ECC REPORT 68

Electronic Communications Committee (ECC)
within the European Conference of Postal and Telecommunications Administrations (CEPT)

COMPATIBILITY STUDIES IN THE BAND 5725 – 5875MHz BETWEEN FIXED WIRELESS ACCESS (FWA) SYSTEMS AND OTHER SYSTEMS

Riga, June 2005

EXECUTIVE SUMMARY

In response to a request from ETSI for the designation of spectrum for FWA systems around 5.8 GHz, the compatibility studies were conducted between these proposed FWA systems and the existing users.

It was decided to conduct compatibility studies between FWA in general and the following services/systems:

1) Radiolocation Service,
2) RTTT,
3) Fixed service (Point to Point links) in the band 5850-5875 MHz,
4) Fixed Satellite (E-s) Service,
5) Non-Specific SRD introduced in accordance with the Recommendation 70-03,
6) Amateur and amateur satellite (s-E) services.

The scope of FWA considered in the studies was broadened beyond the original ETSI request in the interests of achieving a technology neutral solution.

The report has been completed for the compatibility studies in the band 5725-5875 MHz and the following table shows the conditions under which sharing would be feasible[1]:

Existing Service and its operating band[2]	Required conditions for introducing FWA	Comments
Radiolocation (5725–5850 MHz)	A DFS mechanism with appropriate requirements is required	Suitable protection of some frequency hopping radars is not ensured with DFS compliant to the harmonised standard ETSI EN 301893 v1.2.3 or v1.3.1
RTTT (5795-5815 MHz)	The mitigation factors are given in section 6.2	Interference may occur in some scenarios. However, since the FWA has greater vulnerability, co-channel operation should be avoided The probability for FWA to adversely affect the RTTT OBU battery life is very low
Fixed (5850–5875 MHz)	Co-ordination may be needed between FWA and fixed links, where applicable	This is not a CEPT harmonized band for fixed service
Fixed-Satellite (E-s) (5725–5850 MHz)	Sharing is dependent on the ability of FWA system to limit the e.i.r.p. density in the direction of the satellite	The sharing conditions are detailed in section 6.4.5. It should be noted they depend upon the type of FWA deployment
Fixed-Satellite (E-s) (5850-5875 MHz)	Sharing is dependent on the ability of the FWA system to limit the e.i.r.p. density in the direction of the satellite	As above, however the sharing conditions are more restrictive
SRD (5725-5875 MHz)	The mitigation factors are given in section 6.5	Interference may occur in some scenarios. However, since the FWA has greater vulnerability, co-channel operation should be avoided
Amateur (5725-5850 MHz)	The mitigation factors are given in section 6.6	Interference may occur in some scenarios. However, since the FWA has greater vulnerability, co-channel operation should be avoided

Note: Sharing studies have been conducted with FWA systems having a maximum e.i.r.p. of 36 dBm or lower

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[1] More detailed conclusions can be found in Section 7
[2] The operating parameters for FWA systems are given in Annex 1

INDEX TABLE

List of Abbreviations

Abbreviation	**Explanation**
AP	Access Point
AP-MP	Anypoint-to-Multipoint (hybrid of Mesh and P-MP)
BRAN	Broadband Radio Access Networks
CENELEC	European Committee for Electrotechnical Standardization
CEPT	European Conference of Postal and Telecommunications
CS	FWA Central station (e.g. of P-MP system)
DFS	Dynamic Frequency Selection
DVS	Digital Video Sender
ECC	European Electronic Communications
ECCM	Electronic-Counter-Counter-Measures
e.i.r.p.	Equivalent isotropically radiated power
ETSI	European Telecommunications Standards Institute
FSPL	Free Space Propagation Loss
FWA	Fixed Wireless Access
HIPERMAN	High Performance Radio Metropolitan Access Networks
ITU	International Telecommunication Union
LHCP	Left Hand Circular Polarized
MCL	Minimum Coupling Loss
Mesh	Mesh (Multipoint-to-Multipoint)
OBU	On-Board Units (of RTTT)
ODU	Outdoor unit
P-MP	Point-to-Multipoint
POP	Point of presence
P-P	Point-to-Point
PSD	Power Spectral Density
RHCPP	Right Hand Circular Polarized
RPE	Radiation Pattern Envelope
RSS	Received Signal Strength
RSU	Road Side Units (of RTTT)
RTTT	Road Transport and Traffic Telematic
SME	Small and medium enterprise
SOHO	Small office / home office
TDMA	Time Division Multiple Access
Th	Detection threshold (for DFS)
TPC	Transmitter Power Control
TS	FWA Terminal station
WAS/RLANs	Wireless Access Systems including Radio Local Area Networks

COMPATIBILITY STUDIES IN THE BAND 5725 – 5875MHz BETWEEN FIXED WIRELESS ACCESS (FWA) SYSTEMS AND OTHER SYSTEMS

1 INTRODUCTION

In response to a request from ETSI for the designation of spectrum for FWA systems around 5.8 GHz, the studies were conducted on compatibility between these proposed systems and the existing users. The frequency range to be considered was determined to be from 5725 to 5875 MHz.

In addition, during the course of the studies in this report the FWA industry has continued to develop worldwide standards for products aimed at using this band and interoperable products were expected to be available in the market place during 2005.

The 5.8 GHz band is available for similar applications in some countries around the world without the benefit of regulatory co-ordination, e.g. in North America, however there is an additional complexity to the sharing situation in Europe as a result of the allocation across the whole band to the Fixed Satellite Service particular to ITU Region 1, and also due to the previous designation of parts of the spectrum to other uses by CEPT. For this reason, it was not possible to resolve this issue without careful technical analysis, the results of which are presented in this report. An extract of the allocation table can be found in section 5 (Table 5.1). The range 5 850-5 875 MHz is allocated to the Fixed Service in all three Regions. The range 5 725-5 850 MHz is allocated to the Fixed Service in some countries by footnote 5.455.

The term FWA is used throughout this report based on various assumptions for certain systems within the Fixed Service, which have been proposed for deployment. However, this is not intended to result in a restriction on the type of systems/architecture which may actually be deployed. Any designation of spectrum should be technology neutral and defined by a minimum set of essential requirements for protection of relevant services.

2 OVERVIEW OF FIXED WIRELESS ACCESS SYSTEMS

2.1 Fixed Wireless Access Systems

Fixed Wireless Access (FWA) is used here to refer to wireless systems that provide local connectivity for a variety of applications and using a variety of architectures, including combinations of access as well as interconnection. Both the architectures and the applications will continue to develop. For the purposes of this report, the architectures considered are Mesh, Point-to-MultiPoint (P-MP), and Point-to-Point (P-P) topologies. AnyPoint-to-Multipoint (AP-MP) is considered to be a hybrid of Mesh and P-MP.

One useful source of material is the System Reference Document TR 102 079 for ETSI BRAN HIPERMAN systems anticipated in the 5.8 GHz band, but it has been found that this does not include all the broadband fixed wireless system possibilities required by the sharing studies.

2.1.1 Mesh networks

In a mesh network, nodes typically located at customer premises provide both the customer traffic and act as repeaters forwarding traffic to other nodes in the network. Individual user terminals have no need to be directly connected to the access point or central station connected to the network backhaul - it is enough if they can “see” at least one neighbouring terminal that can further route the traffic towards/from the access point. In radio hardware terms the mesh station comprises a building mounted Outdoor Unit (ODU) that can be mounted below roof height or a small distance above roof top height.

As well as subscriber node stations, other nodes provide connectivity into a core-network (which may be as simple as a wire into a gateway, or as complex as a multi-tier wireless backbone network). It is possible that a few nodes may be co-located at the backhaul connection point using sector or directional antennas, in order to aggregate more traffic into a single point. Subscriber nodes are individual installations typically equipped with either omni-directional antennas or directional antennas. In all other aspects their functionality is entirely the same. The definition of whether a node constitutes a “backhaul connection point” or a subscriber node hence entirely depends on what type of device is connected to its network interface.

2.1.2 Point-to-MultiPoint (P-MP) networks

Point-to-Multipoint networks are typically characterised by user terminal stations being connected directly to a central station (although it is possible where difficult terrain exists for repeater stations to be deployed between the user and the central station). This leads to a coverage area around the central station in which the terminal stations can be served. The limits of the coverage area are driven by adequate link budget between the terminals and the central station.

Central stations can be further characterised by their antenna systems, providing either omni-directional coverage or more commonly sectorised coverage depending on the antenna system beamwidth. However, in both cases, the central stations tend to require an elevated position so that the surrounding terminals can achieve an adequate connectivity. Terminal stations are generally equipped with a more directional antennas helping to improve the link budget.

2.1.3 Point-to-Point (P-P) links

Although traditionally point-to-point links have been used to provide infrastructure, they can also be used for access applications or may be integrated with other architectures to provide a backhaul solution. P-P stations are characterised by deploying high gain antennas at each end of the link as the requirement is for connection only to another specific station. Each link is generally a separate entity, unlike the links used in directional mesh networks that are under the control of an “overseeing” network management system that determines the resources available.

3 SPECTRUM REQUIREMENTS

The considered FWA systems may typically use 5 MHz, 10 MHz or 20 MHz channelisation, which is necessary to obtain sufficiently high data rates. In single cell deployments, usually one or two channels suffice. In large area multi-cell deployments an operator might typically use 3 or 4 channels to obtain contiguous coverage. For backhaul an additional channel may be required.

The 5.725-5.875 GHz band should be able to provide sufficient spectrum for commercial operations, even though exclusive frequency allocations and channel co-ordination is not envisaged in this band. This would allow up to 7 x 20 MHz channels, or 15 x 10 MHz channels, which should be sufficient to permit at least 2 different operators in any area.

4 FIXED WIRELESS ACCESS PARAMETERS AND DEPLOYMENT SCENARIOS

Various types of FWA systems have been considered through this report with advice sought from industry on FWA systems that are deployed or are planned to be deployed. For convenience and analysis these different systems fall into 5 main groups or variants thereof. Here we present an overview of deployment scenarios for these Groups and identify the typical parameters that characterise the groups and those factors that were key in supporting these sharing studies. We also consider factors that constrain deployment densities and derive these from the addressable market segments and expected market share of FWA systems.

4.1 Technical Parameters

The studies undertaken in this report have considered five different FWA types (“Groups 1 to 5”), covering a range of possible deployment scenarios. The system types are categorised in table 4.1 and the technical parameters used for each of the system types in the compatibility studies of this report are given in Annex 1. It should be noted that although the report is based on HIPERMAN parameters, these are understood to be representative of a variety of FWA technologies including for example IEEE802.16.

Group	*Description/Reference*
Group 1	Point-to-Multipoint, using Sectored Central Stations including systems based on ETSI HIPERMAN TS 102 177
Group 2	“HIPERMAN Any-point to multipoint” (AP-MP) (as defined by ETSI BRAN in ETSI Technical Report 102079), using “Root Nodes”, “Branch Nodes” and “Leaf Nodes”
Group 3	“HIPERMAN Mesh” network (as defined by ETSI BRAN in ETSI Technical Report 102079), in which all stations (nodes) use omni-directional antennas
Group 4	Directional Mesh (as defined in ETSI TM4 Work Item 04152), in which all stations (nodes) use directional antennas
Group 5	Point-to-Point network, in which all stations use directional antennas

4.2 Deployment Scenarios

4.2.1 Group 1 - Point-to-Multipoint

The P-MP FWA architecture permits an efficient broadband wireless access system configuration using proven technology; this supports the need for last mile connectivity to business and residential users and facilitates a wide variety of service provision. P-MP FWA can also provide a cost efficient backhaul solution for both outdoor and indoor RLANs.

It is assumed that all the remote stations communicate with the central station only during the assigned time slot (in case of Time Division Multiple Access - TDMA). This means that, within a cell, only one station is transmitting at any instant in time irrespective of the number of radios per cell. Consequently it is the number of cells that are proportional to the level of interference.

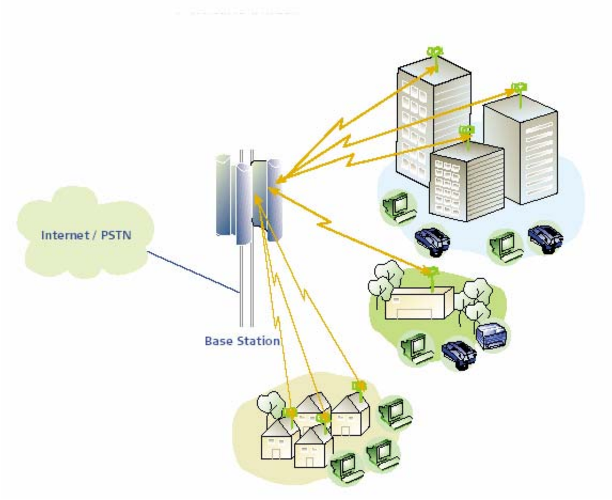

Figure 4.2.1: Typical Point-to-Multipoint System

Radios within a cell can be further characterised by their antenna systems, providing either omni-directional coverage or more commonly sectorised coverage depending on the antenna system beamwidth. Normally, for FWA, the subscriber unit at the customer’s premises is a sectored antenna.

4.2.2 Group 2 - Anypoint-to–Multipoint (AP-MP)

The AP-MP architecture is a hybrid network topology between P-MP and Mesh. Like in the Mesh topology, any node can route traffic to its neighbours and can therefore serve as the Access Point for new nodes in the network. Like in the P-MP topology, nodes attach to a specific Access Point in the network, chosen at installation time. This allows the new node to attach to the network using a directive antenna, with the inherent advantages of increasing range, reducing exposure to interference, and reducing the generation of interference.

Depending on their position in the tree (see Figure 4.2.2), nodes can take the following roles:

- Root: Only one node in the AP-MP network acts as the root, it is the AP for all its one-hop clients.
- Branch (Bx): Nodes that communicate with an upstream AP node, but also assume the AP role to communicate with nodes downstream.
- Leaf (Lx): Nodes that only communicate upstream with an AP.

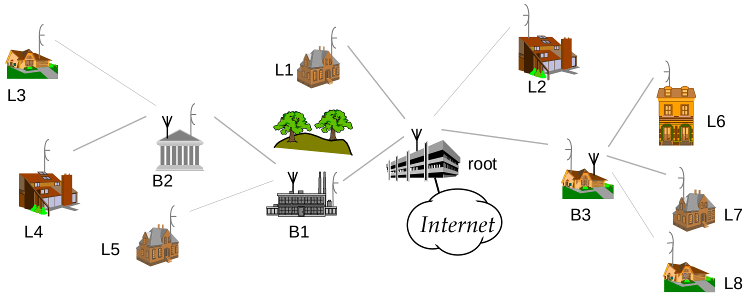

Figure 4.2.2: AP-MP network topology

This architecture allows a high degree of flexibility in deploying the network to address local concerns.

4.2.3 Group 3 – Omni-directional Mesh

In a mesh network, nodes typically located at customer premises provide both the customer traffic and act as repeaters forwarding traffic to other nodes in the network. Individual user terminals have no need to be directly connected to the access point or central station connected to the network backhaul - it is enough if they can "see" at least one neighbouring terminal that can further route the traffic towards/from the access point. In radio hardware terms the mesh station comprises a building-mounted ODU that can be positioned below roof height with a directional antenna or above roof top for omni-directional.

Subscriber nodes are individual installations typically equipped with either omni-directional antennas or directional antennas. In all other aspects their functionality is entirely the same. The definition of whether a node constitutes a "backhaul connection point" or a subscriber node hence entirely depends on what type of device is connected to its network interface.

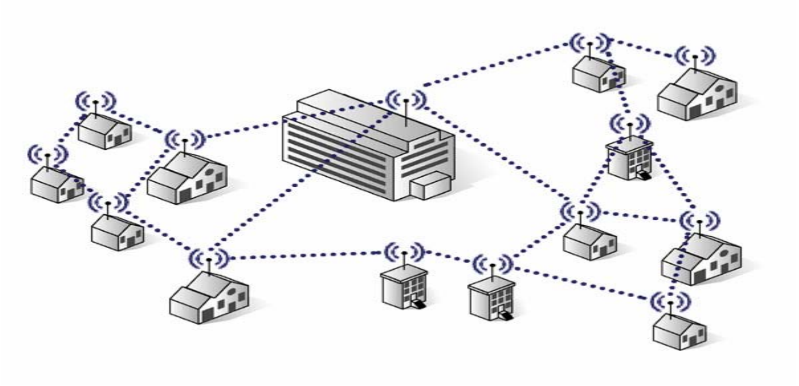

Figure 4.2.3: Mesh network example

4.2.4 Group 4 - Directional Mesh

Mesh Networks deploying directional antennas tend to spread from the backhaul interconnection point in any direction and may even exhibit inter-connected backhaul connection points. The overall result is that the individual operational links making up the network can be pointing in any azimuth direction on a random basis. The frequency and time slot used on any link is chosen by the network management system to optimise re-use and network capacity. As a result use of the specific available channels is spread throughout the network on an apparently random basis.

The term “Directional” can also mean “multi-directional” in which a transmitter can transmit in more than one direction at the same time, but not in all directions. This is typically through the use of an array of antennas covering multiple directions giving near omni coverage and that theoretically all can be transmitting at the same time. More usually only four will be operational at any one time. This is typically deployed with unit densities of 20-25 nodes to give coverage in a 1 km^2 area. However, data rates and topography of the coverage area may mean these numbers change in order to provide a usable service. Some mesh systems provide backhaul access to other RLAN technologies which can result in fewer mesh nodes being deployed at individual subscriber premises.

The following comments on the sharing studies for Directional Mesh systems when compared with Omni-directional Mesh systems have been noted:

1. An ETSI technical report “Requirements for broadband multipoint to multipoint radio systems operating in the Fixed Service frequency bands within the range 3-11 GHz” (ETSI TM4 work item DTR/4152) contrasts many aspects of omni-directional and directional mesh networks.
2. Directional Mesh nodes carry out a traffic routing function as part of the overall network function which results in a higher link utilization factor. Based on a typical 4 antenna system an activity ratio of 25% has been assumed for studies.
3. Horizontal discrimination in directional mesh has to be selective enough for good spectrum efficiency, but low enough to make signal acquisition easy. A horizontal aperture of 20-25 degrees would serve that purpose. Directivity combined with random pointing angle over a large deployment brings a statistical element to the aggregation of power from the network in any given direction. This reduces the interference into a given direction.

4.2.5 Group 5 - Point –to-Point (P-P)

Although traditionally point to point links have been used to provide infrastructure, they can also be used for access applications or may be integrated with other architectures to provide a backhaul solution. P-P stations are characterised by deployment of high gain antennas at each end of the link as the requirement is for connection only to another specific station. Each link is generally a separate entity, unlike the links used in directional mesh networks that are under the control of an “overseeing” network management system that determines the resources available. These are not expected to be in a very high density. Applications include backhaul of other multipoint systems through to business connectivity between buildings.

4.3 Deployment volumes, distribution and densities

4.3.1 Deployment Volumes

FWA systems are designed to provide broadband data and voice services to residential users and small businesses (SMEs).

In this context "broadband" means peak rate typically above 2 Mb/s to provide such services as data, voice and video. Fixed broadband data services can be delivered over conventional telephone wires (xDSL), cable TV wires (cable modem), satellite dishes and through fixed (terrestrial) wireless equipment.

Broadband FWA systems are intended to cost-effectively compete with or complement other broadband wired access systems, such as xDSL and cable modems. Because of this market situation, FWA systems will provide only a fraction of the total number of connections to households and SME, the main addressable market for FWA.

Data, available on the proportions of homes, lines and businesses across economies in Europe, is given in Table 4.3.1 for five EU countries.

Country	Households 000s	Res. lines 000s	Total lines 000s	Enterprises (%) with # of employees:				Number of enterprises
				1 to 9	10 to 49	50 to 249	250 +	
France	23 900	22 400	34 114	86.0	11.6	2.0	0.4	1 147 000
Germany	38 140	36 400	50 220	81.1	16.2	2.1	0.6	2 180 000
Italy	21 176	20 300	27 153	90.1	8.8	0.9	0.2	1 804 000
Spain	12 503	12 500	17 102	88.1	10.3	1.4	0.2	1 064 000
UK	25 085	23 300	35 177	85.1	12.5	1.9	0.5	1 232 000
NOTE: Sources: ITU, Eurostat								

Table 4.3.1: Market statistics for five EU countries

These figures show that the predominant potential market for access will be for residential and SME premises, with the majority of business premises housing less than 10 employees. It is assumed that all businesses will also have telecommunications service.

Extrapolation of the above numbers to the 25 countries of the EU with 600M people, gives 265M households and 16M small businesses (or 1 SME per 17 households). Assuming that FWA market penetration reaches 10% - which is very high for a late market entrant that has to compete with wired infrastructure in most market segments and geographical areas – the total number of FWA systems connections deployed would never exceed 28M.

FWA systems operating in the shared 5.8 GHz band would be fraction of this total. Assuming a very optimistic share of 40% that could be expected to operate in the 5.8 GHz range, this means the total number of FWA systems in this band would not exceed 11.2M across the territory of the EU.

4.3.2 Relative Volumes of FWA types

The numbers for households and business and the properties of the different FWA types suggest a natural distribution of deployed numbers of system types. The households to businesses ratio is 17 to 1. Groups 1 and 2, P-MP and AP-MP systems can be used for a wide range of applications and therefore these are expected to see use in both residential and business access applications. Group 3, Omni-directional Mesh offers low cost solutions for low density applications. Group 4, Directional Mesh systems offer the potential of higher link speeds than P-MP and therefore they are expected to be predominantly used for enterprise access applications without excluding residential use. Thus their relative numbers should reflect the SME to household ratio of 1 in 17, allowing a wide margin. P-P systems in this band tend to be primarily used as private systems although some commercial use is assumed as well.

Based on current market figures, P-P deployment are expected not to exceed 1% of the total number of FWA systems operating in this band. This leads to the following table:

FWA Type[3]	Percentage use
Point-to-Multipoint	90
Mesh	9
Point-to-Point	1

Table 4.3.2: FWA type – relative numbers of usage

4.3.3 FWA Distribution

It is necessary to establish the geographic distribution of terminals throughout the region and hence the relative contribution to the interfering noise power caused by the terminals under different parts of the beam for the various satellites considered in the sharing study.

Population statistics by country were obtained from web based sources, notably: www.cyberatlas.com which has figures based on the CIA World Fact book. Over 37 countries were included, which total over 764 million of population.

A very “all inclusive” view of European countries was taken, for example Ukraine and Turkey added 115 million to the total population alone. On the converse side over 20 countries of those listed each contribute less than 2% to the overall population. See table 4.3.3 for details.

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[3] In this table AP-MP is not separately reflected as it is a hybrid of PMP and mesh.

	Population (millions)	Percentage of total
Austria	8.2	1.1%
Belgium	10.3	1.3%
Bulgaria	7.7	1.0%
Czech Republic	10.3	1.3%
Denmark	5.4	0.7%
Estonia	1.4	0.2%
Finland	5.2	0.7%
France	59.8	7.8%
Germany	83.0	10.9%
Greece	10.6	1.4%
Hungary	10.1	1.3%
Ireland	3.9	0.5%
Italy	58.0	7.6%
Latvia	2.4	0.3%
Lithuania	3.6	0.5%
Luxembourg	0.4	0.1%
Netherlands	16.0	2.1%
Norway	4.5	0.6%
Poland	39.0	5.1%
Portugal	10.1	1.3%
Romania	22.3	2.9%
Russian Federation	145.0	19.0%
Slovakia	5.4	0.7%
Spain	40.0	5.2%
Sweden	8.9	1.2%
Switzerland	7.3	1.0%
Turkey	67.3	8.8%
UK	59.8	7.8%
Ukraine	48.0	6.3%
Others	11.0	1.4%
Total	**764.9**	**100%**

Table 4.3.3 Population statistics[4]

NOTE: “Others” includes - Croatia, Bosnia-Herzegovina, Iceland, Malta, FYR of Macedonia, Monaco, Slovenia

4.3.4 FWA Deployment Density

For assessing the density of residential deployments, it is prudent to use the typical household density and adjust this with the expected highest market penetration of 10%. A margin of error of 50% should be adequate to account for locally higher densities.

Environment:	**Rural**	**Suburban**	**Urban**
Average household density	20	200	2 000
Household density range	5 to 500	100 to 1000	1 000 to 8 000
NOTE: Source: TR 101 177			

Table 4.3.4: Household densities in Europe (Households per square km)

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[4] For this study the total population of the Russian Federation has been included. This is considered to be a reasonable assumption since it will yield a conservative result for the satellite sharing studies.

This leads to the following density figures:

Environment:	**Rural**	**Suburban**	**Urban**
Residential FWA deployment density (links per sq km)	3	30	300
SME FWA deployment density (links per sq km)	.3	3	30

Table 4.3.5: Projected FWA connection densities in Europe

Note: the number of connections corresponds to the number of transmitters that are deployed. Transmitter activity varies with the type of FWA system – it is higher for Mesh and P-P transmitters than is it is for P-MP transmitters.

For completeness, Table 4.3.6 lists the typical link distances based on the information in preceding sections. It is noted that the link distance for Mesh systems has been taken as 1/3 of the maximum range of P-MP systems to accommodate the fact that the number of link hops needed to connect members of a mesh is typically 3.

Environment:	Rural	Suburban	Urban
P-MP/AP-MP maximum link distance (m)	5000	2000	1000
Omni-directional Mesh maximum link distance (m)	1500	600	333
Directional Mesh maximum link distance (m)	5000	2000	1000

Table 4.3.6: Assumed typical FWA link distances

4.4 General considerations on FWA system power limits and interference issues

In general, FWA systems are used to connect users to (wired) infrastructure such as a fibre point of presence (POP). It is obvious that the range of the FWA will determine number of users that can be reached from a given POP. That number, in general, increases with the square of the range achieved. Path loss however typically increases with the 4th power of the distance and therefore a lower e.i.r.p. limit leads to short operating ranges.

Interference is determined by the power/time/space product, a constant e.i.r.p. is a simplification that hides many possibilities for achieving adequate protection of incumbents. By using more directional antennas it may be possible to increase the e.i.rp. without increasing the aggregate interference effect to other incumbents using the band provided that the transmitter power is not increased

For example, if an antenna pattern increases the horizontal on-axis gain by 10 dB, and reduces the off-axis gain accordingly, the probability of pointing towards a given victim is reduced. This increase in signal strength in the main lobe would be matched by a reduced probability of pointing towards the victim. Under normal propagation conditions, such directional systems may not cause more interference than its omni-directional cousin, only the distribution in space is different. Some of these considerations have not been fully explored in this report, future analysis may lead to more flexibility in the determination of e.i.r.p limits.

5 CHARACTERISTICS OF OTHER SERVICES IN THE BAND 5725 - 5875 MHZ

The following services and systems are covered within this study:
5.1 Radiolocation Service
5.2 Road Transport and Traffic Telematic (RTTT) Systems
5.3 Fixed Service (Point-to-Point Links)
5.4 Fixed-Satellite (E-s) Service (FSS)
5.5 General (non-specific) short range devices (SRD)
5.6 Amateur Service, Amateur-satellite (s-E) Service

Table 5.1 is the extract from the ITU Radio Regulations for the bands used through this report.

Table 5.1.1: Extract of Article 5 of the ITU Radio Regulations

Region 1	Region 2	Region 3
5 725-5 830 FIXED-SATELLITE (Earth-to-space) RADIOLOCATION Amateur 5.150 5.451 5.453 5.455 5.456	**5 725-5 830** RADIOLOCATION Amateur 5.150 5.453 5.455	
5 830-5 850 FIXED-SATELLITE (Earth-to-space) RADIOLOCATION Amateur Amateur-satellite (space-to-Earth) 5.150 5.451 5.453 5.455 5.456	**5 830-5 850** RADIOLOCATION Amateur Amateur-satellite (space-to-Earth) 5.150 5.453 5.455	
5 850-5 925 FIXED FIXED-SATELLITE (Earth-to-space) MOBILE 5.150	**5 850-5 925** FIXED FIXED-SATELLITE (Earth-to-space) MOBILE Amateur Radiolocation 5.150	**5 850-5 925** FIXED FIXED-SATELLITE (Earth-to-space) MOBILE Radiolocation 5.150

Table 5.2.1: Extract of Article 5 of the ITU Radio Regulations

<u>Footnotes of RR Art. 5 relevant for CEPT countries:</u>

5.150 The following bands: ... 5 725-5 875 MHz (centre frequency 5 800 MHz), and ... are also designated for industrial, scientific and medical (ISM) applications. Radiocommunication services operating within these bands must accept harmful interference which may be caused by these applications. ISM equipment operating in these bands is subject to the provisions of No. **15.13**.

5.451 *Additional allocation:* in the United Kingdom, the band 5 470-5 850 MHz is also allocated to the land mobile service on a secondary basis. The power limits specified in Nos. **21.2**, **21.3**, **21.4** and **21.5** shall apply in the band 5 725-5 850 MHz.

5.455 *Additional allocation:* in Armenia, Azerbaijan, Belarus, Cuba, the Russian Federation, Georgia, Hungary, Kazakhstan, Latvia, Moldova, Mongolia, Uzbekistan, Kyrgyzstan, Tajikistan, Turkmenistan and Ukraine, the band 5 670-5 850 MHz is also allocated to the fixed service on a primary basis. (WRC-03)

5.1 Radiolocation Service

The bands between 5 725 and 5 850 MHz are allocated to the Radiolocation service on a primary basis.

5.1.1 Technical characteristics

Recommendation ITU-R M.1638 provides characteristics of radars operating under the Radiolocation services in the frequency range 5250-5850 MHz. Within this range, the band between 5 725 and 5 850 MHz is used by many different types of radars on fixed land-based, shipborne and transportable platforms. It should be noted that most of these radars are designed to operate not only in the 5725-5850 MHz band but in a larger portion of the band 5250-5850 MHz.

Table 5.1.1 contains technical characteristics of representative systems deployed in this band. This includes a subset of the radars contained in Recommendation ITU-R M.1638, which are relevant for the frequency band 5725-5850 MHz (radars L, M, N, O and Q) and three additional radars operated by administrations within CEPT (X, Y and Z). This information is generally sufficient for calculation to assess the compatibility between these radars and other systems.

Frequency hopping is one of the most common Electronic-Counter-Counter-Measures (ECCM). Radar systems that are designed to operate in hostile electronic attack environments use frequency hopping as one of its ECCM techniques. This type of radar typically divides its allocated frequency band into channels. The radar then randomly selects a channel from all available channels for transmission. This random occupation of a channel can occur on a per beam position basis where many pulses on the same channel are transmitted or on a per pulse basis. This important aspect of radar systems should be considered and the potential impact of frequency hopping radar should be taken into account in sharing studies.

5.1.2 Operational characteristics of Radiolocation systems

There are numerous radar types, accomplishing various missions, operating within the Radiolocation service throughout the whole range 5250-5850 MHz, and specifically within the 5725-5850 MHz band. Test range instrumentation radars are used to provide highly accurate position data on space launch vehicles and aeronautical vehicles undergoing developmental and operational testing. These radars are typified by high transmitter powers and large aperture parabolic reflector antennas with very narrow pencil beams. The radars have auto-tracking antennas which either skin-track or beacon-track the object of interest. Periods of operation can last from minutes up to 4-5 hours, depending upon the test program. Operations are conducted at scheduled times 24 hours/day, 7 days/week.

Shipboard sea and air surveillance radars are used for ship protection and operate continuously while the ship is underway as well as entering and leaving port areas. These surveillance radars usually employ moderately high transmitter powers and antennas which scan electronically in elevation and mechanically a full 360 degrees in azimuth. Operations can be such that multiple ships are operating these radars simultaneously in a given geographical area. Other special-purpose radars are also operated in the band 5250-5850 MHz.

5.1.3 Protection criteria

The de-sensitising effect on radars operated in this band from other services of a CW or noise-like type modulation is predictably related to its intensity. In any azimuth sectors in which such interference arrives, its power spectral density can simply be added to the power spectral density of the radar receiver thermal noise, to within a reasonable approximation. If power spectral density of radar-receiver noise in the absence of interference is denoted by N_0 and that of noise-like interference by I_0, the resultant effective noise power spectral density becomes simply I_0+N_0. An increase of about 1 dB for the Radiolocation radar would constitute significant degradation. Such an increase corresponds to an $(I+N)/N$ ratio of 1.26, or an I/N ratio of about –6 dB. This protection criteria represent the aggregate effects of multiple interferers, when present. The tolerable I/N ratio for an individual interferer depends on the number of interferers and their geometry, and needs to be assessed in the course of analysis of a given scenario. The aggregation factor can be very substantial in the case of certain communication systems, in which a great number of stations can be deployed.

Characteristics	**Radar L**	**Radar M**	**Radar N**	**Radar O**	**Radar Q**	**Radar X (Note 1)**	**Radar Y (Note 1)**	**Radar Z**
Function	Instrumentation	Instrumentation	Instrumentation	Instrumentation	Surface and air search	Surface and air search	Surface and air search	Search
Platform type (airborne, shipborne, ground)	Ground	Ground	Ground	Ground	Ship	Ground /Vehicle	Ground /Vehicle	Ground /Vehicle
Tuning range (MHz)	5 350-5 850	5 350-5 850	5 400-5 850	5 400-5 850	5 450-5 825	5400 – 5850	5400 – 5850	5250 – 5850
Modulation	None	None	Pulse/chirp pulse	Chirp pulse	None	None	None	Non-Linear FM
Tx power into antenna	2.8 MW	1.2 MW	1.0 MW	165 kW	285 kW	12 kW peak	12 kW peak	70 kW
Pulse width (□s)	0.25, 1.0, 5.0	0.25, 0.5, 1.0	0.25-1 (plain) 3.1-50 (chirp)	100	0.1/0.25/1.0	4-20	4-20	3.5/6/10
Pulse rise/fall time (□s)	0.02-0.5	0.02-0.05	0.02-0.1	0.5	0.03/0.05/0.1	No detail	No detail	N/A
Pulse repetition rate (pps)	160, 640	160, 640	20-1 280	320	2 400/1 200/ 750	1000-7800	1000-7800	2500/3750
Chirp bandwidth (MHz)	N/A	N/A	4.0	8.33	N/A	No detail	No detail	
RF emission bandwidth –3 dB –20 dB (MHz)	0.5-5	0.9-3.6 6.4-18	0.9-3.6 6.4-18	8.33 9.9	5.0/4.0/1.2 16.5/12.5/7.0	5	5	
Antenna pattern type (pencil, fan, cosecant-squared, etc.)	Pencil	Pencil	Pencil	Pencil	Fan	N/A	N/A	N/A
Antenna type (reflector, phased array, slotted array, etc.)	Parabolic	Parabolic	Phased Array	Phased Array	Travelling wave feed horn array	N/A	N/A	Phased Array
Antenna polarization	Vertical/Left-hand circular	Vertical/Left-hand circular	Vertical/Left-hand circular	Vertical/Left-hand circular	Horizontal	Vertical	Vertical	Horizontal
Antenna mainbeam gain (dBi)	54	47	45.9	42	30.0	35	35	31.5

Table 5.1.1: Characteristics of Radiolocation systems

Table 5.1.1 (*CONTINUED*)

Characteristics	**Radar L**	**Radar M**	**Radar N**	**Radar O**	**Radar Q**	**Radar X**	**Radar Y**	**Radar Z**
Antenna elevation beamwidth (degrees)	0.4	0.8	1.0	1.0	28.0	N/A	N/A	43.8
Antenna azimuthal beamwidth (degrees)	0.4	0.8	1.0	1.0	1.6	N/A	N/A	1.75
Antenna horizontal scan rate (degrees/s)	N/A (Tracking)	N/A (Tracking)	N/A (Tracking)	N/A (Tracking)	90	- - N/A (tracking)	180/360	120/180
Antenna horizontal scan type (continuous, random, 360□, sector, etc.)	N/A (Tracking)	N/A (Tracking)	N/A (Tracking)	N/A (Tracking)	30-270□ Sector	N/A	N/A	N/A
Antenna vertical scan rate (degrees/s)	N/A (Tracking)	N/A (Tracking)	N/A (Tracking)	N/A (Tracking)	N/A	N/A	N/A	N/A
Antenna vertical scan type (continuous, random, 360□, sector, etc.) (degrees)	N/A (Tracking)	N/A (Tracking)	N/A (Tracking)	N/A (Tracking)	Fixed	N/A	N/A	N/A
Antenna sidelobe (SL) levels (1st SLs and remote SLs) (dB)	-20	-20	-22	-22	-25	-40	-40	N/A
Antenna height (m)	20	8-20	20	20	40	10	10	6 – 13
Receiver IF 3 dB bandwidth	4.8, 2.4, 0.25 MHz	4, 2, 1 MHz	2-8 MHz	8 MHz	1.2,10 MHz	4MHz	4MHz	N/A
Receiver noise figure (dB)	5	5	11	5	10	5	5	≤ 13dB
Minimum discernable signal (dBm)	–107	–100	–107,–117	–100	–94 (short/medium pulse) –102 (wide pulse)	-103	-103	-108

Note 1: Radars X and Y can operate both in fixed frequency and in hopping mode: the following parameters have to be taken into account in the different compatibility studies in the band 5725-5875 between FWA and Radiolocation service.

Frequency hopping characteristics

Frequency band: 5250-5850MHz or 5470-5875
type of frequency hopping: random
hopping rate : 300 to 1500 Hz
number of frequency : 1 frequency /10MHz

5.2 Road Transport and Traffic Telematics (RTTT) Systems

ECC Decision (02)01 designates the frequency bands 5795-5805 MHz, with possible extension to 5815 MHz, for RTTT. The band 5795-5805 MHz is for use by initial road-to-vehicle systems, in particular road toll systems, with an additional sub-band, 5805-5815 MHz, to be used on a national basis to meet the requirements of multi-lane road junctions.

5.2.1 Parameters

The regulatory parameters (maximum power levels) for RTTT are given in Annex 5 of ERC Recommendation 70-03. The RTTT parameters used in this Report are taken from the EN 300 674 developed by ETSI and the EN12253 developed by CENELEC. It should be noted that the EN 300 674 deals with both Road Side Units (RSU) and On-Board Units (OBU) and is divided in two parts, the part 1 providing general characteristics and test methods, the part 2 containing the essential requirements under article 3.2 of the R&TTE Directive.

	Road Side Units	**On Board Units**
Carrier frequencies (MHz)	5797.5, 5802.5 (5807.5, 5812.5 MHz for multi-lane road junctions at a national level)	
e.i.r.p.	2 W (33 dBm) standard for -35°≤θ≤35° 18 dBm for θ > 35° 8 W (39 dBm) optional	Maximum re-radiated sub-carrier e.i.r.p.: -24 dBm (Medium data rate) -14 dBm (High data rate)
Antenna gain	10-20 dB (assumed front-to-back ratio of 15 dB)	1-10dB (assumed front-to-back ratio of 5dB)
Transmitter Bandwidth	1 MHz	500 kHz
Receiver bandwidth	500 kHz	200 MHz – 1.4 GHz (not used)
Polarization	left circular	left circular
Receiver sensitivity (at the receiver input)	-104 dBm (BPSK)	-60dBm
Co-channel C/I (dB)	6 for 2-PSK, 9 for 4-PSK, 12 for 8-PSK	Not defined

Table 5.2.1: Summary of characteristics of the RTTT systems

5.2.2 Protection Criteria

OBU
The OBU requires a -60 dBm signal in order to function at all and to understand commands from the RSU. Assuming negligible re-radiation loss and a signalling distance of 8 m, the received signal strength at the OBU should be -59 dBm or higher[5]. This corresponds to power density of -56 dBm/MHz. Assuming that simple BPSK is used, the required margin is 6 dB and thus the protection criterion for the OBU would be – 62 dBm/MHz on-axis and -57dBm/MHz off-axis.

RSU
The RSU, when operating in BPSK mode requires a 6 dB margin over its receiver sensitivity: this gives -107 dBm at the receiver input or density of -98 dBm/MHz at the input to an antenna with a -9 dB off-axis gain. Since the RSU antenna points at the road surface, no on-axis gain is taken into consideration.

5.3 Fixed Service (Point-to-Point Links)

ITU-R Recommendation F.383-7 defines the channel arrangements for the lower 6 GHz band. Depending on which channel arrangements are chosen, the frequency range may extend from 5850 – 6425 MHz. ERC Recommendation 14-01 defines the CEPT harmonised channel plans for Radio-frequency channel arrangements for high capacity analogue and digital radio-relay systems operating in the band 5925 MHz - 6425 MHz.
The harmonised CEPT arrangements are based on recommends 1 of Recommendation F.383-7, which do not extend below 5925 MHz. In relation to the bands 5850-7075/7125 MHz, ECC Report 3, "Fixed service in Europe current use and future trends POST-2002" states that "the part of the range below 5925 MHz is used for

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[5] The receiver sensitivity of the RSU is -104 dBm for BPSK. The free space loss over 8 m is 18dB, antenna gain is assumed to be 15 dB at the RSU and 5dB at the OBU; the 1 m loss factor is 47 dB

fixed links only in few European countries and mostly for old analogue links. No further interest for developing FS in this part of the range is indicated."

5.4 Fixed Satellite (E-s) Service (FSS)

As shown in Table 5.1, FSS deployments use the whole band 5725 – 5875 MHz and it is used by transmitting earth stations in the Earth-to-space direction operating only to satellites in geostationary orbits. In the 125 MHz portion of the band up to 5850 MHz, this is a Region 1 allocation only (i.e. only Europe, Africa, and some of the northernmost countries in Asia[6]). Above 5850 MHz the band is part of the heavily utilised FSS global uplink band and most of the currently operating satellites (INTELSAT & New Skies for instance) have receive transponders in this upper portion of the band.

Satellite	Sub-satellite longitude	Part of Frequency range 5725-5875 MHz used	Satellite Maximum Receive Gain G_{sat}(dBi)	Space Station Receiving System Noise Temperature T_{sat} (Kelvin)
A	5° West	Whole band	34	773
B	14° West	Whole band	26.5	1200
C	31.5° West	> 5850 MHz	32.8	700
D	3° East	Whole band	34	773
E	18° West	>5850MHz	32.8	700
F	53° East	Whole band	26.5	1200
G	59.5° East	Whole band	34	1200
H	66° East	>5850 MHz	34.7	700
I	359° East	>5850 MHz	32.8	700

Table 5.4.1: Sample Satellite Data taken from ITU filings for the band 5725 – 5875MHz

Table 5.4.1 provides details of the selection of satellites that have been taken as representative of those requiring protection in the visible portion of the geostationary orbit from Europe. The parameters shown are those required in sharing studies with the FWA systems. In these frequency bands, the satellite beams cover very large areas of the Earth (using global, hemispherical, zonal or regional beams) as can be seen by the satellite footprint coverage plots in Annex 6. These gain contour plots are used to determine the receive gain in the direction of the FWA devices.

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[6] Refer to Article 5 of the ITU Radio Regulations (provisions **5.2** & **5.3**)

Figure 5.4.1 shows the basic sharing scenario between FWA terminals and the FSS service. The studies reported on in Section 6.4 address the aggregate emissions of a large number of FWA terminals into the satellite receivers.

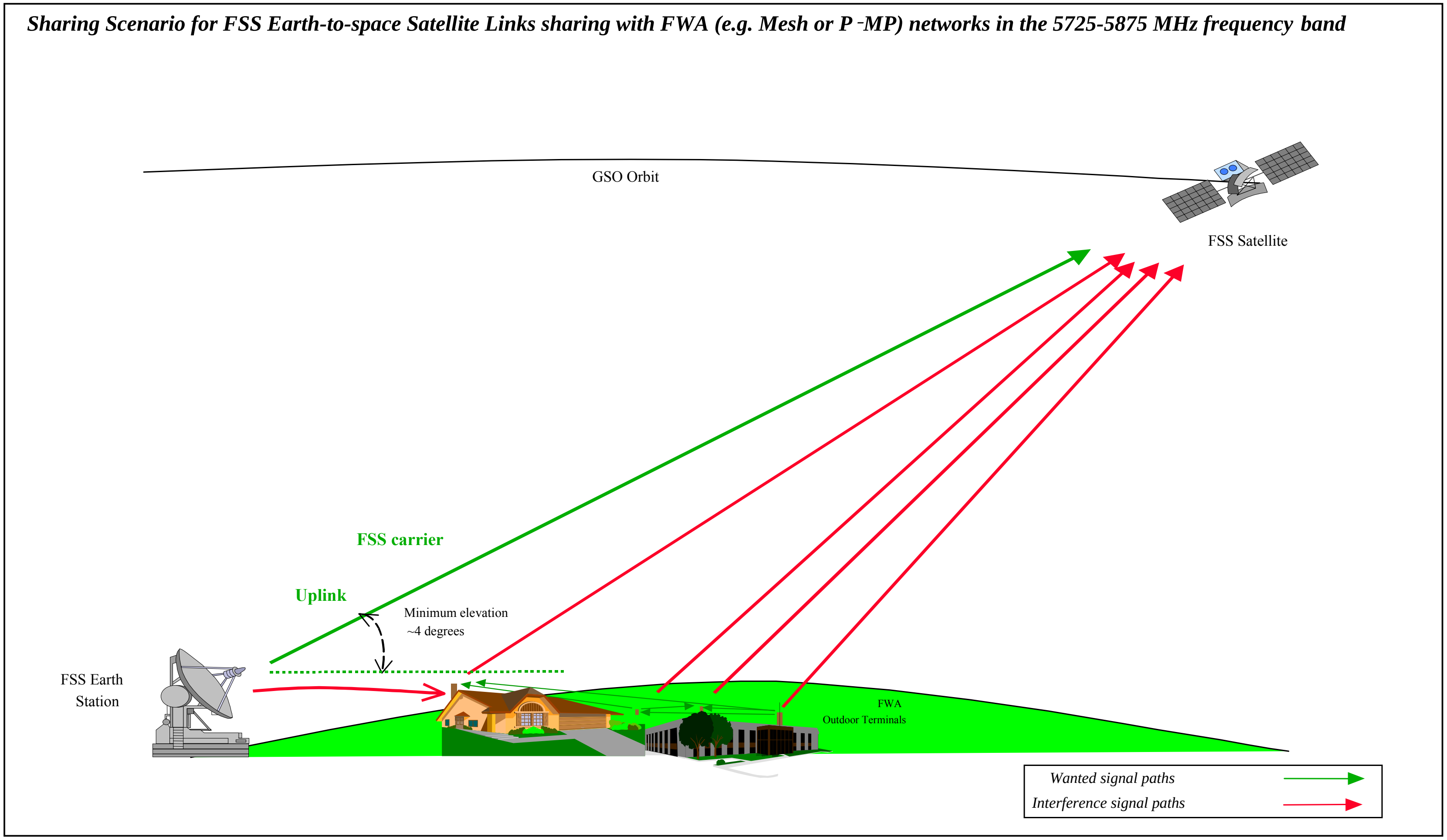

Figure 5.4.1: FSS/FWA Sharing Scenario in the band 5725-5875 MHz

5.5 General (Non-Specific) Short Range Devices

As specified in Annex 1 of ERC Recommendation 70-03, the frequency band 5725-5875 MHz is used by non-specific SRD. From ERC Decision (01)06, this use should comply with the technical characteristics as shown below.

Frequency Band	Power	Antenna	Channel Spacing	Duty Cycle (%)
5725-5875 MHz	25 mW e.i.r.p.	Integral (no external antenna socket) or dedicated	No channel spacing - the whole stated frequency band may be used	No duty cycle restriction

Table 5.5.1: Technical characteristics of SRD

In addition to these regulatory technical characteristics, assumptions on some parameters had to be made in order to carry out sharing studies. These are summarized in the table below.

Parameter	Typical min. RX bandwidth	Typical max. RX bandwidth	DVS RX bandwidth	Comments
	0.25 MHz	20 MHz	8MHz	Note 1, Note 2.
Tx Power, dBm e.i.r.p.	+14	+14	+14	
Ant. Gain, dBi	2 to 20	2 to 24	2	
Ant. Polarization	Circular	Circular	Vertical	
Receiver sensitivity, conducted, dBm	-110	-91	-84	
Co-channel C/I, dB	8	8	20	
Max out-of-band RX interference : dBm	-35	-35	-35	e.g. Limit for RX blocking
Duty cycle : %	Up to 100%	Up to 100%	100%	
RX wake-up time (if applicable)	1 sec	1 sec	N/A	For battery operated equipment
Note 1: The given bandwidths are for non-spread spectrum modulation. *Note 2: For spread spectrum modulation (FHSS, DSSS and other types) the bandwidth can be up to 100 MHz*				

Table 5.5.2: Assumed SRD Parameters

Digital Video sender (DVS) System Planned for use in 5.8GHz Band

The UK Digital TV Group (DTG) Wireless Home Networks group have looked at feasibility studies into using the 5.8 GHz band for Digital Video Senders to re-broadcast DVB-T signals throughout home. They have concluded that the 5.8 GHz band can be used to offer a relatively simple and low cost means of delivering digital TV services to 2nd and 3rd TV's in typical UK homes if both transmit delay diversity and MRC receive diversity processing are used. Transmit delay diversity only would be sufficient if the transmit e.i.r.p. could be increased by 3dB.

Figure 5.5.1 below shows a block diagram of the proposed DVS system (without any diversity processing).

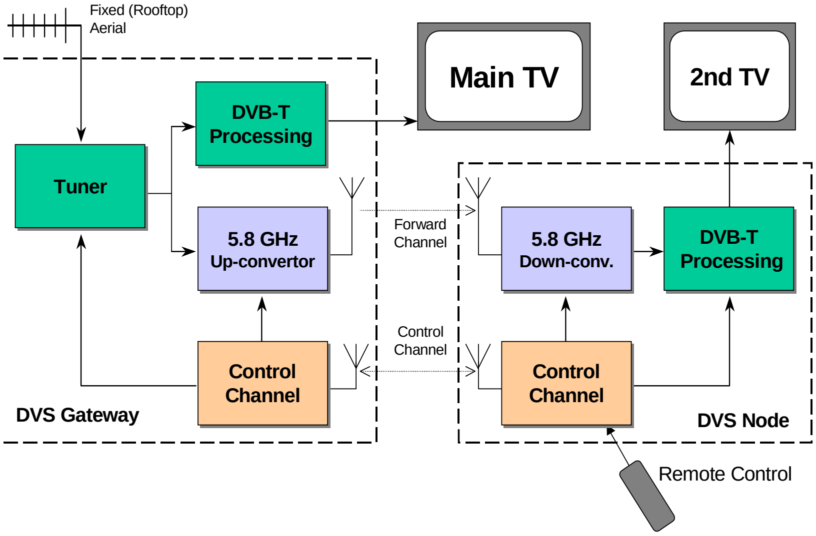

Figure 5.5.1: DVS System

5.6 Amateur Service/Amateur-satellite (s-E) Service

The amateur and amateur-satellite (s-E) services have allocations in the frequency range 5725 – 5850 MHz with secondary status as follows:

5725 – 5830 MHz	Amateur
5830 – 5850 MHz	Amateur Amateur-satellite (space-to-Earth)

Table 5.6.1: Allocation for Amateur Services

The characteristics of the amateur stations and amateur-satellite earth stations are not generally known due to the fact that the amateur service is an experimental service. For interference studies, however amateur activities using relatively large transmitter power (in the order of 10-20 dBW) and state of the art receiver sensitivities (receiver noise figures near 1 dB and receiver bandwidths between 2 kHz and 18 MHz) were assumed. The following characteristics are taken from Draft Recommendation ITU-R M.[char-as].

Mode of operation	**SSB voice**	**FM voice**
Frequency band (MHz)	902-47 200	902-47 200
Necessary bandwidth and class of emission (emission designator)	2K70J3E	11K0F3E 16K0F3E 20K0F3E
Transmitter power (dBW)	3-31.7	3-31.7
Feeder loss (dB)	0-10	0-10
Transmitting antenna gain (dBi)	0-40	0-40
Typical e.i.r.p. (dBW)	1-45	1-45
Antenna polarisation	Horizontal, vertical	Horizontal, vertical
Receiver IF bandwidth (kHz)	2.7	9 15
Receiver noise figure (dB)	1-7	1-7

Table 5.6.2: Characteristics of amateur analogue voice systems

Mode of operation	**Digital voice and multimedia**
Frequency band (MHz)	5 650-10 500
Necessary bandwidth and class of emission (emission designator)	2K70G1D 6K00F7D 16K0D1D 150KF1W 10M5F7W
Transmitter power (dBW)	3
Feeder loss (dB)	1-6
Transmitting antenna gain (dBi)	36
Typical e.i.r.p. (dBW)	38
Antenna polarisation	Horizontal, vertical
Receiver IF bandwidth (kHz)	2.7, 6, 16, 130, 10 500
Receiver noise figure (dB)	2

Table 5.6.3: Characteristics of amateur digital voice and multimedia systems

Mode of operation	**CW Morse 10-50 baud**	**SSB voice, digital voice, FM voice,data**
Frequency band (MHz)	144-5 850	144-5 850
Necessary bandwidth and class of emission (emission designator)	150HA1A 150HJ2A	2K70J3E 16K0F3E 44K2F1D 88K3F1D
Transmitter power (dBW)	10	10
Feeder loss (dB)	0.2-1	0.2-1
Transmitting antenna gain (dBi)	0-6	0-6
Typical e.i.r.p. (dBW)	9-15	9-15
Antenna polarisation	Horizontal, vertical, RHCP, LHCP	Horizontal, vertical, RHCP, LHCP
Receiver IF bandwidth (kHz)	0.4	2.7 16 50 100
Receiver noise figure (dB)	1-3	1-3

Table 5.6.4: Characteristics of amateur-satellite systems in the space-to-Earth direction

Mode of operation	CW Morse10-50 baud
Frequency band (MHz)	902-47200
Necessary bandwidth and class of emission (Emission designator)	150HA1A 150HJ2A
Transmitter power (dBW)	3-31.7
Transmitter line loss (dB)	0-10
Transmitting antenna gain (dBi)	10-40
Typical e.i.r.p. (dBW)	1-45
Antenna polarisation	Horizontal, vertical
Receiver IF bandwidth (kHz)	0.4
Receiver noise figure (dB)	1-7

Table 5.6.5 Characteristics of amateur systems for Morse on-off keying

6 COMPATIBILITY STUDIES

The section details the compatibility studies between the FWA systems detailed in section 4 and other radiocommunications services and systems which were detailed in section 5.

6.1 Radiolocation Service

This section of the report examines the prospects of co-channel sharing between radar systems and FWA operating in frequency band 5725 – 5850 MHz. Information and technical characteristics of the considered radars can be found in section 5.1. This section provides basic calculations of the interference level from a single FWA device into radars and identifies the need for mitigation techniques which are described in subsequent sections.

6.1.1 Determination of the interference level from FWA into Radar

6.1.1.1 Methodology for calculating interference from FWA into Radar

The determination of the maximum tolerable interference level from emissions of a single FWA device at the radar receiver is based on Recommendation ITU-R M.1461, where it is said that this level should be lower than $N + (I/N)$ where N is the radar receiver inherent noise level and I/N the interference to noise ratio. The interference to noise ratio can be taken as –6 dB as given in Recommendations ITU-R M.1461 and ITU-R M.1638.

Interference from FWA into Radars

The horizon of the radars and FWA systems would be relevant for working on a co-channel basis. A basic calculation of interference to radars is shown in the table below.

The method used to calculate the potential interference to Radiolocation devices is based on the Minimum Coupling Loss (MCL) required between radars and FWA systems as described in Recommendation ITU-R M.1461. The separation distances can initially be calculated using the Free Space propagation model.

$$MCL=P_{tr}+10\log\{BW_{radar}/Bw_{Hip}\} - I_{rec}$$

where

MCL	Minimum Coupling Loss in dB
P_{tr}	Maximum Transmit Power, before antenna and feeders (FWA) in dBW
BW_{radar}	Receiver Noise Bandwidth (Radar) in Hz
Bw_{Hip}	Transmitter Bandwidth (FWA) in Hz
I_{rec}	Maximum Permissible Interference at Receiver after antenna and feeder (Radar) in dB

The MCL is then converted into the required propagation loss L as follows:

$$L= MCL + G_{tr} - L_{tr} + G_{rec} - L_{rec}$$

where

G_{tr}	Gain of the FWA antenna in dBi
L_{tr}	FWA feeder loss in dB
G_{rec}	Gain of Radar antenna in dBi
L_{rec}	Radar feeder loss in dB

The required separation distances d (in metres) were calculated, assuming free space propagation, from:

$$d=\lambda/(4\pi)*10^{L/20}$$

where:
λ is the wavelength given in metres.

6.1.1.2 Determination of required separation distance

For these calculations, basic assumptions have been chosen for the FWA parameters:

- transmit power and antenna gain, leading to an e.i.r.p. of 36 dBm in a bandwidth of 20 MHz.

With these assumptions, the results of table 6.1.1 below show that, with all the radars under consideration, the necessary separation distances are determined by the value of the radio-horizon *He* which is calculated with the following formula:

$$He(\mathrm{km})=4.12*(Hfwa^{0.5} + Hrad^{0.5})$$

where:
Hfwa and *Hrad* correspond to the antenna heights of the FWA and radar respectively.

With the assumed antenna heights for *Hfwa* and *Hrad*, *He* is in the order of 40 – 55 km.

It can be concluded that mitigation techniques are required to enable the sharing between FWA systems and radars. The consideration of alternative parameters for FWA systems will not change drastically the required separation distances and will not modify the main conclusion that mitigation techniques are required.

			T=	290	°K			
	characteristics	**L**	**M**	**N**	**O**	**Q**	**X & Y**	**Z**
R	**Tx power into antenna peak**	2800	1200	1000	165	285	12	70
A	**Receiver IF3dB bandwidth MHz**	4.8	4	8	8	10	4	1
D	**Antenna mainbeam gain**	54	47	45.9	42	30	35	31.5
A	**Antenna height (m)**	20	15	20	20	40	10	10
R	**Radar feeder loss**	0	0	0	0	0	0	0
	E.i.r.p radar (dBm)	148.5	137.8	135.9	124.2	114.5	105.8	110.0
	Mini discernible signal (dBm)	-110	-97	-109	-112	-114	-103	-108
	Receiver noise figure	7	4	2.3	3	3	5	13
	N=FkTB (dBm)	-102.2	-103.0	-93.9	-99.9	-94.0	-103.0	-101.0
	N - 6dB	-108.2	-109.0	-99.9	-105.9	-100.0	-109.0	-107.0
B	**FWA e.i.r.p (dBm) outdoor**	**36**						
F	**FWA feeder loss**	**0**						
W	**TPC (dB)**	**0**						
A	**FWA BS antenna height (m)**	**50**						
	Bandwith (MHz)	**20**						
	Bandwidthconversion FWA to radar	6.2	7.0	4.0	4.0	3.0	7.0	13.0
	Required proagation loss	192.0	185.0	177.9	180.0	163.0	173.0	161.5
	Frequency (MHz)	5800.0	5800.0	5800.0	5800.0	5800.0	5800.0	5800.0
	Free space distance (km)	**16402.8**	**7326.9**	**3235.3**	**4120.2**	**582.0**	**1840.4**	**489.7**
	Radio Horizon (km)	48	45	48	48	55	42	42
	Separation distance (km)	48	45	48	48	55	42	42

Table 6.1.1 Results of required separation distances between FWA and radars, based on the radar characteristics stated in section 5.1

6.1.2 The use of Dynamic Frequency Selection (DFS) as a method to enable sharing between Radiolocation service and FWA systems in the 5.8 GHz band'

6.1.2.1 Introduction to DFS

This section will introduce DFS as a concept to enable sharing between the FWA devices and the Radiolocation service in the frequency bands 5 725 - 5850 MHz. The link budget calculations in the previous section have shown that interference mitigation techniques are required to enable sharing between FWA and radar systems. This Section of the report describes and suggests some performance parameters for the interference mitigation technique(s) called DFS[3]. The DFS techniques described here are similar to that specified in the ITU- R Recommendation M.1652. This report looks at some new DFS performance parameters based on typical FWA/Radiolocation implementations.

FWA and radar operating in the 5.8 GHz band will interfere with each other when operating at the same frequencies and within range of each other if no mitigation techniques are used.

DFS is a method that is envisaged to avoid FWA co-channel operation with radiolocation systems in the same vicinity, but enable co-existence of FWA and Radiolocation services in the same region without the risk of harmful interference.

Use of DFS as described herein allows FWA to avoid causing harmful interference to the Radiolocation service. The general principle applied is that FWA devices should detect any radar signal above a defined receiver threshold and make sure that the FWA system shall not use those frequencies identified as being used by the radar. The DFS mechanism would then have the effect of protecting both the FWA and Radar systems from harmful interference.

6.1.2.2 Objective of the use of DFS with respect to protection of radar

The objective of introducing DFS into FWA networks is to provide adequate protection from harmful interference to the radiolocation services operating under a primary allocation in the 5.8 GHz band. This is achieved by avoiding the use of, or vacating, a channel identified as being occupied by a radiolocation system based on detection of radar signals above a defined receiver threshold.

For the purpose of this report, a discussion of Radiolocation systems in the 5.8 GHz band utilised in determining DFS characteristics can be found in table 6.1.1.

The implementation of radar detection mechanisms and procedures used by FWA systems are outside the scope of this Report. The main reasons for this are that:

- FWA design affects implementation;
- practical experience may lead to innovative and more efficient means than can be formulated today;
- different manufacturers can make different implementation choices to achieve the lowest cost for a given level of performance.

6.1.2.3 DFS performance requirements

The DFS performance requirement is stated in terms of response to detection of an interference signal. 5.8 GHz FWA devices should meet the following detection, operational and response requirements.

An example of how a DFS mechanism operating procedures could be described is given in Annex 3.

6.1.2.3.1 Detection requirements

The DFS mechanism should be able to detect interference signals above a minimum DFS detection threshold. The detection threshold is the required Radar signal strength expressed as equivalent power in dBm at the front of the FWA receive antenna. The corresponding threshold value at the input of the receiver is obtained by adding the gain of the FWA receive antenna to the detection threshold.

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[3] The DFS feature specified for the 5.8 GHz FWA devices may also be used to mitigate interference among uncoordinated FWA networks, and to provide optimised spectral efficiency for high-capacity, high bit-rate data transmission

6.1.2.3.2 Operational requirements

The DFS mechanism should be able to perform Channel Availability Check: A check during which the DFS mechanism listens on a particular radio channel for a certain duration (*Channel Availability Check Time*) to identify whether there is a radar operating on that radio channel.

The DFS mechanism should be able to perform in-service monitoring, i.e. monitoring of the operating channel to check that a co-channel radar has not moved or started operation within range of an FWA system. During in-service monitoring the radar detection function continuously searches for radar signals.

In addition, DFS may be used to perform background monitoring of any channel at any time to determine the presence of radiolocation systems.

If the DFS mechanism has not checked a channel (by means of a channel availability check or background monitoring) less than a certain amount of time (*channel revalidation period)* ago, the FWA system shall not start transmission in that channel before completion of the channel availability check.

FWA systems may have any of the architectures listed in section 4 and may use directional antennas. DFS implementations shall take this into account in order to assure that radar detection operates under all circumstances and in all directions. This normally requires that a DFS mechanism is implemented in all devices that make up an FWA system; in some cases a centralized DFS mechanism may be sufficient to protect the radiolocation service.

6.1.2.3.3 Response requirements

When a radar signal has been detected, the FWA System shall cease all transmissions on the operating channel within the *Channel Move Time*. The aggregate duration of transmissions during the *Channel Move Time* should be limited to the *Channel Closing Transmission Time.*

A channel that has been flagged as containing a radar signal, either by a channel availability check or in-service monitoring, cannot be re-occupied before the end of the *Non-Occupancy Period*.

6.1.3 Interference assessment using link budget calculations involving a single FWA device and radiodetermination systems in the 5.8 GHz band

6.1.3.1 Background

This section addresses the case of interference from a single FWA device and is aimed at determining preliminary values for the DFS detection threshold. These values were then used as starting values in the aggregate modelling (see section 6.1.4) to check their relevance for providing adequate protection to the radiolocation systems.

6.1.3.2 Methodology

The calculations presented are based on link budget analysis. The threshold is determined from a link budget analysis, assuming that this threshold must be reached when the radar can be interfered with by emissions of a single FWA device (i.e. when the FWA signal at the radar receiver exceeds the radar tolerable interference level). This is based on the assumption of a symmetrical propagation path between the FWA and the radar.

This method based on link budget is considered appropriate to study static cases which involve one FWA device and one radar. It is based on Recommendations ITU-R SM.337 and ITU-R M.1461 and applied in the specific case of DFS.

After determining the required detection threshold for main beam coupling, one-to-one analysis of the DFS operational margin is evaluated for the case when the FWA and radar are coupled through antenna mainbeams and side lobes.

6.1.3.3 Calculation of the detection threshold based on link budget with mainbeam-to-mainbeam coupling

As explained in section 6.1.1, the required propagation loss L is determined by the maximum tolerable interference level from emissions of a single FWA device at the radar receiver.

The assumption of a symmetrical propagation path between the radar and a single FWA device equipped with DFS enables determination of the required detection threshold by considering the level of radar signal received at the FWA receiver:

$$Th = Prad + Grad - BWfactor - Lfwa - Lrad - L$$

where

Th	Required detection threshold (considered as a power at front of the FWA receive antenna) in dBm,
P_{rad}	Maximum Transmit Power, before antenna and feeder (radar) in dBm
BW_{factor}	Bandwidth conversion factor (= 10log(Brad/Bfwa) if Brad>Bfwa, =0 if not)
G_{rad}	Gain of the radar antenna in dBi
L_{fwa}	FWA feeder loss in dB
G_{fwa}	Gain of FWA antenna in dBi
$Lrad$	Radar feeder loss in dB
L	required propagation loss determined by the maximum allowable interference level from FWA into a radar receiver (see 6.1.1).

With the radar characteristics provided in section 5.1, results of calculation are given in Table 6.1.2 below.

T= 290 °K

	Characteristics	**L**	**M**	**N**	**O**	**Q**	**X & Y**	**Z**
R	**Tx power into antenna peak**	2800	1200	1000	165	285	12	70
A	**Receiver IF3dB bandwidth MHz**	4.8	4	8	8	10	4	1
D	**Antenna mainbeam gain**	54	47	45.9	42	30	35	31.5
A	**Antenna height (m)**	20	15	20	20	40	10	10
R	**Radar feeder loss**	0	0	0	0	0	0	0
	E.i.r.p radar (dBm)	148.5	137.8	135.9	124.2	114.5	105.8	110.0
	Receiver noise figure	5.0	5.0	11.0	5.0	10.0	5.0	13.0
	N=FkTB (dBm)	-102.2	-103.0	-93.9	-99.9	-94.0	-103.0	-101.0
	N - 6dB	-108.2	-109.0	-99.9	-105.9	-100.0	-109.0	-107.0
B	**FWA e.i.r.p (dBm) outdoor**	**36**						
F	**FWA feeder loss**	**0**						
W	**FWA BS antenna height (m)**	**50**						
A	**Bandwith (MHz)**	**20**						
	Antenna gain	**0**						

Bandwidthconversion FWA to radar	6.2	7.0	4.0	4.0	3.0	7.0	13.0
Required propagation loss	192.0	185.0	178	180.0	163.0	173.0	161.5
Bandwidth conversion radar to FWA	0	0	0	0	0	0	0
Necessary detection threshold	-43.5	-47.2	-42.0	-55.8	-48.4	-67.2	-51.5

Table 6.1.2: Calculation of necessary radar signal detection threshold

From Table 6.1.2, under these conditions, the necessary calculated detection threshold is equal to –67.2 dBm to protect radar from a single FWA device transmitting at 4 W in 20 MHz Bandwidth.

In order to take into account the aggregate effect of FWA deployment, it was felt that, for the specific assumptions made (36 dBm FWA E.I.R.P and 20 MHz FWA bandwidth), a detection threshold of -69 dBm would adequately protect the radars. Further work detailed in this section builds upon this value considering the impact of sidelobe coupling, aggregate simulation and FWA system architecture.

6.1.3.4 Impact of FWA antenna gain, bandwidth and E.I.R.P on the required detection threshold (Th)

The detection threshold (*Th*) calculated above is the required radar signal strength expressed as equivalent power in dBm at the front of the FWA receiver antenna. The corresponding threshold value at the input of the receiver is obtained by adding the gain of the FWA receive antenna to the detection threshold (*Th*).

The reference detection threshold (*Th* = -69 dBm) has been determined based on a maximum FWA transmitter Power Spectral Density (PSD) of 4 W E.I.R.P in a bandwidth of 20 MHz. This would translate to the equivalent maximum PSD of 23dBm/MHz.

Increasing the FWA transmit PSD by *X*dB (by appropriately increasing antenna gain) would reduce the necessary detection threshold (*Th*) by *X*dB. The studies have assumed that FWA systems will always have a larger bandwidth than radiolocation systems.

6.1.3.5 Validation of the detection threshold based on one-to-one analysis with various antenna couplings

Results using three propagation models are evaluated

- Model A - Free Space path loss
- Model B - Free Space path loss up to 128 m, then a path loss exponent of 2.8 between 128 m and 1km, then a path loss exponent of 3.3 beyond 1 km;
- Model C - Free Space path loss up to 128 m, then a path loss exponent of 3.5 for all ranges beyond 128 m.

Parameters for the radar types X & Y have been used as previous analysis identified these radars as being the most challenging from the sharing study point of view. Table 6.1.3 shows the results of a one-to-one analysis for each of the different antenna coupling scenarios for a given example. In this example the radar sidelobe pattern is that used in Appendix 1 to Annex 6 of ITU-R Recommendation M.1652 and the FWA side and back lobe levels are based upon Radiation Pattern Envelopes (RPE) drawn from EN302 085.

DFS margin is the difference between the level of received radar signal above the DFS threshold in the FWA device and the level of interference in the radar above the tolerable threshold (I/N= -6dB). This should remain positive to protect the radar and in effect can be considered the safety margin that allows for aggregate interference from multiple devices not triggered by DFS.

		DFS Threshold = -69dBm			DFS Threshold = -77dBm		
DFS Margin		1.8 dB			10.1 dB		
I/N		-6 dB			-14 dB		
Propagation Model		Protection Distance Model A	Protection Distance Model B	Protection Distance Model C	Protection Distance Model A	Protection Distance Model B	Protection Distance Model C
FWA antenna	Radar antenna						
Mainlobe (10 dBi)	Mainlobe (35 dBi)	2592	73	39.2	6511	128.6	66.4
Mainlobe (10 dBi)	First sidelobe (19.25 dBi)	423	24.3	13.9	1062	42.9	23.6
First sidelobe (-7 dBi)	Mainlobe (35 dBi)	366	22.2	12.8	920	39.3	21.7
First sidelobe (-7 dBi)	First sidelobe (19.25 dBi)	59	7.4	4.56	150	13.1	7.7
Mainlobe (10 dBi)	Second sidelobe (-6.5 dBi)	21.8	4.1	2.5	54.8	7.1	4.3
Second sidelobe (-20 dBi)	Mainlobe (35 dBi)	82	8.9	5.5	206	15.9	9.2
Second sidelobe (-20 dBi)	Second sidelobe (-6.5 dBi)	0.7	0.5	0.36	1.7	0.9	0.6

Table 6.1.3:Distances (in km) beyond which DFS will not be triggered for an E.I.R.P of 36 dBm

6.1.3.5.1 Observations

The constant positive DFS margin indicates the margin of safety for DFS operation based on the one-to-one scenario. This does not change with the device antenna sidelobe level because even though the threshold remains constant the resulting e.i.r.p between devices reduces. The margin decreases at less sensitive DFS thresholds or lower radar power. So long as the margin remains positive then the radar will never experience unacceptable interference on a one-to-one basis.

It can be also seen from the table 6.1.3 above that DFS may not be triggered on some FWA devices within the visible horizon of the radar receiver. The impact of this will become apparent when looking at the results of the aggregate interference analysis.

6.1.3.6 Effect of radar characteristics on the DFS margin

The radar e.i.r.p has an impact on the DFS margin. Table 6.1.4 below examines the impact for less constraining radars :

Radar Type	**Radar E.I.R.P (dBm)**	**DFS margin (dB) for Threshold = -69 dBm**	**DFS margin (dB) for Threshold = -77 dBm**	**DFS Threshold for zero margin (dBm)**
Type X & Y	106	1.8	10.1	-67.2
Type Z	110	17.5	25.5	-51.54
Type O	124	13.2	21.2	-55.8
Type O at 1MWatt	132	21.0	29.0	-48.0

Table 6.1.4: DFS Margin (dB) for differing radar systems with FWA E.I.R.P of 36dBm

6.1.3.7 Observations on results of one-to-one analysis

Considering the previous calculation, – 69dBm is the lower DFS Threshold value: it is proposed to adopt a variable detection threshold, like for RLAN:

- for 36 dBm E.I.R.P: -69 dBm
- for 33 dBm E.I.R.P: -66 dBm
- for 30 dBm E.I.R.P: -63 dBm, and so on if necessary.

A generic formula taking into account all of the relevant parameters affecting the final calculation of the DFS threshold at the front of the FWA receive antenna in an operational network is shown below.

DFS Detection Threshold (dBm) = -69 + 23 – (Max Tx E.I.R.P (dBm) – 10logChS(MHz))

The equivalent DFS Detection Threshold at receiver input (dBm) will then be:

$$= -69 + 23 - (\text{Max Tx E.I.R.P (dBm)} - 10\log \text{ChS(MHz)}) + \text{Grx(dBi)}$$

Where ChS is the nominal operating channel width and Grx is the receiver antenna gain.

6.1.4 Parameters and methodology for conducting aggregate interference studies involving FWA and Radiolocation systems in the 5.8 GHz band

In order to address the potential aggregate impact from FWA deployment into radars, aggregate interference studies have been conducted.

The simulation used is similar to Monte-Carlo analysis, using a model containing all of the FWA devices to be considered operating co-channel to the radar system at any given time. This analysis takes DFS into account by assuming that any FWA device will not operate co-channel to the radar under consideration if the radar signal received by the FWA device exceeds a DFS detection threshold which is one of the parameters that can be input into the model. The aggregate I/N at the radar receiver resulting from the remaining co-channel FWA devices will then be computed.

Using the model defined for RLAN in Annex 6 of ITU-R Recommendation M-1652 as a starting point for simulating aggregate interference studies between FWA and radiolocation systems in the 5.8 GHz band, the following considerations were used to define the baseline scenario for studies. Some of the parameters adopted in this analysis differ from that used in M-1652 to take account of the different characteristic and deployment scenarios of FWA networks in comparison to RLAN. Specific differences used in the FWA sharing scenarios are the following:

- Deletion of the 0-20dB indoor/outdoor random attenuation factor;
- Introduction of an input parameter for antenna gain and ability to introduce specific FWA antenna patterns via a separate input file into the model;
- Ability to set one or both ends of a link to perform DFS detection.

Below are the agreed parameters used when modelling DFS aggregate interference in order to determine DFS parameters for sharing between FWA and Radiolocation systems in the 5.8 GHz band:

- Recommendation ITU-R M.1461 was used in interference calculations;
- The radar antenna patterns used are contained in Appendix 1 to Annex 6 of ITU-R Recommendation M.1652;
- The FWA antenna patterns were derived from RPE’s contained in ETSI EN 302 085;
- The probability of detection (see 6.1.3.2) was used in sharing studies to determine the aggregate interference into radar. This probability was set for each step interval (this value can be varied for each radar in input file);
- A step interval of 1° was used;
- Three concentric rings (variable radius) were to define the FWA deployments as shown in Table 6.1.5. Uniform distribution of devices in each zone should be utilised throughout each volumetric zone including height.

	Urban zone	Suburban zone	Rural zone
Radius from the centre (km) (Variable)	0-4	4-10	10-32
FWA user (%) (Variable)	22	28	50
Cell Radius (km)	1	2	5
Maximum Building height (m) (Variable)	15	9	9

TABLE 6.1.5: FWA user distribution

- A total of 74 FWA devices operating on a co-channel basis with a radiodetermination system at a given moment was utilised.
- FWA power distribution in Table 6.1.6 was utilised.

Scenario 1

Power level	**2 W**	**1 W**	**500 mW**	**250 mW**
FWA users (%)	30	30	20	20

Scenario 2

Power level	**4W**	**2 W**	**1 W**	**250 mW**
FWA users (%)	10	30	40	20

TABLE 6.1.6: FWA power distribution

- Tracking radars were modelled starting with random placement and a random start angle and then moving directly overhead to the opposite horizon;
- Maritime radars were modelled starting at the horizon of the rural area and tracked into the centre of the urban zone;
- For ground-based radars a random propagation factor was utilised in determining the propagation path loss to each FWA device. A value from 20 to 35 log(D) was used. In addition a random building/terrain propagation attenuation was used. A uniform distribution was applied in determining these values;
- For maritime radar, free space loss +0-20 dB was used.

A smooth Earth line-of-sight calculation was utilized. Any FWA devices beyond the line-of-sight were discounted.

6.1.4.1 Table of simulation results

From the previous results obtained during the one-to-one analysis (see section 6.1.3) it was shown that the radar types X&Y were the most challenging from a sharing perspective therefore it was decided to concentrate on these radars only for the aggregate sharing analysis. Tables shown in Annex 4 of this report are a summary of the results obtained when running the aggregate model shown above for various different scenarios.

6.1.4.2 Results

FWA Central Station (CS) and Terminal Station (TS) antenna pattern information was drawn from ETSI Standard EN302 085 to develop off axis patterns. These are radiation pattern envelopes for compliance assessment rather than actual patterns.

Simulation results have been produced for two different examples of antenna. The tables in Annex 4 for CS1 show results derived for the sharing case of FWA CS antenna coupling with radars. Tables for TS5 show results derived for the sharing case of FWA TS antenna coupling with radars. Annex 5 also shows an example of a typical input file used in the DFS model.

The following charts summarise the simulation results detailed in tables of Annex 4. These plots for radar types X&Y show the I/N experienced at the radar in the simulation for 1000 trials in each category of zone (urban/suburban/rural) and each detection threshold assumed. The plots indicate the maximum values seen over all 100% of the trial runs, but also provide an indication of the result statistics showing the maximum for 95% and 80% of the trial runs too.

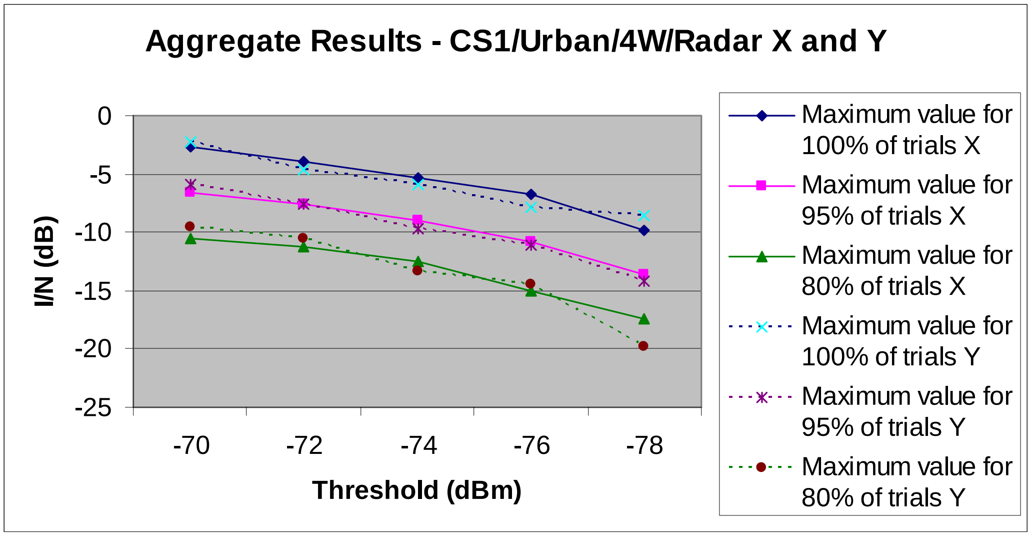


Figure 6.1.1: Summary of aggregate results for Central Station antenna assumption – Urban

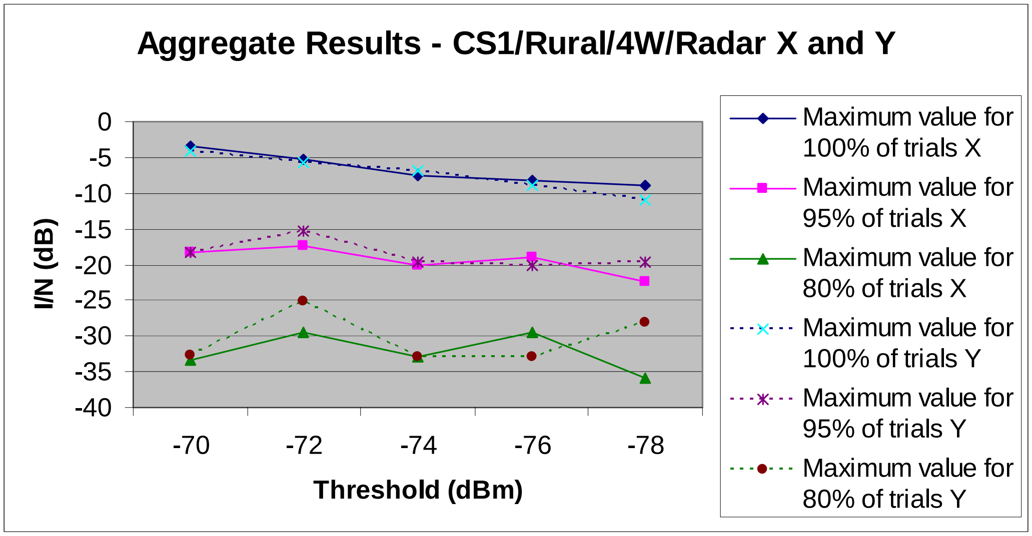


Figure 6.1.2: Summary of aggregate results for Central Station antenna assumption - Rural

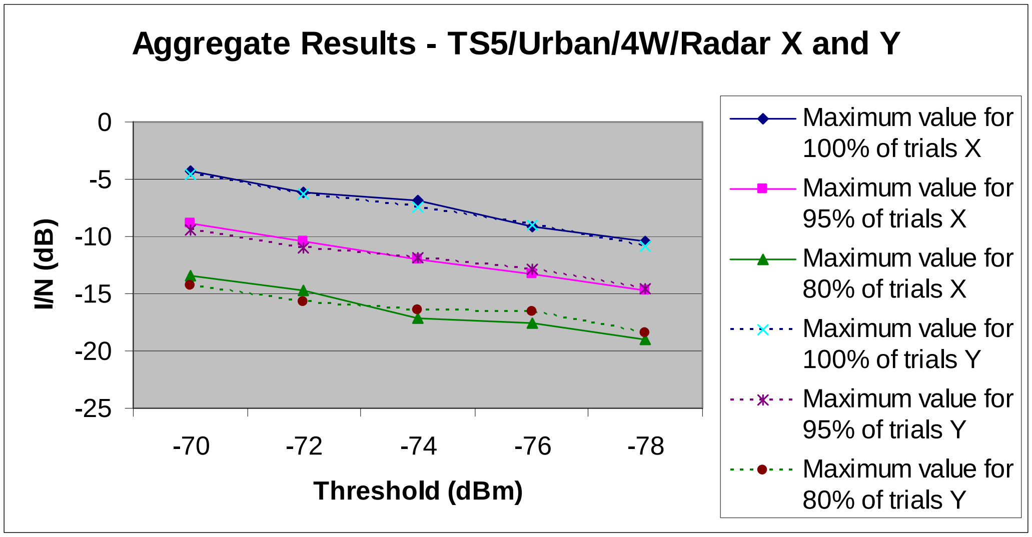


Figure 6.1.3: Summary of aggregate results for Terminal Station antenna assumption - Urban

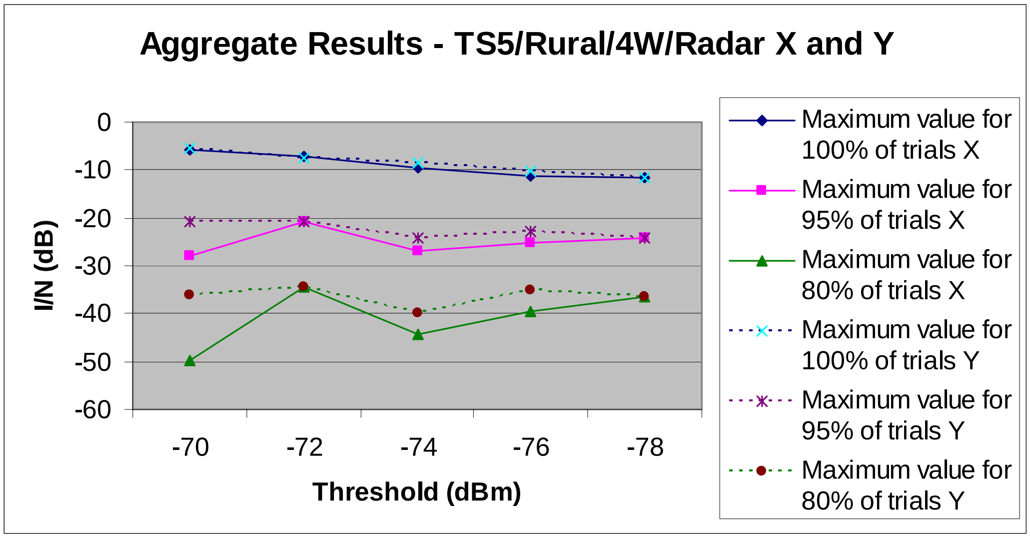


Figure 6.1.4: Summary of aggregate results for Terminal Station antenna assumption - Rural

6.1.4.3 Observations

As expected the results for the aggregate interference assessment show that a more stringent detection threshold would be needed than that previously suggested from the one-to-one analysis. This can be explained by a number of additional factors used in the model that would result in the overall increase in the interference figure calculated at the Radar receiver input.

It can be seen from the extra work done on the side lobe coupling in the one-to-one analysis that calculations show that for some FWA devices their DFS mechanism should not need to be triggered at distances as low as 360 m away from the radar. This depends on the propagation model used and the antenna coupling configuration. As a result a number of potential interferers that are individually below the interference threshold could aggregate to produce an interference level at the radar above the tolerable threshold. It is believed that the aggregation of these interferers accounts for the small number of results in which the I/N threshold of the radar is exceeded when a trigger level of -69 dBm is used. In reality there is a very high probability that another FWA device in the network would detect the presence of radar in this scenario. As the aggregate model only looks at detection at an individual device level then the effect of a detection event elsewhere in the network will not be taken into account and therefore leads to the more stringent detection threshold suggested by the results.

Initial trial runs of the aggregate analysis tool were based on a probability of detection equal to 100% (see Annex 4) as the assumption taken in section 6.1.6 was as follows "*This means that better than 99% detection probability will be achieved within 6 consecutive bursts. For most radars this will be much less*." Therefore, results were also obtained from a number of re-runs of the aggregate analysis tool using the same assumptions as before, except that a probability of detection equalled to 0.99 was set in the input file (see Annex 5) Only a limited set of runs was carried out to assess the impact of the reduced probability of detection and the results are shown inserted into a typical "100% table". The choice of thresholds was arbitrary in this case. One can see from table A4.1 in Annex 4 that:
Tracking Radar X
Based on the specific threshold value and power level chosen:

- At zero degrees, at least 80% of trials result in interference below the tolerable threshold;
- At two degrees, all the results are below the tolerable threshold and similar to the zero degree, 100% probability results;
- The results remain consistently below the tolerable threshold from two degrees up to 180 degrees;
- Without knowing exactly the operational details of the radar system it might be supposed that the system remains at zero degrees for some time before moving in elevation. Therefore results more similar to the 100% probability may be anticipated.

Scanning (Fixed) Radar Y
Based on the specific threshold value and power level chosen:

- At zero degrees, at least 80% of trials result in interference below the tolerable threshold;
- At one degree, all the results are below the tolerable threshold and similar to the zero degree, 100% probability results;
- During the first 360 degree scan there are around 12 angles when 20% of the trials produced results above the tolerable threshold by up to 6dB or so. Most results are several decibels below the threshold.

During the second 360 degree scan, the results are 20-40dB better and there are no occurrences above the tolerable threshold.

6.1.5 Influence of the FWA architecture on the DFS implementation

Due to larger size of FWA coverage area compared to RLANs, the wider use of directional antenna and the architecture of FWA networks, the network point in which DFS detection is carried out will have an impact on the effectiveness of DFS in protecting radar. Below are examples providing an analysis of the effectiveness of DFS in protecting the most susceptible radars from the one-to-one analysis (X&Y) for some of the different architectures likely to be deployed in FWA networks.

In the two following examples based on P-P and directional P-MP deployments respectively, it is assumed that the FWA CS (P1) is equipped with DFS while the FWA TS (P2) is not. In that case, the effect of from P2 transmissions into the radar when the DFS is not triggered in P1 is estimated.

6.1.5.1 Case of P-P FWA networks

	P2 (TS without DFS)		**P1** (CS with DFS)		**Radar Y**	
	E.I.R.P 36dBm		E.I.R.P 36dBm		E.I.R.P: 105.8dBm	
	Bandwidth: 20MHz		Bandwidth: 20MHz		Bandwidth: 4MHz	
	Antenna mainbeam gain: 23dBi		Antenna mainbeam gain: 23dBi		ant: 35dBi	
			sidelobe:-42 dB		N-6: -109 dBm	
receiver sensitivity –65 to –92dBm according to FWA system and modulation used: assumption: -87dBm Antenna beamwidth: 6°						

Figure 6.1.5: Example of P-P WFA link vs radar

Link budget of P-P FWA:

Propagation Loss = 36dBm+23 dB-(-87dBm) = 146 dB

If assuming a margin for link budget (medium distance) of 15dB (fading margin), this will lead to the requirement of 131 dB propagation loss, equivalent to 3 km path using the propagation model B described in 6.1.3.5; it is then assumed that the path length of P-P FWA link is equal to 3km.

Calculation of the different received signals:

I_radaronP1 (dBm) = 105.8+(23-42)-propagation loss(distance[P1-radar])
I_P2onradar (dBm) = 36+35+10*log(4/20)-propagationloss(distance[P2-radar])
= 36+35+10*log(4/20)-propagationloss(distance[P1-radar] + 3km)
I_P1onradar (dBm) = 36 +35 -42 +10*log(4/20) – propagation loss(distance[P1-radar])

The curves below show the three equations above *Received signal = f(distance[P1-radar])* together with the DFS detection threshold at the FWA receiver (-69+23 = -46 dBm) and the maximum permissible level of interference at the radar receiver (Nradar-6=-109 dBm).

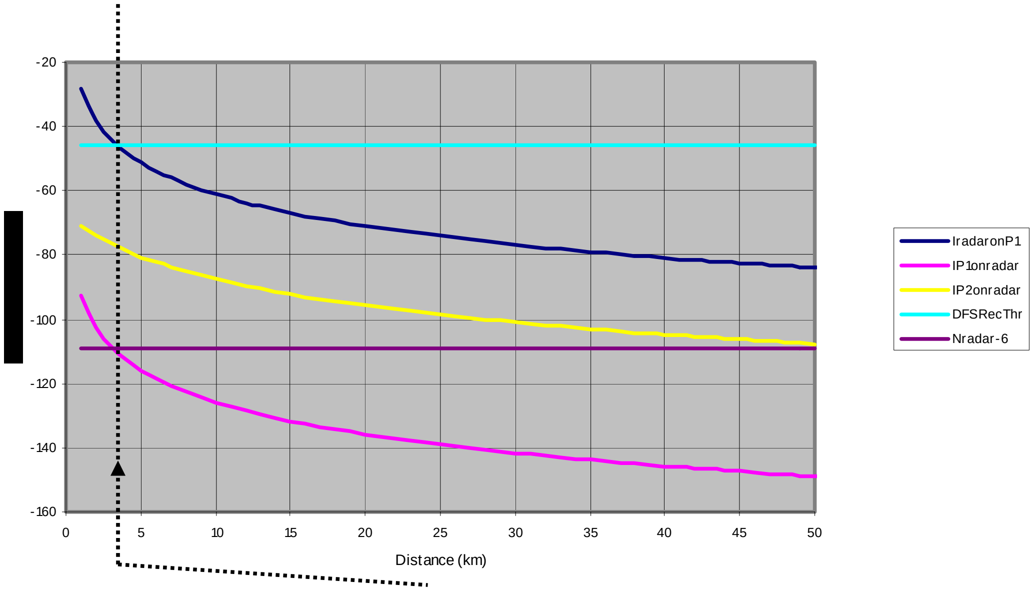
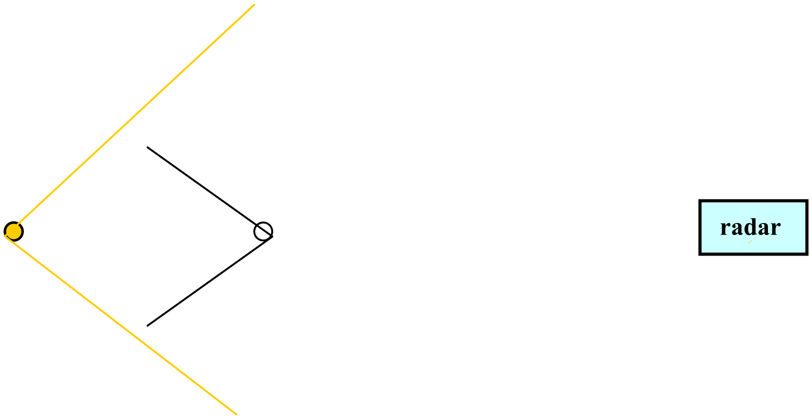


Figure 6.1.6: Received Signals for considered case of P-P FWA link vs radar

6.1.5.1.1 Observation

For distances between the radar and the FWA CS (P1) larger than 3.2 km, the radar signal at the FWA CS receiver is lower than the detection threshold at the FWA CS receiver and, thus, the DFS will not be triggered if DFS is not implemented in the FWA TS (P2 in the above example). It can be noted that the signal from the CS (P1) at the radar receiver is below the maximum permissible interference level at the radar receiver (Nradar-6), i.e. the CS will not create harmful interference into the radar. However, the signal transmitted by the FWA TS (P2) is above Nradar -6 for distances (P1-radar) up to 50 km, which means that in that area, the FWA TS will generate harmful interference into the radar.

6.1.5.2 Case of P-MP FWA networks



	P2 (TS without DFS)		**P1** (CS with DFS)		**Radar Y**	
	E.I.R.P 36dBm		E.I.R.P 36dBm		E.I.R.P: 105.8dBm	
	Bandwidth: 20MHz		Bandwidth: 20MHz		Bandwidth: 4MHz	
	Ant.: 16dBi		Ant.: 17dBi		ant: 35dBi	
	Beamwidth: 60°		sidelobe:-21 to –36dB (assumed as -30 dB)		N-6: -109 dBm	
receiver sensitivity –65 to –92dBm according to FWA system and modulation used: assumption: -74dBm						

Figure 6.1.7: Case of P-MP FWA link vs radar

Link budget of P-MP FWA:

Propagation Loss = 36dBm+17 dB -(-74dBm) = 127dB

Assuming a fading margin for link budget (short distance) of 10 dB, this will lead to the requirement of 117 dB propagation loss, which is equivalent to 1.3 km path using the propagation model B described in 6.1.4.5; it is then assumed that the path length of P-MP FWA link is equal to 1 km.

Calculation of the different received signals:

I_radaronP1 = 105.8+(17-30)-propagation loss(distance[P1-radar])
I_P2onradar = 36+35+10*log(4/20)-propagationloss(distance[P2-radar])
= 36+35+10*log(4/20)-propagationloss(distance[P1-radar] + 1km)
I_P1onradar = 36-30 +10*log(4/20)+35 – propagation loss(distance[P1-radar])

The curves below show the three equations above *Received signal = f(distance[P1-radar])* together with the DFS detection threshold at the FWA receiver (-69+17 = -52 dBm) and the maximum permissible level of interference at the radar receiver (Nradar-6=-109 dBm).

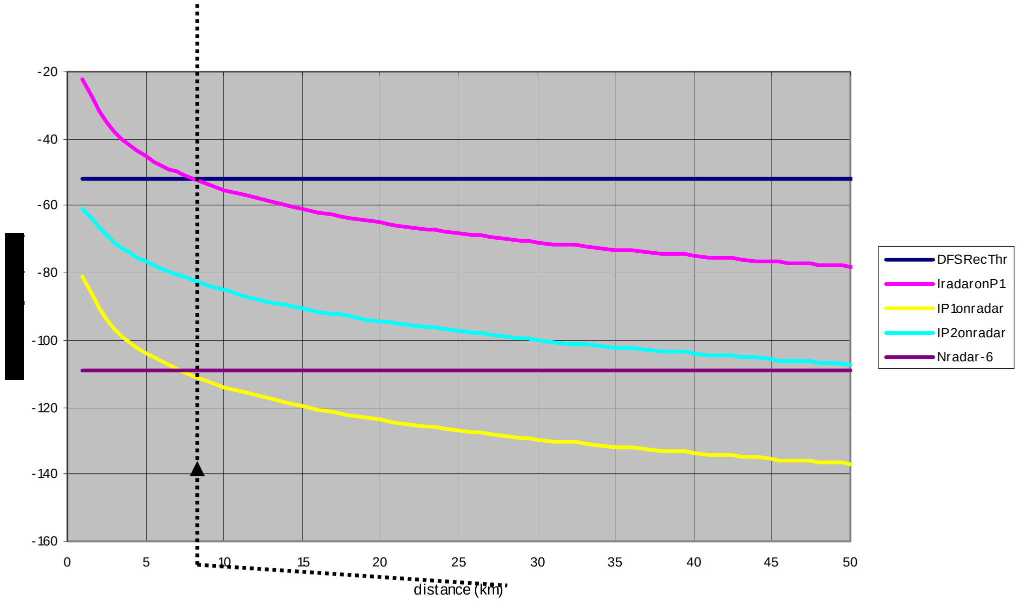


Figure 6.1.8: Received Signals for the case of P-MP FWA link vs radar

6.1.5.2.1 Observation

For distances between the radar and the FWA CS (P1) larger than 7.1 km, the radar signal at the FWA CS receiver is lower than the detection threshold at the FWA CS receiver and, thus, the DFS will not be triggered if DFS is not implemented in the FWA TS (P2). It can be noted that the signal from the CS (P1) at the radar receiver is below the maximum permissible interference level at the radar receiver (Nradar-6), i.e. the CS will not create harmful interference into the radar. However, the signal transmitted by the FWA TS (P2) is above (Nradar-6) for distances (P1-radar) up to 50 km, which means that in that area, the FWA TS will generate harmful interference into the radar.

With omni directional antennas, this problem is less significant, but still exists when implementing systems with larger cell sizes due to the difference in propagation loss between the radar and each end of the FWA link.

6.1.5.3 Conclusions on the influence of the FWA architecture on the detection threshold

From the above analysis it can be seen that in many FWA network configurations radars may be interfered with by the FWA if DFS is only implemented in one end of a FWA link. This is one major difference compared to the implementation of DFS for RLANs in the 5250-5350 and 5470-5725 MHz bands. This is due to the larger size of the FWA coverage, the higher e.i.r.p. limits and the wider use of directional antennas for FWA systems compared to RLANs. It can be concluded that, in general, it is recommended that the DFS mechanism should be implemented in all FWA stations within a network.

6.1.6 Parameters that affect the probability of detection of radiodetermination systems by FWA devices using DFS in the 5.8 GHz band during in-service monitoring

The following parameters affect the probability of detection:

- **FWA traffic load**

The FWA device implementing the DFS detection function is not listening while transmitting. Therefore, probability of detection decreases with increasing traffic load and vice versa.

- **Radar pulse repetition rate**

At higher rates, overlap with FWA transmissions increase and probability of detection decreases.

- **Radar pulse width and modulation**

If radar pulses are longer than the shortest FWA transmission times, the DFS detector may not separate between an FWA transmission and a radar pulse. In order to avoid false alarms from blocking FWA operations, such events may be ignored. In addition, it should be noted that long radar pulses (with width higher than typically 10 µs) are generally modulated and that the modulation may have an impact on the capability of detection by the DFS.

Radar burst length
More pulses per burst may facilitate reliable detection. Therefore, detection probability increases with increasing burst length (measured in pulses per burst).

In addition, detection performance varies with the implementation of the detection function. Experience gained with DFS implementations for RLANs shows that a detection probability of 60% per burst is achievable for all radar types operating in fixed frequency mode identified in section 5.1. This means that better than 99% detection probability will be achieved within 6 consecutive bursts. For most types of radars this will be much less.

- **Radar operating mode (fixed frequency versus frequency hopping)**

The degree of protection of the radars considered depends on the degree to which the FWA system can detect these radars. Electronic-Counter-Counter-Measures (ECCM) implemented by radar systems, such as use of frequency hopping mode by radars, may reduce ability of their detection to the point where FWA systems can not detect these radars and therefore are unable to avoid co-channel operation with these radars.

It is noted from Recommendation ITU-R M.1652 that:
The time required by a WAS for reliable detection varies with the pulse characteristics of the radar. In the case of frequency hopping radars, the time for which the radar occupies the WAS channel (dwell time) also influences the detection probability.
The results will be one of the following:

– *if the dwell time is long enough, DFS detects the radar signal and WAS transmissions will cease on the current channel;*
– *if the dwell time is very short, the probability of detection of the radar by a WAS on the operating channel may be affected, depending on the number of pulses during the dwell time.*

The ability of detection of frequency hopping radars is mainly function of the radar signal strength at the FWA and the number of radar pulses seen by the DFS detector. This latter parameter will depend upon the parameters described above, the frequency hopping characteristics (pulse repetition frequency, “hopping speed”), the radar rotation speed and the radar antenna beamwidth.

6.1.7 Observations taken from practical DFS Testing including the case of frequency hopping radars

Practical tests were being conducted at the time of writing this report in France and Germany on the efficiency of DFS, which has been implemented in RLAN networks operating in the frequency band 5470-5725 MHz. Since it was anticipated that the implementation of DFS in 5.8 GHz FWA may be based on the same principles as DFS used for 5 GHz RLANs and that some of the radars considered in the tests operate both below and above 5470 MHz, it seemed useful to consider the results of these tests in the discussions related to the implementation of DFS in FWA in 5725 – 5875 MHz.

The pieces of equipment under tests were compliant to EN 301893 v1.2.3.

For fixed frequency radars, the results obtained were dependant upon the characteristics of the radar signals. It is expected that a revision of the EN 301893 with extension of the test signals, such as the version EN 301893 v1.3.1, will clarify the requirements for DFS. As a result, the DFS will be more efficient for detecting fixed frequency radars.

The results currently available of both bench and field tests indicate that the detection of some frequency hopping radars by the current implementation of DFS is not successful, although it is recognised that the DFS function, as described in the EN 301893 v1.2.3, was not tested for its ability to detect frequency hopping radars. In addition, it has been shown that when the frequency hopping radar is not detected the impact of a 1 W RLAN is noticeable. It is expected that the work currently in progress in ETSI towards revision of the EN301893 (i.e. EN 301893 v1.3.1), will not improve the detection of these frequency hopping radars.

This has two impacts on the protection of radars:
- The operation of some frequency hopping radars is likely to be affected in the band 5470-5725 MHz. Since some of the frequency hopping radars can operate in both the 5470-5725 MHz and the 5725-5850 MHz bands or parts of them, this should be taken into account when assessing the protection of radars from FWA in the latter bands;
- An implementation of DFS for FWA at 5.8 GHz, which is similar to that for 5 GHz RLANs, will lead to similar results, which is that the operation of some frequency hopping radars is likely to be affected in the band 5725-5850 MHz. This should be considered in conjunction with the specific characteristics of the

FWA at 5.8 GHz, e.g. the increase of e.i.r.p. in the case of FWA systems, the wider use of directional antennas for FWA, the aggregate effect from a real FWA deployment.

6.1.8 Regulatory framework for FWA at 5.8 GHz related to DFS

The requirements and characteristics of the operation of DFS for the 5 GHz bands up to 5.725 GHz for WAS/RLAN systems are defined in ITU-R Recommendation M.1652 and referenced in ECC Decision (04)08. From the equipment conformance point of view these have been developed into regulatory conformance test requirements in harmonised ETSI standard EN301 893.

Since frequencies above 5.725 GHz are outside the scope of all the above documents there is currently no formal definition of DFS for FWA in the 5.8 GHz band. Many of the radars considered in M.1652 operate on frequencies that extend into the 5.8 GHz band. As the characteristics are the same or similar to those in the lower 5 GHz band, the studies have assumed the same DFS characteristics and operational details with only a few exceptions and adjustments to account for the FWA scenario and additional radar systems specific to this band. These included the Detection Threshold levels (discussed in sections 6.1.3 and 6.1.4) and the requirement for radar detection capability in all FWA equipment (discussed in section 6.1.5).

There may be a subsequent need to confirm and formalise the DFS requirements for this band in any regulatory framework.

6.1.9 Conclusion on the sharing analysis for FWA and Radiolocation systems in the band 5 725-5 850 MHz

It has been shown that DFS (Dynamic Frequency Selection) is required to avoid FWA co-channel operation with radars in the same area. The performance requirements for DFS are described in section 6.1.2.3.

After carrying out different studies based on both one-to-one and aggregate models the study has determined a variable detection threshold (for the most critical case) in a 20 MHz bandwidth, as follows:

FWA station e.i.r.p. limit	FWA Power density	DFS detection threshold
36 dBm	23 dBm / MHz	-69 dBm
33 dBm	20 dBm/MHz	-66 dBm
30 dBm	17 dBm/MHz	-63 dBm

Table 6.1.7: Required DFS detection thresholds

The values of the detection threshold are measured at the front of the FWA receive antenna, and are considered to be technically feasible. These values can be adjusted according to the formula in section 6.1.3.7.

The calculations included not only mainbeam-to-mainbeam analysis, but also cases of sidelobe coupling between systems. The DFS mechanism protects both the FWA and Radiolocation system from harmful interference.

The variable thresholds shown above have been determined by taking into account a number of factors. In the one-to-one analysis, it was shown that in the worst case, a DFS detection threshold of at least -67.2 dBm would be needed to ensure that the I/N of -6dB is not exceeded at the radar receiver. In addition, the results of the sidelobe coupling analysis showed that at certain antenna coupling configurations, not all of the FWA devices within the horizon of a radar would have their DFS triggered. From the results of the aggregate interference it was shown that the DFS detection threshold of -74 dBm would be needed to ensure 100% protection for radars from the cumulative effect of FWA interference. It should be noted that the aggregate analysis did not take into account the effect of other FWA devices in an FWA network detecting the radar signal above the threshold.

Considering the above and because of the larger size of the FWA coverage compared to WAS/RLANs and the higher E.I.R.P. limits being discussed, it was agreed to recommend the DFS thresholds shown in the table 6.1.7 above. It is considered that these figures are appropriate detection threshold values for the protection of radars operating in this band considering that the DFS mechanism would normally be implemented by all the FWA stations in a network.

These figures are 1.8 dB more stringent than the threshold shown for the worst case results given by the one-to-one analysis for 4 W systems, but are 5dB less stringent than the worst case results given by the aggregate interference analysis.

Practical testing has been carried out on the DFS mechanisms that have been developed for RLAN systems operating below 5725 MHz. These tests have shown that a revision of the original ETSI standard EN301893 v1.2.3, such as the one contained in the version EN 301893 v1.3.1, is required in order to ensure protection of fixed frequency radars. In addition, the tests have shown that some current DFS implementations do not ensure proper detection of some frequency hopping radars, which may result in harmful interference to these radars. It is expected that the work currently in progress in ETSI towards a revision of the EN301893 (i.e. EN 301893 v1.3.1), will not improve the detection of these frequency hopping radars.

In conclusion, sharing between FWA systems and Radiolocation systems is considered to be feasible provided the appropriate DFS mechanism is applied to FWA devices. The DFS specifications of FWA systems need further consideration, including considerations related to protection of frequency hopping radars. It is noted that these radars might not be deployed in all CEPT countries and some administrations have already allowed the deployment of FWA systems in 5.8GHz.

6.2 Road Transport and Traffic Telematics (RTTT)

6.2.1 Assumptions

The first approach was to focus the sharing studies on the RTTT Road-side Unit (RSU). The analysis is based on the following assumptions and parameters:

a) The distance between the RTTT system and the FWA base station has been set at 2km. which is a typical range for a FWA system;

b) The E.I.R.P and antenna pattern of CS and TS are the same;

	TS	**TS**
E.I.R.P	36dBm	36dBm
Antenna pattern	See Annex 7	See Annex 7

Table 6.2.1

c) The RTTT RSU units are pointing downwards and therefore the effective antenna gain in the direction of the FWA devices is the sidelobe gain; FWA devices are assumed to be outside the main beam of the RSU. The RSU main beam is likely to be less than 20 m away from the position of the RTTT transmitter;

d) For the interference calculations, Free Space path loss has been used up to the first breakpoint. The breakpoint distance and the path loss factor beyond that distance are given in the table 6.2.2.

e)

	Urban		**Suburban**		**Rural**	
breakpoint distance (m) Pt-MP TS, mesh unit	64	128	128	256	256	1024
breakpoint distance (m) CS and other FWA	128	256	256	512	512	2048
Pathloss factor beyond each breakpoint	3.8	4.3	3.3	3.8	2.8	3.3

Table 6.2.2

In order to take into account some concerns, additional studies have been performed to estimate the impact from FWA on the RTTE On-board units (OBU), including false wake up detection and its effect on OBU battery life.

6.2.2 Results of calculations

FWA to RTTT	**Urban**	**Suburban**	**Rural**
Acceptable level interference (dBm)	-98	-98	-98
FWA E.I.R.P (dBm)	36	36	36
Bandwidth ratio (dB)	-15	-15	-15
Polarization loss (dB)	-3	-3	-3
Zero interference distance, FWA to RTTT, TS (m)	**366**	**412**	**619**
Zero interference distance,FWA to RTTT, TS sidelobes(=-14dBr)	**157**	**155**	**195**
Zero interference distance, FWA to RTTT, CS (m)	**689**	**1168**	**1868**
RTTT to FWA			
Acceptable level of interference (dBm)	-119	-119	-119
RTTT E.I.R.P (dBm)	33	33	33
RTTT antenna gain (dB)	-9	-9	-9
Polarization loss (dB)	-3	-3	-3
Zero interference distance, RTTT to FWA CS (m)	**2641**	**6771**	**18975**

Table 6.2.3: Sharing between FWA and RTTT RSU

FWA to RTTT OBU *	
FWA E.I.R.P (dBm)	36
FWA side lobe(dB)	-14
Bandwidth ratio (dB)	-16
Polarization loss (dB)	-3
Effect of TPC(dB)	-5
Car Windscreen Loss(dB)	5-8
Zero interference distance, FWA side lobe to RTTT OBU main lobe, RTTT in allocated band (m)	2
Zero interference distance, FWA side lobe to RTTT OBU main lobe. RTTT OBU with no out of band rejection (m)	9
OBU side beam coupling(dB)	-15
OBU height (m)	1.5
FWA TS height (m)	5
Zero interference distance, FWA main beam to RTTT OBU side lobe, RTTT in allocated band (m)	2
Zero interference distance, FWA main beam to RTTT OBU side lobe. RTTT OBU with no out of band rejection (m)	8

Table 6.2.4: Sharing between FWA and RTTT OBU

*Note: due to short distances the Free Space propagation model is used in all cases.

6.2.3 Interference Assessment

The above analysis applies for a P-MP FWA system, but the results are considered to be representative for all types of FWA systems.

Table 6.2.3 indicates that the level of interference expected from FWA base stations into RTTT RSU is in the same range as that from a number of TS devices all pointing towards the RTTT system. Providing that the RTTT RSU is more than 2km from the FWA CS, the interference from the CS into RTTT will be at an acceptable level. Furthermore for FWA TSs which are close to and directed away from the RTTT RSU, the required separation distance is in the range of a few hundred metres.

The FWA TS path loss has been analysed to determine if the level received by the OBU is above it's Wake Up Trigger Level (parameter D10 of EN12253) and thereby likely to cause false triggering of the OBU leading to early exhaustion of the OBU battery. The OBU must wake up on receiving any frame with a correctly modulated activation signal consisting of a 16 bit preamble followed by an arbitrary number of octets (see CENELEC EN12253). The analysis has ignored the additional protection provided by the specific modulation and coding from a wanted downlink Wake-Up Signal and has assumed any signal above the Wake-Up threshold produced by the FWA TS will trigger a false wake-up. Separation distances have been calculated to ensure false wake-up triggers do not occur.

It has been noted that some OBUs working in the 5 GHz RTTT band offer no discrimination against signals received outside the RTTT band. Consequently the interference potential through false wake-up triggers have been assessed for RTTT OBUs that work within their defined band and also for devices that are open to interference from emissions outside of the RTTT band. Coupling studies were considered with cars parked close to the FWA TS analysing TS side lobe to OBU main lobe and in additional cars parked further away where FWA main lobe would couple into the OBU side lobe.

Applications of RTTT systems located in densely populated areas are likely to present more significant interference, and therefore some form of frequency selection by the FWA systems may be needed to avoid interference.

In areas where there is a high density of RTTT systems the deployment of FWA systems could be severely curtailed.

6.2.4 Conclusion with respect to sharing between FWA and RTTT systems

In conclusion, if FWA and RTTT systems were to be operated co-channel and in close proximity (in the order of hundreds of m to a few kilometres) then interference could occur. However, considering that RTTT does not operate across the entire band proposed for FWA, that it is only deployed in a limited number of locations and that it will interfere with FWA at a greater distance than vice versa (and hence FWA installations would avoid operating in active RTTT channels), sharing between FWA and RTTT systems is considered to be possible.

Sharing studies have shown that where RTTT OBUs receive FWA signals in the band allocated to RTTT devices, then separation protection distances above 2 m between FWA TS and car mounted OBUs are sufficient to ensure that the wake-up trigger level is not exceeded. In the case where the OBUs have no discrimination against signals outside of of the RTTT band, these separation distances must be in the order of 8-9 m.

Where vehicles are in motion the probability of an OBU receiving a FWA signal that appears like a correctly modulated and coded downlink wake-up signal is small due to the limited time the OBU is in the vicinity of the FWA TS. However where cars are parked in the near vicinity of buildings equipped with FWA there is a greater probability that, over time, the packet nature of a FWA TS signal may resemble the correctly modulated and coded RTTT downlink Wake-Up signal. In many cases the TS signal may be masked due to foliage or obstructions, but there could be cases where the car may have clear line of sight to the FWA TS. If, under these circumstances the OBU is triggered by the FWA TS, then battery life may be adversely affected. Typically the low activity ratio of the TS product will also help in reducing the probability that FWA signals will appear as wanted RTTT Wake-Up message.

The sharing situation will be improved by considering filtering or coding at the OBU receiver.

6.3 Fixed Service (Point to Point Links)

Due to the nature of the Fixed Service use of the 5.8 GHz band for point to point links, as described in section 5.3, detailed compatibility studies have not been conducted. It is expected that if those countries which have existing fixed service point-point links were to introduce FWA in the same frequency range, it would be necessary to co-ordinate between the systems. However, since the fixed service use is not harmonised it is difficult to provide detailed guidance on how to achieve this within the scope of this report.

6.4 Fixed Satellite Service (FSS)

This section provides methods and results of sharing studies between different types of FWA systems and geostationary satellite networks of the Fixed Satellite Service (FSS) in the frequency band 5725 – 5875 MHz.

Three types of FWA systems were considered: P-MP, P-P and Mesh. The latter type has two subtypes: Omni-directional and Directional with different contributions to interference into FSS systems.

6.4.1 Methods

6.4.1.1 The “ T/T” approach

The study adopted the ΔT/T approach described in Appendix 8 of the ITU Radio Regulations[7] in order to assess the impact of interference from a large number of FWA devices in the field-of-view of a satellite antenna beam. Although not directly suitable for use in the case of inter-service sharing, it does provide a very simple method of analysing the impact without much knowledge of the characteristics of the carriers used on the satellite network requiring protection. In this technique, the interference from the FWA into the satellite receivers is treated as an increase in thermal noise in the wanted FSS network and hence is converted to a noise temperature (by considering the interference power per Hz) and compared with tolerable percentage increases in noise temperature. Moreover, as explained in Appendix 5 of the ITU RR for the band 5725-5875 MHz, this calculation has to be done separately for uplink and downlink. This approach has the advantage that very few satellite parameters are required to be known and a detailed link budget for every type of carrier (especially those most sensitive to interference) is not required for the satellite network requiring protection.

Recommendation ITU-R S.1432[8] deals with the allowable error performance degradations to the FSS below 15 GHz. For a source of interference that is neither FSS systems, nor systems having co-primary status, a 1% of the aggregate interference budget is recommended. Since there is no harmonized CEPT allocation for FS below 5850 MHz, an interference allowance of 1% was considered. Several countries have a primary allocation to the FS by means of a footnote in Article 5 of the ITU Radio Regulations (e.g. 8 European countries and 39 ITU Region 1 countries in **5.453, 5.455** & **5.456**) so an interference allowance of 6% was also considered.

6.4.1.2 Methods of calculating the interference from FWA devices into an FSS Satellite Receiver

As explained in the previous paragraph, uplink is treated separately from downlink. In this sharing case of interference from FWA devices into an FSS satellite receiver, the study takes only into account the uplink case.

Consequently, the limitation of increase of equivalent noise temperature is expressed by the following relationship:

$$\frac{\Delta T_{sat}}{T_{sat}} < Y\% \qquad (6.4.1)$$

where,

ΔT_{sat} : apparent increase in the receiving system noise temperature at the satellite, due to an interfering emission (K);
T_{sat} : the receiving system noise temperature at the satellite referred to the output of the receiving antenna of the satellite (K)
Y : noise increase allowed (e.g. 1%, 6%, etc.).

In the case under consideration here, ΔT_{sat} is the contribution of aggregate emissions from FWA devices at the input of satellite receiver.

Assuming that FWA interference can be treated similarly to thermal noise, the following relationship can be assumed (linear scale, not dB):

$$\Delta T_{sat} = \frac{EIRP_{FWA} \cdot G_{sat}}{k \cdot l} \quad \text{K} \qquad (6.4.2)$$

where,

$E.I.R.P_{FWA}$: the aggregate E.I.R.P spectral density of the FWA transmitters in the satellite beam and in the direction of the satellite (W*Hz^{-1});
G_{sat} : the gain of receiving antenna of the satellite in the direction of FWA interferer (linear ratio, relative to isotropic);
k : Boltzmann’s constant (1.38x10^{-23} J.K^{-1});
l : uplink Free Space path loss (linear power ratio). Note that this could also include gaseous attenuation due to absorption by water vapour and oxygen molecules;

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[7] ITU Radio Regulations Appendix 8: *Method of calculation for determining if coordination is required between geostationary-satellite networks sharing the same frequency bands*

[8] Rec. ITU-R S.1432 : *Apportionment of the Allowable Error Performance Degradations to Fixed-Satellite Service (FSS) Hypothetical Reference Digital Paths arising from the Invariant Interference for Systems operating below 15 GHz*

Combining the equations (6.4.1 and 6.4.2), we find:

$$EIRP_{FWA} = X \cdot \left(\frac{G_{sat}}{T_{sat}} \right)^{-1} \cdot k \cdot l \qquad \text{W.Hz}^{-1} \qquad (6.4.3)$$

where,
X: noise increase allowed (expressed as a fraction of 1, e.g. 0.06 for 6% etc.).

Two different scenarios can be considered: in the first case, the satellite in question is visible at a high elevation angle from locations in Europe, and in the second case, the satellite in question is visible at a very low elevation angle, for example positioned at longitude further east.

6.4.1.2.1 6.4.1.2.1 High elevation satellites

If the satellite in question is visible at a high elevation angle from locations in Europe, such that all FWA devices have good off-axis gain discrimination in the elevation plane (and in the direction towards the satellite), the logarithmic form of equation (6.4.3) is:

$$EIRP_{FWA} = 10 \cdot \log(X) - 29.35 - 10 \cdot \log\left(\frac{G_{sat}}{T_{sat}} \right) \qquad \text{dB(W.Hz}^{-1}\text{)} \qquad (6.4.4)$$

where,
G_{sat}/T_{sat} is the “G/T” at the satellite receiver input derived from the values of G_{sat} and T_{sat} given in Table 5.4.2 and a particular value of l ($10*\log(l)$=199.24dB) has been calculated to establish the second term of the right-hand side of equation (6.4.4): a frequency of 5750 MHz and a distance of 38000 km has been assumed (distance from Europe to a satellite at the same longitude).

An example of this is the INTELSAT VIII satellite at a geostationary orbital position of 359°E which, as shown in Figure 6.4.1, has a 20 degree elevation angle contour extending well into northern Europe.
As mentioned above, if the satellite elevation angle is sufficiently high, it is reasonable to assume that most FWA devices will not have their main antenna beams pointing directly towards the satellite.

Therefore FWA devices can be considered as a single source and, by applying directly equation (6.4.4), the satellite parameters provided in Table 5.4.1 have been used to calculate the value of the aggregate E.I.R.P spectral density permitted for two values of noise increase at the satellite receiver. These values are provided for each satellite in Table 6.4.1.

Figure 6.4.1: 20 degree elevation angle contour for Intelsat VIII Satellite @ 359°E

Satellite	Satellite orbital position	Part of Frequency range 5725-5875 MHz used	Satellite Maximum Receive Gain, G_{sat} (dBi)	Satellite Receiving System Noise Temperature T_{sat} (K)	Aggregate E.I.R.P[9] dB(W Hz^{-1}) from FWA for $\Delta T_{sat}/T_{sat}$=6%	Aggregate E.I.R.P dB(W Hz^{-1}) from FWA for $\Delta T_{sat}/T_{sat}$=1%
A	5° West	Whole band	34	773	-46.7	-54.5
B	14° West	Whole band	26.5	1200	-37.3	-45.1
C	31.5° West	> 5850 MHz	32.8	700	-45.9	-53.7
D	3° East	Whole band	34	773	-46.7	-54.5
E	18° West	>5850MHz	32.8	700	-45.9	-53.7
F	53° East	Whole band	26.5	1200	-37.3	-45.1
G	59.5° East	Whole band	34	1200	-44.8	-52.6
H	66° East	>5850 MHz	34.7	700	-47.8	-55.6
I	359° East	>5850 MHz	32.8	700	-45.9	-53.7

Table 6.4.1: Derivation of Aggregate E.I.R.P from all FWA transmitters in the satellite beam

Note: ($E.I.R.P_{FWA}$ calculated using Eqn.6.4.4)

With the assumption that all FWA devices in satellite footprint can be considered as a single source and then that the source is not specifically located, therefore it is a simple calculation to work out the number of FWA devices from equation (6.4.4).

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[9] This is the aggregate E.I.R.P from all FWA devices which are assumed to be co-channel and effectively treated as a single source.

The maximum aggregate power towards satellite from FWA devices in one channel can be computed as:

$$EIRP_{FWA_{channel}} = EIRP_{FWA} + 10 \cdot \log(B) \; dBW \qquad (6.4.5)$$

where B is the channel bandwidth in Hz.

Assuming that only one type of FWA device is considered, the number of active devices N (transmitting all the time in only one channel) can be computed as

$$10 \cdot \log(N) = EIRP_{FWA_{channel}} - EIRP_{Device_{channel}} \qquad (6.4.6)$$

where $E.I.R.P_{Device\text{-}channel}$ is the E.I.R.P in dBW/channel of one single FWA device in the direction of the satellite.

The number of devices can then be adjusted by taking into account the transmission duty ratio and the number of channels in the frequency reuse pattern.

6.4.1.2.2 Low elevation satellites

For low elevation satellites (e.g. those at longitudes further East that require quite low elevation angles from some countries in north-west Europe - see Figure 6.4.2) directivity of FWA antennas in elevation plane becomes much more significant because the satellite may easily lie within the main lobe of the FWA antenna[10]. In this case, it is more appropriate to consider the following parameters as variables: i) the e.i.r.p. of the devices; ii) the path loss to the satellite; iii) the receive gain of the satellite.

This results in a more generalised equation where the link noise temperature contribution from a single FWA device can be expressed from Eq. (6.4.2) as follows:

$$\Delta T_{sat\ j} = \frac{G_{sat\ j} \cdot eirp_{FWA\ j}(\theta_j)}{k \cdot l_j} \quad K \qquad (6.4.7)$$

then,

$$\Delta T_{sat} = \sum_{j=1}^{N} \Delta T_{sat\ j} = \frac{1}{k} \sum_{j=1}^{N} \frac{G_{sat\ j} \cdot eirp_{FWA\ j}(\theta_j)}{l_j} \quad K \qquad (6.4.8)$$

where:

$eirp_{FWA\ j}(\theta_j)$ the e.i.r.p. spectral density of a *single* FWA transmitting antenna in the satellite beam and in the direction of the satellite (W.Hz^{-1}))

θ: the off-axis angle of the FWA antenna towards the satellite in the elevation plane (degrees).

N : the total number of FWA devices within the satellite footprint.

Here, the e.i.r.p. for each FWA device must be calculated in the direction of the satellite. Note that $G_{sat\ j}$ and l_j will not be constant, but will vary with the position of FWA device within the satellite beam and its distance to the satellite. For completeness, this can also be taken into account if more information is available.

Equation (6.4.7) is then used to aggregate the interference e.i.r.p from all FWA devices until ΔT_{sat} given by equation (6.4.8), divided by T_{sat}, reaches the specified threshold.

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[10] An examination of elevation plane radiation patterns for omni-directional Mesh and sectoral base stations shows typical half-power beamwidths of 10 degrees or more.

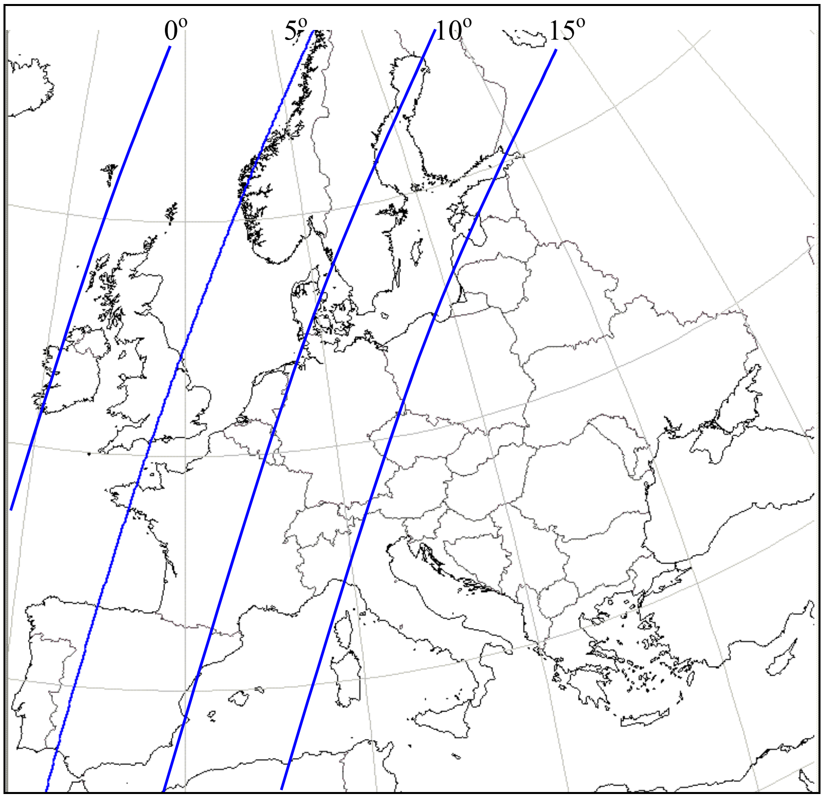


Figure 6.4.2: Elevation Contours for Intelsat Satellite @ 66°E (5 degree intervals)

6.4.1.3 Application of methods

The methods described in Section 6.4.1.2.1 and 6.4.1.2.2 were used as the basis for establishing the interference contribution from FWA devices in each country in Europe taking into account the FWA antenna discrimination in the elevation plane in the direction of the satellite in question.

Table 6.4.2 provides the elevation angles from most of the countries in Europe to the satellites in Table 6.4.1, using the latitude and longitude of a representative city in each country. Section 4.3 contains an explanation of how the population data for each European country is then used to derive the maximum number of terminals expected, based on market penetration assumptions. The number of FWA terminals in each country is assumed to be proportional to the population of the country. The population information was used in two ways:

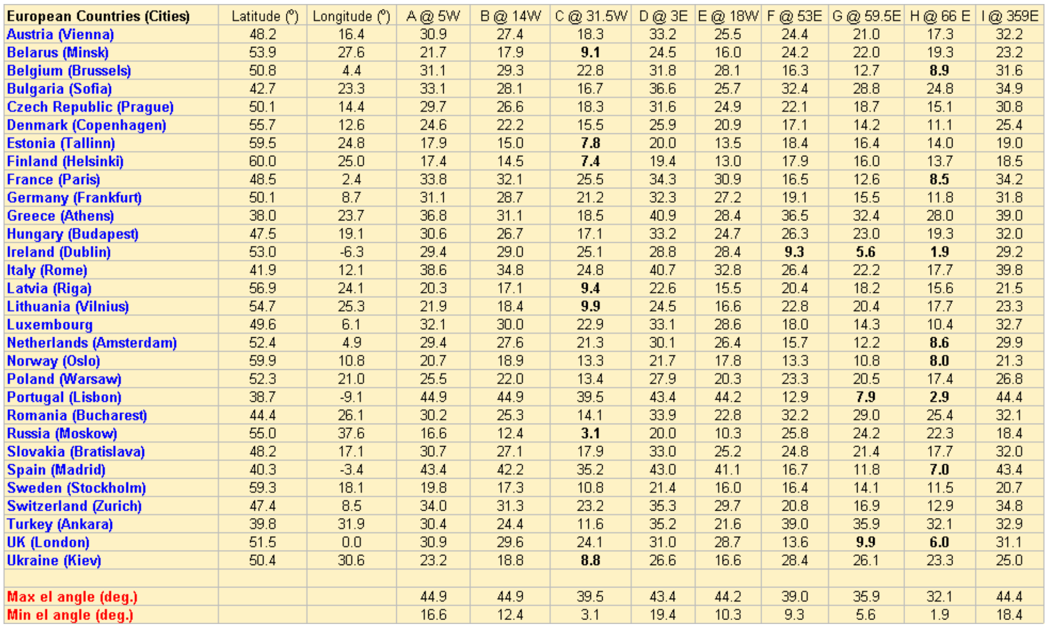
- to estimate a possible total number of terminals based on market penetration assumptions
- to establish geographic distribution of terminals throughout the region and hence the relative contribution to the interfering noise power caused by terminals under different parts of satellite beam. This depends on the elevation angle towards satellite for each orbital position (Table 6.4.2) and hence the relative gain towards the satellite position for FWA antennas.

The second spreadsheet in Annex 8 indicates how the data was used to provide the proportional number of terminals in each country.

An optimistic market estimate for the maximum number of terminals deployed across Europe of 12.5 million was assumed. This is based on wireless penetration of 5% of the population and 40% of this usage in the band 5725-5875 MHz (see first spreadsheet in Annex 8).

As explained in Section 6.4.1.2, the interference was assessed by treating FWA interference as equivalent to an increase in thermal noise at the input to satellite receiver and calculating when the noise percentage increase has reached a specified percentage of the receiver system noise. Increases in noise temperature of both 1% and 6% were considered.

The e.i.r.p. of each FWA device in the direction of satellite was calculated by deriving the transmit power from the on-axis E.I.R.P and then adding the gain (in dBi) in the elevation plane for the appropriate elevation angle from the country being considered. The effects of power control, activity ratio and random channel loading were then applied to arrive at the maximum number of nodes or base station cells that could be deployed without the required noise temperature threshold being exceeded.



European Countries (Cities)	Latitude (°)	Longitude (°)	A @ 5W	B @ 14W	C @ 31.5W	D @ 3E	E @ 18W	F @ 53E	G @ 59.5E	H @ 66 E	I @ 359E
Austria (Vienna)	48.2	16.4	30.9	27.4	18.3	33.2	25.5	24.4	21.0	17.3	32.2
Belarus (Minsk)	53.9	27.6	21.7	17.9	**9.1**	24.5	16.0	24.2	22.0	19.3	23.2
Belgium (Brussels)	50.8	4.4	31.1	29.3	22.8	31.8	28.1	16.3	12.7	**8.9**	31.6
Bulgaria (Sofia)	42.7	23.3	33.1	28.1	16.7	36.6	25.7	32.4	28.8	24.8	34.9
Czech Republic (Prague)	50.1	14.4	29.7	26.6	18.3	31.6	24.9	22.1	18.7	15.1	30.8
Denmark (Copenhagen)	55.7	12.6	24.6	22.2	15.5	25.9	20.9	17.1	14.2	11.1	25.4
Estonia (Tallinn)	59.5	24.8	17.9	15.0	**7.8**	20.0	13.5	18.4	16.4	14.0	19.0
Finland (Helsinki)	60.0	25.0	17.4	14.5	**7.4**	19.4	13.0	17.9	16.0	13.7	18.5
France (Paris)	48.5	2.4	33.8	32.1	25.5	34.3	30.9	16.5	12.6	**8.5**	34.2
Germany (Frankfurt)	50.1	8.7	31.1	28.7	21.2	32.3	27.2	19.1	15.5	11.8	31.8
Greece (Athens)	38.0	23.7	36.8	31.1	18.5	40.9	28.4	36.5	32.4	28.0	39.0
Hungary (Budapest)	47.5	19.1	30.6	26.7	17.1	33.2	24.7	26.3	23.0	19.3	32.0
Ireland (Dublin)	53.0	-6.3	29.4	29.0	25.1	28.8	28.4	**9.3**	**5.6**	**1.9**	29.2
Italy (Rome)	41.9	12.1	38.6	34.8	24.8	40.7	32.8	26.4	22.2	17.7	39.8
Latvia (Riga)	56.9	24.1	20.3	17.1	**9.4**	22.6	15.5	20.4	18.2	15.6	21.5
Lithuania (Vilnius)	54.7	25.3	21.9	18.4	**9.9**	24.5	16.6	22.8	20.4	17.7	23.3
Luxembourg	49.6	6.1	32.1	30.0	22.9	33.1	28.6	18.0	14.3	10.4	32.7
Netherlands (Amsterdam)	52.4	4.9	29.4	27.6	21.3	30.1	26.4	15.7	12.2	**8.6**	29.9
Norway (Oslo)	59.9	10.8	20.7	18.9	13.3	21.7	17.8	13.3	10.8	**8.0**	21.3
Poland (Warsaw)	52.3	21.0	25.5	22.0	13.4	27.9	20.3	23.3	20.5	17.4	26.8
Portugal (Lisbon)	38.7	-9.1	44.9	44.9	39.5	43.4	44.2	12.9	**7.9**	**2.9**	44.4
Romania (Bucharest)	44.4	26.1	30.2	25.3	14.1	33.9	22.8	32.2	29.0	25.4	32.1
Russia (Moskow)	55.0	37.6	16.6	12.4	**3.1**	20.0	10.3	25.8	24.2	22.3	18.4
Slovakia (Bratislava)	48.2	17.1	30.7	27.1	17.9	33.0	25.2	24.8	21.4	17.7	32.0
Spain (Madrid)	40.3	-3.4	43.4	42.2	35.2	43.0	41.1	16.7	11.8	**7.0**	43.4
Sweden (Stockholm)	59.3	18.1	19.8	17.3	10.8	21.4	16.0	16.4	14.1	11.5	20.7
Switzerland (Zurich)	47.4	8.5	34.0	31.3	23.2	35.3	29.7	20.8	16.9	12.9	34.8
Turkey (Ankara)	39.8	31.9	30.4	24.4	11.6	35.2	21.6	39.0	35.9	32.1	32.9
UK (London)	51.5	0.0	30.9	29.6	24.1	31.0	28.7	13.6	**9.9**	**6.0**	31.1
Ukraine (Kiev)	50.4	30.6	23.2	18.8	**8.8**	26.6	16.6	28.4	26.1	23.3	25.0
Max el angle (deg.)			44.9	44.9	39.5	43.4	44.2	39.0	35.9	32.1	44.4
Min el angle (deg.)			16.6	12.4	3.1	19.4	10.3	9.3	5.6	1.9	18.4

Table 6.4.2: Latitude/Longitude of representative cities in various European countries & Elevation Angle in degrees to the satellites in Table 6.4.1[11]

6.4.1.4 FWA assumptions

The FWA system types considered were P-MP (System 1) and omni-directional Mesh systems (System 3). Most of the characteristics were taken from Section 4.1. Exceptions to this and additional information are described below.

For the study using P-MP systems, measured elevation plane antenna patterns were used (see Figures 1-2 in Annex 1). For the Mesh study, the boresight gain was used to derive generic envelope masks in Rec. ITU-R F.1336-1[12]. As a matter of fact, all the elevation plane patterns of the FWA antennas used in these studies can be represented by the envelope patterns in Rec. ITU-R F.1336-1 and this could be used as a design objective to promote satisfactory sharing with the FSS (the analyses were based on the assumption that all FWA antennas should have good off-axis gain discrimination in the elevation plane (and in the direction of the satellite). More details on Rec. ITU-R F.1336-1 and on the used antenna gain patterns, can be found in Annex 10.

The FWA systems make use of Transmit Power Control (TPC). An average reduction in transmitted power of 5 dB due to TPC was considered for all FWA devices. This assumed that subscribers are distributed evenly throughout a P-MP FWA cell and took into account the fact that propagation loss is not Free-space but is proportional to range raised to power 3.5. At the edge of the cell, it was assumed that the maximum power is used (e.i.r.p. 3 dBW). Smaller cells may not need to use the maximum e.i.r.p. (e.g. in urban areas where they may be capacity limited).

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[11] Elevation angles lower than 10deg are shown in bold (where the satellite is in the main beam of the elevation plane of the FWA antenna)

[12] Rec. ITU-R F.1336-1. *Reference radiation patterns of omni-directional, sectoral and other antennas in point-to-multipoint systems for use in sharing studies in the frequency range from 1GHz to about 70GHz.*

All antennas were assumed to be mounted on roof-tops and no blockage was taken into account in the direction of satellites in the geostationary orbit.

It was assumed that there is uniform loading of ‘channels’ across the whole band.

6.4.2 Summary of results

The basic idea behind the methods for the P-MP FWA study, the omni-directional Mesh study and the P-P study is to consider the interference contribution of each individual country independently. For each country, all the FWA devices are assumed to be co-located in its representative city (see Table 6.4.2).

The study has not been able to make a decision on the sharing between directional Mesh systems and the FSS because of insufficient input from experts in this area.

Annex 7 provides a description of the structure and method of calculations for the omni-directional Mesh FWA system together with an example of calculations.

For the same satellite, an example of the calculations for P-MP FWA systems is shown in Annex 8. Similarly, Annex 9 provides an example of calculations for the P-P FWA systems.

Some of the satellites in Table 6.4.1 are particularly significant. Among the satellites that use only the upper portion of the band (C, E, H and I), satellite H @ 66^{o} East is definitely the most sensitive to interference, due to the low T_{sat}, high G_{sat} and low elevation angles to many of the countries in the north and west of Europe. Of the satellites that only operate above 5850 MHz, it is the only one considered in these studies as the worst case.

Among the other satellites, satellites A and D are similar and are the most sensitive, in terms of low T_{sat} and high G_{sat}. However, satellite A @5^{o}West gives rise to slightly lower elevation angles, due to its orbital location. Satellite G at 59.5^{o}East has also to be considered due to the relatively low elevation angles and high value for $G_{sat.}$

The analyses were based on the assumption that all FWA antennas should have good off-axis gain discrimination in the elevation plane (and in the direction of the satellite). All the elevation plane patterns of the FWA antennas used in these studies can be represented by the envelope patterns in Rec. ITU-R F.1336-1 (see Annex 10) and this could be used as a design objective to promote satisfactory sharing with the FSS, as shown below.

The sharing studies have taken the characteristics of FWA systems into account including typical antenna patterns that restrict the amount of radiated energy in the direction of the satellite receivers.

The E.I.R.P spectral density of the transmitter should not exceed the following values for the elevation angle θ above the local horizontal plane (of the Earth):

For sector antennas (e.g. P-MP CS)) and Omni-directional antennas:

-7 dB(W/MHz)	for $0° \leq \theta < 4°$
$-2.2 - (1.2*\theta)$ dB(W/MHz)	for $4° \leq \theta \leq 15°$
$-18.4 - (0.15*\theta)$ dB(W/MHz)	for $\theta > 15°$

For P-MP TS and P-P antennas:

-7 dB(W/MHz)	for $0° \leq \theta < 8°$
$-2.68 - (0.54*\theta)$ dB(W/MHz)	for $8° \leq \theta < 32°$
-20 dB(W/MHz)	for $32° \leq \theta \leq 50°$
$-10 - (0.2*\theta)$ dB(W/MHz)	for $\theta > 50°$

By way of example, systems that are operated at maximum e.i.r.p and are using the antenna patterns provided in Annex 10 have been compared with these masks in Figures 6.4.3 and 6.4.4 for the base station sector antennas.

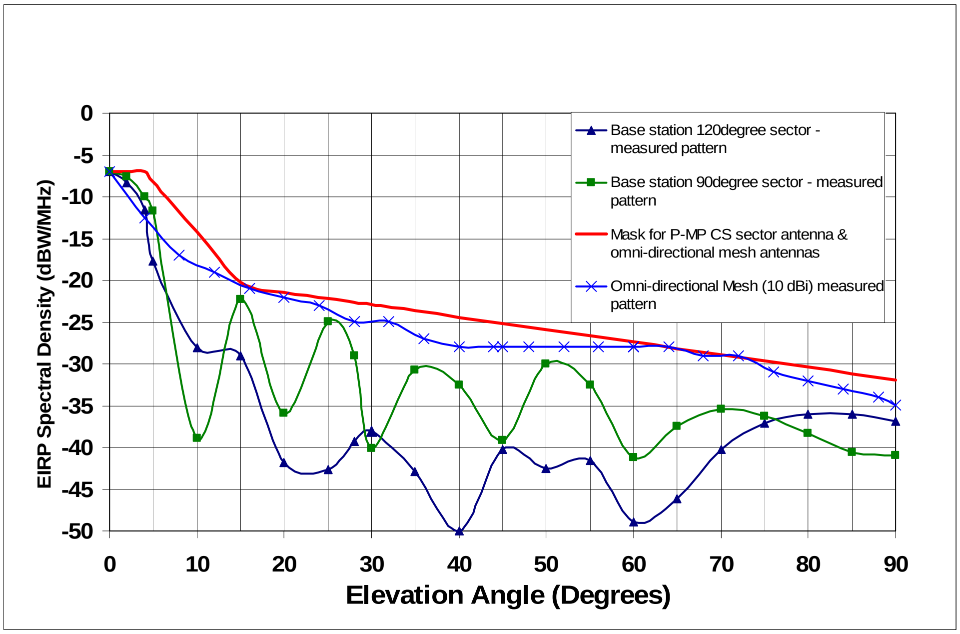

Figure 6.4.3: Comparison between E.I.R.P Density Mask and measured elevation-plane patterns for Base Station (CS) antennas and omni-directional mesh antenna

Notes: 1) Mask is based on patterns in Rec. ITU-R F.1336-1

2) Elevation angle is relative to the horizontal plane of the antenna

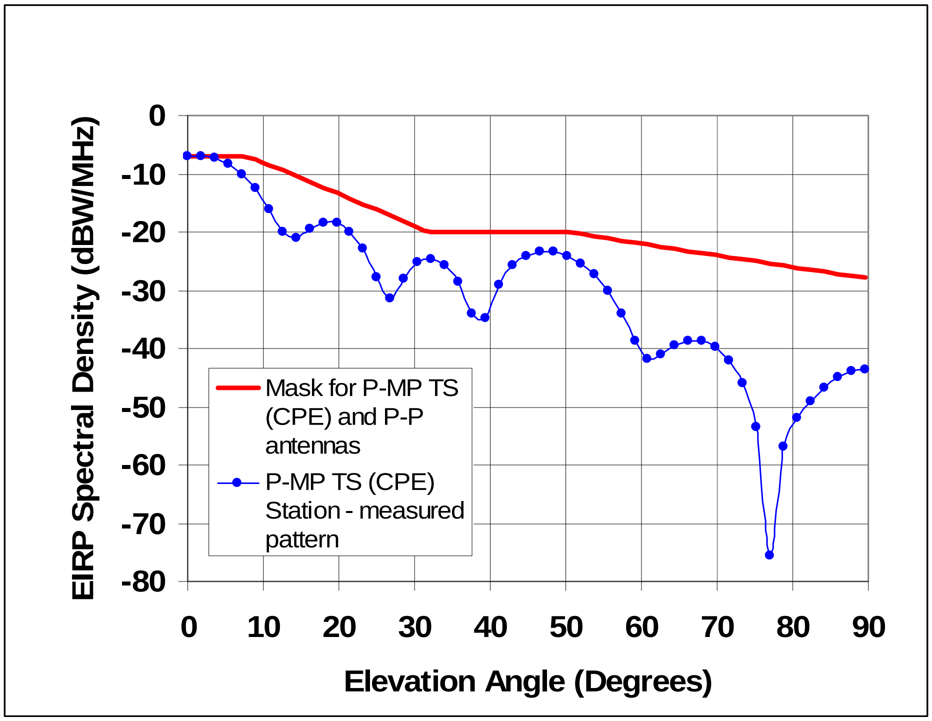

Figure 6.4.4: Comparison between E.I.R.P Density Mask and measured elevation-plane patterns for P-MP TS (CPE) antenna

Notes: 1) Mask is based on patterns in Rec. ITU-R F.1336-1

2) Elevation angle is relative to the horizontal plane of the antenna

6.4.2.1 Point-to-Multipoint FWA Systems

Table 6.4.3 shows, for Satellites A, G and H (which are the most sensitive), a set of results obtained with the above methods. The values shown are the maximum total number of FWA devices that can be deployed in the whole of Europe. These results are obtained using the assumptions outlined earlier and the table shows the maximum number of devices for two $\Delta T_{sat}/T_{sat}$ thresholds of 6% and 1%. 33 dBm is the maximum E.I.R.P of each FWA device specified in Section 4.1. However, the effect of a change in E.I.R.P of 3 dB on the number of devices is also shown in Table 6.4.3.

	Max # of P-MP FWA TS in satellite beam (millions)			
	E.I.R.P = 33 dBm		*E.I.R.P = 36 dBm*	
Satellite	T_{sat}/T_{sat} **=6%**	T_{sat}/T_{sat} **=1%**	T_{sat}/T_{sat} **=6%**	T_{sat}/T_{sat} **=1%**
A	**669**	**111**	**335**	**56**
B	[**]			
D				
F				
G	**518**	**86**	**259**	**43**
H	**130**	**22**	**65**	**11**

Table 6.4.3: Maximum number of Point-to-Multipoint FWA devices in Europe to meet ΔTsat/Tsat noise temperature thresholds for Satellites A @ 5oW, G @ 59.5oE and H @ 66oE

The results for a maximum E.I.R.P of 33 dBm per FWA device indicate that the number of terminals that could be deployed while meeting a satellite criterion of 1% increase in noise is well in excess of an optimistic market estimate of 12.5 million subscriber terminals in Europe. For a noise threshold of 6%, the numbers are much larger. As an example, for the most challenging case of a low subtended elevation satellite (Satellite H with 1% noise increase) over 21 million FWA terminals in the 5725-5875 MHz band can be deployed safely across Europe. For the case of the 6% noise criterion, this number increases to about 130 million (for this type alone). For the less stringent case of Satellite A, about 110 million terminals can be permitted at the 1% threshold level. Annex 8 shows how this number is calculated. The table also shows the results for an E.I.R.P of 36 dBm and indicates that sharing is also possible for this level.

6.4.2.2 Omni-directional Mesh FWA Systems

Table 6.4.4 shows, for Satellites A, B, D, F, G and H, a set of results obtained with the above methods. The values shown are the maximum total number of omni-directional Mesh FWA devices that can be deployed in the whole of Europe. These results are obtained using the assumptions outlined earlier and the table shows the maximum number of devices for two ΔTsat/Tsat thresholds of 6% and 1%. In Section 4.1, the maximum E.I.R.P specified for the omni-directional Mesh devices is 36 dBm. The effect of operating the omni-directional Mesh devices at an E.I.R.P 3 dB lower than this is also shown in Table 6.4.4.

[**] Satellites B, D and F were not the satellites most sensitive to interference and hence the calculations were not carried out for these satellites.

	Max # of omni-directional Mesh TS in satellite beam (millions)			
	E.I.R.P = 36 dBm		*E.I.R.P = 33 dBm*	
Satellite	**$\Delta T_{sat}/T_{sat}$ =6%**	**$\Delta T_{sat}/T_{sat}$ =1%**	**$\Delta T_{sat}/T_{sat}$ =6%**	**$\Delta T_{sat}/T_{sat}$ =1%**
A	**7.2**	**1.2**	**14.4**	**2.4**
B	**27**	**4.5**	**53.8**	**8.9**
D	**7.6**	**1.2**	**15.2**	**2.5**
F	**27.5**	**4.8**	**54.6**	**9.1**
G	**3.4**	**0.5**	**6.9**	**1.1**
H	**0.49**	**0.08**	**0.97**	**0.16**

Table 6.4.4: Maximum number of Omni-directional Mesh FWA devices in Europe to meet $\Delta T_{sat}/T_{sat}$ noise temperature thresholds for Satellites A @5°W, B @14°W, D @3°E, F @53°E, G @59.5°E and H @66°E

For the case of omni-directional Mesh systems sharing with satellites visible at high elevation angles from Europe, the number of terminals that could be deployed is generally in excess of 7 million / 1.2 million, and, in the worst case, 3.4 million / 0.5 million omni-directional Mesh subscriber terminals[13] are allowed (for satellite G at 59.5 degrees East), without giving rise to more than 6% / 1% increase in noise at the input to the satellite receiver.

This has been established for quite pessimistic sharing assumptions about Mesh FWA usage, such as:

- High subscriber transmit/receive activity ratio;
- No blockage towards the satellite has been assumed; in urban areas it is expected that terrain and clutter diffraction losses at low elevation angles will result in additional path loss to the satellite from some FWA terminals;
- All European countries make use of this frequency band for FWA.

In addition, Table 6.4.4 shows that a tightening of the E.I.R.P level by 3 dB promotes a more favourable sharing situation. For the case of omni-directional Mesh systems sharing with satellites that require low elevation angles from parts of Europe (where a substantial number of FWA devices may be deployed) and which lie within the main elevation lobe of the FWA antennas, sharing appears less straightforward. The result for satellite H (at 66° East) in Table 6.4.4 shows that this is more sensitive to interference because there may be more FWA terminals in its main beam. However, this satellite does not use the part of the band below 5850 MHz so the difficulty in sharing here is only constrained to the top 25 MHz of the band, so this consideration does not apply to the whole of the band.

6.4.2.3 Point-to-Point FWA Systems

Table 6.4.5 shows the maximum numbers of P-P FWA links in Europe that will not cause harmful interference to FSS. In calculating these numbers it has been assumed that the band is occupied solely by P-P links. Multipoint and other systems such as mesh networks were not included in this calculation. The results have been calculated for Satellites A, G and H, using the assumptions outlined earlier and the table shows the maximum number of devices for two $\Delta T_{sat}/T_{sat}$ thresholds of 6% and 1%. Results are presented for two examples of P-P antennas: i) on-axis antenna gain of 23 dBi; ii) on-axis antenna gain of 28 dBi.

	Max # of P-P FWA links in satellite beam (millions)			
	$\Delta T_{sat}/T_{sat}$ =6%		**$\Delta T_{sat}/T_{sat}$ =1%**	
FWA Ant Gain	**23dBi**	**28dBi**	**23dBi**	**28dBi**
Sat A	**9.8**	**17.7**	**1.6**	**2.9**
Sat G	**6.0**	**10.9**	**1.0**	**1.8**
Sat H	**3.2**	**5.9**	**0.5**	**0.98**

Table 6.4.5: Maximum number of P-P FWA links in Europe to meet $\Delta T_{sat}/T_{sat}$ noise temperature thresholds for Satellites A @5°W, G @59.5°E and H @66°E

Annex 9 shows an example of how these results were calculated for satellite A.

In the case of P-P links, several important differences to Multipoint deployment can be taken into account:

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[13] This assumes that all FWA devices are of one type (omni-directional) which is an unlikely situation.

- There are only two interference sources (transmitters) per link, as the link operates in TDD mode, only one source at any instance;
- Antenna beam widths of 9 and 5 degrees, representing typically 23-28dBi gain and 30-60cm aperture antenna have been used. Antenna gains could increase to over 30 dBi;
- The total number of P-P transmitters needed to constitute significant market penetration is much less than that needed for multipoint FWA deployment (see Table 4.3.2);

Due to the factors stated below it was felt that the calculated results give a worst case analysis and hence can be considered a very pessimistic estimate for the permitted number of links:

- It was assumed that the P-P links carry traffic for 100% of the time; this clearly will give a pessimistic result. The effect of Transmit Power Control should be to minimise the transmitted power (interference) when no packets are being sent;
- Some links will use narrower beam antennas;
- Study used a maximum E.I.R.P of 100 mW/MHz and a 10 MHz link bandwidth. The maximum number of permitted links scales with the bandwidth used;
- A 5 dB allowance, equivalent to an average of 0.56 of the maximum power range has been taken to simulate the fact that not all links will operate at maximum transmit power.

It should be noted that, in the part of the band above 5850 MHz, there is a global primary allocation to the Fixed Service in the ITU Radio Regulations. This actually allows much higher e.i.r.ps than were considered here[14].

6.4.3 Considerations on multiple types of FWA devices sharing with FSS

P-P links differ from directional Mesh systems only in the higher E.I.R.P levels allowed and the lower numbers expected to be deployed. Assuming higher gain antennas with similar patterns in horizontal and vertical dimensions, the interference potential of the fixed links is only a function of the transmitter power output and the deployed numbers.

Table 6.4.6 puts the above conclusions into a unified perspective. The aim of this table is to show the situation with a mixed deployment of FWA systems. In the final row of Table 6.4.6, the factors have been normalised to the P-MP case.

FWA Type[15]	**P-MP**	**Omni Mesh**	**P-P**
Relative deployment numbers	90%	9%[16]	1%
Number of devices for satellite 'A' and for $\Delta T/T = 6\%$[17]	335m	14.4m	9.8m
Relative interference potential per system[18] (see section 6.4.2)	1/335	1/14.4	1/9.8
Relative interference contribution factor per type[19], reference: P-MP -> FSS	1	2.3	0.16

Table 6.4.6: Derivation of Relative Interference Contribution of different types of FWA systems

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[14] See Nos. **21.2** and **21.4** of ITU RR. E.i.r.p of 35 dBW is permitted for a station in the Fixed Service without recourse to off-pointing from the geostationary orbit

[15] AP-MP is a hybrid of Point to Multi Point and Mesh

[16] It should be noted that directional mesh has not been studied in this analysis and the 9% assumption pertains to the overall market penetration for all types of Mesh systems

[17] An e.i.r.p of 36 dBm was used for P-MP systems (Table 6.4.3); an e.i.r.p of 33 dBm was used for mesh systems (Table 6.4.4); an e.i.r.p of 33 dBm was used for P-P systems (Table 6.4.5)

[18] These numbers are the inverse of the number of devices that can be deployed for satellite A, normalized relative to FSS

[19] These numbers show the relative interference "threat" for the main types of FWA systems: the lower market demand for mesh and point to point systems compensates the higher interference per deployed system

6.4.4 Basic elements for further sharing studies

The following FSS related parameters and data points have been used for the sharing studies in this report:

- Table 6.4.1: Aggregate FWA E.I.R.P
- Table 6.4.2: Population distribution over Europe
- Equations 6.4.2 and 6.4.8: ΔT_{sat} derivation

This information is independent on the specifics of FWA implementation and therefore it provides the basis for studies of future FWA systems.

6.4.5 Conclusions on sharing between FWA systems and the Fixed Satellite Service

The results of this part of the study give information about the total allowable number of some types of FWA devices over the whole European region, which could share with FSS networks.

The total number of devices contributing to the aggregate interference bears a direct relationship to the E.I.R.P of the FWA devices.

For the P-MP FWA (System type 1), with an E.I.R.P of 36 dBm, use of transmit power control[20] and uniform loading across the whole band, around 65 million terminals for $\Delta T_{sat}/T_{sat\,=}$ 6% or 11 million terminals for $\Delta T_{sat}/T_{sat\,=}$ 1% would be acceptable when considering sharing with the satellite H, which is most vulnerable to interference. With these assumptions, the sharing would be feasible. It is proposed to limit P-MP FWA systems' E.I.R.P density to 200 mW/MHz in order to enable sharing between P-MP FWA system and FSS in the band 5725-5875 MHz.

There is an absence of real data on deployment of AP-MP FWA (System type 2) systems. Therefore, based on the data provided in Section 4.1, their characteristics for modelling compatibility with the FSS are assumed to be close to those of conventional P-MP systems, and therefore it is assumed that the same sharing constraints apply.

For the omni-directional Mesh FWA (System type 3), with an E.I.R.P of 36 dBm, use of transmit power control and uniform loading across the whole band, the studies show some difficulty sharing with a deployed number of terminals at around 0.5 million for $\Delta T_{sat}/T_{sat\,=}$ 6% or 80 thousands terminals for $\Delta T_{sat}/T_{sat} =$ 1% (this is for the lowest elevation satellite which only operates above 5850 MHz).

Conservative assumptions about Mesh usage have been used, such as:

- High subscriber transmit/receive activity ratio;
- No blockage towards the satellite has been assumed; in urban areas it is expected that terrain and clutter diffraction losses at low elevation angles will result in additional path loss to the satellite from some FWA terminals;
- All European countries make use of this frequency band for FWA.

On the other hand, the calculations were made only for omni-directional Mesh FWA devices (not taking into account the other types of FWA devices).

Taking these assumptions into account, it is considered that the sharing between omni-directional Mesh FWA devices (System type 3) and FSS in the whole of the band 5725-5875 MHz is not feasible. It is noted that different elements could be considered in order to improve the sharing, e.g. by excluding the use of the band 5850-5875 MHz, or by reducing the maximum E.I.R.P level of each omni-directional Mesh device.

For the P_P FWA (System type 5), with an E.I.R.P density of 100 mW/MHz, use of Time Division Duplex, use of transmit power control[21] and uniform loading across the whole band, around 3 million terminals for $\Delta T_{sat}/T_{sat\,=}$ 6% or 0.5 million terminals for $\Delta T_{sat}/T_{sat\,=}$ 1% would be acceptable when considering sharing with the satellite H, which is most vulnerable to interference. This study assumed 100% FWA traffic activity. With these assumptions, the sharing would be feasible for FWA links of this type. Use of a higher antenna gain (e.g. on-axis gain of 28 dBi instead of 23 dBi) improves the sharing situation (effectively doubling the number of

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[20] An average 5 dB reduction in power level due to transmit power control has been assumed in these studies (see Appendix 6.4A and 6.4B and Section 6.4.1.4)

[21] An average 5 dB reduction in power level due to transmit power control has been assumed in these studies (see Section 6.4.1.4)

deployable links). As there are likely to be a range of antenna sizes used for P-P links, it is therefore unlikely that the interference into Satellite H (which only uses the top 25 MHz of the band) will be as significant as the worst-case situation has indicated.

It is proposed to limit P-P FWA systems' E.I.R.P density to 100mW/MHz in order to enable sharing with the FSS in the band 5725-5875 MHz. It should be noted that the studies have not addressed the situation where multiple types of FWA are deployed, i.e. the interference contributed from several different types. Hence the number of different FWA devices would be lower than those calculated above separately for each type. The sharing situation between various FWA systems and the FSS is summarised in Table 6.4.7

It is considered that FWA systems that conform to the elevation plane E.I.R.P density masks proposed in Section 6.4.2 will provide the best sharing environment with FSS satellites.

FWA Type	**FWA Conditions**	**Frequency Band**	
		5725-5850 MHz	**5850-5875 MHz**
P-MP (System 1)	E.I.R.P : 36 dBm Bandwidth : 20 MHz TPC: 5 dB	Sharing is feasible	Sharing is feasible
AP-MP (System 2)	E.I.R.P : 33 dBm Bandwidth : 20 MHz TPC: 5 dB	Sharing is feasible	Sharing is feasible
Omni-directional Mesh (System 3)	E.I.R.P : 36 dBm Bandwidth : 22 MHz TPC: 5 dB	Sharing is feasible with restrictions	Sharing is not feasible[22]
Directional Mesh (System 4)	E.I.R.P : 33 dBm Bandwidth : 20 MHz TPC: 5 dB	TBD[23]	TBD
Point-to-point (System 5)	E.I.R.P : 33 dBm Bandwidth : 20 MHz TPC: 5 dB	Sharing is feasible	Sharing is feasible

Note: The TPC value in the table is the assumed average reduction of e.i.r.p, not the maximum TPC range

Table 6.4.7: Summary of Sharing Results for FWA and FSS in the band 5725 - 5875 MHz

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[22] Sharing not feasible with these parameters but certain conditions could be applied to enable sharing (section 6.4.2.2)

[23] Mature studies of sharing between directional Mesh FWA systems and the FSS were not available because of the lack of representation of proponents of these systems

6.5 General (Non-Specific) Short Range Devices (SRD)

6.5.1 Assumptions

The analysis was based on the following assumptions and parameters:

a) The SRD antenna is omni-directional;
b) The SRD is typically used indoors, thus a 15 dB wall loss was assumed;
c) The E.I.R.P and antenna pattern of FWA CS and TS are the same;
d) For interference calculations, the propagation parameters of table 6.2.2 were used.

6.5.2 Results of calculations

The table below shows the separation distances required to protect each of the two systems from interference from the other system. The results for FWA CS are representative of all FWA devices located at high elevations whereas the FWA TS models FWA devices deployed at low elevations.

FWA -> SRD	**Distance, m**		
CS	**295**	**441**	**592**
Sidelobes	63	83	94
TS	**213**	**220**	**296**
Sidelobes	91	83	94

SRD –> FWA	**Distance, m**		
TS	**513**	**651**	**1095**
Sidelobes	241	254	350
CS	**781**	**1351**	**2216**
Sidelobes	167	254	350

Table 6.5.1: Results of calculating separation distances between FWA and SRD

6.5.3 Interference Assessment

As shown in the table 6.5.1, the required separation distances are in the order of hundreds of metres for the urban environment. In suburban and rural environments these distance increase to kilometres.

FWA CS and other devices at high locations will see interference from SRD devices at considerable distances, notably in rural environments. For the sidelobe coupling, these distances are much smaller; this means that spectrum sharing could be facilitated by means of selective use of directional antennas. Further, the separation distances in each interference direction are similar enough to result in equal mutual interference, which should provide for avoidance of co-channel operation.

6.5.4 Conclusion on FWA sharing with SRDs

Given that SRD devices and FWA systems are likely to use channelisation with maximum bandwidths in the region of 20 MHz it is feasible to introduce FWA systems into the same environment as SRD devices for the following reasons:

- FWA coverage area are likely to cover large areas using channel re-use pattern;
- The majority of SRD devices are likely to be operated indoors;
- Considering that in any given area at any given time one FWA channel will be in use, approximately 15% of the spectrum available for SRD devices is likely to suffer harmful interference from FWA systems in any given area at any given time;
- The number of SRD devices currently using this band is very low.

6.6 Amateur and Amateur Satellite (s-E) Services

6.6.1 Assumptions

The assumed characteristics for the amateur service can be found in section 5.6 of this report.

The Amateur service operates over a large range of frequencies, power levels, etc. and not all of these require detailed analysis. The following selection of parameters has been chosen so as to give a representative sharing case that can not be resolved by avoiding the coupling of antenna main beams: terrestrial digital voice and multimedia service at 3 dBW output, antenna sidelobe -5dBi, 130 kHz and 10 MHz channel width. The results are assumed to address the case of the impact from FWA into amateur satellite (s-E) operation.

Mode of operation	Digital voice and multimedia
Frequency band (MHz)	5 650-10 500
Necessary bandwidth and class of emission (Emission designator)	150KF1W 10M5F7W
Transmitter power (dBW)	3
Feeder loss (dB)	1-6
Transmitting antenna gain (dBi)	36
Maximum e.i.r.p. (dBW)	38
Antenna polarization	Horizontal, vertical
Receiver IF bandwidth (kHz)	2.7, 6, 16, 130, 10 500
Receiver noise figure (dB)	2

Table 6.6.1: Assumed Parameters of Amateur Service

6.6.2 Results of Calculations

The following table gives the separation distances needed to ensure effective sharing between P-MP FWA systems and the Amateur multimedia service using high gain antennas. Only the Amateur sidelobe gain was considered since main beam coupling can be avoided by the Amateur system. Two receiver bandwidths were considered for the Amateur system: 130 kHz and 10 MHz.

	Required separation distance, m		
FWA –> Amateur, 130 kHz	**Urban**	**Suburban**	**Rural**
CS	**174**	**240**	**289**
Sidelobes	37	45	46
TS	**125**	**120**	**144**
Sidelobes	54	45	46
FWA –> Amateur, 10 MHz			
CS	**1713**	**3333**	**6426**
Sidelobes	367	628	1016
TS	**1233**	**1667**	**3213**
Sidelobes	528	628	1016
Amateur -> FWA			
TS	**1670**	**2473**	**5088**
sidelobes	915	1182	2143
CS	**2967**	**6278**	**13551**
Sidelobes	635	1182	2143

Table 6.6.2: Results of Calculated Separation Distances between FWA and Amateur Service

6.6.3 Interference assessment

The results of calculations show that sharing may not be feasible if the amateur station and FWA system were to operate on the same frequency at less than the separation distances indicated above.

However, a number of mitigation factors need to be taken into account:

- Not all amateurs will operate at the high power level used in the analysis;
- The radio amateur service operates on a 'listen before transmit' basis, however the calculations show that the amateur service will interfere with FWA at a greater distance than in reverse direction and so FWA system can not rely totally on 'polite' amateur operation. 'Listen before transmit' usually can not be implemented in the remotely controlled amateur stations (e.g. relay stations). However coordination between the amateur and FWA stations may be feasible;
- FWA systems should employ DFS to facilitate sharing with radars, this may also protect FWA system from interference from an amateur station where listen before talk is not effective – provided that DFS reacts to simple exceeding of a threshold level, i.e. DFS does not necessarily require the triggering interfering signal to have characteristics of radar signal;
- There is a low density of amateur operation in this band.

6.6.4 Conclusions on sharing between FWA systems and the Amateur Service

The results of worst-case calculations show that interference would occur if the Amateur Service and FWA were to operate co-channel within close proximity (of the order of 100s of metres or a few kilometres). However, taking account of the various mitigation factors (identified in section 6.6.3) it is considered that sharing is feasible. The results are assumed to address also the case of the impact from FWA into the Amateur-Satellite (S-E) Service.

7 CONCLUSIONS

Having completed sharing studies on the sharing between Fixed Wireless Access systems and other systems in the band 5725-5875 the following conclusions were drawn up for each sharing scenario.

7.1 Sharing between FWA and Radiolocation systems

Similar to previous results from sharing between radar and RLANs in the band 5470-5725 MHz, the current studies have shown that DFS (Dynamic Frequency Selection) is required to avoid interference due to FWA co-channel operation with radars in the same vicinity in the band 5725 -5850MHz.

In order to make a judgement on the basic performance requirements for the DFS mechanism studies in this report were based on both one-to-one and aggregate model analysis to determine a new variable detection threshold (for the most critical case). In order to enhance the previous DFS modeling (carried out in the RLAN - radar studies) calculations included not only mainbeam-to-main beam coupling analysis, but also looked at the sidelobe coupling between systems.

By carrying out these different sidelobe coupling studies, this work proved that the DFS mechanism protects both the FWA and Radiolocation systems from harmful interference in any antenna coupling configuration in a one-to-one analysis. This work also calculated the minimum distance from the radar at which the DFS trigger level would not be exceeded for the different antenna coupling configurations. When analysing these results in conjunction with the known limitations of the aggregate interference model, anomalies could be explained between the results for the DFS threshold levels given from one-to-one analysis and the aggregate analysis.

Due to these anomalies and because of the larger size of the FWA coverage (cells) compared to that of WAS/RLANs and the higher E.I.R.P. limits being discussed it was also recommended that the DFS mechanism is normally required for all FWA stations in a network.

The recommended detection thresholds are shown below and are all based on a 20 MHz FWA bandwidth:

FWA station E.I.R.P. limit	Power density	Required DFS detection threshold
36 dBm	23 dBm / MHz	-69 dBm
33 dBm	20dBm / MHz	-66 dBm
30 dBm	17dbm / MHz	-63 dBm

For other FWA channel bandwidths, ChS, the following generic equation applies:

$$\textit{DFS Detection Threshold }(\mathrm{dBm}) = -69 + 23 - (\textit{Max Tx E.I.R.P }(\mathrm{dBm}) - 10*\log \textit{ChS}(\mathrm{MHz}))$$

The values of the detection threshold are defined at the front of the FWA receiver antenna, and are considered to be technically feasible. These values can be adjusted according to the formula in section 6.1.3.7.

On the basis of practical DFS testing conducted for RLANs between 5470-5725 MHz it has been shown that some current DFS implementations compliant to EN301893 v1.2.3 do not ensure timely detection of some frequency hopping radars which have an operating range both above and below 5725 MHz. This may result in harmful interference to these radars. It is expected that the work currently in progress in ETSI towards a revision of the EN301893 (i.e. EN 301893 v1.3.1), will not improve the detection of these frequency hopping radars.

In conclusion, sharing between FWA systems and Radiolocation systems operating in the band 5725-5850 MHz is considered to be feasible provided an appropriate DFS mechanism is implemented in FWA devices. The DFS specifications of FWA systems need further consideration, including considerations related to protection of frequency hopping radars. It is noted that these radars might not be deployed in all CEPT countries and some administrations have already allowed the deployment of FWA systems in 5.8GHz.

7.2 Sharing between FWA and RTTT systems

If FWA and RTTT systems were to be operated co-channel and in close proximity (in the order of 100s m or a few kilometres) then interference could occur.

In addition it has been shown that the probability for FWA to adversely affect the RTTT OBU battery life is very low.

Considering that RTTT systems do not operate across the entire band proposed for FWA, that they are only deployed in a limited number of locations and that RTTT will cause interfere to FWA at a greater distance than in the opposite direction (and hence FWA installations would avoid operating in active RTTT channels), sharing between FWA and RTTT systems is considered to be possible.

7.3 Sharing between FWA systems and the Fixed Service

Due to the nature of the Fixed Service use of the 5.8 GHz band for P-P links, as described in section 5.3, detailed compatibility studies have not been conducted. It is expected that if those countries which have existing fixed service P-P links were to introduce FWA in the same frequency range, it would be necessary to co-ordinate between those two systems.

7.4 Sharing between FWA systems and the Fixed Satellite Service

The studies presented in this report have derived information about the total allowable number of FWA devices over the whole of European region, in various system configurations, which could share with FSS networks. The E.I.R.P and characteristics of the various types of FWA devices have a direct impact on the aggregate interference. This influences the total number of FWA devices that can be deployed, and the obtained numbers were considered suitable for the predicted market penetration of FWA devices in this band.

It can be seen from the studies that sharing is feasible in the band 5725-5850MHz depending on the ability of FWA devices to limit the e.i.r.p. density in the direction of GSO satellites, in the band 5850-5875MHz the conditions to make sharing feasible are more restrictive.

7.5 Sharing between FWA systems and SRDs

Given that SRD applications and FWA systems are likely to use channelisation with maximum bandwidths in the region of 20 MHz it is feasible to introduce FWA systems into the same environment as SRDs for the following reasons:

- FWA coverage area are likely to cover large areas using channel re-use pattern;
- The majority of SRD devices are likely to be operated indoors;
- Considering that in any given area at any given time only one FWA channel will be in use, approximately 15% of the spectrum available for SRDs is likely to suffer harmful interference from FWA systems in any given area at any given time;
- The number of SRDs currently using this band is very low.

7.6 Sharing between FWA systems and the Amateur and Amateur Satellite (s-E) Services

The results of worst-case calculations show that interference would occur if the Amateur/Amateur Satellite (s-E) Services and FWA were to operate co-channel within close proximity (in the order of 100s m or a few kilometres).

However, taking into account the various mitigation factors (identified in section 6.6.3), it is considered that sharing should be permitted.

ANNEX 1: TECHNICAL PARAMETERS OF FWA SYSTEMS 1 TO 5 CONSIDERED AS A BASIS FOR THE COMPATIBILITY STUDIES IN THIS REPORT

Table A1.1: FWA System Parameters

Parameter	Group 1 P-MP	Group 2 (AP-MP)	Group 3 (Omni-directional Mesh)	Group 4 (Directional Mesh)	Group 5 (P-P)
Source	ETSI TR 102 079	ETSI TR 102 079	ETSI TR 102 079	ETSI TR 102 328	
Topology	Sectored Central Station (CS) Units, Terminal Stations (TS).	Root Node, Branch Node, Leaf Node (Rooftop, Eaves, Indoor).	All stations (nodes) deploying Omni-directional antennas.	All stations (nodes) deploying Directional antennas.	All stations deploying Directional antennas.
Channel bandwidth	5 MHz, 10 MHz, 20 MHz	10 MHz, 20 MHz	20 dB bandwidth is 22 MHz	20 MHz	10 MHz, 20 MHz
Duplex/ Access scheme	TDD/TDMA	TDD/TDMA	TDD/TDMA	TDD/TDMA	TDD
Max e.i.r.p.	36 dBm	33 dBm	36 dBm	33 dBm[24]	33 dBm[25] (EIRP)
Power density spectral (dBm/MHz) e.i.r.p.	23 dBm/MHz	20 dBm/MHz	23 dBm/MHz	20 dBm/MHz	20 dBm/MHz
Device TPC Range	20 dB	8 to 10 dB		19 dB	30 dB
Central station antenna gain	15 dBi (90º) 17 dBi (60º)	*Sectored Root Node* 15 dBi *Branch* Directional: 24 dBi Omni: 10 dBi		NA	NA
Root node elevation pattern		3° - 5° beamwidth			
Terminal Station (TS) / Node antenna gain	16 dBi	Range of Leaf Node Antenna Gains: 12 – 18 dBi	10 dBi	10 - 14 dBi Omni	23 dBi
Terminal Station (TS) / Node antenna beamwidth	20° [26]			22.5°	7°
Terminal Station (TS) / Node antenna elevation			-25 dBi @ 0° - 30°	see Recommendation ITU-R M.1652	see Recommendation ITU-R M.1652

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[24] e.i.r.p. set on each link at that just required (including a margin) considering the link length.

[25] Link e.i.r.p. is set on a link by link basis according to the path length and other factors.

[26] Although generally symmetrical in azimuth and elevation, in some cases antennas with a reduced elevation pattern are possible with elevation beamwidths less the 10 degrees.

pattern			-15 dBi @ 30° – 50°		
Antenna pattern	See Figures 1 & 2 of this Annex			See Figure 3 of this Annex	See Figure 3 of this Annex
Polarisation			Vertical		
Receiver sensitivity (BPSK)	-86 dBm (in 20 MHz BW)		-82 dBm @ ½ rate coding -81 dBm @ ¾ rate coding	-87 dBm	-92 dBm
Receiver sensitivity (QPSK)	-80 dBm (in 20 MHz BW)	-83 dBm @ ½ rate coding -81 dBm @ ¾ rate coding	-79 dBm @ ½ rate coding -77 dBm @ ¾ rate coding	-80 dBm	-87 dBm
Receiver sensitivity (16-QAM)	-74 dBm (in 20 MHz BW)	-76 dBm @ ½ rate coding -74 dBm @ ¾ rate coding	-74 dBm @ ½ rate coding -70 dBm @ ¾ rate coding	-74 dBm	-81 dBm
Receiver sensitivity (64-QAM)	-68 dBm (in 20 MHz BW)	-69 dBm @ ½ rate coding -68 dBm @ ¾ rate coding	-66 dBm @ ½ rate coding -65 dBm @ ¾ rate coding		

Table A1.1: FWA System Parameters

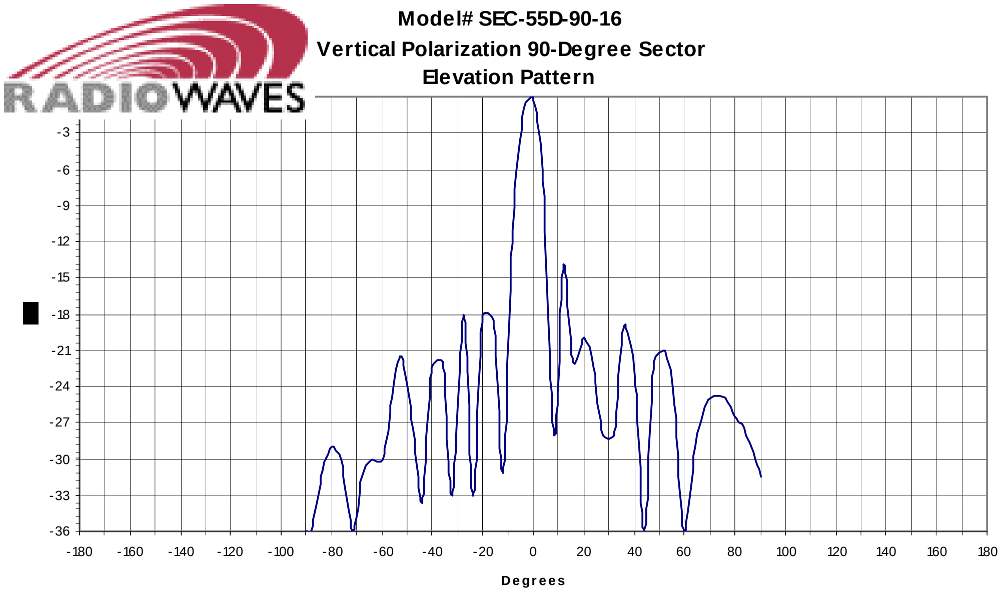


Figure A1.1: FWA System 1 Typical CS Antenna Pattern

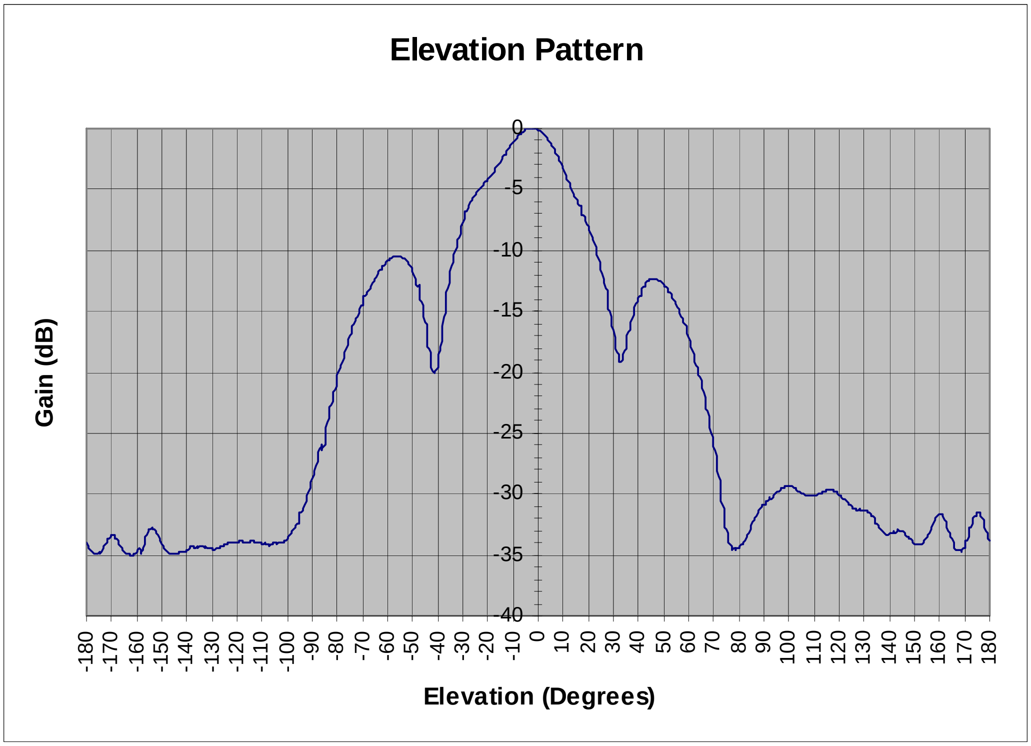


Figure A1.2: FWA System 1 Typical TS Antenna Pattern (18 dBi antenna, 20° beam width)

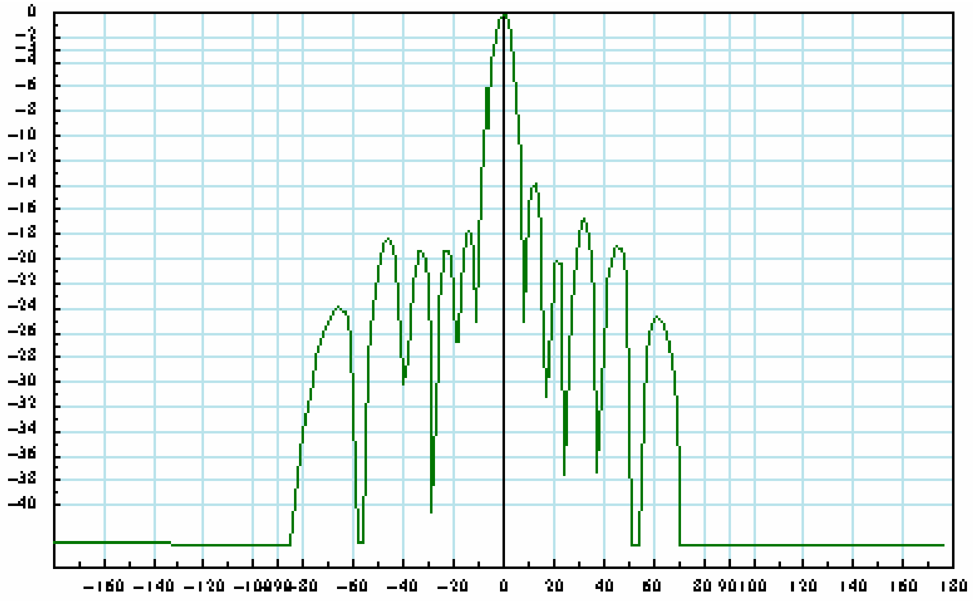


Figure 3: FWA System 5 Typical Antenna Pattern (Symmetrical in Azimuth and Elevation)

ANNEX 2: FWA DEPLOYMENT SCENARIO FACTORS

System 1 P-MP		**System 2 (H'MAN APMP)**		**System 3 (H'MAN Mesh)**		**System 4 (Directional Mesh)**		**System 5 (P-P)**	
% rooftop SUs	20	% Leaf Nodes.	19.7%			Paths	LoS	Paths	LOS and NonLOS
Rooftop excess loss	0dB					Building and clutter losses	0dB		
% eaves-mounted SUs	50%	% Leaf Nodes.	25%			Typical min link length	50m		
Eaves-mount excess loss	10dB					Typical max link length	4000m		
% indoor mounted SUs	30%	% Indoor Leaf Nodes	50%						
						Node Density	100/sq km		
Aggregate SU Tx duty ratio	50%	Activity Factor for Leaf.	0.75%	Node activity factor.	5%	Node activity factor	25% of time	Activity factor	20-80%
Per BSU duty ratio	50%	Activity Factors for Root and Branch	50% and 10% resp.			Azimuth Pointing Angle	Random		
Indoor excess loss	-15dB					Tx Power Setting	5dB above receiver threshold.		
Number of channel in reuse pattern	6					Node Position	Eaves to rooftop + 1 metre		

ANNEX 3: RADAR DETECTION AND EXAMPLE OF ASSOCIATED DFS PROCEDURES

An example of how a DFS mechanism operating procedures could be described is given in this Annex.

A3.1 Definitions

The following definitions are given for use within this annex:

Available channel:	A radio channel on which a channel availability check has not identified the presence of a radar
Received radar signal:	A signal as characterized by all three requirements shown below:

- an RSS equal to or greater than the DFS detection threshold level of T_{DFS} (dBm) within the FWA system channel bandwidth;
- pulse repetition rates in the range provided in table 5.1.1;
- nominal pulse widths in the range provided in the table 5.1.1.

Operating channel:	Once a FWA device starts to operate on an available channel then that channel becomes the operating channel.

A3.2 Procedures

Finding an initial available channel

Before a FWA device transmits, and if no available channel has yet been identified, it shall undertake a channel availability check on a radio channel before it is used for transmission. Consequently, when a network is installed and first powered on, channel availability check(s) should be undertaken, so as to identify at least one available channel. Having identified an available channel, the FWA device can start operation on that channel; the checking of other radio channels to identify other available channels is optional.

Starting operation

Once a FWA device starts to operate on an available channel then that channel becomes the operating channel.

Monitoring the operating channel and other channels

In-service monitoring is performed by the FWA device to re-check the operating channel for co-channel radar signals that may have come within range of the FWA device or started operation on the operating channel.

In addition, an FWA system may perform monitoring of any of its channels at any time to determine the presence of radiolocation systems.

ANNEX 4: RESULTS FROM AGGREGATE ANALYSIS OF SHARING BETWEEN FWA AND RADARS

URBAN

Radar Type	Threshold	Power	Angle	Min_level	Max_level	80%	95%	99%	
X Track Fr	-70	2W	0	-12.75	-3.66	-10.93	-7.3	-3.75	
	-70	4W	0	-12.47	-2.62	-10.47	-6.55	-2.72	
	-72	2W	0	-14.1	-5.78	-12.44	-9.11	-5.86	
	-72	4W	0	-13.09	-3.9	-11.25	-7.57	-3.99	
	-74	2W	0	-16.98	-7.43	-15.07	-11.21	-7.53	
	-74	4W	0	-14.38	-5.32	-12.57	-8.94	-5.41	
	-74	2W	0	-17.34	34.58	-6.58	14.52	34.06	99%
	-74	2W	2	-17.35	-7.82	-15.43	-11.63	-7.92	99%
	-74	2W	180	-18.74	-8.18	-16.64	-12.4	-8.29	99%
	-76	2W	0	-17.61	-8.85	-15.85	-12.36	-8.94	
	-76	4W	0	-17.05	-6.7	-14.99	-10.84	-6.8	
	-76	2W	0	-18.83	35.18	-7.85	14.1	34.64	99%
	-76	2W	1	-18.83	-7.9	-16.63	-12.25	-8.01	99%
	-76	2W	180	-20.28	-10.41	-18.28	-14.34	-10.51	99%
	-78	2W	0	-19.11	-11.21	-17.54	-14.37	-11.29	
	-78	4W	0	-19.36	-9.78	-17.45	-13.6	-9.87	
	-70	2W	0	-13.14	-3.96	-11.27	-7.62	-4.05	
	-70	4W	0	-11.46	-2.23	-9.62	-5.9	-2.32	
	-72	2W	0	-14.37	-5.87	-12.68	-9.26	-5.95	
	-72	4W	0	-12.02	-4.61	-10.51	-7.58	-4.68	
Y	-74	2W	0	-16.16	-7.87	-14.5	-11.17	-7.95	
Fixed	-74	4W	0	-15.23	-5.93	-13.38	-9.65	-6.02	
	-74	2W	0	-15.4	23.16	-7.56	7.91	22.77	99%
	-74	2W	1	-16.42	-6.4	-14.42	-10.41	-6.5	99%
	-74	2W	360	-276.03	-53.14	-55.15	-55.15	-55.15	99%
Fr	-76	2W	0	-17.04	-9.59	-15.54	-12.55	-9.66	
	-76	4W	0	-16.17	-7.83	-14.51	-11.16	-7.91	
	-76	2W	0	-17.31	19.67	-9.72	5.34	19.34	99%
	-76	2W	1	-17.28	-9.35	-15.68	-12.51	-9.43	99%
	-76	2W	360	-276.03	-59.85	-60.28	-60.28	-60.28	99%
	-78	2W	0	-19.6	-11.57	-17.99	-14.79	-11.65	
	-78	4W	0	-22.63	-8.53	-19.76	-14.18	-8.67	

Table A4.1: FWA Central Station Ref: CS1

URBAN

Radar Type	Threshold	Power	Angle	Min_level	Max_level	80%	95%	99%
X Track Fr	-70	2W	0	-12.75	-3.66	-10.93	-7.3	-3.75
	-70	4W	0	-12.47	-2.62	-10.47	-6.55	-2.72
	-72	2W	0	-14.1	-5.78	-12.44	-9.11	-5.86
	-72	4W	0	-13.09	-3.9	-11.25	-7.57	-3.99
	-74	2W	0	-16.98	-7.43	-15.07	-11.21	-7.53
	-74	4W	0	-14.38	-5.32	-12.57	-8.94	-5.41
	-76	2W	0	-17.61	-8.85	-15.85	-12.36	-8.94
	-76	4W	0	-17.05	-6.7	-14.99	-10.84	-6.8
	-78	2W	0	-19.11	-11.21	-17.54	-14.37	-11.29
	-78	4W	0	-19.36	-9.78	-17.45	-13.6	-9.87
Y Fixed Fr	-70	2W	0	-13.14	-3.96	-11.27	-7.62	-4.05
	-70	4W	0	-11.46	-2.23	-9.62	-5.9	-2.32
	-72	2W	0	-14.37	-5.87	-12.68	-9.26	-5.95
	-72	4W	0	-12.02	-4.61	-10.51	-7.58	-4.68
	-74	2W	0	-16.16	-7.87	-14.5	-11.17	-7.95
	-74	4W	0	-15.23	-5.93	-13.38	-9.65	-6.02
	-76	2W	0	-17.04	-9.59	-15.54	-12.55	-9.66
	-76	4W	0	-16.17	-7.83	-14.51	-11.16	-7.91
	-78	2W	0	-19.6	-11.57	-17.99	-14.79	-11.65
	-78	4W	0	-22.63	-8.53	-19.76	-14.18	-8.67

Table A4.2: FWA Central Station Ref: CS1

SUBURBAN

Radar Type	Threshold	Power	Angle	Min_level	Max_level	80%	95%	99%
X Track Fr	-70	2W	0	-13.85	-4.94	-12.07	-8.47	-5.02
	-70	4W	0	-13.66	-2.8	-11.5	-7.12	-2.91
	-72	2W	0	-17	-6.87	-14.98	-10.92	-6.96
	-72	4W	0	-13.56	-4.72	-11.79	-8.26	-4.81
	-74	2W	0	-15.88	-7.27	-14.16	-10.71	-7.36
	-74	4W	0	-14.65	-6.01	-12.92	-9.46	-6.1
	-76	2W	0	-17.16	-9.52	-15.64	-12.56	-9.59
	-76	4W	0	-16.76	-7.68	-14.94	-11.32	-7.77
	-78	2W	0	-21.71	-11.08	-19.59	-15.29	-11.19
	-78	4W	0	-18.56	-9.53	-16.73	-13.15	-9.62
Y Fixed Fr	-70	2W	0	-13.86	-4.44	-11.97	-8.21	-4.53
	-70	4W	0	-12.88	-2.72	-10.86	-6.75	-2.82
	-72	2W	0	-14.87	-6.4	-13.17	-9.79	-6.48
	-72	4W	0	-14.52	-4.29	-12.46	-8.37	-4.39
	-74	2W	0	-15.7	-7.44	-14.05	-10.71	-7.52
	-74	4W	0	-15.35	-6.06	-13.47	-9.76	-6.15
	-76	2W	0	-18.64	-9.2	-16.76	-12.98	-9.29
	-76	4W	0	-16.26	-8.03	-14.62	-11.33	-8.11
	-78	2W	0	-19.39	-10.81	-17.66	-14.23	-10.9
	-78	4W	0	-18.52	-9.98	-16.8	-13.39	-10.07

Table A4.3: FWA Central Station Ref: CS1

RURAL

Radar Type	Threshold	Power	Angle	Min_level	Max_level	80%	95%	99%
X Track Fr	-70	2W	0	-39.19	-6.02	-32.52	-19.27	-6.35
	-70	4W	0	-40.72	-3.46	-33.3	-18.38	-3.83
	-72	2W	0	-34.71	-7.77	-29.32	-18.56	-8.04
	-72	4W	0	-35.59	-5.22	-29.51	-17.35	-5.49
	-74	2W	0	-40.32	-8.95	-34.04	-21.42	-9.23
	-74	4W	0	-39.37	-7.45	-33.01	-20.17	-7.77
	-76	2W	0	-34.81	-10.35	-29.94	-20.12	-10.59
	-76	4W	0	-34.68	-8.31	-29.4	-18.87	-8.57
	-78	2W	0	-42.04	-11.78	-35.98	-23.84	-12.08
	-78	4W	0	-42.63	-8.95	-35.92	-22.3	-9.25
Y Fixed Fr	-70	2W	0	-36.47	-5.02	-30.21	-17.58	-5.33
	-70	4W	0	-40.04	-4	-32.75	-18.25	-4.32
	-72	2W	0	-40.11	-7.41	-33.6	-20.44	-7.7
	-72	4W	0	-29.88	-5.65	-25.05	-15.33	-5.89
	-74	2W	0	-34.37	-8.14	-29.12	-18.59	-8.4
	-74	4W	0	-39.35	-6.85	-32.88	-19.7	-7.11
	-76	2W	0	-37.64	-10.3	-32.19	-21.22	-10.57
	-76	4W	0	-276.03	-9.02	-218.83	-115.93	-11.16
	-78	2W	0	-43.85	-12.35	-37.58	-24.9	-12.6
	-78	4W	0	-32.44	-10.98	-28.14	-19.57	-11.17

Table A4.4: FWA Central Station Ref: CS1

URBAN

Radar Type	Threshold	Power	Angle	Min_level	Max_level	80%	95%	99%
X Track Fr	-70	2W	0	-19.13	-5.71	-16.46	-11.08	-5.82
	-70	4W	0	-15.75	-4.25	-13.46	-8.85	-4.37
	-72	2W	0	-19.56	-7.54	-17.17	-12.33	-7.65
	-72	4W	0	-16.84	-6.11	-14.7	-10.4	-6.22
	-74	2W	0	-19.27	-9.64	-17.34	-13.49	-9.74
	-74	4W	0	-19.64	-6.9	-17.09	-12	-7.03
	-76	2W	0	-21.39	-10.9	-19.29	-15.06	-11.01
	-76	4W	0	-19.69	-9.1	-17.58	-13.31	-9.21
	-78	2W	0	-22.15	-12.76	-20.27	-16.47	-12.85
	-78	4W	0	-21.2	-10.44	-19.06	-14.71	-10.55
Y Fixed Fr	-70	2W	0	-17.29	-6.33	-15.11	-10.71	-6.44
	-70	4W	0	-16.76	-4.63	-14.33	-9.46	-4.75
	-72	2W	0	-19.53	-7.61	-17.16	-12.3	-7.73
	-72	4W	0	-18.06	-6.25	-15.68	-10.97	-6.37
	-74	2W	0	-19.76	-8.29	-17.48	-12.87	-8.4
	-74	4W	0	-18.67	-7.37	-16.41	-11.89	-7.48
	-76	2W	0	-20.34	-11	-18.46	-14.73	-11.09
	-76	4W	0	-18.51	-9	-16.62	-12.81	-9.1
	-78	2W	0	-22.2	-12.83	-20.32	-16.58	-12.92
	-78	4W	0	-20.24	-10.84	-18.36	-14.6	-10.93

Table A4.5: FWA Terminal Station Ref: TS5

SUBURBAN

Radar Type	Threshold	Power	Angle	Min_level	Max_level	80%	95%	99%
X Track Fr	-70	2W	0	-23.7	-6.63	-20.27	-13.45	-6.8
	-70	4W	0	-19.12	-4.99	-16.31	-10.63	-5.12
	-72	2W	0	-22.64	-6.84	-19.46	-13.17	-6.98
	-72	4W	0	-20.72	-6.39	-17.84	-12.13	-6.53
	-74	2W	0	-22.11	-9.51	-19.6	-14.5	-9.62
	-74	4W	0	-21.31	-8.29	-18.72	-13.5	-8.42
	-76	2W	0	-24.06	-11.77	-21.61	-16.64	-11.89
	-76	4W	0	-22.41	-9.49	-19.84	-14.64	-9.62
	-78	2W	0	-23.29	-13.24	-21.29	-17.25	-13.34
	-78	4W	0	-22.57	-10.77	-20.2	-15.49	-10.89
Y Fixed Fr	-70	2W	0	-21.47	-4.92	-18.17	-11.55	-5.09
	-70	4W	0	-23.74	-4.23	-19.83	-12.02	-4.43
	-72	2W	0	-21.48	-7.69	-18.72	-13.18	-7.83
	-72	4W	0	-20.1	-5.97	-17.24	-11.57	-6.11
	-74	2W	0	-22.93	-9.5	-20.24	-14.84	-9.63
	-74	4W	0	-22.51	-7.97	-19.61	-13.79	-8.12
	-76	2W	0	-23.89	-11.1	-21.33	-16.22	-11.23
	-76	4W	0	-22.61	-9.49	-20	-14.74	-9.62
	-78	2W	0	-25.35	-13.24	-22.89	-18.08	-13.36
	-78	4W	0	-22.86	-10.94	-20.47	-15.7	-11.06

Table A4.6: FWA Terminal Station Ref: TS5

RURAL

Radar Type	Threshold	Power	Angle	Min_level	Max_level	80%	95%	99%
X Track Fr	-70	2W	0	-43.15	-7.79	-36.11	-21.84	-8.14
	-70	4W	0	-60.93	-5.88	-49.91	-27.92	-6.43
	-72	2W	0	-43.95	-8.41	-36.8	-22.57	-8.77
	-72	4W	0	-41.28	-7.03	-34.42	-20.74	-7.37
	-74	2W	0	-46.52	-9.68	-39.11	-24.39	-10.05
	-74	4W	0	-53.28	-9.53	-44.48	-27	-9.97
	-76	2W	0	-52.13	-12.58	-44.25	-28.38	-12.94
	-76	4W	0	-46.66	-11.25	-39.5	-25.39	-11.6
	-78	2W	0	-44.08	-14.38	-38.16	-26.24	-14.68
	-78	4W	0	-42.78	-11.71	-36.59	-24.15	-12.02
Y Fixed Fr	-70	2W	0	-42.48	-7.87	-35.52	-21.73	-8.22
	-70	4W	0	-43.79	-5.57	-36.14	-20.76	-5.95
	-72	2W	0	-50.66	-9.52	-42.38	-25.95	-9.93
	-72	4W	0	-41.21	-7.33	-34.43	-20.86	-7.67
	-74	2W	0	-47.8	-10.45	-40.36	-25.4	-10.82
	-74	4W	0	-47.87	-8.48	-39.98	-24.09	-8.87
	-76	2W	0	-42.45	-12.33	-36.45	-24.39	-12.63
	-76	4W	0	-41.47	-10.33	-35.27	-22.8	-10.64
	-78	2W	0	-49.37	-13.43	-42.21	-27.78	-13.79
	-78	4W	0	-42.52	-11.75	-36.39	-24.04	-12.06

R

Table A4.7: FWA Terminal Station Ref: TS5

ANNEX 5: TYPICAL INPUT FILE FOR FWA-RADARS SIMULATION TOOL

```
4                   // Radius of urban area (km)
10                  // Radius of surburban area (km)
32                  // Radius of rural area (km)
16                  // Number of tx in urban 1652
21                  // Number of tx in surburban 826
37                  // Number of tx in rural 275
4                   // Number of power levels to consider
0.2  0.2  0.30 0.30 // power levels probabilty for each device
0.25 0.5  1.0  2.00 // power levels EIRP for each device (Watts)
16.0 16.0 16.0 16.0 // Antenna gain corresponding to device, must be 0 or larger (dBi)
-54  -54  -54  -54  // DFS trigger level for device at specified power and ant gain (dBm) (after antenna Gain)
5 3 3               // Building floor Urban/surburban/rural (floors)
3.0                 // Floor height (m)
0.5                 // Minimum distance Rlans can be from radar (km)
20.0                // WLAN bandwidth (MHz)
2                   // Rlan insertion loss (dB)
1000                // Number of trial to perform for each zone per radar
1                   // Flag for antenna pattern on RLAN (1 -use specified file, 0 -use standard per ITU-R rec 1652)
Ant_file_TS5.txt    // If above antenna flag = 1 use named file (no more than 200 characters)
1                   // Flag to simulate which sides of pt-to-pt link doing DFS, 1 = both sides 0 = one side
5.0                 // Maximum distance between PP links (km) (uniform distribution from 0.01 km to max distance)
0                   // Radar to simulate (0 - all, "radar indicator" ie P to simulate radar P) C, K, P, S
2                   // Number of Radars considered, this should exactly match with number of radar columns below
X       Y           // Radar indicator
T       F           // Radar Type (T=Track, F=Fixed, M=Maritime, A=Air
12      12          // Transmit power (kW)
35      35          // Transmit Gain (dBi)
4       4           // IF 3db Bandwidth (MHz)
5800    5800        // Frequency (MHz)
2       2           // Insertion loss (dB)
5       5           // Noise Figure
10      10          // Ant height (m)
0       0           // Antenna Declination (set to 0 if not used)(degrees)
1.00    1.00        // Prob of detection
0       12          // Rotation Rate (deg/sec) used for number of rotations sim in 60 sec (act 36/12/72/20))
```

Ant_file_CS1.txt

```
7                    // Number of points in antenna mask, the program interpoltes the table on a linear basis (Gain in dB vs angle)
0.0     0.0         // Angle (deg)        Gain (dB) - relative to peak
35.0    -0.0        // note that this must be specified from 0 degrees
67.0    -5.0        // to 180 degrees. Also note that this table
98.0    -10.0       // must be ordered from minimum angle to largest angle.
130.0   -15.0       // No limit to the size of this table
160.0   -20.0
180.0   -20.0
```

Ant_file_TS5.txt

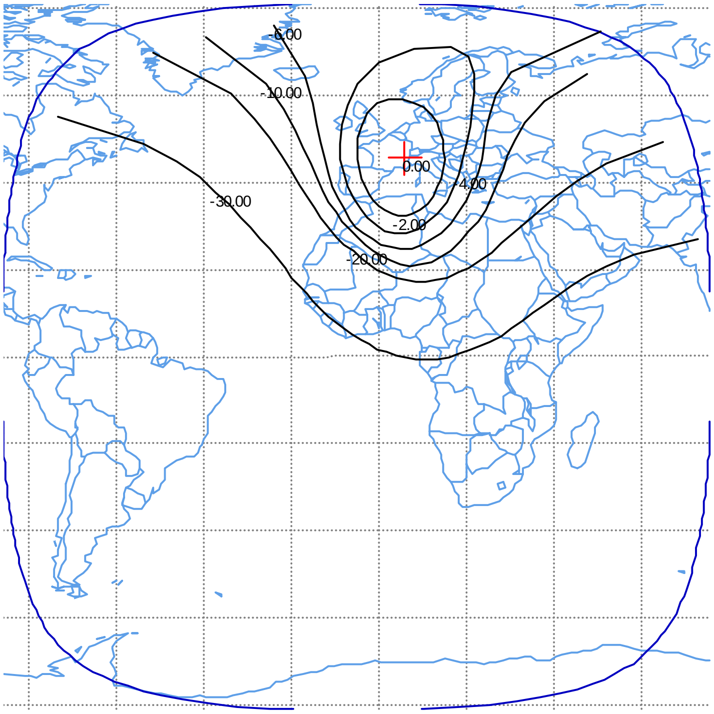
```
6                    // Number of points in antenna mask, the program interpoltes the table on a linear basis (Gain in dB vs angle)
0.0     0.0         // Angle (deg)        Gain (dB) - relative to peak
12.0    0.0         // note that this must be specified from 0 degrees
30.0    -17.0       // to 180 degrees. Also note that this table
90.0    -17.0       // must be ordered from minimum angle to largest angle.
150.0   -30.0       // No limit to the size of this table
180.0   -30.0
```

ANNEX 6:

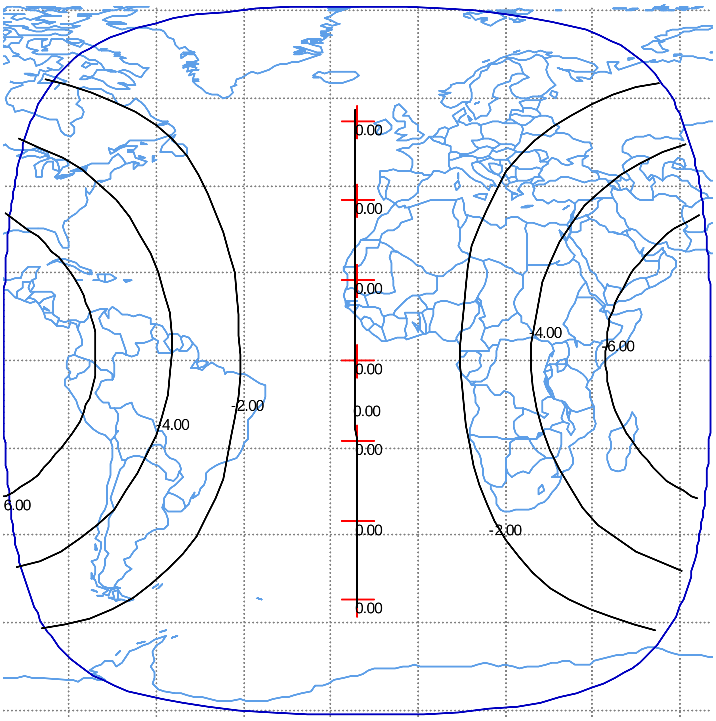
SATELLITE FOOTPRINTS CONSIDERED IN FWA-FSS STUDY IN THE BAND 5725 – 5875 MHZ

The attached figures of satellite footprints are provided to assist with studies for calculating the number of FWA devices that can be deployed in Europe within the footprint of various satellites in geostationary orbit. The red cross on each map indicates the location of the maximum gain which is given in Table 5.4.2 of the main report.

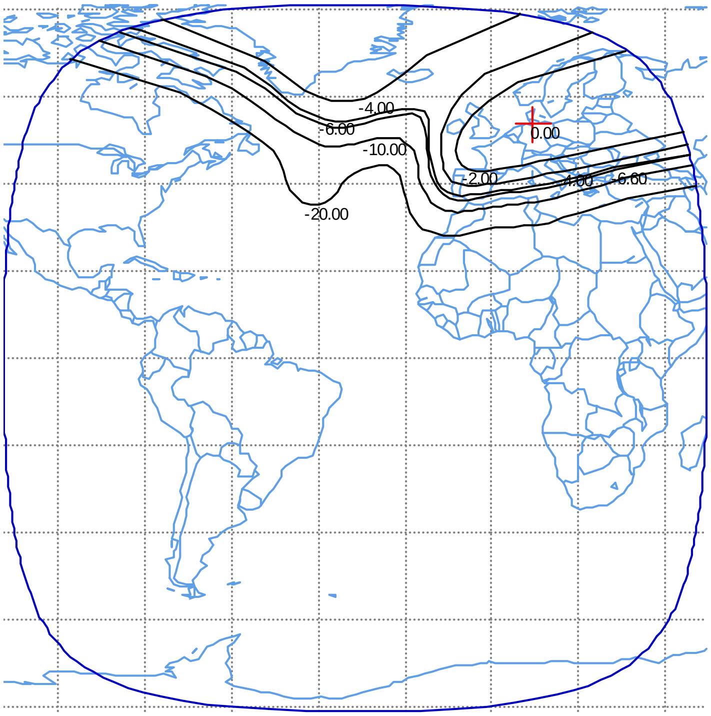
Satellite A footprint (5°W).



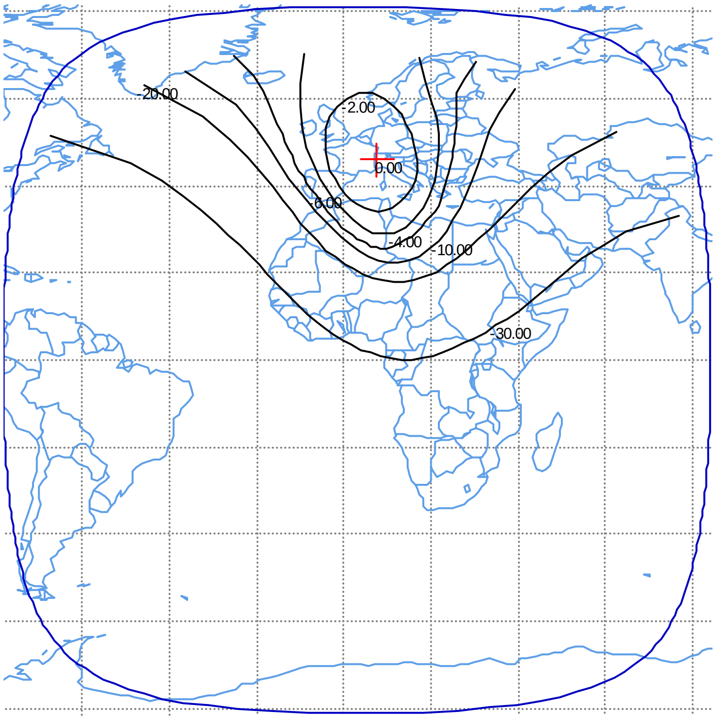
Satellite B footprint. (14°W)



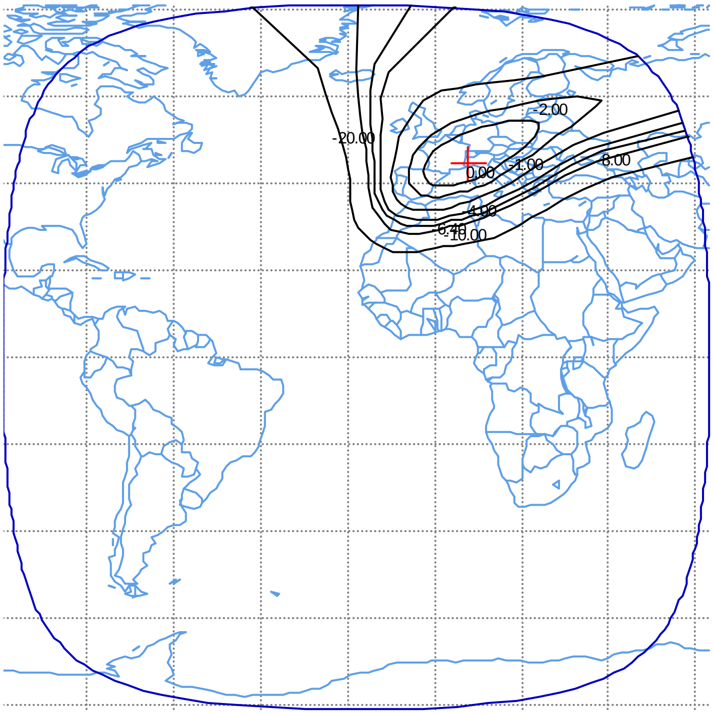
Satellite C Footprint (31.5°W)



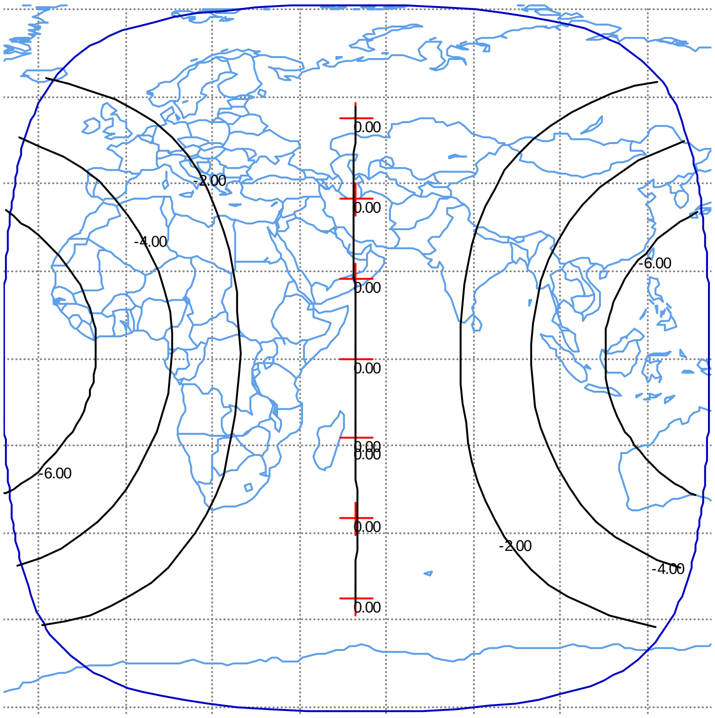
Satellite D Footprint (3°E)



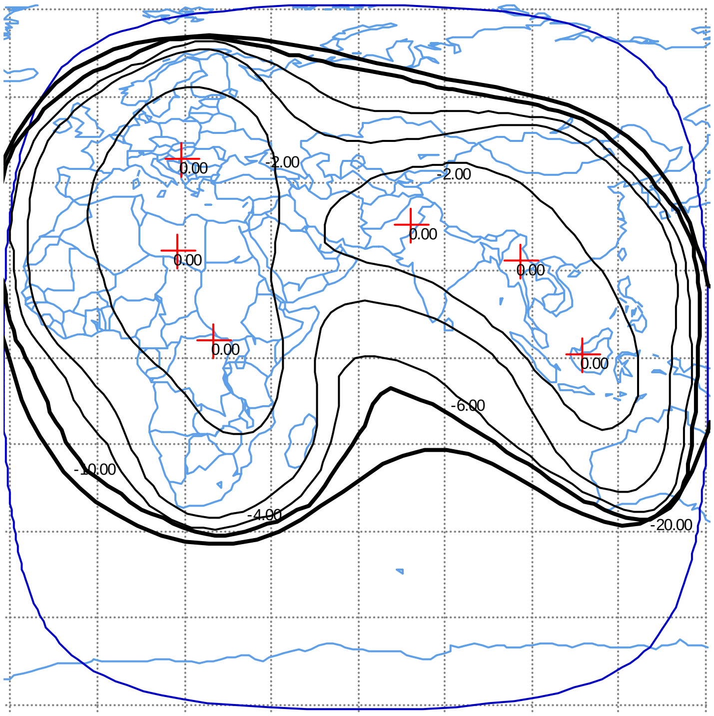
Satellite E Footprint (18°W)



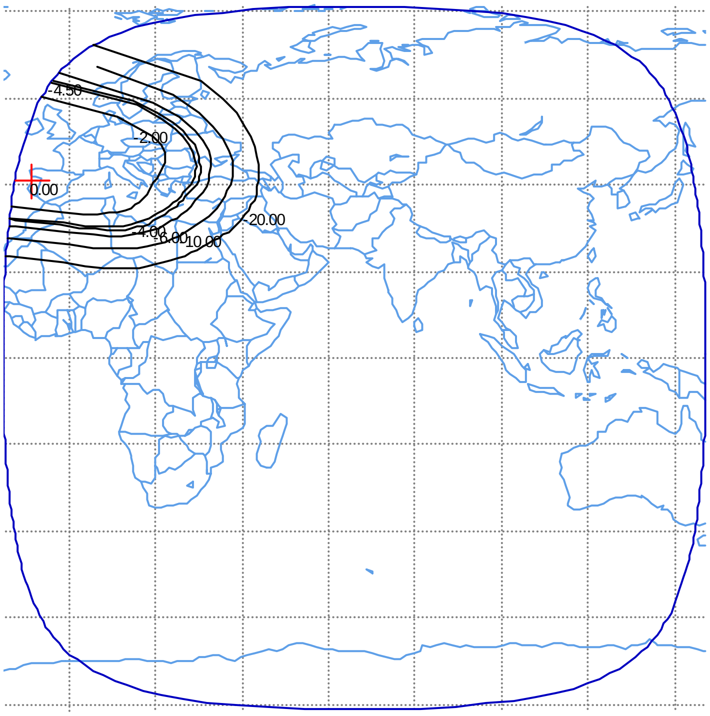
Satellite F Footprint (53°E)



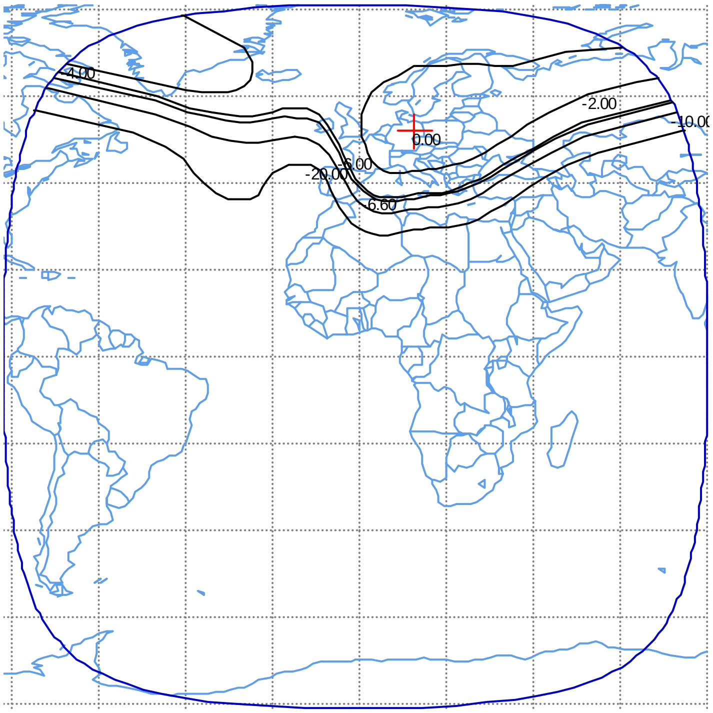
Satellite G footprint (59.5°E)



Satellite Footprint H (66°E)



Satellite Footprint I (1°W)



ANNEX 7: METHOD AND EXAMPLE OF CALCULATIONS FOR OMNI-DIRECTIONAL MESH FWA SHARING WITH FSS

By considering the number of FWA devices to be proportional to the total population in each country, the noise temperature contribution from a single country can be expressed, as follows:

$$\Delta T_{sat\ j} = \frac{G_{sat\ j} \cdot eirp_{FWA\ j}}{k \cdot l_j} \quad \text{K} \qquad \text{(A1)}$$

then

$$\Delta T_{sat} = \sum_{j=1}^{N} \Delta T_{sat\ j} = \frac{1}{k} \sum_{j=1}^{N} \frac{G_{sat\ j} \cdot eirp_{FWA\ j}}{l_j} \quad \text{K} \qquad \text{(A2)}$$

where:

$eirp_{FWA\ j}$: the e.i.r.p. spectral density (W. Hz^{-1}) contribution from all the FWA devices, co-located in the capital of the j^{th} country, in the direction of the satellite;

$\Delta T_{sat\ j}$ (K): apparent increase in the receiving system noise temperature due to the interfering emission (K) from the j^{th} country;

N: the total number of countries within the satellite footprint that will use the 5725-5875 MHz band for Fixed Wireless Access;

$G_{sat\ j}$: (linear ratio, relative to isotropic): the gain of the receiving antenna of the satellite in the direction of the capital of the j^{th} country. The maximum value for G_{sat} in Table 5.4.1 (value in dBi) is then used together with the FSS satellite gain contour patterns in the Annex 6;

k : Boltzmann's constant (1.38×10^{-23} J.K^{-1});

l_j: uplink path loss (numerical power ratio) from the j^{th} country. Note that this should also include the gaseous attenuation due to absorption by water vapour and oxygen molecules (~0.5dB). The total slant path attenuation is approximately 200dB across Europe, but it can change slightly from one country to another due to the varying distance from the satellite.

Equation (A2) is then used to aggregate the interference eirp from all the FWA devices until ΔT_{sat}, divided by T_{sat}, reaches the desired percentage threshold.

In practice, in order to establish the number of Mesh devices that can be deployed in Europe, whilst ensuring protection of the satellite in question, the approach taken is as follows:

- For each country determine: the total population, the elevation angle from the country, any decrease in satellite gain from the maximum given in Table 5.4.2 (and Table 6.4.1) and the path loss, including gaseous absorption;
- Set a "device density" coefficient that determines the number of Mesh devices per million people. This coefficient is then modified until the $\Delta T_{sat}/T_{sat}$ threshold in is satisfied. The following assumption is made: apply the same proportion of Mesh devices per head of population in all European countries, assuming uniform distribution of Mesh devices in each country;
- Compute the e.i.r.p. of the single mesh device. The e.i.r.p. of each Mesh device in the direction of the satellite is calculated by deriving the transmit power from the on-axis e.i.r.p. and calculating the gain in the elevation plane for the appropriate elevation angle from the part of Europe being considered;
- Multiply the e.i.r.p of the single device by the device density and the total population in each country to obtain the total e.i.r.p from all the devices in the country ($eirp_{FWA\ j}$);
- Using equation (A1), evaluate the increase in noise at the satellite receiver input attributable to the country;

- Summing the contribution from the different countries, as in Eq.(A2), calculate the aggregate number of Mesh devices that will cause the specified overall value of $\Delta T_{sat}/T_{sat}$ to be met (the device density coefficient has to be varied until the threshold is reached);

An example of calculations for omni-directional Mesh systems is shown below. The contribution of Mesh devices in one country is considered to satellite A @ 5°W;

Step	Parameter	Value
1	Elevation angle for country being considered	30.9°
2	Frequency	5875 MHz
3	Country Population (million)	59.8[1]
4	Density[2] of mesh devices per million people	18600
5	Number of mesh devices for given country	1112280
6	Average transmitted power (dBW)[3]	-12
7	Tx antenna gain in direction of satellite for mesh device at 30.9° elevation from Figure 1 (dBi)	-8.9
8	Average Tx ratio (%)	5
9	No. of 22 MHz channels (randomly used by mesh devices in satellite beam)	6
10	Total mesh EIRP in direction of satellite (from this country) dBW	18.8
11	G_{sat} for country being considered (dBi)	34
12	Slant-path loss from UK inclusive of 0.5 gas abs. (dB)	200.05
13	Mesh channel bandwidth (MHz)	22
14	ΔT_{sat} increase for contribution of all omni-directional mesh devices in this country (eqn. A1) (K)	6.2
15	T_{sat} (K)	773
16	$\Delta T_{sat} / T_{sat}$ increase from all devices in this country	0.8%
17	The $\Delta T_{sat} / T_{sat}$ are summed for each country in the satellite footprint. If the result is not equal to the overall threshold (e.g. 6% or 1%), the device density in step 4 is iteratively modified.	
18	When the $\Delta T_{sat} / T_{sat}$ from step 17 is equal to the threshold the number of mesh devices (Step 5) are summed all over Europe to find the maximum number of allowed devices, e.g. here for 6%	14 419 613

Table A1. Example calculation to determine the number of FWA omni-directional Mesh nodes that give rise to a satellite receive noise temperature increase of 6% for Satellite A @ 5°W

---

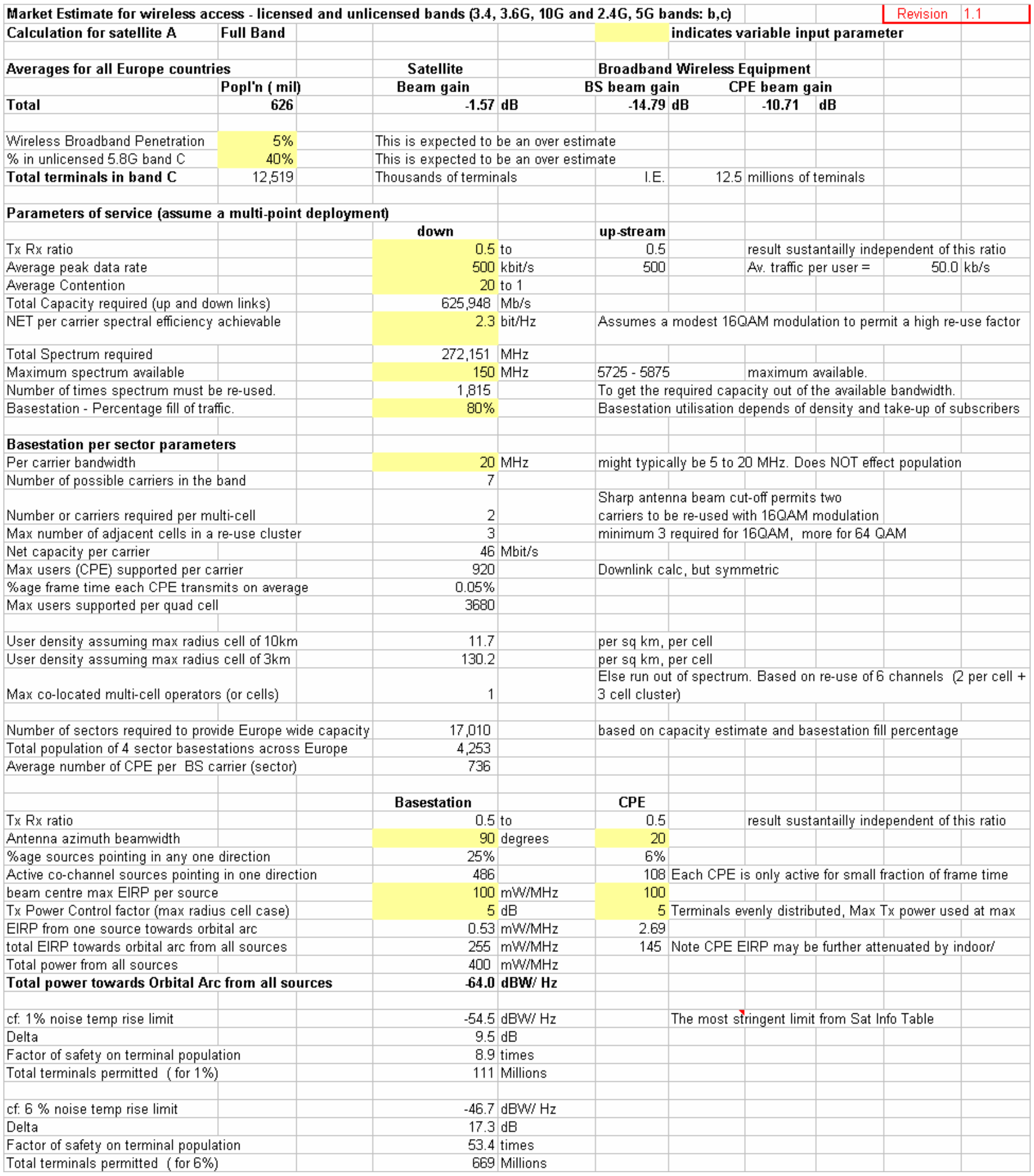
[1] Obtained from Table 6.4.3.

[2] This number is obtained with an iterative procedure by summing all the contributions of the $\Delta T_{sat}/T_{sat}$ due only to Mesh systems over all the countries until it reaches the desired threshold.

[3] Obtained by summing the Tx power for 22MHz channel (-7 dBW) and the average reduction due to Transmit Power Control (-5 dB).

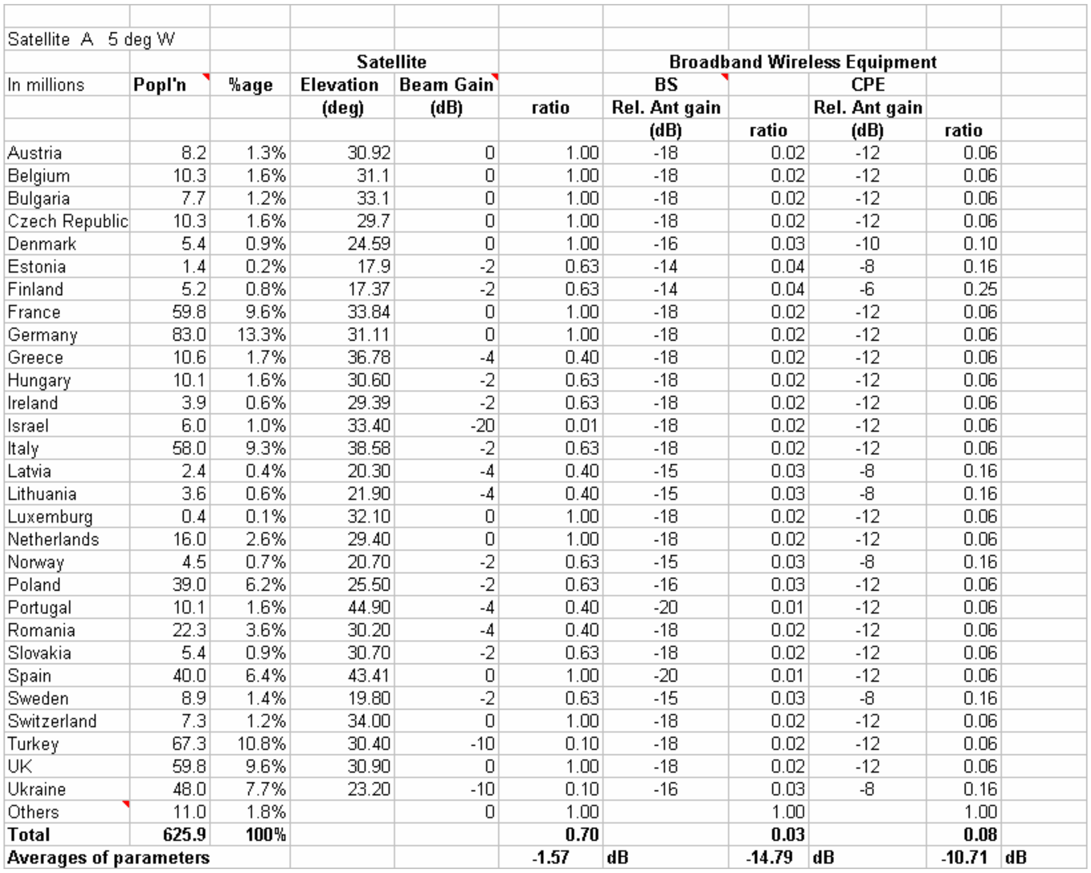
ANNEX 8: METHOD AND EXAMPLE OF CALCULATIONS FOR P-MP FWA SHARING WITH FSS (SATELLITE A EXAMPLE)

The spreadsheet shows how the number of subscriber terminals is derived. Note that the three antenna beam gains (near top of spreadsheet) are derived from average data for each country shown on the separate spreadsheet on the following page.



Market Estimate for wireless access - licensed and unlicensed bands (3.4, 3.6G, 10G and 2.4G, 5G bands: b,c)									Revision	1.1
Calculation for satellite A	**Full Band**					**indicates variable input parameter**				
Averages for all Europe countries			**Satellite**		**Broadband Wireless Equipment**					
	Popl'n (mil)		**Beam gain**		**BS beam gain**		**CPE beam gain**			
Total	**626**		**-1.57**	**dB**	**-14.79**	**dB**	**-10.71**	**dB**		
Wireless Broadband Penetration	5%		This is expected to be an over estimate							
% in unlicensed 5.8G band C	40%		This is expected to be an over estimate							
Total terminals in band C	12,519		Thousands of terminals		I.E.	12.5	millions of teminals			
Parameters of service (assume a multi-point deployment)										
			down		**up-stream**					
Tx Rx ratio			0.5	to	0.5		result sustantailly independent of this ratio			
Average peak data rate			500	kbit/s	500		Av. traffic per user =		50.0	kb/s
Average Contention			20	to 1						
Total Capacity required (up and down links)			625,948	Mb/s						
NET per carrier spectral efficiency achievable			2.3	bit/Hz	Assumes a modest 16QAM modulation to permit a high re-use factor					
Total Spectrum required			272,151	MHz						
Maximum spectrum available			150	MHz	5725 - 5875		maximum available.			
Number of times spectrum must be re-used.			1,815		To get the required capacity out of the available bandwidth.					
Basestation - Percentage fill of traffic.			80%		Basestation utilisation depends of density and take-up of subscribers					
Basestation per sector parameters										
Per carrier bandwidth			20	MHz	might typically be 5 to 20 MHz. Does NOT effect population					
Number of possible carriers in the band			7							
Number or carriers required per multi-cell			2		Sharp antenna beam cut-off permits two carriers to be re-used with 16QAM modulation					
Max number of adjacent cells in a re-use cluster			3		minimum 3 required for 16QAM, more for 64 QAM					
Net capacity per carrier			46	Mbit/s						
Max users (CPE) supported per carrier			920		Downlink calc, but symmetric					
%age frame time each CPE transmits on average			0.05%							
Max users supported per quad cell			3680							
User density assuming max radius cell of 10km			11.7		per sq km, per cell					
User density assuming max radius cell of 3km			130.2		per sq km, per cell					
Max co-located multi-cell operators (or cells)			1		Else run out of spectrum. Based on re-use of 6 channels (2 per cell + 3 cell cluster)					
Number of sectors required to provide Europe wide capacity			17,010		based on capacity estimate and basestation fill percentage					
Total population of 4 sector basestations across Europe			4,253							
Average number of CPE per BS carrier (sector)			736							
			Basestation		**CPE**					
Tx Rx ratio			0.5	to	0.5		result sustantailly independent of this ratio			
Antenna azimuth beamwidth			90	degrees	20					
%age sources pointing in any one direction			25%		6%					
Active co-channel sources pointing in one direction			486		108	Each CPE is only active for small fraction of frame time				
beam centre max EIRP per source			100	mW/MHz	100					
Tx Power Control factor (max radius cell case)			5	dB	5	Terminals evenly distributed, Max Tx power used at max				
EIRP from one source towards orbital arc			0.53	mW/MHz	2.69					
total EIRP towards orbital arc from all sources			255	mW/MHz	145	Note CPE EIRP may be further attenuated by indoor/				
Total power from all sources			400	mW/MHz						
Total power towards Orbital Arc from all sources			**-64.0**	**dBW/ Hz**						
cf: 1% noise temp rise limit			-54.5	dBW/ Hz		The most stringent limit from Sat Info Table				
Delta			9.5	dB						
Factor of safety on terminal population			8.9	times						
Total terminals permitted (for 1%)			111	Millions						
cf: 6 % noise temp rise limit			-46.7	dBW/ Hz						
Delta			17.3	dB						
Factor of safety on terminal population			53.4	times						
Total terminals permitted (for 6%)			669	Millions						

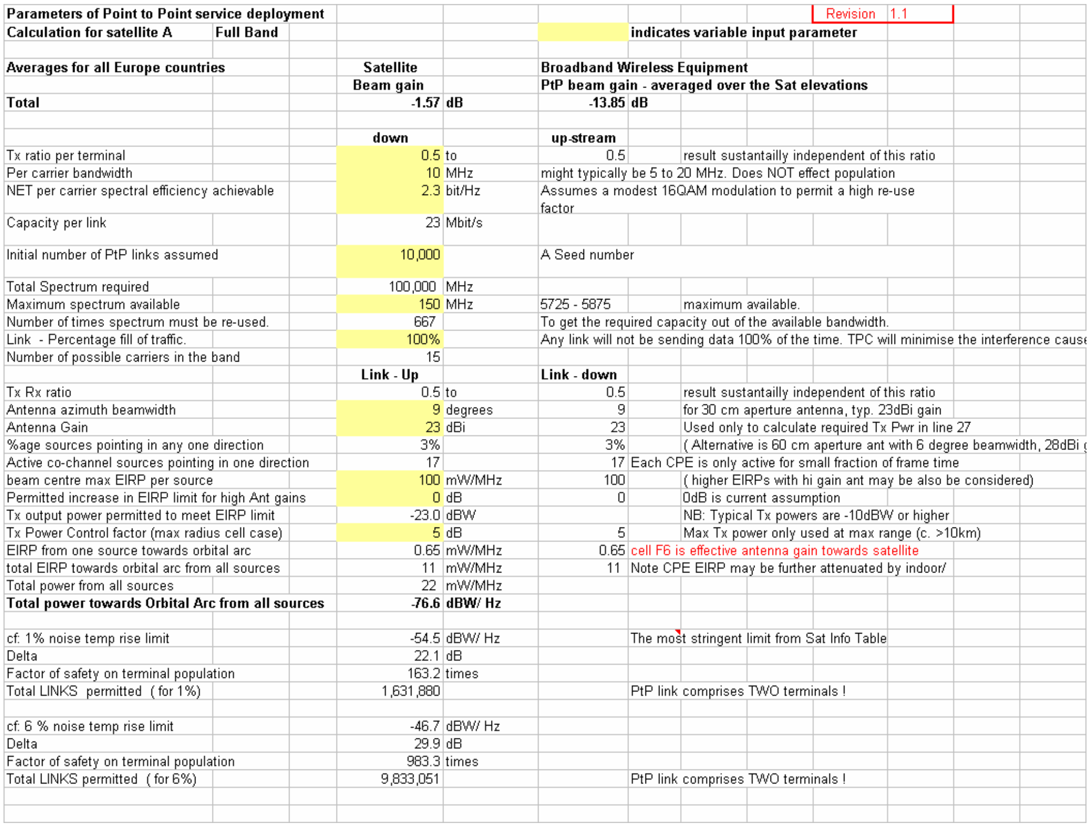
Below is also provided a second spreadsheet, which indicates how the population data for each European country and the elevation angle to the satellite (Satellite A in this case) were used to derive the satellite and FWA antenna beam gains for use in the first spreadsheet.



Satellite A 5 deg W										
			Satellite			**Broadband Wireless Equipment**				
In millions	**Popl'n**	**%age**	**Elevation**	**Beam Gain**		**BS**		**CPE**		
			(deg)	**(dB)**	**ratio**	**Rel. Ant gain**		**Rel. Ant gain**		
						(dB)	**ratio**	**(dB)**	**ratio**	
Austria	8.2	1.3%	30.92	0	1.00	-18	0.02	-12	0.06	
Belgium	10.3	1.6%	31.1	0	1.00	-18	0.02	-12	0.06	
Bulgaria	7.7	1.2%	33.1	0	1.00	-18	0.02	-12	0.06	
Czech Republic	10.3	1.6%	29.7	0	1.00	-18	0.02	-12	0.06	
Denmark	5.4	0.9%	24.59	0	1.00	-16	0.03	-10	0.10	
Estonia	1.4	0.2%	17.9	-2	0.63	-14	0.04	-8	0.16	
Finland	5.2	0.8%	17.37	-2	0.63	-14	0.04	-6	0.25	
France	59.8	9.6%	33.84	0	1.00	-18	0.02	-12	0.06	
Germany	83.0	13.3%	31.11	0	1.00	-18	0.02	-12	0.06	
Greece	10.6	1.7%	36.78	-4	0.40	-18	0.02	-12	0.06	
Hungary	10.1	1.6%	30.60	-2	0.63	-18	0.02	-12	0.06	
Ireland	3.9	0.6%	29.39	-2	0.63	-18	0.02	-12	0.06	
Israel	6.0	1.0%	33.40	-20	0.01	-18	0.02	-12	0.06	
Italy	58.0	9.3%	38.58	-2	0.63	-18	0.02	-12	0.06	
Latvia	2.4	0.4%	20.30	-4	0.40	-15	0.03	-8	0.16	
Lithuania	3.6	0.6%	21.90	-4	0.40	-15	0.03	-8	0.16	
Luxemburg	0.4	0.1%	32.10	0	1.00	-18	0.02	-12	0.06	
Netherlands	16.0	2.6%	29.40	0	1.00	-18	0.02	-12	0.06	
Norway	4.5	0.7%	20.70	-2	0.63	-15	0.03	-8	0.16	
Poland	39.0	6.2%	25.50	-2	0.63	-16	0.03	-12	0.06	
Portugal	10.1	1.6%	44.90	-4	0.40	-20	0.01	-12	0.06	
Romania	22.3	3.6%	30.20	-4	0.40	-18	0.02	-12	0.06	
Slovakia	5.4	0.9%	30.70	-2	0.63	-18	0.02	-12	0.06	
Spain	40.0	6.4%	43.41	0	1.00	-20	0.01	-12	0.06	
Sweden	8.9	1.4%	19.80	-2	0.63	-15	0.03	-8	0.16	
Switzerland	7.3	1.2%	34.00	0	1.00	-18	0.02	-12	0.06	
Turkey	67.3	10.8%	30.40	-10	0.10	-18	0.02	-12	0.06	
UK	59.8	9.6%	30.90	0	1.00	-18	0.02	-12	0.06	
Ukraine	48.0	7.7%	23.20	-10	0.10	-16	0.03	-8	0.16	
Others	11.0	1.8%		0	1.00		1.00		1.00	
Total	**625.9**	**100%**			**0.70**		**0.03**		**0.08**	
Averages of parameters					**-1.57**	**dB**	**-14.79**	**dB**	**-10.71**	**dB**

ANNEX 9: METHOD AND EXAMPLE OF CALCULATIONS FOR P-P FWA SHARING WITH FSS (SATELLITE A EXAMPLE)

The following spreadsheet shows how the number of subscriber terminals is derived. Note that the three antenna beam gains (near top of spreadsheet) are derived from average data for each country shown on the second spreadsheet in Annex 8.



Parameters of Point to Point service deployment					Revision 1.1
Calculation for satellite A	**Full Band**			🟨	**indicates variable input parameter**
Averages for all Europe countries		**Satellite**		**Broadband Wireless Equipment**	
		Beam gain		**PtP beam gain - averaged over the Sat elevations**	
Total		**-1.57**	**dB**	**-13.85**	**dB**
		down		**up-stream**	
Tx ratio per terminal		0.5	to	0.5	result sustantailly independent of this ratio
Per carrier bandwidth		10	MHz	might typically be 5 to 20 MHz. Does NOT effect population	
NET per carrier spectral efficiency achievable		2.3	bit/Hz	Assumes a modest 16QAM modulation to permit a high re-use factor	
Capacity per link		23	Mbit/s		
Initial number of PtP links assumed		10,000		A Seed number	
Total Spectrum required		100,000	MHz		
Maximum spectrum available		150	MHz	5725 - 5875	maximum available.
Number of times spectrum must be re-used.		667		To get the required capacity out of the available bandwidth.	
Link - Percentage fill of traffic.		100%		Any link will not be sending data 100% of the time. TPC will minimise the interference cause	
Number of possible carriers in the band		15			
		Link - Up		**Link - down**	
Tx Rx ratio		0.5	to	0.5	result sustantailly independent of this ratio
Antenna azimuth beamwidth		9	degrees	9	for 30 cm aperture antenna, typ. 23dBi gain
Antenna Gain		23	dBi	23	Used only to calculate required Tx Pwr in line 27
%age sources pointing in any one direction		3%		3%	(Alternative is 60 cm aperture ant with 6 degree beamwidth, 28dBi
Active co-channel sources pointing in one direction		17		17	Each CPE is only active for small fraction of frame time
beam centre max EIRP per source		100	mW/MHz	100	(higher EIRPs with hi gain ant may be also be considered)
Permitted increase in EIRP limit for high Ant gains		0	dB	0	0dB is current assumption
Tx output power permitted to meet EIRP limit		-23.0	dBW		NB: Typical Tx powers are -10dBW or higher
Tx Power Control factor (max radius cell case)		5	dB	5	Max Tx power only used at max range (c. >10km)
EIRP from one source towards orbital arc		0.65	mW/MHz	0.65	cell F6 is effective antenna gain towards satellite
total EIRP towards orbital arc from all sources		11	mW/MHz	11	Note CPE EIRP may be further attenuated by indoor/
Total power from all sources		22	mW/MHz		
Total power towards Orbital Arc from all sources		**-76.6**	**dBW/ Hz**		
cf: 1% noise temp rise limit		-54.5	dBW/ Hz		The most stringent limit from Sat Info Table
Delta		22.1	dB		
Factor of safety on terminal population		163.2	times		
Total LINKS permitted (for 1%)		1,631,880			PtP link comprises TWO terminals !
cf: 6 % noise temp rise limit		-46.7	dBW/ Hz		
Delta		29.9	dB		
Factor of safety on terminal population		983.3	times		
Total LINKS permitted (for 6%)		9,833,051			PtP link comprises TWO terminals !

ANNEX 10: ANTENNA GAIN PATTERNS USED FOR P-MP AND OMNI-DIRECTIONAL MESH FWA SYSTEMS (MEASURED OR DERIVED FROM REC. ITU-R F.1336-1)

Figure A10.1 below provides an example of elevation plane antenna gain patterns, G(θ), for P-MP BSU and SU and omnidirectional Mesh, where the boresight gain $G_{0,}$ derived from Section 4.1, together with the antenna gain pattern in the current Rec. ITU-R F.1336-1 have been used.

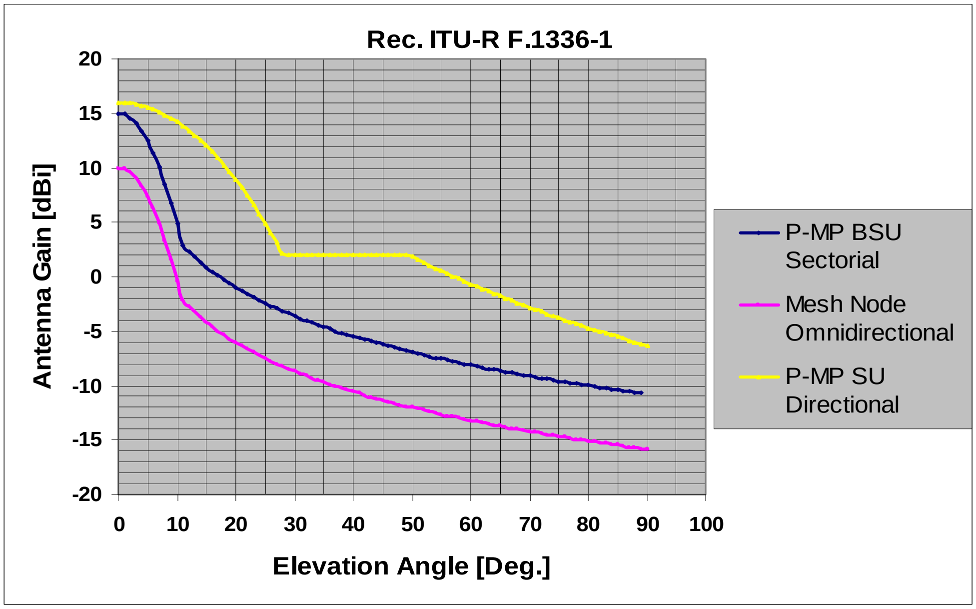


Figure A10.1
Elevation plane antenna gain patterns of P-MP and Omni-directional Mesh FWA devices computed using Rec. ITU-R F.1336-1[4]
Note:(On-axis gains from Section 4.1 used)

Specifically, for P-MP base station sectoral antenna and for the Mesh omni-directional antenna the gain is given by:

$$G(\theta) = \max\left[G_1(\theta), G_2(\theta)\right] \quad \text{(D1a)}$$

$$G_1(\theta) = G_0 - 12\left(\frac{\theta}{\theta_3}\right)^2 \quad \text{(D1b)}$$

$$G_2(\theta) = G_0 - 12 + 10\log\left[\left(\max\left\{\frac{|\theta|}{\theta_3}, 1\right\}\right)^{-1.5} + k\right] \quad \text{(D2)}$$

where:

θ : absolute value of the elevation angle relative to the angle of maximum gain (degrees)

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[4] The patterns shown here are effectively peak sidelobe envelopes. ITU-R WP9D are developing a revised version of Rec. F.1336-1 which differentiates between scenarios in which it might be appropriate to consider antenna radiation patterns representing *average* sidelobe levels and those that should use *peak* sidelobe envelopes in sharing studies. Specifically it is stated that it is appropriate to use the radiation pattern representing average side-lobe levels to predict the aggregate interference to a geostationary or non-geostationary satellite from numerous fixed wireless stations, as is the case for the sharing studies being undertaken here. The use of average sidelobes would be expected to improve the sharing situation.

θ_3: the 3 dB beamwidth in the vertical plane (degrees)

$k = 0$

The relationship between the gain (dBi) and the 3 dB beamwidth in the elevation plane (degrees) is:

$$\theta_3 = 107.6 \times 10^{-0.1\,G_0} \qquad \text{for omni-directional Mesh} \qquad \text{(D3)}$$

$$\theta_3 = \frac{31\,000 \times 10^{-0.1\,G_0}}{\varphi_S} \qquad \text{for P-MP base station} \qquad \text{(D4)}$$

where φ_S is the 3 dB beamwidth of the sector in the azimuthal plane (degrees).

For the sharing study with omnidirectional Mesh FWA devices, the antenna pattern in Figure A10.1 has been used.

Section 6.4 indicates that sharing between FWA and the FSS satellites is likely to be more favourable if the actual elevation plane gain patterns of the antennas are able to meet the envelope curves in Rec. ITU-R F.1336-1[5]. For the sharing study using P-MP systems, the measured elevation-plane antenna patterns shown in Figures 1-2 in Sec.4.1 were used. They are plotted again in Fig. A10.2 together with the corresponding curves derived from Rec. ITU-R F.1336-1 and, as it can be observed, the agreement is quite good except for a minor exceedance in the sidelobes.

In general, the measured elevation-plane sidelobes of a typical base station sectoral antenna seem to be within the boundaries specified by Rec. ITU-R F.1336-1.

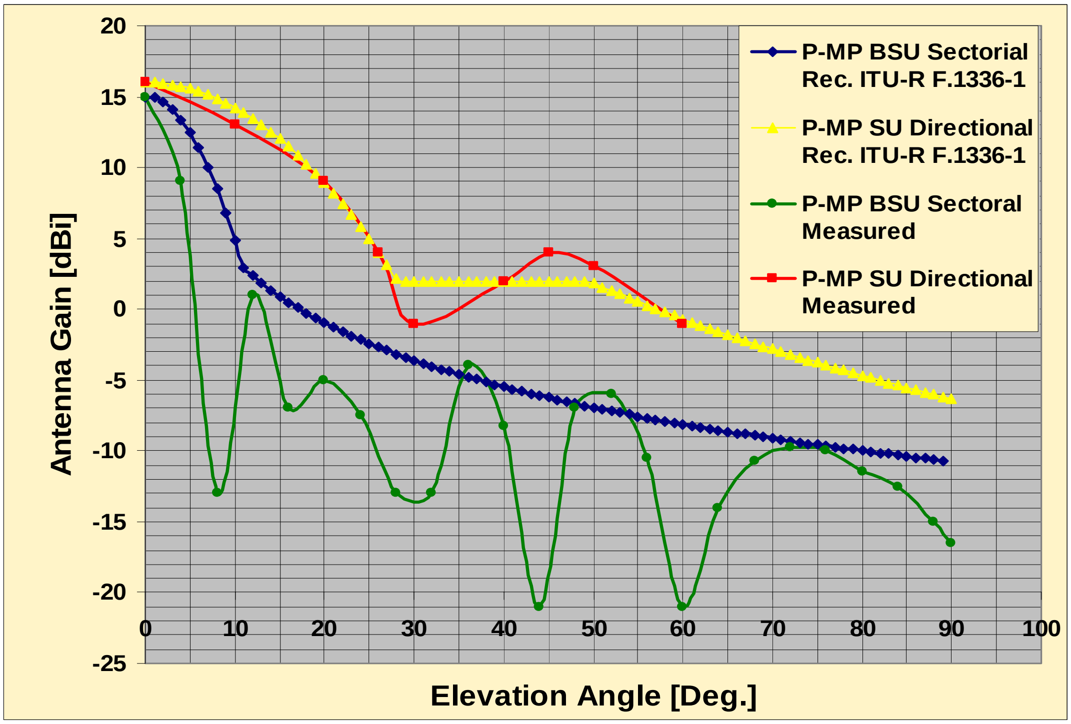

Figure A10.2

Elevation plane gain of the measured P-MP CS (BSU) and TS (SU) antennas used in the sharing studies compared with the corresponding reference radiation patterns curves in Rec. ITU-R F.1336-1

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[5] If this were adopted it is not intended that all sidelobe peaks should fall within the envelope masks in Rec. ITU-R F.1336. Either a small exceedance above the envelope could be recommended (within x dB). The *k* parameter in the Recommendation also allows practical factors such as the use of electrical downtilt, pattern degradations at band-edges and production variations to be accommodated (e.g. the phasing used to introduce down-tilt produces grating lobes in the upward radiation pattern).

As further example of P-MP base station sectoral antennas, Figure A10.3 shows the measured elevation-plane gain pattern of a European Antennas sectoral antenna developed for use in the 5.8 GHz band together with another measured gain elevation pattern. All curves refer to sectoral antennas with a 3 dB beamwidth in the azimuthal plane of 90^o and on-axis gain, G_0, of 15 dBi. The Rec. 1336-1 curve for a sectoral antenna is also shown, where the off-axis performance is derived from the on-axis gain.

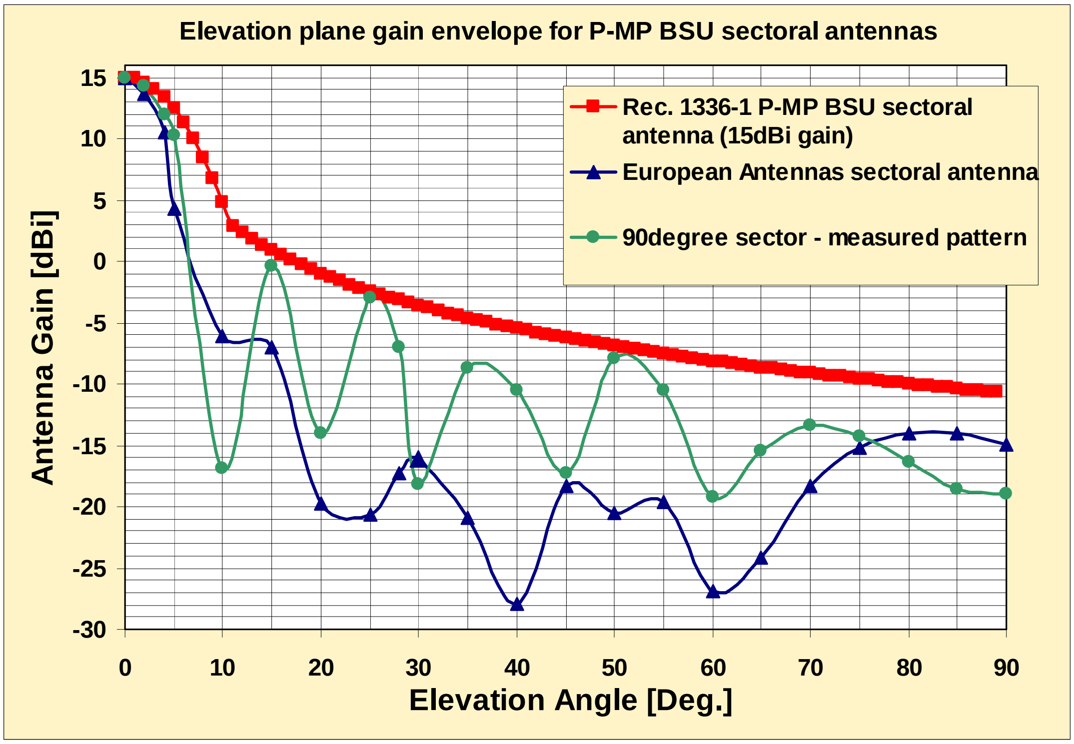

Figure A10.3

Elevation plane sidelobe gain of measured P-MP sectoral antennas compared with the reference radiation patterns curve in Rec. ITU-R F.1336-1 (on-axis gain: 15dBi, 3 dB azimuthal beamwidth: 90^o)