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Annex 30 to Joint Task Group 4-5-6-7 Chairman's Report

WORKING DOCUMENT TOWARDS PRELIMINARY DRAFT NEW REPORT ITU-R M.[RADAR2700]

Studies on the impact of IMT use on radar systems in the frequency band 2 700-2 900 MHz

1 Overall consideration of results of studies

The attachments to this document represent submissions to JTG, and have not been reviewed in detail or agreed.

Several studies have been carried out with respect to the frequency band 2 700-2 900 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 2 700-2 900 MHz frequency band or a portion thereof by the mobile service for the implementation of 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 the mobile service into the 2 700-2 900 MHz frequency band, 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 2 700-2 900 MHz frequency band 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 band 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 band between 2 700-3 100 MHz.

Attachment 1:	Co-existence of mobile broadband systems and radars in the frequency band 2 700-2 900 MHz
Attachment 2:	Sharing between IMT systems and radars in the 2 700-2 900 MHz band
Attachment 3:	Updated study on sharing between IMT systems and radars in the 2 700-2 900 MHz band
Attachment 4:	Sharing between IMT systems and radars in the 2 700-2 900 MHz band
Attachment 5:	Analysis of required mitigation for IMT systems and radars to share the 2 700-2 900 MHz band
Attachment 6:	Sharing between IMT-Advanced and radiodetermination systems in the band 2 700-2 900 MHz
Attachment 7:	Necessary guard band for compatibility between radiolocation systems and mobile broadband systems in the 2 700-2 900 MHz ban
Attachment 8:	Co-existence of mobile broadband systems and radars in the frequency band 2 700-2 900 MHz
Attachment 9:	Studies on the impact of IMT interference on radar systems with pulse compression operating in the frequency range 2 700-3 100 MHz

ATTACHMENT 1

Co-existence of mobile broadband systems and radars in the frequency band 2 700-2 900 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 2 700-2 900 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.

ATTACHMENT 2

Sharing between IMT systems and radars in the 2 700-2 900 MHz band

1 Assumptions

Required separation distances were calculated for radars which technical characteristics and protection criteria were extracted from Recommendations ITU-R M.1460 and ITU-R M.1464. They were defined for the case of interference from single IMT base station and IMT base stations network. 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. 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 radio paths. Influence of the tropospheric scattering to the separation distances were taken into account. The estimation assumed that ground radar antenna altitude was 10 metres and IMT base station antenna altitude was 30 metres. The results were obtained assuming a cold sea radio path.

The following interference scenarios were considered in relation to aggregate interference. They were:

– Scenario 1 as shown in Figure 1. The scenario assumes that the IMT system transmitters are deployed behind the line located at a distance R from the ground-based radar. The radar receiver is deployed in the immediate vicinity to a town surrounded with a suburban area and a rural one. The IMT transmitters are deployed in those areas with station density and antenna heights corresponding to the data shown in Table 1. The radar receiver antenna height assumed to be 10 metres. The estimation also assumed an urban area of 30 km^2 surrounded with suburban (30 km^2) and rural (90=120-30 km^2) areas;

– Scenario 2 as shown in Figure 2. The scenario also assumes that the IMT system transmitters are deployed behind the line located at a distance R from the ground-based radar. However contrary to Scenario 1 they are deployed in a rural area with density corresponding to the data for the cell radius as shown in Table 1. Assumed height of the IMT base station antenna suspension is 30 metres and that of AMT ground-based receiver antenna is 10 metres.

FIGURE 1

Scenario 1 of interference effect on the ground-based radar

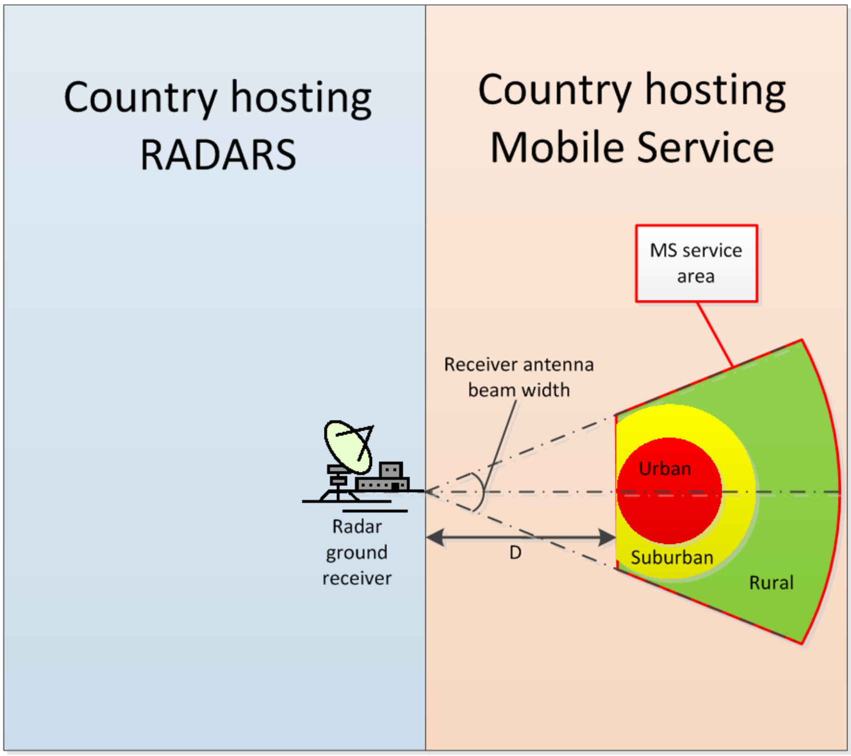
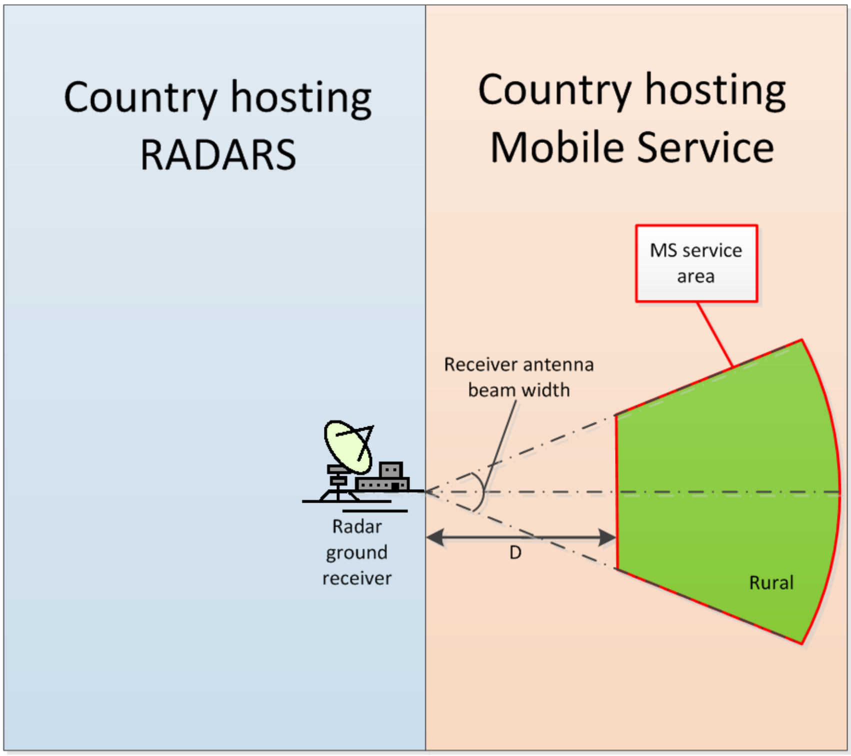


FIGURE 2

Scenario 2 of interference effect on the ground-based radar



2 Methodology

The acceptable interference level was calculated using the following equation:

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

where:

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

$\left(I/N\right)_{acc}$ – 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 – operation wavelength, m.

It was taken into consideration that in most cases operational receiver passband of considered radars 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.

Necessary separation distances were defined for estimated values of E_{acc} and $e.i.r.p._{eff}$ using propagation model from Recommendation ITU-R P.1546-4.

3 Results

The required protection distances for the radars were estimated for all above mentioned radar types considering interference from IMT transmitters using signals of 5 MHz bandwidth. The considered estimations took into consideration directional radar performances discussed in Recommendation ITU-R M.1464.

Figure 3 below reflects interference-to-noise ratio for the radars under consideration as a function of distances to the area where the IMT transmitters are deployed assuming a land radio path. Herein and hereafter curve A corresponds to Radar A; curve B – to Radar B; curve C – to Radar C; curve E – to Radar E; curve F – to Radar F; curve G – to Radar G; curve H – to Radar H; curve I – to Radar I and curve J – to Radar J. Figure 4 presents interference-to-noise ratio for the radars concerned as a function of a distance to the deployment area for IMT transmitters as gained in relation to Scenario 2 for a land radio path.

FIGURE 3

Interference-to-noise ratio as a function of a distance between the radar and the IMT network deployment area for Scenario 1 and for a land radio path

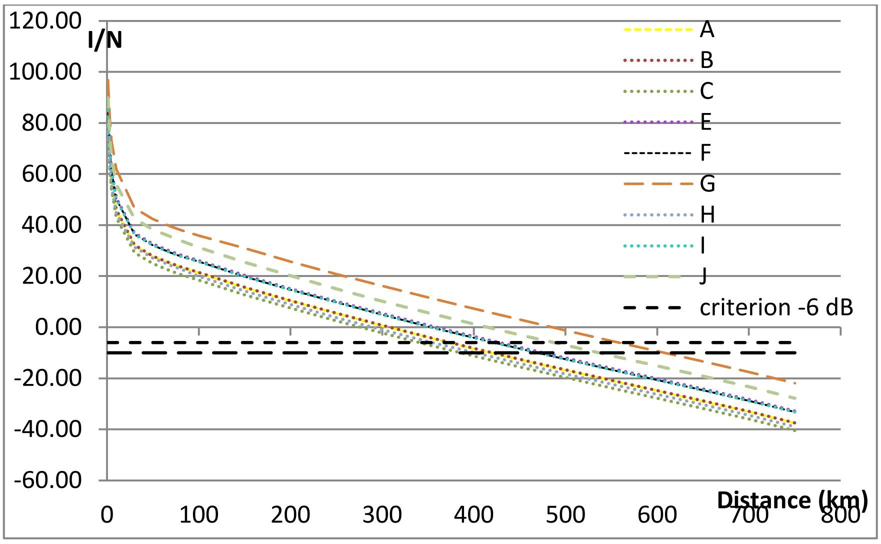


FIGURE 4

Interference-to-noise ratio as a function of a distance between the radar and the IMT network deployment area for Scenario 2 and for a land radio path

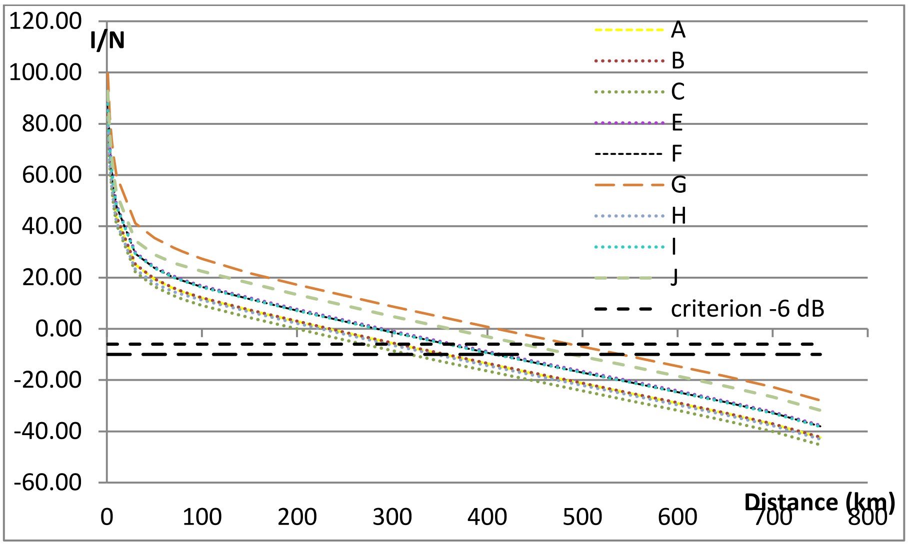


Figure 5 shows interference-to-noise ratio for the radars concerned as a function of a distance to the deployment area for IMT transmitters as gained in relation to Scenario 1 for a mixed radio path. Figure 6 reflects interference-to-noise ratio for the radars concerned as a function of a distance to the deployment area for IMT transmitters as gained in relation to Scenario 2 for a mixed radio path.

FIGURE 5

Interference-to-noise ratio as a function of a distance between the radar and the IMT network deployment area for Scenario 1 and for a mixed radio path

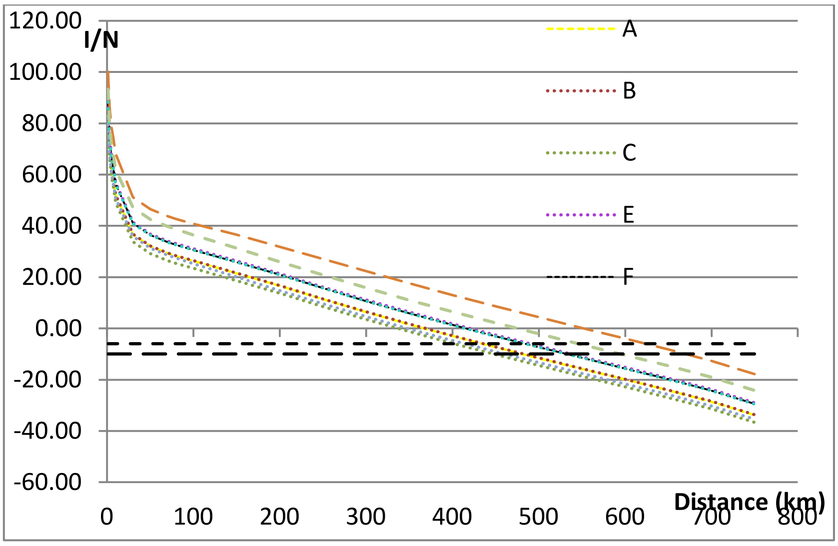
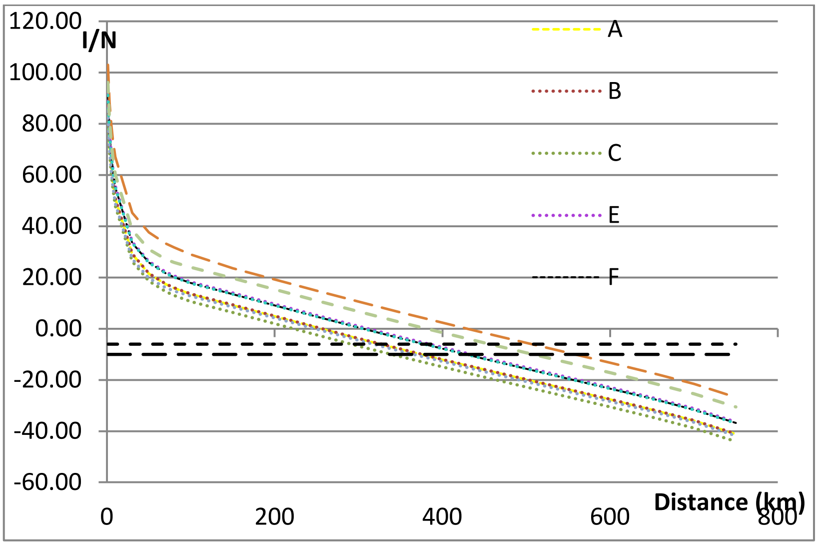


FIGURE 6

Interference-to-noise ratio as a function of a distance between the radar and the IMT network deployment area for Scenario 2 and for a mixed radio path



The curves reflected in Figures 3-6 were used for estimating the protection distances shown in Table 1.

TABLE 1

Protection distances for radiodetermination radars in the frequency band 2 700-2 900 MHz

	Land path		**Mixed path**	
	Scenario 1	**Scenario 2**	**Scenario 1**	**Scenario 2**
Radar A	420	350	480	370
Radar B	420	350	486	378
Radar C	380	310	450	340
Radar E	480	410	540	440
Radar F	470	410	530	430
Radar G	600	540	670	580
Radar H	400	350	460	370
Radar I	410	360	420	380
Radar J	480	440	540	460

Analysis of the gained results shows that accounting for aggregate interference would result in significant increasing the required protection distances ensuring interference-free operation of the radars in the frequency band 2 700-2 900 MHz. Based on that a conclusion may be drawn that it would be extremely difficult to provide for compatibility of the IMT systems and the radars in the band concerned.

The conducted studies showed that to provide for sharing between the IMT networks and Radiodetermination radars with regards to aggregate interference could require protection distances exceeding 600 kilometres for land radio paths and 670 kilometres for mixed radio paths. Based on that a conclusion may be drawn that the IMT networks cannot operate effectively in the frequency band 2 700-2 900 MHz.

4 Detailed calculations of single interference source

4.1 Introduction

The sphere of [JTG 4-5-6-7] activity includes consideration of potential frequency bands appropriate for compatibility studies with IMT systems. The frequency band 2 700-2 900 MHz is one of the proposed candidate bands [(Annex 8 to Document 4-5-6-7/113) *Note Cannot be referred to in a DNR*]. In addition some Administrations suggested that feasibility of implementing the IMT systems both in parts of the frequency band 2 700-2 900 MHz and in parts of the frequency band 2 900-3 100 MHz should be analysed.

At the latest [JTG 4-5-6-7] meeting Russian Federation (RF) presented [Document 4-5-6-7/158 *Note cannot be referred to in a DNR*], which proposed to avoid consideration of the frequency band 2 700-3 100 MHz as a candidate one for IMT systems. The proposal was based on the results of previous studies which concluded that sharing between IMT systems and radars operating in the frequency band 2 700-3 100 MHz would be extremely difficult.

To confirm the above proposal RF conducted additional studies in feasibility of sharing between IMT systems and radiolocation systems in the frequency band 2 700-3 100 MHz. The results of those studies are described below.

4.2 Technical characteristics and protection criteria for radars in the frequency band 2 700-3 100 MHz

The frequency band 2 700-3 100 MHz is used by different types of radars evenly accommodated in the whole band. Characteristics of those radars may be found in Recommendations ITU-R M.1460 and ITU-R M.1464. Table 1 below shows extracted from those Recommendations technical characteristics of aeronautical radionavigation radars and meteorological radars. Table 2 presents technical characteristics of government radiolocation radars reflected in the above Recommendations ITU-R. Table 3 contains technical characteristics of ship-borne and land-based radiolocation radars as extracted from Recommendation ITU-R M.1460. The above mentioned technical characteristics were used for calculations.

TABLE 2

Technical characteristic of aeronautical radionavigation radars and meteorological radars operating in the frequency band 2 700-3 100 MHz (as described in Recommendation ITU-R M.1464)

	Aeronautical radionavigation radars					**Meteorological radars**	
Type	**Radar A**	**Radar B**	**Radar C**	**Radar E**	**Radar F**	**Radar G**	**Radar H**
Operation frequency range, MHz	2 700-3 100					2 700-3 000	2 700-2 900
Receiver gain, *Grec*, dBi	33.5	33.5	34	34.3	33.5	45.7	38.0
Receiver noise figure, *NF*, dB	4	4	3.3	2.1	2.0	630	500
Receiver pass band, Δ*F*, kHz	5 000	653	15 000	1 200	4 000	2.1	9.0
Protection criterion, *I/N*, dB	–10						

TABLE 3

Technical characteristic of generic Government radiolocation radars operating in the frequency band 2 700-3 400 MHz (as described in Recommendation ITU-R M.1464)

Type	Radar I	Radar J
Operation frequency range, MHz	2 700-3 100	2 700-3 100
Receiver gain, *Grec*, dBi	33.5	40
Receiver noise figure, *NF*, dB	2	1.5
Receiver pass band, Δ*F*, kHz	3 500	10 000
Protection criterion, *I/N*, dB	–6	

TABLE 4

Technical characteristics of ship-borne radiolocation radars and land-based radiolocation radars operating in the frequency band 2 900-3 100 MHz (as described in Recommendation ITU-R M.1460)

	Ship-borne radiolocation radars	Land-based radiolocation radars		
Type	**Radar No. 1**	**Radar No. 4**	**Radar No. 5**	**Radar No. 6**
Operation frequency range, MHz	2 910–3 100.5	2 905–3 080	2 901.5–3 098.4	2 900–3 100
Receiver gain, *Grec*, dBi	37	41	38	36.7
Receiver noise figure, *NF*, dB	–	–	–	–
Receiver noise temperature, *Tn*, K	–	–	–	–
Receiver pass band Δ*F*, kHz	500	350	1 600	1 100
Noise level, dBm	–109	–116	–105	–105
Protection criterion, *I/N*, дБ	–6			

4.3 Potential technical characteristics of mobile stations in the frequency band 2 700-3 100 MHz

The [third JTG 4-5-6-7 meeting] discussed technical characteristics of IMT systems in different frequency bands. [Those characteristics compiled by WP 5D were presented in Document 4-5-6-7/236 *Note cannot be referred to in a DNR*.] [The document was used for preparing Annex 2 to JTG 4-5-6-7 Chairman's Report (Document 4-5-6-7/242). *Note cannot be referred to in a DNR*] which contained technical and operational characteristics presented by [relevant] ITU-R [Working Parties] for using in studies related to feasibility of compatibility and frequency sharing. Table 5 below shows IMT system technical characteristics which were used in the studies concerned.

TABLE 5

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.

4.4 Estimation of protection distances required for radar receivers operating in the frequency band 2 700-3 100 MHz

Shown in Tables 1 – 3 characteristics of radar receivers were used for estimating an acceptable interference level at radar receiver front end. The acceptable 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 – operation wavelength, m.

Estimated values of acceptable interference power and associated values of maximum admitted interference field strength for the radar types under consideration are shown in Tables 6 – 8.

TABLE 6

Estimates of protection distances for radars operating in the frequency band 2 700-3 100 MHz without accounting tropospheric scattering

	Radar A	**Radar B**	**Radar C**	**Radar E**	**Radar F**	**Radar G**	**Radar H**
Receiver noise temperature, Tn, K	438	438	330	180	170	180	2 014
Receiver thermal noise, dBW	–135	–144	–132	–145	–140	–148	–139
Acceptable interference power, dBW	–145	–154	–142	–155	–150	–158	–149
Acceptable interference field strength, dB(µV/m)	–5.9	–14.7	–2.8	–16.7	–11.0	–30.9	–13.7
	Protection distances						
Interference bandwidth, MHz	5; 10						
$e.i.r.p._{eff}$, dBW	25.0	16.2	25.0	18.8	24.0	16.0	15.0
Land path, km	193	193	165	231	227	> 324	172
Sea path, km	572	572	534	631	624	> 773	545
Interference bandwidth, MHz	20						
$e.i.r.p._{eff}$, dBW	22.0	13.1	22.0	15.8	21.0	13.0	12.0
Land path, km	165	165	139	204	203	> 299	144
Sea path, km	526	523	506	589	586	> 728	509

TABLE 7

Estimates of protection distances for radars operating in the frequency band 2 700-3 100 MHz without accounting tropospheric scattering

	Radar I	**Radar J**
Receiver noise temperature, Tn, K	170	120
Receiver thermal noise, dBW	–141	–138
Acceptable interference power, dBW	–147	–144
Acceptable interference field strength, dB(μV/m)	–7.5	–11.0
	Protection distances	
Interference bandwidth, MHz	5	
$e.i.r.p._{eff}$, dBW	23.5	25.0
Land path, km	194	236
Sea path, km	572	637
Interference bandwidth, MHz	10	
$e.i.r.p._{eff}$, dBW	23.4	28.0
Land path, km	193	262
Sea path, km	572	678
Interference bandwidth, MHz	20	
$e.i.r.p._{eff}$, dBW	20.4	25.0
Land path, km	165	236
Sea path, km	534	637

TABLE 8

Estimates of protection distances for radars operating in the frequency band 2 700-3 100 MHz without accounting tropospheric scattering

	Radar No. 1	**Radar No. 4**	**Radar No. 5**	**Radar No. 6**
Receiver thermal noise, dBW	–139	–140	–135	–135
Acceptable interference power, dBW	–145	–146	–141	–141
Acceptable interference field strength, dB(μV/m)	–9.2	–14.2	–6.2	–4.9
	Protection distances			
Interference bandwidth, MHz	5; 10			
$e.i.r.p._{eff}$, dBW	15.0	13.5	20.1	18.4
Land path, km	168	164	151	123
	Radar No. 1	**Radar No. 4**	**Radar No. 5**	**Radar No. 6**
Sea path, km	500	532	513	478
Interference bandwidth, MHz	20			
	Radar No. 1	**Radar No. 4**	**Radar No. 5**	**Radar No. 6**
$e.i.r.p._{eff}$, dBW	12.0	10.4	17.0	15.4
Land path, km	108	135	122	99
Sea path, km	454	493	480	435

The technical characteristics of IMT stations presented in Table 4 were used for estimating the minimum separation distances for protection of radar receivers from interference caused by base stations of potential 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 in most cases operational receiver passband of considered radars 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 Tables 6 – 8.

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 radio paths. The estimation assumed that ground radar antenna altitude was 10 metres. The results of protection distance estimation are shown in Tables 6 – 8.

The results obtained show that the required protection distance related to interference of 5 MHz and 10 MHz bandwidth would vary from 123 to 324 kilometres for a land path and from 478 to 773 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 99 kilometres for a land path and 435 kilometres for a sea path.

It is worth mentioning that the protection distances shown in Tables 6 – 8 were estimated without accounting for tropospheric scattering therefore they would not provide a complete protection for radar systems from the interference concerned. Tables 9 – 11 below reflect the protection distance estimates accounting the tropospheric scattering.

TABLE 9

Estimates of protection distances for radars operating in the frequency band 2 700-3 100 MHz accounting tropospheric scattering

	Radar A	**Radar B**	**Radar C**	**Radar E**	**Radar F**	**Radar G**	**Radar H**
Receiver noise temperature, *Tn*, K	438	438	330	180	170	180	2014
Receiver thermal noise, dBW	–135	–144	–132	–145	–140	–148	–139
Acceptable interference power, dBW	–145	–154	–142	–155	–150	–158	–149
Acceptable interference field strength, dB(μV/m)	–5.9	–14.7	–2.8	–16.7	–11.0	–30.9	–13.7
	Protection distances						
Interference bandwidth, MHz	5; 10						
$e.i.r.p._{eff}$, dBW	25.0	16.2	25.0	18.8	24.0	16.0	15.0
Land path, km	257	256	227	303	298	415	234
Sea path, km	582	582	542	642	635	783	550
Interference bandwidth, MHz	20						
$e.i.r.p._{eff}$, dBW	22.0	13.1	22.0	15.8	21.0	13.0	12.0
Land path, km	228	228	200	273	268	385	209
Sea path, km	544	535	508	604	596	754	518

TABLE 10

Estimates of protection distances for radars operating in the frequency band 2 700-3 100 MHz accounting tropospheric scattering

	Radar I	**Radar J**
Receiver thermal noise, dBW	170	120
Acceptable interference power, dBW	–141	–138
Acceptable interference field strength, dB(µV/m)	–147	–144
Receiver thermal noise, dBW	–7.5	–11.0
	Protection distances	
Interference band width, MHz	5	
$e.i.r.p._{eff}$, dBW	23.5	25.0
Land path, km	258	308
Sea path, km	583	648
Interference band width, MHz	10	
$e.i.r.p._{eff}$, dBW	23.4	28.0
Land path, km	257	339
	Radar I	**Radar J**
Sea path, km	582	687
Interference band width, MHz	20	
$e.i.r.p._{eff}$, dBW	20.4	25.0
Land path, km	228	308
Sea path, km	544	648

TABLE 11

Estimates of protection distances for radars operating in the frequency band 2 700-3 100 MHz accounting tropospheric scattering

	Radar No. 1	**Radar No. 4**	**Radar No. 5**	**Radar No. 6**
Receiver thermal noise, dBW	–139	–140	–135	–135
Acceptable interference power, dBW	–145	–146	–141	–141
Acceptable interference field strength, dB(μV/m)	–9.2	–14.2	–6.2	–4.9
	Protection distances			
Interference bandwidth, MHz	5; 10			
$e.i.r.p._{eff}$, dBW	15.0	13.5	20.1	18.4
Land path, km	195	227	214	187
Sea path, km	500	542	524	488
Interference bandwidth, MHz	20			
$e.i.r.p._{eff}$, dBW	12.0	10.4	17.0	15.4
Land path, km	169	198	186	162
Sea path, km	464	504	488	454

Analysis of data presented in Tables 8 – 11 shows that accounting for the tropospheric scattering results in significant increasing of the required protection distances. As for interference of 5 MHz and 10 MHz bandwidth the required protection distance would be from 187 kilometres to 415 kilometres for a land radio path and from 488 kilometres to 783 kilometres for a sea path. For interference of 20 MHz bandwidth the values of protection distances would be reduced. However in that case the required protection distance would be of 162 kilometres for a land radio path and of 754 kilometres for a sea path.

The results shown in Tables 8 – 10 were obtained assuming a cold sea radio path. Consideration of a warm sea radio path would result in ever 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.

The results obtained without taken into account tropospheric scattering show that the required protection distance related to interference of 5 MHz and 10 MHz bandwidth would vary from 123 to 324 kilometres for a land path and from 478 kilometres to 773 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 99 kilometres for a land path and 435 kilometres for a sea path.

Accounting for the tropospheric scattering leads to significant increase of the required protection distances. As for interference of 5 MHz and 10 MHz bandwidth the required protection distance would be from 187 to 415 kilometres for a land radio path and from 488 to 783 kilometres for a sea path. For interference of 20 MHz bandwidth the values of protection distances would be reduced. However in that case the required protection distance would be of 162 kilometres for a land radio path and of 754 kilometres for a sea path.

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.

The required protection distances for the radars were estimated for all above mentioned radar types accounting for interference from IMT transmitters using signals of 5 MHz bandwidth. The considered estimations took into consideration directional radar performances discussed in Recommendation ITU-R M.1464. Assessment of the results showed that accounting for aggregate interference would result in increasing the required protection distance up to 600 kilometres for a land radio path.

Analysis of the obtained results shows that providing protection for radars operating in the frequency bands 2 700-2 900 MHz and 2 900-3 100 MHz would require separation distances exceeding 780 kilometres. Considering a global nature of radiolocation service allocations a conclusion could be drawn that sharing between IMT stations and the mentioned radars in the frequency bands 2 700-2 900 MHz and 2 900-3 100 MHz would be extremely hard to implement.

4.5 Conclusions

Analysis of the obtained results shows that providing protection for radars operating in the frequency bands 2 700-2 900 MHz and 2 900-3 100 MHz would require separation distances exceeding 780 kilometres. Considering a global nature of radiolocation service allocations a conclusion could be drawn that sharing between IMT stations and the mentioned radars in the frequency bands 2 700-2 900 MHz and 2 900-3 100 MHz would be extremely hard to implement and would prevent from providing effective operation of IMT systems.

Based on the above it is proposed to exclude the frequency bands 2 700-2 900 MHz and 2 900-3 100 MHz from consideration as a candidate for satisfying WRC-15 agenda item 1.1.

ATTACHMENT 3

Updated study on sharing between IMT systems and radars in the 2 700-2 900 MHz band

1 Introduction

WRC-15 agenda item 1.1 is considering additional spectrum allocations to the mobile service and the identification of additional frequency bands for IMT, and JTG 4-5-6-7 is performing studies in relation to this, as well as for WRC-15 agenda item 1.2. Sweden has proposed a number of potential candidate bands for IMT, including frequencies between 2.7 and 2.9 GHz.

Currently, the band 2 700-2 900 MHz is allocated to aeronautical radionavigation service (ARNS) on a primary basis and radiolocation service on a secondary basis; and the systems operating in this band include air traffic control (ATC) radars and meteorological radars.

This contribution contains an updated study of adjacent channel coexistence between IMT and radars operating in the 2 700-2 900 MHz band; and investigates the necessary isolation or separation between IMT station and a radar system.

2 Discussion

Previous sharing studies for the 2.7-2.9 GHz band in ITU-R (e.g., those in Report ITU-R M.2112 that were undertaken prior to WRC-07) have concentrated on co-channel sharing between mobile (IMT) and radars, and indicate that co-channel sharing in the same geographic area is extremely difficult. More recent contributions to JTG 4-5-6-7 have indicated that adjacent channel coexistence may be possible. In this study the methodology is based on the radar equation and hopefully this can be used as an argument into the PDNR on the matter.

3 Proposal

The material in Annex 1 is proposed to supplement the analysis in the [working document towards a preliminary draft new Report M.[AERO-IMT]].

Annex: 1

ANNEX

Co-existence study between Radar (1-7) and IMT in the 2 700-2 900 MHz frequency range

Executive summary

This study shows that with a separation of 10 MHz between emission band edges and by utilizing mitigation methods the radar service is protected to *I/N* = –10 dB from IMT transmitters.

IMT (LTE) system parameters

Technical characteristics of the IMT (LTE) system are described in this section beginning with the base station characteristics, and finishing with the user equipment (UE) characteristics.

Base station (Node B)

The base station characteristics shown in Table 1 are based on the suburban macro cell characteristics [for JTG 4-5-6-7 sharing studies contained in the Chairman’s report, Document 4-5-6-7/242 Annex 2]. A bandwidth of 10 MHz has been used.

TABLE 1

IMT base station characteristics

Base station		**Units**	**LTE**
Downlink frequency		MHz	2 800
Bandwidth		MHz	10
Maximum transmitter power	BW=5 MHz	dBm	43
	BW = 10 MHz		46
	Power density	dBm/MHz	36
Spurious emission limits	limit	dBm/MHz	−30
Max antenna gain (3-sector sites assumed for macro)		dBi	16
Feeder loss		dB	3
Antenna height		m	30
Antenna down tilt		Degrees	6
Antenna type			Sectoral (3 sectors)
Antenna pattern			Rec. ITU-R F.1336-3
Polarization			±45° cross-polarized
3 dB antenna aperture in elevation		Degrees	12
3 dB antenna aperture in azimuth		Degrees	65
Receiver noise figure (worst case)		dB	5
Receiver thermal noise level	BW = 5 MHz	dBm	−102
	BW = 10 MHz		−99
	Power density	dBm/MHz	−109
Required *I/N*		dB	−6

User equipment (UE)

The UE characteristics shown in Table 2 [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]. A bandwidth of 10 MHz has been used for the IMT system.

TABLE 2

IMT UE characteristics

Base station		**Units**	**LTE**
Downlink frequency		MHz	2 800
Bandwidth		MHz	10
Maximum transmitter power		dBm	23
		dBm/MHz	13
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	BW = 10 MHz	dBm	−95
	Power density	dBm/MHz	−105
Required *I/N*		dB	−6

Radar (Radar 1-7) system parameters

Radar characteristics

Use		**Units**	**Air Traffic Control**			**Defence**		**Meteorological**	
Transmitter			**Radar 1**	**Radar 2**	**Radar 3**	**Radar 4**	**Radar 5**	**Radar 6**	**Radar 7**
Power to the antenna		dBW	47.8	44.8	44	48	53	59	57
		dBm/MHz	73.8	75.8	71.2	74	73	89	89.2
3 dB emission bandwidth		MHz	2.5	0.8	1.9	2.5	10	1	0.6
Rec. ITU-R SM.329/1541 spurious emission limits		dBc	60	60	60	60	60	100	100
		dBm	17.8	14.8	14	18	23	−11	−13
		dBm/MHz	13.8	15.8	11.2	14	13	−11	−10.8
Receiver									
Noise Figure		dB	2	1.4	3.3	2	1.5	2	2.1
3 dB bandwidth		MHz	1.5	0.8	15	1.5	10	1	0.63
Receiver thermal noise floor		dBm	−110.2	−113.6	−98.9	−110.2	−102.5	−112.0	−113.9
		dBm/MHz	−112.0	−112.6	−110.7	−112.0	−112.5	−112.0	−111.9
Required *I/N*		dB	−10			−10		−10	
1 dB compression point		dBm	−10	10	10	−16.8	−10.3	10	−17
Antenna									
Pattern			Cosecant squared			Cosecant squared		Pencil	
Polarization			Mixed			Mixed		Circular	
Gain		dBi	33.5	35	34	33.5	40	43	45.7
Antenna aperture		m^2	2.2	3.1	2.5	2.2	9.8	19.6	36.5
Feeder loss		dB	2			2		2	
Azimuthal beamwidth		degrees	1.5	1.4	1.45	1.5	1.1	0.92	0.92
Elevation beamwidth		degrees	4.8	4.5	4.8	4.8		0.92	0.92
Rotation		Rpm	15	15	15		60	3	3
Location			Ground			Ground	Shipborne	Ground	
Nominal height		M	15			15	30	15	
Aeronautical safety factor		dB	6			0		0	
Attenuation of interfering signal by radar IF selectivity assuming guard band of	10 MHz	dB	90.7	111.5	25.6	90.7	35.0	104.1	119.6
	20 MHz	dB	110.9	132.2	39.7	110.9	50.8	124.6	140.4
	30 MHz	dB	123.2	144.7	49.5	123.2	61.4	137.1	152.9

Note that Radars 3, 4, 5 and 7 appear to correspond to Radars C, I, J and G in Recommendation ITU-R M.1464-1, respectively.

A number of changes and additions have been made to the parameters in the table including:

- Modification of the 1 dB compression point for Radars 4 and 5 (and related antenna aperture calculation).
- Radar intermediate frequency (IF) selectivity characteristics.

For Radars 4 and 5 (corresponding to Recommendation ITU-R M.1464-1 Radars I and J), the 1 dB compression point is given in terms of the power density at the antenna in W/m^2. For these radars, the 1 dB compression point at the front end receiver input is calculated by multiplying the power density by the antenna aperture in square metres. However, the power density values provided in Recommendation ITU-R M.1464-1 do not seem reasonable as they give rise to 1 dB compression point values of in excess of 80 dBm (100 kW) for the receiver. [In the last WP 5B meeting in Annex 19 of Document 5B/304 the following note is made, "Chairman’s note: Are the receiver 1 dB compression points and on tune saturation levels correct as they appear a little high. Should they be raise to the power (-)?"]. If we assume a typographical error here, as suggested by the Chairman’s note, and assume that the power density at the antenna for Radar I, J (or 4 and 5), K and L is 1.5×10^{-5}, 5×10^{-5} W/m^2 rather than $1.5 \times 10^{+5}$, $5 \times 10^{+5}$ W/m^2, then we obtain more reasonable values of −16.8 and −10.3 dBm for the 1 dB compression points, respectively.

The antenna aperture is calculated for each radar assuming a frequency of 2 700 MHz. This is required to convert the 1 dB compression point power density at the antenna provided in Recommendation ITU-R M.1464-1 for Radar 4 and 5 to the 1 dB compression point at the receiver input.

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 guard band of between 10 and 30 MHz has been assumed between the radar and IMT system channel edges, and an IMT system bandwidth of 10 MHz.

Methodology

The ratio between the interference and noise is calculated, the attenuation between the base station (node b) and the radar receiver is calculated by using free space attenuation.

IMT mitigation methods

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.

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, thanks 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 shown in a 2.6 GHz antenna pattern given in Figure 26(b) of Report ITU-R F.1336.

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.

Base station out-of-band and spurious emissions

Base station unwanted emissions are given in 3GPP 36.104 for IMT-Advanced[1]. 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 −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.

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.

Summary of IMT mitigation methods

Method	Effect
Base station downtilt with suppression	–25 dB
Base station out-of-band and spurious emissions	–25 dB Compared to 3GPP 36.104
Additional RF filtering	–60 dB
Total	**–110 dB**

Calculations

Base station (node B)

The interfering power in the radar receiver from the base station is, with mitigation on the transmitter (IMT) side:

$$\begin{aligned}&realistic\ unwanted\ emission + maximal\ base\ station\ antenna\ gain - antenna\ downtilt\\&- additional\ RF\ filtering + radar\ antenna\ gain\\&- attenuation\ between\ the\ base\ station\ and\ radar\\&\Leftrightarrow\ -55 + 16 - 25 - 60 + radar\ antenna\ gain - attenuation\\&= -124 + radar\ antenna\ gain - attenuation\ [\text{dBm/10 MHz}]\end{aligned}$$

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[1] 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.

From the radar characteristics table one can see that the thermal noise floor for each radar is:

	Unit	Air Traffic Control			Defence		Meteorological	
		Radar 1	**Radar 2**	**Radar 3**	**Radar 4**	**Radar 5**	**Radar 6**	**Radar 7**
Receiver thermal noise floor	dBm/MHz	−112.0	−112.6	−110.7	−112.0	−112.5	−112.0	−111.9

The above information enables us to calculate the interference to noise ratio, remembering that Radars 1-3 have an aeronautical safety factor of 6 dB.

	Radar 1	Radar 2	Radar 3	Radar 4	Radar 5	Radar 6	Radar 7
Maximal allowed interference [dBm/MHz]	–128	–128.6	–126.7	–122	–122.5	–122	–121.9
Received power (radar antenna gain included) assuming no attenuation (no radar mitigation) [dBm/MHz]	–100.5	–99	–100	–100.5	–94	–91	–88.3
Necessary attenuation	27.5	29.6	26.7	21.5	28.5	31	33.6
Necessary separation distance	Some hundred meters						

User equipment

Since the UE turns of all transmission when the UE is above a certain distance from the base station (node B) there is no interference into the radar system from the UE when the UE is beyond this distance from the radar.

By instructing the UE to update the position with short intervals and thereby force the UE to turn off transmission an arbitrary short time after the UE has lost connection to the base station interference surpassing the protection criteria can be avoided.

Conclusion

As can be seen the necessary geometrical separation between the base station and the radar receiver is only a few hundred meters with mitigation on the IMT transmitter, in special cases it might be beneficial to include measures of mitigation also in the radar receiver, examples of these measures in included in the study but not used in the end result.

The overall conclusion is that the necessary separation between IMT and Radars 1-7 in the 2 700-2 900 MHz frequency range is acceptable.

ATTACHMENT 4

Sharing between IMT systems and radars in the 2 700-2 900 MHz band

1 Introduction

WRC-15 agenda item 1.1 is considering additional spectrum allocations to the mobile service and the identification of additional frequency bands for IMT, [and JTG 4-5-6-7] is performing studies in relation to this, as well as for WRC-15 agenda item 1.2. The GSMA has proposed a number of potential candidate bands for IMT [(see Document 4-5-6-7/88) *Note cannot be referred to in a DNR*], including frequencies between 2.7 and 2.9 GHz.

Currently, the band 2 700-2 900 MHz is allocated to aeronautical radionavigation service (ARNS) on a primary basis and radiolocation service on a secondary basis; and the systems operating in this band include air traffic control (ATC) radars and meteorological radars.

This contribution contains a study of adjacent channel coexistence between IMT and radars operating in the 2 700-2 900 MHz band; and evaluates the sensitivity to some mitigation techniques and how these might ease coexistence.

2 Discussion

Previous sharing studies for the 2.7-2.9 GHz band in ITU-R (e.g., those in Report ITU-R M.2112 that were undertaken prior to WRC-07) have concentrated on co-channel sharing between mobile (IMT) and radars, and indicate that co-channel sharing in the same geographic area is extremely difficult. More recent contributions [to JTG-4-5-6-7] have indicated that adjacent channel coexistence may be possible.

[JTG 4-5-6-7] has begun a working document towards a preliminary draft new Report based on contribution [Document 4-5-6-7/219 *Note cannot be referred to in DNR*]. Although the analyses suggest that adjacent channel interference to the incumbent service would be unacceptable based on standard parameters, there are a range of possible mitigation approaches to address this. In this contribution, the sensitivity to a range of mitigation approaches for compatibility between IMT systems and radars are analysed, assuming that some or all of these mitigation approaches are adopted. [Document 4-5-6-7/193 *Note cannot be referred to in DNR*] has indicated that the economic benefits of making this spectrum available to IMT would more than offset the costs of mitigating interference to radars.

3 Proposal

The material in the Annex is proposed to supplement the analysis in the working document towards a preliminary draft new Report M.[AERO-IMT] [contained in Attachment 4 of Annex 6 to the Chairman's Report of the 3rd meeting of JTG 4-5-6-7 (Document 4-5-6-7/242)].

Annex: 1

ANNEX

Coexistence between IMT systems and radars in the 2 700-2 900 MHz frequency band

1 Introduction

In this contribution, the deterministic study of adjacent channel coexistence in the [working document toward a PDNR M.[IMT.AERO]] [(Document 4-5-6-7/242 Annex 6 Attachment 4)] is extended to include estimated coupling between base station antennas for the separations considered. [During the third JTG 4-5-6-7 meeting] the parameters for IMT were revised, and these are contained in [Document 4-5-6-7/242 Annex 2]. The adjacent channel analysis has been updated to take account of these parameters.

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 2 700-2 900 MHz band has been proposed as a candidate band for WRC-15 agenda item 1.1. Previous studies of the band, for example Report ITU-R M.2112, suggest that co-channel sharing between IMT and the incumbent radar service in the same geographic area is not feasible; however more recent studies suggest that adjacent channel coexistence may be possible. This document contains a deterministic adjacent 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 based on those contained in working document towards a preliminary draft new Report ITU-R M.[AERO-IMT].

TABLE 1

Radar characteristics

Use		**Units**	**Air Traffic Control**			**Defence**		**Meteorological**	
Transmitter			**Radar 1**	**Radar 2**	**Radar 3**	**Radar 4**	**Radar 5**	**Radar 6**	**Radar 7**
Power to the antenna		dBW	47.8	44.8	44	48	53	59	57
		dBm/MHz	73.8	75.8	71.2	74	73	89	89.2
3 dB emission bandwidth		MHz	2.5	0.8	1.9	2.5	10	1	0.6
Rec. ITU-R SM.329/1541 spurious emission limits		dBc	60	60	60	60	60	100	100
		dBm	17.8	14.8	14	18	23	−11	−13
		dBm/MHz	13.8	15.8	11.2	14	13	−11	−10.8
Receiver									
Noise Figure		dB	2	1.4	3.3	2	1.5	2	2.1
3 dB bandwidth		MHz	1.5	0.8	15	1.5	10	1	0.63
Receiver thermal noise floor		dBm	−110.2	−113.6	−98.9	−110.2	−102.5	−112.0	−113.9
		dBm/MHz	−112.0	−112.6	−110.7	−112.0	−112.5	−112.0	−111.9
Required *I/N*		dB	−10			−10		−10	
1 dB compression point		dBm	−10	10	10	−16.8	−10.3	10	−17
Antenna									
Pattern			Cosecant squared			Cosecant squared		Pencil	
Polarization			Mixed			Mixed		Circular	
Gain		dBi	33.5	35	34	33.5	40	43	45.7
Antenna aperture		m^2	2.2	3.1	2.5	2.2	9.8	19.6	36.5
Feeder loss		dB	2			2		2	
Azimuthal beamwidth		degrees	1.5	1.4	1.45	1.5	1.1	0.92	0.92
Elevation beamwidth		degrees	4.8	4.5	4.8	4.8		0.92	0.92
Rotation		Rpm	15	15	15		60	3	3
Location			Ground			Ground	Shipborne	Ground	
Nominal height		M	15			15	30	15	
Aeronautical safety factor		dB	6			0		0	
Attenuation of interfering signal by radar IF selectivity assuming guard band of	10 MHz	dB	90.7	111.5	25.6	90.7	35.0	104.1	119.6
	20 MHz	dB	110.9	132.2	39.7	110.9	50.8	124.6	140.4
	30 MHz	dB	123.2	144.7	49.5	123.2	61.4	137.1	152.9

Note that Radars 3, 4, 5 and 7 appear to correspond to Radars C, I, J and G in Recommendation ITU-R M.1464-1, respectively.

A number of changes and additions have been made to the parameters in the table including:

– Modification of the 1 dB compression point for Radars 4 and 5 (and related antenna aperture calculation).

– Radar intermediate frequency (IF) selectivity characteristics.

For Radars 4 and 5 (corresponding to Recommendation ITU-R M.1464-1 Radars I and J), the 1 dB compression point is given in terms of the power density at the antenna in W/m^2. For these radars, the 1 dB compression point at the front end receiver input is calculated by multiplying the power density by the antenna aperture in square metres. However, the power density values provided in Recommendation ITU-R M.1464-1 do not seem reasonable as they give rise to 1 dB compression point values of in excess of 80 dBm (100 kW) for the receiver. [In the last WP 5B meeting in Annex 19 of Document 5B/304 the following note is made, "[*Chairman's note: Are the receiver 1 dB compression points and on tune saturation levels correct as they appear a little high. Should they be raise to the power (-)?*]". If we assume a typographical error here, as suggested by the Chairman's note, and] assume that the power density at the antenna for Radar I, J (or 4 and 5), K and L is 1.5×10^{-5}, 5×10^{-5} W/m^2 rather than $1.5 \times 10^{+5}$, $5 \times 10^{+5}$ W/m^2, then we obtain more reasonable values of −16.8 and −10.3 dBm for the 1 dB compression points, respectively.

The antenna aperture is calculated for each radar assuming a frequency of 2 700 MHz. This is required to convert the 1 dB compression point power density at the antenna provided in Recommendation ITU-R M.1464-1 for Radar 4 and 5 to the 1 dB compression point at the receiver input.

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 guard band of between 10 and 30 MHz has been assumed between the radar and IMT system channel edges, and an IMT system bandwidth of 10 MHz.

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 user equipment (UE) characteristics.

3.1.2.1 Base station

The base station characteristics shown in Table 2 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. A bandwidth of 10 MHz has been used.

TABLE 2

IMT base station characteristics

Base station		**Units**	**LTE**
Downlink frequency		MHz	2 800
Bandwidth		MHz	10
Maximum transmitter power	BW=5 MHz	dBm	43
	BW = 10 MHz		46
	Power density	dBm/MHz	36
Spurious emission limits	limit	dBm/MHz	−30
Max antenna gain (3-sector sites assumed for macro)		dBi	16
Feeder loss		dB	3
Antenna height		m	−25
Antenna down tilt		Degrees	6
Antenna type			Sectoral (3 sectors)
Antenna pattern			Rec. ITU-R F.1336-3
Polarization			±45° cross-polarized
3 dB antenna aperture in elevation		Degrees	12
3 dB antenna aperture in azimuth		Degrees	65
Receiver noise figure (worst case)		dB	5
Receiver thermal noise level	BW = 5 MHz	dBm	−102
	BW = 10 MHz		−99
	Power density	dBm/MHz	−109
Required *I/N*		dB	−6

3.1.2.2 User equipment (UE)

The UE characteristics shown in Table 3 are based on the characteristics agreed for [JTG 4-5-6-7] sharing studies [contained in the Chairman’s report, Document JTG-4-5-6-7/242 Annex 2].
A bandwidth of 10 MHz has been used for the IMT system.

TABLE 3

IMT UE characteristics

Base station		Units	LTE
Downlink frequency		MHz	2 800
Bandwidth		MHz	10
Maximum transmitter power		dBm	23
		dBm/MHz	13
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	BW = 10 MHz	dBm	−95
	Power density	dBm/MHz	−105
Required *I/N*		dB	−6

3.1.3 Combined characteristics

The technical characteristics that are dependent on the parameters assumed for both the IMT and radar systems are described in this section.

The antenna gains of the radar developed toward the UE and base station, and the base station antenna gain developed toward the radar are a function of the relative heights and separations. In this study, the suburban macrocell base station height is assumed to be 25 metres, the microcell base station height is assumed to be 6 metres, the UE height is assumed to be 1.5 metres and the radar antenna height is assumed to be 15 metres for Radars 1-4, 6-7 and 30 metres for Radar 5. Table 4 shows the elevation angles measured at the radar receiver for the IMT macro- and microcell base station.

TABLE 4

Elevation angles of IMT base station antennas determined at radar antenna

			Radars 1-4, 6-7	**Radar 5**
IMT Terminal	**Separation**	**Height**	**15 m**	**30 m**
Suburban macrocell base station	1 km	25 m	0.6°	−0.3°
Microcell base station	1 km	6 m	−0.5°	−1.4°

The antenna gains of the radar in the direction of the UE and base stations are summarized in Table 5.

The [Working Document towards a preliminary draft new Report ITU-R M.[AERO-IMT]] provides the relative gain (–10 dB) for the cosecant characteristic that applies to Radars 1-5. The relative antenna gains toward the base stations are estimated using the vertical antenna pattern for the radar given in Figure 1 in the [working document towards a preliminary draft new Report ITU-R M.[AERO-IMT]].

In the case of Radars 6 and 7, in line with Report ITU-R M.2112, it is assumed that the pencil beam has the characteristics defined in the Federal Meteorological Handbook No. 11, Part B, § 3.28, replicated below:

– Antenna sidelobe levels of the WSR-88D are described as follows:

  In any plane, the first sidelobe level is less than or equal to –27 dB relative to the peak of the main lobe. In the region between +2 and +10 degrees from the axis of the main lobe, the sidelobe level shall lie below a straight line connecting –29 dB at +2 degrees and –34 dB at +10 degrees. Between +10 degrees and +180 degrees the sidelobe envelope is less than or equal to –40 dB relative to peak of the main lobe. Generally, the actual pattern is about 5 dB below the prescribed envelope in the region beyond +2 degrees. Other characteristics of interest that are frequency dependent and vary across the operational band include:

  - first sidelobe maximum is at about +1.5 degrees from the main lobe axis;
  - first null is at about +1.2 degrees.

In the absence of more detailed information; for the meteorological radars (Radars 6 and 7) a relative gain of –27 dB is developed toward the UE (on the basis that 1.5 degrees below horizontal corresponds to the first sidelobe). Note that the main beam of Radars 6 and 7 can be directed at any elevation angle above the horizontal. As the elevation angle to the suburban macrocell base station is above the horizontal, and therefore may lie within the main beam, then no reduction in radar antenna gain is assumed for Radars 6 and 7. In the case of the microcell base station, which lies 0.5 degrees below the horizontal, a relative gain of 3.8 dB may be assumed, on the basis that the main lobe will be of the form $-12 \times (\theta/\theta_3)^2$ dB, where θ_3 is the 3 dB beamwidth of the antenna.

TABLE 5

Radar antenna gain toward IMT receiver

IMT Terminal	Radars 1-4	Radar 5	Radars 6-7
UE	−10 dB	−10 dB	−27 dB
Suburban macrocell base station	−1.4 dB	−2.4 dB	0 dB
Microcell base station	−2.8 dB	−3.8 dB	−3.8 dB

The UE and base station antenna gains in the direction of the radar are summarized in Table 6. In the case of the UE, then no variation of gain with elevation angle is modelled. For base stations, the base station parameters together with the patterns described in Recommendation ITU-R F.1336-4 are used, in conjunction with the elevation angles calculated above, to calculate the effective antenna gain for each path.

TABLE 6

Gain of IMT antennas relative to maximum in direction of radar antenna

IMT Terminal	Gain	Vertical beamwidth	Radars 1-4, 6-7	Radar 5
UE	−3 dBi	N/A	0 dB	0 dB
Suburban macrocell base station (6° downtilt)	16 dBi	12°	−2.4 dB	−3.3 dB
Microcell base station	5 dBi	34°	−0.003 dB	−0.02 dB

The gains of the IMT and radar antennas in each path in Tables 5 and 6 are additive. Note that the reduction in gain for the microcell base station is negligible and will therefore be ignored.

Furthermore, radars and IMT systems use different polarizations. IMT systems use linear polarization. Radars 1-5 use mixed polarization with an average polarization loss of 3 dB, however Radars 6 and 7 use circular polarization, so the loss will be 3 dB.

3.2 Mitigation of adjacent band interference

Coexistence between radar systems in the 2 700-2 900 MHz band with IMT in the 2 500-2 690 MHz band have 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 to enable coexistence between IMT and radars in adjacent segments of the 2 700-2 900 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 the UK, the remediation approach involves 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 [[2]]. In this case, the lowest radar frequency was given as 2 750 MHz, so the separation from the lowest radar frequency to the edge of the IMT band was 60 MHz.

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[2] Selex System Integration, “Watchman Radar: Receiver Selectivity Improvements in the 2 700-3 100 MHz band”, Final Report, Ref SSI-PS0305-ENG-405, 1 December 2009 downloaded from http://stakeholders.ofcom.org.uk/binaries/spectrum/spectrum-awards/awards-in-preparation/757738/592_Watchman_Radar_Receiver1.pdf on 9 September 2013.

A report by Isotek, commissioned by Ofcom [3] considered what filtering might be practical to separate these bands. The study was based on combline filter designs, and concluded that 60 MHz offset (as used in the remediation programme) would enable > 60 dB rejection to be attained, with a variety of wide pass bands, with insertion losses in the region of 0.15 dB. Reducing the offset to 30 MHz resulted in rejection of only 35 dB with similar insertion losses. Further reduction to 10 MHz resulted in increased insertion losses (0.27-0.3 dB) but rejection of 22-23 dB and unacceptable phase distortion (corresponding to 0.4 degrees deviation from linear phase across the pass band).

In this work, a 10 MHz passband filter which could operate at an offset of 10 MHz was proposed for fixed frequency operation. In this case the loss was increased to 0.94 dB and the rejection 35 dB.

Much greater rejections can be achieved with combline filters if the phase variation requirements can be relaxed; in principle, the variation may be compensated elsewhere in the receiver. In this case rejections of around 60 dB can be achieved with 10 MHz separation.

In the mitigation sensitivity analysis presented later, the RF filter rejection is assumed to be 22 dB, 28.5 dB and 35 dB for frequency offsets of 10, 20 and 30 MHz, respectively. Note that the value of 28.5 dB for a 20 MHz offset is simply a geometric mean of the 10 and 30 MHz values.

3.2.1.2 Improving IF filtering

The receiver IF-rolloff, 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 guard bands 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-rolloff of 100 dB/decade is assumed yielding the rejection values shown in Table 7. This rejection is additional to the rejection offered by RF filtering summarized at the end of section 3.2.1.1.

TABLE 7

Radar IF selectivity assuming an IF-rolloff of 100 dB/decade and guard bands of 10, 20 and 30 MHz

		Units	**Air Traffic Control**			**Defence**		**Meteorological**	
Parameter			**Radar 1**	**Radar 2**	**Radar 3**	**Radar 4**	**Radar 5**	**Radar 6**	**Radar 7**
Attenuation of interfering signal by radar IF selectivity assuming guard band of:	10 MHz	dB	114.9	140.9	34.0	114.9	45.5	131.6	150.9
	20 MHz	dB	140.7	167.3	51.9	140.7	65.7	157.8	177.5
	30 MHz	dB	156.3	183.1	64.3	156.3	79.1	173.6	193.4

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[3] Isotek Electronics Ltd, “High Q Filter Feasibility Study for Base-Station and Radar Receiver Applications”, Ref IF26, 15 October 2009 downloaded from http://stakeholders.ofcom.org.uk/binaries/consultations/872_876_mhz/annexes/highq.pdf on 9 September 2013.

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, thanks 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 shown in a 2.6 GHz antenna pattern given in Figure 26(b) of Report ITU-R F.1336 [[4]].

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.

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[5]. 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 −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 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.

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[4]. ITU-R, Recommendation 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.

[5] 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.

Unwanted emissions of IMT UE 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.

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.

In the mitigation sensitivity analysis presented later we assume that UE emissions can be reduced to −50 dBm/MHz in the radar receiver bandwidth.

3.2.4 Microcells in areas around radars as a mitigation option

The microcell base station characteristics shown in Table 8 are based on the characteristics agreed for [JTG 4-5-6-7] sharing studies [contained in the Chairman’s report, Document JTG-4-5-6-7/242 Annex 2]. A bandwidth of 10 MHz has been used for this analysis.

TABLE 8

Base station characteristics

Base station		**Units**	**LTE**
Downlink frequency		MHz	2 800
Bandwidth		MHz	10
Maximum transmitter power	BW = 10 MHz	dBm	35
	Power density	dBm/MHz	25
Spurious emission limits	limit	dBm/MHz	−30
Max antenna gain		dBi	5
Feeder loss		dB	N/A
Antenna height		m	6
Antenna down tilt		Degrees	N/A
Antenna type			Omni
Antenna pattern			Rec. ITU-R F.1336-3
Polarization			Linear
3 dB antenna aperture in elevation		Degrees	34
3 dB antenna aperture in azimuth		Degrees	360
Receiver noise figure (worst case)		dB	5
Receiver thermal noise level	BW = 5 MHz	dBm	−102
	BW = 10 MHz		−99
	Power density	dBm/MHz	−109
Required *I/N*		dB	−6

Potentially, the area around the radar could be provided with microcell coverage outdoor and picocell coverage indoor. The benefit is that because the path losses are considerably lower, as microcell base stations have reduced transmit power, the UE will have proportionately reduced power. Consequently, the 11 dB difference in base station transmit power will result in a similar 11 dB reduction in the UE transmit power distribution, and therefore it will be possible to limit the UE maximum transmit power in a microcell to only 12 dBm. Careful siting of microcell base station antennas, out of line-of-sight could allow the path loss to the radar antennas to be substantially increased over the free space values included in the analyses. These potential benefits have not been included in our analyses.

When the option of using microcells is assumed in the mitigation sensitivity analysis presented later, the parameter values in Table 8 are assumed.

4 Analysis

In this section the assumptions, methodology, calculations and results are described for the deterministic analysis of adjacent 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 a single interferer on a single victim.
- The following minimum separations are assumed and the required additional attenuation for compatibility is evaluated:
  - Base station = one kilometre
  - UE = 500 m
- Maximum transmission power is assumed.

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 2 700-2 900 MHz. The studies address IMT systems in the adjacent 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 adjacent 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 Potential interferer spurious emissions in the victim 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 potential interferer at the victim 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 potential interferer at the victim receiver

$SPSD_{TX}$ = spurious PSD of the potential interfering 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 victim

PL = free space path loss

G_{RX} = receive antenna gain

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

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 for aeronautical services).

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 victim receiver is dominated by spurious emissions rather than out of band emissions (OOBEs).

4.2.2 Victim receiver rejection of the potential interferer fundamental 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 potential interferer at the victim 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 potential interferer at the victim receiver front end
PSD_{TX} = PSD of the potential interfering 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 victim
PL = free space path loss
G_{RX} = receive antenna gain
$G_{RX,REL}$ = receive antenna gain relative to maximum in direction of interferer
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 potential interferer at the victim 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 potential interferer at the victim receiver
P_{TX} = power of the potential interfering transmitter
FL_{TX} = transmit feeder loss
G_{TX} = transmit maximum antenna gain
$G_{TX,REL}$ = transmit antenna gain relative to maximum in direction of victim
PL = free space path loss
G_{RX} = receive antenna gain
$G_{RX,REL}$ = receive antenna gain relative to maximum in direction of interferer
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 adjacent 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 adjacent channel mitigation techniques. Refer to section 3.1 and section 3.2 for details of the technical characteristics assumed for the ‘baseline’ and ‘mitigation’ cases, respectively.

4.3.1 Baseline adjacent channel (no mitigation)

First the baseline calculations are considered.

4.3.1.1 IMT suburban 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 guard band of 10 MHz is assumed for the Category B −30 dBm/MHz base station spurious emissions limit to apply.

TABLE 9

IMT suburban 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	
Base station feeder loss	dB	3.0			3.0		3.0	
Base station maximum antenna gain	dBi	16.0			16.0		16.0	
Relative base station antenna gain in direction of the radar	dB	−2.4			−2.4	−3.3	−2.4	
Free space path loss for one kilometre separation	dB	101.4			101.4		101.4	
Radar maximum antenna gain	dBi	33.5	35.0	34.0	33.5	40.0	43.0	45.7
Relative radar gain in direction of the base station	dB	−1.4	−1.4	−1.4	−1.4	−2.4	0.0	0.0
Radar feeder loss	dB	2.0			2.0		2.0	
Polarization loss	dB	3.0			3.0		3.0	
Power at the receiver front-end	**dBm/MHz**	**−93.7**	**−92.2**	**−93.2**	**−93.7**	**−89.1**	**−82.8**	**−80.1**
Radar thermal noise floor	dBm/MHz	−112.0	−112.6	−110.7	−112.0	−112.5	−112.0	−111.9
Required *I/N*	dB	−10.0			−10.0		−10.0	
Safety factor	dB	6.0			0.0		0.0	
Acceptable interference level	**dBm/MHz**	**−128.0**	**−128.6**	**−126.7**	**−122.0**	**−122.5**	**−122.0**	**−121.9**
Required additional attenuation	**dB**	**34.3**	**36.4**	**33.5**	**28.3**	**33.4**	**39.2**	**41.8**

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 10. The required additional attenuation is calculated for guard bands of between 10 MHz and 30 MHz.

TABLE 10

IMT suburban base station wanted signal suppressed by radar IF selectivity

		Units	**Radar 1**	**Radar 2**	**Radar 3**	**Radar 4**	**Radar 5**	**Radar 6**	**Radar 7**
Base station transmit power		dBm/MHz	36	36	36	36	36	36	36
Base station feeder loss		dB	3	3	3	3	3	3	3
Base station maximum antenna gain		dB	16	16	16	16	16	16	16
Relative base station antenna gain in direction of the radar		dB	−2.4	−2.4	−2.4	−2.4	−3.3	−2.4	−2.4
Free space path loss for one kilometre separation		dB	101.4	101.4	101.4	101.4	101.4	101.4	101.4
Radar maximum antenna gain		dBi	33.5	35.0	34.0	33.5	40.0	43.0	45.7
Relative radar gain in direction of the base station		dB	−1.4	−1.4	−1.4	−1.4	−2.4	0.0	0.0
Radar feeder loss		dB	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Polarization loss		dB	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Power at the receiver front-end		**dBm/MHz**	**−27.7**	**−26.2**	**−27.2**	**−27.7**	**−23.1**	**−16.8**	**−14.1**
Radar thermal noise floor		dBm/MHz	−112.0	−112.6	−110.7	−112.0	−112.5	−112.0	−111.9
Required *I/N*		dB	−10	−10	−10	−10	−10	−10	−10
Safety factor		dB	6	6	6	0	0	0	0
Attenuation of interfering signal by radar IF selectivity assuming guard band of	10 MHz	dB	90.7	111.5	25.6	90.7	35.0	104.1	119.6
	20 MHz	dB	110.9	132.2	39.7	110.9	50.8	124.6	140.4
	30 MHz	dB	123.2	144.7	49.5	123.2	61.4	137.1	152.9
Acceptable interference level assuming guard band of	**10 MHz**	**dBm/MHz**	**−37.3**	**−17.1**	**−101.1**	**−31.3**	**−87.5**	**−17.9**	**−2.3**
	20 MHz	**dBm/MHz**	**−17.1**	**3.6**	**−87.0**	**−11.1**	**−71.7**	**2.6**	**18.5**
	30 MHz	**dBm/MHz**	**−4.8**	**16.1**	**−77.2**	**1.2**	**−61.1**	**15.1**	**31.0**
Required additional attenuation assuming guard band of	**10 MHz**	**dB**	**9.6**	**−9.1**	**73.9**	**3.6**	**64.4**	**1.2**	**−11.8**
	20 MHz	**dB**	**−10.6**	**−29.8**	**59.8**	**−16.6**	**48.6**	**−19.4**	**−32.6**
	30 MHz	**dB**	**−22.9**	**−42.3**	**50.0**	**−28.9**	**38.0**	**−31.9**	**−45.1**

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 11.

TABLE 11

IMT suburban base station wanted signal on the 1 dB compression point of a radar receiver

	Units	**Radar 1**	**Radar 2**	**Radar 3**	**Radar 4**	**Radar 5**	**Radar 6**	**Radar 7**
Base station transmit power	dBm	46.0			46.0		46.0	
Base station feeder loss	dB	3.0			3.0		3.0	
Base station maximum antenna gain	dB	16.0			16.0		16.0	
Relative base station antenna gain in direction of the radar	dB	−2.4			−2.4	−3.3	−2.4	
Free space path loss for one kilometre separation	dB	101.4			101.4		101.4	
Radar maximum antenna gain	dBi	33.5	35.0	34.0	33.5	40.0	43.0	45.7
Relative radar gain in direction of the base station	dB	−1.4	−1.4	−1.4	−1.4	−2.4	0.0	0.0
Radar feeder loss	dB	2.0			2.0		2.0	
Polarization loss	dB	3.0			3.0		3.0	
Power at the receiver front-end	**dBm**	**−17.7**	**−16.2**	**−17.2**	**−17.7**	**−13.1**	**−6.8**	**−4.1**
Radar 1 dB compression point	**dBm**	−10.0	10.0	10.0	−16.8	−10.3	10.0	−17.0
Safety factor	**dBm**	6.0			0.0		0.0	
Acceptable interference level	**dBm**	**−16.0**	**4.0**	**4.0**	**−16.8**	**−10.3**	**10.0**	**−17.0**
Required additional attenuation	**dB**	**−1.7**	**−20.2**	**−21.2**	**−0.9**	**−2.8**	**−16.8**	**12.9**

4.3.1.2 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 12. A guard band of 15 MHz is assumed for the −30 dBm/MHz UE spurious emissions limit to apply for a channel bandwidth of 10 MHz.

TABLE 12

IMT UE 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	
UE body loss	dB	4.0			4.0		4.0	
UE maximum antenna gain	dBi	−3.0			−3.0		−3.0	
Free space path loss for 500 m separation	dB	95.4			95.4		95.4	
Radar maximum antenna gain	dBi	33.5	35.0	34.0	33.5	40.0	43.0	45.7
Relative radar antenna gain in direction of UE	dB	−10.0					−27.0	
Radar feeder loss	dB	2.0			2.0		2.0	
Polarization loss	dB	3.0			3.0		3.0	
Power at the receiver front-end	**dBm/MHz**	**−113.9**	**−112.4**	**−113.4**	**−113.9**	**−107.4**	**−121.4**	**−118.7**
Radar thermal noise floor	dBm/MHz	−112.0	−112.6	−110.7	−112.0	−112.5	−112.0	−111.9
Required *I/N*	dB	−10.0			−10.0		−10.0	
Safety factor	dB	6.0			0.0		0.0	
Acceptable interference level	**dBm/MHz**	**−128.0**	**−128.6**	**−126.7**	**−122.0**	**−122.5**	**−122.0**	**−121.9**
Required additional attenuation	**dB**	**14.1**	**16.2**	**13.3**	**8.1**	**15.1**	**0.6**	**3.2**

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 13. The required additional attenuation is calculated for guard bands of between 10 MHz and 30 MHz.

TABLE 13

IMT UE wanted signal suppressed by radar IF selectivity

		Units	**Radar 1**	**Radar 2**	**Radar 3**	**Radar 4**	**Radar 5**	**Radar 6**	**Radar 7**
UE transmit power		dBm/MHz	13	13	13	13	13	13	13
UE body loss		dB	4	4	4	4	4	4	4
UE maximum antenna gain		dB	−3	−3	−3	−3	−3	−3	−3
Free space path loss for 500 m separation		dB	95.4	95.4	95.4	95.4	95.4	95.4	95.4
Radar maximum antenna gain		dBi	33.5	35.0	34.0	33.5	40.0	43.0	45.7
Relative radar antenna gain in direction of UE		dB	−10.0	−10.0	−10.0	−10.0	−10.0	−27.0	−27.0
Radar feeder loss		dB	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Polarization loss		dB	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Power at the receiver front-end		**dBm/MHz**	**−70.9**	**−69.4**	**−70.4**	**−70.9**	**−64.4**	**−78.4**	**−75.7**
Radar thermal noise floor		dBm/MHz	−112.0	−112.6	−110.7	−112.0	−112.5	−112.0	−111.9
Required *I/N*		dB	−10.0	−10.0	−10.0	−10.0	−10.0	−10.0	−10.0
Safety factor		dB	6.0	6.0	6.0	0.0	0.0	0.0	0.0
Attenuation of interfering signal by radar IF selectivity assuming guard band of	10 MHz	dB	90.7	111.5	25.6	90.7	35.0	104.1	119.6
	20 MHz	dB	110.9	132.2	39.7	110.9	50.8	124.6	140.4
	30 MHz	dB	123.2	144.7	49.5	123.2	61.4	137.1	152.9
Acceptable interference level assuming guard band of	**10 MHz**	**dBm/MHz**	**−37**	**−17**	**−101**	**−31**	**−88**	**−18**	**−2**
	20 MHz	**dBm/MHz**	**−17**	**4**	**−87**	**−11**	**−72**	**3**	**19**
	30 MHz	**dBm/MHz**	**−5**	**16**	**−77**	**1**	**−61**	**15**	**31**
Required additional attenuation assuming guard band of	**10 MHz**	**dB**	**−33.6**	**−52.3**	**30.7**	**−39.6**	**23.2**	**−60.4**	**−73.3**
	20 MHz	**dB**	**−53.8**	**−73.0**	**16.6**	**−59.8**	**7.3**	**−81.0**	**−94.2**
	30 MHz	**dB**	**−66.1**	**−85.5**	**6.8**	**−72.1**	**−3.3**	**−93.4**	**−106.7**

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 14.

TABLE 14

IMT UE wanted signal on the 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	23.0			23.0		23.0	
UE body loss	dB	4.0			4.0		4.0	
UE maximum antenna gain	dB	−3.0			−3.0		−3.0	
Free space path loss for 500 m separation	dB	95.4			95.4		95.4	
Radar maximum antenna gain	dBi	33.5	35.0	34.0	33.5	40.0	43.0	45.7
Relative radar antenna gain in direction of UE	dB	−10.0					−27.0	
Radar feeder loss	dB	2.0			2.0		2.0	
Polarization loss	dB	3.0			3.0		3.0	
Power at the receiver front-end	**dBm**	**−60.9**	**−59.4**	**−60.4**	**−60.9**	**−54.4**	**−68.4**	**−65.7**
Radar 1 dB compression point	dBm	−10.0	10.0	10.0	−16.8	−10.3	10.0	−17.0
Safety factor	dBm	6.0			0.0		0.0	
Acceptable interference level	**dBm**	**−16.0**	**4.0**	**4.0**	**−16.8**	**−10.3**	**10.0**	**−17.0**
Required additional attenuation	**dB**	**−44.9**	**−63.4**	**−64.4**	**−44.0**	**−44.0**	**−78.4**	**−48.7**

4.3.2 Adjacent channel with mitigation

The calculations in section 4.3.1 are repeated in this section, but with the assumption that various adjacent channel mitigation techniques are applied, as described in section 3.2.

4.3.2.1 IMT suburban 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:

- Typical base station spurious emissions of −55 dBm/MHz for a guard band of 10 MHz.
- Inclusion of an RF transmit chain filter (of 60 dB rejection).
- Base station downtilt with upper sidelobe suppression (−25 dB relative antenna gain in the direction of the radar).

TABLE 15

IMT suburban macrocell base station 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
Base station spurious emissions	dBm/MHz	−55.0			−55.0		−55.0	
RF transmit chain filter rejection	dB	60			60		60	
Base station feeder loss	dB	3.0			3.0		3.0	
Base station maximum antenna gain	dBi	16.0			16.0		16.0	
Relative base station antenna gain in direction of the radar	dB	−25			−25		−25	
Free space path loss for one kilometre separation	dB	101.4			101.4		101.4	
Radar maximum antenna gain	dBi	33.5	35.0	34.0	33.5	40.0	43.0	45.7
Relative radar antenna gain in direction of base station	dB	−1.4	−1.4	−1.4	−1.4	−2.4	0.0	0.0
Radar feeder loss	dB	2.0			2.0		2.0	
Polarization loss	dB	3.0			3.0		3.0	
Power at the receiver front-end	**dBm/MHz**	**−201.3**	**−199.8**	**−200.8**	**−201.3**	**−195.8**	**−190.4**	**−187.7**
Radar thermal noise floor	dBm/MHz	−112.0	−112.6	−110.7	−112.0	−112.5	−112.0	−111.9
Required *I/N*	dB	−10.0			−10.0		−10.0	
Safety factor	dB	6.0			0.0		0.0	
Acceptable interference level	**dBm/MHz**	**−128.0**	**−128.6**	**−126.7**	**−122.0**	**−122.5**	**−122.0**	**−121.9**
Required additional attenuation	**dB**	**−73.3**	**−71.2**	**−74.1**	**−79.3**	**−73.3**	**−68.4**	**−65.8**

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).

– 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 guard bands of between 10 MHz and 30 MHz.

TABLE 16

IMT suburban macrocell base station wanted signal suppressed by radar selectivity (with mitigation)

		Units	**Radar 1**	**Radar 2**	**Radar 3**	**Radar 4**	**Radar 5**	**Radar 6**	**Radar 7**
Base station transmit power		dBm/MHz	36	36	36	36	36	36	36
Base station feeder loss		dB	3	3	3	3	3	3	3
Base station maximum antenna gain		dB	16	16	16	16	16	16	16
Relative base station antenna gain in direction of the radar		dB	−25	−25	−25	−25	−25	−25	−25
Free space path loss for one kilometre separation		dB	101.4	101.4	101.4	101.4	101.4	101.4	101.4
Radar maximum antenna gain		dBi	33.5	35.0	34.0	33.5	40.0	43.0	45.7
Relative radar antenna gain in direction of base station		dB	−1.4	−1.4	−1.4	−1.4	−2.4	0.0	0.0
Radar feeder loss		dB	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Polarization loss		dB	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Power at the receiver front-end		**dBm/MHz**	**−50.3**	**−48.8**	**−49.8**	**−50.3**	**−44.8**	**−39.4**	**−36.7**
Radar thermal noise floor		dBm/MHz	−112.0	−112.6	−110.7	−112.0	−112.5	−112.0	−111.9
Required *I/N*		dB	−10	−10	−10	−10	−10	−10	−10
Safety factor		dB	6	6	6	0	0	0	0
Attenuation of interfering signal by radar selectivity assuming guard band of	10 MHz	dB	136.9	162.9	56.0	136.9	67.5	153.6	172.9
	20 MHz	dB	169.2	195.8	80.4	169.2	94.2	186.3	206.0
	30 MHz	dB	191.3	218.1	99.3	191.3	114.1	208.6	228.4
Acceptable interference level assuming guard band of	**10 MHz**	**dBm/MHz**	**8.9**	**34.3**	**−70.7**	**14.9**	**−55.0**	**31.6**	**51.0**
	20 MHz	**dBm/MHz**	**41.2**	**67.2**	**−46.3**	**47.2**	**−28.3**	**64.3**	**84.1**
	30 MHz	**dBm/MHz**	**63.3**	**89.5**	**−27.4**	**69.3**	**−8.4**	**86.6**	**106.5**
Required additional attenuation assuming guard band of	**10 MHz**	**dB**	**−59.2**	**−83.1**	**20.9**	**−65.2**	**10.2**	**−70.9**	**−87.7**
	20 MHz	**dB**	**−91.5**	**−116.0**	**−3.4**	**−97.5**	**−16.5**	**−103.7**	**−120.8**
	30 MHz	**dB**	**−113.6**	**−138.3**	**−22.3**	**−119.6**	**−36.4**	**−126.0**	**−143.2**

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 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 22 dB rejection for a guard band of 10 MHz.

TABLE 17

IMT suburban macrocell base station wanted signal on the 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
Base station transmit power	dBm	46.0			46.0		46.0	
Base station feeder loss	dB	3.0			3.0		3.0	
Base station maximum antenna gain	dB	16.0			16.0		16.0	
Relative base station antenna gain in direction of the radar	dB	−25			−25	−25	−25	
Free space path loss for one kilometre separation	dB	101.4			101.4		101.4	
Radar maximum antenna gain	dBi	33.5	35.0	34.0	33.5	40.0	43.0	45.7
Relative radar antenna gain in direction of base station	dB	−1.4	−1.4	−1.4	−1.4	−2.4	0.0	0.0
Radar feeder loss	dB	2.0			2.0		2.0	
Polarization loss	dB	3.0			3.0		3.0	
Power at the receiver front-end	**dBm**	**−40.3**	**−38.8**	**−39.8**	**−40.3**	**−34.8**	**−29.4**	**−26.7**
Radar 1 dB compression point	dBm	−10.0	10.0	10.0	−16.8	−10.3	10.0	−17.0
RF filter rejection	dB	22.0	22.0	22.0	22.0	22.0	22.0	22.0
Safety factor	dBm	6.0			0.0		0.0	
Acceptable interference level	**dBm**	**6.0**	**26.0**	**26.0**	**5.2**	**11.7**	**32.0**	**5.0**
Required additional attenuation	**dB**	**−46.3**	**−64.8**	**−65.8**	**−45.5**	**−46.5**	**−61.4**	**−31.7**

4.3.2.2 IMT microcell base station impact on radar (with mitigation)

One method of easing the coexistence between IMT services and radar is to deploy microcells rather than macrocells in the surrounding area of the radar installation as described in section 3.2.4.

The calculation of the required additional attenuation when considering the impact of IMT microcell base station spurious emissions on the pass-band of a radar receiver is shown in Table 18. Also some of the mitigation measures assumed for macrocells are applied for the microcell scenario including:

- Typical base station spurious emissions of −55 dBm/MHz for a guard band of 10 MHz.
- Inclusion of an RF transmit chain filter (of 60 dB rejection).

TABLE 18

IMT microcell base station 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**
Base station spurious emissions	dBm/MHz	−55.0			−55.0		−55.0	
RF transmit chain filter rejection	dB	60			60		60	
Base station feeder loss	dB	0.0			0.0		0.0	
Base station maximum antenna gain	dBi	5.0			5.0		5.0	
Free space path loss for one kilometre separation	dB	101.4			101.4		101.4	
Radar maximum antenna gain	dBi	33.5	35.0	34.0	33.5	40.0	43.0	45.7
Relative radar antenna gain in direction of base station	dB	−2.8	−2.8	−2.8	−2.8	−3.8	−3.8	−3.8
Radar feeder loss	dB	2.0			2.0		2.0	
Polarization loss	dB	3.0			3.0		3.0	
Power at the receiver front-end	**dBm/MHz**	**−185.7**	**−184.2**	**−185.2**	**−185.7**	**−180.2**	**−177.2**	**−174.5**
Radar thermal noise floor	dBm/MHz	−112.0	−112.6	−110.7	−112.0	−112.5	−112.0	−111.9
Required *I/N*	dB	−10.0			−10.0		−10.0	
Safety factor	dB	6.0			0.0		0.0	
Acceptable interference level	**dBm/MHz**	**−128.0**	**−128.6**	**−126.7**	**−122.0**	**−122.5**	**−122.0**	**−121.9**
Required additional attenuation	**dB**	**−57.7**	**−55.6**	**−58.5**	**−63.7**	**−57.7**	**−55.2**	**−52.6**

The calculation of the required additional attenuation when considering the suppression of an IMT microcell base station wanted signal by the selectivity of a radar is shown in Table 19. Also some of the mitigation measures assumed for macrocells are applied for the microcell scenario including:

– 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 guard bands of between 10 MHz and 30 MHz.

TABLE 19

IMT microcell base station wanted signal rejected by radar selectivity (with mitigation)

		Units	**Radar 1**	**Radar 2**	**Radar 3**	**Radar 4**	**Radar 5**	**Radar 6**	**Radar 7**
Base station transmit power		dBm/MHz	25	25	25	25	25	25	25
Base station feeder loss		dB	0	0	0	0	0	0	0
Base station maximum antenna gain		dB	5	5	5	5	5	5	5
Free space path loss for one kilometre separation		dB	101.4	101.4	101.4	101.4	101.4	101.4	101.4
Radar maximum antenna gain		dBi	33.5	35.0	34.0	33.5	40.0	43.0	45.7
Relative radar antenna gain in direction of base station		dB	−2.8	−2.8	−2.8	−2.8	−3.8	−3.8	−3.8
Radar feeder loss		dB	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Polarization loss		dB	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Power at the receiver front-end		**dBm/MHz**	**−45.7**	**−44.2**	**−45.2**	**−45.7**	**−40.2**	**−37.2**	**−34.5**
Radar thermal noise floor		dBm/MHz	−112.0	−112.6	−110.7	−112.0	−112.5	−112.0	−111.9
Required *I/N*		dB	−10	−10	−10	−10	−10	−10	−10
Safety factor		dB	6	6	6	0	0	0	0
Attenuation of interfering signal by radar selectivity assuming guard band of	10 MHz	dB	136.9	162.9	56.0	136.9	67.5	153.6	172.9
	20 MHz	dB	169.2	195.8	80.4	169.2	94.2	186.3	206.0
	30 MHz	dB	191.3	218.1	99.3	191.3	114.1	208.6	228.4
Acceptable interference level assuming guard band of	**10 MHz**	**dBm/MHz**	**8.9**	**34.3**	**−70.7**	**14.9**	**−55.0**	**31.6**	**51.0**
	20 MHz	**dBm/MHz**	**41.2**	**67.2**	**−46.3**	**47.2**	**−28.3**	**64.3**	**84.1**
	30 MHz	**dBm/MHz**	**63.3**	**89.5**	**−27.4**	**69.3**	**−8.4**	**86.6**	**106.5**
Required additional attenuation assuming guard band of	**10 MHz**	**dB**	**−54.6**	**−78.5**	**25.5**	**−60.6**	**14.8**	**−68.7**	**−85.5**
	20 MHz	**dB**	**−86.9**	**−111.4**	**1.2**	**−92.9**	**−11.9**	**−101.5**	**−118.6**
	30 MHz	**dB**	**−109.0**	**−133.7**	**−17.7**	**−115.0**	**−31.8**	**−123.8**	**−141.0**

The calculation of the required additional attenuation when considering the impact of an IMT microcell base station wanted signal on the 1 dB compression point of a radar receiver is shown in Table 20. Also as for the macrocells case, the inclusion of an RF filter before the radar LNA (as described in section 3.2.1.1) is assumed. This is assumed to yield 22 dB rejection for a guard band of 10 MHz.

TABLE 20

IMT microcell base station wanted signal on the 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**
Base station transmit power	dBm	35.0			35.0		35.0	
Base station feeder loss	dB	0.0			0.0		0.0	
Base station maximum antenna gain	dB	5.0			5.0		5.0	
Free space path loss for one kilometre separation	dB	101.4			101.4		101.4	
Radar maximum antenna gain	dBi	33.5	35.0	34.0	33.5	40.0	43.0	45.7
Relative radar antenna gain in direction of base station	dB	−2.8	−2.8	−2.8	−2.8	−3.8	−3.8	−3.8
Radar feeder loss	dB	2.0			2.0		2.0	
Polarization loss	dB	3.0			3.0		3.0	
Power at the receiver front-end	**dBm**	**−35.7**	**−34.2**	**−35.2**	**−35.7**	**−30.2**	**−27.2**	**−24.5**
Radar 1 dB compression point	dBm	−10.0	10.0	10.0	−16.8	−10.3	10.0	−17.0
RF filter rejection	dB	22.0	22.0	22.0	22.0	22.0	22.0	22.0
Safety factor	dBm	6.0			0.0		0.0	
Acceptable interference level	**dBm**	**6.0**	**26.0**	**26.0**	**5.2**	**11.7**	**32.0**	**5.0**
Required additional attenuation	**dB**	**−41.7**	**−60.2**	**−61.2**	**−40.9**	**−41.9**	**−59.2**	**−29.5**

4.3.2.3 IMT UE impact on radar (with mitigation)

Calculation of the required additional attenuation for the scenario of IMT UE 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 21 assuming UE unwanted emissions of −50 dBm/MHz.

TABLE 21

IMT UE unwanted 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 emissions	dBm/MHz	−50.0			−50.0		−50.0	
UE body loss	dB	4.0			4.0		4.0	
UE maximum antenna gain	dBi	−3.0			−3.0		−3.0	
Free space path loss for 500 m separation	dB	95.4			95.4		95.4	
Radar maximum antenna gain	dBi	33.5	35.0	34.0	33.5	40.0	43.0	45.7
Relative radar antenna gain in direction of UE	dB	−10.0					−27.0	
Radar feeder loss	dB	2.0			2.0		2.0	
Polarization loss	dB	3.0			3.0		3.0	
Power at the receiver front-end	**dBm/MHz**	**−133.9**	**−132.4**	**−133.4**	**−133.9**	**−127.4**	**−141.4**	**−138.7**
Radar thermal noise floor	dBm/MHz	−112.0	−112.6	−110.7	−112.0	−112.5	−112.0	−111.9
Required *I/N*	dB	−10.0			−10.0		−10.0	
Safety factor	dB	6.0			0.0		0.0	
Acceptable interference level	**dBm/MHz**	**−128.0**	**−128.6**	**−126.7**	**−122.0**	**−122.5**	**−122.0**	**−121.9**
Required additional attenuation	**dB**	**−5.9**	**−3.8**	**−6.7**	**−11.9**	**−4.9**	**−19.4**	**−16.8**

The calculation of the required additional attenuation when considering the rejection of the UE wanted signal by the radar selectivity is shown in Table 22 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 guard bands of between 10 MHz and 30 MHz.

TABLE 22

IMT UE wanted signal rejected by radar selectivity
(with mitigation)

		Units	**Radar 1**	**Radar 2**	**Radar 3**	**Radar 4**	**Radar 5**	**Radar 6**	**Radar 7**
UE transmit power		dBm/MHz	13	13	13	13	13	13	13
UE body loss		dB	4	4	4	4	4	4	4
UE maximum antenna gain		dB	−3	−3	−3	−3	−3	−3	−3
Free space path loss for 500 m separation		dB	95.4	95.4	95.4	95.4	95.4	95.4	95.4
Radar maximum antenna gain		dBi	33.5	35.0	34.0	33.5	40.0	43.0	45.7
Relative radar antenna gain in direction of UE		dB	−10.0	−10.0	−10.0	−10.0	−10.0	−27.0	−27.0
Radar feeder loss		dB	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Polarization loss		dB	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Power at the receiver front-end		**dBm/ MHz**	**−70.9**	**−69.4**	**−70.4**	**−70.9**	**−64.4**	**−78.4**	**−75.7**
Radar thermal noise floor		dBm/MHz	−112.0	−112.6	−110.7	−112.0	−112.5	−112.0	−111.9
Required *I/N*		dB	−10.0	−10.0	−10.0	−10.0	−10.0	−10.0	−10.0
Safety factor		dB	6.0	6.0	6.0	0.0	0.0	0.0	0.0
Attenuation of interfering signal by radar selectivity assuming guard band of	10 MHz	dB	136.9	162.9	56.0	136.9	67.5	153.6	172.9
	20 MHz	dB	169.2	195.8	80.4	169.2	94.2	186.3	206.0
	30 MHz	dB	191.3	218.1	99.3	191.3	114.1	208.6	228.4
Acceptable interference level assuming guard band of	**10 MHz**	**dBm/MHz**	**8.9**	**34.3**	**−70.7**	**14.9**	**−55.0**	**31.6**	**51.0**
	20 MHz	**dBm/MHz**	**41.2**	**67.2**	**−46.3**	**47.2**	**−28.3**	**64.3**	**84.1**
	30 MHz	**dBm/MHz**	**63.3**	**89.5**	**−27.4**	**69.3**	**−8.4**	**86.6**	**106.5**
Required additional attenuation assuming guard band of	**10 MHz**	**dB**	**−79.7**	**−103.6**	**0.4**	**−85.7**	**−9.4**	**−109.9**	**−126.7**
	20 MHz	**dB**	**−112.1**	**−136.6**	**−24.0**	**−118.1**	**−36.0**	**−142.7**	**−159.8**
	30 MHz	**dB**	**−134.2**	**−158.9**	**−42.9**	**−140.2**	**−56.0**	**−164.9**	**−182.2**

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 23 assuming the inclusion of an RF filter before the radar LNA (as described in section 3.2.1.1) yielding 22 dB rejection for a guard band of 10 MHz.

TABLE 23

IMT UE wanted signal on the 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	23.0			23.0		23.0	
UE body loss	dB	4.0			4.0		4.0	
UE maximum antenna gain	dB	−3.0			−3.0		−3.0	
Free space path loss for 500 m separation	dB	95.4			95.4		95.4	
Radar maximum antenna gain	dBi	33.5	35.0	34.0	33.5	40.0	43.0	45.7
Relative radar antenna gain in direction of UE	dB	−10.0					−27.0	
Radar feeder loss	dB	2.0			2.0		2.0	
Polarization loss	dB	3.0			3.0		3.0	
Power at the receiver front-end	**dBm**	**−60.9**	**−59.4**	**−60.4**	**−60.9**	**−54.4**	**−68.4**	**−65.7**
Radar 1 dB compression point	dBm	−10.0	10.0	10.0	−16.8	−10.3	10.0	−17.0
RF filter rejection	dB	22.0	22.0	22.0	22.0	22.0	22.0	22.0
Safety factor	dBm	6.0			0.0		0.0	
Acceptable interference level	**dBm**	**6.0**	**26.0**	**26.0**	**5.2**	**11.7**	**32.0**	**5.0**
Required additional attenuation	**dB**	**−66.9**	**−85.4**	**−86.4**	**−66.0**	**−66.0**	**−100.4**	**−70.7**

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 Baseline adjacent channel case (no mitigation)

The additional attenuation required to enable coexistence for each of the interference mechanisms studied with the baseline characteristics are given in Table 24; 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 selectivity is a problem for the wider bandwidth Radars 3 and 5.

TABLE 24

Required additional attenuation for IMT systems into radar measured in dB

				Victim						
				Radar 1	**Radar 2**	**Radar 3**	**Radar 4**	**Radar 5**	**Radar 6**	**Radar 7**
IMT system	**Suburban macrocell base station**	Unwanted emissions (assuming 10 MHz guard band)		**34.3**	**36.4**	**33.5**	**28.3**	**33.4**	**39.2**	**41.8**
		Effect of wanted signal on radar 1 dB compression point		**−1.7**	**−20.2**	**−21.2**	**−0.9**	**−2.8**	**−16.8**	**12.9**
		Wanted signal rejection by radar IF selectivity assuming guard band of	10 MHz	**9.6**	**−9.1**	**73.9**	**3.6**	**64.4**	**1.2**	**−11.8**
			20 MHz	**−10.6**	**−29.8**	**59.8**	**−16.6**	**48.6**	**−19.4**	**−32.6**
			30 MHz	**−22.9**	**−42.3**	**50.0**	**−28.9**	**38.0**	**−31.9**	**−45.1**
	UE	Unwanted emissions (assuming 15 MHz guard band)		**14.1**	**16.2**	**13.3**	**8.1**	**15.1**	**0.6**	**3.2**
		Effect of wanted signal on radar 1 dB compression point		**−44.9**	**−63.4**	**−64.4**	**−44.0**	**−44.0**	**−78.4**	**−48.7**
		Wanted signal rejection by radar IF selectivity assuming guard band of	10 MHz	**−33.6**	**−52.3**	**30.7**	**−39.6**	**23.2**	**−60.4**	**−73.3**
			20 MHz	**−53.8**	**−73.0**	**16.6**	**−59.8**	**7.3**	**−81.0**	**−94.2**
			30 MHz	**−66.1**	**−85.5**	**6.8**	**−72.1**	**−3.3**	**−93.4**	**−106.7**

4.4.2 Adjacent 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 UE, RF filtering at the base stations and at the radars, improved radar IF selectivity, downtilt with upper sidelobe suppression for the macrocell base stations, exclusion zone around the radar from a UE at a 500 metre separation or a base station at one kilometre, and sufficient guard band. Also the deployment of microcells in the vicinity of radars is considered as a mitigation option. 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 initial study.

The additional attenuation required to enable coexistence for each of the interference mechanisms studied with the improved characteristics are given in Table 25; 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 and 5 requires a guard band between 10 and 20 MHz in order to achieve coexistence with macrocells and UE, and such a guard band is also likely to be adequate for microcells if the path loss is increased through site shielding.

TABLE 25

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

				Victim						
				Radar 1	**Radar 2**	**Radar 3**	**Radar 4**	**Radar 5**	**Radar 6**	**Radar 7**
IMT systems	**Suburban macrocell base station**	Unwanted emissions (assuming 10 MHz guard band)		−73.3	−71.2	−74.1	−79.3	−73.3	−68.4	−65.8
		Effect of wanted signal on radar 1 dB compression point (assuming 10 MHz guard band)		−46.3	−64.8	−65.8	−45.5	−46.5	−61.4	−31.7
		Wanted signal rejected by radar IF selectivity assuming guard band of	10 MHz	−59.2	−83.1	20.9	−65.2	10.2	−70.9	−87.7
			20 MHz	−91.5	−116.0	−3.4	−97.5	−16.5	−103.7	−120.8
			30 MHz	−113.6	−138.3	−22.3	−119.6	−36.4	−126.0	−143.2
	Microcell base station	Unwanted emissions (assuming 10 MHz guard band)		−57.7	−55.6	−58.5	−63.7	−57.7	−55.2	−52.6
		Effect of wanted signal on radar 1 dB compression point (assuming 10 MHz guard band)		−41.7	−60.2	−61.2	−40.9	−41.9	−59.2	−29.5
		Wanted signal rejection by radar IF selectivity assuming guard band of	10 MHz	−54.6	−78.5	25.5	−60.6	14.8	−68.7	−85.5
			20 MHz	−86.9	−111.4	1.2	−92.9	−11.9	−101.5	−118.6
			30 MHz	−109.0	−133.7	−17.7	−115.0	−31.8	−123.8	−141.0
	UE	Unwanted emissions		−5.9	−3.8	−6.7	−11.9	−4.9	−19.4	−16.8
		Effect of Wanted signal on radar 1 dB compression point (assuming 10 MHz guard band)		−66.9	−85.4	−86.4	−66.0	−66.0	−100.4	−70.7
		Wanted signal rejection by radar IF selectivity assuming guard band of	10 MHz	−79.7	−103.6	0.4	−85.7	−9.4	−109.9	−126.7
			20 MHz	−112.1	−136.6	−24.0	−118.1	−36.0	−142.7	−159.8
			30 MHz	−134.2	−158.9	−42.9	−140.2	−56.0	−164.9	−182.2

5 Summary/Conclusions

In this contribution a deterministic study has been presented supplementing that in the [Working Document toward a PDNR M.[IMT.AERO]], which extends the analysis of operation in adjacent 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 metre and free space path loss indicates that additional attenuation is required.

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 guard band of less than 20 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. For a frequency division duplex (FDD) system, the guard bands for uplink and downlink need not be the same size.

This deterministic study assumes worst-case conditions for a single IMT base station or UE. Monte Carlo modelling may be used to examine any aggregate effects, and to calculate probabilities of unacceptable interference occurring. Follow-on studies may also be used to determine geographic separation distances where different mitigation measures are required, and the degree of mitigation that is required / can be provided by different measures.

ATTACHMENT 5

Analysis of required mitigation for IMT systems and radars to share the 2 700-2 900 MHZ band

1 Introduction

This contribution is supplementary to the deterministic study submitted [for the 4th JTG 4-5-6-7 meeting], however for completeness and to make this contribution useful in its own right the relevant technical data and calculations from the deterministic study are included. This study is analysing the effect of; aggregate power, random location of IMT UE, mitigation required, for UE and base stations to protect radar. This is achieved by emulating an IMT system operating under normal conditions using Monte Carlo modelling and analyse the result of this either deterministic or probabilistic as appropriate.

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

2 Background

The 2 700-2 900 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 adjacent channel coexistence may be possible. This document contains a probabilistic and deterministic adjacent channel/band coexistence analysis, 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.

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 WP 5B].

TABLE 1

Radar characteristics

Use		Units	Air Traffic Control			Defence		Meteorological	
Transmitter			**Radar 1**	**Radar 2**	**Radar 3**	**Radar 4**	**Radar 5**	**Radar 6**	**Radar 7**
Power to the antenna		dBW	47.8	44.8	44	48	53	59	57
		dBm/MHz	73.8	75.8	71.2	74	73	89	89.2
3 dB emission bandwidth		MHz	2.5	0.8	1.9	2.5	10	1	0.6
Rec. ITU-R SM.329/1541 spurious emission limits		dBc	60	60	60	60	60	100	100
		dBm	17.8	14.8	14	18	23	−11	−13
		dBm/MHz	13.8	15.8	11.2	14	13	−11	−10.8
Receiver									
Noise Figure		dB	2	1.4	3.3	2	1.5	2	2.1
3 dB bandwidth		MHz	1.5	0.8	15	1.5	10	1	0.63
Receiver thermal noise floor		dBm	−110.2	−113.6	−98.9	−110.2	−102.5	−112.0	−113.9
		dBm/MHz	−112.0	−112.6	−110.7	−112.0	−112.5	−112.0	−111.9
Required *I/N*		dB	−10			−10		−10	
1 dB compression point		dBm	−10	10	10	−16.8	−10.3	10	−17
Antenna									
Pattern			Cosecant squared			Cosecant squared		Pencil	
Polarization			Mixed			Mixed		Circular	
Gain		dBi	33.5	35	34	33.5	40	43	45.7
Antenna aperture		m^2	2.2	3.1	2.5	2.2	9.8	19.6	36.5
Feeder loss		dB	2			2		2	
Azimuthal beamwidth		Degrees	1.5	1.4	1.45	1.5	1.1	0.92	0.92
Elevation beamwidth		Degrees	4.8	4.5	4.8	4.8		0.92	0.92
Rotation		Rpm	15	15	15		60	3	3
Location			Ground			Ground	Shipborne	Ground	
Nominal height		M	15			15	30	15	
Aeronautical safety factor		dB	6			0		0	
Attenuation of interfering signal by radar IF selectivity assuming guard band of	10 MHz	dB	90.7	111.5	25.6	90.7	35.0	104.1	119.6
	20 MHz	dB	110.9	132.2	39.7	110.9	50.8	124.6	140.4
	30 MHz	dB	123.2	144.7	49.5	123.2	61.4	137.1	152.9

Note that Radars 3, 4, 5 and 7 appear to correspond to Radars C, I, J and G in Recommendation ITU-R M.1464-1, respectively.

A number of changes and additions have been made to the parameters in the table including:

– Modification of the 1 dB compression point for Radars 4 and 5 (and related antenna aperture calculation).

– Radar intermediate frequency (IF) selectivity characteristics.

For Radars 4 and 5 (corresponding to Recommendation ITU-R M.1464-1 Radars I and J), the 1 dB compression point is given in terms of the power density at the antenna in W/m^2. For these radars, the 1 dB compression point at the front end receiver input is calculated by multiplying the power density by the antenna aperture in square metres. However, the power density values provided in Recommendation ITU-R M.1464-1 do not seem reasonable as they give rise to 1 dB compression point values of in excess of 80 dBm (100 kW) for the receiver. [In the last WP 5B meeting in Annex 19 of Document 5B/304 *Note should not be referred to in a DNR*] the following note is made, "[Chairman's note: Are the receiver 1 dB compression points and on tune saturation levels correct as they appear a little high. Should they be raise to the power (-)?". If we assume a typographical error here, as suggested by the Chairman's note, and]assume that the power density at the antenna for Radar I, J (or 4 and 5), K and L is 1.5×10^{-5}, 5×10^{-5} W/m^2 rather than $1.5 \times 10^{+5}$, $5 \times 10^{+5}$ W/m^2, then we obtain more reasonable values of −16.8 and −10.3 dBm for the 1 dB compression points, respectively.

The antenna aperture is calculated for each radar assuming a frequency of 2 700 MHz. This is required to convert the 1 dB compression point power density at the antenna provided in Recommendation ITU-R M.1464-1 for Radar 4 and 5 to the 1 dB compression point at the receiver input.

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 guard band of between 10 and 30 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

FIGURE 1

Vertical pattern

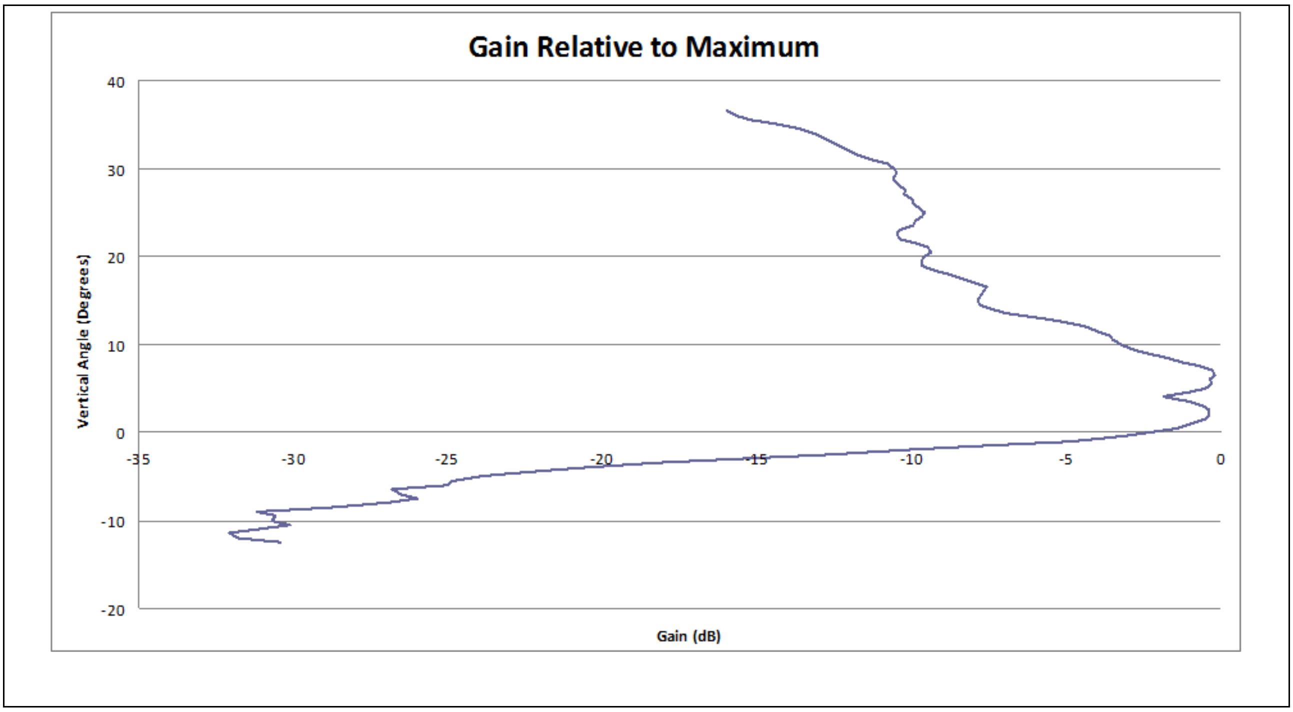

FIGURE 2

Horizontal Pattern

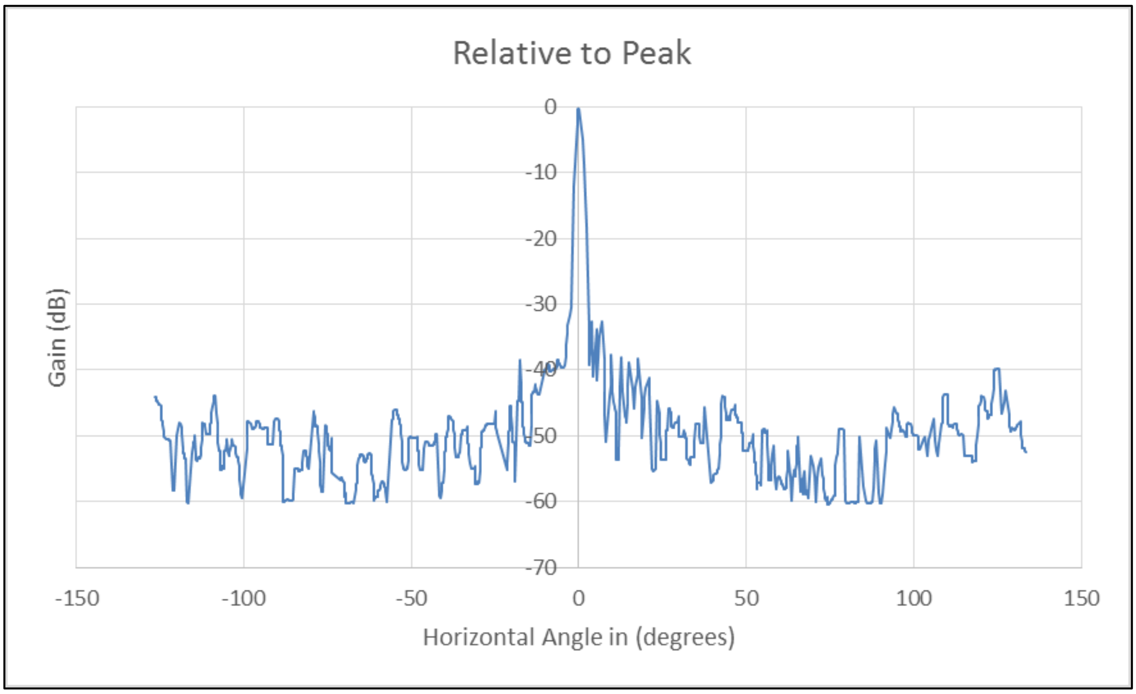

TABLE 2

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/rural macrocell characteristics for [JTG 4-5-6-7] sharing studies [contained in the Chairman’s Report, Document 4-5-6-7/242 Annex 2]. A bandwidth of 10 MHz has been used.

TABLE 3

IMT base station characteristics

Base station		**Units**	**IMT**
Downlink frequency		MHz	2 800
Bandwidth used		MHz	10
Maximum transmitter power	BW=5 MHz	dBm	43
	BW = 10 MHz		46
	Power density	dBm/MHz	36
Spurious emission limits	Limit	dBm/MHz	−30
Max antenna gain (3-sector sites assumed for macro) suburban/rural		dBi	16/18
Feeder loss		dB	3
Antenna height suburban/rural		m	25/30
Antenna down tilt suburban/rural		Degrees	6/3
Antenna type			Sectoral (3 sectors)
Antenna pattern			Rec. ITU-R F.1336-3
Polarization			±45° cross-polarized
3 dB antenna aperture in elevation		Degrees	12
3 dB antenna aperture in azimuth		Degrees	65
Receiver noise figure (worst case)		dB	5
Receiver thermal noise level	BW = 5 MHz	dBm	−102
	BW = 10 MHz		−99
	Power density	dBm/MHz	−109
Required *I/N*		dB	−6

3.1.2.2 User equipment

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]. A bandwidth of 10 MHz has been used for the IMT system.

TABLE 4

IMT UE characteristics

User Equipment (UE)		**Units**	**IMT**
Uplink frequency		MHz	2 800
Bandwidth		MHz	10
Maximum transmitter power		dBm	23
		dBm/MHz	13
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	BW = 10 MHz	dBm	−95
	Power density	dBm/MHz	−105
Required *I/N*		dB	−6

3.1.3 Combined characteristics

The technical characteristics that are dependent on the parameters assumed for both the IMT and radar systems are described in this section.

The antenna gains of the radar developed toward the UE and base station, and the base station antenna gain developed toward the radar are a function of the relative heights and separations. In this study, the suburban macrocell base station height is assumed to be 25 metres, The rural macrocell height is assumed to be 30 m, the microcell base station height is assumed to be 6 m, the UE height is assumed to be 1.5 m and the radar antenna height is assumed to be 15 metres for Radars 1-4, 6-7 and 30 m for Radar 5. Table 5 shows the elevation angles measured at the radar receiver for the IMT macro- and microcell base station.

TABLE 5

Elevation angles of IMT base station antennas determined at radar antenna

			Radars 1-4, 6-7	**Radar 5**
IMT terminal	**Separation**	**Height**	**15 m**	**30 m**
Suburban macrocell base station	1 km	25 m	0.6°	−0.3°
Microcell base station	1 km	6 m	−0.5°	−1.4°

The antenna gains of the radar in the direction of the UE and base stations are summarized in Table 6.

The [working document towards a preliminary draft new Report ITU-R M.[AERO-IMT]] provides the relative gain (–10 dB) for the cosecant characteristic that applies to Radars 1-5. The relative antenna gains toward the base stations are estimated using the vertical antenna pattern for the radar given in Figure 1 in the [working document towards a preliminary draft new Report ITU-R M.[AERO-IMT]].

In the case of Radars 6 and 7, in line with Report ITU-R M.2112, it is assumed that the pencil beam has the characteristics defined in the Federal Meteorological Handbook No. 11, Part B, § 3.28, replicated below:

> Antenna sidelobe levels of the WSR-88D are described as follows:
>
> In any plane, the first sidelobe level is less than or equal to –27 dB relative to the peak of the main lobe. In the region between +2 and +10 degrees from the axis of the main lobe, the sidelobe level shall lie below a straight line connecting –29 dB at +2 degrees and –34 dB at +10 degrees. Between +10 degrees and +180 degrees the sidelobe envelope is less than or equal to –40 dB relative to peak of the main lobe. Generally, the actual pattern is about 5 dB below the prescribed envelope in the region beyond +2 degrees. Other characteristics of interest that are frequency dependent and vary across the operational band include:
>
> - first sidelobe maximum is at about +1.5 degrees from the main lobe axis;
> - first null is at about +1.2 degrees.

In the absence of more detailed information; for the meteorological radars (Radars 6 and 7) a relative gain of –27 dB is developed toward the UE (on the basis that 1.5 degrees below horizontal corresponds to the first sidelobe). Note that the main beam of Radars 6 and 7 can be directed at any elevation angle above the horizontal. As the elevation angle to the suburban macrocell base station is above the horizontal, and therefore may lie within the main beam, then no reduction in radar antenna gain is assumed for Radars 6 and 7. In the case of the microcell base station, which lies 0.5 degrees below the horizontal, a relative gain of 3.8 dB may be assumed, on the basis that the main lobe will be of the form $-12 \times (\theta/\theta_3)^2$ dB, where θ_3 is the 3 dB beamwidth of the antenna.

TABLE 6

Radar antenna gain toward IMT receiver

IMT terminal	Radars 1-4	Radar 5	Radars 6-7
UE	−10 dB	−10 dB	−27 dB
Suburban macrocell base station	−1.4 dB	−2.4 dB	0 dB
Microcell base station	−2.8 dB	−3.8 dB	−3.8 dB

The UE and base station antenna gains in the direction of the radar are summarized in Table 7. In the case of the UE, then no variation of gain with elevation angle is modelled. For base stations, the base station parameters together with the patterns described in Recommendation ITU-R F.1336-4 are used, in conjunction with the elevation angles calculated above, to calculate the effective antenna gain for each path.

TABLE 7

Gain of IMT antennas relative to maximum in direction of radar antenna

IMT Terminal	Gain	Vertical beamwidth	Radars 1-4, 6-7	Radar 5
UE	−3 dBi	N/A	0 dB	0 dB
Suburban Macrocell Base Station (6° downtilt)	16 dBi	12°	−2.4 dB	−3.3 dB
Microcell Base Station	5 dBi	34°	−0.003 dB	−0.02 dB

The gains of the IMT and radar antennas in each path in Tables 5 and 6 are additive. Note that the reduction in gain for the microcell base station is negligible and will therefore be ignored.

Furthermore, radars and IMT systems use different polarizations. IMT systems use linear polarization. Radars 1-5 use mixed polarization with an average polarization loss of 3 dB, however Radars 6 and 7 use circular polarization, so the loss will be 3 dB.

3.2 Mitigation of adjacent 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 adjacent segments of the 2 700-2 900 MHz band.

In order to be able to utilize the band for IMT systems improvements are likely to 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 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 the UK, the remediation approach involves 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 [[6]]. In this case, the lowest radar frequency was given as 2 750 MHz, so the separation from the lowest radar frequency to the edge of the IMT band was 60 MHz.

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[6] Selex System Integration, "Watchman Radar: Receiver Selectivity Improvements in the 2 700-3 100 MHz band", Final Report, Ref SSI-PS0305-ENG-405, 1 December 2009 downloaded from http://stakeholders.ofcom.org.uk/binaries/spectrum/spectrum-awards/awards-in-preparation/757738/592_Watchman_Radar_Receiver1.pdf on 9 September 2013.

A report by Isotek, commissioned by Ofcom [7] considered what filtering might be practical to separate these bands. The study was based on combline filter designs, and concluded that 60 MHz offset (as used in the remediation programme) would enable >60 dB rejection to be attained, with a variety of wide pass bands, with insertion losses in the region of 0.15 dB. Reducing the offset to 30 MHz resulted in rejection of only 35 dB with similar insertion losses. Further reduction to 10 MHz resulted in increased insertion losses (0.27-0.3 dB) but rejection of 22-23 dB and unacceptable phase distortion (corresponding to 0.4 degrees deviation from linear phase across the pass band).

In this work, a 10 MHz passband filter which could operate at an offset of 10 MHz was proposed for fixed frequency operation. In this case the loss was increased to 0.94 dB and the rejection 35 dB.

Much greater rejections can be achieved with combline filters if the phase variation requirements can be relaxed; in principle, the variation may be compensated elsewhere in the receiver. In this case rejections of around 60 dB can be achieved with 10 MHz separation.

In the mitigation analysis presented later, the RF filter rejection is assumed to be 22 dB, 28.5 dB and 35 dB for frequency offsets of 10, 20 and 30 MHz, respectively.

3.2.1.2 Improving IF filtering

The receiver IF-rolloff, 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 guard bands 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-rolloff of 100 dB/decade is assumed yielding the rejection values shown in Table 8. This rejection is additional to the rejection offered by RF filtering summarized at the end of section 3.2.1.1.

TABLE 8

Radar IF selectivity assuming an IF-rolloff of 100 dB/decade and guard bands of 10, 20 and 30 MHz

		Units	Air Traffic Control			Defence		Meteorological	
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 separation of	10 MHz	dB	114.9	140.9	34.0	114.9	45.5	131.6	150.9
	20 MHz	dB	140.7	167.3	51.9	140.7	65.7	157.8	177.5
	30 MHz	dB	156.3	183.1	64.3	156.3	79.1	173.6	193.4

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[7] Isotek Electronics Ltd, "High Q Filter Feasibility Study for Base-Station and Radar Receiver Applications", Ref IF26, 15 October 2009 downloaded from http://stakeholders.ofcom.org.uk/binaries/consultations/872_876_mhz/annexes/highq.pdf on 9 September 2013.

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 shown in a 2.6 GHz antenna pattern given in Figure 26(b) of Report ITU-R F.1336 [[8]].

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

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[9]. 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 around −55 dBm/MHz at 10 MHz offset falling to around −65 dBm/MHz by 20 MHz offset.

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”.

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 networks, including 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 UE are generally considerably better than the specification. 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.

3.2.4 Microcells in areas around radars as a mitigation option

The microcell base station characteristics shown in Table 9 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]. A bandwidth of 10 MHz has been used for this analysis.

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[8] 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.

[9] 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.

TABLE 9

Base station characteristics

Base station		**Units**	**IMT**
Downlink frequency		MHz	2 800
Bandwidth		MHz	10
Maximum transmitter power	BW = 10 MHz	dBm	35
	Power density	dBm/MHz	25
Spurious emission limits	Limit	dBm/MHz	−30
Max antenna gain		dBi	5
Feeder loss		dB	N/A
Antenna height		m	6
Antenna down tilt		Degrees	N/A
Antenna type			Omni
Antenna pattern			Rec. ITU-R F.1336-3
Polarization			Linear
3 dB antenna aperture in elevation		Degrees	34
3 dB antenna aperture in azimuth		Degrees	360
Receiver noise figure (worst case)		dB	5
Receiver thermal noise level	BW = 5 MHz	dBm	−102
	BW = 10 MHz		−99
	Power density	dBm/MHz	−109
Required *I/N*		dB	−6

Potentially, where required, the area around the radar could be provided with microcell coverage outdoor and picocell coverage indoor. The benefit is that because the path losses are considerably lower, as microcell base stations have reduced transmit power, the UE will have proportionately reduced power. Consequently, the 11 dB difference in base station transmit power will result in a similar 11 dB reduction in the UE transmit power distribution, and therefore it will be possible to limit the UE maximum transmit power in a microcell to only 12 dBm. Careful siting of microcell base station antennas, out of line-of-sight could allow the path loss to the radar antennas to be substantially increased over the free space values included in the analyses. These potential benefits have not been included in our analyses.

When the option of using microcells is assumed in the mitigation sensitivity analysis presented later, the parameter values in Table 9 are assumed.

4 Analysis

In this section the results of the deterministic analysis of adjacent 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.

4.1 Assumptions

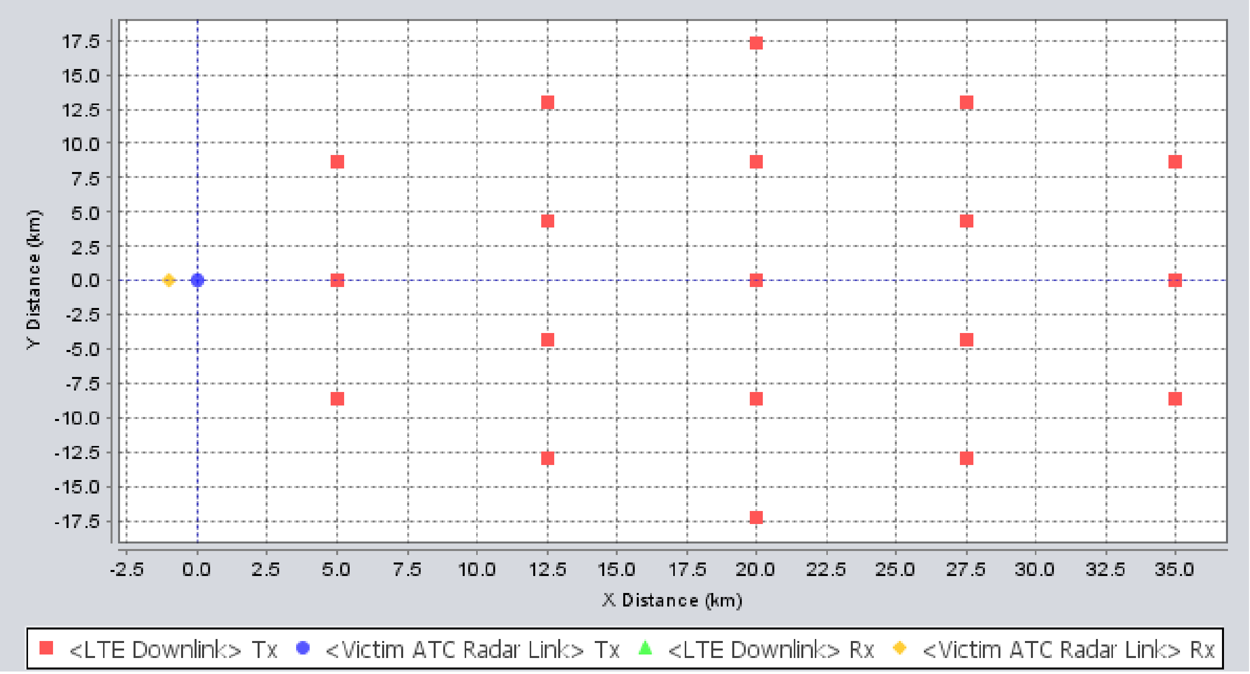
In addition to the assumptions described in section 3, the following assumptions apply:

- 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 = ≥ 5.5 km
  - UE = ≥ 500 m.
- Maximum transmission power is assumed for IMT base stations and the powers from a 'real life' IMT system are emulated for the UE by Seamcat's built-in OFDMA module.
- Suburban for base stations [(reference Document 4-5-6-7/353)] and rural environment for the analysis of mitigation, to increase the power to maximum and to avoid discussions about what type of environment an airport constitutes when the propagation model Recommendation ITU-R P.452-14 is used.
- Base station antenna down tilt of 3º for rural and 6º for suburban.
- The assumption of a 1 dB compression point of –10 dBm for the radars has been made in the absence of parameters [from WP 5B] or ITU recommendations.

4.2 IMT cell structure for the analysis

The IMT parameters in Tables 2 and 3 [(as provided to JTG 4-5-6-7 from WP 5D)] are used to set up the Seamcat OFDMA module for the IMT network for this frequency range. Below in Figure 3 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 metres exclusion zone for the UE. The IMT parameters [from WP 5D] 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 3



4.3 Baseline adjacent 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 10; 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 needs improvement for most of the radars in the case where an IMT base station is operating in the adjacent channel/band to a radar.

TABLE 10

Required additional attenuation for IMT systems into radar measured in dB

				Victim						
				Radar 1	**Radar 2**	**Radar 3**	**Radar 4**	**Radar 5**	**Radar 6**	**Radar 7**
IMT system	Suburban macrocell base station	Unwanted emissions (assuming 10 MHz guard band)		34.3	36.4	33.5	28.3	33.4	39.2	41.8
		Effect of wanted signal on radar 1 dB compression point		−1.7	−20.2	−21.2	−0.9	−2.8	−16.8	12.9
		Wanted signal rejection by radar IF selectivity assuming guard band of	10 MHz	9.6	−9.1	73.9	3.6	64.4	1.2	−11.8
			20 MHz	−10.6	−29.8	59.8	−16.6	48.6	−19.4	−32.6
			30 MHz	−22.9	−42.3	50.0	−28.9	38.0	−31.9	−45.1
	UE	Unwanted emissions (assuming 15 MHz guard band)		14.1	16.2	13.3	8.1	15.1	0.6	3.2
		Effect of wanted signal on radar 1 dB compression point		−44.9	−63.4	−64.4	−44.0	−44.0	−78.4	−48.7
		Wanted signal rejection by radar IF selectivity assuming guard band of	10 MHz	−33.6	−52.3	30.7	−39.6	23.2	−60.4	−73.3
			20 MHz	−53.8	−73.0	16.6	−59.8	7.3	−81.0	−94.2
			30 MHz	−66.1	−85.5	6.8	−72.1	−3.3	−93.4	−106.7

4.4 Calculations

In the following calculations the parameters [from WP 5B and WP 5D] 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 suburban macrocell base station is located one kilometre from a radar. Then this is recalculated for a rural macrocell to take account of the increased power and antenna height 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 a rather conservative or strict requirement 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.

4.4.1 Base station adjacent channel calculations

In the following the base station calculations are considered.

4.4.1.1 Single IMT suburban base station spurious emissions impact on radar (no mitigation) at one kilometre 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 11. A guard band of 10 MHz is assumed for the Category B −30 dBm/MHz base station spurious emissions limit to apply.

TABLE 11

IMT suburban 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	
Base station feeder loss	dB	3.0			3.0		3.0	
Base station maximum antenna gain	dBi	16.0			16.0		16.0	
Relative base station antenna gain in direction of the radar	dB	−2.4			−2.4	−3.3	−2.4	
Free space path loss for one kilometre separation	dB	101.4			101.4		101.4	
Radar maximum antenna gain	dBi	33.5	35.0	34.0	33.5	40.0	43.0	45.7
Relative radar gain in direction of the base station	dB	−1.4	−1.4	−1.4	−1.4	−2.4	0.0	0.0
Radar feeder loss	dB	2.0			2.0		2.0	
Polarization loss	dB	3.0			3.0		3.0	
Power at the receiver front-end	**dBm/MHz**	**−93.7**	**−92.2**	**−93.2**	**−93.7**	**−89.1**	**−82.8**	**−80.1**
Radar thermal noise floor	dBm/MHz	−112.0	−112.6	−110.7	−112.0	−112.5	−112.0	−111.9
Required *I/N*	dB	−10.0			−10.0		−10.0	
Safety factor	dB	6.0			0.0		0.0	
Acceptable interference level	**dBm/MHz**	**−128.0**	**−128.6**	**−126.7**	**−122.0**	**−122.5**	**−122.0**	**−121.9**
Required additional attenuation	**dB**	**34.3**	**36.4**	**33.5**	**28.3**	**33.4**	**39.2**	**41.8**

The above results from a single base station into a radar receiver at one kilometre is recalculated for a rural environment 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 2 as this is the most critical.

For Radar 2 the calculation of the spurious emissions using free space propagation provides aggregate interference power at the radar receiver of –102.53 dBm which is 26.07 dB above the threshold of –128.6 dBm (–10 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 (suburban macro) is fixed at one kilometre. In this 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 kilometres distance to the radar to provide coverage for the UE up to a distance of 500 metres from the radar.

At distances between 5.5 and 40 kilometres free space propagation clearly is not a valid model even for base stations and the more suitable propagation model in Rec. 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 propagation models.

Recalculating the spurious emissions using Recommendation ITU-R P.452-14 propagation model at 0.001% time and aggregate power provides -96.35 dBm at the radar receiver or 32.25 dB above the threshold of –128.6 dBm (–10 dB *I/N*, –6 dB safety factor).

Taking the above into consideration 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.

4.4.1.2 Single IMT suburban macro base station impact on radar IF selectivity (no mitigation) at a one kilometre 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 12. The required additional attenuation is calculated for a guard band of 10 MHz.

TABLE 12

IMT suburban base station wanted signal suppressed by radar IF selectivity

		Units	**Radar 1**	**Radar 2**	**Radar 3**	**Radar 4**	**Radar 5**	**Radar 6**	**Radar 7**
Base station transmit power		dBm/MHz	36	36	36	36	36	36	36
Base station feeder loss		dB	3	3	3	3	3	3	3
Base station maximum antenna gain		dB	16	16	16	16	16	16	16
Relative base station antenna gain in direction of the radar		dB	−2.4	−2.4	−2.4	−2.4	−3.3	−2.4	−2.4
Free space path loss for one kilometre separation		dB	101.4	101.4	101.4	101.4	101.4	101.4	101.4
Radar maximum antenna gain		dBi	33.5	35.0	34.0	33.5	40.0	43.0	45.7
Relative radar gain in direction of the base station		dB	−1.4	−1.4	−1.4	−1.4	−2.4	0.0	0.0
Radar feeder loss		dB	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Polarization loss		dB	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Power at the receiver front-end		**dBm/MHz**	**−27.7**	**−26.2**	**−27.2**	**−27.7**	**−23.1**	**−16.8**	**−14.1**
Radar thermal noise floor		dBm/MHz	−112.0	−112.6	−110.7	−112.0	−112.5	−112.0	−111.9
Required *I/N*		dB	−10	−10	−10	−10	−10	−10	−10
Safety factor		dB	6	6	6	0	0	0	0
Attenuation of interfering signal by radar IF selectivity assuming guard band of	10 MHz	dB	90.7	111.5	25.6	90.7	35.0	104.1	119.6
Acceptable interference level assuming guard band of	**10 MHz**	**dBm/MHz**	**−37.3**	**−17.1**	**−101.1**	**−31.3**	**−87.5**	**−17.9**	**−2.3**
Required additional attenuation assuming guard band of	**10 MHz**	**dB**	**9.6**	**−9.1**	**73.9**	**3.6**	**64.4**	**1.2**	**−11.8**

Recalculating the IF selectivity for Radar 1 using free space propagation and aggregate interference power for a rural environment provides –124.71 dBm at the radar receiver, 3.29 dB above the threshold of –128.0 dBm (–10 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 for a rural environment provides –118.54 dBm, 9.46 dB above the threshold of –128.0 dBm (–10 dB *I/N* –6 dB safety factor).

Where required the selectivity may be enhanced by an improved roll-off of the IF filter but as the radar receiver may also need improved 1 dB compression point characteristic a RF front end filter may be required. This filter will also provide the additional selectivity required. Assuming an RF front end filter with 20 dB attenuation at ≥ 10 MHz frequency separation will using Recommendation ITU-R P.452-14 propagation model at 0.001% time and aggregate power for a rural environment provide –144.27 dBm at the radar receiver or 16.27 dB below the threshold of –128.0 dBm (–10 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, calculating this will using Recommendation ITU-R P.452-14 propagation model at 0.001% time and aggregate power for a rural environment provide –102.35 dBm at the radar receiver threshold of –126.7 dBm (–10 dB *I/N* –6 dB safety factor) or 24.35 dB above the threshold. This can be mitigated by either replacing the radar by a modern more frequency efficient radar or ensuring a frequency separation between radar and the IMT base stations for this type of radar of ≥ 30 MHz which will also provide –129.2 dBm or 2.5 dB below the radar receiver threshold of –126.7 dBm (–10 dB *I/N* –6 dB safety factor).

Radar 5 will also need a RF front end filter and a 100 dB/decade IF filter and this will using Recommendation ITU-R P.452-14 propagation model at 0.001% time and aggregate power for a rural environment provide –105.42 dBm at the radar receiver or 17.08 dB above the radar receiver threshold of –122.5 dBm (–10 dB *I/N*). This can be mitigated by either replacing the radar by a modern more frequency efficient radar or ensuring a frequency separation between radar and the IMT base stations for this type of radar of ≥ 20 MHz which will also provide –125.32 dBm or 2.82 dB below the radar receiver threshold of –122.5 dBm (–10 dB *I/N*).

4.4.1.3 Single IMT rural base station impact on radar 1 dB compression point (no mitigation) at a one kilometre 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 13.

TABLE 13

IMT suburban base station wanted signal on the 1 dB compression point of a radar receiver

	Units	**Radar 1**	**Radar 2**	**Radar 3**	**Radar 4**	**Radar 5**	**Radar 6**	**Radar 7**
Base station transmit power	dBm	46.0			46.0		46.0	
Base station feeder loss	dB	3.0			3.0		3.0	
Base station maximum antenna gain	dB	16.0			16.0		16.0	
Relative base station antenna gain in direction of the radar	dB	−2.4			−2.4	−3.3	−2.4	
Free space path loss for one kilometre separation	dB	101.4			101.4		101.4	
Radar maximum antenna gain	dBi	33.5	35.0	34.0	33.5	40.0	43.0	45.7
Relative radar gain in direction of the base station	dB	−1.4	−1.4	−1.4	−1.4	−2.4	0.0	0.0
Radar feeder loss	dB	2.0			2.0		2.0	
Polarization loss	dB	3.0			3.0		3.0	
Power at the receiver front-end	**dBm**	**−17.7**	**−16.2**	**−17.2**	**−17.7**	**−13.1**	**−6.8**	**−4.1**
Radar 1 dB compression point	**dBm**	−10.0	10.0	10.0	−16.8	−10.3	10.0	−17.0
Safety factor	**dBm**	6.0			0.0		0.0	
Acceptable interference level	**dBm**	**−16.0**	**4.0**	**4.0**	**−16.8**	**−10.3**	**10.0**	**−17.0**
Required additional attenuation	**dB**	**−1.7**	**−20.2**	**−21.2**	**−0.9**	**−2.8**	**−16.8**	**12.9**

Recalculating the 1 dB compression point for Radar 1 using free space propagation and aggregate interference power for a rural environment provides –23.9 dBm at the radar receiver, 7.9 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 and aggregate power for a rural environment provides –17.72 dBm, 1.72 dB below the threshold of –16 dBm (1 dB compression point –6 dB safety factor).

Mitigation may be required for radars with a 1 dB compression point below –10 dBm. This requires the installation of a RF front end filter in the radar receiver and assuming the filter outlined in 3.2.1.1 the calculation now using Recommendation ITU-R P.452-14 propagation model at 0.001% time and aggregate power for a rural environment provides –43.46 dBm, 27.46 dB below the threshold of –16 dBm (1 dB compression point –6 dB safety factor).

4.4.2 IMT UE calculations

4.4.2.1 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 14.

TABLE 14

IMT UE 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	
UE body loss	dB	4.0			4.0		4.0	
UE maximum antenna gain	dBi	−3.0			−3.0		−3.0	
Free space path loss for 500 m separation	dB	95.4			95.4		95.4	
Radar maximum antenna gain	dBi	33.5	35.0	34.0	33.5	40.0	43.0	45.7
Relative radar antenna gain in direction of UE	dB	−10.0					−27.0	
Radar feeder loss	dB	2.0			2.0		2.0	
Polarization loss	dB	3.0			3.0		3.0	
Power at the receiver front-end	**dBm/MHz**	**−113.9**	**−112.4**	**−113.4**	**−113.9**	**−107.4**	**−121.4**	**−118.7**
Radar thermal noise floor	dBm/MHz	−112.0	−112.6	−110.7	−112.0	−112.5	−112.0	−111.9
Required *I/N*	dB	−10.0			−10.0		−10.0	
Safety factor	dB	6.0			0.0		0.0	
Acceptable interference level	**dBm/MHz**	**−128.0**	**−128.6**	**−126.7**	**−122.0**	**−122.5**	**−122.0**	**−121.9**
Required additional attenuation	**dB**	**14.1**	**16.2**	**13.3**	**8.1**	**15.1**	**0.6**	**3.2**

4.4.2.2 IMT UE MC calculations for spurious emissions of multiple UE in the IMT system

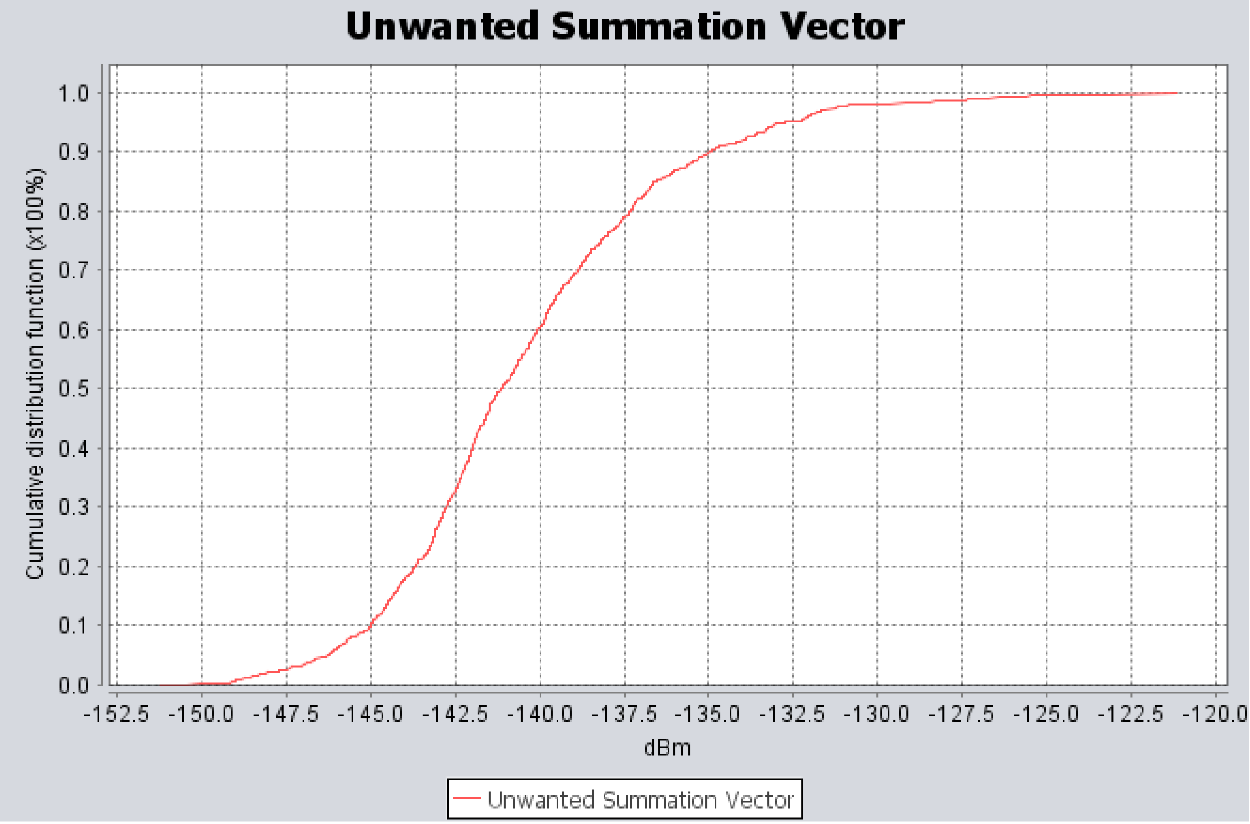
The above results from a single UE into a radar receiver at 500 metres is recalculated using the cellular structure from above and aggregate power from randomly located UE at distances from 500 metres to 40 kilometres (the size of the simulated IMT system). The calculations have been performed for Radar 2 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 14.1 dB for Radar 1.

The simple but costly solution would be just to ‘tighten’ the spurious emissions requirements of the UE by the required 14.1 dB. The result of this is shown below in Figure 4 as a ‘bench mark’.

FIGURE 4

UE with –44.1 dBm/MHz spurious emissions, free space propagation and aggregate power of UE in the radar beam pointing into the IMT system



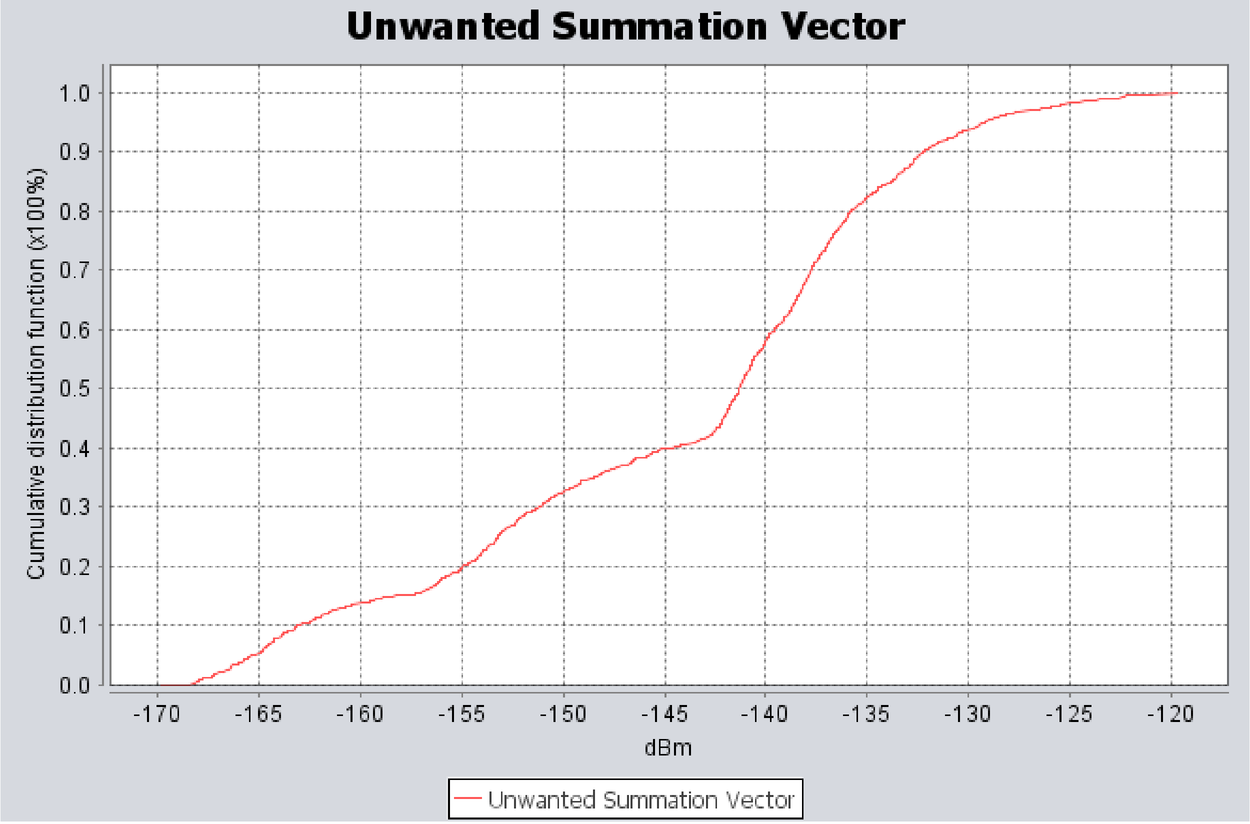
The number of events where the aggregate interference power in this scenario is exceeding the threshold of –128.6 dBm (–10 dB *I/N* and 6 dB ATC safety factor) is 1.3% with 0.2% of events exceeding the *I/N* threshold by around 2.5 dB (the maximum value).

The scenario above assumes free space propagation to be a valid model at distances of up to 40 km and that all 570 active UE are transmitting continuously, of course, neither of those 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 5 shows the impact of this on the ‘unmitigated’ baseline scenario.

FIGURE 5

UE with standard –30 dBm/MHz spurious, free space propagation, correlation factor and aggregate of UE in the radar beam pointing into the IMT system

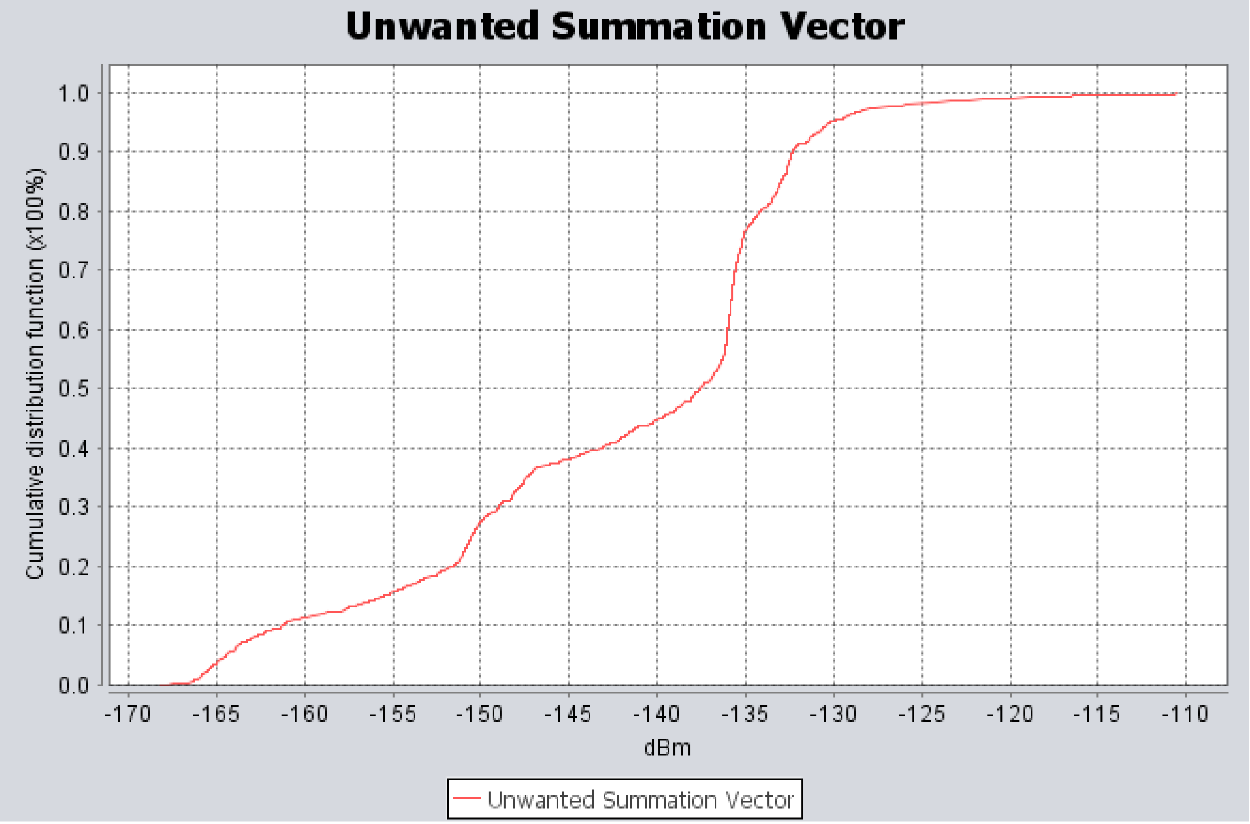


The number of events where the aggregate interference power in this scenario is exceeding the threshold of –128.6 dBm (–10 dB *I/N* and 6 dB ATC safety factor) is 3.4% with 0.4% exceeding the *I/N* threshold.

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 6.

FIGURE 6

UE with a 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



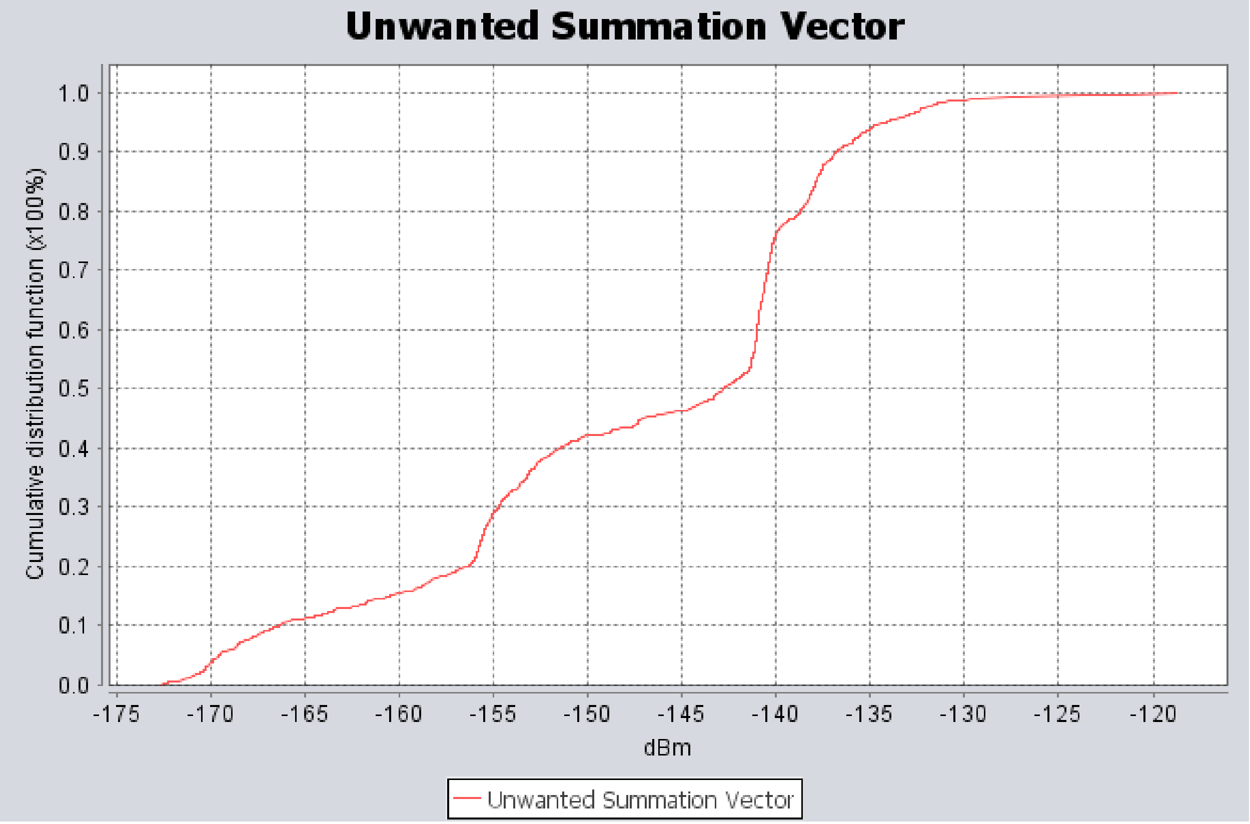
The number of events where the aggregate interference power in this scenario is exceeding the threshold of –128.6 dBm (–10 dB *I/N* and 6 dB ATC safety factor) is 2.7% with 1.2% exceeding the *I/N* threshold

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 7) and 10 dB (Figure 8) respectively.

FIGURE 7

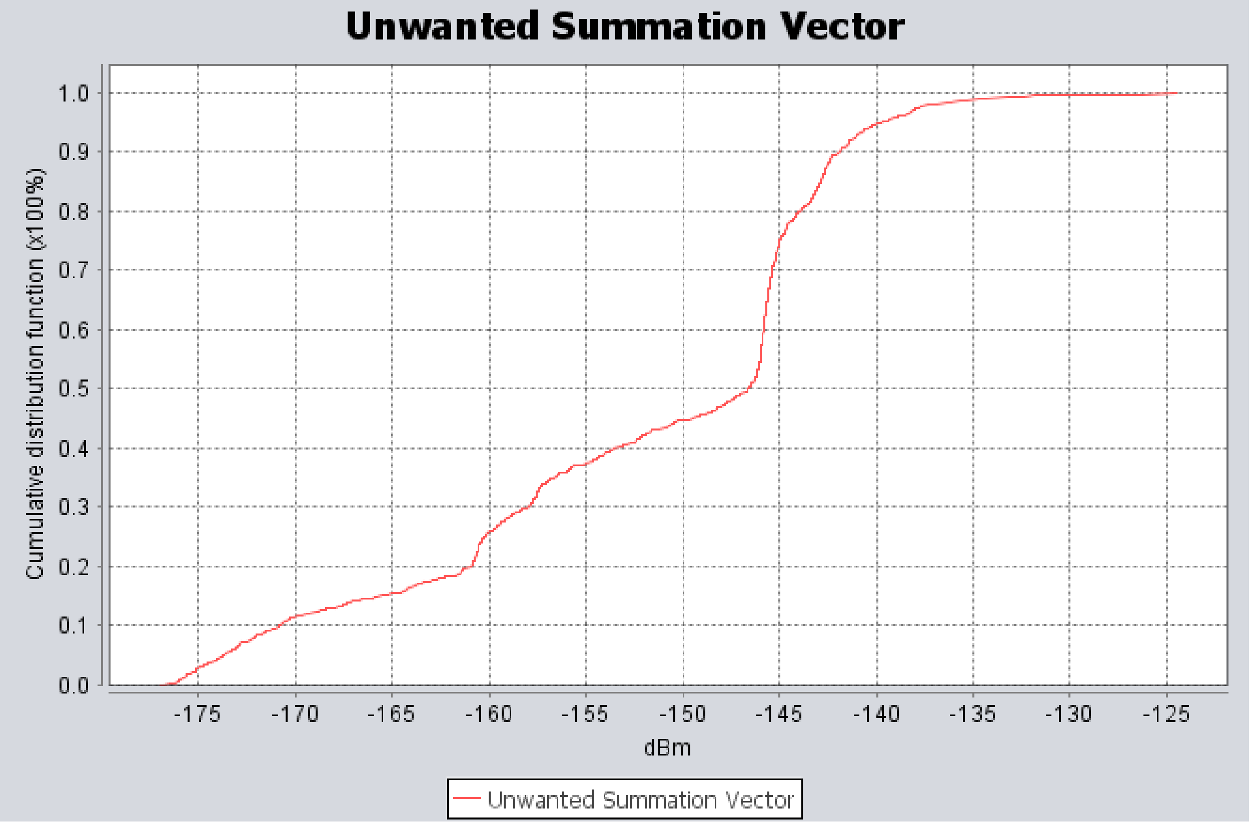
UE with a –35 dBm/MHz spurious, correlation factor, with propagation model Recommendation ITU-R P.452-14 at 0.001% time and aggregate of UE in the radar beam pointing into the IMT system



The number of events where the aggregate interference power in this scenario is exceeding the threshold of –128.6 dBm (–10 dB *I/N* and 6 dB ATC safety factor) is 0.8% with 0.3% exceeding the *I/N* threshold, mean value –147.91 dBm.

FIGURE 8

UE with a –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 number of events where the aggregate interference power in this scenario is exceeding the threshold of –128.6 dBm (–10 dB *I/N* and 6 dB ATC safety factor) is 0.2% with 0% exceeding the *I/N* threshold, mean value –152.39 dBm

4.5 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 15 below is the results for IMT base stations.

TABLE 15

MCL, base station to Radar at 10 MHz guard band Required attenuation	**1 km single, free space**	**Aggregate interference power P452-14**	**Mitigation assumed**	**Result**
Spurious emissions				
Radar 1 ATC	36.4	32.25	20 dB improved spurious emissions on all base station, coordination within 65 km of radar, site engineering of these (extra TX filter)	🟩
Selectivity				
Radar 1	9.6	9.46	Radar RF front end filter	–16.27
Radar 3	73.9	🟥	Radar RF front end filter, a 100 dB/dec IF filter and 20 MHz additional guard band or replace radar to be more spectrum efficient	–2.5
Radar 5	64.4	🟥	Radar RF front end filter, a 100 dB/dec IF filter and 10 MHz additional guard band or replace radar to be more spectrum efficient	–2.82
1 dB Compression point				
Radar 1 ATC	–1.7	–1.72	Radar RF front end filter Assuming that the actual 1 dB compression point figures might be lower than specified also Radars 2, 4, 6 and 7 may require a similar filter	–27.46

Whilst microcell base stations have not been calculated in the above it is clear from the technical data given that these could form a valuable mitigation for coverage in areas where it would be difficult to deploy macrocell base stations. The microcell base stations would only have compatibility issues with the older less frequency efficient Radars 3 and 5.
Table 16 below is the results for IMT user equipment

TABLE 16

UE uplink	**Spurious emissions (Green signifies compatibility)**	
MCL at 500 m distance, single UE, free space propagation (required attenuation)	🟥 17.5 dB	
Radar interference criteria for Monte Carlo simulations (Radar 2, ATC, worst case) (The figures below give% of events exceeding the interference criteria)	–128.6 dBm (–10 dB *I/N* and 6 dB ATC safety factor)	–122.6 dBm (–10 dB *I/N*)
Aggregate interference power, free space propagation, spurious –47.5 dBm ‘bench mark’ scenario	🟩 1.3%	🟩 0.2%
Aggregate interference power, correlation factor, Recommendation ITU-R P.452-14 propagation model at 0.001% time, ‘generic’ spurious emissions — –30 dBm/MHz	🟥 3.4%	🟥 0.4%
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	🟩 0.8%	🟥 0.3%
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 and 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 two 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 is not exceeded.

5 Conclusions

This contribution 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 guard band 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. Some 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 Radars 3 and 5 which in addition will require an IF filter with a roll-off of around 100 dB/decade. Radars 3 and 5 will also require a guard band of around 20 MHz. 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 in the adjacent band provided a 10 MHz guard band 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 may be required for the radars and around 20 dB improved spurious emissions 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, transmitter chain filter or both. Also, Radars 3 and 5 are likely to require an improved IF filter and a minimum guard band of 20 MHz.

In principle, it would be possible to operate IMT uplink in the adjacent channel with a guard band 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.

ATTACHMENT 6

Sharing between IMT-Advanced and radiodetermination systems in the band 2 700-2 900 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 2 700-3 100 MHz band, which is currently allocated to radionavigation and radiolocation services.

In some countries, there is minimal or inefficient usage of the band 2 700-3 100 MHz by radiodetermination services - prompting administrations to explore opportunities for other services such as wireless broadband systems to exploit the band (or some portion of it) toward further facilitating national economic growth and development.

A contribution [(Document 4-5-6-7/130) to a previous meeting of JTG 4-5-6-7] illustrated the opportunities for segmentation of the band 2 700-3 100 MHz, based on studies [submitted to ITU-R Working Party 5B and included in the Chairman’s Report (see Document 5B/167, Annex 29)] that demonstrated the potential for improved usage efficiency throughout this band.

This contribution builds on preliminary studies submitted [(Document 4-5-6-7/277) to the last meeting of JTG 4-5-6-7] and presents more detailed technical sharing studies that investigate the minimum necessary frequency and geographic separation necessary to protect systems in the aeronautical radionavigation service (including meteorological radars) from unacceptable interference caused by emissions of IMT-Advanced fixed and mobile stations.

The more detailed studies reported in this contribution have focused on modelling adjacent-channel operating scenarios to illustrate the potential of alternative approaches:

i) local segmentation of the band (per Recommendation ITU-R SM.1132) to accommodate IMT-Advanced systems in one segment and incumbent systems in an adjacent segment; 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 also suggest a possible basis 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

In Article **5** of the International Radio Regulations (RRs), the frequency band 2 700-2 900 MHz is currently allocated to the aeronautical radionavigation service (RNS) on a primary basis, and restricted to ground-based radar and associated transponders through RR No. **5.337**, and the radiolocation service (RLS) on a secondary basis. Additionally, RR No. **5.423** permits the use of ground-based meteorological radars on an equal basis to the aeronautical RNS. Similarly, the band 2 900-3 100 MHz is currently allocated to the radiolocation and radionavigation services for maritime radar applications, as well as ground-based aeronautical radars under RR No. **5.426**.

[The technical characteristics for the RNS and IMT systems were derived from the ***Compilation of material maintained by the Joint Task Group 4-5-6-7 Working Groups***, Annex 2 to the JTG 4-5-6-7 Chairman's Report of the 3rd Meeting (Document 4-5-6-7/242). *Note cannot be referred to in a DNR.*]

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.1464-1 – Characteristics of radiolocation radars, and characteristics and protection criteria for sharing studies for aeronautical radionavigation and meteorological radars in the radiodetermination service operating in the frequency band 2 700-2 900 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.

Where parameter values were not available in the above reference sources, supplementary references highlighted by previous contributions were also consulted, including:

- NTIA Report 13-490 – Analysis and Resolution of RF Interference to Radars Operating in the Band 2 700-2 900 MHz from Broadband Communication Transmitters (October 2012).
- ECC Report 174 – Compatibility between the mobile service in the band 2 500-2 690 MHz and the radiodetermination service in the band 2 700-2 900 MHz.
- Ofcom Report AY4051, – The Report of an Investigation into the Characteristics, Operation and Protection Requirements of Civil Aeronautical and Civil Maritime Radar Systems.

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

The radio propagation environments were modelled in accordance with [the recent liaison advice from Working Parties 3K and 3M (Document 4-5-6-7/141) along with *Note cannot be referred to in a DNR*] 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.452-12 – 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

Recommendation ITU-R M.1464 identifies Radar type G as representative of modern meteorological radars, and Radar type C as representative of next-generation aeronautical radars already being deployed in many countries. It was noted in Recommendation ITU-R M.1464 that Radar type C should augment and/or replace Radar types A, B and F after 2010.

Therefore, the following technical characteristics (*based on Radar* ***C*** *and Radar* ***G****, respectively, of Recommendation ITU-R M.1464-1*) have been assumed for radar systems in these studies:

TABLE 1

Radar systems technical characteristics

Parameter	Units	Aeronautical	Meteorological
Transmitter			
RF Output Type	–	Solid state	Klystron
Peak Power into Antenna	dBW	43.9	57
3dB emission bandwidth	MHz	1.9	0.6
Receiver			
Noise Figure	dB	3.3	2.1
RF bandwidth	MHz	280.6	1.6
IF bandwidth	MHz	15	0.63
IF Selectivity roll-off[10]	dB/decade	80	80
Target *I/N*	dB	–10	–10
Additional safety margin	dB	–6	0
Min sensitivity	dBm	–110	–115
RF 1 dB Compression	dBm	–20	–17
Antenna			
Pattern type	–	Cosec-squared	Pencil* (volume scanning)
Polarisation	–	Mixed	Horizontal
Boresight Gain	dBi	34	45.7
Azimuth beamwidth	degrees	1.45	0.92
Nominal height	m (AGL)	8	30

* NOTE: For low-elevation (<3° above horizon) beam pointing, the vertical illumination pattern is assumed to be similar to recommended patterns defined in Recommendation ITU-R M.1851 *Mathematical models for radiodetermination radar systems antenna patterns for use in interference analyses*.

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[10] 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 have been assumed 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: 25 Urban: 20	1.5
Cell radius	km	Rural: 4 Suburban: 0.8 Urban: 0.4	–
Antenna down-tilt	degrees	Rural: 3 Suburban: 6 Urban: 10	–
Typical body loss	dB	–	4
User terminal density (in active mode)	Users/5 MHz/km^2	–	Rural: 0.17 Suburban: 2.16 Urban: 3
Transmitter*			
Maximum Tx Power	dBm	43	23
Dynamic Power Control	–	No	Yes
Max Tx e.i.r.p.	dBm	58	20
Channel bandwidth	MHz	10	10
Average activity factor	%	50	–
Receiver*			
Ref sensitivity	dBm	–101.5	–95
Noise Figure	dB	5	9
Blocking	dBm	–15	+6
Adjacent Channel Selectivity	dB	[–58 dB @ 2.5 MHz offset]	33

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

The out-of-band (OOB) and spurious emission characteristics of IMT base-stations and user equipment (UEs) are based on maximum mask specified in the 3GPP technical specification series 36 (TS 36). Commercial IMT products typically offer significantly better performance[11] 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 UE is assumed:

TABLE 3

IMT OOB and spurious emission limits

Parameter	**Units**	**Value**	**Notes**
IMT Base-stations – for 5, 10, 15 and 20 MHz channel bandwidths (3GPP TS 36.104)			
OOB emissions	dBm/MHz	–15	Category B – for frequency separation of up to 10 MHz from channel edge above and below operating band
Spurious emissions	dBm/MHz	–30	Category B – except for OOB emission region noted above, in the range 1-12.75 GHz
IMT UE – for 10 MHz channel bandwidth (3GPP TS 36.101)			
OOB emissions	dBm/30 kHz	–18	0-1 MHz separation from channel edge
	dBm/MHz	–10	1-5 MHz
	dBm/MHz	–13	5-10 MHz
	dBm/MHz	–25	10-15 MHz
Spurious emissions	dBm/MHz	–30	except for OOB emission region noted above, in the range 1-12.75 GHz

Note: [In accordance with WP 5D advice[12] to the JTG 4-5-6-7: t]These unwanted emission limits are the upper limits defined in 3GPP specifications for laboratory testing while the UE 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 above, the studies reported in this contribution have focused on *adjacent channel* sharing, in support of those administrations reviewing the efficiency of current usage of the band 2 700-3 100 MHz by aeronautical, meteorological and maritime radars in their own country. While the deployment of these systems may be widespread in some countries, other countries have deployed few such systems (or none, in some cases) in this band—and, in the latter case, administrations are exploring the possibility for greater utilisation of the band 2 700-3 100 MHz (in particular, by IMT-Advanced systems) in an effort to facilitate further national economic growth and development.

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

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

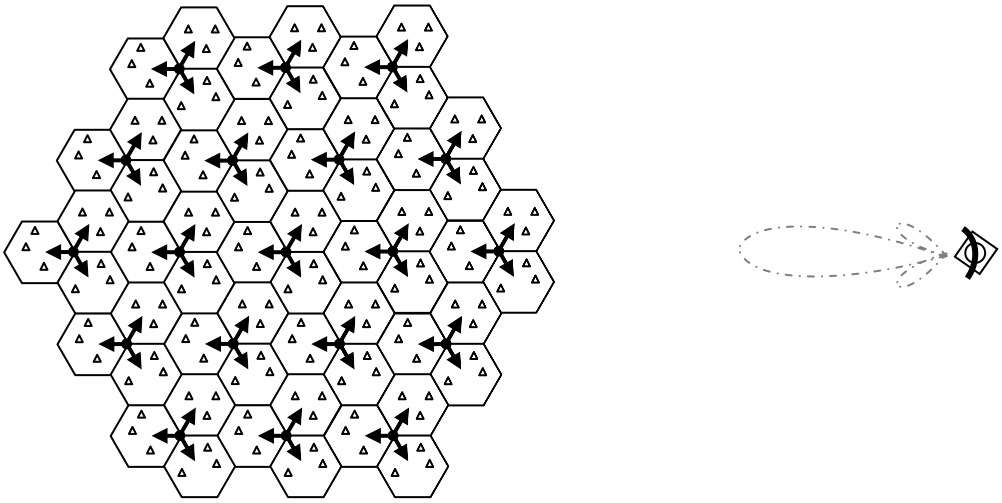
4.1 Approach

4.1.1 Implications of IMT uplink

To evaluate the implications of IMT emissions (both uplink and downlink) on a nearby radar system, a cluster of nineteen 3-sector cells is taken to represent the IMT network in accordance with the agreement already established[by a previous meeting of JTG 4-5-6-7]. To evaluate the impact of multiple UE, each sector in the cluster hosts a specific 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 1

Network model for sharing analysis



The active UE are randomly located within each sector, reflecting the random mobility of users with 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.

A 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.

The terrain profile is assumed to be smooth-earth. 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) should also be included.

4.1.2 Implications of IMT Downlink

Since IMT base stations are immobile, evaluation of the downlink scenario is achieved using a minimum coupling loss approach. The emission levels of all base stations in the 19-cell cluster, in the direction of the radar system, taking account of base-station separation distance, antenna downtilt and azimuth orientation, are aggregated to derive the effective interference level to the radar.

The terrain profile is assumed to be smooth earth. However, to reflect the typical situation of an IMT base-station being sufficiently elevated above ground to be reasonably clear of clutter and meet IMT network coverage objectives, two alternative radio propagation models are considered:

- 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 – and including relevant adjustments for: operating frequency of around 2 800 MHz; land path; field strength exceeded for 1%, 10% and 50% of time; transmitter height above ground; radar height above ground; and smooth earth scenario. It is noted that for distances less than about 0.04 km, propagation losses determined using Recommendation ITU-R P.1546-5 are approaching that of the free-space model; and
- 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 $0.001 \leq p \leq 50\%$. It is noted that for distances less than about 5 km, propagation losses determined using Recommendation ITU-R P.452 are approaching that of the free-space model.

4.2 Assumptions

As highlighted in several previous contributions[13], in some countries there may be scope to rationalise and consolidate the use of the band 2 700-3 100 MHz by radiolocation and radionavigation systems, resulting in some spectrum being released to satisfy the growing spectrum needs of mobile broadband systems including IMT. As noted in these previous contributions, there are several alternative ways of arranging the spectrum blocks to more efficiently utilise this band —refer to the diagram in Annex 1. Several interference scenarios should therefore be evaluated:

- IMT UE uplink emissions impacting on aeronautical radars.
- IMT base-station downlink emissions impacting on aeronautical radars.
- Aeronautical radar emissions impacting on IMT base-station receivers.
- IMT base-station downlink emissions impacting on meteorological radars.

To accommodate other possible arrangements, two additional interference scenarios may also be relevant:

- IMT UE uplink emissions impacting on meteorological radars.
- Meteorological radar emissions impacting on IMT base-station receivers.

This contribution focuses on:

i) Monte Carlo analysis of IMT UE uplink emissions impacting on aeronautical and meteorological radars; and the associated reverse case.

ii) Aeronautical and meteorological radar emissions impacting on IMT base station receivers.

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[13] Refer to Documents 5B/101, 4-5-6-7/130 and 4-5-6-7/277.

Other contributions address the cases of IMT base-station downlink emissions impacting on aeronautical and meteorological radars.

4.2.1 Radio propagation model

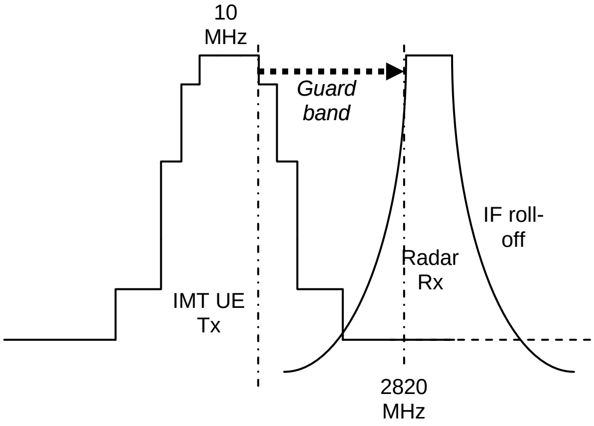
As noted above, and due to the very low elevation of IMT UE above ground (1.5 metres), the propagation model of Recommendation ITU-R P.1546 is used to derive interference impact on radar receivers. [Notably, reflecting the advice received from the Chairmen of WP 3K and 3M, and noted in Document 4-5-6-7/393 Annex 2, '*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*'.] Further, for path lengths less than about 5 km, Recommendation ITU-R P.1546 exhibits negligible difference between the field strength data for 1%, 10% or 50% time probability. In these studies, however, the 1% curves have been used.

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 2

Illustration of assumed guard-band scenarios



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 WP 5D] 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

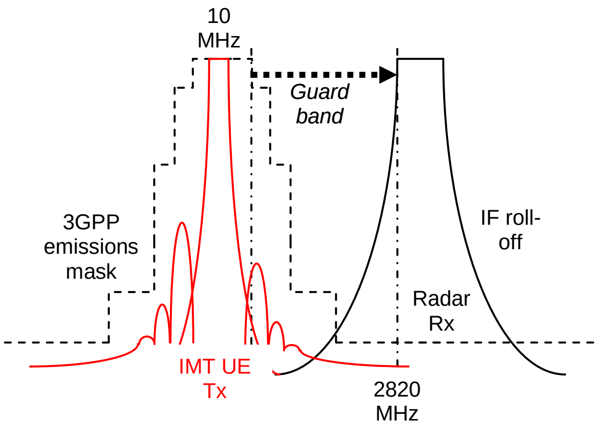
These studies have assumed that emissions of each UE occupy the full 10 MHz channel bandwidth—that is, each active UE is assigned all available channel resources (PRBs). This scenario is considered to be *worst-case,* because: although resource assignment is dependent on the particular scheduler algorithm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

Furthermore, in this study the UE emissions are assumed to be aligned to band-edge, nearest to the radar channel. In a moderately-loaded network, not only will UE typically be assigned some lesser portion of the available bandwidth, but the assigned resources may be only infrequently aligned to at band-edge, and often will be spectrally positioned 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 3

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 aligned with recent review by others of relevant ICAO flight safety and systems reliability recommendations[14].

– 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.

4.3 Results

4.3.1 IMT UE Interference to radar receivers

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 UE = one kilometre.
- Minimum guard-band between radar system (lower –3 dB channel edge set at 2 820 MHz) and IMT UE emissions (upper –3 dB emission mask edge, per 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.

As noted, two representative radar systems taken from Table 1 of Recommendation ITU-R M.1464 are evaluated:

– Aeronautical radar – System C – solid state.

– Meteorological radar – System G – klystron.

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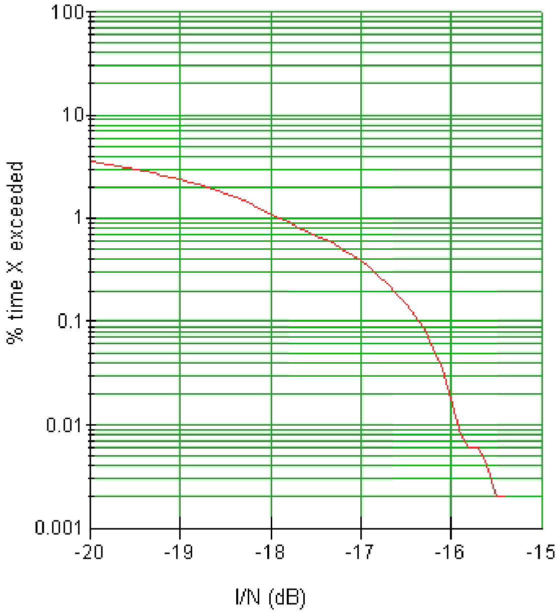
[14] ICAO Document 9859 *Safety Management Manual* is the key reference for regional/national air traffic safety procedures—for example, the 4th part of Eurocontrol Safety Regulatory Requirement (ESARR4), and UKCAA Publication CAP760 which provides a useful matrix of risk classification/tolerability.

4.3.1.1 Baseline *I/N* exceedance probability

The baseline results for each of the urban, suburban and rural geographic scenarios are shown in the following plots[15], and key values in Table 4—see Annex 2 for more detail of 0.1% and 0.01% threshold crossing values:

FIGURE 4

System C – urban environment – one kilometre separation – 10 MHz guard-band



These results show that at one kilometre separation and by use of a 10 MHz guard-band, the maximum interference objective consisting of *I/N* = –10 dB plus a –6 dB safety margin as recommended by ICAO can be met for around 0.02% of time.

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[15] 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 5

System C – suburban environment – one kilometre & 1.2 km separation – 10 MHz guard-band

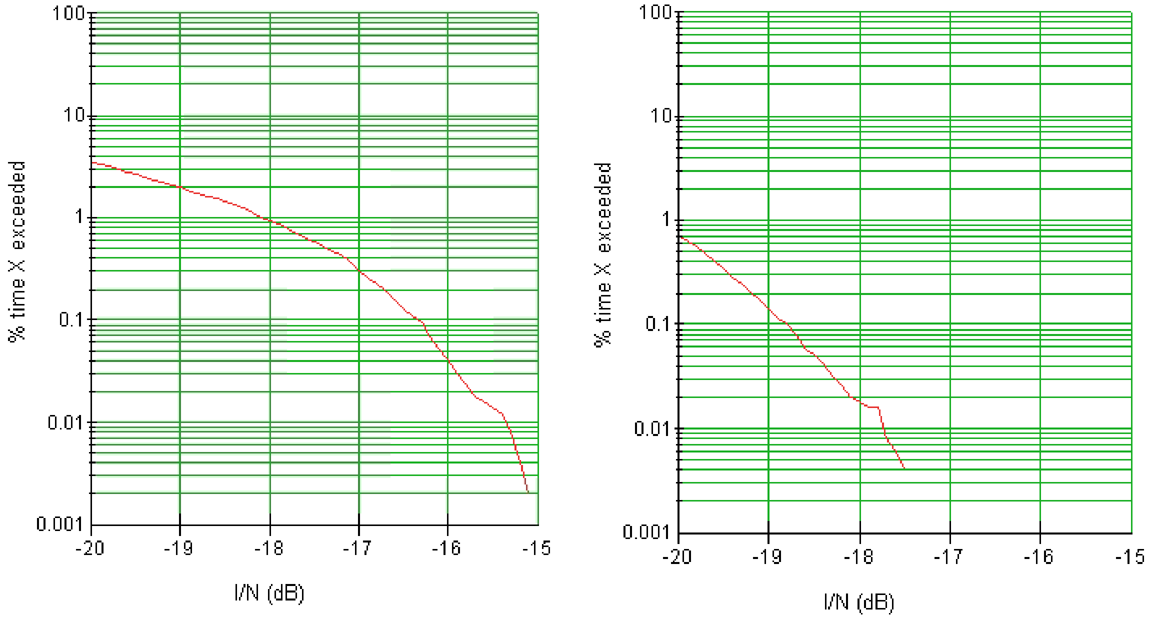
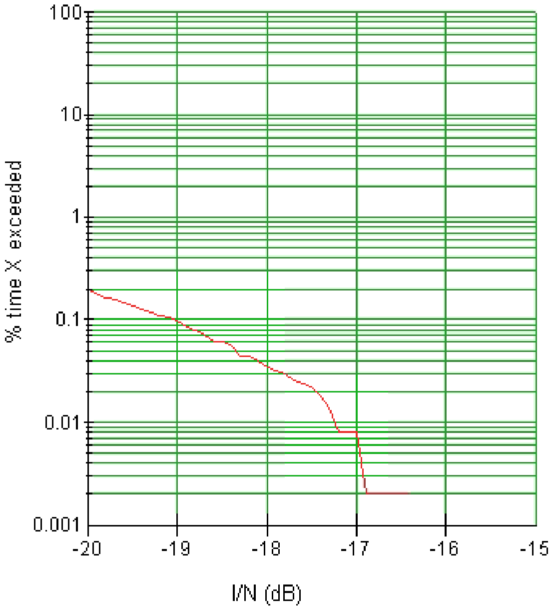


FIGURE 6

System C – rural environment – one kilometre separation – 10 MHz guard-band



Both the suburban and rural cases, for one kilometre separation and 10 MHz guard-band, can also comfortably meet the maximum interference objective of *I/N* = –16 dB (including ICAO safety margin) for at least 0.04% and less than 0.002% of time respectively.

Similar baseline urban/suburban/rural Monte Carlo sharing studies for Radar System G were also undertaken.

A summary of baseline results showing the radar *I/N* with 0.1% and 0.01% probability of exceedance levels:

TABLE 4

Summary of baseline *I/N* results – one kilometre separation – 10 MHz guard-band

$Pr_{exceedance}$	Radar System C			Radar System G		
	Urban	**Suburban**	**Rural**	**Urban**	**Suburban**	**Rural**
0.1%	**–16.3**	**–16.4**	**–19.0**	**–4.5**	**–4.9**	**–8.5**
0.01%	**–15.7**	**–15.4**	**–17.0**	**–3.8**	**–3.9**	**–5.9**

On the assumption of 0.1% probability of exceedance, the aeronautical radar (System C) appears to be sufficiently protected (*including* the 6 dB safety margin recommended by ICAO) by implementing a one kilometre separation to the nearest IMT UE and a 10 MHz guard-band.

However, a larger geographic/spectral separation is clearly required to protect Radar System G. Physical separation values greater than one kilometre were thus explored—as well as the trade-off between separation distance and guard-band—and presented in the following sensitivity analysis.

4.3.1.2 Sensitivity analysis

To evaluate the sensitivity of 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 C:

TABLE 5.1

Sensitivity analysis – urban scenario – Radar System C

***I/N* (dB) for 0.1% time exceedance**		Urban – geographic separation (km)		
		1.0	**1.2**	**1.5**
Frequency separation (MHz)	8	**–12.8**	**–15.4**	**–18.5**
	10	**–16.3**	**–19.0**	**–22.0**

TABLE 5.2

Sensitivity analysis – urban scenario – Radar System C

***I/N* (dB) for 0.01% time exceedance**		Urban – geographic separation (km)		
		1.0	**1.2**	**1.5**
Frequency separation (MHz)	8	**–12.3**	**–14.8**	**–17.8**
	10	**–15.7**	**–18.5**	**–21.4**

These results suggest that, for the aeronautical Radar System C, a guard-band of 8 MHz could potentially be offset by a larger separation distance of about 1.4 kilometres. However, larger separation distances may be difficult to enforce for aerodromes (radars) located on the fringe of major urban centres. A separation distance of 1.2 kilometres (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 G, evaluation of separation distances of 1.5 kilometres and 1.6 kilometres was undertaken—and results illustrated in the following plots:

FIGURE 7

System G – urban environment – 1.5 km separation – 10 MHz guard-band

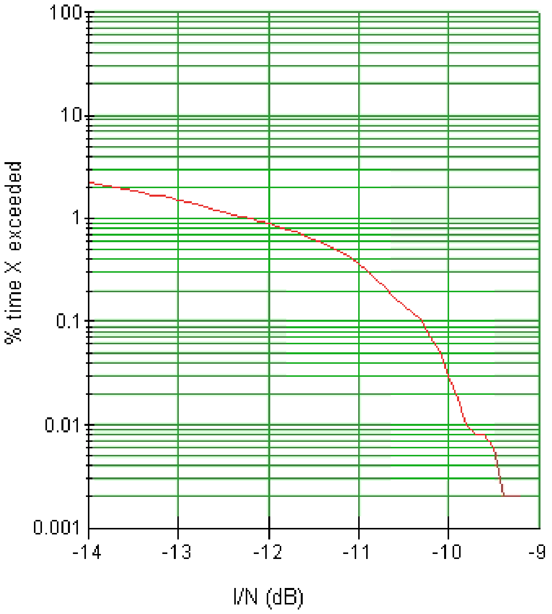
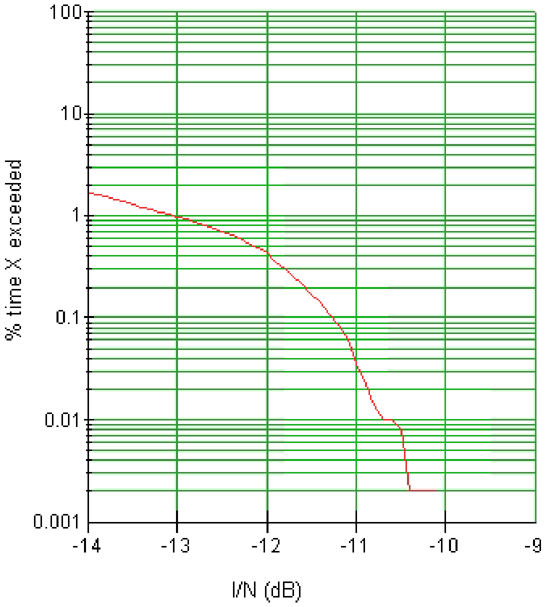


FIGURE 8

System G – urban environment – 1.6 km separation – 10 MHz guard-band



The urban and suburban scenarios again consistently showed higher interference impact on radar receivers than is the case for a rural environment—due to the higher-density of UE, collectively located closer to the radar station. However, to meet the maximum interference objective *I/N* = –10 dB applicable to meteorological radar systems, the minimum separation distance was found to be around 1.5 kilometres, for a 10 MHz guard-band—with a 0.03% time probability of exceedance.

A summary of results for System G sensitivity analysis is provided in following tables:

TABLE 5.3

Sensitivity analysis – urban scenario – Radar System G

***I/N* (dB) for 0.1% time exceedance**		**Urban – geographic separation (km)**		
		1.0	**1.2**	**1.6**
Frequency separation (MHz)	8	**+4**	**+1.4**	–
	10	**–4.5**	**–7.2**	**–11.2**

TABLE 5.4

Sensitivity analysis – urban scenario – Radar System G

***I/N* (dB) for 0.01% time exceedance**		**Urban – geographic separation (km)**		
		1.0	**1.2**	**1.6**
Frequency separation (MHz)	8	**+4.8**	**+2.1**	–
	10	**–3.8**	**–6.5**	**–10.5**

These results suggest that Radar System G would need a minimum guard-band of 10 MHz and a minimum geographic separation of 1.6 kilometres.

Therefore, suggested minimum values to avoid interference by IMT UE into solid-state radar receivers in the 2 700-2 900 MHz band are therefore:

– Minimum guard-band = 10 MHz

– Minimum geographic separation[16] = 1.2 km – for aeronautical radars; and
= 1.6 km – for meteorological radars.

4.3.2 Radar interference to IMT base-station receivers

To properly accommodate IMT ‘uplink’ systems within the band 2 700-2 900 MHz via segmentation, it is also prudent to consider the impact of radar emissions on IMT base-station receivers.

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[16] 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 UE).

4.3.2.1 IMT base-station blocking

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

TABLE 6

Aeronautical radar blocking of IMT base-station receiver

Parameter	Values			Units
	Urban	Suburban	Rural	
Radar Tx power	+73.9			dBm
Radar antenna max gain	+34			dBi
Radar signal e.i.r.p.	+107.9			dBm
IMT base-station antenna gain	16	16	18	dBi
IMT Rx blocking limit[17]	–15			dBm
Worst-case IMT Rx protection requirement	138.9	138.9	140.9	dB
Path loss (one kilometre free-space)	101.4			dB
Minimum additional filter OOB rejection	37.5	37.5	39.5	dB

According to 3GPP[18], minimum IMT base-station receiver selectivity performance offers at least 57.9 dB of protection (for ≤ 1 dB receiver degradation) from an adjacent channel wide-band (5 MHz) carrier (at 2.5075 MHz offset). With contemporary filtering systems readily able to provide at least 60-80 dB of protection at 10 MHz offset, achieving an additional 37-40 dB of protection at 10 MHz offset using external filtering equipment is not considered a particularly challenging objective.

In the case of meteorological radars, it can be similarly shown that minimum addition filter rejection required is about 62-65 dB at 10 MHz offset—still not a particularly challenging out-of-band filtering objective, given typical site filtering performance and the space availability at IMT base-station sites.

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 adjacent transmitter are sometimes more challenging, and may determine the potential for co-existence.

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[17] See 3GPP TS 36.104 V10, Table 7.6.2.1-1 for bands 11 and 21.

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

Radar systems operating in the [S-band] can generally meet an out-of-band emissions limit[19] of at least –60 dBc. Solid-state radars seem able to achieve this limit within 12 MHz of the main carrier[20]. Assuming that the radar antenna is directed at the victim IMT base-station site (for a portion of 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 Aero radar

Parameter	**Values**			**Units**
	Urban	**Suburban**	**Rural**	
Radar Tx power	+73.9			dBm
Radar emission bandwidth	1.9			MHz
Radar antenna max gain	+34			dBi
OOB emissions	–60.0			dBc
Radar OOB emissions	+45.1			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	166.0	166.0	168.0	dB

While the required protection may seem a somewhat challenging objective, there are several mitigation measures that are 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).

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

[20] Legacy vacuum-tube radars may not meet these emissions limits—so future IMT co-existence in the 2 700-2 900 MHz band 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 – one kilometre	101			dB
Use of obstructions	15-20			dB
Antenna orientation	20-40			dB
Radar OOB filtering[21]	45			dB
Nett additional protection requirement	**–15** ~ **10**	**–15** ~ **10**	**–13** ~ **12**	dB

Therefore, identification of practical mitigation measures would not seem 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 aeronautical and meteorological radar systems in the band 2 700-2 900 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. Depending on actual radar characteristics, there may be need for local 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 2 700-2 900 MHz (Attachment 4 to Annex 6 of Document 4-5-6-7/393) 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 section 4.2.1 of Attachment 4 of the Working Document in Annex 6 of Document 4-5-6-7/393.]

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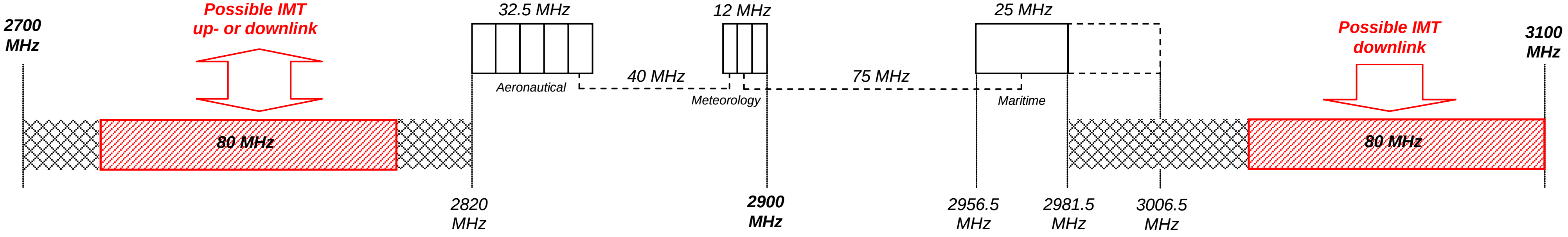
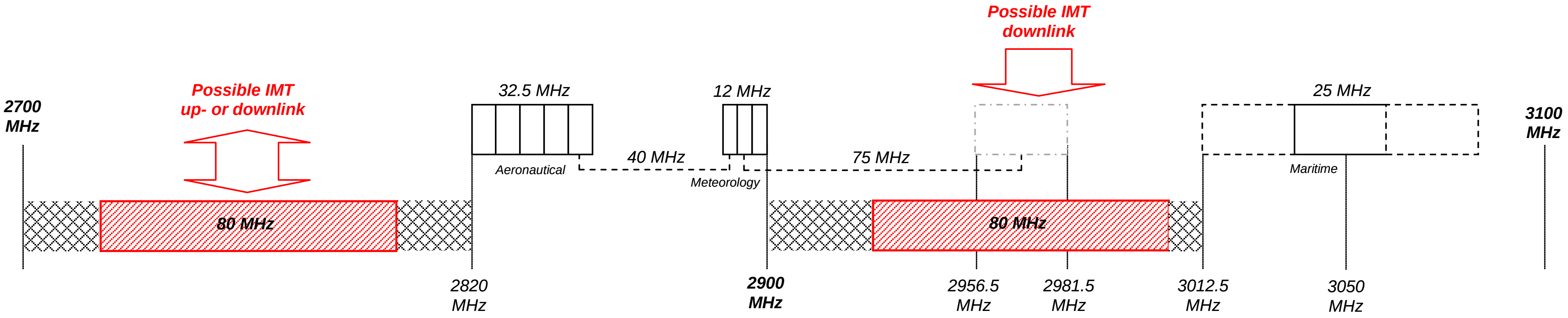
[21] There have been some observations at prior ITU-R meetings that contemporary radar systems exhibit considerably lower out-of-band emissions that reported in ITU-R Recommendations. Thus, the need for additional filtering may be subject to verification of actual radar performance.

ANNEX 1

Possible alternate arrangements for rationalising and consolidating use of the band 2 700-3 100 MHz

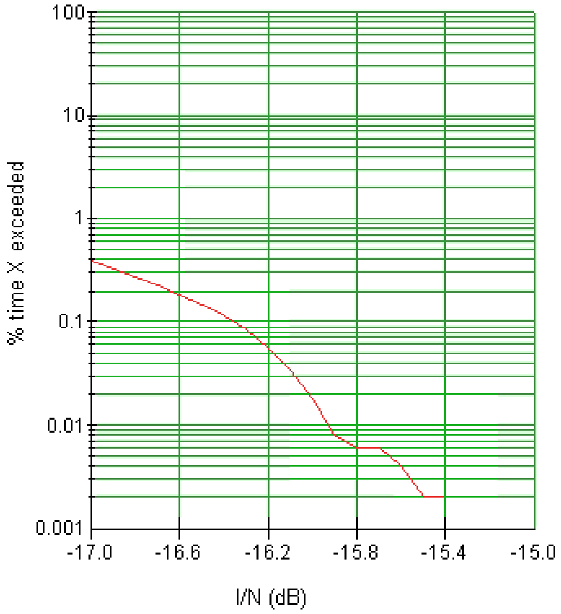




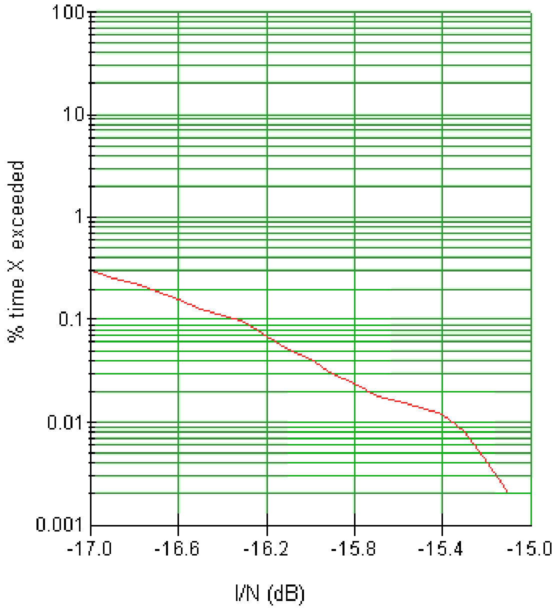
ANNEX 2

Radar *I/N* exceedance thresholds – higher resolution plots

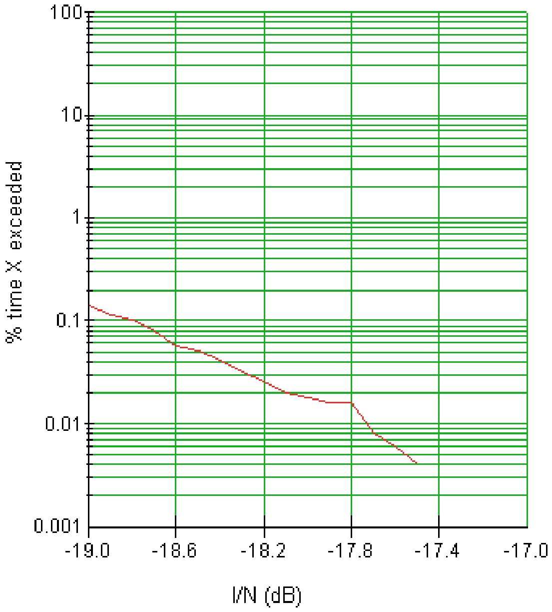
Case 1.1 – Urban scenario – one kilometre separation – 10 MHz guard-band – System C



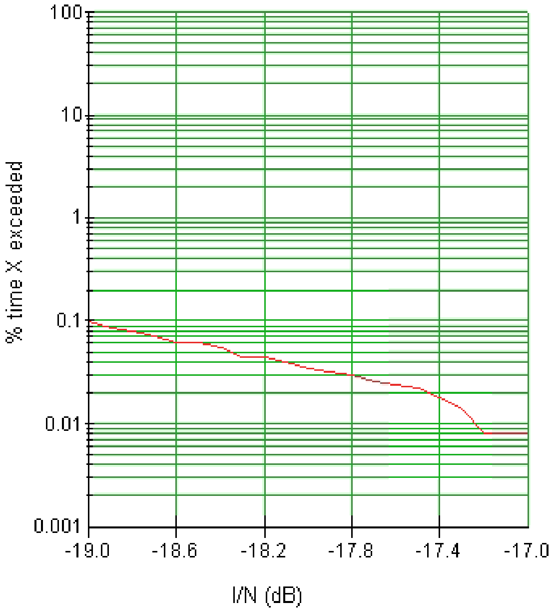
Case 1.2 – Suburban scenario- one kilometre separation – 10 MHz guard-band – System C



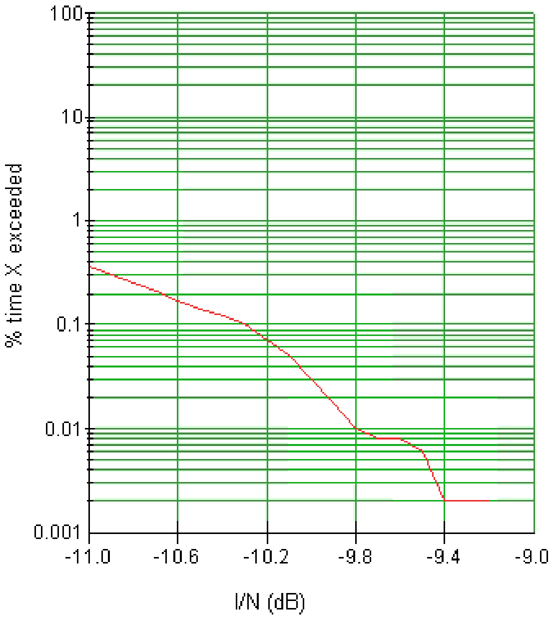
Case 1.3 – Suburban scenario – 1.2 km separation – 10 MHz guard-band – System C



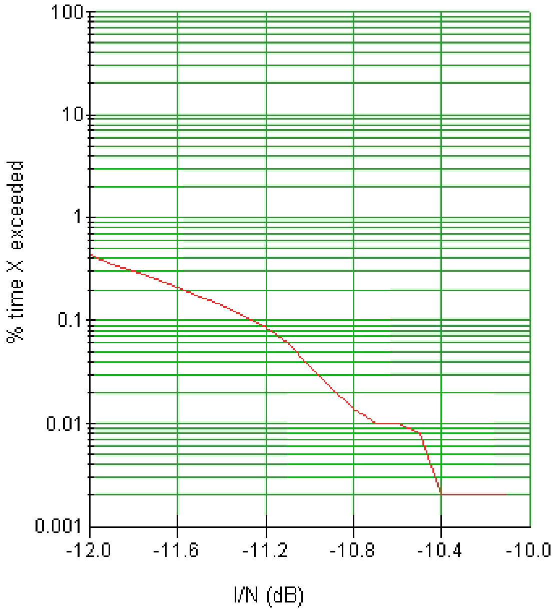
Case 1.4 – Rural scenario – one kilometre separation – 10 MHz guard-band – System C



Case 2.1 – Urban scenario – 1.5 km separation – 10 MHz guard-band – System G



Case 2.2 – Urban scenario – 1.6 km separation – 10 MHz guard-band – System G



ATTACHMENT 7

Necessary guard band for compatibility between radiolocation systems and mobile broadbandsystems in the 2 700-2 900 MHz band

1 Background

Under agenda item 1.1 of the WRC-15 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 are considered, to facilitate the development of terrestrial mobile broadband applications, in accordance with Resolution **233 (WRC-12)**.

The associated Resolution **233 (WRC-12)** invites ITU-R to study potential candidate frequency bands. This includes sharing and compatibility studies with services that already have allocations in the potential candidate bands and in adjacent bands, taking into account the current and planned use of these bands by the existing services, as well as the applicable studies already performed in ITU-R.

Within the Joint Task Group (JTG 4-5-6-7), the responsible group for the WRC-15 agenda item 1.1, the frequency bands 2 700-2 900 MHz is considered as potential candidate bands for IMT.

[The working document in Attachment 4 to Annex 6 of Document 4-5-6-7/393 (issued 24 October 2013) collects a lot of background for radars operating in S-band and for IMT advanced systems working at different cell sizes and at uplink or downlink: mainly LTE base station and user equipment (UE).]

This contribution proposes a method to evaluate the necessary guard band for compatibility between radiolocation systems and mobile broadband systems in the 2 700-2 900 MHz band.

2 Determination of the guard band

When LTE systems and radar operate with low separation distances, adequate guard band is to be considered depending on the radar filtering roll-off[22]. From experience and from on-going remediation programs, the guard band[23] should be about 50-60 MHz. Lesser values down to 10-20 MHz are mentioned when more efficient and neater filtering models are assumed.

This paragraph presents an approach to preserve overall radar performance in any situation. Rejection calculation is done in terms of the frequency offset between the centre of radar channel and the centre of the closest LTE channel.

Radar and communication systems’ performance come from adjustment of different hardware components and depend on the operating scenario. e.i.r.p. and Rx filtering are designed to satisfy a one-way or two way power budget at a given distance. In presence of noticeable interferer, the loss at victim could be partially compensated. Equilibrium must be recovered by reducing power or by tuning radiating beam or by reinforcing filtering (at interfering Tx or at victim Rx).

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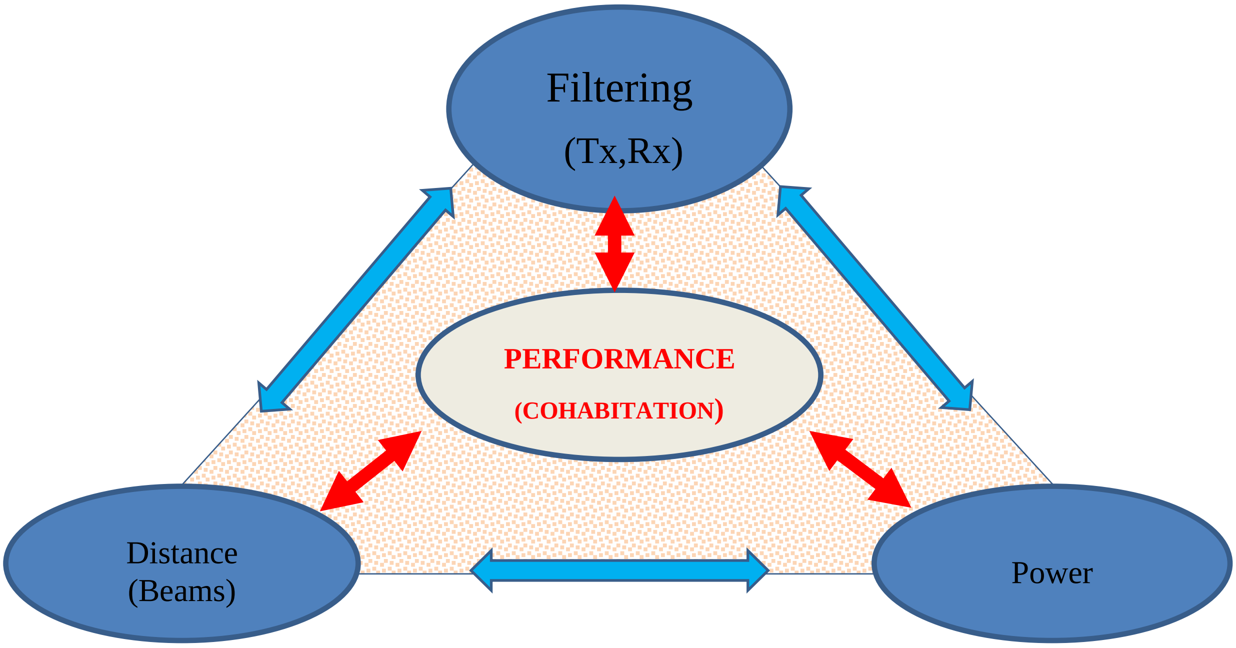
[22] The roll-off is the steepness of the transmission function of the filter.

[23] The guard band is the frequency separation between the edges of the two necessary bandwidths.

FIGURE 1

Radar budget components



3 Co-existence scenario

LTE network is deployed where existing radar operates (one says one radar with typical ATC design). It is considered that distance from the closer LTE base station to the radar could fall down to one kilometre. The LTE base station is assumed operating just below the radar band, so the frequency offset is negative, typically between –100 MHz and minus the half sum of their bandwidths.

Radar emission (power, e.i.r.p., beams) and also the separation distance from the base station being given, the key point becomes the balance between extra rejection added to the radar and the tolerance to continue detection at long range.

4 Admissible RF insertion loss

Addition of new device in existing radar RF subset must be monitored under reasonable degradation.

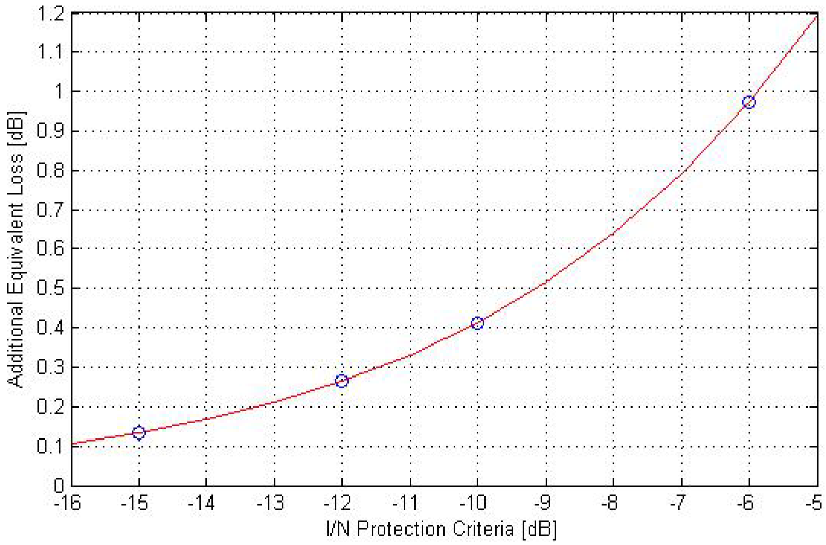
Firstly, the insertion equivalent loss resulting into the radar budget must be less than a threshold T, one says a fraction of decibel. The threshold is determined according with the acceptable degradation driven by usual protection criteria I/N. Figure 2 shows the relation between the equivalent loss and this well-known I/N criteria. It is about 1 dB for usual $I/N \leq -6$ and 0.5 dB for $I/N = -10$ in ATC context or less than 0.3 dB for more exigent radar application. Roughly the threshold T could be aimed at the half of equivalent loss associated to a given I/N, so in ATC context it could be at about 0.2 dB to 0.3 dB. Then this threshold T can be appreciated as reasonable permanent reduction (< 2%) of detection range.

Secondly, VSWR (return loss in the band) must be also taken in account. The usual constraint is VSWR less than 1.25:1.

Thirdly, constraints for designing new device should consider dispersion on signal quality over the radar agility band or over its instantaneous bandwidth. Filters with linear phase response are desirable, due to their flat group delay. Such filters maximally preserve the wave shape of the passing signal, since they delay all frequency components of the signal by the same amount (i.e., do not cause phase distortion). The relevant parameter is expressed as the deviation from linear phase. The maximum deviation is about a few tenths of degree per MHz.

FIGURE 2

***I/N* criteria versus insertion loss**



5 RF filters

There are many types of filtering technology. The choice depends on several factors: central frequency and bandwidth under consideration, maximum insertion loss and minimum attenuation required, power of signals and size limitation. In addition to these electrical requirements it is also influenced by the operating temperature range, and also by cost considerations.

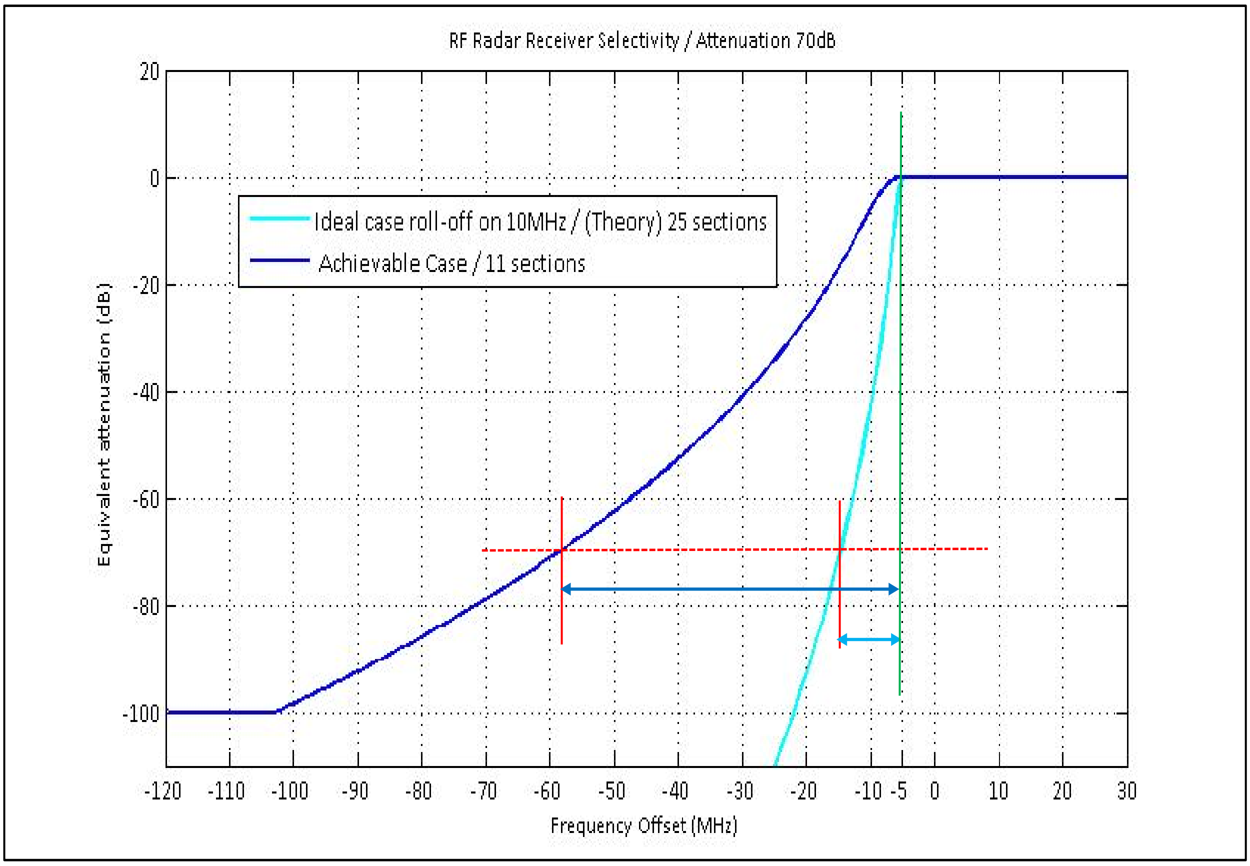
For RF filtering in radar domain, cavity filters allow low insertion and sharp selectivity. Since a very low insertion loss or high power is a requirement, waveguide filters are generally chosen. The vast majority of these filters can be synthesized from an addition of many band-pass filtering elementary cells.

This paragraph is a tentative to address the performance of RF filters facing the need to reduce as much as possible the guard band between LTE and radar, despite severe insertion loss constraint.

Based on the theoretical Chebyshev band-pass pattern, illustrative responses of filters are calculated for the 200 MHz band-pass, and then compared in Figure 3.

FIGURE 3

Typical passband responses (based on theoretical low-pass prototype)



The insertion loss depends on the slope of the filter: the insertion loss IL in mid-band can be expressed[24] as $K*\Sigma(Q_{ui}*g_i)$ where Q_{ui} is the unloaded Q factor of i-th resonator and g_i are the g-parameters of band-pass prototype.

Assuming the same attenuation curve on both sides, 300 MHz between the two stop bounds at –70 dB level and that Q_{ui} is about the same Q_u for all resonators and for any number of resonators, Figure 4 shows the IL multiplicative (in dB) dependence on the roll-off slope. For a given technology, reducing the transition from 53 MHz down to 10 MHz will probably increase the loss insertion by 3.

More than 0.6 dB loss will lead to exceed the level related to *I*/*N* = –10 dB.

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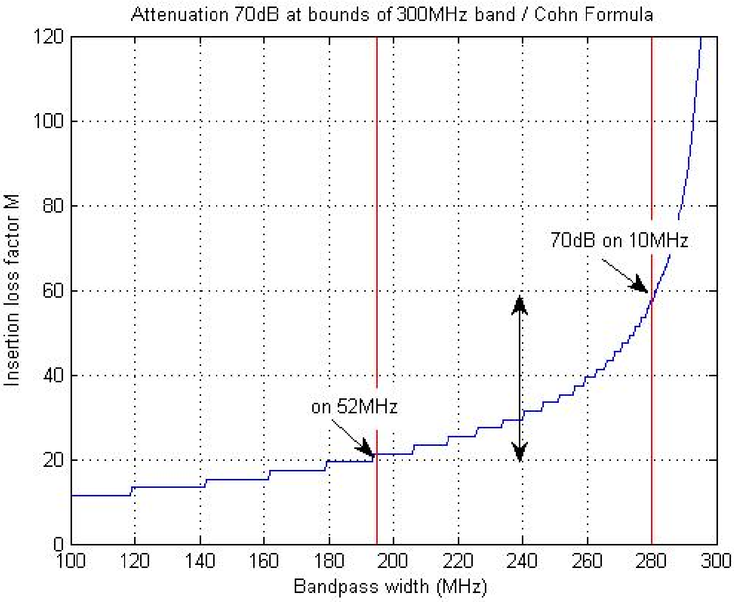
[24] “Dissipation Loss in multiple-coupled resonator filters”, S.B Cohn. Proc IRE vol 47, pp 1 342-1 358, Aug 1959.

FIGURE 4

Typical insertion loss factor M (theoretical estimation)



6 Frequency Dependent Rejection

This paragraph deals a bit more precisely with the filtering impact on curves FDR(d) where *d* is the offset in MHz. Radar operates at 5 MHz from its lower bandpass bound.

7 Radar model

Three models of radar's RF stages will be considered: no filter, achievable filter with 11 cavity-sections, or an ideal filter with 25 cavity-sections.

8 LTE model

Three base station configurations are considered. The spectra have been built using masks described in ETSI document[25] (3GPP) for 10 MHz, 15 MHz and 20 MHz channels. The three corresponding responses in dBc are plotted in Figure 5:

– LTE 20 MHz at spectrum mask level (in black colour),

– Cumulative spectrum for LTE spectrum (in red colour). 70 MHz FDD and 70 MHz TDD are shared by four operators (FDD=2*20 MHz+2+15 MHz and TDD=7*10 MHz). It is considered that emitters operate at mask level from the same locus,

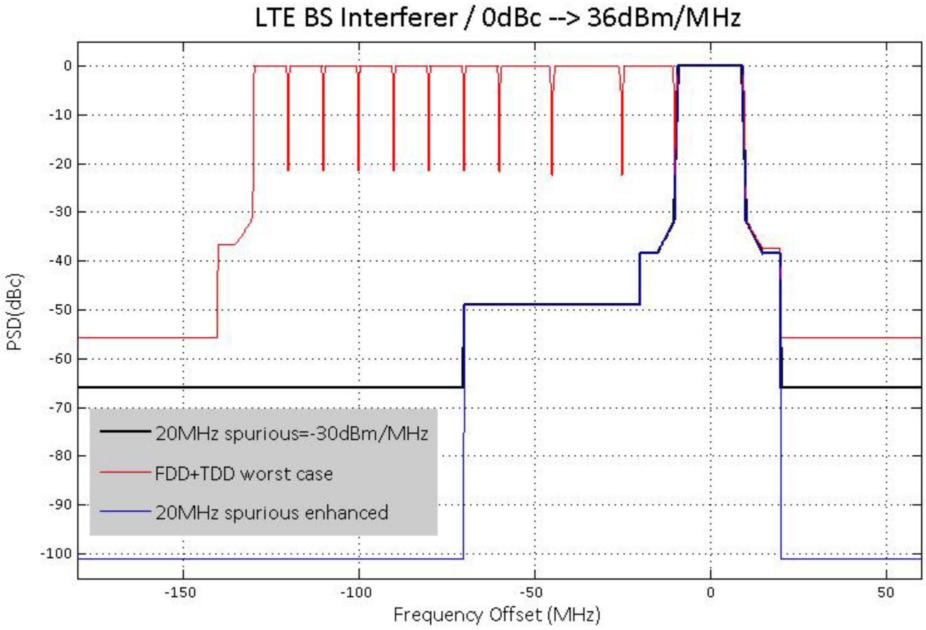
– LTE 20 MHz with enhanced spurious level (–30 dB below the mask).

---

[25] 3GPP ETSI TS 36.141 version 11.3.0 Release 11 (2013-02).

FIGURE 5

Typical Interfering base station LTE (spectrum)



9 FDR-RF calculation

The frequency dependent rejection (FDR) is calculated using data from Figure 5 and following usual procedure described in the Annex.

FDR-RF taking into account RF selectivity is plotted in Figure 6 versus frequency offset on the x-axis:

– LTE 20 MHz case is in black colour and cumulative FDD+TDD case is in red colour and LTE 20 MHz with enhanced spurious is in blue,

– RF filtering level is associated to dash-dot line for the ideal filter, to dashed line when no-filter and to solid line for the achievable filter (present state of the art).

Rejection of about 55 dB is asymptotically obtained at –65 MHz offset (i.e., 50 MHz guard) in the case of LTE 20 MHz (point A1). The slope in adjacent band starting at –15 MHz depends mainly on the shape of receiver selectivity to reach the floor (here –60dBc). The difference between FDR-RF (–60) and FDR-RF(0) is reduced by about 10 dB when cumulative case is evaluated. Rejection is bounded to 55 dB when spurious LTE level is at limit mask (LTE 20 MHz and cumulative case).

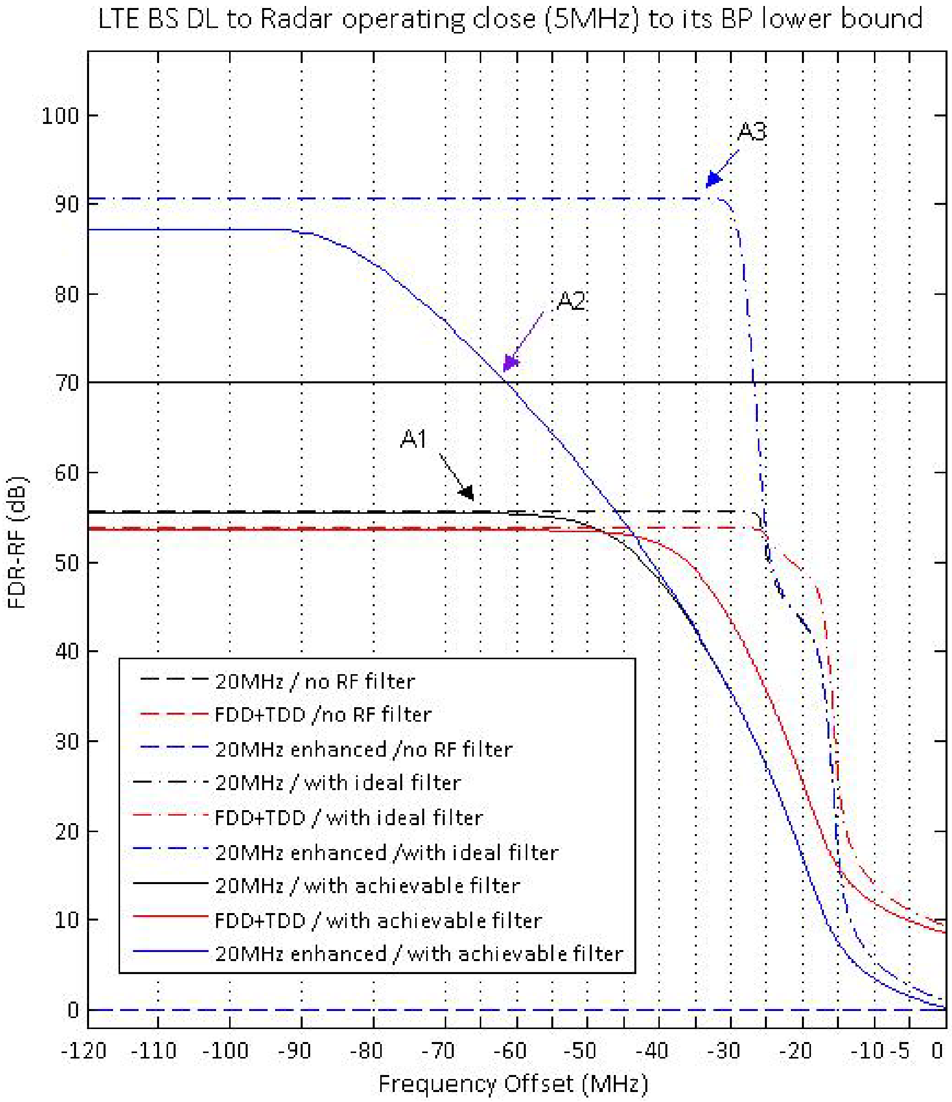
For example, if the interference study required an additional 70dB rejection with a RF achievable filter (solid line in blue), enhanced LTE 20 MHz and –62 MHz offset (i.e., 47 MHz guard) have to be jointly considered (point A2).

Moreover, if the interference study required another additional rejection, the same method could be applied.

It is also verified that an ideal filter could asymptotically induce typical 20 MHz guard band at 90 dB rejection (point A3).

FIGURE 6

Typical resulting FDR-RF



10 Parameters to be also considered

Previous paragraph illustrates how to reach sufficient additional rejection at radar receiver with an additional filter and sufficient guard band. Other parameters of variability have to be considered to define a reasonable and realistic value for the guard band.

This paragraph is a tentative to select more useful parameters and to summarize the constraints to be introduced in future reasoning for remediation and in rejection calculations. Table 1 gives a set of parameters entering the trade-off between better selectivity, radar budget performance and signal quality degradation.

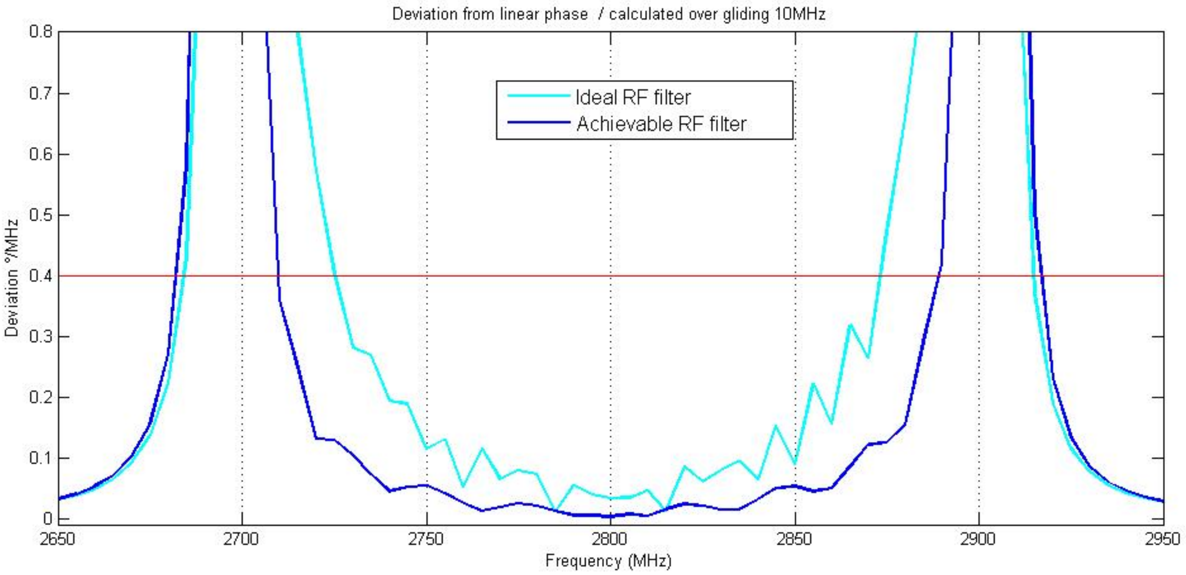
TABLE 1

Additional RF filtering

Item	Prescribed value	Remark
Insertion loss IL	< 0.2 dB	Over operating radar band
VSWR	< 1.25:1	Over operating radar band
Phase deviation from linearity	< 0.4°/MHz over any 10 MHz interval	The time relationships between signal components at different frequencies of the instantaneous band could be critical depending on radar design.
Size	–	Depending on the radar design
Temperature range	about idem for the antenna feeder	Temperature variation will modify the lower limit of the radar bandpass. This incertitude must be added to guard band.

FIGURE 7

Comparison of deviations for RF achievable and ideal filters



Similarly to a previous study[26], the phase deviation inserted by the RF filter has to be taken into account. Figure 7 shows phase deviations for the two filters presented in Figure 3: one ideal RF filter with 25 sections & 10 MHz roll-off, and one achievable RF filter with 11 sections and 60 MHz roll-off. Dramatically, it appears that the useful bandwidth defined by the 0.4°/MHz maximum criteria is reduced when using the stronger roll-off filter.

In order to take into account all these parameters, it is proposed to correct the raw value of guard band obtained by the FDR method with an additional estimated value of 10 MHz.

Moreover, some margin need to be added to take into account that computations of FDR in previous paragraph have been done with smooth shapes of filters and spectrum, and that intermodulation products in the radar receiver have not been modelled.

---

[26] High Q filter Feasibility Study for OFCOM, ISOTEK IF26, 15/10/09.

11 Magnitude of extra rejection

The proposed method for determining the guard band between LTE emission and radar reception leads to the following table[27] which could be useful for interference studies:

Additional RF rejection	**Estimated Guard band**
60 dB	50 MHz
70 dB	60 MHz
80 dB	75 MHz

12 Conclusion

When LTE systems and radar operate with short separation distances, adequate guard band should be considered depending on radar filtering roll-off to occur. From experience and from on-going remediation programs at 2 700 MHz, it is verified that a 60 MHz guard band (2 690-2 750 MHz) allows mobile and radionavigation services in adjacent band. Lesser values down to 10 -20 MHz are mentioned in interferences studies, but feasibility of filters need to be considered.

State of the art in filter design, integrating lot of parameters such as roll-off FDR, phase linearity, temperature stability, VSWR, need to be taken into account to determine the necessary guard band without excessive degradation of the desired radar coverage.

Most compatibility studies performed for adjacent band and short distance separation required an additional rejection obtained by insertion of an additional RF filter. This study proposes a method which demonstrates for example that in order to obtain an extra 70 dB rejection, a necessary guard band greater than 60 MHz is required for compatibility between mobile systems and radiolocation systems in the 2 700-2 900 MHz band.

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[27] Values determined with Figure 6 and conclusion of paragraph "other parameters to be also considered".

ANNEX

FDR

When radar is jammed by noise-like interferer, Recommendation ITU-R M.1461 procedure could be applied to monitor the impact to the victim receiver. Two relevant figures are calculated:

The interfering power P collected to the input of IF stage receiver (LNA).

The rejection FDR due to receiver selectivity R(f): this effect depends on the shift Δf between central frequencies $f_{\text{interferer}}$ and f_{victim}.

Then, in order to decide if a scenario is prone to interference, P is compared to the admissible threshold power before compression at 1dB (P1dB_in). If there is any specific RF filtering ahead, the rejection enters the calculation. I (=P-FDR) is compared with a fraction of the total noise N within IF band. Extras or margins M can be also added to improve the assessment: shielding offered by terrain or man-made obstructions, main lobe(s) mismatch and polarisation loss factor (PLF), when interferer and victim antennas are polarized differently.

The interfering power P collected to the input of IF stage receiver is calculated as:

$$P = P_t - L_d - L_a + G - L + M$$

P : interfering power (dBW)
P_t : interferer power (dBW)
L_d : distance dispersion loss (dB)
L_a : atmospheric attenuation (dB)
G : receiver antenna gain in the direction of the interferer (dB)
L : insertion loss between antenna and the input of IF stage receiver (dB)
M : margin (dB).

Frequency-dependent rejection (FDR) is calculated as

$$FDR\,(\Delta f) = 10\log_{10}\left[\frac{\int_{-\infty}^{\infty} PSDi(f)\,df}{\int_{-\infty}^{\infty} PSDi(f)\,R(f+\Delta f)\,df}\right]$$

where PSDi(f) is the power spectral density of the interferer (dBW/Hz), and R(f) is the normalised selectivity of the radar victim receiver, and Δf is frequency offset. FDR allows taking into account in-band and out-of-band situations, and spurious interference when precise data exist. FDR ranges from 0 dB up to 80 dB, depending on systems characteristics and frequency offset. Stronger rejection (85 dB-100 dB) can be obtained when the systems are very well designed: spectrum and selectivity having strong slopes and as close as possible to the necessary band and having very low spurious level outside.

ATTACHMENT 8

Co-existence of mobile broadband systems and radars in the frequency band 2 700-2 900 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 2 700-2 900 MHz.

Currently, the frequency band 2 700-2 900 MHz is used by ATC, defence and meteorological radars. ATC radars are mainly, but not exclusively, deployed close to airports with defence and meteorological radars deployed in more rural areas. Additionally defence radars are also deployed on board vessels. The band 2 900-3 100 MHz, which is used by maritime radars, would be adjacent to any new communications usage up to 2 900 MHz.

This initial 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 2 700-2 900 MHz. It draws on extensive experience from the recent UK radar remediation programme that studied and implemented the necessary modifications to ATC radars in such a way that they could co-exist with the mobile broadband systems (e.g., LTE and WiMAX) being introduced below 2 690 MHz. This coexistence also relied on practical experience that the emissions from these systems above 2 700 MHz was substantially below the limits defined in the product specifications. As such, the primary focus in this study presented here is the effect of proposed new communications services on ATC radar. It should also be noted that very similar impacts would be expected for other users such as defence and meteorological radar.

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

– Mobile base station impact on radar

– Mobile user equipment impact on radar

– Radar impact on mobile base station

– Radar impact on mobile user equipment.

This study only considers aggregate interference for mobile picocell deployment, however this issue may need to be considered for all scenarios in subsequent studies. All the assessments are high level and would require further consideration to provide detailed results.

2 Background

The frequency band 2 700-2 900 MHz is allocated on a primary basis to the aeronautical radionavigation service, restricted to ground based radar and associated transponders through footnote RR No. **5.337**, and the radiolocation service on a secondary basis. RR No. **5.423** permits the use of ground based radars for meteorological purposes on an equal basis to radars operating in the aeronautical radionavigation service. 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.1464-1 – Characteristics of radiolocation radars, and characteristics and protection criteria for sharing studies for aeronautical radionavigation and meteorological radars in the radiodetermination service operating in the frequency band 2 700-2 900 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.

This information was supplemented, where parameters were missing with information from the following sources:

- ECC Report 174 – Compatibility between the mobile service in the band 2 500-2 690 MHz and the radiodetermination service in the band 2 700-2 900 MHz.
- Ofcom Report AY4051 – The Report of an Investigation into the Characteristics, Operation and Protection Requirements of Civil Aeronautical and Civil Maritime Radar Systems.
- ICAO Document 9718 – Handbook on Radio Frequency Spectrum Requirements for Civil Aviation.

Characteristics of the mobile broadband systems are based on those for IMT systems operating in the frequency range 2 500–2 690 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.
- Previous studies within the ITU:
  - Report ITU-R M.2112 – Compatibility/sharing of airport surveillance radars and meteorological radar with IMT systems within the 2 700-2 900 MHz band

Information on the radar remediation programme in the UK can be found on the Ofcom website at: http://stakeholders.ofcom.org.uk/spectrum/clearance-coexistence/800MHz_2_6_clearance/.

This includes a notice requiring mobile broadband licensees operating in the bands 2 500-2 690 MHz to coordinate their base station deployments with aeronautical radionavigation radar operating in the band above 2 700 MHz.

3 Technical characteristics

3.1 Radar systems

The following radar system characteristics are based on those contained in Recommendations ITU-R SM.329, ITU-R M.1461, ITU-R M.1464, ITU-R M.1849 and ITU-R M.1851.

TABLE 1

Radar characteristics

Use		**Units**	**Air Traffic Control**			**Defence**		**Meteorological**	
Transmitter			**Radar 1**	**Radar 2**	**Radar 3**	**Radar 4**	**Radar 5**	**Radar 6**	**Radar 7**
Output Device			TWT	Solid State		TWT	Solid State	Klystron	Klystron
Power to the Antenna		dBW	47.8	44.8	44	48	53	59	57
		dBm/MHz	73.8	75.8	71.2	74	73	89	89.2
Modulation			Non-Linear FM			Non-Linear FM		Non-Linear FM	
Duty Cycle		%	2	8.25	9.34	2.5	20		0.21
Pulse rise time		us	0.015	0.169	0.32	10	0.05	0.08	0.12
Pulse width		us	0.4 to 40	1 & 100	1	0.4	0.1	0.8	1.6
Emission Bandwidth	3 dB		2.5	0.8	1.9	2.5	10	1	0.6
	20 dB		16.8	2	5.6	3.5			
	40 dB		55	4	4.75	6.25	25	25	4.6
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	17.8	13.8	14	18	23	–11	–13
		dBm/MHz	13.8	14.8	11.7	14	13	–11	–10.8
Receiver									
Noise Figure		dB	2	1.4	3.3	2	1.5	2	2.1
3 dB Bandwidth		MHz	1.5	0.8	15	1.5	10	1	0.63
Receiver thermal noise figure		dBm	–110	–114	–99	–110	–102	–112	–114
		dBm/MHz	–112	–113	–111	–112	–112	–112	–112
Required *I/N*		dB	–10			–10		–10	
1 dB Compression Point[28,29]		dBm	–10	10	10	51.4	56.6	10	–17
		dBm/MHz	–8.2	9	22	53.2	66.6	10	–19
Antenna									
Pattern			Cosecant squared			Cosecant squared		Pencil	
Polarisation			Mixed			Mixed		Circular	
Gain		dBi	33.5	35	34	33.5	40	43	45.7
Feeder loss		dB	2			2		2	
Azimuthal beamwidth		degrees	1.5	1.4	1.45	1.5	1.1	0.92	0.92
Elevation beamwidth		degrees	4.8	4.5	4.8	4.8		0.92	0.92
Rotation		rpm	15	15	15		60	3	3
Location			Ground			Ground	Shipborne	Ground	
Nominal height			15			15	30	15	
Aeronautical Safety Factor[30]		dB	6			0		0	

---

[28] The 1 dB compression point specifies the output power of an amplifier at which the output signal lags behind the nominal output signal by 1 dB and is regarded as the point at which interference occurs.

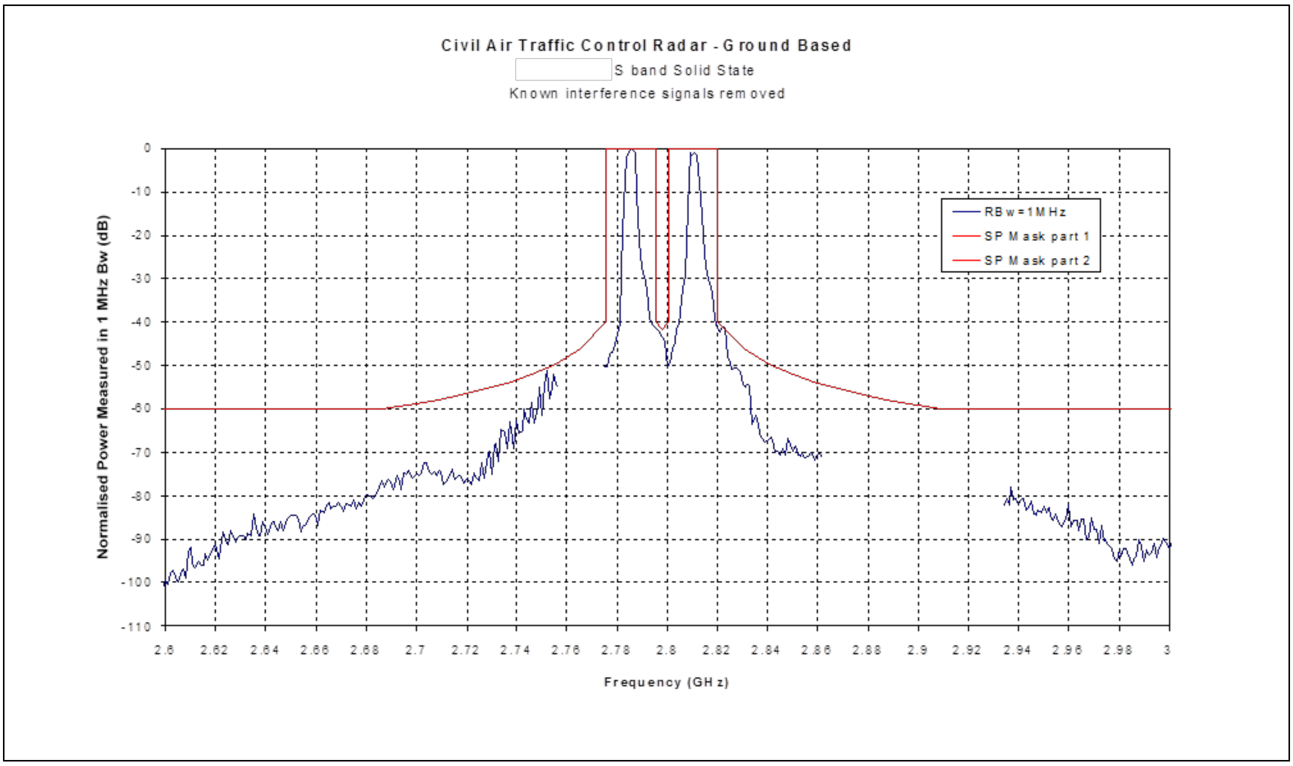
[29] Measurements made within Europe indicate that the 1 dB compression points taken from the existing Recommendation may be over optimistic and that the true values are much lower, e.g., for Radar 1 they were measured at –48 dBm (see http://www.itu.int/md/R07-WP5B-C-0389/en), i.e., the systems may be more susceptible than is indicated in the Table 1.

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

3.1.1 Solid State ATC radar RF emissions

FIGURE 1

Solid state ATC radar emissions



3.1.2 Representative air traffic control antenna polar diagrams

FIGURE 2

Vertical pattern

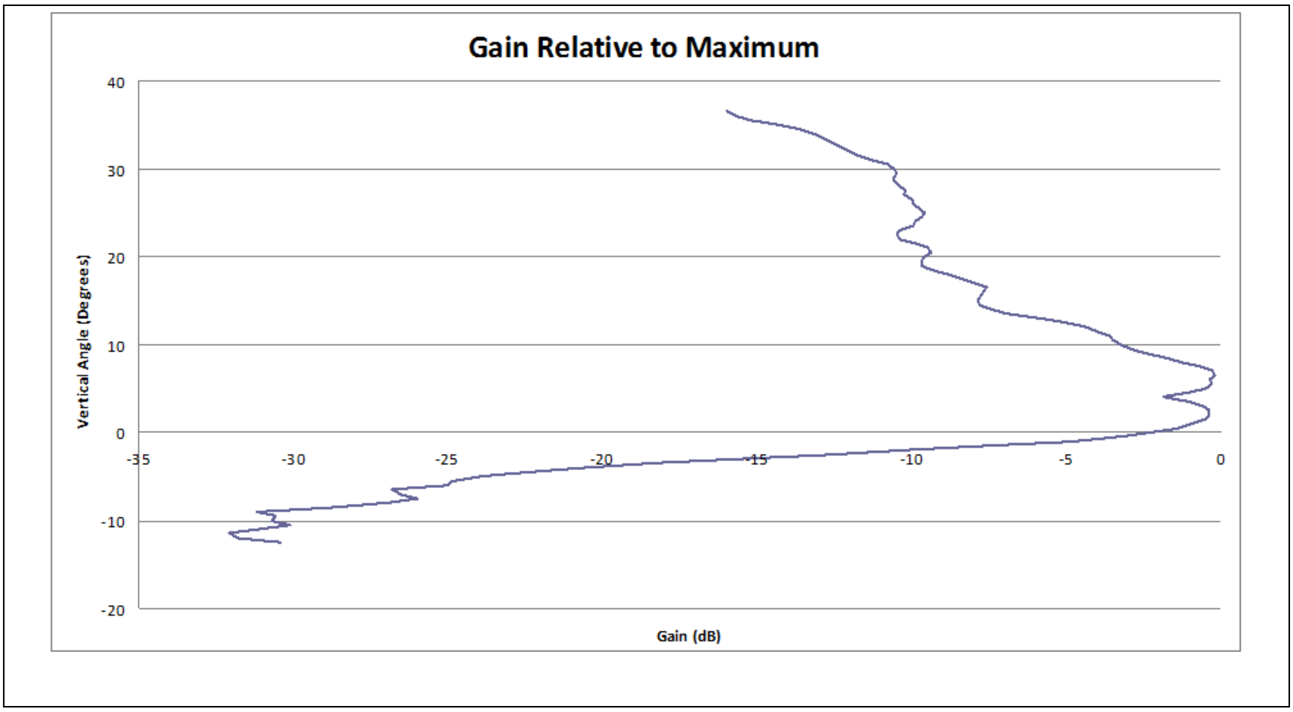


FIGURE 3

Horizontal pattern

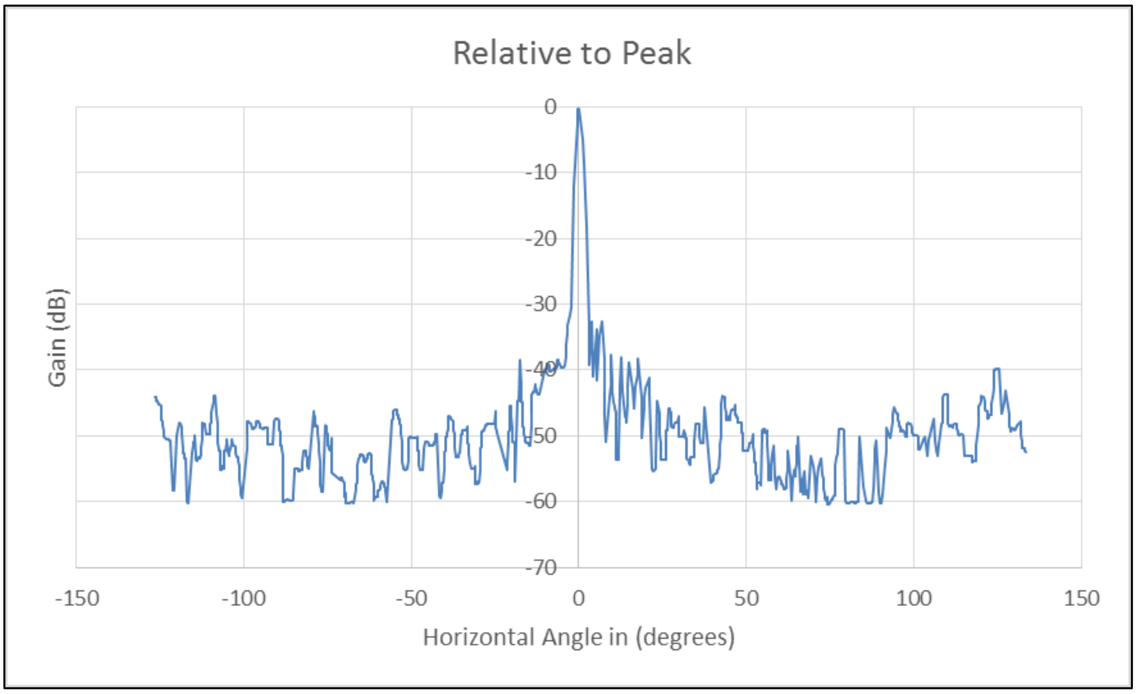


TABLE 2

Percentage of radar antenna relative gains falling within the following limits

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 –50 dB	45.8%
Greater than –50 dB	52.8%

3.2 Assumed mobile broadband system parameters

3.2.1 Base station characteristics

TABLE 3

Macrocell characteristics

Parameter		**Units**	**LTE**
Downlink frequency FDD		MHz	2 800[31]
Bandwidth		MHz	5, 10 or 20
Maximum transmitter power	BW=5 MHz	dBm	43
	BW = 10 MHz		46
	Power density	dBm/MHz	36
Spurious emission limits	limit	dBm/MHz	–30
Max Antenna gain		dBi	18 (Rural)/ 16 (Urban/Suburban)
Feeder loss		dB	3
Typical antenna height		m	30 (Rural),25(Suburban), 20 (Urban)
Antenna down tilt		degrees	3 (Rural), 6 (Suburban),10 (urban)
Antenna type			Sectorial (3 sectors)
Antenna Pattern			Rec. ITU-R F.1336-2
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 in 5 MHz		dBm	–102
Receiver thermal noise level in 5 MHz		dBm	–99
Receiver thermal noise power density (level in 1 MHz)		dBm/MHz	–109
Required *I/N* ratio		dB	–6
Receiver adjacent channel selectivity (5 MHz)		dB	–52
Receiver adjacent channel selectivity (10 MHz)		dB	–52

---

[31] Assumed as the centre frequency for this study.

We note that Recommendation ITU-R M.1580-4 and 3GPP TS 36.104 contain emission limits for certain frequency ranges that are substantially below the generic spurious emissions limit of –30 dBm/MHz. It is likely that a similar reduction would be feasible for the 2 700-2 900 MHz band, which would improve coexistence.

3.2.2 Pico base station characteristics

TABLE 4

Picocell characteristics

Parameter	Units	LTE
Downlink frequency FDD	MHz	2 800 (Note 1)
Bandwidth	MHz	5
Maximum transmitter power	dBm	24
	dBm/MHz	17
Antenna gain	dBi	0
Antenna height	m	3
Building penetration loss	dB	20
Antenna type		Omnidirectional
Polarization		Linear
Picocells assumed in in propagation modelling, figure		10,100

3.2.3 User equipment characteristics

TABLE 5

User equipment characteristics

Parameter		Units	LTE
Downlink frequency FDD		MHz	2 800 (Note 1)
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[32] for a 20 MHz channel	20 MHz	dB	27

---

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

3.3 Maritime radar considerations

As the 2 700-2 900 MHz band becomes increasingly occupied by communications signals an interference risk to maritime radar emerges.

The current UK position is that measurements indicate maritime radars operating in the 2 900-3 100 MHz band have low susceptibility to the new communications signals in the 2 500-2 690 MHz band. The low susceptibility is related to the selectivity of the radar receiver as shown in (Fig. 4), showing a modest but noticeable increase in the loss in probability of detection performance of the radar receiver, as the interferer increases in frequency from 2 700-2 900 MHz.

In (Fig. 5), which shows a measured maritime radar antenna, significant increased gain in the frequency range from 2 700-2 900 MHz compared with 2 500-2 690 MHz is indicated. This raises the risk of communications in the 2 700-2 900 MHz band causing interference to the maritime radar.

FIGURE 4

Measured maritime magnetron radar receiver susceptibility signals in the band 2 700-2 900 MHz (interference power required to reduce radar detection Pd by 5%)

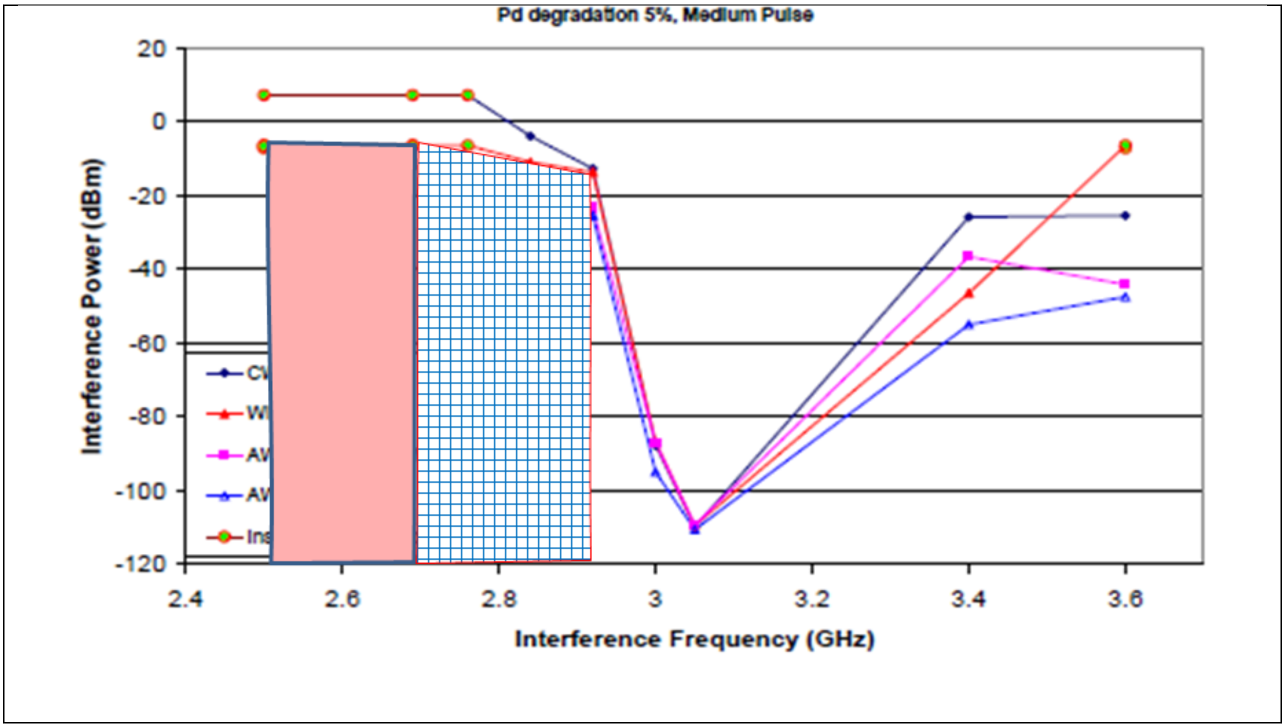
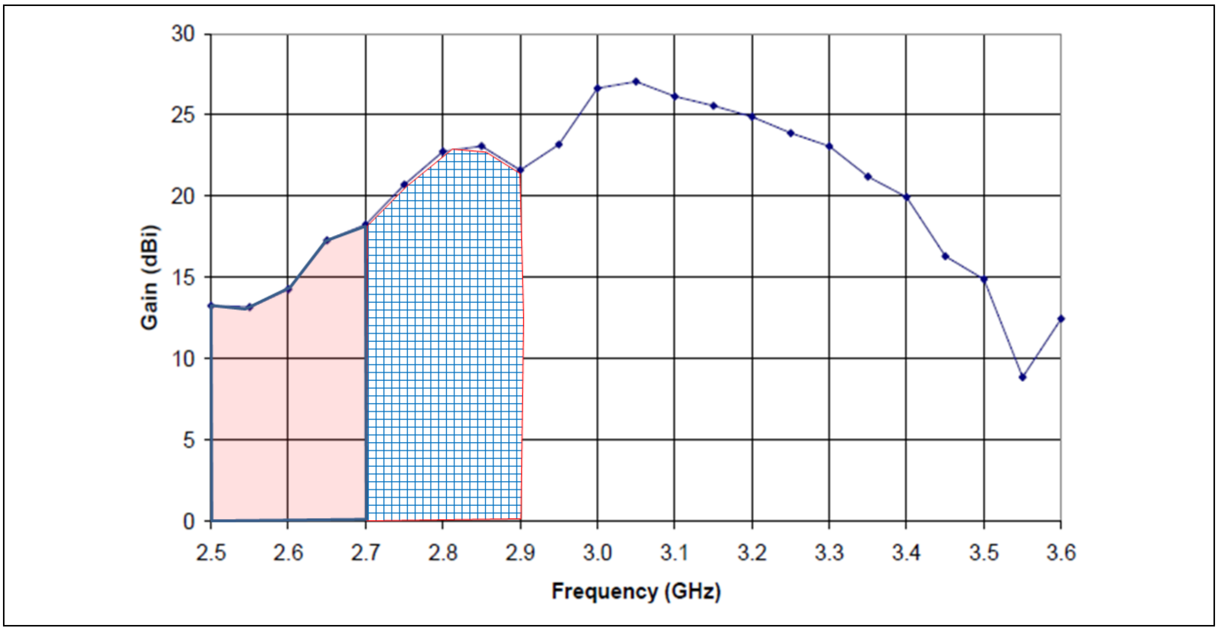


FIGURE 5

Measured maritime magnetron radar antenna gain to signals in the band 2 700-2 900 MHz



3.4 Meteorological radar

Some S-band meteorological radars have similar characteristics to civil ATC radar and similar impacts may be expected to the ATC analysis.

4 Analysis

4.1 Assumptions

- Studies based on the impact of a single interferer on a single victim.
- Minimum separation:
  - Base station = one kilometre
  - User equipment = 500 m.
- That peak transmission power is used.
- That the mobile base station and radar will be in the main beam of the other.
- That typical mobile user equipment will be 3.5 degrees[33] below the main beam of the radar reducing the antenna gain by 10 dB in accordance with Fig. 1.
- That cumulative effects can be ignored in all cases except when considering spurious emissions from mobile base stations on a single mast or picocells into the radar receiver[34].

---

[33] Based on the user equipment at 1.5 m the radar at 15 m and a separation of 500 m

[34] The rationale being:
For a radar, given its directive antenna with good sidelobe suppression (> 30 dB), the probability that more than one mobile macro 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.

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.

To provide sensitivity analysis section 4.4 considers variations in some parameters. These are chosen as a result of the UK radar remediation program, they are the:

- 1 dB compression point;
- level at which the communications signal will cause increase in noise level in the radar due to IMPs at the input to the LNA.

4.2 Methodology

The following analysis is based on determining the required additional attenuation required for a reference minimum separation distance using free space path loss to ensure compatibility between mobile broadband systems and radar in the frequency band 2 700-2 900 MHz. The studies address both co-channel and adjacent channel issues.

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 metres for user equipment) 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 with 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).

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.

Adjacent channel Analysis

The adjacent channel analysis considers the impact of both the spurious emissions from the potential interference source that fall within the passband of the victim receiver and the victim receiver adjacent band rejection of the fundamental signal of the interferer are analysed.

Potential interferer spurious emissions in the victim passband

This analysis calculates the power at the victim receiver from the spurious emissions of the potential interference source for a given separation distance (1 km for a base station and 500 m for user equipment) 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.

Victim receiver rejection of the potential interferer spurious emissions

This analysis calculates either:

- the power at the victim receiver from the potential interference source as attenuated by the adjacent channel rejection of the victim receiver for a given separation distance (one kilometre for a base station and 500 metres for user equipment)assuming free space path loss (mobile equipment) and compares it against the receiver interference level;

  or

- the power at the victim receiver from the potential interference source for a given separation distance (one kilometre for a base station and 500 metres for user equipment) assuming free space path loss and compares it with the 1 dB compression point (radar).

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.

Adjacent channel rejection

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).

Power of the potential interferer at the victim receiver:

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

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

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.

1 dB Compression point

Receiver interference level:

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

where:

IL_{CP} = Receiver interference level for 1 dB compression point
CP_{RX} = Receiver 1dB compression point
SM = Safety margin (only applicable for aeronautical services).

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:

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

where:

IM = Interference margin
IL_{CP} = Receiver interference level for 1 dB compression point
P_{RX} = Power of the potential interferer at the victim receiver.

4.3 Results

Details of the calculations undertaken are contained in the Annex 1 to this report, the summaries are shown below.

4.3.1 Co-channel

TABLE 6

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	Macro base station	–109.5/ –107.5	–112.0/ –110.0	–109.0/ –107.0	–103.5/ –101.5	–110.0/ –108.0	–113.0/ –111.0	–115.7/ –113.7
	Pico cell base station	–55.5	–58.0	–55.0	–49.5	–56.0	–59.0	–61.7
	User equipment	–74.5	–77.0	–74.0	–68.5	–75.0	–78.0	–80.7

In the worst case this would theoretically equate to a free space separation distance of more than 500 000 kilometres for macro base station 1 000 kilometres for a picocell and 15 000 kilometres for user equipment, i.e. the radio frequency horizon and propagation effects will dominate.

TABLE 7

Interference margin for radar systems into mobile systems measured in dB

		Victim	
		Mobile base station	**Mobile user equipment**
Interferer	Radar 1	–134.3/–132.3	–108.3
	Radar 2	–137.8/–135.8	–111.8
	Radar 3	–132.2/–130.2	–106.2
	Radar 4	–134.5/–132.5	–108.5
	Radar 5	–140.0/–138.0	–114.0
	Radar 6	–159.0/–157.0	–133.0
	Radar 7	–161.9/–159.9	–135.9

In the worst case this would theoretically equate to a free space separation distance of more than 100 000 000 kilometres. However, if the statistics of the radar signal including 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 8

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 (note, radar receiver is open for target returns)	
Percentage of time	90.66%	98%

4.3.2 Adjacent channel

TABLE 9

Interference margin for mobile systems into radar measured in dB

			Victim						
			Radar 1	**Radar 2**	**Radar 3**	**Radar 4**	**Radar 5**	**Radar 6**	**Radar 7**
Interferer	Macro base station	Spurious	–41.5	–44.0	–41.0	–35.5	–42.0	–45.0	–47.7
		Fundamental	2.5/4.5	21.0/23.0	22.0/24.0	69.9/71.9	86.6/88.6	19.0/21.0	–10.7/–8.7
	Pico cell base station	Spurious	10.5	8.0	11	16.5	10	7	4.3
		Fundamental	56.5	75.0	65.0	70.5	64	61	43.3
	User equipment	Spurious	–21.5	–24.0	–21.0	–15.5	–22.0	–25.0	–27.7
		Fundamental	37.5	56.0	57.0	104.9	103.6	54.0	24.3

In the worst case this would theoretically equate to a free space separation distance of more than 250 kilometres for a macro base station 0.5 kilometres for a picocell and 32 kilometres for user equipment.

TABLE 10

Interference margin for radar systems into mobile systems measured in dB

			Victim	
			Mobile base station	**Mobile user equipment**
Interferer	Radar 1	Spurious	–74.3/–71.3	–48.3
		Fundamental	–51.6/–48.6	–35.6
	Radar 2	Spurious	–76.8/–73.8	–50.8
		Fundamental	–55.1/–52.1	–39.1
	Radar 3	Spurious	–72.7/–69.7	–46.7
		Fundamental	–54.1/–51.1	–38.1
	Radar 4	Spurious	–74.5/–71.5	–48.5
		Fundamental	–51.8/–48.8	–35.8
	Radar 5	Spurious	–80.0/–77.0	–54.0
		Fundamental	–57.3/–54.3	–41.3
	Radar 6	Spurious	–59.0/–56.0	–33.0
		Fundamental	–76.3/–73.3	–60.3
	Radar 7	Spurious	–61.9/–58.9	–35.9
		Fundamental	–79.2/–76.2	–63.2

In the worst case this would theoretically equate to a free space separation distance of more than 8 000 kilometres. However if the time percentages for which the radar signals are present, as indicated above, can be taken into account then these levels of interference margin may not be an issue.

4.3.3 Inter device interference map

In (Fig. 6 to Fig. 9) the blue shading indicates areas where interference would be received using the 0.1% and 0.5% propagation model assumption for Rural mobile base station interference into a solid state radar and solid state radar interference to a mobile base station respectively (these are not necessarily indicative of them being an appropriate value to use in this compatibility situation). For the radar the period when the radar is transmitting peak power with the main beam gain is noted.

FIGURE 6

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

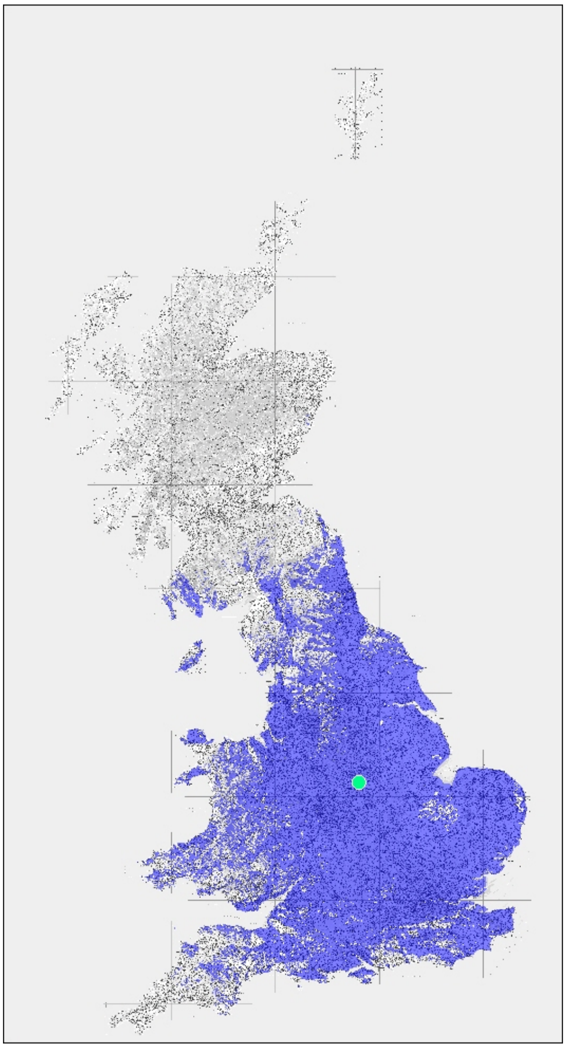
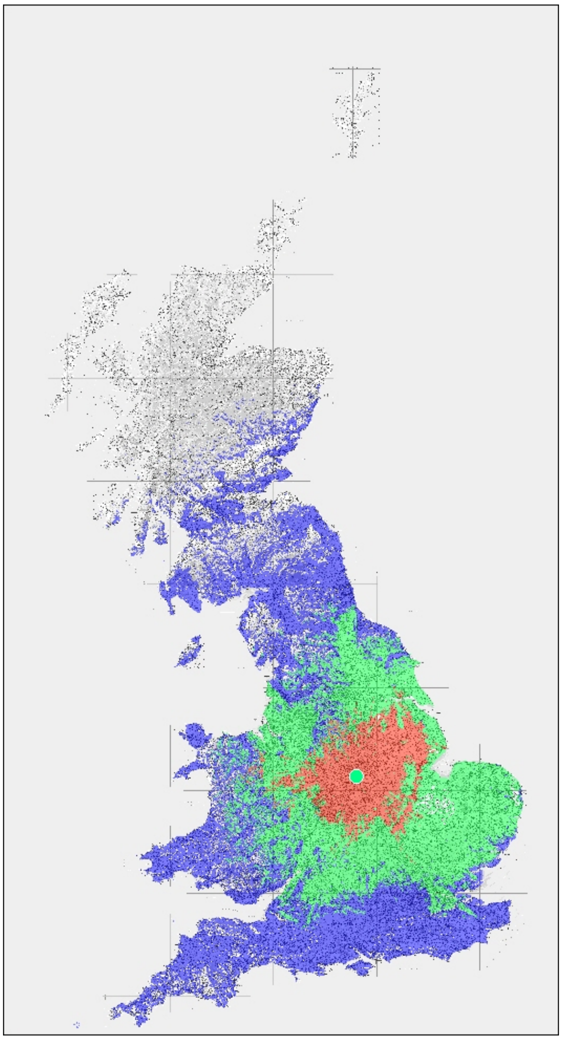


FIGURE 7

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 8

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

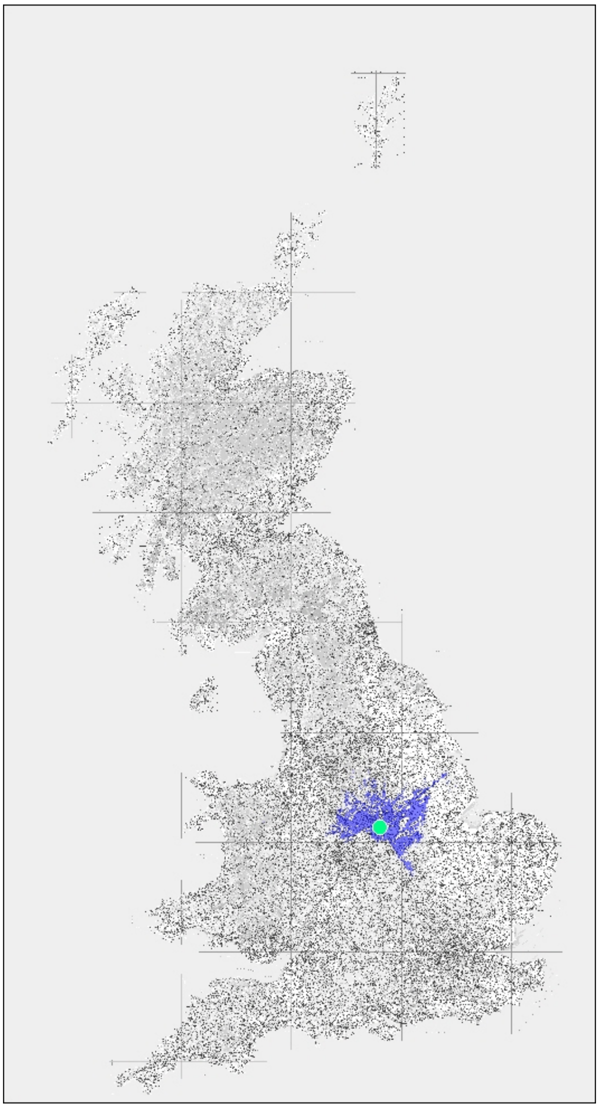
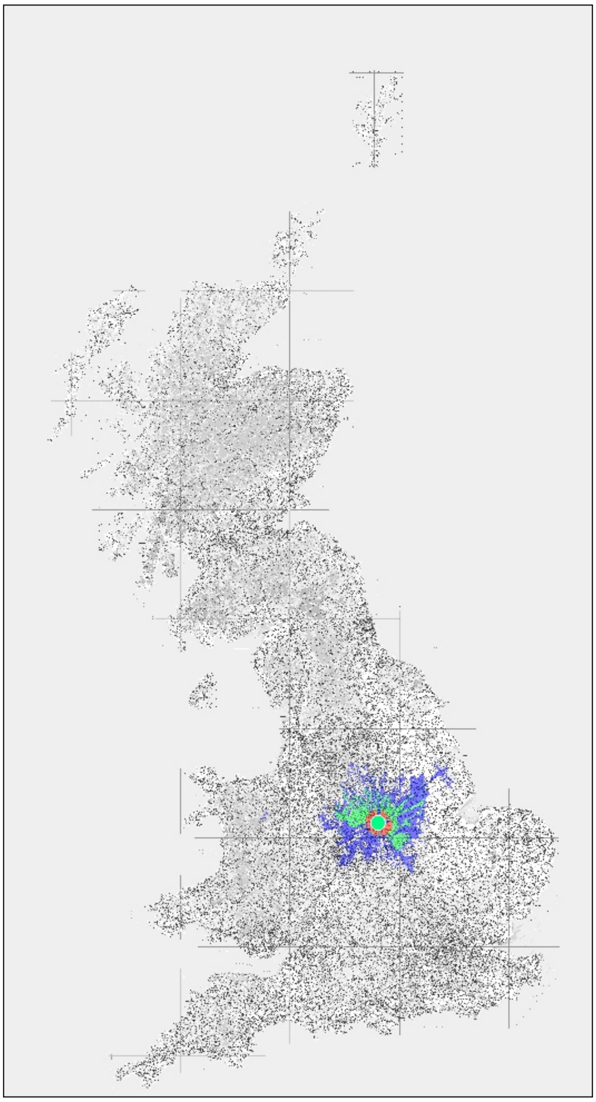


FIGURE 9

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

4.4 Results using experience from 2.6 GHz radar remediation program

4.4.1 Introduction

This section uses the methodology as in the ITU calculations in section 4.2 but supplements the analysis by using parameters similar to those that were found appropriate for the 2.6 GHz radar remediation program which enhanced the UK knowledge base. As in the previous calculations, the interference margin is shown.

To provide sensitivity analysis some parameters will be varied, the range is closely related to the parameters used in the remediation program. The ITU parameters for Radar 1 are used as a baseline.

In practice, as in the previous calculations, when the ranges would be extended, there will be effects of clutter and RF horizon that will reduce the signal level and ranges significantly and cumulative effects should be used to have higher fidelity results as in the figures above.

TABLE 11

Variations in input levels to the LNA to cause 1 dB compression or 3rd order product effects

Parameter		**Variation (dBm)**
1 dB compression point (pre LNA reference point)	1DB1	–20
	1DB2	–30
Signal level for 3rd order IMPs threshold pre filter modification (pre LNA reference point)	IMP1	–50
	IMP2	–60

4.4.2 Radar requirement for base station communications signal in adjacent band - without additional filtering

TABLE 12

Mobile base station fundamental signal on the 1 dB compression point and IMP thresholds of a radar receiver – without additional filtering

	Units	**Radar 1 ITU 1 dB compression point**	**Radar 1DB1**	**Radar 1DB2**	**Radar IMP1**	**Radar IMP2**
Mobile base station transmit power	dBm/MHz	36.0				
Mobile base station feeder loss	dB	3.0				
Mobile base station antenna gain	dB	18.0/16.0				
Free space path loss for 1 km	dB	101.0				
Radar maximum antenna gain	dBi	33.5				
Radar feeder loss	dB	2.0				
Power at the receiver front-end	dBm/MHz	–18.5/–20.5				
Radar compression point	dBm	–10.0	–20	–30	–50	–60
Safety factor	dBm	6.0				
Interference point	dBm	–16.0	–26	–36	–56	–66
Interference margin negative number indicates the amount of additional attenuation required	dB	2.5/4.5	–7.5/–5.5	–17.5/ –15.5	–37.5/ –25.5	–47.5/ –45.6

The values indicate that for one base station at one kilometre the shortfall for the:

- 1 dB compression point at –20 dBm is 7.5 dB
- 1 dB compression point at –30 dBm is 17.5 dB
- IMP1 generation level requirement at –50 dBm the shortfall is 37.5 dB
- IMP2 generation level requirement at –60 dBm the shortfall is 47.5 dB.

Thus, there is a requirement to have RF selectivity to operate with this specification of communications equipment at one kilometre and significant ranges beyond.

Note: In practical deployments the e.i.r.p. may be larger and there has been no multiple signal effects considered.

4.4.3 Radar requirement for base station communications signal in adjacent band - with additional filtering

TABLE 13

Mobile base station fundamental signal on the 1 dB compression point and IMP thresholds of a radar receiver – with additional filtering

	Units	**Radar 1 ITU 1 dB compression point**	**Radar 1DB1**	**Radar 1DB2**	**Radar IMP1**	**Radar IMP2**
Radar compression point	dBm	–10.0	–20	–30	–50	–60
Interference margin from Table 12 (no filtering)	dB	2.5	–7.5	–17.5	–37.5	–47.5
With 60 dB additional filtering	dB	57.5	52.5	42.5	22.5	12.5

The values indicate that for a mobile base station at one kilometre, the margin for:

- 1 dB compression point at –20 dBm is 52.5 dB
- 1 dB compression point at –30 dBm is 42.5 dB
- IMP generation level requirement at –50 dBm is 22.5 dB, thus
- IMP generation level requirement at –60 dBm is 12.5 dB.

This suggests that filtering in the region of 60 dB **or more** should be considered to avoid IMP issues with typical ATC radar so that adjacent band operation is achievable as per the UK 2.6 program. This was for one base station.

4.4.4 Communication noise/spurious margin for ATC radar with threshold level of –128 dBm/MHz

TABLE 14

Mobile base station spurious emissions falling in the radar pass band

	Units	**ITU level**	**ITU – 20**	**ITU – 30**	**ITU – 40**	**ITU – 50**
Mobile base station spurious emission limit	dBm/MHz	–30.0	–50	–60	–70	–80
Mobile base station feeder loss	dB	3.0				
Mobile base station antenna gain	dBi	18.0/16.0				
Free space path loss for 1 km	dB	101.0				
Radar maximum antenna gain	dBi	33.5				
Radar feeder loss	dB	2.0				
Power at the receiver front-end	**dBm/MHz**	**–84.5/ –86.5**	**–104.5/ –102.5**	**–114.5/ –112.5**	**–124.5/ –122.5**	**–134.5/ –132.5**
Radar thermal noise floor	dBm/MHz	–112.0				
Required *I/N*	dB	–10.0				
Safety factor	dB	6.0				
Interference level	**dBm/MHz**	**–128.0**				
Interference margin negative number indicates the amount of additional attenuation required	**dB**	**–43.5/–41.5**	**–23.5/–21.5**	**–13.5/–11.5**	**–3.5/–1.5**	**7.5/9.5**

The results indicate that the communications OOB /spurious emissions need to be of the order of 40 to 50 dB below the ITU spurious level to be below the radar threshold.

Fig. 10 shows an example of a measured 2.6 GHz base station conducted emissions in the radar band. The majority of the band has noise/spurious emissions are < 80 dBm/MHz (conducted).

Fig. 11 shows an example of a measured 2.6 GHz UE conducted emissions in the radar band. The majority of the band has noise/spurious emissions are < 80 dBm/MHz (conducted).

In Annex 7, there are some order of magnitude calculations, indicating the extent of interference on radar using picocells. For the arbitrary number of picocells used to illustrate the issue, there are substantial interference effects.

4.5 UK technical coordination at 2 500-2 690 MHz

Work carried out in the UK reported in (ECC Report 174) to enable the implementation of LTE and WiMAX below 2 690 MHz has indicated that radars operating above 2 700 MHz could be protected from mobile service signals below 2 690 MHz. This has been achieved by:

– specifying a cumulative mobile base station noise spectral power flux density threshold in the frequency band 2 720-3 100 MHz equal to the value shown below:

$$-131 + 10log_{10}\left(\frac{BW}{120}\right) dBm/MHz/m^2$$

where *BW* is the total 2.6 GHz bandwidth assigned to the licensee for downlink transmissions; this may require additional filtering;

– taking into account real mobile equipment performance that can achieve spurious emission levels significantly lower than the –30 dBm/MHz regulatory limit.

– Modifying the radar front ends to increase the adjacent band rejection of the radar receiver by at least 60 dB whilst ensuring that the total loss was less than 0.4 dB in the presence of the new communications signals.

– Introduction of an effective guard band of 30 MHz[35] to allow the radar filter roll off to occur.

Additionally, taking into account the radar emission mask, an example of which is given in (Fig. 1) may assist in achieving protection of the mobile systems.

In line with the findings of ECC Report 174, the UK has initiated a programme of upgrades to existing radar deployed in the frequency band 2 700-2 900 MHz (the radar remediation programme). These upgrades are designed to improve the ability of radar receivers to reject signals from transmitters in the band below 2 690 MHz. Together with certain constraints placed on the deployment of mobile broadband systems, these upgrades allow radar systems to coexist with mobile broadband systems deployed below 2 690 MHz. Similar upgrades and deployment constraints may be feasible for the case of mobile broadband systems deployed within the 2 700-2 900 MHz frequency band but would require re-engineering of the radar systems where these have been previously upgraded to take account of the mobile transmissions below 2 690 MHz.

The specification of the radar upgrades was to ensure that radar performance was not degraded when the equivalent of a total power flux density of **5 dBm/m^2** from signal transmissions in the adjacent band is incident on the face of the radar antenna in its main beam. This figure was derived on the basis that 14 mobile broadband transmitters each transmitting at 61 dBm e.i.r.p. in the adjacent band at a distance of one kilometre all simultaneously falling within the radar main beam.

As mentioned above, the UK has constrained base station deployment by imposing a coordination requirement which is triggered if the following radar protection thresholds are breached:

TABLE 15

The example of the UK 2.6 GHz coordination requirements

	Power flux density threshold for mobile broadband signals in the adjacent band (dBm/m^2)	**Spectral power flux density threshold for mobile broadband signals in radar band (dBm/MHz/m^2)**
Radar protection thresholds	$5 + 10*\log_{10}(BW/120)$	$–131 + 10*\log_{10}(BW/120)$
Where: *BW* is the total bandwidth (MHz) assigned to the base station transmissions in the adjacent band. For the case of this example (based on the UK 2.6 GHz coordination requirements), the total bandwidth assigned is 120 MHz.		

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[35] In a number of cases the modified radar receiver designs required a minimum separation of 50-60 MHz in order to achieve the required roll-off.

5 Summary

5.1 Discussion of the findings

The results of the studies based purely on high power communications transmissions indicate that there is a significant missing interference margin for both the co and adjacent channel scenarios using the current radar parameters and assumed communications emissions associated with high power base stations.

For compression effects, analysis using the typical Radar 1 dB compression point (which will be optimistic when there are communications signals that will generate IMPs) suggests a shortfall.

In the case of lower threshold values of –50 to –60 dBm, associated with UK radar remediation program IMP control, the shortfall is more substantial.

In relation to noise and spurious emissions, the parameters contained in ITU-R Recommendations result in a significant shortfall in the radar requirements.

Referring to a small sample of measured 2.6 GHz communications equipment noise and spurious emissions in the radar band, if these values are representative of production equipment, the levels, with some communications / radar co-ordination applied, would be suitable for deployment adjacent to the radar.

If there is sufficient filtering fitted to radars such that their roll off is similar to that achieved as part of the UK radar remediation program for 2.5 to 2.69 GHz communications band use, the possibility of co-existence in adjacent bands (i.e. not in the radar allocated frequencies) is high. This would however also require constraints on the communication system in order to achieve the required level of protection in terms of the total communications signal field strength at the radar face and also the noise and spurious emissions from the communications equipment similar to the 2.6 GHz coordination requirements.

Radar band sharing is not a technically simple option, however it may be considered for low power systems but there are significant spectrum management issues that would need resolving.

Furthermore, the studies have not covered:

- The possibility of low power co-channel deployments in detail using clutter and propagation aspects.
- The possibility of translation of the ATC / Meteorological / Defence radar band higher in frequency towards the maritime band.
- The detailed effects of the communications signals on maritime radar, ATC, Meteorological and Defence radar signals.
- The coexistence of all radar types which may be operating in the 2 900-3 100 MHz band.
- Peak to average power ratios of the possible communications deployments, which would be dependent on the waveforms being used.

5.2 Conclusions

Based on this study, the following provisional conclusions can be drawn:

- That co-channel sharing does not appear practical within the same geographical area.
- That the conclusions of Report ITU-R M.2112 are still valid, including when taking into account the new technologies such as LTE or WiMAX.

- Adjacent frequency band operation assuming band segmentation within the same geographical area may be practical provided:
  - certain constraints are placed on the deployment of mobile broadband systems (e.g., coordination of base station deployment in the vicinity of radar and control of base station and/or user equipment spurious emissions);
  - the ability of mobile broadband receivers to reject signals in adjacent bands is improved relative to the characteristics provided for studies;
  - the ability of radar receivers to reject signals in adjacent bands is improved.
- To implement mobile broadband services in a portion of the frequency band 2 700-2 900 MHz, radars would have to be re-planned in such a way as to release a useable amount of contiguous spectrum and the radar receivers suitably modified to improve their rejection capability.
- In order to estimate the amount of contiguous spectrum that could be released the following work would be necessary:
  - assess the amount of spectrum required in order to accommodate radar requirements;
  - determine the improvements that could be made to both mobile broadband and radar equipment in terms of adjacent channel rejection and spurious emissions performance and hence the size of the required guard band. Where these reduced noise and emission levels are an essential element of achieving compatibility with radar systems then it may be necessary for the mobile equipment standards to be tightened accordingly in order to provide a regulatory baseline.

Annexes: 7

ANNEX 1

Detailed Calculations

A1.1 Co-channel

A1.1.1 Mobile base station impact on radar

TABLE 1

Co-frequency 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	
Mobile base station feeder loss	dB	3.0			3.0		3.0	
Mobile base station antenna gain	dBi	18.0/16.0			18.0/16.0		18.0/16.0	
Free space path loss for 1 km	dB	101.0			101.0		101.0	
Radar maximum antenna gain	dBi	33.5	35.0	34.0	33.5	40.0	43.0	45.7
Radar feeder loss	dB	2.0			2.0		2.0	
Power at the receiver front-end	dBm/MHz	–18.5/ –20.5	–17.0/ –19.0	–18.0/ –20.0	–18.5/ –20.5	–12.0/ –14.0	–9.0/ –11.0	–6.3/ –8.3
Radar thermal noise floor	dBm/MHz	–112.0	–113.0	–111.0	–112.0	–112.0	–112.0	–112.0
Required *I/N*	dB	–10.0			–10.0		–10.0	
Safety factor	dB	6.0			0.0		0.0	
Interference level	dBm/MHz	–128.0	–129.0	–127.0	–122.0	–122.0	–122.0	–122.0
Interference margin Negative number indicates the amount of additional attenuation required	dB	–109.5/ –107.5	–112.0/ –110.0	–109.0/ –107.0	–103.5/ –101.5	–110.0/ –108.0	–113.0/ –111.0	–115.7/ –113.7

A1.1.2 Mobile user equipment impact on radar

TABLE 2

Co-frequency 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	
Mobile user equipment feeder loss	dB	0.0			0.0		0.0	
Mobile user equipment antenna gain	dBi	–3.0			–3.0		–3.0	
Free space path loss for 500 m	dB	95.0			95.0		95.0	
Radar maximum antenna gain	dBi	33.5	35.0	34.0	33.5	40.0	43.0	45.7
Relative gain (3° below max)		–10.0			–10.0		–10.0	
Radar feeder loss	dB	2.0			2.0		2.0	
Power at the receiver front-end	dBm/MHz	–50.5/ –53.5	–49.0/ –52.0	–50.0/ –53.0	–50.5/ –53.5	–44.0/ –47.0	–41.0/ –44.0	–38.3/ –41.3
Radar thermal noise floor	dBm/MHz	–112.0	–113.0	–111.0	–112.0	–112.0	–112.0	–112.0
Required *I/N*	dB	–10.0			–10.0		–10.0	
Safety factor	dB	6.0			0.0		0.0	
Interference level	dBm/MHz	–128.0	–129.0	–127.0	–122.0	–122.0	–122.0	–122.0
Interference margin Negative number indicates the amount of additional attenuation required	dB	–74.5	–77.0	–74.0	–68.5	–75.0	–78.0	–80.7

A1.1.3 Radar impact on mobile base station

TABLE 3

Co-frequency 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	73.8	75.8	71.2	74.0	73.0	89.0	89.2
Radar feeder loss	dB	2.0			2.0		2.0	
Radar maximum antenna gain	dBi	33.5	35.0	34.0	33.5	40.0	43.0	45.7
Free space path loss for 1 km	dB	101.0			101.0		101.0	
Mobile base station antenna gain	dBi	18.0/16.0			18.0/16.0		18.0/16.0	
Mobile base station feeder loss	dB	3.0			3.0		3.0	
Power at the receiver front-end	dBm/MHz	19.3/ 17.3	22.8/ 20.8	17.2/ 15.2	19.5/ 17.5	25.0 /23.0	44.0/ 42.0	46.9/ 44.9
Base station thermal noise floor	dBm/MHz	–109.0			–109.0		-109.0	
Required *I/N*	dB	–6.0			–6.0		–6.0	
Interference level	dBm/MHz	–115.0			–115.0		–115.0	
Interference margin Negative number indicates the amount of additional attenuation required	**dB**	–134.3/ –132.3	–137.8/ –135.8	–132.2/ –130.2	–134.5/ –132.5	–140.0/ –138.0	–159.0/ –157.0	–161.9/ –159.9

A1.1.4 Radar impact on mobile user equipment

TABLE 4

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	73.8	75.8	71.2	74.0	73.0	89.0	89.2
Radar feeder loss	dB	2.0			2.0		2.0	
Radar maximum antenna gain	dBi	33.5	35.0	34.0	33.5	40.0	43.0	45.7
Relative gain (3° below max)		–10.0			–10.0		–10.0	
Free space path loss for 500 m	dB	95.0			95.0		95.0	
User equipment antenna gain	dBi	–3.0			–3.0		–3.0	
User equipment feeder loss	dB	0.0			0.0		0.0	
Power at the receiver front-end	dBm/MHz	–3.3	–/8	–4.8	–2.5	3.0	23.0	24.9
User equipment thermal noise floor	dBm/MHz	–105.0			–105.0		–105.0	
Required *I/N*	dB	–6.0			–6.0		–6.0	
Interference level	dBm/MHz	–111.0			–111.0		–111.0	
Interference margin Negative number indicates the amount of additional attenuation required	dB	–108.3	–111.8	–106.2	–108.5	–114.0	–133.0	–135.9

A1.2 Adjacent Channel

A1.2.1 Mobile base station impact on radar

TABLE 5

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	
Mobile base station feeder loss	dB	3.0			3.0		3.0	
Mobile base station antenna gain	dBi	18.0/16.0			18.0/16.0		18.0/16.0	
Free space path loss for 1 km	dB	101.0			101.0		101.0	
Radar maximum antenna gain	dBi	33.5	35.0	34.0	33.5	40.0	43.0	45.7
Radar feeder loss	dB	2.0			2.0		2.0	
Power at the receiver front-end	dBm/MHz	–86.5	–85.0	–86.0	–86.5	–80.0	–77.0	–74.3
Radar thermal noise floor	dBm/MHz	–112.0	–113.0	–111.0	–112.0	–112.0	–112.0	–112.0
Required *I/N*	dB	–10.0			–10.0		–10.0	
Safety factor	dB	6.0			0.0		0.0	
Interference level	dBm/MHz	–128.0	–129.0	–127.0	–122.0	–122.0	–122.0	–122.0
Interference margin Negative number indicates the amount of additional attenuation required	dB	-41.5	-44.0	-41.0	-35.5	-42.0	-45.0	-47.7

TABLE 6

Mobile base station fundamental signal on the 1 dB compression point of 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	
Mobile base station feeder loss	dB	3.0			3.0		3.0	
Mobile base station antenna gain	dB	18.0/16.0			18.0/16.0		18.0/16.0	
Free space path loss for 1 km	dB	101.0			101.0		101.0	
Radar maximum antenna gain	dBi	33.5	35.0	34.0	33.5	40.0	43.0	45.7
Radar feeder loss	dB	2.0			2.0		2.0	
Power at the receiver front-end	dBm/MHz	–18.5/ –20.5	–17/–19.0	–18.0/ –20.0	–18.5/ –20.5	–30.0/ –32.0	–9.0/–11.0	–6.3/–8.3
Radar 1 dB compression point	dBm	–10.0	10.0	10.0	51.4	56.6	10.0	–17.0
Safety factor	dBm	6.0			0.0		0.0	
Interference point	dBm	–16.0	4.0	4.0	51.4	56.6	10.0	–17.0
Interference margin Negative number indicates the amount of additional attenuation required	dB	2.5/4.5	21.0/23.0	22.0/24.0	69.9/71.9	86.6/88.6	19.0/21.0	–10.7/ –8.7

A1.2.2 Mobile user equipment impact on radar

TABLE 7

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	
Mobile user equipment feeder loss	dB	0.0			0.0		0.0	
Mobile user equipment antenna gain	dBi	–3.0			–3.0		–3.0	
Free space path loss for 500 m	dB	95.0			95.0		95.0	
Radar maximum antenna gain	dBi	33.5	35.0	34.0	33.5	40.0	43.0	45.7
Relative gain (3° below max)		–10.0			–10.0		–10.0	
Radar feeder loss	dB	2.0			2.0		2.0	
Power at the receiver front-end	dBm/MHz	–106.5	–105.0	–106.0	–106.5	–100.0	–97.0	–94.3
Radar thermal noise floor	dBm/MHz	–112.0	–113.0	–111.0	–112.0	–112.0	–112.0	–112.0
Required *I/N*	dB	–10.0			–10.0		–10.0	
Safety factor	dB	6.0			0.0		0.0	
Interference level	dBm/MHz	–128.0	–129.0	–127.0	–122.0	–122.0	–122.0	–122.0
Interference margin Negative number indicates the amount of additional attenuation required	dB	–21.5	–24.0	–21.0	–15.5	–22.0	–25.0	–27.7

TABLE 8

Mobile user equipment fundamental signal on the 1 dB compression point of 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	
Mobile user equipment feeder loss	dB	0.0			0.0		0.0	
Mobile user equipment antenna gain	dB	–3.0			–3.0		–3.0	
Free space path loss for 500 m	dB	95.0			95.0		95.0	
Radar maximum antenna gain	dBi	33.5	35.0	34.0	33.5	40.0	43.0	45.7
Relative gain (3° below max)		–10.0			–10.0		–10.0	
Radar feeder loss	dB	2.0			2.0		2.0	
Power at the receiver front-end	dBm/MHz	–53.5	–52.0	–53.0	–53.5	–47.0	–44.0	–41.3
Radar 1 dB compression point	dBm	–10.0	10.0	10.0	51.4	56.6	10.0	–17.0
Safety factor	dBm	6.0			0.0		0.0	
Interference point	dBm	–16.0	4.0	4.0	51.4	56.6	10.0	–17.0
Interference margin Negative number indicates the amount of additional attenuation required	dB	37.5	56.0	57.0	104.9	103.6	54.0	24.3

A1.2.3 Radar impact on mobile base station

TABLE 9

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	13.8	14.8	11.7	14.0	13.0	–11.0	–10.8
Radar feeder loss	dB	2.0			2.0		2.0	
Radar maximum antenna gain	dBi	33.5	35.0	34.0	33.5	40.0	43.0	45.7
Free space path loss for 1 km	dB	101.0			101.0		101.0	
Mobile base station antenna gain	dBi	18.0/15.0			18.0/15.0		18.0/15.0	
Mobile base station feeder loss	dB	3.0			3.0		3.0	
Power at the receiver front-end	dBm/MHz	–43.7	–41.2	–45.3	–43.5	–38.0	–59.0	–56.1
Base station thermal noise floor	dBm/MHz	–109.0			–109.0		–109.0	
Required *I/N*	dB	–6.0			–6.0		–6.0	
Interference level	dBm/MHz	–115.0			–115.0		–115.0	
Interference margin Negative number indicates the amount of additional attenuation required	dB	–74.3/ –71.3	–76.8/ –73.8	–72.7/ –69.7	–74.5/ –71.5	–80.0/ –77.0	–59.0/ –56.0	–61.9/ –58.9

TABLE 10

Radar fundamental signal suppressed by the mobile base station filtering

	Units	**Radar 1**	**Radar 2**	**Radar 3**	**Radar 4**	**Radar 5**	**Radar 6**	**Radar 7**
Radar power to the antenna	dBm/MHz	73.8	75.8	71.2	74.0	73.0	89.0	89.2
Radar feeder loss	dB	2.0			2.0		2.0	
Radar maximum antenna gain	dBi	33.5	35.0	34.0	33.5	40.0	43.0	45.7
Free space path loss for 1 km	dB	101.0			101.0		101.0	
Mobile base station antenna gain	dBi	18.0/15.0			18.0/15.0		18.0/15.0	
Mobile base station feeder loss	dB	3.0			3.0		3.0	
Power at the receiver front-end	dBm/MHz	16.3	19.8	18.8	16.5	22.0	41.0	43.9
Base station thermal noise floor	dBm/MHz	–109.0			–109.0		–109.0	
Required *I/N*	dB	–6.0			–6.0		–6.0	
Maximum adjacent channel rejection	dB	82.7			82.7		82.7	
Interference level	dBm/MHz	–32.3			–32.3		–32.3	
Interference margin Negative number indicates the amount of additional attenuation required	dB	–51.6/ –48.6	–55.1/ –52.1	–54.1/ –51.1	–51.8/ –48.8	–57.3/ –54.3	–76.3/ –73.3	–79.2/ –76.2

A1.2.4 Radar impact on mobile user equipment

TABLE 11

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	13.8	14.8	11.7	14.0	13.0	–11.0	–10.8
Radar feeder loss	dB	2.0			2.0		2.0	
Radar maximum antenna gain	dBi	33.5	35.0	34.0	33.5	40.0	43.0	45.7
Relative gain (3° below max)		–10.0			–10.0		–10.0	
Free space path loss for 500 m	dB	95.0			95.0		95.0	
User equipment antenna gain	dBi	–3.0			–3.0		–3.0	
User equipment feeder loss	dB	0.0			0.0		0.0	
Power at the receiver front-end	dBm/MHz	–62.7	–60.2	–64.3	–62.5	–57.0	–78.0	–75.1
User equipment thermal noise floor	dBm/MHz	–105.0			–105.0		-105.0	
Required *I/N*	dB	–6.0			–6.0		–6.0	
Interference level	dBm/MHz	–111.0			–111.0		–111.0	
Interference margin Negative number indicates the amount of additional attenuation required	dB	–48.3	–50.8	–46.7	–48.5	–54.0	–33.0	–35.9

TABLE 17

Radar fundamental signal suppressed by the mobile user equipment filtering

	Units	**Radar 1**	**Radar 2**	**Radar 3**	**Radar 4**	**Radar 5**	**Radar 6**	**Radar 7**
Radar power to the antenna	dBm/MHz	73.8	75.8	71.2	74.0	73.0	89.0	89.2
Radar feeder loss	dB	2.0			2.0		2.0	
Radar maximum antenna gain	dBi	33.5	35.0	34.0	33.5	40.0	43.0	45.7
Relative gain (3° below max)		–10.0			–10.0		–10.0	
Free space path loss for 500 m	dB	95.0			95.0		95.0	
User equipment antenna gain	dBi	–3.0			–3.0		–3.0	
User equipment feeder loss	dB	0.0			0.0		0.0	
Power at the receiver front-end	dBm/MHz	–2.7	0.8	–0.2	–2.5	3.0	22.0	24.9
User equipment thermal noise floor	dBm/MHz	–105.0			–105.0		–105.0	
Required *I/N*	dB	–6.0			–6.0		–6.0	
Maximum adjacent channel rejection	dB	72.7			72.7		72.7	
Interference level	dBm/MHz	–38.3			–38.3		–38.3	
Interference margin Negative number indicates the amount of additional attenuation required	dB	–35.6	–39.1	–38.1	–35.8	–41.3	–60.3	–63.2

ANNEX 2

A2.1 Communications to radar power flux density calculation

The power flux density (field strength) path loss for communications to radar equipment should be calculated using Recommendation ITU-R P.452 “Prediction procedure for the evaluation of microwave interference between stations on the surface of the Earth at frequencies above 0.7 GHz”.

It predicts signal levels exceeded for a given percentage of time, the assessment will use a time percentage of 1% as included in the table above. It is used to model propagation mechanisms that are dependent on a range of variable parameters (such as atmospheric conditions/weather).

It describes the proportion of time during which the estimated field strength may be exceeded, e.g., a value of 1% means that on average the field strength exceeds the value estimated by the model 1% of the time.

Predictions are based on the terrain profile and clutter along the path.

TABLE 1

Parameters used in ITU-R P.452 for figures

Time percentage	1.00%
Sea level surface refractivity N0	325
delta N = [N(0 m) – N(1 000 m)]	45
Dry air pressure (hPa)	1 013
Temperature (°C)	15.0
Path centre latitude (°)	51.0
Clear-air propagation attenuation components included:	– Line of sight/Diffraction – Diffraction – Multipath and focussing effects – Gaseous absorption – Tropospheric scatter – Gaseous absorption – Ducting/Layer reflection – Gaseous absorption
The path centre latitude must be selected on a case by case basis, i.e., the evaluation of the propagation based on location based parameters should use the mid distance of the propagation path under consideration.	

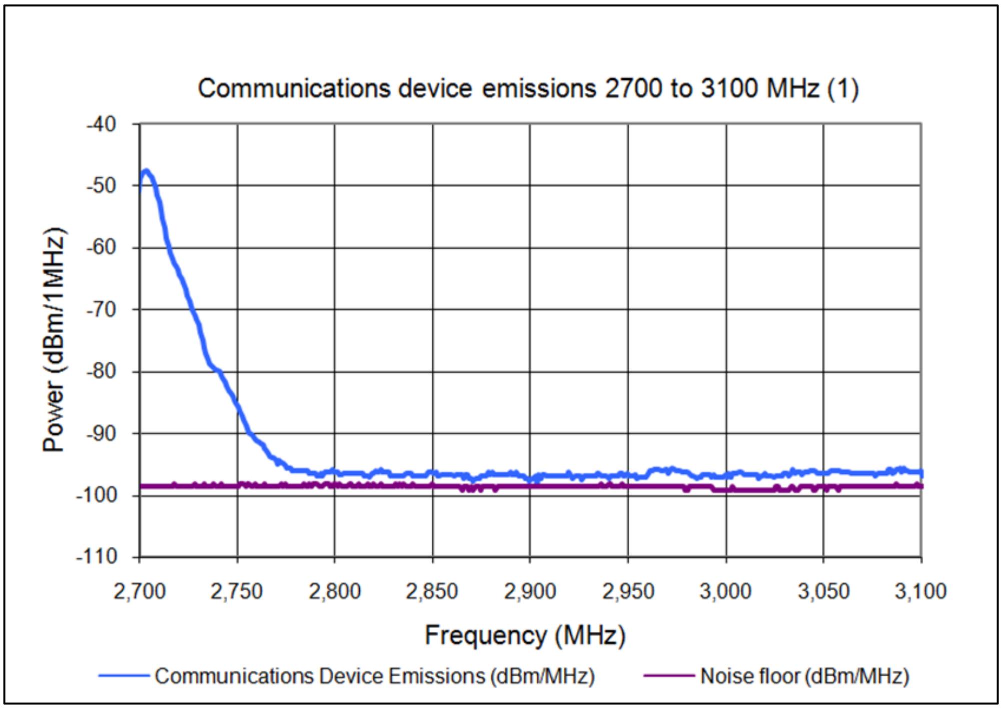
ANNEX 3

A3.1 2.6 GHz base station and user equipment OOB emissions

A3.1.1 2.6 GHz base station OOB emissions

FIGURE 1

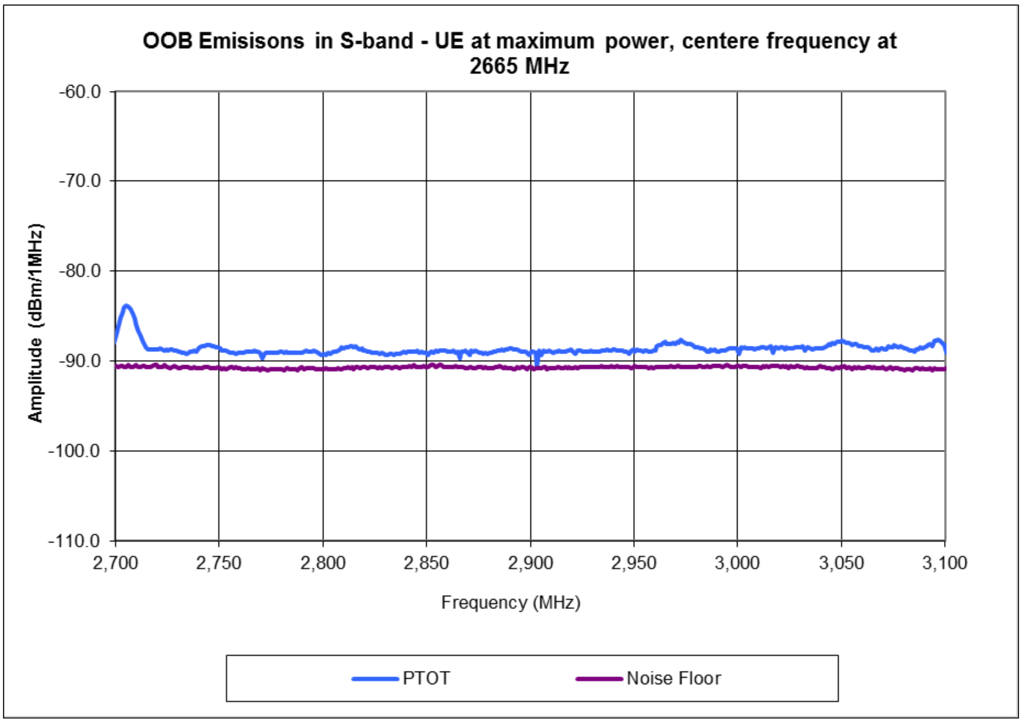
Measured 2.6 GHz base station OOB noise and spurious measurement with a 20 MHz bandwidth



A3.1.2 2.6 GHz user equipment OOB emissions

FIGURE 2

Measured 2.6 GHz user equipment OOB noise and spurious measurement with a 20 MHz bandwidth



ANNEX 4

A4 Radar receiver detrimental effects, RF Scenarios 1 to 5

In the analysis of interference from mobile into radar it is necessary to distinguish between the use of co-channel and adjacent channel in respect of radar RF and IF bandwidths (a similar argument would apply to radar to mobile interference). Below are a number of radar interference situations that could arise depending on the interfering communications signal and the radar RF and IF bandwidth and radar and communication frequencies (Figs. 1 to 5).

Whilst the radar RF bandwidth is identified schematically, that bandwidth may or may not cover the adjacent communications band.

In the scenarios represented diagrammatically the radar RF bandwidth is represented in the blue line, the communications signal by red, the radar final bandwidth set at the radar operation frequency in black and then radar generated intermodulation products (IMPs) caused by the communications signal is in green dashed lines. There is no significance of the levels of the lines other than to describe general effects and regions.

– **Scenario 1:** is regarded as adjacent band operation, similar in analysis to Scenarios 2, 4, 5 but where the introduction of a high performance RF filter reduced the communications signal to a level where any intermodulation effects induced in the radar are lower than the radar noise threshold. The dynamic range, and particularly the receiver linearity, is required to assess the permitted communications signal level where the IMPs would not affect the radar performance. This typically results in a noise and spurious limit on the performance, indicated by (a) in Scenario 1 after the filter has reduced the interfering signal.

– **Scenario 2:** is regarded as adjacent band. In this example, the least stressing sharing scenario, the single communications signal will be seen by the LNA but the 3rd order will not be seen in the radar final bandwidth. In this case the limit is noise at (b) or the dynamic range compression causing target reduction or clutter effects. This are causes 1(a) and 1(b).

– **Scenario 3:** is regarded as co-band/co-channel operation. In this case the extreme sharing case the communications signal is co-channel with the radar operating frequency. This will be the most difficult RF scenario and is simply calculated by the communications power flux density at the radar face and the radar losses and thresholds.

– **Scenario 4:** is regarded as adjacent band. In this case the 3rd order IMP generated in the radar falls in the radar final bandwidth at the radar frequency. The dynamic range and particularly the receiver linearity is required to assess the permitted communications signal level where the IMPs would not affect the radar performance.

– **Scenario 5:** is regarded as adjacent band. In this case the 3rd order IMP generated by the radar non-linearity combined with multiple communications signals fall in the falls in the radar final bandwidth at the radar frequency. The dynamic range and particularly the receiver linearity is required to assess the permitted communications signal level where the IMPs would not affect the radar performance.

The analysis, whilst being fundamentally the same calculation requires different parameter values depending on the scenario.

The UK radar remediation program postulated communications scenarios that allowed the manufacturers to design filters with high level of communications signal suppression.

FIGURES 1 TO 5

Communications to radar interference scenarios considered

FIGURE 1

**Single communications transmission outside radar RF bandwidth – noise effects–
Scenario 1**

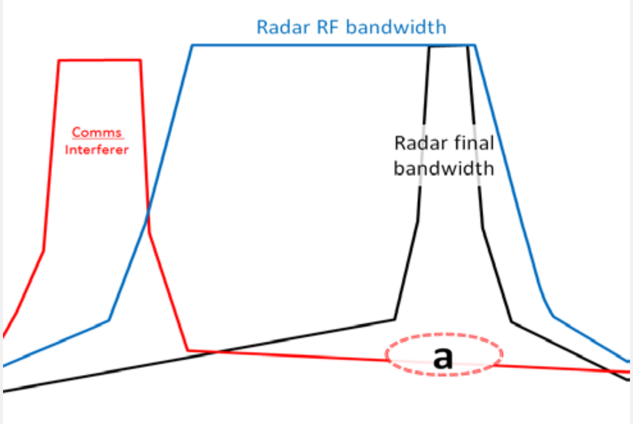


FIGURE 2

**Single communications transmission inside radar RF bandwidth – noise effects –
Scenario 2**

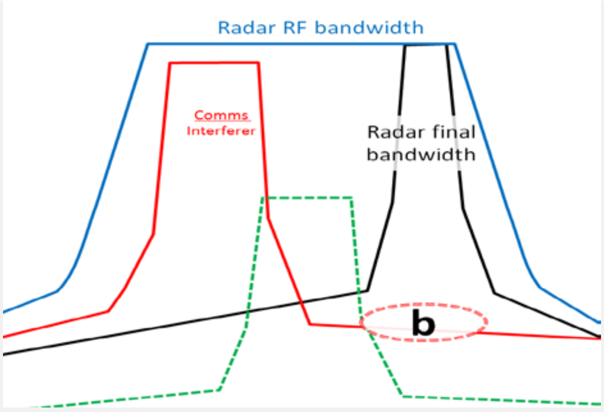


FIGURE 3

**Single communication transmission at the radar frequency – co-channel/co-frequency noise effect –
Scenario 3**

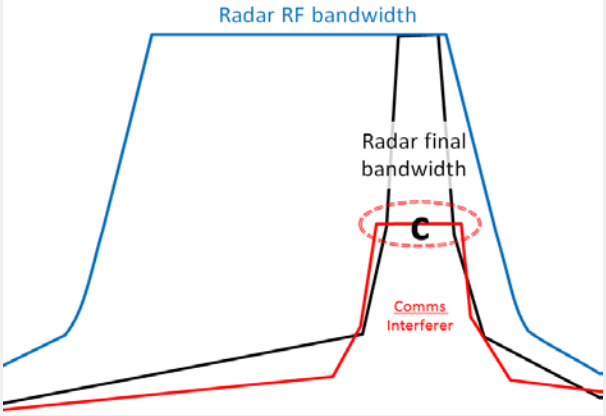


FIGURE 4

**Single communications base station transmission adjacent to radar frequency – IMP effects –
Scenario 4**

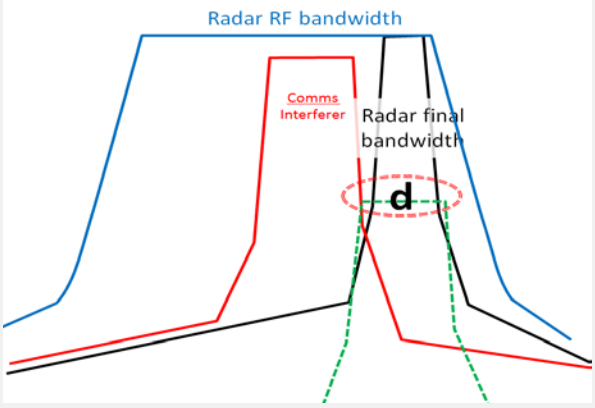
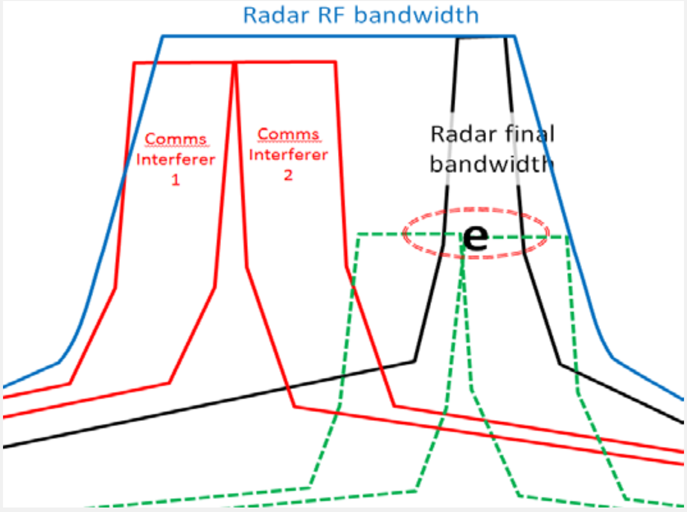


FIGURE 5

Multiple communications transmission in radar RF bandwidth – IMP effects – Scenario 5



ANNEX 5

A5.1 ATC radar summary of options considerations

This option summary represents an initial consideration of possible issues. Further work is progressing in the UK in this area.

TABLE 1

Band options – Issues summary

Option	Description	Issues to be resolved	Advantages accrued
1a.	Partitioning the 2 700-2 900 MHz band and allocating some fraction to communications devices solely and compress the radar band	Due to UK high density of radar deployment the ATC radar frequency allocation would need to be 'compressed' by improved frequency management for high power radar systems and the communications would require coordination and management. This may be difficult to generate significant communications bandwidth The fraction allocated to new communication services may be relatively small The radar would need to be modified with new filters to replace the previous design The roll off of the filter would be a significant percentage of the total band, particularly when referred to the new frequency span of the communications systems and radar allocation	Previous experience in this type of radar modification. Some new communications spectrum made available.
1b	Partitioning the 2 700-2 900 MHz band and allocating some fraction to communications devices solely and compress the radar band **AND** allowing/encouraging ATC radar to operate more in the 2 900-3 100 MHz band	Due to UK high density of radar deployment the ATC radar frequency allocation would need to be 'compressed' by improved frequency management for high power radar systems and the communications would require coordination and management. The bandwidth allocated to new communication services may greater than in 1a Modern solid state ATC radar transmitters do not operate in the 2 900-3 100 MHz band There would need to be a receiver modifications including new filters to replace the previous design and for some radars, to deal with the new frequency range, there would need to be transmitter, stalo, diplexer modifications The program cost would be higher for the radar re-engineering than 1a There would need to be consideration of maritime radar vulnerability to frequencies shared with land based radar	This may allow an increased communication bandwidth to become available. The roll off of the filter would be a smaller percentage of the total band, particularly when referred to the new frequency span of the communications systems and radar allocation.

Option	Description	Issues to be resolved	Advantages accrued
1c	Moving the ATC radar frequencies to the upper part of the 2 700-3 100 MHz radionavigation band, i.e. the 2 900-3 100 MHz radionavigation band typically used for ship borne radars and share the radar frequencies between the land based and maritime based operations	There would need to be significant modifications of some ATC radar Modern solid state ATC radar transmitters do not operate in the 2 900-3 100 MHz band There would need to be a receiver modifications including a new radar re-engineering programme with new filters to replace the previous design and for some radars to deal with the new frequency range For some radars there would need to be transmitter, stalo, diplexer modifications. The program cost would be higher for the radar modification than 1a and 1b There would need to be consideration of maritime radar vulnerability to frequencies shared with land based radar and vice versa ATC radar close to the coast would need managing for interference both to and from maritime radars	This may allow an increased communication bandwidth to become available. The bandwidth allocated to new communication services may greater than 1a and 1b The roll off of the filter would be a smaller percentage of the total band, particularly when referred to the new frequency span of the communications systems and radar allocation Some radars would require modest modifications
2	Total band sharing of both services	Communications power very restricted thus the use would be restricted Blocking, IMPs, noise all of concern and would need managing Difficult to manage with a high degree of certainty especially due to risk of co-frequency usage. It may not be possible to justify safe operation of the radar systems There would be an implied freezing of radar frequency allocations and restrictions on further deployments	Maximum use of spectrum

A5.2 UK work program

An initial assessment of some of the issue with these options can be found in Table 1. Further work is progressing in the UK to fully understand the full range of issues and the implications. This work will cover:

Allocate a portion of the frequency band 2.7-2.9 GHz to the mobile service:

- Re-plan radar assignments in to the remainder of the frequency band
- Determine the optimal radar planning criteria
- Determine the minimum amount of spectrum needed to support radar requirements taking into account a reasonable level of planning flexibility
- Determine the optimal additional radar filter design and the guard band required
- Cross-border co-ordination issues
- How to indicate the split in the Radio Regulations
- Determine regulatory implications for mobile mask (e.g., out of band limits)
- Potential guard band requirements to protect maritime radar

Re-plan radar assignments in the remainder of the frequency band and above 2.9 GHz:

- As above
- Frequency planning requirements between maritime and land based radar
- Potential need for WRC action to include an allocation to the aeronautical radionavigation service in the frequency band 2.9-3.1 GHz
- Redesign of solid state radar to operate above 2.9 GHz.

Allocate the Frequency Band 2.7-2.9 GHz to the Mobile Service:

- Band-sharing:
    - Required mobile to radar planning criteria and co-ordination procedures
    - Determine the optimal additional radar filter design and the guard band required
    - Spectral capacity released to mobile systems
    - Ensuring continued flexibility for designing and planning radar systems
    - Impact of co-frequency radar emissions on mobile receivers
    - Required additional regulatory limitation on mobile transmitters/receivers.
- Band release:
    - Determine alternative technology that offers equivalent or better performance to existing radar
    - Potential guard band requirements to protect maritime radar
    - Cost and timescale implications
    - Radio Regulatory action to support the implementation of the alternative technology.

ANNEX 6

A6 Causes of interference and potential frequency plan options

A6.1 Causes of communications to radar interference

The high duty cycle of a communication transmitter results in a RF signal that is generally present, should the interference level cause detrimental effects at the radar, the detrimental effects would be on-going. In the case that front end RF filter has significant pass band in the adjacent communications band, (or the band is shared) communications signals can enter into the radar receiver chain. The level of RF energy impinging on the front end radar components, particularly (but not exclusively) the LNA, can cause a risk of detrimental performance effects in the radar.

These performance effects can be divided into two broad categories;

A. Radar generated effects associated with the level of the communications **signal** in the communications band in the radar.

B. Communications RF emissions (**noise and spurious**) outside the communications band but in the radar final bandwidth at the radar operating frequency.

Category (A) may cause:

1) Dynamic range compression of radar components resulting in:
   a) loss of target signal amplitude which can cause a reduction in signal to noise performance of the radar;
   b) modification of the radar clutter characteristics which can cause increased clutter component in the detection process.
2) Dynamic range compression of radar components generating communications signal intermodulation power in the radars final band width. The radar LNA will, under compression, generate the 3rd (and higher) order intermodulation products which are in the frequency band around the communications signals frequencies.
3) RF mixing of the communication signal with the radar local oscillator via some nth order product that appears in the radar final bandwidth. Whilst being an infrequent occurrence, this can cause unexpected effects unless accounted for in the radar selectivity design.

All are associated with insufficient selectivity of the radar at either RF or IF frequencies.

Category (B) may cause the reduction of radar performance due to the communication **noise and spurious** appearing in the radar final bandwidth.

In summary, the requirement for the radar is to avoid the conditions where the:

– Signal level from the broadband communications signals in the radar cause IMPs to occur at a level that would cause detrimental noise like effects. This is a radar selectivity and communications signal power management issue

– Noise and spurious emissions from the communications systems in the radar is high enough to be above the radar noise detection threshold requirement

A6.2 Causes of radar to communications interference

There are several possible reasons for degradation of communication performance; however blocking may be regarded as a primary performance effect in this circumstance which depends on the transmission characteristics of the radar.

For radar to communications interference, the high peak power of radar transmission combined with the high gain of the radar antenna produces high power flux densities compared with many RF transmissions, however:

1) The low duty cycle of the radar waveforms result in interference that is usually not present as the radar is usually not transmitting.
2) The radar antenna gain is highly directional.

The radar power can only be observable when the radar is transmitting, 9.34% of the time for solid state radar or 2% of the time for TWT or less for magnetron radar.

It can be noted the narrow ATC radar beam (of the order of 1.5^o) results in beam selectivity in regards to the reception of multiple base stations if they are diverse in deployment. The radar –30 dB beamwidth is in the direction of a victim communications receiver, approximately 1.42% of the time, where the gain is between 0 dB and –30 dB with respect to the main beam peak gain.

In relation to the sidelobes, the radar gain in any one direction will be between 30 dB and 50 dB below the peak gain for 45.8% of the time and over 50 dB below the peak gain for 52.8% of time

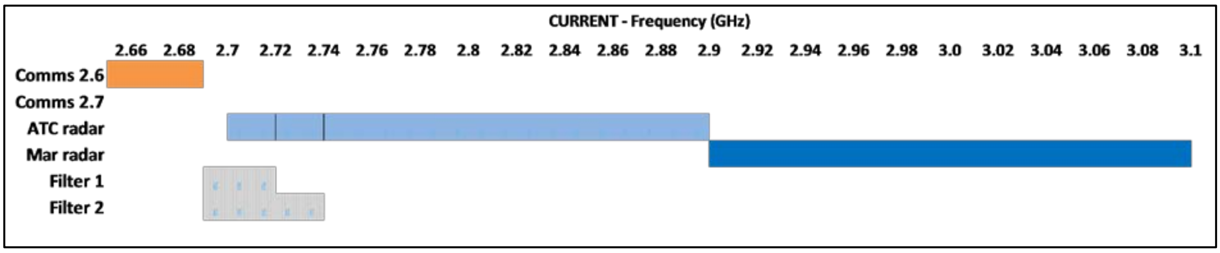
This is then combined with the duty cycle information on the radar in (Table 8) with respect to what would be received for a continuous wave transmitting signal with the peak antenna gain. For any particular radar these figures can be established with appropriate waveform and antenna information.

A6.3 2 700-2 900 MHz ATC and communications options

In this section some theoretical options are considered at high level. The frequencies are illustrative and would require further detailed study to refine. The current frequency usage is shown diagrammatically in (Fig. 1).

FIGURE 1

Current frequency allocations and typical ATC radar filter roll-off



If communications services are allocated into the 2 700-2 900 MHz band, there are potentially high levels of interference that can be caused in the radar receivers due to the radars high gain antennas, low RF selectivity and low noise receivers.

For the purpose of this report, step change new technologies, such as multi-static radar are not considered, however there is work progressing in this area. Thus immediate options considered at this stage for the 2 700-2 900 MHz band for communications revolves around the following possibilities:

1) Adjacent band options:
    a. Splitting the band and allocating some fraction to communications devices solely and compress the radar band. In this case, the radar filtering is allocated notionally to be below 2 800 MHz.

b. Splitting the band and allocating some fraction to communications devices solely and compress the radar band. In this case, the radar filtering is allocated notionally to be above 2 800 MHz.

c. Moving all the ATC radar to the upper part of the 2 700-3 100 MHz radionavigation band, i.e. the radionavigation band, 2 850-3 100 MHz, mostly used for ship borne radars and share the radar frequencies between the land and maritime based operations. In this postulated option, the allocation of (in effect) a guard band, 2 850 MHz to 2 900 MHz, allows radar filter roll-off yet retain current radar frequency diversity options.

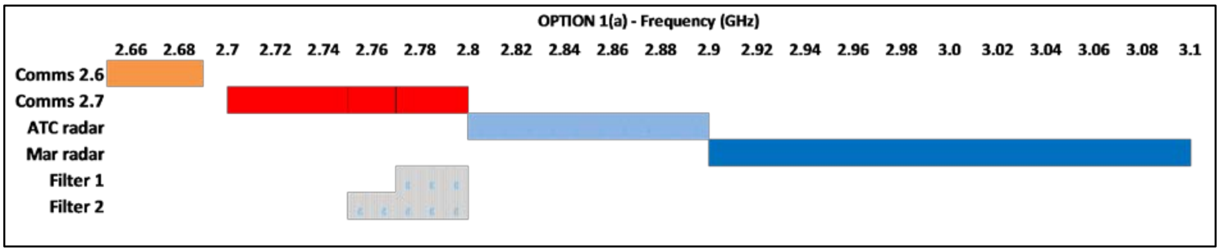
d. Moving all the ATC radar to the upper part of the 2 700-3 100 MHz radionavigation band, i.e. the radionavigation band (2 900-3 100 MHz) used for ship borne radars and share the radar frequencies between the land based and maritime based operations. There is the allocation of (in effect) a guard band, 2 900 MHz to 2 950 MHz, to allow filter roll-off with reduced radar frequency diversity options.

2) The full band sharing option of the radar and communications equipment.

A6.3.1 **Option 1** – Adjacent band options

FIGURE 2

Option 1(a) – Allocations and typical ATC radar filter roll-off

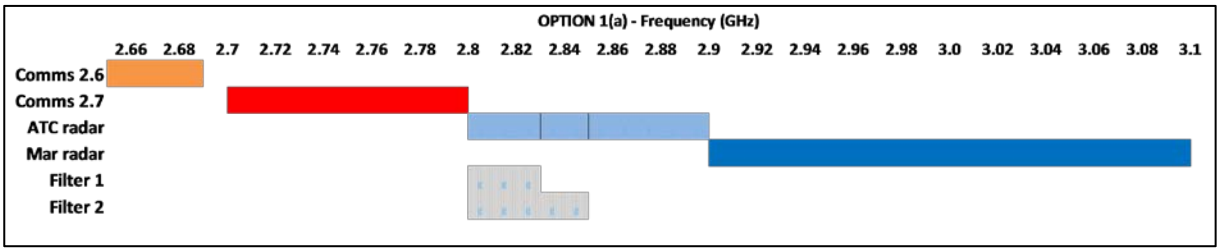


The adjacent band communications operation in 2 700-2 900 MHz with the radar band translating to 2 800-2 900 MHz or some other fraction of the band would require radar re-planning and modifications to the radar receiver, such as a new RF filter.

In (Fig. 2), the radar has moved to occupy the frequencies 2 800-2 900 MHz. The required new filter roll-off is allocated to a guard band in the radar 2 750-2 800 or 2 770-2 800 depending on the exact filter designs used. This would leave approximately 50 MHz available for high power communications use. The 100 MHz for the radar allocation is relatively low as the use of frequency diversity in the radar may cause a modest restriction as to the frequency plan that is permitted for radar performance needs however this would need further planning assessment.

FIGURE 3

Option 1(b) – Allocations and typical ATC radar filter roll-off

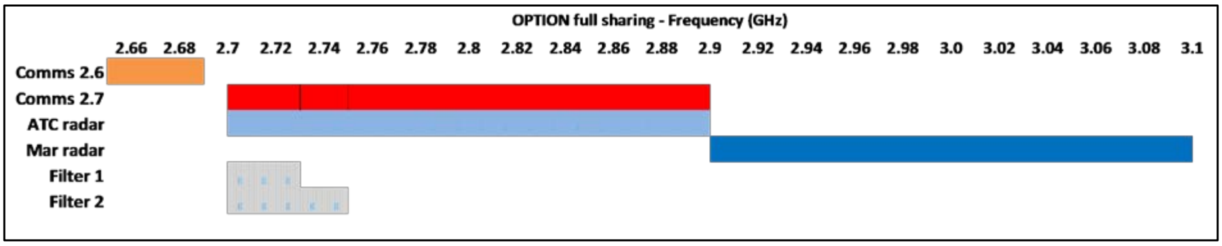


In (Fig. 3) the radar has moved to occupy 2 800 to 2 900 MHz. The required new filter roll-off is allocated to a guard band in the radar 2 800 to 2 830 MHz or 2 800 to 2 850 MHz depending on the exact filter designs used. This would leave approximately 100 MHz available for high power communications use. The 50 MHz for the radar allocation is extremely low as the use of frequency diversity in the radar will cause a restriction as to the frequency plan that is permitted for radar performance needs.

A6.3.2 Option 2 – Full band sharing of the radar and communications equipment

FIGURE 4

Full band sharing – allocations and typical ATC radar filter roll-off



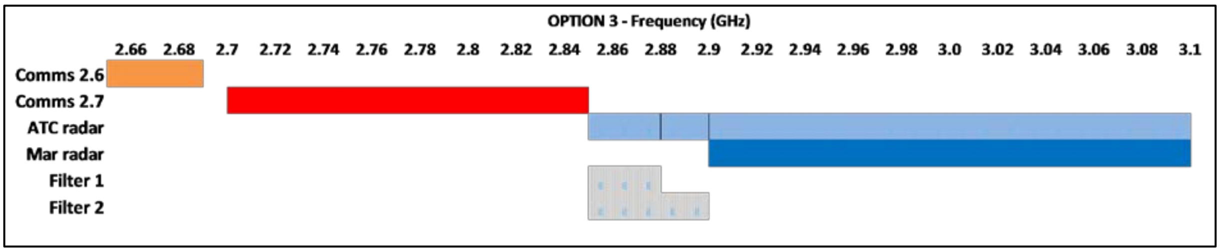
Band sharing, such as indicated in (Fig. 4) would require consideration of low power transmitters (such as picocells), frequency and geography frequency planning. This would require little or no radar modifications. However, the use of low power communications transmitters in the radar final bandwidth would require significant geographical spacing to be considered for co-band operation. Even for ‘adjacent band operation’ very significant geographical, frequency and possibly onerous licence management would be required and the close to carrier OOB emissions would be of risk to the radar.

The use of the 2 700 to 2 900 MHz band for communications may be enhanced by consideration of the adjacent maritime radar spectrum. The maritime band is already partially used by certain ATC radar designs, is adjacent and it may be possible to be used. Possible usage is envisaged below.

A6.3.3 Use of the maritime frequency band

FIGURE 5

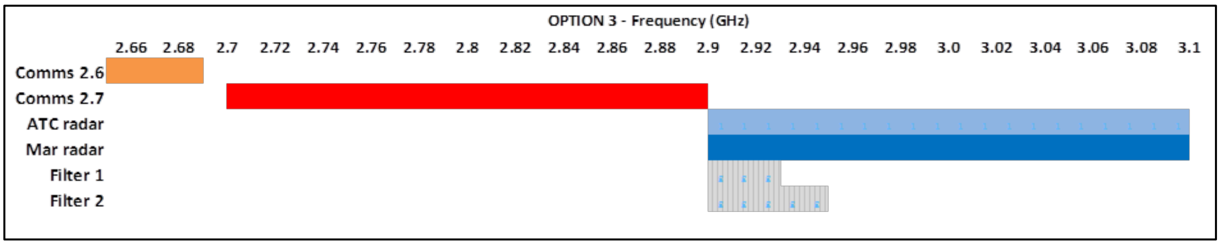
Option 1(c) – Allocations and typical ATC radar filter roll-off



In (Fig. 5) the radar has moved to occupy 2 850-3 100 MHz. The required new filter roll-off is allocated to a guard band in the radar 2 850-2 900 or 2 870-2 900 depending on the exact filter designs used. This would leave approximately 150 MHz available for high power communications use. The 250 MHz for the radar allocation, after the typical selectivity filters are installed, results in a usable bandwidth of 200 MHz and frequency diversity bandwidth could be retained. Some radars would need to modify transmitters as well as the receiver for all options other than the full sharing Option 2. There is the potential for significant maritime interference from both compression and OOB emissions from the communications systems. Measurements of maritime radar would be required to establish the magnitude of this risk.

FIGURE 6

Option 1 (d) - allocations and typical ATC radar filter roll-off



In (Fig. 6) the radar has moved to occupy 2 900-3 100 MHz. The required new filter roll-off is allocated to a guard band in the radar 2 900-2 930 or 2 900-2 950 depending on the exact filter designs used. This would leave approximately 200 MHz available for high power communications use. The 200 MHz for the radar allocation, after the typical selectivity filters are installed, results in an available bandwidth of 150 MHz and frequency diversity bandwidth could be retained. Some radars would need to modify transmitters as well as the receiver for all options other than the full sharing Option 2. There is a much increased risk for the potential of significant maritime interference from both compression and OOB emissions from the communications systems. Measurements of maritime radar would be required to establish the magnitude of this risk.

ANNEX 7

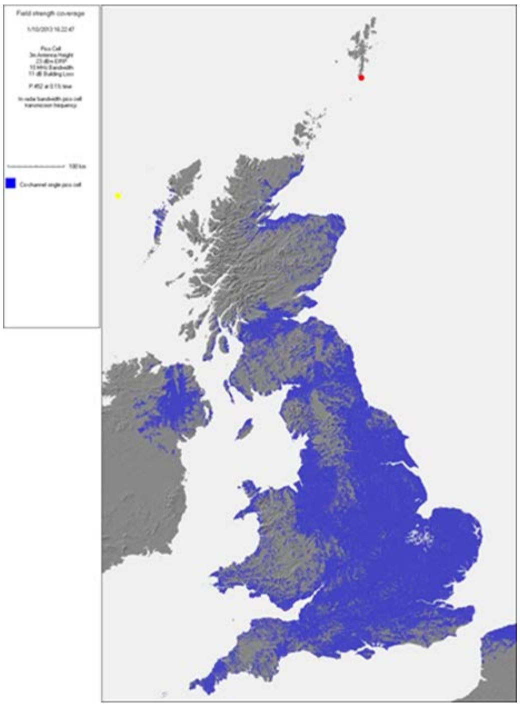
Indoor Picocells

A7.1 Figures of interference ranges with propagation for one co-channel and 10 or 100 adjacent channel pico base stations

FIGURES 1 TO 3

FIGURE 1

Interference effects from one co-channel pico base station into an ATC radar

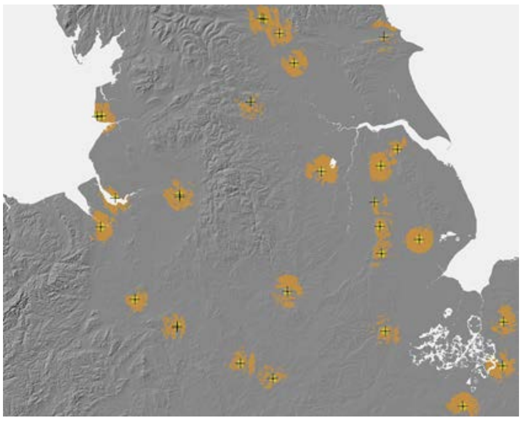


Yellow – 10 pico base station range
Orange – 100 pico base station range
11 dB building penetration loss

FIGURE 2

Interference into ATC radar from 10 and 100 adjacent channel pico base stations

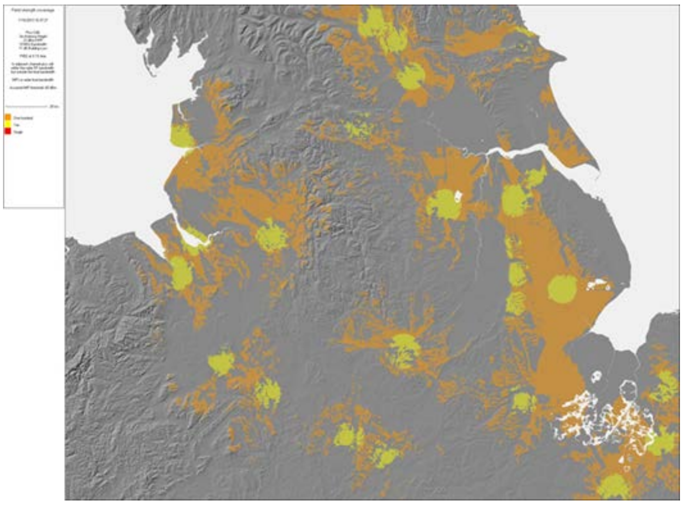
Yellow – 10 pico base station range
Orange – 100 pico base station range
20 dB building penetration loss



The diagrams above provide a visualisation of the ranges that radar could receive interference from co-channel and adjacent channel pico base stations. Note the building loss is assumed to be 20 dB from Table 4 and 11 dB as an estimate of the sensitivity of the result to assumptions.

FIGURE 3

Interference into ATC radar from 10 and 100 adjacent channel pico base stations



Serious incident: An incident involving circumstances indicating that there was a high probability of an accident and is associated with the operation of an aircraft, which in the case of a manned aircraft, takes place between the time any person boards the aircraft with the intention of flight until such time as all such persons have disembarked, or in the case of an unmanned aircraft, takes place between the time the aircraft is ready to move with the purpose of flight until such time it comes to rest at the end of the flight and the primary propulsion system is shut down.

Major incident: An incident associated with the operation of an aircraft, in which the safety of the aircraft may have been compromised, having led to a near collision between aircrafts, with ground or obstacles.

Significant incident: An incident involving circumstances indicating that an accident, a serious or major incident could have occurred, if the risk had not been managed within safety margins, or if another aircraft had been in the vicinity.

No immediate effect: An incident where there is no immediate effect on safety.

Tolerability of risk

Acceptable: The consequence is so unlikely or not severe enough to be of concern. The risk is tolerable and the Safety Objective has been met. However, consideration should be given to reducing the risk further to as low as reasonably practical in order to further minimise the risk of an accident or incident.

Review: The consequence and/or likelihood is of concern; measures to mitigate the risk to as low as reasonably possible should be sought. Where the risk still lies within the 'Review' region after as low as reasonably possible risk reduction has been undertaken, then the risk may be accepted provided that the risk is understood and has the endorsement of the individual ultimately accountable for safety within the organisation.

Unacceptable: The likelihood and/or severity of the consequence is intolerable. Major mitigation or redesign of the system may be necessary to reduce the likelihood or severity of the consequences associated with the hazard.

Interference from either mobile base station(s) or user equipment(s) by definition will have an impact. If it is assumed that the impact must fall into the lowest category of severity (e.g., no immediate effect) and that this impact must be acceptable then the probability of interference would have to be less than 1 in 10^{-3} incidents per hour or 0.1% of time. This does assume that the mobile systems can take all of the interference margin which would not be acceptable.

A7.2 Conclusion

That the radar interference level should not be exceeded more than 0.1% of time and hence this time percentage should be used in the propagation models

ATTACHMENT 9

Studies on the impact of IMT interference on radar systems with pulse compression operating in the frequency range 2 700-3 100 MHz

1 Introduction

In accordance with Resolution **233 (WRC-12)**, WRC-15 agenda item 1.1 seeks to allocate additional spectrum to the mobile service and to identify additional frequency bands for IMT in order to meet the expected increased demand for mobile broadband. [The frequency bands 2 700-2 900 MHz and 2 900-3 100 MHz are under consideration by JTG 4-5-6-7 as potential candidate bands for IMT. These frequency bands are currently allocated to the aeronautical radionavigation and radiolocation; and radiolocation and radionavigation services respectively. These frequency bands are used extensively by air traffic control, meteorological and government radar applications.]

The attached study investigates the impact of IMT interference with $I/N = -6$ dB on the performance of a shipborne radar utilising pulse compression in the frequency range 2 700-3 100 MHz.

2 Proposal

[*Text considered as a note:* Working document towards a preliminary draft new Report ITU-R M.[RADAR2700] (Attachment 4 to Annex 6 of Document 4-5-6-7/393) and working document towards a preliminary draft new Report ITU-R M.[RADAR2900] (Attachment 5 to Annex 6 of Document 4-5-6-7/393) contain studies on the compatibility of mobile broadband systems and radars in the frequency bands 2 700-2 900 MHz and 2 900-3 100 MHz.

Australia proposes to incorporate the study given in the Annex to this contribution into appropriate sections of the working Documents ITU-R M.[RADAR2700] and ITU-R M.[RADAR2900].]

Annex: 1

ANNEX

Studies on the impact of IMT interference on radar systems with pulse compression operating in the frequency range 2 700–3 100 MHz

1 Background

Radar systems which use pulse compression have their intermediate frequency (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 lead to degradation of the radar performance in excess of the 1 dB reduction in signal-to-noise ratio that would otherwise be expected. The probability of detection performance of Radar System M from the working document towards a preliminary draft revision of Recommendation ITU-R M.1464-1 [(Annex 16 to Document 5B/475)[36] *Note cannot be referred to in a DNR*] in the presence of an IMT signal is examined below.

2 Assumptions

The following radar characteristics are assumed:

Characteristics	**Radar M**[37]
Tuning range, MHz	2 700-3 400
Receiver gain, Grec, dBi	40
Receiver noise figure, NF, dB	1.5
Receiver pass band, ΔF, kHz	10 000
Pulse repetition frequency, kHz	10
Pulse width, μs	20
Antenna azimuth beamwidth, degrees	2
Antenna horizontal scan rate, degrees/s	80
Chirp bandwidth, MHz	2

A pulse repetition frequency (PRF) of 10 kHz is used, which is the highest in the given range.
A duty cycle of 20% is used, which is the highest in the given range. This defines the pulse width to be 20 μs. Assuming 2 degrees of azimuth beamwidth, and 80 degrees/s azimuth scan rate, the length of the coherence processing intervals (CPIs) is set to 25 ms. A linear frequency modulation waveform with chirp bandwidth of 2 MHz is used.

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[36] The working document towards preliminary draft revision of Recommendation ITU-R M.1460-1 [(Annex 15 to Document 5B/475) *Note cannot be referred to in a DNR*] has the same radar as Radar 3B in Table 1.

[37] The radar characteristics are given in the form of ranges of value in the Recommendation ITU-R M.1464. The exact values used in the study are shown in the table.

IMT interference is simulated using an LTE signal generated according to 3GPP LTE Release 8 specifications. Fully loaded LTE frames with 25 resource blocks (5 MHz channel bandwidth) with FDD duplexing, QPSK modulation, single transmission antenna, and single receiving antenna are used. The interference power level at the radar receiver is set to 6 dB below the noise floor.

For comparison, Gaussian interference 6 dB below the receiver noise floor is also applied in order to show that interference caused by LTE signals differ from typical Gaussian interference.

Note that interfering signals can be co-channel or adjacent channel to the radar receiver.

3 Methodology

Simulated radar received data consisting of receiver noise, interference, and a non-fluctuating target is passed through standard radar signal processing steps. These steps include matched-filtered pulse compression, Doppler processing, and constant false alarm rate (CFAR) detection. The probability of detection curves against signal-to-noise ratios are shown in Figure 1. The false alarm rate is set at 10^{-4} for all the cases.

In the ‘average’ case, the target was injected with a random range and velocity, thus it has an equal likelihood of appearing in any range-Doppler cell. In the ‘worst’ case, the target was injected with particular range and velocity parameters such that it will appear in the range-Doppler cell where highest CFAR noise estimate was found, thus has less probability of detection.

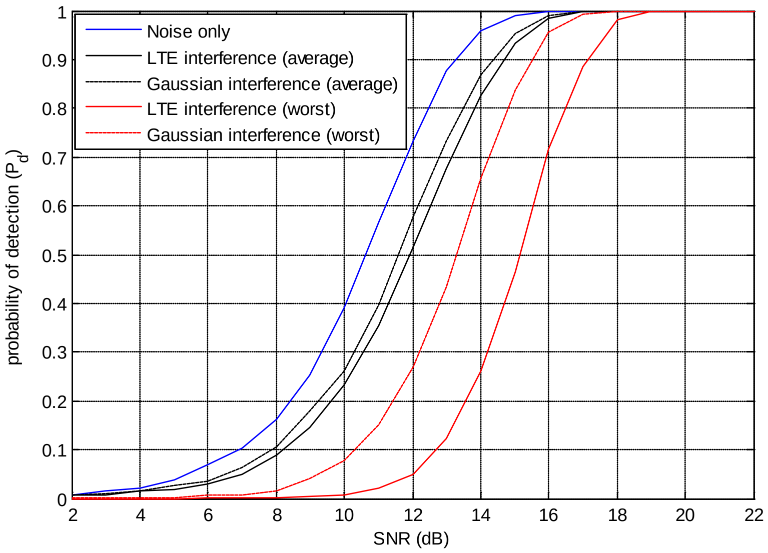
4 Results

The results show a significant reduction in radar detection performance in the presence of IMT interference. To achieve the same detection probability of 0.5 compared to the noise only case, an additional target SNR of 1.3 dB is required in the ‘average’ case, and in the ‘worst’ case additional target SNR of 4.5 dB is required.

Results also indicate that IMT signals cannot be treated as typical Gaussian interference, and the impact of IMT interference on the radar is worse than simply an increased noise floor. As expected, in the ‘average’ case the reduction in signal-to-noise ratio in the presence of Gaussian interference is 1 dB when $I/N = -6$ dB. In the ‘worst’ case, Gaussian interference degrades signal-to-noise ratio by 2.7 dB. However, as stated above, radar detection performance is significantly further degraded in the presence of IMT interference at the same interference power level.

FIGURE 1

Probability of detection of a non-fluctuating target at presence of LTE interference and Gaussian interference. False alarm rate is set at 10^{-4}



A summary of the results is shown in Table 1 for both interference types, and compared with the noise only case.

TABLE 1

Required SNR to achieve probability of detection = 0.5

	I/N **= -∞ dB (noise only)**	***I/N*** **= –6 dB (‘average’ case)**	***I/N*** **= –6 dB (‘worst’ case)**
IMT interference	10.6 dB	11.9 dB	15.1 dB
Gaussian interference	10.6 dB	11.6 dB	13.3 dB

5 Discussion

The protection criteria of *I/N* = –6 dB is often used to in interference studies as being equivalent to a 1 dB reduction in signal-to-noise ratio. However, as shown above, the impact of IMT interfering signals on radar performance can be significantly greater in systems which use pulse compression. These systems have their IF bandwidth matched to the compressed pulse and act as a matched filter for minimum S/N degradation. Pulse compression filters may be partially matched to and hence increase the effect of IMT interference. In some cases, the recommended *I/N* protection criteria of –6 dB may not be adequate and further studies or compatibility measurements may be necessary to assess the interference in terms of the operational impact on the radar’s performance.

6 Conclusions

Administrations considering deployment of IMT systems in the frequency range 2 700-3 100 MHz should be aware that an interference margin greater than the level recommended in relevant ITU-R Recommendations may be necessary, to minimise the impact of IMT interference on radar systems.