Compatibility study in preparation for the award of the 2.6 GHz band

a report from Plum Consulting

Consultant Report

Reference: ComReg 19/59c

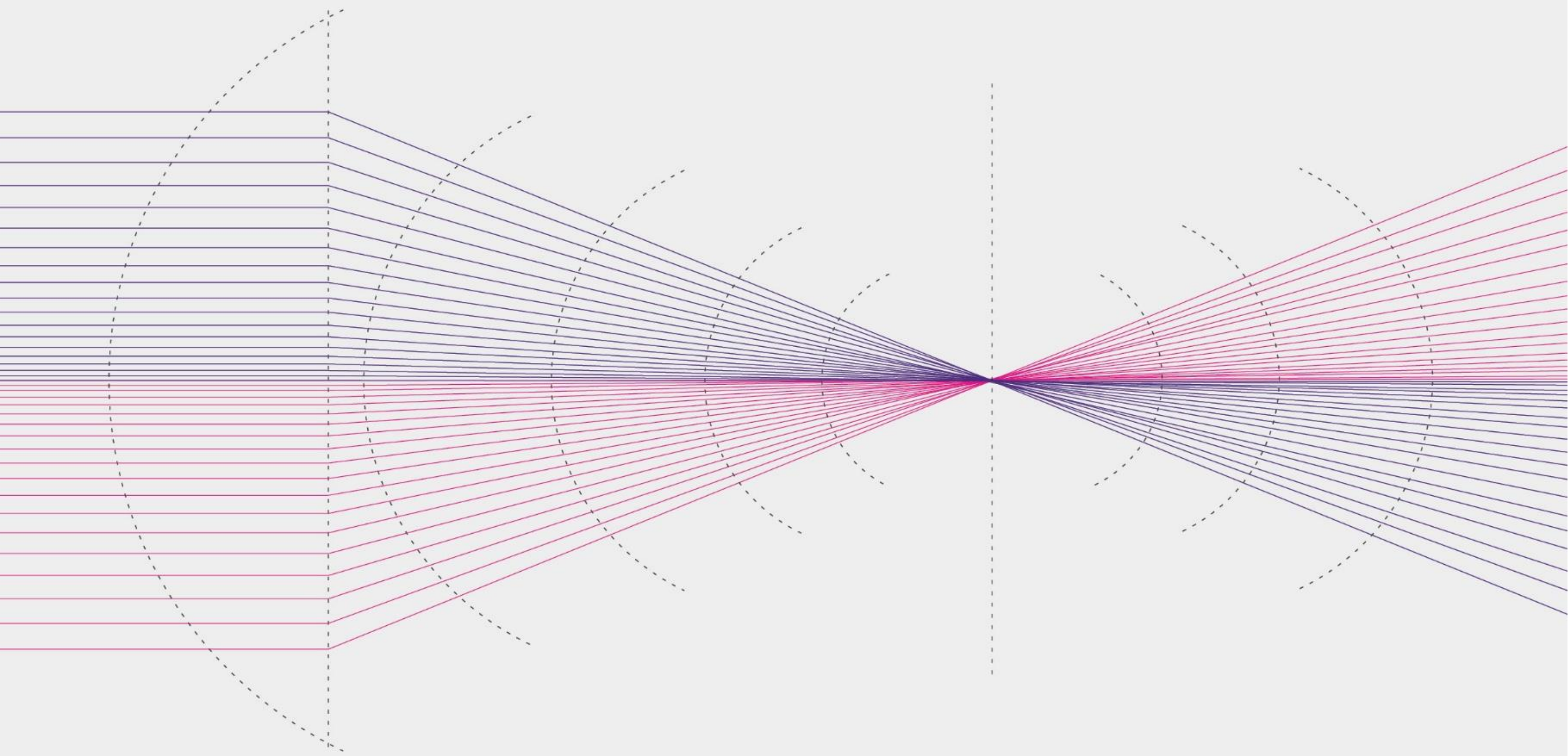
Date: 18/06/2019

An Coimisiún um Rialáil Cumarsáide
Commission for Communications Regulation
1 Lárcheantar na nDugaí, Sráid na nGildeanna, BÁC 1, Éire, D01 E4X0.
One Dockland Central, Guild Street, Dublin 1, Ireland, D01 E4X0.
Teil | Tel +353 1 804 9600 Suíomh | Web www.comreg.ie

Compatibility study in preparation for the award of the 2.6 GHz band

April 2019

Val Jervis, Selcuk Kirtay, Richard Rudd



About Plum

Plum is an independent consulting firm, focused on the telecommunications, media, technology, and adjacent sectors. We apply extensive industry knowledge, consulting experience, and rigorous analysis to address challenges and opportunities across regulatory, radio spectrum, economic, commercial, and technology domains.

About this study

This study for ComReg identifies the approaches adopted by other countries in regards the award of the 2600 MHz band and in particular the co-existence considerations and the associated technical conditions and interference mitigation approaches that were implemented and the applicability in the Ireland context.

Plum Consulting
10 Fitzroy Square
London
W1T 5HP

T +44 20 7047 1919
E info@plumconsulting.co.uk

Contents

Executive Summary

This report for ComReg considers the compatibility and coexistence of incumbent aeronautical radar services in the 2700 – 2900 MHz (the 2.7 GHz band) with Mobile/Fixed Communications Networks (MFCN) services operating in the adjacent 2500 – 2690 MHz band (the 2.6 GHz band). This study focuses on experiences of France, Belgium and the UK and subsequently draws conclusions from these reports to present recommendations to ComReg for the Irish context.

The issue of adjacent band co-existence between mobile broadband in the 2.6 GHz band and aeronautical radars in the 2.7 GHz band, and how it could be facilitated, was considered in around the year 2010 in France, Belgium and the UK, as was well as in ECC (SE PT 21) and ITU-R (Working Party 5B). ECC Report 174[1], published in March 2012, addresses the compatibility between the mobile services in the 2.6 GHz band and the radionavigation and radiolocation services in the 2.7 GHz band, this report is described in Appendix B.

Studies in France, Belgium and the UK examined the implications of blocking, intermodulation and unwanted emissions (spurious emissions)[2] due to mobile broadband transmitters interfering with radar receivers. Measurements were also undertaken in Belgium and the UK to confirm the analysis.

To facilitate adjacent band co-existence, the administrations in France, Belgium and the UK have taken two measures:

- Implementation of additional filtering on the older radars that do not have the necessary receiver selectivity to minimise the impact of interference resulting in receiver blocking and intermodulation, and

- Setting radar protection thresholds in the form of power flux density limits.

In all three countries, implementation of additional filtering was used to improve the receiver selectivity at the radar receivers, based on worse case interference calculations between the mobile base stations and radar receivers. This approach minimises the risk of blocking and intermodulation and was achievable without impacting on the performance of the radars – for example, there was only a minimal insertion loss. The design of the filters was developed with the manufacturers and trialled to establish that they were effective in meeting the required radar operational parameters. Once the filter design was complete, they were fitted, and the full recalibration of the radars was undertaken.

In the case of minimising the impact of mobile base station transmitter unwanted emissions, an approach based on defining a power flux density (pfd) limit at the radar receiver location and antenna height was used. In France, a pfd limit of -155 dBW/m^2/MHz was adopted. This limit is based on a measured spurious emission threshold at the radar receiver which is then translated into an effective pfd limit by taking account of the radar antenna gain and the feeder loss between the radar antenna and receiver. The value of-155 dBW/m^2/MHz assumes that interference is through the radar receiver main lobe. Similarly, in Belgium, a pfd limit of -149 dBW/m^2/MHz was defined. This assumes that the interference entry is through the radar off-beam[3], therefore resulting in a 6 dB relaxed limit. In the UK, protection levels shown in the Table 1.1 were adopted.

[1] Compatibility between the mobile service in the band 2500 – 2690 MHz and the radiodetermination service in the band 2700 – 2900 MHz

[2] Blocking and intermodulation effects are the result of strong MFCN interfering signals overloading the radar receiver low noise amplifier and causing non-linearity, the lack of sufficient receiver selectivity is the key reason for this type of interference. The third type of interference relates to spurious emissions which are generated by MFCN transmitters and fall within the receiving band of the radars.

[3] The off-beam interference entry is an assumption based on geography of radar locations and potential MFCN heights in Belgium

Table 1.1: Radar protection levels adopted in the UK

	In-band communication signal		Communications out of band noise
	Pre-remediation	Post-remediation	Pre- and post-remediation
	Power flux density threshold for signals in the 2570-2690 MHz band (dBm/m^2) [1,2]	Power flux density threshold for signals in the 2570-2690 MHz band (dBm/m^2) [1,2]	Noise spectral power flux density threshold at 2720 MHz to 3100 MHz (dBm/MHz/m^2) [1,2]
Radar protection thresholds	$-74+10*\log_{10}(\frac{BW}{120})$	$5+10*\log_{10}(\frac{BW}{120})$	$-131+10*\log_{10}(\frac{BW}{120})$
Where: BW is the total 2.6 GHz bandwidth assigned to the licensee for downlink transmissions (combining both paired and unpaired spectrum) in the band 2570 – 2690 MHz Note [1]: The protection thresholds are defined at the peak of the main radar beam. Note [2]: The protection thresholds are defined during the 'on' period of the transmit signal.			

As can be seen the pfd limit for the spurious emissions in the UK is -161 dBW/m^2/MHz assuming a total downlink bandwidth of 120 MHz.

The difference in pfd levels specified for the three countries is mainly due to the fact that a range of radars are considered and the measured interference thresholds vary for each radar type. For example, in France the interference threshold level is -122 dBm/MHz as opposed to -128 dBm/MHz assumed to be used to derive the UK protection level.

The following table (Table 1.2) provides our main findings on the adjacent band co-existence between mobile broadband and radars.

Table 1.2: Key findings on approaches adopted internationally

	France	Belgium	UK
Key issue(s) identified	Blocking and LTE BS out-of-band emissions.	Blocking, intermodulation and spurious emissions from 4G networks at the radar receiver.	Base station interference including blocking effects and out-of-band emissions impacting 80 radars requiring large combined exclusion areas to provide protection to radars.
Proposed solution(s)	Blocking resolved by installing additional filters at radar receivers. LTE out-of-band emissions addressed by defining pfd limit of -155 dBW/m^2/MHz at the radar location within the radar antenna main lobe.	Blocking and intermodulation addressed by adding filters to radar receivers. Spurious emissions mitigated by defining a pfd limit of -149 dBW/m^2/MHz at the radar location.	Remediation programme adopted where radars were fitted with filters to prevent receiver blocking. Pre- and Post-remediation pfd limits defined at the radar location to limit blocking effects. Pfd limit is also defined to minimise the impact of out-of-band emissions from mobile networks. Pfd limit of -161 dBW/m^2/MHz (as shown in Table 1.1).
Implementation details	Radars were upgraded over an 18 month period with one exception (Charles de Gaulle) with 3 years upgrade period.	Radar filters were fitted over a 20 month period. Base stations are not permitted within 1 km[4] of the radar unless detailed coordination with the radar operator and BIPT is undertaken. Outside the 1km coordination zone, mobile network operators must ensure they meet the corresponding pfd limit.	Remediation programme was implemented where radars were fitted with filters. Indicative timeline from Ofcom 2009 information update[5] was for piloting 2010 – 2012/2013 and rollout of remediation 2011 – 2013 with possible extension to middle of 2014[6].

In summary, the commonly used approach in these benchmark countries for addressing co-existence requirements was to:

- Identify, through measurement studies[7], the protection levels at radar receivers necessary to address blocking and intermodulation and unwanted emissions from interfering transmitters;
- implement filtering requirements at radar receivers using the blocking and intermodulation protection levels identified; and

[4] Our understanding is that a 1 km coordination zone around radar receivers was in place before and after the radars were fitted with filters.
[5] "Coexistence of S Band radar systems and adjacent future services"
[6] In practice the 2.6 GHz auction was delayed so the timescales were less stringent.
[7] Measurement studies were undertaken in Belgium and the UK – it is our understading that France referred to measurement studies undertaken by others. This report uses measured threshold levels obtained from the Belgian measurement study.

- impose pfd limits, applicable at the radar location and antenna height, using the radar protection levels identified for unwanted emissions.

The filters that have been developed for the different radars, including those for the Thales STAR 2000, should be suitable for deployment in any country, including Ireland, where the radars are of an age that additional filtering is required.

The fact that the 2.6 GHz band is now being used for LTE in France, Belgium and the UK, and that the protection measures are already identified and successfully implemented, should considerably shorten any timescales and limit any uncertainty regarding the effectiveness of the measures. The approaches adopted by the identified benchmark countries in this report have enabled adjacent channel co-existence between radar services and MFCN base stations without any problems. In fact, in Belgium, the coordination requirements were recently reviewed based on the lack of any issues and it is understood that the UK may also reconsider the coordination requirement.

In the context of Ireland, the key scenario to consider is interference between MFCN base stations and Thales Star 2000 aeronautical radars deployed in Shannon, Cork and Dublin airports. By implementing filters developed for radar receivers by Thales as implemented in France, Belgium and the UK, the likelihood of interference due to blocking and intermodulation will be minimised, particularly at the Thales Star 2000 radars deployed in these three airports. In order to limit the impact of MFCN transmitter spurious emissions, a pfd threshold at the radar location can be defined.

Our recommendations based on the analysis in this report are summarised below.

- Irish radars should be fitted with filters as implemented in France, Belgium and the UK to address the impact of blocking and intermodulation.

- If MFCNs are deployed before radar filters are fitted, an in-band radiation limit is required in the frequency range of 2575-2690 MHz to address the impact of blocking and intermodulation effects at radar receivers in the adjacent band. This restriction should be applied in the form of a pfd limit of -83 dBW/m^2 at the radar receiver. This limit is derived as follows:

  – The representative Thales Star 2000 radar blocking and intermodulation threshold levels for an assumed 64-QAM interfering signal are -20 and -44 dBm, respectively[8]. The level of -44 dBm is more stringent than the level of -20 dBm. Therefore, this level can be used to define an appropriate pfd limit to accommodate blocking and intermodulation effects.

  – The interference entry is through the radar receiver main beam; hence the radar receiver antenna gain is 33.5 dBi, including feeder losses.

  – The corresponding pfd level[9] is -78 dBW/m^2. This level accommodates interference from all MFCN licensees.

  – If it is assumed that there are three licensees[10] the corresponding pfd limit to be complied by each operator is -83 dBW/m^2.

[8] These threshold values were measured in the Belgian measurement study.
[9] Pfd (dBW/m^2) = Interference threshold at radar receiver input (dBW) – Radar antenna gain (dBi) + 10 x log($4\pi/\lambda^2$) where λ is the wavelength in meters.
[10] If any other number is assumed for the potential licence holders the calculated total pfd value (-78 dBW/m^2) needs to be reduced by 10 x log (no of assumed operators)

Following the successful implementation of filters on the existing radars in Dublin, Shannon and Cork, this obligation will no longer be required to mitigate against blocking and intermodulation interference.

- Out-of-band spurious emissions from MFCN BS operating in 2500-2690 MHz require additional mitigation to protect radar services in 2700-2900 MHz band. A pfd limit of -145 dBW/m^2/MHz at the radar receiver antenna location addresses the impact of MFCN spurious emissions[11]. This limit is derived as follows:
  - The Thales Star 2000 radar spurious emission threshold level for an assumed 64-QAM interfering signal is -106 dBm/MHz (measured in the Belgian measurement study)[12].
  - The interference entry is through the radar receiver main beam; hence the radar receiver antenna gain is 33.5 dBi, including feeder losses.
  - The corresponding pfd level is -140 dBW/m^2/MHz. This level accommodates interference from all MFCN licensees.
  - If it is assumed that there are three licensees[13] the pfd limit to be complied by each operator is -145 dBW/m^2/MHz.
- Base stations within 1 km of the radar receiver must be coordinated with the radar operator on an individual basis[14]. Outside the 1 km coordination zone, each potential MFCN operator needs to verify the compliance with the above pfd limits.

[11] It should be noted the pfd limit is based on the measured threshold at the radar receiver and corresponds to the maximum allowed aggregate interference from each potential MFCN operator regardless of the choice of duplex configuration (e.g. TDD/FDD).
[12] This value can be verified through testing in Ireland. Also note that Belgian measurement study includes measured thresholds for other test signals. In this report, the threshold level measured for 64-QAM has been used as a representative interfering signal.
[13] If any other number is assumed for the potential licence holders the calculated total pfd value (-140 dBW/m^2) needs to be reduced by 10 x log (no of assumed operators)
[14] This approach has been adopted by the Belgian administrator to protect radar receivers from interference caused by base stations located nearby.

1 Introduction

This report for ComReg considers the approaches adopted in three benchmark countries to facilitate co-existence between aeronautical radar services in the 2700 – 2900 MHz (the 2.7 GHz band) and base stations for mobile broadband services operating in the 2500 – 2690 MHz band (the 2.6 GHz band)[15]. The benchmark countries identified for this report are France, Belgium and the UK all of which have implemented approaches to facilitate adjacent band co-existence between aeronautical radars in the 2.7 GHz band and mobile systems in the 2.6 GHz.

Chapter Two describes the compatibility and co-existence issues identified by France, Belgium and the UK and outlines the methods adopted by each of the benchmark countries to mitigate any compatibility issues with MFCN base stations in adjacent bands. In particular, it summarises publicly available information on the measures taken to minimise the potential of interference from mobile network transmitters into the radar receivers.

Chapter Three provides an overview of the Irish context with regards to potential compatibility and co-existence issues between radar services in the 2.7 GHz band and the deployment, in Ireland, of MFCN base stations operating in the adjacent 2.6 GHz band. Considering the approaches discussed in Chapter Two and relating to the Irish situation, this report provides preliminary conclusions and recommendations to ComReg in which successful mitigation can be achieved to facilitate co-existence between the incumbent radar services in Dublin, Cork and Shannon with potential deployment of MFCN base stations in adjacent bands.

[15] The ITU allocates the 2690-2700 MHz frequency range to earth exploration satellite (passive), radio astronomy and space research (passive). The protection of radio astronomy service (RAS) in the 2690-2700 MHz band is addressed in ITU Recommendation RA 769-2. This report does not consider usage in the 2690-2700 MHz band.

2 Approach adopted in benchmark countries to facilitate co-existence between radars and mobile systems

2.1 Introduction

The three benchmark countries identified for this report are France, Belgium and the UK. In the three benchmark countries it should be noted that the assumption was that the 2.6 GHz band will be used for LTE[16]. In Belgium the 2.6 GHz spectrum (FDD and TDD) was awarded in November 2011, in France FDD spectrum was awarded in September 2011 and in the UK FDD and TDD spectrum in February 2013. There were a number of countries that awarded 2.6 GHz TDD and FDD spectrum prior to the studies in the ECC, but no information is easily accessible on whether they implemented any technical measures to protect radars.

2.2 France

2.2.1 Introduction

Researching available online resources such as ANFR, ECC and ECO revealed limited publicly available information on the background to the approach adopted by France. The exception is an input paper to SE PT 21 and notes to COMSIS[17] regarding pfd values to protect radars from LTE base station transmissions.

2.2.2 Approach adopted to ensure protection of radar receivers

Information on the approach adopted in France to ensure protection of radars is provided in an input into the SE PT 21 for the August 2011 meeting[18]. The input document noted that, prior to the auction, it was decided that:

- Blocking should be solved through the addition of filters to the radars to improve the receiver selectivity, and
- Unwanted emissions should be solved by the LTE base station transmitters. It was decided that the pfd generated by the unwanted emissions of an LTE base station at a radar level should not exceed -155 dBW/m^2/MHz. The rationale for setting the pfd value at the radar location, rather than at the LTE base station, was "*to take into account the additional isolation provided by terrain (shielding + additional antenna discrimination) as well as buildings or other propagation effects such as multipath*". This was viewed as providing flexibility for the operator in terms of base station deployment.

Filters approach

The French radars operated by the Civil Aviation in the 2.7 GHz band were used for primary navigation and used near the following major airports: Toulouse-Blagnac, Nice, Orly, Roissy Paris Charles-de-Gaulle and

[16] Early UK studies assumed the use of UMTS and WiMAX.
[17] The COMSIS procedure is an inter-ministerial procedure to ensure compliance with EMC requirements. All base stations are subject to the COMSIS authorisation and, on the basis of files submitted by the operator, agreement or refusal for the site may be decided by the involved ministerial organisations.
[18] Doc SE21(11)047: National measures, related to the deployment of mobile base stations, for the protection of radars.

Strasbourg. The radar upgrade dates for fitting filters to mitigate the impact of blocking were between January 2013 and July 2014 with an exception for Charles-de-Gaulle which was from April 2012 until 2015.

PFD approach

It was decided to adopt a similar approach to that adopted with respect to UMTS base stations operating in the 2 GHz band with respect to the same civil radars. That approach defines the level of unwanted radiation at the radar level and provides the mobile network operators (MNO) with flexibility in deploying base stations taking into account the terrain, orientation of base station with the radar and any other appropriate parameters.

The procedure defined in the note to COMSIS[19] required the MNO to calculate the power flux density level (due to out-of-band emissions from the base station) in front of the radar antenna. This could be done using available planning tools[20] and taking into account, as appropriate, terrain, obstructions etc.

The pfd threshold proposed in the main lobe of the radar was:

Pfd=I-G+30.1+LF, where

'I' is the permissible interference level (-122 dBm/MHz or -153 dBW/MHz)

'G' is the maximum antenna gain (34 dBi)

'LF' is the feeder loss (1 dB).

The outcome was a pfd threshold level of -155 dBW/m²/ MHz which was found to be sufficient to mitigate the impact of out-of-band emissions. MNOs have to commit that out-of-band emissions from base stations would not exceed this limit in the main lobe of the radar. This approach has been effective and has not required any modification.

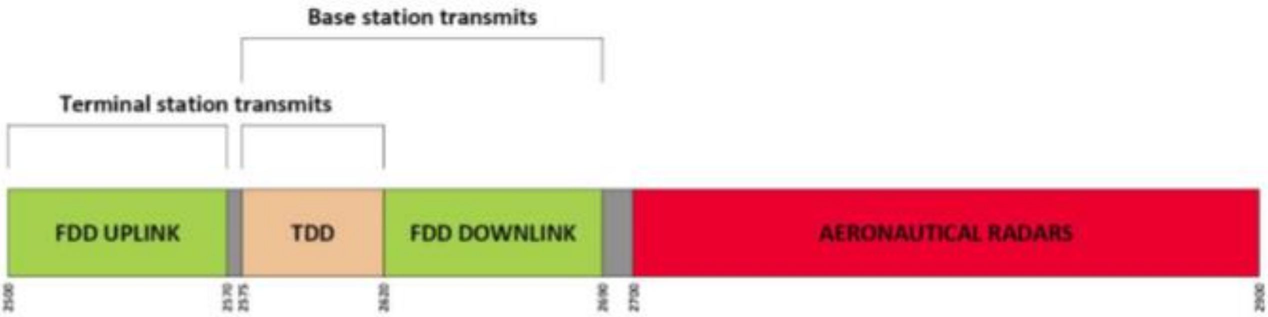
2.3 Belgium

2.3.1 Introduction

In Belgium the use of the radio spectrum between 2500 and 2900 MHz is shown in Figure 2.1. In the following sections information is provided on the interference to radars caused by 4G networks, a measurement study undertaken by Intersoft Electronics and the solutions implemented in Belgium to protect the radars. This is based on documents available in the public domain including the Decisions of the Belgian Institute for Postal services and Telecommunications (BIPT) Council in October 2011[21] and September 2017[22] addressing "the coexistence between 4G operators in the 2500 – 2690 MHz band and radars in the 2700 – 2900 MHz band" as well as the Intersoft Electronics measurement report.

[19] https://www.anfr.fr/fileadmin/mediatheque/documents/etudes/Procedure_intermediaire_version_avril_2012.pdf
[20] The mobile operator could choose the propagation model they used for the calculations.
[21] https://www.bipt.be/en/operators/radio/rights-of-use/terminated-allocation-procedures/2-6-ghz-band/decision-of-the-bipt-council-on-the-coexistence-between-4g-operators-in-the-2500-2690-mhz-band-and-radars-in-the-2700-2900-mhz-band
[22] https://www.bipt.be/en/operators/radio/rights-of-use/decision-of-the-bipt-council-of-11-september-2017-on-the-coexistence-between-4g-operators-in-the-2500-2690-mhz-band-and-radars-in-the-2700-2900-mhz-band

Figure 2.1: Use of 2500 to 2900 MHz spectrum in Belgium (Source: BIPT Council Decision 3 October 2011)



The 2690 – 2700 MHz band is not used in Belgium and was considered as a guard band between the 4G operators and the aeronautical radars.

There were ten radars that required protection from adjacent channel interference, specifically:

- TA10 radars located at Beauvechain, Charleroi, Florennes, Kleine Brogel and Ostend.
- STAR2000 radars at Florennes, Liege, Ostend and Zaventem.
- ASR9 radar at Zaventum.

2.3.2 Co-existence considerations

The BIPT considered both the interference caused by 4G networks (MFCN base stations) in radars as well as interference caused by radars in 4G networks. This report for ComReg focuses on the former type of interference (4G networks into radars) for which BIPT identified two types of interference:

- Spurious emissions from the 4G equipment that could be generated by a single station or intermodulation products by co-located stations and falling within the receiving band of the aeronautical radars, and
- Blocking and intermodulation at the radar receiver which can appear as an overload of the Low Noise Amplifier (LNA) or a third order intermodulation product in the band. The lack of selectivity of the radar receivers is the main cause of this type of interference.

It is noted in the BIPT Decision of October 2011 that for spurious emissions, whilst they can be caused by both base stations and user terminals, it is not possible to impose restrictions on the latter when considering free movement with the European Union and also they are likely to be less of an issue because of[23]:

- The much higher propagation loss;
- The greater frequency separation, and
- The much weaker radiated power level.

[23] Also applicable to Ireland.

The conclusion was that the impact of spurious emissions from the MFCN base station transmitters could be minimised by imposing pfd limits[24].

In the case of interference caused by blocking and intermodulation it is noted by BIPT that base stations are the main concern, for the same reasons noted above, and this type of interference can be solved by:

- Adding filters to the radars to improve selectivity, and
- Changing that radar's frequency to enhance frequency separation[25].

2.3.3 Measurement study

In Belgium a measurement study of the performance degradation of air surveillance radars due to interference of 4G technologies was undertaken, on behalf of BIPT, by Intersoft Electronics in 2011[26]. The study examined three different interference mechanisms:

- Blocking of the radar's broadband receivers,
- Effect of spurious emissions from LTE base stations and user equipment on the noise floor, and
- Intermodulation products in the radar receiver.

The effects of blocking and spurious emissions were tested on all types of S-band radars (TA-10, ASR-9 and STAR2000) and the results were consistent with the findings of other studies such as those undertaken in France and the UK. The test report summarises the measurement results obtained for TA-10, ASR-9 and STAR 2000 radars operating in Belgian airports.

It is noted that tests were conducted using both continuous wave (CW) and broadband (e.g. 64-QAM) signals[27]. In the measurements, the probability of target detection (Pd) of 60% was identified as the point where the radar receiver had a high sensitivity and performance degradation could be observed. For example, inserting 0.5 dB extra loss resulted in Pd decreasing from 60% to 35% which confirmed that the test set-up could capture a degradation in the target detection. The interference power level resulting in the degradation was recorded as the interference threshold.

Table 2.1 below shows representative interference threshold levels measured at the STAR2000.

[24] BIPT note that interference due to Spurious Emissions could be solved by adding filters at the level of the basis stations which the interference originates from.

[25] The greater the frequency separation the greater the roll-off of the radar selectivity. This will vary by radar. Of course, any improvement in radar selectivity will make the interference problem easier to solve and thereby make it easier to develop filters. It is unlikely that increased frequency separation will solve the problem on its own especially noting that filters have been fitted in the radars in all three benchmark countries.

[26] https://www.bipt.be/en/operators/radio/rights-of-use/terminated-allocation-procedures/study-of-the-performance-degradation-of-the-belgian-s-band-air-surveillance-radars-due-to-the-interference-of-upcoming-4g-technologies

[27] The 64-QAMtest signals were injected in front of the LNA and extracted behind the ploy extractor. This allowed the whole receiver chain to be included in the measurements. For more details see the Test Report from Intersoft Electronics.

Table 2.1: Representative Interference Threshold Levels for STAR 2000 Radars (Ref: Belgian Test Report from Intersoft Electronics)

Parameter	Threshold for STAR2000
Blocking (based on tests with an interfering 64-QAM signal)	-20 dBm
Intermodulation (based on tests with two interfering 64-QAM signals)	-44 dBm
Spurious Emissions (based on tests with an interfering 64-QAM signal)	-106 dBm/MHz

The additional isolation requirements necessary to meet the above required levels is calculated in the test report assuming a separation of 1 km[28] between a base station and the radar equating to a path loss of 101 dB.

The report noted that for LTE to co-exist with S-band radars mitigation measures could be taken at three different levels in order to obtain the required additional isolation:

- Addition of filtering at the radar to protect against LTE signals causing Intermodulation in the radar receiver chain and Blocking.
- Filtering at the LTE base stations to supress LTE out-of-band emissions.
- Separation distance of UE and radar to avoid user equipment coming close to the radars.

2.3.4 Coordination approach

BIPT issued a draft decision on the coexistence between 4G operators in the 2.6 GHz band[29] and radars in the 2.7 GHz band in July 2011 followed by the final decision in October 2011[30]. To protect all types of radars it was decided that a pfd limit of -149 dBW/m²/MHz should be adopted to limit the level of spurious emissions[31]. The problems of blocking and intermodulation were to be addressed in two ways, by:

- Adding filters to the radar receivers, and
- Changing the radar's frequency to increase frequency separation.

[28] The 1 km protection perimeter is considered to be practical and feasible as any closer will require extremely high additional solation. Other reasons quoted in the report (Annex 7) include:
- Height of any constructions is limited on and close to airports;
- Protection perimeters are already in place at airports;
- Health and safety limits for working close to radars;
- Interference from radars into 4G;
- BS filter requirements extremely difficult to meet closer to the radar; and
- Compliance of BS station with the EMC Directive.

[29] It is assumed that 2500 – 2570 MHz (uplink) is paired with 2620 – 2690 MHz (downlink), the 2575 – 2620 MHz is TDD and 2690 – 2700 MHz is allocated to radio astronomy but was not used in Belgium.

[30] www.bipt.be/public/files/nl/436/3602_nl_decision_radar_nl.pdf

[31] Based on the measured / agreed absolute protection level at the radar receiver which is translated into a pfd level by taking account of radar antenna gain and feeder loss as described in the section addressing the French pfd limit.

The modifications were to be made "*at the level of the aeronautical radars in order for the emissions in the 2575-2690 MHz band coming from 4G base stations situated at one km at least from the radar; not to affect the radar's operation*". The 1 km distance is based on the base station having line of sight to the radar and transmitting at maximum allowed power towards the radar. No base stations can be deployed within one km of a radar unless detailed coordination has been undertaken. All base stations had to be notified to BIPT, except those situated inside buildings at more than 2.5 km from all radars, before it was taken into use.

BIPT also noted in the decision that until 1 July 2013[32] the 4G operators had to limit the power level from their base stations in the upper band (2575-2690 MHz) to minimise total radiation into each radar before the filters were fitted. Also, to protect the 4G operators there should be a requirement for the aeronautical radars to meet the spurious emission requirements in international standards for the 2.6 GHz band[33] of -30 dBm/MHz or 100 dB attenuation peak envelope power supplied to the antenna's transmission line. It was noted that a *"period of adaption (until July 2013) was necessary to allow Belgocontrol and the Ministry of Defence to make the necessary modifications to their aeronautical radars*".

2.3.5 Updated coordination approach

An updated Decision was published on 11 September 2017 that replaced the Decision from 2011. In regards protection of the radars, it notes that the 2011 Decision imposed a pfd limit of -149 dBW/m²/MHz (spectral power density at the different radars). In the 2017 Decision, this has not been changed. However, it is noted that the risk of exceeding this value was much less than estimated in 2011 presumably this is because the measured levels of unwanted emissions are less than those assumed. In regards blocking and intermodulation, the 2017 Decision notes that the period for modification of radars had expired so the additional restrictions in terms of coordination are no longer required. Base stations less than 1 km away are always subject to coordination on a case by case basis.

The 2011 Decision required notification to BIPT for all 4G base stations, with the exception of stations located within a building, more than 2.5 km from all radars and whose maximum EIRP is less than 30 dBm. The aim was to be able to verify that conditions were respected. However, this led to a heavy workload for BIPT and operators and could cause delays in network deployment. It is now considered that this approach provides very limited added value so base stations more than 1 km away should no longer be notified.

2.4 UK

2.4.1 Introduction

Ofcom undertook a number of studies and published updates, regarding coexistence of 2.7 GHz (S band) radars and adjacent future services (mobile systems) over the period 2008 until the publication of the Information Memorandum for the award of the spectrum in the 800 MHz and 2.6 GHz bands in November 2012[34].

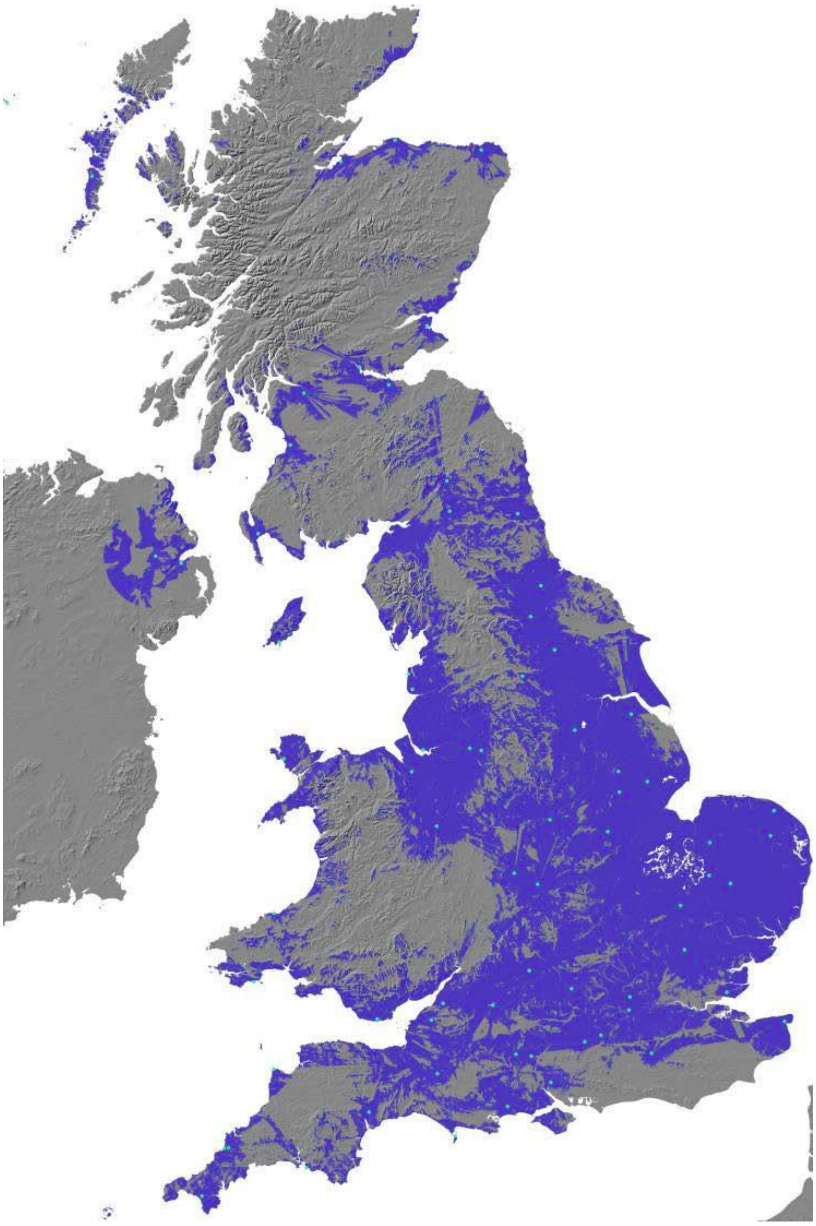
In 2010 there were around 80 S-band ATC radars operating within the British Isles consisting of 42 civil radars in the UK and 3 in the Channel Islands and Isle of Man, together with 35 military ATC radars. These were made up of around ten different radar types and their derivatives. Over half of the S band ATC radars in the UK were

[32] This date was set out in the BIPT decision to complete necessary adaptions to radar equipment.
[33] Specifically, CEPT Recommendation REC 74/01 and ITU Recommendation ITU-R SM.329.
[34] https://www.ofcom.org.uk/spectrum/spectrum-management/spectrum-awards/awards-archive/800mhz-2.6ghz

Watchman radars and without any mitigation measures it would be necessary to have geographic separation of some 10's of kilometres between the radars and the 2.6 GHz base stations. There was a single STAR2000 radar.

Ofcom undertook modelling[35] of the potential combined effect of imposing geographic restrictions on the 2.6 GHz band. Figure 2.2 below illustrates the estimated coordination area required between MFCN base stations and radars which covers 43% of the total land mass.

Figure 2.2: Estimated coordination area around ATC radar for 2.6 GHz base stations with 61 dBm eirp and 30m antenna height (not including air defence radars) (Source: Ofcom)



[35] This included four land-based maritime radars. The safety parameters used were agreed with the Steering Group consisting of CAA, MOD and MCA.

2.4.2 Co-existence considerations

To determine the necessary co-existence requirements for the large number of different radars Ofcom classified the radars into two categories (A and B) with the Star 2000 being categorised as type B. Based on inputs from the Civil Aviation Authority (CAA) the protection levels for Category B radars were estimated "*based on the assumption that the maximum adjacent power input to the radar receiver (prior to the onset of unacceptable degradation) is -27 dBm*" and the protection level is between 3 to 7 dB below the input levels for a 1 dB LNA output compression. Ofcom then derived indicative potential coordination thresholds (maximum field strength incident at a radar antenna) and for mobile applications for radar category B the value was tentatively given as 82 dB(μV/m) as described in Annex 2 to the information document[36]. The coordination threshold levels for ATC radars to be applied during the transitional period, agreed within the radar working group[37], were provided for the two radar categories although it was noted that they were still to be finalised based on other studies. Specifically, Table A2.3 "*derived the radar protection levels in terms of the maximum field strength incident at the radar antenna based on the maximum receive signal power at the radar receive*", see below:

	Radar Category A	Radar Category B	
Maximum adjacent channel receive power at radar receiver input	-41	-27	dBm
Feeder loss	2	2	dB
Pre LNA filter loss @ 2690 MHz	0	0	dB
Antenna gain to horizon (wrt Omni)	28	28	dBi
Antenna cross-polarisation factor	3	3	dB
Multiple interference allowance	6	6	dB
Antenna pattern and antenna siting variation	2	2	dB
Additional margin (apportionment of interference)	6	6	dB
Maximum power at radar face	-78	-64	dBm
Maximum field strength incident at a radar antenna during the application of interim coordination arrangements	68	82	dB(μV/m)

Indicative separation distances for Category B radars to avoid interference from adjacent transmissions were in the order of tens of kilometres[38].

Annex 2 of the information document also provides the agreed propagation modelling parameters to be used for interim coordination arrangements as shown below:

	Modelling parameters
Propagation model	Rec. P. 452-12 or later
Propagation modelling interference time percentage setting	0.10%
Propagation modelling short term enhancements selected	Clear air effects: Multipath & Focusing Effects, Tropospheric Scatter and Ducting / Layer Reflection

[36] Information update from Ofcom on "Coexistence of S Band radar systems and adjacent future services", December 2009.
[37] CAA, MOD and Ofcom
[38] In the case of Category A radars, separation distances were well beyond the horizon.

	Modelling parameters
Other modelling requirements	Use of 50m terrain database with coverage limited 200 km of adjacent radar

2.4.3 Measurement study

The UK submitted a paper into ITU-R Working Party 5B in November 2009 on radar adjacent band selectivity[39] which provided a first set of results from an investigative study on the potential for interference to ATC radar receivers from use in the 2.6 GHz band. The *"objective of the study was to provide an indication of the maximum level of transmissions that a radar could tolerate at its receiver in terms of: the out-of-band interference into the radar IF pass band; blocking performance due to the effects of amplifier saturation within the radar receiver pass-band; and adjacent channel selectivity from receiving adjacent channel power due to imperfect radar receiver filtering characteristics*".

There were two different sets of measurements undertaken using four types of signals (CW, AWGN[40] and test WiMAX / UMTS signals). In the first approach the interfering signals were injected into the radar and the "*interference level required to reduce the probability of detection (Pd) from an initial level that is varied relative to the Reference Signal to 50% allowing for measurement tolerances*", measured. *"The wanted return signal level was then adjusted to simulate various probabilities of detection in the absence of interference*". Good correlation between theory and the results were obtained from these studies.

In the flight trials, the signals were injected using a horn antenna mounted on a pump-up mast at a range of 350 metres from the main beam of the radar antenna, so it had direct line of sight with the radar. The impact on the test radar was assessed using a flight calibration aircraft which undertook a number of flight runs and seeing when it disappeared from the radar screen. A total of 18 runs were undertaken using various interference waveforms and at various signal levels and the probability of detection over a specified range.

The next step was to develop a theoretical model for the test radar and predict the impact of adjacent band signals. This would allow the feasibility of modifying the radar receiver to be investigated. As a result of the mathematical modelling possible modifications to the radar receiver were identified that "*theoretically met the adjacent band performance requirement without compromising the operational performance of the radar*". It should be noted that the design of the filter was based on worst case requirements and was based on every slot in the mobile system being loaded and the maximum number of antennas installed on a mast.

A second phase of flight trials were undertaken to test the effectiveness of the proposed mitigation modifications, but the results were not conclusive.

There was a further trial undertaken to ensure that the receiver modifications did not affect the performance of the radars – in particular the Moving Target Indicator in the absence of 2.6 GHz transmissions.

2.4.4 Coordination approach

The information document from December 2008 proposed a coordinated approach. The Notice of coordination procedures required for 2.6 GHz licensees was published by Ofcom on 1 March 2013[41]. This Notice specifies the protection thresholds and coordination procedure necessary to ensure the protection of existing radars

[39] https://www.itu.int/md/R07-WP5B-C-0389/en
[40] Additive Gaussian White Noise
[41] https://www.ofcom.org.uk/__data/assets/pdf_file/0026/56951/final_radar_coordination.pdf

operating in the 2.7 GHz bands from potential harmful interference from the deployment of networks in the 2.6 GHz band.

In Section 4 of the notice, radar protection thresholds are provided (also shown in Table 2.2 below). In the case of in-band signal thresholds there is one for pre-remediation and another for post-remediation. A protected radar list was also provided which would be updated to show where remediation had been completed. By 2nd October 2017, all the radar sites had been remediated.

It is the responsibility of the 2.6 GHz licensee to assess whether it meets the protection thresholds based on specified modelling parameters and radar antenna pattern detailed in the coordination procedure. The procedure also specifies the relevant propagation models to be used:

- For 2.6 GHz deployments further than 1.5 km from the Protected Radar, ITU-R P.452-14 with the parameters given in Annex 1.
- For 2.6 GHz deployments at or within 1.5 km from the Protected Radar, ITU-R P.525-2 (Free Space Path Loss) + 6 dB additional margin1.

The protection thresholds cannot be exceeded in any pointing direction based on the antenna gain patterns provided in Annex 2 of the coordination procedure.

Table 2.2: Radar protection thresholds

	In-band communication signal		**Communications out of band noise**
	Pre-remediation	**Post-remediation**	**Pre- and post-remediation**
	Power flux density threshold for signals in the 2570-2690 MHz band (dBm/m^2) [1,2]	**Power flux density threshold for signals in the 2570-2690 MHz band (dBm/m^2)** [1,2]	**Noise spectral power flux density threshold at 2720 MHz to 3100 MHz ($dBm/MHz/m^2$)** [1,2]
Radar protection thresholds	$-74+10*\log_{10}(\frac{BW}{120})$	$5+10*\log_{10}(\frac{BW}{120})$	$-131+10*\log_{10}(\frac{BW}{120})$
Where: BW is the total 2.6 GHz bandwidth assigned to the licensee for downlink transmissions (combining both paired and unpaired spectrum) in the band 2570 – 2690 MHz Note [1]: The protection thresholds are defined at the peak of the main radar beam. Note [2]: The protection thresholds are defined during the 'on' period of the transmit signal.			

As can be seen the pfd limit for the spurious emissions in the UK is -161 $dBW/m^2/MHz$ assuming a total downlink bandwidth of 120 MHz.

2.4.5 Airport deployment study

A report, by Real Wireless for Ofcom[42], was issued in July 2011 that considered airport deployment. The study considered the likelihood of interference, after radar remediation, in a practical deployment, based on Heathrow airport, of base stations and mobile stations operating in a mix of indoor and outdoor environments. The analysis was based on simulations and assumed a generic radar with improved selectivity[43]. Two interference conditions were considered – challenging case[44] where the radar towers were low and base station transmitter powers high and typical case to cover realistic deployments.

The challenging case consisted of 13 base stations at distances ranging between 50m and 1674m and mobile stations density consistent with that found at airports. Spurious emissions were assumed to meet relevant specifications and mobile handsets were transmitting at full power. Whereas the typical case, whilst it also consisted of 13 base stations at distances between 50m and 1674m and same density of mobile stations, assumed significantly lower spurious emission levels than specified in the specifications based on measurements and inputs from vendors[45]. It was also assumed the mobile stations would be power controlled. Also, a measured case was undertaken based on emissions in the S-band from an LTE FDD mobile device to model the impact of spurious emissions co-channel with the radar receiver.

The findings of the study were summarised in a table in the Real Wireless report which is shown below:

	Challenging Case	Typical Case
Base Station	*Impact:* Blocking occurs and I/N threshold is exceeded *Mitigation:* • Careful planning of antenna orientation • Upgrade installation to power control the base station when in the radar main beam • Adhere to a significantly improved spurious emission mask (24 dB improvement suggested over current limits) • Apply a coordination zone *Suggested coordination zones:* • Base stations may be deployed outdoors at distances greater than 660m from the radar if combined with the other suggested mitigation options listed above. This increases to 1 km if no extra mitigation action is taken. • Indoor base stations may be deployed at distances greater than 120m from the radar if the suggested reduction in spurious emissions is also applied.	*Impact:* Blocking levels not exceeded. I/N threshold marginally exceeded but only for 1% of the time the radar points in the direction of the highest interference source. *Mitigation:* Careful planning of mast height and antenna orientation at base station deployment.

[42] Airport Deployment Study Ref MC/045
[43] This was a typical ATC radar receiver design modified to the new improved front end selectivity levels specified by Ofcom
[44] Represented the more difficult deployment cases.
[45] It was found that mobile devices have reduced spurious emissions of a round 50 dB below the specification limits in the radar band. The typical case assumed a margin 20 dB below the specification limit into the radar band.

	Challenging Case	Typical Case
Mobile Equipment	*Impact:* Blocking occurs and I/N threshold is exceeded *Mitigation:* • Adhere to a significantly improved spurious emission mask (26 dB improvement suggested over current limits) • Apply a coordination zone *Suggested coordination zones:* • Mobile stations may be deployed outdoors at distances greater than 300m from the radar if combined with the other suggested mitigation options listed above. • Mobile stations may be deployed indoors at distances greater than 70m from the radar if the suggested reduction in spurious emissions is also applied.	*Impact:* Blocking levels not exceeded. I/N threshold marginally exceeded but only for 1% of the time the radar points in the direction of the highest interference source. *Mitigation:* Ensure good quality handsets with low spurious emissions as interference is already close to an acceptable level.

The report also provides proposals for base station interference mitigation techniques, comments on the likely impact (e.g. reduced coverage or availability) and provides an estimate of the cost of implementing such mitigation techniques on the cost of 2.6 GHz deployment.

3 Irish Context

3.1 Introduction

The feasibility of adjacent band co-existence between mobile systems[46] and radars has been analysed in the context of Ireland. The details of the assumptions made for the analysis in this report are provided in Appendix A.

In Ireland, there are currently four primary aeronautical radars operating in 2.7 GHz band located in Shannon, Cork and two in Dublin. From our discussions in meeting with the IAA[47], it is understood that one of the two radars located in Dublin uses an older model Thales TA 10M TD radar. This radar is currently being decommissioned and replaced with a radar which includes the appropriate filtering to mitigate issues identified in this report. Therefore, this report considers the remaining three radars, the Thales Star 2000, used in Shannon, Cork and Dublin and assumes that the Thales TA 10M TD radar will not be in operation when MFCNs are deployed.

Based on the outcome of the studies in France, Belgium and the UK, discussed in Chapter 2, the key interference areas to consider in an Irish context are blocking, intermodulation and spurious emissions. Blocking and intermodulation effects are the result of strong MFCN interfering signals overloading the radar receiver low noise amplifier and causing non-linearity, the lack of sufficient receiver selectivity is the key reason for this type of interference. The third type of interference relates to spurious emissions which are generated by MFCN transmitters and fall within the receiving band of the radars.

The implications of blocking, intermodulation and spurious emissions are examined in the following sections.

3.2 Analysis Method

The analysis in this report is based on the use of blocking, intermodulation and spurious emission protection levels measured in the Belgian study for the Thales Star 2000 radar type, which is assumed to be the same as those currently deployed at Shannon, Cork and Dublin. The aim of the analysis is to determine geographic areas surrounding aeronautical radar receiver locations where the deployment of MFCN base stations would not be feasible without exceeding the threshold levels measured in the Belgian study for spurious, blocking and intermodulation interference mechanisms, respectively.

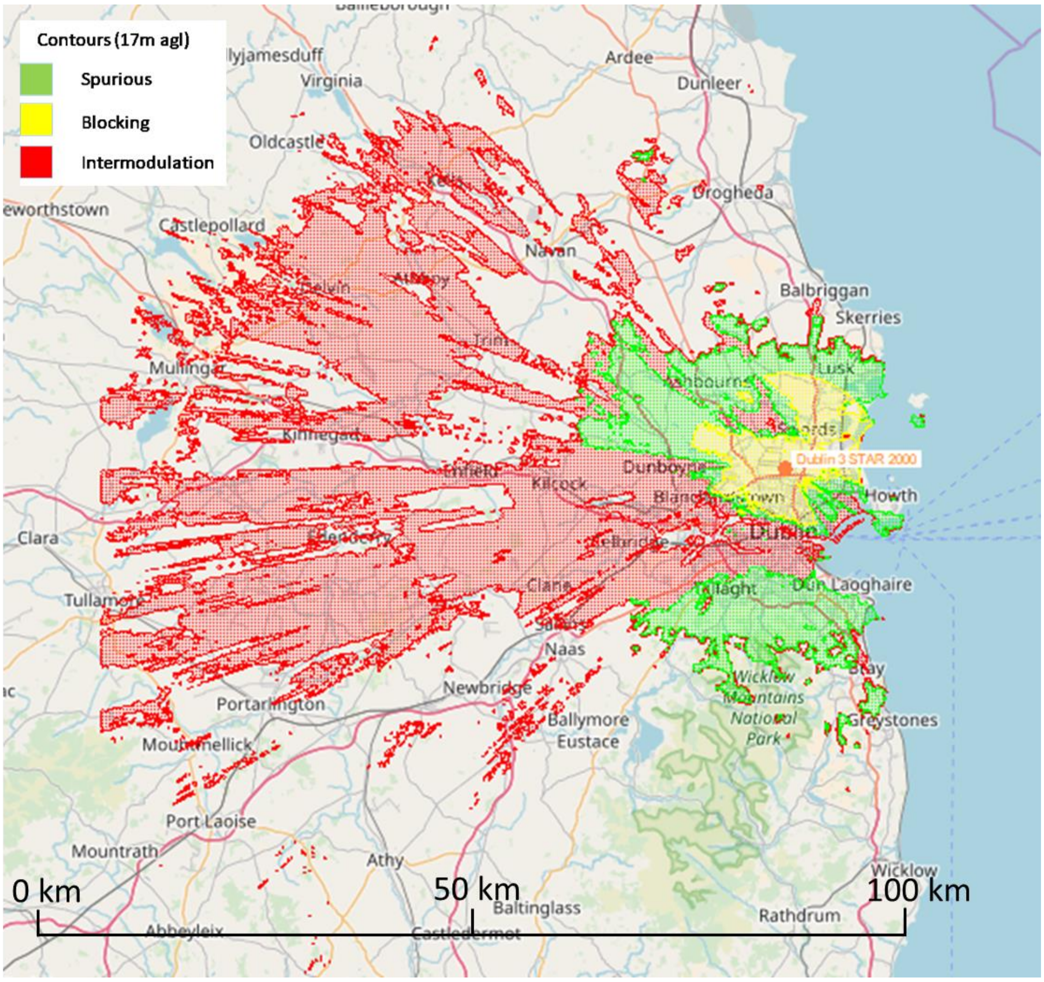
3.3 Results

Plots presented in this section show the interference contours (i.e. the potential interference areas) calculated for the three Irish radar sites. The contours shown in green, yellow and red illustrate interference areas where the operation of an MFCN base station would not be feasible without exceeding the threshold levels measured in the Belgian study for spurious, blocking and intermodulation interference mechanisms, respectively. Assumed parameter values are provided in Appendix A.

The following plot shows interference contours for the radar at the Dublin airport.

[46] ECC Report 174 concludes that Mobile Terminals would not be an issue, therefore only mobile base stations have been considered. See Appendix B which contains a summary of ECC Report 174.
[47] ComReg and Plum met with the IAA on 25 September 2018 in the IAA offices in Shannon.

Figure 3.1: Interference contours for the Dublin airport radar with no mitigation in place (0.1% time)[48]



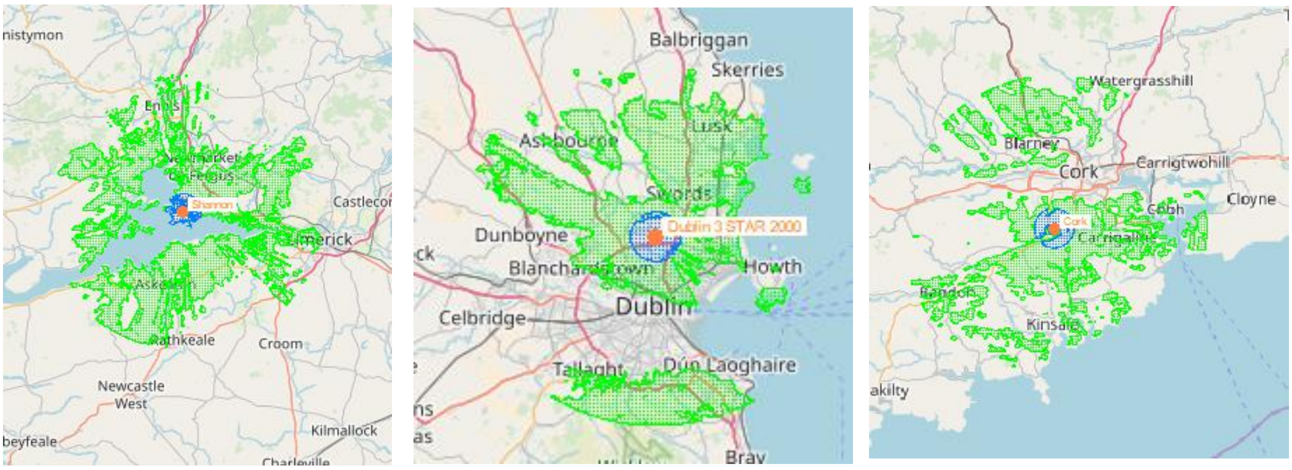
As can be seen, MFCN base stations could not be deployed within distances of up to approximately 80 km from the radar location without exceeding the intermodulation threshold. Similarly, MFCN base stations could not be deployed within up to approximately 15 km from the radar location to satisfy the blocking threshold. These distances could be reduced to the assumed 1 km coordination distance with the use of filters at the radar receiver as demonstrated in the Belgium study.

In order to meet the spurious emission threshold, MFCN base stations should not be deployed within distances up to approximately 30 km from the radar locations. However, the interference contours shown for spurious emissions assume that, in the worst case, the MFCN base station antenna gain is 18 dBi and this gain is maintained throughout both MFCN and radar bands. In practice, the gain is likely to fall to a lower value outside the MFCN operating band[49]. A plausible assumption is that the gain might reduce to about 0 dBi within the radar receive band. This would imply that interference contours will reduce significantly at all three sites as shown below in Figure 3.2.

[48] Input document 4-5-6-7/423 into ITU-R Task Group 4-5-6-7 (10 February 2014) addressing WRC-15 states that radar interference levels should not be exceeded more than 0.1% of time and should be used in propagation models.

[49] We have however been unable to find any specifications or measurements relating to the out of band performance of MFCN antennas

Figure 3.2: Interference contours for spurious emissions with assumed MFCN antenna gain of 18 dBi (green contour) and 0 dBi (blue contour) in the radar receiver operating band



The three Plots above (Figure 3.2) show that if more realistic base station gain values are considered within the radar receiver bandwidth, distances required to protect the radar receivers are in the order of a few kilometres.

The associated impact on population[50] (per person) coverage relating to the potential spurious emission interference for 18 dBi gain and 0 dBi gain are captured in Table 3.1 below which suggests that in a more practical scenario, the impact of spurious emission on radar receivers would be limited to a smaller area (i.e. the blue contour).

Table 3.1: Populations for different BTS antenna assumptions (spurious case)

	Dublin	Cork	Shannon	Total
Spurious (18dBi antenna)	423,635 (426,321)	113,454 (113,937)	98,594 (98,741)	635,683 (639,313)
Spurious (0dBi antenna)	21,142 (21,256)	1,803 (1,809)	1,955 (1,958)	24,900 (25,023)

The required separation distances for radars at Shannon and Cork airports are shown in the following figures:

[50] Population based on 2011 census data and values in brackets based on 2016 census data changes estimation.

Figure 3.3: Interference contours for the Shannon airport radar with no mitigation in place (0.1% time)

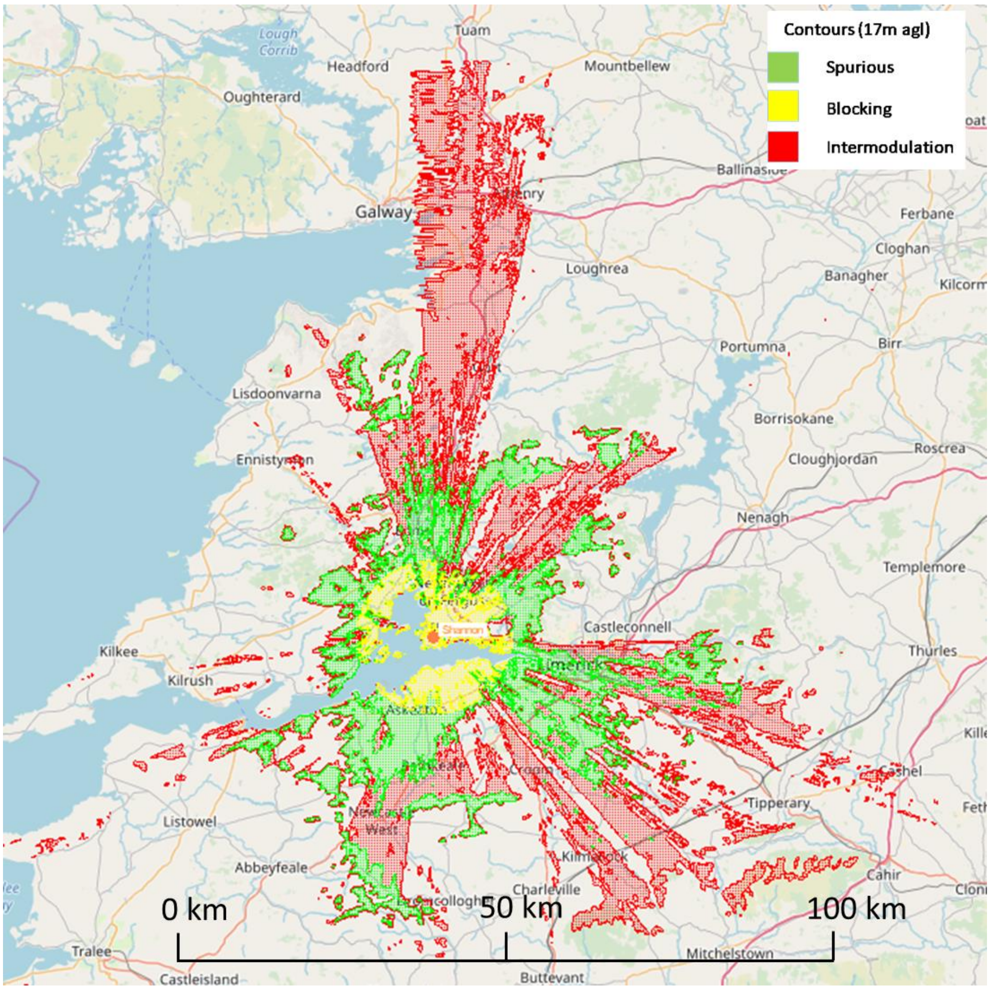
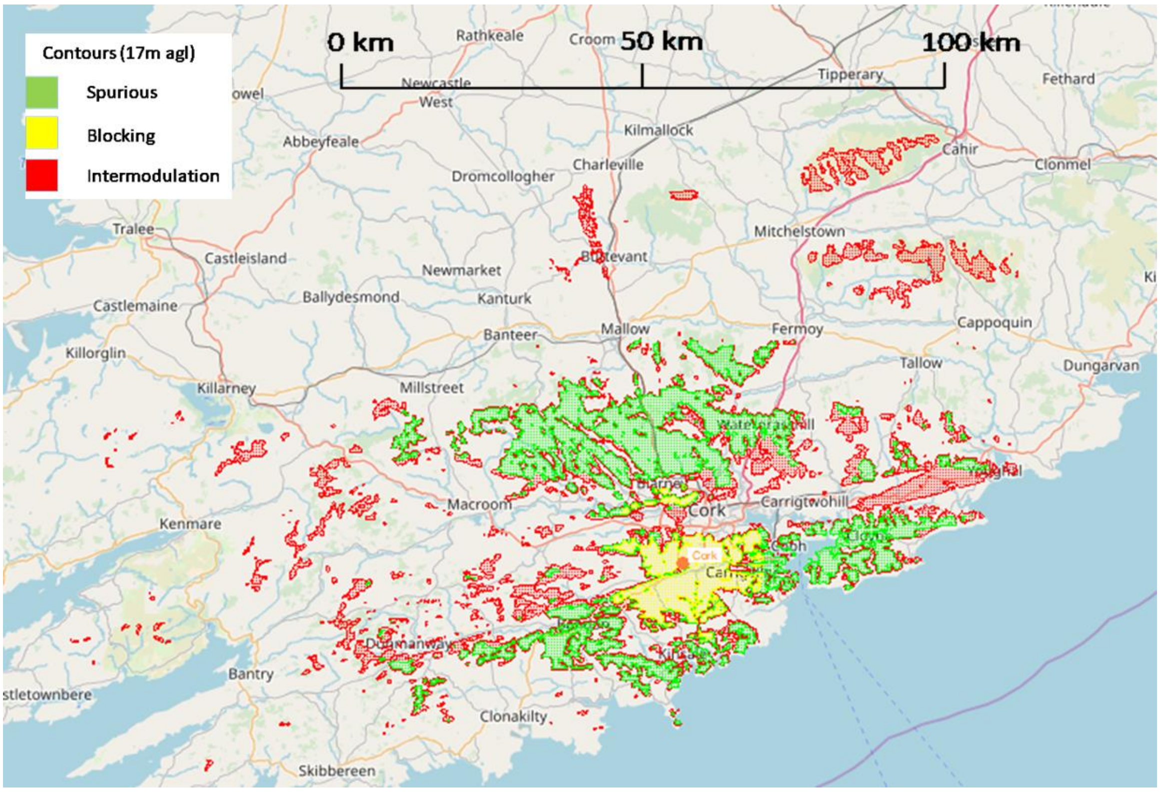


Figure 3.4: Interference contours for the Cork airport radar with no mitigation in place (0.1% time)



The populations[51] (number of persons) falling within the potential interference areas are tabulated below.

Table 3.2: Populations within interference contours

	Dublin	Cork	Shannon	Total
Intermodulation (Note 1)	926,976 (932,853)	120,581 (121,093)	256,318 (256,702)	1,303,875 (1,310,648)
Spurious	423,635 (426,635)	113,454 (113,937)	98,594 (98,741)	635,683 (639,313)
Blocking	136,715 (137,582)	49,157 (49,366)	13,489 (13,509)	199,361 (200,457)

Note 1: The total population impacted by intermodulation, spurious and blocking effects is the same as the intermodulation value.

The maps below show the joint impact of the interference thresholds for all three sites for each mechanism in turn.

[51] Population data is from the 2011 Irish Census, via the Gridded Population of the World (GPWv4). Figures in brackets are based on 2016 Irish Census data by applicable constituency within the geographic areas covered by the interference contours and an estimation of the population increase from 2011.

Figure 3.5: Interference contours for the intermodulation mechanism with no mitigation in place i.e. no filters (0.1% time)

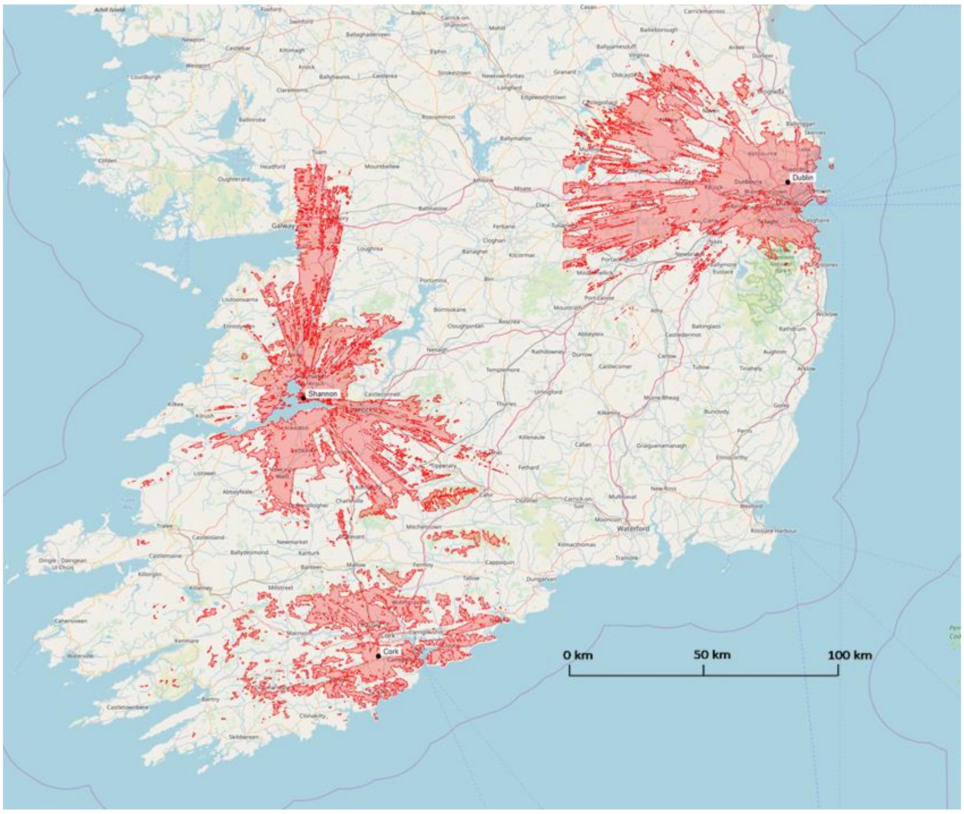
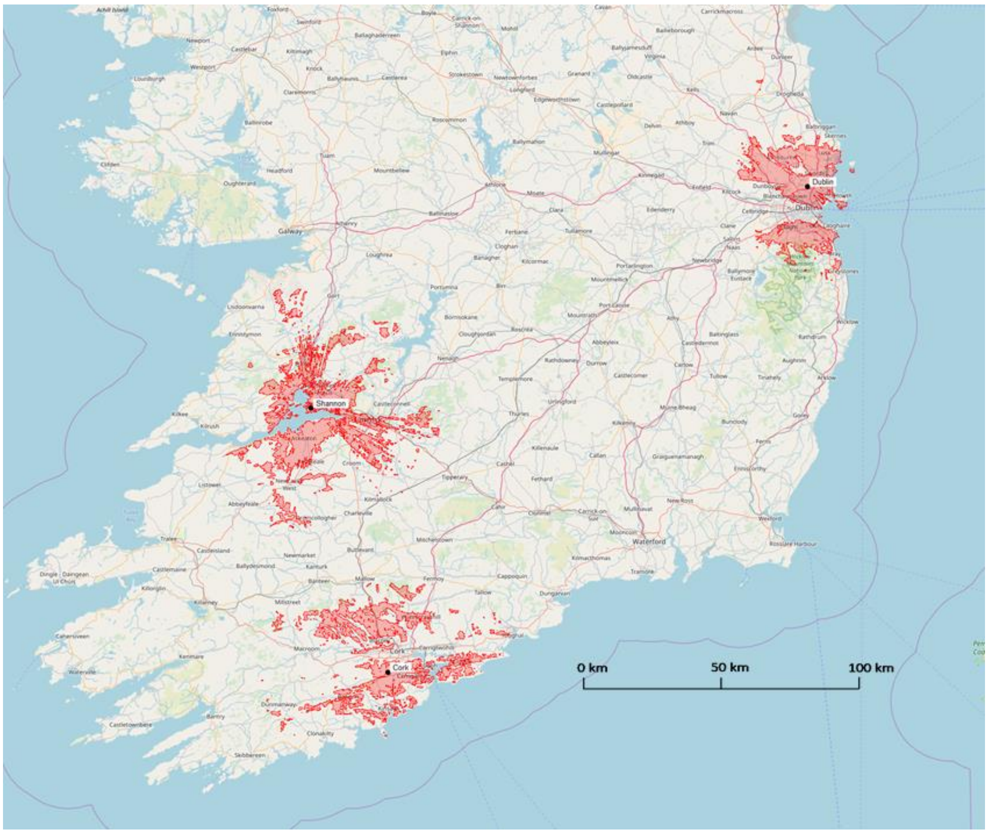


Figure 3.6: Interference contours for the blocking mechanism with no mitigation in place i.e. no filters (0.1% time)

Figure 3.7: Interference contours for spurious emissions with no mitigation in place i.e. no filters (0.1% time)



3.4 Conclusions

This report considered studies in France, Belgium and the UK which examined three primary types of interference (blocking, intermodulation and spurious emissions[52]) as a result of mobile broadband transmitters interfering with radar receivers. The analysis in this Chapter examined the potential impact of MFCN base stations on radar systems in Ireland. Based on the results of the three benchmark countries, it can be concluded that a number of mitigation techniques can be applied to the Irish context to ensure potential inference from MFCN base stations to radars is minimised. These include the combination of pfd limits, implementation of filtering at the impacted radars and 1 km co-ordination zone[53] from the radar to minimise the following types of interference:

- Blocking and Intermodulation: With the use of filters as implemented in the benchmark countries, the likelihood of interference due to blocking and intermodulation will be minimised. Therefore, the limitations defined by yellow and red interference contours (Figures 3.1, 3.2 and 3.3) will no longer be applicable. The experience in benchmark countries indicates that radar filters have worked well, and no cases of interference have been reported. The information obtained from the UK CAA suggests that the radar filters are designed with sufficient margins to accommodate a range of interference scenarios.

[52] Blocking and intermodulation effects are the result of strong MFCN interfering signals overloading the radar receiver low noise amplifier and causing non-linearity, the lack of sufficient receiver selectivity is the key reason for this type of interference. The third type of interference relates to spurious emissions which are generated by MFCN transmitters and fall within the receiving band of the radars.

[53] For example, in the UK, Ofcom has specified the coordination procedure in a "Notice of coordination procedure required under spectrum access licences in the 2.6 GHz band". https://www.ofcom.org.uk/__data/assets/pdf_file/0028/37396/im2.pdf

If MFCNs are deployed before radar filters are fitted, an in-band radiation limit is required in the frequency range of 2575-2690 MHz to address the impact of blocking and intermodulation effects at radar receivers in the adjacent band. The restriction derived in this report for the Irish context is in the form of a pfd limit of -83 dBW/m^2 at the radar receiver. This limit is derived based on the following assumptions[54]:

– The representative Thales Star 2000 radar blocking and intermodulation threshold levels for an assumed 64-QAM interfering signal are -20 and -44 dBm, respectively[55]. The level of -44 dBm is more stringent than the level of -20 dBm. Therefore, this level can be used to define an appropriate pfd limit to accommodate blocking and intermodulation effects.

– The interference entry is through the radar receiver main beam; hence the radar receiver antenna gain is 33.5 dBi, including feeder losses.

– The corresponding pfd level[56] is -78 dBW/m^2. This level accommodates interference from all MFCN licensees.

– If it is assumed that there are three licensees[57] the corresponding pfd limit to be complied by each operator is -83 dBW/m^2.

- Spurious Emissions: The impact of MFCN base station out-of-band spurious emissions can be reduced by defining a pfd threshold at the radar receiver location. This is the approach adopted in the benchmark countries. This report concludes that a pfd limit of -145 dBW/m^2/MHz at the radar receiver antenna location should be imposed to address the impact of MFCN spurious emissions[58]. This limit is derived based on the following assumptions[59]:

  – The Thales Star 2000 radar spurious emission threshold level for an assumed 64-QAM interfering signal is -106 dBm/MHz (measured in the Belgian measurement study)[60].

  – The interference entry is through the radar receiver main beam; hence the radar receiver antenna gain is 33.5 dBi, including feeder losses.

  – The corresponding pfd level is -140 dBW/m^2/MHz. This level accommodates interference from all MFCN licensees.

  – If it is assumed that there are three licensees the pfd limit to be complied by each operator is -145 dBW/m^2/MHz[61].

  This limit is based on the use of Thales Star 2000 radar spurious emission threshold level, radar main beam antenna gain and assumed three MFCN licensees. The difference in pfd levels is mainly attributed to the fact that the Belgium measurement study considered different types of radars and that the measured protection level is -122 dBm/MHz. In Ireland's case the protection level is -106 dBm/MHz

[54] Assumptions are subject to verification through measurement studies in Ireland.
[55] These threshold values were measured in the Belgian measurement study.
[56] Pfd (dBW/m^2) = Interference threshold at radar receiver input (dBW) – Radar antenna gain (dBi) + 10 x log($4\pi/\lambda^2$) where λ is the wavelength in meters.
[57] If any other number is assumed for the potential licence holders the calculated total pfd value (-78 dBW/m^2) needs to be reduced by 10 x log (no of assumed operators).
[58] It should be noted the pfd limit is based on the measured threshold at the radar receiver and corresponds to the maximum allowed aggregate interference from each potential MFCN operator regardless of their choice on the technology they prefer to use (e.g. TDD/FDD).
[59] Assumptions are subject to verification through measurement studies in Ireland.
[60] This value will be verified through testing in Ireland.
[61] There are a number of mitigation techniques operators can utilise to meet this limit such as, but not limited to, reducing BS E.I.R.P levels, installing more efficient antenna filters, optimising antenna orientation, increase downtilt of antenna, lower antenna height or moving base station further away from radar.

which corresponds to STAR 2000 radars only. An additional step has been taken for the Irish case which apportioned the pfd allowance among assumed three operators to derive a pfd limit of -145 dBm/m^2/MHz.

3.5 Recommendations

This section provides a number of recommendations to ComReg following the conclusions drawn in the previous section from the experiences of France, Belgium and the UK included in this report. These recommendations are detailed below:

- to address interference due to blocking and intermodulation, filters as implemented in the benchmark countries should be installed at the radars in Ireland.
- to address the impact of MFCN spurious emissions, a pfd limit of -145 dBW/m^2/MHz at the radar receiver antenna location should be satisfied by each operator[62];
- to ensure protection of radars from MFCN base stations where they are operating in close proximity, a 1 km coordination zone, as adopted in Belgium, should be applied around the radars in Dublin, Shannon and Cork assuming that radar receivers are fitted with filters:
  - Inside the 1 km coordination zone, MFCN operators are required to coordinate with the radar operator, regardless of antenna gain value or compliance with pfd limit.
  - Outside the 1 km coordination zone, each potential MFCN operator is required to comply with the defined pfd limit (-145 dBW/m^2/MHz)[63].
- If MFCNs are deployed before radar filters are fitted, an additional in-band radiation limit is required in the frequency range of 2575-2690 MHz to address the impact of blocking and intermodulation effects at radar receivers in the adjacent band. This restriction as derived in this report is a pfd limit of -83 dBW/m^2 at the radar receiver[64].

[62] This limit is derived assuming three licensed operators, if there are four or five licensed operators the pfd limit per operator should be -146 dBW/m^2/MHz and -147 dBW/m^2/MHz respectively.
[63] The compliance with pfd limits could be demonstrated by the MNOs using their own analysis tools as adopted, for example, in France.
[64] Following successful installation of filters at the radar receiver, no in-band radiation limit is required as filtering at the radar receiver should address the impact of blocking and intermodulation effects at the radar receiver in the adjacent band.

Appendix A Co-existence Analysis Assumptions

ComReg is intending to award the 2.6 GHz band for Mobile/Fixed Communications Networks (MFCN). The band 2690 – 2700 MHz is allocated to Radio Astronomy, Earth Exploration Satellite Service (passive) and Space Research Service (passive). Aeronautical Radionavigation Service systems operate in the 2.7 GHz band. In this context, an important consideration is the compatibility between MFCN operating below 2690 MHz and aeronautical radars operating above 2700 MHz.

This Appendix firstly provides modelling assumptions related to the analysis of adjacent band interference from MFCN base stations to aeronautical radar receivers. This is followed by a summary of radar and MFCN system characteristics which is the basis of modelling assumptions.

A.1 Modelling Assumptions

The modelling has been performed with Plum software toolkit which is used to calculate interference contours for a defined set of RF parameters, terrain data and propagation model. These parameters are provided in the following table.

Table A.1: Modelling Assumptions

Parameter	Assumptions			Comments
	Aeronautical Radars			
	Dublin (Head 3)	Shannon	Cork	
Radar Model	Thales STAR 2000			ComReg data
Latitude / Longitude	53° 26′ 17.9′′ / 6° 15′ 26.9′′	52° 42′ 5.03′′ / 8° 56′ 11.74′′	51° 49′ 19.68′′ / 8° 31′ 16′′	
Height (a.s.l.) (m)	55	14.3	160	
Antenna Height (a.g.l.) (m)	12.5	25.8	12	
First and Second Assigned Operating Frequencies (MHz)	2715 / 2875	2730 / 2870	2715 / 2875	
Channel Bandwidth (MHz)	10			
Blocking Protection Level (dBm)	-20			Referred to the receiver input after the receive antenna Based on tests with an interfering 64-QAM signal (Belgian Study)

Parameter	Assumptions	Comments
Inter Modulation Protection Level (dBm)	-44	Referred to the receiver input after the receive antenna Based on tests with two interfering 64-QAM signals (Belgian Study)
Spurious Emissions Protection Level (dBm/MHz)	-106	Referred to the receiver input after the receive antenna Based on tests with an interfering 64-QAM signal (Belgian Study)
Max Antenna Gain (dBi)	33.5	ComReg data
	MFCN	
	BS	
Maximum EIRP (dBm/5MHz)	61	Based on EC Decision 2008/477/EC.
Spurious Emissions Limit (dBm/MHz)	-30	Based on 3GPP TS 36.104 Refers to the transmitter output before the transmit antenna
Maximum Antenna Gain (dBi)	18	Assumed to be a representative gain value (Belgian Study)
Antenna Height (a.g.l.) (m)	17	Assumed to be a representative height (corresponding to the minimum base station antenna height below which planning permission is generally required)
	Propagation	
Path Loss Model	ITU-R Rec.452	
Percentage Time	50%	
Terrain Model	SRTM	

A.2 Irish Primary Radars

In Ireland, there are four primary aeronautical radars operating in the 2.7 GHz band. These are at Shannon, Cork and Dublin (note that Dublin has two radars). The key radar receive parameters are summarised in Table A.2.

Table A.2: Primary Aeronautical Radar Receive Parameters

Parameter	Dublin (Head 2)	Dublin (Head 3)	Shannon	Cork
Radar Model	Thales TA 10M TD	Thales STAR 2000	Thales STAR 2000	Thales STAR 2000
Latitude / Longitude (deg/min/sec) (WGS84)	53° 26′ 20.82″ / 6° 15′ 8.30″	53° 26′ 17.9″ / 6° 15′ 26.9″	52° 42′ 5.03″ / 8° 56′ 11.74″	51° 49′ 19.68″ / 8° 31′ 16″
Height (a.s.l.) (m)	21	55	14.3	160
Antenna Height (a.g.l.) (m)	19	12.5	25.8	12
First and Second Assigned Operating Frequencies (MHz)	2740 / 2840	2715 / 2875	2730 / 2870	2715 / 2875
Channel Bandwidth (MHz)	10			
Antenna Model	Thales AC 316 K	Thales AN 2000		
Max Antenna Gain (dBi)	35	33.5		
3-dB Beamwidth (deg)	1.4	1.3		
Polarisation	Linear (switchable to circular in severe rain and snow storms)			
Radar Interference Thresholds	Based on measurement results presented in the Belgian Report (see Table 2.1)			

A.3 MFCN Characteristics

Information provided in EC Decision 2008/477/EC and 3GPP specifications are relevant.

The European Commission Decision 2008/477/EC provides conditions for the harmonisation of the 2.6 GHz band for terrestrial systems capable of providing electronic communications services in the Community[65]. The Decision is based on the work presented in CEPT Report 19[66] and includes Block Edge Masks (BEMs) to ensure co-existence between neighbouring MFCN. BEMs are based on 5-MHz wide blocks of spectrum and define limits for both in-block and out-of-block emissions in FDD and TDD deployment scenarios.

It is important to note that BEMs do not consider co-existence with other in-band and adjacent band services. The Decision states that '*For other systems and services appropriate sharing criteria for coexistence may be based on national considerations*'.

[65] https://www.ecodocdb.dk/document/80
[66] https://www.ecodocdb.dk/document/19

The Decision provides a maximum in-block EIRP limit of 61 dBm/5MHz for BSs.

3GPP technical specifications provide base station and user terminal emission limits. The most commonly used specifications are the 36 series which address 'LTE (Evolved UTRA), LTE-Advanced and LTE-Advanced Pro radio technologies'. There are also 38 series specifications which are currently being developed to address 'radio technology beyond LTE', i.e. 5G.

3GPP TS 36.104 (V15.3.0, June 2018) defines BS specifications for LTE (Evolved UTRA), LTE-Advanced and LTE-Advanced Pro. In Section 6.6 of 3GPP TS 36.104, it is stated that '*The Operating band unwanted emissions define all unwanted emissions in each supported downlink operating band plus the frequency ranges 10 MHz above and 10 MHz below each band. Unwanted emissions outside of this frequency range are limited by a spurious emissions requirement.*'

In the context of co-existence between MFCN BSs operating below 2690 MHz and aeronautical radar receivers operating above 2700 MHz, the BS spurious emissions limit is therefore applicable to limit MFCN BS emissions in the aeronautical radar receiver band.

In Section 6.6.4.1 of 3GPP TS 36.104, mandatory spurious emission limits are defined for Category A & B base stations. Category B limits are more stringent than Category A limits and adopted in Europe[67]. The Category B limit defined for the frequency range 1 – 12.75 GHz is -30 dBm/MHz.

It should be noted that the work relating to the use of 2.6 GHz band by MFCN is currently ongoing within CEPT. Issues considered include the use of Active Antenna Systems and their implications in spectrum sharing. The work is planned to be completed in summer 2019.

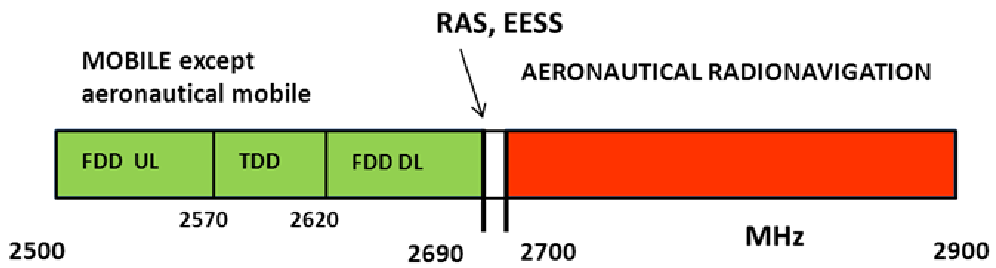
[67] Rec. ITU-R SM.329-12

Appendix B Summary of ECC Report 174

B.1 Introduction

ECC Report 174[68], published in March 2012, addresses the compatibility between the mobile services in the 2.6 GHz band and the radionavigation and radiolocation services in the 2.7 GHz band as shown in Figure B.1 below.

Figure B.1: Primary frequency allocations in the band 2500 – 2900 MHz (Source: ECC Report 174)



The studies provided in the Report are based on possible mobile technologies of LTE FDD, LTE TDD and Mobile WiMAX with the TDD systems deployed in the centre gap of 2570 – 2620 MHz. Bandwidths of 5, 10 and in the case of LTE 20 MHz. Different representative categories of radar were considered – a number of which were applicable to ATC (Air Traffic Control) use.

In the Report, four interference scenarios are considered.

- radar interferes with a terminal of the mobile service;
- radar interferes with a base station of the mobile service;
- A base station of the mobile service interferes with radar; and
- A terminal of the mobile service interferes with radar.

For each scenario, two types of interference mechanisms are considered:

- Blocking: where a signal outside of the nominal receiver bandwidth causes the victim receiver to experience an increased noise level or go into compression, thus producing non-linear responses.
- Unwanted emissions: where the unwanted emissions (OOB and spurious) of the interfering transmitter fall into the receiving bandwidth of the victim receiver.

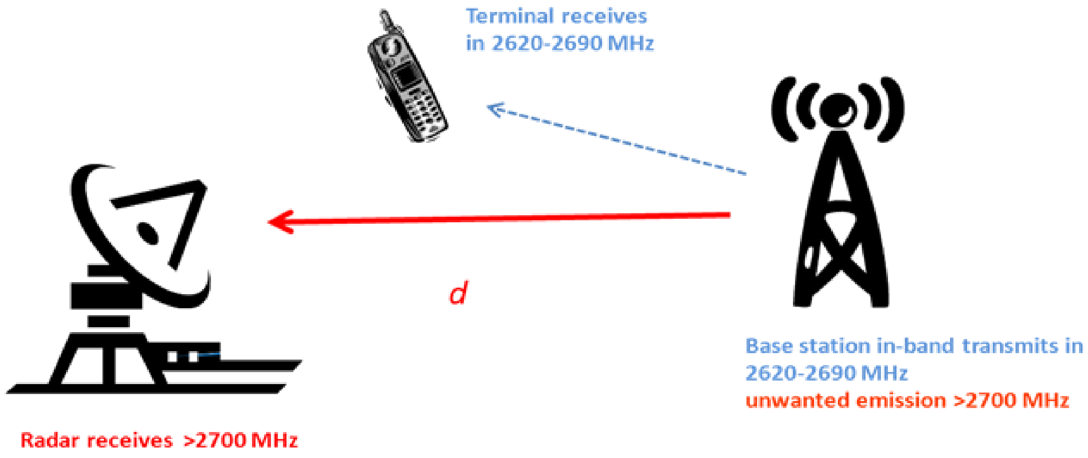
The main considerations for this report, looking at the protection required for radars, are those of Scenarios 3 and 4.

[68] Compatibility between the mobile service in the band 2500 – 2690 MHz and the radiodetermination service in the band 2700 – 2900 MHz

B.2 Mobile service interference into the radar

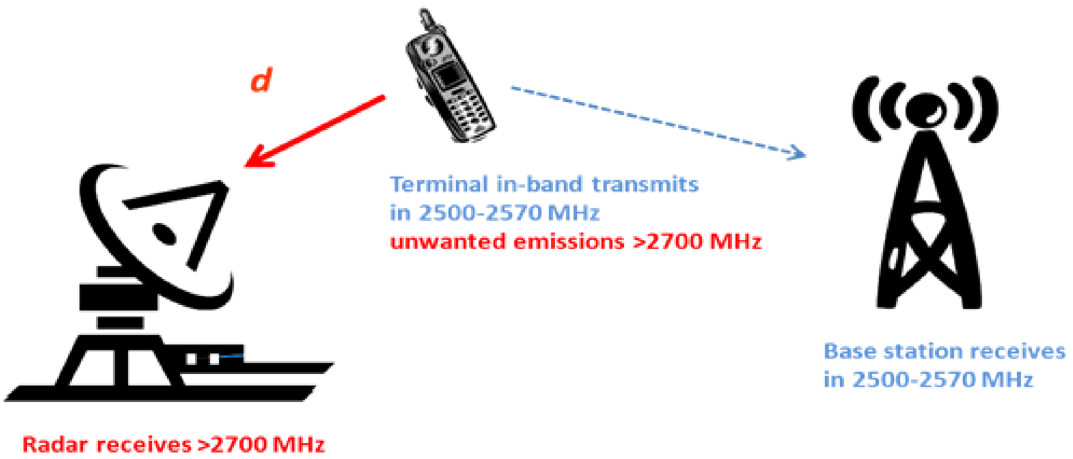
The two interfering scenarios with respect to interference into radars are shown below:

Figure B.2: Base station of mobile service interferes into the Radar, FDD frequency arrangement (Source ECC Report 174)



In this scenario the worst case occurs when the antennas are mounted well above the surrounding buildings and there is direct line of sight between the mobile base station and the radar.

Figure B.3: Terminal of mobile service interferes into radar, FDD arrangement (Source: ECC Report 174)



The terminal can be randomly located in the radio cell and MCL combined with free space provides the worst-case analysis. The extended Hata model could be used to provide a more realistic outcome by considering the antenna height of the terminal and terrain.

Results showing the shortfall in isolation versus separation distance between the radar receiver and mobile transmitter, for the unwanted emissions and blocking scenarios, are provided in Section 4.4 of the ECC Report. The impact on Type 2 ATC radars (representative of ATC radars), defined in Table 5 of the ECC Report, are provided based on the protection ratios in Table 6 of the ECC Report. The two figures below from the ECC Report show the impact of one base station or one terminal, operating at maximum power, on a Type 2 radar in a rural and an urban environment respectively. It is also noted that where more than 2 LTE blocks are being used the curves for blocking scenarios would be up to 10 dB more stringent.

Figure B.4: Impact of LTE BS and UE in rural environment on Type 2

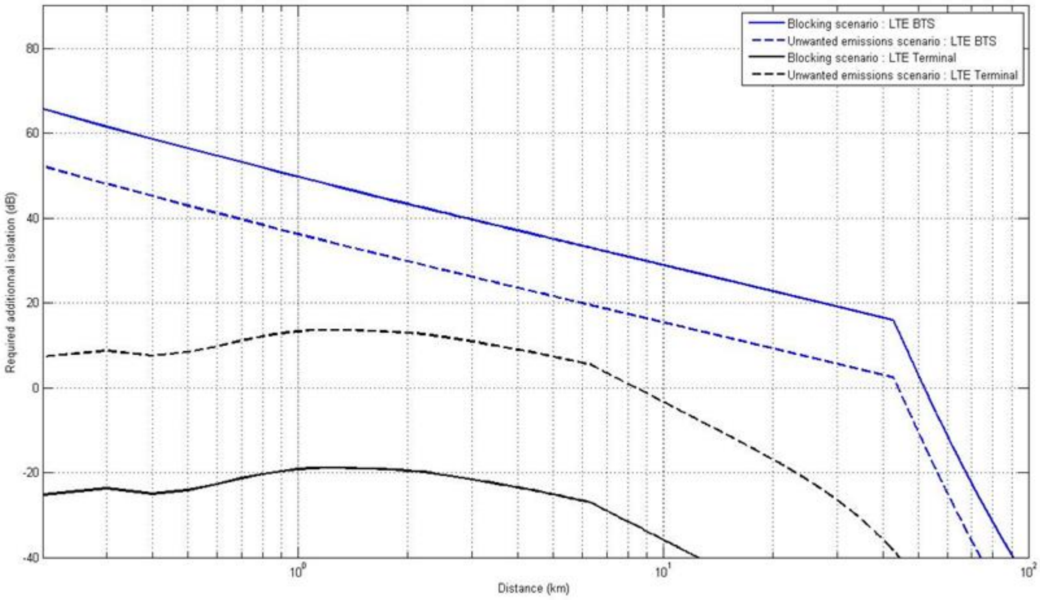
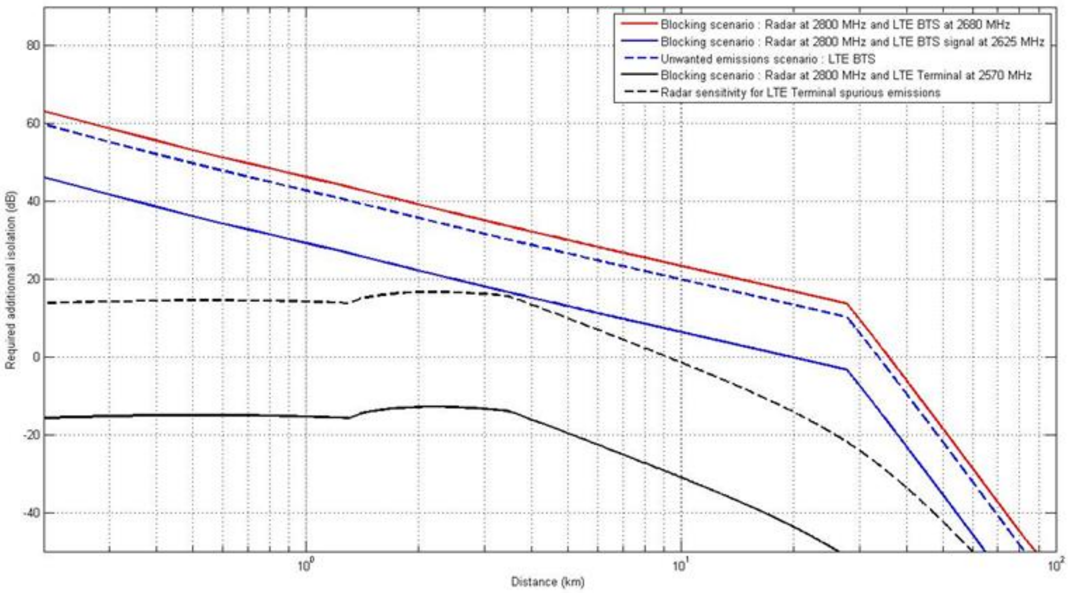


Figure B.5: Impact of LTE BS and UE in urban environment on Type 2



In the analysis it notes that blocking by mobile terminals is not expected to be a problem for any kind of radar. Mobile terminals measured typically have spurious emissions below -50 dBm/MHz which is 20 dB below the unwanted emission level of -30 dBm/MHz. In the case of the base station the main problem was the lack of sensitivity of the radar chain or due to saturation of the LNA. It is noted that an additional 50 dB of isolation is required if a base station is located 1 km from the radar.

The ECC Report proposes a list of possible mitigation techniques:

- Improvement of the receiver selectivity – achieved by fitting filters;
- Reduce unwanted transmissions of transmitters - measurements have indicated that actual equipment performance may be better than the regulatory / standards limits and, for example, reduce the unwanted transmitter emissions.;
- Reduced power from the mobile service base stations – could be used in specific circumstances such as at sites close to the radar;
- Site specific deployment – avoid mobile base stations pointing to the radars and take advantage of natural shielding (terrain and buildings);
- Physical separation between the radar and mobile services base stations – increase the distance but needs to be balanced against the mobile network coverage requirements; and
- Frequency separation.

The likely effectiveness of such measures is discussed in more detail in the ECC Report. It is noted that the solutions will vary by country.