CEPT ECC
Electronic Communications Committee

ECC Report 210

Compatibility/sharing studies related to Broadband Direct-Air-to-Ground Communications (DA2GC)
in the frequency bands 5855-5875 MHz,
2400-2483.5 MHz and 3400-3600 MHz

Approved 31 January 2014

0 EXECUTIVE SUMMARY

This ECC Report addresses sharing and compatibility studies between Broadband Direct-Air-to-Ground Communications (DA2GC) in the frequency bands 5 855-5875 MHz, 2400-2483.5 MHz and 3400-3600 MHz and incumbent services / systems. In the course of the studies it turned out that the frequency bands 2400-2483.5 MHz and 3400-3600 MHz are less appropriate for the deployment of DA2GC due to the expected constraints for the protection of other services/applications. In consequence ECC removed these frequency bands from the list of candidate bands for DA2GC. The studies carried out so far can be found in ANNEX 3: and ANNEX 4: of this Report.

Three DA2GC system proposals based on ETSI System Reference documents were considered:

- A LTE based system with preference on FDD mode operation according to ETSI TR 103 054 [3];
- A beam forming system with TDD mode operation according to ETSI TR 101 599 [30] and;
- A UMTS based system with TDD mode operation according to ETSI TR 103 108 [31] .

Sharing and compatibility studies were conducted between DA2GC and the following services/systems in the 5.8 GHz band:

1. Broadband Fixed Wireless Access (BFWA)
2. Fixed Satellite Service (E-s)
3. Non-specific Short Range Devices (SRD)
4. Intelligent Transport Systems / Road Transport and Traffic Telematics (ITS/RTTT)
5. Radiolocation Systems.

The results of the studies and the conditions under which operation of DA2GC in the frequency band 5855-5875 MHz would be feasible are shown in section 6 of this report. The conclusions on compatibility for each of the three DA2GC system proposals are included in three separate summary tables in that section. For the system described in ETSI TR 103 054 [3] the results showed that operation of DA2GC in the band 5855-5875 MHz is not feasible. For the other two systems described in ETSI TR 101 599 [30] and ETSI TR 103 108 [31] the conditions for coexistence with other services / applications are summarised in the tables in section 6 of this report. It should be noted that that in several cases mitigation techniques are needed in order to provide compatibility between the services and the systems studied.

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LIST OF ABBREVIATIONS

Abbreviation	
3GPP	3rd Generation Partnership Project
ACIR	Adjacent Channel Interference Ratio
ACLR	Adjacent Channel Leakage Power Ratio
ACR	Adjacent Channel Rejection
ACS	Adjacent Channel Selectivity
AS	Aircraft Station
ATPC	Automatic Transmit Power Control
B(F)WA	Broadband (Fixed) Wireless Access
BS	Base Station
CEPT	European Conference of Postal and Telecommunications Administrations
DA2GC	Direct Air-to-Ground Communication
ECA	European Common Allocation
ECC	Electronic Communications Committee
EESS	Earth Exploration Satellite Service
FDD	Frequency Division Duplex
FDMA	Frequency Division Multiple Access
FL	Forward Link
FS	Fixed Service
FSS	Fixed Satellite service
GS	Ground Station
GSM	Global System for Mobile Communications
GSO	Geostationary Satellite orbit
IMT	International Mobile Telecommunications
IMT-A	IMT-Advanced (4G)
ISM	Industrial Scientific Medical
ITS	Intelligent Transport System
ITU	International Telecommunication Union
I/N	Interference-to-Noise
LOS	Line-of-Sight
LTE	Long Term Evolution
MS	Mobile Service
OBU	Onboard Unit
OFDMA	Orthogonal Frequency-Division Multiple Access
RFID	Radio Frequency Identification
RL	Reverse Link
SAB	Services Ancillary to Broadcasting
SAP	Services Ancillary to Programme making
SEM	Spectrum Emission Mask
SOS	Space Operation Service
SRD	Short Range Device
S/I	Signal-to-Interference
SRS	Space Research Service
TDD	Time Division Duplex
TDMA	Time Division Multiple Access
UE	User Equipment
UMTS	Universal Mobile Telecommunications System

UL	Uplink
w	with
w/o	without
WiFi	Wireless Fidelity

1 INTRODUCTION

In response to a request from ETSI for the designation of spectrum for Direct-Air-to Communication systems (DA2GC) the frequency bands 5855-5875 MHz, 2400-2483.5 MHz and 3400-3600 MHz were identified by CEPT as possible candidate bands for the deployment of DA2GC. Studies were conducted on compatibility between the proposed systems and the existing users. In the course of the studies it turned out that the frequency bands 2400-2483.5 MHz and 3400-3600 MHz are less appropriate for the deployment of DA2GC due to the expected constraints for the protection of other services/applications. In consequence ECC removed these frequency bands from the list of candidate bands for DA2GC.

Studies in the framework of the EC mandate to assess and identify alternative uses of the unpaired terrestrial 2 GHz frequency bands (1900-1920 MHz and 2010-2025 MHz) for which DA2GC is one of the candidate applications are covered in other ECC deliverables.

A Broadband DA2GC system constitutes an application for various types of telecommunications services, such as internet access and mobile multimedia services. It aims to provide access to broadband communication services during continental flights on a Europe-wide basis. The request for spectrum is related to the direct-air-to-ground radio solution. The connection with the flight passengers' user terminals on-board aircraft is to be realised by already available fixed or Wi-Fi-based on-board connectivity network and/or via GSMOBA and in the future possibly also via UMTS and/or LTE.

The main application field would be Air Passenger Communications (APC). In addition a Broadband DA2GC system could also support Airline Administrative Communications services (AAC) and thus improving aircraft operation, resulting in particular in reduced OPEX for the airlines. Safety-relevant communications such as Air Traffic Control (ATC) and related services are not intended to be covered.

Currently, there is no spectrum designated for Broadband DA2GC in Europe. In order to allow European citizens and airlines to profit from the social and economic benefits of the implementation of such a radio application (intended to provide broadband connectivity between the aircraft and a terrestrial based network), a harmonised spectrum designation within CEPT would be necessary. The potential solution would ideally include implementation throughout all CEPT countries

2 DEFINITIONS

Term	Definition
Aircraft Station (AS):	Entity onboard aircraft providing the radio, control and telecommunication functionalities for broadband DA2G communication
Direct-Air-to-Ground	Direct radio link between an Aircraft Station (AS) and a Ground Station (GS)
Forward Link (FL)	Communication from Ground station to Aircraft station (downlink)
Ground station (GS)	Entity on the ground providing the radio, control and telecommunication functionalities for broadband DA2G communication
Reverse Link (RL)	Communication from Aircraft station to Ground station (uplink)

3 FREQUENCY USAGE

Services/systems currently operating in the bands and in adjacent bands (Source: European Common Allocation Table)

3.1 FREQUENCY USAGE IN THE BAND 5855-5875 MHz

Table 1: Utilizations in the 5.8 GHz band

European Common Allocation	Frequency range MHz	Utilisation
FIXED FIXED-SATELLITE (E-s) MOBILE	5850-5925	BFWA FSS ISM ITS Non-Specific SRDs Radiodetermination applications

3.2 FREQUENCY USAGE IN THE BAND 2400-2483.5 MHz

Table 2: Utilizations in the 2.4 GHz band

European Common Allocation	Frequency range MHz	Utilisation
FIXED MOBILE Amateur Radiolocation	2300-2400	Aeronautical Telemetry Amateur Mobile applications SAP/SAB
FIXED MOBILE Amateur-satellite Radiolocation	2400-2450	Amateur Amateur Satellite ISM Non-Specific SRDs Radiodetermination applications Railway applications RFID Wideband Data Transmission
FIXED MOBILE	2450-2483.5	ISM Non-Specific SRDs Radiodetermination applications Railway applications RFID Wideband Data Transmission
FIXED MOBILE MOBILE-SATELLITE (S/E) 5.371: Radiodetermination-satellite (S/E)	2483.5 -2500	IMT Satellite component ISM Mobile applications Mobile satellite applications SAP/SAB

3.3 FREQUENCY USAGE IN THE BAND 3400-3600 MHz

Table 3: Utilizations in the 3.5 GHz band

European Common Allocation	Frequency range MHz	Utilisation
RADIOLOCATION	3300-3400	Defence systems Radars (Upper limit for airborne radars 3410 MHz)
FIXED FIXED-SATELLITE (S/E) MOBILE 5.430A Amateur Radiolocation	3400-3500	Amateur BWA FSS IMT (planned for future applications) Mobile applications (SAB/SAP) Radars
FIXED FIXED-SATELLITE (S/E) MOBILE	3500-3600	BWA FSS IMT (planned for future applications) Mobile applications (SAB/SAP)
FIXED FIXED-SATELLITE (S/E) MOBILE	3600-3800	BWA FSS Medium/high capacity fixed links

4 BROADBAND DA2GC SYSTEM CHARACTERISTICS

4.1 DA2GC SYSTEM ACCORDING TO ETSI TR 103 054

The system parameters used for evaluation of interference impact are chosen according to information given by 3GPP on LTE transmitter and receiver characteristics for UE [6] and BS [7]. The DA2GC systems parameter are modified according to the need for the aeronautical use case (mainly related to antenna characteristics as well as Tx power of the AS).The following Table 4 and Table 6 give an overview of the main characteristics used for the ground station and aircraft station according to the ETSI system reference document TR 103 054 of the DA2GC. Paired spectrum of 2 x 10 MHz for FDD operation is considered necessary to cope with short- to medium-term demand. Unpaired spectrum for TDD operation (20 MHz) would also be an option, but it might be more complicated to identify a contiguous block of 20 MHz for TDD operation. The DA2GC system is applied only as transport medium to transfer data from user terminals onboard aircraft to the internet or vice versa. The relevant radio link is between the aircraft station and the ground stations of the ground network. Onboard aircraft passengers have access to internet services via separate radio technologies like GSM and WiFi. These onboard networks were already considered in other CEPT activities (e.g. see [4]). As they have no relevance for the DA2GC system implementation in the 3400-3600 MHz band, they are not considered in this document.

4.1.1 Ground station parameters

As it is assumed that DA2GC base stations will be mainly implemented in rural environments due to better line-of-sight (LOS) conditions to aircraft compared to sites in urban areas, only macro cell stations of the terrestrial LTE network are considered for the evaluations. Due to the propagation conditions at about 3500 MHz and different GS antenna adjustment, sufficient decoupling should be achieved between the DA2GC ground stations and possible micro or pico cell stations of the terrestrial LTE network in neighbouring urban areas.

Table 4 gives an overview of the main parameters used for the ground stations.

Table 4: Main parameters used for ETSI DA2GC ground stations (TR 103 054)

Parameter	DA2GC ground station	
	FDD	TDD
Base station type	Macro	Macro
Environment	Rural	Rural
Cell radius (max.)	Up to 100 km	Up to 100 km
Tx power	46 dBm	46 dBm
Antenna type	3 x 120° sector antennas (90° half power beam width)	3 x 120° sector antennas (90° half power beam width)
Antenna gain	Up to 20 dBi	Up to 20 dBi
Antenna height	50 m	50 m
Antenna tilt	10°(up-tilt) (Note 1)	10°(up-tilt) (Note 1)
Channel bandwidth	2 x 10 MHz (FDD)	15 or 20 MHz (TDD)
Frequency re-use factor	1	1
Signal bandwidth (related to number of occupied resource blocks with bandwidth of 180 kHz)	9 MHz (FDD)	13.5 or 18 MHz (TDD)
Rx thermal noise	-104.5 dBm (FDD)	-102.7 or -101.5 dBm (TDD)
Rx noise figure	5 dB	
Rx noise floor	-99.5 dBm (FDD)	-97.7 or -96.5 dBm (TDD)

Parameter	DA2GC ground station	
	FDD	TDD
Rx reference sensitivity level	-101.5 dBm (FDD) (Note 2)	-99.7 or -98.5 dBm (TDD) (Note 2)
Interference protection ratio I/N	-6 dB	-6 dB
Interference protection level	-105.5 dBm (FDD) (Note 2)	-103.7 or -102.5 dBm (TDD) (Note 2)
Tx spectrum emission mask (SEM) / Spurious emissions	According to [7]	According to [7]
Adjacent channel leakage ratio (ACLR) limit	45 dB (Note 3)	45 dB (Note 3)
Rx in-band / out-of-band blocking	According to [7]	According to [7]
Rx adjacent channel selectivity (ACS)	43.5 dB (according to [7])	43.5 dB (according to [7])

Note 1: The antenna up-tilt is dependent on the final characteristic of the antenna and the cell radius to be covered. The value used here is suitable for large cells; for cells with smaller radius the main lobe should have higher up-tilt.

Note 2: In [14] the sensitivity level of -101.5 dBm is also applied for signal bandwidths above 10 MHz, as only up to 25 resource blocks (RB) are assigned to a single UE link, even if more RBs are feasible.

Note 3: In general the ACLR limit given in the table or the absolute limit of -15 dBm/MHz is valid, whichever is less stringent (macro BS according category B) [7]

4.1.1.1 Antenna characteristics

For the DA2GC GS antennas with 3 sectors per site are assumed. The horizontal and vertical antenna patterns used in the evaluations are shown in Figure 1 and Figure 2, respectively, as screen shots of SEAMCAT.

The horizontal antenna pattern is based on the characteristics defined in 3GPP TR 36.814 [15]. The pattern is very similar to the antenna characteristics given in Recommendation ITU-R F.1336 [20] which were applied for compatibility studies in the ITU-R Report M.2109 [12].

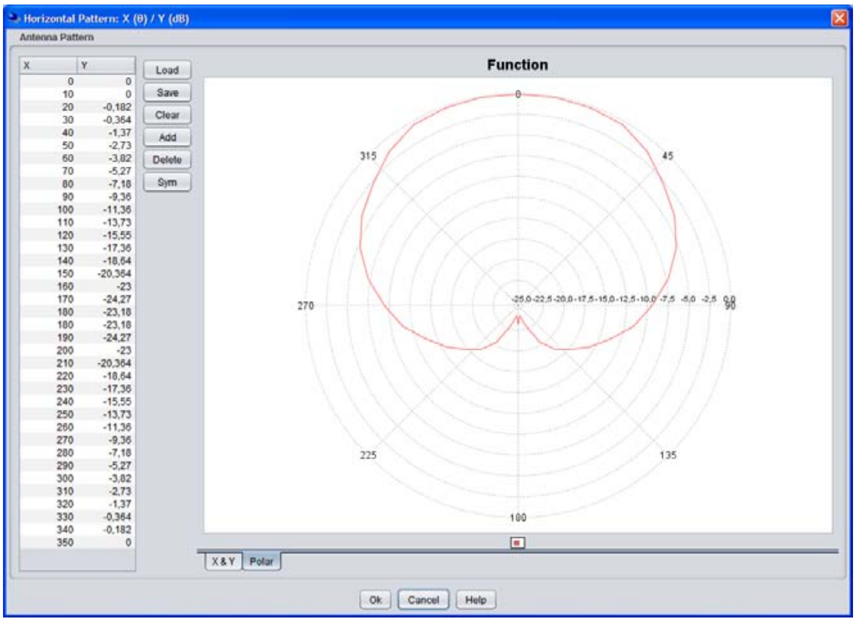


Figure 1: Horizontal sector antenna pattern of the base stations

The vertical diagram of the DA2GC GS has been adapted to a cosecant-squared characteristic which is better suited for air coverage compared to usual sector antennas for terrestrial mobile radio systems as the Rx power is nearly constant with increasing distance between GS and aircraft [23].

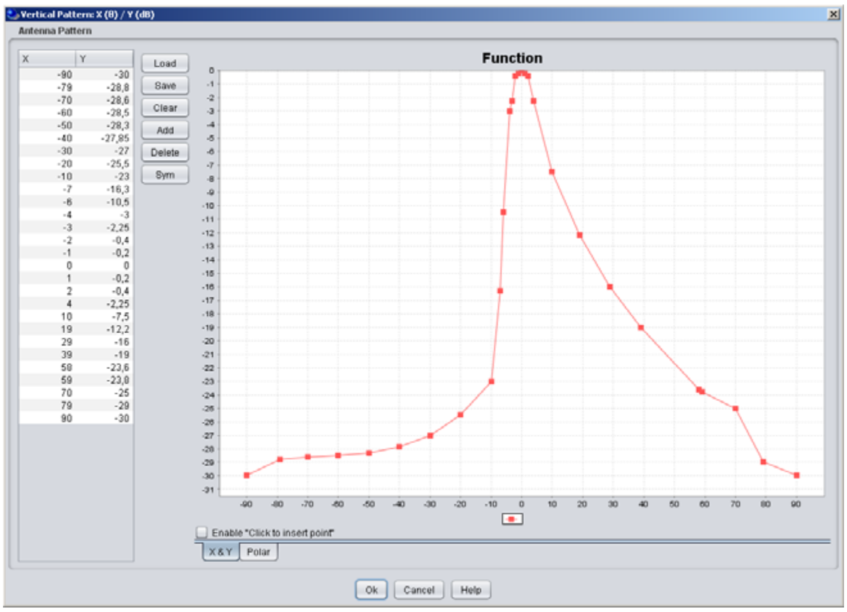


Figure 2: Vertical sector antenna pattern (cosecant-squared) characteristic of the DA2GC BS (screen shot of SEAMCAT GUI; up-tilt not considered in the diagram)

4.1.1.2 Unwanted emissions

The spectrum emission limits for DA2GC and terrestrial LTE BSs are assumed to be the same. The corresponding values are defined by 3GPP and can be found in Table 5.

Table 5: Unwanted emission limits for DA2GC ground stations adapted to LTE base stations for channel bandwidth of 10 MHz according to [7]

Frequency offset of measurement filter -3dB point, Δf	Frequency offset of measurement filter centre frequency, f_offset	Minimum requirement	Measurement bandwidth
0 MHz ≤ Δf < 5 MHz	0.05 MHz ≤ f_offset < 5.05 MHz	$-7dBm - \frac{7}{5}\cdot\left(\frac{f\_offset}{MHz} - 0.05\right)dB$	100 kHz
5 MHz ≤ Δf < 10 MHz	5.05 MHz ≤ f_offset < 10.05 MHz	-14 dBm	100 kHz
10 MHz ≤ Δf < 25 MHz	10.5 MHz ≤ f_offset < 24.5 MHz	-15 dBm	1MHz
25 MHz ≤ Δf	25.5 MHz ≤ f_offset	-30 dBm (Note 1)	1MHz
Note 1: Spurious emissions valid for frequency offset larger than 250% of necessary bandwidth [17].			

4.1.2 Aircraft station parameters

Table 6 provides the main parameters of the aircraft station.

Table 6: Main parameters used for ETSI DA2GC aircraft stations (TR 103 054)

Parameter	DA2GC aircraft station	
	FDD	TDD
Tx power (max./min.) (Note 1)	40 dBm / -23 dBm	40 dBm / -23 dBm
Antenna type	Azimuth: Omni-directional Elevation: See Figure 3	Azimuth: Omni-directional Elevation: See Figure 3
Antenna gain	6.54 dBi (Note 2)	6.54 dBi (Note 2)
Antenna height	3000 - 13000 m (Note 3)	3000 - 13000 m (Note 3)
Channel bandwidth	2 x 10 MHz	15 or 20 MHz
Signal bandwidth (related to number of occupied resource blocks with bandwidth of 180 kHz)	9 MHz	13.5 or 18 MHz
Rx thermal noise	-104.5 dBm	-102.7 or -101.5 dBm
Rx noise figure	9 dB	9 dB
Rx noise floor	-95.5 dBm	-93.7 or -92.5 dBm
Rx reference sensitivity level	-97.5 dBm	-95.7 or -94.5 dBm
Interference protection ratio I/N	-6 dB	-6 dB
Interference protection level	-101.5 dBm	-99.7 or -98.5 dBm
Tx spectrum emission mask (SEM) / Spurious emissions	According to [6]	According to [6]
Adjacent channel leakage ratio (ACLR) limit	37 dB (Note 4)	37 dB (Note 4)
Rx in-band / out-of-band blocking	According to [6]	According to [6]
Rx adjacent channel selectivity (ACS)	33 / 30 / 27 dB for channel bandwidths of 10 / 15 / 20 MHz (according to [6])	33 / 30 / 27 dB for channel bandwidths of 10 / 15 / 20 MHz (according to [6])

Note 1: The Tx power of the mobile station is dependent on the power control implementation applied by the equipment provider.
Note 2: For former evaluation a simple omni-directional characteristic with 0 dBi gain was assumed. The final diagram incl. the gain will be dependent on further antenna optimization steps as well as on limits set by the regulation. In the range just below the horizontal aircraft plane the antenna gain will normally be higher (up to about 6 dBi) to allow access of the OBU to the BS at the cell edge.
Note 3: The current assumption for a DA2GC OBU is that it will not transmit for altitudes below 3000 m as the GSM/WiFi onboard wireless access networks for the passengers have to be switched off below that threshold. In case the airlines are interested to use the DA2GC also for their operational services (non-safety relevant), it has to be clarified with the regulatory authorities under which conditions DA2GC radio links can kept until the aircraft reaches the airport ground (only wired access in the aircraft below the altitude threshold allowed).
Note 4: A higher ACLR value is required to keep the maximum allowed out-of-band emission level given in [6] in case of higher maximum Tx power of up to 40 dBm for the DA2GC OBU.

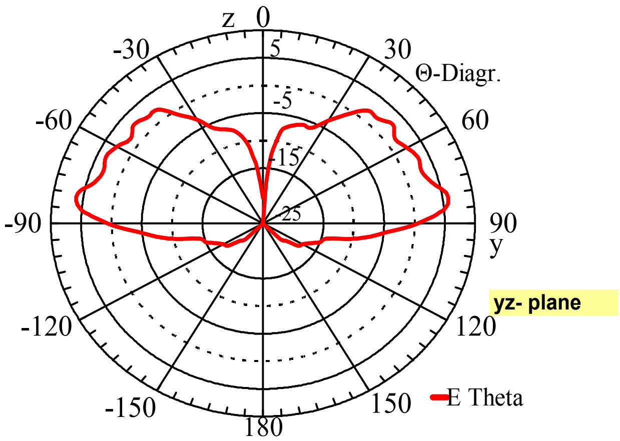


Figure 3: Vertical antenna pattern (monopol) for the DA2GC AS (gain of 6.54 dBi; direction to earth at 0°, to the horizon at ±90°)

4.2 DA2GC SYSTEM ACCORDING TO ETSI TR 101 599

4.2.1 Ground station equipment

A feature of this DA2GC system is the simultaneous use of four separate integrated radio transceivers/phased array antenna assemblies at the ground station. Such an arrangement enables each ground station to cover the entire visible air space, from horizon to horizon, at all azimuths. Each integrated 8-element antenna array is capable of simultaneously producing multiple co-frequency shaped beams which need to maintain sufficient spatial separation to avoid self-interference, such that three simultaneous beams per sector (or quadrant), or twelve beams per ground station can be assumed operationally. This is shown diagrammatically in Figure 4.

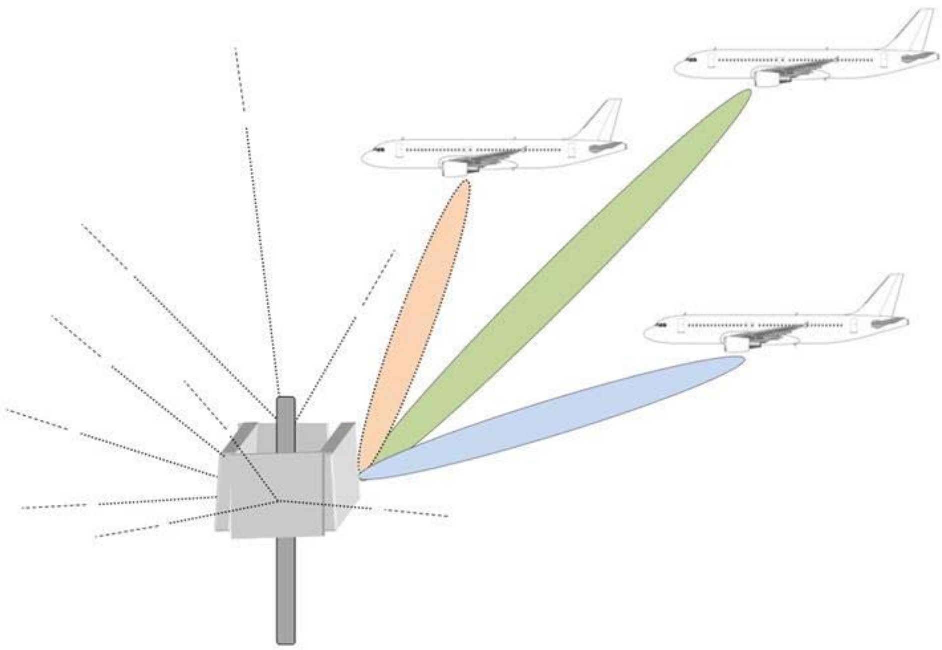


Figure 4: Typical Ground Station antenna arrangement showing three beams per quadrant

Note: The above diagram contains a much simplified depiction of the use of multiple beams at the Ground Station and is not intended as an accurate representation of the beam shapes. In reality, each Ground Station antenna array employs fixed beamforming in the elevation plane and dynamic beamforming in the azimuth direction. The individual beams produced therefore have a fixed shape in the elevation plane (defined by the pattern shown in Figure 7) and a narrower steered pattern in the azimuth plane (shown in Figure 8).

The use of TDMA and FDMA could further increase the number of individual data paths established (and hence number of aircraft served) to much higher numbers, but that would be at the cost of reduced data rate per aircraft, since the total power (and hence total capacity) per beam would remain the same.

Potential problems of cross-talk between the transmit and receive paths of the various aircraft links at a given ground station antenna are eliminated due to the use of TDD, together with synchronisation of signals such that all paths from that ground station are in transmit or receive mode at the same time when each beamforming array is generating multiple beams. Furthermore, the overall network synchronisation is arranged such that only half the DA2GC Ground Stations (and half the total number of aircraft) are transmitting (or receiving) at any instant.

Figure 5 contains a block diagram of the main components within the wireless access point showing the basic connectivity within the radio equipment and outputs to the antenna array.

Figure 6 is a simplified depiction of the antenna array itself. Together, these two diagrams represent one of the four separate integrated radio transceiver/phased array assemblies at the ground station referred to earlier.

It should be noted that, for the sake of simplicity, both Figure 5 and Figure 6 show only four transmission chains and four antenna elements respectively. However, in reality, the equipment intended for use in the 5.8 GHz band comprises eight separate transmission chains and eight phased array antenna elements with identical connectivity to that depicted in the diagrams.

By referring to Figure 5, it can be deduced that several potential sources of spurious emissions exist, which are spread around the system such that some of them are affected by power control but some are not. For example, any spurious generated within the stages up to and including the RF transceiver will vary in level with TPC, whereas those generated after this point (e.g. in the final power amplifiers) will be at a constant level.

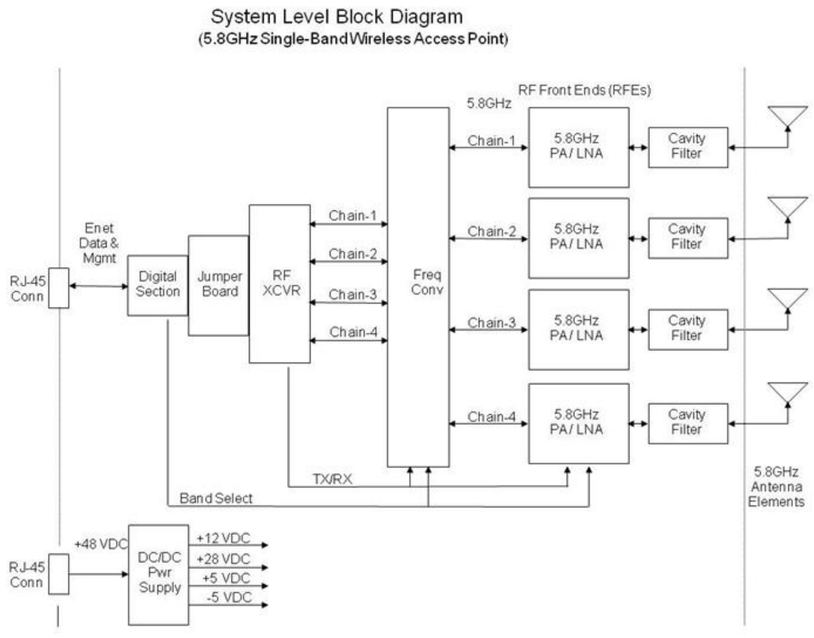


Figure 5: Radio transceiver unit basic connectivity (only 4 chains shown)

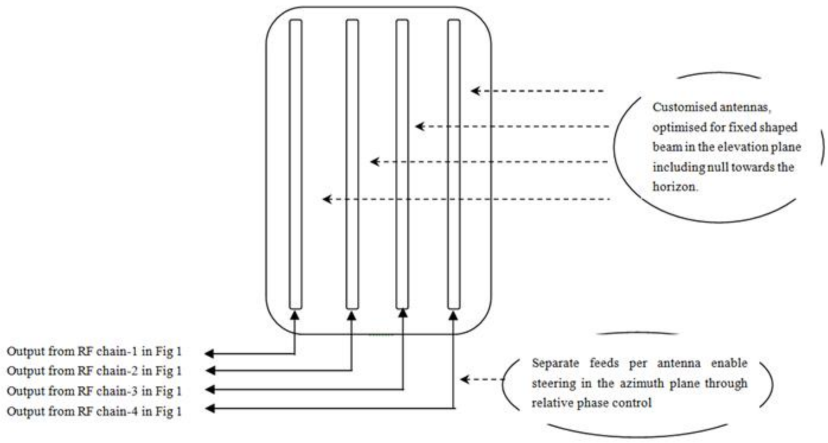


Figure 6: Antenna array assembly (only 4 elements shown)

Also, because of the varying causes of these spurious signals, they cannot be regarded as being correlated, in general. For these reasons, the studies assumed no benefits from correlation of these spurious signals and no variation in the level of any of these components due to power control.

Given the specifics of the technology described here, these can be regarded as worst-case assumptions.

4.2.2 Transmitter parameters

4.2.2.1 Transmitter Output Power / Radiated Power

Table 7: DA2GC Transmitter characteristics

Parameter	Tx output	e.i.r.p.
Maximum ground station TX output power (dBm)[1]	22	45
Maximum aircraft TX output power (dBm)[1]	28	45
ATPC used?	Yes	
Maximum operational ATPC range (dB)	30	
Max e.i.r.p. GS	32 dBm/MHz	
Max e.i.r.p. AS	32 dBm/MHz	
Maximum number of antenna arrays per Ground Station	4	
Number of operationally simultaneous beams per Ground Station antenna array	3	

NOTE: The e.i.r.p. levels in Table 7 represent the maximum operational levels at all times for a single beam, including link acquisition, since the periodic beacon signal transmitted from the ground station radiates lower transmit powers than the signals used to carry data once the aircraft links are established. Antenna Characteristics

[1] The quoted TX output power level is the total transmit power delivered to all antennas and antenna elements of a single ground station or aircraft station antenna array when the transmitter is operating at its maximum power level. .

Table 8: DA2GC Antenna characteristics

Parameter	Value
Ground station peak gain using 8 antenna array (dBi)	23
Aircraft peak gain (dBi) using >4 antenna array	17
NOTE: The Ground Station peak gains given above are for a single antenna array.	

Use of phased array antennas and beamforming results in beam shapes which can be optimised for the intended operational frequency bands and co-existence scenarios. The beamforming algorithms used at the ground station and on the aircraft station permit highly accurate beam pointing, i.e. with an accuracy of 0.1 degrees, and the pointing is refreshed at a rate of at least 200 times per second implying a 5 ms minimum refresh period. This enables accurate control to be maintained during all phases of a flight, including the ability to maintain pointing direction to within 0.5 degrees or less even during periods of flight turbulence or extreme manoeuvres.

4.2.2.2 Example radiation patterns

Example elevation and azimuth radiation patterns are shown in Figure 7 and Figure 8 respectively, for the ground station antennas, when operating in the 5.8 GHz bands. These are based on measurement performed at 5.8 GHz on the latest generation products using 8-element antenna arrays at the ground station. Figure 9 and Figure 10 show the elevation and azimuth patterns respectively for the multi-element antenna arrays on the aircraft

The Ground Station antenna array has a fixed beamforming pattern in the vertical plane, but is designed to use dynamic beamforming in azimuth so that one or more aircraft can be tracked during flight. Although, in practise, the radiation pattern will vary as the beam is scanned, the pattern given in Figure 7 can be assumed to be the worst case for all azimuths. i.e. the gain at any azimuth pointing direction will be less than or equal to the values shown, for any given elevation angle.

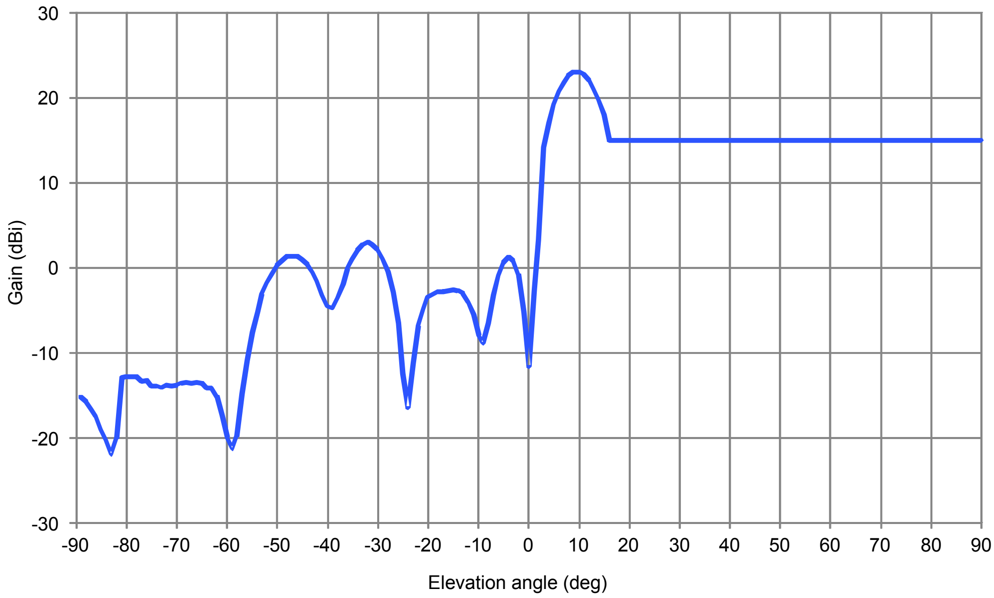


Figure 7: Ground Station Antenna Elevation Pattern (8-antenna array)

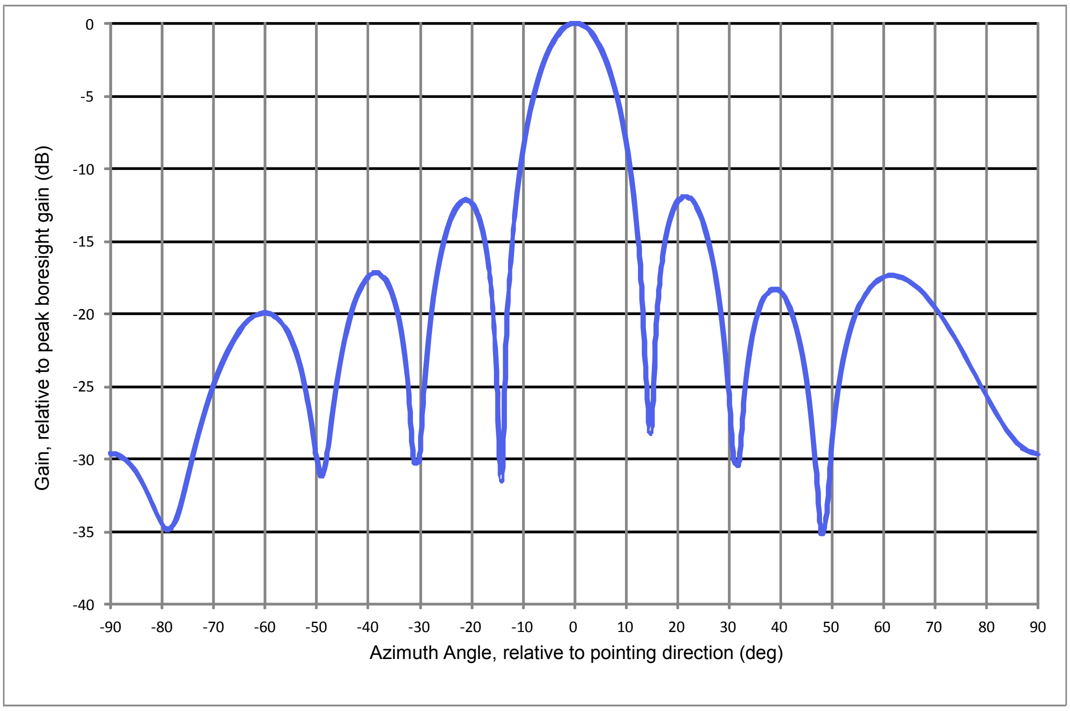


Figure 8: Ground Station Antenna Azimuth Pattern (8-antenna array)

Note that, for three dimensional computations, the resulting ground station antenna gain in any given pointing direction is the sum of the relevant elevation and azimuth gains shown in Figure 7 and Figure 8 respectively.

The beam produced by the aircraft antenna array is steered in both azimuth and elevation so that the main lobe tracks the ground station as the aircraft traverses its flight path. Figure 9contains a sample of the aircraft antenna elevation patterns for selected beam pointing directions.

Note that, in these plots, an elevation angle of 0 degrees represents the horizon pointing direction and 90 degrees is straight down. Each pointing direction is represented by a different coloured plot. It can be seen that the main lobe becomes narrower as the elevation angle increases. The off-axis azimuth radiation pattern shown in Figure 10 can be assumed to be the worst case for all main lobe pointing directions.

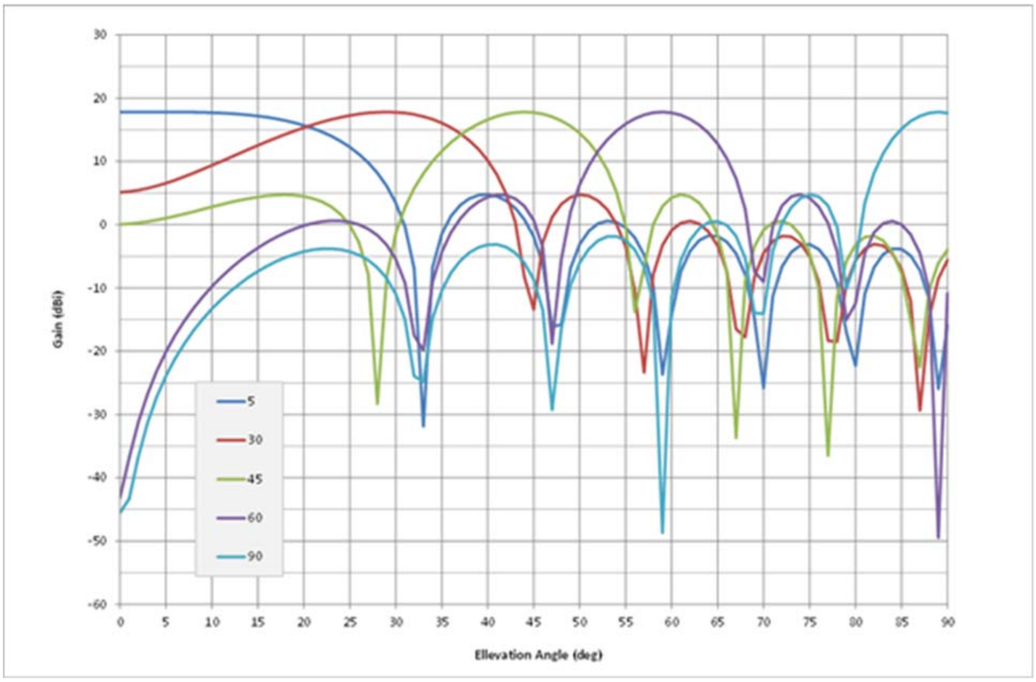


Figure 9: Aircraft Station Antenna Elevation Patterns (16-antenna array)

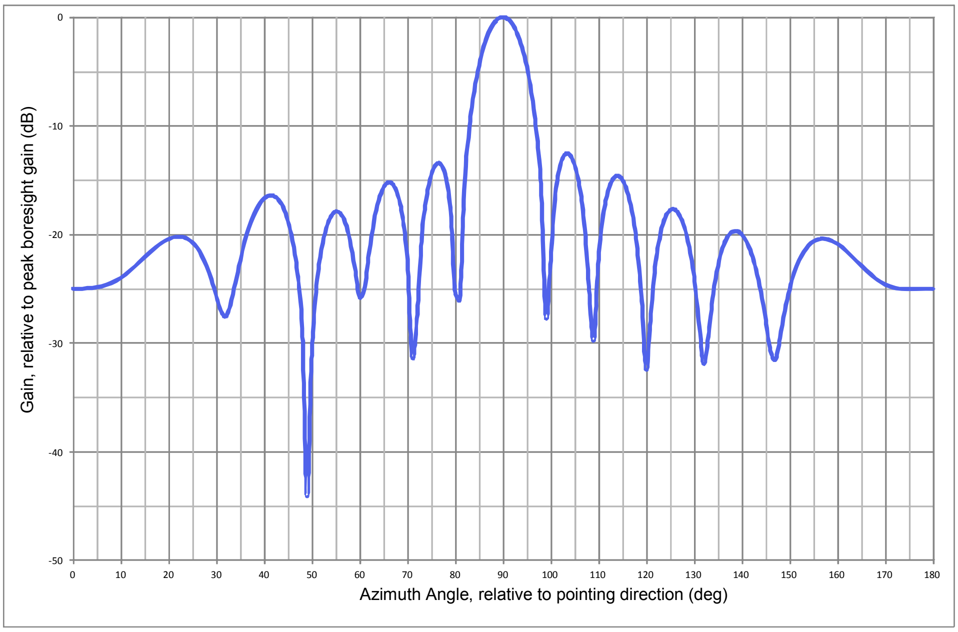


Figure 10: Aircraft Station Antenna Azimuth Pattern (16-antenna array)

Note that, for three dimensional computations, the resulting aircraft station antenna gain for any given pointing direction is the sum of the relevant elevation and azimuth gains shown in Figure 9 and Figure 10 respectively.

4.2.2.3 Operating Frequency

The scope of the System Reference Document is restricted to operation within the 2400 to 2483.5 MHz band and/or the 5 855 MHz to 5 875 MHz band. However, the technology is capable of operating in any frequency band within the range from 790 MHz to 6 GHz.

4.2.2.4 Bandwidth

The necessary bandwidth (as defined by Articles 1.152 and 1.153 of the ITU Radio Regulations) is 20 MHz and the occupied bandwidth complies with Clause 4.3.2.6 of ETSI EN 300 328 V1.8.1 [28] for operation in the 2400 MHz to 2483.5 MHz band and falls within the emission mask specified in Figure 11 for operation in the 5855 MHz to 5875 MHz band.

4.2.2.5 Unwanted emissions

1. Out-of-Band emissions

The out-of-band ground station and aircraft station emissions when operating in the 5 855 MHz to 5 875 MHz band fall within the limits given in Figure 11 when operating under highest output power conditions.

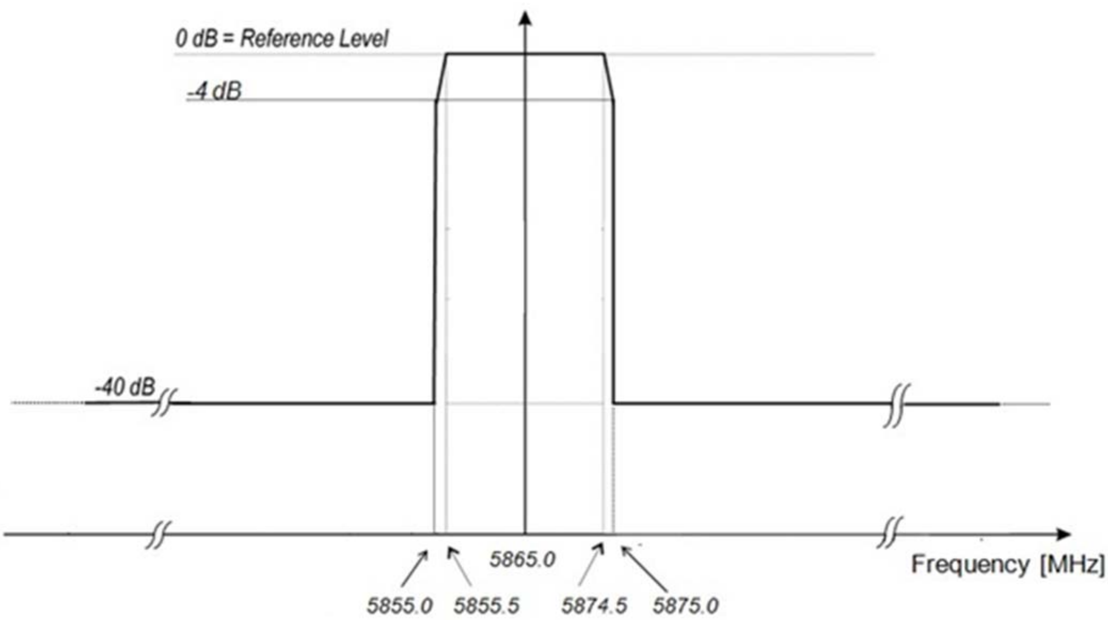


Figure 11: Emission mask

2. Spurious emissions

The spurious emissions for both aircraft and ground stations will not exceed a fixed level of -42dBm/MHz. The quoted spurious level relates to the total conducted power due to spurious emissions delivered to all antennas and antenna elements of a single ground or aircraft station antenna array.

3. Unwanted emissions below 5850 MHz

In addition to the above specifications which apply in-band and up to the transmit channel edges, both the Out-of-Band and Spurious emissions will be reduced to significantly lower levels at frequencies below 5850 MHz through the use of digital pre-distortion and filtering techniques. (See ANNEX 1:). Levels as low as

-70dB relative to full carrier power can be achieved.

4.2.3 Receiver parameter

Table 9 below lists the key receiver parameters for use in sharing studies and which are valid for both the aircraft and Ground Station receivers.

Table 9: Key Ground Station and Aircraft Station parameters

Parameter	Value
Receiver sensitivity (dBm)	-87
Receiver noise figure (dB)	4
Thermal noise power (dBm/MHz)	-110
Thermal noise power (dBm/20 MHz)	-97
Maximum interference level (I/N =-10dB) (dBm/20 MHz)	-107
In-band processing gain/interference rejection (dB relative to wanted signal)	up to 50
Adjacent channel selectivity (dB)	43.5

Note: The I/N criterion of -10 dB relates to interference that can be tolerated in the absence of signal processing. The application of signal processing enables signals up to 50 dB greater than the wanted carrier signal level to be cancelled out..

4.2.4 Channel access parameters

The operational channel access parameters such as frame duration, resource grouping and allocation in time and frequency, random access procedures, are fully configurable.For operation in the 5.8 GHz band, the system employs 5 ms frames with 50 % forward/50 % return link (2.5 ms ground to air, 2.5ms air to ground). The frequencies are broken into 12 to 24 channels, depending on the scheduler. The access is fully scheduled using MAC messaging inside the 5 ms frame.

4.3 DA2GC SYSTEM ACCORDING TO ETSI TR 103 108

4.3.1 Technical Description

The system is essentially based on 3G UMTS TDD standards that have been adapted for operation in the 5,8 GHz band. It uses multi-sector antennas to optimise the ground infrastructure performance by providing coverage when and where required while reducing interference. Essentially the signal in space is compliant with 3GPP standards apart from the operating frequency. Doppler shift and range compensation is introduced by the air station such that the base station considers the mobile to be near stationary with a fixed range. Both vertical and horizontal polarisations may be used.

4.3.1.1 Transmitter

The transmission modulation technology is CDMA. It is important to note that for any given cell at any given instant the resource scheduler dedicates all the available capacity to one aircraft thereby effectively restricting the total number of aircraft transmitters to one. The maximum values of the transmitter parameters are listed below:

Table 10: DA2GC Transmitter characteristics

Parameter	Unit	Value
Channel bandwidth	MHz	5 or 10
Transmitter maximum output power (GS)	dBm	38 (10 MHz channel) 35 (5 MHz channel)
Transmitter maximum output power (AS)	dBm	36 (10 MHz channel) 33 (5 MHz channel)
Transmitter feeder loss (GS)	dB	2
Max. antenna gain (GS Sector Antenna)	dBi	15
Max. antenna gain (GS	dBi	24 (Note 1)

Parameter	Unit	Value
Directional Antenna)		
Transmitter maximum e.i.r.p. (GS – Sector Antenna)	dBm/MHz	41
Transmitter maximum e.i.r.p. (GS – Directional Antenna)	dBm/MHz	50
Antenna up-tilt (GS – Sector Antenna)	deg.	6
Antenna up-tilt (GS – Directional Antenna)	deg.	3
GS antenna height	m	10 – 50 (Note 2)
Transmitter feeder loss (AS)	dB	4
Max. antenna gain AS	dBi	7
Transmitter maximum e.i.r.p. (AS)	dBm/MHz	29
Estimated number of GS across Europe	230	

Note 1: The directional antenna will only be used where maximum range is required. This will be mainly over sea. To protect any systems located near the coast, the main beam shall not illuminate any landfall within 4 km. The directional antenna may be used in remote areas, such as desert regions, subject to agreement by the regulatory administration(s).

Note 2: The preferred ground station antenna location is on the roof of a tall building resulting in a height of 50 metres or more. However remote locations could result in lower antenna heights.

4.3.1.2 Receiver

Frequency conversion to/from 5.8 GHz as well as range and Doppler shift compensations are achieved within the avionics receiver. The receiver modem characteristics are compliant with 3GPP release 7 at the physical layer.

The receiver characteristics are listed below:

Table 11: Receiver characteristics

Parameter	Unit	Value
Bandwidth	MHz	5 or 10
Thermal noise power density	dBm/MHz	-114
Thermal noise floor	dBm	-107 (5 MHz channel) -104 (10 MHz channel)
Receiver noise figure	dB	2.5
Receiver thermal noise level	dBm	-104.5 (5 MHz channel) -101.5 (10 MHz channel)
Interference protection ratio (I/N)	dB	-6
Interference protection level	dBm	-110.5 (5 MHz channel) -107.5 (10 MHz channel)
Interference protection level	dBm/MHz	-117.5
Receiver adjacent channel selectivity (ACS)	dB	36 (5 MHz channel) 33 (10 MHz channel)

4.3.1.3 Antenna parameters

Table 12: DA2GC Antenna Parameters

Parameter	Unit	Value
Max antenna gain (AS)	dBi	7
Max antenna gain (GS Omni)	dBi	7
GS omni antenna up-tilt	degrees	15
Max antenna gain (GS Sector)	dBi	15
GS sector antenna up-tilt	degrees	6
Max antenna gain (GS Directional)	dBi	24
GS directional antenna up-tilt	degrees	3

The planned network is based on the use of sector GS antennas and every ground station is so equipped. Hence the ground station e.i.r.p. mask, as described in ETSI TR 103 108, has been derived using this type of antenna.

During flight testing the omni-directional GS antenna was also used. It would be convenient to use this type of antenna for some flight testing/validation of aircraft installations while respecting the e.i.r.p. mask. However such use would be very limited and intermittent.

In the event that a directional GS antenna is used, the interference level at elevation angles below about 8 degrees would be up to 9 dB higher. However, since such directional antennas are only intended to be operated at coastal locations to provide additional range out to sea, there is not considered to be any additional risk of interference into BFWA, ITS, RTTT or SRD systems. Maritime radars (Radar Q) operate in the band 5450-5825 MHz and the additional frequency separation would ensure that any unwanted emission interference would respect the limit specified in ETSI TR 103 108. Finally, the azimuthal bearing angle would be such as to not align with FSS satellites.

The antenna patterns depicted in Figure 12 to Figure 18 are referenced to boresight and do not include any tilt.

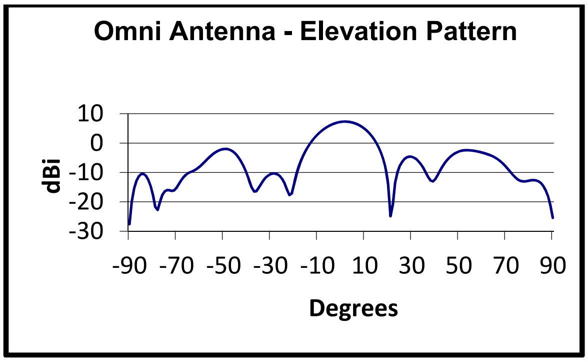


Figure 12: Omni Antenna Pattern – Elevation

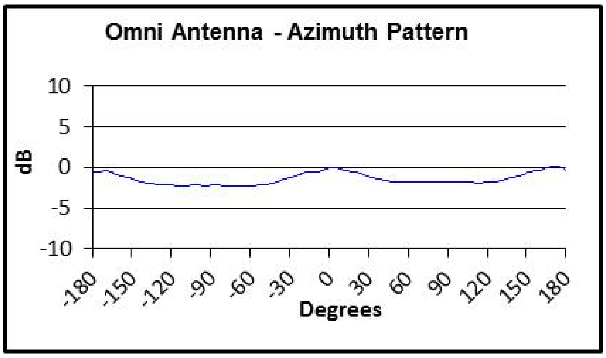


Figure 13: Omni Antenna Pattern - Azimuth

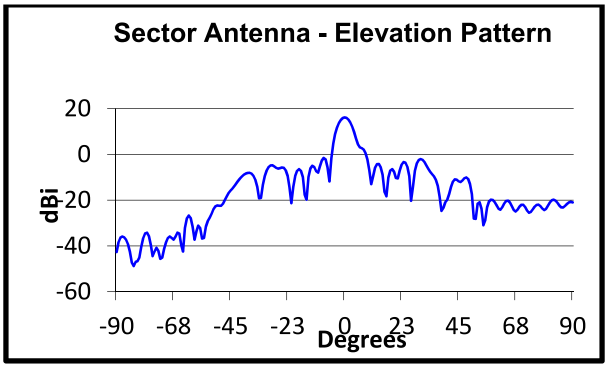


Figure 14: Sector Antenna Pattern – Elevation

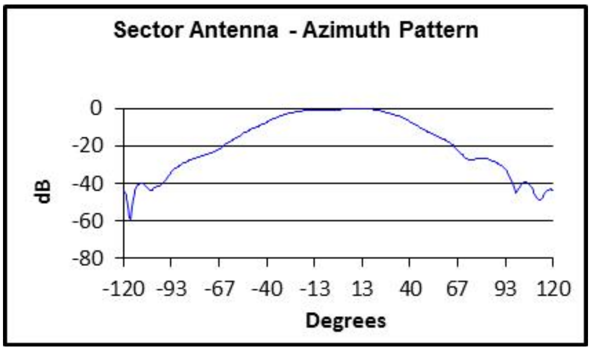


Figure 15: Sector Antenna Pattern – Azimuth

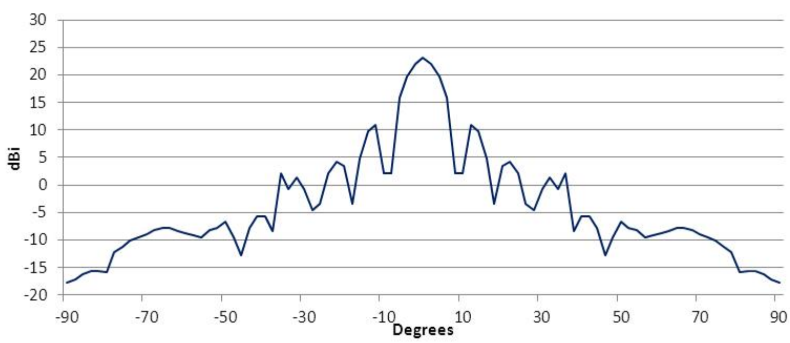


Figure 16: Directional Antenna Elevation and Azimuth Pattern

The elevation pattern of the aircraft antenna used for analysis is illustrated below:

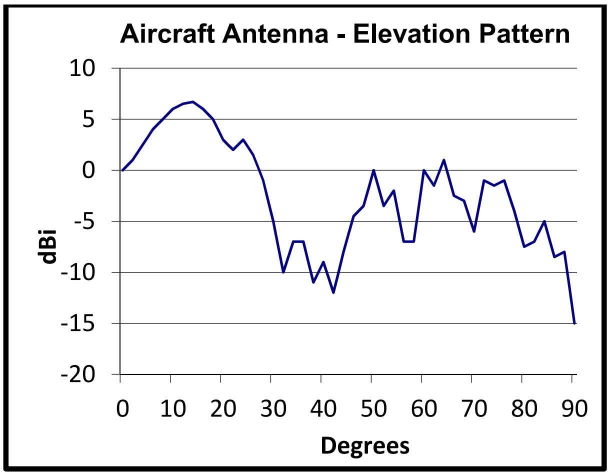


Figure 17: Aircraft Antenna Pattern – Elevation

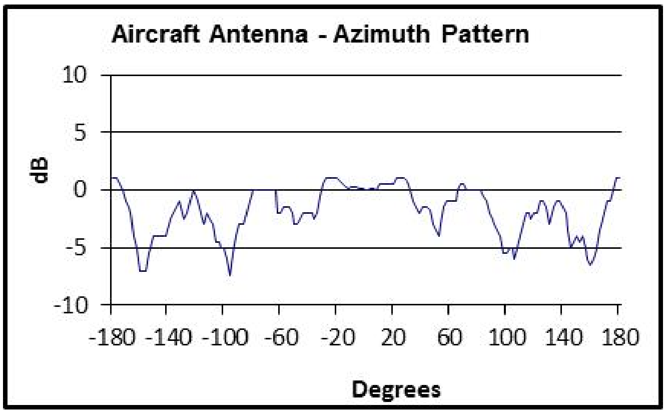


Figure 18: Aircraft Antenna Pattern - Azimuth

Some measured patterns are presented below for information purposes:

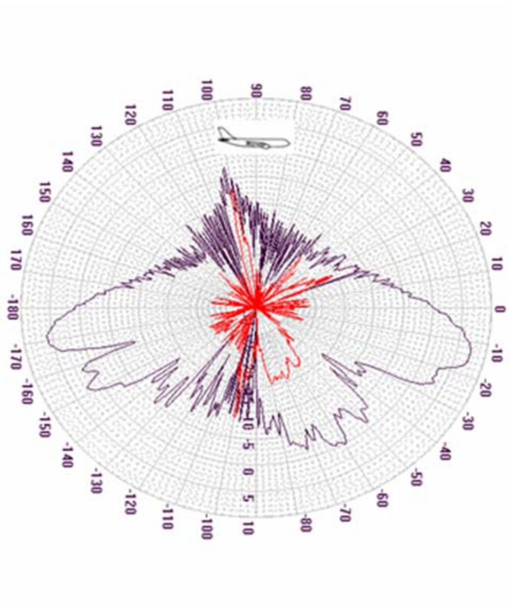


Figure 19: A/C Antenna Pattern – Elevation (Measured)

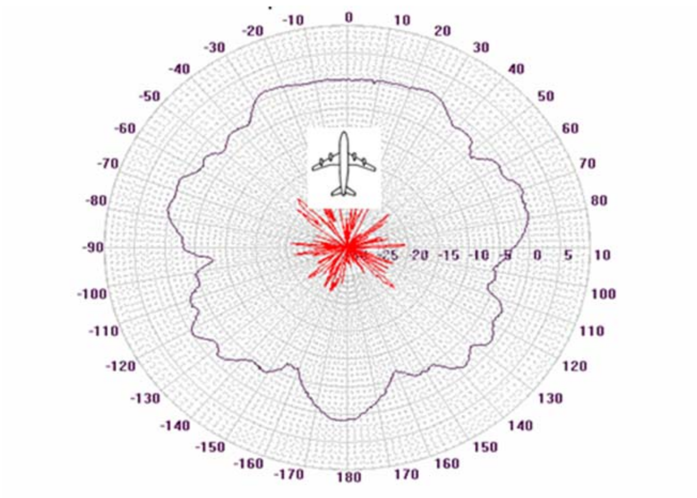


Figure 20: A/C Antenna - Azimuth (Measured)

4.3.1.4 Ground Station Elevation e.i.r.p. Mask

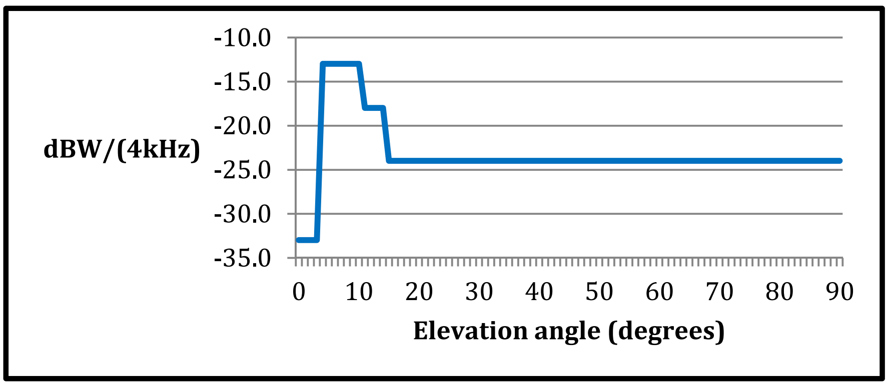


Figure 21: Ground Station Elevation e.i.r.p. Mask

This mask is assumed for all azimuth angles.

4.3.1.5 Aircraft Station Elevation e.i.r.p. Masks

The following elevation masks for the aircraft station is taken from ETSI TR 103 108. The elevation angle in the following figure denotes angles below the fuselage where 0 degrees is the horizontal.

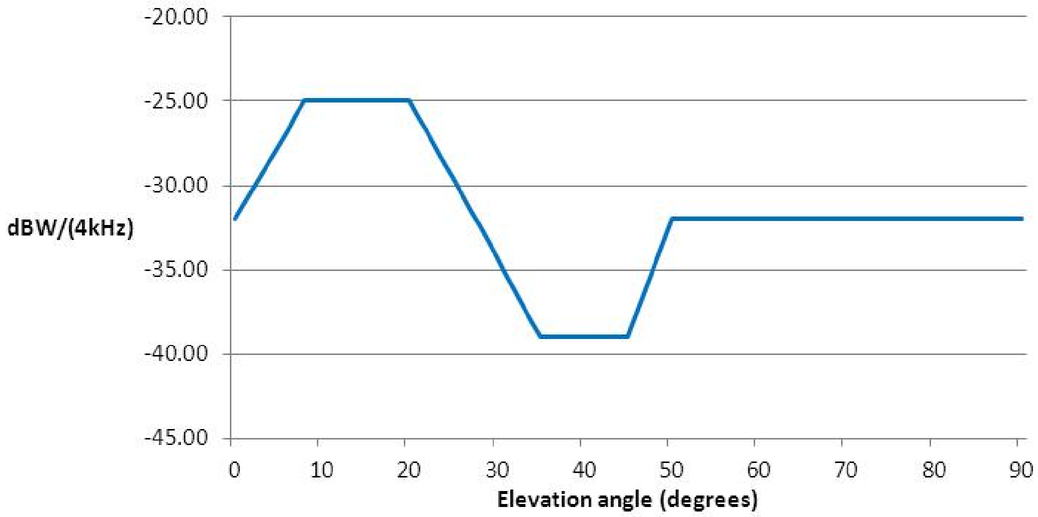


Figure 22: Aircraft Station Elevation e.i.r.p. Mask (Below fuselage)

The elevation angle in the following figure denotes angles above the fuselage where 0 degrees is the horizontal.

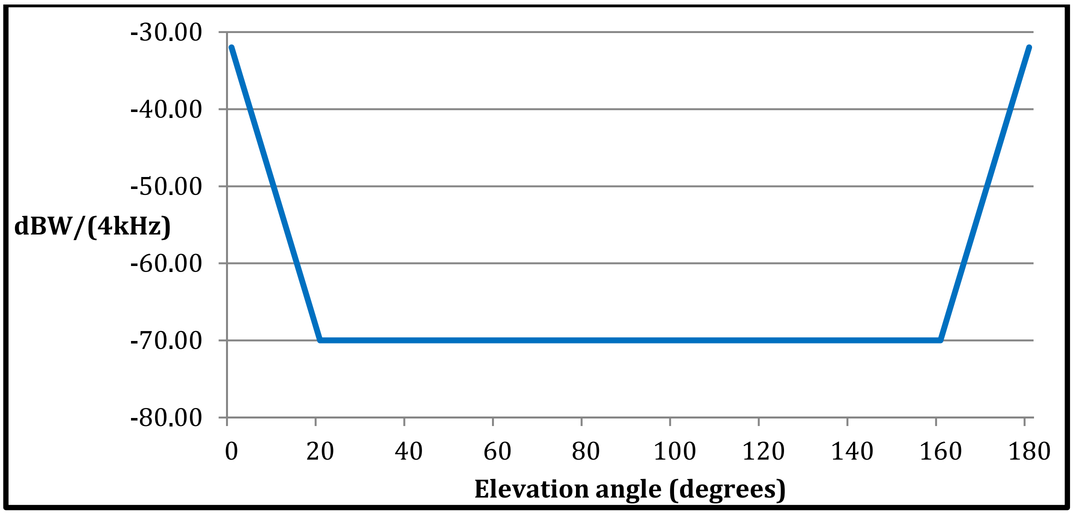


Figure 23: Aircraft Station Elevation e.i.r.p. Mask (Above fuselage)

4.3.1.6 Spectrum Emission Mask

The spectrum emission mask taken from ETSI TR 103 108 is given below:

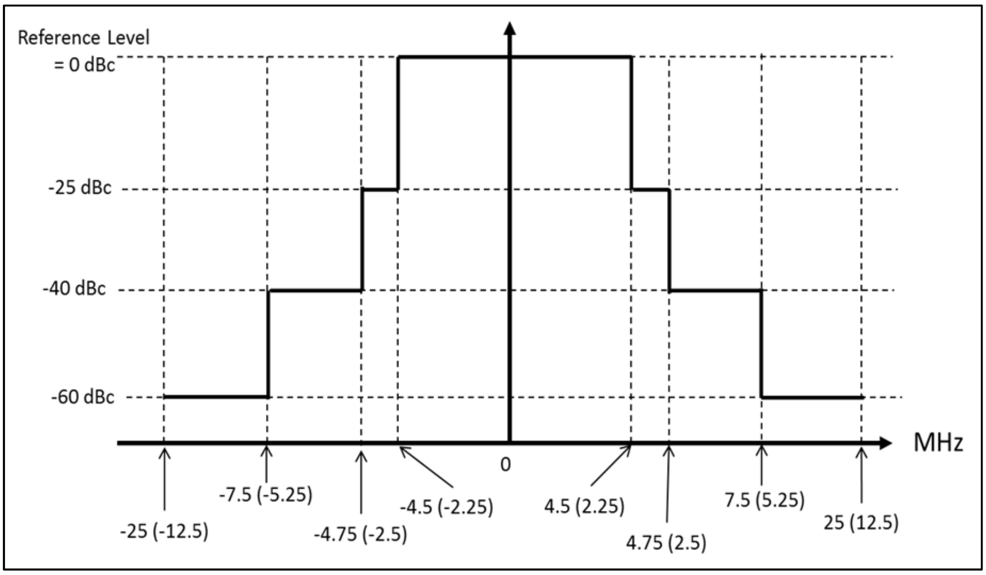


Figure 24: Spectral Emission Mask for both GS and AS

Note 1:	*0 dBc Reference Level is the spectral density relative to the maximum spectral power density of the transmitted signal. For example:* *i) for a Ground Station with a directional antenna, using a 10 MHz bandwidth, the Reference level (0 dBc) would be 60 dBm/(10 MHz) = 50 dBm/MHz* *ii) for an Aircraft Station using a 5 MHz bandwidth, the Reference level (0 dBc) would be 39dBm/(5 MHz) = 32 dBm/MHz*
Note 2 to Figure 24*:*	*On the Frequency Offset axis, the figures apply to a 10 MHz bandwidth system, whereas the figures in parentheses apply to a 5 MHz bandwidth system.*

4.3.1.7 Unwanted Emissions

The spurious emissions from the antenna connector during transmit mode are defined as unwanted power in the bands from 30 MHz up to Fc -2.5*BW and from Fc +2.5*BW up to 5*Fc, where Fc is the carrier frequency and BW is the signal bandwidth (5 MHz or 10 MHz). This frequency band covers both in-band and out-of-band emissions.

The maximum level of spurious emission is:	-36 dBm/(100 kHz),	for 9 kHz ≤ f ≤ 1 GHz
	-30 dBm/MHz ,	for 1 GHz < f ≤ 26 GHz
The maximum level of unwanted emission is:	-50 dBm/MHz,	for 5,250 GHz < f ≤ 5,850 GHz

4.3.1.8 Aircraft Station Mitigation Attenuation

The AS introduces additional transmitter attenuation according to its altitude as follows:

Table 13: AS transmitter attenuation

Altitude (metres)	Attn (dB)
3000 to 4999	8
5000 to 5999	6
6000 to 6999	4
7000 and above	0

5 COMPATIBILITY AND SHARING SCENARIOS FOR THE BAND 5855-5875 MHz

Table 14 contains the services and systems deployed in the frequency band 5.8 GHz. Figure 25 shows the sharing scenarios in both interference directions when assuming TDD mode of the DA2GC system.

Table 14: Incumbent services/systems deployed in the 5.8 GHz band

System	Frequency range/MHz	Compatibility issues
BFWA	5725 – 5875	ECC/REC (06)04 [37], Technical characteristics ETSI TR 102 079 [40] , EN 302 502 [39], Fixed Systems according to Recommendation ITU-R F.758 [49].
FSS (E-s)	5725 – 5875	ECC Report 068 [32] contains sample of GSO satellite data taken from the ITU filings for the band 5725- 5875 MHz. Annex 3 of ECC/REC/(06)04 [37] contains e.i.r.p. spectral density limits in the elevation plane to protect GSO satellite receivers in the FSS.
SRDs	5725 – 5875	Non-Specific SRDs according ERC/REC 70-03 Annex 1 [36], Technical parameters EN 300 440, 25 mW e.i.r.p.
ITS	5875 – 5925 5855 – 5875	Safety related ITS applications Non-safety related ITS applications ECC Report 101 [44] details spectrum sharing studies between ITS systems (Roadside and onboard unit) within the frequency band 5855-5925 MHz and the other services and applications in this frequency range and identifies conditions for ITS applications that facilitate spectrum sharing. ECC Reports 109 [51] and 110 [51] supplement these studies. Technical parameters can also be found in EN 302 571 [42]
Radiolocation	5725 – 5850	Recommendation ITU-R M.1638 [25] provides characteristics of radars operating under the Radiolocation services in the frequency range 5250-5850 MHz

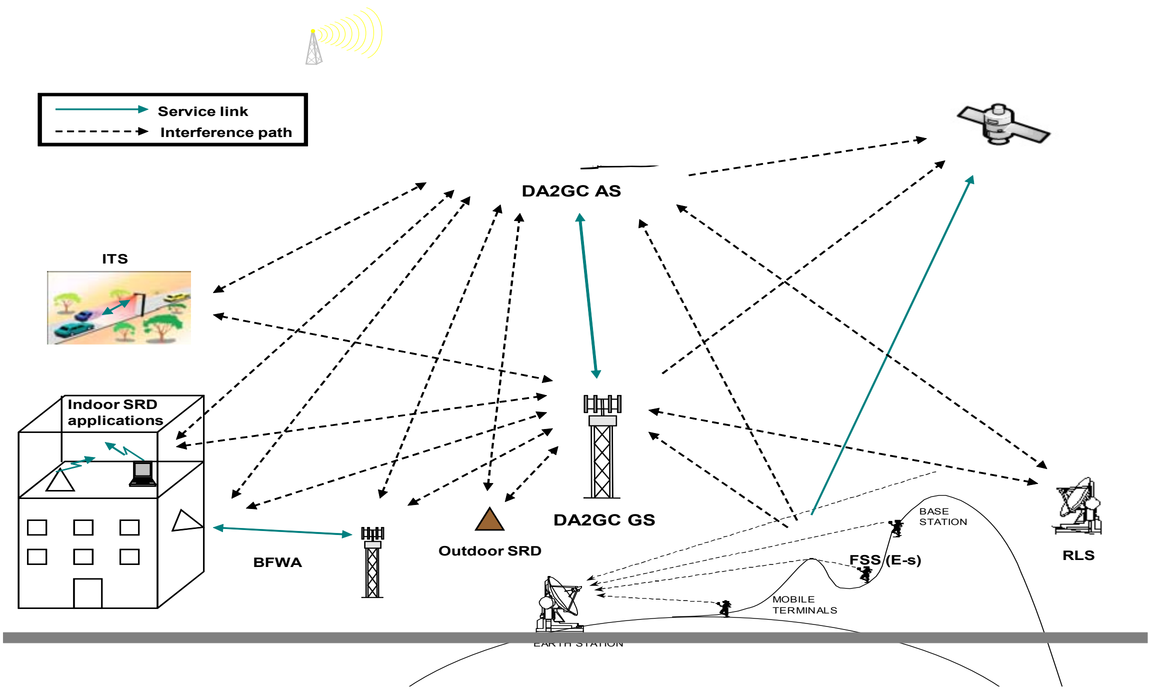


Figure 25: Interference scenarios for BDA2GC in the frequency band 5855 -5875 MHz

5.1 COMPATIBILITY BETWEEN DA2GC AND BFWA AT 5.8 GHZ

5.1.1 Technical characteristics of BFWA systems

For BFWA, the system parameters as provided in ECC Report 068 [32] and in ETSI TR 102 079 [40] (System Reference Document for BFWA (HIPERMAN) in the 5.8 GHz band) have been used. The following Table 15: BFWA system parameter contains the technical parameters of a BFWA P-MP system. Annex D of ETSI TR 102 079 provides various radio parameters, especially table D.7 shows the parameters for different modulation schemes. Figure 28 shows a typical deployment scenario for a BFWA P-MP network.

Table 15: BFWA system parameter

Parameter	P-MP
Topology	Sectored Central Station (CS) Terminal Stations (TS).
Channel bandwidth	20 MHz
Duplex/ Access scheme	TDD/TDMA
Max e.i.r.p.	36 dBm
Power density spectral (dBm/MHz) e.i.r.p.	23 dBm/MHz
Antenna gain	17 dBi
Antenna pattern CS	See Figure 26
Antenna pattern TS	See Figure 27
Receiver sensitivity (16-QAM)	-74 dBm (in 20 MHz BW)
Interference protection ratio C/I (16 QAM)	20 dB
Interference protection ratio C/I	30 dB

Parameter	P-MP
(64-QAM)	
Receiver sensitivity(64-QAM)	-68 dBm (in 20 MHz BW)
Interference protection level (16-QAM system)	-107 dBm /MHz
Interference protection level (64-QAM system)	-111 dBm/MHz

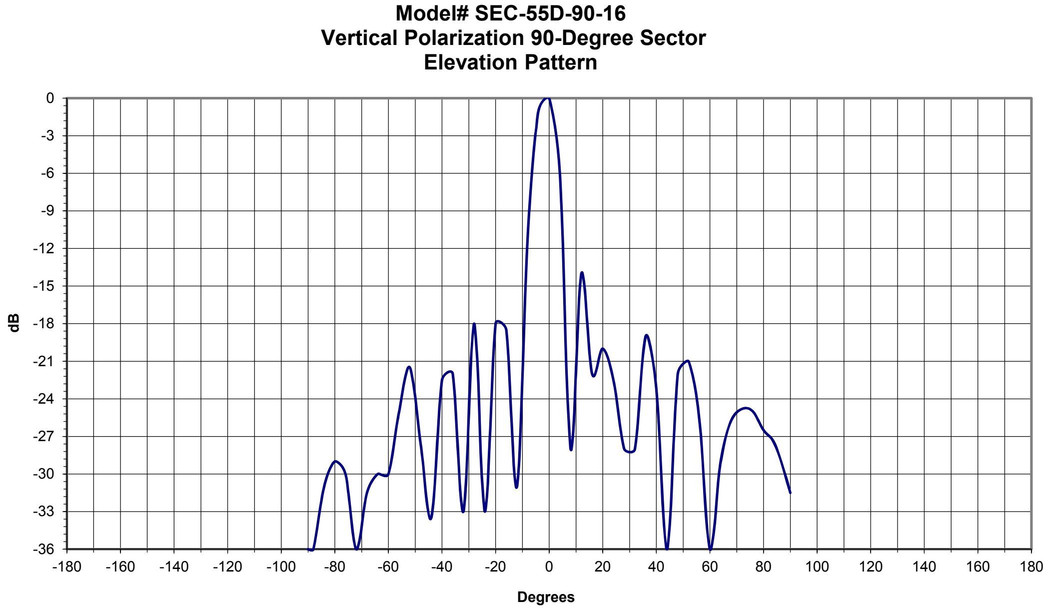


Figure 26: Typical P-MP Central station antenna pattern (see Annex 1 of ECC Report 68)

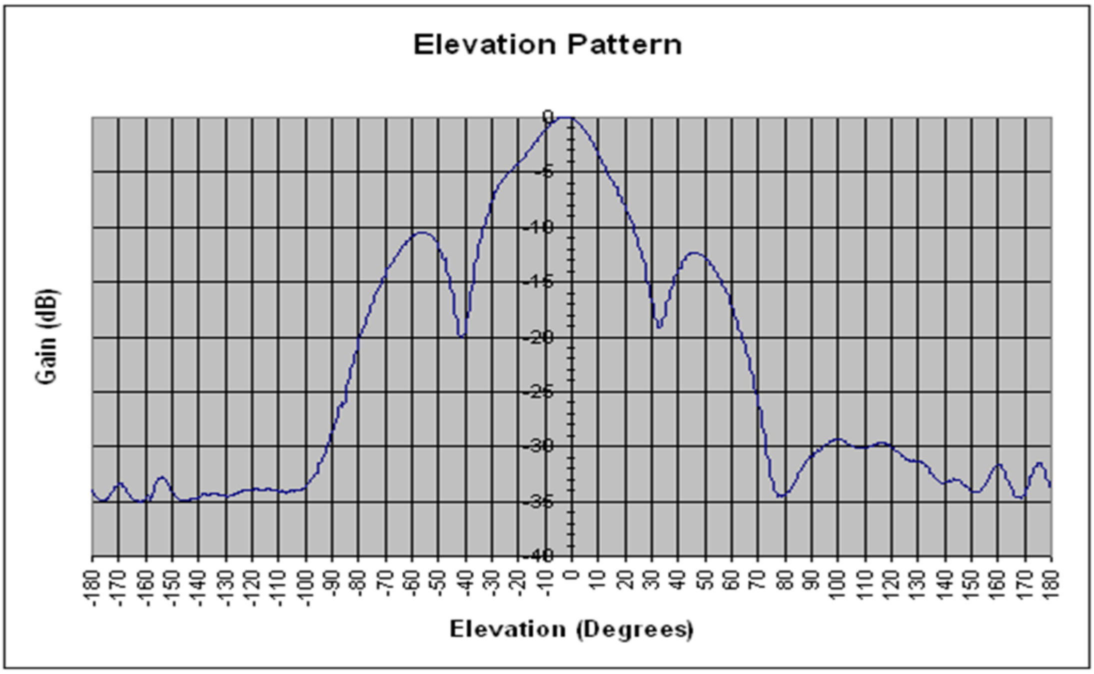


Figure 27: BFWA Terminal Station Elevation pattern (20 degree beam width)

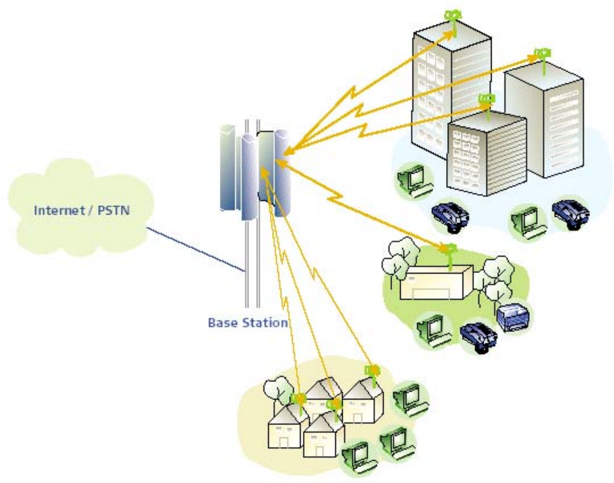


Figure 28: Typical P-MP deployment scenario

5.1.2 Compatibility between DA2GC AS (ETSI TR 103 054) and BFWA

5.1.2.1 Methodology

It is considered that the DA2GC aircraft station is approaching the BFWA CS at a given altitude (3000m and 10000m). The interference level arriving at the victim receiver was calculated taking into account the transmit power density of the interfering system, the great circle distance, the aircraft elevation (up to 90 degrees), the resulting free space loss, the antenna characteristics of the interfering and the victim system and the interference protection level of the victim system. The following Figure 29 illustrates the scenario between a BFWA BS and a DA2GC AS. In this analysis the 16-QAM system was used as a reference. A protection criterion (C/I) of 20 dB was assumed in the calculations. It should be noted that systems operating with high data rates may need a C/I of up 30 dB for their operation. For both station types (CS and TS) a maximum power spectral density of 23 dBm/MHz was considered in this study.

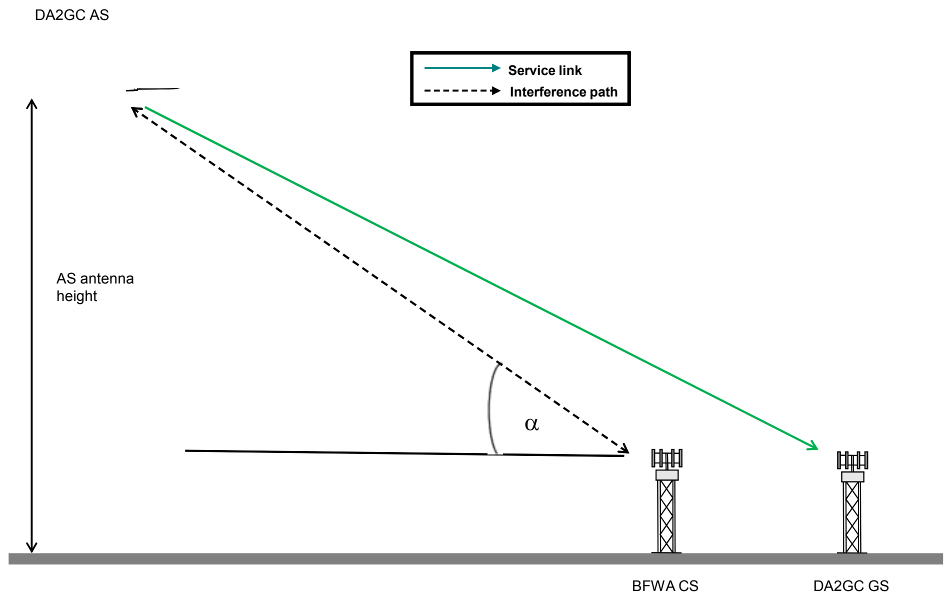


Figure 29: Interference scenario

5.1.2.2 Results

Figure 30 to Figure 37 show the

- received power spectral density (PSD) in dBm/MHz at the BFWA stations and the DA2GC AS and also
- resulting interference-to-noise ratio (I/N) compared to the different thresholds of both systems

along the great circle distance from 0 km to 100 km.

Line-of-sight propagation was assumed between BFWA CS/TS and DA2GC AS. Therefore, free space loss was considered. Only co-channel transmission was evaluated.

Interference scenarios between BFWA CS and DA2GC AS as well as between BFWA TS and DA2GC AS are considered for aircraft altitudes of 3 km and 10 km, respectively.

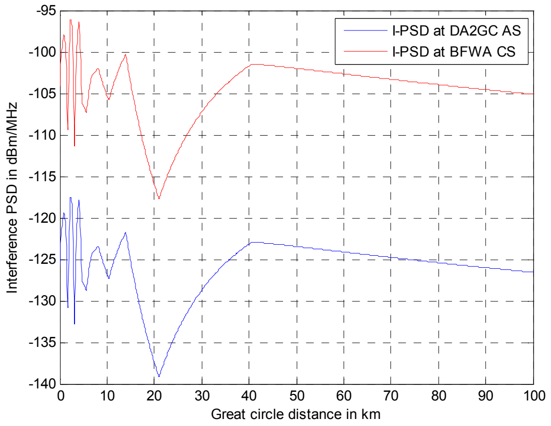


Figure 30: Received PSD (aircraft altitude 3000 m)

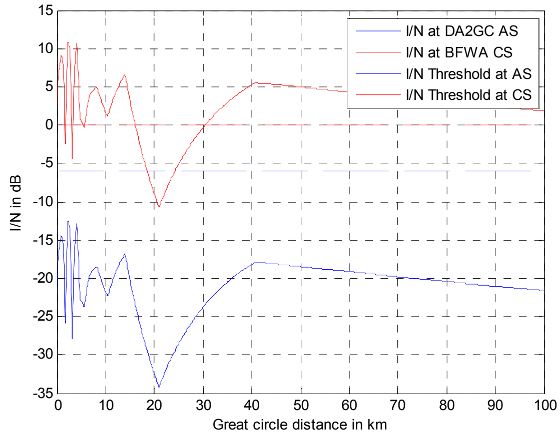


Figure 31: Resulting I/N ratio (aircraft altitude 3000 m)

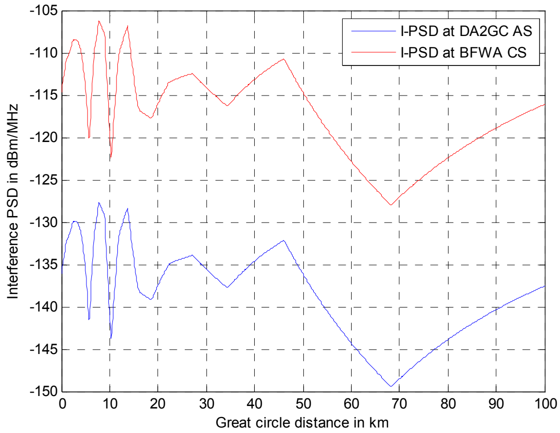


Figure 32: Received PSD (aircraft altitude 10.000 m)

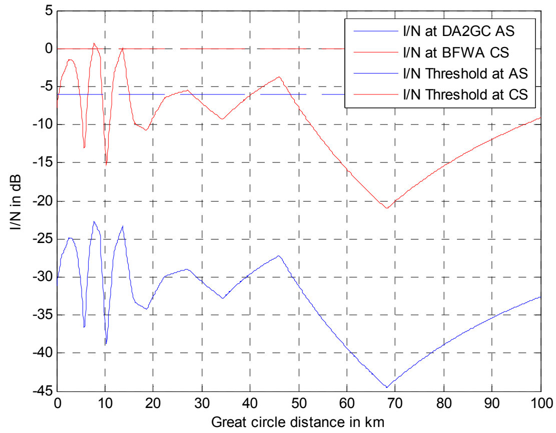


Figure 33: Resulting I/N ratio (aircraft altitude 10.000 m)

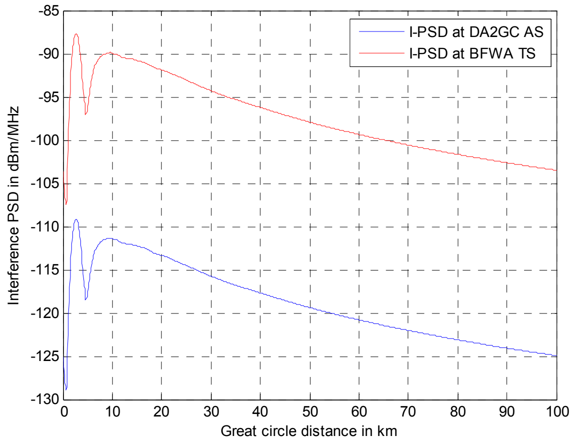


Figure 34: Received PSD (aircraft altitude 3000 m)

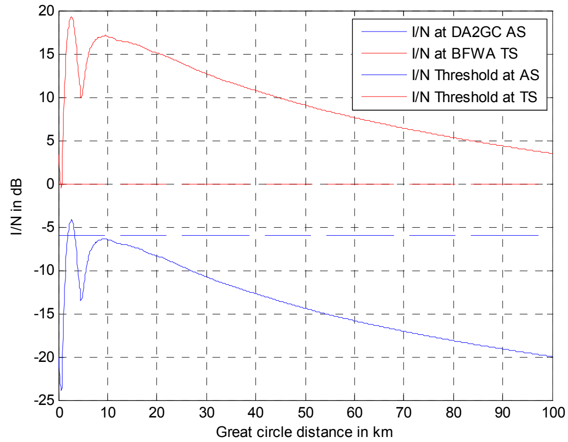


Figure 35: Resulting I/N ratio (aircraft altitude 3000 m)

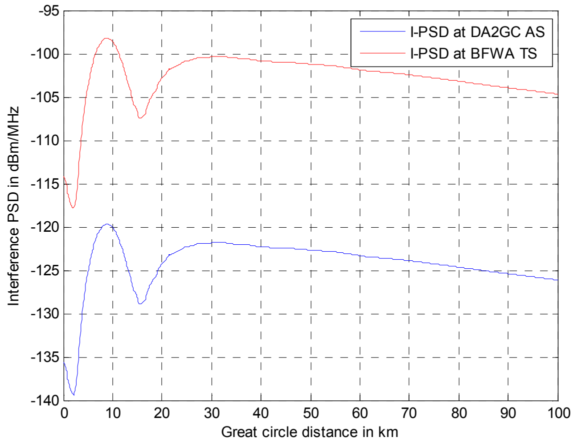


Figure 36: Received PSD (aircraft altitude 10000 m)

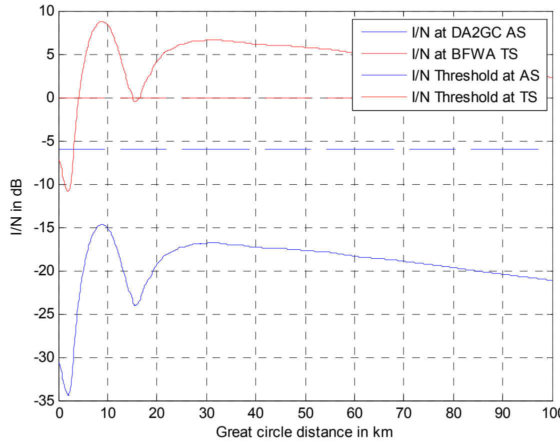


Figure 37: Resulting I/N ratio (aircraft altitude 10000 m)

Figure 38 to Figure 41 show the resulting PSD at the BFWA (CS and TS) receiver input in dependence of the aircraft elevation. Considering an aircraft approaching at an altitude of 3000 meters, it can be observed (Figure 38 and Figure 39), that the protection criterion of the BFWA will be exceeded by a wide margin. Figure 40 and Figure 41 shows the situation, when the aircraft is approaching at an altitude of 10000 meters. It can be observed that an additional free space loss of 10.5 dB is achieved independently of the aircraft elevation. In case of the BFWA CS for aircraft heights above 8000 meters, the protection level is continuously met. Interference at the TS can still be observed up to 10.000 meters (see Figure 41).

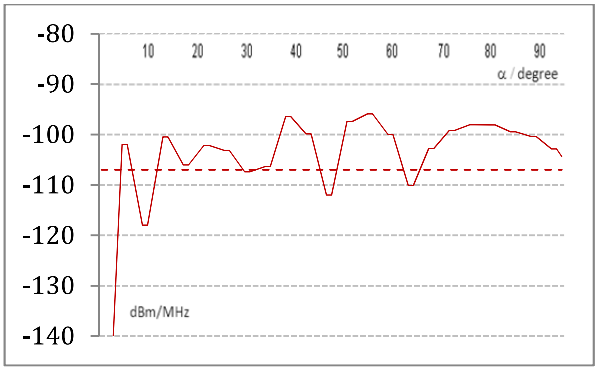


Figure 38: Resulting interference at the BFWA CS antenna input caused by a DA2GC AS (altitude 3000m)

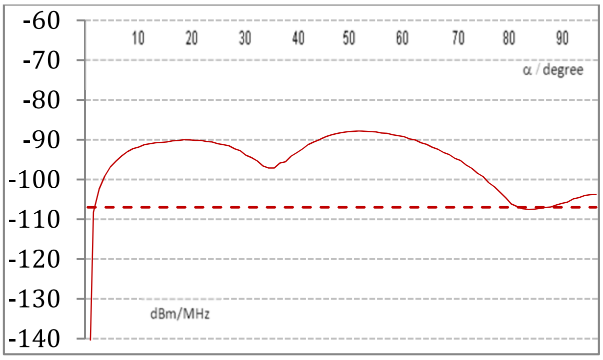


Figure 39: Resulting interference at the BFWA TS antenna input caused by a DA2GC AS (altitude 3000m)

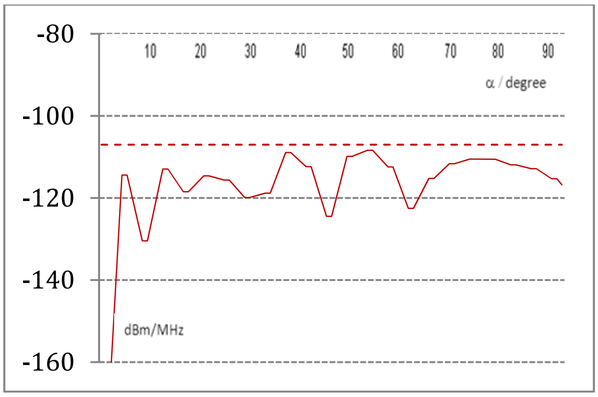


Figure 40: Resulting interference at the BFWA CS antenna input caused by a DA2GC AS (altitude 10.000 m)

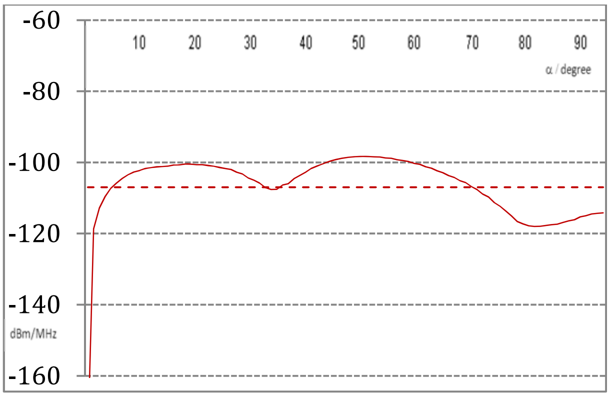


Figure 41: Resulting interference at the BFWA TS antenna input caused by a DA2GC AS (altitude 10.000m)

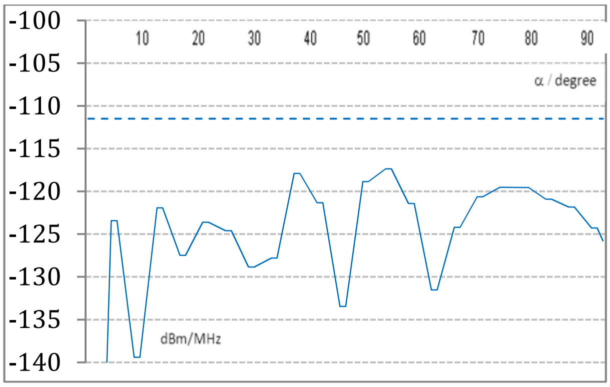


Figure 42: Resulting interference at the DA2GC AS antenna input caused by a BFWA CS (aircraft altitude 3000m)

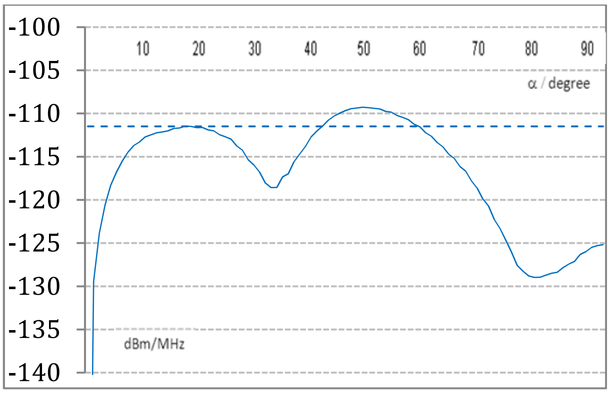


Figure 43: Resulting interference at the DA2GC AS antenna input caused by a BFWA TS (aircraft altitude 3000m)

Figure 42 and Figure 43 showing an approach of an aircraft at an altitude of 3000m.It can be noted that the protection criterion is continuously met in case of the CS. In case of the BFWA TS as the interfering system interference of 2.3 dB can still be observed. Above an aircraft altitude of about 3900 meters compatibility is achieved.

5.1.3 Compatibility between DA2GC GS (ETSI TR 103 054) and BFWA

Table 16 shows the technical parameters of the DA2GC Ground Station. According to the system description of the DA2GC Ground station an antenna up-tilt of 10 degree was assumed, leading to a maximum horizontal gain of 8 dBi, which was used in the calculation.

Table 16: Technical parameters of the DA2GC GS (TR 103 054)

DA2GC GS Parameter	Value	Unit
DA2GC Tx power	46,0	dBm
Antenna gain (mainlobe)	20,0	dBi
e.i.r.p. max	66,0	dBm
Power spectral density	53,4	dBm/MHz
GS Antenna tilt	10,0	degree
Antenna gain(horizontal)	8,0	dBi
DA2GC GS antenna height	50,0	m
Signal bandwidth	18,0	MHz
Rx thermal noise	-101,4	dBm
Rx noise figure	5,0	dB
Rx noise floor	-96,4	dBm
Rx sensitivity level	-98,5	dBm
Interference protection ratio I/N	-6,0	dB
Interference protection level	-102,5	dBm
Interference protection level	-115,1	dBm/MHz

5.1.3.1 Methodology

On the basis of above assumptions, the minimum required path loss values have been calculated for the interference criteria of -98 dBm/20MHz for BFWA and -102.5 dBm/20 MHz for DA2GC using the following equation.

Min Req Path Loss (dB)
= Tx Power (dBm) + Tx Ant Gain (dBi) + Rx Ant Gain (dBi) – Int Criterion (dBm)

The required separation distances between DA2GC GS and BFWA were calculated by applying the same propagation model as used in ECC Report 068 [32] and ECC Report 101 [44].

$$L_{FS} = \begin{cases} 20Log\left(\frac{\lambda}{4\pi d}\right) & d \le d_0 \\ 20Log\left(\frac{\lambda}{4\pi d_0}\right) - 10n_0 Log\left(\frac{d}{d_0}\right) & \text{if } d_0 < d \le d_1 \\ 20Log\left(\frac{\lambda}{4\pi d_0}\right) - 10n_0 Log\left(\frac{d_1}{d_0}\right) - 10n_1 Log\left(\frac{d}{d_1}\right) & d > d_1 \end{cases}$$

Table 17: Propagation parameters

	Urban	Rural
Breakpoint distance d_0 (m)	64	256
Pathloss factor n_0 beyond the first break point	3.8	2.8
Breakpoint distance d_1 (m)	128	1024
Pathloss factor n_1 beyond the second breakpoint	4.3	3.3

5.1.3.2 Results

The following Table 18 and Table 19 show the calculated separation distances between a DA2GC Ground station and a BFWA Central station.

Table 18: Required separation distances (DA2GC victim)

BFWA to DA2GC GS	Required Attenuation (dB)	Required separation – urban (km)	Required separation – rural (km)
BFWA ML - DA2GC	146	1.9	10.3
BFWA 1st SL (0 dBi) - DA2GC	129	0.78	3.2
BFWA 2nd SL (-10 dBi) - DA2GC	119	0.45	1.6

Table 19: Required separation distances (BFWA victim)

DA2GC GS to BFWA	Required Attenuation (dB)	Required separation – urban (km)	Required separation – rural (km)
DA2GC - BFWA ML	165	5.3	39
DA2GC - BFWA 1st SL (0 dBi)	148	2.1	11.9
DA2GC - BFWA 2nd SL (-10 dBi)	138	1.3	5.9

5.1.3.3 Conclusions

- Impact on BFWA

For aircraft altitudes of about 3 km the I/N threshold will be generally exceeded at the BFWA TS, and also in a large range at the CS. The results are strongly dependent on the antenna characteristic applied for BFWA installation, especially the impact of the side lobes is recognizable in the I/N curves.

The I/N threshold at the TS is exceeded even at an aircraft altitude of 10 km. For the CS single critical peaks occur only near its location, but for medium altitudes the threshold can no more be kept in that area.

Thus, it is concluded that co-channel operation of DA2GC reverse link (air-to-ground) and BFWA systems in the band 5855-5875 is not feasible.

- Impact on DA2GC AS

At higher altitudes the impact of BFWA transmitters on the receiving DA2GC AS is negligible. Only in distances below 10 km from a BFWA TS the receiving DA2GC AS at altitudes of 3 km and below can be slightly affected by interference.

Thus it is concluded that single BFWA CS and TS should be uncritical for the DA2GC forward link (ground-to-air), but a larger deployment of BFWA CS and TS in an area may create noticeable performance degradation due to the aggregation of interference signals at the receiving DA2GC AS.

- Interference between BFWA CS and BDA2GC GS

Compatibility studies between BFWA CS (Central Station) and BDA2GC GS (Ground Stations according to ETSI TR 103 054 have been carried out. The separation distances for all possible cases have been calculated. However, there is no need to consider the suitability of the separation distances more in detail because the compatibility studies between BFWA and DA2GC AS (ETSI TR 103 054) have shown that co-channel sharing is not feasible.

5.1.4 Compatibility between DA2GC AS (ETSI TR 101 599) and BFWA

5.1.4.1 Methodology

For the deterministic case the same methodology as described in section 5.1.3.1 was used. The aircraft antenna beam was assumed to be steered so that the main lobe tracks the ground station as the aircraft traverses its flight path

5.1.4.2 Results

1. Deterministic approach DA2GC AS on BFWA

Figure 44 and Figure 45 show the results in case of the beamforming DA2GC system (17 dBi AS antenna, 23 dBi GS antenna). It can be observed that in case the elevation angle of the aircraft in relation to its ground station is below seven degree, no interference is observed at the BFWA CS receiver. The green dotted lines in the graphs show the great-circle-distance and the solid green line the distance on the ground (values on the right hand vertical coordinate). It can be seen that the lower the elevation angles of the aircraft, the higher the interference level at the BFWA receiver. This can be explained by the higher transmit power required on the aircraft station to get the link with the ground station and the corresponding ATPC range at higher elevations. Table 20 shows an example calculation for BFWA that is in 10 km distance (ground distance) to an aircraft (aircraft altitude 10 km). The corresponding distance between aircraft and the DA2GC GS is about 27.5 km

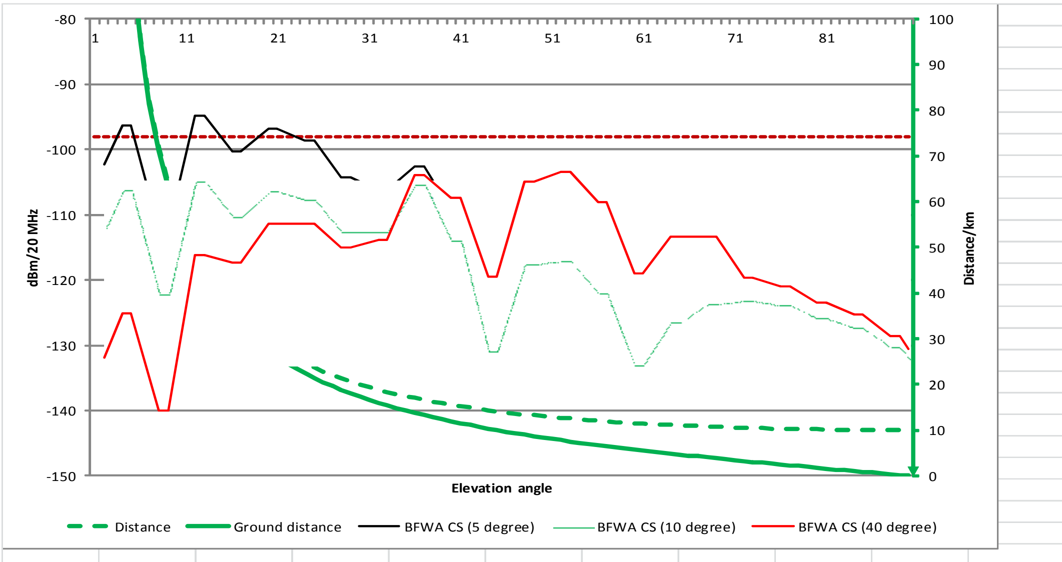


Figure 44: Interference level at BFWA CS

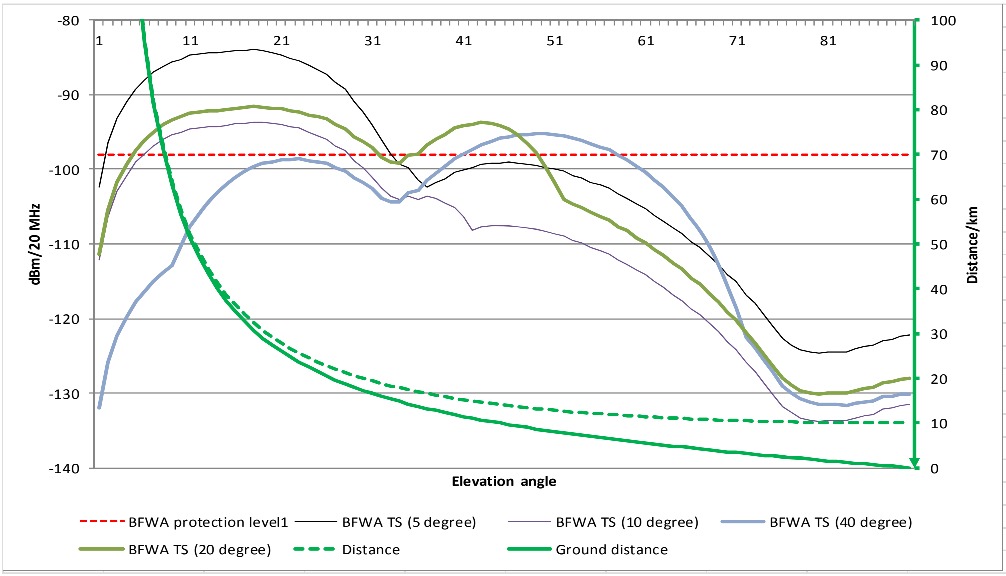


Figure 45: Interference level at BFWA TS

Table 20: Interfering Link budget

Link budget at 10 km height	value
Required Rx level at GS receiver (dBm)	-87
Elevation Angle (degree)	20
Antenna gain AS (dBi)	17
FSL (dB)	136.9
Antenna gain GS (dBi)	15
Required Tx level at AS (dBm)	18.3
Resulting e.i.r.p. (dBm)	35.3
BFWA TS at 10 km distance (on the ground)	
BFWA gain towards DA2GC AS (dBi)	4.5
DA2GC AS gain towards BFWA (dBi)	14.1
FSL (dB)	130.7
I max (dBm)	-98
I calculated (dBm)	-93.8
Limit exceedance (dB)	**4.2**

- Deterministic approach BFWA on DA2GC

According to the system description the required protection criterion for the AS receiver is I/N = -10 dB. The noise floor of the aircraft station receiver is at -97 dBm which leads to a protection level of -107 dBm for the AS receiver. Figure 46 shows the required separation distances in case a BFWA CS or TS is in the same azimuth as the DA2GC AS. For the sidelobe case a 0 dBi AS antenna gain was used in the calculation. It can be noted that in case the aircraft flies at an altitude of 10 km the AS receiver will be interfered nearly constantly by BFWA in a mainlobe configuration. In case the BFWA CS is pointing to the sidelobe of the AS antenna interference can be observed at aircraft altitudes up to 3 km; in case of an interfering TS interference can be observed up to 10 km aircraft height.

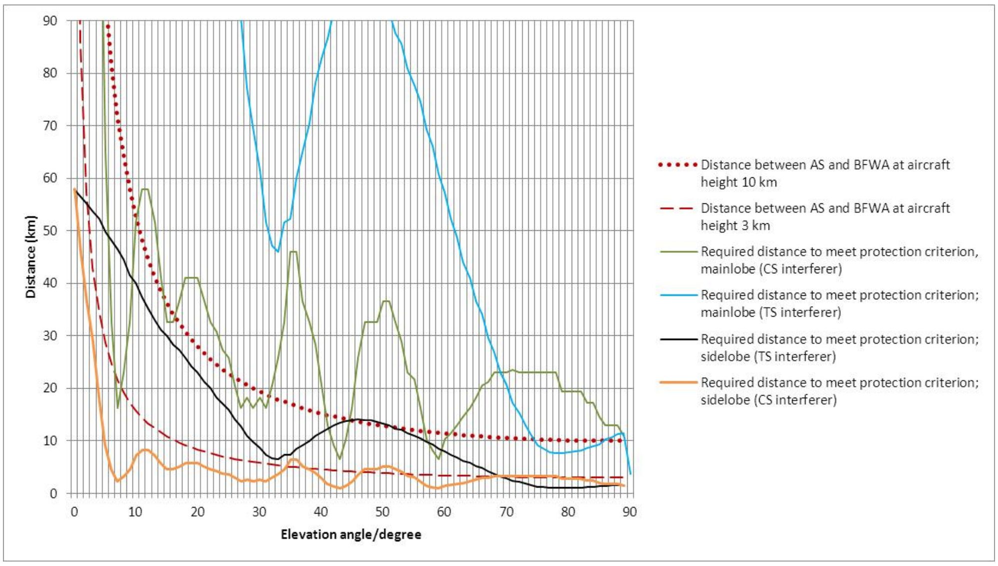


Figure 46: Required separation distances as a function of the elevation angle

- Statistical approach BFWA on DA2GC AS

For this calculation a density of 0.0056 BFWA CS stations/ km2 and 0.112 TS stations/ km2 was assumed which is in accordance with the actual deployment data of BFWA systems in Germany. The simulation radius was set to 100 km, leading to a number of 176 CS on the simulated area. In the simulation ¼ of the TS are set to be active uniform distributed over the frequency range 5765-5865 MHz. The emission mask of BFWA systems at 5.8 GHz is given in ETSI EN 302 502 and was used in the simulation A SEAMCAT screenshot of the emission mask is given in Figure 47. The mean e.i.r.p. of the BFWA system was set to 30 dBm. Table 21 and Table 22 shows the main characteristics used in the simulation.

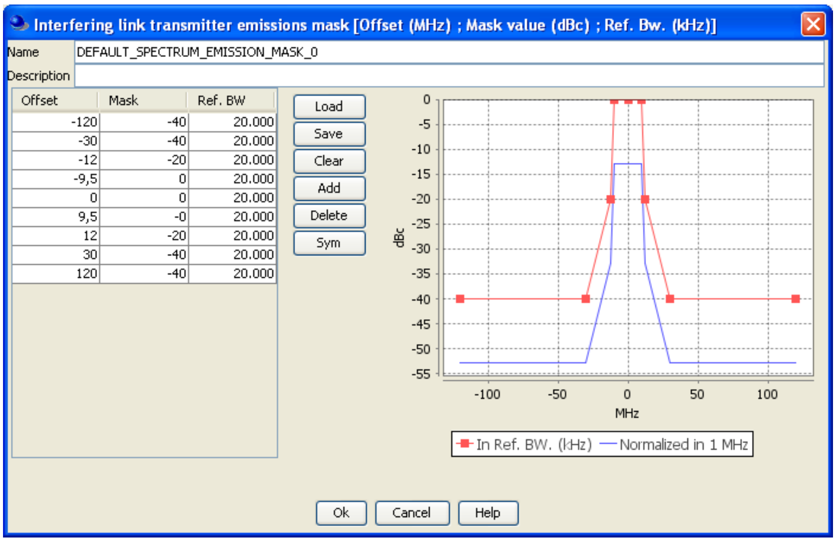


Figure 47: BFWA emission mask

Table 21: Main BFWA characteristics used in the simulation

Interfering link transmitter	BFWA CS	BFWA TS
TX power	13 dBm (+/- 6 dB)	13 dBm +- 6 dB
Antenna gain (max.)	17 dBi	17 dBi
Antenna pattern	Figure 48 and Figure 49	Figure 50 and Figure 51
Antenna height	30 m	10 m
Emission mask	Figure 47	Figure 47
Operating frequency	5765 – 5865 MHz (uniform distributed)	5765 – 5865 MHz (uniform distributed)
Transmitter to receiver path	5 km coverage radius, ITU-R P. 526	5 km coverage radius, ITU-R P. 526

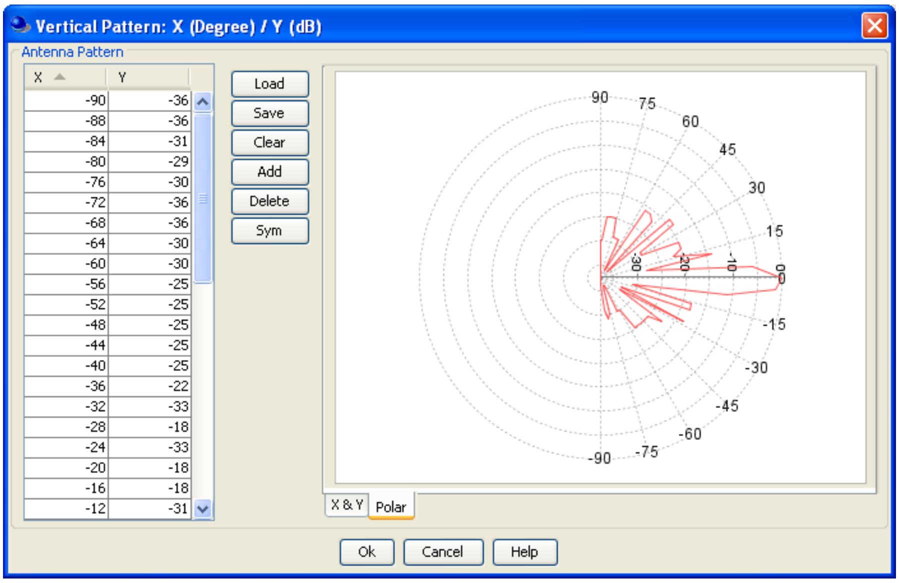


Figure 48: Typical P-MP Central station antenna pattern

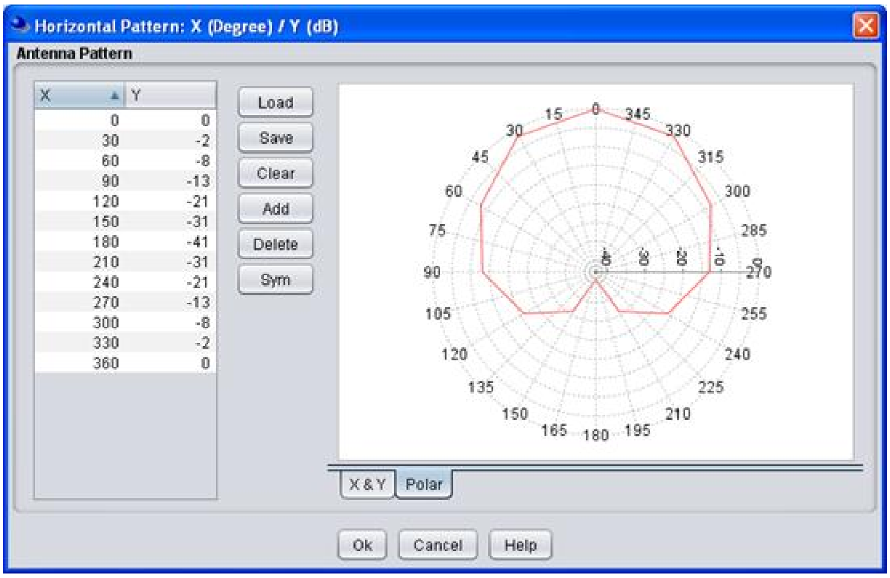


Figure 49: Typical P-MP Central station horizontal antenna pattern

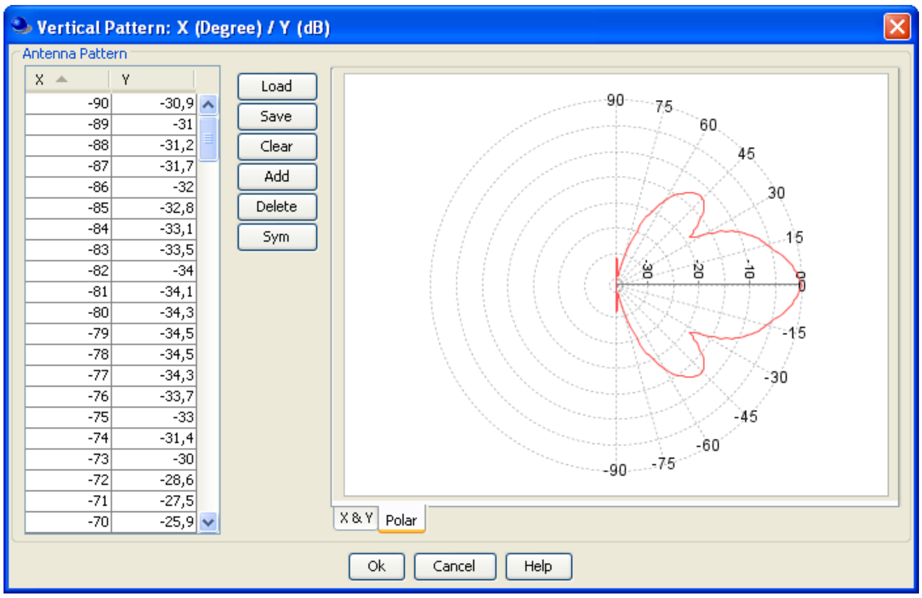


Figure 50: Typical BFWA Terminal Station Elevation pattern (20 degree beam width)

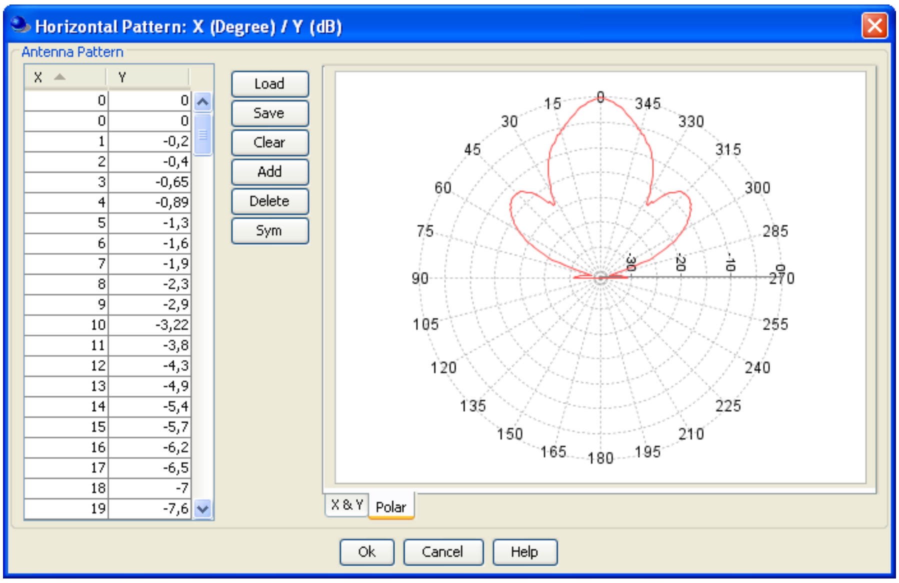


Figure 51: BFWA Terminal station horizontal pattern

Table 22: Main DA2GC characteristics used in the simulation

Victim Link Receiver	DA2GC AS
dRSS (desired received signal strength)	-84 dBm
Antenna peak gain	17 dBi
Antenna pattern	Figure 9 and Figure 10
Antenna height	3000 – 10000 m (uniform distributed)
Antenna pointing	In azimuth and elevation to the Tx
Reception bandwidth	20 MHz
Frequency	Constant at 5865 MHz
Noise floor	-97 dBm
Sensitivity	-87 dBm
Interference criterion I/N	-10 dB
Transmitter to receiver path	100 km coverage radius, Free space
Density of interferers	0.112 TS/km^2 / 0.0056 CS/km^2

Figure 52 and Figure 53 show the C.D.F. of the unwanted level produced by the BFWA TS and the BFWA CS on the DA2GC AS. It can be noted that an interference probability of 96 % for an interfering BFWA TS and 38% for the BFWA CS is calculated.

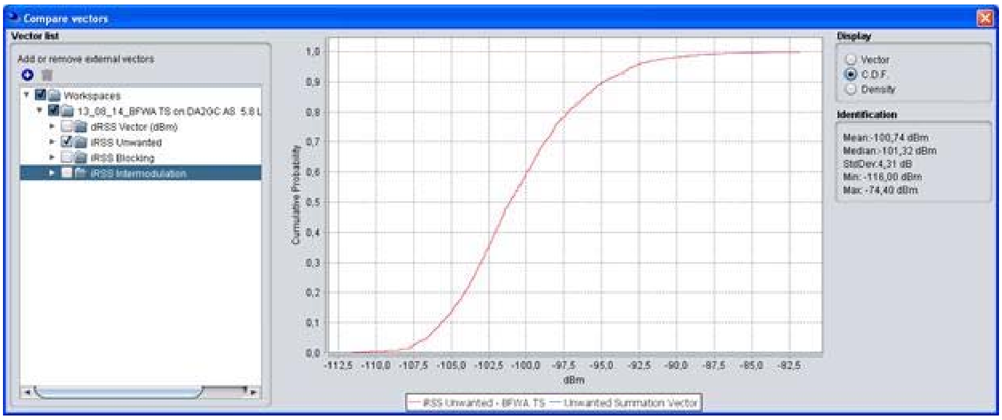


Figure 52: iRSS Unwanted BFWA TS

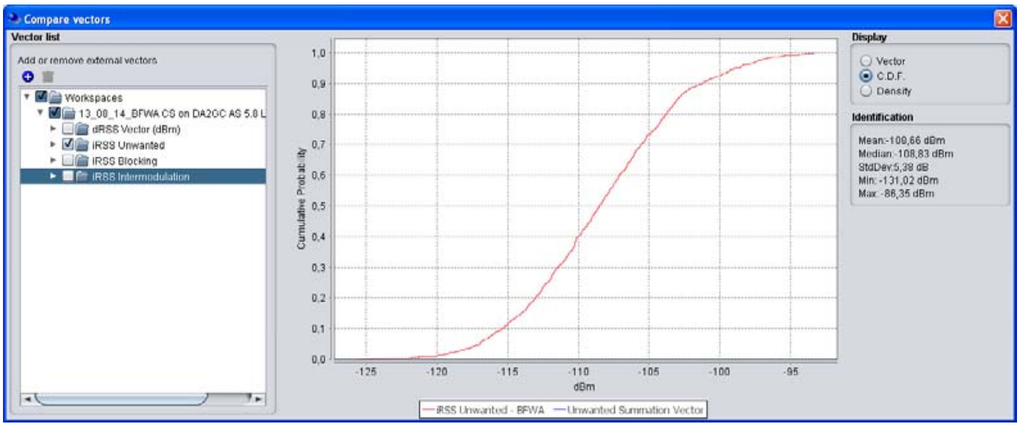


Figure 53: iRSS unwanted BFWA CS

5.1.5 Compatibility between DA2GC GS (ETSI TR 101 599) and BFWA

The analysis of interference from DA2GC ground stations into BFWA receivers is based on minimum separation distance calculations corresponding to static interference alignments. This is very much a worst-case assumption since, in practice, the transmitted beams from the DA2GC Ground Station will be dynamically tracking the aircraft with which it is communicating, thereby introducing a further statistical element to the interference results.

Initially, it is assumed that the BFWA receiver is directly pointing at the DA2GC ground station terminal. According to the system description the DA2GC ground station maximum transmits power is 22 dBm.

Due to the steep characteristic of the antenna pattern below 10 degree and the fact that a possible victim BFWA can be located at a higher location than the GS an antenna gain of 0 dBi in direction to the victim BFWA was assumed in the calculations.

Table 23and Table 24 show the loss values translated into minimum required separation distances by using the same methodology as described in Section 5.1.3.1 of this Report

Table 23: Required Separation Distances (DA2GC victim)

BFWA to DA2GC GS	Required Attenuation (dB)	Required separation – urban (km)	Required separation – rural (km)
BFWA ML - DA2GC	143	1.6	8.4
BFWA 1st SL (0 dBi) - DA2GC	126	0.7	2.6
BFWA 2nd SL (-10 dBi) - DA2GC	116	0.4	1.3

Table 24: Required Separation Distances (BFWA victim)

DA2GC GS to BFWA	Required Attenuation (dB)	Required separation – urban (km)	Required separation – rural (km)
DA2GC - BFWA ML	137	1.2	5.5
DA2GC - BFWA 1st SL (0 dBi)	120	0.5	1.7
DA2GC - BFWA 2nd SL (-10 dBi)	110	0.3	0.8

The separation figures in the table above relate to the DA2GC ground terminal supporting a single aircraft either towards the horizon when the power into the antenna is at its maximum.

5.1.6 Conclusions on compatibility between DA2GC (ETSI TR 101 599) and BFWA

5.1.6.1 Compatibility between DA2GC AS and BFWA

1. DA2GC aircraft stations into BFWA

It can be assumed that the compatibility with BFWA systems cannot be ensured for all geometries without additional mitigation techniques. Such cases may be handled through the implementation of a Detect & Avoid mechanism as outlined in Annex 2. However due to the moving of the aircraft and the low detection threshold of -106 dBm at the AS receiver proposed by the proponent (see Annex 2) it may be triggered unintentionally by ITS stations or other radio transmitters using the same frequency. However it is assumed that received signals from ITS stations will be at lower power levels than signals from BFWA and by optimizing the trigger power level, false triggers from ITS could be minimized.

2. BFWA interference into DA2GC

The above results show that interferences can be observed on the DA2GC AS receiver according to ETSI TR 101 599 [30] at aircraft altitudes up to 10 km produced by one BFWA system. According to a SEAMCAT analysis using the actual deployment data of BFWA in one country an interference probability of 96% for interfering TS and 38% for interfering CS is calculated for those areas where BFWA is deployed at the terminal densities assumed, noting that terminal activity is taken to be 100%. For lower levels of activity (e.g. 25%) the probability of interference from Terminal Stations would be 30%. Mitigation measures are required in order to minimise interference in those areas where BFWA is deployed.

5.1.6.2 Compatibility between DA2GC GS and BFWA

Based on the worst case static analysis of DA2GC Ground Stations interfering into BFWA receivers presented in this section, a separation of 1.6 km in urban environment and 8.4 km in rural environment is required when a BFWA system points to a DA2GC ground station. In case of a sidelobe configuration the distances amount up to 0.7 km in urban environment and up to 2.6 km in rural environment.

5.1.7 Compatibility between DA2GC AS (ETSI TR 103 108) and BFWA

5.1.7.1 Methodology

The AS elevation e.i.r.p. mask (below fuselage) defined in 4.3.1 has been used. The aircraft source is assumed to fly at a constant altitude (10 kms or 3 kms) from a ground range from the BFWA victim station of between 0 kms and the maximum shown in the associated graph. The worst case scenario was always assumed wherein the BFWA antenna was always pointing at the aircraft.

5.1.7.2 Results

The results of the analysis are presented below:

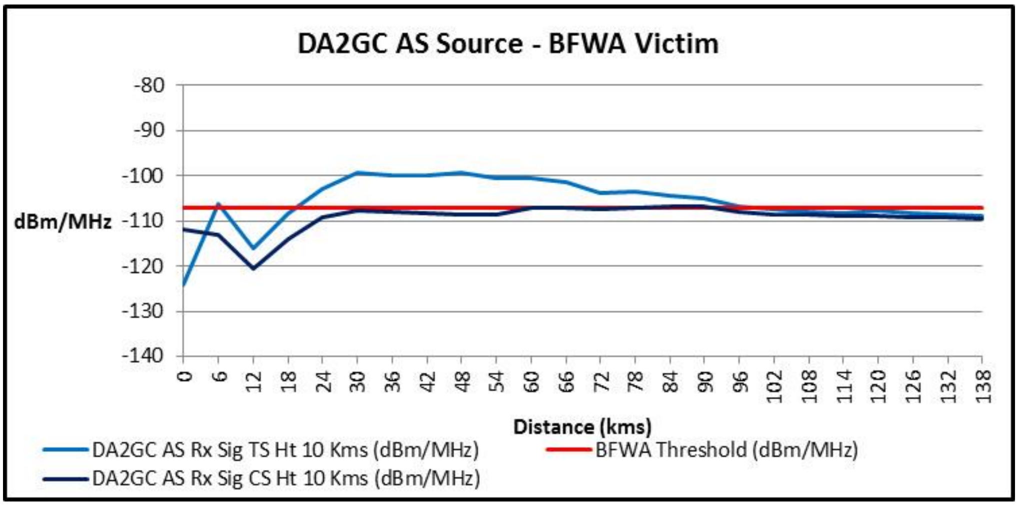


Figure 54: DA2GC AS Source (10 km) / BFWA Victim

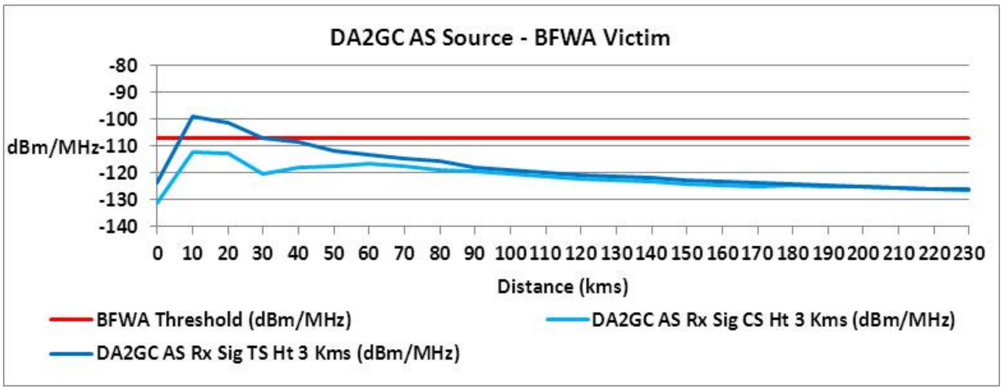


Figure 55: DA2GC AS Source (3 km) / BFWA Victim

Alternatively an antenna diagram according to Recommendation ITU-R F.1336 [20] (‘Reference radiation patterns of omnidirectional, sectoral and other antennas in point-to-multipoint systems for use in sharing studies in the frequency range from 1 GHz to about 70 GHz’) as shown in Figure 56 has been used in the calculations. Note that at 3 km AS altitude a transmitter attenuation of 8 dB according to the system description was used. The results for this analysis are presented in Figure 57.

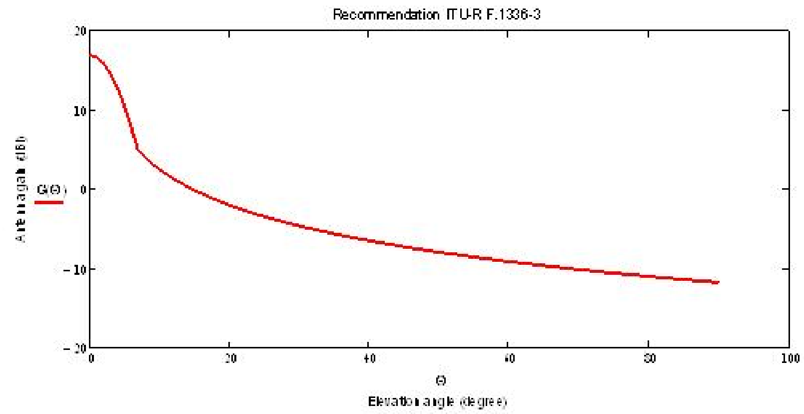


Figure 56: Average side-lobe pattern according to Recommendation ITU-R F. 1336-3 (G0=17 dBi, k=0)

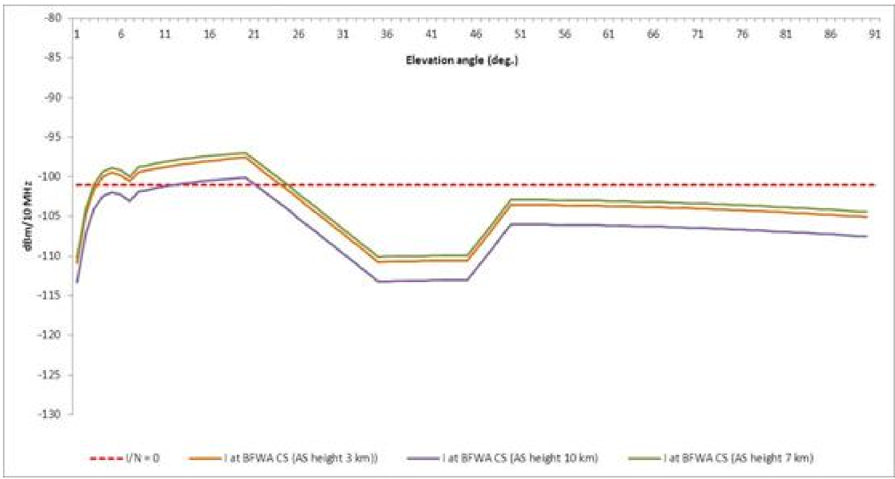


Figure 57: Interference signal power at BFWA CS

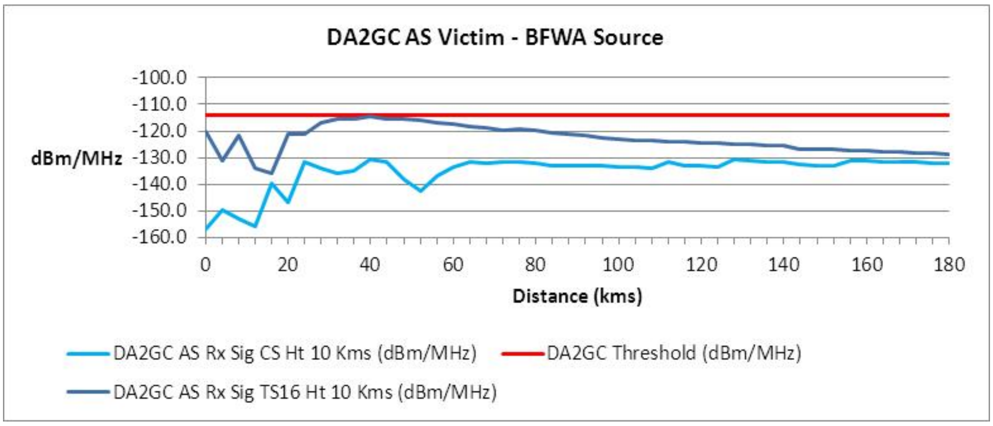


Figure 58: DA2GC AS Victim (10 km) / BFWA Source

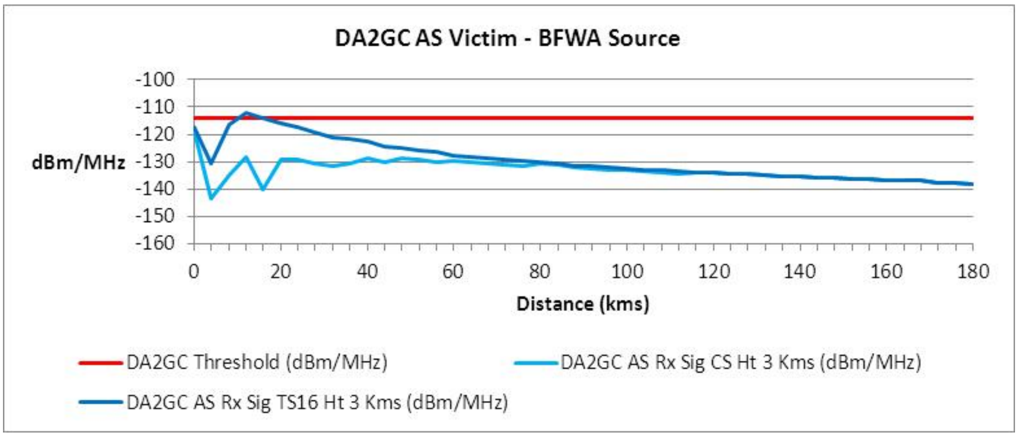


Figure 59: DA2GC AS Victim (3 km) / BFWA Source

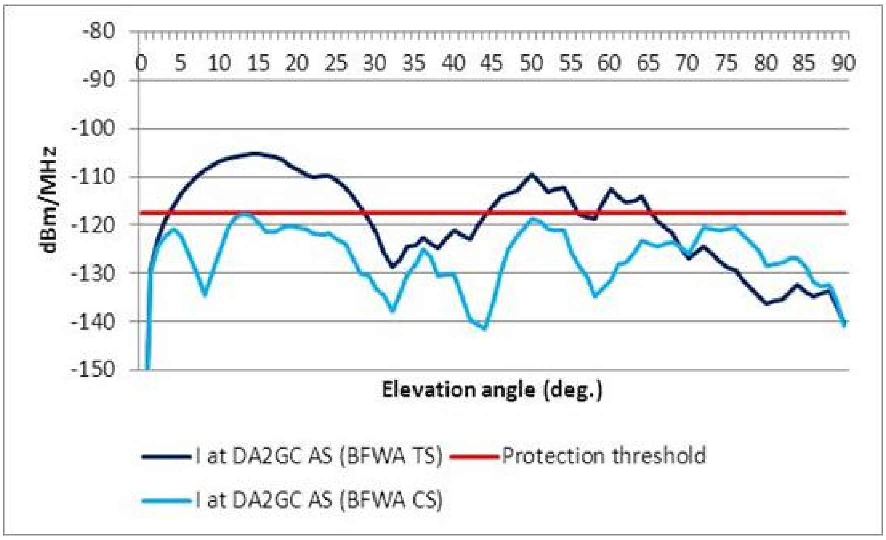


Figure 60: DA2GC AS Victim (3 km) / BFWA Source

- Statistical approach BFWA on DA2GC AS

For the SEAMCAT simulation the same scenario as described in section 5.1.4 was assumed. The technical parameters of the BFWA system are shown in Table 21. The DA2GC receiver parameters used in the simulation are shown in Table 25.

Table 25: Main DA2GC characteristics used in the simulation

Victim Link Receiver	DA2GC AS
dRSS (desired received signal strength)	-100 dBm
Antenna peak gain	7 dBi
Antenna pattern	Figure 61 and Figure 62
Antenna height	3000 – 10000 m (uniform distributed)
Reception bandwidth	10 MHz
Frequency	5865 MHz
Noise floor	-101.5 dBm
Sensitivity	-103 dBm
Interference criterion I/N	-6 dB
Transmitter to receiver path	100 km coverage radius, Free space
Density of interferers	0.112 TS/km^2 / 0.0056 CS/km^2

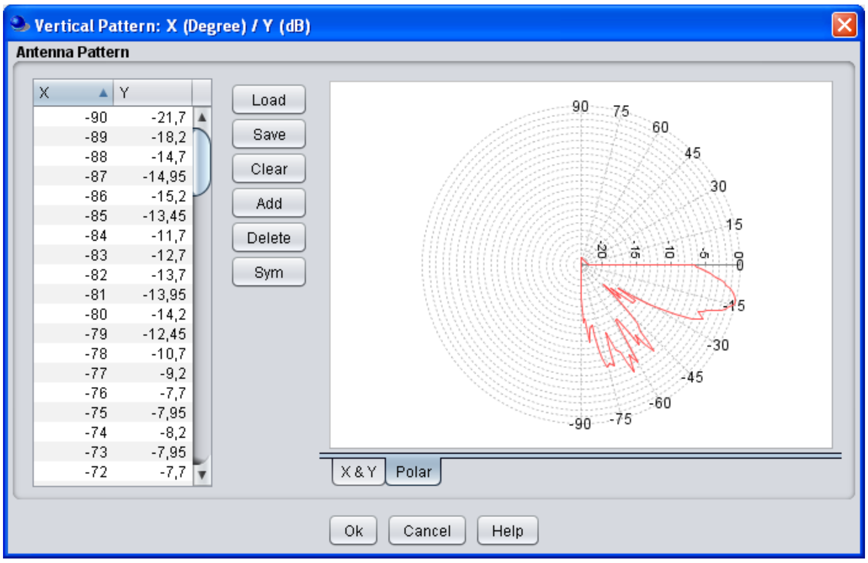


Figure 61: DA2GC AS antenna elevation pattern (TR 103 108)

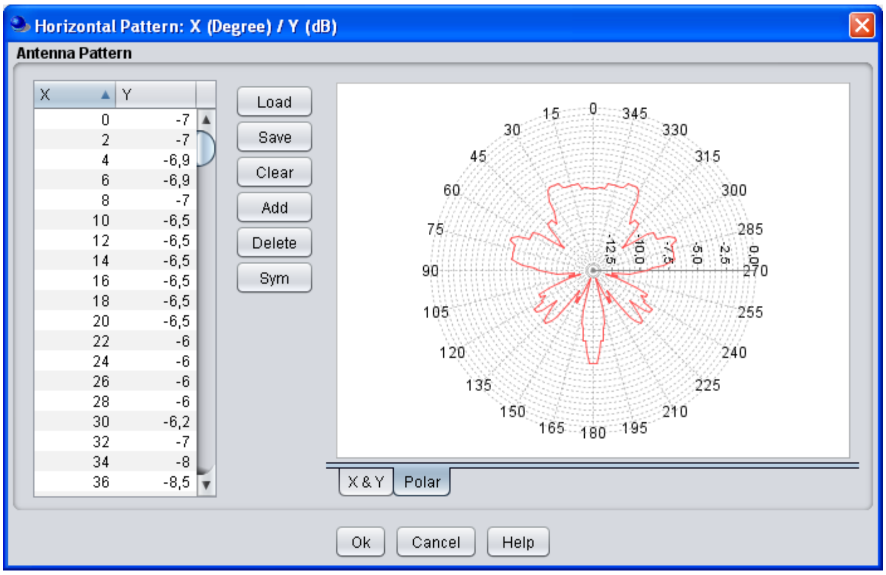


Figure 62: DA2GC AS horizontal pattern (TR 103 108)

The following Figure 63 and Figure 64 show the C.D.F. of the unwanted level produced by the BFWA TS and the BFWA CS on the DA2GC AS. It can be noted that an interference probability of 64 % for interfering BFWA TS and 1% for interfering BFWA CS is calculated.

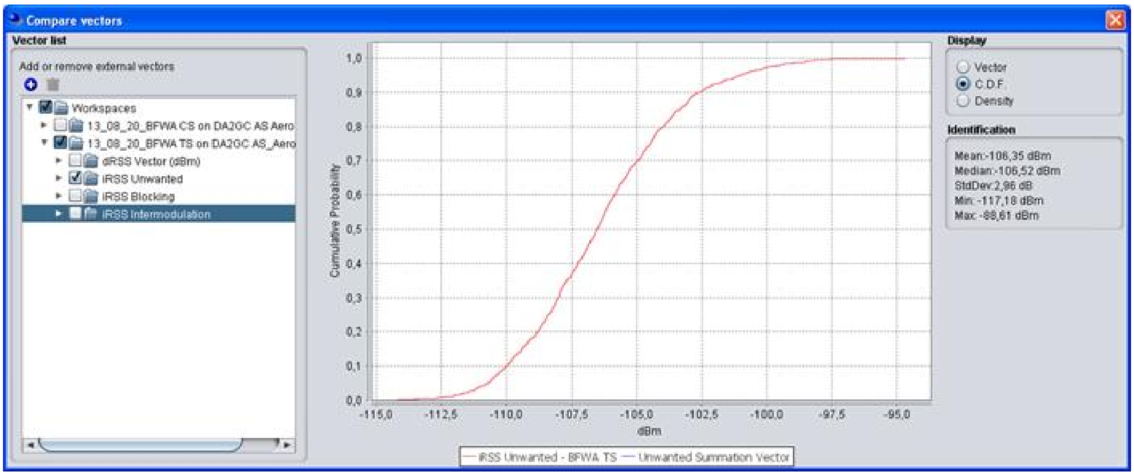


Figure 63: iRSS Unwanted BFWA TS

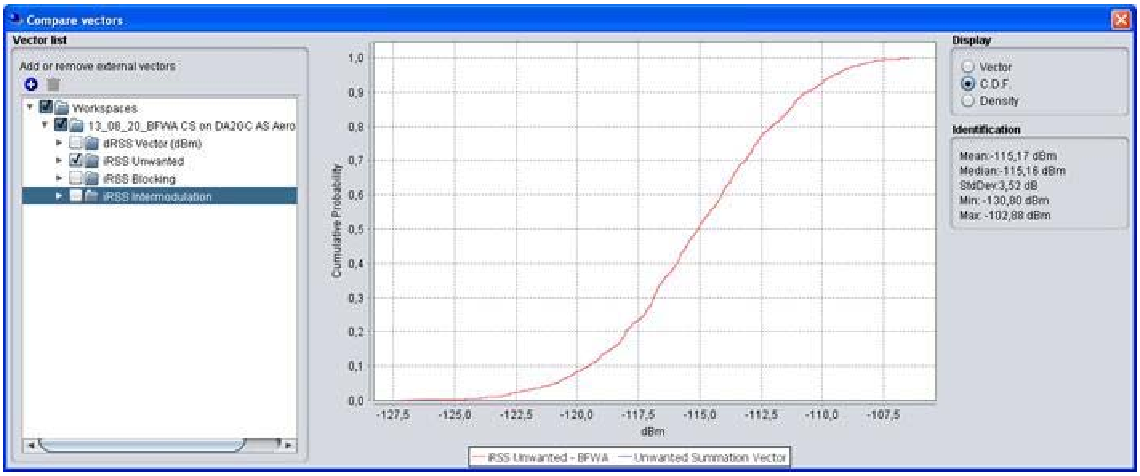


Figure 64: iRSS Unwanted BFWA CS

5.1.8 Compatibility between DA2GC GS (ETSI TR 103 108) and BFWA

5.1.8.1 Methodology

The GS elevation e.i.r.p. mask defined in Section 4.3.1 has been used. The GS source is assumed to be at given ranges from the BFWA victim station of between 0 km and the maximum shown in the associated graph. The worst case scenario was always assumed wherein the BFWA antenna was always pointing at the GS.

All ground stations are planned to be sited in an urban environment to benefit from the existing points of presence offered by the telecommunications infrastructure. However, in addition, a rural scenario has also been analysed for comparison purposes. The following Figures show the minimum required separation distances by using the same methodology as described in Section 5.1.3.1 of this Report.

5.1.8.2 Results

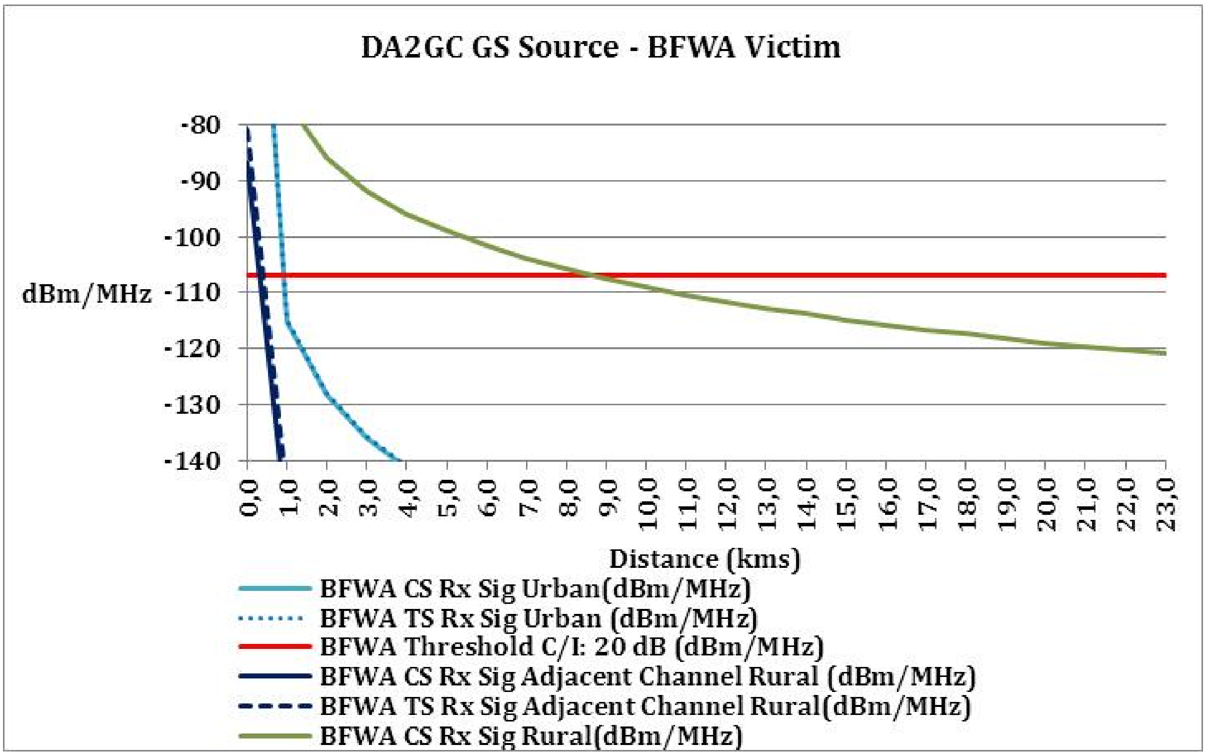


Figure 65: DA2GC GS Source / BFWA Victim

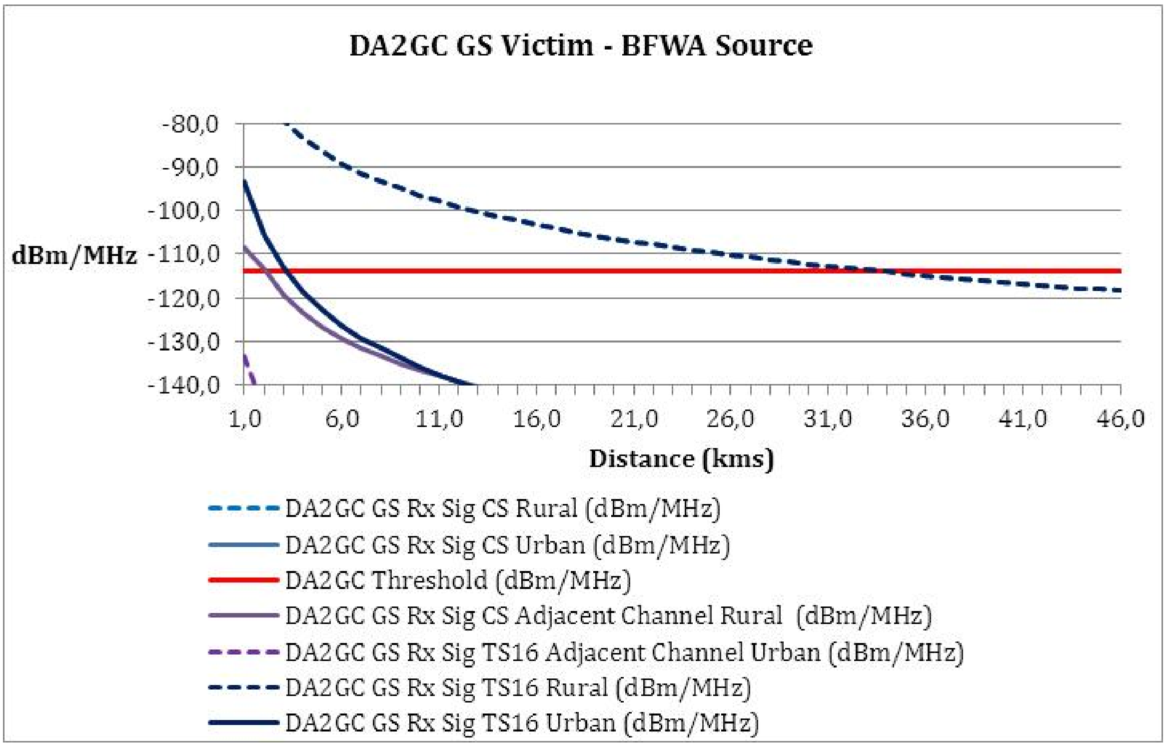


Figure 66: DA2GC GS Victim / BFWA Source

5.1.8.3 Conclusions for the Aircraft Station

It was shown that with the proposed AS elevation mask according to ETSI TR 103 108 [31] the protection criterion of BFWA cannot be fulfilled for all geometries. The coexistence of a Broadband DA2GC system according to ETSI TR 103 108 with co-channel BFWA may only be ensured by applying the additional mitigation measure. of lowering the AS e.i.r.p. by an additional 4 dB for an aircraft station height up to 7 kms when flying over a region with co-channel BFWA use.

It was shown that interferences can be observed on the DA2GC AS receiver according to ETSI TR 103 108 [31] at aircraft altitudes up to 10 km produced by one BFWA TS.

According to a SEAMCAT analysis using the actual deployment data of BFWA in one country an interference probability of 64% for interfering TS and 1% for interfering CS is calculated for those areas where BFWA is deployed at the terminal densities assumed, noting that terminal activity is taken to be 100%. For lower levels of actvity (e.g. 25%) the probability of interference from Terminal Stations would be 9.1%. It is noted that a linear distribution was assumed for aircraft height. Mitigation measures are required in order to minimise interference in those areas where BFWA is deployed.

5.1.8.4 Conclusions for the Ground station

1. DA2GC Source:
For the urban scenario, co-channel compatibility is achieved with a separation distance of 1 km while, for the rural scenario, co-channel compatibility is achieved with a separation distance of 9 km. Given the flexibility in siting DA2GC ground stations it is concluded that the separation distances can be assured through site planning. Adjacent channel compatibility is achieved for a separation distance less than 100 m.

2. DA2GC Victim:
For the urban scenario, co-channel compatibility is achieved with a separation distance of 3 km while, for the rural scenario, co-channel compatibility is achieved with a separation distance of 30 km. Given that the ground stations will normally be sited in an urban environment, these separation distances are operationally acceptable. Adjacent channel compatibility is achieved for a separation distance less than 1 km.

5.2 COMPATIBILITY BETWEEN DA2GC AND FSS

5.2.1 Technical characteristics of GSO satellite systems

Table 26: Derivation of acceptable aggregate e.i.r.p. from interferers in the satellite beam (see ECC Report 101)

Satellite	Satellite orbital position	Receiver Gain, G_{Sat}	Satellite Receiving system	Aggregate e.i.r.p. dB(W Hz^{-1})	Satellite Name	Administration	Beam
A	5° West	34	773	-54.1	TELECOM-2B	Fr	MET
B	14° West	26.5	1200	-44.7	EXPRESS-2	RUS	ZER
C	31.5° West	32.8	700	-53.3	INTELSAT8	USA	9Z3
D	3° East	34	773	-54.1	TELECOM-2C	Fr	MET
E	18° West	32.8	700	-53.3	INTELSAT8	USA	9Z3
F	53° East	26.5	1200	-44.7	EXPRESS-5	RUS	ZER
G	59.5°	34	1200	-52.2	No longer		

Satellite	Satellite orbital position	Receiver Gain, G_{Sat}	Satellite Receiving system	Aggregate e.i.r.p. dB(W Hz^{-1})	Satellite Name	Administration	Beam
	East				existing		
H	66° East	34.7	700	-55.2	INTELSAT9	USA	9Z1
I	359° East	32.8	700	-53.3	INTELSAT8	USA	9Z3

5.2.2 Technical characteristics of FSS Earth stations

Table 27: Assumed FSS parameters (see ECC Report 101 [44])

Earth Station	ST1	ST2	ST3	ST4	ST5
Elevation (deg)	10	10	33	33	8
Antenna Diameter (m)	4.6	32.5	4.6	32.5	11
Power (dBW/MHz)	21.3	2.0	21.3	2.0	5.4
Max antenna gain (dBi)	47.8	63	47.8	63	54
Height (m)	4.3	18.25	4.3	18.25	10
Antenna pattern	Recommendation ITU-R S.465 [26]				

5.2.3 Compatibility between DA2GC AS (TR 101 599) and FSS

In practice since we are dealing with a TDD DA2GC system the aggregate interference into the satellite receiver will be a mix of interference from aircraft transmitters and DA2GC ground terminal transmitters. These have been treated separately in the following sub-sections. It can be noted however that these two contributions should not be added to obtain the aggregate interference at the satellite since TDD does not allow for simultaneous transmission by both ends of the same link.

5.2.3.1 Methodology

A similar situation has been analysed previously in ECC Report 068 [32] with respect to the potential for Fixed Wireless Access systems to interfere with geostationary satellites receiving in the band 5725-5875 MHz. The situation here is similar, but with aircraft transmitters substituting for BFWA transmitters.

The analysis in ECC Report 068 identified Satellite H at 66°E as the most sensitive to interference due to the high G/T associated with its European coverage. See Figure 67 below for the geographic nature of Satellite H's coverage.

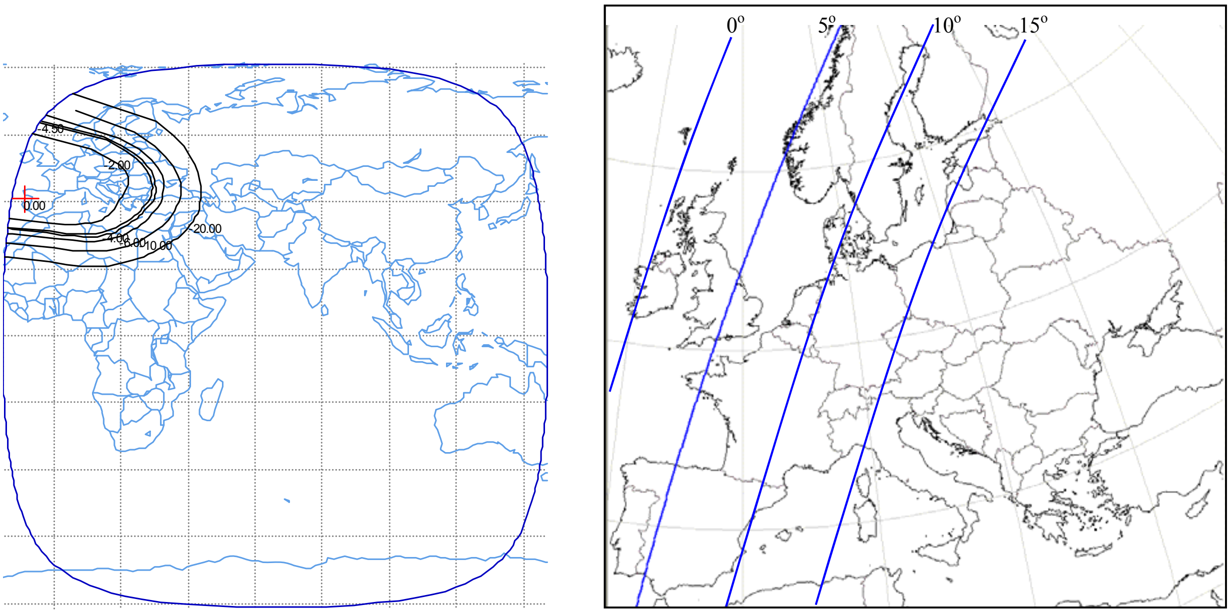


Figure 67: Beam Contours for FSS Satellite H at 66° East (from ECC Report 68)

Satellite H is therefore used here to ensure that a worst-case scenario is considered and the parameter values for assessing the potential for interference from DA2GC are contained in Table 28 below

Table 28: DA2GC and FSS parameter values

Parameter	Value	Unit	Comment
Frequency	5865	MHz	Centre of 20 MHz channel of interest.
Slant path loss (free space)	198.9 – 200.2	dB	90° to 0° elevation at the ground. *(Note 1)*
Atmospheric loss	0.5	dB	As used in ECC Report 68
Satellite H receive gain (max)	34.7	dBi	From ECC Report 68
Satellite H receive system noise temperature (T)	700	K	From ECC Report 68
Satellite ΔT/T criterion	6	%	Co-Primary Services
Power to aircraft antenna (max)	24.7	dBm	
Aircraft antenna gain (max)	17.8	dBi	
Aircraft emission density	-60.5	dBW/Hz	Power in 20 MHz channel
Power to ground terminal antenna	24.7	dBm	At 5° elevation
Ground terminal antenna gain	20.7	dBi	At 5° elevation
Ground terminal emission density	-57.6	dBW/Hz	Power in 20 MHz channel

Note 1 – The higher path loss is applicable to limb of earth geometry being considered below

The power density received by a satellite due to one aircraft =

Aircraft emission - Losses + Satellite Gain

= -60.5 dBW/Hz - 200.2 dB - 0.5 dB + 34.7 dBi = -226.5 dBW/Hz

This is equivalent to an increase in satellite receive system noise temperature which =
Power density received by satellite - Boltzmann's constant
= -226.5 dBW/Hz - -228.6 dBW/K/Hz = 2.1 dBK = 1.6 K

This would allow for 26 aircraft for the 6% ΔT/T criterion (42 K increase allowable).

At this point it should be noted that the geometry giving rise to the increase in satellite noise temperature identified above will in itself be a rare occurrence as it depends on the exact alignment of aircraft, DAG2C base station and satellite as the aircraft comes over the horizon (with respect to the DAG2C base station) and starts operating at 5° elevation. The likelihood of more than one aircraft achieving the same geometrical alignment at the same time is even smaller.

In the more general case the interference entry from the aircraft will emanate from the aircraft sidelobes or be almost entirely obscured by the fuselage. Furthermore, because of the power control employed on the DAG2C link the impact on the satellite receiver is further reduced. For example, if we assume that the aircraft antenna gain is some 13 dB down[2] on the main lobe and the power into the antenna is 7 dB down[3] on its maximum then the following figures would apply.

The power density received by a satellite due to one aircraft =
Aircraft emission - Losses + Satellite Gain
= -80.5 dBW/Hz - 200.2 dB - 0.5 dB + 34.7 dBi = -246.5 dBW/Hz

This is equivalent to an increase in satellite receive system noise temperature which =
Power density received by satellite - Boltzmann's constant
= -246.5 dBW/Hz - -228.6 dBW/K/Hz = -17.9 dBK = 0.016 K

This would allow for 2625 aircraft for the 6% ΔT/T criterion (42 K increase allowable). Note that in this case there is no special alignment involved. However, it is still the case that this situation would only apply where the aircraft are operating at the limb of the earth (with respect to the satellite) so that emissions from the underside of the aircraft are barely obstructed by the fuselage. It can be expected that aircraft away from the limb of the earth and operating more towards the sub-satellite point will have their emissions towards the satellite almost totally obscured. There is a ground plane above the antenna so the antenna gain in any direction above the aircraft horizon (0° / 180° elevation) and towards the satellite will be at least 40 – 50 dB below the aircraft horizon (0° / 180° elevation) gain. These interference entries can therefore be safely ignored.

5.2.3.2 Conclusions

In the general case, and noting that it is only aircraft operating at the limb of the earth that generate interference, it can be considered that the tolerable numbers of aircraft indicated by the analysis above are sufficient to accommodate the DA2GC system.

5.2.4 Compatibility between DA2GC GS (TR 101 599) and FSS

5.2.4.1 Initial analysis

Due to the reciprocal nature of the TDD link between aircraft and associated ground terminals, and similar antenna gains at both ends of the link, a comparable but not simultaneous level of potential interference from DA2GC ground terminals into the FSS satellite receiver can be expected. The worst case, which will occur for very short periods of time, relies on a ground terminal, aircraft, satellite alignment that gives the minimum 5 degrees of elevation at the DA2GC ground terminal

For this alignment the power density received by a satellite due to one DA2GC ground terminal =
Ground terminal emission - Losses + Satellite Gain
= -57.6 dBW/Hz - 200.2 dB - 0.5 dB + 34.7 dBi = -223.6 dBW/Hz

[2] This is the level of the first sidelobe.
[3] Power control is exercised over a 14.7 dB range.

This is equivalent to an increase in satellite receive system noise temperature which =
Power density received by satellite - Boltzmann's constant
= -223.6 dBW/Hz - -228.6 dBW/K/Hz = 5 dBK = 3.2 K

This would allow for 13 ground terminals for the 6% ΔT/T criterion (42 K increase allowable).

As already noted, and similar to the aircraft interference case, the geometry giving rise to the increase in satellite noise temperature identified above will in itself be a rare occurrence and the likelihood of more than one DA2GC ground terminal achieving the same geometrical alignment at the same time is even smaller.

In the more general case the interference entry from the DA2GC ground terminal will be at a much lower level because of the power control employed on the link. For example, if we assume that the power into the antenna is 7 dB down[4] on its maximum and the DA2GC ground terminal antenna gain is at 15 dBi (for all elevations between 16 and 90 degrees) then the following figures would apply.

The power density received by a satellite due to one DA2GC ground terminal =
Ground terminal emission - Losses + Satellite Gain
= -70.3 dBW/Hz - 200.2 dB - 0.5 dB + 34.7 dBi = -236.3 dBW/Hz

This is equivalent to an increase in satellite receive system noise temperature which =
Power density received by satellite - Boltzmann's constant
= -236.3 dBW/Hz - -228.6 dBW/K/Hz = -7.7 dBK = 0.17 K

This would allow for 247 DA2GC ground terminals for the 6% ΔT/T criterion (42 K increase allowable).

On the basis that the DA2GC cell radius is approximately 100 km, and taking account of the relevant water / land mass ratio, it is estimated that 150 hexagonal cells would fall within Satellite H's European coverage. The tolerable number of ground terminals indicated by the analysis above shows that the DA2GC system can be accommodated without causing undue interference.

5.2.4.2 Further Analysis

An FSS satellite receiver will be subject to an aggregation of interference from all visible DA2GC Ground Stations. Figure 68 gives an example layout of DA2GC Ground Stations across Europe. In the absence of real deployment data, and for the sake of simplicity, the assumed grid of Ground Stations is a regular pattern across Europe. As such, it has not been optimised for any particular route coverage. However, the precise placement of individual ground stations has little impact on the aggregate interference experienced at the geostationary orbit and this simplified distribution forms an acceptable basis for the statistics presented later in this document.

[4] Power control is exercised over a 14.7 dB range.

Figure 68: Example distribution of DA2GC Ground Stations (not optimised for coverage)

5.2.4.3 e.i.r.p. statistics for a single DA2GC Ground Station

Each DA2GC Ground Station has the same e.i.r.p. statistics if it is assumed that each one is simultaneously transmitting towards 12 aircraft using beam-forming techniques. If the 12 aircraft are randomly distributed across the Ground Station's coverage area then the statistics will be the same in all directions of azimuth. The statistic of interest with respect to a FSS victim satellite receiver is therefore the e.i.r.p. as a function of elevation. This is shown in Figure 69 below.

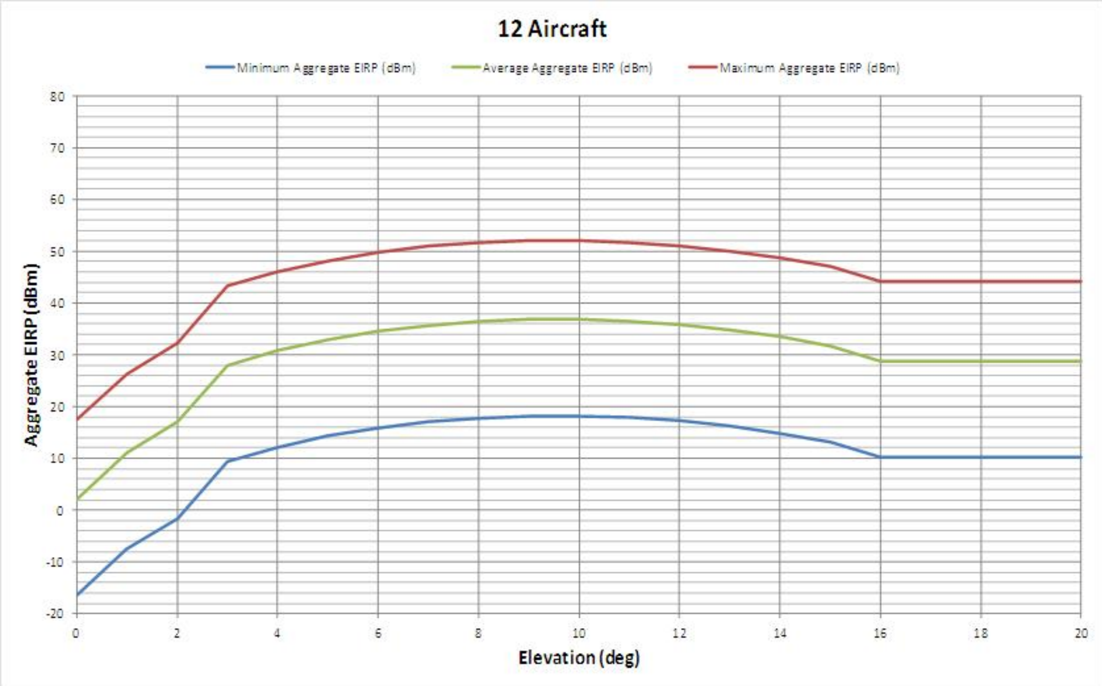


Figure 69: Min / Av / Max aggregate e.i.r.p. from a single DA2GC Ground Station supporting 12 aircraft simultaneously (Max. average at 10 degrees = 36.8 dBm / 20 MHz, ≥ 16 degrees = 28.8 dBm / 20 MHz)

Because an FSS victim satellite experiences an aggregation of interference from multiple DA2GC Ground Stations, and the variations in power levels emitted from each individual Ground Station in the direction of the satellite are not correlated in any way, it is the average e.i.r.p. per Ground Station that should be used.

Figure 69 simply shows the e.i.r.p. statistics in terms of minimum, average and maximum levels. It should be noted that the maximum levels occur with very small probability (e.g. 0.00001%). This can be seen from the full e.i.r.p. distributions shown in Figure 70, below. Each of the curves in Figure 70 represents a vertical slice through the curves of Figure 69 at the respective elevation angle.

Starting at the left hand side of Figure 69 above, i.e. at zero degrees elevation, the aggregate e.i.r.p. cumulative distribution at this elevation is represented by the solid purple line at the left of Figure 70, below.

Moving from left to right in Figure 69 above through elevations between zero degrees to the “peak” at 10 degrees, the aggregate e.i.r.p. cumulative distributions at the intervening elevations are represented by the dashed purple lines moving from left to right in Figure 3 below, culminating in the “peak” at 10 degrees represented by the solid red line.

Continuing to move from left to right in Figure 69 above (beyond the “peak” at 10 degrees), the aggregate e.i.r.p. cumulative distributions in Figure 70 fall back i.e. move from right to left as represented by the dotted red lines until they reach a constant distribution for elevation angles of 16 degrees up to 90 degrees as represented by the solid orange line.

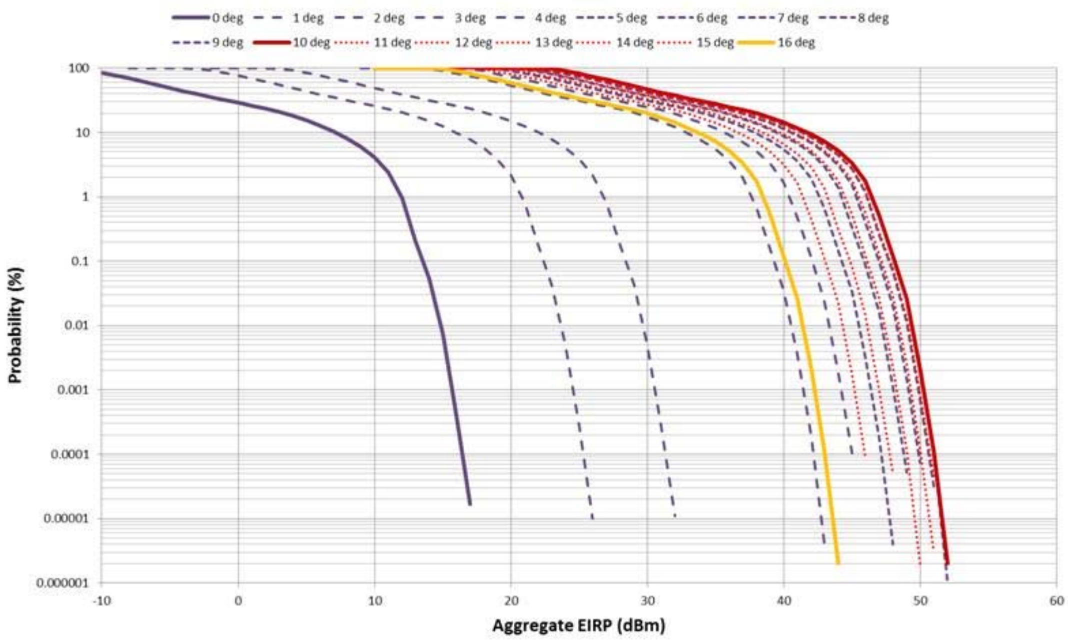


Figure 70: Cumulative distributions of aggregate e.i.r.p. from a singleDA2GC Ground Station supporting 12 aircraft simultaneously

5.2.4.4 DA2GC ground station elevation statistics

In order to assess the total interference from all DA2GC Ground Stations (as shown in Figure 68) into a victim FSS receiver it is necessary to know the elevation statistics from all the Ground Stations to a given orbital position. These statistics are shown in Figure 71.

It can be seen from these curves that the DA2GC Ground Stations subtend elevations in the range 20 to 45 degrees towards a FSS satellite above Europe (e.g. at 15 degrees East) and 5 to 30 degrees towards an easterly inter-continental satellite (e.g. at 60 degrees East).

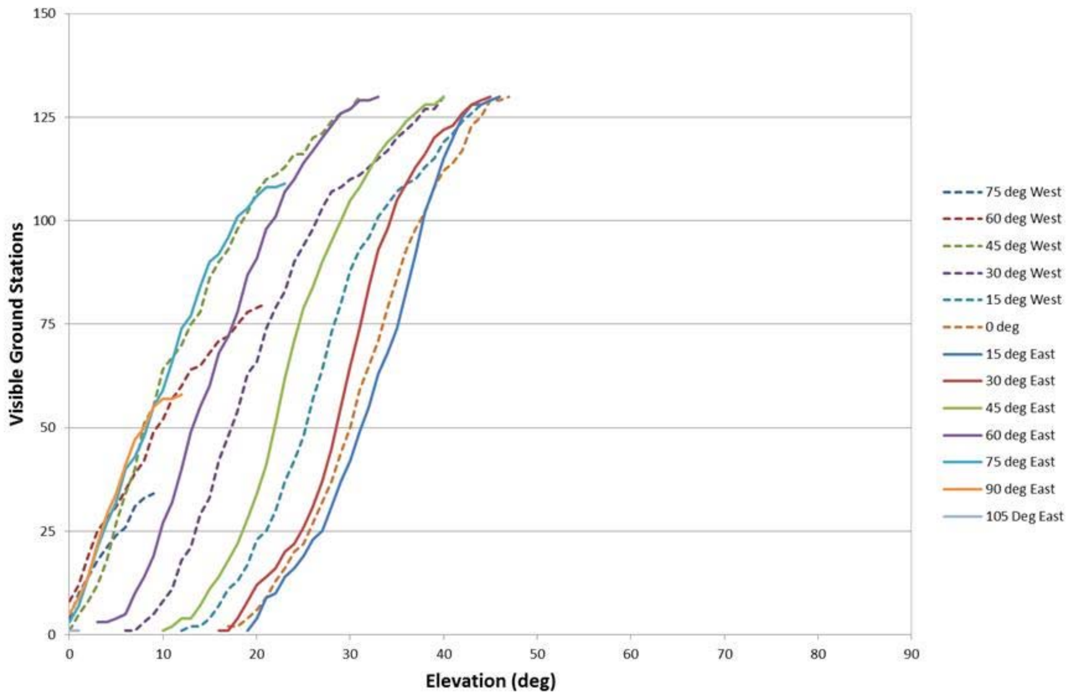


Figure 71: Cumulative distribution of DA2GC Ground Station elevations towards a range of orbital locations

5.2.4.5 Interference received by FSS satellite

The initial analysis indicated that Satellite H at 66 degrees East is the most susceptible to interference so in order to ensure that the worst-case has been considered the current assessment is also based on this satellite.

From the 60 degree East orbital location curve (closest to 66 degrees East of Satellite H) shown in Figure 71 it can be seen that 60 DA2GC Ground Stations subtend an elevation angle in the range 5 to 15 degrees and 70 DA2GC Ground Stations subtend an elevation angle 16 degrees or greater.

The numeric average e.i.r.p. between 5 and 15 degrees elevation is 35.3 dBm and is 28.8 dBm for elevation angles 16 degrees or greater as seen in Figure 69. The aggregate e.i.r.p. from 130 DA2GC Ground Stations towards a satellite at 60 degrees East is therefore 51.1 dBm on average. This figure is obtained by weighting the e.i.r.p. values by the relevant numbers of Ground Stations. It should further be noted that only half the Ground Stations are transmitting at any instant because of TDD synchronisation across the network (a fact not taken into account in the earlier analyses.

The aggregate interference received by Satellite H is then given by:

I = 51.1 dBm – 30 (to dBW) – 73 dBHz – 200.2 dB (FSPL) – 0.5 dB (atmospheric) + 34.7 dBi

I = –217.9 dBW/Hz

T = –217.9 dBW/Hz – –228.6 dBW/K/Hz = 10.7 dBK = 11.75 K

ΔT/T = 11.75 K / 700 K (Satellite H system noise temperature) = 1.7%

It can be seen from the above calculation that the aggregate e.i.r.p. from multiple DA2GC Ground Stations gives rise to an increase in satellite noise temperature for Satellite H of 11.75 K, a rise of 1.7 % in the system noise temperature (2.5 dB less than the revised ΔT/T criterion of 3% as the basis for studies).

The above further analyses have indicated that a mask as shown in Figure 72, when applied to an individual DA2GC Ground Station employing beamforming antennas would be appropriate to ensure protection of FSS satellites. As considered in earlier contributions, the proposed mask would also provide regulatory equivalence with BFWA at the lower elevation angles.

The proposed mask is based on three levels:

Table 29: Proposed e.i.r.p. levels

Angle range	Proposed level (dBW/4 kHz)
< 2.5°	-31
2.5° to 16°	-27.7
>16°	-35.7

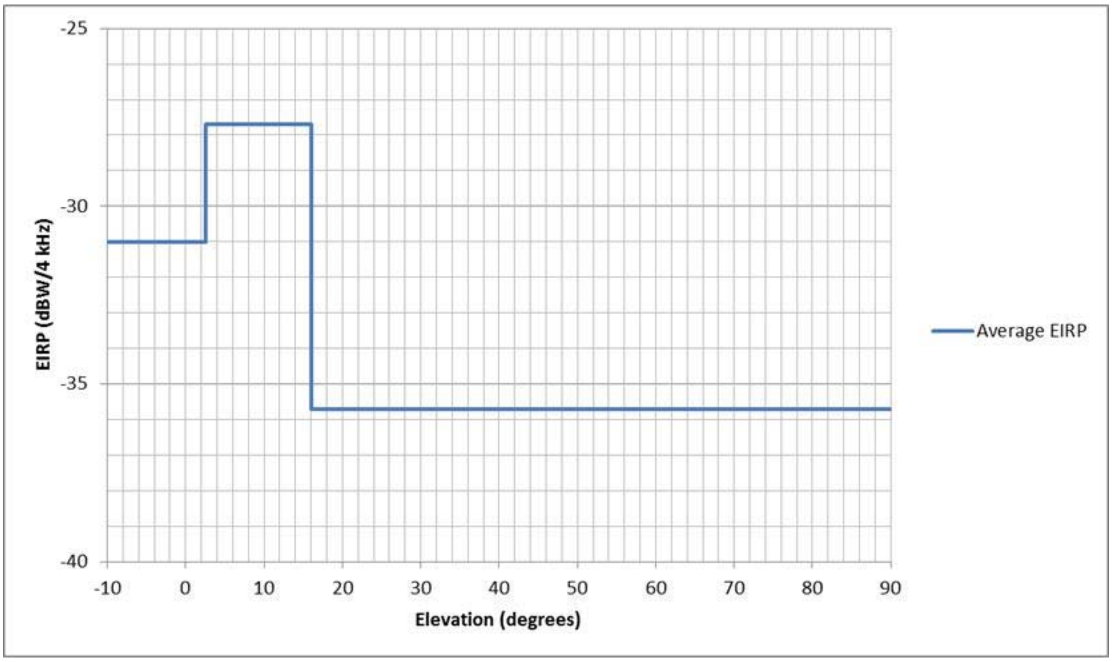


Figure 72: Proposed average e.i.r.p. mask

5.2.4.6 e.i.r.p. behavior vs. generic mask

There will always be some inconsistency between the interference results obtained from actual e.i.r.p. behaviour and a generic mask that is designed to be technology neutral.

Table 30 below compares two cases where the first reflects the result obtained with the actual e.i.r.p. lobe of Figure 73. The other result is based on a “squared-off” mask as shown in Figure 72. A real implementation fitting within this mask would be expected to give a ΔT/T of 3% whereas the theoretical ΔT/T based on the “squared-off” mask would be 3.9% as indicated in the table below.

Table 30: Comparison of the results

Basis of calculations	5° to 15° e.i.r.p. contribution	>15° e.i.r.p. contribution	Aggregate e.i.r.p. (TDD	Resulting ΔT/T
Actual (Figure 1)	60 x 35.3 dBm	70 x 28.8 dBm	51.1 dBm	1.7%
Mask (Figure 2)	60 x 39.3 dBm	70 x 31.3 dBm	54.8 dBm	3.9

A visual comparison of the actual e.i.r.p. produced by the beamforming system described in ETSI TR 101 599 and the proposed average e.i.r.p. mask is provided in Figure 73 below.

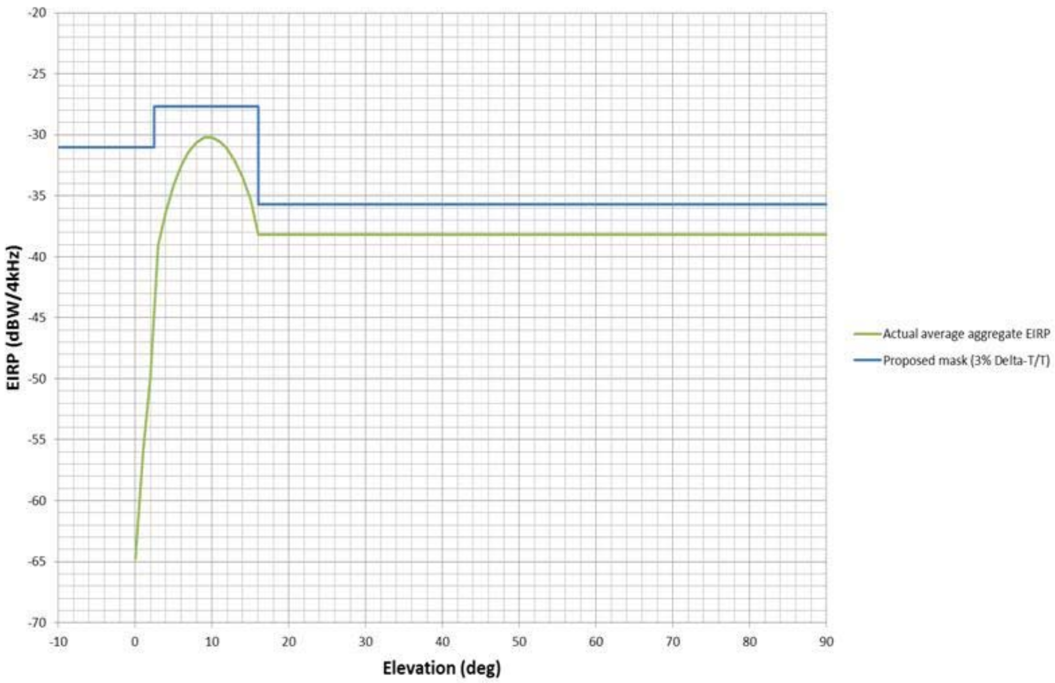


Figure 73: e.i.r.p. comparison

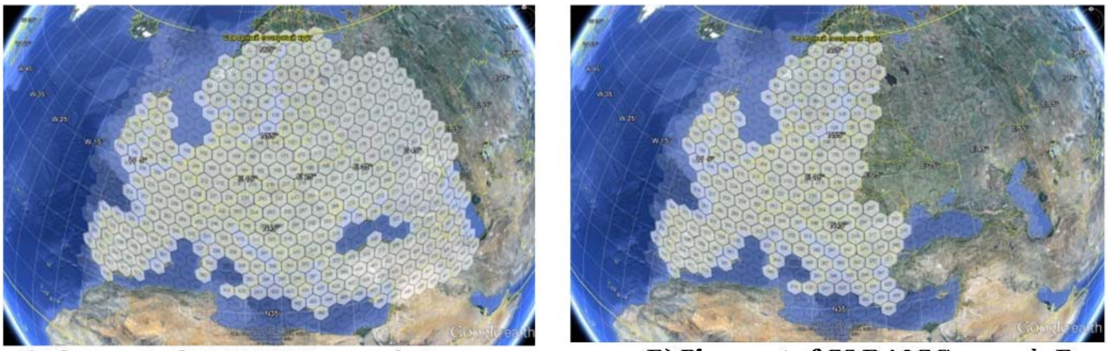
5.2.4.7 Placement of DA2GC ground stations.

Two scenarios were considered and are shown in Figure 74.

Scenario 1: The coverage of the European part of the continent to 50 deg. east longitude.

Scenario 2: Coverage of European countries.

To ensure uniform coverage in Scenario 1 requires about 340 Ground stations. To ensure uniform coverage in Scenario 2 requires about 186 ground stations. Placement of Ground stations was performed taking into account the cell radius of about 110 km, while the distance between the nearest ground stations were from 175 to 195 km. The location and numbering of the GS is shown in Figure 75.



A) Placement of GS DA2GC, scenario 1 B) Placement of GS DA2GC, scenario B

Figure 74: Location of ground stations DA2GC (cellular structure)

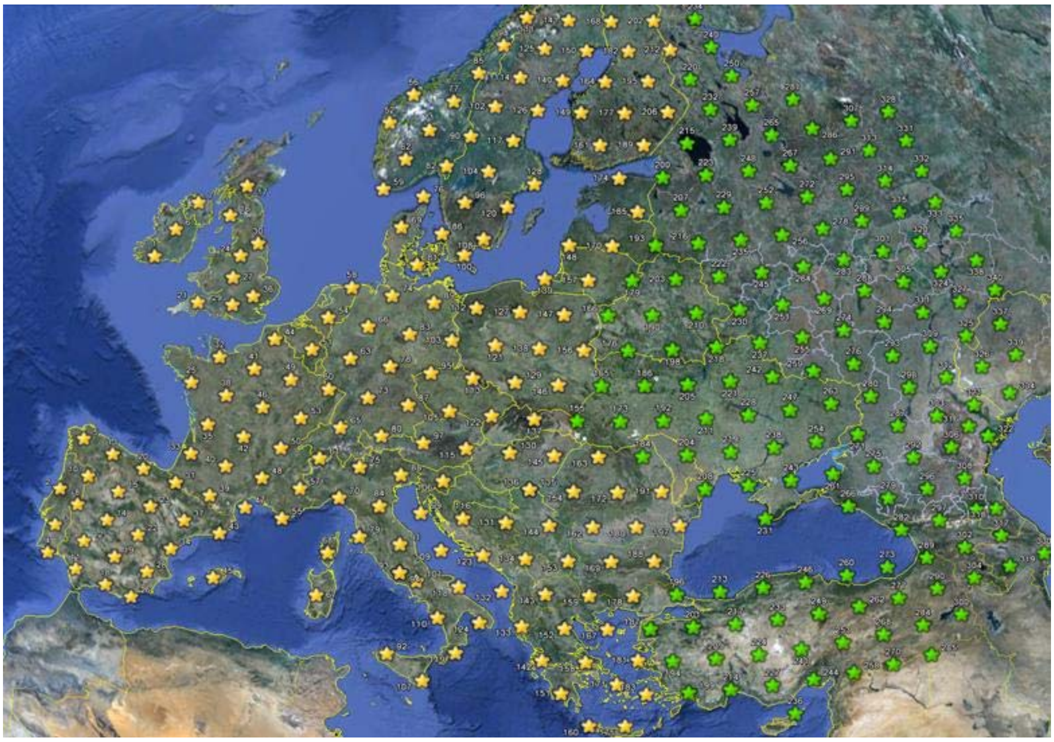


Figure 75: Location and numbering of Ground stations

- Scenario with 340 Base stations (taking into account assumption of coverage territory of Russia, Belorussia, Turkey)

Allowable interference on Satellite H: -155,4 dBW/MHz

Total interference from BS: -150,5 dBW/MHz

dT/T: 9,13 %

Necessary additional attenuation of e.i.r.p. mask in Figure 72 = 4.8 dB

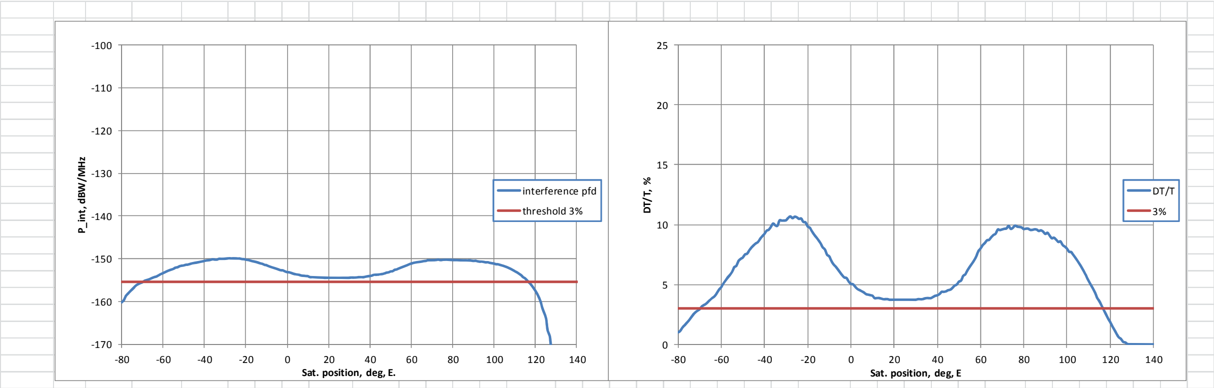


Figure 76: Interference on satellite H (scenario with 340 GS)

- Scenario with 186 Base stations (taking into account assumption with approx. 100 km radius of BS coverage):

Allowable interference on Satellite H: -155,4 dBW/MHz

Total interference form BS: -151,5 dBW/MHz

dT/T: 7,29 %

Necessary additional attenuation of e.i.r.p. mask in Figure 72 = 3.9 dB

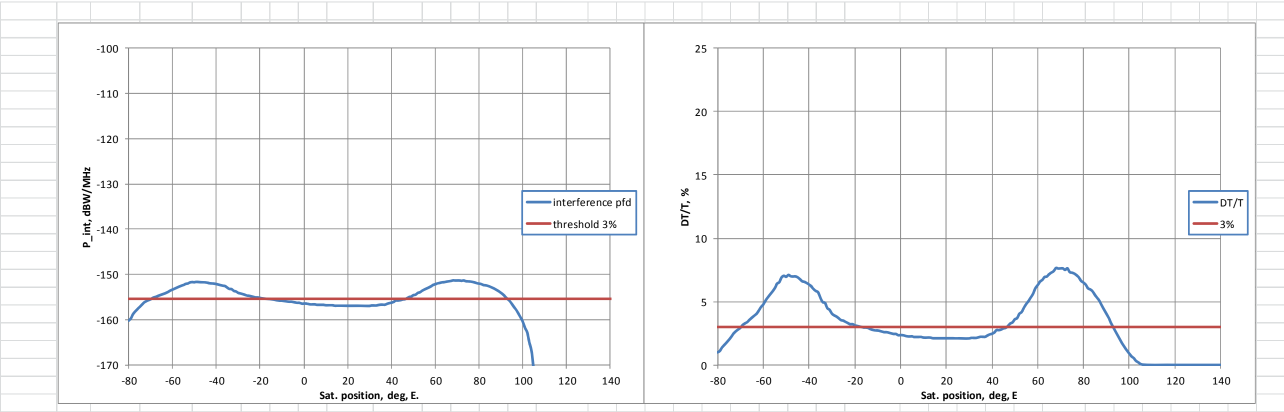


Figure 77: Interference on satellite H (scenario with 180 GS)

- Scenario with 130 Base stations:

Figure 78: Placement of the ground stations

Allowable interference on Satellite H: -155,4 dBW/MHz

Total interference from BS: -153,4 dBW/MHz

dT/T: 4,69 %

Necessary additional attenuation of e.i.r.p. mask in Figure 72 = 1.9 dB

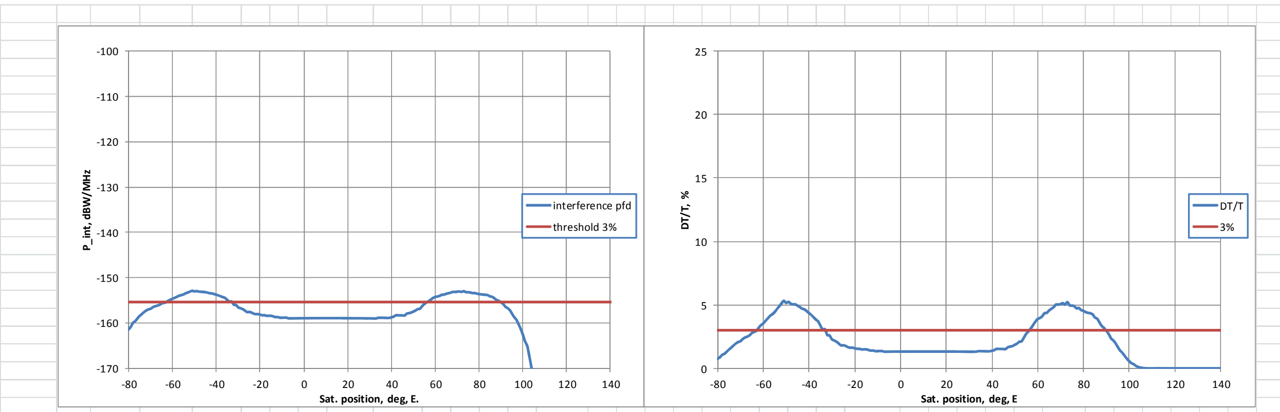


Figure 79: Interference on satellite H (scenario with 180 GS)

5.2.4.8 Results

Scenario	Sat position deg.	G-Sat (dB)	Noise temp (K)	Allowable interference (dBW/MHz)	Interference (dBW/MHz)	dT/T (%)	Required additional attenuation
130 BS	66	34.70	700	-155.4	-153.4	4.69	1.9
186 BS	66	34.70	700	-155.4	-151.5	7.29	3.9

Scenario	Sat position deg.	G-Sat (dB)	Noise temp (K)	Allowable interference (dBW/MHz)	Interference (dBW/MHz)	dT/T (%)	Required additional attenuation
340 BS	66	34.70	700	-155.4	-150.5	9.13	4.8
141BS (Note 1)	66	34.70	700	-155.4	-153.3	4.84	2.1

Note 1- 141 Base stations: 130 BS + 11 BS for covering European part of Russia and Belarus

The analyses described in Sections 5.2.4.1to 5.2.4.6 indicate that the Fixed Satellite Service can be protected if the DA2GC Ground Station e.i.r.p. mask in Figure 72 is used. However, the additional analyses in Section 5.2.4.7(with a slightly different disposition of DA2GC Ground Stations) indicate that the proposed DA2GC Ground Station mask in Figure 72 would exceed the agreed Fixed Satellite Service protection criterion by 2 dB. It was concluded that the relevant power levels of the e.i.r.p. mask should be reduced, accordingly, by 2dB.

The following mask, therefore, meets the requirement to protect satellites operating in the Fixed Satellite Service.

The proposed mask is shown in Figure 80 below and is based on three levels:

Table 31: Proposed EIRP levels

Angle range	Proposed level (dBW/4 kHz)
< 2°	-49.7
2° to 16°	-29.7
>16°	-37.7

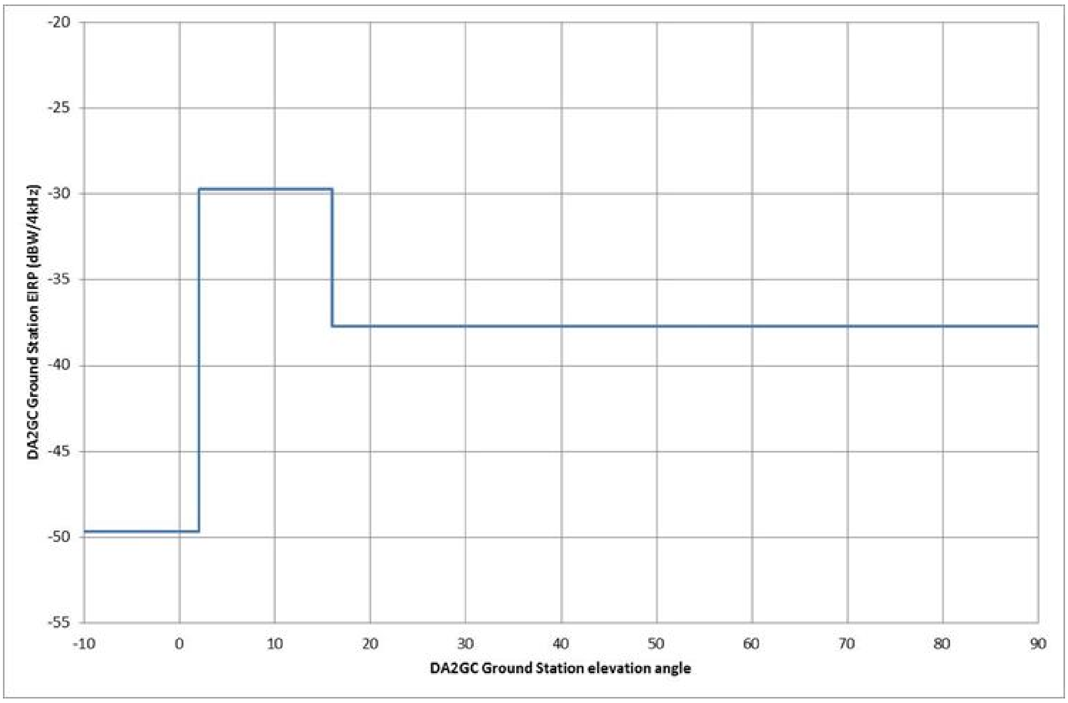


Figure 80: Proposed average DA2GC Ground Station e.i.r.p. mask

5.2.4.9 Conclusions

Analyses have shown that sharing is feasible between FSS satellite receivers and the assumed number of DA2GC Ground stations (around 140 GS) using the average e.i.r.p. mask. In practice, a higher number of ground stations could be deployed without exceeding the satellite protection criterion, since the total number of aircraft served (assumed to be around 1600 by 2020) would remain the same (i.e. the average number of beams per ground station, and hence average e.i.r.p. per ground station, would be lower). The agreed FSS protection criterion can be used to construct an average e.i.r.p. mask to be applied to DA2GC Ground Stations in the 5.8 GHz band order to provide appropriate levels of protection to FSS services operating on a co-frequency basis.

A suitable mask has been derived, based on an FSS protection criterion of 3% ΔT/T within which the DA2GC beamforming Ground Station comfortably operates (based on around 1600 GS antenna beams).

5.2.5 Compatibility between DA2GC AS (TR 103 108) and FSS

5.2.5.1 Methodology

Earth-space propagation losses have already been accounted for in the table above when calculating the maximum allowable aggregate interference.

The satellite interference threshold is given by:

$$H = 10log_{10}(kTBC) \qquad \text{dBW}$$

where:

k = Boltzmann's constant = 1.38 * 10^{-23} (joules/K)
T = noise temperature of the receiver (degrees K)
C = Δt/t (%)
B = bandwidth of the receiver

The aggregate signal received at the satellite is derived as follows.

For a single DA2GC aircraft station, the source signal is given by:

$$Sig_{Rx} = Eirp_{DA2GC} - Satellite\ Antenna\ Factor - Polarisation\ Factor$$

where:

Satellite Antenna Factor accounts for any reduction in power due to the position of the DA2GC AS within the satellite antenna beam.
Polarisation Factor = 3 dB
e.i.r.p.$_{DA2GC}$ is derived from the associated masks in ETSI TR 103 108

The aggregate signal becomes:

$$Sig_{Aggregate} = 10log_{10}(\sum_{1}^{Max\ GS} 10^{\frac{Sig_{Rx}}{10}})$$

It is noted from ETSI TR 103 108 that in a given cell only one transmission is active (i.e. ground station or one aircraft station).

It has been assumed that the AS is transmitting at maximum power, i.e. there has been no reduction in transmit power to take account of ATPC.

5.2.5.2 Results

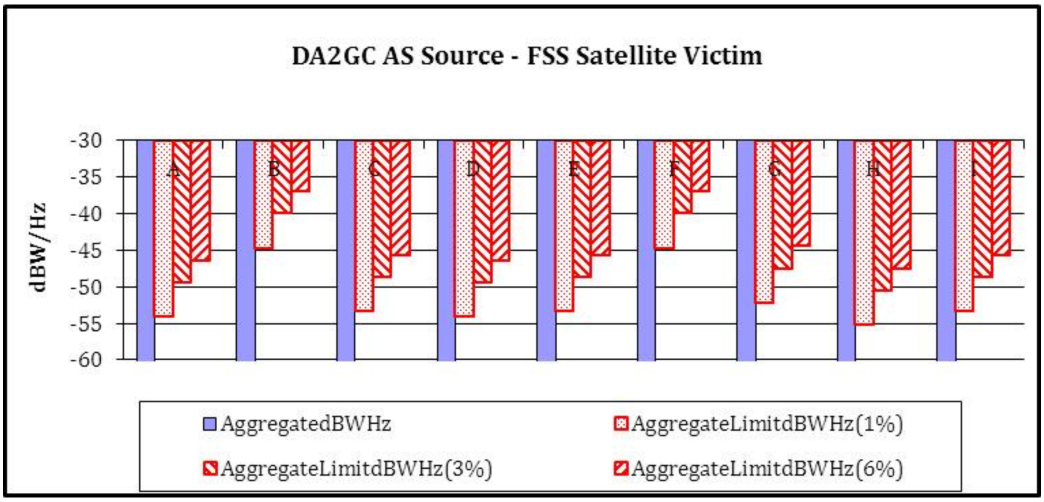


Figure 81: DA2GC AS Source / FSS Satellite Victim

The figure shows that for all satellites the aggregate power is less than the aggregate limit for Δt/t = 1% (and hence also for Δt/t = 3% and Δt/t = 6%).

5.2.6 Compatibility between DA2GC GS (TR 103 108) and FSS

5.2.6.1 Methodology

Earth-space propagation losses have already been accounted for in the table above when calculating the maximum allowable aggregate interference.

The satellite interference threshold is given by:

$$H = 10log_{10}(kTBC) \qquad \text{dBW}$$

where:
k = Boltzmann's constant = 1.38 * 10^{-23} (joules/K)
T = noise temperature of the receiver (degrees K)
C = Δt/t (%)

The aggregate signal received at the satellite is derived as follows.
e.i.r.p.$_{DA2GC}$ is derived from the associated masks in ETSI TR 103 108

The aggregate signal becomes:

$$Sig_{Aggregate} = 10log_{10}(\sum_{1}^{Max\ GS} 10^{\frac{Sig_{Rx}}{10}})$$

It is noted from ETSI TR 103 108 that is a given cell only one transmission is active (i.e. ground station or one aircraft station).

No ATPC has been used.

For a single DA2GC ground station the source signal is given by:

$$Sig_{Rx} = Eirp_{DA2GC} - Satellite\ Antenna\ Factor - Polarisation\ Factor$$

where:

Satellite Antenna Factor accounts for any reduction in power due to the position of the DA2GC GS within the satellite antenna beam.

Polarisation Factor = 3 dB

e.i.r.p.$_{DA2GC}$ is derived from the associated masks in ETSI TR 103 108

The aggregate signal becomes:

$$Sig_{Aggregate} = 10log_{10}(\sum_1^{Max\ GS} 10^{\frac{Sig_{Rx}}{10}})$$

It is noted from ETSI TR 103 108 that is a given cell only one transmission is active (i.e. ground station or one aircraft station).

No ATPC has been used.

The ground station transmissions are dominant, given that the aircraft station transmissions will be subject to the aircraft airframe shadowing. Hence the ground station interference is the worst case. The ground station only services one aircraft at a given instant and one antenna sector is used for this purpose. The other sectors do not transmit. To achieve the necessary cell range at 5.8 GHz it is necessary to have at least 6 sectors of which one is for overhead coverage. Assuming a uniform distribution of aircraft, the probability of a particular sector radiating is given by:

$$Probability_{Overhead} = Coverage\ Area_{Overhead}/Coverage\ Area_{Cell}$$

$$Probability_{Sector} = \frac{(1 - Probability_{Overhead})}{Number\ \ of\ Remaining\ Sectors}$$

where:

Coverage AreaCell = 64,274 sq km

Coverage AreaOverhead = 2,372 sq km

Number of Remaining Sectors = 4

5.2.6.2 Results

The number of ground stations is 230. The aggregate interference into the respective satellites is shown below in Figure 82.

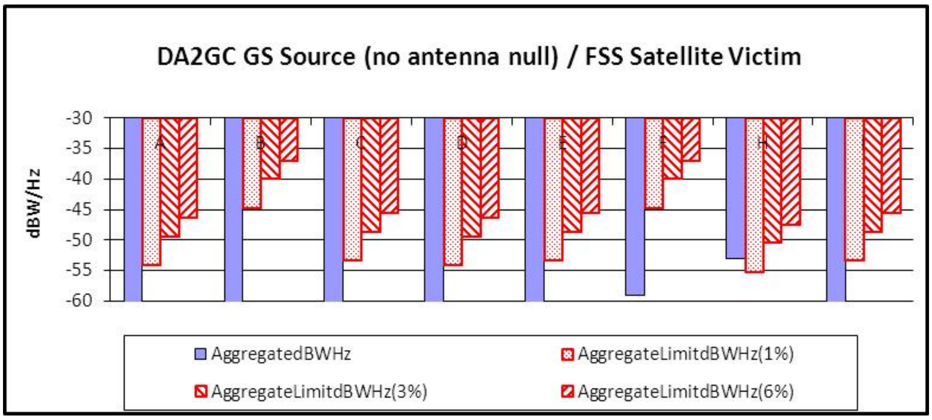


Figure 82: DA2GC GS Source / FSS Satellite Victim

The figure shows that the aggregate power is less than the aggregate limit for Δt/t of 1%, except for Satellite H, for which the interference is less than Δt/t of 3%. It is noted that Satellite H is the most vulnerable.

If it is required to meet a Δt/t limit of 1% for Satellite H, it is necessary to introduce additional attenuation by pointing a ground station antenna null of -2.5 dB, with respect to the bore sight gain, towards satellite H. The result of doing this is shown below:

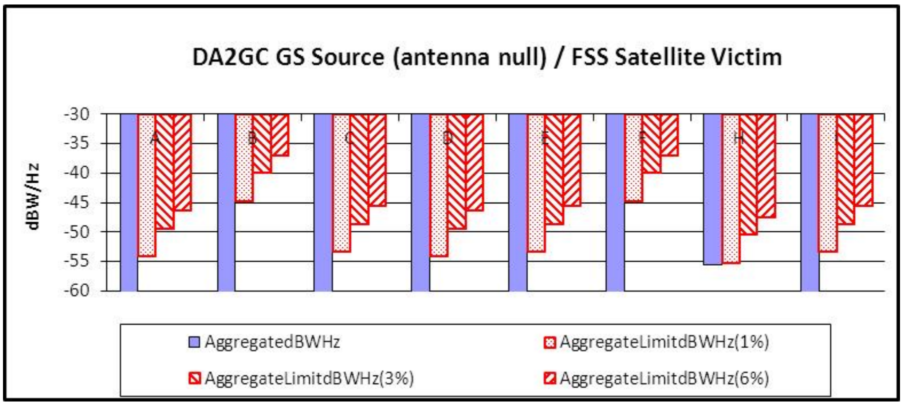


Figure 83: DA2GC GS Source / FSS Satellite Victim

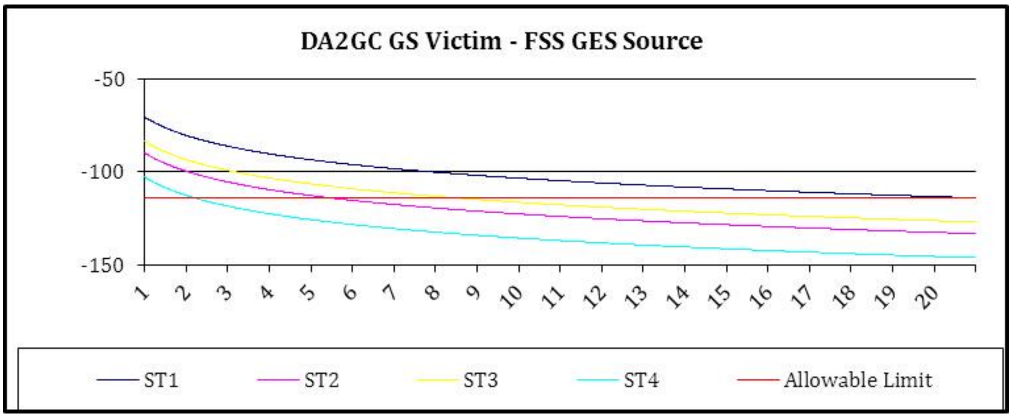


Figure 84: DA2GC GS Victim / FSS GES Source

The effect of interference from the FSS Ground Station into the DA2GC Ground Station as a function of separation distance, for different FSS Ground Stations, is shown in Figure 84.

5.2.7 Conclusions

5.2.7.1 Aircraft Station

Compatibility is achieved for the case where the FSS satellite is the victim. The FSS Earth-space transmissions will interfere with the aircraft station causing an effective loss of signal. However, given the narrow beamwidth and the aircraft speed, this interference will only exist for a short period and is operationally acceptable to the DA2GC.AS.

5.2.7.2 Ground Station

Given that the number of GS operating on the same 10 MHz channel is limited to 200, and, taking into account the fixed null in the azimuth pattern, the interference caused to FSS satellites is less than 1% Δt/t in all cases. Any FSS GES interference to the DA2GC GS is compatible with a separation distance of 20 km. This is easily achievable through the site planning for DA2GC GS.

Summary

Co-channel compatibility between DA2GC GS and FSS is considered to be achieved.

5.2.8 Impact of FSS Earth Stations on DA2GC AS

Member States provided information about the use of FSS Earth stations in conjunction with the harmonization of the usage of BWA in the band 3400-3800 MHz. Annex 1 of document RSCOM 10-28 provides an overview on authorized Earth Stations per country. The number of ES amounts to 170 operating in the range 3400-3800 MHz and 303 operating in the frequency range 3800-4200 MHz. Since it is likely that some of these stations use both frequency ranges the absolute number of ES cannot be derived from this paper. It can however be stated that at least 303 Earth stations are listed in the C-Band in Europe and also using spectrum within the uplink band 5850-6100 MHz. These stations are mainly used for regional or intercontinental connections for various services. According to Article 21.9 of the ITU Radio Regulations there is no restriction for the e.i.r.p. transmitted by an Earth station for angles of the elevation of the horizon greater than 5 degree. Because these Earth stations are operated down to the lower band edge 5850 MHz co-channel sharing between FSS and DA2GC needs to be considered. Table 32 below summarizes the main parameters of the ES (ST5 in **Error! Reference source not found.**).

Table 32: FSS Earth Station parameters

ES Parameter	Value	Unit
Operating frequency	5869	MHz
Transmit power	120	W
Transmitter bandwidth	36	MHz
Antenna gain	54	dBi
Max power density	59	dBW/MHz
Antenna pattern	according to Recommendation ITU-R S.465	

Table 33: DA2GC receiver parameter

DA2GC receiver parameter (TR 103 054)	Value	Unit
Operating frequency	5865	MHz
Receiver bandwidth	20	MHz
Antenna gain	0	dBi
Rx noise floor	-92.5	dBm
I/N	-6	dB
Protection level	-98.5	dBm

5.2.8.1 Results

1. Co-channel case

The maximum power density is the power in the mainbeam direction of the Earth station. As the half power beamwidths of the Earth station antennas are very small (<= 2 degree) the probability is low that an aircraft is flying through the main beam of the antenna. Since the transmit power into the antenna is constant, the reception level at the receiver depends on the antenna off-axis gain discrimination in direction to the plane. For a first estimation the aircraft was placed at a constant distance of 100 km around the Earth station. The resulting Free Space loss is about 148 dB. Figure 85 shows the received interference level in dependence of the off-axis gain of the Earth station antenna. Interference can be observed from off-axis angles up to 17 degrees. This means that within an area with a radius of 31 km interference can be observed on the Aircraft station receiver. The protection level of an aircraft station receiver which is crossing this area with a velocity of 900 km/h is exceeded for more than 4 minutes. The maximum exceedance of the protection level is around 53 dB.

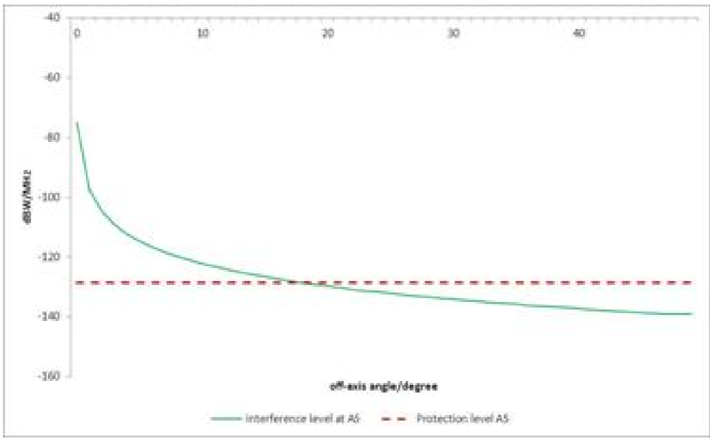


Figure 85: Interference at the AS receiver co-channel; Distance AS-ES = 100 km

In case of a Direct-Air-to-Ground communication aircraft station which is in the visibility of an Earth station only the resulting free space propagation loss between Earth station and aircraft can be used in the calculations. Thus great decoupling distances can be expected between a FSS Earth station and a DA2GC AS receiver. The above example shows that even with a large separation distance of 100 km, interferences at the AS receiver can be expected.

2. Unwanted emissions

Appendix 3 of the ITU Radio Regulations (Table II) provides the maximum spurious emission limits for Earth Stations in a 4 kHz bandwidth.

43 + 10 log (P), or 60 dBc, whichever is less stringent

In case of the 120 W (21 dBW) station the 60 dBc value has to be used, leading to an unwanted emission level of -39 dBW/4kHz (equivalent to 28 dBm/20 MHz) into the antenna.

Figure 86 shows the interference received at an AS with a distance of 20 km from the ES. Interference can be observed from off-axis angles up to 9 degrees, leading to an interference area with a radius of 3.2 km. The protection level of an aircraft station receiver which is crossing this area with a velocity of 900 km/h is exceeded for around 26 seconds.

Figure 87 shows the interference received at an AS with a distance of 100 km from the ES. Interference can be observed from off-axis angles up to 3 degrees, leading to an interference area with a radius of 5.2 km. The protection level of an aircraft station receiver which is crossing this area with a velocity of 900 km/h is exceeded for around 42 seconds.

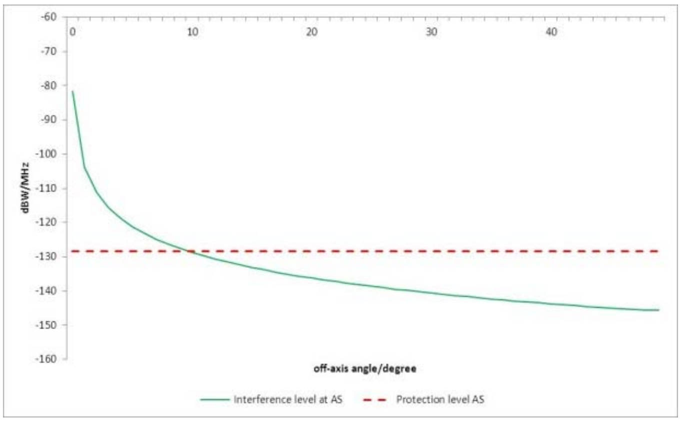


Figure 86: Interference due to unwanted emissions caused by an ES; Distance AS-ES = 20 km

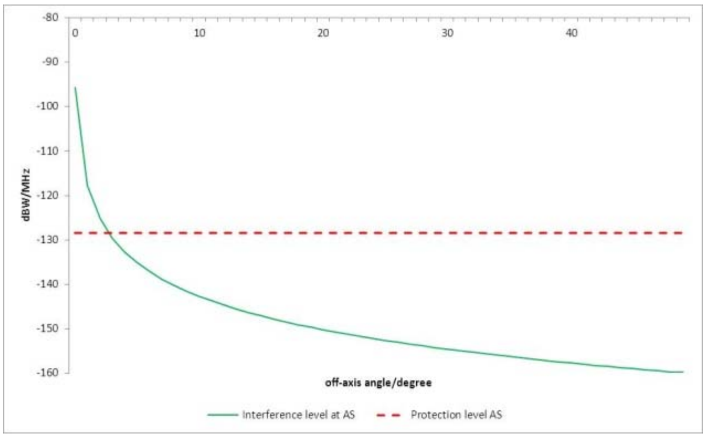


Figure 87: Interference due to unwanted emissions caused by an ES; Distance AS-ES = 100 km

5.2.8.2 Conclusions

According to information provided by Member States at least 303 FSS Earth stations are operated in the C-Band from 5 850 – 6 100 MHz (E-s). Because some of these Earth stations are operated down to the lower band edge 5 850 MHz co-channel sharing between FSS Earth stations and DA2GC needs to be considered. The locations of Earth stations usually have a great decoupling to terrestrial systems like radio relay stations because of the selected environment and the terrain profile around the Earth stations. In case of a Direct-Air-to-Ground communication Aircraft station which is in the visibility of an Earth station only the resulting free space propagation loss between Earth station and aircraft can be used in the calculations.

In the co-channel case it was shown that even with a large separation distance of 100 km, the protection level of an aircraft station receiver (according to ETSI TR 103 054) which is crossing the beam with a velocity of 900 km/h is exceeded for around 4 minutes. It was also shown that the protection level of an AS receiver can be exceeded by the unwanted emissions of a FSS Earth Station operating above the band 5855-5875 MHz for more than 40 seconds.

Finally it can be concluded that interferences can also be observed on AS receivers according to other system proposals (ETSI TR 101 599 [30] and ETSI TR 103 108 [31]) due to the high emission levels of the Earth stations. A detailed calculation is omitted here, since the facts are evident. It should also be noted that the selected Earth station technical parameters do not cover the worst case which means that the level of interference at the AS receiver can be higher than calculated in this contribution. Mitigation measures as described by the proponent of ETSI TR 101 599 [30] may improve the situation but it should be noted that in the case of interference rejection, the directions from which the interfering signals would be received is basically not known. A variety of approaches and corresponding methods for obtaining the necessary knowledge of received signals can be found in the literature with respect to adaptive filters and adaptive antennas. However, these methods have advantages and disadvantages. Some of the methods depend on the application (Modulation scheme) and the estimation of interference directions can be disturbed by noise and interference signals and are therefore always subject to error. So all adaptive methods only approximate the directions of interference. With respect to the proposed antenna nulling it might be the case that the DA2GC system will lose gain in its service direction leading to a loss of data or to an increase of the transmit power at the AS transmitter in order to keep the required C/I at the GS receiver because the main beam of the AS cannot longer be directed towards its GS. In the latter case the interference probability for other incumbent applications and services (in- and out of band) would rise.

5.3 COMPATIBILITY BETWEEN DA2GC AND SRD

5.3.1 Technical characteristics of SRDs

- *General (Non-Specific) Short Range Devices characteristics*

As specified in Annex 1 of ERC/REC 70-03 [36], the frequency band 5725-5875 MHz is used by non-specific SRD. This use should comply with the technical characteristics as shown below.

Table 34: Technical characteristics of SRD

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

In addition to these regulatory technical characteristics, assumptions on some parameters had to be made in order to carry out compatibility studies. Three kinds of SRD are considered for the interference assessment (see the following table).

Table 35: Assumed SRD parameters

Parameter	SRD I	SRD II	SRD III	Comments
Typical bandwidth BW (MHz)	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, dBm	-110	-91	-84	
Receiver noise dBm/MHz	-114	N/A	N/A	
Protection criterion, dB	I/N=0dB	C/I=8dB	C/I=20dB	
SRD Noise figure F	9.00 dB	N/A	N/A	
FkTB	-105 dBm/MHz	N/A	N/A	
Max OoB 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*				

5.3.2 Compatibility between DA2GC AS (TR 103 108) and SRD

5.3.2.1 Methodology

The unwanted interference has been calculated according to the following equation:

$$Interfering\ Signal = Eirp_{Source} - AS_{Mitigation} - Loss_{Prop} + Antenna\ Gain_{Rx}$$

For DA2GC, both $Eirp_{Source}$ and $Antenna\ Gain_{Rx}$ are defined in section 4.3.

5.3.2.2 Results

The results of the analysis are presented below:

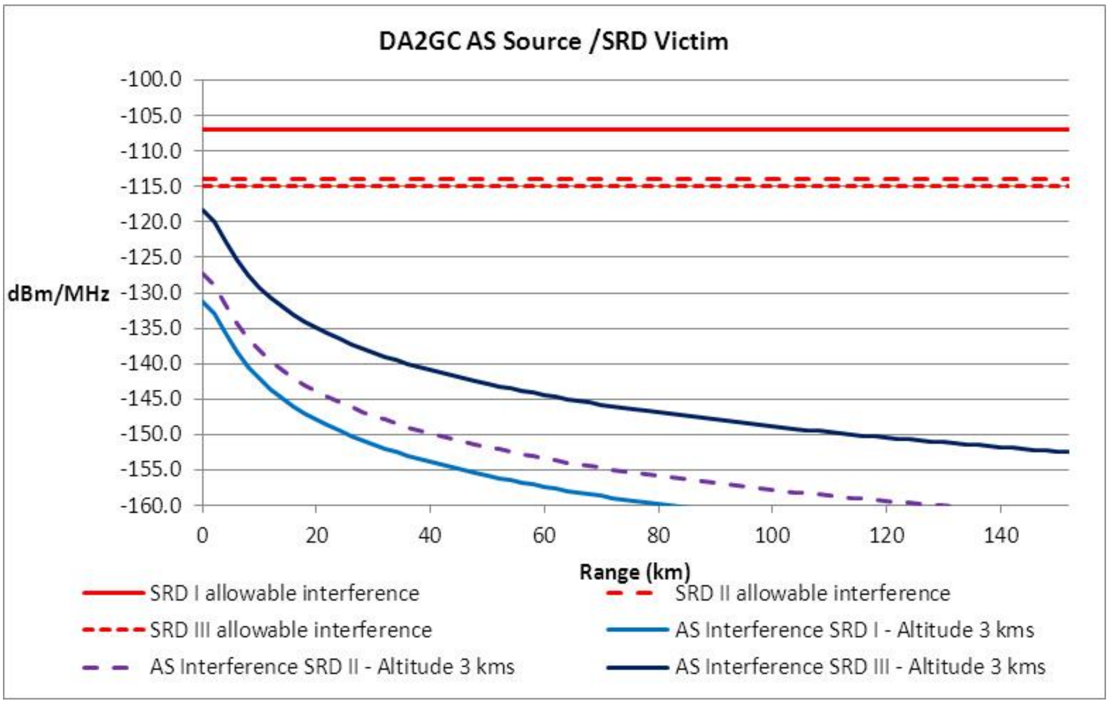


Figure 88: DA2GC AS Source (3 kms) / SRD Victim

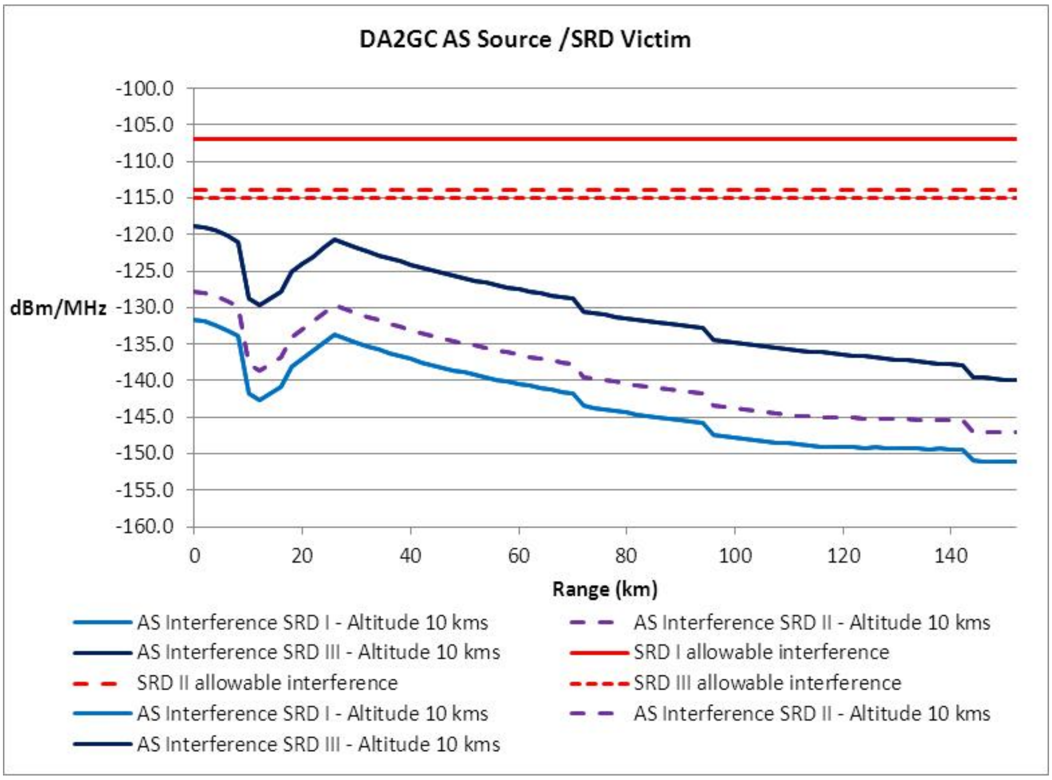


Figure 89: DA2GC AS Source (10 kms) / SRD Victim

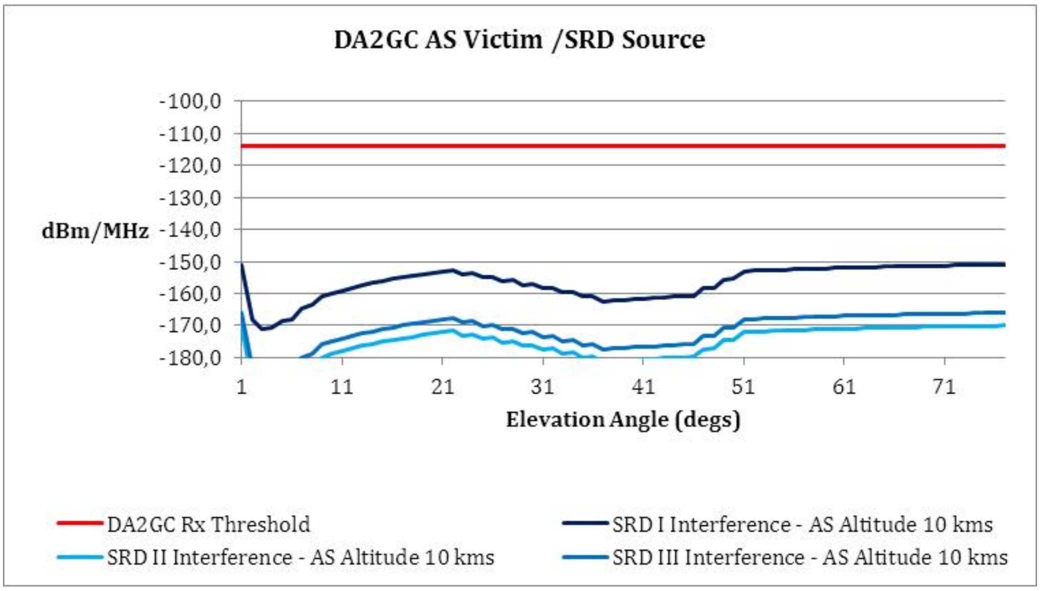


Figure 90: DA2GC AS Victim (10 kms) / SRD Source

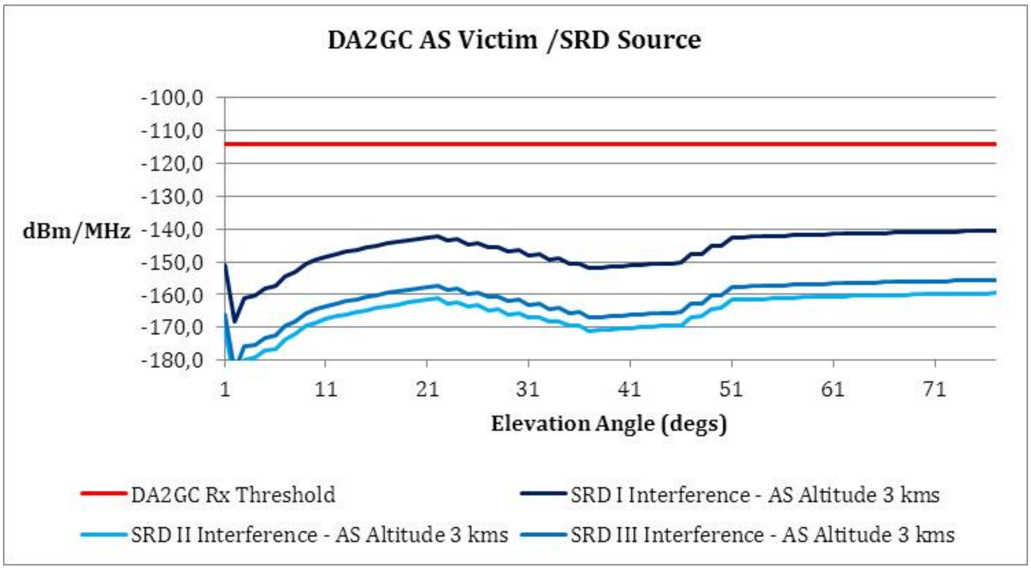


Figure 91: DA2GC AS Victim (3 kms) / SRD Source

5.3.3 Compatibility between DA2GC GS (TR 103 108) and SRD

5.3.3.1 Methodology

All ground stations are planned to be sited in an urban environment to benefit from the existing points of presence offered by the telecommunications infrastructure.

No ATPC has been used for terrestrial scenarios.

The unwanted interference has been calculated according to the following equation:

$$Interfering\ Signal = Eirp_{Source} - Loss_{Prop} + Antenna\ Gain_{Rx}$$

For DA2GC, both $Eirp_{Source}$ and $Antenna\ Gain_{Rx}$ are defined in 4.3.

5.3.3.2 Results

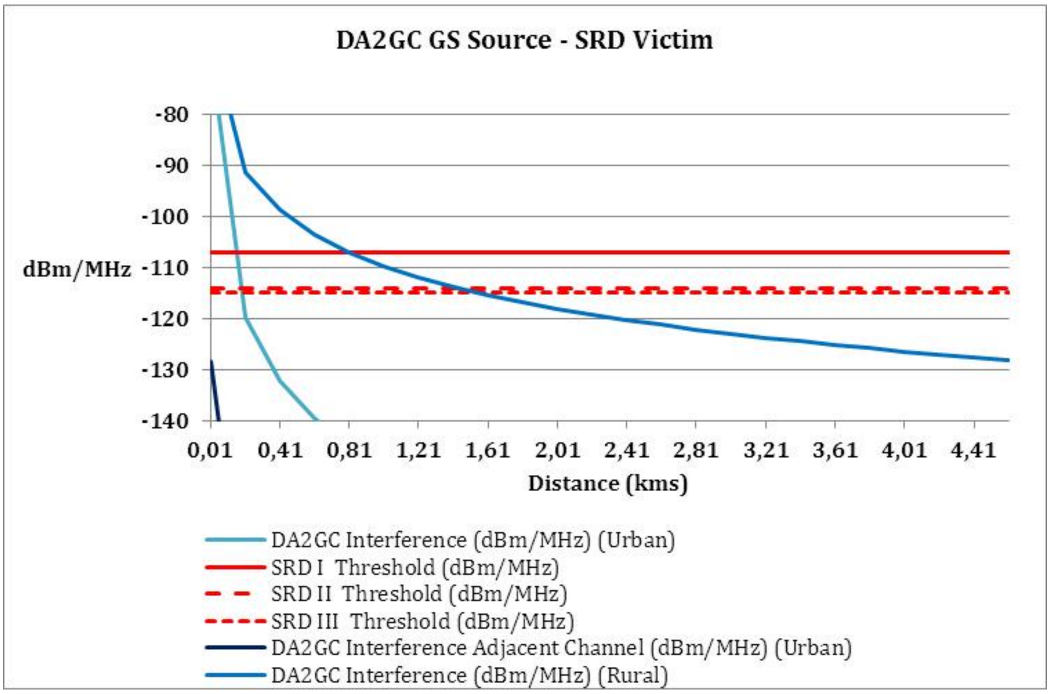


Figure 92: DA2GC GS Source / SRD Victim

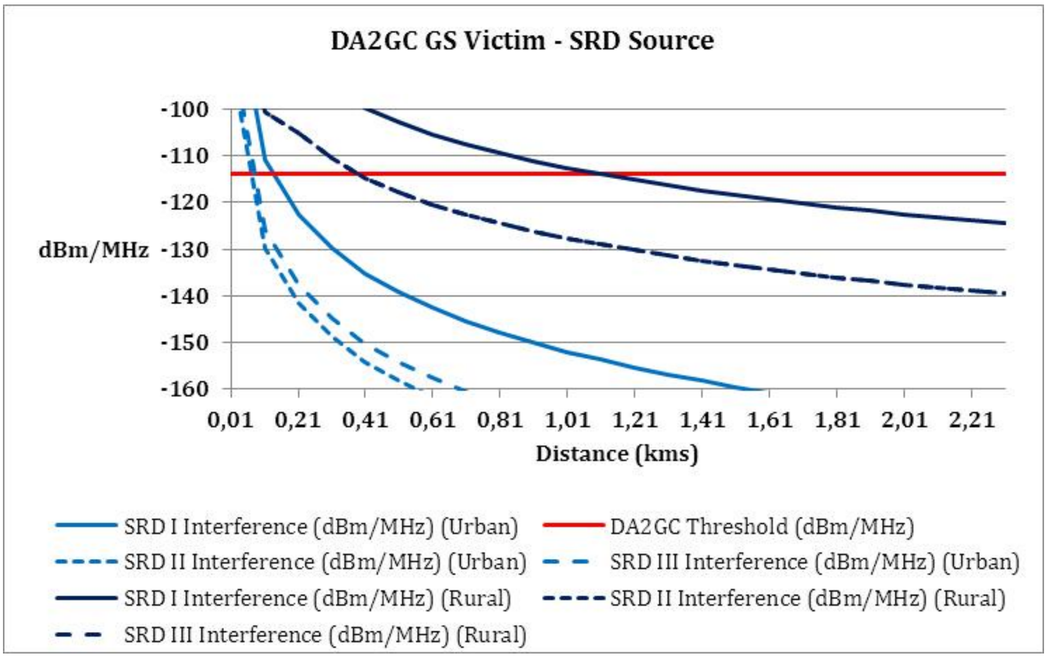


Figure 93: DA2GC GS Victim / SRD Source

5.3.4 Conclusions

5.3.4.1 Aircraft Station

Figure 88 to Figure 91 show that co-channel interference levels will be below the threshold for acceptable interference.

5.3.4.2 Ground Station

Figure 92 and Figure 93 show that co-channel compatibility is achieved with a separation distance of 1.5 km assuming rural propagation. For the urban case the separation distance is reduced to about 200 metres.

5.3.4.3 Summary

Co-channel compatibility between DA2GC GS and SRD is considered to be achieved.

5.4 COMPATIBILITY BETWEEN DA2GC AND ITS

5.4.1 Technical characteristics of ITS

Table 36: System parameter of ITS (not exhaustive)

Parameter	Value	Comments
Frequency stability	10 ppm	According to ETSI EN 302 571 V1.2.2 (2011-10)
Maximum radiated power (e.i.r.p.)	Channel 5860, 5910 and 5920 MHz: 0 dBm, -10 dBm/MHz Channel 5870 and 5890 MHz: 23 dBm, 13 dBm/MHz Channel 5880 and 5900 MHz: 33 dBm, 23 dBm/MHz	According to ETSI EN 302 571 V1.2.2 (2011-10) and ETSI EN 302 663 V1.3.1 (2012-06) There are no equipment classes anymore. There are different power limits for different channels with highest allowed power for the most critical channels. See figure 1.
Antenna beam shape/gain	For RSU and OBU use antenna model ITU-R F.1336-3 with parameters G_0 5 dB, k 1.2, max gain in +10 deg elevation	See Figure 95 and Equation 1. In ECC Report 101 [44] there were 2 possible antennas, one very directional and one omnidirectional ITU-R F.1336-1 [20]. However ITS systems development shows that the omnidirectional will be the dominant type and therefore only this should be used in these compatibility studies. There is a new version of model ITU-R F.1336-3 which should be used. Both versions 1 and 3 results in exactly the same antenna performance with these parameter settings.
Polarization	Vertical linear	The antenna performance is not described in ETSI ITS however the vertical linear polarization is dominant.
Modulation scheme	BPSK QPSK 16QAM 64QAM	According to ETSI EN 302 571 V1.2.2 (2011-10) and ETSI EN 302 663 V1.3.1 (2012-06)
Data rates	3/4.5 /6/9/12/18 /24/27 Mbit/s Mandatory: 3/6/12 Mbit/s	According to ETSI EN 302 571 V1.2.2 (2011-10) and ETSI EN 302 663 V1.3.1 (2012-06)
Channel Bandwidth	10 MHz	According to ETSI EN 302 571 V1.2.2 (2011-10) and ETSI EN 302 663 V1.3.1 (2012-06)
Communication mode	Half-duplex, broadcast	Half-duplex and broadcast are believed to be adequate for the applications considered to date.
Receiver sensitivity	See **Error! Reference source not found.**	ETSI EN 302 571 V1.2.2 (2011-10) specifies minimum required sensitivity..

Parameter	Value	Comments
Protection criterion	Channel 5880, 5890 and 5900 MHz: C/I=12dB Other channels: C/I=6dB	The three ITS-G5A channels are decided by the European Commission to be used for road safety communication and therefore a higher C/I value of 12 dB should be used for these channels. Add Footnote

FN: To ensure that ITS will not disturb other radio services in the band 5855 to 5875 MHz, there is a demand on ITS to use Listen Before Talk (LBT) with a threshold of -85 dBm assuming a 0 dBi antenna gain. When the ITS LBT is triggered the ITS radio is not allowed to transmit. Most probably the ITS LBT will not be able to distinguish between DA2GC and other non-ITS signals and therefore it is important that the DA2GC transmissions will not exceed the LBT threshold.

In the sharing studies of DA2GC the criterion have been not to exceed the power of -88 or -91 dBm into the ITS receiver, including C/I of 6 dB. In the same studies a maximum gain of 5 dB with the ITS receiver antenna have been used resulting in a LBT threshold of -80 dBm into the ITS receiver. In summary the ITS receiving criterion is more critical than ITS LBT and therefore the ITS LBT have not been further studied.

Communication channels will be open for the applications within the respective usage category (either road safety related or not, i.e. used for traffic management).

The required power levels (e.i.r.p.) range from 3 dBm to 33 dBm to achieve communication distances of up to 1000 m.

To avoid collisions of radio messages in areas with a lot of vehicles, a mechanism DCC (dynamic congestion control) in ITS radios will when necessary reduce the output power and the available time to transmit.

There is a mechanism in ITS radios which will reduce the output power or available time to transmit when the radios are close to 5.8 GHz RTTT road tolling stations.

Unwanted emission levels are given by to ETSI EN 302 571 V1.2.2 (2011-10) for the out of band domain and SM.329 and ERC Recommendation 74-01 for the spurious domain.

Table 37: Transmitter unwanted emission limits inside the 5 GHz ITS bands (e.i.r.p.)

Power spectral density at the carrier center fc (dBm/MHz)	±4,5 MHz Offset (dBm/MHz)	±5,0 MHz Offset (dBm/MHz)	±5,5 MHz Offset (dBm/MHz)	±10 MHz Offset (dBm/MHz)	±15 MHz Offset (dBm/MHz)
23	23	-3	-9	-17	-27
The limits are reduced by 10 dB for the 5870 and 5890 channels and by 33 dB for 5860, 5910 and 5920 channels.					

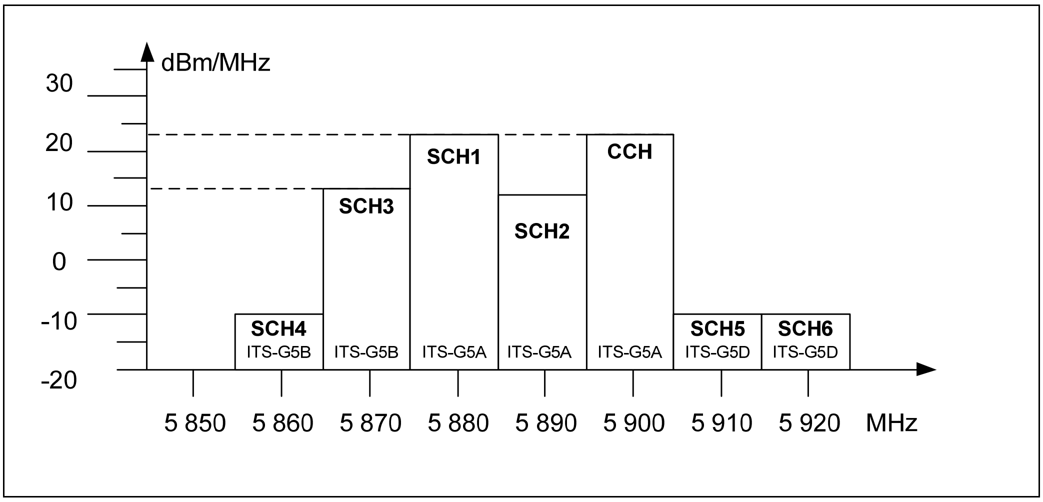


Figure 94: Maximum limit of mean spectral power density for each channel type in ITS-G5A, ITS-G5B, and ITS-G5D

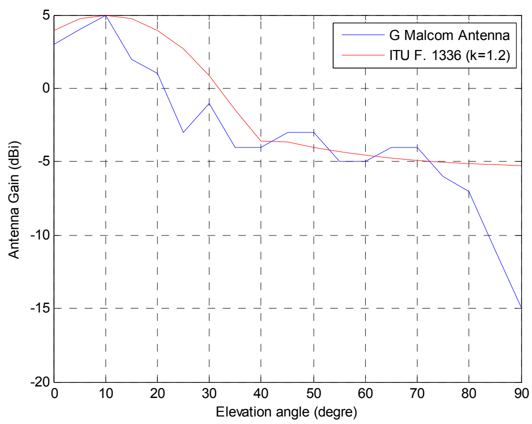


Figure 95: OBU and RSU antenna pattern

Table 38: Minimum required receiver sensitivity; receivers will have up to 10 dB better sensitivity

Modulation	Coding rate	Minimum sensitivity (dBm)
BPSK	1/2	–85
BPSK	3/4	–84
QPSK	1/2	–82
QPSK	3/4	–80
16-QAM	1/2	–77
16-QAM	3/4	–73
64-QAM	2/3	–69
64-QAM	3/4	–68

$$G(\theta) = \begin{cases} G_0 - 12\left(\dfrac{\theta}{\theta_3}\right)^2 & \text{for} \quad 0 \leq |\theta| < \theta_4 \\ G_0 - 12 + 10\ \log(k+1) & \text{for} \quad \theta_4 \leq |\theta| < \theta_3 \\ G_0 - 12 + 10\ \log\left[\left(\dfrac{|\theta|}{\theta_3}\right)^{-1.5} + k\right] & \text{for} \quad \theta_3 \leq |\theta| \leq 90° \end{cases} \qquad (1a)$$

with:

$$\theta_3 = 107.6 \times 10^{-0.1\,G_0} \qquad (1b)$$

$$\theta_4 = \theta_3 \sqrt{1 - \frac{1}{1.2}\log(k+1)} \qquad (1c)$$

where:

- $G(\theta)$: gain relative to an isotropic antenna (dBi)
- G_0 : the maximum gain in the azimuth plane (dBi)
- θ : elevation angle relative to the angle of the maximum gain (degrees) ($-90° \leq \theta \leq 90°$)
- θ_3 : the 3 dB beamwidth in the elevation plane (degrees)
- k: parameter which accounts for increased side-lobe levels above what would be expected for an antenna with improved side-lobe performance

Equation 1: Antenna model ITU-R F.1336-3 [20]; use G0 5 dB, k=1.2, max gain in +10 deg elevation

These traffic systems support communication between vehicles using on-board units (OBU) and fixed road-side units (RSU). The most well know application is road tolling but there are many other applications some having a safety aspect and others that are less critical. The earlier generation system, RTTT, supported solely RSU-OBU communication whereas the newer system, ITS, also supports communication between vehicles.

The RTTT system has similarities with passive RFID systems in that the RSU activates and powers the OBU. The ITS system is more conventional in that active transceivers exist at both ends of the link.

Regarding coexistence studies where these systems are potentially victims of interference from other systems, representative receivers have been used as follows:

- In the case of ITS the RSU is considered to point towards the ground from an elevated position whereas the OBU uses an aerial that is omnidirectional in the horizontal plane and has some directivity in the vertical plane. The most susceptible of these is the vehicular unit which is used as the victim in the remainder of this document;
- In the case of RTTT the OBU is passive and requires a significant received power level in order to be activated / powered. In general this means that this part of the system can be ignored as such levels of interference are very unlikely to occur. The RSU is therefore considered to be the most susceptible unit although since it is pointing towards the ground from an elevated position (as in the case of the ITS example above) its susceptibility will be limited.

5.4.2 Compatibility between DA2GC AS (TR 101 599) and ITS/RTTT

5.4.2.1 Methodology

Two victims representing the ITS and RTTT systems were used, as follows:

- A vehicle that uses an aerial which is omnidirectional in the horizontal plane and has some directivity (up to 8 dBi) in the vertical plane (ITS)
- A road side unit that uses a directional aerial which points downwards towards the road (RTTT). It will be assumed that it has uniform rear lobes above the horizontal plane (i.e. towards the sky). A 0 dBi reference level is used for the modelling and the results can be interpreted as appropriate.

5.4.2.2 Criteria

With reference to the two representative victims identified above, the interference criteria are shown in **Error! Reference source not found.**, noting that the values included here are specified at the input to the receiver (i.e. after the antenna).

Table 39: ITS / RTTT interference criteria

Victim	Rx sensitivity (dBm)	Rx bandwidth (MHz)	C/I criterion (dB)	I criterion in Rx bandwidth (dBm)	I criterion (dBm / MHz)
ITS vehicle	-82	10	6	-88	-98
RTTT road side unit	-104	0.5	6	-110	-107

5.4.2.3 Results based on static interference alignments

In order to scope the statistical results presented in the following section it is instructive to know the interference signal level received by the ITS / RTTT receivers in certain static situations. Three cases are presented; where the interfering aircraft is on the horizon and transmitting at its maximum e.i.r.p. towards the victim, where the aircraft is at 16 degrees elevation which represents a nominal worst case combination of e.i.r.p., path loss and antenna gain, and where the interfering aircraft is directly overhead (minimum e.i.r.p. and minimum path loss).

Table 40: Received interference levels (Static configurations)

Config.	AS Tx (dBm)	AS antenna gain (dBi)	OOB suppression (dB)	Path loss (dB)	Victim antenna gain (dBi)	Bandwidth correction (dBi)	Interference (dBm)
ITS vehicle – Horizon	24.3	17.8	Co-frequency	-158.9	8	-3	-111.8
ITS vehicle – 16° el	19.1	17.8	Co-frequency	-138.9	6	-3	-99.0
ITS vehicle – Zenith	8.0	17.8	Co-frequency	-127.8	-5	-3	-110.0
ITS vehicle – Horizon	24.3	17.8	-40	-158.9	8	-3	-151.8
ITS vehicle – 16° el	19.1	17.8	-40	-138.9	6	-3	-139.0

Config.	AS Tx (dBm)	AS antenna gain (dBi)	OOB suppression (dB)	Path loss (dB)	Victim antenna gain (dBi)	Bandwidth correction (dBi)	Interference (dBm)
ITS vehicle – Zenith	8.0	17.8	-40	-127.8	-5	-3	-150.0
RTTT RSU – Horizon	24.3	17.8	-40	-158.9	0	-16	-172.8
RTTT RSU – 16° el	19.1	17.8	-40	-138.9	0	-16	-158.0
RTTT RSU – Zenith	8.0	17.8	-40	-127.8	0	-16	-158.0

Note – Based on aircraft at 10 km altitude

Comparing the interference criteria of **Error! Reference source not found.** with the levels of received nterference shown in Table 40 it can be seen that very significant margins exist for the adjacent channel cases (50 dB and more) and significant margin exists for the co-frequency ITS case (11 dB).

5.4.2.4 Results from statistical analysis

The three results that follow are (in order of presentation):

- Co-frequency interference from 1 and 100 aircraft at 10 km altitude into ITS ground based vehicular receivers having an antenna gain of 5 dBi and 8 dBi.
- Out-of-band interference from 1 and 100 aircraft at 10 km altitude into ITS ground based vehicular receivers having an antenna gain of 5 dBi and 8 dBi.
- Out-of-band interference from 1 and 100 aircraft at 10 km altitude into RTTT ground based fixed road side receiver having a residual antenna gain of 0 dBi.

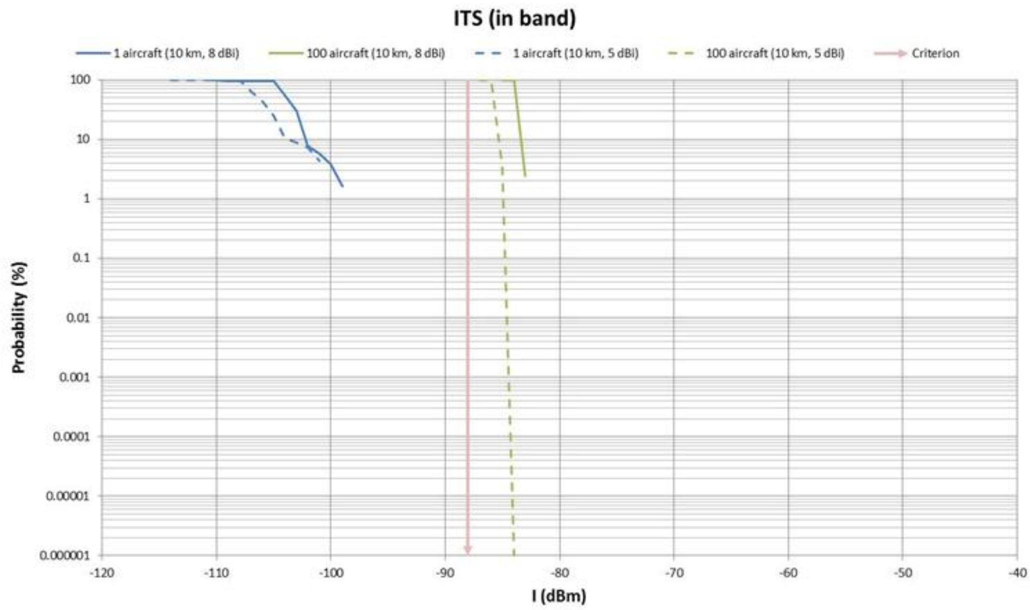


Figure 96: Interference into ITS receiver (co-frequency)

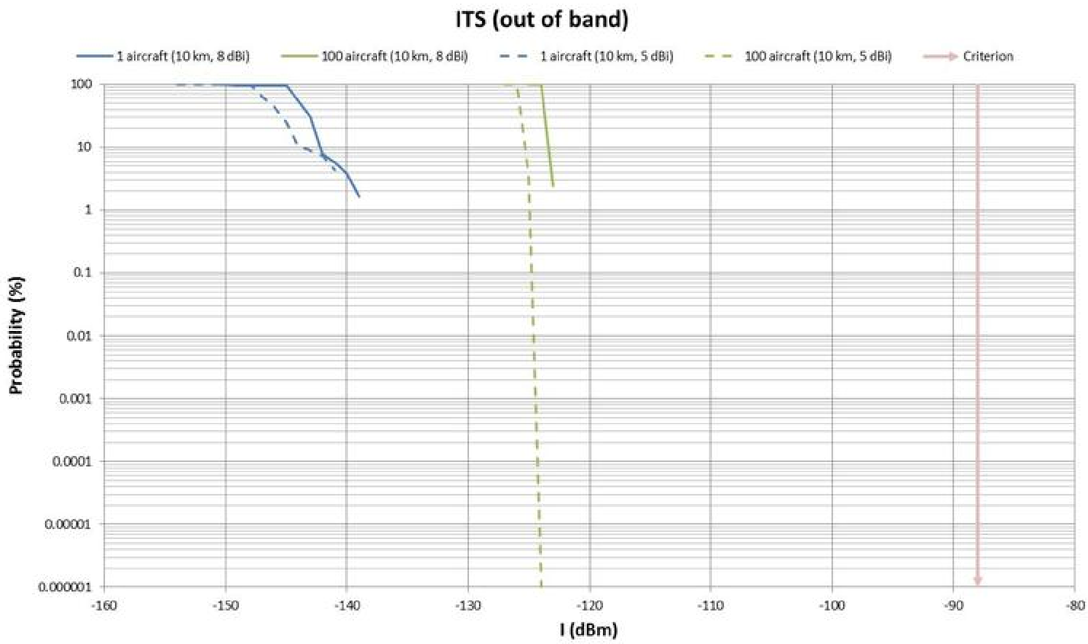


Figure 97: Interference into ITS receiver (out-of-band)

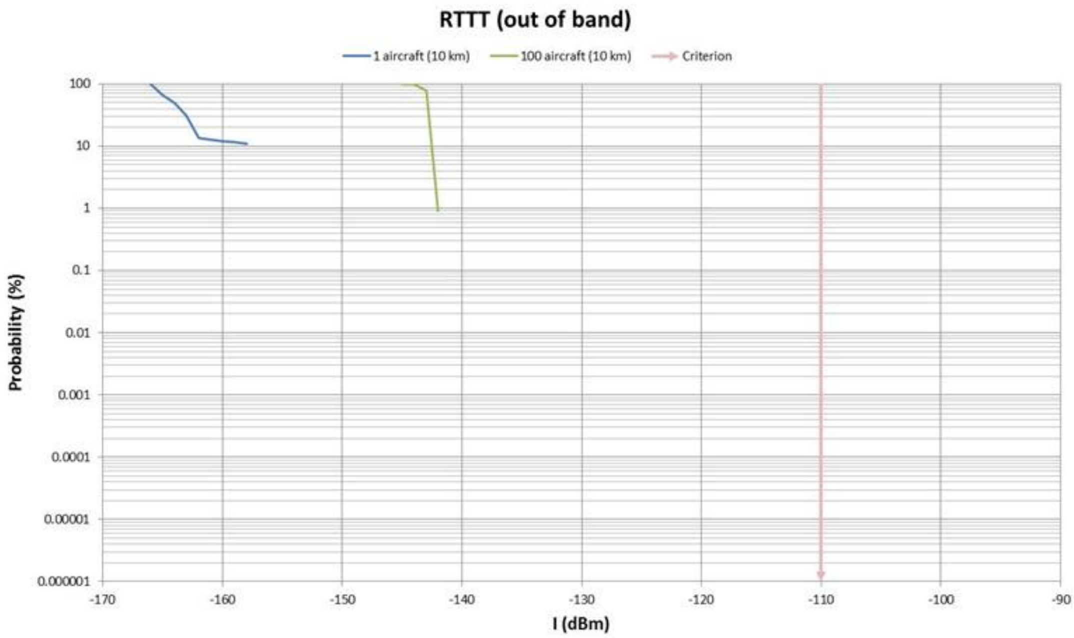


Figure 98: Interference into RTTT receiver (out-of-band)

It can be seen for the two out-of-band cases (ITS in Figure 97 and RTTT in Figure 98) that even with the aggregation of 100 aircraft high margins are still available; 35 dB in the case of RTS and 32 dB in the case of RTTT.

For the ITS co-frequency case (Figure 96) the criterion is exceeded by a few dB. This result is predicated on a smooth earth geometry and therefore does not take account of clutter, screening or horizon elevation due to terrain. Noting that the density of interfering aircraft as seen by the victim ITS terminal is greatest at low elevation angles, 70% being below 2 degrees, it can be seen that the number of simultaneously transmitting aircraft that can be seen by the ITS terminal will be significantly less than the 100 aircraft assumed above. Furthermore, atmospheric loss and other propagation effects will have an impact at very low elevation angles thereby reducing the effect of the aircraft that can still be seen.

5.4.2.5 Development of Aircraft Station e.i.r.p. Masks

Interference received from a single DA2GC Aircraft Station by an ITS terminal having a gain of 5 dBi and co-located with the DA2GC Ground Station can be represented by the profile as a function of elevation angle as shown in Figure 99. For this particular geometry there is no discrimination afforded by the DA2GC aircraft antenna. The shape of the interference profile therefore comes from a combination of:

- ITS antenna pattern in the elevation plane
- DA2GC Ground Station antenna pattern in the elevation plane (which influences the Aircraft e.i.r.p. because of ATPC)
- Slant path loss which is a function of elevation.

1. The collocated case

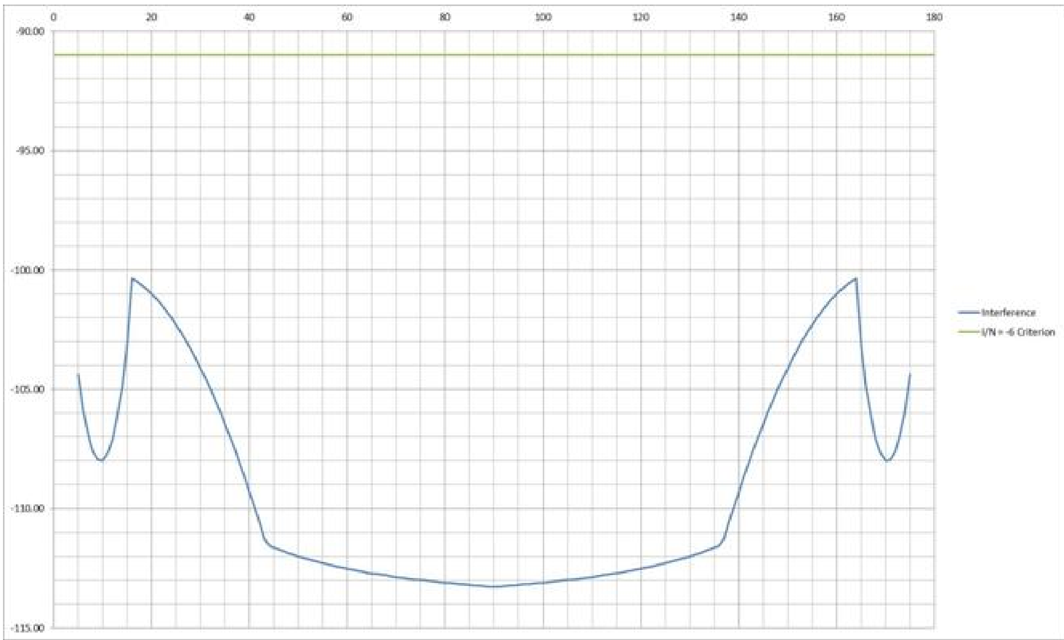


Figure 99: Interference received by ITS terminal (G = 5 dBi) co-located with DA2GC Ground Station (Altitude independent because of DA2GC use of ATPC)

2. The worst case location

The worst case location in terms of the highest level of received single entry interference can be identified from surface plots, an example of which is shown in Figure 100.

In the case of an aircraft at an altitude of 10 km the worst case single entry level of interference is experienced by an ITS receiver situated 78 km from the DA2GC Ground Station. The level of interference is -95.9 dBm (in the ITS receive bandwidth) and arrives at the victim receiver at an elevation of just over 20 degrees.

In the case of an aircraft at an altitude of 3 km the ITS worst case location is 25.2 km from the DA2GC Ground Station. The level of interference is -95.1 dBm (in the ITS receive bandwidth) and arrives at the victim receiver at an elevation of just over 20 degrees.

The interference profile for a victim ITS receiver in its worst case location is shown in Figure 101. This profile relates to an aircraft at an altitude of 10 km. The profile for a victim ITS receiver at its worst case location for an aircraft at altitude 3 km is virtually the same in all aspects (because of the use of ATPC) except that the worst case margin is 4 dB rather than 5 dB. This interference profile differs in appearance when compared to the co-located case as the DA2GC aircraft antenna's discrimination pattern comes into play providing different degrees of discrimination as the aircraft follows its flight path.

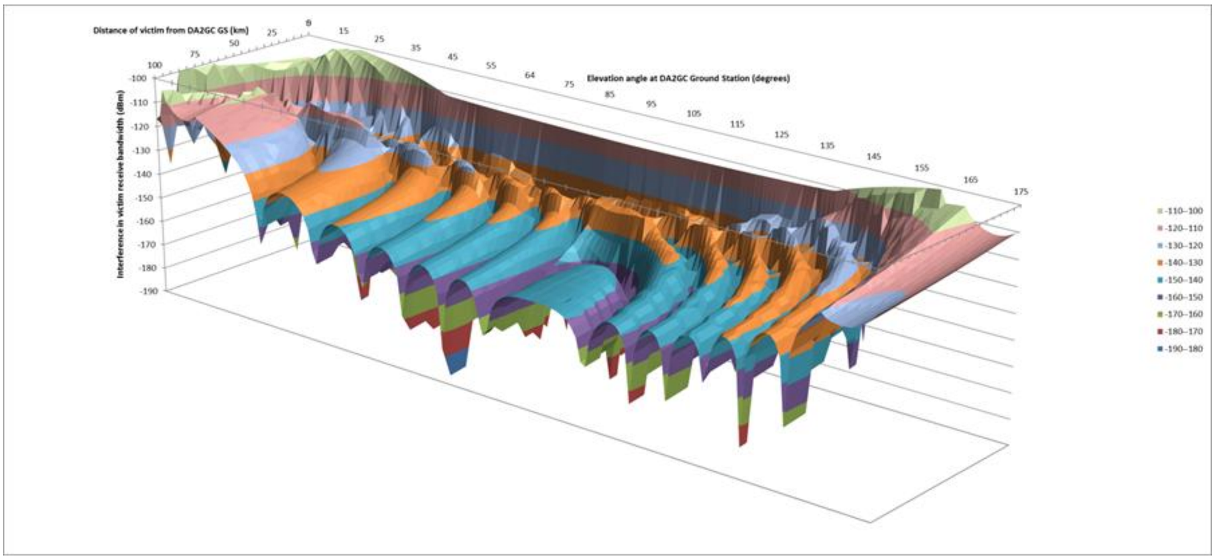


Figure 100: Example surface plot of interference received by ITS terminal (G = 5 dBi) as a function of distance offset from and elevation at DA2GC Ground Station (Aircraft altitude = 10 km)

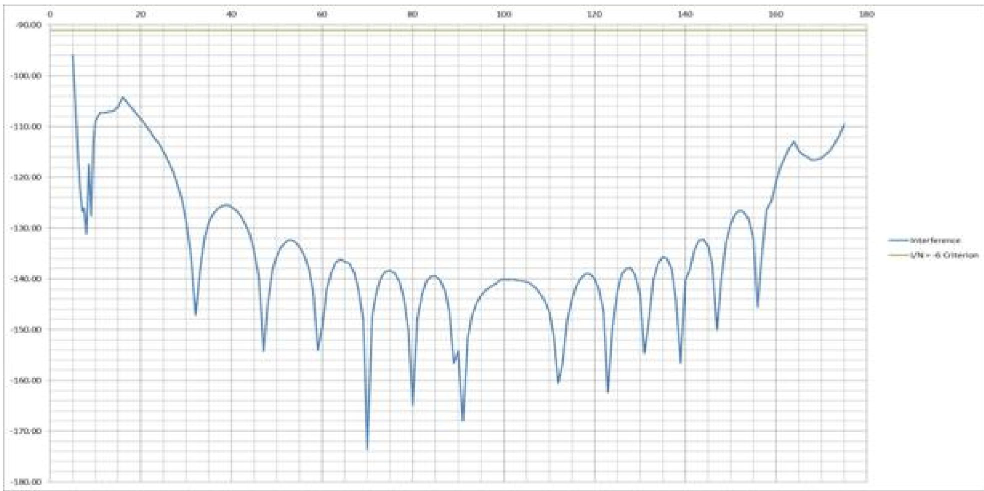


Figure 101: Interference received by ITS terminal (G = 5 dBi) at 78 km from DA2GC Ground Station (Aircraft altitude = 10 km)

The ITS interference profiles can be reverse engineered to show an Aircraft e.i.r.p. profile to meet the criterion. This Aircraft e.i.r.p. profile will be altitude dependent; Figure 102 shows the profile for 10 km altitude. By way of comparison the actual e.i.r.p. profile of a beamforming DA2GC aircraft (example based on system described in ETSI TR 101 599) is also shown in Figure 102. This figure shows two pairs of results; one pair where the victim ITS is co-located with the DA2GC Ground Station (labelled as “Allowable e.i.r.p. based on co-location” and “Actual e.i.r.p. towards GS”) and the other pair where the victim ITS worst case location is offset from the DA2GC Ground Station (labelled as “Allowable e.i.r.p. based on worst case” and “Actual e.i.r.p. towards victim (worst case location)”).

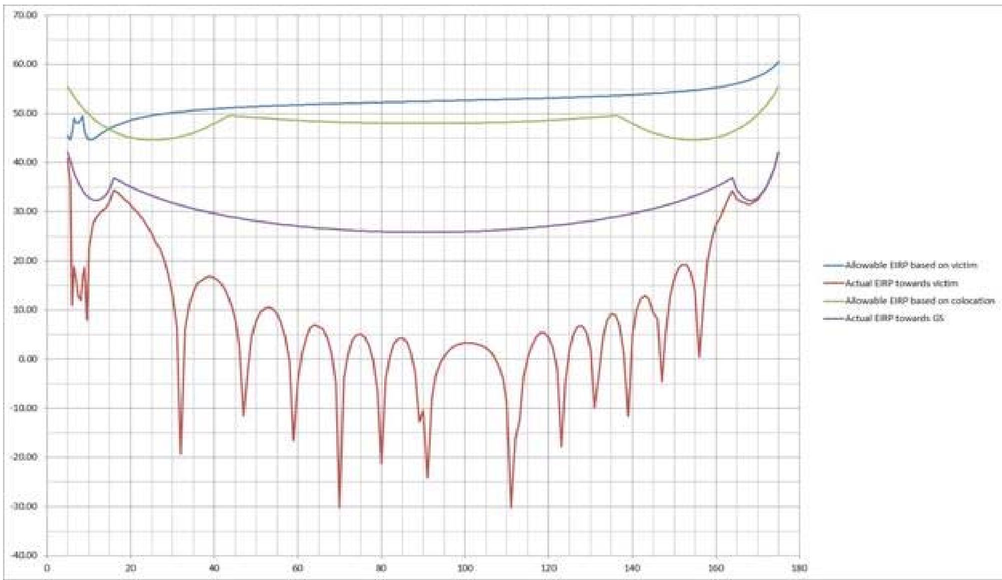


Figure 102: Derived allowable Aircraft Station e.i.r.p. compared to actual e.i.r.p. from beamforming DA2GC aircraft at 10 km altitude. Victim co-located and in single entry worst case location (78 km offset from DA2GC GS)

It can be seen In Figure 102 that the co-location margin of 10 dB originally indicated in Figure 99 is also shown here as is the offset margin of 5 dB from Figure 101.

3. Aggregation effects

The interference statistics generated by a single aircraft and twelve aircraft supported by a single DA2GC Ground Station (where the ITS terminal is assumed to be co-located) are shown in Figure 103 for aircraft at 10 km altitude (results are virtually identical for other altitudes because of DA2GC ATPC).

Comparable statistics are shown in Figure 104 for the case where the victim is offset from the DA2GC Ground Station. This offset represents the location where the worst case level of single entry interference is experienced by the victim: -96 dBm (Figure 103) compared with -101 dBm (Figure 104).

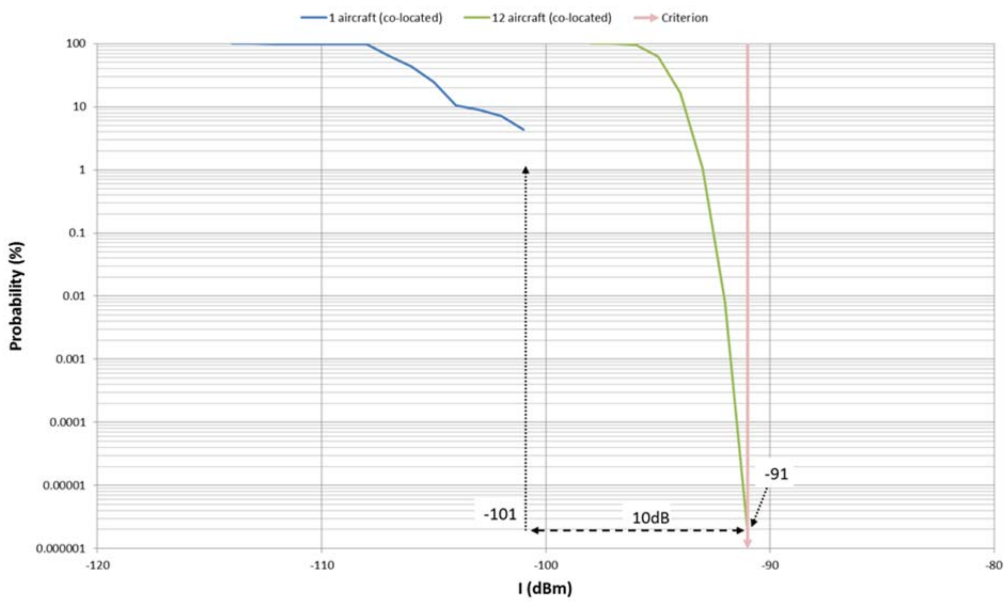


Figure 103: ITS interference statistics with respect to 1 and 12 DA2GC aircraft (the co-located case)

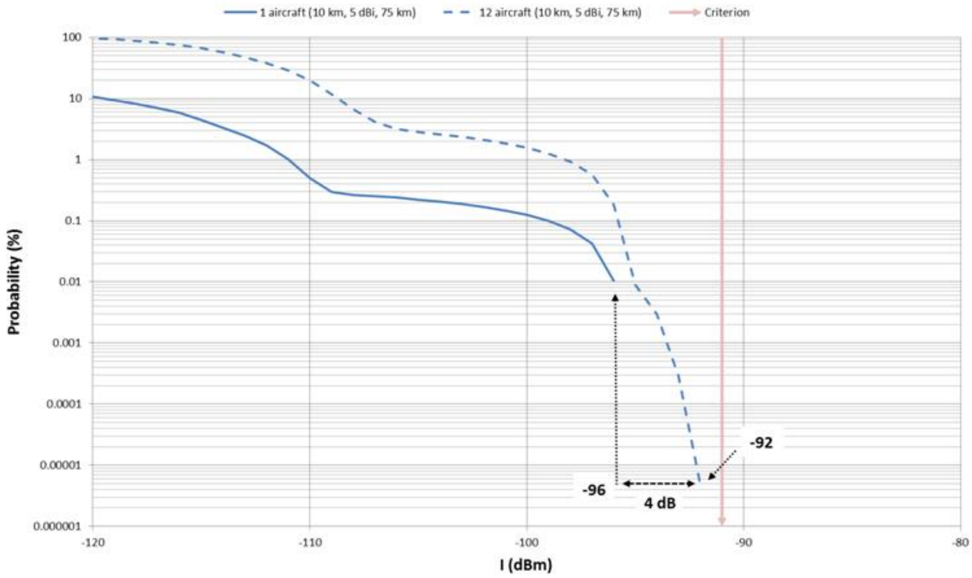


Figure 104: ITS interference statistics with respect to 1 and 12 DA2GC aircraft (the 75 km offset case)

4. Development of Aircraft Station e.i.r.p. and PFD Masks

In order to develop masks which can be specified at any point on the ground, the worst case location graphs need to be rescaled so that the x-axis represents the elevation at the victim rather than the elevation at the DA2GC Ground station. This results in the extensive interference variations due to the aircraft lobes (evenly spread across Figures 3 and 4) becoming bunched-up towards the right hand side of the graph – noting that for the co-located case no aircraft antenna discrimination comes into play.

The proposed aircraft e.i.r.p. mask is then shown in Figure 105 and Figure 107 for two aircraft heights (3 km and 10 km) and is defined mathematically in Table 41 and Table 42 respectively. The following traces are shown in each graph:

Green = the allowable aircraft e.i.r.p. towards the ITS victim (i.e. maximum level which just meets the ITS protection criterion) where the victim is in the worst case location which is 74 km away from the DA2GC Ground Station in the direction towards the aircraft. This is also the point when the aircraft is at 5 degrees elevation with respect to the DA2GC Ground Station (i.e. when it first switches on its transmission) and 20 degrees elevation with respect to the ITS victim.

Maroon = the actual/operational aircraft e.i.r.p. towards the ITS victim when then ITS victim is co-located with the DA2GC Ground Station. i.e. the ITS victim is always on the boresight of the aircraft antenna and there is no variation in the received interference due to the aircraft antenna pattern, but only due to the ITS antenna pattern, DA2GC Ground Station antenna pattern and variation in path length/loss as the aircraft traverses its route.

Purple = the actual/operational aircraft e.i.r.p. towards the ITS victim when then ITS victim is in the worst-case location (74 km away from the DA2GC Ground Station as above). i.e. variation in interfering signal level at the ITS victim is due to off-beam changes in the aircraft antenna pattern, as well as the changes due to the ITS antenna pattern, DA2GC Ground Station antenna pattern and variation in path loss.

Light blue = the proposed e.i.r.p. mask which encompasses both the co-located and offset cases. It closely matches the actual e.i.r.p. profile of the DA2GC Aircraft Station for the co-located case (Maroon) and encompasses the worst case (Purple) where this exceeds co-located values.

Dark blue = the PFD mask of Figure 109 converted to an equivalent e.i.r.p. mask. This is mostly obscured by the proposed e.i.r.p. mask as they are closely equivalent.

Constructing an e.i.r.p. mask (light blue) that encompasses both the ITS co-located case (maroon) and the ITS worst case location (purple), and at the same time falls within ITS allowable levels (green), means that the proposed mask covers all locations.

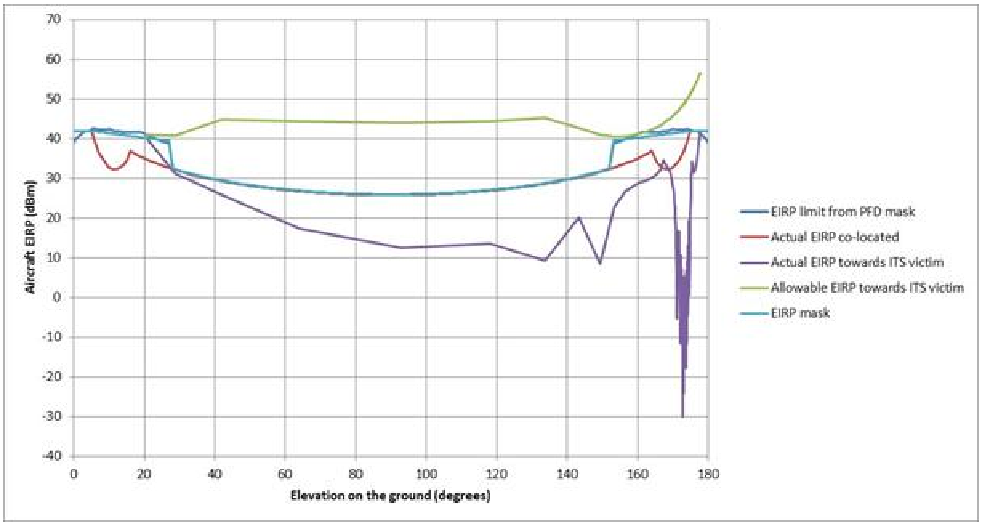


Figure 105: Derivation of Aircraft e.i.r.p. mask (10 km altitude)

Table 41: Suitable Aircraft e.i.r.p. mask (10 km altitude) (Light blue trace in Figure 105 above)

Elevation at ground (degrees)	Aircraft e.i.r.p. (dBm)	Note
0 to 5 degrees	42	
5 to 27 degrees	42 to 39.5	Straight line interpolation
27 to 28 degrees	39.5 to 32.5	Straight line interpolation
28 to 90 degrees	$-65 + 10 \log 4\pi d^2$	where: $d = \sqrt{(R^2 + (R + h)^2 - 2R(R + h)\cos\alpha)}$ in metres $\alpha = 90 - \sin^{-1}(R\cos(El)/(R + h)) - El$ in degrees where El = Elevation at ground (in degrees) $R = 6371*10^3$ m $h = 10^4$ m

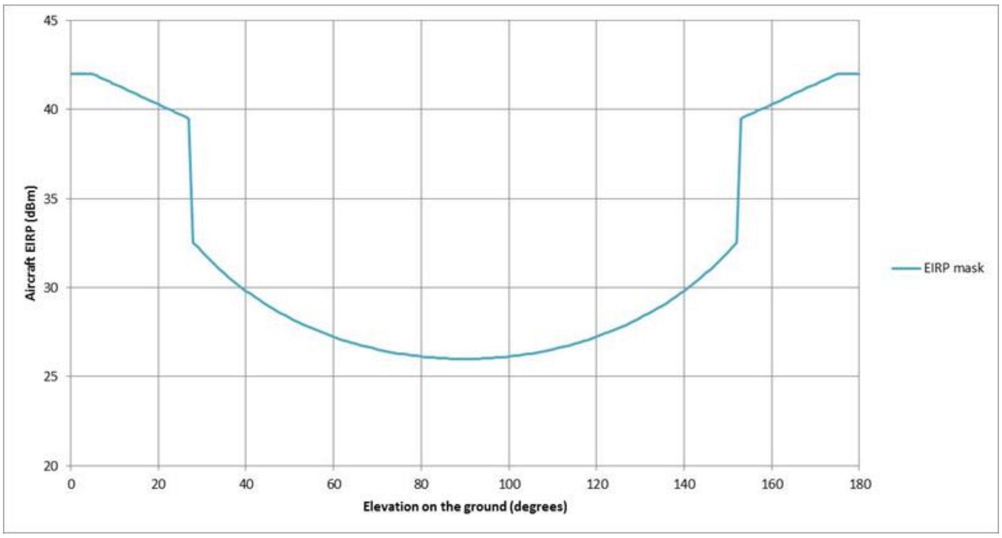


Figure 106: Suitable Aircraft e.i.r.p. mask (10km altitude)

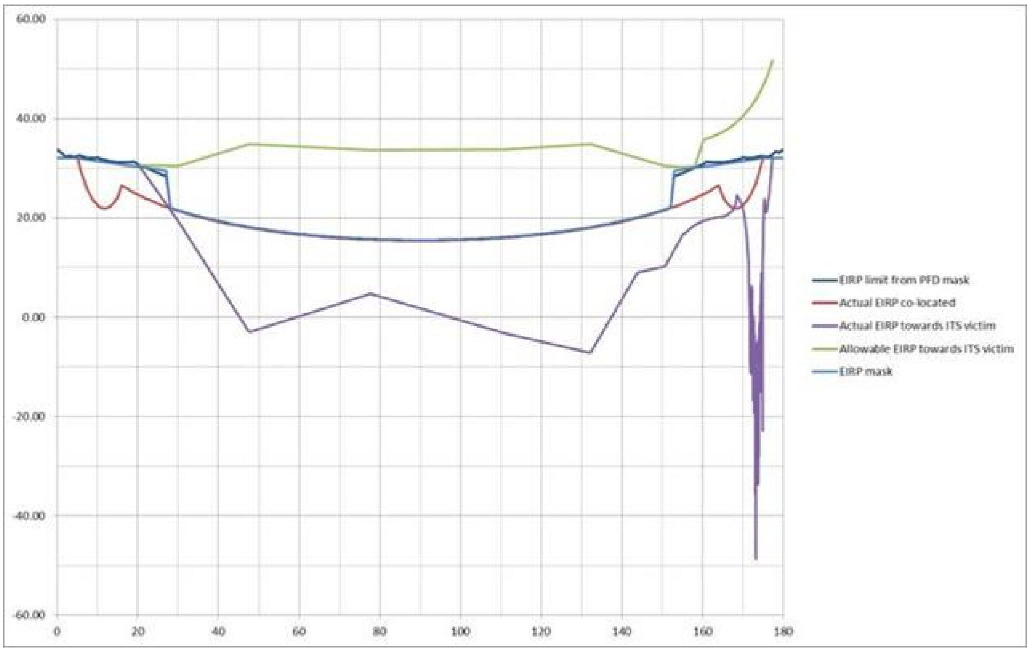


Figure 107: Derivation of Aircraft e.i.r.p. mask (3 km altitude)

Table 42: Suitable Aircraft e.i.r.p. mask (3 km altitude) – light blue trace in Figure 107 above

Elevation at ground (degrees)	Aircraft e.i.r.p. (dBm)	Note
0 to 5 degrees	32	
5 to 27 degrees	32 to 29.5	Straight line interpolation
27 to 28 degrees	29.5 to 22.1	Straight line interpolation
28 to 90 degrees	$-65 + 10 \log 4\pi d^2$	Where: $d = \sqrt{(R^2 + (R + h)^2 - 2R(R + h)\cos\alpha)}$ in metres $\alpha = 90 - \sin^{-1}(R\cos(El)/(R + h))$ –

Elevation at ground (degrees)	Aircraft e.i.r.p. (dBm)	Note
		El in degrees Where El = Elevation at ground (degrees) R = 6371*10^3 m h = 3*10^3 m

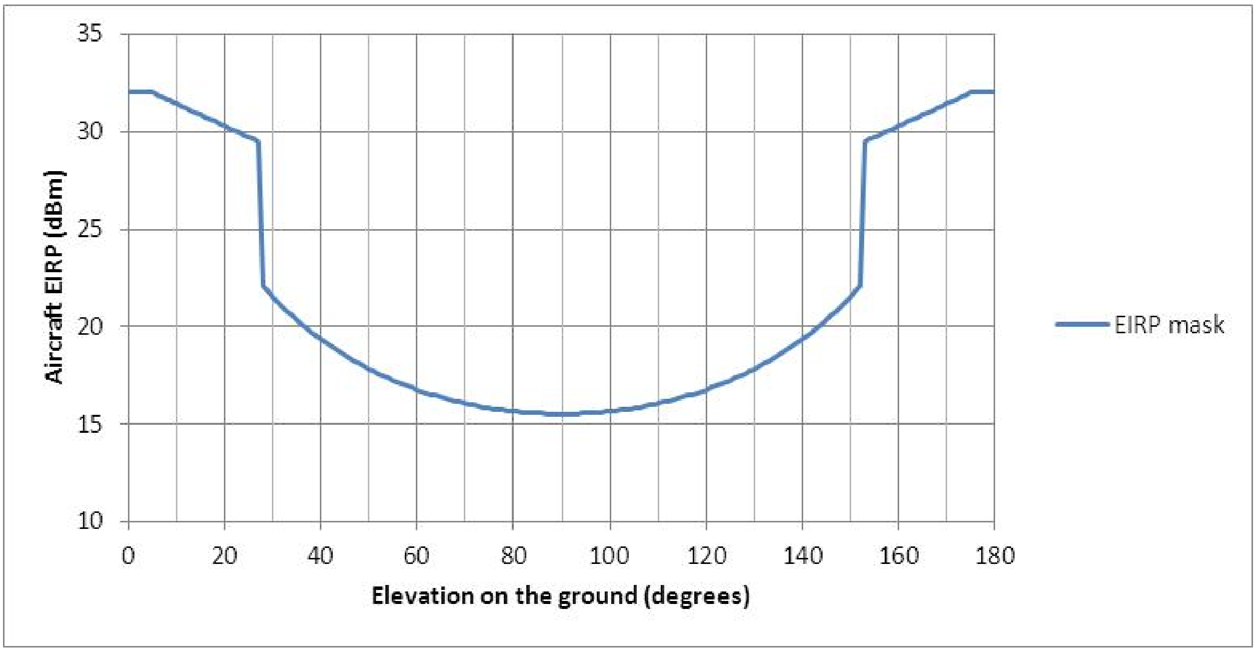


Figure 108: Suitable Aircraft e.i.r.p. mask (3km altitude)

An alternative means of defining the mask, which offers equivalent protection to ground based systems, is a ground related PFD mask, as illustrated in Figure 109.

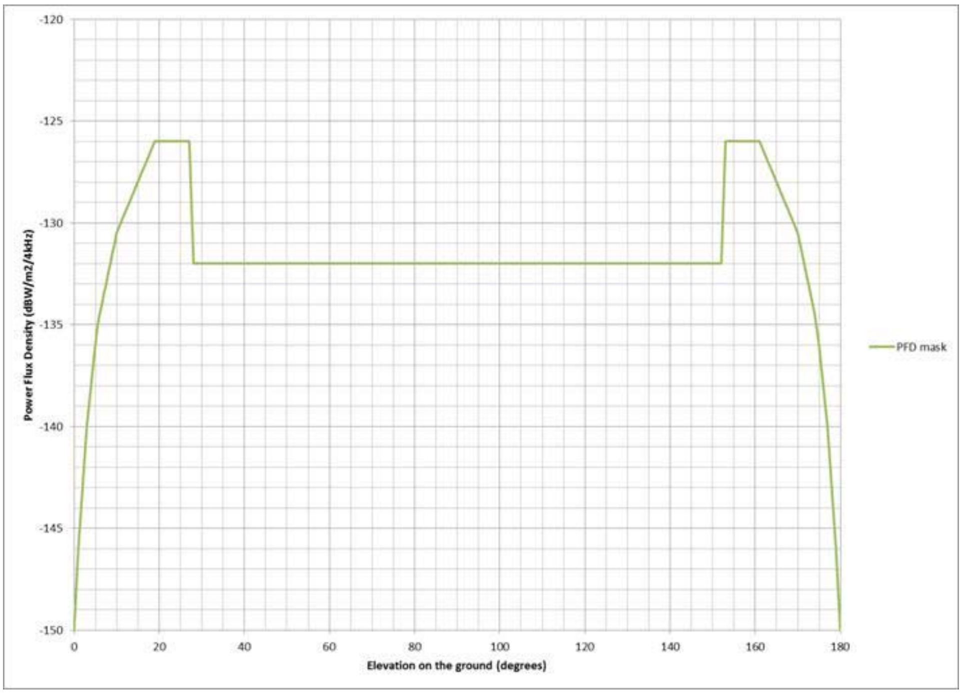


Figure 109: Suitable Aircraft PFD mask

The above graph is made up of a number of straight line segments and is symmetrical about 90 degrees. The breakpoints are defined as follows:

0 degree	-150 dBW/m^2/4kHz
1 degree	-146
3 degrees	-138
5.5 degrees	-135
10 degrees	-130.5
19 degrees	-126
27 degrees	-126
28 degrees	-132
90 degrees	-132

5.4.2.6 Additional simulations based on the proposed pfd and e.i.r.p. masks for the AS

Different simulation methods can be used to investigate compatibility performance. In these simulations it was the intention to find the worst interference cases of the ITS communication. ITS radios will in a near future be mounted in each vehicle and there will be millions of ITS radios spread all over Europe. Because of the large amount of ITS radios there will always be some ITS radios positioned in the worst geographical position were the maximum DA2GC signals touch the ground.

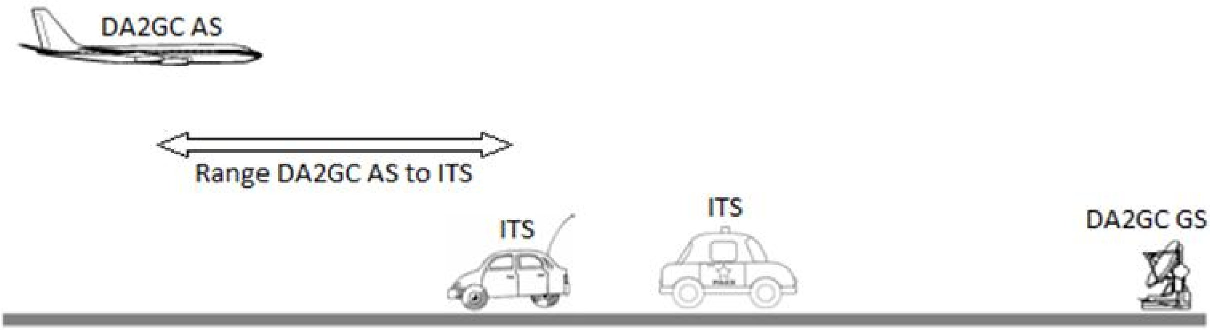


Figure 110: Interference scenario

The figure above illustrates the assumed worst scenario. A receiving ITS victim is placed in the communication line between DA2GC AS and GS. The simulations tries to find out at what distance the strongest DA2GC AS signal is received in the ITS receiver.

The maximum sensitivity is required at BPSK coding rate ½ with a minimum sensitivity of -85 dBm. Because the bandwidth is 10 MHz this corresponds to a sensitivity of -95 dBm/MHz. The protection criteria are for road safety channels 12 dB and for the other channels 6 dB. This results in the following receiver interference thresholds:

5855-5875 MHz -101 dBm/MHz

5875-5905 MHz -107 dBm/MHz

5905-5925 MHz -101 dBm/MHz

The propagation model from ECC Report101 was used for ground to ground propagation.

$$L_{FS} = \begin{cases} 20Log\left(\frac{\lambda}{4\pi d}\right) & d \le d_0 \\ 20Log\left(\frac{\lambda}{4\pi d_0}\right) - 10n_0 Log\left(\frac{d}{d_0}\right) & d_0 < d \le d_1 \\ 20Log\left(\frac{\lambda}{4\pi d_0}\right) - 10n_0 Log\left(\frac{d_1}{d_0}\right) - 10n_1 Log\left(\frac{d}{d_1}\right) & d > d_1 \end{cases}$$

Table 43: Propagation parameter

	Urban	Suburban	Rural
Breakpoint distance d_0 (m)	64	128	256
Pathloss factor n_0 beyond the first break point	3.8	3.3	2.8
Breakpoint distance d_1 (m)	128	256	1024
Pathloss factor n_1 beyond the second breakpoint	4.3	3.8	3.3

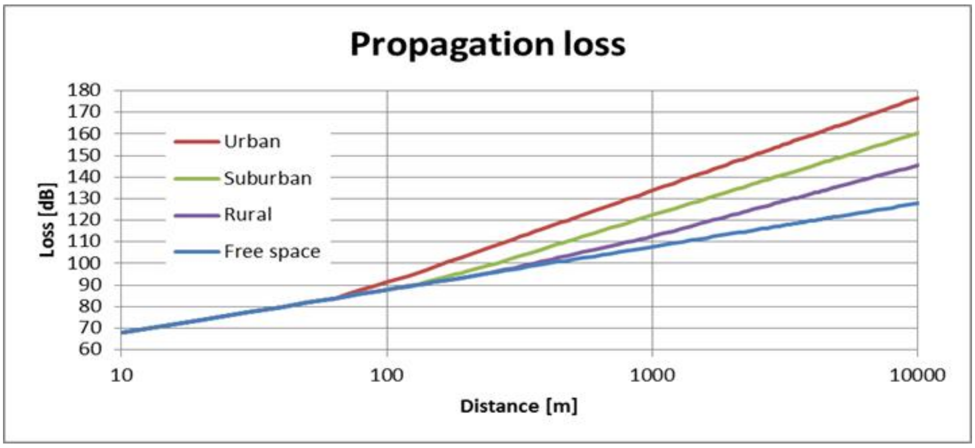


Figure 111: Propagation loss

The system parameters used in these simulations are not the same as described in the original ETSI TR 101 599, the parameters used are presented below.

Frequency range: 5855 - 5875 MHz

Transmitter bandwidth 20 MHz

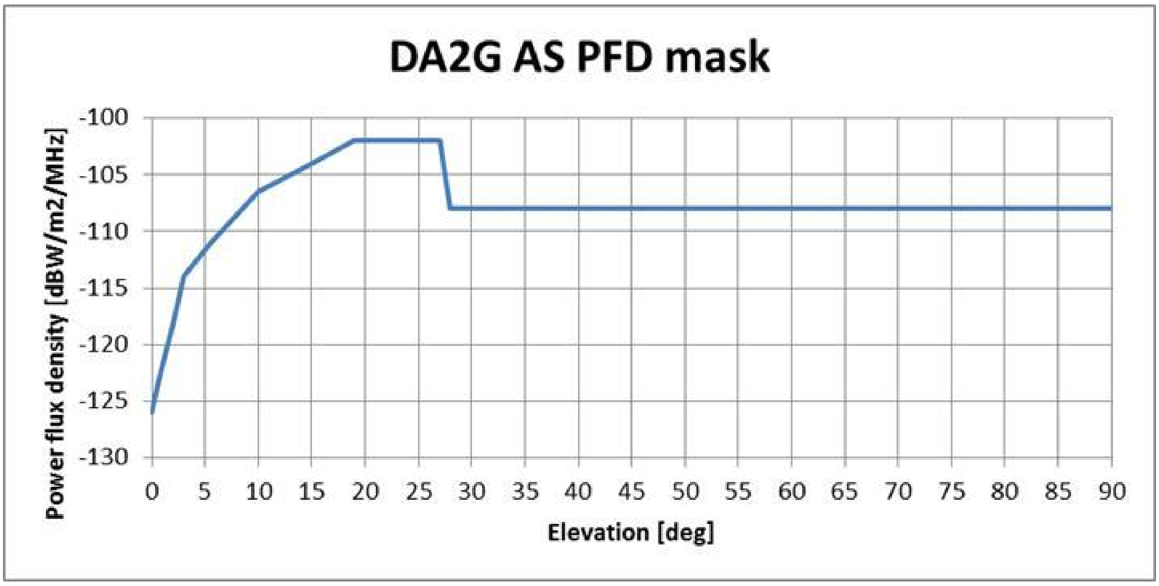


Figure 112: Proposed PFD mask

The output power is defined by a power flux density mask shown in the figure above.

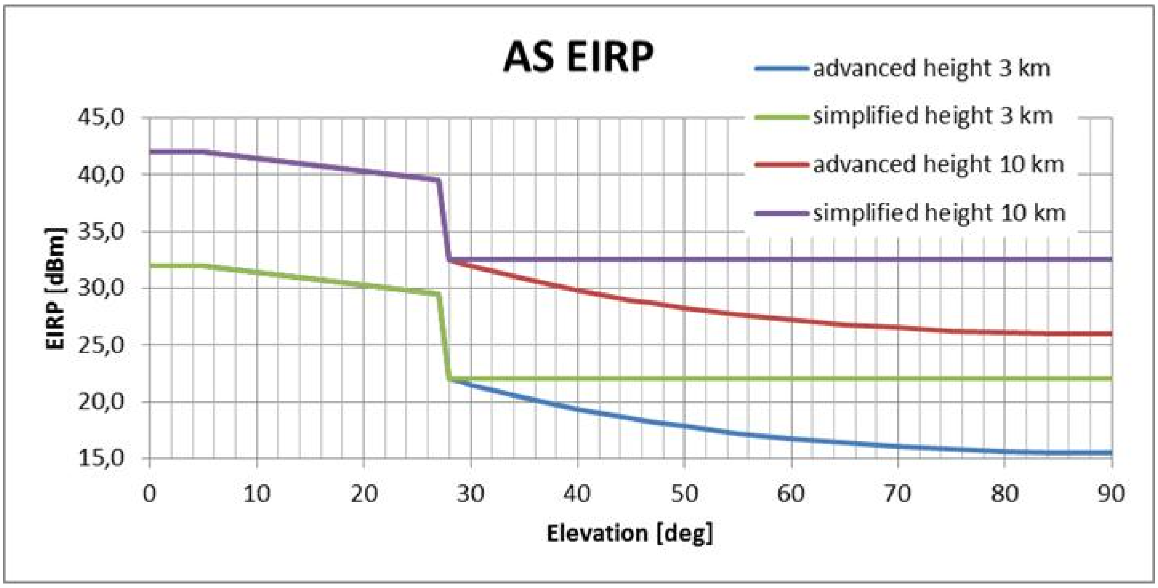


Figure 113: Proposed e.i.r.p. masks

It is assumed the maximum allowed flight height is 12 km.

Each ground station can simultaneously receive transmissions from 3 aircrafts in a quadrant sector. In total the ground station can simultaneously receive transmissions from 12 aircrafts.

1. Inband simulations 5855 - 5875 MHz with pfd mask

The following graphs shows simulation results at different flight heights.

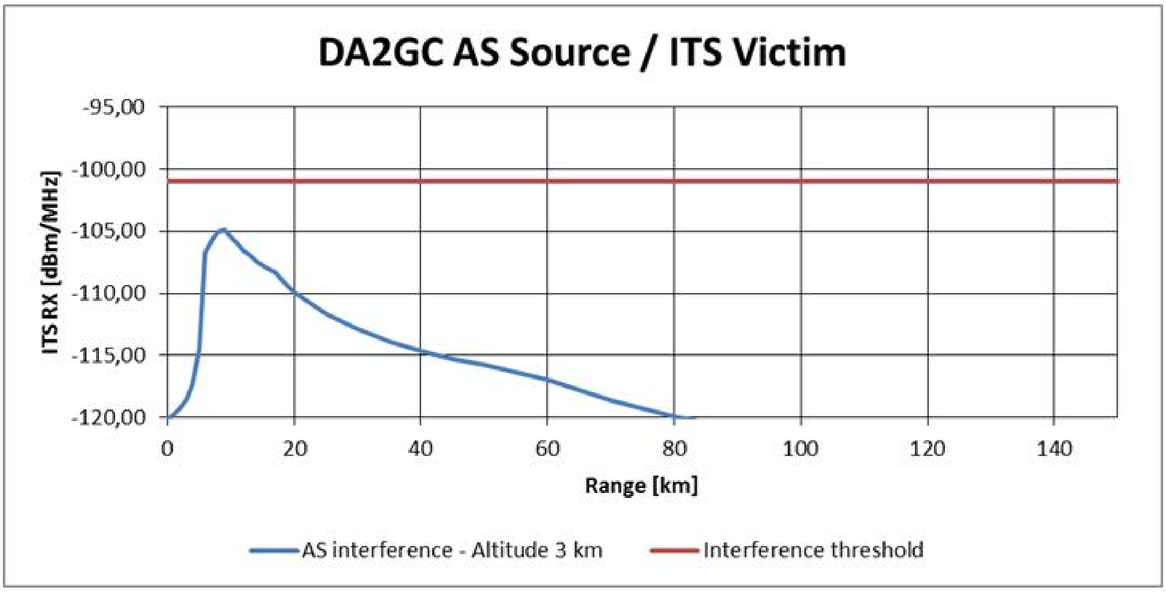


Figure 114: DA2GC AS Source / ITS Victim (Aircraft altitude 3 km)

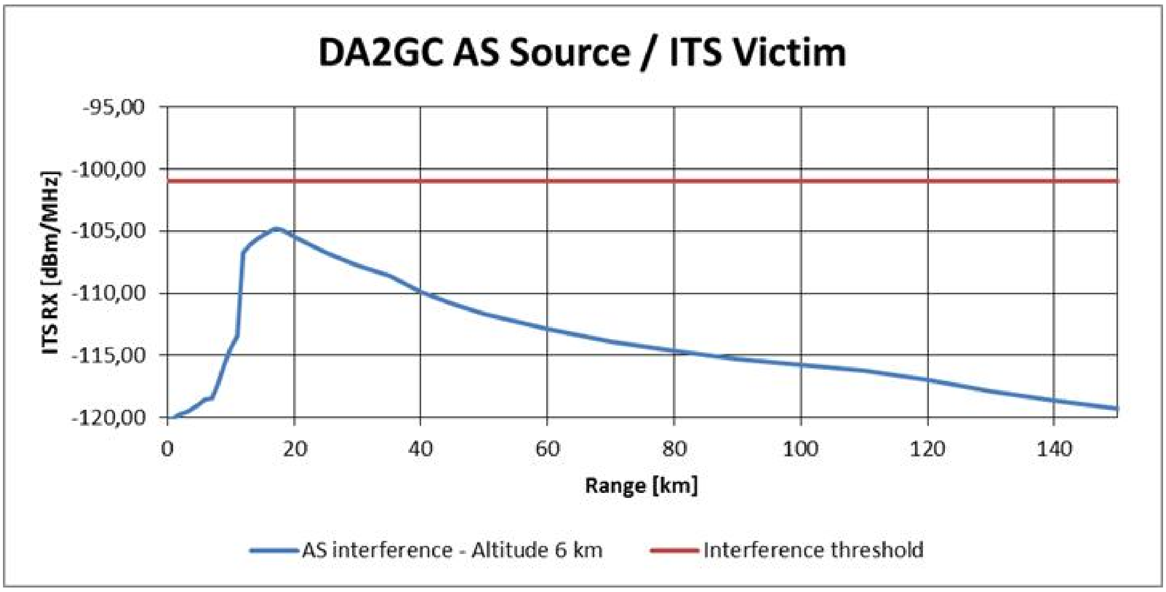


Figure 115: DA2GC AS Source / ITS Victim (Aircraft altitude 6 km)

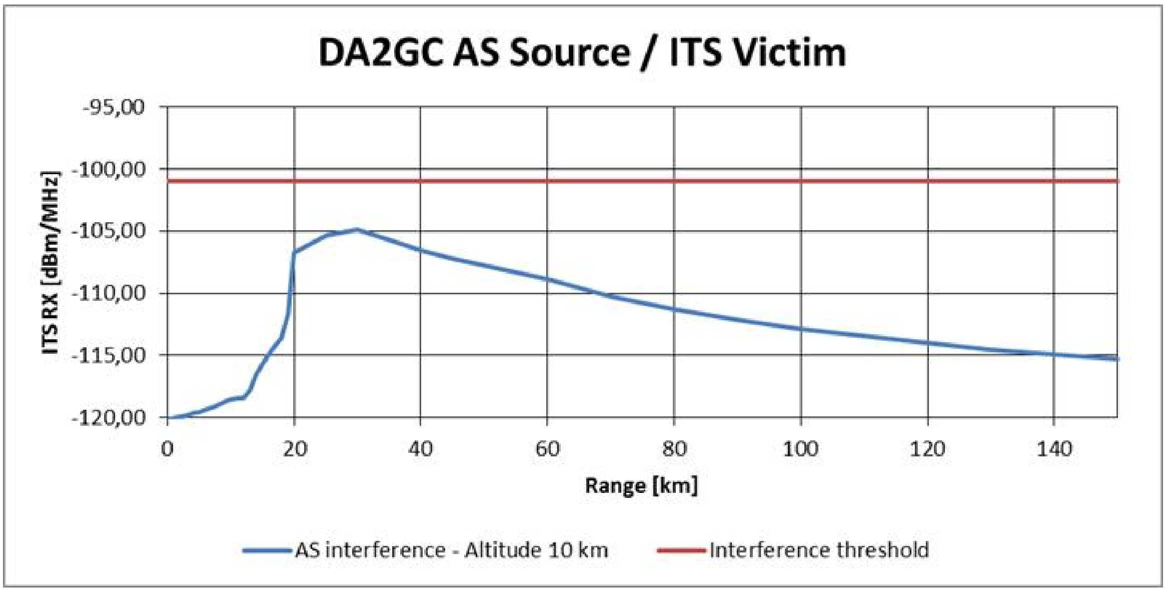


Figure 116: DA2GC AS Source / ITS Victim (Aircraft altitude 10 km)

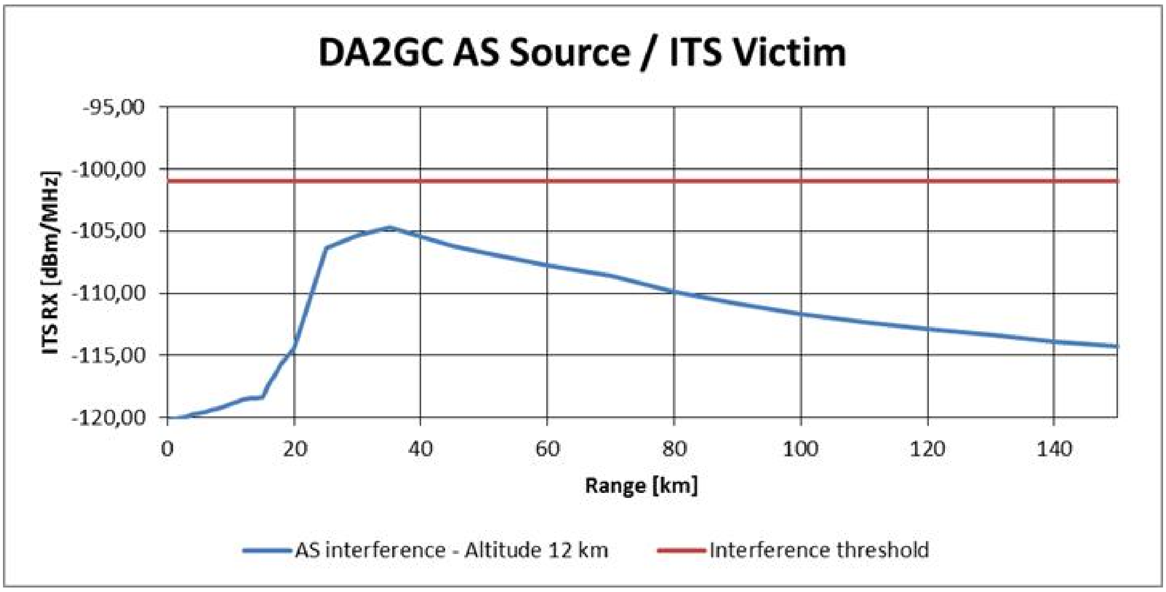


Figure 117: DA2GC AS Source / ITS Victim (Aircraft altitude 12 km)

2. Inband simulations 5855 - 5875 MHz with e.i.r.p. masks
The following graphs shows simulation results at different flight heights.

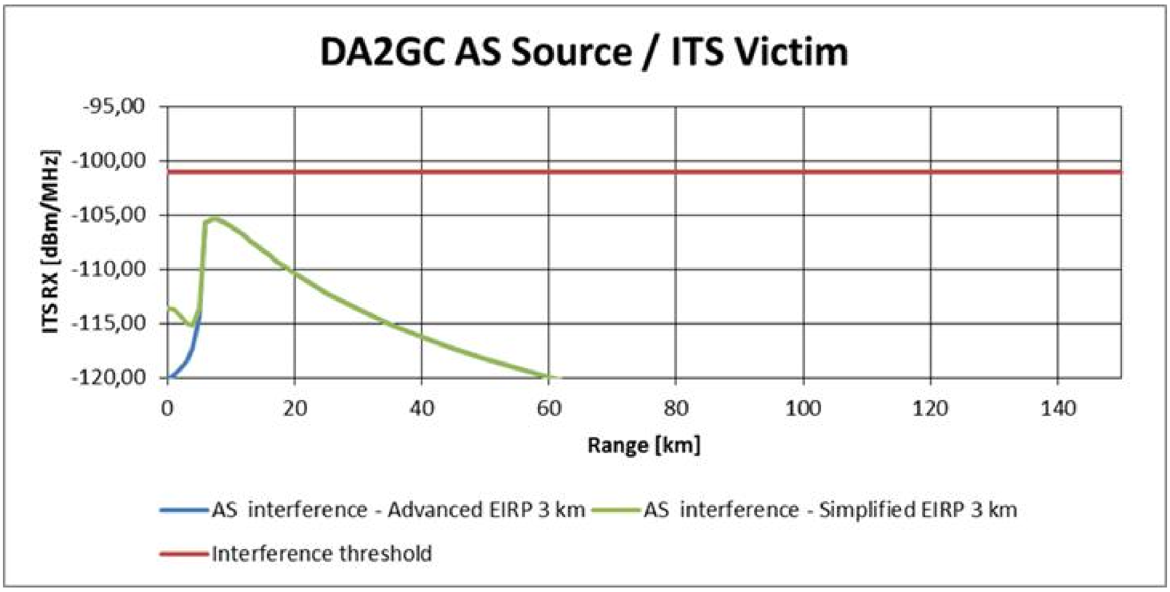


Figure 118: DA2GC AS Source / ITS Victim (Aircraft altitude 3 km)

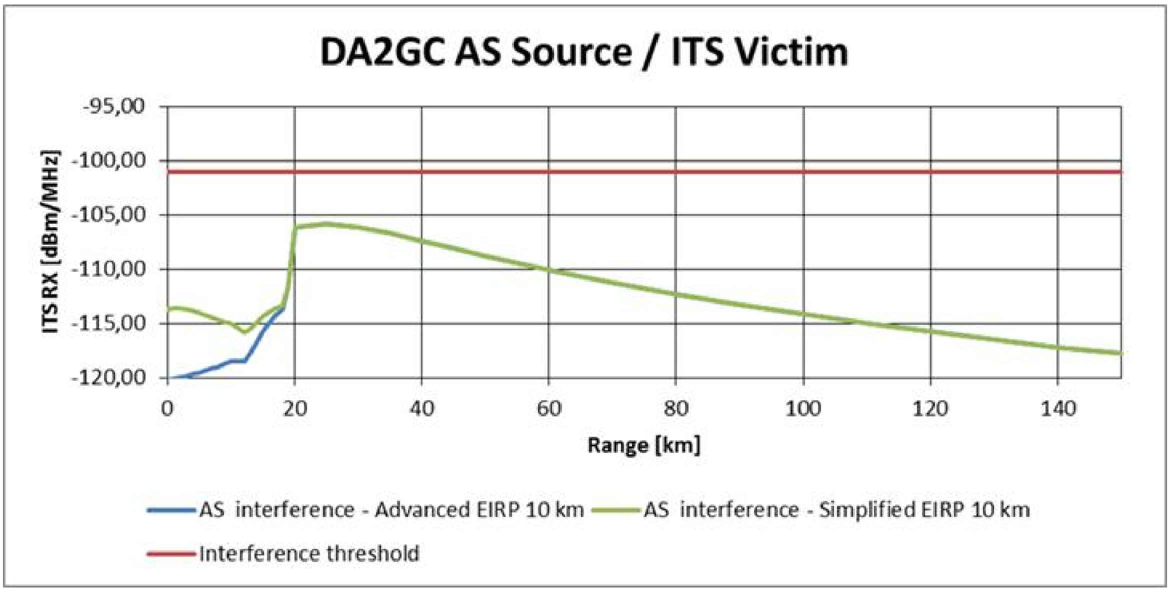


Figure 119: DA2GC AS Source / ITS Victim (Aircraft altitude 10 km)

3. Out of band simulations 5875 - 5925 MHz

The ITS channels 5875 – 5905 have 6 dB harder interference criteria. However the unwanted emissions are 40 dB less. Therefore the margin for interference from the DA2GC AS is 34 dB higher.

4. Aggregation effects

The ground station can communicate with 3 airplanes in each quadrant, in total 12 airplanes. The contribution from each of the 12 DA2GC AS into one ITS receiver can result in a stronger interference signal. The sum of interference depends on the positions of the 12 airplanes, individual output power, individual transmitter direction and individual distance to the ITS receiver.

Figure 120: Typical distribution of airplanes

The figure above shows a typical map of airplanes, it was recorded with www.flightradar24.com at 16:38 the 30 July 2013. Studying this map we can observe some interesting observations:

- The airplanes are flying typically in a long straight line (flight corridors).

- At some points the planes are leaving/arriving from different directions (crossing flight corridors).

Based on these observations we could do some assumptions:

It is not unlikely that an ITS victim will be positioned under a flight corridor and the DA2GC GS is close to the fight corridor. If this happens it is likely that the ITS receiver will receive interference from 6 DA2GC AS transmitters, 3 AS from one side and 3 from the opposite side.

But how much does each AS contribute? The simulation results from earlier chapter shows an interference margin of 4 dB with one airplane at distances DA2GC AS – ITS receiver between 30 to 40 km at flight height 12000 m. Outside this area the signal strength drops dramatic and because of this we only need to take care about the AS inside this 30 to 40 km distance.

There is a probability that two AS will be in this 30 to 40 km distance. This will result in a 3 dB stronger interference signal and we will achieve a margin of 1 dB. The possibility that 3 AS are in the 30 to 40 km distance at the same time is probably very small.

Now assume the ITS victim is close to the GS. We could receive interference from two AS from one side of the GS and two from the opposite side. This will end up in 6 dB more interference signal and with 2 dB to little margin.

In the case there is a DA2GC GS close to crossing flight corridors then according to our earlier discussions we could theoretically receive interference from 8 AS, two in each direction. However this very special case have not been studied further because of the low probability for placement of a GS in a flight corridor crossing, the probability that 8 airplanes (2 in each quadrant at a distance of 30 to 40 km) and also the 3 dB width of the DA2G AS antenna is only some few km wide.

5.4.2.7 Conclusions

- Out of band simulations shows no interference at all on ITS and RTTT systems.
- Calculations with the PFD and the advanced e.i.r.p. masks shows approximately the same interference level.
- The simplified e.i.r.p. mask shows higher interference level at close distances. The interference level at these distances is very low and can be neglected.
- In band simulations with single DA2GC AS shows interference is changing with the range with a minimum margin of 4 dB.
- If a DA2GC GS is placed close to a flight corridor and when the ITS victim is far away from the GS, the aggregated interference signal from two AS can sometimes result in 3 dB stronger interference signal ending up in 1 dB margin.
- When a DA2GC GS is placed close to a flight corridor and when the ITS victim is close to the GS, the simulations based on this PFD mask shows an interference with 2 dB to strong signal. In this special case the AS is only 40 km away from the GS and according to the system supplier the DA2G AS will transmit less power than according to the PFD mask and there will be no interference.
- In this study we only studied one DA2GC GS. Because the smallest margin is at a relatively close distance to the GS we could probably neglect the neighbouring GS and its associated AS contributions to the aggregate effect.

5.4.3 Compatibility between DA2GC GS (TR 101 599) and ITS/RTTT

5.4.3.1 Methodology

The analysis of interference from DA2GC ground station into ITS / RTTT systems presented here is, as before, based on minimum separation distance calculations corresponding to static interference alignments. This is very much a worst-case assumption since, in practice, the transmitted beams from the DA2GC Ground Station will be dynamically tracking the aircraft with which it is communicating, thereby introducing a further statistical element to the interference results.

Initially, it is assumed that the ITS maximum gain is pointing directly at the DA2GC ground station terminal and that the DA2GC terminal is operating at its maximum power level. In the case of the RTTT RSU it is assumed that there will be a gain of 0 dBi towards the DA2GC ground station.

On the basis of above assumptions, the minimum required path loss values have been calculated for the ITS (RTTT) interference criteria using the following equation.

Minimum Required Path Loss (dB) = DA2GC Power into antenna (dBm) + DA2GC Transmit Antenna Gain (dBi) + ITS (RTTT) Antenna Gain (dBi) – Interference Criterion (dBm)

The power into the antenna takes account of the relevant OOB suppression specified by the emission mask (Figure 11) . Bandwidth correction also needs to be applied.

Table 44: Worst case minimum path loss requirement

Config.	GS Tx (dBm)	GS antenna gain (dBi)	OOB suppression (dB)	Victim antenna gain (dBi)	Interf. Crit. (dBm)	Bandwidth correction (dBi)	Req. path loss (dB)
ITS co-frequency	24.3	-7.5 (Note 1)	0	8.0	-98.0	-3.0	119.8
ITS adjacent	24.3	0 (Note 2)	-40	8.0	-98.0	-3.0	87.3
RTTT adjacent	24.3	0 (Note 2)	-40	0	-107.0	-16.0	75.3

Note 1: Although the ground station antenna gain at 0 degrees elevation is -11.6 dBi a higher gain has been used here to reflect the slightly negative elevation angles (approaching 1.5 degrees) with respect to victim receivers around 800 metres away.
Note 2: Similarly, a residual sidelobe gain has been used here to reflect the greater negative elevation angles (more than 10 degrees) with respect to victim receivers less than 100 metres away.

The minimum required loss values shown in Table 44 above are translated into minimum required separation distances by using a multi-slope median path loss propagation model, where the loss is calculated using free space model up to 100 metres and d3.5 for distances greater than 100 m.

Table 45: ITS / RTTT separation distances required

Victim	Path loss (dB)	Distance (m)
ITS co-frequency	119.8	822
ITS adjacent	87.3	95
RTTT adjacent	75.3	24 *(Note)*

Note: For small distances such as this it is likely that the RTTT reference gain of 0 dBi will be higher at 10 dBi. The distance would then increase to 75 m.

For close distances it also needs to be determined that the RTTT OBU activation level is not exceeded by the DA2GC main emission as the OBU will likely have a wide bandwidth front end. The OBU activation level is -60 dBm. The DA2GC total transmit power is 24.3 dBm e.i.r.p. (assuming a 0 dBi antenna gain towards the OBU) and if the OBU has an antenna gain of 0 dBi then the received power is -51.1 dBm at 24 m, -61 dBm at 75 m and -63.5 dBm at 100 m. A separation distance of 75 metres is therefore required to prevent accidental OBU activation.

As for the case of victim radars (discussed in Section 5.6.3) the separation distance values calculated above have been based on the DA2GC ground station transmitting a single beam. Each ground station will on average be generating 12 simultaneous co-frequency beams and therefore one needs to take account of interfering power towards the victim ITS / RTTT receiver due to the power into the ground station antenna supporting each of these 12 beams.

As before, this is not simply a question of a x12 increase in interfering power as the beams will be distributed in terms of their pointing direction and therefore discrimination will be provided by the DA2GC ground station's overall antenna azimuth pattern and further mitigated by grating lobe nulls (discussed earlier and represented by Figure 121 below).

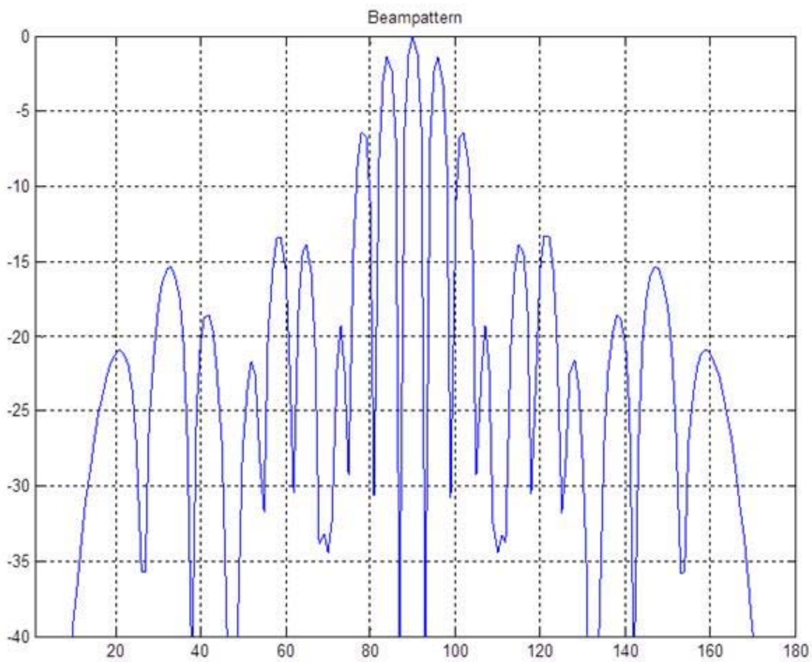


Figure 121: DA2GC ground station azimuth beam pattern for 8 element array showing grating lobes / nulls which enable interference cancellation

The additional interference power due to the aggregation of the remaining 11 beams in the direction of the victim ITS/RTTT receiver will be related to a number that fall in the grating lobe nulls (-30 dB), those that give a discrimination away from the main lobe and which are not subject to grating lobe nulling (-12 to -25 dB), and those where the victim is located behind the ground plane of the array supporting the beam (at least -30 dB).

Under these circumstances the increase in total interference power (over and above that produced by a single beam interference) towards the victim ITS / RTTT receiver will be small (of the order of 0.6 dB) and will make an insignificant difference to the separation distances calculated above.

5.4.3.2 Additional simulations based on the proposed e.i.r.p. mask for the GS

The system parameters used in these simulations are not the same as described in the original ETSI TR 101 599, the parameters used are presented below.

Frequency range: 5855-5875 MHz

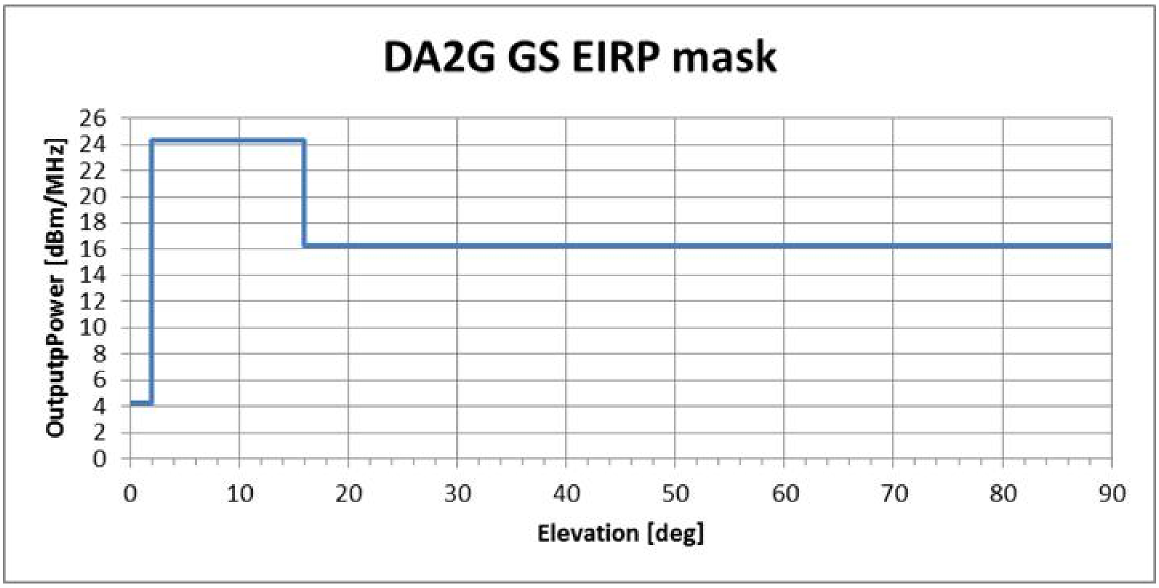


Figure 122: Proposed DA2GC e.i.r.p. mask

Height over ground DA2GC GS antenna in urban environment is assumed 30 m. Height over ground DA2GC GS antenna in rural environment is assumed 20 m.

1. In band simulations 5855 - 5875 MHz Urban and Rural environment

The following graph shows simulation results when the surroundings of DA2GC GS is flat.

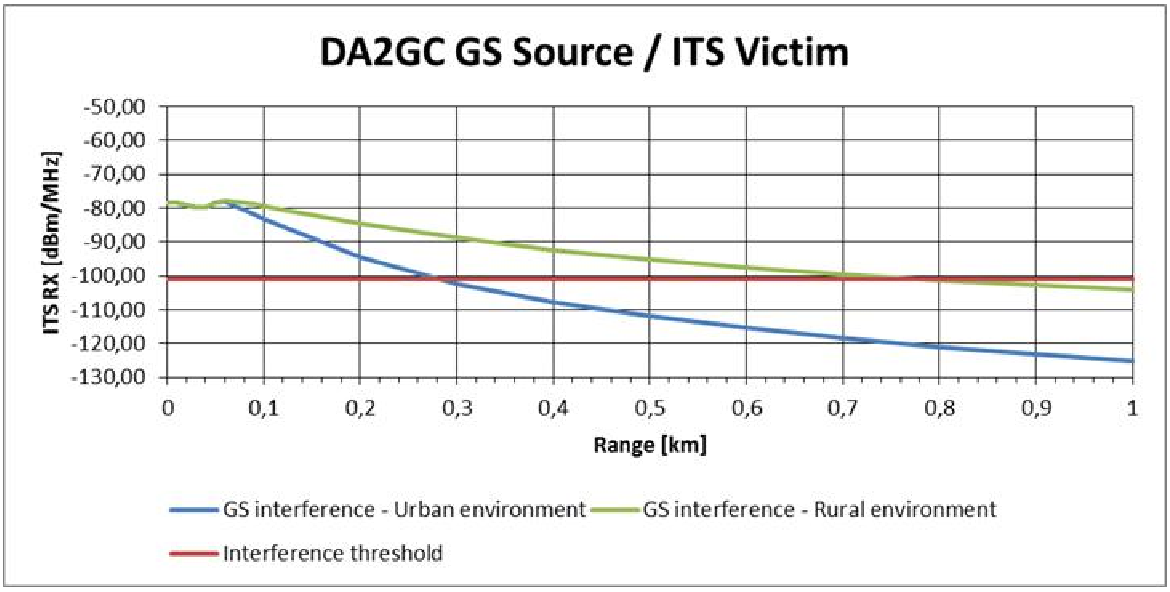


Figure 123: DA2GC GS Source / ITS Victim (Same Antenna Height)

The following Figures show simulation results when the surrounding roads of DA2GC GS are at higher altitude than the DA2GC GS.

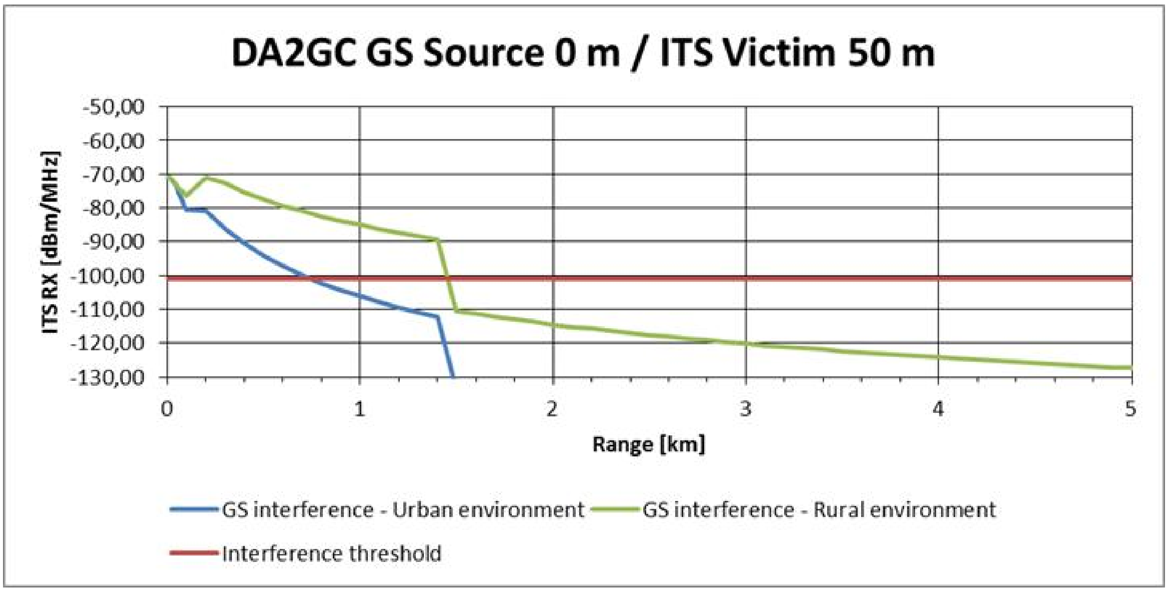


Figure 124: DA2GC GS Source / ITS Victim (ITS Antenna 50 meters above DA2GC)

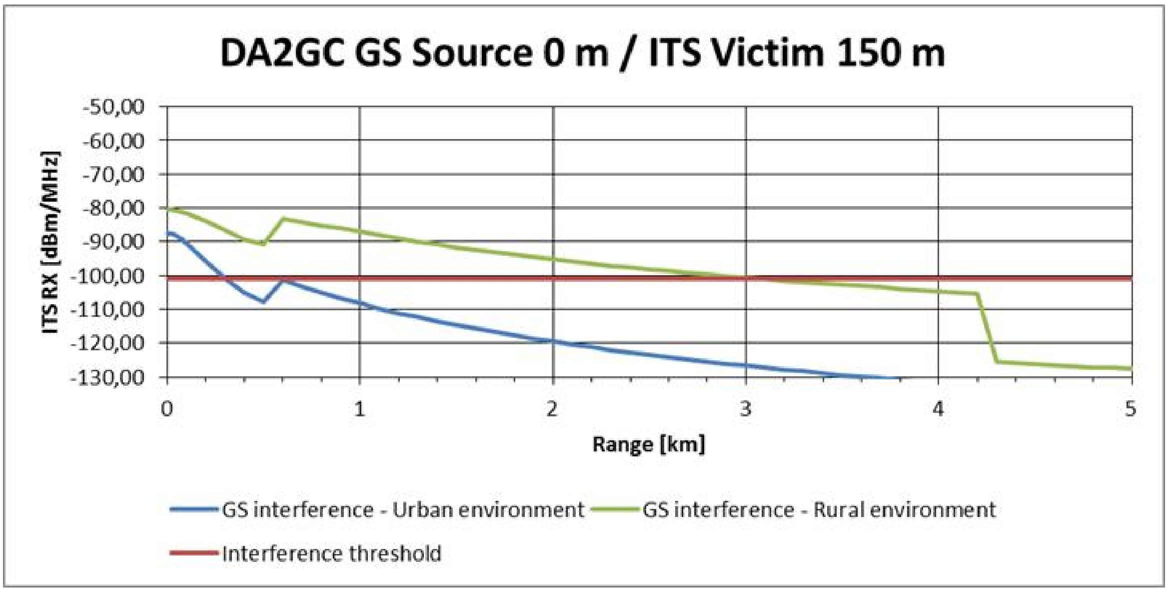


Figure 125: DA2GC GS Source / ITS Victim (ITS Antenna 150 meters above DA2GC)

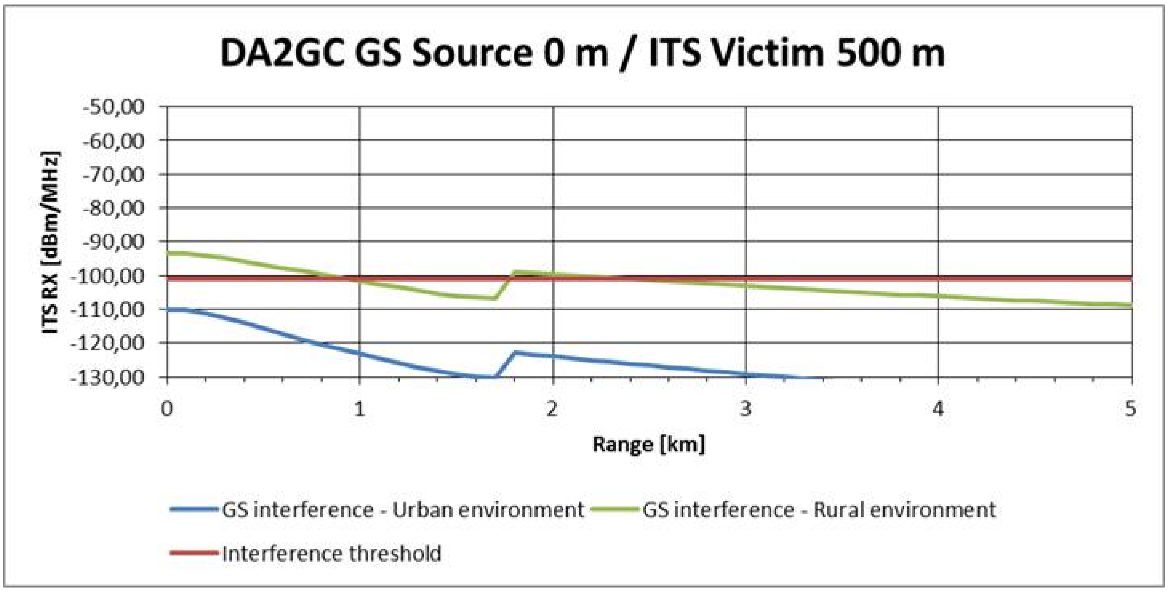


Figure 126: DA2GC GS Source / ITS Victim (ITS Antenna 500 meters above DA2GC)

5.4.3.3 Conclusions

Out of band simulations show no interference at all on ITS and RTTT systems.

- Out of band simulations show no interference at all on ITS and RTTT systems
- In band simulations show a required separation distance of 300 m for urban environment and 700 m for rural environment.
- In urban environment the required separation distance is 800 m when the road is 50 m above the GS antenna. In rural environment the required separation distance is 3 km when the road is 150 m above the GS antenna.

5.4.4 Compatibility between DA2GC AS (TR 103 108) and ITS

5.4.4.1 Methodology

The unwanted interference has been calculated according to the following equation:

$$Interfering\ Signal = Eirp_{Source} - AS_{Mitigation}] - Loss_{Prop} + Antenna\ Gain_{Rx}$$

5.4.4.2 Results

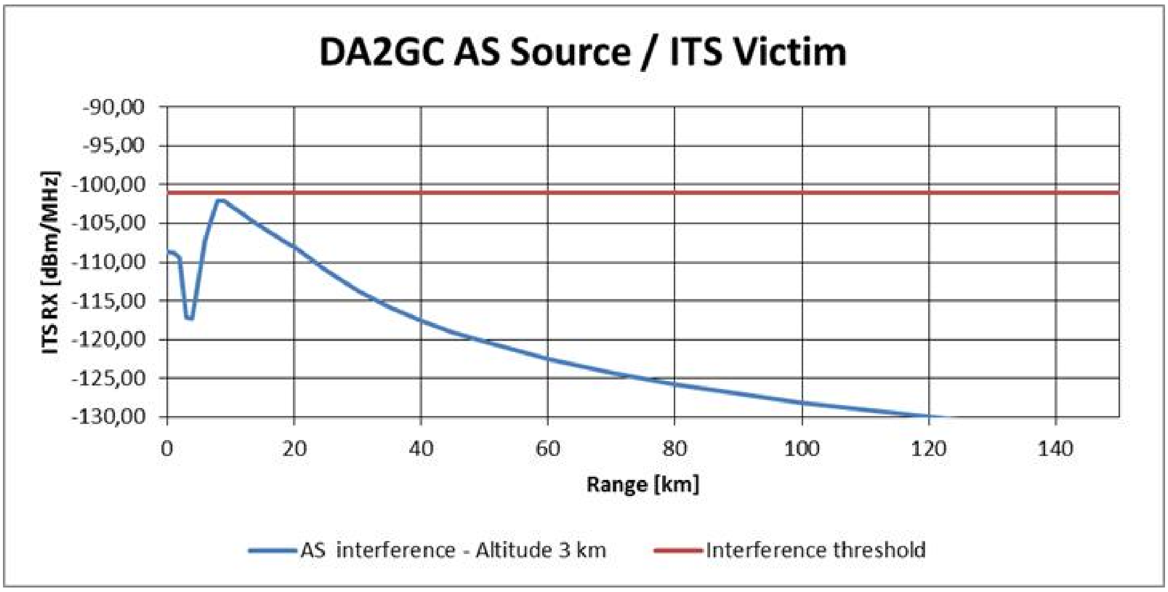


Figure 127: DA2GC AS Source (3 km) / ITS Victim

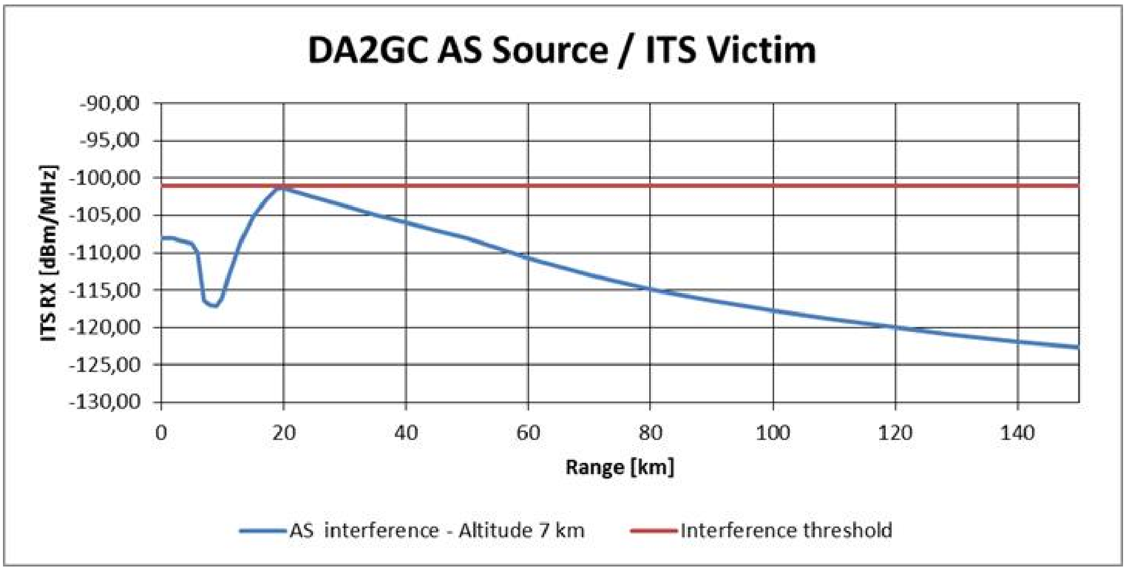


Figure 128: DA2GC AS Source (7 km) / ITS Victim

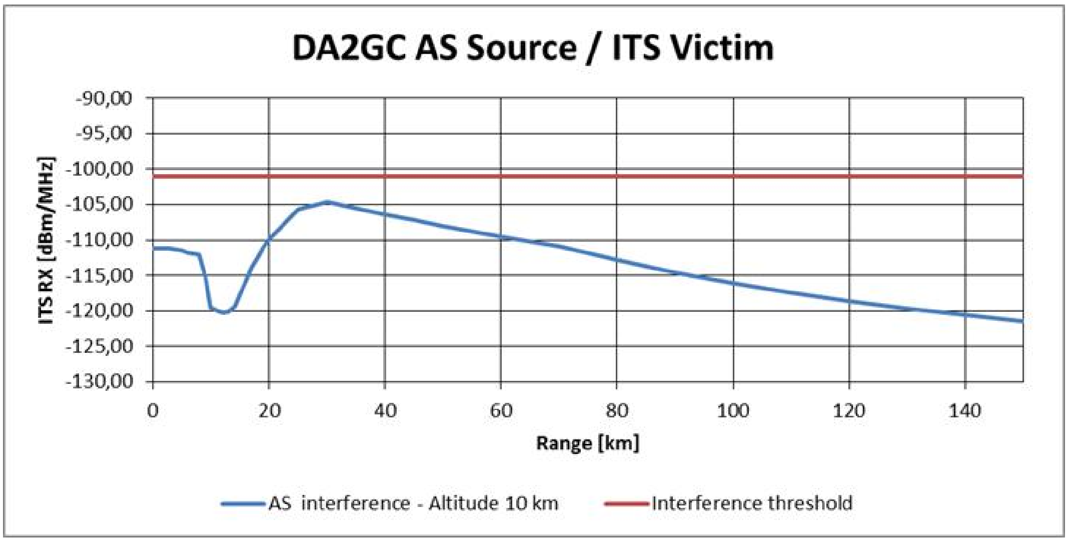


Figure 129: DA2GC AS Source (10 km) / ITS Victim

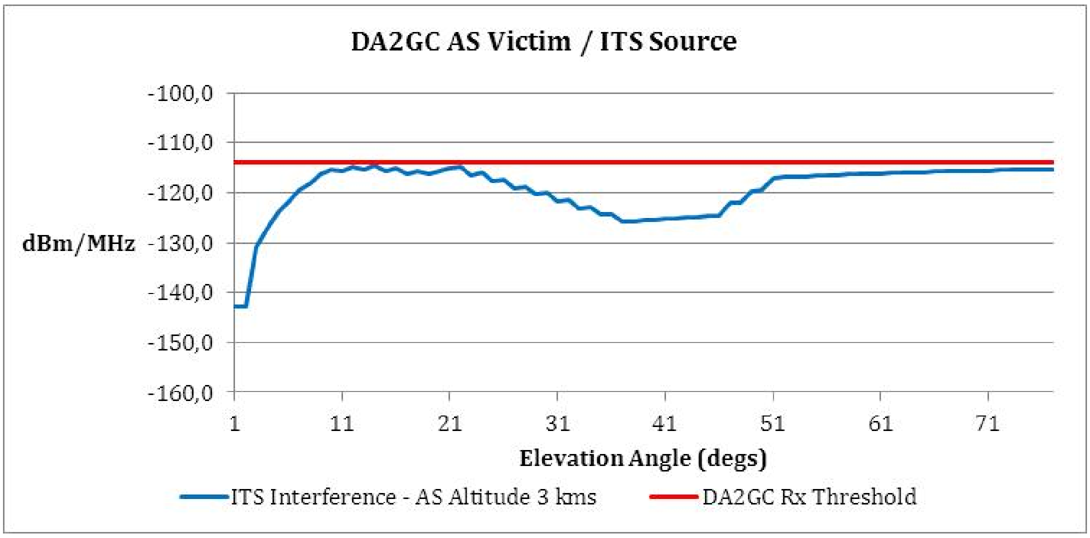


Figure 130: DA2GC AS Victim (3 km) / ITS Source

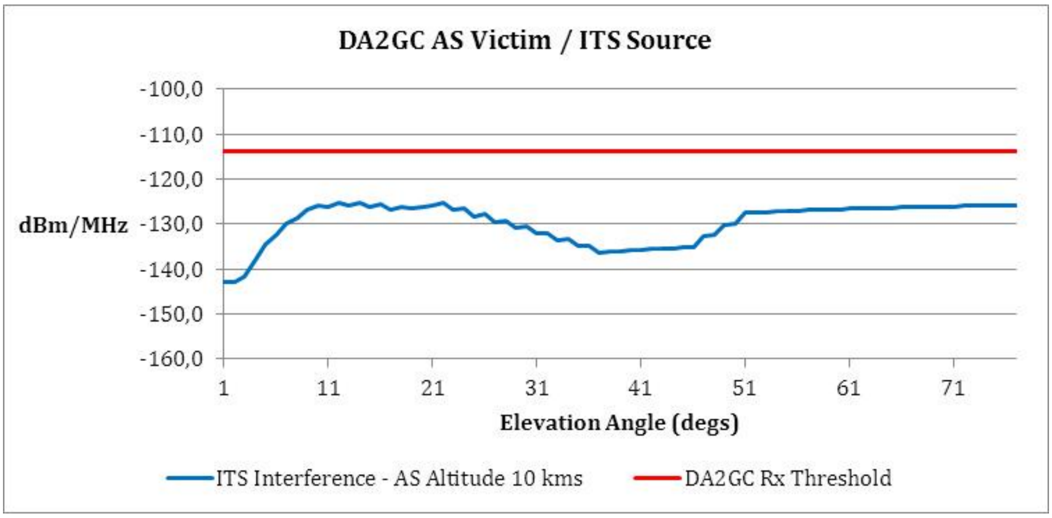


Figure 131: DA2GC AS Victim (10 km) / ITS Source

The results for the DA2GC AS demonstrate that:

- Out of band and in-band simulations show no interference to ITS systems.
- The interference received from ITS systems is significantly less than the DA2GC AS limit.

5.4.5 Compatibility between DA2GC GS (TR 103 108) and ITS

5.4.5.1 Methodology

The propagation model from ECC Report101 was used for ground to ground propagation.

$$L_{FS} = \begin{cases} 20Log\left(\frac{\lambda}{4\pi d}\right) & d \le d_0 \\ 20Log\left(\frac{\lambda}{4\pi d_0}\right) - 10n_0 Log\left(\frac{d}{d_0}\right) & d_0 < d \le d_1 \\ 20Log\left(\frac{\lambda}{4\pi d_0}\right) - 10n_0 Log\left(\frac{d_1}{d_0}\right) - 10n_1 Log\left(\frac{d}{d_1}\right) & d > d_1 \end{cases}$$

Table 46: Propagation parameter

	Urban	Suburban	Rural
Breakpoint distance d_0 (m)	64	128	256
Pathloss factor n_0 beyond the first break point	3.8	3.3	2.8
Breakpoint distance d_1 (m)	128	256	1024
Pathloss factor n_1 beyond the second breakpoint	4.3	3.8	3.3

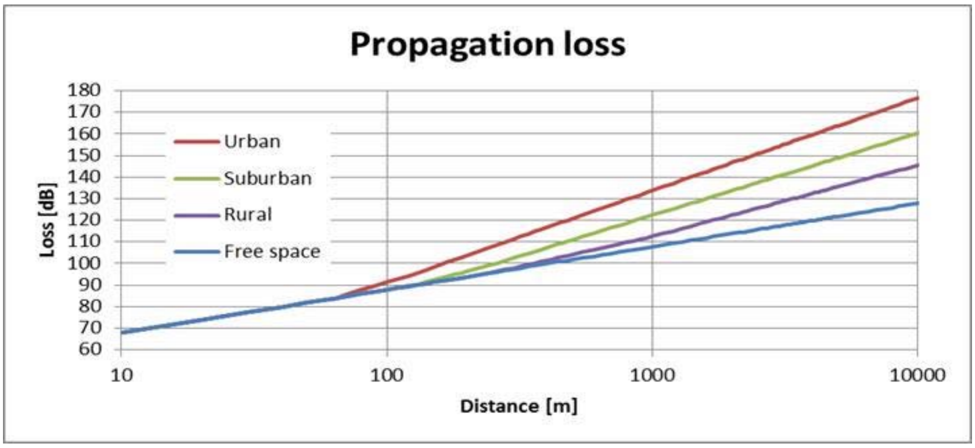


Figure 132: Propagation loss

5.4.5.2 Results

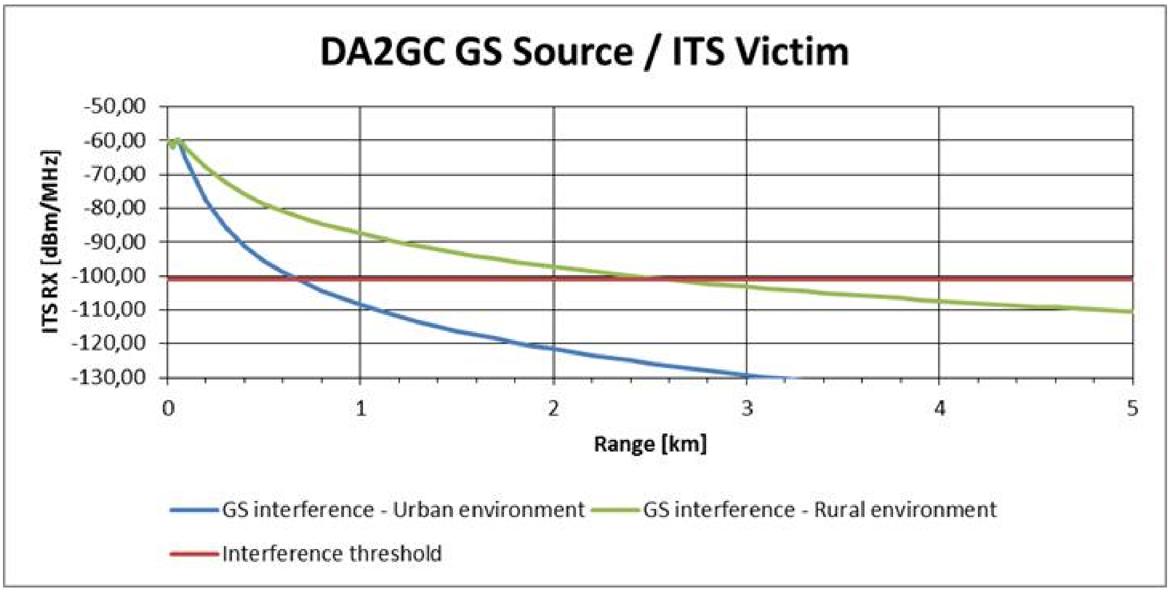


Figure 133: DA2GC GS Source / ITS Victim (Same Antenna Height)

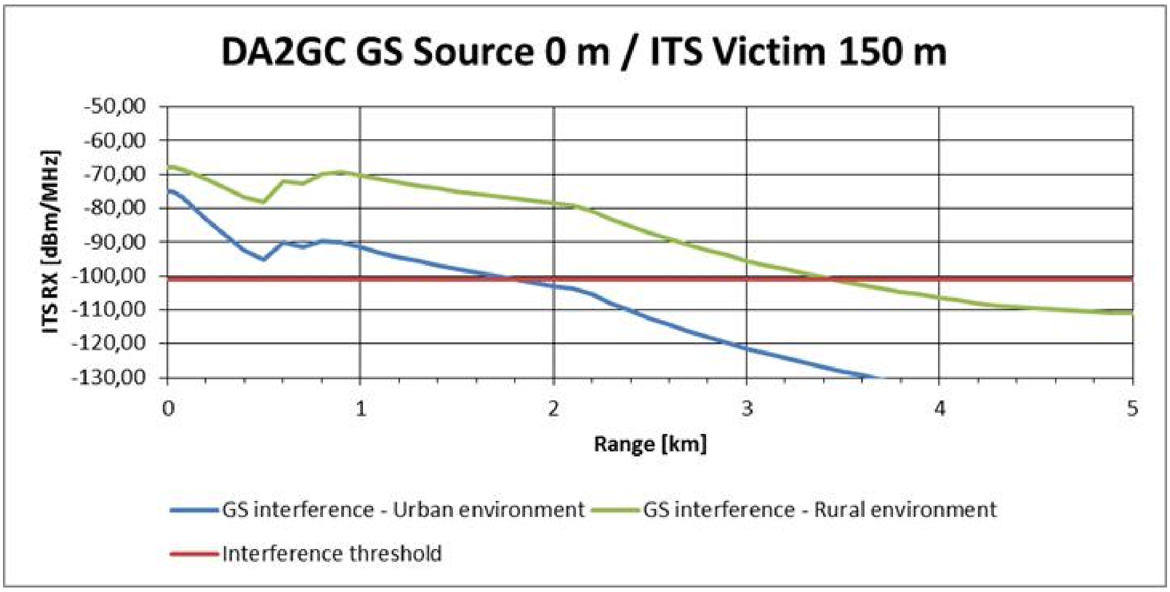


Figure 134: DA2GC GS Source / ITS Victim (ITS Antenna 150 meters above DA2GC)

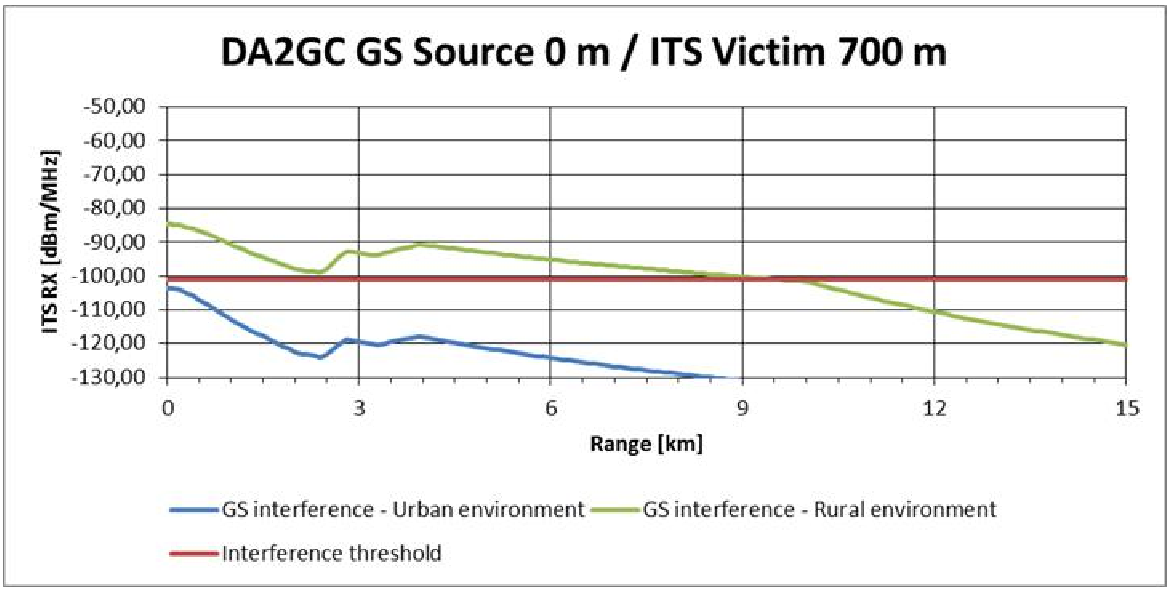


Figure 135: DA2GC GS Source / ITS Victim (ITS Antenna 700 meters above DA2GC)

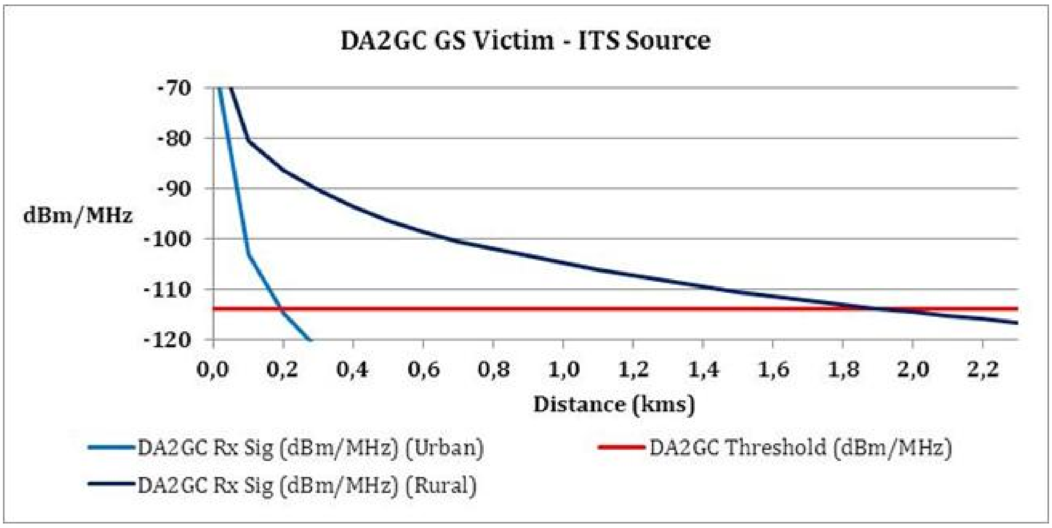


Figure 136: DA2GC GS Victim / ITS Source

The results demonstrate that:

- Out of band simulations shows no interference to ITS systems.
- In band simulations shows a required separation distance of 600 m for urban environment and 2.5 km for rural environment.
- Simulations show it is very important that the DA2GC GS antenna should be placed above the road. In urban environment the required separation distance is 1.8 km if the road is 150 m above the GS antenna. In rural environment the required separation distance is 10 km if the road is 700 m above the DA2GC GS antenna.
- The DA2GC GS may be protected by an appropriate minimum separation distance between 200 metres (urban) and 2 km (rural).

5.4.6 Conclusions

5.4.6.1 Aircraft Station

Compatibility is achieved for all cases. Out of band and in-band simulations show no interference to ITS systems. The interference received from ITS systems is significantly less than the DA2GC AS limit.

5.4.6.2 Ground Station

- Out of band simulations shows no interference to ITS systems.
- In band simulations shows a required separation distance of 600 m for urban environment and 2.5 km for rural environment.
- Simulations also show it is very important that the DA2GC GS antenna should be placed above the road. In urban environment the required separation distance is 1.8 km if the road is 150 m above the GS antenna. In rural environment the required separation distance is 10 km if the road is 700 m above the DA2GC GS antenna.
- The DA2GC GS may be protected by an appropriate minimum separation distance between 200 metres (urban) and 2 km (rural).

5.5 COMPATIBILITY BETWEEN DA2GC AND RTTT SYSTEMS

5.5.1 Technical characteristics of RTTT systems

Table 47: Summary of characteristics of the RTTT systems

	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)	
Frequency stability	5 ppm	modulation 100 ppm
e.i.r.p.	2 W (33 dBm) standard for 0°≤θ≤70° 18 dBm for θ > 70° 8 W (39 dBm) optional	Maximum re-radiated sub-carrier e.i.r.p.: -14 dBm
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
Modulation scheme transmitter	Two level amplitude	BPSK
Receiver bandwidth	500 kHz	approx, 300 MHz
Polarization	left circular	left circular
Receiver sensitivity (at the receiver input)	-104 dBm (BPSK)	-60dBm
Co-channel C/I (dB)	6 dB	6 dB

The technical requirements of the RTTT DSRC devices are split into two categories:

- the Road Side Unit is an active device with a high level of emission and the sensitivity value can be compared to the value of ITS devices
- the On Board Unit is a passive device with reduced level of emission (back-scattering uplink communication) and poor level of sensitivity (downlink communication).

Technical data from ETSI EN 300 674 V1.2.1 (2004-08) [52] and CEN EN 12253 [53].

5.5.2 Compatibility between DA2GC AS (TR 103 108) and RTTT systems

5.5.2.1 Results

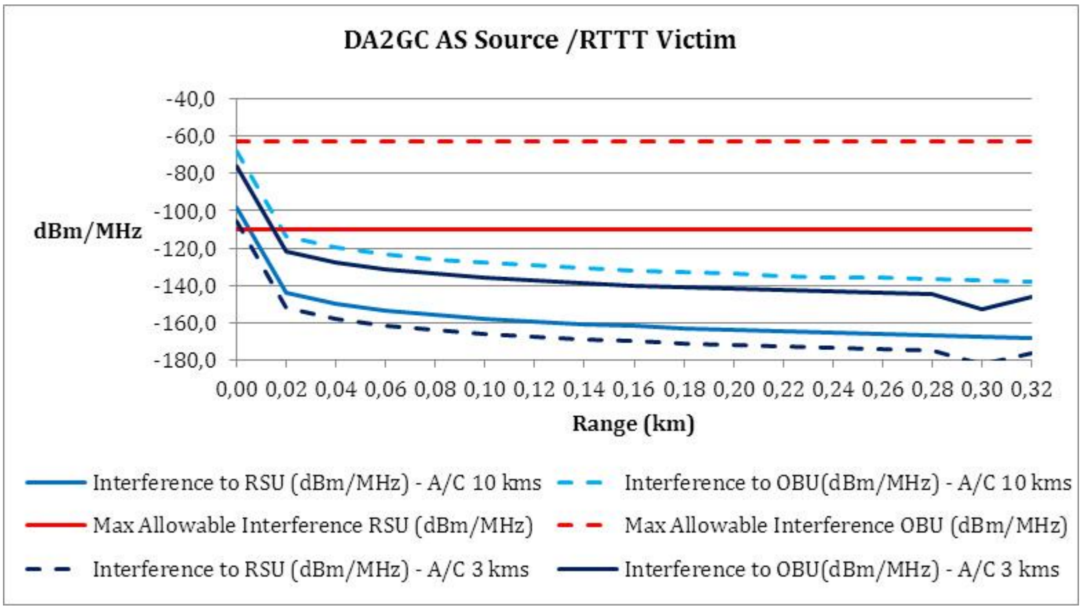


Figure 137: DA2GC AS Source / RTTT Victim

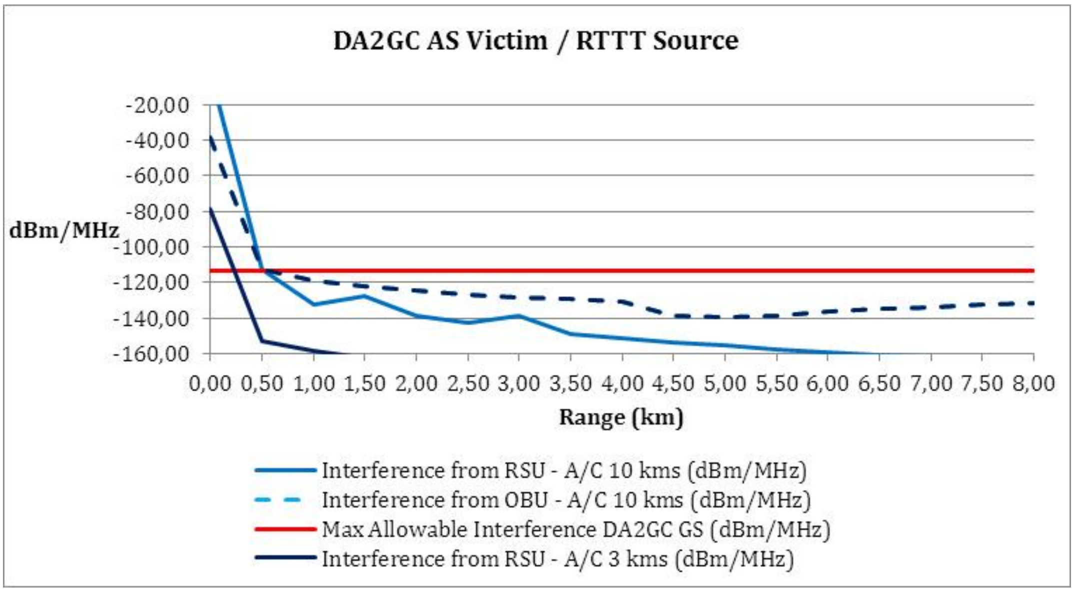


Figure 138: DA2GC AS Victim / RTTT Source

5.5.3 Compatibility between DA2GC GS (TR 103 108) and RTTT systems

5.5.3.1 Results

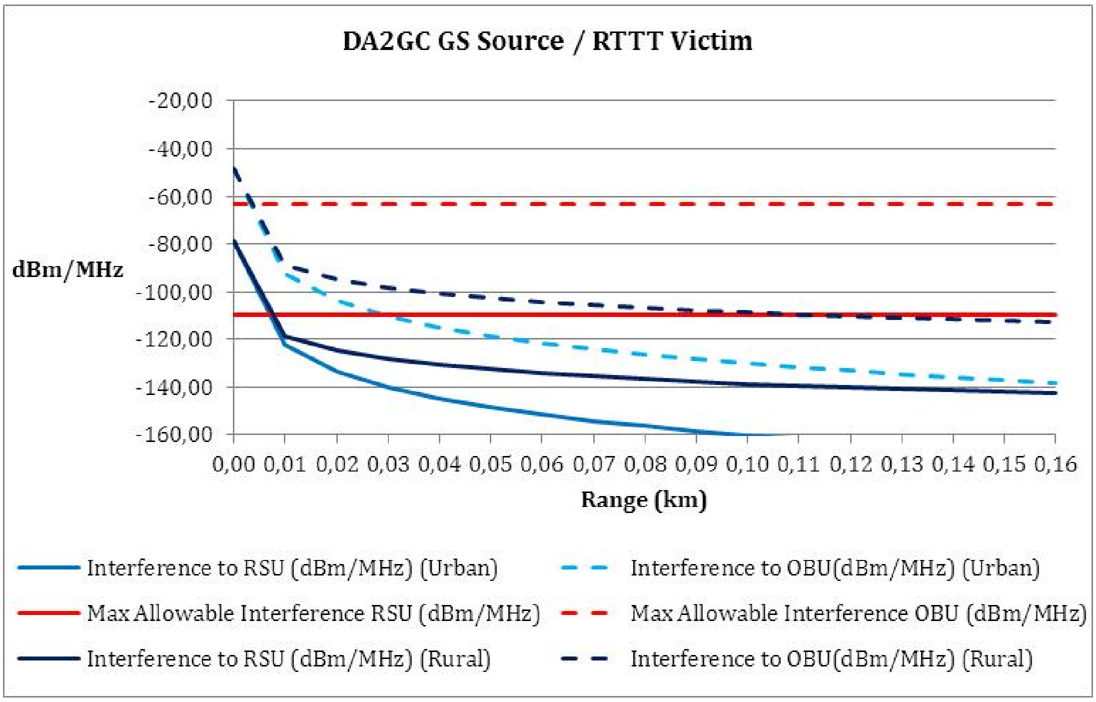


Figure 139: DA2GC GS Source / RTTT Victim

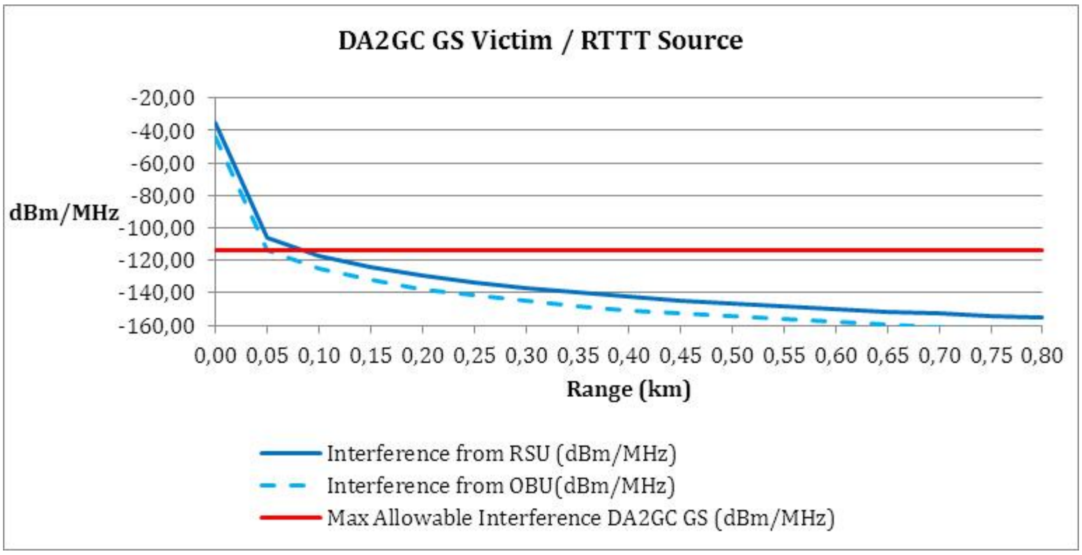


Figure 140: DA2GC GS Victim / RTTT Source

5.5.4 Conclusions

5.5.4.1 Aircraft Station

Compatibility is achieved for all cases.

5.5.4.2 Ground Station

Compatibility is achieved.

5.5.4.3 Summary

Compatibility between DA2GC GS and RTTT is considered to be achieved.

5.6 COMPATIBILITY BETWEEN DA2GC AND RADIOLOCATION SYSTEMS

5.6.1 Technical characteristics of Radiolocation systems

Recommendation ITU-R M.1638 [25] 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, ship borne 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.

Additionally, ITU-R Recommendation M.1851 (2009) provides mathematical models for radiodetermination radar systems antenna patterns for use in interference analyses

Error! Reference source not found. contains technical characteristics of representative systems deployed n this band. This includes a subset of the radars contained in Recommendation ITU-R M.1638 [25] [5] 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.

[5] It should be noted that the Recommendation ITU-R M.1638-0 was under revision in point of time when this ECC Report was adopted.

Table 48: Characteristics of radiolocation systems

Characteristics	Radar L	Radar M	Radar N	Radar O	Radar Q	Radar X&Y	Radar Z
Function	Instrumentation				Surface and air Search		Search
Platform type	Ground				Ship	Ground/Vehicle	
Tuning range (MHz)	5 350-5 850		5 400-5 850		5 450-5 825	5400 – 5850	5250 – 5850
Modulation	None	None	Pulse/chirp pulse	Chirp pulse	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	70 kW
Pulse width (µs)	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	3.5/6/10
Pulse rise/fall time (µs)	0.02-0.5	0.02-0.05	0.02-0.1	0.5	0.03/0.05/0.1	No detail	N/A
Pulse repetition rate (pps)	160, 640	160, 640	20-1 280	320	2 400/1 200/750	1000-7800	2500/3750
Chirp bandwidth (MHz)	N/A	N/A	4.0	8.33	N/A	No detail	
RF emission bandwidth (MHz) at 3 dB at 20 dB	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	
Antenna pattern type	Pencil	Pencil	Pencil	Pencil	Fan	N/A	N/A
Antenna type	Parabolic	Parabolic	Phased Array	Phased Array	Travelling wave feed horn array	N/A	Phased Array
Antenna polarization	Vertical/Left-hand circular				Horizontal	Vertical	Horizontal
Antenna main beam gain (dBi)	54	47	45.9	42	30.0	35	31.5
Antenna elevation beamwidth (degrees)	0.4	0.8	1.0	1.0	28.0	N/A	43.8
Antenna azimuth beamwidth (degrees)	0.4	0.8	1.0	1.0	1.6	N/A	1.75
Antenna rejection (1st SLs and remote SLs) (dB)	-20	-20	-22	-22	-25	-40	N/A [6]
Antenna height (m)	20	8-20	20	20	40	10	6 – 13
Receiver IF 3 dB bandwidth (MHz)	4.8, 2.4, 0.25	4, 2, 1	2-8	8	1.2,10	4	N/A
Receiver noise figure (dB)	5	5	11	5	10	5	≤ 13dB

[6] No value is provided in Recommendation ITU-R M.1638, therefore for the compatibility analyses a value of -40dB was considered.

5.6.2 Impact of DA2GC AS (TR 103 054) on Radiolocation systems

The out-of-band emissions produced by an aircraft station described in ETSI TR 103 054 [3] are in accordance with the standard 3GPP TS 36.101 (see Table 49). For the centre frequency of the DA2GC carrier at 5865 MHz and a 20 MHz channel bandwidth the maximum OOB emission level into the antenna connector for the band below 5850 MHz is -13 dBm/MHz. The antenna pattern of the AS can be found in Figure 3. The maximum antenna gain is 7 dBi at around -13 degrees.

Table 49: Spectrum emission mask according to 3GPP TS 36.101

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

5.6.3 Impact of DA2GC AS (TR 101 599) on Radiolocation systems

The out-of-band emissions produced by an aircraft station described in TR 101 599 can be found in Figure 11. The maximum transmit power into the AS antenna is 28 dBm equivalent to 15 dBm/MHz (0 dB reference level). Thus the maximum OOB emission level into the antenna connector below 5850 MHz is -25 dBm/MHz. It was indicated by the proponent of TR 101 599 that levels as low as -70 dB relative to full carrier power can be achieved below 5850 MHz by using digital filtering techniques. This leads to maximum OOB emissions of -55 dBm/MHz below 5850 MHz. Both values have been used for the calculations. The antenna pattern of the AS can be found in Figure 10. The maximum antenna gain is around 17 dBi. The mainbeam is steered in direction to the DA2GC Ground station.

5.6.4 Impact of DA2GC AS (TR 103 108) on Radiolocation systems

The emission mask of the system described in TR 103 108 is given in Figure 24. The mask describes the inband and OOB levels for a 10 and 5 MHz channel. It was indicated by the proponent that basically a 10 MHz channel is used. Thus the following calculations are based on a 10 MHz channeling. The transmitter mean transmit power is 36 dBm in a 10 MHz channel, equivalent to 26 dBm/MHz, which is the 0 dBc reference level in Figure 24. Assuming a DA2GC carrier frequency of 5860 MHz, the maximum OOB level below 5850 MHz is -60 dBc leading to a maximum absolute OOB level of -34 dBm/MHz into the antenna connector. According to the system description the OOB emissions can be reduced to -50 dBm/MHz measured at the antenna connector from 5250 MHz to 5850 MHz. Both values have been used for the calculations. The antenna pattern of the AS can be found in Figure 17. The maximum antenna gain is 7 dBi at around -14 degrees.

5.6.5 Methodology

5.6.5.1 Scenario for the DA2GC AS described in ETSI TR 103 054 and ETSI TR 103 108

In this scenario the DA2GC Aircraft Station transmits to the DA2GC Ground Station within which service area it flies. This is the desired signal indicated as a green line in Figure 141. The radar receives this DA2GC signal however as interference (indicated in red). It is assumed that the AS is flying at an altitude of 3000 m and transmitting with maximum output power at the cell edge. The radar mainbeam is directed to the Aircraft station. Free Space loss was assumed for the interference path.[7] The expected interference levels are calculated for DA2GC systems with a signal bandwidth of 20 MHz for the LTE system (ETSI TR 103 054 [3]) and 10 MHz for the UMTS based system (ETSI TR 103 108[31]).

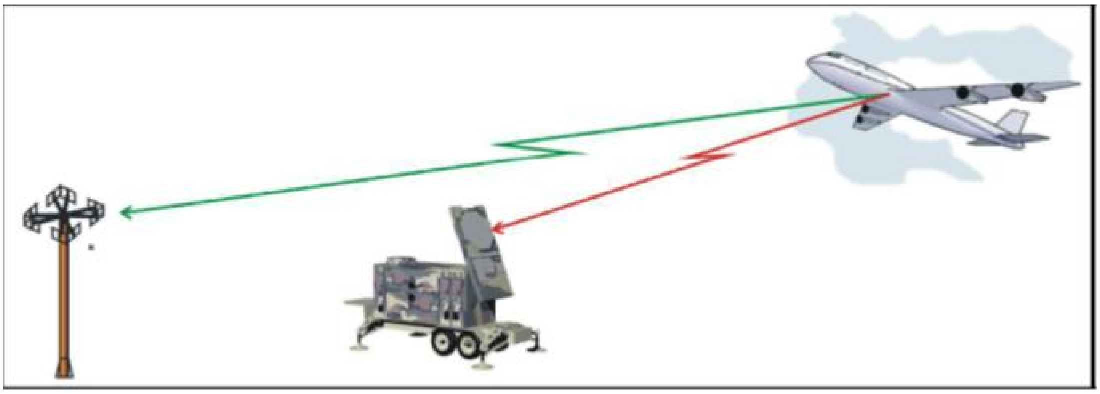


Figure 141: DA2GC Aircraft Station interference on the radar

The maximum interference level at the radar receiver can be derived as follows:

$I(dBm/MHz)=P_{unw\ (AS)}+G_{AS}-FSL_{Slant}+G_{Rad}$

with:

$P_{unw(AS)}$	Unwanted power of the AS transmitter into the antenna connector
G_{AS}	Antenna gain of the AS towards the victim radar
FSL_{Slant}	Slant path attenuation between interfering transmitter and victim receiver
G_{Rad}	Maximum radar antenna gain

Figure 142 and Figure 143 show the interference received at the Radar receiver type L (radar types according to Recommendation ITU-R M.1638 [25], see Table 48) caused by the DA2GC AS (TR 103 054 and TR 103 108). It can be noted that the maximum interference level at the radar receiver is -80 dBm/MHz in case of an interfering DA2GC AS according to ETSI TR 103 054 and -114 dBm/MHz in case of an interfering DA2GC AS according to ETSI TR 103 108 (-98 dBm/MHz without extended filtering for comparision).

Worst-case calculations have been performed for all other radar types. The results are shown in Table 50.

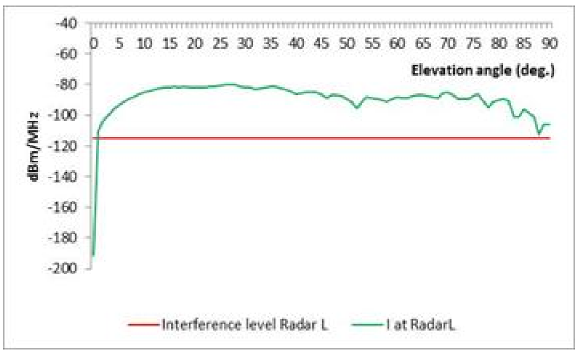


Figure 142: I at Radar type L, Interfering DA2GC AS TR 103 054

[7] It is noted that according to Recommendation ITU-R P.528 [16] the propagation loss could be slightly lower than the free-space-loss for very low probabilities.

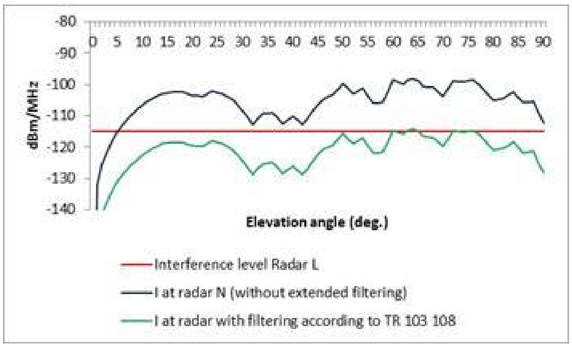


Figure 143: I at Radar type L, Interfering DA2GC AS TR 103 108

5.6.5.2 Scenario for the DA2GC AS described in TR 101 599

In case of the beamforming / beamsteering DA2GC AS the interfering signal is most severe when the radar points its receiving antenna beam at the aircraft and the beam of the DA2GC antenna is pointing in the direction to the radar.

For the interference analysis in this scenario free space loss calculations are used to estimate the signal attenuation as a function of distance. The aircraft is assumed to fly at the edge of the DA2GC Ground Station (a distance of 50 km) service area and transmitting at maximum power. The minimum distance to the radar, at which the radar can be within the DA2GC Aircraft Station mainbeam, is derived to be ~10 km (since the elevation beam width of the Aircraft Station antenna is 30°).

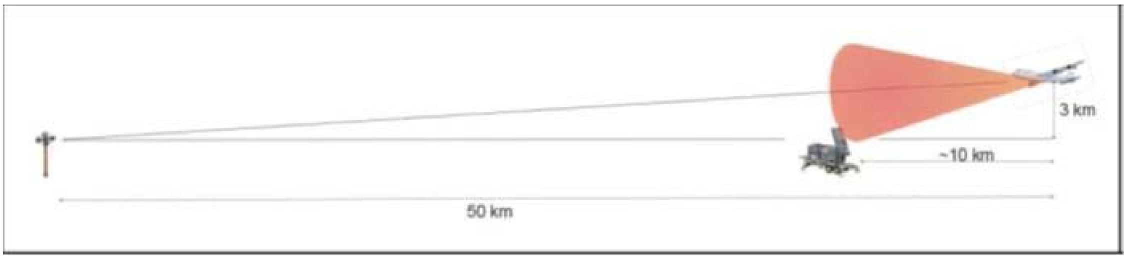


Figure 144: Detailed view of DA2GC Aircraft Station interference on the radar

It is assumed that the DA2GC Aircraft Stations will only transmit at altitudes above 3000 m. This specific case of DA2GC Aircraft Station interfering with the radar is shown schematically in Figure 144. The expected interference levels are calculated for DA2GC systems with a signal bandwidth of 20 MHz.

Figure 145 shows the calculated AS Antenna gain towards the victim radar in dependence of the ground distance. For the determination of the maximum interference level at the radar receiver the same formula as given in section 5.6.5.1 has been used. Figure 146 shows the interference received at the Radar receiver type L for example (radar types according to Recommendation ITU-R M.1638 [25], see Table 48). It can be observed that the maximum interference level is -82 dBm/MHz at the radar receiver at a ground distance of around 8 km from the interfering transmitter. With the proposed extended filtering this maximum level can be reduced to -112 dBm/MHz (see green line in Figure A).

Worst-case calculations have been performed for all other radar types. The results are shown in Table 50.

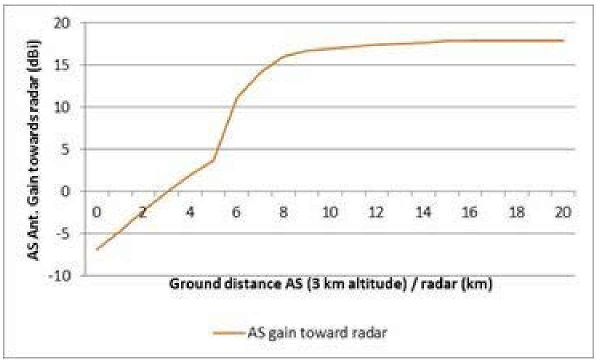


Figure 145: AS antenna gain towards victim radar

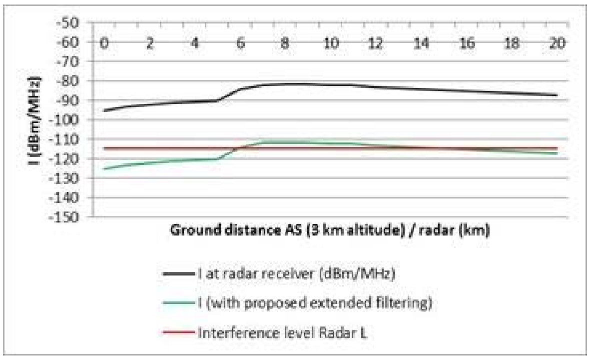


Figure 146: I at Radar type L, Interfering DA2GC AS TR 103 199

5.6.6 Results

The calculations in Table 50 show that the most sensitive radar system is Radar L. The maximum allowable OOB emission are -48 dBm/MHz (TR 103 054), -58 dBm/MHz (TR 101 599) and -51dBm/MHz (TR 103 108). It can be observed that in case of the beamforming system (TR 101 599) the level has to be 10 dB lower than in the case of the LTE system (TR 103 054). As both systems are assumed to be operated in 20 MHz bandwidth in the band 5855 – 5875 MHz the difference could be explained by the 10 dB higher antenna gain of the beamforming system. As for the system described in TR 103 108 (UMTS based) the transmitter bandwidth is 10 MHz and the spectral density is 3 dB higher which explains the difference of 3 dB between the required levels for TR 103 054 and TR 103 108.

Table 50: Max. allowable OOB emission levels for DA2GC AS

	Radar L	Radar M	Radar N	Radar O	Radar Q	Radar X&Y	Radar Z
RADAR							
Antenna main beam gain (dBi)	**54**	**47**	**45.9**	**42**	**30.0**	**35**	**31.5**
Receiver noise figure (dB)	5	5	11	5	10	5	≤ 13dB
Receiver Noise (dBm/MHz)	-109	-109	-107	-109	-104	-109	-101
Protection criterion (I/N)	-6	-6	-6	-6	-6	-6	-6
Max. acceptable interference level (dBm/MHz)	**-115**	**-115**	**-109**	**-115**	**-110**	**-115**	**-107**
DA2GC AS							
TR 103 054							
Transmit power max (dBm) per	40						

	Radar L	Radar M	Radar N	Radar O	Radar Q	Radar X&Y	Radar Z
channel							
Max power into the radar band (dBm/MHz)	-13						
TR 101 599							
Transmit power max (dBm) per channel	28						
Max power into the radar band (dBm/MHz) according to TR 101 599	-25						
Max power into the radar band with proposed extended filtering (dBm/MHz)	-55						
TR 103 108							
Transmit power max (dBm) per channel	36						
Max power into the radar band (dBm/MHz) without filtering	-34						
Max power into the radar band with filtering according to TR 103 108 (dBm/MHz)	-50						
RESULTS							
TR 103 054							
I max. at radar receiver (dBm/MHz) see 5.6.5.1	-80	-87	-88	-92	-104	-99	-102
Excess (dB)	**35**	**28**	**21**	**23**	**6**	**16**	**5**
Max. allowable OOB level (dBm/MHz)	**-48**	**-41**	**-38**	**-36**	**-19**	**-29**	**-18**
TR 101 599							
I max. at radar receiver (dBm/MHz)) according to TR 101 599 see 5.6.5.2	-82	-89	-90	-94	-106	-101	-105
Excess (dB)	**33**	**26**	**19**	**21**	**4**	**14**	**2**
I max. at radar receiver with proposed extended filtering (dBm/MHz) see 5.6.5.2	-112	-119	-120	-124	-136	-131	-135
Excess (dB)	**3**	**-4**	**-11**	**-9**	**-26**	**-16**	**-28**
Max. allowable OOB level (dBm/MHz)	**-58**	**-51**	**-48**	[illegible]	[illegible]	**-39**	[illegible]
TR 103 108							
I max. at radar receiver (dBm/MHz)) without filtering see 5.6.5.1	-98	-105	-106	-109	-121	-116	-120
Excess (dB)	**17**	**10**	**3**	**6**	**-11**	**-1**	**-13**
I max. at radar receiver with filtering according to TR 103 108 (dBm/MHz) see 5.6.5.3	-114	-121	-122	-125	-137	-132	-136
Excess (dB)	**1**	**-6**	**-13**	**-10**	**-27**	**-17**	**-29**
Max. allowable OOB level (dBm/MHz)	**-51**	**-44**	**-41**	[illegible]	[illegible]	**-32**	[illegible]

5.6.7 Conclusions on the impact of DA2GC AS on Radars

Worst case calculations regarding the impact of the DA2GC AS on radiolocation systems have shown that the maximum allowable OOB emission are -48 dBm/MHz for the DA2GC AS described in TR 103 054, -58 dBm/MHz for the DA2GC AS described in TR 101 599 and -51 dBm/MHz for the DA2GC AS described in TR 103 108. According to the system descriptions of TR 101 599 and TR 103 108 the OOB emissions in the radar band below 5850 MHz can be reduced to -55dBm/MHz and -50dBm/MHz respectively. Thus a small exceedance between 1 and 3 dB can be observed at one Radar type in case of one interfering aircraft. In the scope of this study, it seems a fair approach to consider a margin of 3 dB for TPC. Thus the following requirement for the maximum radiated emissions of a DA2GC AS below 5850 MHz with respect to the protection of radars could be derived under the assumption that DA2GC AS transmissions will be ceased below an aircraft height of 3000 m:

$$\mathrm{Imax} := -38 - 10 \cdot \log\left(\frac{20}{\mathrm{BW}}\right) \text{ dBm/MHz}$$

with:
I_{max} = Maximum radiated (out-of-band) AS emissions below 5850 MHz
BW = AS transmitter bandwidth (MHz)

5.6.8 Impact of DA2GC GS (TR 103 054) on Radars

According to the system description for the GS according to ETSI TR 103 054 the spectrum emission limits for the GS can be found in the standard 3GPP TS 36.104. Table 51 shows the values for a wide Area BS category B which was assumed in the calculations.

For the center frequency of the DA2GC carrier at 5865 MHz and a 20 MHz channel bandwidth the maximum OOB emission level into the antenna connector is -15 dBm/MHz below 5850 MHz. Figure 2 shows the GS vertical antenna pattern. The maximum antenna gain is 20 dBi and the antenna up-tilt is given by 10 degrees. From Figure 2 a gain of -3 dBi at 0 degree elevation can be derived. Due to the steep characteristic of the antenna pattern below 10 degree and the fact that possible victim radar can be situated at a higher location than the GS an antenna gain of 0 dBi in direction to the victim radar was assumed in the calculations.

Table 51: Wide Area BS operating band unwanted emission limits for 5, 10, 15 and 20 MHz channel bandwidth (E-UTRA bands >1GHz) for Category B

Frequency offset of measurement filter -3dB point, Δf	Frequency offset of measurement filter centre frequency, f_offset	Minimum requirement (Note 1)	Measurement bandwidth (Note 4)
0 MHz ≤ Δf < 5 MHz	0.05 MHz ≤ f_offset < 5.05 MHz	$-7dBm - \frac{7}{5} \cdot \left(\frac{f\_offset}{MHz} - 0.05\right) dB$	100 kHz
5 MHz ≤ Δf < min(10 MHz, Δf_{max})	5.05 MHz ≤ f_offset < min(10.05 MHz, f_offset_{max})	-14 dBm	100 kHz
10 MHz ≤ Δf ≤ Δf_{max}	10.5 MHz ≤ f_offset < f_offset_{max}	-15 dBm (Note 2)	1MHz

NOTE 1: For a BS supporting non-contiguous spectrum operation the minimum requirement within sub-block gaps is calculated as a cumulative sum of adjacent sub blocks on each side of the sub block gap. Exception is Δf ≥ 10MHz from both adjacent sub blocks on each side of the sub-block gap, where the minimum requirement within sub-block gaps shall be -15dBm/1MHz.
NOTE 2: The requirement is not applicable when Δf_{max} < 10 MHz.

5.6.9 Impact of DA2GC GS (TR 101 599) on Radars

The out-of-band emissions produced by an aircraft station described in TR 101 599 can be found in Figure 11. The maximum transmit power into the GS antenna is 22 dBm equivalent to 9dBm/MHz (0 dB reference level). Thus the maximum OOB emission level into the antenna connector below 5850 MHz is -31dBm/MHz. It was indicated by the proponent of TR 101 599 that levels as low as -70dB relative to full carrier power below 5850 MHz can be achieved by using digital filtering techniques. This leads to maximum OOB emissions of -61 dBm/MHz below 5850 MHz.

Figure 7 shows the GS vertical antenna pattern. Due to the steep characteristic of the antenna pattern below 10 degree and the fact that a possible victim radar can be situated at a higher location than the GS an antenna gain of 0 dBi in direction to the victim radar was assumed in the calculations.

5.6.10 Impact of DA2GC GS (TR 103 108) on Radars

The emission mask of the system described in TR 103 108 is given in Figure 24. The mask describes the inband and OOB levels for a 10 and 5 MHz channel. It was indicated by the proponent that basically a 10 MHz channel is used. Thus the following calculations are based on a 10 MHz channelling. The maximum transmit power is 38 dBm in a 10 MHz channel, equivalent to 28 dBm/MHz, which is the 0 dBc reference level. Assuming a DA2GC carrier frequency of 5860 MHz, the maximum OOB level below 5850 MHz is -60 dBc leading to an absolute (mean) OOB level of -32 dBm/MHz into the antenna connector. According to the system description the OOB emissions can be reduced to -50 dBm/MHz measured at the antenna connector from 5250 to 5850 MHz.

The antenna pattern of the GS can be found in Figure 14 (up-tilt of 6 degree not considered). The maximum antenna gain is 15 dBi at around 6 degrees. Due to the steep characteristic of the antenna pattern below 6 degree and the fact that possible victim radar can be situated at a higher location than the GS an antenna gain of 0 dBi in direction to the victim radar was assumed in the calculations.

5.6.11 Methodology

In this scenario, a DA2GC Ground Station is transmitting to an Aircraft Station at the edge of the service area, using maximum transmit power. This is the desired communication, indicated with a green line in Figure 147. This transmitted signal is perceived as interference by the radar (indicated with the red line). The interfering signal is most severe when the radar points its receiving antenna beam at the DA2GC ground station and the antenna beams of both systems are directed at each other.

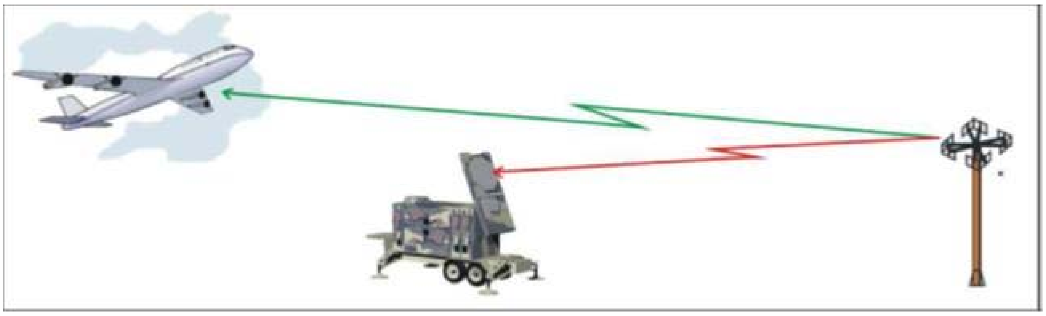


Figure 147: DA2GC Ground Station interference on the radar

In this scenario the propagation of the radio signals is over the surface of the earth. A free space propagation model is not applicable in this case. The presence of obstacles in the path between DA2GC Ground Station and the radar will have a significant effect on the level at which the interference will be received. In this case the Irregular Terrain Model (ITM) [29] has been used to calculate the signal attenuation as a function of distance, which takes into account several relevant parameters, e.g. antenna heights, polarisation, climate conditions and terrain roughness. Calculation results obtained with this model provide a good first impression on the interference level as a function of distance between both systems. In Figure 148 the propagation loss predictions obtained with the ITM are depicted. Note that the average propagation loss that can be expected increases more rapidly compared to free-space-loss at distances above 4 km. As mentioned above, the ITU-R P.452 model should be used for more detailed coordination purposes.

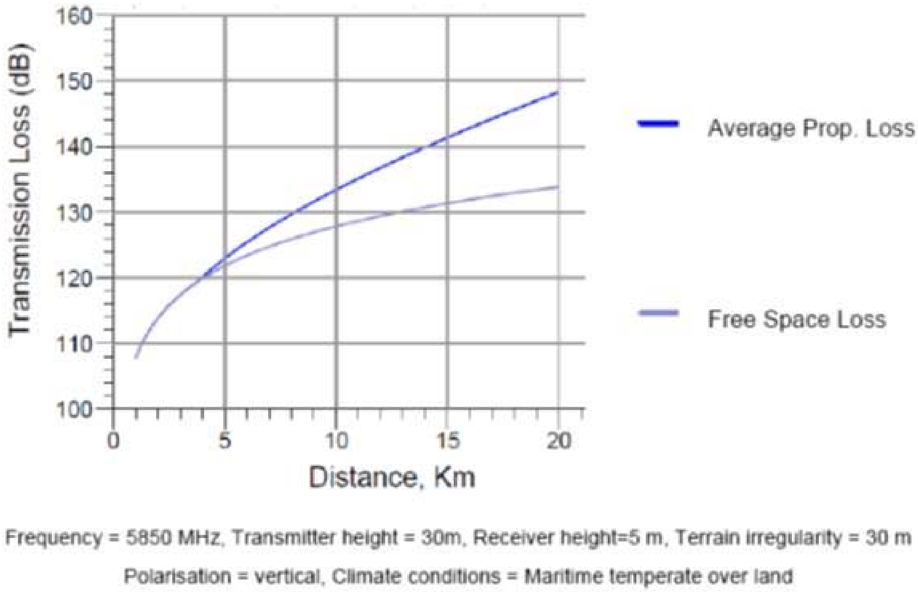


Figure 148: Propagation loss calculated with the Irregular Terrain Model

When a DA2GC Ground Station communicates with an Aircraft Station flying at 3 km altitude at the edge of the service area (thus a distance of 50 km), the elevation angle of the Ground Station antenna beam will be relatively low, about 3.5°. A practical antenna gain in the horizontal direction of approximately 0 dBi is estimated. It should be noted, however, that the antenna gain curve has a steep course for low elevation angles. At 1° elevation angle the antenna gain is already 17 dBi. Thus a small difference in horizontal alignment will have a significant effect in the interference that a nearby radar may experience. The expected interference levels are calculated for DA2GC systems with a signal bandwidth of both 10 MHz for the DA2GC system described in TR 103 108 and 20 MHz for the systems described in TR103 054 and 101 599.

5.6.12 Results

Table 36 shows the required separation distances between the different DA2GC GS and Radars. The green and blue values show the results which can be achieved through additional filtering. It can be observed that Radar L is the most sensitive one. The separation distances vary between 13 km and 25 km in case no additional filtering at the GS is implemented. This can be reduced according to the information provided by LH Systems and Aero3G to 1 - 3.5 km.

Table 52: Required separation distances between different DA2GC GS and Radars

	Radar L	Radar M	Radar N	Radar O	Radar Q	Radar X&Y	Radar Z
RADAR							
Antenna main beam gain (dBi)	**54**	**47**	**45.9**	**42**	**30.0**	**35**	**31.5**
Receiver noise figure (dB)	5	5	11	5	10	5	≤ 13dB
Receiver Noise (dBm/MHz)	-109	-109	-103	-109	-104	-109	-101
Protection criterion (I/N)	-6						
Max. acceptable interference level (dBm/MHz)	**-115**	**-115**	**-109**	**-115**	**-110**	**-115**	**-107**
DA2GC GS							
TR 103 054							
Transmit power max (dBm) per channel	46						

	Radar L	Radar M	Radar N	Radar O	Radar Q	Radar X&Y	Radar Z
Max power into the radar band (dBm/MHz)	-15						
TR 101 599							
Transmit power max (dBm) per channel	22						
Max power into the radar band (dBm/MHz)	-31						
	-61 (with additional filtering)						
TR 103 108							
Transmit power max (dBm) per channel	38						
Max power into the radar band (dBm/MHz)	-32						
	-50 (with filtering according to ETSI TR 103 108)						
Antenna gain (in direction to the radar) (dBi)	0						
RESULTS							
TR 103 054							
Required propagation loss (dB)	154	147	140	142	125	135	123.5
Resulting separation distance ITM-4 propagation model (km)	24.7	19	14	15.6	5.8	11	5.4
TR 101 599							
Required propagation loss (dB)	138	131	123,9	126	109	119	107,5
	108	**101**	**93,9**	**96**	**79**	**89**	**77,5**
Resulting separation distance ITM-4 propagation model (km)	13	8,7	5,5	6,6	1,16	3,4	0,97
	1	**0,46**	**0,2**	**0,26**	**0,04**	**0,12**	**0,03**
TR 103 108							
Required propagation loss (dB)	137	130	127	125	108	118	106,5
	119	**112**	**109**	**107**	**90**	**100**	**88,5**
Resulting separation distance ITM-4 propagation model (km)	12.6	8.2	6.8	6.5	7,3	3.1	0.87
	3,5	**1,6**	**0,73**	**0,92**	**0,13**	**0,41**	**0,11**

5.6.13 Conclusions on the impact of DA2GC GS on Radars

From these results it can be concluded that in order to avoid interference from a DA2GC Ground Station to radars, a separation distance of at least 13 to 25 km should be taken into account in case no additional filtering is implemented in the DA2GC GS. According to the information provided by the proponents so far, these separation distances can be reduced to 1 – 3.5 km depending on the system proposal. The separation distances will increase in the event of the radar site being higher than the DA2GC GS (e.g. this could occur in mountainous areas).

5.6.14 Impact of Radars on DA2GC AS

The radar characteristics below are derived from **Error! Reference source not found.**.

Table 53: Radar characteristics in the DA2GC band

Emission part: RL	Unit	Type of Radar						
		L	M	N	o	Q	X&Y	Z
e.i.r.p radar	dBm	148.5	137.8	135.9	124.2	114.5	105.8	110
Receiver IF3dB bandwidth	MHz	4.8	4	8	8	10	4	1

Emission part: RL	Unit	Type of Radar						
		L	M	N	o	Q	X&Y	Z
MHz								
e.i.r.p radar	dBm/MHz	141.7	131.8	126.9	115.2	104.5	99.8	110.0
Unwanted attenuation factor (Spurious)	dBpp	60.0	60.0	60.0	60.0	60.0	60.0	60.0
e.i.r.p radar in the ITS band	dBm/MHz	81.7	71.8	66.9	55.2	44.5	39.8	50.0
Noise Temperature	°K	290	290	290	290	290	290	290

5.6.15 Methodology

The following scenario has been considered:

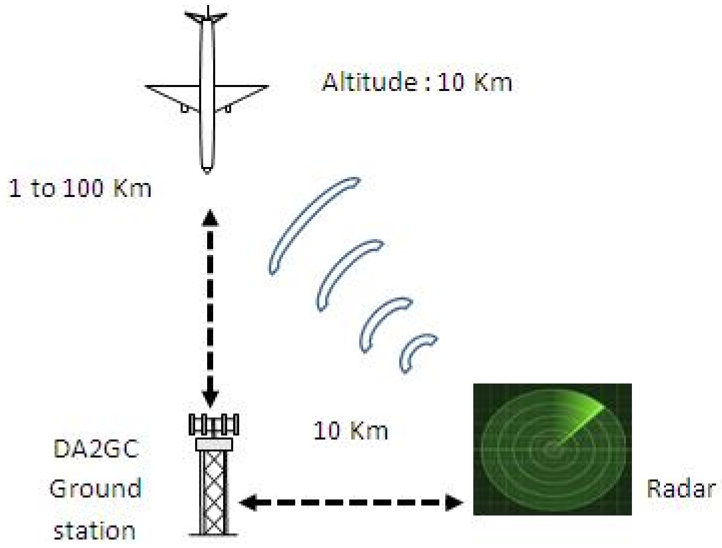


Figure 149: Interference scenario Radar on DA2GC AS

5.6.16 Results for DA2GC according to ETSI TR 101 599

Receiver NF: 4
Thermal noise: -114 + 4 = -110 dBm/MHz
Maximum acceptable interference:
I/N=-10dB: -120dBm/MHz

The aircraft receiver antenna gain takes in account:

- The aircraft azimuth antenna gain pattern
- The aircraft elevation antenna gain pattern

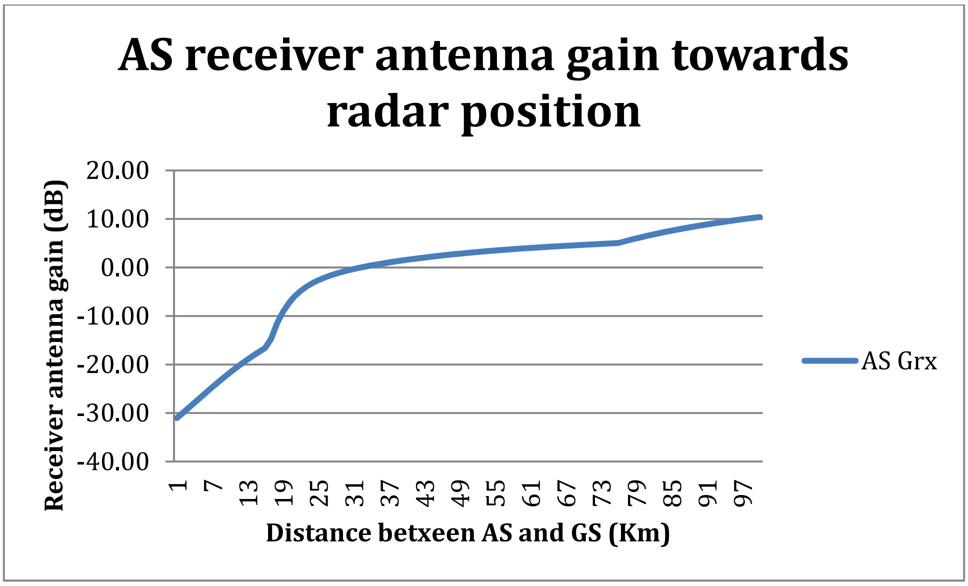


Figure 150: Aircraft antenna gain towards radar derived from TR 101 599

5.6.16.1 Interference level

1. From radar peak power:

I=e.i.r.p radar (dBm/MHz)(peak power) – FSL –GantRX

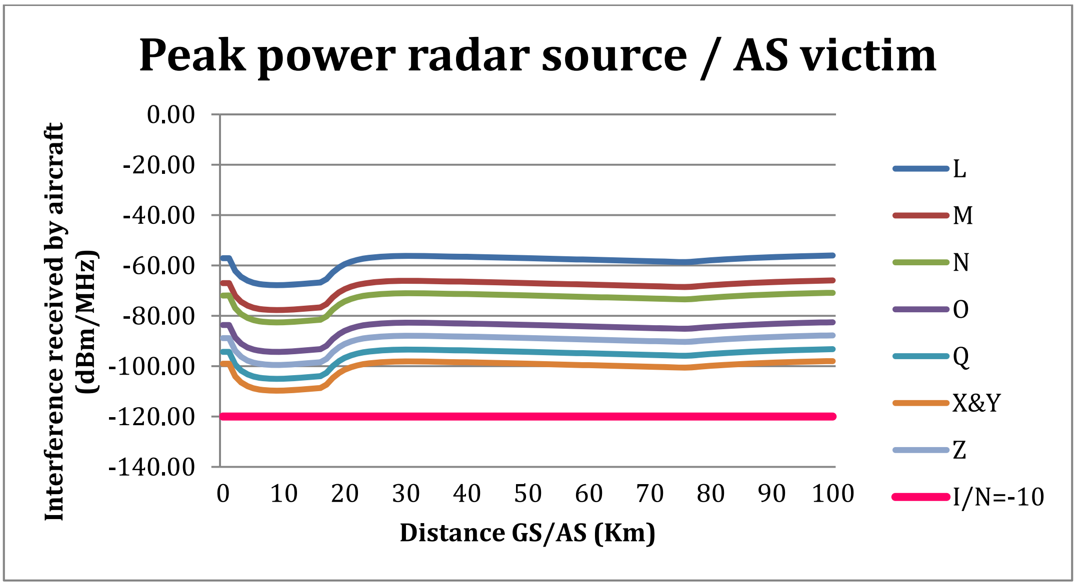


Figure 151: Interferences from radars to DA2GC AS (peak power- TR 101 599)

Figure 151 shows that receiver maximum interference level might be excedeed by 60 dB.

2. From radar mean power:

I=e.i.r.p radar (dBm/MHz)(mean power) – FSL –GantRX

Table 54: Mean radar Tx power taking in account duty cycle

Emission part: RL	Unit	Type of Radar						
		L	M	N	o	Q	X&Y	Z
Peak power	dBm/MHz	81,7	71,8	66,9	55,2	44,5	39,8	50
Pulse width	µs	1	0.5	1	100	0.25	N/A	N/A
Pulse Repetition rate	pps	160	160	20	320	1200	N/A	N/A
Duty cycle factor	dB	-38	-41	-46	-15	-35		
Mean power	dBm/MHz	43,7	30,8	20,9	40,2	9,5		

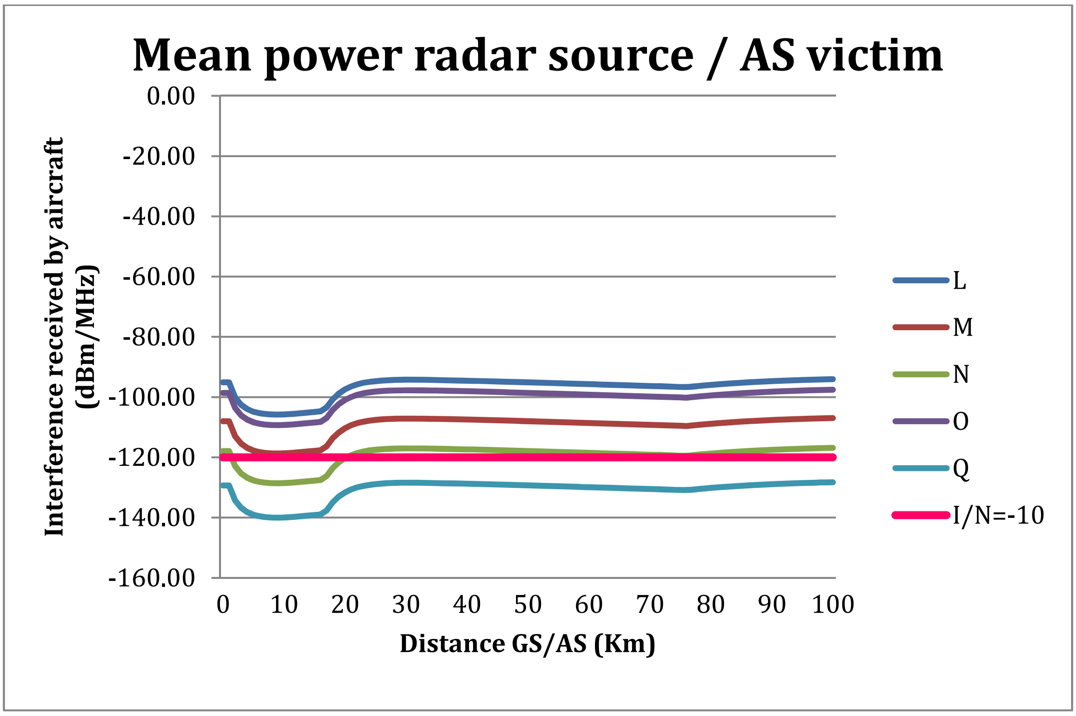


Figure 152: Interferences from radars to DA2GC AS (mean power- TR 101 599)

5.6.17 Results for DA2GC according to ETSI TR 103 108

Receiver NF: 2.5
Thermal noise: -114 + 2.5 = -111.5 dBm/MHz

Maximum acceptable interference:
I/N = -6dB: -117.5 dBm/MHz

5.6.17.1 Interference level

1. From radar peak power

I=e.i.r.p radar (dBm/MHz)(peak power) – FSL –GantRX

Because of the lack of information on receiver antenna gain in each direction (no formula for calculation), the study takes in account these following values as assumptions:
Aircraft elevation antenna gain :
0 to 20° : 5dB (maximum aircraft antenna gain : 7 dBi)
20 to 30° : 0 dB
30 to 90° : -5dB
Aircraft azimuth antenna gain : 0dB

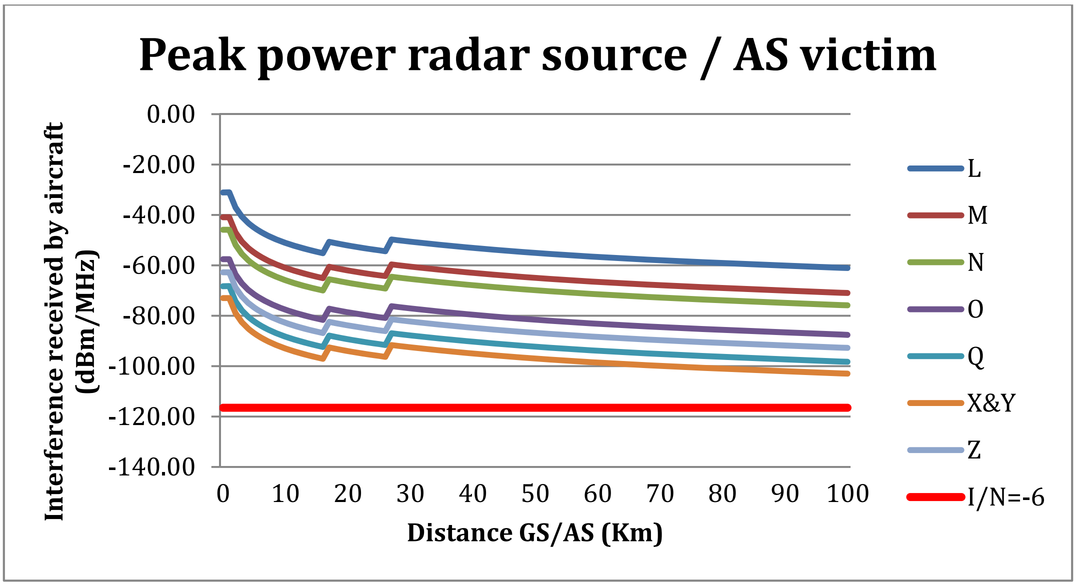


Figure 153: Interferences from radars to DA2GC AS (peak power- TR 103 108)

Figure 153 shows that receiver maximum interference level might be exceeded by 60 dB.

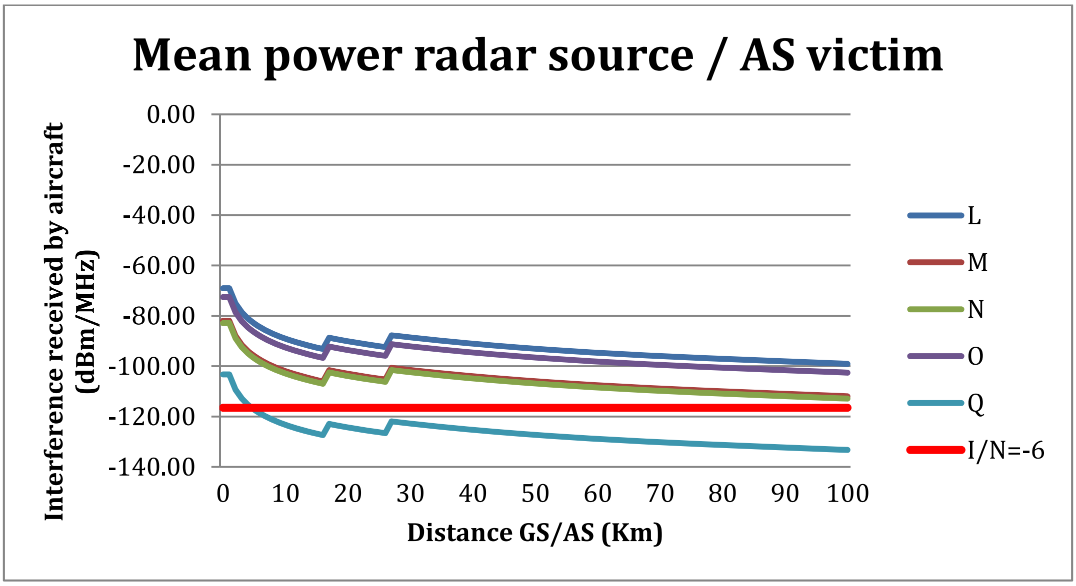


Figure 154: Interferences from radars to DA2GC AS (mean power-TR 103 108)

5.6.18 Additional analyses

Due to the symmetry of aircraft antenna gain patterns in azimuth as well as in elevation, the interference from 0 Km up to -100 Km might be considered as the same as those for 0 to +100 Km:

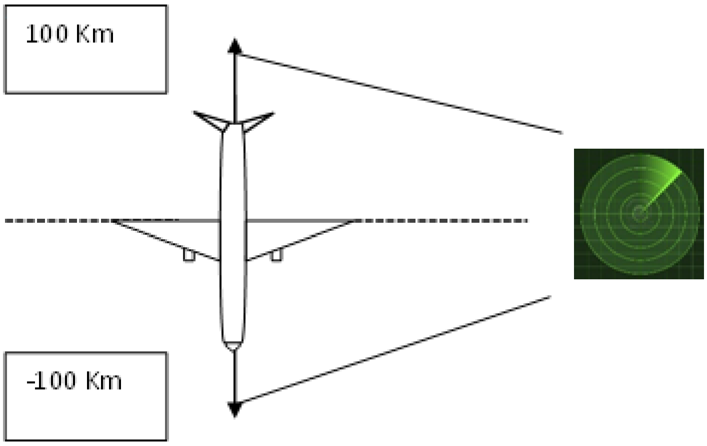


Figure 155: Interference scenario

5.6.19 Conclusions

From these studies, it can be seen that in theory aircraft stations will experience very high levels of interference from radars over very long distances (up to +60dB above acceptable maximum interference level over 200Km).

These interferences turn out to be “sporadic” because of the rotational motion of the radar antenna. Nevertheless, other factors should be taken under consideration:

- Over such long distances, the aircraft station could experience interferences from several radars;
- These interferences could add to interferences from other services (FSS);
- At this stage, we have no technical information on the way the receivers will withstand for such high levels of interferences;
- Such interferences could lead to troubles on aircraft ATPC way of working or in the steering management of the “beamforming” (TR 101 599);
- The impact of such frequent and regular interferences during few minutes on the broadband application itself is not known (error performance, acceptable disruptions, and synchronisation matters)
- The spurious emission limit of -60dBpp may significantly overestimate the unwanted emissions falling within the channel used by DA2GC;
- In case of tactical radars which have a very narrow beam width in the horizontal plane (wide beam in vertical plane) the combination of their antenna pattern with their temporary deployment scenarios will result in a very low probability and very short duration of interference occurring to AS.

6 CONCLUSIONS

6.1 CONCLUSIONS ON THE DA2GC SYSTEM ACCORDING TO ETSI TR 103 054

Table 55: Conclusions on compatibility for the LTE based DA2GC system according ETSI TR 103 054 with other services in the band 5855-5875 MHz

Services and applications	Section of the report	DA2GC as interferer	DA2GC as victim
BFWA (Co-channel)	5.1.3 5.1.2	Ground Station The separation distances for all possible cases have been calculated. However, there is no need to consider the suitability of the separation distances more in detail because the compatibility studies between BFWA and DA2GC AS have shown that co-channel sharing is not feasible. Aircraft Station For aircraft altitudes of about 3 km the protection threshold will be generally exceeded at the BFWA TS, and also in a large range at the CS. The protection threshold at the TS is exceeded even at an aircraft altitude of 10 km. For the CS single critical peaks occur only near its location, but for medium altitudes the threshold can no more be kept in that area. **Thus, it is concluded that co-channel operation of DA2GC reverse link (air-to-ground) and BFWA systems in the band 5855-5875 is not feasible (see Note 1).**	Ground Station The separation distances for all possible cases have been calculated. However, there is no need to consider the suitability of the separation distances more in detail because the compatibility studies between BFWA and DA2GC AS have shown that co-channel sharing is not feasible. Aircraft Station At higher altitudes the impact of BFWA transmitters on the receiving DA2GC AS is negligible. Only in distances below 10 km from a BFWA TS the receiving DA2GC AS at altitudes of 3 km and below can be slightly affected by interference. Thus it is concluded that single BFWA CS and TS should be uncritical for the DA2GC forward link (ground-to-air), but a larger deployment of BFWA CS and TS in an area may create noticeable performance degradation due to the aggregation of interference signals at the receiving DA2GC AS.
FSS (E-s) (Co-channel)	 5.2.8	Ground Station Not considered. Aircraft Station Not considered.	Ground Station Not considered. Aircraft Station In the co-channel case it was shown that even with a large separation distance of 100 km, the protection level of an aircraft station receiver which is crossing the beam with a velocity of 900 km/h is exceeded for around 4 minutes. It was also shown that the protection level of an AS receiver can be exceeded by the unwanted emissions of a FSS Earth Station operating above the band 5855-5875 MHz for more than 40 seconds.
Radiolocation (Below 5850	5.6.8	Ground Station In order to avoid interference to radars, a separation distance of at	Ground Station Not considered.

Services and applications	Section of the report	DA2GC as interferer	DA2GC as victim
MHz)		least 13 to 25 km should be taken into account in case no additional filtering is implemented in the DA2GC GS. The separation distances will increase in the event of the radar site being higher than the DA2GC GS (e.g. this could occur in mountainous areas).	
	5.6.2	Aircraft Station The protection of radars could be derived under the assumption that DA2GC AS transmissions will be ceased below an aircraft height of 3000 m: $\mathrm{Imax} := -38 - 10 \cdot \log\left(\frac{20}{\mathrm{BW}}\right)$ dBm/MHz With: Imax = Maximum radiated (out-of-band) AS emissions below 5850 MHz BW = AS transmitter bandwidth (MHz)	Aircraft Station Not considered.

Note 1: This result lead to the decision to consider also the 2 GHz unpaired bands for the implementation of DA2GC.

6.2 CONCLUSIONS ON THE DA2GC SYSTEM ACCORDING TO ETSI TR 101 599

The table below provides an overview of the different compatibility studies showing the most relevant aspects, when considering DA2GC operating in TDD mode with a 20 MHz channel bandwidth.

Table 56: Conclusions of compatibility studies

Services and applications	Section of the report	DA2GC as interferer	DA2GC as victim
BFWA (Co-channel)	5.1.5	Ground Station Compatibility is achieved using minimum separation distances of between a few hundred metres and a few kilometres.	Ground Station Compatibility is achieved using minimum separation distances of between a few hundred metres and a few kilometres.
	5.1.4	Aircraft Station In countries / regions where deployed some BFWA systems can experience interference from DA2GC. The detect and avoid mechanism as described ANNEX 2:is required to protect such BFWA systems.	Aircraft Station DA2GC may experience interference. Mitigation measures such as signal processing or beam switching may be required.
FSS (E-s) (Co-channel)	5.2.4	Ground Station Aggregate DA2GC interference into GSO satellites within 3% ΔT/T criterion for practical implementations when operating within the Ground	Ground Station Separation distances up to several tens of kilometres may be required, depending on terrain, ability of DA2GC GS receiver to cancel interference or

Services and applications	Section of the report	DA2GC as interferer	DA2GC as victim
		Station e.i.r.p. mask as shown in Figure 156.	adopt other mitigation such as site shielding.
	5.2.3	Aircraft Station Interference into GSO satellites from aircraft is lower than Ground Station interference due to fuselage screening. GS and AS interference is non-additive for TDD operation.	Aircraft Station High power FSS uplinks may result in DA2GC outages. Outage durations depend on ability of DA2GC receiver to cancel interference. For TR 101 599, maximum outage durations would be a few seconds.
SRDs (Co-channel)		No studies carried out. Similar results are expected as for the system described in TR 103 108 (compatibility achieved).	No studies carried out. Similar results are expected as for the system described in TR 103 108 (compatibility achieved).
ITS (non-safety) (Co-channel) ITS (safety) (Adjacent channel)	5.4.3	Ground Station Compatibility is achieved using minimum separation distances of between a few hundred metres and a few kilometres when level ground is considered. Therefore the DA2GC GS antenna should be higher than roads in its vicinity to avoid the need for greater separation distances.	Ground Station Separation distances necessary to protect ITS will be more than sufficient to also ensure that DA2GC receiver is protected from ITS emissions.
	5.4.2	Aircraft Station The e.i.r.p. / PFD masks in Figure 157 to Figure 159 were based on ITS protection criteria, so compatibility is ensured for systems operating within it.	Aircraft Station Mitigation techniques may be necessary in areas of high ITS usage.
RTTT (Below 5815 MHz)	5.4.3	Ground Station RTTT receivers are protected with separation distances of less than 100m.	Ground Station Likely to be less than separation distances required to protect RTTT due to frequency separation.
	5.4.2	Aircraft Station RTTT systems are fully protected by the limits on aircraft emissions below 5850MHz required for protection of radars (see below)	Aircraft Station Aggregation of power from multiple RTTT transmitters at aircraft receiver likely to be within acceptable levels (due largely, to RTTT downward transmitter pointing and frequency separation).
Radiolocation (Below 5850 MHz)	5.6.9	Ground Station With suitable mitigation measures separation distances can be reduced to 0.03 – 3.5 kms depending on the type of radar. The separation distances will increase in the event of the radar site being higher than the DA2GC GS (e.g. this could occur in mountainous areas).	Ground Station Some rare exceedances of DA2GC receiver interference threshold may occur, where radars are operating in the near vicinity of the Ground Station but mitigation techniques can be used to reduce these to acceptable levels.
	5.6.3 and 5.6.14	Aircraft Station Radars are fully protected provided that DA2GC aircraft emissions below	Aircraft Station Exceedances of DA2GC receiver interference threshold can occur (up to

Services and applications	Section of the report	DA2GC as interferer	DA2GC as victim
		5850 MHz do not exceed -38 -10log (20/BW) dBm/MHz radiated power. BW = AS transmitter bandwidth (MHz)	60 dB) and in such cases mitigation techniques can be used to achieve an acceptable performance (see ANNEX 2:).

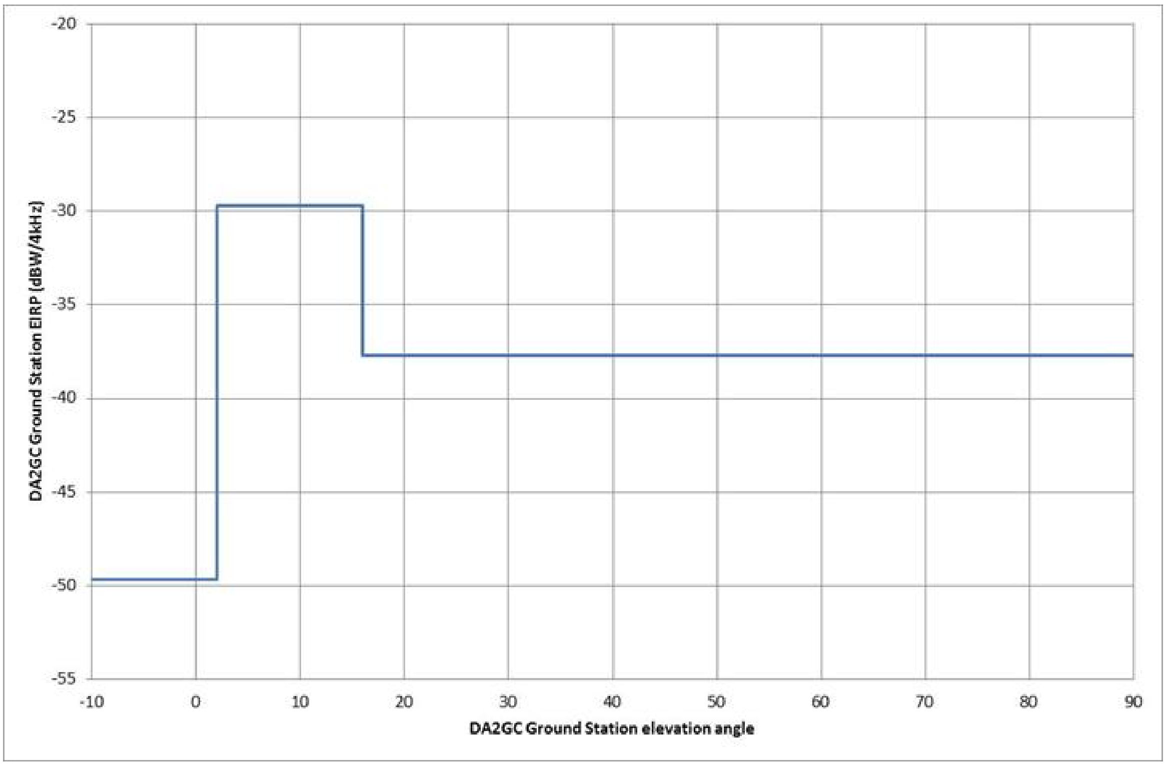


Figure 156: Suitable Average e.i.r.p. Mask for the Ground station according to ETSI TR 101 599

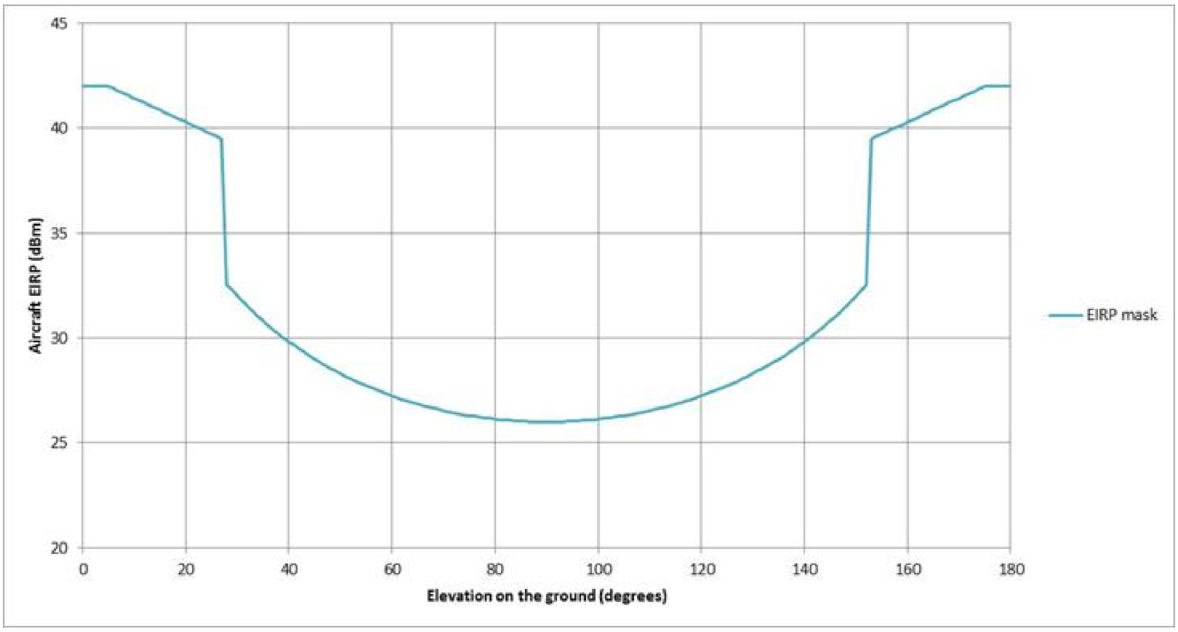


Figure 157: Suitable e.i.r.p. mask for the aircraft station according to ETSI TR 101 599 (10 km altitude)

Table 57: Suitable Aircraft e.i.r.p. mask (10 km altitude)

Elevation at ground (degrees)	Aircraft e.i.r.p. (dBm)	Note
0 to 5 degrees	42	
5 to 27 degrees	42 to 39.5	Straight line interpolation
27 to 28 degrees	39.5 to 32.5	Straight line interpolation
28 to 90 degrees	$-65 + 10 \log 4\pi d^2$	where: $d = \sqrt{(R^2 + (R + h)^2 - 2R(R + h)\cos\alpha)}$ in metres $\alpha = 90 - \sin^{-1}(R\cos(El)/(R + h)) - El$ in degrees where El = Elevation at ground (in degrees) $R = 6371{*}10^3$ m $h = 10^4$ m

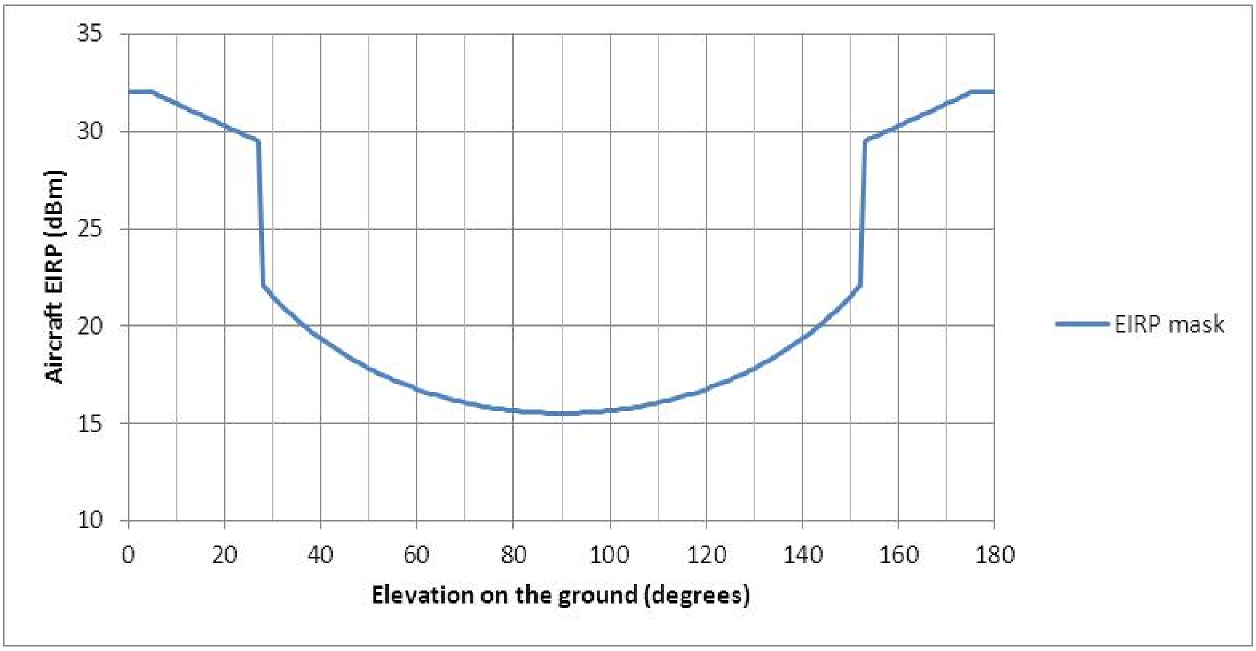


Figure 158: Suitable e.i.r.p. mask for the aircraft station according to ETSI TR 101 599 (3 km altitude)

Table 58: Suitable Aircraft e.i.r.p. mask (3 km altitude)

Elevation at ground (degrees)	Aircraft e.i.r.p. (dBm)	Note
0 to 5 degrees	32	
5 to 27 degrees	32 to 29.5	Straight line interpolation
27 to 28 degrees	29.5 to 22.1	Straight line interpolation
28 to 90 degrees	$-65 + 10 \log 4\pi d^2$	where: $d = \sqrt{(R^2 + (R + h)^2 - 2R(R + h)\cos\alpha)}$ in metres $\alpha = 90 - \sin^{-1}(R\cos(El)/(R + h)) - El$ in degrees where El = Elevation at ground (degrees) $R = 6371*10^3$ m $h = 3*10^3$ m

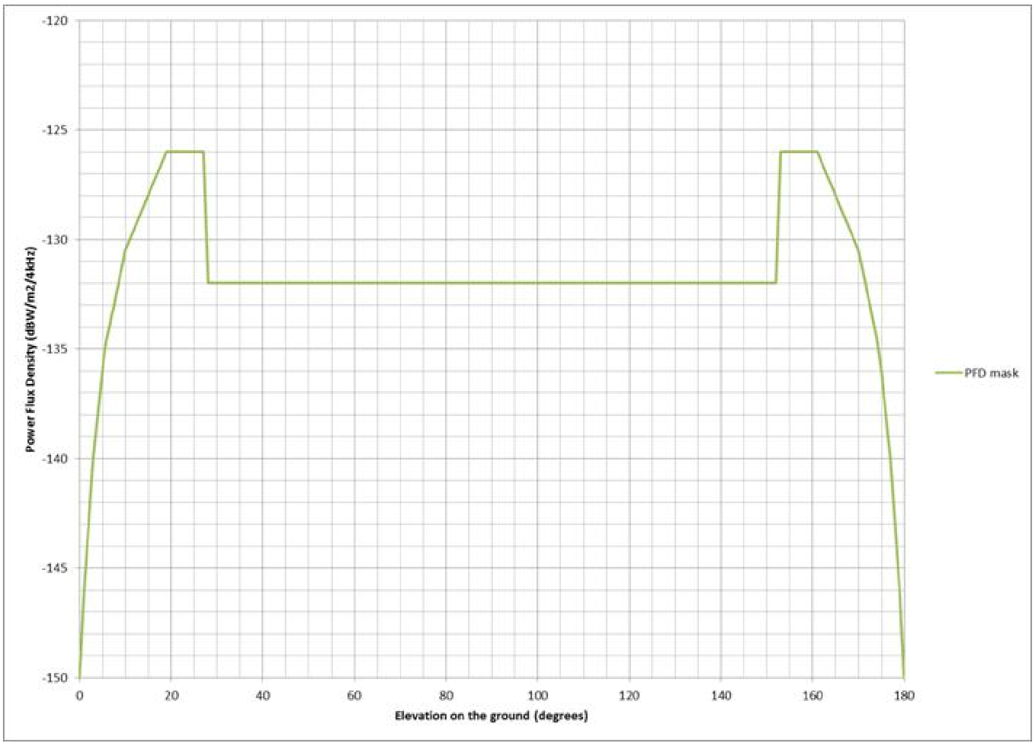


Figure 159: Suitable Aircraft PFD mask

The above graph is made up of a number of straight line segments and is symmetrical about 90 degrees. The breakpoints are defined as follows:

0 degree	-150 dBW/m^2/4kHz
1 degree	-146
3 degrees	-138
5.5 degrees	-135
10 degrees	-130.5
19 degrees	-126
27 degrees	-126
28 degrees	-132
90 degrees	-132

6.3 CONCLUSIONS ON THE DA2GC SYSTEM ACCORDING TO ETSI TR 103 108

Table 59: Results of the compatibility studies in the band 5855 to 5875 MHz for the System according to ETSI TR103 108

Services and applications	Section of the report	DA2GC as interferer	DA2GC as victim
BFWA (Co-channel)	5.1.8	Ground Station Compatibility is achieved using minimum separation distances of between a few hundred metres and a few kilometres.	Ground Station Compatibility is achieved using minimum separation distances of between a few hundred metres and a few kilometres.
	5.1.7	Aircraft Station Compatibility is achieved by the additional reduction in maximum e.i.r.p. by 4 dB, for aircraft altitudes up to 7 km, in regions where co-channel BFWA is used.	Aircraft Station Compatibility is achieved.
FSS (E-s) (Co-channel)	5.2.6	Ground Station Compatibility is achieved. Aggregate DA2GC interference into GSO satellites is within 3% ΔT/T criterion. However, a 1% ΔT/T criterion can be achieved by aligning the fixed antenna null towards the most sensitive satellite (Satellite H) for all ground stations.	Ground Station Compatibility is achieved using a separation distances of a few kilometres. Given the relatively small number of DA2GC GS, site planning can ensure this.
	5.2.5 and 5.2.8	Aircraft Station Compatibility is achieved. Aggregate interference into GSO satellites from aircraft is lower than 1% ΔT/T.	Aircraft Station High power FSS uplinks may result in DA2GC AS outages. Outage durations depend on the aircraft's flight profile. The DA2GC system is designed to minimise the impact as perceived by the user and these outages are operationally acceptable.
SRDs (Co-channel)	5.3.3	Compatibility is achieved for all cases.	Compatibility is achieved for all cases.
ITS (non-safety) (Co-channel) ITS (safety) (Adjacent channel)	5.4.5	Ground Station Co-channel compatibility is achieved using separation distances of between a few hundred metres and a few kilometres when level ground is considered. Therefore the DA2GC GS antenna should be higher than roads in its vicinity to avoid the need for greater separation distances. Adjacent channel compatibility is achieved.	Ground Station Compatibility is achieved using separation distances of between a few hundred metres and a few kilometres when the DA2GC GS antenna is at the same height as that of the ITS source. Adjacent channel compatibility is achieved.
	5.4.4	Aircraft Station Compatibility is achieved for all cases.	Aircraft Station Compatibility is achieved for all cases.

Services and applications	Section of the report	DA2GC as interferer	DA2GC as victim
RTTT (Below 5815 MHz)	5.5.2 and 5.5.3	Compatibility is achieved for all cases.	Compatibility is achieved for all cases.
Radiolocation (Below 5850 MHz)	5.6.10	Ground Station Compatibility can be achieved with separation distances of between a few hundred metres and a few kilometres depending on the type of radar. It is noted that the preferred DA2GC GS location is urban. The separation distances will increase in the event of the radar site being higher than the DA2GC GS (e.g. this could occur in mountainous areas).	Ground Station It is unlikely that interference above the DA2GC GS interference threshold will occur given the urban location of the GS. However, where radars are likely to be operating in the near vicinity of the Ground Station, additional mitigation techniques such as site shielding can be applied.
	5.6.4 and 5.6.14	Aircraft Station Compatibility is achieved by the maximum level of unwanted emissions of -50dBm/MHz according to the TR 103 108 system description	Aircraft Station The DA2GC receiver interference threshold may be exceeded by up to 60 dB, but the proponents of this system believe that mitigation techniques can be used to achieve an acceptable performance.

ANNEX 1: REDUCTION OF UNWANTED EMISSIONS FOR THE DA2GC SYSTEM IN TR 101 599

A1.1 INTRODUCTION

In the context of discussions on the 5.8GHz band, it became clear that protection of radars operating in the bands below 5850 MHz requires stringent OOB and spurious emission limits to be applied to DA2GC transmissions.

This section explains how such limits can be met for the system described in ETSI TR101 599 through the use of appropriate design techniques.

A1.2 SYSTEM DESIGN FEATURES

A1.2.1 Basic transceiver architecture

The basic system architecture is described in section 4.2 which included a block diagram showing the basic RF transceiver connectivity. For convenience, this is reproduced in Figure 160 below.

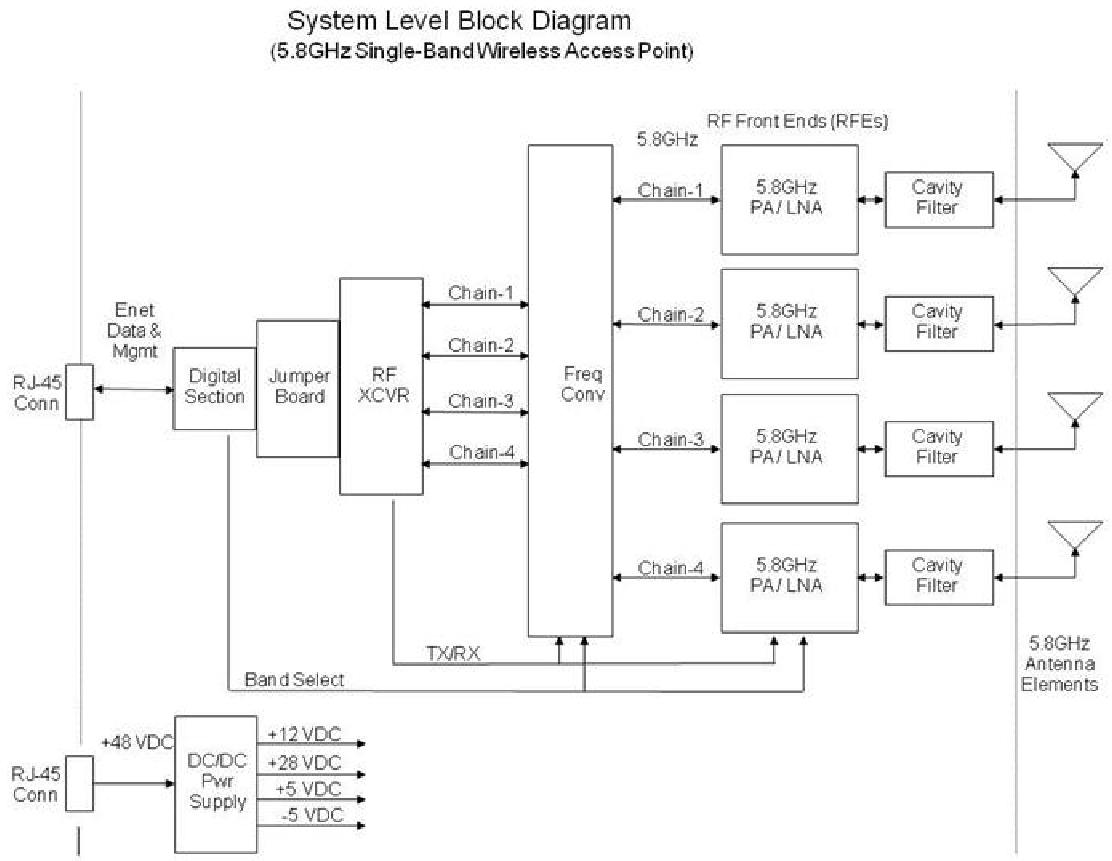


Figure 160: Radio transceiver unit basic connectivity (only 4 chains shown)

It should be noted that the above transceiver architecture is identical for both the Ground Station and Aircraft Station transceivers, the only difference being in the antenna configurations.

A1.3 DIGITAL PRE-DISTORTION

Although not a separate physical item, and therefore not shown in Figure 97, an essential feature of the RF transceiver design is the use of digital pre-distortion, which is implemented in software in order to overcome non-linearities in the transmit chain (mainly due to PA effects). In this way, the OFDM signal can be optimised to achieve maximum performance in the bandwidth available and compensate for filter losses towards the edge of the channel.

This technique can also be used to generate a spectral envelope which has extremely sharp drop-off at the channel edge. An example plot is shown in Figure 161 below, where the raw signal (before pre-distortion) is shown in blue and the resulting trace after processing is shown in Green. (This example was based on a measured signal at 2.14GHz, but identical performance is achievable at 5.8GHz, since the implementation is done in software and is not frequency dependent).

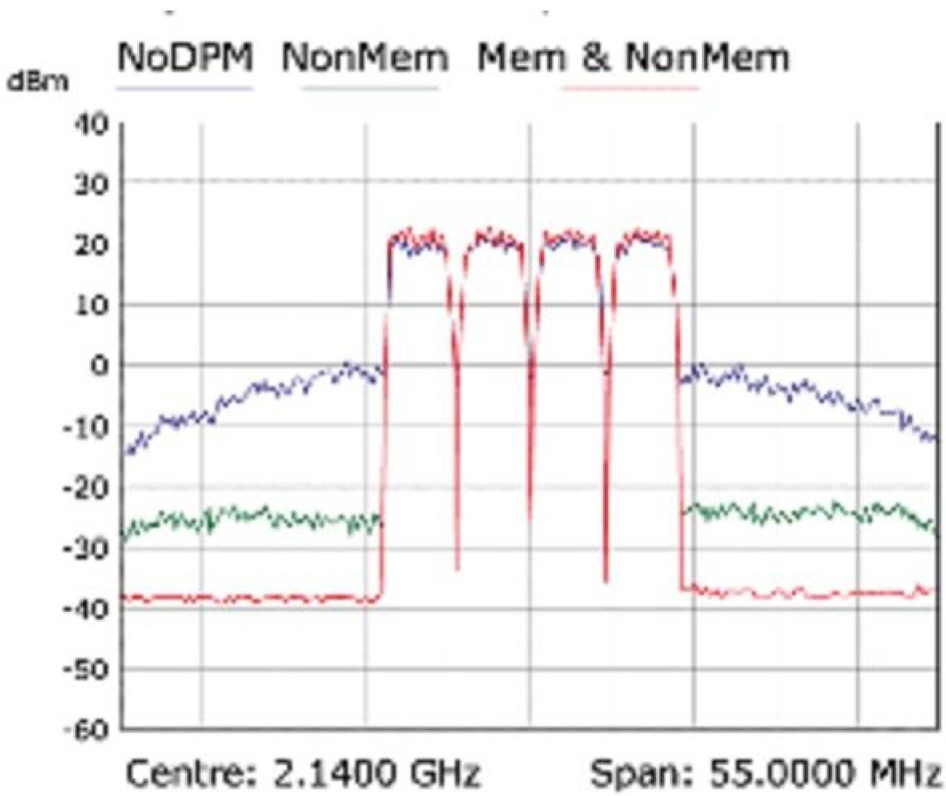


Figure 161: Example of signal suppression using DPD techniques

It can be seen from Figure 161 that OOB signal suppression, relative to maximum carrier power, of around 45dB is achievable through the use of Digital Pre-Distortion (DPD) techniques. This, in itself, is more than sufficient to enable the -40dBc OOB specification from ETSI TR 101 599 [30] to be achieved at band edge (5855 MHz).

The third plot in Figure 161 (shown in red) represents the application of additional techniques to improve the linearity of the PA's themselves which result in state-of-the-art suppression levels, but this requires additional hardware and complexity to achieve and goes beyond what would be required at band edge for the present application. Instead, further suppression of OOB and spurious emissions can more readily be achieved using traditional analogue filters as described in the next section. Such filters have the added benefit of providing ever increasing attenuation with frequency offset, enabling very low emission levels to be achieved in the spurious domain.

A1.4 OUTPUT FILTERING

The cavity filters fitted to the output of each of the final power amplifiers are custom designed to achieve the maximum suppression achievable at 5850 MHz (and continue to roll off below this frequency), whilst minimizing the amount of pre-distortion needed to compensate for the impact of the filter response on the wanted OFDM signal within the 20MHz pass band. The frequency response of the cavity filters shown in Figure 160 is illustrated in Figure 162 below.

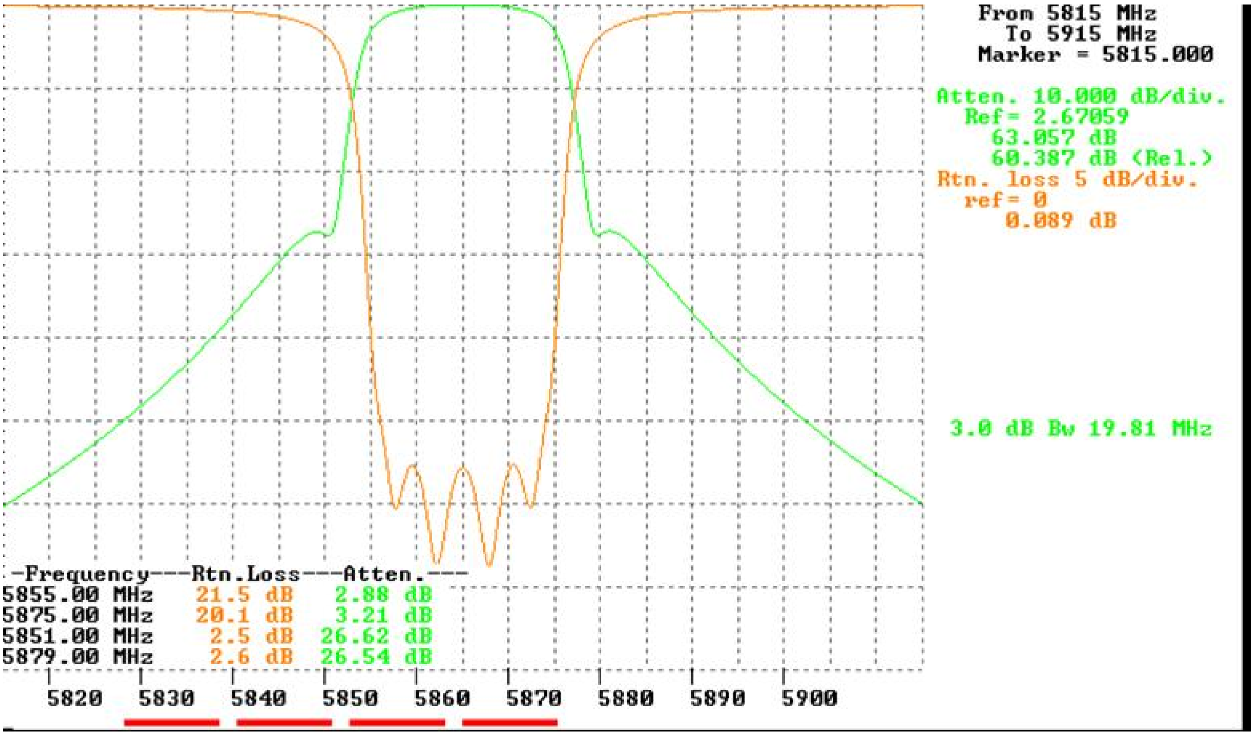


Figure 162: Transceiver output cavity filter response plot

It can be seen from Figure 162 that a suppression of approximately 28dB is achievable at 5850 MHz, relative to the maximum in-band carrier level, through the application of one such cavity filter on each of the PA outputs.

A1.5 ACHIEVABLE OOB AND SPURIOUS SUPPRESSION LEVELS

From Section A1.3, it can be seen that the DPD gives rise to approximately 45dB of signal suppression at 5855MHz and below. (This enables the current ETSI spec of -40dBc for OOB signals to be met with a few dB of margin).Section A1.4 illustrates how an additional 28dB of suppression is achieved through the use of cavity filters on the transceiver PA outputs for frequencies of 5850 MHz and below. The total unwanted emissions below 5850 MHz can therefore be readily limited to -70dB or better, relative to full carrier power, with increasing roll-off due to the cavity filters resulting in extremely low power levels in the spurious domain below 5815MHz.

A1.6 SUMMARY

This Annex has described how the levels of unwanted emissions from the system described in ETSI TR 101 599 in the OOB and spurious domains can readily be reduced to meet the most stringent levels required for the protection of radars (and all other systems) in adjacent bands, through the use of established technology, known software techniques and commercially available products.

ANNEX 2: DETECT AND AVOID' CAPABILITIES FOR THE DA2GC SYSTEM IN TR 101 599

A2.1 INTRODUCTION

The results of the studies between BFWA and DA2GC indicate that BFWA systems may experience interference above acceptable criteria. This situation needs to be avoided through technical means and a so called 'Detect and Avoid' mechanism is likely to be an important element in the overall solution. This could be a part-solution in the case of DA2GC Ground Stations but is likely to be the only means of dealing with the potential for interference into BFWA systems from DA2GC aircraft stations, since more 'traditional' coordination methods would be impracticable for such moving interference sources.

This Annex examines the feasibility of implementing 'Detect and Avoid' mechanisms in respect of DA2GC aircraft stations, by way of a two-stage approach. Firstly, in Section A2.2, the Detection sensitivity of the DA2GC receiver in respect of BFWA transmissions is examined, to determine whether such signals can be detected before the DA2GC transmissions give rise to unacceptable interference at the BFWA receiver. Section A2.3 then considers the way in which Avoidance techniques could be applied, once the presence of BFWA terminals is detected.

A2.2 DETECTION

Digital Signal Processing (DSP) techniques as used in the beam-forming DA2GC system allow for signals 9 dB below the DA2GC receiver noise floor to be detected. The DA2GC receivers used have a noise figure of 4 dB so the noise floor (in the 20 MHz receive bandwidth) is – 97 dBm. Received BFWA signal levels of 106 dBm can therefore be detected.

A2.2.1 BFWA Base Station

Taking a BFWA Base Station in its worst case location which is 15 km from the DA2GC Ground Station towards the aircraft, the interference power received by the BFWA Base Station is shown in Figure 163 and Figure 164below, where Figure 163 is with reference to elevation angle at the DA2GC Ground Station and Figure 164 is with reference to elevation angle at the BFWA Base Station. It can be seen that interference exceeding the long term criterion occurs over a small range of elevation angles; 5 to 7½ degrees with reference to DA2GC Ground Station elevation angles (Figure 163) and 6 to 9 degrees with reference to BFWA Base Station elevation angles (Figure 164)

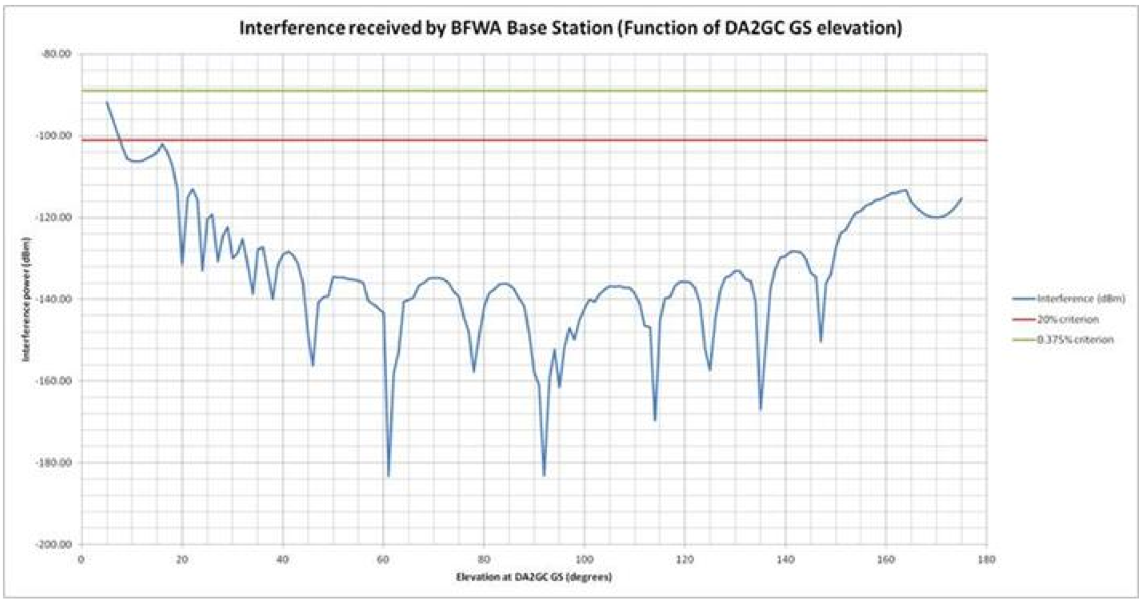


Figure 163: Interference received at worst case location BFWA Base Station (15 km offset from DA2GC Ground Station) with reference to DA2GC Ground Station elevation angle.

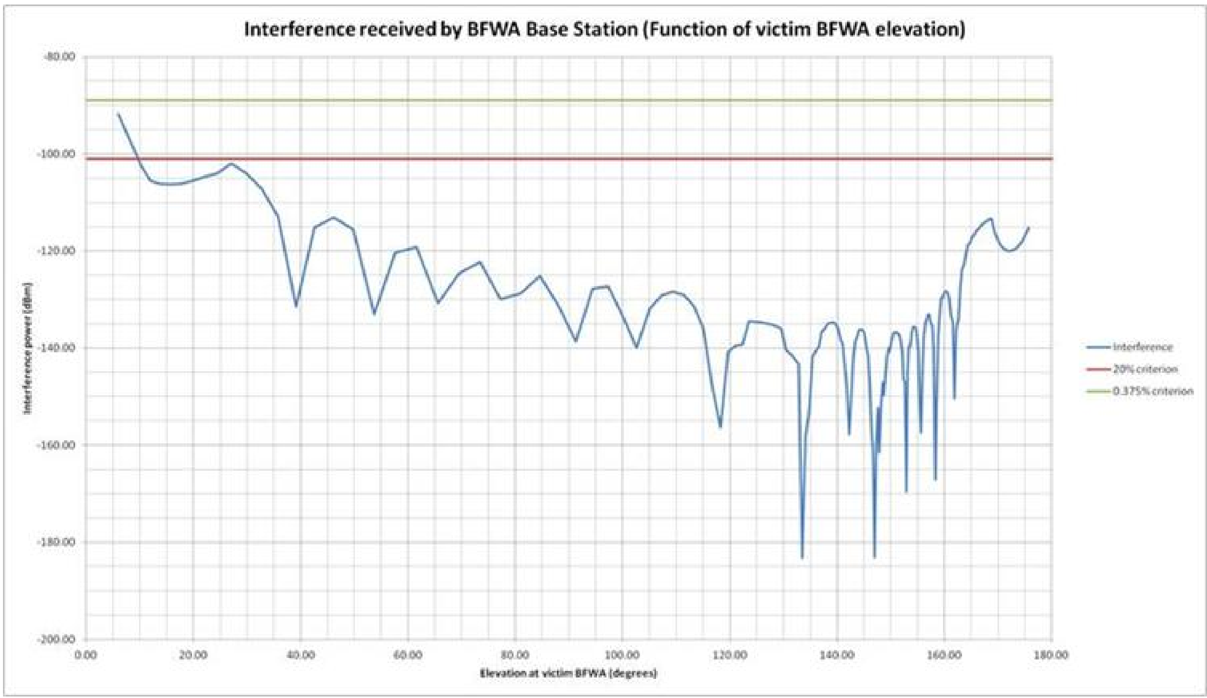


Figure 164: Interference received at worst case location BFWA Base Station (15 km offset from DA2GC Ground Station) with reference to BFWA Base Station elevation angle.

At the same time as the BFWA Base Station is receiving interference power from the DA2GC aircraft as indicated in Figure 163 and Figure 164 above, the aircraft is receiving power from the BFWA Base Station (P = 19 dBm, G = 17 dBi) as shown in Figure 165below.

It can be seen that the DA2GC aircraft receiver will be able to detect BFWA signals greater than -106 dBm which extend from 0 to 15 degrees (with respect to DA2GC Ground Station elevation) and 0 to 32 degrees (with respect to BFWA Base Station elevation).

The Detectable and ‘need to Avoid’ ranges can be compared as follows:

Elevation angle base	Interference to be avoided between (degrees)	Interference detected between (degrees)
DA2GC Ground Station	5 to 7½	0 to 15
BFWA Base Station	6 to 9	0 to 32

It is therefore clear that potential BFWA Base Station victims of interference can be detected before they experience unacceptable levels of interference, such that avoidance techniques (see Section A2.3) can be put in place.

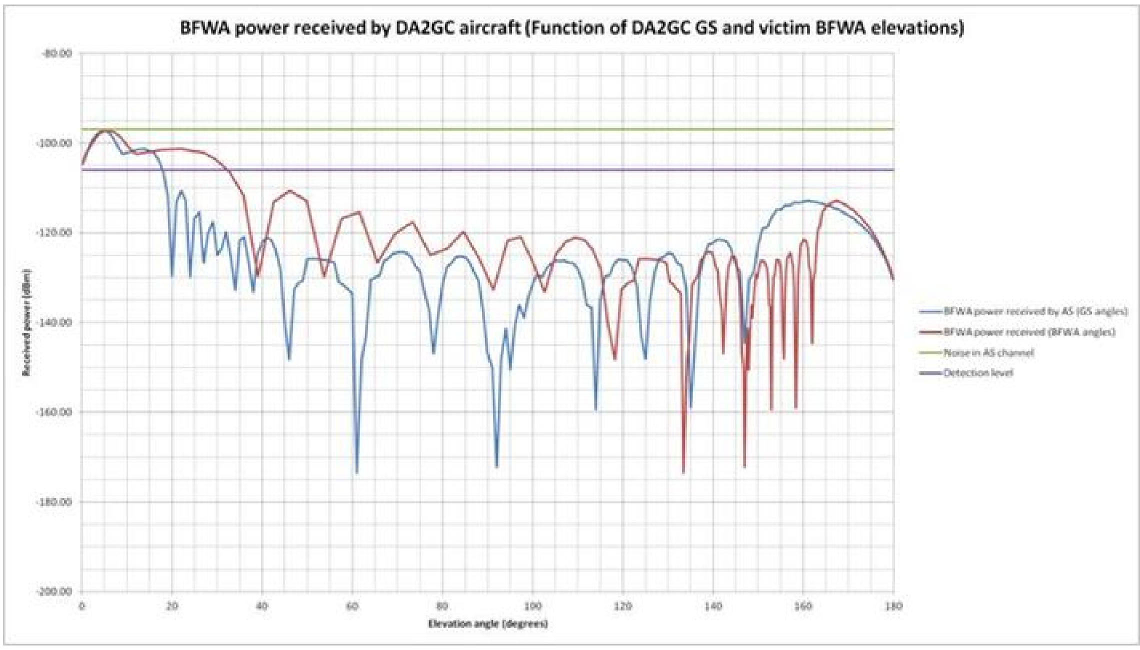


Figure 165: BFWA Base Station power received at DA2GC aircraft with reference to BFWA Base Station (15 km offset) and DA2GC Ground Station elevation angles.

A2.2.2 BFWA User Terminal

Taking a BFWA User Terminal in its worst case location which is 65 km from the DA2GC Ground Station towards the aircraft, the interference power received by the BFWA User Terminal is shown in Figure 166 and Figure 167 below, where Figure 166 is with reference to elevation angle at the DA2GC Ground Station and Figure 167 is with reference to elevation angle at the BFWA User Terminal.

It can be seen that interference exceeding the long term criterion occurs over a range of elevation angles; 5 to 7 degrees with reference to DA2GC Ground Station elevation angles (Figure 166) and 14 to 32 degrees with reference to BFWA User Terminal elevation angles (Figure 167).

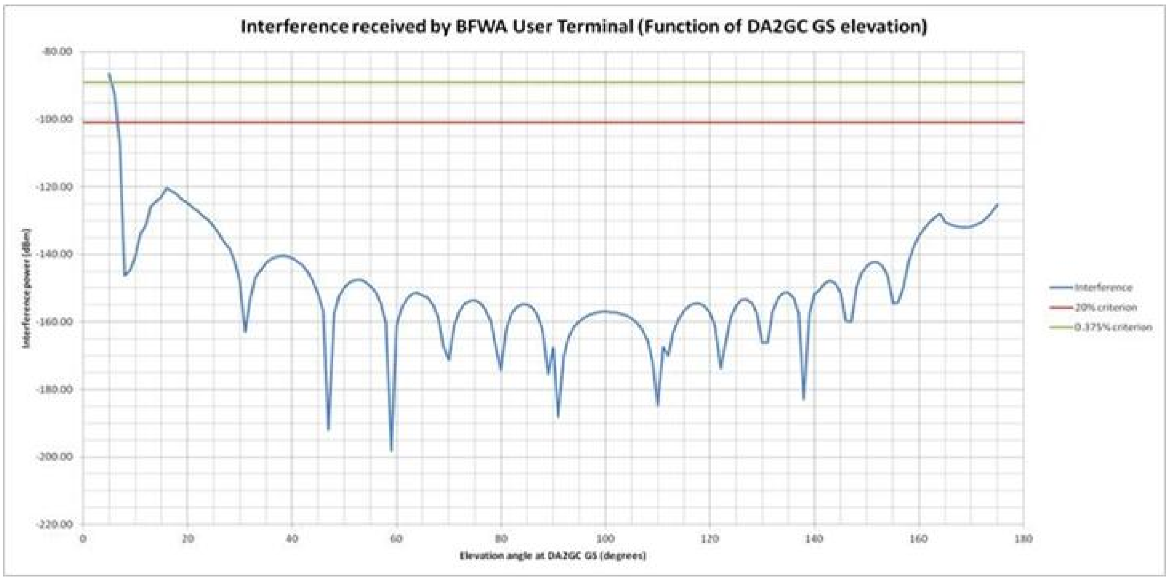


Figure 166: Interference received at worst case location BFWA User Terminal (65 km offset from DA2GC Ground Station) with reference to DA2GC Ground Station elevation angle

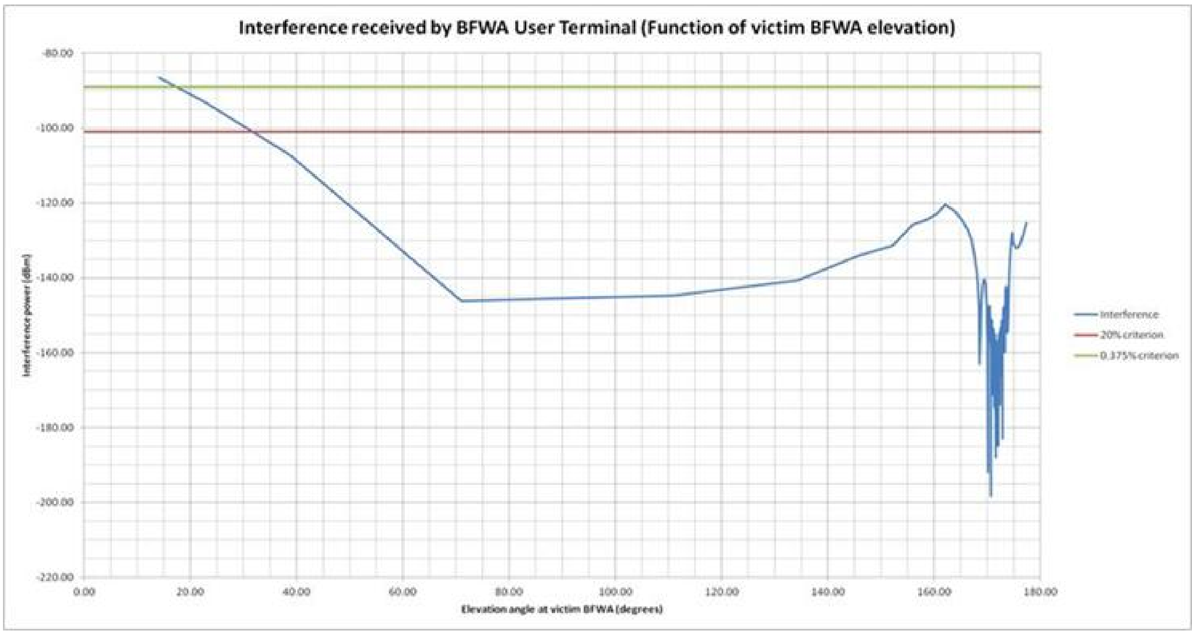


Figure 167: Interference received at worst case location BFWA User Terminal (65 km offset from DA2GC Ground Station) with reference to BFWA User Terminal elevation angle.

At the same time as the BFWA User Terminal is receiving interference power from the DA2GC aircraft, the aircraft is receiving power from the BFWA User Terminal (P = 19 dBm, G = 17 dBi) as shown in Figure 168below.

It can be seen that the DA2GC aircraft receiver will be able to detect BFWA signals greater than -106 dBm which extend from 0 to 7 degrees (with respect to DA2GC Ground Station elevation) and 1 to 37 degrees (with respect to BFWA User Terminal elevation).

The Detect and ‘need to Avoid’ ranges can be compared as follows:

Table 60: Detect and ‘need to Avoid’ ranges comparison

Elevation angle base	Interference to be avoided between (degrees)	Interference detected between (degrees)
DA2GC Ground Station	5 to 7	0 to 7
BFWA User Terminal	14 to 32	1 to 37

It is therefore clear that potential BFWA User Terminal victims of interference can be detected before they experience unacceptable levels of interference, such that avoidance techniques can be put in place.

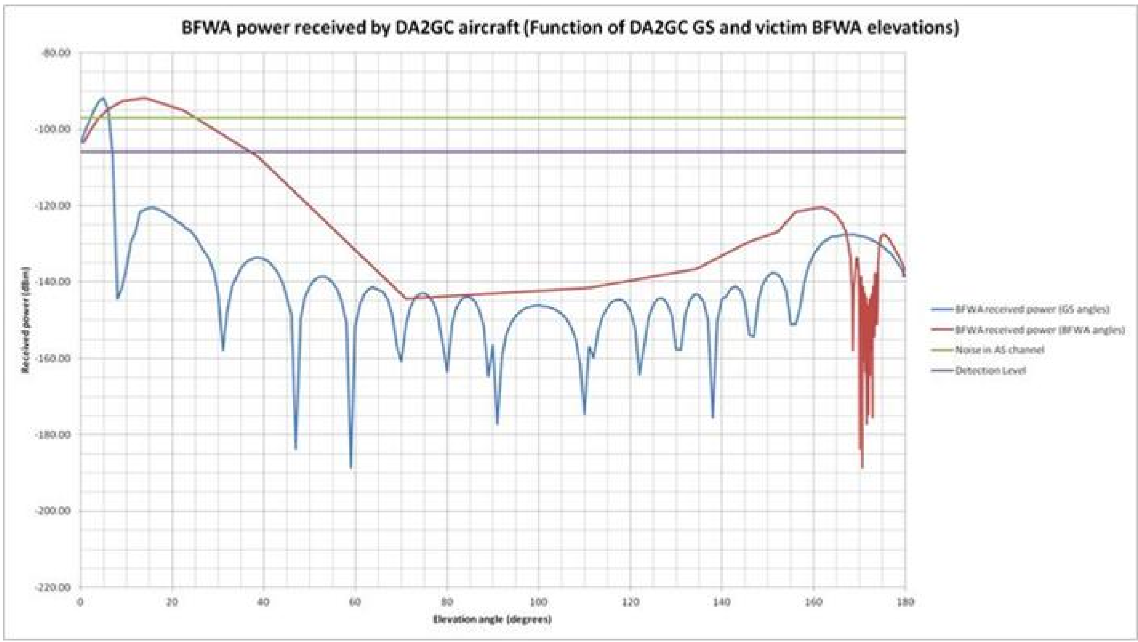


Figure 168: BFWA User Terminal power received at DA2GC aircraft with reference to BFWA User Terminal (65 km offset) and DA2GC Ground Station elevation angles

A2.3 AVOIDANCE TECHNIQUES

The previous section has shown that BFWA terminals can be detected before the DA2GC transmissions give rise to unacceptable interference at the BFWA receiver. Given this, we need to consider three strategies that can be employed to prevent interference from occurring, namely:

- Antenna nulling;
- Adaptive OFDM spectral power density;
- DA2GC Ground Station diversity.

A2.3.1 Antenna Nulling

Each aircraft antenna array has a number of degrees of freedom to manipulate grating lobes dynamically in order to direct nulls and maxima in desired directions. Areas where BFWA terminals are located can therefore be placed in a null where a suppression of interfering power of the order of 40 dB can be achieved. The capability of this technology is shown in Figure 169 below. This diagram relates to the use of this technology for DA2GC Ground Stations in relation to adjacent band radars and other services. However, the technology is equally applicable to the DA2GC aircraft antenna arrays.

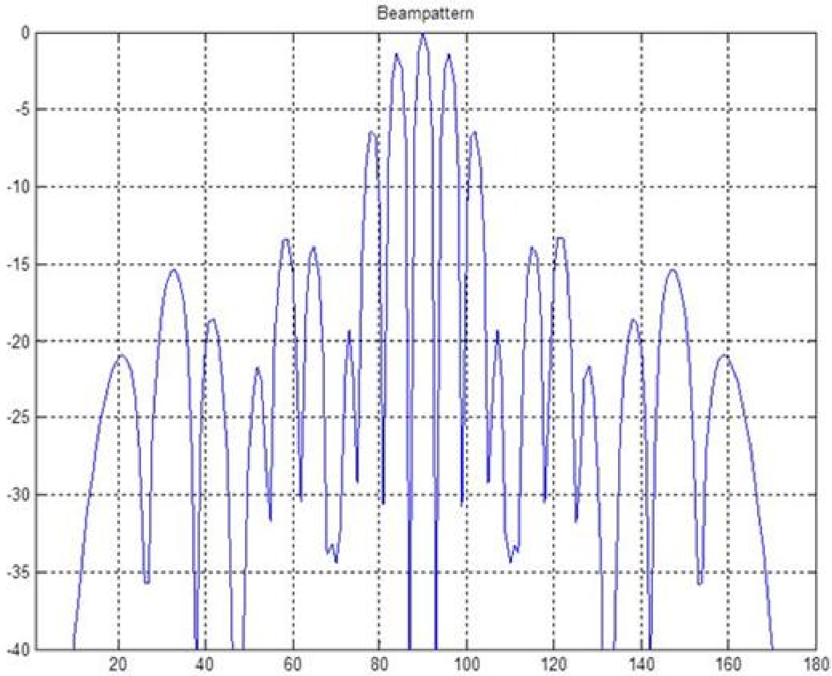


Figure 169: Example DA2GC ground station azimuth beam pattern for 8 element array showing grating lobes / nulls enable interference cancellation – equally applicable to DA2GC aircraft antenna arrays

In the example given above the outline of the main lobe can be seen between approximately 70 and 110 degrees along the x-axis. Within that main lobe six deep nulls have been synthesised. These nulls can either be narrow and deep or wide and less deep; a 40 dB null would subtend approximately 2½ degrees and a 15 dB null would subtend approximately 10 degrees at the aircraft antenna array. The depth / width required can be synthesised as required.

It can be noted from earlier analyses that the potential interference exceedance at a BFWA terminal is, depending on the criterion used, up to 9 dB in the case of a Base Station and up to 15 dB in the case of a User Terminal. It can therefore be seen that complete flexibility is available in terms of how to deal with individual BFWA terminals and groups of terminals over an area.

Figure 196 earlier shows that a BFWA User Terminal in the worst case location receives unacceptable interference from a DA2GC aircraft in the range from 14 to 32 degrees of elevation (at the BFWA terminal). In this geometry, and assuming that there are other potential victim BFWA terminals in a town of radius 2 km, it would be necessary to deploy a null of 6 degrees across at the aircraft antenna which is well within the capability of this technology. The geometry of this is shown in Figure 170 below.

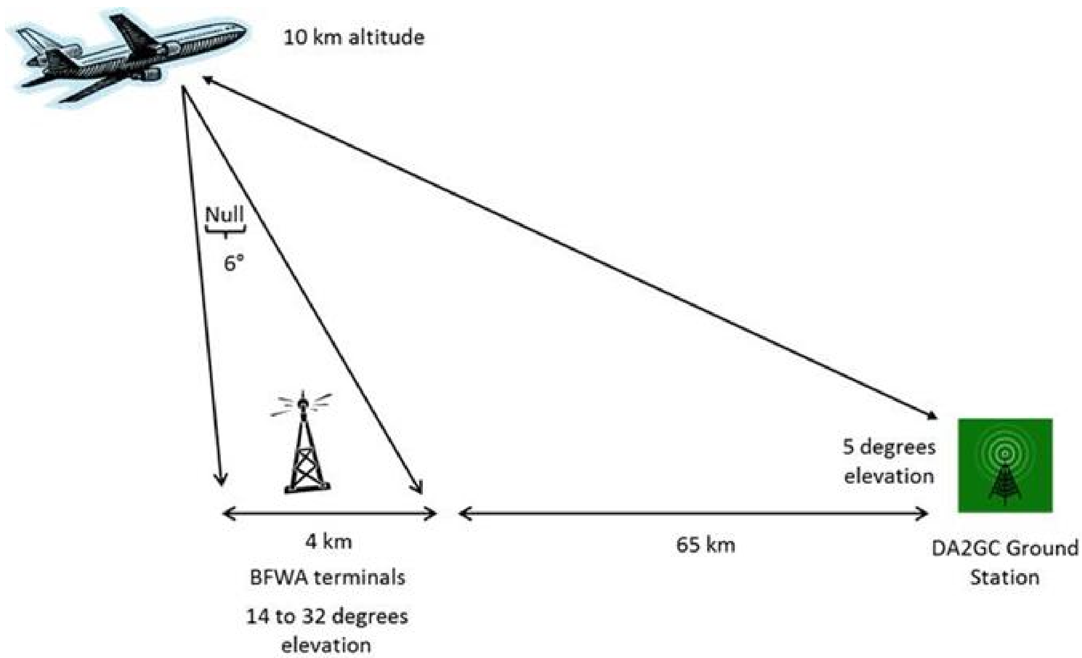


Figure 170: Nulling geometry required to protect a representative town

A2.3.2 Adaptive OFDM spectral power density

Where the potential for interference amounts to a few dB, and in rare cases where the nulling technique may not be fully effective, it is also possible to adapt dynamically the transmitted spectral power density by reducing the number of sub-carriers that are used in the OFD Multiplex when a potential BFWA victim is sensed. In this way, the total power received within the victim BFWA receiver bandwidth can be reduced to acceptable levels. This would be at the cost of a temporary lowering of the data rate on the aircraft return (air-to-ground) link, but would be acceptable to the DA2GC operator in the context of a low-cost service, particularly since data traffic is likely to be quite asymmetrical, with a much higher requirement on the forward (ground-to-air) link.

A2.3.3 DA2GC Ground Station diversity

As an alternative to the power reduction technique described above, another option to cover those rare cases where nulling may not be a fully effective remedy would be to switch the ‘offending’ aircraft beam to re-point towards the nearest alternative DA2GC Ground Station. This would be an effective mitigation technique, since it is only the alignments involving the main lobe of the aircraft antenna pattern which give rise to interfering powers above the BFWA allowable threshold criteria.

A2.4 CONCLUSIONS

This Annex has described how, in the first instance, the presence of BFWA terminals (both Base Stations and User terminals) can be detected through signal processing at the aircraft receiver. Furthermore, it has been shown that this detection capability is sufficient for the BFWA transmissions to be detected before the DA2GC aircraft transmissions give rise to unacceptable interference at the BFWA receiver.

In the event that BFWA transmissions are detected, there are three techniques that can prevent interference from occurring. The most effective of these is antenna nulling whereby DA2GC transmissions are suppressed to an appropriate level in the direction of the BFWA terminal (or grouping of terminals e.g. in a town). In rare cases where nulling may not be fully effective it is possible to reduce the DA2GC transmitted power spectral density towards the BFWA terminal(s) by reducing the number of sub-carriers in the OFD Multiplex or by switching the DA2GC aircraft beam to an alternative Ground Station.

ANNEX 3: COMPATIBILITY AND SHARING SCENARIOS FOR THE BAND 2400 – 2483.5 MHz (INFORMATIVE)

The band 2400-2483.5 MHz is heavily used by RLAN, Bluetooth, Zigbee and other applications. According to ERC/REC 25-10 [35] the band is also used by Cordless cameras, portable video links and mobile video links airborne and vehicular. Technical parameters can be found in ERC Report 038 [33]. ECC Report 002 [34] gives information about the spectrum use and future requirements of these systems.

Figure 171 depicts the sharing scenarios in the band 2400 -2483.5 MHz in both interference directions when assuming TDD mode of the DA2GC system.

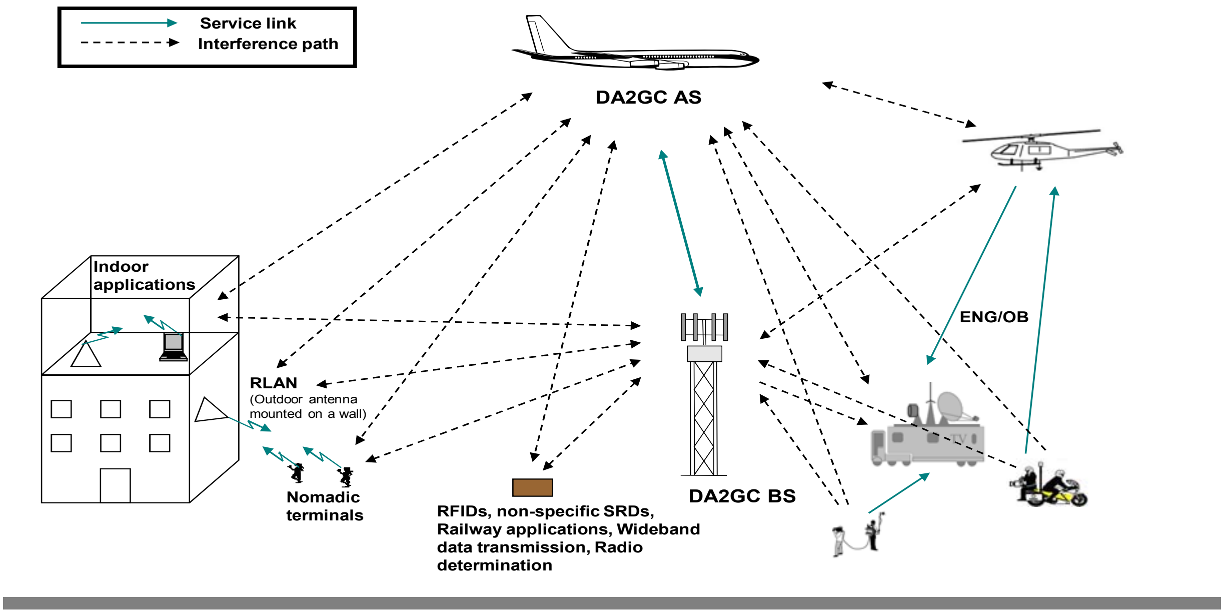


Figure 171: Interference scenarios for BDA2GC in the frequency band 2 400 – 2 483.5 MHz

A3.1 TECHNICAL CHARACTERISTICS OF SRDS

The relevant technical characteristics and protection criteria for the compatibility studies are given in Table 61. An overview of SRD applications is attached to the Table.

Table 61: Technical characteristics and protection criteria for SRDs in the 2.4 GHz band

	RLAN/ Wifi – Outdoor (including p2p, p2mp, mesh,.)	RLAN/ Wifi – indoor	Bluetooth	Bluetooth (class 1)	Zigbee – 802.15.4	RFID
Tx power dBm(conducted)	10 – 17 dBm	13 – 17	0 – 5	13	5 – 15	14
Bandwidth (MHz)	20 / 40	20 / 40	1	1	5	3
Rx sensitivity (dBm)	-82 / -79	-82 / -79	-90	-90	-83	-90
Antenna gain (dBi)	3 – 10	3 - 7	0 - 3	0 - 3	0 - 3	6
Duty cycle (%)	Up to 100	Up to 100	Up to 100	Up to 100	100	Up to 100
Hopper/non hopper	Non-hopper	Non-hopper	Hopper	Hopper	Hopper	Non-hopper
Uniform density per km^2	50	5000 (e.g. Monaco)	10.000 (e.g. Monaco)	1000	100	100
Rural/Urban	Rural + urban	Urban	Urban	Urban	Urban	Rural + urban
Protection Criterion (C/I)	≥ 10 dB	≥ 10 dB	≥ 10 dB	≥ 10 dB	≥ 10 dB	≥ 10 dB
Percentage indoor (%)	0	99	75	98	99	75
Wall attenuation	0	15	15	15	15	15

A3.1.1 Overview of 2.4 GHz applications:

- WIFI or IEEE 802.11 based consumer and enterprise applications, including smart phones etc.. These products comply with ETSI EN 300 328 [28]and Annex 3 of ERC/REC 70-03 [36]. Maximum output power is 100 mW e.i.r.p.
  - In 2011 only, in total 1 billion (1.000.000.000) chipsets were shipped.

- Bluetooth for short distance links used in Mobile (smart) phones, notebooks, game consoles...). These products comply with EN 300 328 and Annex 3 of ERC/REC 70-03. Maximum output power ranges from 1 mW e.i.r.p. (Class 3) to 100 mW (Class 1).
  - In 2011 only, in total 2 Billion (2.000.000.000) chipsets were shipped.

- ZigBee or 802.15.4 used in applications for Home Automation, Smart Grid, Building Automation, etc... These products comply with EN 300 328 and Annex 3 of ERC/REC 70-03. Maximum output power is 100 mW e.i.r.p.
  - In 2010, in total 60 million chipsets were shipped.

- Other applications include
  - non specific SRDs (ERC/REC 70-03 Annex 1 / EN 300 440 [38])
  - Railway applications in 2446-2454 MHz (ERC Rec 70-03 Annex 4 / EN 300 761)
  - Radiodetermination applications (ERC/REC 70-03 Annex 6 / EN 300 440
  - RFID (ERC/REC 70-03 Annex 11 / EN 300 440).

A3.2 COMPATIBILITY BETWEEN BROADBAND DA2GC (ETSI TR 103 054) AND RLANS

The most critical compatibility scenario seems to be between Broadband DA2GC and outdoor RLANs as described in Table 61. Therefore this scenario has studied first. An RLAN access point with a maximum antenna gain of 10 dBi and a RLAN device equipped with an omni-directional antenna were assumed in this study (see Figures 5-2 and 5-3). The maximum e.i.r.p. for RLANs is 20 dBm according to ERC/REC 70-03 [36] (Annex 3). As the band 2400-2483.5 MHz is heavily used by RLANs (density of 50 devices per km^2) and the location and operating frequencies are not known for each individual device, DA2GC could only be deployed in this band, if co-channel sharing would be feasible.

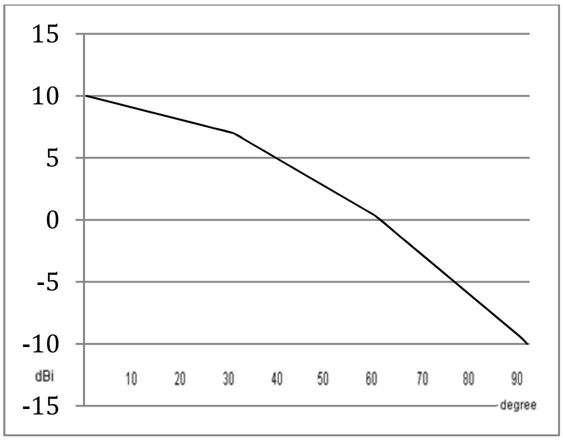


Figure 172: RLAN AP antenna elevation gain pattern

Figure 173: RLAN omni antenna elevation gain pattern

A3.2.1 METHODOLOGY

It is considered that one single DA2GC aircraft station is approaching the RLAN device under consideration at a given altitude (3000m and 10000m). The interference level resulting at the victim receiver was calculated taking into account the transmit power density of the interfering system, the aircraft altitude, the resulting free space loss, the antenna characteristics of the interfering and the victim system and the interference protection level of the victim system. The Interference protection ratio I/N=0 corresponds to C/I of 10dB at Rx power level of -82 dBm.

A3.2.2 RESULTS

The below Figure 174 and Figure 176 show the received power spectral density (PSD) in dBm/MHz at the RLAN GS and the DA2GC AS and the resulting interference-to-noise ratio (I/N) compared to the different thresholds of both systems at aircraft altitudes of 3000 and 10.000 meters. RLANs equipped with omnidirectional antenna and directional antenna was considered. Figure 182 and Figure 183 show the PSD at an RLAN AP receiver input, depending on the aircraft elevation relative to the victim RLAN. Severe interference at the RLAN can be observed at aircraft altitudes of 3000 m and 10000 m.

A3.2.2.1 IMPACT FROM DA2GC AS ON OUTDOOR RLANs

By considering the AS at 3 000 m the protection criterion for the RLAN receiver will be exceeded significantly. Even at 10 000 m severe interference at the RLAN receiver will be caused.

Thus it is concluded that co-channel operation of a BDA2GC reverse link (air-to-ground) and outdoor RLAN systems in the band 2400-2483.5 is not feasible.

A3.2.2.2 IMPACT FROM OUTDOOR RLANS ON DA2GC AS

At higher altitudes the impact of one RLAN transmitter on the receiving BDA2GC AS is negligible due to the low e.i.r.p. of the outdoor RLAN device. This is also the case for larger distances between the outdoor RLAN device and the AS, even at lower altitudes.

The main problem arises due to the high number of outdoor RLAN devices leading to an aggregation of interference signals at the receiving DA2GC AS. Taking into account a density of 50 outdoor RLAN devices / km^2, there are about 15700 outdoor RLAN devices visible in the range of about 10 km around the receiving DA2GC AS. Even by assuming that these RLAN devices are partly operated on different channels and not during the same time, a sufficient high number of RLAN devices will remain to interfere the reception at the DA2GC AS. This is the case for AS at 3 000 m as well as at 10 000 m. Capacity estimations for BDA2GC based on LTE when aggregated interference of RLANs occurs can be found in ANNEX 1:.

RLAN equipped with omni-antenna

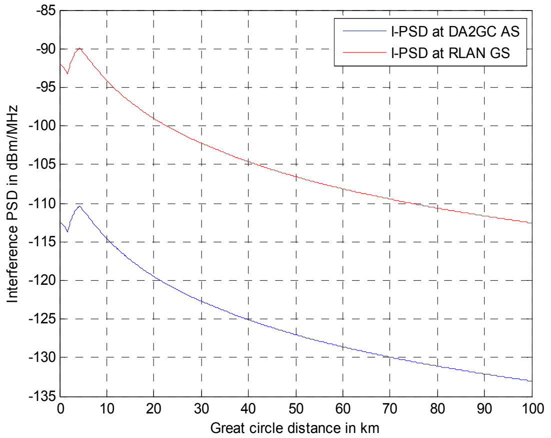


Figure 174: Received PSD (aircraft altitude 3000 m)

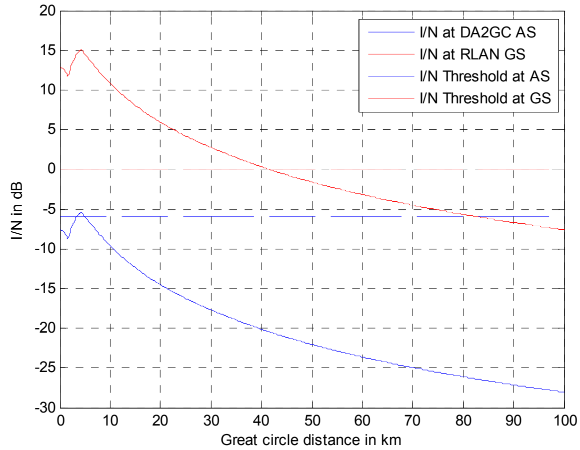


Figure 175: Resulting I/N ratio (aircraft altitude 3000 m)

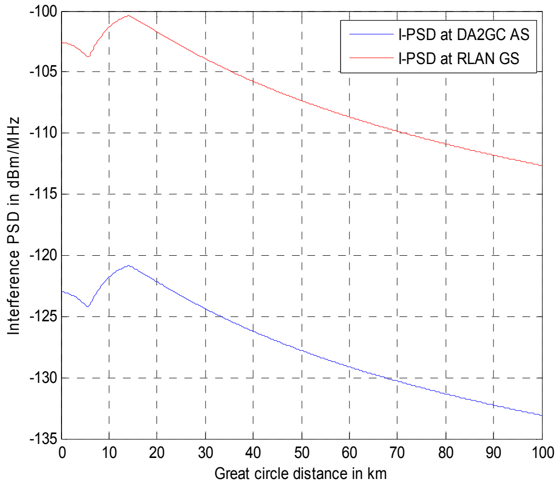


Figure 176: Received PSD (aircraft altitude 10000 m)

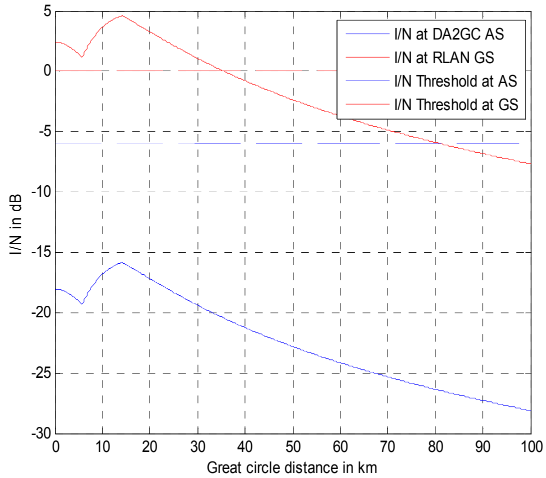


Figure 177: Resulting I/N ratio (aircraft altitude 10000 m)

RLAN equipped with directional antenna

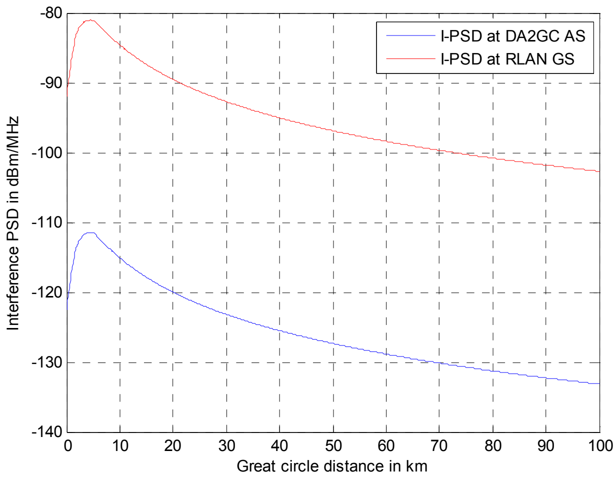


Figure 178: Received PSD (aircraft altitude 3000 m)

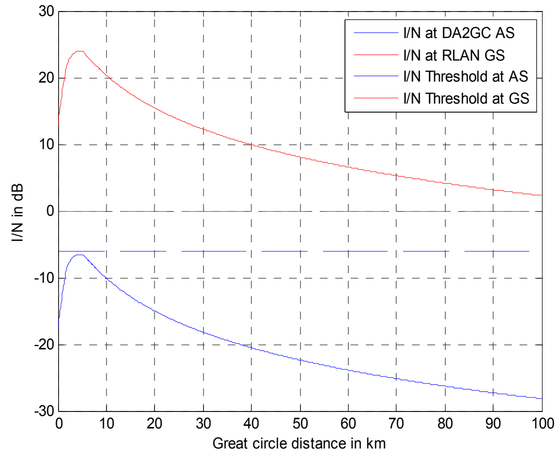


Figure 179: Resulting I/N ratio (aircraft altitude 3000 m)

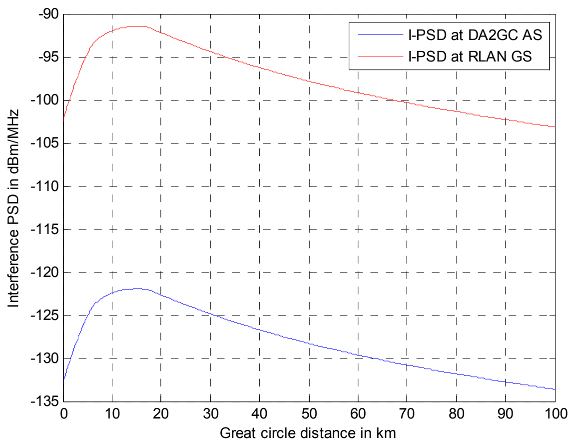


Figure 180: Received PSD (aircraft altitude 10000 m)

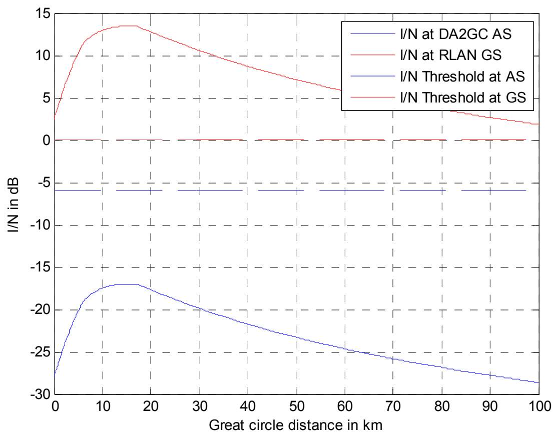


Figure 181: Resulting I/N ratio (aircraft altitude 10000 m)

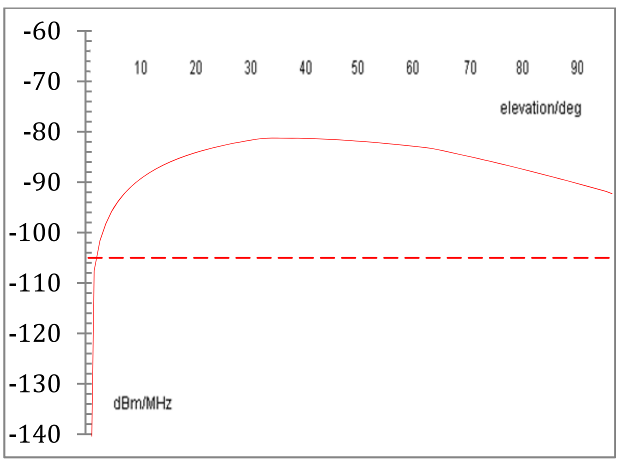


Figure 182: Received PSD at RLAN AP (altitude 3000 m)

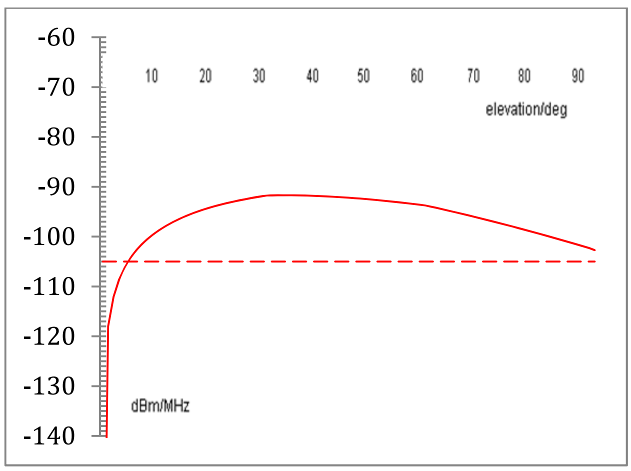


Figure 183: Received PSD at RLAN AP (altitude 10000m)

A3.2.3 CONCLUSIONS ON DA2GC (ETSI TR 103 054) ON RLANs

Based on a consideration of the BDA2GC system described in ETSI TR 103 054 [3], by taking into account the aggregate effect, it is concluded that co-channel operation of a DA2GC forward link (ground-to-air) and outdoor RLAN devices in the band 2400-2483.5 MHz is not feasible. This would also be the case if only a few RLAN devices were operated on the same channel. It is concluded that co-channel operation of a DA2GC reverse link (air-to-ground) and outdoor RLAN devices in the band 2400-2483.5 MHz is not feasible because the RLAN devices would significantly be interfered (by considering an altitude for the AS of 3 000 m or 10 000 m).

A3.3 COMPATIBILITY BETWEEN BROADBAND DA2GC (ETSI TR 101 599 [30]) AND RLANS

A3.3.1 METHODOLOGY

Error! Reference source not found. shows the interference scenario. It is considered that one single A2GC aircraft station is approaching the RLAN device under consideration at an altitude of 10 000m. Co-channel sharing was assumed. The interference level resulting at the victim receiver was calculated taking into account the transmit power of the interfering system, the aircraft elevation (up to 90 degree), the resulting free space loss, the antenna characteristics of the interfering and the victim system and the interference protection level of the victim system. The aircraft antenna beam was assumed to be steered so that the main lobe tracks the ground station as the aircraft traverses its flight path. The antenna pattern of the 2^{nd} generation of the ground station was used in this study. The red line in Figure 184 shows the required e.i.r.p. of the DA2GC AS as a function of the elevation angle in order to achieve an input level of -87 dBm at the ground station receiver as indicated in the system description. It can be observed that the maximum e.i.r.p. of +45 dBm (see section 7.2.2.1 of ETSI TR 101 599 [30]) of the AS is needed in case the elevation angle is about 3 degree. Thus the ATPC range between 3 and 90 degree elevation is about 27 dB.

The dotted lines show for information the great-circle distance and the resulting free space loss (values on the right hand vertical coordinate).

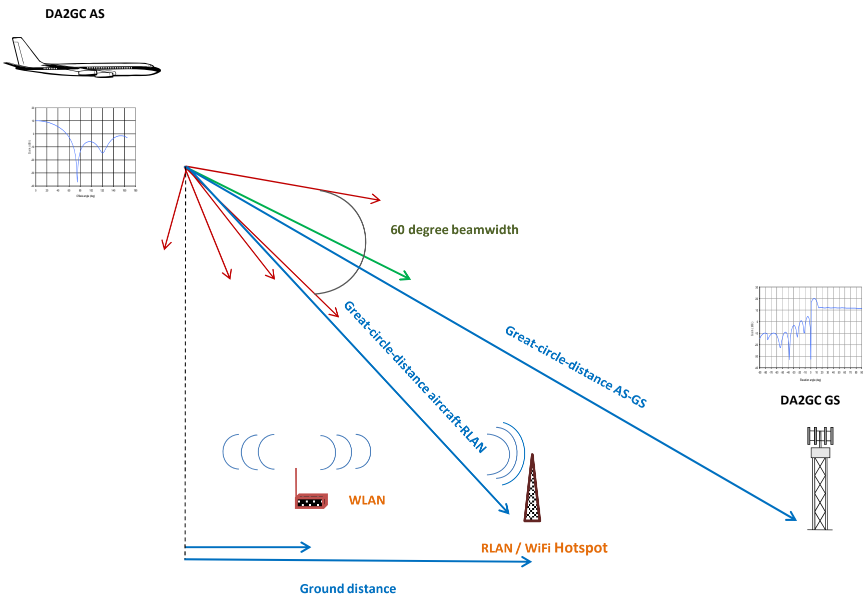


Figure 184: Interference scenario

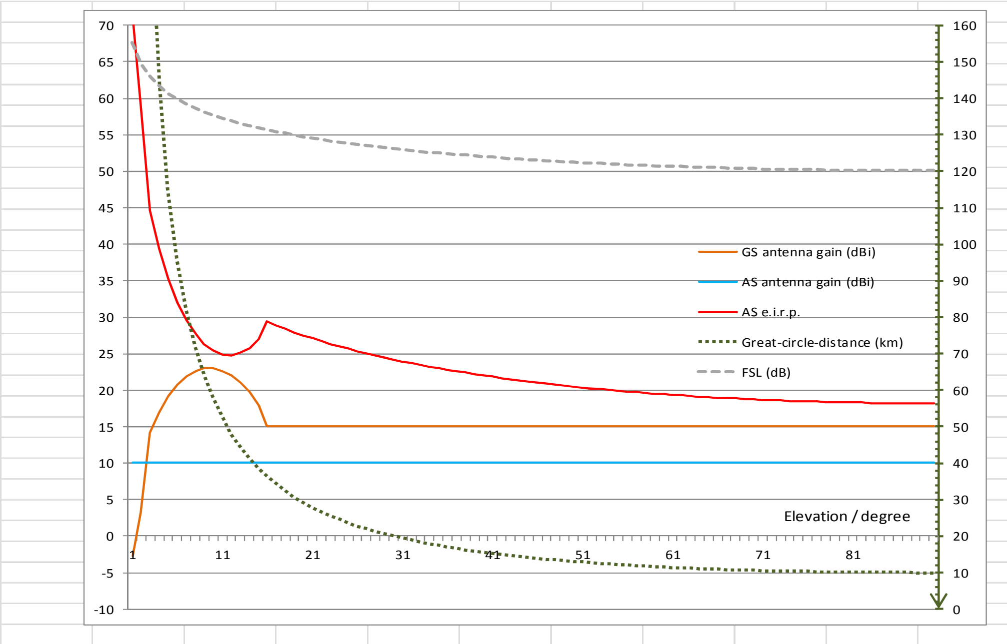


Figure 185: Resulting aircraft station e.i.r.p.

A3.3.2 RESULTS

A3.3.2.1 IMPACT FROM DA2GC AS ON RLANs

Figure 186 shows the results of the analyses with regard to an RLAN equipped with a 0 dBi omni-directional antenna. It can be observed that in case the elevation angle of the aircraft in relation to its ground station is equal or above five degree, no interference is observed at the RLAN receiver. For all elevation angles below 5 degree RLANs will experience interference produced by one DA2GC aircraft station. Figure 187 shows the results for RLANs equipped with a 10dBi sector antenna. Interference can be observed for elevation angles up to about 20 degree. The dotted lines in the graphs show the great-circle-distance and the distance on the ground (values on the right hand vertical coordinate). For example Figure 187 shows that in case the aircraft elevation is five degree RLANs may be affected at a distance from 5.5 km to 63 km vertically below the aircraft on the ground. The maximum width of the beam is approximately 11.5 km in case the antenna height is 10 km. In both figures it can be seen that the lower the elevation angles of the aircraft, the higher the interference level at the RLAN receiver. This can be explained by the 3 dB beamwidth of the aircraft antenna of about 60 degree and the higher transmit power required on the aircraft station to get the link with the ground station. Because the distance from the aircraft station to the affected RLANs is lower than the distance to the DA2GC ground station, the resulting power level at the RLAN receiver may rise above the threshold. Looking at the same example in Figure 187 the free space loss to the DA2GC ground station is about 141 dB, whereas to the affected RLANs the FSL varies from 121 to 135 dB. Table 62 shows an example calculation for an RLAN that is in 10 km distance (ground distance) to an aircraft (aircraft altitude 10 km).

Table 62: Interfering Link budget

Link budget DA2GC at 10 km height	
Required Rx level at GS receiver (dBm)	-87
Elevation Angle (degree)	5
Antenna gain AS (dBi)	10.07
FSL	141.4

Link budget DA2GC at 10 km height	
Antenna gain GS (dBi)	19.13
Required Tx level at AS (dBm)	25.2
Resulting e.i.r.p. (dBm)	35.27
RLAN at 10 km distance (on the ground)	
Max RLAN antenna gain (dBi)	10
RLAN gain towards DA2GC AS (dBi)	3.55
DA2GC AS gain towards RLAN (dBi)	5.5
FSL (dB)	123.2
RLAN Rx sensitivity (dBm)	-82
RLAN protection criterion C/I (dB)	10
I max (dBm)	-92
I calculated (dBm)	-88.95
Limit exceedance (dB)	3.05

Similar results for lower aircraft altitudes can be expected by taking into account the ATPC range of the transmitter. In that case the affected area will be smaller due to the smaller width of the beam.

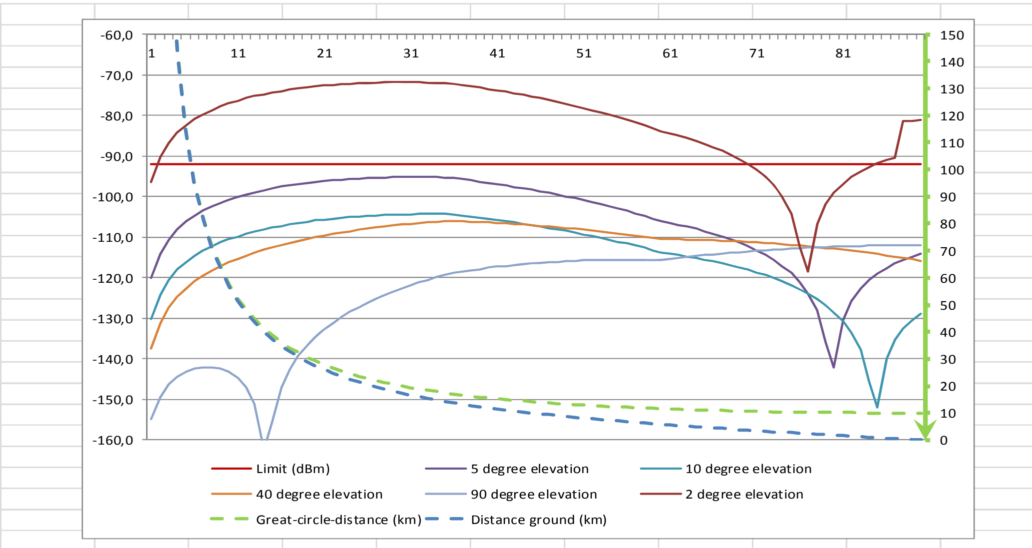


Figure 186: Interference level at RLANs with omni-antenna (0 dBi)

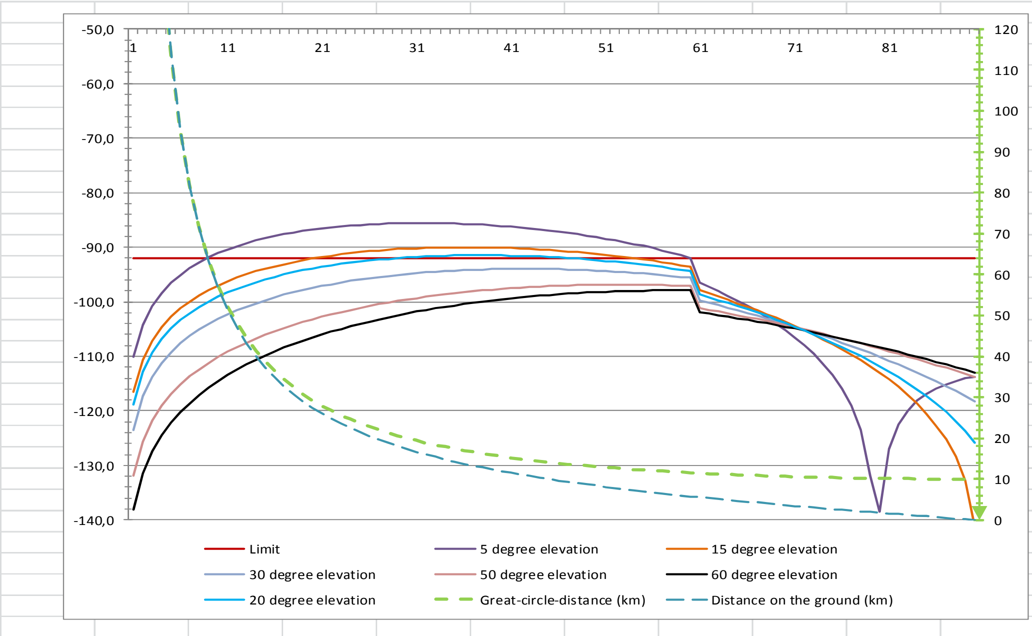


Figure 187: Interfering level at RLANs with 10 dBi sector antenna

A3.3.2.2 IMPACT FROM OUTDOOR RLANs ON DA2GC AS

According to the system description the sensitivity of the aircraft station receiver is better than or equal to -87 dBm in a 20MHz bandwidth. Considering an interference criterion of I/N = 0 dB, the protection threshold of the aircraft station receiver is at -101 dBm.

A simple calculation shows that in case the aircraft is right above (90 degree elevation) its ground station, a separation distance of 11 km for an RLAN equipped with omni-antenna and 3.5 km for an RLAN equipped with a 10 dBi sector antenna is required. The 3 dB beamwidth of the aircraft antenna is about 60 degree, which means that the mainbeam of the antenna will cover an area of 105 km^2 (9,5 km^2) in case the aircraft flies at an altitude of 10 km (3 km). As the uniform density of the RLANs on the ground can be assumed by 50/ km^2 (see Table 61) an amount of 5250 (475) RLANs can be considered in the mainbeam of the AS receiver. It can be supposed that the receiver of the aircraft station will be continuously affected due to the many sources of interference lying in its mainbeam. Since this is only a static view, the required separation distance as a function of the elevation angle of the aircraft is shown in the following Figure 188.

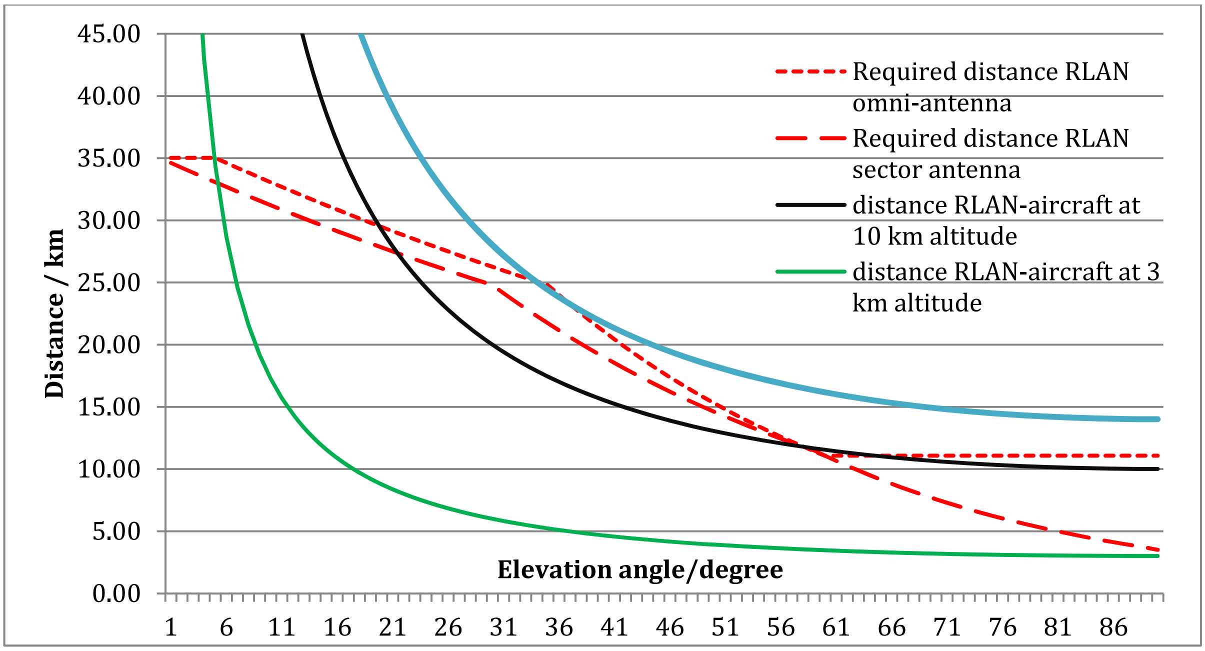


Figure 188: Separation distances as a function of the elevation angle

The red dotted lines in Figure 188 show the required minimum separation distances for the two types of RLANs considered in this document. Higher separation distances are always required in case of RLANs equipped with omni-directional antennas. The green line represents an aircraft altitude of 3 km. Interference can be observed from 5 to 90 degree elevation angle caused by one of the two types of RLANs. Aircrafts approaching at 10 km altitude will experience interference from 20 – 90 degree elevation angle caused by one omni-directional RLAN and from 22 to 58 degree elevation angle caused by one RLAN equipped with a sector antenna located in the mainbeam of the aircraft station antenna.

Capacity estimations for BDA2GC based on LTE when aggregated interference of RLANs occurs can be found in ANNEX 1:

A3.3.3 CONCLUSIONS ON DA2GC (ETSI TR 101 599 [30]) ON RLANs

Co-channel single entry compatibility studies between the DA2GC Aircraft Station as described in Draft ETSI TR 101 599 in 10 km altitude and RLANs on the ground in the band 2400 – 2 483.5 MHz have shown that

- RLANs equipped with sector antennas will be interfered by one DA2GC aircraft station in case the angle between the DA2GC aircraft station and the DA2GC ground station is 20 degree or less.
- RLANs equipped with omnidirectional antennas will be interfered by one DA2GC aircraft station in case the angle between the DA2GC aircraft station and the DA2GC ground station is below 5 degree.
- The same results for lower aircraft altitudes can be expected by taking into account the ATPC range of the transmitter.

Co-channel single entry compatibility studies between RLANs on the ground in the band 2400-2483.5 MHz and the DA2GCAircraft Station as described in Draft ETSI TR 101 599 have shown that

- at an aircraft altitude of 3 km interference can be observed on the aircraft station receiver from 5 to 90 degree elevation angle caused by one RLAN located in the mainbeam of the aircraft station.
- at an aircraft altitude of 10 km interference can be observed from 20 – 90 degree elevation angle caused by one omni-directional RLAN and from 22 to 58 degree elevation angle caused by one RLAN equipped with a 10 dBi sector antenna located in the mainbeam of the aircraft station.
- at aircraft altitudes above 14 km, no interference at the DA2GC AS is observed.
- The RLAN transmissions would severely reduce the throughput in the DA2GC system

Additional improvements to mitigate interferences in this band could be considered in a next step. Furthermore it may be expected that a statistical approach using a Monte–Carlo simulation may lead to more favourable results of the studies. However, due to the high density of other applications in the band 2400 – 2483.5 MHz and due to the expected constraints resulting from their protection requirements, other frequency bands may be more favourable for the deployment of DA2GC.

ANNEX 4: COMPATIBILITY AND SHARING SCENARIOS FOR THE BAND 3400-3600 MHz (INFORMATIVE)

The following services/systems, for which compatibility studies with Broadband DA2GC should be conducted, have been identified:

- FSS (Space-to-Earth);
- MFCN;
- BWA;
- ENG/OB, otherwise referred to as SAB/SAP;
- Radiolocation;
- FS.

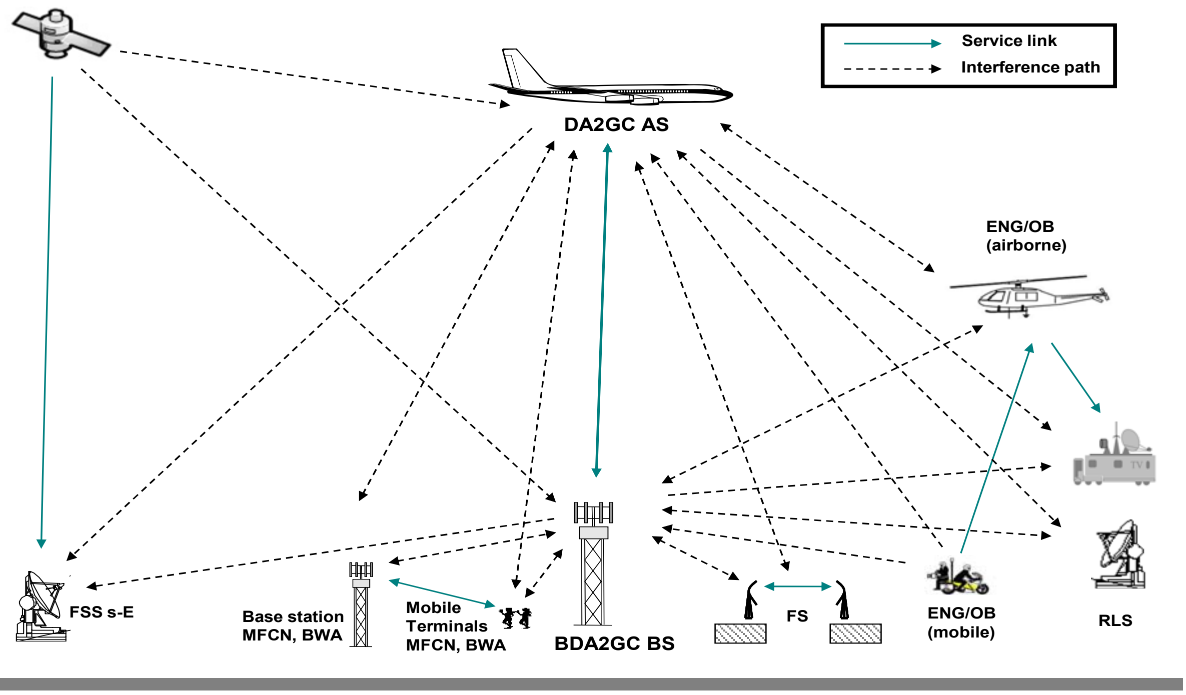


Figure 189 describes the interference scenarios for TDD mode in both directions. In the Radio Regulations, the band 3400-3475 MHz is also allocated on a secondary basis to the Radio Amateur service in two CEPT countries through RR No. 5.431. In the 3400-3410 MHz band, the amateur service operates on a secondary basis in some CEPT countries in accordance with ERC Report 25 [50]. Table 63 summarizes the incumbent services/applications in the 3.4-3.6 GHz band.

Table 63: Incumbent services deployed in the 3.4 – 3.6 GHz band

System	Frequency range/MHz	Compatibility issues
RADARS	3100-3600	Above 3400 secondary, upper limit for airborne radars is 3410 MHz.
Amateur	3400-3410	The band 3400-3475 MHz is also allocated on a secondary basis to the Radio Amateur service in two CEPT countries through RR No. 5.431.
BWA		Technical parameters for BWA systems (Central stations

System	Frequency range/MHz	Compatibility issues
	3400-3800	and Terminal stations) can be found in ECC Report 100 [43], EN 302 217 [46], EN 302 326 [47]
FSS (s-E)	3400-4200 (3400-3625) some MSS feeder links)	Limited number of licensed FSS satellite earth stations receiving transmissions below around 3520MHz within Europe, and particularly those that operate down to 3400 MHz. Report ITU-R S.2199 [45] Studies provides compatibility studies of broadband wireless access system and fixed satellite service network in the 3400 to 4200 MHz band
MFCN (including IMT)	3400-3800	Two band planes (FDD and TDD) according to ECC/DEC(11)06 for MFCN
SAP/SAB	3400-3600	According to ERC/REC 25-10 [35] the band is used by mobile video links (airborne and vehicular). Technical characteristics can be found in ERC Report 038 [33]. According to ECC Report 002 [34] for occasional SAP/SAB use on a co-ordinated basis.
Radars	3100-3600	Above 3 400 MHz secondary, upper limit for airborne radars is 3410 MHz. Technical characteristics can be found in Recommendation ITU-R M.1465 [48]
FS P-MP	3400-3800	Technical parameter according to Recommendation ITU-R F. 758-5[49]

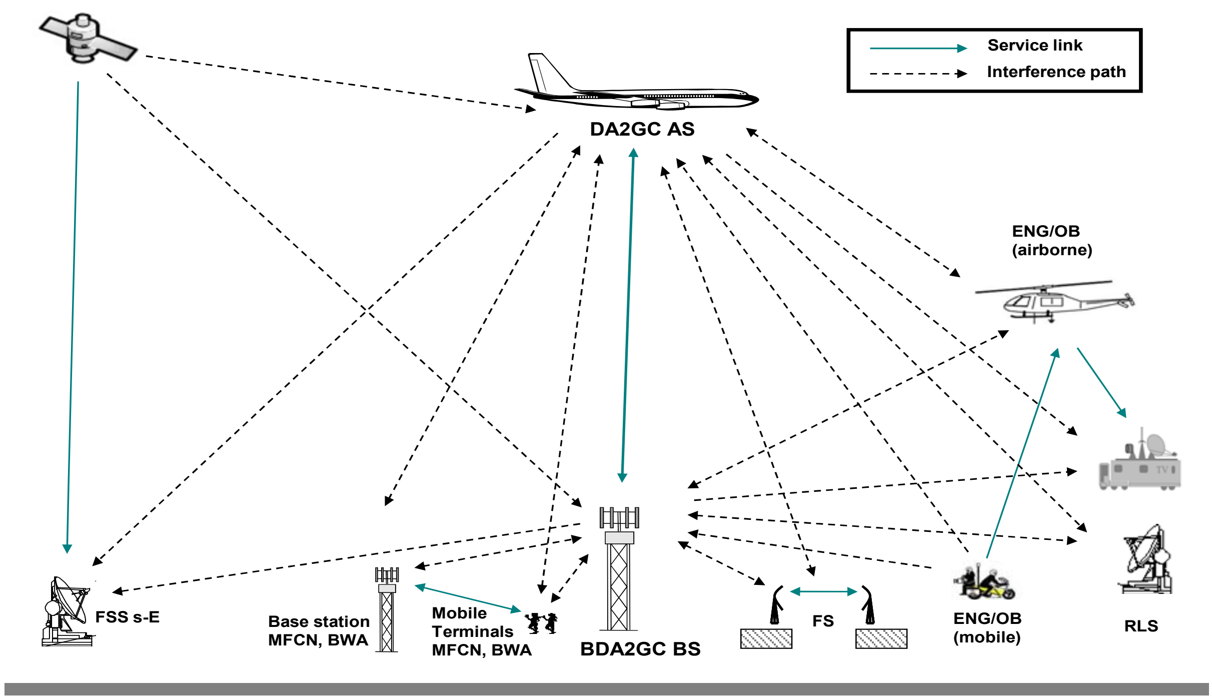


Figure 189: Interference scenarios for BDA2GC in the frequency band 3400 - 3600 MHz

A4.1 COMPATIBILITY BETWEEN DA2GC AND FSS

The band 3400-3600 MHz is allocated to the fixed satellite service (FSS) for space-to-Earth operations. A recent survey by the Commission counted 170 earth stations authorized in the band 3400-3800 MHz among the 28 countries of the EEA (see RSCOM10-28, 14 June 2010). In addition, there are likely to be many more receive only earth stations deployed, since such earth stations (generally used for TV reception) are typically not licensed by member states. While it is recognized the band 3400-3600 MHz has a smaller number of earth stations deployed than other parts of the C-band (i.e., 3700-4200 MHz), the licensed earth stations deployed in Europe which operate in the 3400-3600 MHz band and in the band just above 3600 MHz would require protection from interference from proposed BDA2GC systems.

A4.1.1 FSS EARTH STATION CHARACTERISTICS

The characteristics of BDA2GC base stations and aircraft stations used in this study are shown in the tables Table 4 and Table 6. Two examples of existing C-band earth stations are used:

Table 64: Example earth station locations

Earth Station	Location
Brookman's Park (UK)	N51:43:44, W0:10:39
Burum (Netherlands)	N53:17:2.2, E6:13:2.9

For each earth station, the following parameters values are used.

Table 65: Example earth station parameter values

	Brookmans Park	Burum
Antenna height a.g.l. (m)	5	
Antenna gain (dBi)	52	
Antenna gain pattern	ITU-R S.465	
Antenna elevation (deg)	9.4	12.2
Antenna azimuth (deg)	114	120.4
Delta N (see ITU-R P.452)	45	45

It should be further noted some FSS earth stations deployed in Europe operate to significantly lower elevation angles than assumed above. As a consequence, for such earth stations, the horizon antenna gain will be higher than assumed within this study increasing the necessary separation distance to protect the earth station receivers.

This study adopts the approach identified in ECC Report 100 [43] (Section 4.3), to derive two interference criteria that are used to assess the potential for interference for co-frequency operations. The criteria are specified in terms of a long term and short term interference allowance based on the method in Recommendation ITU-R SF.1006. Using Equation 4 of Annex-1 of Rec. SF.1006 and assuming a receiver noise temperature, Tr, of 76K, a reference bandwidth, B, of 4 kHz, a fade margin, Ms, of 2 dB, a link noise contribution, $N_{L,}$ of 1 dB and ratio of incremental thermal noise power to interference power of 0 dB in the reference bandwidth, and with a value of n_2=1 corresponding to single entry of interference, one can arrive at the long and short term interference criteria for FSS C-band earth stations as follows:

Table 66: Protection criteria for FSS C-band earth stations

	Permissible interference, Pr(p) in 4 kHz reference bandwidth (dBW)	*Equivalent interference to noise (I/N) ratio* (dB)	Percentage of time *p* for which *Pr(p)* may be exceeded (%)
Long term	-184	-10.2	20
Short term	-175.1	-1.3	0.005

In addition to the potential for interference on the FSS receiver system noise temperature, the potential impact of saturation of the earth station receiver from BDA2GC emissions in the adjacent band should also be considered as a possible interference mechanism. This interference scenario may be relevant for FSS earth stations operating above 3600MHz and which are adjacent to BDA2GC systems operating in the band 3400-3600 MHz. Here, the BDA2GC emissions may cause the earth station low noise amplifier block (LNB) to be driven into non-linearity or possible output saturation, and consequently block the reception of the wanted signal anywhere in the entire 3400-4200MHz band. Again following the approach in ECC Report 100 [43], a separation distance can be estimated assuming a LNB saturation level of -50 dBm. However, such a value may well be considered too high for some earth station receiver designs. ECC Report 100 observes that non-linear effects can start to become significant from interference at about 10dB lower than the saturation power (i.e., -60 dBm), leading to generation of unacceptable intermodulation products within the receiver pass-band and suppression of wanted carriers.

A4.1.2 IMPACT FROM DA2GC GS ON FSS EARTH STATIONS

The figures below estimate the exclusion areas for the two example earth stations with respect to BDA2GC base stations operating co-frequency. Terrain data with 90m resolution has been used with the Recommendation ITU-R P.452 propagation model, which includes the diffraction model in Recommendation P.526. Figure 190 shows the likely exclusion areas for the two example earth stations, considering the long-term interference criterion and with interference time percentage *p*=20% in the propagation model. Figure 191 shows the exclusion areas for the same BDA2GC base-stations but considering the short term criterion and with *p*=0.005% in the propagation model. The red shaded areas show where the criterion is exceeded. The blue circles, centred on each FSS earth station are of radius 100km, 200km and 300km.

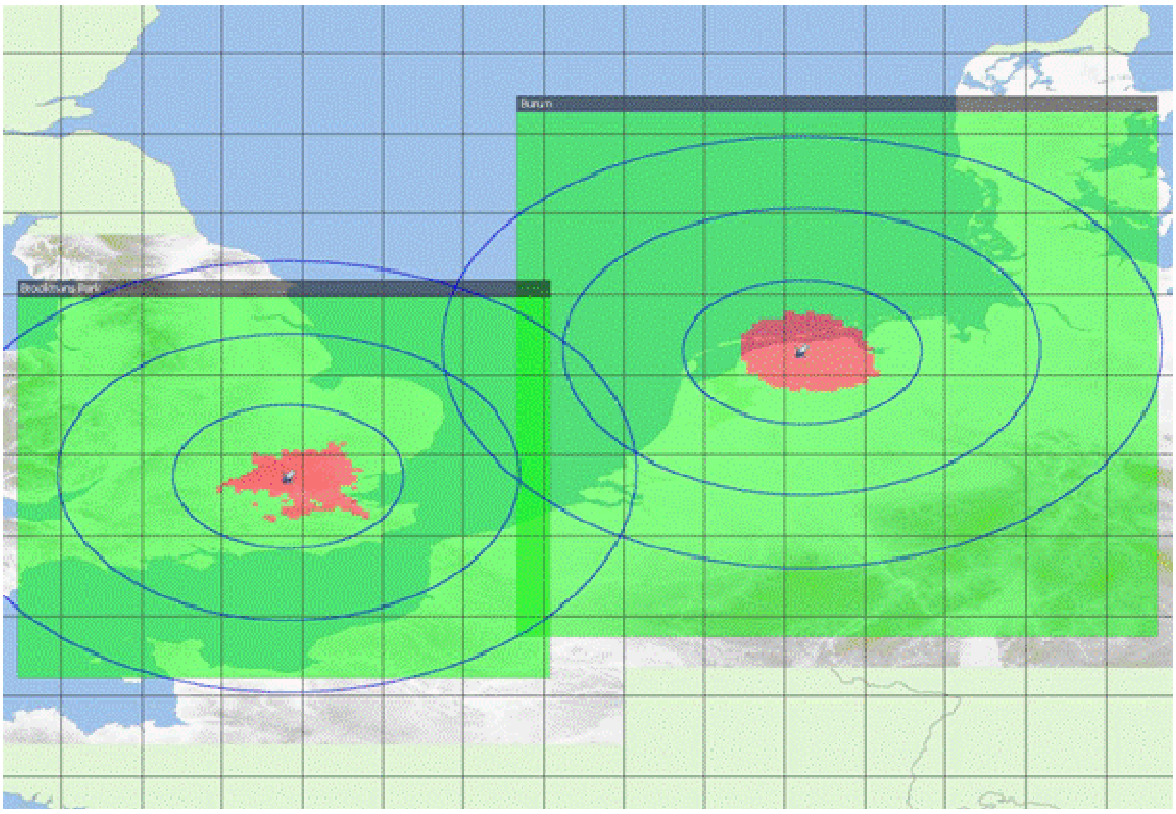


Figure 190: Exclusion areas based on long-term propagation

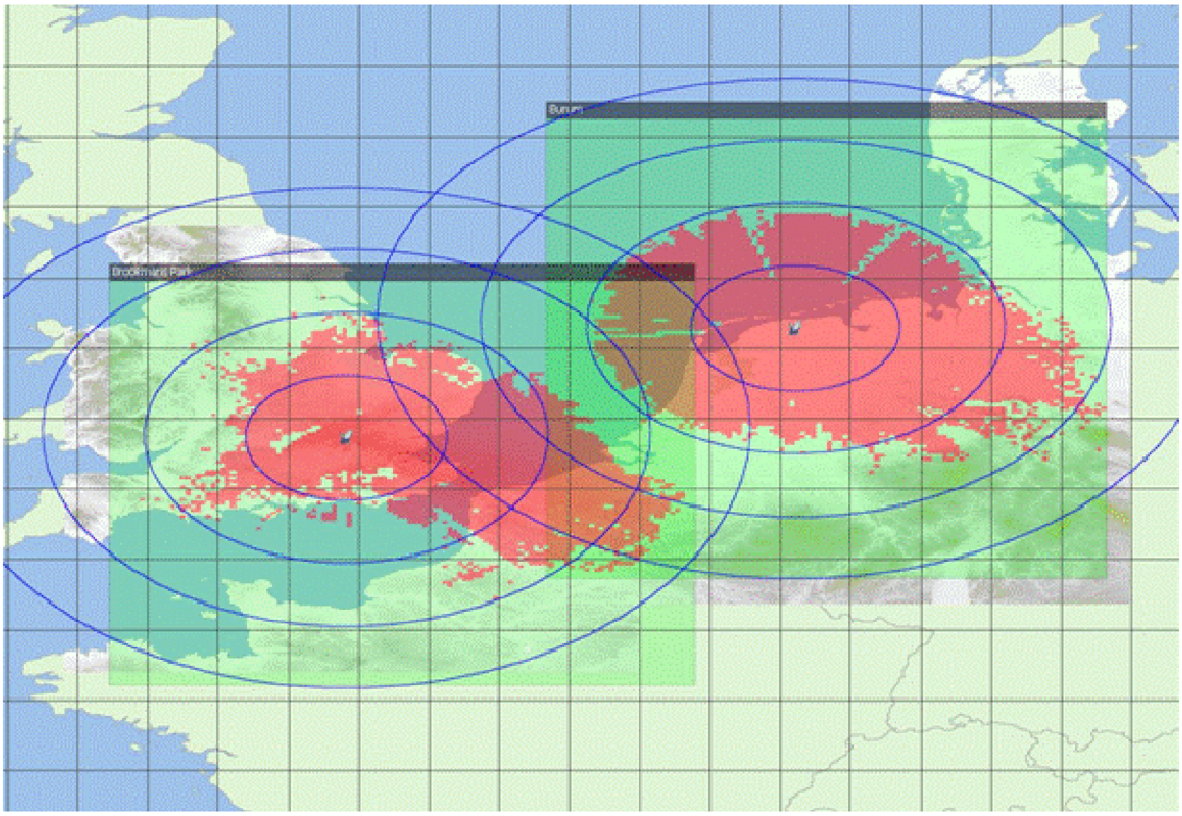


Figure 191: Exclusion areas based on short-term propagation

The results show for the long term interference criteria to be met, the required separation distances between the BDA2GC base-stations and FSS receiver is around 50 km, and with a worst case separation distance for these two example considered of around 85 km. For the short term propagation criteria to be met, the required separation distances increases to around 100-200 km in azimuths around the earth-station, but can extend up to 350 km in specific directions in a worse case

A4.1.3 IMPACT FROM DA2GC AS ON FSS EARTH STATIONS

Interference may also be caused to FSS earth station receivers from BDA2GC aircraft transmissions. To assess the potential for interference two separate scenarios are considered: a “boresight” case, where it is assumed that an aircraft transmitter is sighted within the main beam of the FSS earth station antenna; and a “sidelobe” case, where it is assumed that any interference from the aircraft transmitter is received through the FSS earth station antenna sidelobes (having a gain of -10 dBi).

For the boresight scenario, as the occurrence of an aircraft within the main beam will typically be of short duration, the short term interference criterion is used. While for the sidelobe scenario, since interference may occur for long periods of time, the long-term criterion is used. For both scenarios, it is assumed interference occurs from a single aircraft transmitter having a minimum operating altitude of about 10,000 feet, and hence a minimum separation distance of 3 km is assumed. The increase in potential for interference from multiple transmitters or if the operational height is lower than assumed will need to be confirmed and is not taken into account.

Table 67: Interference from a single aircraft to a FSS earth station

	Boresight	Sidelobe
Aircraft e.i.r.p. (dBm in 4 kHz)	6.4	6.4
Aircraft e.i.r.p. (dBW in 4 kHz)	-23.6	-23.6
Aircraft to earth station distance (km)	3	3
Freq (MHz)	3600	3600
Free space loss	113.1	113.1
Earth station antenna gain (dBi)	52	-10
Polarisation discrimination (dB)	2	0
Receiver noise in 4 kHz	-173.8	-173.8
I/N	-1.3	-10.2
I max in 4 kHz	-175.1	-184.0
Interfernce received (dBW in 4 kHz)	-86.7	-146.7
Excess interference (dB)	**88.4**	**37.3**

In the case of boresight interference, the link budget analysis shows interference is received 88.4 dB above the criterion. Consequently, to remove this excess, the aircraft would need to be beyond line-of-sight of the FSS earth station, which for an aircraft at 40,000 feet, is beyond about 450 km from the earth station. While, in the case of interference through the sidelobes, the excess interference is 37.3 dB above the criterion. In this case to meet the interference criterion for sidelobe interference, the aircraft would need to be at least 220 km from the earth station. It is noted even if the aircraft transmission powers were reduced significantly the separation distances are still significant such that compatible co-frequency operation will not be possible.

Table 68 shows a similar analysis, but considering the receiver overload criterion. In this scenario, the potential for aircraft interference necessary to cause the earth station LNB to be overloaded is estimated.

Table 68: Interference from a single aircraft to a FSS earth station compared to overload criterion

	Boresight	Sidelobe
Aircraft e.i.r.p. (dBm)	40	40
Aircraft to earth station distance (km)	3	3
Freq (MHz)	3600	3600
Free space loss	113.1	113.1
Earth station antenna gain (dBi)	52	-10
Polarisation discrimination (dB)	2	0
I max (dBm)	-50.0	-50.0
Interference received (dBm)	-23.1	-83.1
Excess interference (dB)	**26.9**	-33.1

The results show that interference may be cased to earth stations operating in different parts of C-band to BDA2GC systems. As these are frequency independent results, there is a high potential of receiver compression at FSS earth-stations when high power aircraft transmitters pass through the main beam of earth stations antennas.

A4.1.4 CONCLUSIONS

The operation of BDA2GC base stations in any parts of the band 3400-3600 MHz would require coordination with FSS earth stations. The exclusion area would need to be determined on a case-by-case basis for each earth station. In the example cases considered in this contribution, in the case of co-frequency operations, the maximum exclusion distance is about 350 km. Although not analysed above, exclusion areas would also be required for BDA2GC base stations operating on different frequencies from the FSS earth stations. This would be necessary due to possible overload (or blocking) of the earth station LNB, and also due to reception of out-of-band emissions from the BDA2GC base station. Examples of required exclusion distances may be provided in due course.

The operation of BDA2GC aircraft stations would also require coordination with FSS earth stations. In the case of co-frequency operations, an aircraft operating within the visibility of an earth station could cause harmful interference. Assuming the maximum altitude of an aircraft of 40,000 feet, the visibility distance (assuming 2/3 earth radius for atmospheric refraction effects) is about 450 km. The potential area of operation of an aircraft station could be controlled by the location of the base stations. If the BDA2GC base station has a range of 100 km, the exclusion distance of the base station with respect to the FSS earth station would need to be extended by this amount to 550 km.

The operation of BDA2GC aircraft stations on different frequencies from the FSS earth station also has the potential to cause harmful interference, due to unwanted emissions from the BDA2GC aircraft station and due to overload of the earth station LNB. In principle, the possibility of overload could be avoided by the inclusion of filters at the earth station however the cost and practicality of adding filters would need to be assessed. As FSS receivers are of very wide-band band, it is viewed filtering will be greatly assisted if any operation of BDA2GC aircraft transmission are identified to specific channels and having a maximum separation with existing FSS earth-stations operations (e.g., identified for operation at frequencies close to 3400MHz instead of close to 3500 MHz).

The effect of receiver blocking can also be reduced if the maximum aircraft e.i.r.p. is reduced from the 40dBm assumed and/or if directional antenna could be used for any BDA2GC systems deployed in the 3400-3600 MHz band. The potential for compression of FSS receivers through the main beam from interference from high power omni-directional BDA2GC aircraft transmissions should be noted.

A4.2 COMPATIBILITY BETWEEN DA2GC AND IMT/IMT-A IN THE BAND 3400-3600 MHz

The ECC approved Decision ECC/DEC/(11)06 [24] on harmonised frequency arrangements for mobile/fixed communications networks (MFCN) (including IMT) operating in the bands 3400-3600 MHz and 3600-

3800 MHz with the intention to facilitate high data rate International Mobile Telecommunications (IMT) services supported by larger channel bandwidths as an evolution to the existing framework in this band, without the consequential requirement for a replacement of systems based on the existing regulatory framework. Two different arrangements are provided for the implementation of either TDD or FDD operation. The TDD arrangement is based on a block size of 5 MHz starting at the lower edge of 3400 MHz.

- Frequency arrangement for the 3400-3600 MHz band based on TDD

The frequency arrangement is a TDD arrangement, based on a block size of 5 MHz starting at the lower edge of 3400 MHz.

If blocks need to be offset to accommodate other users, the raster should be 100 kHz. Narrower blocks can be defined adjacent to other users, to allow full use of spectrum. It has to be noted that TDD in one extreme case also covers downlink only operation.

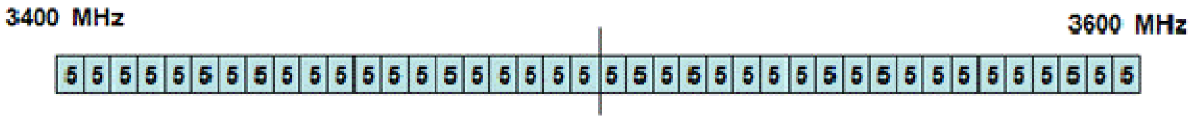


Figure 192: ANNEX 1 of Draft ECC/DEC/(11)HH on Harmonised frequency arrangements for mobile/fixed communications networks (MFCN) (including IMT) operating in the bands 3400-3600 MHz and 3600-3800 MHz

- Frequency arrangement for the 3400-3600 MHz band based on FDD

The frequency arrangement is an FDD arrangement, based on a block size of 5 MHz starting at the lower edge of 3410 MHz. The sub-band 3410-3490 MHz is used for the uplink, the sub-band 3510-3590 MHz is used for the downlink. The resulting duplex gap is 20 MHz (3490-3510 MHz).

If blocks need to be offset to accommodate other uses, the raster should be 100 kHz. Narrower blocks can be defined adjacent to other users, to allow full use of spectrum.

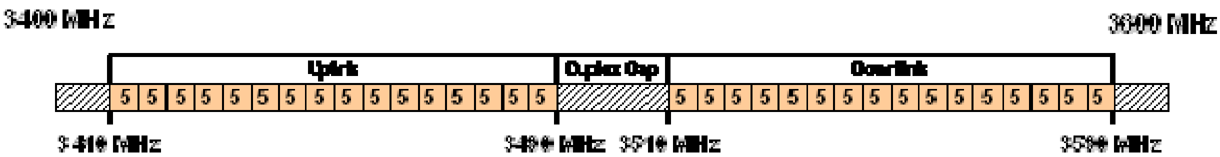


Figure 193: ANNEX 2 of Draft ECC/DEC/(11)HH on Harmonised frequency arrangements for mobile/fixed communications networks (MFCN) (including IMT) operating in the bands 3400-3600 MHz and 3600-3800 MHz

A4.2.1 LTE SYSTEM CHARACTERISTICS

The terrestrial IMT/IMT-A system is assumed to be based on 3GPP LTE (also called E-UTRA) standard (Rel. 8 or higher) [1][2]. The unwanted emission requirements for LTE base stations are given in Table 69.

Table 69: Main parameters used for base station LTE (BS)

Parameter	LTE base station (BS)	
	FDD	TDD
Base station type	Macro	Macro
Environment	Rural	Rural
Cell radius (max.)	Up to 5 km (typically 3 km)	Up to 5 km (typically 3 km)
Tx power	46 dBm	46 dBm
Antenna type	3 x 120° sector antenna (90° half power beam width)	3 x 120° sector antenna (90° half power beam width)

Parameter	LTE base station (BS)	
	FDD	TDD
Antenna gain	Up to 20 dBi	Up to 20 dBi
Antenna height	30 m	30 m
Antenna tilt	-2° (down-tilt)	-2° (down-tilt)
Channel bandwidth	2 x 10 MHz	15 or 20 MHz
Frequency re-use factor	1	1
Signal bandwidth (related to number of occupied resource blocks with bandwidth of 180 kHz)	9 MHz	13.5 or 18 MHz
Rx thermal noise	-104.5 dBm	-102.7 or -101.5 dBm
Rx noise figure	5 dB	5 dB
Rx noise floor	-99.5 dBm	-97.7 or -96.5 dBm
Rx reference sensitivity level	-101.5 dBm (Note 1)	-99.7 or -98.5 dBm (Note 1)
Interference protection ratio I/N	-6 dB	-6 dB
Interference protection level	-105.5 dBm (Note 1)	-103.7 or -102.5 dBm (Note 1)
Tx spectrum emission mask (SEM) / Spurious emissions	According to [7]	According to [7]
Adjacent channel leakage ratio (ACLR) limit	45 dB (Note 2)	45 dB (Note 2)
Rx in-band / out-of-band blocking	According to [7]	According to [7]
Rx adjacent channel selectivity (ACS)	43.5 dB (according to [7])	43.5 dB (according to [7])

Note 1: In [14] the sensitivity level of -101.5 dBm is also applied for signal bandwidths above 10 MHz, as only up to 25 resource blocks (RB) are assigned to a single UE link, even if more RBs are feasible.
Note 2: In general the ACLR limit given in the table or the absolute limit of -15 dBm/MHz is valid, whichever is less stringent (macro BS according category B) [7].

For the LTE BS the vertical pattern given in Recommendation ITU-R F.1336 [20] was applied, which is usually used for compatibility studies with mobile radio and RLAN systems by ITU-R and CEPT workings groups. The diagram is shown in Figure 194. As proposed in the recommendation the side lobes are not explicitly used in the evaluations, only the approximated characteristic is applied.

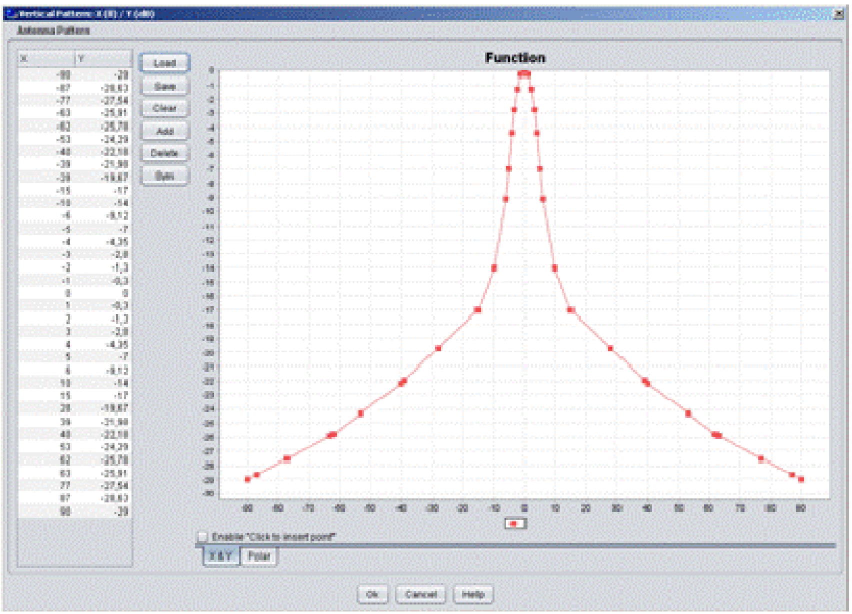


Figure 194: Vertical sector antenna pattern of the LTE BS according to Recommendation ITU-R F.1336 (screen shot of SEAMCAT GUI; down-tilt not considered in the diagram)

Table 70: Main parameters used for mobile station LTE (UE)

Parameter	LTE mobile station (UE)	
	FDD	TDD
Tx power (max./min.) (Note 1)	23 dBm / -40 dBm	23 dBm / -40 dBm
Antenna type	Omni-directional	Omni-directional
Antenna gain	0 dBi	0 dBi
Antenna height	1.5 m	1.5 m
Channel bandwidth	2 x 10 MHz	15 or 20 MHz
Signal bandwidth (related to number of occupied resource blocks with bandwidth of 180 kHz)	9 MHz	13.5 or 18 MHz
Rx thermal noise	-104.5 dBm	-102.7 or -101.5 dBm
Rx noise figure	9 dB	9 dB
Rx noise floor	-95.5 dBm	-93.7 or -92.5 dBm
Rx reference sensitivity level	-97.5 dBm	-95.7 or -94.5 dBm
Interference protection ratio I/N	-6 dB	
Interference protection level	-101.5 dBm	-99.7 or -98.5 dBm
Tx spectrum emission mask (SEM) / Spurious emissions	According to [6]	According to [6]
Adjacent channel leakage ratio (ACLR) limit	30 dB (according to [6])	30 dB (according to [6])

Parameter	LTE mobile station (UE)	
	FDD	TDD
Rx in-band / out-of-band blocking	According to [6]	According to [6]
Rx adjacent channel selectivity (ACS)	33 / 30 / 27 dB for channel bandwidths of 10 / 15 / 20 MHz (according to [6])	33 / 30 / 27 dB for channel bandwidths of 10 / 15 / 20 MHz (according to [6])
Note 1: The Tx power of the mobile station is dependent on the power control implementation applied by the equipment provider.		

The main difference is the maximum Tx power required at the aircraft to get access to the DA2GC BS at locations near the cell edge. The spectrum emission limits defined by 3GPP for LTE UEs are given in Table 71 (according to [6]).

Table 71: General LTE UE spectrum emission limits

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

A4.2.2 CO-CHANNEL CASE

This section presents coexistence studies between a LTE base station in the frequency band 3400-3600 MHz and a BDA2GC AS located on an aircraft at various altitudes from 3000 to 13 000 meters.

Figure 195 below represents the average antenna gain in elevation for an omnidirectional antenna (with 0° tilt) calculated with the model from Recommendation ITU-R F.1336 [20].

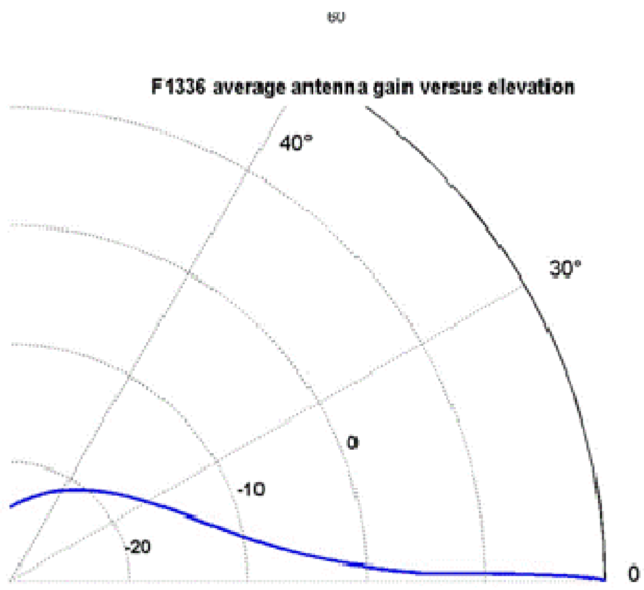


Figure 195: LTE BS antenna pattern in elevation for an omnidirectional antenna

A4.2.3 METHODOLOGY

The intent is to study the compatibility between a LTE base station or a LTE-UE and a DA2GC AS in both directions (i.e DA2GC as interferer and then as victim).

The LTE base station (or LTE-UE) is considered to be located at (G0, L0).

When considering the LTE station as the victim and DA2GC AS as the interferer, the interference level arriving to the victim receiver from an aircraft at a given altitude H (from 3000 m up to 13 km) around the LTE station location (i.e. 1° by 1° horizontal square around (G0,L0)) is calculated and mapped as illustrated in the Figure 196 below.

When considering the LTE station as the interferer and DA2GC on board aircraft as the victim, the calculations are very similar since the antenna gain is the same in emission and reception for both systems. The only difference lies in the protection criterion and the emission levels to take into account.

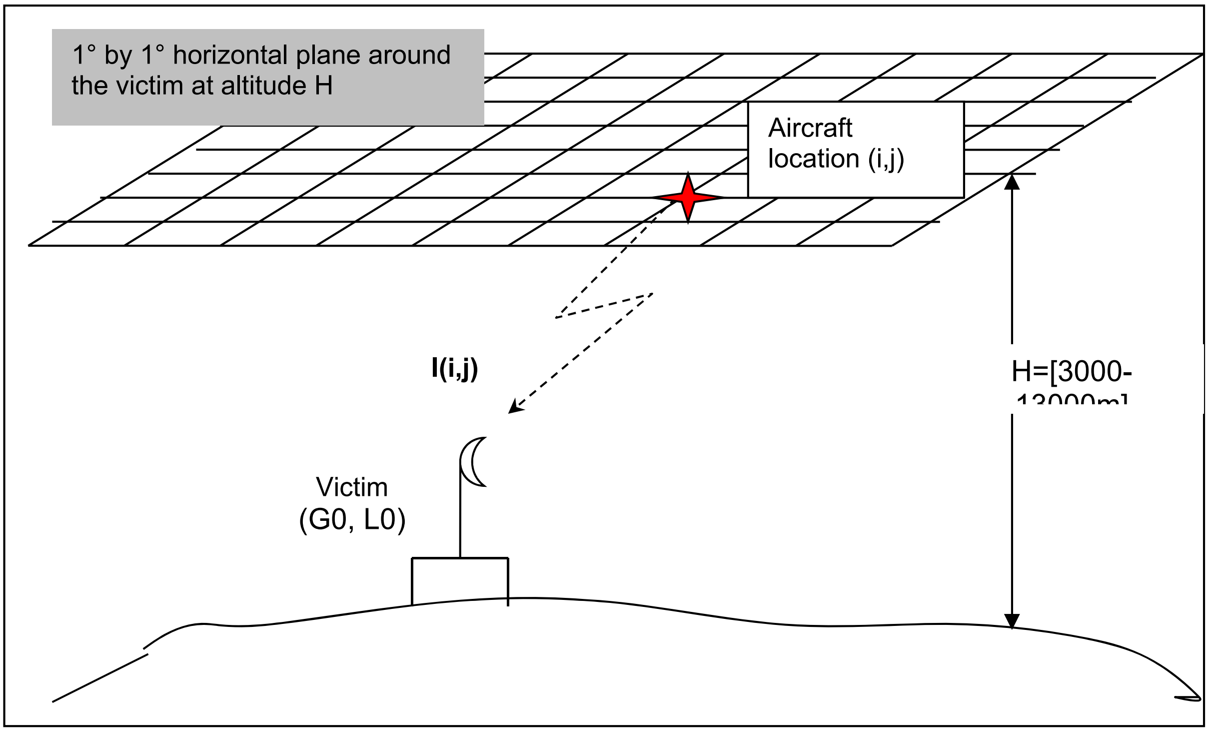


Figure 196: Illustration of the configuration used for interferences calculations

Negative aircraft elevations relative to the victim receiver are suppressed. For positive aircraft elevations, the free space loss is used.

A4.2.4 RESULTS OF IMPACT FROM DA2GC AS ON LTE BS

For Pe below 30 dBm: No interferences are observed whatever the aircraft altitude (i.e. from 3000m to 13000m)

For Pe=30 dBm, interferences occur at 3000m as figure below exemplifies. It can be noted that the DA2GC AS - LTE BS distance of 4365 m corresponding to the maximum distance where interferences occur equals a horizontal radius of 3171 meters. The black annulus in Figure 196 represent the aircraft position where I/N>=-6 dB. This happens for LTE BS – aircraft distances from 3514 m to 4365 m, and relative elevations between 58.62° and 43.40°.

For higher aircraft altitudes higher than 3000 m, the SNR ratio is below the protection criterion (I/N=< -6 dB).

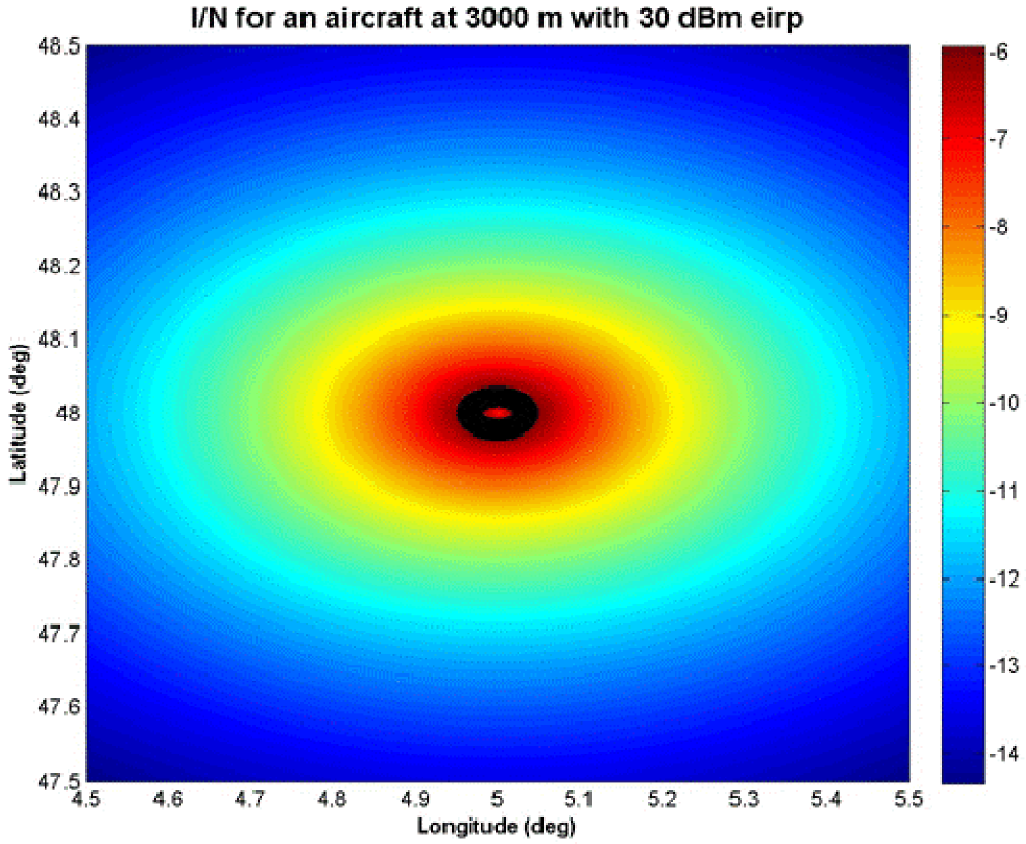


Figure 197: Interfering level at the LTE base station depending on the aircraft position for Pe=30dBm and H=3000m.

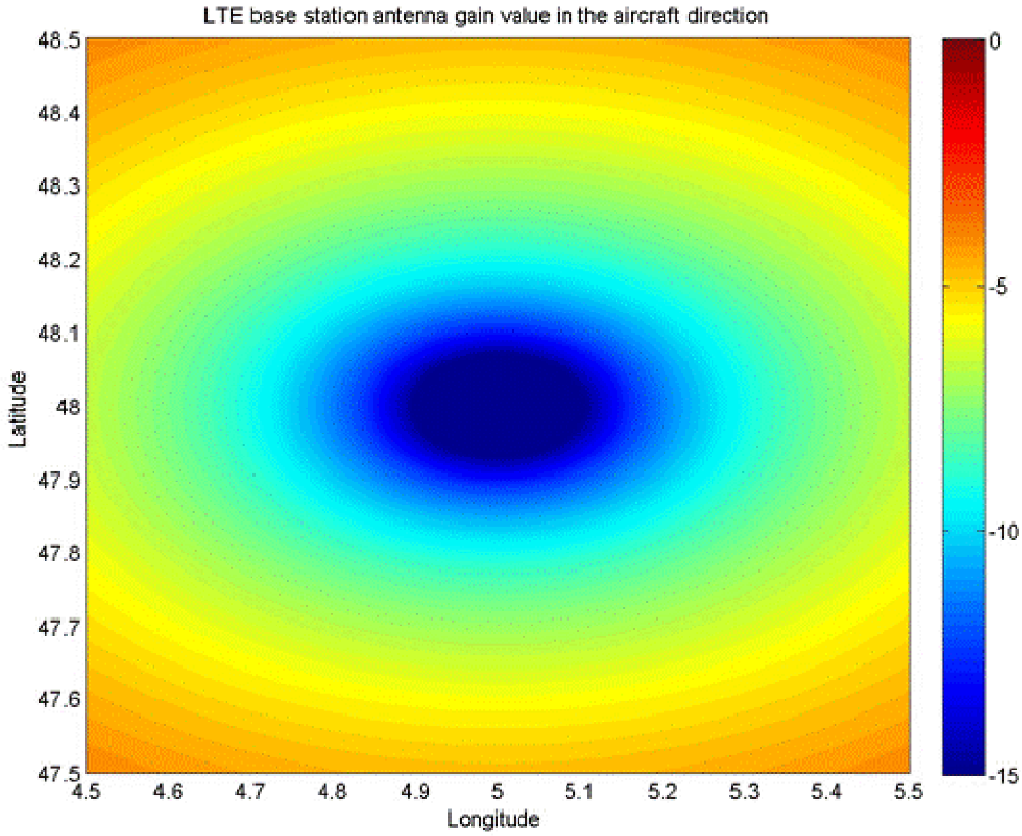


Figure 198: LTE BS antenna gain value in the aircraft direction flying at 3000m height. Maximum value is about -4 dBi at elevations lower than 2.26°, and minimum value is-23.8 dBi at zenith

For Pe=40 dBm, interferences occur for altitudes below 9 500 meters as figure below exemplifies. It can be noted that the DA2GC OBU - LTE BS distance of 11 199 meters corresponding to the minimum distance where interferences occur equals a horizontal radius of 5930 meters, thus interferences occur where the aircraft not above the LTE BS cell.

For aircraft altitudes higher than 9 500 **meters**, the SNR ratio is below the protection criterion.

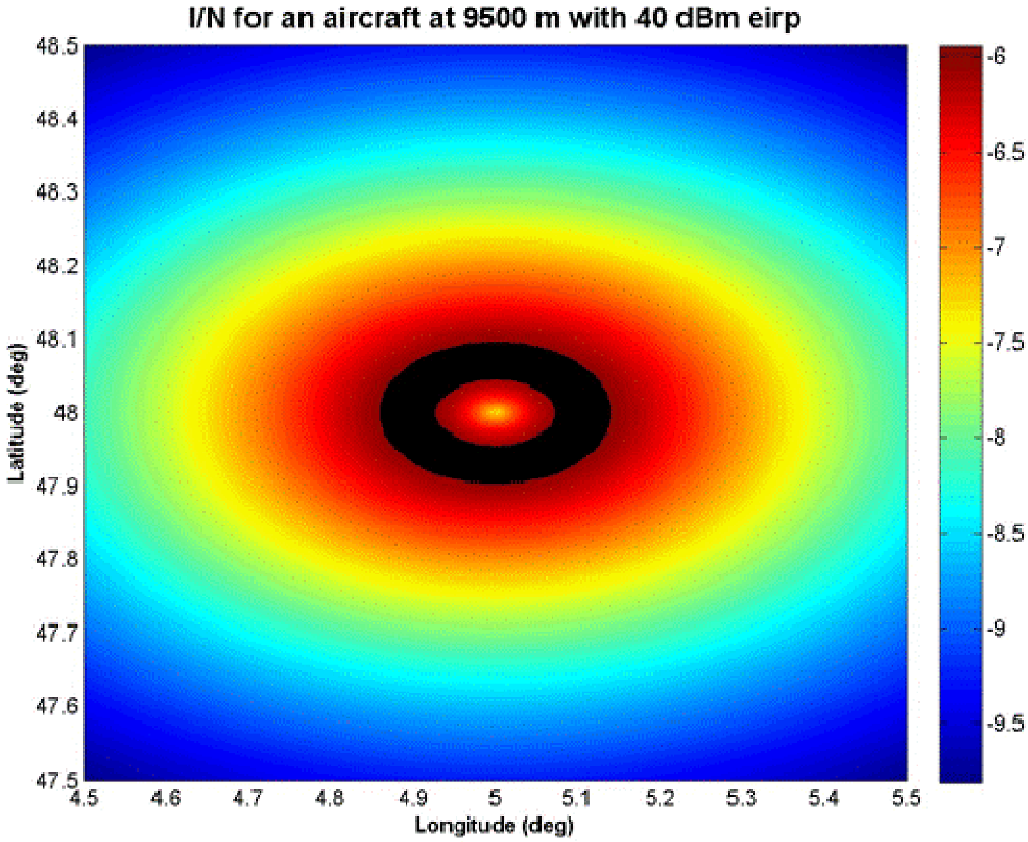


Figure 199: Interfering level at the LTE base station depending on the aircraft position for Pe=40dBm and H=9500m.

The black annulus represent the aircraft position where I/N>=-6 dB. This happens for LTE BS – aircraft distances from 11199m to 13703m, and relative elevations between 58° and 43.85°.

A4.2.5 RESULTS OF IMPACT FROM DA2GC AS ON LTE UE

One the one hand the LTE-UE antenna gain value (0 dBi) is higher than the LTE-BS values in the aircraft direction (from -23 dBi to -4 dBi for an aircraft at 3000 meters).

On the other hand the protection criterion for LTE-UE receivers is 4 dB less stringent than for LTE-BS receivers.

Considering co-channel emissions, the critical DA2GC emission level is **11.5 dBm** for LTE-UE (instead of 30 dBm for LTE BS). Below this value, no interferences are observed at the receiver level even at an aircraft altitude of 3000 m. With an emission power of 11.5 dBm, interferences occur when the aircraft flies above the LTE-UE at 3000 m altitude.

A4.2.6 RESULTS OF IMPACT FROM LTE BS ON DA2GC AS

The DA2GC AS suffers from interferences for aircraft altitudes below 12000 m as Figure 200 shows. The black annulus represent the aircraft position where I/N>=-6 dB. This happens for LTE BS – aircraft distances from 14538 m to 16663 m, and relative elevations between 55.59° and 46.01°.

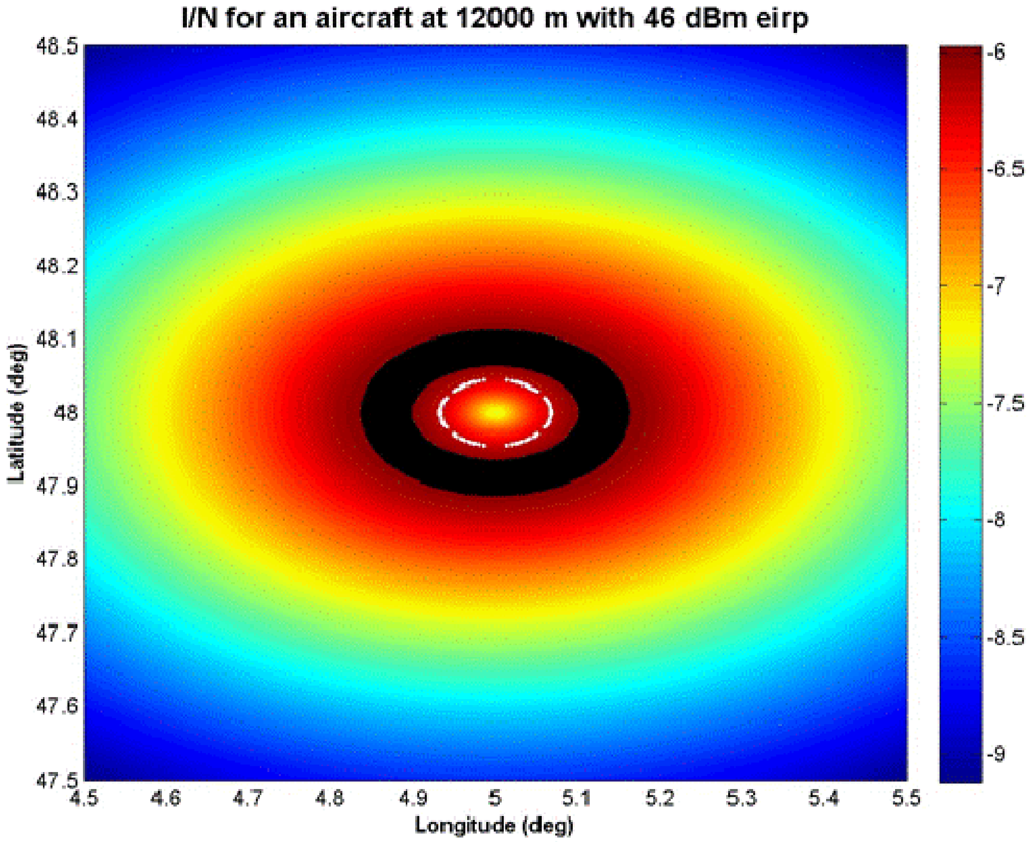


Figure 200: Interfering level at the DA2GC OBU from a LTE base station with Pe=46dBm and H=12000m.

A4.2.7 RESULTS OF IMPACT FROM LTE UE ON DA2GC AS

Since the characteristics of LTE-UE and DA2GC AS are identical (protection criterion and antenna pattern), the calculations are the same considering DA2GC AS as interferer or victim and LTE UE as victim or interferer.

A4.2.8 SUMMARY

Considering a DA2GC AS with an emission bandwidth of 10 MHz located on an aircraft at various altitudes above a LTE station with a 10 MHz bandwidth, the results can be summarized as follows:

A4.2.8.1 Emissions from DA2GC-AS to LTE-BS

For DA2GC AS power emissions lower than 30 dBm, no interferences occur (whatever the aircraft altitude);

For a DA2GC AS power emission of 30 dBm, interferences occur at 3000m (see black annulus in Figure 199), but not for higher aircraft altitudes;

For a DA2GC AS power emission of 40 dBm, interferences occur until 9500m (see black annulus in Figure 6), but not for higher aircraft altitudes;

A4.2.8.2 Emissions from LTE-BS to DA2GC-OBU

With a LTE-BS power of 46 dBm, interferences will occur at the DA2GC receiver for aircraft altitudes up to 12 km.

A4.2.8.3 Coexistence between DA2GC-OBU and LTE-UE

If one of the systems (either DA2GC-AS or LTE-UE) have a power emission higher than 11.5 dBm, interferences occur if the distance between the LTE UE and the aircraft is less than 3000m;

A4.2.9 ADJACENT CHANNEL CASE

For the simulations the block raster for FDD and TDD, respectively, is considered as a basis for implementing the DA2GC system, i.e. only full block numbers of N x 5 MHz are used for spectrum occupation.

Whereas for terrestrial mobile radio networks cross-border coordination between different countries can be applied to keep interferences between IMT/IMT-A systems on a sufficiently low level to avoid noticeable performance degradations, such a procedure is not suitable for a DA2GC system. Inter-frequency channel handovers between base stations are in principle supported by underlying system functionalities. However, due to the required large cell sizes of up to about 100 km and especially by the interference range an aircraft at high altitudes of more than 10 km would cause, a co-channel usage of the DA2GC system with terrestrial IMT/IMT-A systems is not feasible. The introduction of a DA2GC system would require a pan-European designation of the same frequency blocks with a single transmission mode (TDD or FDD). To be at least to some extent independent from the arrangements finally used in the different European countries, an implementation of a DA2GC system using TDD mode using the FDD duplex gap may be one possible solution, if compatibility can be achieved to neighbouring FDD and/or TDD blocks.

This section provides results on the compatibility between DA2GC and IMT/IMT-A in the band 3400-3600 MHz. The results correspond to simulations each with one

- DA2GC Base Station (BS)
- DA2GC aircraft incl. so-called Onboard Unit (OBU)
- IMT/IMT-A Base Station (BS)
- IMT/IMT-A User Equipment (UE).

A4.2.9.1 INTERFERENCE SCENARIO

Figure 201 shows the general interference scenario considered in present evaluations, which is based on single service and interfering links for and in between both systems. The BSs itself can be co-located at the same site or placed at different sites.

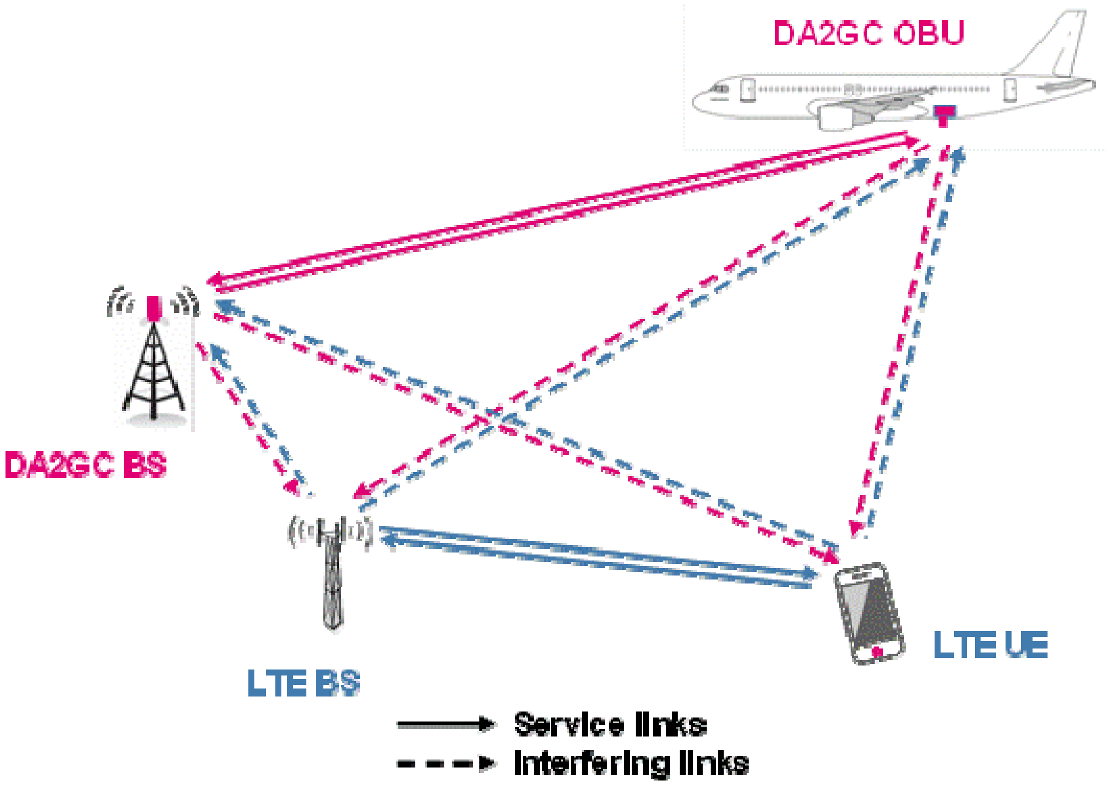


Figure 201: General interference scenarios considered (single link based)

This scenario describes the use of a TDD mode for the terrestrial LTE system as well as for the DA2GC system in an unsynchronized way, i.e. it may happen that one of the systems is transmitting in the downlink direction and the other simultaneously in the uplink (and vice versa) resulting in stronger interference levels compared to FDD transmission.

A4.2.9.2 PROPAGATION MODELS

In the different service and interfering links in the considered scenario are exemplarily shown. There are strong differences in propagation conditions: In one case the transmitter/receiver is near the ground and its counterpart is at high altitudes (DA2GC) and in the other case both are near the ground resulting in additional path loss by terrain and clutter (classical mobile radio use case). Therefore, different propagation models were applied for service and interfering links as shown in Table 72.

Table 72: Propagation models applied for service and interfering links

Link	Link characteristic	Propagation model
DA2GC BS ↔ DA2GC AS	Service link	LOS (free space)
DA2GC GS ↔ LTE BS	Interfering link	LOS (free space)
DA2GC GS ↔ LTE UE	Interfering link	ITU-R P.452-14
DA2GC AS ↔ LTE BS	Interfering link	LOS (free space)
DA2GC AS ↔ LTE UE	Interfering link	LOS (free space)
LTE BS ↔ LTE UE	Service link	ITU-R P.452-14

The LOS model is based on the simple free space path loss model described in ITU-R Rec. P.525-2 [21]. It is applied for the links between the DA2GC AS at higher altitudes and the GS/BS or the LTE UE, respectively. For the link DA2GC AS ↔ LTE UE this is a worst case assumption, as even in a rural environment, the LOS link to the aircraft will be frequently obstructed by terrain or vegetation near the UE at the ground.

Details of the second model, which is suited to predict interference levels between stations at the Earth surface, can be found in ITU-R Rec. P.452-14 [22]. Both models are available in the SEAMCAT tool box. For the P.452-14 model parameters according to the chosen rural environment were set (see [5]). This model was also used in other sharing studies for IMT-A in the 3.5 GHz range (e.g. see [13]).

A4.2.10 RESULTS (DETERMINISTIC)

A4.2.10.1GENERAL INFORMATION ON SCENARIO

Following results are based on the assumption that both GS and BS are co-located at the same site. In addition, adjustment of the sector antennas in the same direction is considered. The positions of the LTE UE as well as of the aircraft with the DA2GC AS are varied on a straight line in the main BS antenna beam (LTE UE for distances up to 5 km, DA2GC AS up to 100 km). Only results for the lowest altitude of the DA2GC AS (about 3 km) have been included in the present document, as this represents the worst case for the interference into the terrestrial LTE network.

For the interference protection ratio a I/N value of -6dB has been considered in the evaluations as already stated in Table 69 and Table 70 Two center frequencies for the LTE and DA2GC signal have been chosen from the middle of the 3400-3600 MHz band with a difference of 20 and 25 MHz each, i.e. the frequency guard band between the channel block edges is 0 and 5 MHz, respectively. The channel bandwidth of both signals is assumed to be 20 MHz, i.e. 100 RBs are assumed to be covered per OFDMA signal resulting in 18 MHz RF bandwidth [1][2].

As said before all evaluations are based on deterministic scenarios only. Statistical evaluations based on Monte-Carlo simulations with SEAMCAT will follow in the next step.

4.2.10.1.1 SENARIO 1: IMPACT FROM DA2GC AS INTO LTE SYSTEM

The next figures show the impact of the DA2GC AS on the terrestrial LTE network (see Figure 202 and Figure 203: Resulting I/N by interference caused by DA2GC OBU into LTE UE in the adjacent channel (frequency guard bands of 0 and 5 MHz between channel block edges)

The resulting I/N values are given in relation to the distance between the aircraft and the site with the 2 co-located BSs (please consider the non-linear scaling of the distance axis). Figure 203 it is assumed that the LTE UE is at a distance of 5 km from the site (cell edge).

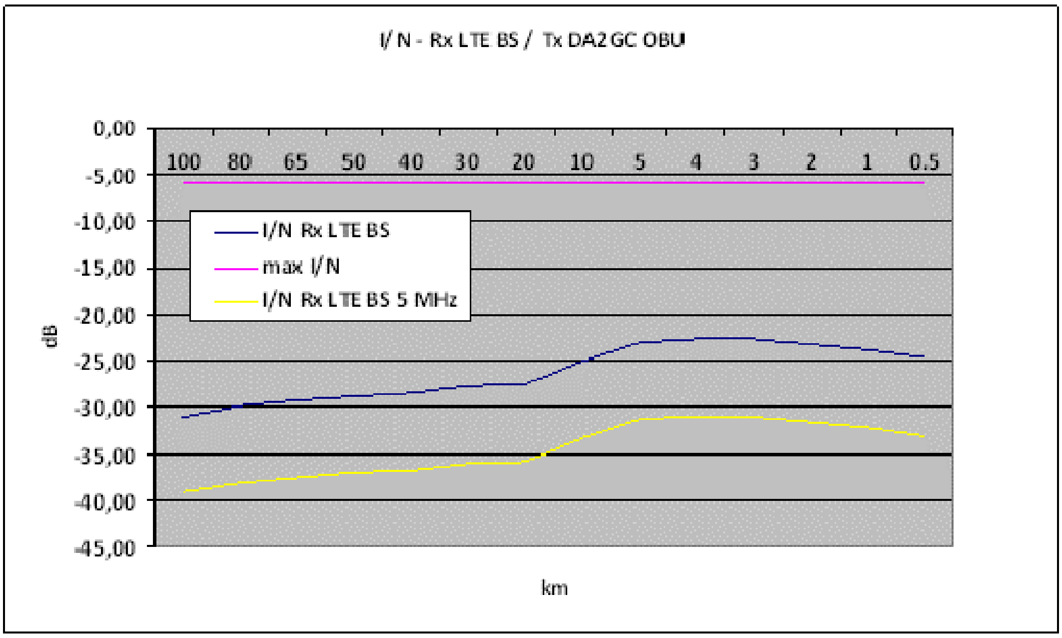


Figure 202: Resulting I/N by interference caused by DA2GC OBU into LTE BS in the adjacent channel (frequency guard bands of 0 and 5 MHz between channel block edges)

The results in Figure 202 are computed for the worst case, i.e. the DA2GC AS is always transmitting with highest power of 40 dBm. Normally the power control mechanism will reduce the Tx power when the aircraft is moving from the cell edge into the main coverage area of a DA2GC ground station, i.e. for the present scenario the I/N would be further reduced at distances nearer the site.

Nevertheless, as the cell size of the DA2GC system is much larger than the size of the LTE cells, the aircraft will often cross other base stations of the LTE network. In the worst case the aircraft is flying at cell edge transmitting with maximum power, and a LTE base station is near to the aircraft. This situation will frequently happen in real scenarios.

The resulting I/N values are below the threshold. This is mainly caused on one hand by the increased ACLR value as a result of an improved emission mask, and on the other hand there is always a signal strength attenuation for a path distance of at least 3 km. In case the DA2GC system should be in operation also for lower altitudes e.g. near airports, additional evaluations need to be performed.

The interference from the DA2GC AS into the LTE UE is also below the threshold (see Figure 203). The comments made before on power control are also valid for this scenario. As omni-directional antennas are assumed for both equipment parts, it is not expected that higher interferences will occur with possibly changed antenna diagrams at the aircraft, because this would result only in higher gain just below the horizontal aircraft plane having only impact at larger distances between the aircraft and the LTE UE, but in such cases the interference level is strongly reduced by the additional path loss.

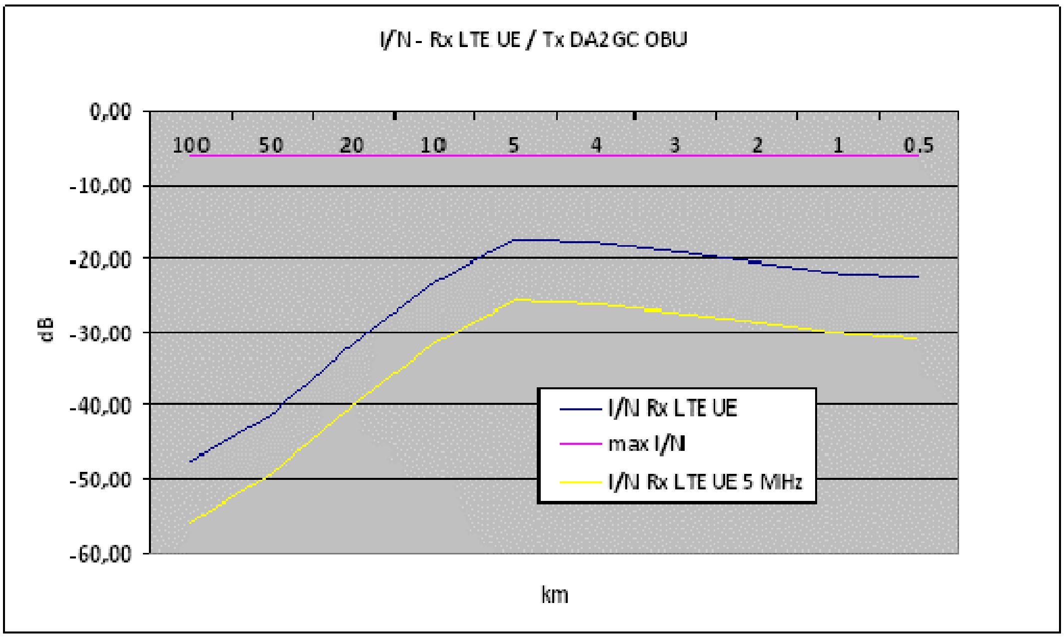


Figure 203: Resulting I/N by interference caused by DA2GC OBU into LTE UE in the adjacent channel (frequency guard bands of 0 and 5 MHz between channel block edges)

4.2.10.1.2 SENARIO 2: IMPACT FROM LTE UE INTO DA2GC

Similar to scenario 1 the next figures show the impact of the LTE UE on the DA2GC system. In addition the transmitter mask for the LTE UE has been implemented in SEAMCAT via the maximum emission limit settings given in Table 71 which results in a lower ACLR value compared to the 3GPP specification (about 24 dB instead of 30 dB). Therefore an additional margin of about 6 dB is available.

In Figure 204 the I/N values produced by the LTE UE at the DA2GC BS are given. With the adaptation of the GS antenna diagram (increased side lobe attenuation to the ground) the I/N values are below the threshold even for small distances.

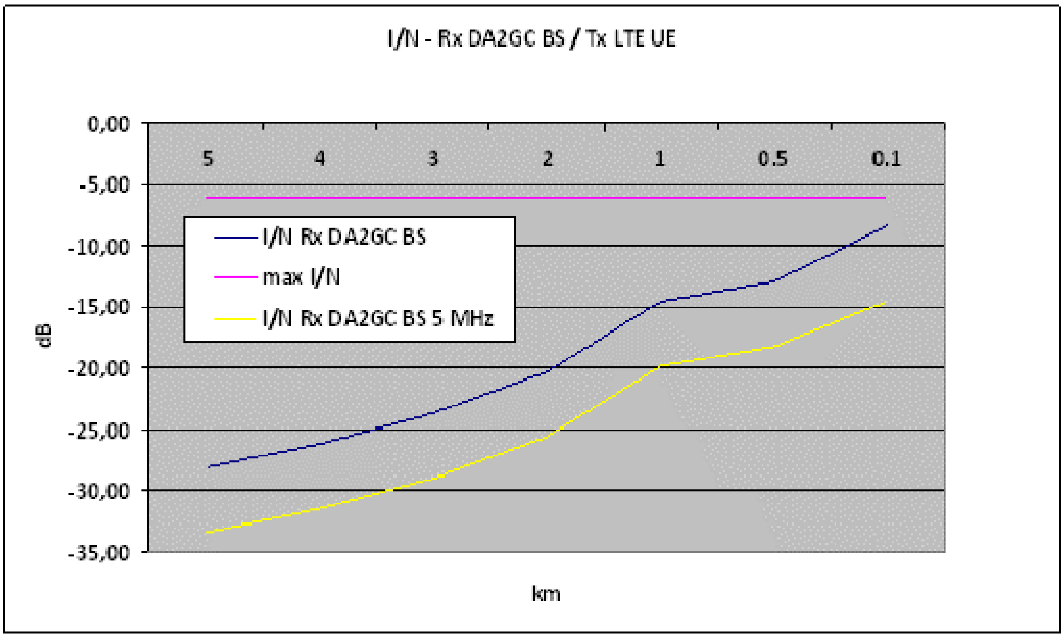


Figure 204: Resulting I/N by interference caused by LTE UE into DA2GC BS in the adjacent channel (frequency guard bands of 0 and 5 MHz between channel block edges)

Figure 205 shows the resulting I/N similar to Figure 203 in the opposite transmission direction with the LTE UE placed at a distance of 5 km from the site. Again the interference impact is negligible due to available path loss for a distance of at least 3 km.

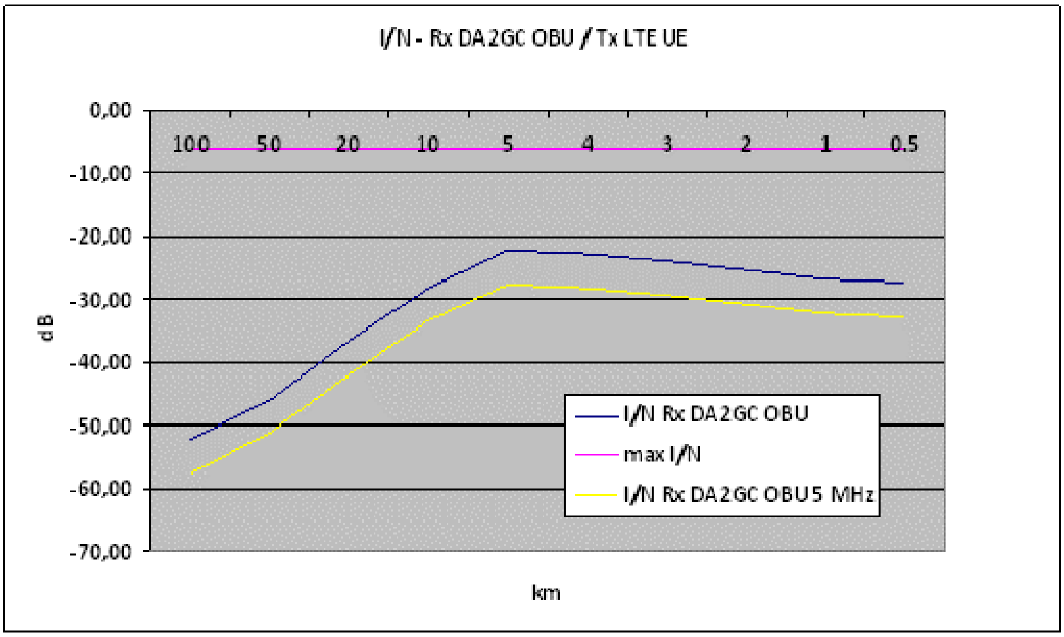


Figure 205: Resulting I/N by interference caused by LTE UE into DA2GC AS in the adjacent channel (frequency guard bands of 0 and 5 MHz between channel block edges)

4.2.10.1.3 SENARIO 3: IMPACT FROM DA2GC GS INTO LTE

Figure 206 provides the I/N values caused by the DA2GC GS at the LTE UE.

The threshold is exceeded for distances less than 1 km from the site. With 5 MHz guard band only the locations near the site are affected. As already noted the interference will have only low impact on the final performance in case of co-location of LTE BS and DA2GC GS, as it will decrease in the same manner as the power from the LTE BS service link will go down, i.e. the resulting S/I will stay in the same range or will be improved with increasing distance due to impact of different vertical antenna orientations (up-tilt vs. down-tilt).

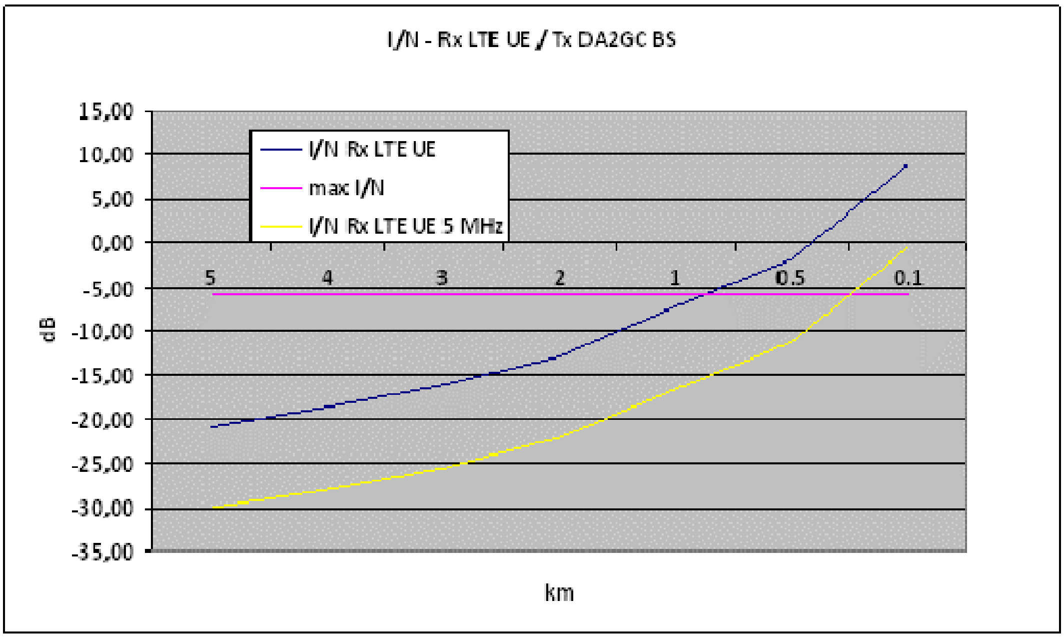


Figure 206: Resulting I/N by interference caused by DA2GC BS into LTE UE in the adjacent channel (frequency guard bands of 0 and 5 MHz between channel block edges)

The impact of co-location of GS and BS for unsynchronized TDD or TDD/FDD usage in adjacent frequency blocks is still a problem, even if the adaptation of the vertical BS antenna side lobes will reduce the disturbance caused by the Tx output of one station to the Rx input of the other station. With the parameter sets used for the evaluation in this document (incl. the path loss for vertical antenna distance of 20 m between both systems) and an ACLR value of 45 dB, about 15 dB additional isolation is required to keep the I/N threshold (6 dB with 5 MHz guard band).

Another issue is the co-location of GS and BS for unsynchronized TDD or TDD/FDD usage in adjacent frequency blocks. In that case the Tx output will disturb the Rx input of the other station (at least during certain time intervals). Possible solutions are seen in improved isolation between the antennas and in increased guard bands. Typical isolation values to be achieved at the same mast are in the order of about 50 dB [2]. Alternatively, the GS and BS have to be placed at different sites to achieve sufficient decoupling in between the antenna links via the resulting path loss.

There is also no difference to the case of common LTE deployments in frequency bands assigned to TDD usage or in bands with mixed FDD/TDD usage [2][15]. The only distinction in the DA2GC case is the GS antenna tilt in the vertical plane.

With the parameter sets used for the evaluation in this document (incl. the path loss for vertical antenna distance of 20 m between both systems) and an ACLR value of 45 dB, about 28 dB additional isolation are required to keep the I/N threshold.

4.2.10.1.4 SENARIO 4: IMPACT FROM LTE BS INTO DA2GC

As shown in Figure 207: Resulting I/N by interference caused by LTE BS on DA2GC AS in the adjacent channel (frequency guard bands of 0 and 5 MHz between channel block edges)

for this scenario the I/N threshold at the DA2GC OBU is kept due to sufficient high ACLR values of the LTE BS and the path loss between LTE BS and the aircraft. So even in the case the aircraft is near the edge of a DA2GC cell and also near a LTE BS, the coupling loss should be adequate to avoid any strong impact on the performance of the DA2GC link.

The impact from the LTE BS on the DA2GC GS is the same as the impact from the DA2GC GS on the LTE BS already described in subsection 4.2.10.1.3.

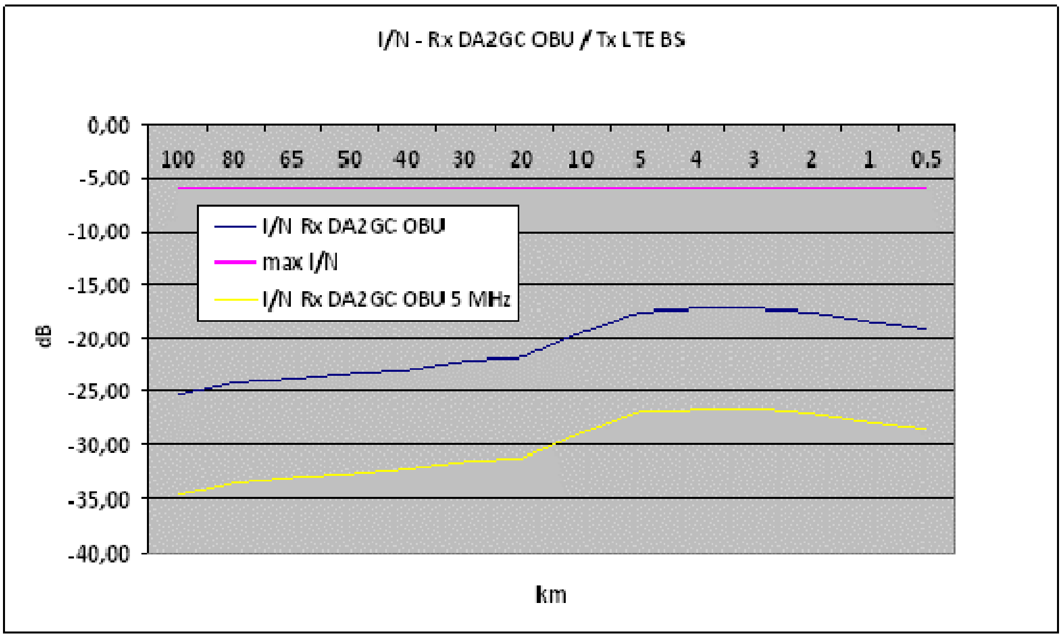


Figure 207: Resulting I/N by interference caused by LTE BS on DA2GC AS in the adjacent channel (frequency guard bands of 0 and 5 MHz between channel block edges)

4.2.10.1.5 DYNAMIC INTERFERENCE SCENARIOS

Except of static scenarios SEAMCAT allows to evaluate the impact of interferences in more realistic dynamic network scenarios similar to those applied e.g. for system level simulations, i.e. not only single static links are considered, but also connections between a homogeneous BS network to different users (UEs in the case of terrestrial LTE, OBUs in case of DA2GC), which are randomly placed in the coverage areas.

For both terrestrial LTE and Broadband DA2GC hexagonal cellular networks are applied with cells consisting of 3 sectors each. The main difference between both networks is the radius of the hexagonal cell, which is much smaller for terrestrial LTE. 6-20 shows an exemplary network constellation with DA2GC as victim system and LTE as interfering system. Due to drastically smaller cell radius the LTE network is only seen as the magenta colored part in the middle of the DA2GC network. For the evaluations the inter-site-distance (ISD) of DA2GC was set to 156 km which corresponds to a cell radius of approximately 90 km. The terrestrial LTE system has a radius of 4.33 km, i.e. the ISD is 7.5 km.

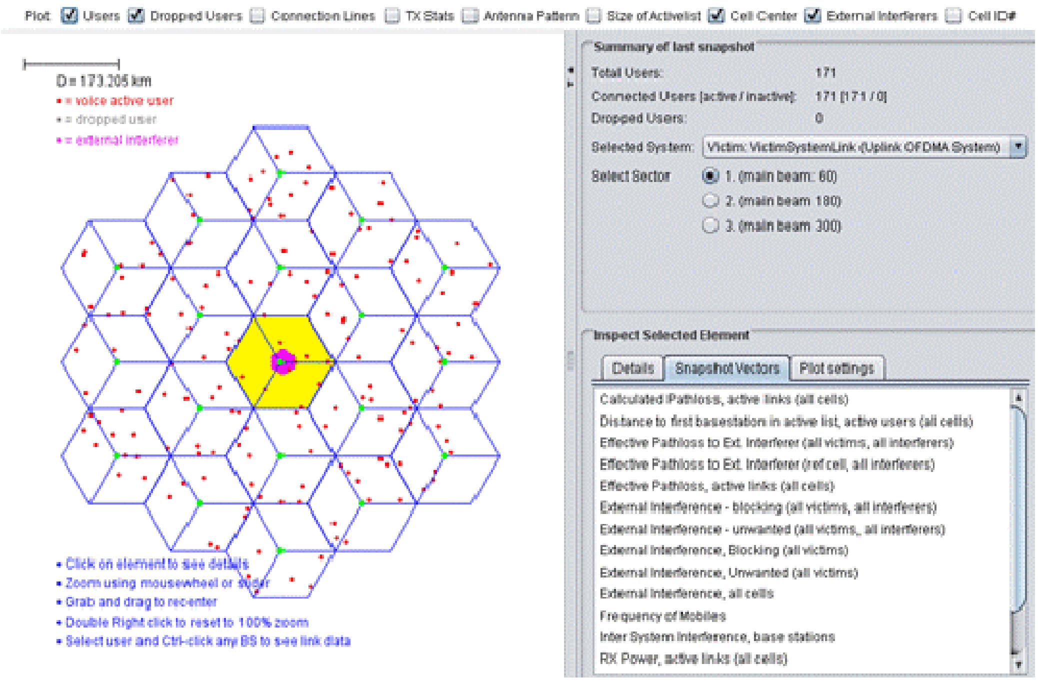


Figure 208: Exemplary network constellation for DA2GC as victim system and terrestrial LTE as interfering system (screen shot of SEAMCAT GUI)

Due to the large difference in the coverage areas of the 2 networks the interference evaluation in SEAMCAT cannot consider all possible situations that could occur in real world. To cover several samples a differentiation was made with respect to the placement of the network centers. The terrestrial LTE network was shifted by 4 km and 50 km, respectively, for some simulations, i.e. the center sites are not co-located in those cases.

For the Monte Carlo simulation it is assumed that always 5 mobile stations (MS, i.e. UEs and OBUs, respectively) are connected to a BS sector (red dots in Figure 208 for DA2GC). Therefore the signal bandwidth of both networks has to be split between the MSs. In the case of a signal bandwidth of 9 MHz used for simulation (LTE channel bandwidth of 10 MHz) 1.8 MHz will be assigned to each user (10 out of 50 resource blocks with bandwidth of 180 kHz each).

In contrast to the terrestrial LTE system where all UEs have the same antenna height of 1.5 m different altitudes have to be assigned to the aircraft OBUs. An altitude distribution has been selected according to a statistical evaluation for European continental air traffic for altitudes between 3 and 11 km. The corresponding cumulative distribution function is shown in Figure 209 (step size of 500 m). There is a higher probability of altitudes above 7 km as altitudes in the low range only occur during departure and landing phases.

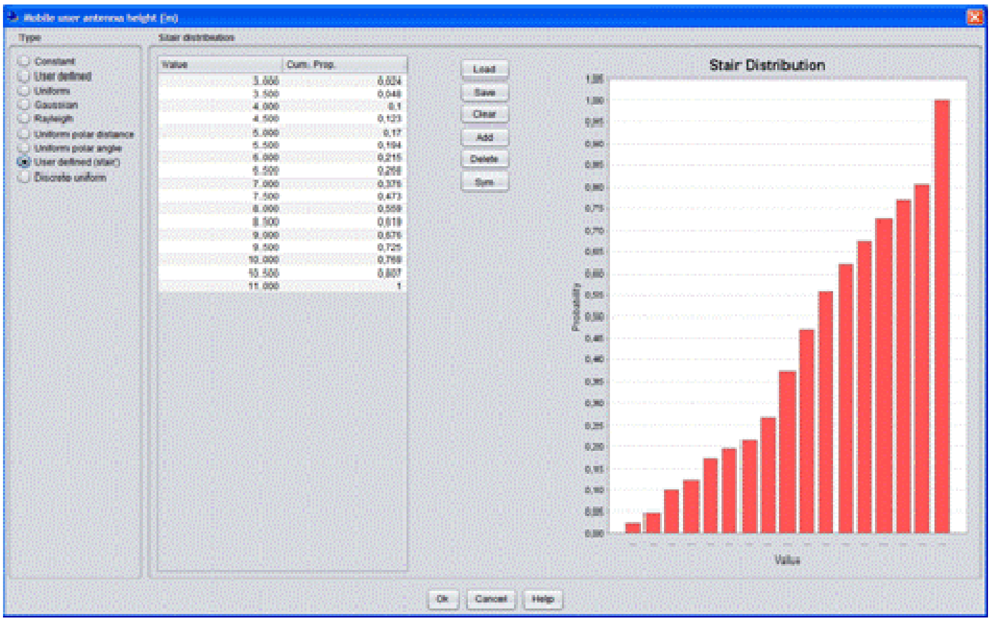


Figure 209: Cumulative distribution function of aircraft altitudes applied for Monte Carlo simulation (screen shot of SEAMCAT GUI)

The Monte Carlo simulation in SEAMCAT is running several repetitions, so called snapshots, for the placement of MSs within the coverage areas to produce results with certain reliability. The simulation was set to 1000 snapshots to guarantee high reliabilities (changes only in second position after decimal point). The exemplary output screen shot of SEAMCAT in Figure 210 is demonstrating the impact of interference on capacity and bit rate of the victim system for each performed snapshot. It has to be noted that SEAMCAT distinguishes between the impact on the inner reference cell (the yellow area in 6-20) and the total system (all cells incorporated).

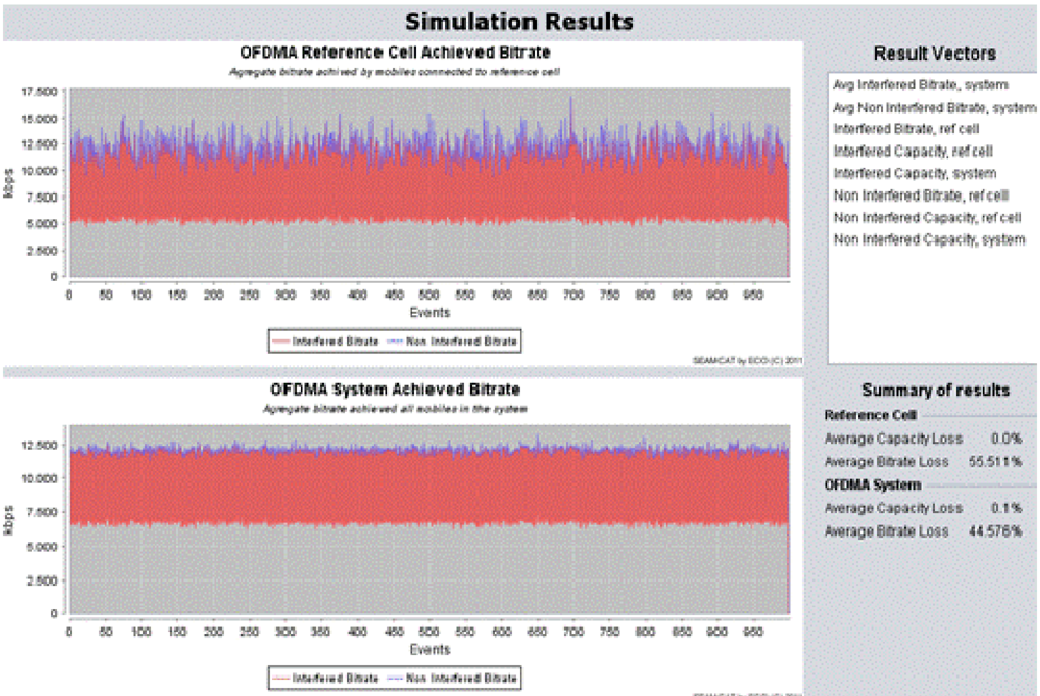


Figure 210: Exemplary output of dynamic compatibility evaluation (screen shot of SEAMCAT GUI)

To allow the determination of capacity and bit rate values in SEAMCAT based on resulting SINR information a suitable conversation curve is needed. In SEAMCAT a default link level data curve is already integrated for LTE systems according to a definition given by 3GPP in [7], which provides the link capacity in bit/s/Hz dependent on SINR. The curve shown in Figure 211 is applied for the terrestrial LTE system. For the DA2GC radio link the curve has been adapted according to measurement results performed under flight conditions with line-of-sight between BS and aircraft antenna (see Figure 212).

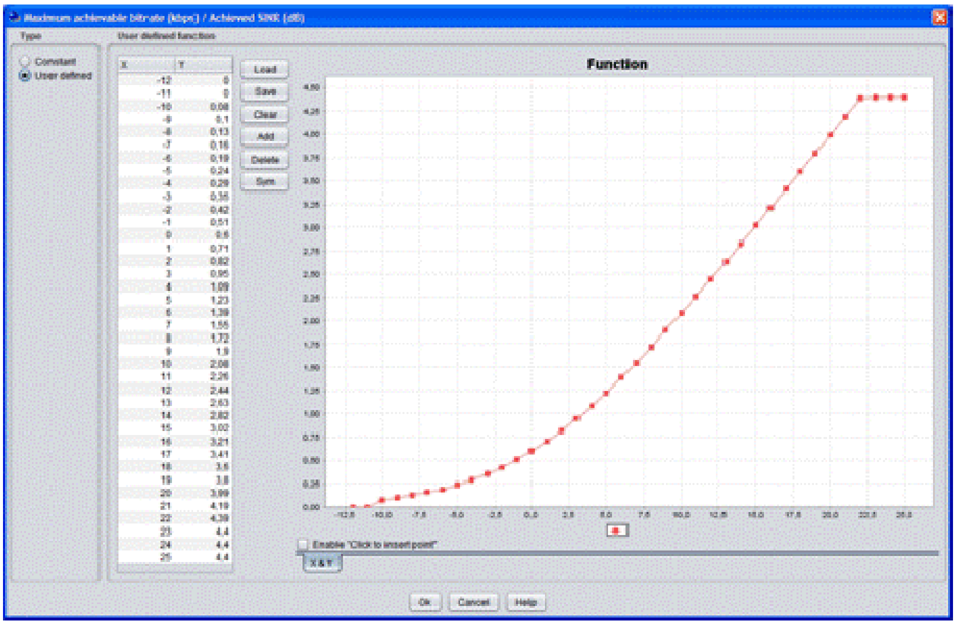


Figure 211: Link level data curve for conversion of SINR to capacity for terrestrial LTE (screen shot of SEAMCAT GUI)

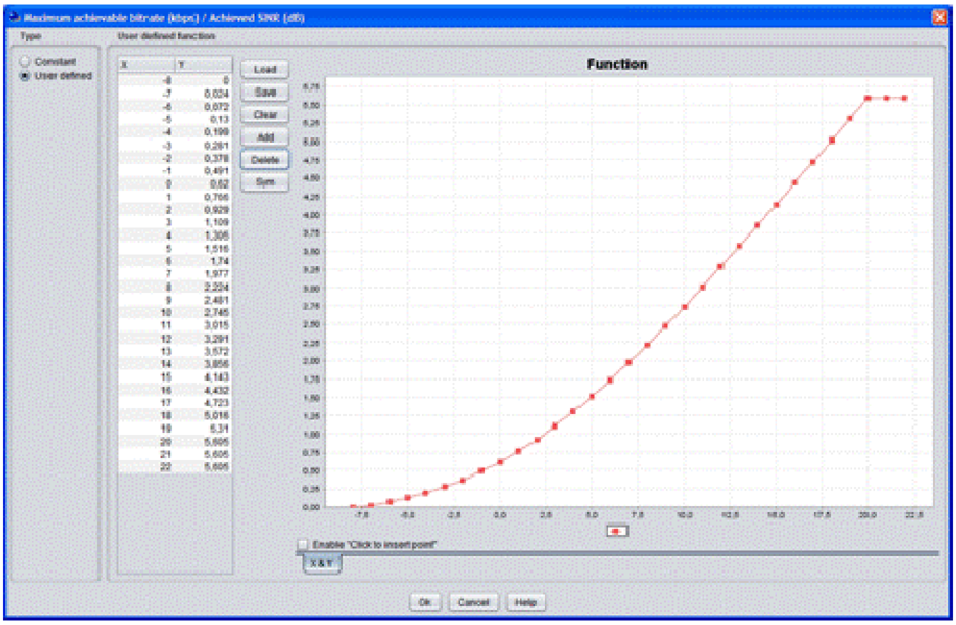


Figure 212: Link level data curve for conversion of SINR to capacity for DA2GC (screen shot of SEAMCAT GUI)

4.2.10.1.6 SYSTEM AND NETWORK PARAMETER

In the following table the main parameters for the signals and network constellations applied in the evaluations are summarized. Parameters not listed in Table 73 are unchanged compared to those given in for deterministic scenarios.

Table 73: Main parameters of signal and network constellations used in dynamic interference evaluations with SEAMCAT

Parameter	LTE		DA2GC	
	Downlink	Uplink	Downlink	Uplink
Carrier frequency	3500 MHz	3500 MHz	3510 / 3515 MHz	3510 / 3515 MHz
Channel bandwidth	10 MHz	10 MHz	10 MHz	10 MHz
Signal bandwidth	9 MHz	9 MHz (1.8 MHz/UE)	9 MHz	9 MHz (1.8 MHz/OBU)
Number of mobile stations	5	5	5	5
Link level data (SINR to C)	3GPP default (Note 1)	3GPP default (Note 1)	Modified 3GPP (Note 2)	Modified 3GPP (Note 2)
Cell radius	4.33 km	4.33 km	90 km	90 km
ISD	7.5 km	7.5 km	156 km	156 km
BS antenna height	30 m	30 m	50 m	50 m
Vertical tilt of BS antenna	-2°	-2°	10°	10°
Vertical pattern of BS antenna	ITU-R F.1336	ITU-R F.1336	Cosecant-squared (Note 3)	Cosecant-squared (Note 3)
Gain BS / MS antenna	17 dBi / 0 dBi	17 dBi / 0 dBi	15 dBi / 0 dBi	15 dBi / 0 dBi
MS height	1.5 m	1.5 m	3 - 11 km (Note 4)	3 - 11 km (Note 4)

Note 1: Link level data applied according to 3GPP TS 36.814 [15]; see also Figure 211: Link level data curve for conversion of SINR to capacity for terrestrial LTE (screen shot of SEAMCAT GUI)
.
Note 2: Link level data applied according to Figure 212.
Note 3: Vertical antenna diagram according to Figure 2
Note 4: Altitude distribution of aircraft OBUs according to Figure 209 Figure 209: Cumulative distribution function of aircraft altitudes applied for Monte Carlo simulation (screen shot of SEAMCAT GUI)

A4.2.11 RESULTS

In Table 74 the results achieved on the basis of the SEAMCAT Monte Carlo simulations are listed for the case that the terrestrial LTE system is interfered by a DA2GC system. As mentioned before different cases are considered related to the transmission direction (DL and UL), a possible frequency guard band of 5 MHz between the channel block edges of both signals and a offset of the centers of the two networks.

The impact of the DA2GC network on terrestrial LTE is generally very low except of the UL/DL case for co-located center sites (center offset equal to 0 km). Here the same interference influence arises as in the well-known deterministic case described before where the Tx output of one BS will disturb the Rx input of the other BS for unsynchronized TDD or TDD/FDD usage in adjacent frequency blocks. This is valid for the reference cell. If all cells are incorporated the system-based loss will get smaller, but it is still significant.

Table 74: Output of dynamic interference evaluations (capacity and bit rate loss) with SEAMCAT for terrestrial LTE as victim system and DA2GC as interfering system

Transmit direction LTE / DA2GC	Output	Loss [%]	Guard band [MHz]	Center offset [km]	Guard band [MHz]	Center offset [km]	Guard band [MHz]	Center offset [km]
			0	0	5	0	5	50
DL / DL	Reference cell	Capacity	0.0	0.0	0.0	0.0	0.0	0.0
		Bit rate	0.001	0.001	0.001	0.001	0.001	0.001
	System	Capacity	0.1	0.2	0.2	0.1	0.2	0.2
		Bit rate	0.036	0.019	0.147	0.036	0.019	0.147
UL / DL	Reference cell	Capacity	0.0	0.0	0.0	0.0	0.0	0.0
		Bit rate	45.534	38.856	0.0	45.534	38.856	0.0
	System	Capacity	0.401	0.2	0.2	0.401	0.2	0.2
		Bit rate	2.822	2.248	0.186	2.822	2.248	0.186
DL / UL	Reference cell	Capacity	0.0	0.02	0.0	0.0	0.02	0.0
		Bit rate	0.0	0.55	0.0	0.0	0.55	0.0
	System	Capacity	0.0	0.006	0.1	0.0	0.006	0.1
		Bit rate	0.0	0.233	0.034	0.0	0.233	0.034
UL / UL	Reference cell	Capacity	0.0	0.0	0.0	0.0	0.0	0.0
		Bit rate	0.001	0.001	0.001	0.001	0.001	0.001
	System	Capacity	0.0	0.201	0.0	0.0	0.201	0.0
		Bit rate	0.001	0.174	0.001	0.001	0.174	0.001

Also in the opposite case, i.e. when the DA2GC system is interfered by the terrestrial LTE system, the same behavior for the UL/DL case is perceptible, now with increased impact due to different antenna constellations at BSs (see Table 75). In the other cases the finally observable loss in the DA2GC transmission is negligible.

Table 75: Output of dynamic interference evaluations (capacity and bit rate loss) with SEAMCAT for terrestrial LTE as victim system and DA2GC as interfering system

Transmit direction LTE / DA2GC	Output	Loss [%]	Guard band [MHz]	Center offset [km]	Guard band [MHz]	Center offset [km]	Guard band [MHz]	Center offset [km]
			0	0	5	0	5	4
DL / DL	Reference cell	Capacity	0.907	0.576	0.536	0.907	0.576	0.536
		Bit rate	1.05	0.885	0.923	1.05	0.885	0.923
	System	Capacity	0.252	0.198	0.228	0.252	0.198	0.228
		Bit rate	0.475	0.403	0.402	0.475	0.403	0.402
UL / DL	Reference cell	Capacity	0.0	0.0	0.0	0.0	0.0	0.0
		Bit rate	100.0	100.0	37.155	100.0	100.0	37.155
	System	Capacity	0.0	0.0	0.0	0.0	0.0	0.0
		Bit rate	12.746	12.8	4.751	12.746	12.8	4.751
DL / UL	Reference cell	Capacity	0.0	0.0201	0.0	0.0	0.0201	0.0
		Bit rate	0.054	0.02	0.026	0.054	0.02	0.026
	System	Capacity	0.003	0.002	0.102	0.003	0.002	0.102
		Bit rate	0.008	0.003	0.125	0.008	0.003	0.125
UL / UL	Reference cell	Capacity	0.0	0.0	0.0	0.0	0.0	0.0
		Bit rate	0.396	0.134	0.393	0.396	0.134	0.393

Transmit direction LTE /	Output	Loss [%]	Guard band [MHz]	Center offset [km]	Guard band [MHz]	Center offset [km]	Guard band [MHz]	Center offset [km]
	System	Capacity	0.3	0.0	0.3	0.3	0.0	0.3
		Bit rate	1.016	0.017	0.426	1.016	0.017	0.426

The evaluations with dynamic system behaviour confirm the results achieved with the static scenarios. In particular, co-location of sites of both networks will lead to interference problems, except if both systems would operate in FDD mode.

A4.2.12 CONCLUSIONS

The results for static worst case single link scenarios as well as for statistical network evaluations state that in principle a LTE-based DA2GC system can co-exist with a terrestrial mobile radio system with similar characteristics in the adjacent channel. This is primarily true if FDD mode operations are considered for both systems. No additional guard band between the channel block edges is required in that case.

For TDD or mixed FDD/TDD mode operations the main problem to be solved is the decoupling of the BS antennas which requires sufficient isolation in space and/or frequency or alternatively the usage of different sites for the systems. According to ECC decision ECC/DEC/(11)06 [24] both FDD and TDD arrangements for IMT/IMT-A systems in the band 3400-3600 MHz are possible in European countries in the future. Therefore, even with an implementation of DA2GC in FDD mode, frequency guard bands > 5 MHz would be required for deployment at least in countries with TDD arrangement for terrestrial IMT/IMT-A.

A4.3 COMPATIBILITY BETWEEN DA2GC AND FSS IN THE BAND 3400 – 3600 MHz

This document presents coexistence studies between a station from the Fixed Service in the frequency band 3400-3600 MHz and a BDA2GC aircraft station flying at an altitude from 3000 to 13 000 meters.

A4.3.1 DA2GC AS PARAMETER

The DA2GC aircraft station characteristics used in this study are extracted from Section 4.1.2and summed up in the following table:

Table 76: Characteristics of the DA2GC AS

Parameter	DA2GC aircraft station	
	FDD	TDD
Tx power (max./min.)	40 dBm / -23 dBm	40 dBm / -23 dBm
Antenna type	Omni-directional	Omni-directional
Antenna gain	0 dBi	0 dBi
Antenna height	3000 - 13000 m	3000 - 13000 m
Channel bandwidth	2 x 10 MHz	15 or 20 MHz
Signal bandwidth	9 MHz	13.5 or 18 MHz
Resulting e.i.r.p in dBm/MHz	30.4/-32.5 dBm/MHz	28.7/-34.3 dBm/MHz 27.4/-35.5 dBm/MHz
Rx noise floor (kTF)	-105.5 dBm/MHz	-105.5 dBm/MHz
Interference protection ratio I/N	-6 dB	-6 dB
Tx spectrum emission mask (SEM) / Spurious emissions	See Figure 214	See Figure 214
Adjacent channel leakage ratio (ACLR) limit	37 dB	37 dB

DA2GC aircraft station Out-Of-Band emissions for the aircraft station is derived from Table 6.6.2.1.1-1 of the 3GPP TS 36.101, reproduced below in Figure 213.

Table 6.6.2.1.1-1: General E-UTRA spectrum emission mask

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

Figure 213: OOB spectrum emission mask for the aircraft AS

For a 10 MHz channel bandwidth, the DA2GC AS spectrum emission mask is illustrated Figure 214.

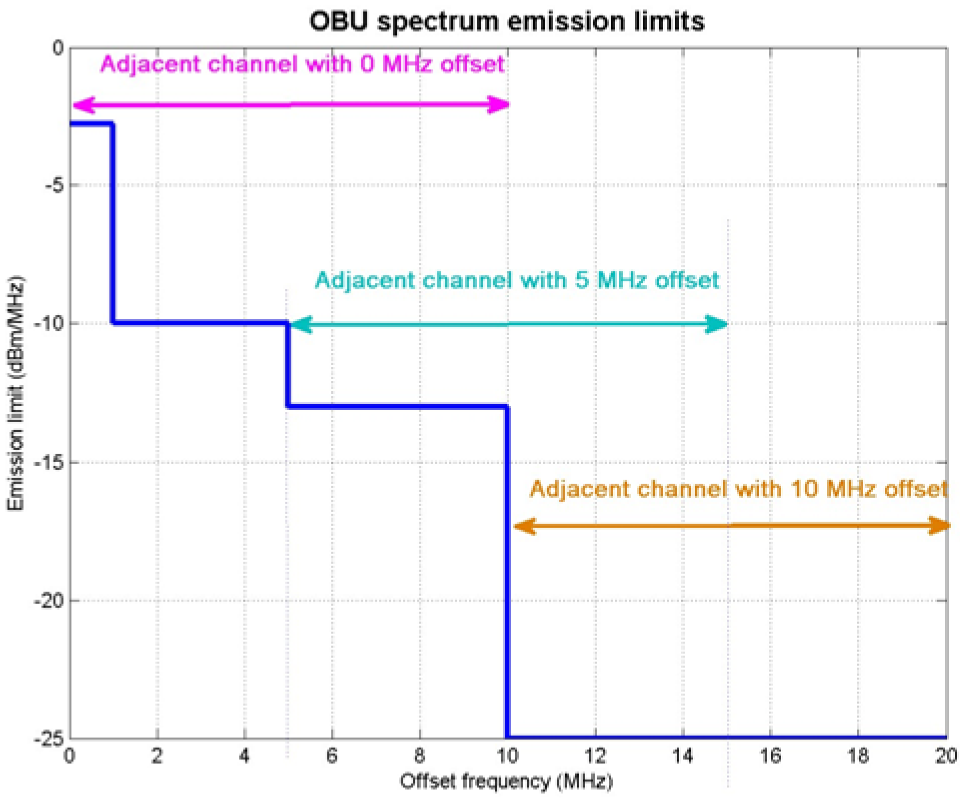


Figure 214: DA2GC spectrum emission limits for 10 MHz emission bandwidth

The total power in the 10 MHz adjacent channels is the following:

Table 77: DA2GC aircraft station emissions in adjacent bands

Frequency offset beween edges (MHz)	Power (in 10 MHz) (dBm)
0	0.715
5	-5.74
10	-15

A4.3.2 FS PARAMETER

The characteristics of the FS stations are extracted from revised ITU-R F.758-4 [49]

Table 78: Characteristics of the FS stations from revised ITU-R F.758-4

Frequency range (GHz)	3.600-4.200		3.700-4.200
Reference ITU-R Rec.	F.635		F. 382
Modulation	64-QAM	512-QAM	QPSK
Channel spacing and receiver noise bandwidth (MHz)	10,30, 40, 60, 80, 90	10,30, 40, 60, 80, 90	28, 29
Maximum Tx output power range (dBW)	−1	7	0
Maximum Tx output power density range (dBW/MHz)	−16…−11	−9.0	−15
Minimum feeder/multiplexer loss range (dB)	0	3	3
Maximum antenna gain range (dBi)	42	40	37
Maximum e.i.r.p. range (dBW)	41	44	38
Maximum e.i.r.p. density range (dBW/MHz)	26…31	28	23
Receiver noise figure (dB)	3	2	4
Receiver noise power density typical (=NRX) (dBW/MHz)	−141	−142	−140
Normalized Rx input level for 1 × 10–6 BER (dBW/MHz)	−114.5	−106.5	−126.5
Nominal long-term interference power density (dBW/MHz)	−141 + I/N	−142 + I/N	−140 + I/N

(3) There are two modulations (QPSK and 4FSK) described and QPSK is selected.

The formulas retained for the calculation of the antenna radiation patterns for FS-PP are the ones of the Recommendation ITU-R F.699 which is usually assumed in sharing studies when a single FS system is considered as victim/interferer.

For the antenna elevation, some countries reported an elevation range of 3 to 10 degree. Note that a range of maximum elevation angle from 15 to 30 degree has been reported in some countries in rare cases.

In order to stay in a neutral way and to simplify the calculation, an elevation angle of 0° for P-P FS links was retained to perform the studies. An azimuth direction of 45° was assumed.

Figure 215 shows the antenna gain towards an aircraft flying at 3000m and 13000m altitude considering a FS station which main beam is 45° in azimuth and 0° in elevation.

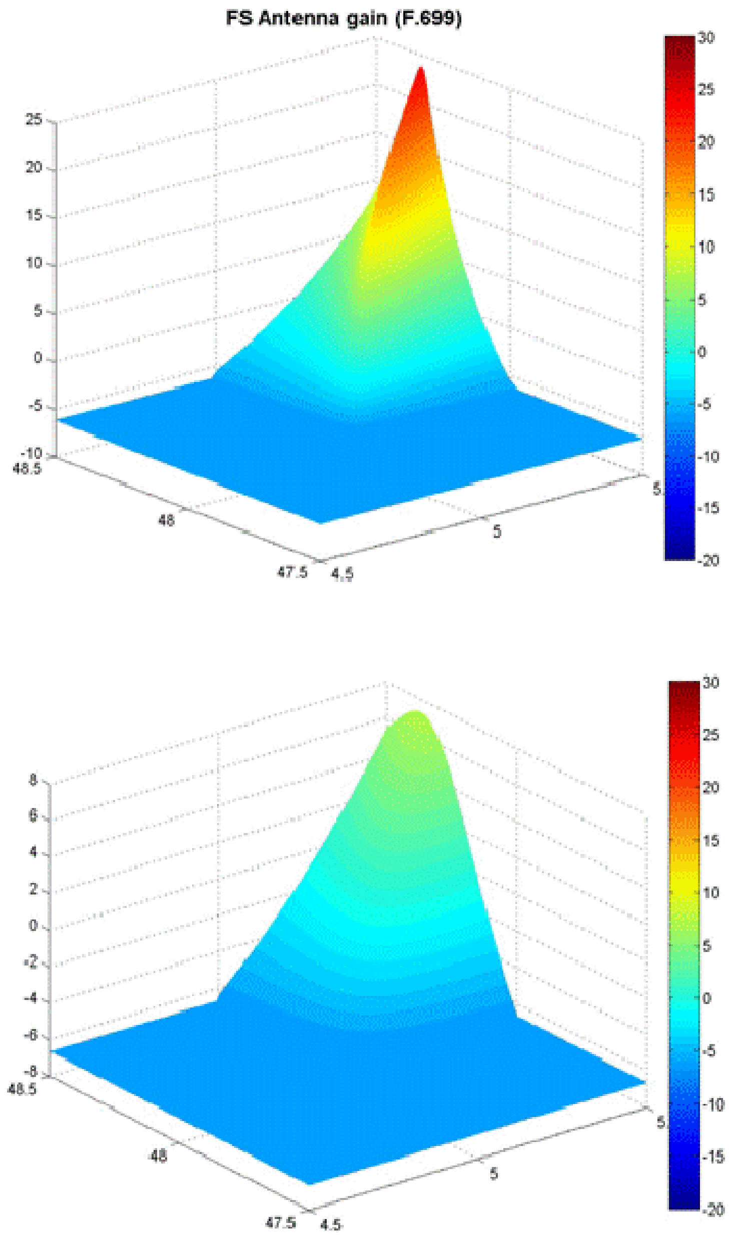


Figure 215: Antenna gain towards an aircraft located at 3000m altitude (top) and 13000m altitude (bottom) for a FS link of 45° azimuth and 0° elevation.

Regarding the I/N protection criteria, FS systems (for both P-P and P-MP systems) commonly adopt I/N ≤ □10 dB. It should be noted that ITU-R SG5 has recently confirmed this criterion in the draft revision of Recommendation ITU-R F.758-4 [49].

Furthermore it is important to highlight that the same characteristics for 3.6-3.8 GHz frequency band can be used for the 3.4-3.6 GHz band.

The OOB emissions for the Fixed Service are described in Annex 12 of Recommendation ITU-R SM.1541 [54]. The emission mask is represented in Figure 216 and is used for studies in adjacent bands with the FS station as interferer.

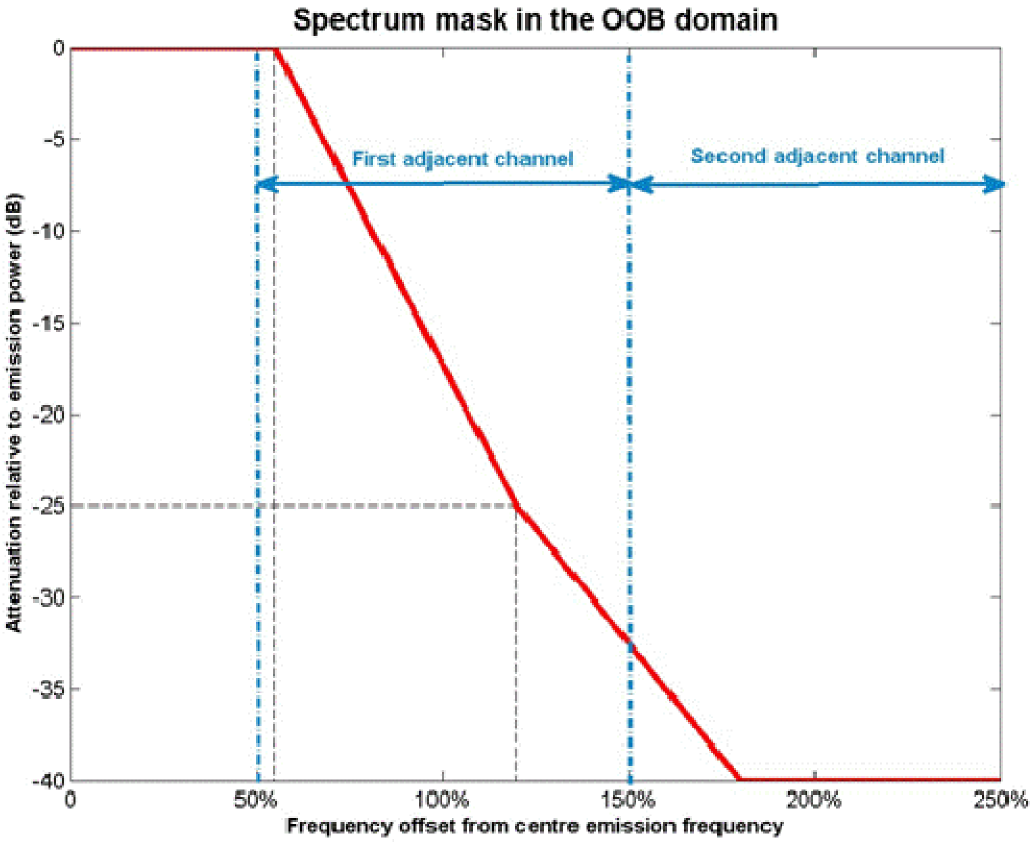


Figure 216: OOB emissions of the FS station

A4.3.3 METHODOLOGY

The aim is to study the compatibility between a FS station and a DA2GC AS located on board an aircaft in both directions (i.e DA2GC as an interferer and then as a victim).

The FS station is located at (G0, L0).

When considering the FS station as the victim and DA2GC AS as the interferer, the interference level arriving to the victim receiver from an aircraft at a given altitude H (from 3000 m up to 13 000 m) around the FS station location (i.e. 1° by 1° horizontal square around (G0,L0)) is calculated and mapped with Matlab as illustrated Figure 217.

When considering the FS station as the interferer and DA2GC AS as the victim, the calculations are very similar since the antenna gains remain unchanged for both systems. The only difference lies in the protection criterion and the emission levels.

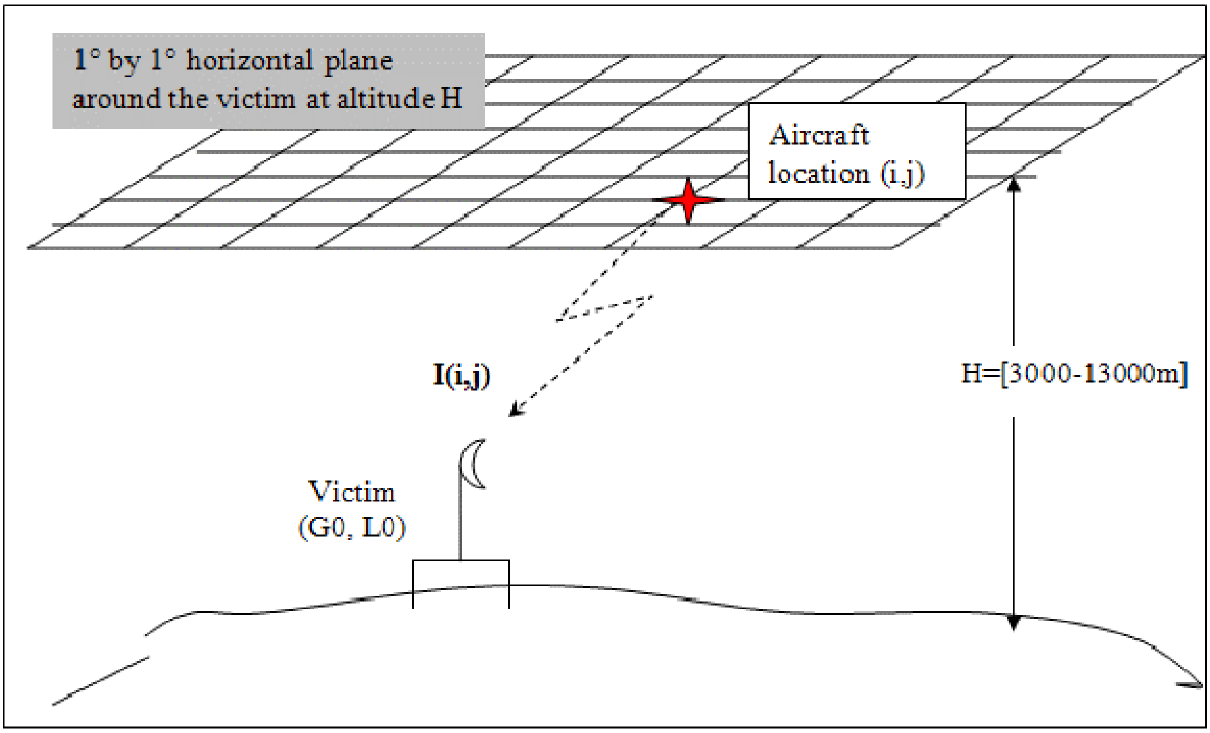


Figure 217: Illustration of the configuration used for interferences calculations

Negative aircraft elevations relative to the victim receiver are suppressed. For positive aircraft elevations, the free space loss attenuation is used.

A4.3.4 IMPACT FROM DA2GC AS ON FSS

A4.3.4.1 Co-channel case

By co-channel emission, it is meant that the DA2GC AS emission bandwidth covers the FS receiver bandwidth. Since the receiver bandwidth (10 MHz) is larger than the emission bandwidth (9 MHz), the power received by the FS station is the total emission of the DA2GC AS.

The maximum interference level is -111 dBm (-141 dBW) at the FS station receiver.

Considering a DA2GC AS with full power (40 dBm), the FS station I/N criterion is largely exceeded at 3000m and also at 13000m, whatever the aircraft position (see Figure 218)

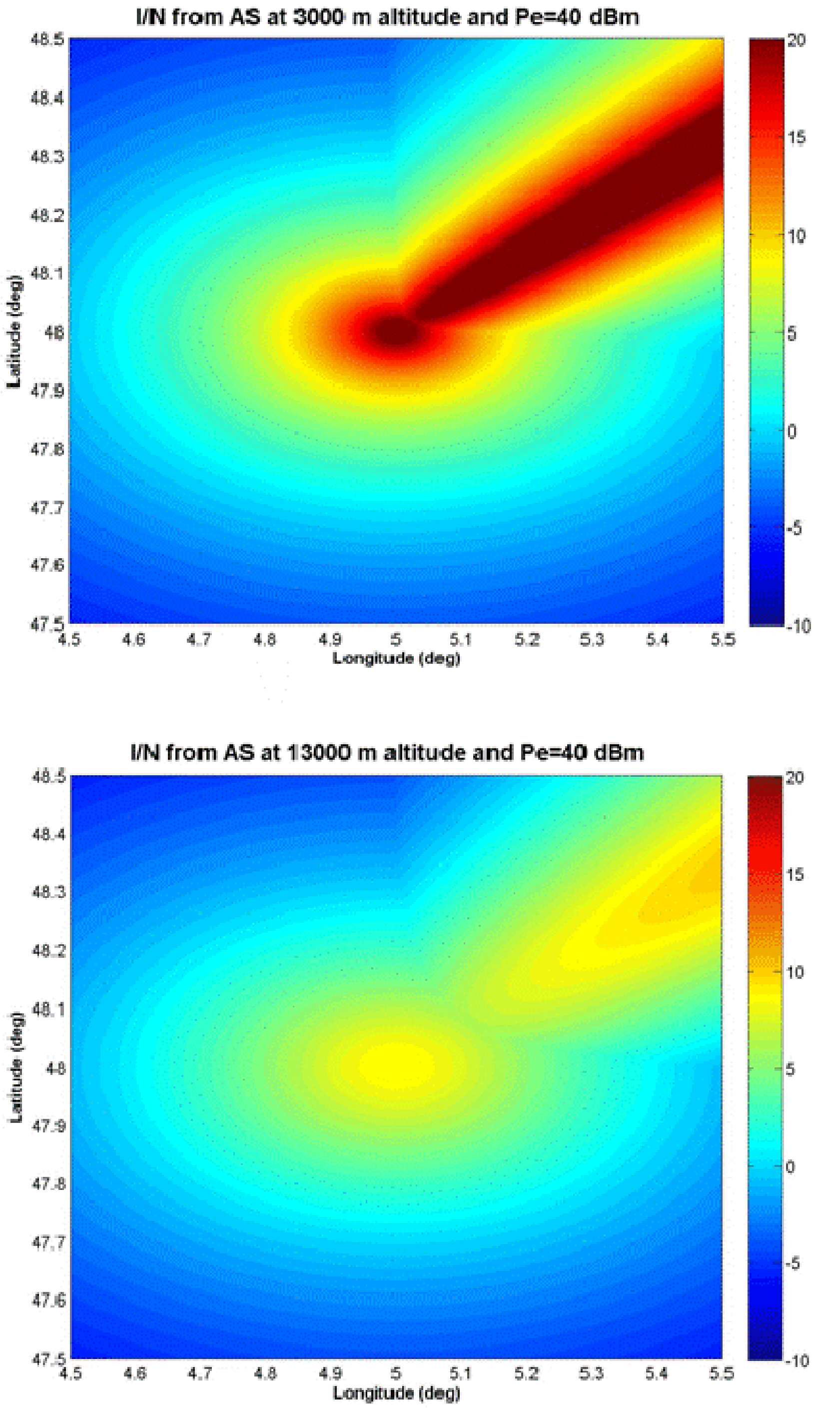


Figure 218: I/N level at the FS station from a DA2GC AS with 40 dBm emission power at 3000m (top) and 13000m (bottom) altitude.

When considering an aircraft at 3000m, interferences disappear when Pe is below 3 dBm and when considering an aircraft at 13000m, interferences disappear when Pe is below 20 dBm.

Full power emissions (40 dBm) from DA2GC-AS lead to interferences to the FS station whatever the aircraft altitude. To avoid interferences, the emission power of the DA2GC must not exceed 3 dBm.

A4.3.4.2 Emissions in adjacent bands

From Figure 213, the power in a 10 MHz receiver in the first adjacent channel is 0.715 dBm, which is below the value of 3 dBm identified above for the DA2GC AS to cause no interferences. Therefore no interferences are expected if the FS receiver is in the first adjacent channel.

A4.3.5 IMPACT FROM FSS ON DA2GC AS

A4.3.5.1 Co-channel case

The maximum e.i.r.p. for the FS station is 41 dBW at 0° elevation and 45° azimuth, which correspond to a power emission of 0 dBW (30 dBm).

The maximum interference level is -101.5 dBm at the DA2GC receiver.

Thus the FS emission power is 10 dB lower than the maximum AS emission power and the protection criterion is about 10 dB less stringent, therefore the interferences from the SF station to the AS exists. As Figure 219 shows, an aircraft AS at 3000m altitude will suffer from interferences when the aircraft crosses the SF main lobe azimuth or fly just above the FS station. At 13000m, interferences are observed in the FS main lobe for elevations lower than 0.285°.

Interferences from the FS station to the DA2GC AS occur when the aircraft is in the same azimuth as the FS link (even at 13000m altitude).

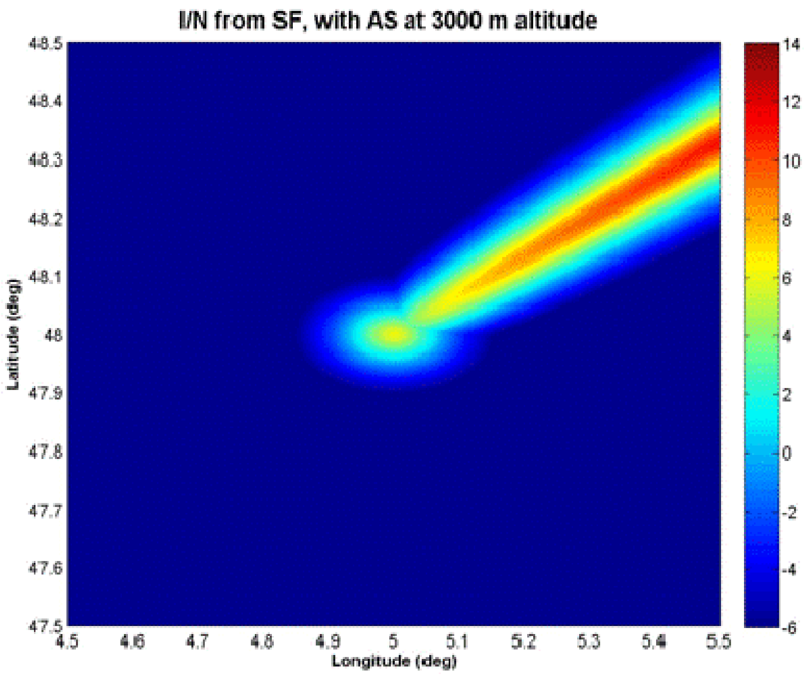


Figure 219: I/N level at the DA2GC AS at 3000m altitude from a FS station

A4.3.5.2 Emissions in adjacent bands

Considering the OOB FS emission mask of Figure 3, the power received in the first adjacent channel of 10 MHz is about 22 dBm. This leads to interferences at the DA2GC-AS receiver in the FS link azimuth for aircraft altitudes lower than 6500m. Figure 220 show that the I/N criterion of -6 dB is exceeded when the aircraft crosses the FS link azimuth at 6000m altitude. For altitudes higher than 6500m, no interferences are observed.

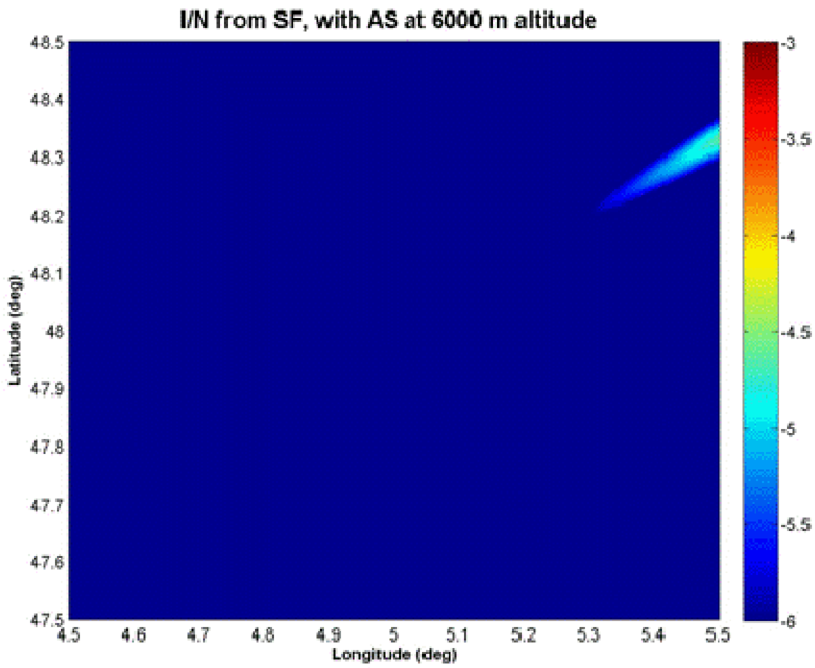


Figure 220: I/N level at the DA2GC AS at 6000m altitude from a FS station

A4.3.6 CONCLUSIONS

The scenarios studied here show that coexistence in co-channel is not possible. Co-existence with an offset of 10 MHz (first adjacent channel) is possible, but interferences from FS link to DA2GC-AS may occur when aircraft is in the same azimuth as FS links.

ANNEX 5: CAPACITY ESTIMATIONS FOR BROADBAND DA2GC BASED ON LTE

This study tries to investigate what capacity and throughput a BDA2GC system based on LTE can achieve in a rural deployment scenario. The calculations are based on the Shannon bound with LTE specific corrections for effective frequency usage, overhead and pilot tones.

Possible uplink/downlink configurations for a LTE-TDD system are summarized in Table 79.

Table 79: LTE-TDD uplink/downlink configurations.
D means downlink, U means uplink and S is the switch between downlink and uplink and consists of three parts, DwPTS(downlink part), GP(guard period) and UpPTS(uplink part)

Uplink/downlink configuration	Downlink-to-Uplink Switch-point periodicity	Subframe number									
		0	1	2	3	4	5	6	7	8	9
0	5 ms	D	S	U	U	U	D	S	U	U	U
1	5 ms	D	S	U	U	D	D	S	U	U	D
2	5 ms	D	S	U	D	D	D	S	U	D	D
3	10 ms	D	S	U	U	U	D	D	D	D	D
4	10 ms	D	S	U	U	D	D	D	D	D	D
5	10ms	D	S	U	D	D	D	D	D	D	D
6	5 ms	D	S	U	U	U	D	S	U	U	D

The different DwPTS, GP and UpPTS configurations are in the normal case:

Table 80: Normal LTE-TDD uplink/downlink configurations.
The downlink part (DwPTS) can be 3, 9, 10, 11 or 12 symbols.
Depending on the DwPTS value the guard period (GP) and the uplink can differ

	DwPTS								
	12	11		10		9		3	
GP	1	1	2	2	3	3	4	9	10
UpPTS	1	2	1	2	1	2	1	2	1

Capacity estimations are based on different uplink/downlink configurations as well as different configurations of the special subframe S in order to establish both a best case and a worst case configuration scenario.

- **The Shannon bound**

The channel capacity is the tightest upper bound on the amount of information that can be reliably transmitted over a communications channel in a given scenario (bandwidth, noise and interference).

For a SiSo (single input, single output) system the Shannon bound is (in bits per Hertz). All equations are in logarithmic scale (dB)

$$SiSo = log_2\left(1 + 10^{S/_{10\times N}}\right)\ \left[\frac{Bit}{Hz}\right]$$

For multi antenna systems the theoretical increase in SNR is maximum = $N_{receive} \times N_{transmit}$ for none correlated paths.

In figure 1 the Shannon bound for different antenna configurations are depicted. Perfect orthogonality is assumed.

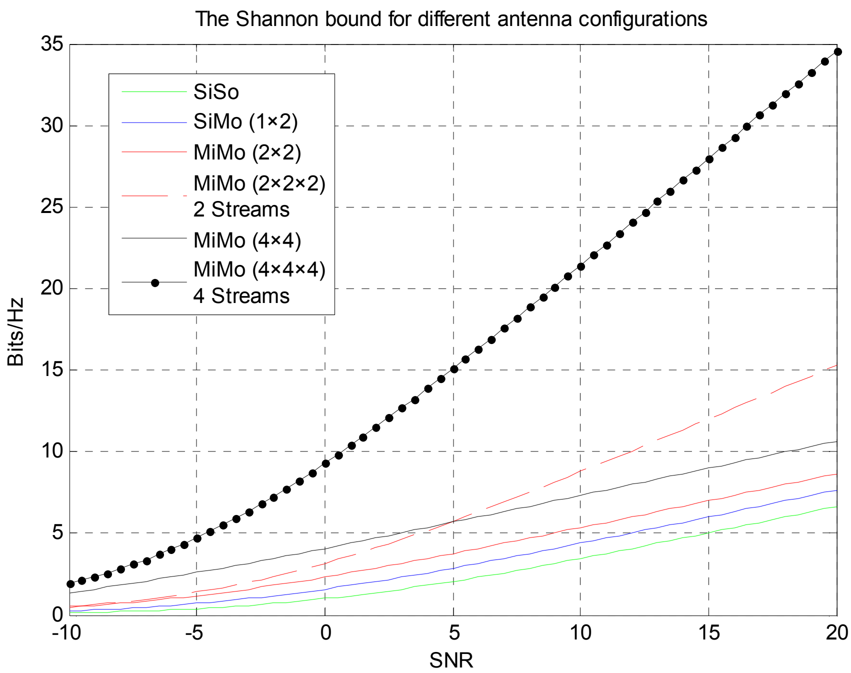


Figure 221: The Shannon bound from SiSo up to 4×4×4 MiMo (4 streams).

- **Transport capacity of LTE**

From a radio point of view, LTE is very close to the Shannon bound and in the following calculations LTE is assumed to have a channel capacity that is only limited by the Shannon bound. This slightly overestimates the LTE capacity but is accurate enough for this study.

- **Spectral efficiency**

The spectral efficiency of a LTE system can be calculated as

$$Spectral\ efficiency = \frac{BW}{ChBW}$$

Where BW is the bandwidth and ChBW is the channel bandwidth.

BW is calculated by multiplying the number of resource blocks with the subcarrier spacing and the number of subcarriers per resource block.

That is

$$SE = \frac{NRB \times SCS \times RB}{ChBW}$$

For a 20 MHz (ChBW) LTE system:

NRB (**N**umber of **R**esource **B**locks) = 100

SCS (**S**ub **C**arrier **S**pacing) = 15×10^3

RB (Number of subcarriers per **R**esource **B**lock)

Hence the spectral efficiency of a 20 MHz LTE system is 0,90.

- **Time domain structure**

With normal prefix structure a LTE system transmits 14 OFDM symbols per subframe. With extended prefix structure 12 OFDM symbols are transmitted in one subframe. Each symbol is nominally (1/spectral efficiency).

The efficiency in the time domain can be calculated as

$$TD\ efficiency = \frac{Number\ of\ OFDM\ symbols\ per\ frame}{Length\ of\ subframe \times spectral\ efficiency}$$

The length of a subframe is 1 ms, the number of OFDM symbols are 14 or 12 depending on the structure (normal structure gives 12 OFDM symbols per subframe). The spectral efficiency can be calculated as explained in the previous section.

For a LTE system with spectral efficiency of 0,9 that is transmitting 14 OFDM symbols each subframe the TD efficiency is

$$TD\ E = \frac{14}{1 \times 10^{-3} \times 0{,}9} = 0{,}93$$

- **Pilot tones**

During one slot (7 symbols, 0,5 ms) 4 reference symbols are transmitted in each resource block. This leads to a reduction of 4/(12*7) for a SiSo system.

For MiMo systems the overhead is increased due to the fact that only one antenna can send a reference signal on each carrier at a specific time. This gives 4×2×2 occupied slots and a reduction of 2×2×4/(12×7×2) for a 2 MiMo system.

A 4 MiMo system has a reduction of (4×2+2×2) ×4/(12×7×4).

- **Control signaling overhead**

In each subframe the 1-3 first symbols are used for control signaling, since there is no mixing of control signaling and data in an OFDM symbol. The more users in a cell, the more control signaling is needed, for the BDA2GC system only 1 symbol for control signaling is assumed.

This gives an available payload of $\frac{14-1}{14}$.

- **Uplink/downlink configuration**

If uplink/downlink configuration number 1 (in Table 79) is used, 4 out of 10 subframes are used for downlink. 2 subframes are switch subframes and 4 are used for uplink. In the switch subframes 3-12 symbols can be used for downlink transmission. This gives a downlink efficiency of

((4×14+2×3)/(10×14) to (4×14+2×12)/(10×14) = 44 to 57 [%]

- **Capacity for a LTE system as a function of SNR**

A LTE system (considered to be on the Shannon boundary[8]) that is subject to the above reductions the result (as a function of Signal to Noise ratio) have a channel capacity that is depicted below, this capacity includes the payload header that needs to be removed before the “user data capacity” is calculated.

[8] Intentional overly positive assumption

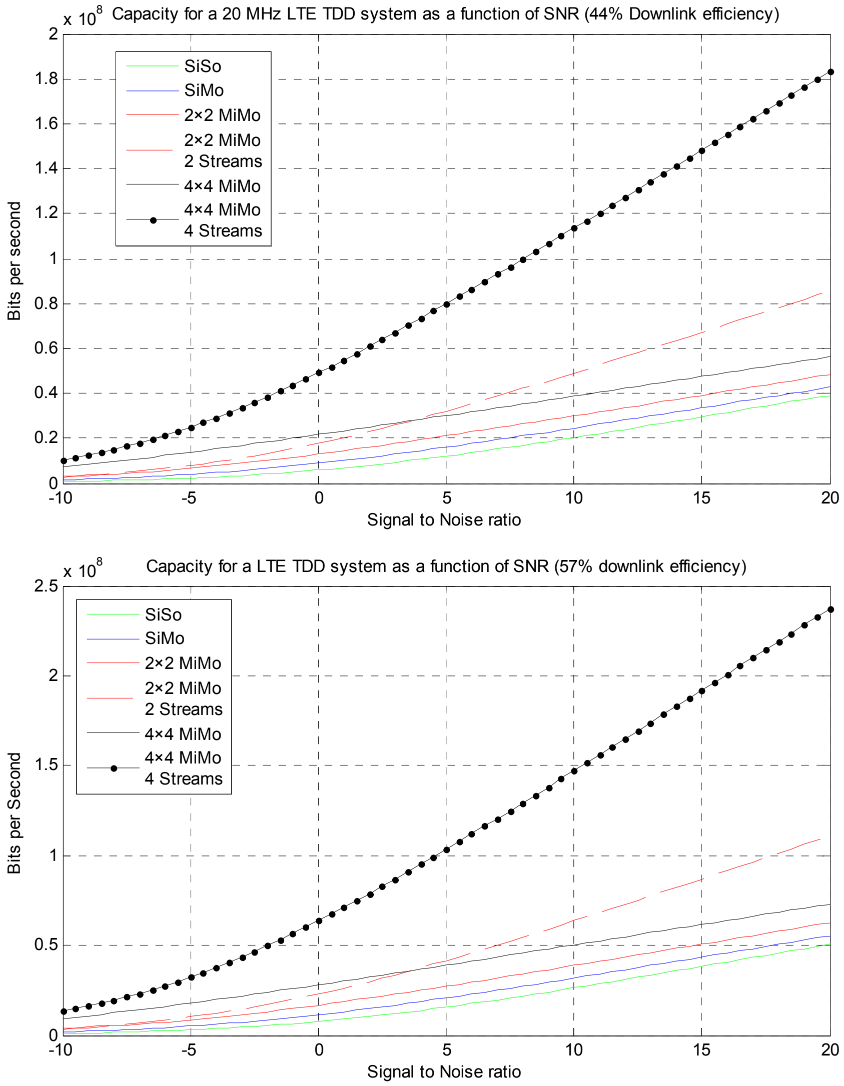


Figure 222: Channel capacity for a 20 MHz LTE TDD with different uplink/downlink configurations that gives a downlink efficiency of 44 % and 57 %.

A5.1.1 Sharing between RLAN and BDA2GC in the 2.4 GHz band.

In the license exempt 2,4 GHz band numerous transmitters are deployed, the most common are RLAN and Bluetooth. RLAN has been chosen as the aggressor in this sharing study.

A5.1.1.1 Deployment scenario of BDA2GC Base stations according to ETSI TR 103 054.

A BDA2GC cell radius is 150 km and the base station e.i.r.p. is 55 dBm.

The RLAN density is 50 RLAN per square km for the rural case. It is assumed that RLAN frequencies are equally spaced in the 2.4 GHz band, i.e. ¼ of the RLAN is transmitting co-channel with the BDA2GC system, resulting in an effective density of 12.5 transmitters per square kilometer.

- *Rural case*

Assuming free space attenuation between the BDA2GC terminal (aircraft) and both the BDA2GC base station and all RLANs. The RLANs are considered to be equally spaced in a circle with 150 km radius. All RLANs are assumed to transmit with 20 dBm (e.i.r.p.)

The aggregated co-channel interference from RLAN to the BDA2GC terminal is plotted below as a function of radius, as can be seen in the picture the aggregated interference from RLAN is asymptotically approaching -57 dBm.

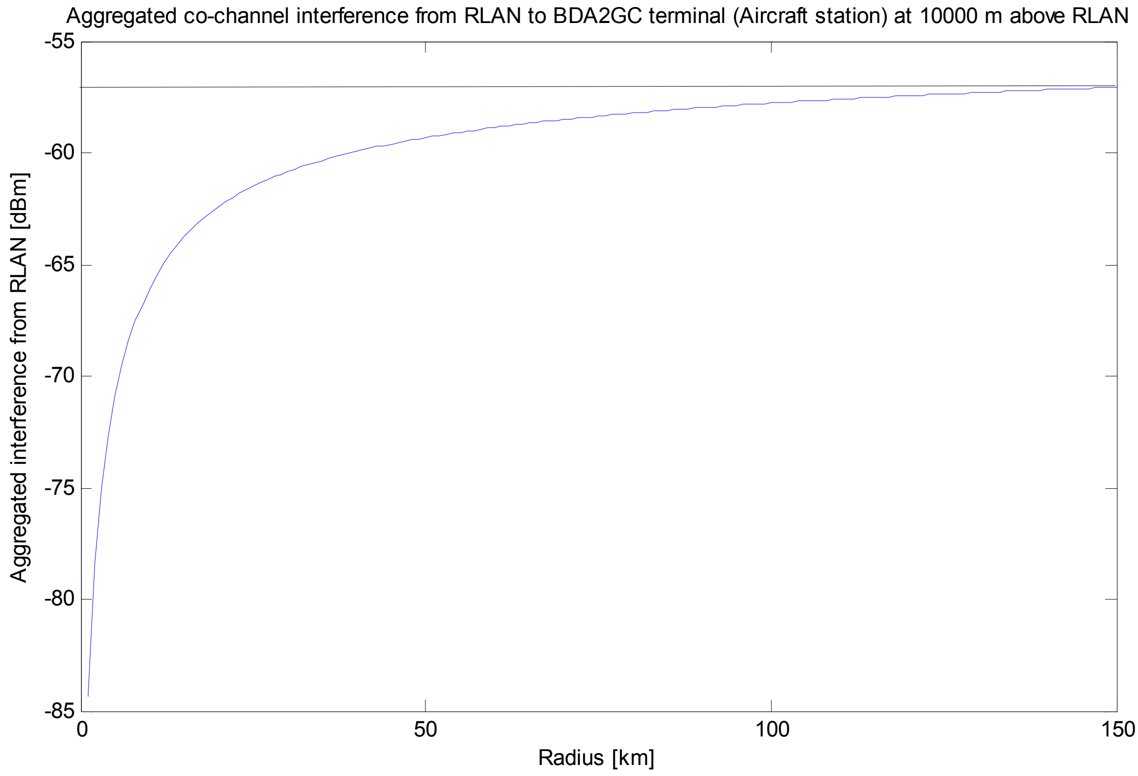


Figure 223: Aggregated co-channel interference from RLAN to AS

Interference from adjacent bands as well as the channel leakage is assumed to be magnitudes lower than the co channel interference and is therefore not part of the study.

One can easily see that the aggregated interference is asymptotically reaching -57 dBm. As this value is roughly 40 dB higher than the internal noise in the BDA2GC receiver the internal noise is not a limiting factor in the sharing between RLAN and BDA2GC and thus the Signal to Interference ratio will be used in the channel capacity calculations.

- *BDA2GC channel capacity in the rural case, aircraft on cell edge*

The BDA2GC base station, when transmitting 55 dBm to an aircraft on 10 000 m height at the cell edge, is approximately 150 km away from aircraft and will give a received power of 55 (TX e.i.r.p.) – 144 (Free space loss) = -89 dBm.

Since the aggregated co channel interference is -57 dBm /20 MHz the signal to interference ratio is -32 dBm.

When the signal to interference ratio is used as SNR in the Shannon model one can see that the maximal channel capacity is almost zero.

- *Interference from other base stations*

On the border between two cells a terminal, belonging to one of the cells, will experience interference from the other cell. This interference will increase the interference and thereby influence the maximal throughput.

- *Network scheduling*

The scheduler controls the allocation of available resources among users at each given time. Depending on the chosen scheduling algorithm and radio environment, a terminal (in a multi terminal environment) is given a ratio of the available resources.

A5.1.1.2 Deployment scenario of BDA2GC Base stations according to ETSI TR 101 599.

A BDA2GC cell radius is 90 km and the base station e.ir.p. is 48 dBm.

The RLAN density is 50 RLAN per square km for the rural case. It is assumed that RLAN frequencies are equally spaced in the 2.4 GHz band, i.e. ¼ of the RLAN is transmitting co-channel with the BDA2GC system, resulting in an effective density of 12.5 RLAN transmitters per square kilometer. At any instant, half of the RLAN's is considered to be transmitting. This gives a density of RLAN's that can interfere with the aircraft station of 6,25 RLAN's per square kilometer.

- *Rural case*

Assuming free space attenuation between the BDA2GC terminal (aircraft) and both the BDA2GC base station and all RLANs. The RLANs are considered to be equally spaced in a circle with 150 km radius. All RLANs are assumed to transmit with 20 dBm (e.i.r.p.)

- *Interference from RLAN's in a rural scenario.*

In order to investigate the effect from the aggregated interference from all (from the aircraft visible) RLANs the aircraft station beamforming antenna must be taken into account. Since the system uses beamforming the received interfering power is depending on the angle (as seen from the aircraft station) between the (wanted) signal from the base station and the interfering signal from each RLAN. All affecting RLANs in each square kilometer is (6,25 RLAN tranmitters, see above), for computational reasons, replaced with one transmitter (with increased power 6,25×20 dBm = 28 dBm) in the center of each square kilometer. This does not affect the outcome of the following calculations.

The interference is calculated in the following way:

1. A position for the base station is fixed, and the angle (and thereby the antenna gain), a1, b1, c1 etc, to each of the combined transmitters (in each square kilometer) is calculated (assuming free space loss) and the cumulative interfering power is stored as belonging to this position.

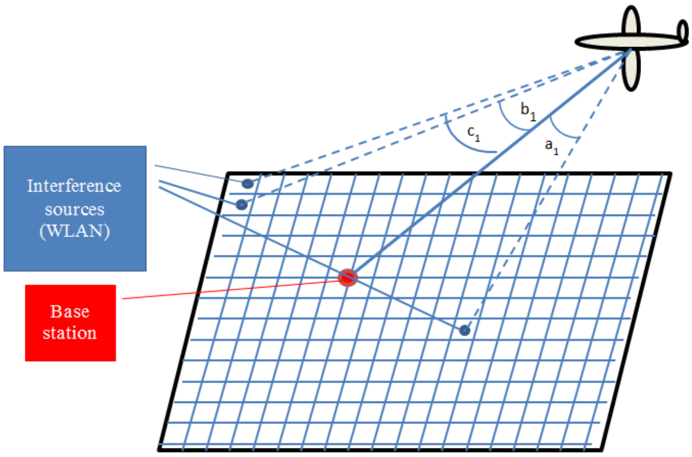


Figure 224: Illustration where the position for the base station is fixed

2. The base station position is moved to another position and the process in 1. is repeated.

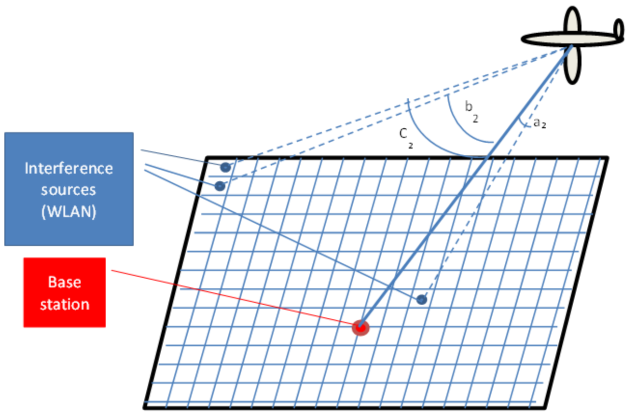


Figure 225: Illustration where the position for the base station is moved

3. This is repeated for all possible base station positions, giving the next Figure

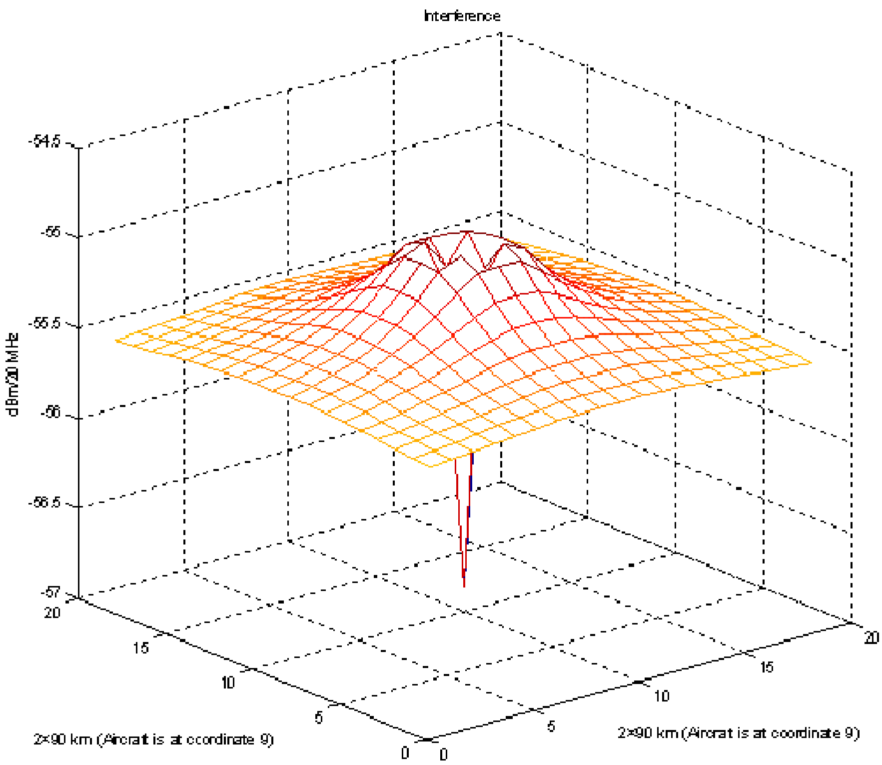


Figure 226: Signal strength from different base station positions relative to the aircraft station and resulting signal to interference ratio.

The received signal strength from each base station position is calculated using the same free space assumption as above, giving the Figure below.

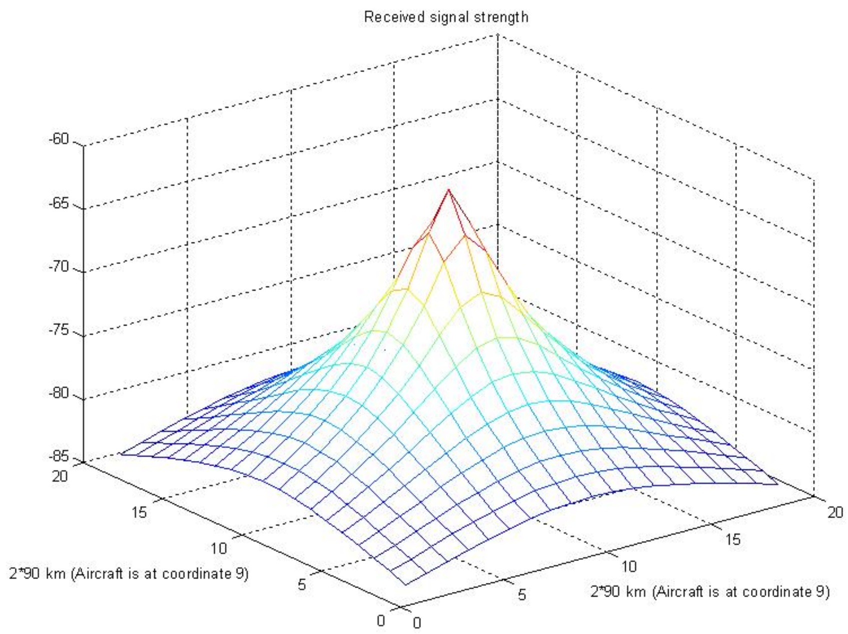


Figure 227: Received signal strength from each base station position (Free space)

The resulting signal to interference ratio is:

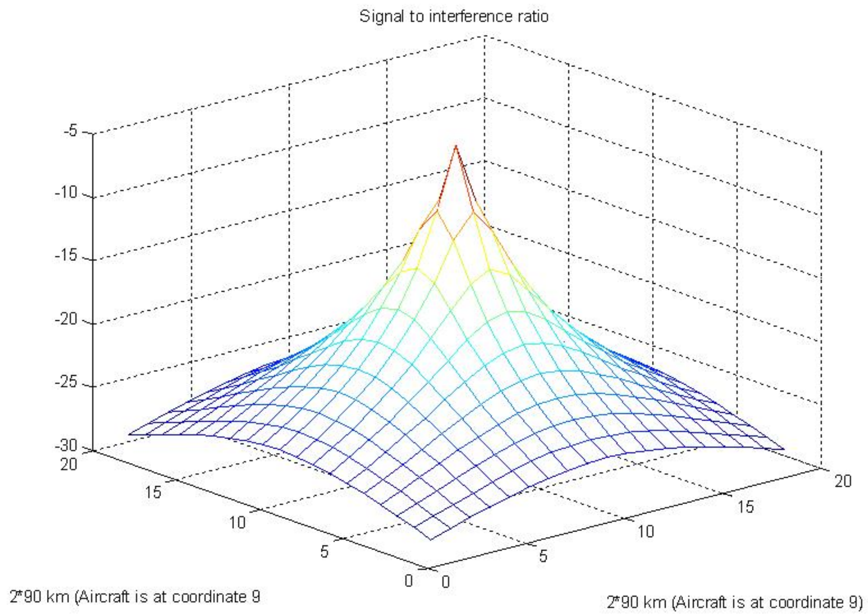


Figure 228: resulting signal to interference ratio (Free space)

The best signal to interference ratio is achieved when the base station is located directly under the aircraft, in this position there are two conditions that are maximizing the signal to interference ratio;
1. the distance between aircraft station and ground station is minimized and
2. the main lobe foot print is also minimized compared to all other main lobe directions. The signal to interference ratio is however very low even when the base station is located directly under the aircraft, -5 dB.

Interference from adjacent bands as well as the channel leakage is assumed to be magnitudes lower than the co channel interference and is therefore not part of the study.

- BDA2GC channel capacity in the rural case.

The BDA2GC base station, when transmitting 25+23 = 48 dBm (e.i.r.p.) to an aircraft on 10 000 m height at the cell edge, is approximately 90 km away from aircraft and will give a received power of 48 (TX e.i.r.p.) + 10 dB (antenna gain in aircraft receiver) – 139 (Free space loss) = -81 dBm.

The aggregated co channel interference from all RLANs (when the aircraft is on the cell edge) is -55 dBm /20 MHz the signal to interference ratio is -36 dBm When the aircraft is right above the base station the received signal is 48 dBm (e.i.r.p.) + 10 dB (antenna gain in aircraft receiver) – 120 dB = -62 dBm. The interference seen from the aircraft is -57 dBm. This gives a signal to interference ratio of -5 dBm. When the signal to interference ratio is used as SNR in the Shannon model one can see that the maximal channel capacity is almost zero.

- Interference from other base stations

On the border between two cells a terminal, belonging to one of the cells, will experience interference from the other cell. This interference will increase the interference and thereby influence the maximal throughput.

- Network scheduling

The scheduler controls the allocation of available resources among users at each given time. Depending on the chosen scheduling algorithm and radio environment, a terminal (in a multi terminal environment) is given a ratio of the available resources.

A5.1.2 Conclusion on DA2GC according to ETSI TR 103 054

The interference produced by RLANs in the 2400 to 2483.5 MHz frequency range will severely reduce the throughput in the BDA2GC system and for this reason the 2.4 GHz band is not viable for BDA2GC deployment.

A5.1.3 Conclusion on DA2GC according to ETSI TR 101 599 [30]

The interference produced by RLANs in the 2400 to 2483.5 MHz frequency range will severely reduce the throughput in the BDA2GC system even when the BDA2GC system is equipped with a beamforming antenna and for this reason the 2.4 GHz band is not viable for BDA2GC deployment.

ANNEX 6: LIST OF REFERENCE

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