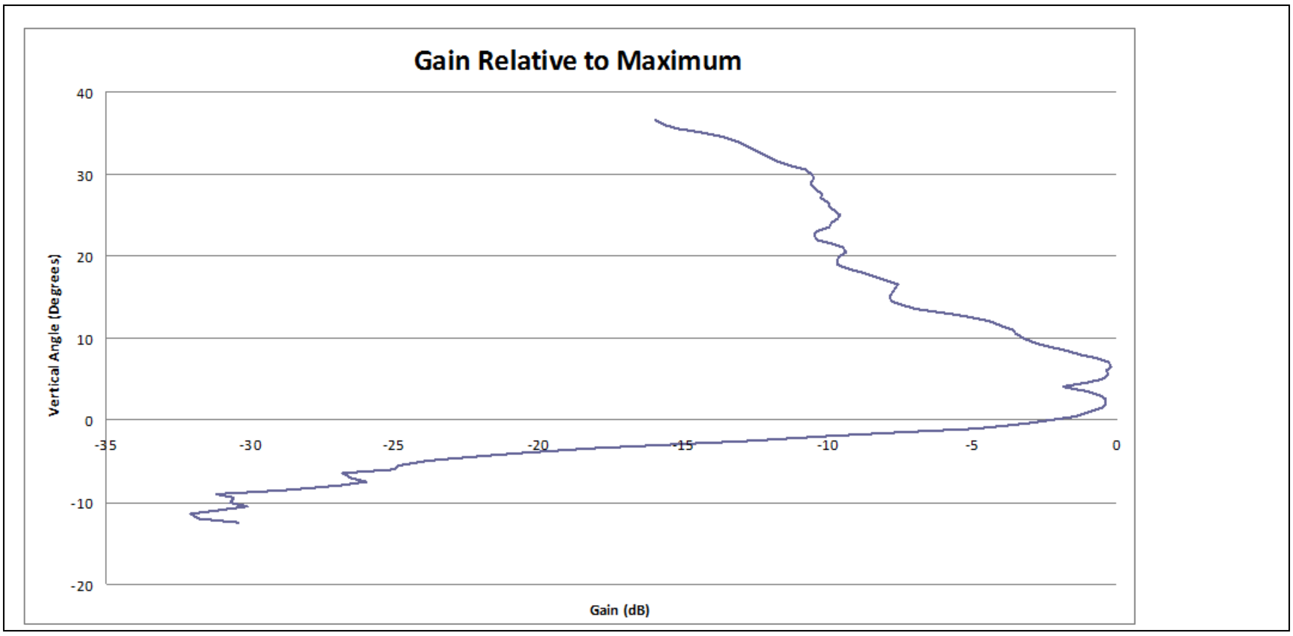


FIGURE 2

Horizontal Pattern

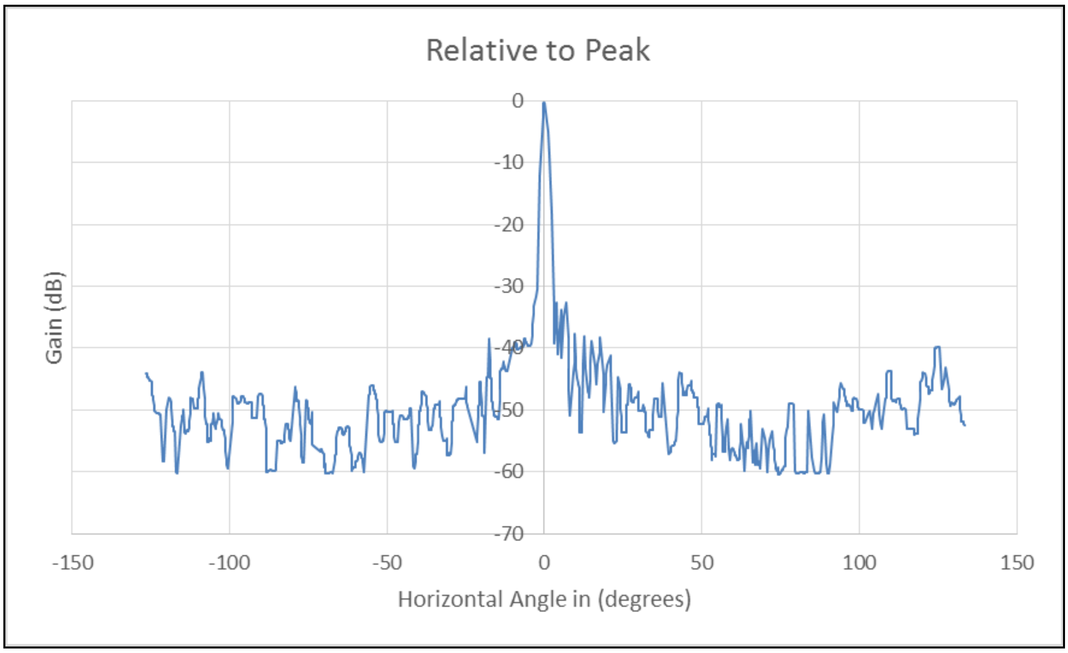


TABLE 2

Percentage of radar antenna relative gains falling within the following limits (dB below the peak of beam)

0 to –30 dB	1.42%
–30 to –50dB	45.8%
Greater than –50 dB	52.8%

3.1.2 IMT system

The baseline technical characteristics of the IMT system are described in this section beginning with the base station characteristics, and finishing with the UE characteristics.

3.1.2.1 Base station

The base station characteristics shown in Table 3 are based on the suburban macrocell characteristics[for JTG 4-5-6-7 sharing studies contained in the Chairman's Report, Document 4-5-6-7/242 Annex 2 *Note cannot be referred to like this in a DNR*]. A bandwidth of 10 MHz has been used.

TABLE 3

Base station characteristics

Base Station		**Units**	**IMT**
Downlink frequency FDD		MHz	1350[29]
Bandwidth		MHz	10
Maximum transmitter power		dBm	
	BW = 10 MHz		46
	PeakPower density	dBm/MHz	36
Spurious emission limits	Limit	dBm/MHz	–30
Max Antenna gain		dBi	18
Feeder loss		dB	3
Typical antenna height		m	30
Antenna down tilt		degrees	3 to 10
Antenna type			Sectoral (3 sectors)
Antenna Pattern			Rec. ITU-R F.1336
Polarization			± 45° cross-polarized
Typical feeder loss		dB	3
3 dB antenna aperture in elevation		degrees	1.57
3 dB antenna aperture in azimuth		degrees	65
Receiver Noise Figure (worst case)		dB	5
Receiver thermal noise level		dBm	
	BW = 10 MHz		–99
	Power density	dBm/MHz	–109
Required I/N		dB	–6
Relative adjacent channel selectivity[30]		dB	
	10 MHz		79.7

[29] Assumed as the centre frequency for this study.
[30] Based on a blocking level of –15 dBm.

3.1.2.2 User equipment (UE)

The UE characteristics shown in Table 4 are based on the characteristics agreed for [JTG 4-5-6-7] sharing studies[contained in the Chairman's Report, Document 4-5-6-7/242, Annex 2 *Note cannot be referred to like this in a DNR*]. A bandwidth of 10 MHz has been used for the IMT system.

TABLE 4

User equipment characteristics

User Equipment (UE)	Units	IMT
Downlink frequency FDD	MHz	1350
Bandwidth	MHz	10
Access technique		SC-FDMA
Modulation type		QPSK/16-QAM/64-QAM
Maximum transmitter power	dBm	23
Antenna gain	dBi	-3
Antenna height	m	1.5
Antenna type		Omnidirectional
Polarization		Linear
Body loss	dB	4
Spurious emission limits	dBm/MHz	–30
Receiver Noise Figure (worst case)	dB	9
Receiver thermal noise level	dBm	–95
Required I/N	dB	–6

3.2 Mitigation of non-co-channel band interference

Coexistence between radar systems in the 2 700-2 900 MHz band with IMT in the 2 500-2 690 MHz band has been extensively studied, and indeed in the United Kingdom, coexistence is being ensured through a remediation program to improve radar receiver selectivity. Similar techniques may be used, if required, to enable coexistence between IMT and radars in the 1 300-1 400 MHz band.

In order to be able to utilize the band for IMT systems improvements will be necessary at some of the radar receivers and to the IMT system emissions to ensure coexistence. A number of candidate improvements are described in this section.

3.2.1 Improving radar selectivity

The radar selectivity can be improved by adding RF filtering before the low noise amplifier (LNA) or by improving the IF filtering.

3.2.1.1 Adding RF filtering before the LNA

The main problems relate to gain compression or intermodulation product generation in the LNA, and downstream components. For fixed frequency allocations, the most effective means of suppressing such problems is RF filtering prior to the LNA. The disadvantage is the insertion loss of the filter, which adds to the noise figure of the LNA, reducing detection range. In many cases, replacing the LNA of the radars, with a LNA with a lower noise figure that offsets the insertion loss of the filter, leaving the performance unchanged may be possible. For the mitigation and where required a RF filter providing 28.5 dB at separations $\geq$ 5 MHz has been used.

3.2.1.2 Improving IF filtering

The receiver IF-roll off, of 80 dB/decade from the 3 dB bandwidth of the IF filters, should be sufficient to provide adequate protection for the narrower bandwidth filters; however, with small frequency offset s and wide IF bandwidths (particularly for Radar 3), the IF selectivity is likely to be insufficient. Replacement of the IF filter will not have as significant effect on receiver sensitivity as the insertion of an RF filter prior to the LNA; however it cannot protect the LNA from compression, although it can protect the IF amplifiers.

For the mitigation sensitivity analysis presented later where improved IF filtering is assumed, a receiver IF-roll off of 100 dB/decade is assumed yielding the rejection values shown in Table 5. This rejection is additional to the rejection offered by RF filtering summarized at the end of section 3.2.1.1.

TABLE 5

Radar IF selectivity assuming an IF-roll off of 100 dB/decade

Parameter			**Radar 1**	**Radar 2**	**Radar 3**	**Radar 4**	**Radar 5**	**Radar 6**	**Radar 7**
Attenuation of interfering signal by radar IF selectivity assuming frequency offset of	10 MHz	dB	141.9	147.1	73.1	122.3	120.1	136.9	124.0
	20 MHz	dB	168.4	173.6	96.6	148.4	146.1	163.3	150.1
	30 MHz	dB	184.2	189.5	111.4	164.1	161.7	179.1	165.8

3.2.2 Improvements to IMT base station emissions

Possible options for improving emissions from IMT base stations are to apply antenna downtilt, assume more typical spurious emissions levels and include an RF filter in the transmit chain.

3.2.2.1 Base station downtilt

Typical base station installations use downtilt to reduce inter-cell interference. The same technique can be used to afford some protection to the radar receiver, especially if its location and height is known. Although nulls exist in the vertical polar diagram, the full depth may not be achieved, due to pointing inaccuracy; however, antennas may be designed to suppress the upper sidelobe, and such antennas can achieve relative gains of -25 dB over 8 degrees above the main beam, as can be seen in Report ITU-R F.1336[31].

Base station downtilt reduces the power of both the wanted and the unwanted emissions of the base station in the direction of the radar.

For the mitigation sensitivity analysis presented later, a relative antenna gain of −25 dB is assumed due to base station downtilt with upper sidelobe suppression.

[31] Recommendation ITU-R F.1336-3, “Reference radiation patterns of omnidirectional, sectoral and other antennas in point-to-multipoint systems for use in sharing studies in the frequency range from 1 GHz to about 70 GHz”, March 2012.

3.2.2.2 Base station out-of-band and spurious emissions

Base station unwanted emissions are given in 3GPP 36.104 for IMT-Advanced[32]. At 10 MHz outside the downlink transmit band, the spurious emissions levels apply. For Category B, wide area base stations these are −30 dBm/MHz. However, typical performances can be significantly better, e.g. −55 dBm/MHz at 10 MHz offset falling to around −65 dBm/MHz by 20 MHz offset.

For the mitigation sensitivity analysis presented later, the base station unwanted emissions are assumed to be −55 dBm/MHz for a frequency offset of 10 MHz.

3.2.2.3 Additional RF filtering

Base station unwanted emissions can be improved further by the addition of an RF filter to the transmit chain. Such an approach can yield up to 60 dB reduction in emissions with guard bands of 10 MHz and above, with standard filter design techniques, as described in Appendix 2 to Annex 2 of Report ITU-R M.2112, the appendix being entitled, “IMT base station front-end filters”.

For the mitigation sensitivity analysis presented later, the inclusion of an RF filter in the transmit chain is considered, yielding 60 dB reduction in unwanted emissions for a guard band of 10 MHz or more.

3.2.3 IMT UE unwanted emissions

There is considerably less flexibility in improving UE unwanted emissions. It should be noted that in general IMT macrocell networks are designed to serve UE located in buildings, and therefore maximum power UE transmissions outside are fairly unlikely due to the planning margins employed.

Unwanted emissions of IMT UEs are generally considerably better than the specification. In our mitigated analysis, the unwanted emissions in the radar receive band is assumed to be −50 dBm/MHz well aware that this may be challenging commercially.

Collocation of the base station with the radar may also be a possibility, in order that the UE will be power controlled to deliver a low power level to the base station, and therefore also to the radar.

4 Analysis

In this section the assumptions, methodology, calculations and results are described for the deterministic analysis of non-co-channel compatibility of IMT base stations and UE with radar systems both for the ‘baseline’ case based on the technical characteristic outlined in Section 3.1 and for the case where the improvements in section 3.2 are assumed.

4.1 Assumptions

In addition to the assumptions described in Section 3, the following assumptions apply.

– The studies are based on the impact of single IMT transmitter on a single radar receiver.

– The following minimum separation distances to radar are assumed.

  – Base station = 1 km

  – UE = 500 m

– Maximum transmission power is assumed.

[32] 3GPP, TS 36.104 v11.5.0 (2013-07): 3rd Generation Partnership Project; “LTE; Evolved Universal Terrestrial Radio Access (E-UTRA)”, (Release 11), July 2013.

– Rural environment.

– The assumption of a 1 dB compression point of –10 dBm for the radars has been made in the absence of parameters from ITU-R or ITU recommendations.

– It is recognised that the radar antenna gain used in error is the transmitter gain.

4.2 Methodology

The following analysis is based on determining the additional attenuation required for a reference minimum separation distance using free space path loss to ensure compatibility between IMT systems and radar in the frequency band 1 300-1 400 MHz. The studies address IMT systems in the non-co-channel to radar systems, and consider compatibility with and without the application of various mitigation techniques. The methodology is the same regardless of whether mitigation is considered or not; instead some of the parameter values differ as described in Section 3.

The non-co-channel analysis considers the impact of both the unwanted emissions from the IMT system and the radar receiver adjacent channel/band rejection of the wanted signal of the IMT system.

4.2.1 IMT spurious emissions in radar receiver passband

This analysis calculates the power spectral density (PSD) at the radar receiver from the unwanted emissions of the IMT system for a given separation distance (1 km for a base station and 500 metres for a UE) assuming free space path loss and compares it against the acceptable receiver interference PSD level. The difference between the PSD of the IMT system at the radar receiver and the acceptable receiver interference PSD level represents the additional attenuation required. A positive number represents the additional suppression required to achieve compatibility whilst a negative number represents the degree of compatibility.

Spurious PSD of the IMT transmitter at the radar receiver:

$$SPSD_{RX} = SPSD_{TX} - FL_{TX} + G_{TX} + G_{TX,REL} - PL + G_{RX} + G_{RX,REL} - FL_{RX} - POL_{RX}$$

where:

$SPSD_{RX}$ = spurious PSD of the IMT system at the radar receiver

$SPSD_{TX}$ = spurious PSD of the IMT transmitter

FL_{TX} = transmit feeder loss for base stations or body loss for UE

G_{TX} = transmit maximum antenna gain

$G_{TX,REL}$ = transmit antenna gain relative to maximum in direction of radar

PL = free space path loss

G_{RX} = receive antenna gain

$G_{RX,REL}$ = receive antenna gain relative to maximum in direction of IMT system

FL_{RX} = receive feeder loss

POL_{RX} = polarization loss

Acceptable receiver interference PSD level:

$$ILPSD = TNPSD + I/N - SM$$

where:

$ILPSD$ = acceptable receiver interference PSD level

TN = receiver thermal noise PSD level

I/N = required interference to noise protection level

SM = safety margin (only applicable ATC radars)

Required additional attenuation:

$$ATT = SPSD_{RX} - ILPSD$$

where:

ATT = required additional attenuation

$SPSD_{RX}$ = spurious PSD of the potential interferer at the victim receiver

$ILPSD$ = acceptable receiver interference PSD level

In this analysis, the guard band between the radar and IMT systems is assumed to be sufficient to ensure that the interference at the radar receiver is dominated by spurious emissions rather than out of band emissions (OOBEs).

4.2.2 Radar receiver rejection of the IMT wanted signal

This analysis calculates:

the PSD at the radar receiver from the wanted signal PSD of the IMT system as attenuated by the adjacent channel rejection of the radar receiver for a given separation distance (one kilometre for a base station and 500 metres for a UE) assuming free space path loss and compares it against the acceptable receiver interference PSD level;

and

the power at the radar receiver from the wanted signal of the IMT system for a given separation distance (one kilometre for a base station and 500 metres for a UE) assuming free space path loss and compares it with the 1 dB compression point (radar).

The difference between the PSD/power of the IMT system at the radar receiver and the acceptable receiver interference PSD/power level represents the additional attenuation required. A positive number represents the additional suppression required to achieve compatibility whilst a negative number represents the degree of compatibility.

4.2.2.1 Adjacent channel rejection

PSD of the IMT transmitter at the radar receiver:

$$PSD_{RX} = PSD_{TX} - FL_{TX} + G_{TX} + G_{TX,REL} - PL + G_{RX} + G_{RX,REL} - FL_{RX} - POL_{RX}$$

where:

PSD_{RX} = PSD of the IMT transmitter at the radar receiver front end;

PSD_{TX} = PSD of the IMT transmitter;

FL_{TX} = transmit feeder loss for base stations or body loss for a UE;

G_{TX} = transmit maximum antenna gain;

$G_{TX,REL}$ = transmit antenna gain relative to maximum in direction of radar;

PL = free space path loss ;

G_{RX} = receive antenna gain;

$G_{RX,REL}$ = receive antenna gain relative to maximum in direction of IMT system;

FL_{RX} = receive feeder loss;

POL_{RX} = polarization loss.

Acceptable receiver interference PSD level:

$$ILPSD = TNPSD + I/N - SM + ACR_{RX}$$

where:

$ILPSD$ = acceptable receiver interference PSD level;

$TNPSD$ = receiver thermal noise PSD level;

I/N = required interference to noise protection level;

SM = safety margin (only applicable for aeronautical services);

ACR_{RX} = maximum adjacent channel rejection of the receiver.

Required additional attenuation:

$$ATT = PSD_{RX} - ILPSD$$

where:

ATT = required additional attenuation;

PSD_{RX} = PSD of the potential interferer at the victim receiver;

IL = acceptable receiver interference PSD level.

4.2.2.2 1 dB compression point

Power of the IMT transmitter at the radar receiver:

$$P_{RX} = P_{TX} - FL_{TX} + G_{TX} + G_{TX,REL} - PL + G_{RX} + G_{RX,REL} - FL_{RX} - POL_{RX}$$

Where:

P_{RX} = power of the IMT transmitter at the radar receiver;

P_{TX} = power of the IMT transmitter;

FL_{TX} = transmit feeder loss;

G_{TX} = transmit maximum antenna gain;

$G_{TX,REL}$ = transmit antenna gain relative to maximum in direction of radar;

PL = free space path loss;

G_{RX} = receive antenna gain;

$G_{RX,REL}$ = receive antenna gain relative to maximum in direction of IMT system;

FL_{RX} = receive feeder loss;

POL_{RX} = polarization loss.

Acceptable receiver interference level:

$$IL_{CP} = CP_{RX} - SM$$

where:

IL_{CP} = acceptable receiver interference level for 1 dB compression point;

CP_{RX} = receiver 1 dB compression point;

SM = safety margin (only applicable for aeronautical services).

Required additional attenuation:

$$ATT = P_{RX} - IL_{CP}$$

where:

ATT = required additional attenuation;

P_{RX} = power of the potential interferer at the victim receiver;

IL_{CP} = acceptable receiver interference level for 1 dB compression point.

4.3 Calculations

The calculations of co-channel and non-co-channel interference between IMT systems and radar systems are described in this section. These include ‘baseline’ calculations in which no mitigation is assumed, and calculations that do consider the application of non-co-channel mitigation techniques. Refer to sections 3.1 and section 3.2 for details of the technical characteristics assumed for the ‘baseline’ and ‘mitigation’ cases, respectively.

4.3.1 Co-channel

4.3.1.1 Baseline co-channel (no mitigation)

First the baseline calculations are considered.

4.3.1.2 IMT base station (rural) impact on radar

TABLE 6

Co-channel base station on a radar receiver

	Units	**Radar 1**	**Radar 2**	**Radar 3**	**Radar 4**	**Radar 5**	**Radar 6**	**Radar 7**
Base station transmit power	dBm/MHz	36.0	36.0	36.0	36.0	36.0	36.0	36.0
Base station feeder loss	dB	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Base station antenna gain	dBi	18.0	18.0	18.0	18.0	18.0	18.0	18.0
Free space path loss for 1 km	dB	95.0	95.0	95.0	95.0	95.0	95.0	95.0
Radar antenna gain	dBi	34.5	34.2	38.2	38.5	34	35	34.5
Radar feeder loss	dB	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Polarisation Loss	dB	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Power at the receiver front-end	**dBm/MHz**	**–14.5**	**–14.8**	**–11.8**	**–11.5**	**–15.0**	**–14.0**	**–14.5**
Receiver noise floor	dBm/MHz	–112.0	–112.0	–109.3	–111.4	–109.8	–105.0	–110.8
Required I/N	dB	–6.0	–6.0	–6.0	–6.0	–6.0	–6.0	–6.0
Safety margin	dB	6.0	6.0	0.0	0.0	0.0	0.0	0.0
Interference level	**dBm/MHz**	**–124.0**	**–124.0**	**–115.3**	**–117.4**	**–116.0**	**–114.0**	**–118.0**
Required attenuation	**dB**	**109.5**	**109.2**	**104.5**	**106.9**	**100.7**	**97.0**	**102.3**

4.3.1.3 IMT user equipment impact on radar

TABLE 7

Co-channel user equipment on a radar receiver

	Units	**Radar 1**	**Radar 2**	**Radar 3**	**Radar 4**	**Radar 5**	**Radar 6**	**Radar 7**
UE transmit power	dBm/MHz	23.0	23.0	23.0	23.0	23.0	23.0	23.0
UE transmit power	dBm/MHz	13.0	13.0	13.0	13.0	13.0	13.0	13.0
UE body loss	dB	4.0	4.0	4.0	4.0	4.0	4.0	4.0
UE antenna gain	dBi	–3.0	–3.0	–3.0	–3.0	–3.0	–3.0	–3.0
Free space path loss for 500 m	dB	89.0	89.0	89.0	89.0	89.0	89.0	89.0
Radar antenna gain	dBi	34.5	34.2	38.2	38.5	34	35	34.5
Relative gain (3° below max)		–10.0	–10.0	–10.0	–10.0	–10.0	–10.0	–10.0
Radar feeder loss	dB	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Polarisation Loss	dB	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Power at the receiver front-end	**dBm/MHz**	**–63.5**	**–63.8**	**–59.8**	**–59.5**	**–64.0**	**–63.0**	**–63.5**
Receiver noise floor	dBm/MHz	–112.0	–112.0	–109.3	–111.4	–109.8	–105.0	–110.8
Required I/N	dB	–6.0	–6.0	–6.0	–6.0	–6.0	–6.0	–6.0
Safety margin	dB	6.0	6.0	0.0	0.0	0.0	0.0	0.0
Interference level	**dBm/MHz**	**–124.0**	**–124.0**	**–115.3**	**–117.4**	**–115.8**	**–111.0**	**–116.8**
Required attenuation	**dB**	**60.5**	**60.2**	**55.5**	**57.9**	**57.9**	**48.0**	**53.3**

4.3.2 Baseline non-co-channel (no mitigation)

First the baseline calculations are considered.

4.3.2.1 IMT rural base station impact on radar (no mitigation)

The calculation of the required additional attenuation when considering the impact of IMT base station unwanted emissions on the radar receiver is shown in Table 9. A frequency offset of 10 MHz is assumed for the Category B −30 dBm/MHz base station spurious emissions limit to apply.

TABLE 8

IMT base station spurious emissions falling in the pass-band of a radar receiver

	Units	**Radar 1**	**Radar 2**	**Radar 3**	**Radar 4**	**Radar 5**	**Radar 6**	**Radar 7**
Base station spurious emission limit	dBm/MHz	–30.0	–30.0	–30.0	–30.0	–30.0	-30.0	-30.0
Base station feeder loss	dB	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Base station antenna gain	dBi	18.0	18.0	18.0	18.0	18.0	18.0	18.0
Free space path loss for 1 km	dB	95.0	95.0	95.0	95.0	95.0	95.0	95.0
Radar antenna gain	dBi	34.5	34.2	38.2	38.5	34	35	34.5
Radar feeder loss	dB	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Polarisation Loss	dB	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Power at the receiver front-end	**dBm/MHz**	**–80.5**	**–80.8**	**–76.8**	**–76.5**	**–81.0**	**–80.0**	**–80.5**
Receiver noise floor	dBm/MHz	–112.0	–112.0	–109.3	–111.4	–109.8	–105.0	–110.8
Required I/N	dB	–6.0	–6.0	–6.0	–6.0	–6.0	–6.0	–6.0
Safety margin	dB	6.0	6.0	0.0	0.0	0.0	0.0	0.0
Interference level	**dBm/MHz**	–124.0	–124.0	–115.3	–117.4	–115.8	–111.0	–116.8
Required attenuation	**dB**	**43.5**	**43.2**	**38.5**	**40.9**	**34.7**	**31.0**	**36.3**

The calculation of the required additional attenuation when considering the suppression of the IMT base station wanted signal by the radar IF selectivity is shown in Table 9. The required additional attenuation is calculated for a frequency offset of 10 MHz.

TABLE 9

Radar IF Selectivity (60 dB/decade) rejection of base station transmission

	Units	Radar 1	Radar 2	Radar 3	Radar 4	Radar 5	Radar 6	Radar 7
Base station transmit power	dBm/MHz	36.0	36.0	36.0	36.0	36.0	36.0	36.0
Base station feeder loss	dB	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Base station antenna gain	dBi	18.0	18.0	18.0	18.0	18.0	18.0	18.0
Relative base station antenna gain	dB	0	0	0	0	0	0	0
Free space path loss for 1 km	dB	95.0	95.0	95.0	95.0	95.0	95.0	95.0
Radar antenna gain	dBi	34.5	34.2	38.2	38.5	34	35	34.5
Radar relative height loss	dB	0	0	0	0	0	0	0
Radar feeder loss	dB	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Polarisation Loss	dB	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Power at the receiver front-end	**dBm/MHz**	**–14.5**	**–14.8**	**–11.8**	**–11.5**	**–15.0**	**–14.0**	**–14.5**
Receiver noise floor	dBm/MHz	–112.0	–112.0	–109.3	–111.4	–109.8	–105.0	–110.8
Required I/N	dB	–6.0	–6.0	–6.0	–6.0	–6.0	–6.0	–6.0
Safety margin	dB	6.0	6.0	0.0	0.0	0.0	0.0	0.0
IF selectivity at 10 MHz frequency offset (FO)	dB	112.4	116.5	57.2	96.7	94.9	108.3	98.0
Acceptable interference level at 10 MHz FO	**dBm/MHz**	**-11.6**	**-7.5**	**-58.1**	**-20.7**	**-20.9**	**-2.7**	**-18.8**
Required attenuation at 10 MHz FO	**dB**	**-2.9**	**-7.3**	**47.3**	**10.2**	**5.8**	**-11.4**	**4.2**

The calculation of the required additional attenuation when considering the impact of the IMT base station wanted signal on the 1 dB compression point of a radar receiver is shown in Table 10.

TABLE 10

IMT base station wanted emissions compared with input 1 dB compression point of a radar receiver (–10 dBm assumed)

	Units	Radar 1	Radar 2	Radar 3	Radar 4	Radar 5	Radar 6	Radar 7
Base station transmit power	dBm	46	46	46	46	46	46	46
Base station feeder loss	dB	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Base station antenna gain	dBi	18.0	18.0	18.0	18.0	18.0	18.0	18.0
Free space path loss for 1 km	dB	95.0	95.0	95.0	95.0	95.0	95.0	95.0
Radar antenna gain	dBi	34.5	34.2	38.2	38.5	34	35	34.5
Radar relative height loss	dB	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Radar feeder loss	dB	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Polarisation Loss	dB	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Power at the receiver front-end	**dBm**	**-4.5**	**-4.8**	**-0.8**	**-0.5**	**-5.0**	**-4.0**	**-4.5**
Radar 1 dB compression point (assumed)	**dBm**	-10.0	-10.0	-10.0	-10.0	-10.0	-10.0	-10.0
Safety margin	dB	6.0	6.0	0.0	0.0	0.0	0.0	0.0
Acceptable interference level	**dBm**	**-16.0**	**-16.0**	**-10.0**	**-10.0**	**-10.0**	**-10.0**	**-10.0**
Required attenuation	**dB**	**11.5**	**11.2**	**9.2**	**9.5**	**5.0**	**6.0**	**5.5**

4.3.2.2 IMT UE impact on radar (no mitigation)

The calculation of the required additional attenuation when considering the impact of IMT UE spurious emissions on the pass-band of a radar receiver is shown in Table 11. A frequency offset of 15 MHz is used for this calculation for the UE spurious emissions to apply.

TABLE 11

User equipment spurious emissions falling in the pass-band of a radar receiver

	Units	**Radar 1**	**Radar 2**	**Radar 3**	**Radar 4**	**Radar 5**	**Radar 6**	**Radar 7**
UE spurious emission limit	dBm/MHz	–30.0	–30.0	–30.0	–30.0	–30.0	–30.0	–30.0
UE antenna gain	dBi	–3.0	–3.0	–3.0	–3.0	–3.0	–3.0	–3.0
UE body loss	dB	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Free space path loss for 500 m	dB	89.0	89.0	89.0	89.0	89.0	89.0	89.0
Radar antenna gain	dBi	34.5	34.2	38.2	38.5	34	35	34.5
Relative gain (3° below max)		–10.0	–10.0	–10.0	–10.0	–10.0	–10.0	–10.0
Radar feeder loss	dB	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Polarisation loss	dB	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Power at the receiver front-end	**dBm/MHz**	**–106.5**	**–106.8**	**–102.8**	**–102.5**	**–107.0**	**–106.0**	**–106.5**
Receiver noise floor	dBm/MHz	–112.0	–112.0	–109.3	–111.4	–109.8	–105.0	–110.8
Required I/N	dB	–6.0	–6.0	–6.0	–6.0	–6.0	–6.0	–6.0
Safety margin	dB	6.0	6.0	0.0	0.0	0.0	0.0	0.0
Interference level	**dBm/MHz**	**–124.0**	**–124.0**	**–115.3**	**–117.4**	**–115.8**	**–111.0**	**–116.8**
Required attenuation	**dB**	**17.5**	**17.2**	**12.5**	**14.9**	**8.7**	**5.0**	**10.3**

The calculation of the required additional attenuation when considering the suppression of the IMT UE wanted signal by the radar IF selectivity is shown in Table 12. The required additional attenuation is calculated for a frequency offset of 10 MHz.

TABLE 12

Radar IF Selectivity (60 dB/decade) rejection of user equipment transmission

	Units	Radar 1	Radar 2	Radar 3	Radar 4	Radar 5	Radar 6	Radar 7
UE transmit power	dBm/MHz	13.0	13.0	13.0	13.0	13.0	13.0	13.0
UE body loss	dB	4.0	4.0	4.0	4.0	4.0	4.0	4.0
UE antenna gain	dBi	–3.0	–3.0	–3.0	–3.0	–3.0	–3.0	–3.0
Free space path loss for 500 m	dB	89.0	89.0	89.0	89.0	89.0	89.0	89.0
Radar antenna gain	dBi	34.5	34.2	38.2	38.5	34	35	34.5
Relative gain (3° below max)		–10.0	–10.0	–10.0	–10.0	–10.0	–10.0	–10.0
Radar feeder loss	dB	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Polarisation Loss	dB	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Power at the receiver front-end	**dBm/MHz**	**–63.5**	**–63.8**	**–59.8**	**–59.5**	**–64.0**	**–63.0**	**–63.5**
Receiver noise floor	dBm/MHz	–112.0	–112.0	–109.3	–111.4	–109.8	–105.0	–110.8
Required I/N	dB	–6.0	–6.0	–6.0	–6.0	–6.0	–6.0	–6.0
Safety margin	dB	6.0	6.0	0.0	0.0	0.0	0.0	0.0
IF selectivity at 10 MHz frequency offset (FO)	dB	112.4	116.5	57.2	96.7	94.9	108.3	98.0
Acceptable interference level at 10 MHz FO	**dBm/MHz**	**-11.6**	**-7.5**	**-58.1**	**-20.7**	**-20.9**	**-2.7**	**-18.8**
Required attenuation at 10 MHz FO	**dB**	**-51.9**	**-56.3**	**-1.7**	**-38.8**	**-43.1**	**-60.3**	**-44.7**

The calculation of the required additional attenuation when considering the impact of the IMT UE wanted signal on the 1 dB compression point of a radar receiver is shown in Table 13.

TABLE 13

IMT user equipment wanted emissions compared with input 1 dB compression point of a radar receiver

	Units	Radar 1	Radar 2	Radar 3	Radar 4	Radar 5	Radar 6	Radar 7
UE transmit power	dBm	23	23	23	23	23	23	23
UE body loss	dB	4.0	4.0	4.0	4.0	4.0	4.0	4.0
UE antenna gain	dBi	–3.0	–3.0	–3.0	–3.0	–3.0	–3.0	–3.0
Free space path loss for 500 m	dB	89.0	89.0	89.0	89.0	89.0	89.0	89.0
Radar antenna gain	dBi	34.5	34.2	38.2	38.5	34	35	34.5
Relative gain (3° below max)		–10.0	–10.0	–10.0	–10.0	–10.0	–10.0	–10.0
Radar feeder loss	dB	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Polarisation Loss	dB	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Power at the receiver front-end	**dBm**	**-53.5**	**-53.8**	**-49.8**	**-49.5**	**-54.0**	**-53.0**	**-53.5**
Radar 1 dB compression point	dBm	-10.0	-10.0	-10.0	-10.0	-10.0	-10.0	-10.0
Safety factor	dBm	6	6	0	0	0	0	0
Acceptable interference level	**dBm**	**-16.0**	**-16.0**	**-10.0**	**-10.0**	**-10.0**	**-10.0**	**-10.0**
Required attenuation	**dB**	**-37.5**	**-37.8**	**-39.8**	**-39.5**	**-44.0**	**-43.0**	**-43.5**

4.3.3 Co-channel with mitigation

The calculations in section 4.3.1 are repeated in this section, but with the mitigation techniques applied, using a down tilt antenna with suppressed upper lobe for the base station as described in section 3.2.

TABLE 14

Co-channel IMT base station on a radar receiver

	Units	Radar 1	Radar 2	Radar 3	Radar 4	Radar 5	Radar 6	Radar 7
Base station transmit power	dBm/MHz	36.0	36.0	36.0	36.0	36.0	36.0	36.0
Base station feeder loss	dB	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Base station antenna gain	dBi	18.0	18.0	18.0	18.0	18.0	18.0	18.0
Relative base station antenna gain	dB	-25	-25	-25	-25	-25	-25	-25
Free space path loss for 1 km	dB	95.0	95.0	95.0	95.0	95.0	95.0	95.0
Radar antenna gain	dBi	34.5	34.2	38.2	38.5	34	35	34.5
Radar feeder loss	dB	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Polarisation Loss	dB	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Power at the receiver front-end	**dBm/MHz**	**–39.5**	**–39.8**	**–36.8**	**–36.5**	**–40.0**	**–39.0**	**–39.5**
Receiver noise floor	dBm/MHz	–112.0	–112.0	–109.3	–111.4	–109.8	–105.0	–110.8
Required I/N	dB	–6.0	–6.0	–6.0	–6.0	–6.0	–6.0	–6.0
Safety margin	dB	6.0	6.0	0.0	0.0	0.0	0.0	0.0
Interference level	**dBm/MHz**	**–124.0**	**–124.0**	**–115.3**	**–117.4**	**–116.0**	**–114.0**	**–118.0**
Required attenuation	**dB**	**84.5**	**84.2**	**79.5**	**81.9**	**75.7**	**72.0**	**77.3**

4.3.4 Non co-channel with mitigation

The calculations in section 4.3.2 are repeated in this section, but with the assumption that various non-co-channel channel mitigation techniques are applied, as described in section 3.2.

4.3.4.1 IMT rural macrocell base station impact on radar (with mitigation)

The calculation of the required additional attenuation when considering the impact of IMT base station spurious emissions on the pass-band of a radar receiver is shown in Table 15 when various mitigation techniques are adopted. The mitigation measures include

– Base station
  – Lower spurious emissions (–55 dBm/MHz rather than –30 dBm/MHz)
  – RF Transmit filter giving 60 dB suppression
  – Downtilt + upper sidelobe suppression (–25 dB gain toward radar)

TABLE 15

IMT base station spurious emissions falling in the pass-band of a radar receiver (60 dB filter)

	Units	Radar 1	Radar 2	Radar 3	Radar 4	Radar 5	Radar 6	Radar 7
Base station spurious emission limit	dBm/MHz	-55	-55	-55	-55	-55	-55	-55
Base station RF transmit chain filter rejection	dB	60	60	60	60	60	60	60
Base station feeder loss	dB	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Base station antenna gain	dBi	18.0	18.0	18.0	18.0	18.0	18.0	18.0
Relative base station antenna gain	dB	-25	-25	-25	-25	-25	-25	-25
Free space path loss for 1 km	dB	95.0	95.0	95.0	95.0	95.0	95.0	95.0
Radar antenna gain	dBi	34.5	34.2	38.2	38.5	34	35	34.5
Radar relative height loss	dB	0	0	0	0	0	0	0
Radar feeder loss	dB	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Polarisation Loss	dB	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Power at the receiver front-end	**dBm/MHz**	**-190.5**	**-190.8**	**-186.8**	**-186.5**	**-191.0**	**-190.0**	**-190.5**
Receiver noise floor	dBm/MHz	–112.0	–112.0	–109.3	–111.4	–109.8	–105.0	–110.8
Required I/N	dB	–6.0	–6.0	–6.0	–6.0	–6.0	–6.0	–6.0
Safety margin	dB	6.0	6.0	0.0	0.0	0.0	0.0	0.0
Interference level	**dBm/MHz**	–124.0	–124.0	–115.3	–117.4	–115.8	–111.0	–116.8
Required attenuation	**dB**	**-66.5**	**-66.8**	**-71.5**	**-69.1**	**-75.3**	**-79.0**	**-73.7**

The calculation of the required additional attenuation when considering the rejection of the IMT base station wanted signal by the radar selectivity is shown in Table 16 assuming various mitigation measures. The mitigation measures include

– Base station
  – downtilt with upper sidelobe suppression (−25 dB relative antenna gain in the direction of the radar).
– Radar
  – IF selectivity rolloff of 100 dB/decade rather than 80 dB/decade.
  – RF filter before the LNA (as described in section 3.2.1.1).
– The required attenuation is calculated for a frequency offset of 10 MHz.

TABLE 16

Radar IF selectivity (100 dB/decade) rejection of IMT base station transmission (with mitigation)

	Units	Radar 1	Radar 2	Radar 3	Radar 4	Radar 5	Radar 6	Radar 7
Base station transmit power	dBm/MHz	36.0	36.0	36.0	36.0	36.0	36.0	36.0
Base station feeder loss	dB	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Base station antenna gain	dBi	18.0	18.0	18.0	18.0	18.0	18.0	18.0
Relative base station antenna gain	dB	-25	-25	-25	-25	-25	-25	-25
Free space path loss for 1 km	dB	95.0	95.0	95.0	95.0	95.0	95.0	95.0
Radar antenna gain	dBi	34.5	34.2	38.2	38.5	34	35	34.5
Radar relative height loss	dB	0	0	0	0	0	0	0
Radar feeder loss	dB	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Polarisation Loss	dB	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Power at the receiver front-end	**dBm/MHz**	**-39.5**	**-39.8**	**-35.8**	**-35.5**	**-40.0**	**-39.0**	**-39.5**
Receiver noise floor	dBm/MHz	–112.0	–112.0	–109.3	–111.4	–109.8	–105.0	–110.8
Required I/N	dB	–6.0	–6.0	–6.0	–6.0	–6.0	–6.0	–6.0
Safety margin	dB	6.0	6.0	0.0	0.0	0.0	0.0	0.0
IF selectivity at 10 MHz frequency offset (FO)	dB	170.4	175.6	101.6	150.8	148.6	165.4	152.5
Acceptable interference level at 10 MHz FO	**dBm/MHz**	**46.4**	**51.6**	**-13.7**	**33.4**	**32.8**	**54.4**	**35.7**
Required attenuation at 10 MHz FO	**dB**	**-86.0**	**-91.4**	**-22.1**	**-69.0**	**-72.9**	**-93.4**	**-75.3**

The calculation of the required additional attenuation when considering the impact of the IMT base station wanted signal on the 1 dB compression point of a radar receiver is shown in Table 17 assuming the following mitigation measures are adopted.

– Base station downtilt with upper sidelobe suppression (–25 dB relative antenna gain).

– Inclusion of an RF filter before the radar LNA (as described in Section 3.2.1.1) yielding 28.5 dB rejection at ≥ 5 MHz frequency offset.

TABLE 17

IMT base station wanted emissions compared with input 1 dB compression point of a radar receiver (-10 dBm 1 dB compression point assumed and with mitigation)

	Units	Radar 1	Radar 2	Radar 3	Radar 4	Radar 5	Radar 6	Radar 7
Base station transmit power	dBm	46	46	46	46	46	46	46
Base station feeder loss	dB	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Base station antenna gain	dBi	18.0	18.0	18.0	18.0	18.0	18.0	18.0
Relative base station antenna gain	dB	-25	-25	-25	-25	-25	-25	-25
Free space path loss for 1 km	dB	95.0	95.0	95.0	95.0	95.0	95.0	95.0
Radar antenna gain	dBi	34.5	34.2	38.2	38.5	34	35	34.5
Radar relative height loss	dB	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Radar feeder loss	dB	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Polarisation Loss	dB	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Power at the receiver front-end	**dBm**	**-29.5**	**-29.8**	**-25.8**	**-25.5**	**-30.0**	**-29.0**	**-29.5**
Radar 1 dB compression point (assumed)	**dBm**	-10.0	-10.0	-10.0	-10.0	-10.0	-10.0	-10.0
RF filter rejection	dB	28.5	28.5	28.5	28.5	28.5	28.5	28.5
Safety margin	dB	6.0	6.0	0.0	0.0	0.0	0.0	0.0
Acceptable interference level	**dBm**	**12.5**	**12.5**	**18.5**	**18.5**	**18.5**	**18.5**	**18.5**
Required attenuation	**dB**	**-42.0**	**-42.3**	**-44.3**	**-44.0**	**-48.5**	**-47.5**	**-48.0**

4.3.4.2 IMT UE impact on radar (with mitigation)

Calculation of the required additional attenuation for the scenario of IMT UEs coexisting with radars when mitigation measures are applied is considered in this section.

The calculation of the required additional attenuation when considering the impact of UE unwanted emissions on the radar receiver is shown in Table 18 assuming UE unwanted emissions of −50 dBm/MHz.

TABLE 18

IMT user equipment spurious emissions falling in the pass-band of a radar receiver (with mitigation)

	Units	Radar 1	Radar 2	Radar 3	Radar 4	Radar 5	Radar 6	Radar 7
UE spurious emission limit	dBm/MHz	-50	-50	-50	-50	-50	-50	-50
UE antenna gain	dBi	–3.0	–3.0	–3.0	–3.0	–3.0	–3.0	–3.0
UE body loss	dB	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Free space path loss for 500 m	dB	89.0	89.0	89.0	89.0	89.0	89.0	89.0
Radar antenna gain	dBi	34.5	34.2	38.2	38.5	34	35	34.5
Relative gain (3° below max)		–10.0	–10.0	–10.0	–10.0	–10.0	–10.0	–10.0
Radar feeder loss	dB	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Polarisation loss	dB	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Power at the receiver front-end	**dBm/MHz**	**-126.5**	**-126.8**	**-122.8**	**-122.5**	**-127.0**	**-126.0**	**-126.5**
Receiver noise floor	dBm/MHz	–112.0	–112.0	–109.3	–111.4	–109.8	–105.0	–110.8
Required I/N	dB	–6.0	–6.0	–6.0	–6.0	–6.0	–6.0	–6.0
Safety margin	dB	6.0	6.0	0.0	0.0	0.0	0.0	0.0
Interference level	**dBm/MHz**	**–124.0**	**–124.0**	**–115.3**	**–117.4**	**–115.8**	**–111.0**	**–116.8**
Required attenuation	**dB**	**-2.5**	**-2.8**	**-7.5**	**-5.1**	**-11.3**	**-15.0**	**-9.7**

The calculation of the required additional attenuation when considering the rejection of the UE wanted signal by the radar selectivity is shown in Table 19 assuming various mitigation measures. The mitigation measures include:

– A radar IF selectivity rolloff of 100 dB/decade rather than 80 dB/decade.

– Also the radar selectivity includes the rejection due to an RF filter before the LNA (as described in section 3.2.1.1).

The required additional attenuation is calculated for a frequency offset of 10 MHz.

TABLE 19

Radar IF selectivity (100 dB/decade) rejection of user equipment transmission (with mitigation)

	Units	Radar 1	Radar 2	Radar 3	Radar 4	Radar 5	Radar 6	Radar 7
UE transmit power	dBm/MHz	13.0	13.0	13.0	13.0	13.0	13.0	13.0
UE body loss	dB	4.0	4.0	4.0	4.0	4.0	4.0	4.0
UE antenna gain	dBi	–3.0	–3.0	–3.0	–3.0	–3.0	–3.0	–3.0
Free space path loss for 500 m	dB	89.0	89.0	89.0	89.0	89.0	89.0	89.0
Radar antenna gain	dBi	34.5	34.2	38.2	38.5	34	35	34.5
Relative gain (3° below max)		–10.0	–10.0	–10.0	–10.0	–10.0	–10.0	–10.0
Radar feeder loss	dB	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Polarisation Loss	dB	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Power at the receiver front-end	**dBm/MHz**	**–63.5**	**–63.8**	**–59.8**	**–59.5**	**–64.0**	**–63.0**	**–63.5**
Receiver noise floor	dBm/MHz	–112.0	–112.0	–109.3	–111.4	–109.8	–105.0	–110.8
Required I/N	dB	–6.0	–6.0	–6.0	–6.0	–6.0	–6.0	–6.0
Safety margin	dB	6.0	6.0	0.0	0.0	0.0	0.0	0.0
IF selectivity at 10 MHz frequency offset (FO)	dB	170.4	175.6	101.6	150.8	148.6	165.4	152.5
Acceptable interference level at 10 MHz FO	**dBm/MHz**	**46.4**	**51.6**	**-13.7**	**33.4**	**32.8**	**54.4**	**35.7**
Required attenuation at 10 MHz FO	**dB**	**-110.0**	**-115.4**	**-46.1**	**-93.0**	**-96.9**	**-117.4**	**-99.2**

The calculation of the required additional attenuation when considering the impact of the UE wanted signal on the 1 dB compression point of a radar receiver is shown in Table 20 assuming the inclusion of an RF filter before the radar LNA (as described in section 3.2.1.1) yielding 28.5 dB rejection at separations ≥5 MHz.

TABLE 20

IMT user equipment wanted emissions compared with input 1 dB compression point of a radar receiver (with mitigation)

	Units	Radar 1	Radar 2	Radar 3	Radar 4	Radar 5	Radar 6	Radar 7
UE transmit power	dBm	23	23	23	23	23	23	23
UE body loss	dB	4.0	4.0	4.0	4.0	4.0	4.0	4.0
UE antenna gain	dBi	–3.0	–3.0	–3.0	–3.0	–3.0	–3.0	–3.0
Free space path loss for 500 m	dB	89.0	89.0	89.0	89.0	89.0	89.0	89.0
Radar antenna gain	dBi	34.5	34.2	38.2	38.5	34	35	34.5
Relative gain (3° below max)		–10.0	–10.0	–10.0	–10.0	–10.0	–10.0	–10.0
Radar feeder loss	dB	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Polarisation Loss	dB	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Power at the receiver front-end	**dBm**	**-53.5**	**-53.8**	**-49.8**	**-49.5**	**-54.0**	**-53.0**	**-53.5**
Radar 1 dB compression point	dBm	-10.0	-10.0	-10.0	-10.0	-10.0	-10.0	-10.0
RF filter rejection	dB	28.5	28.5	28.5	28.5	28.5	28.5	28.5
Safety factor	dBm	6	6	0	0	0	0	0
Acceptable interference level	**dBm**	**12.5**	**12.5**	**18.5**	**18.5**	**18.5**	**18.5**	**18.5**
Required attenuation	**dB**	**-66.0**	**-66.3**	**-68.3**	**-68.0**	**-72.5**	**-71.5**	**-72.0**

4.4 Results

A summary is presented in this section of the ‘baseline’ results and results where the application of various mitigation techniques is assumed.

4.4.1 Co-channel

The results provided in Table 21 are the required additional attenuation for avoidance of interference to radar in the co-channel case with no mitigation

TABLE 21

Required attenuation (dB) for IMT systems co-channel into radar

		Victim						
		Radar 1	**Radar 2**	**Radar 3**	**Radar 4**	**Radar 5**	**Radar 6**	**Radar 7**
Interferer	Base Station	**109.5**	**109.2**	**104.5**	**106.9**	**100.7**	**97.0**	**102.3**
	User equipment	**60.5**	**60.2**	**55.2**	**57.9**	**51.70**	**48.0**	**53.3**

4.4.1.1 Co-channel with mitigation

The results provided in Table 22 are the required additional attenuation for avoidance of interference to radar in the co-channel case using a down tilt antenna with suppressed upper lobe for the base station.

TABLE 22

Required attenuation (dB) for IMT systems co-channel into radar (with mitigation)

		Victim						
		Radar 1	**Radar 2**	**Radar 3**	**Radar 4**	**Radar 5**	**Radar 6**	**Radar 7**
Interferer	Base Station	**84.5**	**84.2**	**79.5**	**81.9**	**75.7**	**72.0**	**77.3**
	User equipment	**60.5**	**60.2**	**55.2**	**57.9**	**51.70**	**48.0**	**53.3**

4.4.2 Baseline non-co-channel case (no mitigation)

The attenuation required to enable coexistence for each of the interference mechanisms studied with the baseline characteristics are given in Table 23; where the values are negative (green), then this indicates compatibility. Unwanted emissions from the IMT transmitters in the radar band need some improvements, and radar RF selectivity is a problem for all the radars and IF selectivity as well for the wider bandwidth radars 3, 4, 5 and 7.

TABLE 23

Required attenuation for IMT systems into radar measured in dB

			Radar 1	**Radar 2**	**Radar 3**	**Radar 4**	**Radar 5**	**Radar 6**	**Radar 7**
IMT system	base station	Spurious emissions	**43.5**	**43.2**	**38.5**	**40.9**	**34.7**	**31.0**	**36.3**
		Radar 1 dB compression point -10 dBm assumed	**11.5**	**11.2**	**9.2**	**9.5**	**5.0**	**6.0**	**5.5**
		Radar IF selectivity at 10 MHz frequency offset	**-2.9**	**-7.3**	**47.3**	**10.2**	**5.8**	**-11.4**	**4.2**
	UE	Spurious emissions at 15 MHz frequency offset	**17.5**	**17.2**	**12.5**	**14.9**	**8.7**	**5.0**	**10.3**
		Radar 1 dB compression point -10 dBm assumed	**-37.5**	**-37.8**	**-39.8**	**-39.5**	**-44.0**	**-43.0**	**-43.5**
		Radar IF selectivity at 10 MHz frequency offset	**-51.9**	**-56.3**	**-1.7**	**-38.8**	**-43.1**	**-60.3**	**-44.7**

4.4.2.1 Non co-channel with mitigation

The results are presented in this section assuming that all of the mitigation measures described in section 3.2 are adopted, namely improved unwanted emissions of the IMT base stations and UEs, RF filtering at the base stations and at the radars, improved radar IF selectivity, downtilt with upper sidelobe suppression for the rural macrocell base stations, exclusion zone around the radar from a UE at 500 metres separation or a base station at one kilometre, and a frequency offset of 10 MHz. Clearly there are many intermediate cases where some but not all of these mitigation measures are applied, however calculation of detailed results for these is beyond the scope of this study.

The attenuation required to enable coexistence for each of the interference mechanisms studied with the improved characteristics are given in Table 24; where the values are negative (green), then this indicates compatibility. The unwanted emissions from IMT into the radar band that are assumed here are now acceptable, and the selectivity of the wider bandwidth Radars 3, 4, 5 and 7 requires a frequency offset of 10 MHz in order to achieve coexistence with macrocells and UEs.

TABLE 24

Required attenuation for IMT systems into radar measured in dB (with mitigation)

			Radar 1	**Radar 2**	**Radar 3**	**Radar 4**	**Radar 5**	**Radar 6**	**Radar 7**
IMT system	base station	Spurious emissions	**-66.5**	**-66.8**	**-71.5**	**-69.1**	**-75.3**	**-79.0**	**-73.7**
		Radar 1 dB compression point -10 dBm assumed	**-42.0**	**-42.3**	**-44.3**	**-44.0**	**-48.5**	**-47.5**	**-48.0**
		Radar IF selectivity at 10 MHz frequency offset	**-86.0**	**-91.4**	**-22.1**	**-69.0**	**-72.9**	**-93.4**	**-75.3**
	UE	Spurious emissions	**-2.5**	**-2.8**	**-7.5**	**-5.1**	**-11.3**	**-15.0**	**-9.7**
		Radar 1 dB compression point -10 dBm assumed	**-66.0**	**-66.3**	**-68.3**	**-68.0**	**-72.5**	**-71.5**	**-72.0**
		Radar IF selectivity at 10 MHz frequency offset	**-110.0**	**-115.4**	**-46.1**	**-93.0**	**-96.9**	**-117.4**	**-99.2**

5 Conclusions

A deterministic study presented in this Annex supplements those presented in the other annexes and extends the analysis of operation in non-co-channel spectrum, focusing on the impact of IMT transmissions on the radar. Performing the analysis using baseline assumptions with a base station to radar separation of one kilometre and a UE to radar separation of 500 metres and free space path loss indicates that additional attenuation is required.

From the results it is clear that co-channel operation in the same geographical area is not practical, however the results for non-co-channel operation with a guard band to allow for filters to work are encouraging.

To enable coexistence, a number of possible mitigation techniques are considered, including improved emissions performance of the IMT transmitters, downtilt of base station antennas to avoid main lobe coupling with the radar, RF filtering at radars and base stations, and improved IF filtering for the wider bandwidth radars. Applying all of these techniques would enable the radar receivers to coexist with IMT systems with a frequency offset of less than 10 MHz. It is important to note that coexistence may be achieved with a subset of the techniques outlined, and also that these are not the only possible approaches to achieve this.

ANNEX 11

Analysis of required mitigation for IMT systems and radars to share the 1 300-1 400 MHz

The results of the deterministic analysis (Study 10 above) of non-co-channel compatibility of IMT base stations and UE with radar systems for the 'baseline' case are used as a starting point to determine which interference mechanisms should be investigated further.

1 Assumptions

In addition to the assumptions described in Section 3, the following assumptions apply.

– The studies are based on the impact of multiple IMT transmitters on a single radar receiver.

– The following minimum separation distances to radar are assumed.

  – Base station = $\geq$ 5.5 km

  – UE = $\geq$ 500 m

– Maximum transmission power is assumed for IMT base stations and the powers from a 'real life' IMT system are emulated for the UEs by Seamcat's built-in OFDMA module.

– Rural environment.

– Base station antenna down tilt of 3º.

– The assumption of a 1 dB compression point of –10 dBm for the radars has been made in the absence of parameters from ITU-R or ITU recommendations.

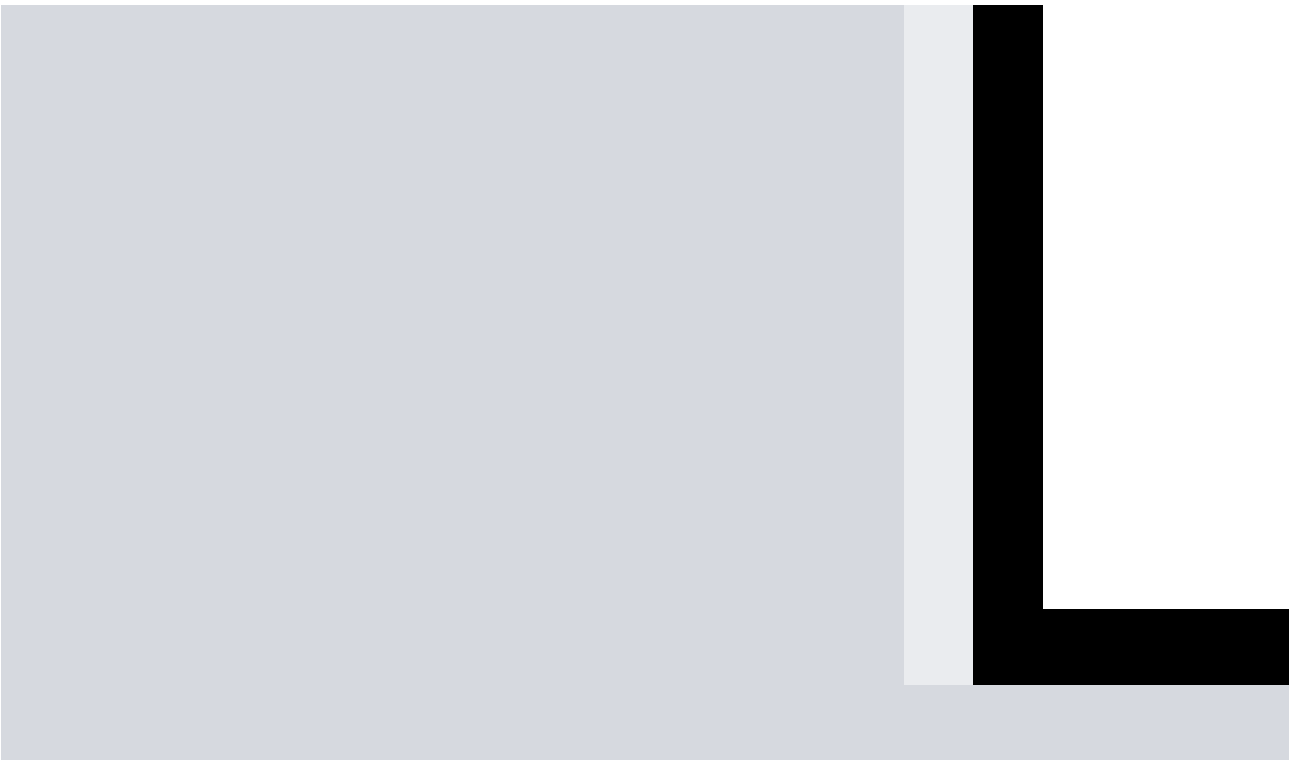
– Guard band of 10 MHz from edge of IMT band to radar receiver's closest 3 dB point (half bandwidth from centre frequency).

– It is recognised that the radar antenna gain used in error is the transmitter gain.

2 IMT cell structure for the analysis

The IMT parameters in Tables 2 and 3 (as provided by ITU-R) are used to set up the Seamcat OFDMA module for the IMT network for this frequency range. Below in Figure 1 are shown the IMT network base station positions in relation to the radar receiver (yellow diamond). The IMT system is a rural macro network with 5 km cell radius, hence the distance between the closest base station and the radar receiver of 5.5 km as this provides a 500 m exclusion zone for the UEs. The IMT parameters from ITU-R also specify the active user density as 0.17/5 MHz/km^2. For this frequency band and the 10 MHz IMT system specified this translates into around 420 active users, we have however implemented a more conservative 570 active users with 50/50 split between indoor and outdoor use.

FIGURE 1



3 Baseline non-co-channel case results (no mitigation) obtained from the deterministic study

In the following the critical interference mechanisms identified in the MCL study are presented. The attenuation required to enable coexistence for each of the interference mechanisms studied with the baseline characteristics are given in Table 1; where the values are negative (green), then this indicates compatibility and where the values are red this indicates that some sort of mitigation is required to achieve compatibility.

It is clear that the unwanted emissions from the IMT transmitters in the radar band need some improvements, and radar RF selectivity is a problem for all the radars in the case where an IMT base station is operating in the non-co-channel/band to a radar.

TABLE 1

Required attenuation for IMT systems into radar measured in dB

			Radar 1	**Radar 2**	**Radar 3**	**Radar 4**	**Radar 5**	**Radar 6**	**Radar 7**
IMT system	base station	Spurious emissions	**43.5**	**43.2**	**38.5**	**40.9**	**34.7**	**31.0**	**36.3**
		Radar 1 dB compression point -10 dBm assumed	**11.5**	**11.2**	**9.2**	**9.5**	**5.0**	**6.0**	**5.5**
		Radar IF selectivity at 10 MHz frequency offset	**-2.9**	**-7.3**	**47.3**	**10.2**	**5.8**	**-11.4**	**4.2**
	UE	Spurious emissions at 15 MHz frequency offset	**17.5**	**17.2**	**12.5**	**14.9**	**8.7**	**5.0**	**10.3**
		Radar 1 dB compression point -10 dBm assumed	**-37.5**	**-37.8**	**-39.8**	**-39.5**	**-44.0**	**-43.0**	**-43.5**
		Radar IF selectivity at 10 MHz frequency offset	**-51.9**	**-56.3**	**-1.7**	**-38.8**	**-43.1**	**-60.3**	**-44.7**

4 Calculations

In the following calculations the parameters from ITU-R have been used together with the additional assumptions mentioned in 4.1. The calculations have been performed firstly for the base stations followed by the UE. The cellular structure set-up used in Seamcat is the same for both base stations and UE. Seamcat's built-in IMT module has been used to randomly position the 570 active UE and provide the link power required for the terminals to operate in a real environment for both the indoor and outdoor UE. The position of each UE, for each event, is then used to calculate the interference path loss to the radar with the interference power from those UE being within the antenna beam of the radar receiver being aggregated. Similarly for the base stations and whilst not changing position, the interference power from those falling within the radar receiver's main beam is aggregated.

For each of the identified interference mechanisms, for the base station to radar case, firstly the deterministic calculation is shown for the case where a base station is located one kilometre from a radar. Then this is recalculated using the cellular structure shown above where the closest base station is located at 5.5 kilometres from the radar and where the interference powers from further base stations in the radar receiver antenna main beam are also taken into account.

A further calculation has been performed using a more appropriate propagation model than free space. It was found that at the distances up to 40 kilometres the free space model is really not meaningful and that Recommendation ITU-R P.452-14 is a better choice. This has been used at a time percentage of 0.001%, even though this would appear rather conservative and unnecessarily strict when compared to the variations in the returned power from a target. Unsurprisingly the resulting aggregate interference power increased allowing to calculate a more accurate/conservative mitigation requirement. Where relevant the impact of the required mitigation has also been calculated.

Also for the identified interference mechanisms for the UE to radar, firstly the deterministic calculation is shown for the case where a single UE is located 500 metres from the radar.

Then this is recalculated using the cellular structure shown above where the closest UE may be located 500 metres from the radar and where the interference powers from the randomly distributed UE in the radar main beam are taken into account up to a distance of 40 kilometres. The calculation uses the requirement identified in the deterministic study to establish a ‘bench mark’.

The calculations also consider the likelihood of the UE transmitting a data burst at the time a radar beam sweeps past and takes this into account as a correlation factor.

Further the calculations are performed using Recommendation ITU-R P.452-14 propagation model at a time percentage of 0.001% instead of free space, and finally the impact of the mitigation is calculated.

4.1 Base station non-co-channel calculations

In the following the base station calculations are considered for IMT downlink.

4.1.1 Single IMT rural base station spurious emissions impact on radar (no mitigation) at 1 km separation distance, obtained from the deterministic study.

The calculation of the required additional attenuation when considering the impact of IMT base station unwanted emissions on the radar receiver is shown in Table 2. A frequency offset of 10 MHz is assumed for the Category B −30 dBm/MHz base station spurious emissions limit to apply.

TABLE 2

IMT base station spurious emissions falling in the pass-band of a radar receiver

	Units	**Radar 1**	**Radar 2**	**Radar 3**	**Radar 4**	**Radar 5**	**Radar 6**	**Radar 7**
Base station spurious emission limit	dBm/MHz	–30.0	–30.0	–30.0	–30.0	–30.0	-30.0	-30.0
Base station feeder loss	dB	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Base station antenna gain	dBi	18.0	18.0	18.0	18.0	18.0	18.0	18.0
Free space path loss for 1 km	dB	95.0	95.0	95.0	95.0	95.0	95.0	95.0
Radar antenna gain	dBi	34.5	34.2	38.2	38.5	34	35	34.5
Radar feeder loss	dB	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Polarisation Loss	dB	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Power at the receiver front-end	**dBm/MHz**	**–80.5**	**–80.8**	**–76.8**	**–76.5**	**–81.0**	**–80.0**	**–80.5**
Receiver noise floor	dBm/MHz	–112.0	–112.0	–109.3	–111.4	–109.8	–105.0	–110.8
Required I/N	dB	–6.0	–6.0	–6.0	–6.0	–6.0	–6.0	–6.0
Safety margin	dB	6.0	6.0	0.0	0.0	0.0	0.0	0.0
Interference level	**dBm/MHz**	–124.0	–124.0	–115.3	–117.4	–115.8	–111.0	–116.8
Required attenuation	**dB**	**43.5**	**43.2**	**38.5**	**40.9**	**34.7**	**31.0**	**36.3**

The above results from a single base station into a radar receiver at one kilometre are recalculated using the cellular structure and aggregate power from the base stations at distances from 5.5 kilometres to 40 kilometres. The calculations have been performed for Radar 1 as this is the most critical.

For radar 1 the calculation of the spurious emissions using free space propagation provides aggregate interference power at the radar receiver of –93.32 dBm/MHz which is 30.68 dB above the threshold of –124.0 dBm/MHz (–6 dB I/N -6 dB safety factor).

This value is different to the required attenuation of –43.5 dB of the deterministic study because in the deterministic study there is no aggregation of power and the base station is fixed at one kilometre. In this rural environment there is no requirement to have a base station this close to the radar, in fact it is unwanted. The closest base station is positioned at 5.5 kilomeres distance to the radar to provide coverage for the UEs up to a distance of 500 metres from the radar.

At distances between 5.5 to 40 km free space propagation clearly is not a valid model even for base stations and the more suitable propagation model in Recommendation ITU-R P.452-14 is used. The model is producing propagation losses very close to Free Space propagation for the first 5 kilometres and only a slow roll off thereafter so a very pessimistic model compared to other models.

Recalculating the spurious emissions using Recommendation ITU-R P.452-14 propagation model at 0.001% time and aggregate power provides –87.3 dBm/MHz at the radar receiver or 36.7 dB above the threshold of -124.0 dBm/MHz (–6 dB I/N, –6 dB safety factor).

Taking the above into account and under the above assumptions all base stations would need to have spurious emissions 20 dB better than the generic specification in the radar frequency range and the base stations within 65 kilometres of a radar would need to be coordinated and be required to have further improved spurious emissions specification or an additional transmitter chain filter installed, or both, according to the distance to the radar; this however is a relatively trivial matter that can be part of normal site engineering.

4.1.2 Single IMT rural base station impact on radar IF selectivity (no mitigation) at 1 km separation distance, obtained from the deterministic study.

The calculation of the required additional attenuation when considering the suppression of the IMT base station wanted signal by the radar IF selectivity is shown in Table 3. The required additional attenuation is calculated for a frequency offset of 10 MHz.

TABLE 3

Radar IF Selectivity rejection of IMT base station transmission

	Units	Radar 1	Radar 2	Radar 3	Radar 4	Radar 5	Radar 6	Radar 7
Base station transmit power	dBm/MHz	36.0	36.0	36.0	36.0	36.0	36.0	36.0
Base station feeder loss	dB	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Base station antenna gain	dBi	18.0	18.0	18.0	18.0	18.0	18.0	18.0
Relative base station antenna gain	dB	0	0	0	0	0	0	0
Free space path loss for 1 km	dB	95.0	95.0	95.0	95.0	95.0	95.0	95.0
Radar antenna gain	dBi	34.5	34.2	38.2	38.5	34	35	34.5
Radar relative height loss	dB	0	0	0	0	0	0	0
Radar feeder loss	dB	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Polarisation Loss	dB	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Power at the receiver front-end	**dBm/MHz**	**–14.5**	**–14.8**	**–11.8**	**–11.5**	**–15.0**	**–14.0**	**–14.5**
Receiver noise floor	dBm/MHz	–112.0	–112.0	–109.3	–111.4	–109.8	–105.0	–110.8
Required I/N	dB	–6.0	–6.0	–6.0	–6.0	–6.0	–6.0	–6.0
Safety margin	dB	6.0	6.0	0.0	0.0	0.0	0.0	0.0
IF selectivity at 10 MHz frequency offset (FO)	dB	112.4	116.5	57.2	96.7	94.9	108.3	98.0
Acceptable interference level at 10 MHz FO	**dBm/MHz**	**-11.6**	**-7.5**	**-58.1**	**-20.7**	**-20.9**	**-2.7**	**-18.8**
Required attenuation at 10 MHz FO	**dB**	**-2.9**	**-7.3**	**47.3**	**10.2**	**5.8**	**-11.4**	**4.2**

Recalculating the IF selectivity for radar 1 using free space propagation and aggregate interference power provides –122.74 dBm/MHz at the radar receiver, 1.26 dB above the threshold of –124 dBm/MHz (–6 dB I/N –6 dB safety factor). Again, the variation in the result to the deterministic study is due to distances and aggregation of interference power.

Using Recommendation ITU-R P.452-14 propagation model at 0.001% time and aggregate power provides –116.71dBm/MHz, 7.29 dB above the threshold of –124.0 dBm/MHz (–6 dB I/N –6 dB safety factor).

This could be mitigated by an improved roll-off of the IF filter but as the radar receiver also need improved 1 dB compression point characteristic a RF front end filter is required. This filter will also provide the additional selectivity required. Assuming an RF front end filter with 28.5 dB attenuation at more than 5 MHz frequency separation will provide – 144.51 dBm/MHz at the radar receiver or 20.51 dB below the threshold of –124.0 dBm/MHz (–6 dB I/N –6 dB safety factor).

Radar 3 will in addition to the RF front end filter also require a 100 dB/decade IF filter or replace by a more spectrum efficient radar.

4.1.3 Single IMT rural base station impact on radar 1 dB compression point (no mitigation) at 1 km separation distance, obtained from the deterministic study.

The calculation of the required additional attenuation when considering the impact of the IMT base station wanted signal on the 1 dB compression point of a radar receiver is shown in Table 4.

TABLE 4

IMT base station wanted emissions compared with input 1 dB compression point of a radar receiver (-10 dBm 1 dB compression point assumed)

	Units	Radar 1	Radar 2	Radar 3	Radar 4	Radar 5	Radar 6	Radar 7
Base station transmit power	dBm	46	46	46	46	46	46	46
Base station feeder loss	dB	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Base station antenna gain	dBi	18.0	18.0	18.0	18.0	18.0	18.0	18.0
Free space path loss for 1 km	dB	95.0	95.0	95.0	95.0	95.0	95.0	95.0
Radar antenna gain	dBi	34.5	34.2	38.2	38.5	34	35	34.5
Radar relative height loss	dB	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Radar feeder loss	dB	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Polarisation Loss	dB	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Power at the receiver front-end	**dBm**	**-4.5**	**-4.8**	**-0.8**	**-0.5**	**-5.0**	**-4.0**	**-4.5**
Radar 1 dB compression point (assumed)	**dBm**	-10.0	-10.0	-10.0	-10.0	-10.0	-10.0	-10.0
Safety margin	dB	6.0	6.0	0.0	0.0	0.0	0.0	0.0
Acceptable interference level	**dBm**	**-16.0**	**-16.0**	**-10.0**	**-10.0**	**-10.0**	**-10.0**	**-10.0**
Required attenuation	**dB**	**11.5**	**11.2**	**9.2**	**9.5**	**5.0**	**6.0**	**5.5**

Recalculating the 1 dB compression point for Radar 1 using free space propagation and aggregate interference power provides –16.59dBm at the radar receiver, 0.59 dB below the threshold of –16 dBm (1 dB compression point –6 dB safety factor). Again, the variation in the result to the deterministic study is due to distances and aggregation of interference power.

Using Recommendation ITU-R P.452-14 propagation model at 0.001% time, aggregate power provides –10.57 dBm, 5.43 dB above the threshold of -16 dBm (1 dB compression point –6 dB safety factor).

Mitigating this requires the installation of a RF front end filter in the radar receiver and assuming the same filter used to mitigate the selectivity the calculation now provides –42.56 dBm, 26.56 dB below the threshold of –16 dBm (1 dB compression point –6 dB safety factor).

4.2 IMT UE calculations

4.2.1 IMT UE MCL calculations for spurious emissions from a single UE at 500 m separation distance of the radar, obtained from the deterministic study

The calculation of the required additional attenuation when considering the impact of IMT UE spurious emissions on the pass-band of a radar receiver is shown in Table 5.

TABLE 5

IMT user equipment spurious emissions falling in the pass-band of a radar receiver

	Units	**Radar 1**	**Radar 2**	**Radar 3**	**Radar 4**	**Radar 5**	**Radar 6**	**Radar 7**
UE spurious emission limit	dBm/MHz	–30.0	–30.0	–30.0	–30.0	–30.0	–30.0	–30.0
UE antenna gain	dBi	–3.0	–3.0	–3.0	–3.0	–3.0	–3.0	–3.0
UE body loss	dB	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Free space path loss for 500 m	dB	89.0	89.0	89.0	89.0	89.0	89.0	89.0
Radar antenna gain	dBi	34.5	34.2	38.2	38.5	34	35	34.5
Relative gain (3° below max)		–10.0	–10.0	–10.0	–10.0	–10.0	–10.0	–10.0
Radar feeder loss	dB	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Polarisation loss	dB	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Power at the receiver front-end	**dBm/MHz**	**–106.5**	**–106.8**	**–102.8**	**–102.5**	**–107.0**	**–106.0**	**–106.5**
Receiver noise floor	dBm/MHz	–112.0	–112.0	–109.3	–111.4	–109.8	–105.0	–110.8
Required I/N	dB	–6.0	–6.0	–6.0	–6.0	–6.0	–6.0	–6.0
Safety margin	dB	6.0	6.0	0.0	0.0	0.0	0.0	0.0
Interference level	**dBm/MHz**	**–124.0**	**–124.0**	**–115.3**	**–117.4**	**–115.8**	**–111.0**	**–116.8**
Required attenuation	**dB**	**17.5**	**17.2**	**12.5**	**14.9**	**8.7**	**5.0**	**10.3**

4.2.2 IMT UE MC calculations for spurious emissions of multiple UE in the IMT system

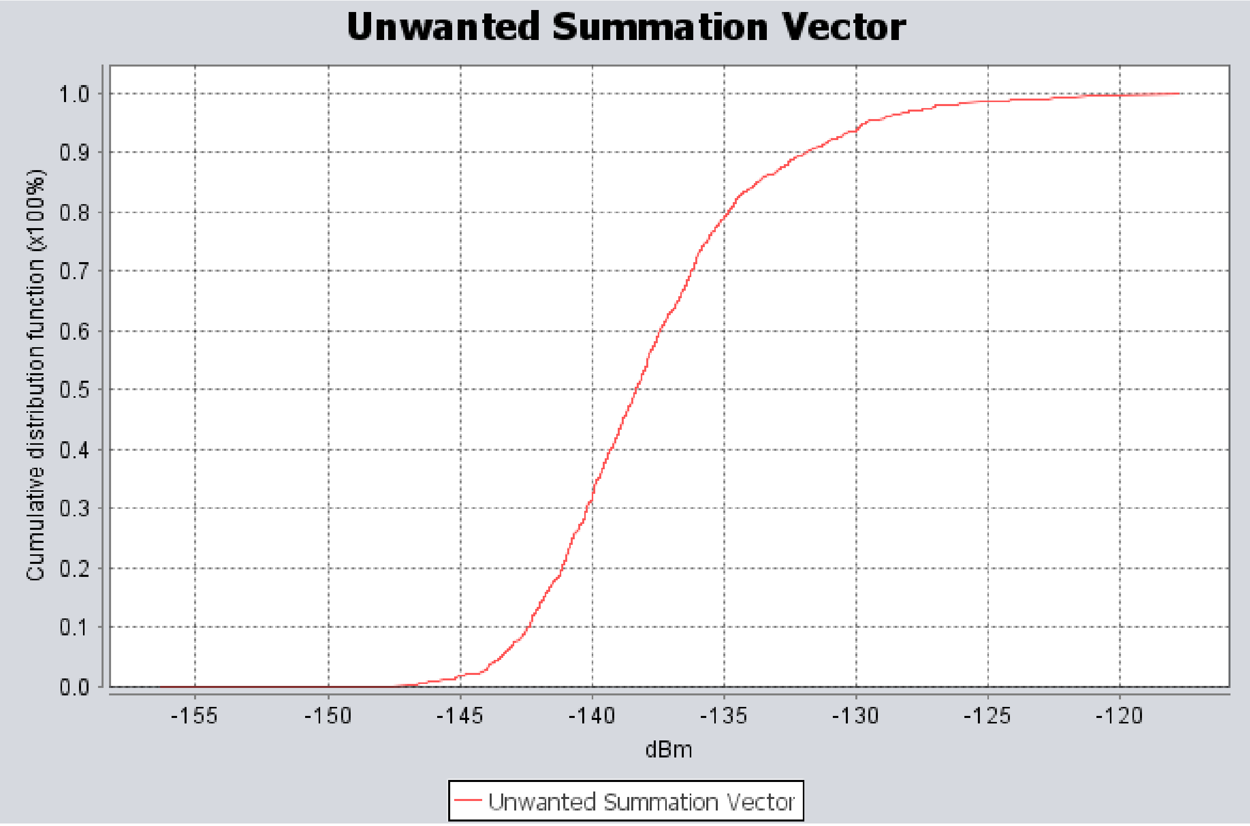
The above results from a single UE into a radar receiver at 500 metres is recalculated using the cellular structure from above and aggregate power from randomly located UEs at distances from 500 metres to 40 kilometres (the size of the simulated IMT system). The calculations have been performed for Radar 1 as this is the most critical ATC radar.

In the deterministic study shown above the required attenuation of spurious emissions at 500 metres distance between an UE and the radar is 17.5 dB for the most critical, Radar 1.

The simple but costly solution would be just to ‘tighten’ the spurious emissions requirements of the UE by the required 17.5 dB. The result of this is shown below in figure 4 as a ‘bench mark’.

FIGURE 2

UEs with -47.5 dBm/MHz spurious emissions, free space propagation and aggregate power of UEs in the radar beam pointing into the IMT system



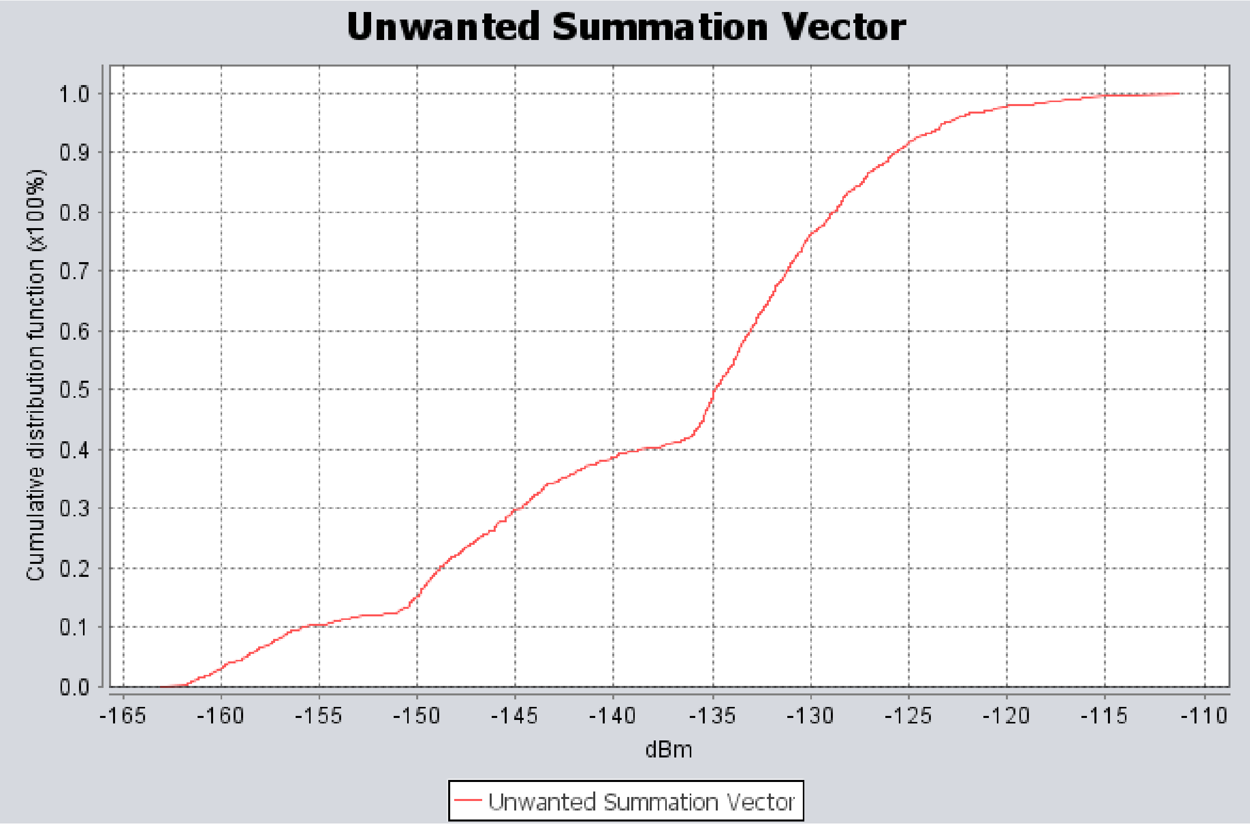
The amount of events where the aggregate interference power in this scenario is exceeding the threshold of –124.0 dBm/MHz (–6 dB I/N and 6 dB ATC safety factor) is 1.0 % with 0.2 % of events exceeding the I/N threshold by around 1.5 dB (the maximum value)

The scenario above assumes free space propagation to be valid model at distances of up to 40 kilometres and that all 570 active UE are transmitting continuously, of course, neither of these two requirements is realistic or possible.

So if we first look at the activity of the UE e.g. in a voice over IP call. The data rate in uplink is more than ten times what is required to support a VoIP call and of course there are also no transmissions of data during any silence or listening which accounts for more than half the time so even with overhead for the link maintenance this easily justifies a one in twenty probability of the UE transmitting during the very short period of time when the main radar beam sweeps past. Also for data applications, any particular UE will only be transmitting on the uplink for a small percentage of the time. Transmissions over IMT for data applications will generally be comprised of a number of relatively short bursts, most data applications require transmission of significantly more data on the downlink than on the uplink, and even when a UE is engaged in an active data session it will not be transmitting continuously. 10% is a highly conservative figure for the probability that an UE will be transmitting at any particular time. For practical reasons we have used this more conservative one in ten probability (correlation factor) in the following scenarios below, Figure 3 shows the impact of this on the ‘unmitigated’ baseline scenario.

FIGURE 3

UEs with standard -30 dBm/MHz spurious, free space propagation, correlation factor and aggregate of UE in the radar beam pointing into the IMT system

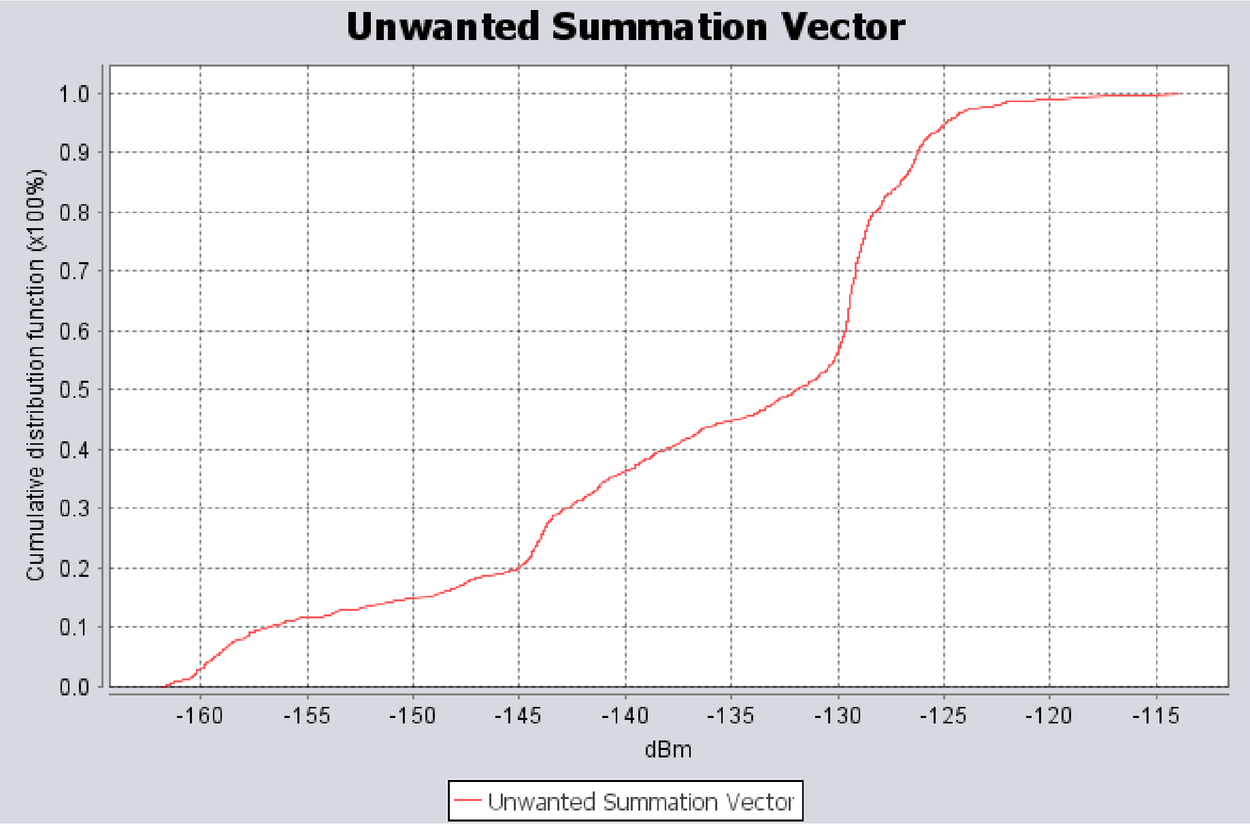


The amount of events where the aggregate interference power in this scenario is exceeding the threshold of –124.0 dBm/MHz (–6 dB I/N and 6 dB ATC safety factor) is 8.8 % with 3 % exceeding the I/N threshold

Next we look at the propagation to include the aggregate powers from terminals at up to 40 kilometres distance. Clearly, free space propagation is not a valid model at these distances and a more appropriate propagation model to deal with this is Recommendation ITU-R P.452-14. The result of this is shown below in Figure 4.

FIGURE 4

UEs with standard -30 dBm/MHz spurious, Recommendation ITU-R P.452-14 propagation model at 0.001% time, correlation factor and aggregate of UE in the radar beam pointing into the IMT system



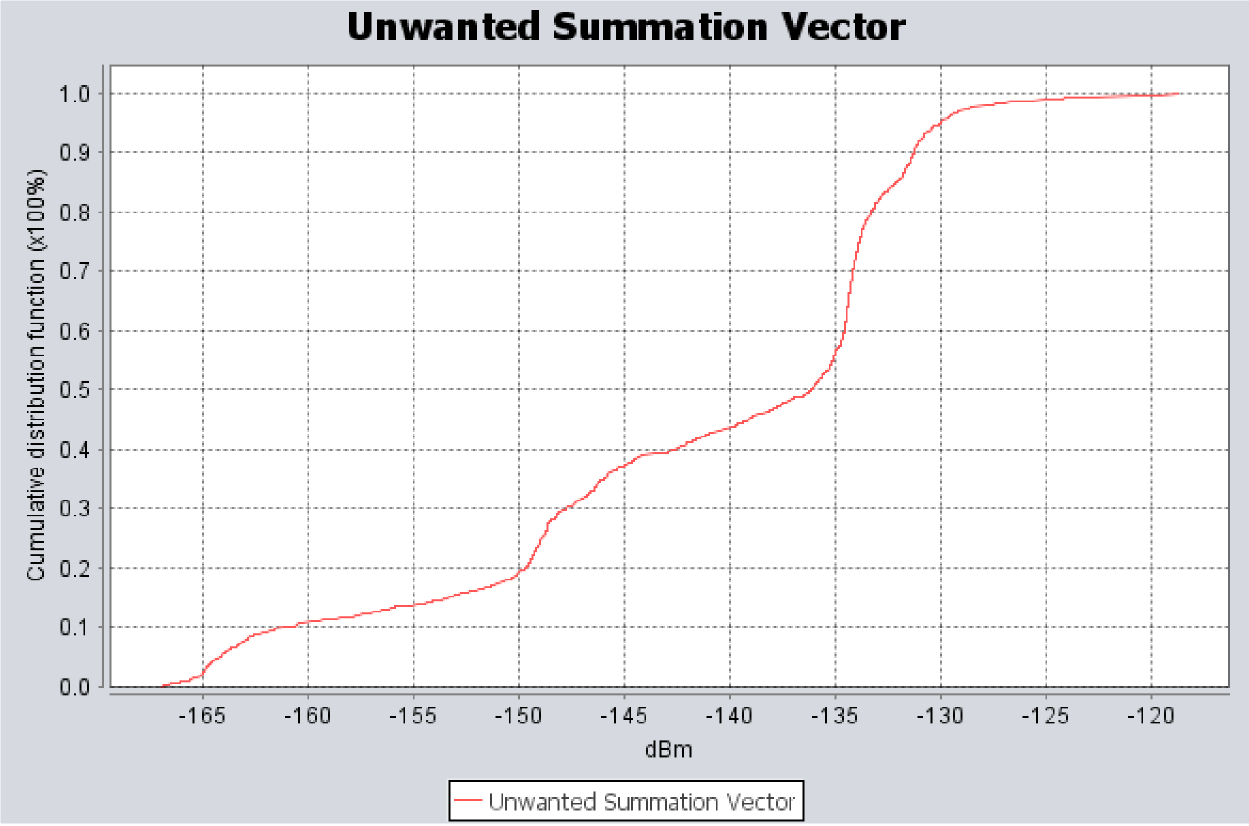
The amount of events where the aggregate interference power in this scenario is exceeding the threshold of –124.0 dBm/MHz (–6 dB I/N and 6 dB ATC safety factor) is 6 % with 1.3 % exceeding the I/N threshold

With the more realistic conditions interference is still exceeding the bench mark and it is clear that under these assumptions the spurious emissions from the UE would need to be reduced to an acceptable level.

In the following two scenarios the spurious emissions are reduced by 5 dB (Figure 5) and 10 dB (Figure 6) respectively.

FIGURE 5

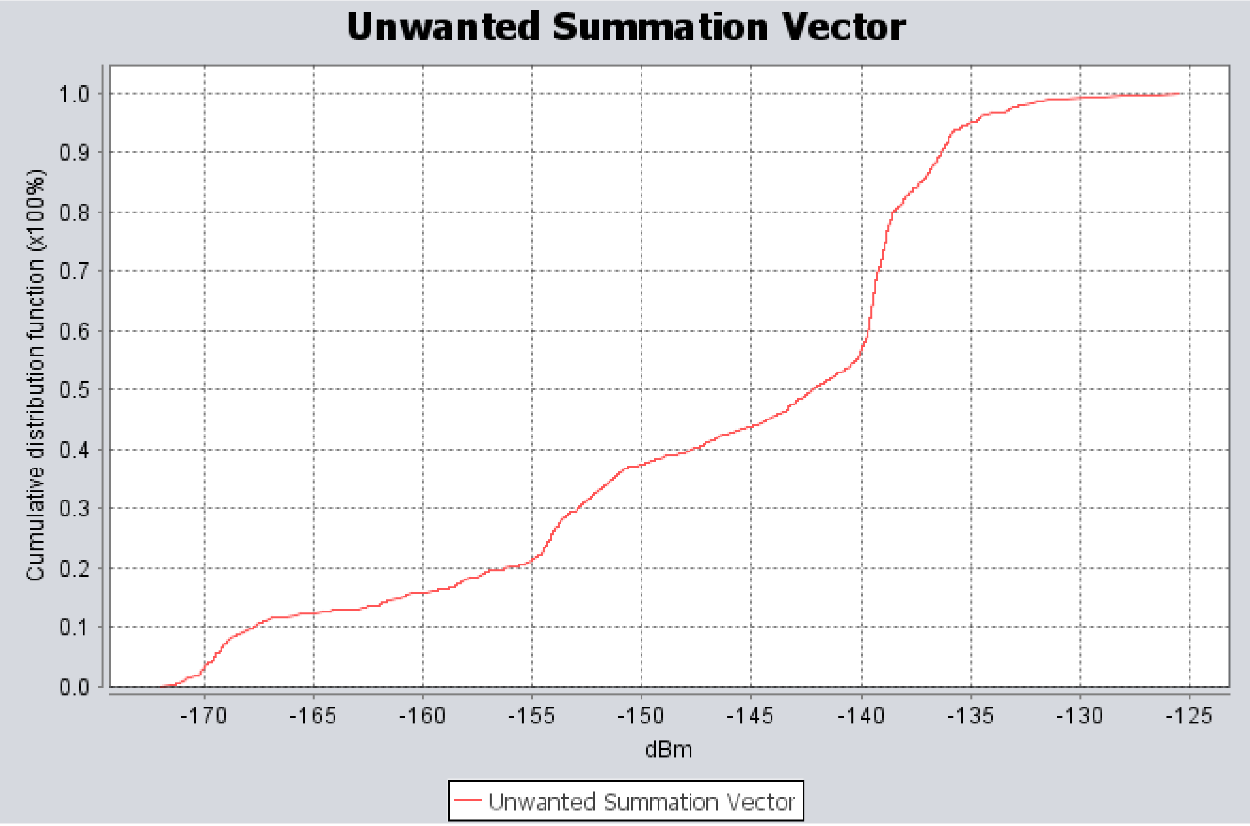
UEs with -35 dBm/MHz spurious, correlation factor, with propagation model Recommendation ITU-R P.452-14 at 0.001 % time and aggregate of UE in the radar beam pointing into the IMT system



The amount of events where the aggregate interference power in this scenario is exceeding the threshold of –124.0 dBm/MHz (-6 dB I/N and 6 dB ATC safety factor) is 0.7 % with 0.5 % exceeding the I/N threshold, mean value –141.69 dBm/MHz

FIGURE 6

UEs with -40 dBm/MHz spurious, correlation factor, propagation model Recommendation ITU-R P.452-14 at 0.001 % time and aggregate of UE in the radar beam pointing into the IMT system



The amount of events where the aggregate interference power in this scenario is exceeding the threshold of –124.0 dBm/MHz (–6 dB I/N and 6 dB ATC safety factor) is 0.2 % with 0 % exceeding the I/N threshold, mean value –147.02 dBm/MHz

5 Results

A summary for Radar 1 is presented in this section for the ‘baseline’ results and results where the application of various mitigation techniques is assumed.

Table 6 below is the results for IMT base stations:

TABLE 6

Base stations, downlink Attenuation required, negative values indicates compatibility	Spurious emissions	Radar IF selectivity	Radar 1 dB comp
1 km distance, free space propagation	43.5 dB	-2.9 dB	11.5 dB
Aggregate interference power, Recommendation ITU-R P.452-14 propagation model at 0.001% time	36.7 dB	7.29 dB	5.43 dB
Aggregate interference power, Recommendation ITU-R P.452-14 propagation model at 0.001% time. Mitigation assumed; radar front end RF filter (28.5 dB at ≥ 5MHz Δf), all base stations 20 dB better than the generic specification, coordination of base stations within 65 km of the radar and site engineering for spurious emissions on these. There is plenty of scope for further mitigation in the few cases where a base station is closer to radar than the 5.5 km used, see Section 3.2. Radar 3 either needs replacing with spectrum efficient radar or additionally a 100 dB/decade IF filter and be moved to a frequency providing at least 20 MHz frequency offset to IMT base stations		-20.51 dB	-26.56 dB

Table 7 below is the results for IMT user equipment.

TABLE 7

UE uplink	Spurious emissions	
500 m distance, free space propagation (required attenuation)	17.5 dB	
Radar interference criteria for Monte Carlo simulations (The figures below give % of events exceeding the interference criteria)	-125.1 dBm (-6 dB I/N and 6dB safety factor)	-119.1 dBm (-6 dB I/N)
Aggregate interference power, free space propagation, spurious –47.5 dBm/MHz ‘bench mark’ scenario	1 %	0.2 %
Aggregate interference power, correlation factor, Recommendation ITU-R P.452-14 propagation model at 0.001% time, spurious emissions –30 dBm/MHz	6 %	1.3 %
Aggregate interference power, correlation factor, Recommendation ITU-R P.452-14 propagation model at 0.001% time. Mitigation applied; UE spurious emissions -35 dBm/MHz	0.7%	0.5%
Aggregate interference power, correlation factor, Recommendation ITU-R P.452-14 propagation model at 0.001% time. Mitigation applied; UE spurious emissions -40 dBm/MHz	0.2 %	0 %

Discussion of the results

A way of relating to the 0.2 % of events exceeding the 6 dB safety factor with 0 % of events exceeding the I/N value is; for any given direction of the radar antenna, out of 1 000 rotations of the radar antenna sweeping past this direction there are 2 instances where an interfering signal is present which will exceed the safety factor threshold of 6 dB, it will however have no impact on the radar performance because the I/N threshold has not been exceeded.

6 Conclusions of Study 8

This study has been produced as a supplement to the deterministic studies already presented. The study provides an analysis of what and how much mitigation is likely to be required for an IMT system and radar to coexist with a 10 MHz frequency offset under normal operating conditions.

From the simulations performed it is likely that the use of the band for uplink will require UE with improved spurious emissions of around 10 dB lower than the generic specification. For uplink there are no requirements for any mitigation to the radars even if these have significantly worse specifications than assumed in this study.

For downlink operation all base stations are likely to require spurious emissions in the radar band around 20 dB below the generic specification. There is also likely to be a need for coordination of the base stations within a distance of around 65 kilometres of the radar and within this range to have further improved spurious emissions, a transmitter chain filter added or both. The radars may require a RF front end filter to improve the 1 dB compression point; this filter will also provide the additional attenuation needed for the IF selectivity, apart from Radar 3 which in addition will require an IF filter with a roll-off of around 100 dB/decade. For the few cases where a base station is close to the radar, there are many more potential mitigating techniques available as can be seen in section 3.2.

In summary: The results of this study indicate that it is possible to operate IMT uplink on the non-co-channel basis provided a 10 MHz frequency offset is implemented and the UE have spurious emissions in the radar band around 10 dB lower than the generic spurious emissions specification.

It is also possible to operate IMT downlink in the band; in this case however a RF front end filter is required for the radar and around 20 dB improved spurious emissions specification for all base stations compared with the generic specification. Coordination of the IMT base stations within around 65 kilometres of radar is also likely to be required because these may need further improved spurious emissions. Also, Radar 3 is likely to require an improved IF filter.

In principle, it would be possible to operate IMT uplink in the non-co-channel with a frequency offset smaller than 10 MHz. This however would require use of much more of the mitigation techniques mentioned in 3.2, filtering of most radars and the UE to have further reduced spurious emissions which may not be commercially viable.