CEPT ECC
Electronic Communications Committee

ECC Report 370

Sharing and Compatibility Studies of Microwave Security Scanners (MWSSc) in the 3.6-10.6 GHz frequency band with incumbent radio services

approved 30 January 2026

0 EXECUTIVE SUMMARY

The study evaluated the coexistence of Microwave Security Scanners (MWSSc) in the 3.6-10.6 GHz frequency band with incumbent radio services.

Assumptions related to the deployment of UWB devices made for this report are specific to Security Scanners.

Results show that operation of MWSSc is feasible if its emission values towards victim systems remain limited (to -60 dBm/MHz for outdoor and -41.3 dBm/MHz for indoor deployment) while additional mitigations are required for specific scenarios.

Emission values mentioned below are assumed to be measured during 1 ms outside of the scanner (Mean *e.i.r.p.* spectral density).

Studies in the report and the derived values which are shown in both tables below do already consider aggregation effects of multiple MWSSc emissions.

No sharing studies between MWSSc and MFCN (including IMT) were conducted.

0.1 MWSSC OPERATING OUTDOORS AT -60 DBM/MHZ

Amateur, fixed, and Earth Exploration Satellite Services, can tolerate emissions from outdoor MWSSc operating at -60 dBm/MHz without harmful interference.

Studies show that the radioastronomy, the aeronautical mobile, the radiolocation, and aeronautical radionavigation services can be interfered with outdoor MWSSc targeted emissions of -60 dBm/MHz.

Table 1 summarises some mitigation measures that ensure protection of these services and its applications from MWSSc. This mitigation shall provide sufficient attenuation of the MWSSc radiation in direction of the location of the services to be protected. The MWSSc need to be installed and maintained by professional trained personnel in order to ensure professional installation and consideration of the necessary mitigation techniques. It is expected that typical installation of MWSSc can easily fulfil at least one mitigation listed.

Table 1: Overview of mitigations required to protect services/applications in specific scenarios from outdoor MWSSc *e.i.r.p.* of -60 dBm/MHz

Victim service / application	Mitigation needed	M1 (h separation)	M2 (v separation)	M3 (orientation)	M4 (clutter / shielding)
RAS	14.3 dB at 2.1 km distance	13.8 km 2.1 km, if M3 applied No separation needed, if both M3 and M4 are applied		Opposite orientation (separation reduces to ~2.1 km)	NLOS due to clutter or shielding (e.g. roof, wall)
Radiolocation (weather radars)	8.4 dB	1.5 km	> 5.4 m	Opposite orientation	
ANRS (altimeter)	11.9 dB towards the sky	0.1 km lateral to runway/route 6.3 km aligned to runway/route	> 300 m		

Victim service / application	Mitigation needed	M1 (h separation)	M2 (v separation)	M3 (orientation)	M4 (clutter / shielding)
ARNS (On-board weather radar)	4.2 dB	~ 0.6 km		Opposite orientation	
ARNS (Airport surface detection equipment (ASDE))	11.7 dB	~ 0.8 km	> ~70 m (based on the 30 m and 100 m results)	Opposite orientation	

- M1 considers horizontal separation as mitigation technique.
- M2 considers vertical separation as mitigation technique.
- M3 considers the orientation of the MWSSc as mitigation technique. Due to a misaligned orientation of the MWSSc with respect to the victim service, an additional attenuation of approximately 14.3 dB is assumed to be achievable, corresponding, for example, to a 90° rotation relative to the entrance of the scanning area. This accounts for the MWSSc inherent shielding and housing in specific directions.
- M4 considers additional clutter/shielding as mitigation technique. Additional attenuation would appear if NLOS conditions apply or when the MWSSc is placed inside of a thermal efficient building (because calculations were done under LOS & traditional building conditions).

0.2 MWSSC OPERATING INDOORS AT -41.3 DBM/MHZ

Studies show that the radioastronomy, the aeronautical mobile, the radiolocation, aeronautical radionavigation, amateur and fixed services can be interfered by indoor MWSSc radiation operated with targeted emissions of -41.3 dBm/MHz average *e.i.r.p.*

Table 2 summarises some mitigation measures that ensure protection of these services and its applications from MWSSc. This mitigation shall provide sufficient attenuation of the MWSSc radiation in direction of the location of the services to be protected. The MWSSc need to be installed and maintained by professional trained personnel in order to ensure professional installation and consideration of the necessary mitigation techniques. It is expected that typical installation of MWSSc can easily fulfil at least one mitigation listed.

When deployed inside thermal efficient buildings as defined Recommendation ITU-R P.2109 [9], MWSSc benefit from sufficient attenuation to ensure the protection of incumbent services. Except for RAS, where a minimum separation distance of ~2.6 km is needed then.

On the other hand, the risk of interference increases significantly, if MWSSc operated at -41.3 dBm/MHz are accidentally operated outdoors (e.g. MWSSc placed in close proximity to building entrances, where radiation is expected outdoors without attenuation of walls).

Table 2: Overview of mitigations required to protect services/applications in specific scenarios from indoor (except installations close to building entrances) MWSSc *e.i.r.p.* of -41.3 dBm/MHz

Victim service / application	Mitigation needed	M1 (h separation)	M2 (v separation)	M3 (orientation)	M4 (clutter/shielding)
RAS	14.3 dB at 2.9 km distance	15.7 km 2.9 km, if M3 applied No separation needed, if both M3 and M4 are applied		Opposite orientation (separation reduces to 2.9 km)	NLOS due to clutter or shielding (e.g. thermal efficient building)

Victim service / application	Mitigation needed	M1 (h separation)	M2 (v separation)	M3 (orientation)	M4 (clutter/shielding)
FS	1.1 dB	Closer than 1.2 km Farther than 2.4 km	> 15 m	Opposite orientation	
AS*	2.2 dB	~ 0.3 km	> 8 m	Opposite orientation	
Radiolocation (weather radars)	9.6 dB	2 km	> 5.4 m	Opposite orientation	
Radiolocation* (military radars)	2.2 dB	0.4 km	> 5 m	Opposite orientation	
ARNS* (altimeter)	14.1 dB towards the sky	0.1 km lateral to runway/route 6.3 km aligned to runway/route	> 300 m		
ARNS (On-board weather radar)	10.3 dB	~ 1.5 km		Opposite orientation	
ARNS (Airport surface detection equipment (ASDE))	13.4 dB	~ 1.0 km	> ~80 m (based on the 30 m and 100 m results)	Opposite orientation	

Note 1: results for traditional buildings are derived from -60 dBm/MHz outdoor scenario. Indoor operation at -41.3 dBm/MHz and assuming additional losses of 16.5 dB in the C-band and additional 17.6 dB in the X-band lead to comparable results. For the C-band interference would increase by 2.2 dB, for the x-band interference would increase by 1.1 dB.

- M1 considers horizontal separation as mitigation technique.
- M2 considers vertical separation as mitigation technique.
- M3 considers the orientation of the MWSSc as mitigation technique. Due to a misaligned orientation of the MWSSc with respect to the victim service, an additional attenuation of approximately 14.3 dB is assumed to be achievable, corresponding, for example, to a 90° rotation relative to the entrance of the scanning area. This accounts for the MWSScs inherent shielding and housing in specific directions.
- M4 considers additional clutter/shielding as mitigation technique. Additional attenuation would appear if NLOS conditions apply or when the MWSSc is placed inside of a thermal efficient building (because calculations were done under LOS & traditional building conditions).

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LIST OF ABBREVIATIONS

Abbreviation	Explanation
ATR	Automatic Threat Recognition
BLA	beam look angles
BNetzA	Federal Network Agency (Germany)
CEPT	European Conference of Postal and Telecommunications Administrations
ECA	European Common Allocation
ECC	Electronic Communications Committee
e.i.r.p.	equivalent isotropically radiated power
GGRF	Global Geodetic Reference Frame
IMT	International Mobile Telecommunications
LiDAR	Light Detection And Ranging
MFCN	Mobile/Fixed communications networks
MIMO	Multiple Input Multiple Output
MLC	Minimum Coupling Loss
MWSSc	Microwave Security Scanner
PAX	Person to be checked by the Security Scanner/Microwave Security Scanner
RAS	Radio Astronomy Services
RF	Radio Frequency
SRS	Space Research Service
SRTM	Shuttle Radar Topography Mission
SSc	Security Scanner
SWE	Snow Water Equivalent
UWB	Ultra-Wide Band
VLBI	Very Long Baseline Interferometry

1 INTRODUCTION

This Report examines the potential impact of operating new Low Frequency Microwave Security Scanners (MWSSc) using Ultra-Wideband (UWB) technology. These scanners operate on a non-protected, non-interference basis in the frequency range from 3.6-10.6 GHz.

This Report includes:

- Sharing studies between MWSSc and existing radio systems in the 3.6-10.6 GHz band;
- Compatibility studies in the adjacent 10.6-10.7 GHz band.

The studies are based on the emission characteristics described in SRdoc ETSI TR 103 730. In addition, a reduced operating frequency range of 3.6-10.6 GHz is considered, along with scenarios using a mean *e.i.r.p.* spectral density (measured over 1 ms) that differs from the value of -41.3 dBm/MHz given in the SRdoc.

2 SYSTEM DESCRIPTION OF MICROWAVE SECURITY SCANNERS IN 3.6-10.6 GHZ

2.1 INTRODUCTION

A Security Scanner (SSc) is a device that detects objects on a person's body without the need of physical contact.

SScs have seen use in security screening at airports for several years now. Their success is based on the non-ionizing nature of microwaves as well as their strong interaction with potentially dangerous materials. Combined with microwave imaging techniques, SScs have proven their fitness to provide security for both known and previously unknown threats.

Besides the established airport security application, SScs have seen an increased demand also in non-aviation markets such as loss prevention or securing soft targets (i.e. public events). These new applications are related to the existing ones but differ in some critical aspects. As a consequence, new technical approaches are required. MWSScs provide the performance to address those requirements.

The MWSSc considered in this Report operates in the frequency band between 3.6 GHz and 10.6 GHz within the centimetric-wave range. This allows them to perform better in rough environments. At the same time MWSScs are also required to detect and locate objects on the human body. In order to differentiate between benign and dangerous/target objects a focused microwave image in range and cross-range is required. High absolute and fractional bandwidths, combined with large antenna arrays, are the consequences.

An advantage is the "walk through" feature. During operation, people can walk through the scanner in a normal manner without standing still or taking any special pose. This speeds up the scanning process and throughput of persons / hour.

An example for an MWSSc and a measurement result for this system, with suspected threats marked, is presented in Figure 1.



Figure 1: Rohde & Schwarz®QPS Walk2000 System (left) and exemplary measurement result with suspected threats marked in orange (right)

2.2 BASIC OPERATION PRINCIPLE OF A MWSSC

MWSScs use a large number of transmitters and receivers to create an as large as possible physical antenna aperture. More than 100 of each transmitters and receivers might be employed to meet a specific applications requirement. This is because cross-range and range resolution of these types of systems depend significantly on the size of the aperture.

The workflow of an MWSScs can be summarised as follows:

a) Activate transmitters and receivers in a controlled and synchronised manner;
b) Collect the reflected signals for each transmitter with each receiver;
c) Apply a calibration to the reflected signals;
d) Reconstruct the microwave image;
e) Search for threats on the microwave image via an ATR (Automatic Threat Recognition);
f) Display the ATR's result to an operator;
g) Depending on the result, let PAX (Person to be checked by the SSc/MWSSc) pass the check point or take appropriate measures to resolve suspected threats.

The basic block diagram of an MWSSs is presented in Figure 2.

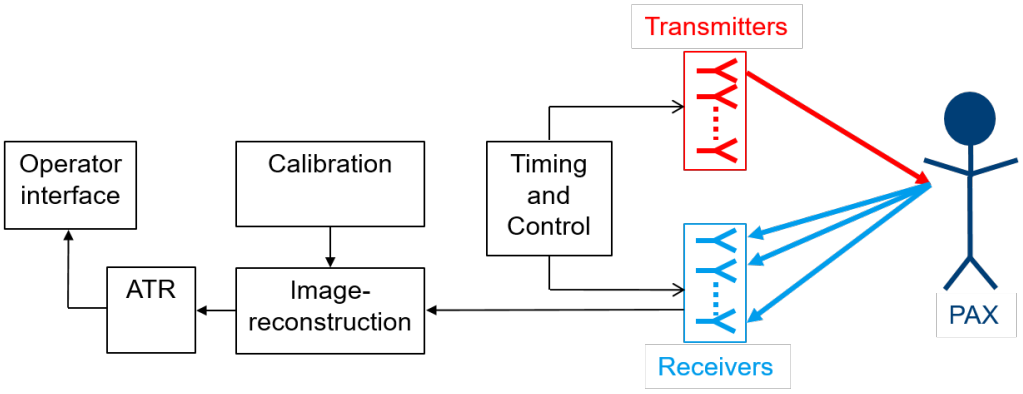


Figure 2: Basic block diagram of an MWSSc

A typical scenario which is considered is shown below, where the MWSSc is used at an indoor security checkpoint.

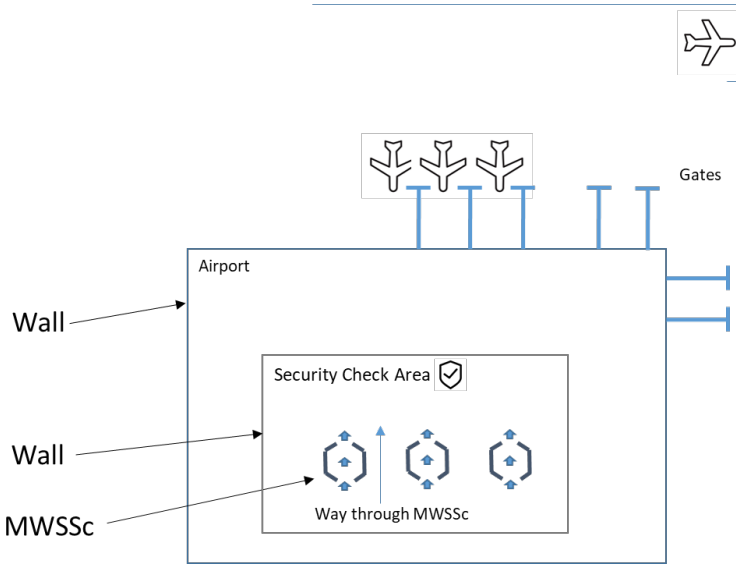


Figure 3: Typical use case of an MWSSc at an airport inside the security check area

2.3 MARKET INFORMATION

MWSScs enhance security in areas where potential threat by persons can occur. These are areas where a certain protection level is required and many people appear. Therefore a walk-through feature is required to maintain a high level of throughput.

The potential market is diverse, with a large variety of potential sites, such as:

a) Airports;
b) Public events;
c) Loss prevention for factories, data centres, authorities etc.;
d) Public transportation;
e) Shopping malls;
f) Military facilities;
g) Prisons;
h) Government offices and courts;
i) Education facilities.

For selected application, the tasks are described in more detail in the following list:

a) Airports:
   - Prevent entrance of dangerous items to the terminal areas where persons are screened even before they enter security areas where they are screened by high resolution SScs;
   - Major well known incidents in the past (9/11, Attack on Brussels Airport 03/2016);
   - SScs are already widely deployed in security checks before boarding the plane.

b) Public events:
   - Prevent dangerous items from entering stadiums/concert halls/etc;
   - Large crowds of people at public events have been targets for attacks in the past;
   - Besides security needs also commercial needs of the organizer can be addressed by SScs. SScs can prevent people from bringing beverages and food into the event.

c) Loss prevention for factories, data centres, authorities etc.:
   - Prevent items from being smuggled in and out of facilities;
   - Examples – Prevent smuggling of:
     - Data storage devices in and out of data centres;
     - Data storage devices out of research and development facilities;
     - Unreleased items out of factories;
     - Valuable goods out of factories;
     - Confidential information/items out of authority buildings

d) Public transportation:
   - Prevent prohibited items to be carried into public transportation hubs;
   - Public transportation has seen many attacks in the past.

e) Shopping malls:
   - Prevent dangerous items to be carried into shopping malls;
   - Currently many countries see the need to employ security measures on shopping mall entrances.

2.4 TECHNICAL INFORMATION

As an example, the RF specifications of an MWSSc from Rohde & Schwarz (R&S) are given in Table 3:

Table 3: RF specifications of R&S®QPS Walk2000

Parameter	Value
Number of transmitting antennas per panel	224
Number of transmitting antennas per panel – H polarisation	112
Number of transmitting antennas per panel – V polarisation	112
Number of receiving antennas per panel	448
Number of receiving antennas per panel – H polarisation	224
Number of receiving antennas per panel – V polarisation	224
Number of antenna tiles per SSc	28
Number of transmitting antennas per tile	8
Number of receiving antennas per tile	16
Physical aperture size	~6,4 m²
Beam width of an antenna (horizontal and vertical)	~40°
Pulse frequency range	3.6 GHz – 9.6 GHz
Pulse packet	~1.25 us
Pulse centre frequency	6.6 GHz
Pulse repetition frequency	12 MHz
Polarisation	0° (H polarisation) and 90° (V polarisation)

2.4.1 Maximum peak *e.i.r.p.*

From the SRDoc ETSI TR 103 730 [2], the maximum peak *e.i.r.p.* spectral density of -5 dBm/50 MHz was mentioned. According to one manufacturer a maximum peak *e.i.r.p.* spectral density of -15 dBm/50 MHz was declared.

MWSScs make use of high resolution and high dynamic range microwave images in order to identify threats on the human body. The upper frequency f_H is of key importance for all aspects of the microwave image and thus influences the MWSScs performance significantly. The typical peak output power of an MWSSc is lower than -15 dBm/50 MHz measured according to ETSI EN 303 883-1 V1.2.0, clause 5.3 “Radiated Power”.

2.4.2 Mean *e.i.r.p.* spectral density

To obtain the mean *e.i.r.p.* from the peak *e.i.r.p.*, the methodology from Recommendation ITU-R SM.1757, described in Annex 2, should be considered and the pulse repetition frequency (PRF) needs to be taken into account. It should be noted that the PRF can and probably will be different for different SSCs.

2.4.3 Parameters related to the mitigation factors of MWSScs

The following parameters contribute to mitigate MWSScs emissions levels and may be necessary for the technical coexistence studies.

2.4.3.1 Duty cycle

Depending on the signal processing and victim system under investigation the duty cycle may be applicable as a mitigation technique depending on the SSC and its UWB signal type and form this duty cycle may be taken into account

In this SSC considered, no duty cycle is taken into account so far.

CF_DC = 0 dB

2.4.3.2 Activity factor

In some systems it can be assumed that scanning will be paused between two people entering the area of observation. However, in this case it is not assumed that the SSC will be switched off. Therefore, the activity factor is considered to be

CF_AF = 0 dB

2.4.3.3 Antenna pattern

The antenna pattern is already included in the *e.i.r.p.* values. However, radiation towards sky might be of interest, because the antennas have a fixed orientation and do not point towards the sky.

Therefore, a representative simulation of the antenna pattern is shown below. The simulation shows the results (Figure 4), where the sidelobe level has been estimated to -7.2 dB in the direction of +/- 90° below the peak. The 3 dB bandwidth is about 46.5°.

3 dB BW: 46.7°

+/- 90° Attenuation: -7.2 dB in horizontal plane and “very low” dB in vertical plane according to the simulation.

CF_ANT_h = [0, -14.3] dB

The lowest antenna gain in the vertical direction was found at 90° with a value of -10 dBi.

CF_ANT_v = [0,-17.1] dB

These plots do not consider the effects of the random material and housings, which have additional losses, but just a single antenna. Further, the antennas in the crowns of the SSC have a down tilt of 45° and no radiation towards the sky (see Figure 7) occurs intentionally. The radiation towards the sky can be considered as shielded in comparison to a horizontal measurement into the SSC when seeing an antenna boresight from ground.

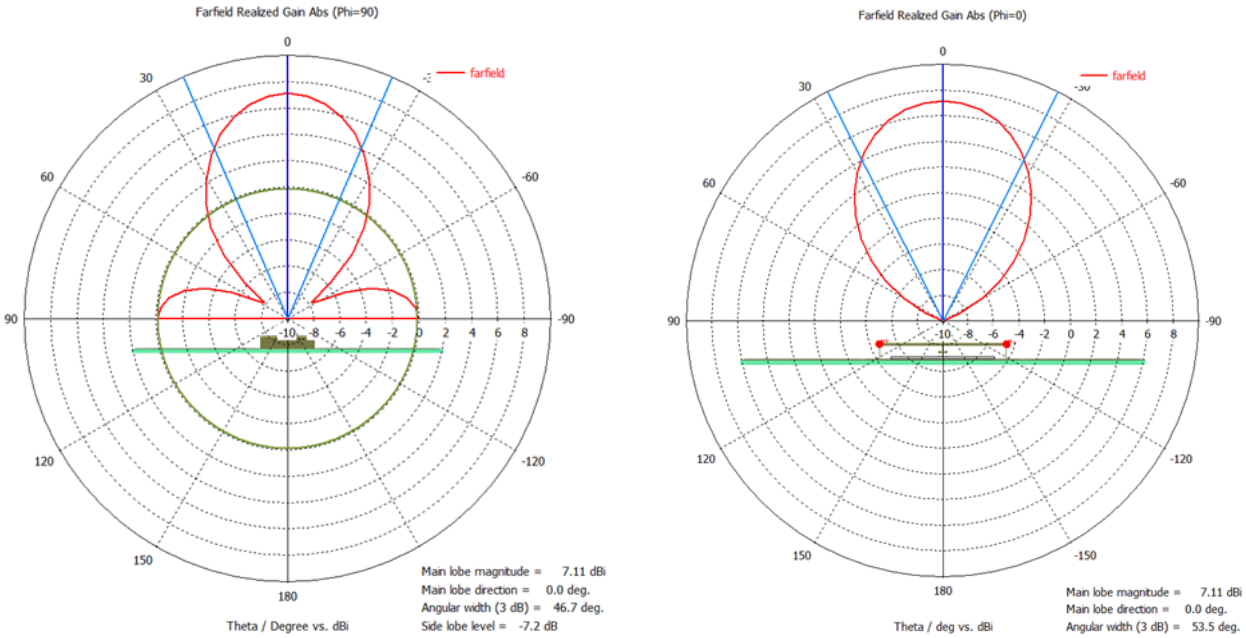


Figure 4: Simulated Antenna Pattern of MWSSc in horizontal (left) and vertical direction (right)

2.4.3.4 Geometrical correction factor / power outside the scenario / indirect emission

The type of MWSSc considered in these studies is based on specifications provided by a single manufacturer. According to this design, the radiated MWSSc signal power is neither isotropic nor constant over time. As pointed out in section 2.4, from any observation or measurement position (named OMP in this Report) located more than 10 m away from the MWSSc, only 32 of the 224 transmitting antenna main beams are “visible” and contribute to the mean power visible for a receiver outside the MWSSc. The remaining 192 are either attenuated by at least 7 dB or so strongly attenuated that their radiation is negligible. Because only the 32 visible antennas contribute significantly, the radiation observed from any OMP varies over time.

Additionally, the MWSSc antennas do not transmit simultaneously but sequentially resulting in a temporally discontinuous radiation intensity at each OMP. The exact sequence in which antennas are activated is not disclosed by the manufacturer. However, for these studies, it is assumed that the 32 visible antennas are activated sequentially, such that the transmitted UWB pulse burst observed at a specific OMP has a constant peak *e.i.r.p.* over a duration of 40µs. This behaviour is shown in Figure 5.

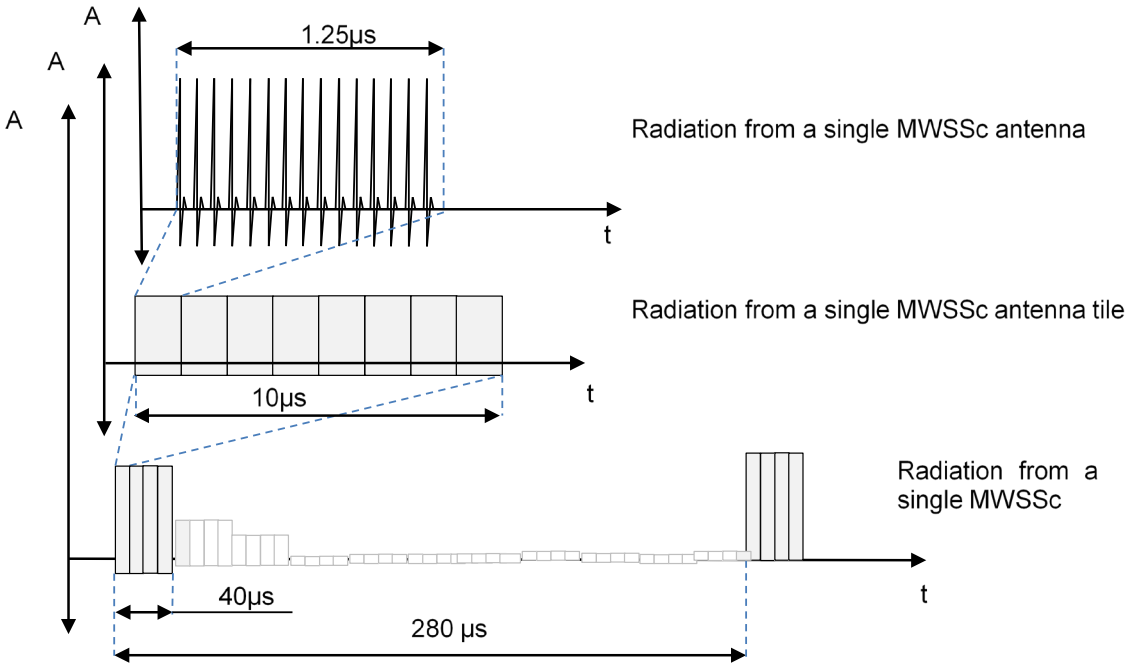


Figure 5: Amplitude of the MWSSc radiation

As shown above, the *e.i.r.p.* of the MWSSc fluctuates over time, with stable periods of approximately 40 µs. As a consequence, the maximum average radiated power is lower than the maximum peak power, if the averaging time is longer than 20 µs. The ECC Decision (06)04 defines a maximum mean *e.i.r.p.* spectral density as the highest signal strength measured in any direction at any frequency within the defined range. The mean *e.i.r.p.* spectral density is measured with a 1 MHz resolution bandwidth, an RMS detector and an averaging time of 1 ms or less. The *e.i.r.p.* of the considered MWSSc measured according ECC Decision (06)04 is significantly lower than the maximum mean *e.i.r.p.* The ratio of those two *e.i.r.p.* can be expressed by a geometrical correction factor. The derivation of the geometrical correction factor is made based on a binary “yes” or “no” raytracing approach. If a ray issued by the antenna can be seen at the outside, it is counted as “yes”. If it the ray cannot be seen, it is counted as “no”. Besides the neglected antenna pattern, no reflection or diffraction have been considered for simplicity. However, a reflected transmitted signal will be attenuated strongly at low distances of below 3 meters already and therefore contribute very little to the overall power. Within these assumptions, the obtained result can be considered as a worst-case.

This raytracing calculation results in a reduction of mean power level of -8.2 dB.

CF_GEO_h = 10*log10(0.15) = -8.2 dB

In addition, according to Figure 4, only two antenna tiles are visible and in line of sight. Underneath these two tiles, additional 3 antennas are visible which leads to in total 8 antennas. Considering these 28,5% of visible antenna tiles in the geometrical factor -5.5 dB additional loss have to be considered.

CF_GEO_v = 10*log10(0.28) = -5.5 dB

This is a factor that describes the ratio of periods where antenna tiles remain within the victim's line of sight. It may be used for scenarios with signals integration over a period longer than the scan duration of a MWSSc.

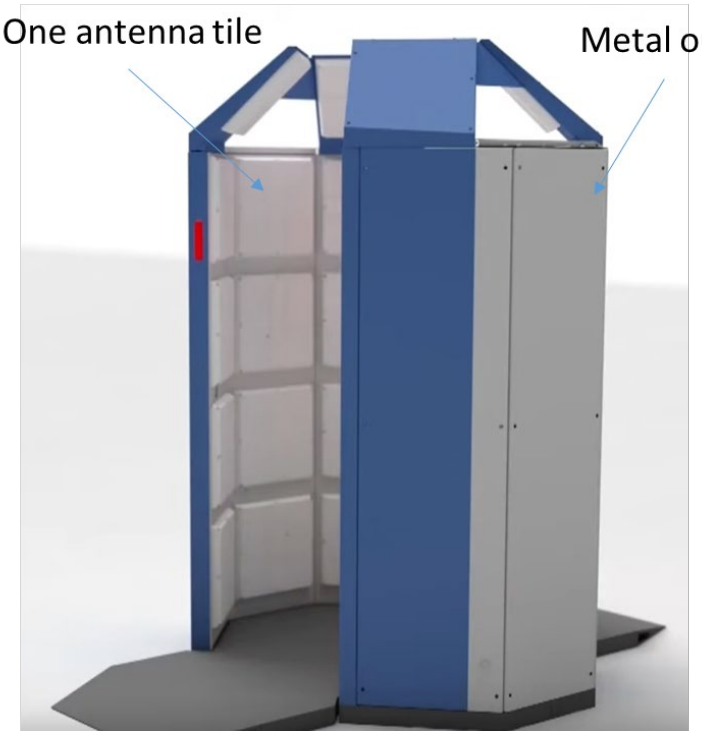


Figure 6: Image of the Rohde & Schwarz MWSSC

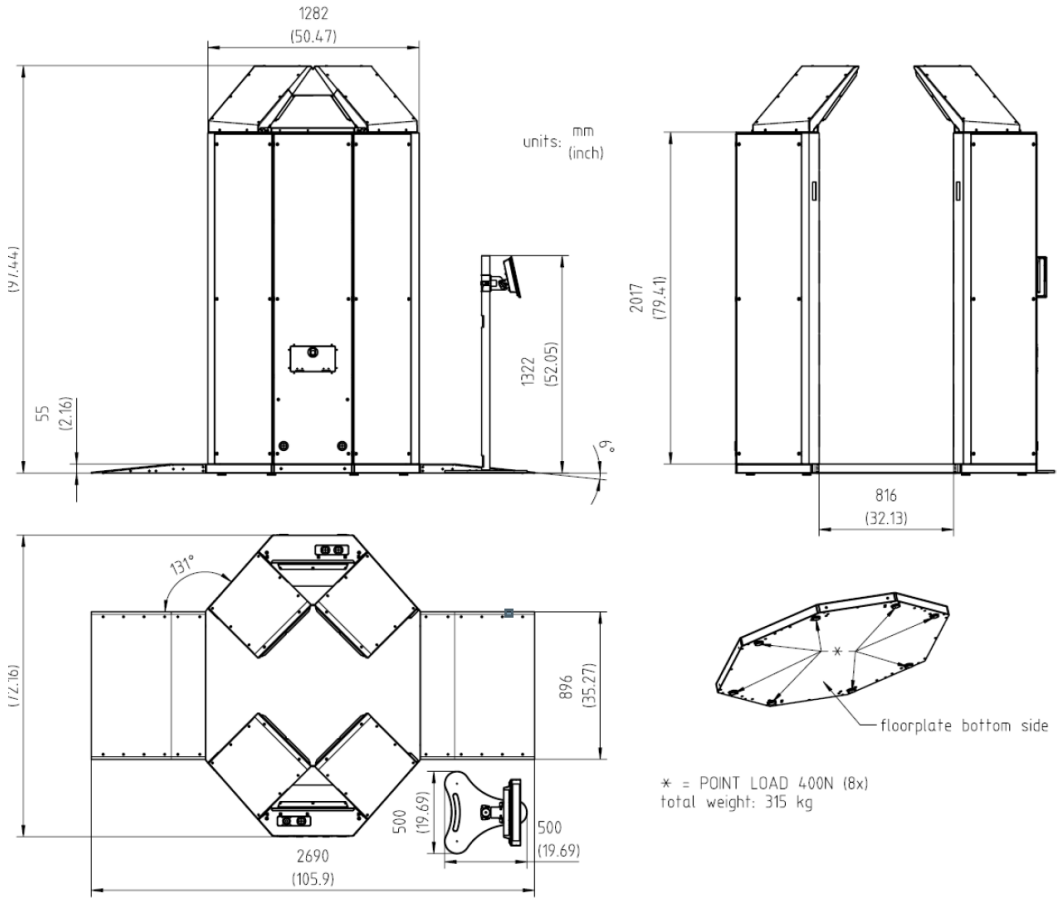


Figure 7: Technical dimensions according to the Rohde & Schwarz MWSSC datasheet

2.4.3.5 Polarisation

Depending on the SSC antenna polarisation and services studied the polarisation may be taken into account.

SSC considered in this Report uses many different polarisations. Therefore, no further polarisation factor is considered if the victim receiver is co-polarised, but 3 dB attenuation can be applied if the victim receiver has a single polarisation only.

C_Pol = 3 dB (if mis-polarised)

2.4.3.6 Aggregation

In case of deploying several SSCs the radiation of a single SSC could theoretically be correlated with the radiation from another one. This could result in constructive or destructive correlation. To account on this a more complex scenario and simulation has to be considered. In this case the spatial aspect, like the geometric layout of SSCs, their antenna pattern and the victim receiver position have to be considered carefully.

2.4.3.7 Building entry loss

To estimate an indoor scenario, it is important to consider the building entry loss (BEL). For a typical traditional building a median BEL of -16.5 dB can be assumed at 5.6 GHz (Recommendation ITU-R P.2109-2, figure 1), when SSC are deployed indoor [9]).

BEL = 16.5 @5.6 GHz

2.4.3.8 Applicability for studies

According to the factors above the following results can be summarised for outdoor deployment and different victim receivers on earth and in the sky.

Table 4: Summary of potential mitigation factors of MWSSc

Factor	Value	Applicable to single interferer mean *e.i.r.p.* studies	Applicable for aggregation studies	Applicable for Monte Carlo studies	Applicable for victims on the ground	Applicable for victims in the sky
CF_DC	0 dB	depends on victim and SSC signal	Yes	Yes	Yes	Yes
CF_AF	0 dB					
CF_ANT_v	[0, -17.1] dB	Yes, depending on scenario / lowest value corresponds to 90° of elevation				
CF_ANT_h	[0] dB	No, already included in measured value				
CF_GEO_v	-5.5 dB	Yes	Yes	Yes	No	Yes
CF_GEO_h	-8.2 dB	Yes	Yes	Yes	Yes	No
CF_Pol	-3 dB	if single polarisation is used by victim	Yes	Yes	Yes	Yes
BEL	-16.5 dB (@5.6 GHz)	Yes, BEL value depending on scenario (indoor only) and frequency, mean value may not be used for Monte Carlo studies				

3 EXISTING BAND USAGE

MicroWave Security Scanners are intended to operate in the 3.6-10.6 GHz band. This envisaged frequency range is already allocated for different radio services in the in-band and the out-of-band domain. An overview of those is given in the ERC Report 025 (ECA Table) [5]. Other systems could be in operation on a national basis.

A simplified visualisation of the band in focus is given in Figure 8. Simplifications were needed to reduce the amount of single entries for the benefit of better clarity. All the simplifications that were done are given in Table 4.

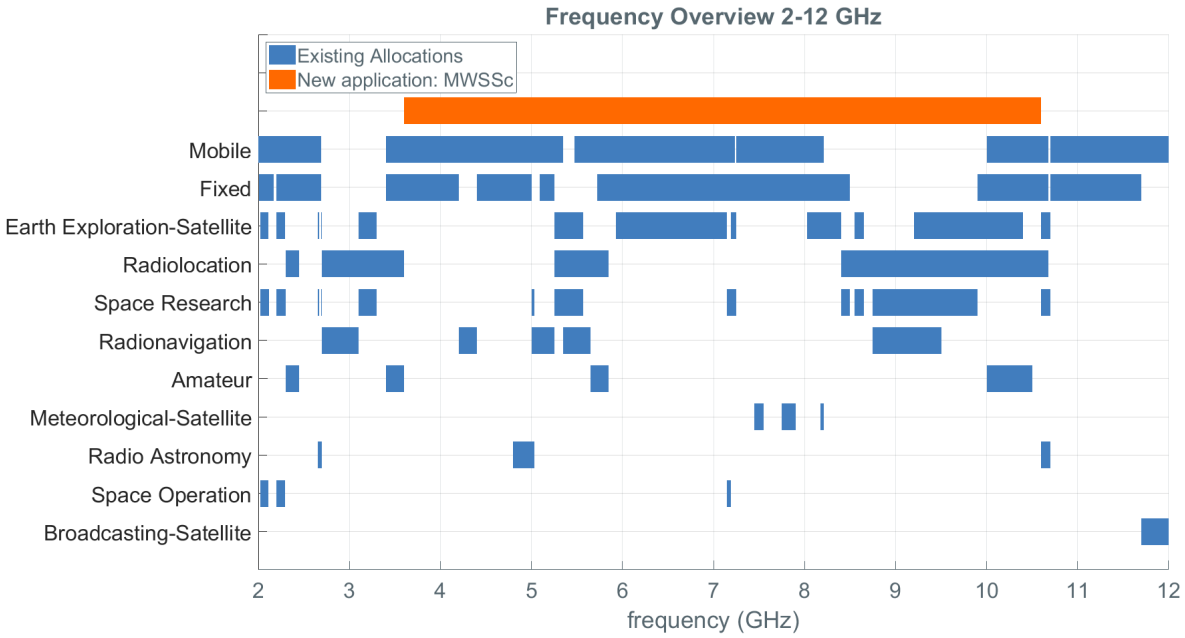


Figure 8: Simplified visualisation of the frequency band 2-12 GHz based on the ECA Table

Table 5: Overview on simplifications in Figure 8 compared to the ECA Table

Simplified Allocation in Figure 8	Represented Allocations according to ECA Table
Amateur	Amateur Amateur-Satellite Amateur-Satellite (Earth-To-Space) Amateur-Satellite (Space-To-Earth)
Broadcasting-Satellite	Broadcasting-Satellite
Earth Exploration-Satellite	Earth Exploration-Satellite (Active) Earth Exploration-Satellite (Earth-To-Space) Earth Exploration-Satellite (Earth-To-Space) (Space-To-Space) Earth Exploration-Satellite (Passive) Earth Exploration-Satellite (Space-To-Earth) Earth Exploration-Satellite (Space-To-Earth) (Space-To-Space) Earth Exploration-Satellite (Active) Earth Exploration-Satellite (Passive)
Fixed	Fixed Fixed-Satellite (Earth-To-Space)

Simplified Allocation in Figure 8	Represented Allocations according to ECA Table
	Fixed-Satellite (Earth-To-Space) (Space-To-Earth) Fixed-Satellite (Space-To-Earth) Fixed
Meteorological-Satellite	Meteorological-Satellite (Earth-To-Space) Meteorological-Satellite (Space-To-Earth)
Mobile	Aeronautical Mobile Aeronautical Mobile (R) Aeronautical Mobile-Satellite (R) Maritime Mobile-Satellite (Space-To-Earth) Mobile Mobile Except Aeronautical Mobile Mobile-Satellite (Earth-To-Space) Mobile-Satellite (Space-To-Earth) Mobile Mobile Except Aeronautical Mobile Mobile-Satellite (Space-To-Earth)
Radio Astronomy	Radio Astronomy Radio Astronomy
Radiolocation	Radiolocation Radiolocation
Radionavigation	Aeronautical Radionavigation Maritime Radionavigation Radionavigation Radionavigation-Satellite (Earth-To-Space) Radionavigation-Satellite (Space-To-Earth) (Space-To-Space)
Space Operation	Space Operation (Earth-To-Space) (Space-To-Space) Space Operation (Space-To-Earth) (Space-To-Space) Space Operation (Earth-To-Space)
Space Research	Space Research Space Research (Active) Space Research (Deep Space) (Earth-To-Space) Space Research (Deep Space) (Space-To-Earth) Space Research (Earth-To-Space) Space Research (Earth-To-Space) (Space-To-Space) Space Research (Passive) Space Research (Space-To-Earth) Space Research (Space-To-Earth) (Space-To-Space) Space Research Space Research (Earth-To-Space) Space Research (Active) Space Research (Passive)

3.1 EUROPEAN COMMON ALLOCATION ALLOCATIONS INBAND

Table 6 is an excerpt of the ECA Table for the inband domain.

Table 6: Excerpt of the ECA Table for the inband domain

Applications	Frequency ranges in MHz
Active sensors (satellite)	5250-5570, 8550-8650, 9500-9800
Aeronautical military systems	4200-5000, 8500-10500
Aeronautical navigation	8500-10000
Aeronautical telemetry	5150-5250
Altimeters	4200-4400
Amateur	5650-5850, 10000-10500
Amateur-satellite	5650-5725, 5830-5850, 10450-10500
BBDR	4800-4990, 5150-5250
BFWA	5725-5925
ESV	3600-4200, 5925-6700
Earth exploration-satellite	8025-8400
FSS Earth stations	3600-4200, 4500-4800, 5850-7075
FWA	10000-10400
Feeder links	5150-5250, 6700-7075
Fixed	3600-4200, 5925-8500, 10000-10400, 10500-10600
GALILEO	5000-5030
ISM	5725-5925
ITS	5850-6700
Land military systems	4400-5000, 7250-7750, 7900-8400, 10000-10500
Land mobile	8025-8215
MBR	5850-5925
MFCN	3600-4200
MLS	5030-5091
MSS Earth stations	7250-7450, 7900-8025
Maritime military systems	4400-5000, 10000-10500
Maritime radar	5250-5725
Non-specific SRDs	5725-5925
PMSE	4400-5000, 6700-8500, 10000-10600
Passive sensors (satellite)	4200-4400, 4800-4990, 5925-7145, 7190-7250
RLAN	5150-5350, 5470-5725, 5925-6700
Radio astronomy	4800-5030, 6650-6675.2
Radiodetermination applications	4500-10600

Applications	Frequency ranges in MHz
Radiolocation (civil)	8500-10500
Radiolocation (military)	5250-5850, 8500-10500
Satellite navigation systems	5000-5030
Satellite systems (military)	7250-7750, 7900-8400, 9300-10000
Space research	8400-8500
Synthetic aperture radar	9200-9300, 9900-10400
TTT	5725-5830
Telemetry/Telecommand (military)	4400-5000
UWB applications	3600-4800, 5925-9000
WAIC	4200-4400
WIA	5725-5925
Weather radar	5250-5850, 9300-9500
Weather satellites	7450-7550, 7750-7900

4 SHARING STUDIES IN THE OPERATIONAL BAND OF 3.6-10.6 GHZ

4.1 RADIO ASTRONOMY IN THE BAND 3.6-10.6 GHZ

4.1.1 Use of the band by RAS and regulatory status

In the band of 3.6-10.6 GHz, RAS has several allocations with varying levels of protection for different purposes. Table 7 summarises the frequency bands allocated and used by RAS. The RAS bands used in this study are taken from the ECA Table [5], which contains all frequencies and applications used in Europe.

Table 7: RAS frequency allocation and usage

RAS frequency bands	Bandwidth	Allocation, Footnote	RAS, type of Observation	Interference with RAS
4800–4990 MHz	190.0 MHz	secondary	Continuum	inband
4990–5000 MHz	10.0 MHz	primary	Continuum	inband
5000–5010 MHz	10.0 MHz	secondary	Continuum	inband
5010–5030 MHz	20.0 MHz	secondary	Continuum	inband
6650–6675.2 MHz	25.2 MHz	5.149	Spectral	inband
8215–8400 MHz	185.0 MHz	(This band is not allocated to RAS)	Geo-VLBI (legacy)	inband
10.60–10.68 GHz	0.08 GHz	primary	Continuum	adjacent
10.68–10.7 GHz	0.02 GHz	passive (5.340)	Continuum	spurious

One of the most significant uses of the band around 5 GHz is the study of formaldehyde (H_2CO) interstellar clouds at 4829.66 MHz. The H_2CO line at this frequency is one of the most important radio lines in the entire spectrum, primarily because it can be detected by absorption in almost any direction. In addition, providing independent evidence of the distribution of interstellar material, H_2CO clouds can also aid in understanding the structure of our galaxy. Also, H_2CO has been observed in absorption against microwave cosmic 3 K blackbody radiation. Carbon-12 and Oxygen-18 H_2CO lines have been detected, and their isotopic abundances are being studied.

The band 6650–6675.2 MHz is crucial for observing methanol (CH_3OH). With RR 5.149, the ITU-R recognised the importance of methanol observations in the 6.6 GHz band. The methanol line has evolved into one of the most important tools for studying star formation in its early stages since then. Observations of star formation in its early stages can only be made by detecting and studying it in the inner parts of star forming regions. The methanol molecule also produces strong masers, allowing us to detect it over cosmic distances, such as in the cores of active galaxies orbiting supermassive black holes, providing insights into black hole physics and high-energy processes within their vicinity. A large number of radiotelescopes in the CEPT region are currently observing this band.

The 8215-8400 MHz band is used for the legacy X-band (8.10-8.95 GHz) observations by the Geodetic Very Long Baseline Interferometry (VLBI) system in combination with the S band (2.20–2.38 GHz). The band is critical for inferring positions on Earth with a precision of the order of a centimetre within the Global Geodetic Reference frame (GGRF). However, the frequency range from 8215 MHz to 8400 MHz is allocated to the Space Research Service (SRS) for the Earth-space link. Although RAS may observe in this band, there is no RAS allocation in the band. Therefore, this band is not considered in this study.

The 10.6 GHz band is mainly used for continuum observations and VLBI. To analyse the (continuum) radiation mechanisms of cosmic sources, it is important to observe them at various distinct frequency bands throughout the radio spectrum. Only with good spectral coverage one can distinguish between thermal emission of hot electron plasma, relativistic particles within magnetic fields or dust in the interstellar medium. The band

10.68 - 10.70 GHz is a passive band according to RR 5.340 of the radio regulations, which states that no radio transmissions are permitted [5].

The list of radio telescopes (RTs) in CEPT countries which use frequencies in the band 3.6-10.6 GHz is shown in Table 8.

Table 8: List of CEPT countries with RAS stations operating in the frequency band 3.6-10.6 GHz

Observatory	Country	Latitude (N)	Longitude (E)
Metsähovi	Finland	60°13'05"	24°23'36"
Nançay	France	47°22'55"	02°11'41"
Effelsberg	Germany	50°31'29"	06°53'01"
Wettzell		49°08'42"	12°52'40"
Matera	Italy	40°38'56"	16°42'16"
Medicina		44°31'15"	11°38'49"
Noto		36°52'34"	14°59'21"
Sardinia		39°29'34"	09°14'42"
Irbene	Latvia	57°33'13"	21°51'18"
Westerbork	Netherlands	52°54'54"	06°36'13"
Ny Ålesund	Norway	78°56'36"	11°51'17"
Santa Maria	Portugal	36°59'07"	-25°07'33"
Yebes	Spain	40°31'29"	-03°05'13"
Onsala	Sweden	57°23'35"	11°55'04"
Bleien	Switzerland	47°20'23"	08°06'42"
Kayseri	Turkey	38°42'37"	35°32'44"
Cambridge	United Kingdom	52°10'01"	0°02'15"
Darnhall		53°09'22"	-02°32'07"
Defford		52°06'01"	-02°08'39"
Knockin		52°47'24"	-02°59'49"
Pickmere		53°17'18"	-02°26'44"
Jodrell Bank		53°14'10"	-02°18'26"

4.1.2 Outline of the study

Given the nature of the application, the distribution is considered as not dense. Hence, a single-entry worst-case study should suffice, which avoids unnecessary complexity without loss of accuracy. The calculations in this study have been performed with the free open-source software package for Python, pycraf [7].

4.1.3 MWSSc parameters

Table 9 shows the MWSSc parameters used in this study.

Table 9: MWSSc Transmitter parameters

Parameter	Value
Frequency band	3.6-10.6 GHz
Max. mean *e.i.r.p.* (average over 1 ms) spectral density	-60 dBm/MHz

4.1.4 RAS receiver parameters

Protection criteria for RAS are defined in Recommendation ITU-R RA.769-2 [8] and summarised in Table 10 for convenience. With the aim of simplifying the study, the bands 4800-4990 MHz, 4990-5000 MHz, 5000-5010 MHz, 5010-5030 MHz are grouped together and treated as a single band.

Table 10: Radio astronomy technical parameters

System Parameter	Value	Remarks
Integration time	2000 s	
Side lobe gain, G_r	0 dBi	According to Recommendation ITU-R RA.769-2 [8], only side lobe reception needs to be considered
Threshold interference level Spectral power, $P_{lim,v}$	5 GHz: -186.7 dBm/MHz	Derived from Recommendation ITU-R RA.769-2 [8]: Table 1 for continuum observations, Table 2 for spectroscopic observations
	6.6 GHz: -175.2 dBm/MHz	
	10.6 GHz: -191.7 dBm/ MHz	
Effective RAS bandwidth	5 GHz: 10 MHz	Derived from Recommendation ITU-R RA.769-2 [8]: Table 1 for continuum observations, Table 2 for spectroscopic observations
	6.6 GHz: 50 kHz	
	10.6 GHz: 100 MHz	
Antenna height, h_{rt}	D/2	The height of the receiver is estimated as the half of the antenna diameter

Table 9 presents a comprehensive overview of these RAS bands and their associated observation types. It is crucial to recognise that different kinds of RAS observations are carried out, which are categorised as continuum, spectral-line and VLBI types. They all have different protection requirements and thus, Recommendation ITU-R RA.769-2 [8] provides different threshold values for them. It is noted that the RA.769 spectral power density values in Table 9 are not necessarily related to the total bandwidth of a RAS allocation. For example, for spectral line observations, the width of a spectral channel is relevant. For convenience, the values of the protection criteria values are derived as power spectral density and are expressed in dBm/MHz.

As this study represents the single-entry worst-case scenario, clutter losses were not considered. For aggregation calculations, clutter would have to be considered. Likewise, the building entry losses should only be applied, if the transmitter is guaranteed to be indoors and not located near an open area, such as a doorway in a shopping mall close to a door as typical application in shopping mall.

4.1.5 Methodology adopted for single-entry studies

In the following sections, two types of studies are presented: a generic case study and a site-specific study.

For both studies the received spectral power at the RAS station is as follows:

$$P_R = P_T + G_R + G_T - PL - CL - BEL \quad (1)$$

where (all values in dB):

- PR: the power received by the radio astronomy receiver (dBm/MHz);
- PT: the transmitter power (dBm/MHz) in the RAS band;
- GR: the gain of the radio telescope in the direction of the transmitter, which is assumed to be 0 dBi (representing a mean sidelobe gain of this value) in accordance with Recommendation ITU-R RA.769-2 [8];
- GT: the (side-lobe) gain of the transmitter in the direction of the radio receiver (set to 0 dBi, if PT is provided as *e.i.r.p.*);
- PL: Path propagation loss, e.g. according to Recommendation ITU-R P.452-17 [13] (excluding clutter losses, but including atmospheric attenuation);
- CL: Clutter losses (according to Recommendation ITU-R P.452-17 [13]), but set to zero for single-entry worst-case scenario;
- BEL: Building entry loss (according to Recommendation ITU-R P.2109-1 [9]), as appropriate.

Following this, the margin, which represents the difference between the actual link budget and the Minimum Coupling Loss (MCL), is determined and can be used to infer coordination zones around CEPT RAS sites. The MCL depends on the technical parameters provided above. The MCL formula is articulated as follows:

$$MCL = EIRP_{PSD} - PSD_{lim}\ (dB) \quad (2)$$

4.1.6 Generic case study

The generic case study is a simplified analysis assuming the radio telescope is located on flat terrain, with only Earth's curvature taken into account. This study is intended as a general guideline for defining coordination areas around RAS stations. However, the site-specific scenario described in the next section provides a more accurate assessment by identifying the locations from which transmissions would be most harmful to the radio astronomy receiver. The propagation model Recommendation ITU-R P.452-17 [13] is applied here using a time percentage of 2 % (like given in Recommendation ITU-R RA.1513-2). Based on the input parameters in Table 11, the separation distances are shown in Table 11. The protection criteria are displayed in Table 10 which are according to Recommendation ITU-R RA.769-2 [8]. The indoor scenario is considered by taking into account the Building Entry Loss (BEL) as an additional loss. The BEL values (16.3 dB for 5 GHz band, 16.8 dB for 6.6 GHz band) are derived from Recommendation ITU-R 2109-2 [9] by assuming median traditional building losses due to the worst case.

Table 11: Input parameters for generic case

Parameter	Value
Height RT	30 m
Height Tx	outdoor/ indoor: 2.5 m
Transmitter mean *e.i.r.p.* (average over 1 ms) spectral density	-60 dBm/MHz

Table 12: Separation distance for generic case

Frequency	Scenario	Separation Distance (Tx @ -60 dBm/MHz)
5 GHz	outdoor	13.8 km
	indoor	1.7 km
6.6 GHz	outdoor	2.3 km
	indoor	0.3 km

4.1.7 Generic case study: Additional results for different MWSSc mean *e.i.r.p.* values

Table 13 shows additional results for the generic study taking into account possible other mean *e.i.r.p.* values for MWSSc.

Table 13: Separation distances for different MWSSc mean *e.i.r.p.* values

Frequency	Scenario	Separation Distance (for different MWSSc mean *e.i.r.p.* (average over 1 ms) spectral density)		
		-60 dBm/MHz	-50 dBm/MHz	-41.3 dBm/MHz
5 GHz	outdoor	13.8 km	22.4 km	31.2 km
	indoor	1.7 km	6.0 km	15.7 km

4.1.8 Single-entry and site-specific study

Different scenarios are evaluated using real terrain elevation data, from Lidar databases[1]. The calculation area encompasses a 160 km square around the site. In Table 14, MCLs are provided for two different bands, according to the calculation explained in section 4.1.5.

Table 14: Single entry results in terms of MCL respectively in the bands under study

RAS frequency bands	RA Observation	Transmitter mean *e.i.r.p.* (average over 1 ms) spectral density	PSDlim (derived from Recommendation ITU-R RA.769-2 Table 1, Table 2 [8])	MCL
4800-5030 MHz	Continuum	-60 dBm/MHz	-186.7 dBm/MHz	126.7 dB
6650-6675.2 MHz	Spectral	-60 dBm/MHz	-175.2 dBm/MHz	115.2 dB

Based on the above considerations, Figure 9 presents the results of outdoor scenario of Yebes radio telescope.

[1] Yebes: Instituto Geográfico Nacional (IGN): DTM 5m, DTM 2m, https://centrodedescargas.cnig.es/CentroDescargas; License: Creative Commons Attribution 4.0 International (CC BY 4.0)
Nançay: Institut national de l'information géographique et forestière (IGN): RGE ALTI, DTM 5 m https://geoservices.ign.fr/rgealti Licence: https://geoservices.ign.fr/cgu-licences
Westerbork: Actueel Hoogtebestand Nederland (AHN): AHN2 DTM http://www.ahn.nl/, https://www.pdok.nl/introductie/-/article/actueel-hoogtebestand-nederland-ahn; License: CC0 1.0 Universal (CC0 1.0)
Medicina: Regione Emilia-Romagna: DTM 5 m https://geoportale.regione.emilia-romagna.it/catalogo/dati-cartografici/altimetria/layer-2; License: Creative Commons Attribution 4.0 International (CC BY 4.0)
Jodrell Bank: Environment Agency: Lidar Composite DTM 10 m https://environment.data.gov.uk/dataset/ce8fe7e7-bed0-4889-8825-19b042e128d2; Licence: Open Government Licence https://www.nationalarchives.gov.uk/doc/open-government-licence/version/3/;

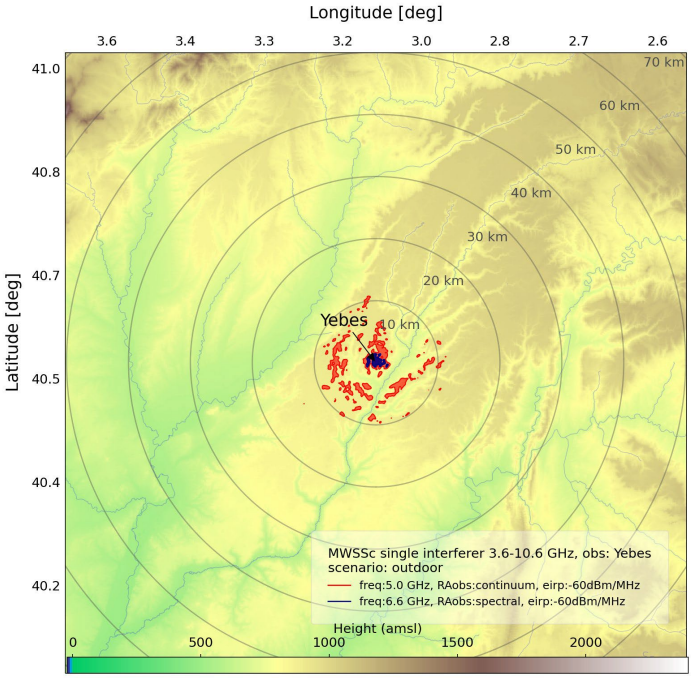


Figure 9: Single-entry interference area considering the Yebes radio astronomy site. Scenario: outdoor

Results show that the interference area for the 5 GHz band are somewhat larger than 6.6 frequency band. This is not surprising as continuum observations have stronger protection criteria and propagation losses are smaller at lower frequencies.

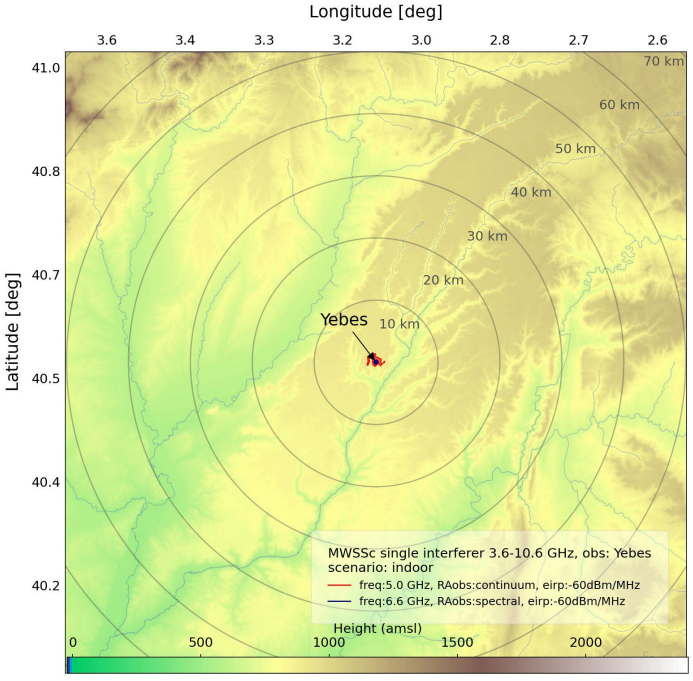
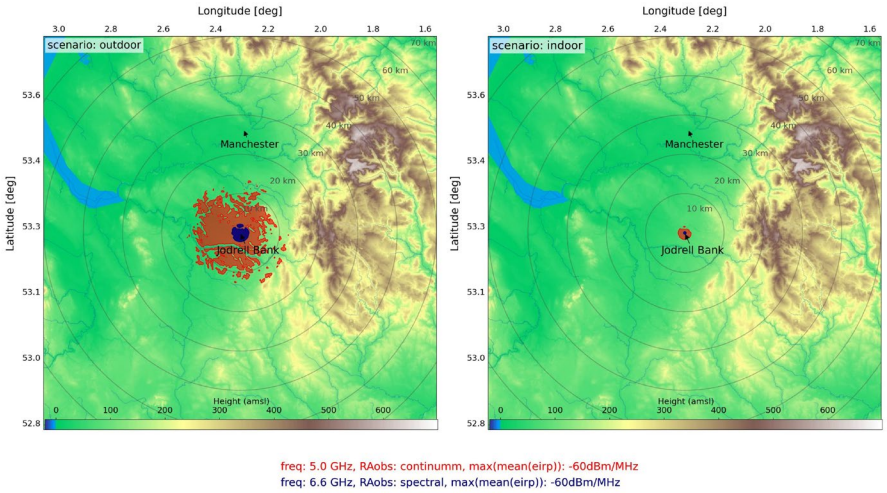


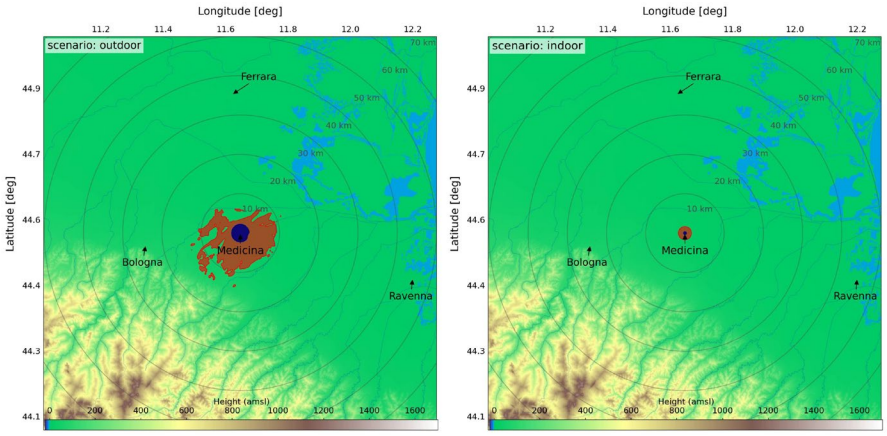
Figure 10: Single-entry interference area considering the Yebes radio astronomy site. Scenario: indoor

Figure 11, Figure 12, Figure 13 and Figure 14 show the results of the same study for the calculation of the separation distance extended to other RAS sites such as Jodrell Bank (UK), Medicina (IT), Nançay (FR) and Westerbork (NL). Table 15 lists the separation radii at 5 GHz (which is the most affected frequency band with respect to 6.6 GHz).



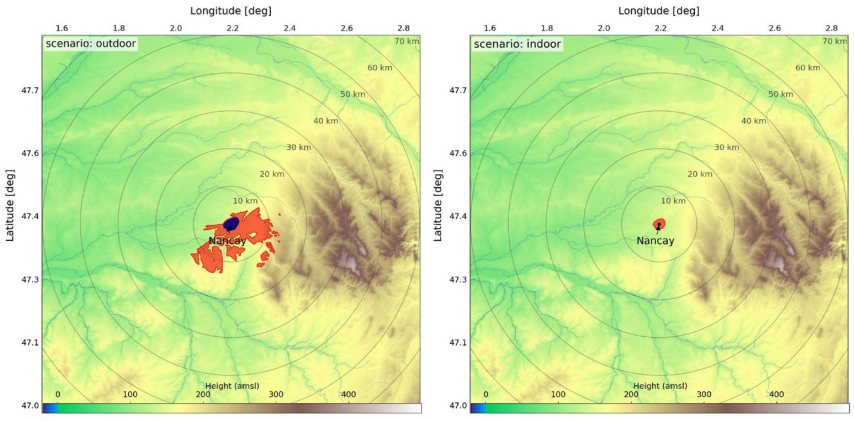
freq: 5.0 GHz, RAobs: continumm, max(mean(eirp)): -60dBm/MHz
freq: 6.6 GHz, RAobs: spectral, max(mean(eirp)): -60dBm/MHz

Figure 11: Single-entry interference area of the Jodrell Bank radio astronomy site, scenario: outdoor (left), indoor (right)



freq: 5.0 GHz, RAobs: continumm, max(mean(eirp)): -60dBm/MHz
freq: 6.6 GHz, RAobs: spectral, max(mean(eirp)): -60dBm/MHz

Figure 12: Single-entry interference area of the Medicina radio astronomy site, scenario: outdoor (left), indoor (right)



freq: 5.0 GHz, RAobs: continumm, max(mean(eirp)): -60dBm/MHz
freq: 6.6 GHz, RAobs: spectral, max(mean(eirp)): -60dBm/MHz

Figure 13: Single-entry interference area of the Nancay radio astronomy site, scenario: outdoor (left), indoor (right)

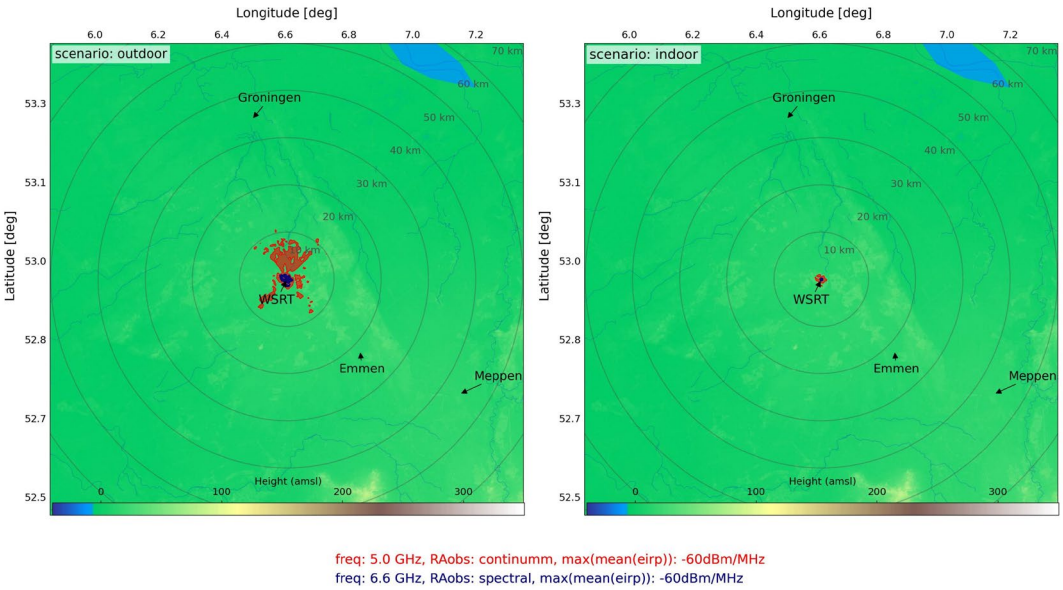


Figure 14: Single-entry interference area of the Westerbork radio astronomy site, scenario: outdoor (left), indoor (right)

Table 15: Site-specific, single-entry results overview

RT Site	Country	Separation distance	
		Outdoor	Indoor
Yebes	Spain	10.1 km	1.5 km
Medicina	Italy	13.2 km	1.7 km
Jodrell Bank	UK	13.0 km	1.7 km
Nançay	France	13.4 km	1.7 km
Westerbork	Netherland	8.8 km	1.4 km

As expected, from site-specific scenario results the outdoor scenario is the most critical for all RAS sites under test where the separation distances are from 8.8 km (Westerbork) up to 13.2 (Medicina). The indoor scenarios show minimal impact, with required separation distances of approximately 1.5 km. The RAS sites located close to at least one airport are Jodrell Bank (UK) and Westerbork (NL).

4.1.9 Generic case study - Monte Carlo approach

In the generic case study (see section 4.1.6) it was assumed that no clutter losses occur, representing a worst-case scenario. The single-entry calculations resulted in certain separation distances as shown in Table 12.

In practical deployments, MWSSc I would often experience losses due to clutter particularly in urban areas or at airports, but not necessarily all cases (e.g. MWSScs deployed in an open field on a rural area). However, clutter is minimal in rural, open-field locations. The clutter loss described in Recommendation ITU-R P.2108-1 [14] provides a statistical estimate of environmental attenuation caused by buildings, vegetation, and other obstructions in the vicinity of the transmitter or receiver.

The Recommendation ITU-R P.2108, section 3.2 [14] was developed for IMT equipment in urban and sub-urban areas with purely terrestrial propagation and the base stations are installed below the rooftops. For cases considering terrain profile and no clutter, the site-specific analyses with MWSScs deployed outdoor as laid out in the previous section should be taken into account (see Table 15).

In addition to applying clutter losses, transmitter antenna pointings may be random, which also needs to be covered statistically. For this reason, a Monte Carlo analysis was performed in which a number of parameters was varied, where the typical deployment of devices in an area around the RAS station would be simulated. A workspace using SEAMCAT (Spectrum Engineering Advanced Monte Carlo Analysis Tool) V 5.5.0 was set up.

Simulation Configuration

Constant parameters:

- Frequency 5 GHz;
- No clutter (Recommendation ITU-R P.2108-1 [14]) at RAS site;
- Number of active transmitters 10;
- Fixed distance;
- Tx Antenna pattern from Figure 4 used;
- Rx Antenna pattern omnidirectional 0 dBi;
- Antenna heights (RAS = 20.5 m, SSC = 2 m);
- A power spectral density level is chosen from: -60 dBm/MHz, -50 dBm/MHz and -41.3 dBm/MHz.
- Distance: 1 km, 2.5 km and 7.5 km
- 20000 iterations

Varying parameters (for each of the 10 independent MWSSc):

- Propagation model: Recommendation ITU-R P.452-17 with time variance (0.001-50% uniform);
- Clutter at MWSSC site only (Recommendation ITU-R P.2108-1 [14] variable percentage of location (0.1% – 100%));
- Azimuth angle placement of MWSSc relative to RAS station (0° – 360°);
- Direction of Tx Antenna uniform distributed (0° – 360°).

Figure 15 shows an illustration of a single MWSSC and RAS station at a certain distance. However, in the following Monte Carlo simulations, it was considered to have a number of ten arbitrary active outdoor MWSSc in different simulation cases, respectively. In addition, simulation cases with different power level were simulated. As shown in Figure 15 provides a sketch of the Monte Carlo setup showing only a single MWSSc.

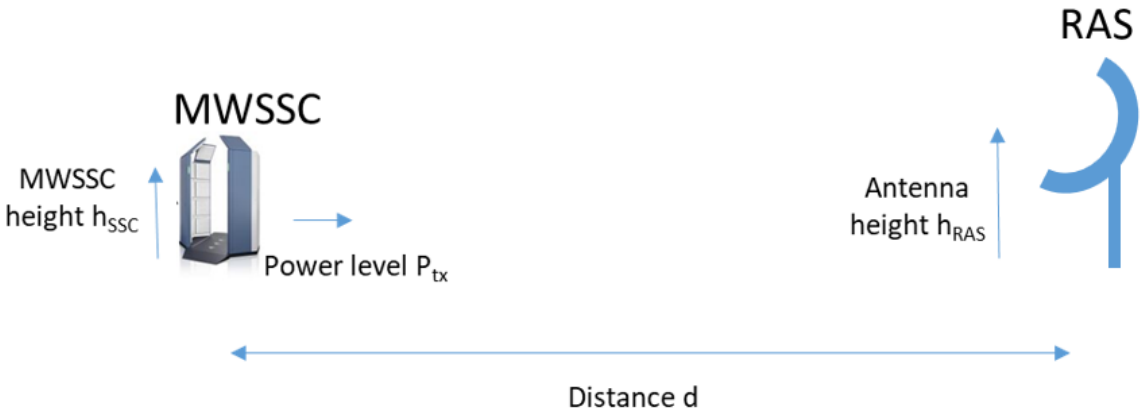


Figure 15: SEAMCAT Monte Carlo setup for a generic site, showing a single representative MWSSc and a RAS antenna

RAS stations are typically deployed in remote areas, often shielded by natural terrain such as valleys or mountainous areas, to minimize man-made radio interference. Many RAS facilities are situated within legally protected zones where radio transmitter deployment is restricted or prohibited to protect highly sensitive radio astronomical observations from even weak or unintentional emissions. Consequently, MWSScs are unlikely to

be deployed within 3 km of a RAS station; however, a 1 km minimum separation is adopted as a worst-case scenario for this Monte Carlo simulation.

An overview of simulation cases with varying transmitter power spectral density is given in Table 16.

Table 16: MWSSC - RAS SEAMCAT simulation cases

Ptx [dBm/MHz]	Simulated Distance d [km]	Placement	Active outdoor MWSSC
-60	1	Circular around RAS	10
-50	2.5	Circular around RAS	10
-41,3	7.5	Circular around RAS	10

All simulation cases represent a number of 10 MWSSc placed in an arbitrary azimuth angle in a circle around the RAS station. As the RAS station has a considered horizontal antenna gain of 0 dBi there is no difference if the MWSSC are placed in a circle around the RAS or in a cluster at a certain position and direction from the RAS. Figure 16 shows the geometries for all iterations combined, displayed in SEAMCAT. It is to be noted that the relative distance shown is always 2.5 km. Due to slight variation of Rx placement in SEAMCAT, the MWSSc had to vary each time in the same manner.

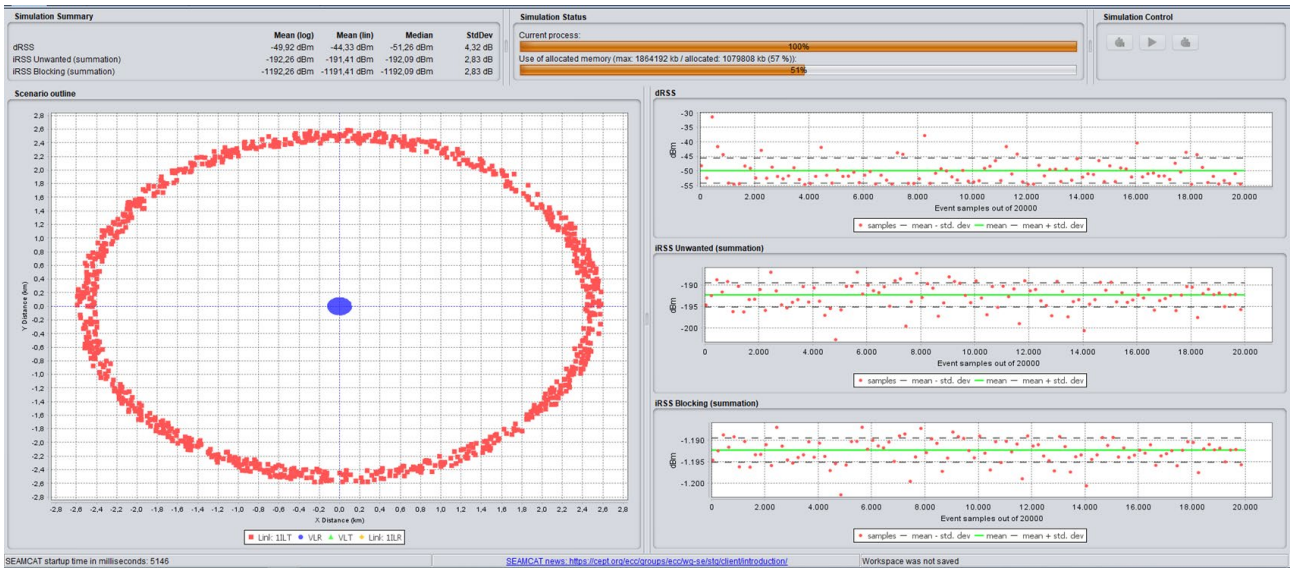


Figure 16: Geometrical Layout of RAS (blue dot) and MWSSC (red dots). Note that ten MWSSC are active for each iteration

From the considered simulation cases the iRSS is the figure of merit under evaluation. The iRSS value represents the total aggregated interfering signal power received at a radio astronomy station from MWSSC sources and is used to ensure that the cumulative interference remains below the threshold defined to protect sensitive astronomical observations.

The iRSS unwanted signal, represented as a cumulative distribution function was calculated. Figure 17 shows the simulation case with PSD of -60 dBm/MHz. The acceptable dataloss 2% for RAS is outlined by Recommendation ITU-R P.1513-2 [28] results in approximately iRSS -188 dBm and shows a margin of 1.3 dB to the Recommendation ITU-R RA.769 threshold value.

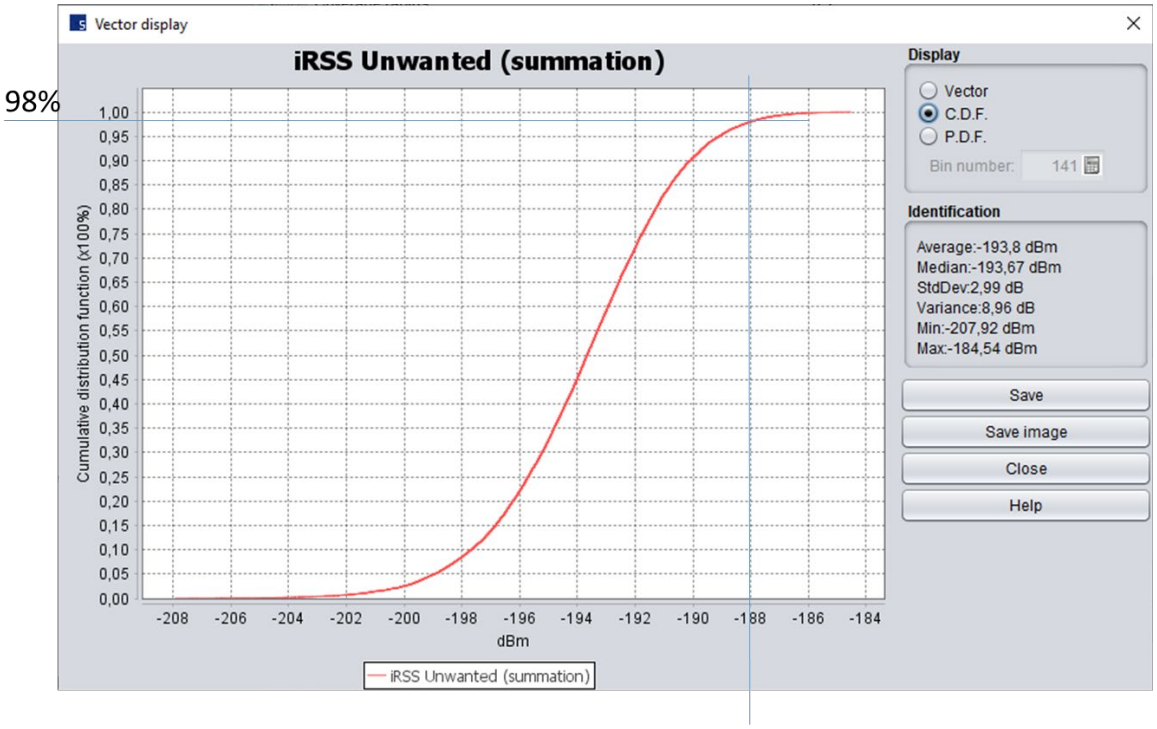


Figure 17: CDF of simulation results for a transmit PSD of -60 dBm/MHz

Results for PSD values of -50 dBm/MHz and -41.3 dBm/MHz are minimum separation distances of 2.5 km and 7.5 km.

Simulation Results

The list of results is shown in Table 17, where the minimum separation distance corresponds to an iRSS level at about 98% which ensures protection of RAS.

Table 17: Monte Carlo results

Ptx [dBm/MHz]	Minimum separation Distance d [km]
-60	1
-50	2.5
-41.3	7.5

According to SEAMCAT MWSSC - RAS simulation with the MWSSC at different power levels, distances and numbers, the following findings were made:

- The Monte Carlo simulation setup produced similar results across equivalent simulation cases compared to the generic case single entry study, supporting its reliability for the analyses conducted;
- The accuracy of the Monte Carlo simulation is in the range of below 1 dB as shown by varying the number of events from 20000/100000/1000000, which shows the stability of simulation results;
- Increasing the RAS antenna height to 30 m has no significant impact on the overall result;
- 10 outdoor MWSSc with Tx powers of -60, -50, and -41.3 dBm/MHz require minimum separation distances of 1 km, 2.5 km, and 7.5 km, respectively, from a RAS receiver to ensure its protection.

4.1.10 Conclusions

In terms of sharing with the Radio Astronomy Service, the results of single-entry generic studies indicate that outdoor MWSSc operating at mean *e.i.r.p.* of -60 dBm/MHz (average over 1 ms) requires a minimum separation distance of 13.8 km. For the indoor case, this reduces to 1.7 km. Site-specific studies for five RAS sites (Table 15 shows the results) indicate that those distances are ranging from 8.8 km to 13.4 km (outdoor) and 1.4 km to 1.7 km (indoor). No site-specific scenarios with different power spectral densities, rather than -60 dBm/MHz, are provided.

A generic site Monte Carlo simulation considering urban and suburban scenarios indicated that a minimum separation distance of 1 km is required if the mean spectral power is -60 dBm/MHz, increasing to 7.5 km when the mean spectral power is -41.3 dBm/MHz.

4.2 AMATEUR AND AMATEUR SATELLITE SERVICE

The amateur and amateur-satellite services have allocations within the range of the study around 5.65 GHz and 10 GHz. In the past years, activity of amateur radio stations in this frequency range has increased. It has led to interesting propagation studies and has contributed to the knowledge development of young microwave engineers. Ongoing experimentation, high performance frequency sources and innovative adaptation of commercial chipsets has led to growth in activity which can be currently categorised as:

- Weak-signal reception of Narrowband (e.g. CW-Morse or Voice) terrestrial operations in harmonised sub-bands (including over Earth-Moon-Earth (EME) paths and through geostationary and non-geostationary amateur satellite transponders);
- Growing use of wider bandwidth modes for experimentation with Digital Amateur TV (DATV) and data links;
- Usage of fixed beacon transmitting stations for propagation research and equipment alignment.

4.2.1 Technical and Operational Characteristics

Recommendation ITU-R M.1732-3 [15] provides ranges of characteristics for the amateur service and the amateur-satellite service for use in sharing studies. Recommendation ITU-R M.1732-3, Tables 1B, 2B, 3B, 5, 6 and 7 [15] are applicable for both the 5.65 GHz band and the 10 GHz band. In Table 18 and Table 19, some typical figures are provided:

Table 18: Examples of amateur service characteristics in the band 5650-5850 MHz and amateur-satellite characteristics in the bands 5650-5670 MHz (E-s), 5830-5850 MHz (s-E)

Parameter	CW-Morse	SSB Voice	NBFM Voice	DATV
Receiver IF bandwidth (kHz)	0.5	2.7	15	4000
Typical Feeder Loss (dB)	1	1	1	1
Antenna gain (dBi)	10–42 (typically: 32 but up to 46 for EME)	10–42 (typically: 32 but up to 46 for EME)	10–42 (typically: 32)	10–42 (typically: 32)
Antenna polarisation	Horizontal, Vertical	Horizontal, Vertical	Horizontal, Vertical	Horizontal, Vertical
Receiver Noise Figure (dB)	0.5–1 (typically 1)	0.5–1 (typically 1)	0.5–1 (typically 1)	0.5–1 (typically 1)

Table 19: Examples of amateur service characteristics in the band 10-10.5 GHz and amateur-satellite characteristics in the band 10.45-10.5 GHz

Parameter	CW-Morse	SSB Voice	NBFM Voice	DATV
Receiver IF bandwidth (kHz)	0.5	2.7	15	4000
Typical Feeder Loss (dB)	1	1	1	1
Antenna gain (dBi)	10–42 (typically: 38 but up to 46 for EME)	10–42 (typically: 38 but up to 46 for EME)	10–42 (typically: 38)	10–42 (typically: 38)
Antenna polarisation	Horizontal, Vertical	Horizontal, Vertical	Horizontal, Vertical	Horizontal, Vertical
Receiver Noise Figure (dB)	0.5–1 (typically 1)	0.5–1 (typically 1)	0.5–1 (typically 1)	0.5–1 (typically 1)

For terrestrial (point to point) operations, amateur stations can be mounted up to 12 m above ground and are generally rotatable in azimuth. The antenna location is chosen to provide uncluttered paths to surrounding distant stations. For amateur service EME and amateur-satellite non-geostationary activities the antennas will also be adjustable in elevation to enable either satellite or Moon tracking as required. In all cases the aim is for the antenna beam to be clear of local clutter as far as is practicable.

Amateur geostationary satellite downlinking takes place in the 10.45-10.5 GHz range to ground based receivers. It is possible for these to be installed in cluttered ground locations if there is good visibility towards the geostationary satellite. The same characteristics as Table 19 can be assumed but the NBFM Voice application is not relevant.

DATV stations may be fixed repeater relay stations and could be mounted at heights up to 100 m.

4.2.2 MCL study

In this single interferer study the separation distance between a MWSSc and an Amateur Service (AS) receiver will be calculated based on an MCL approach.

Therefore, it is assumed that the AS receiver is pointing towards the MWSSc. The pointing direction of the MWSSc is towards the AS receiver. Two scenarios are considered. For the first scenario the security scanner is placed outdoors and will be calculated without any building entry loss (BEL).

Both are assumed to operate at 2 m height in this worst-case assessment.

The MWSScs mean *e.i.r.p.* emission level in this single interferer study is assumed to be -60.0 dBm/MHz. In addition, the study investigates the mean *e.i.r.p.* of -55 and -50 dBm/MHz.

For indoor scenarios the traditional building type is used to reflect worst-case conditions. For modern, thermally efficient buildings (metallised glass, foil-backed panels) significantly higher losses are expected.

Clutter losses are not considered for this worst-case MCL calculation.

The propagation model used is the Free Space Loss model as described in Recommendation ITU-R P.525 [16].

Table 20 summarises the parameters which are used for the MCL calculation.

Table 20: MCL Parameters for AS study

Parameter	Value	Source / Formula
Frequency	5.65 GHz	Lowest allocated frequency in relevant range
Rx PSD_noise	-113.9 dBm/MHz	$PSD_{noise} = 10 * \log_{10}(k * B * T) + 10 * \log_{10}(\frac{1000}{B})$
Rx Feeder/multiplexer loss typical	-1 dB	ECC Report 302 [20]
Rx Receiver noise figure typical	-1 dB	ECC Report 302 [20]
Rx I/N (protection criterion)	-10 dB	Recommendation ITU-R F.758-7, table 5 [22]
Rx FS antenna gain	32.0 dBi	
Rx PSD_max	121.9 dBm/MHz	$PSD_{max} = PSD_{noise} + NF + feeder + \frac{I}{N}$
Tx PSD_SSc	-60 dBm/MHz -55 dBm/MHz -50 dBm/MHz	
MCL outdoor (-60 / -55 / -50 dBm/MHz)	93.9 / 98.9 / 103.9 dB	$MCL_{outdoor} = PSD_{SSc} - PSD_{max} - G_{Rx}$
BEL = Building Entry-Loss Probability = 0,5 / Traditional building type Frequency : 5.0 GHz and horizontal paths	16.3 dB	Recommendation ITU-R P.2109-2 [9]
MCL indoor (-60 / -55 / -50 dBm/MHz)	77.4 / 82.4 / 87.4 dB	$MCL_{indoor} = MCL_{outdoor} - BEL$

Results are given in Table 21. Under Line of Sight conditions and aligned antennas separation distances between 31 m and 668 m are needed to prevent harmful interference.

Table 21: SSc vs FS - summary of results for the MCL study

Scenario	Separation distance (PSD = -50 dBm/MHz)	Separation distance (PSD = -55 dBm/MHz)	Separation distance (PSD = -60 dBm/MHz)
Outdoor SSc	~ 668 m	~ 375 m	~ 211 m
Indoor traditional SSc	~ 100 m	~ 56 m	~ 31 m

4.2.3 MCL for Interference Intensity Study

To be able to interpret the results from the previous MCL study, additional single interferer calculations were done for an area around an AS receiver. In addition to the assumptions made in the previous MCL study, the vertical separation between the antennas is considered.

In this MCL study the impact of a single interferer is calculated on each point of the area considering the antenna patterns. For MWSSc transmitters omni-directional antennas were used, and for the AS receiver the antenna defined in Recommendation ITU-R F.699 [23] was used.

In contrast to the previous MCL study now clutter losses according to the description of Recommendation ITU-R P.2108 [14] are used for distances greater or equal 250 m.

A schematic view from the top is given in Figure 18.

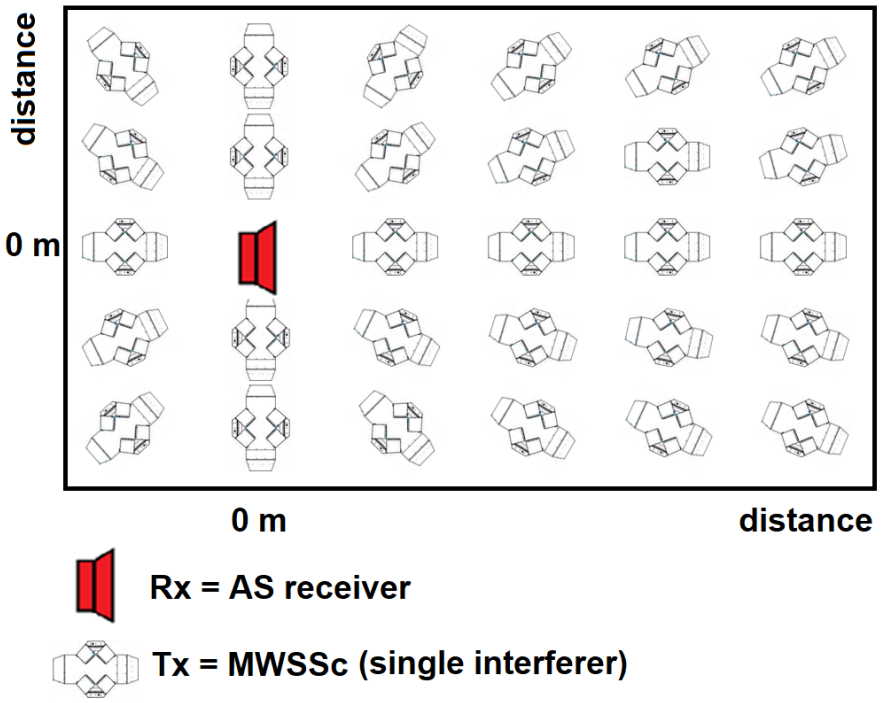


Figure 18: MCL scenario top view

The AS antenna is pointing to 0° in elevation. The MWSSc antenna is assumed at a height of 2 m. A schematic view from the side is given in Figure 19.

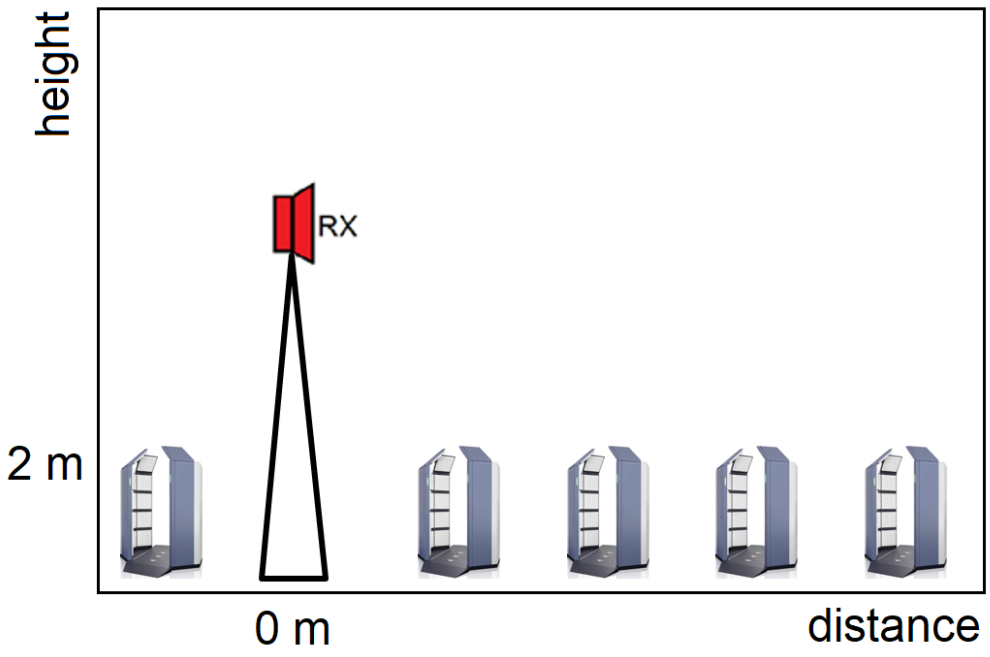


Figure 19: MCL with elevation scenario side view

The impact of a single interferer is calculated on each point of the area. The coloured areas in the resulting plots highlight the amount of exceedance of the protection criterion. A red contour highlights the potential area where the protection criterion is exceeded. The parameters used and also the results are noted on the plots, respectively. Maximum and minim separation distances found are noted as “Circle radius” and “max. separation”.

The resulting maximum received *e.i.r.p.* level found on the plot and its corresponding distance is noted as "max. exc.".

Main beam to main beam results represents the MCL calculation, where no vertical nor horizontal geometry was considered.

The calculations are repeated for different heights/frequencies of the AS receiver and for outdoor and indoor SSc scenarios. Table 22 gives an overview of the scenarios studied.

Table 22: MWSSc vs AS - scenarios

Scenario	Frequency	AS height	Building entry loss
Outdoor MWSSc	5.65 GHz	2 m - 12 m	-
Indoor traditional MWSSc – worst case	5.65 GHz	2 m - 12 m	Traditional building p = 50% angles calculated

At the following plots below, you will find the results for the different scenarios. The maximum separation distance with 211 m can be found in outdoor scenario with a frequency of 5.65 GHz and a height of 2 m for AS, which represent the Main beam to Main beam scenario.

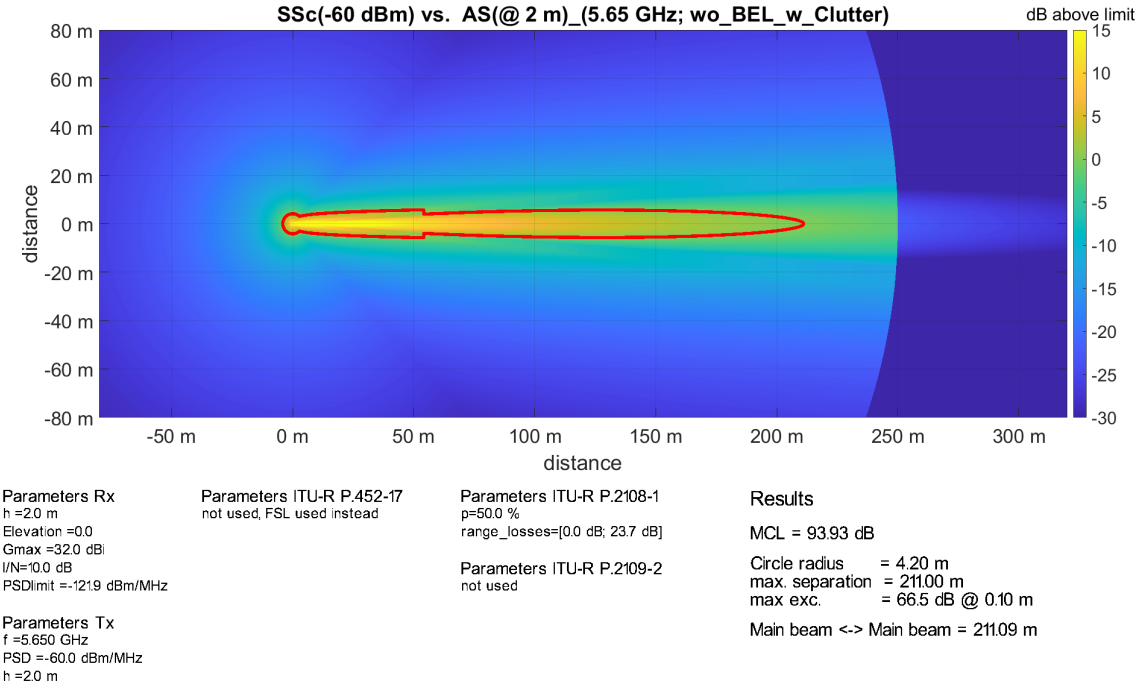


Figure 20: Results for outdoor MWSSc vs. AS @ 2 m height

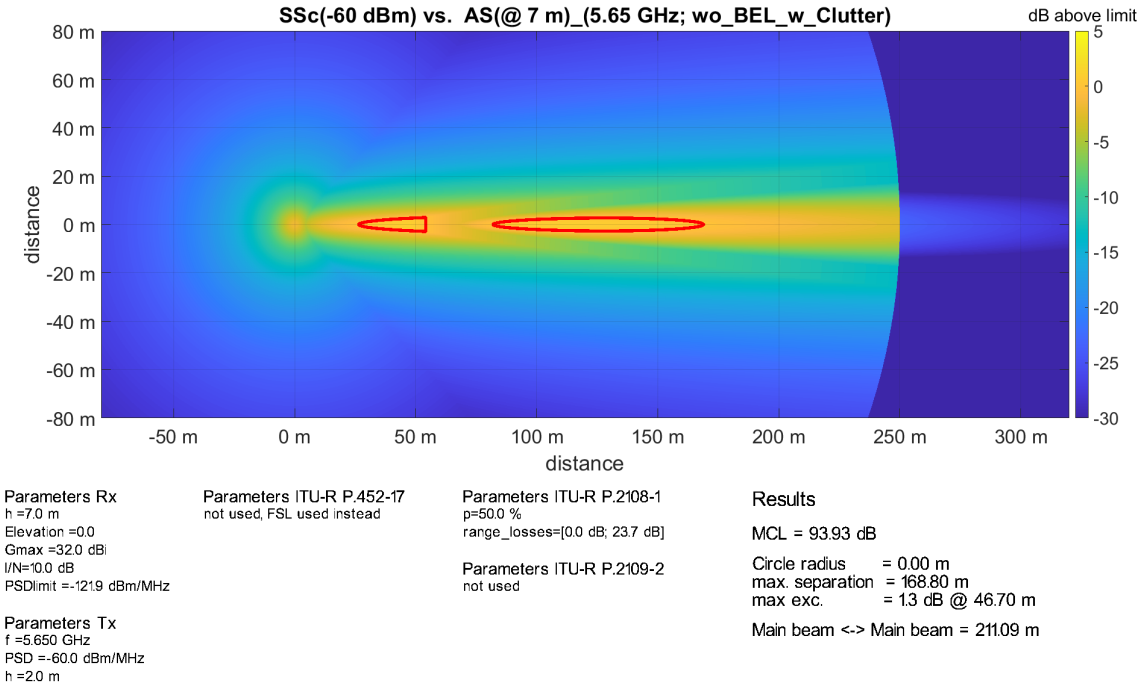


Figure 21: Results for outdoor MWSSc vs. AS @ 7 m height

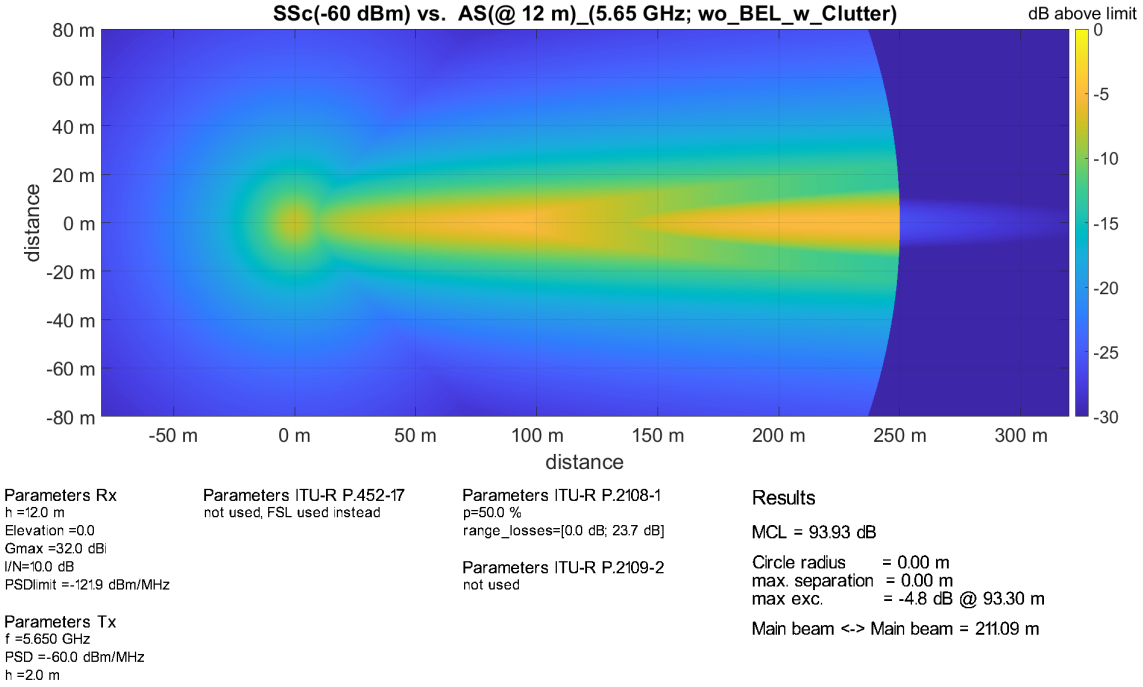


Figure 22: Results for outdoor MWSSc vs. AS @ 12 m height

Considering indoor scenarios for traditional buildings, the maximum separation distance of ~31 m was calculated at the height of 2 m for AS. The results for indoor SSc scenarios are given in Figure 23 and Figure 24.

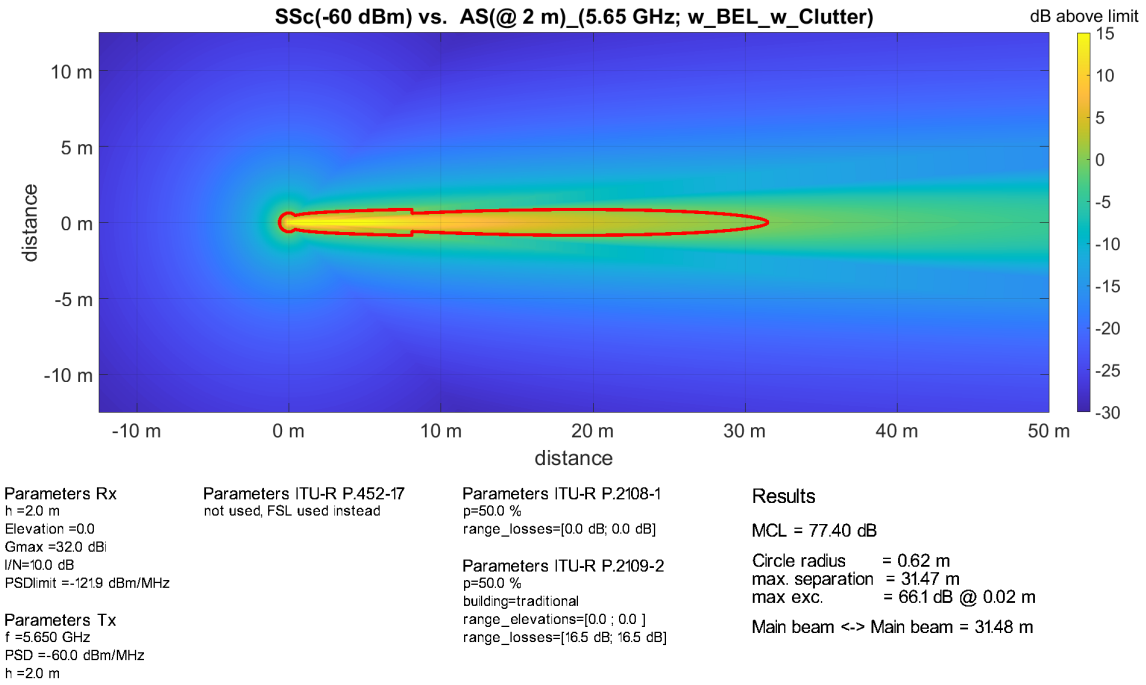


Figure 23: Results for indoor (traditional) MWSSc vs. AS @2 m height

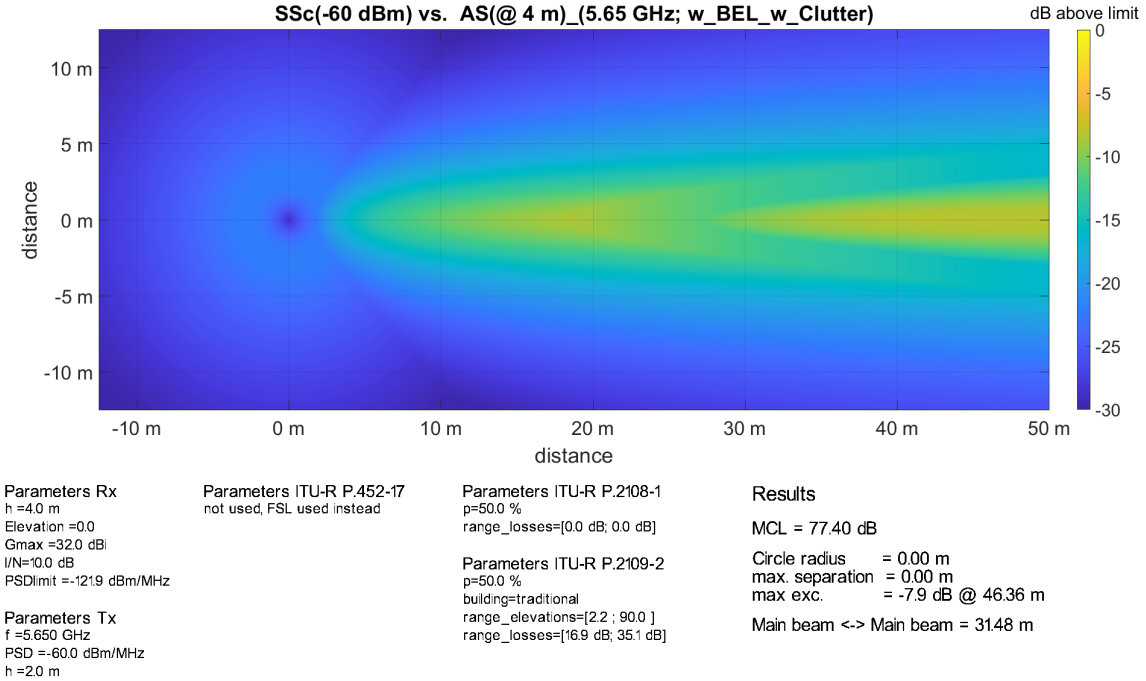


Figure 24: Results for indoor (traditional) MWSSc vs. AS @4 m height

According to the MCL interference intensity study separation distances are summarised in Table 23.

Table 23: MWSSc @ -60 dBm/MHz vs AS (P2P) - summary of results

Scenario	Frequency	AS height	Separation distance
Outdoor MWSSc	5.65 GHz	2 m 4 m 6 m 7 m 8 m 12 m	~ 211 m ~ 206 m ~ 185 m ~ 170 m 0 m 0 m
Indoor traditional MWSSc	5.65 GHz	2 m 4 m 12 m	~ 31.5 m 0 m 0 m

4.2.4 Additional study with elevation of the AS antenna for EME and SAT

An additional study was conducted with varying elevation angles of the AS antenna to analyse the Earth-Moon-Earth (EME) scenario at an elevation angle of 10°, and the Earth-Satellite (SAT) scenario at an elevation angle of 30°.

For the sake of simplicity, the 5.65 GHz frequency was selected. Although this frequency yields marginally lower performance compared to 5.83 GHz, the difference in results is minimal and does not significantly affect the overall data integrity or conclusions of the analysis.

Figure 25 and Figure 26 below show the scenarios.

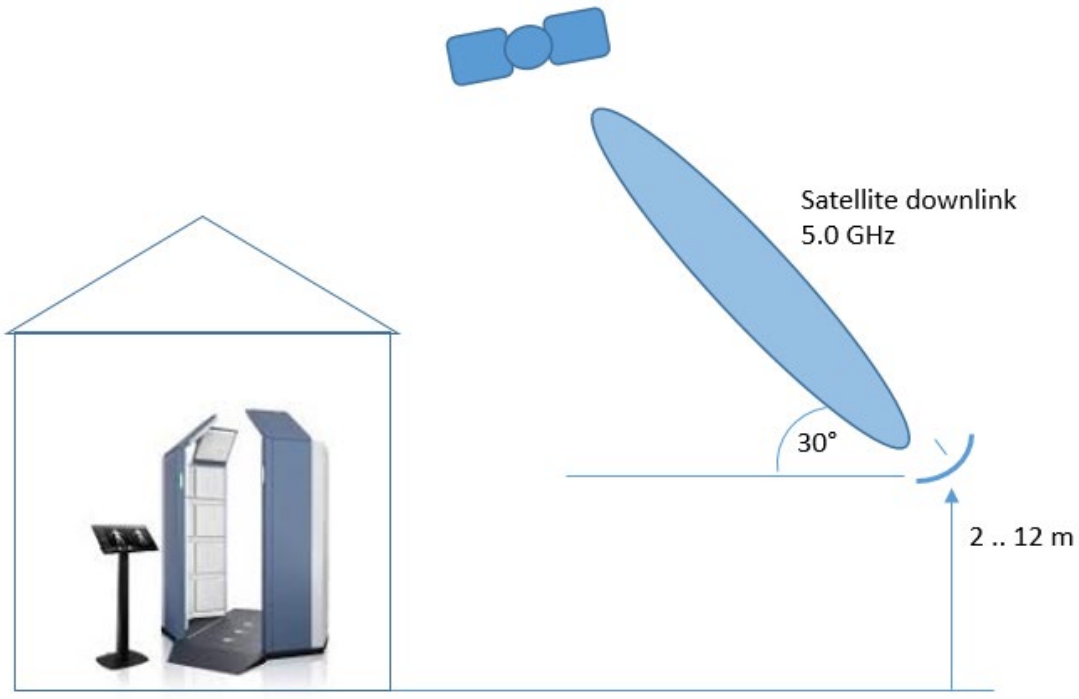


Figure 25: Setup for calculation Satellite downlink with MWSSc inside a building

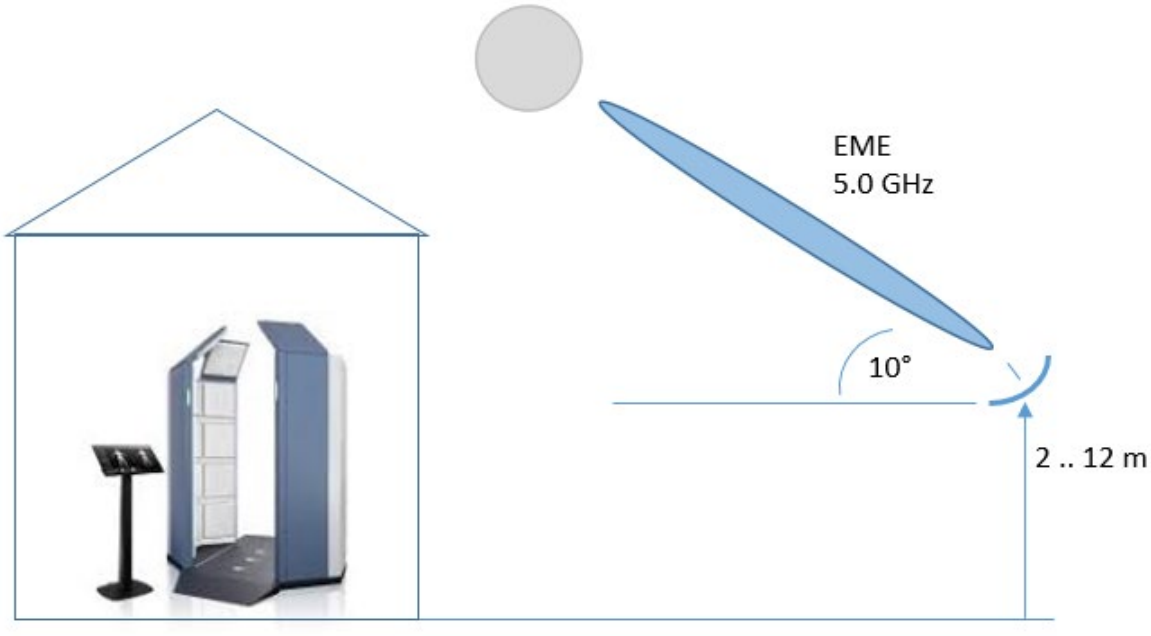


Figure 26: Setup for calculation EME link with MWSSc inside a building

For both scenarios an MCL interference intensity study was conducted. Additionally, an outside scenario was calculated for both scenarios. The results for the different scenarios are presented in the plots from Figure 27, Figure 28, Figure 29 and Figure 30.

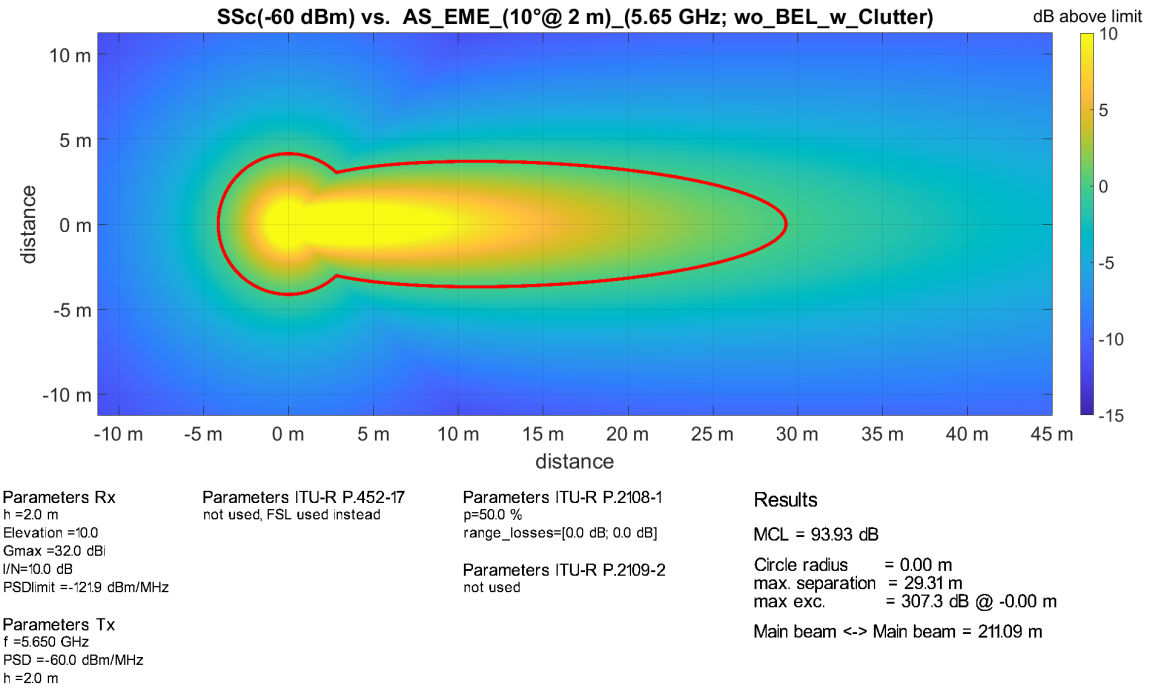


Figure 27: Results for outdoor MWSSc vs. AS for EME(10°) and 5.65 GHz

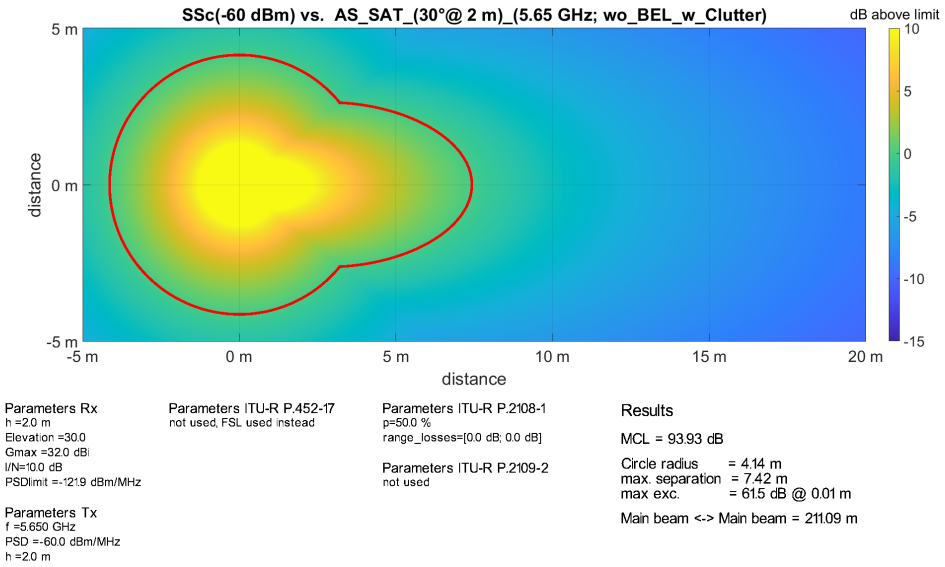


Figure 28: Results for outdoor MWSSc vs. AS for SAT(30°) and 5.65 GHz

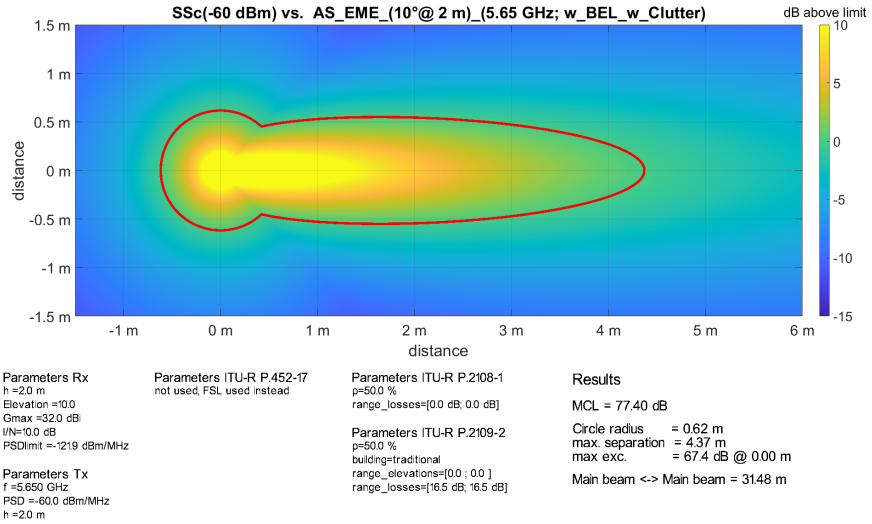


Figure 29: Results for indoor (traditional) vs. AS for EME(10°) and 5.65 GHz

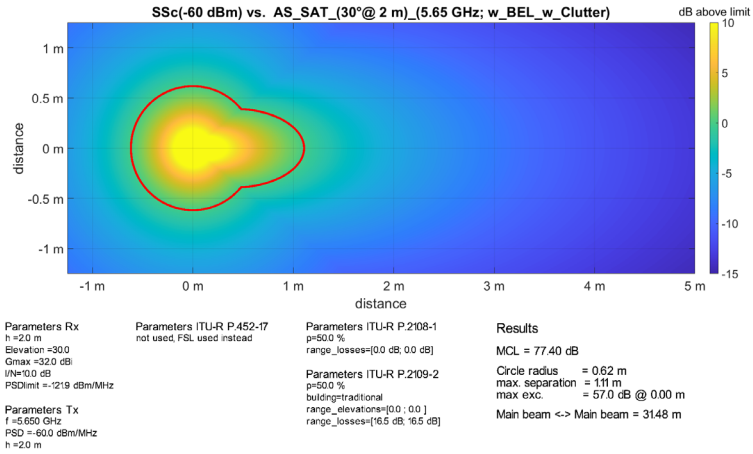


Figure 30: Results for indoor (traditional) vs. AS for SAT(30°) and 5.65 GHz

In Table 24 and Table 25, the separation distances are displayed. The scenario with the maximum separation distance occurs when the SSc is positioned outdoors, and the AS operates at 5.65 GHz with an elevation angle of 10° for the satellite link. Furthermore, these tables provide the separation distances for 5.65 GHz frequencies, for both indoor and outdoor scenarios, with results for elevation angles of 10° and 30°.

Table 24: MWSSc @ -60 dBm/MHz vs AS @ 2 m - summary of results for EME(10°)

Scenario	Frequency	AS height	Separation distance
Outdoor SSc	5.65 GHz	2 m	~ 29 m
Indoor traditional SSc	5.65 GHz	2 m	~ 4.5 m

Table 25: MWSSc @ -60 dBm/MHz vs AS @ 2 m - summary of results for SAT(30°)

Scenario	Frequency	AS height	Separation distance
Outdoor SSc	5.65 GHz	2 m	~ 7.5 m
Indoor traditional SSc	5.65 GHz	2 m	~ 1 m

4.2.5 Conclusions on sharing with the amateur service (AS)

MCL studies for indoor MWSSc at -50, -55 and -60 dBm/MHz indicate minimum risk of interference towards the AS. Separation distances are lower than 100 m and restricted to a small angle within the AS pointing direction. Clutter losses were not considered. This result indicates that sharing is possible due to a low probability of both services operating within the separation distance.

MCL studies for outdoor MWSSc at -60 and -55 dBm/MHz indicate a risk of interference towards the AS up to a separation distance of 100 m and 200 m, restricted to a small angle within the AS pointing direction. Clutter losses were not considered. Those results indicate that sharing is possible due to a low probability of both services operating within the separation distance.

MCL studies for outdoor MWSSc at -50 dBm/MHz indicate an increased risk of interference towards the AS up to a separation distance of 700 m under LOS conditions, restricted to a small angle within the AS pointing direction. Due to the relatively large separation distance no conclusion can be drawn for this scenario.

Similar results are expected for the 10 GHz band, because the constant increase in free space loss (~5 dB) and the increase of the typical AS antenna gain (~6 dB) will cancel out each other. In addition, due to the higher antenna gain, the beam width becomes smaller which decreases the angle of the interference area in comparison with the 5 GHz results.

4.3 FIXED SERVICE AT 5.925 GHZ

4.3.1 MCL study

In this single interferer study the separation distance between a MWSSc and a fixed service (FS) receiver will be calculated based on a MCL approach.

Therefore, it is assumed that the FS receiver is pointing towards the MWSSc. The pointing direction of the MWSSc is towards the FS receiver. Two scenarios are considered. For the first scenario the security scanner is placed outdoors and will be calculated without any building entry loss (BEL).

Both are assumed to operate at 2 m height in this worst-case assessment.

The MWSScs mean *e.i.r.p.* emission level in this single interferer study is assumed to be -60.0 dBm/MHz. In addition, the study investigates the mean *e.i.r.p.* of -55 and -50 dBm/MHz.

For indoor scenarios the traditional building type is used to reflect worst-case conditions. For modern, thermally efficient buildings (metallised glass, foil-backed panels) significantly higher losses are expected.

Clutter losses are not considered for this calculation.

The propagation model used is the Free Space Loss model described in Recommendation ITU-R P.525 [16].

Table 26 summarises the parameters which are used for the MCL calculation.

Table 26: MCL Parameters for FS study

Parameter	Value	Source / Formula
Frequency	5.925 GHz	Lowest allocated frequency in relevant range
Rx PSD_noise	-114 dBm/MHz	$PSD_{noise} = 10 * \log_{10}(k * B * T)$
Rx Feeder/multiplexer loss typical	1.3 dB	ECC Report 302 [20]
Rx Receiver noise figure typical	4 dB	ECC Report 302 [20]
Rx I/N (protection criterion)	20 dB	Recommendation ITU-R F.758-7, table 5 [22]
Rx FS antenna gain	46.6 dBi	ECC Report 302 [20]
Rx PSD_max	-175.3 dBm/MHz	$PSD_{max} = PSD_{noise} + NF + feeder - \frac{I}{N} - G_{Rx}$
Tx PSD_SSc	-60 dBm/MHz -55 dBm/MHz -50 dBm/MHz -41.3dBm/MHz (Indoor)	
MCL outdoor (-60 dBm(MHz)	115.3 dB	$MCL_{outdoor} = PSD_{SSc} - PSD_{max}$
MCL outdoor (-55 dBm(MHz)	120.3 dB	$MCL_{outdoor} = PSD_{SSc} - PSD_{max}$
MCL outdoor (-50 dBm(MHz)	125.3 dB	$MCL_{outdoor} = PSD_{SSc} - PSD_{max}$
BEL = Building Entry-Loss Probability = 0,5 / Traditional building type Frequency: 5.925 GHz and horizontal paths	16.6 dB	Recommendation ITU-R P.2109-2 [9]
MCL indoor (-60 dBm(MHz)	98.7 dB	$MCL_{indoor} = MCL_{outdoor} - BEL$
MCL indoor (-55 dBm(MHz)	103.7 dB	$MCL_{indoor} = MCL_{outdoor} - BEL$
MCL indoor (-50 dBm(MHz)	108.7 dB	$MCL_{indoor} = MCL_{outdoor} - BEL$
MCL indoor (-41.3 dBm(MHz)	117.4 dB	$MCL_{indoor} = MCL_{outdoor} - BEL$

The values above show the worst-case scenario where the beam of FS antenna is aligned direct to the SSc. These scenarios do not represent the real situation for fixed service. Therefore, in the next chapter the MCL interference intensity study is done.

Table 27: SSc vs FS - summary of results for classic MCL study

Scenario	Separation distance (PSD = -41.3 dBm/MHz)	Separation distance (PSD = -50 dBm/MHz)	Separation distance (PSD = -55 dBm/MHz)	Separation distance (PSD = -60 dBm/MHz)
Outdoor SSc	Not applicable	~ 7393 m	~ 4157 m	~ 2338 m
Indoor traditional SSc	~ 2971 m	~ 1091 m	~ 614 m	~ 345 m

4.3.2 MCL Interference Intensity Study

To be able to interpret the results from the previous MCL study, single interferer calculations were done for an area around a Fixed Service receiver. In addition to the assumptions made in the previous MCL study, the vertical separation between the antennas is considered.

The clutter model described in Recommendation ITU-R P.2108 [14] was used for the calculations at p=50%. For the single scenario, where interference areas occurred, an additional calculation was done without assuming clutter losses.

In this MCL study the impact of a single interferer is calculated on each point of the area considering the antenna patterns. For MWSSc transmitters omni-directional antennas were used, and for the Fixed Service receiver the antenna defined in Recommendation ITU-R F.699-8 [23] was used. A schematic view from the top is given in Figure 31.

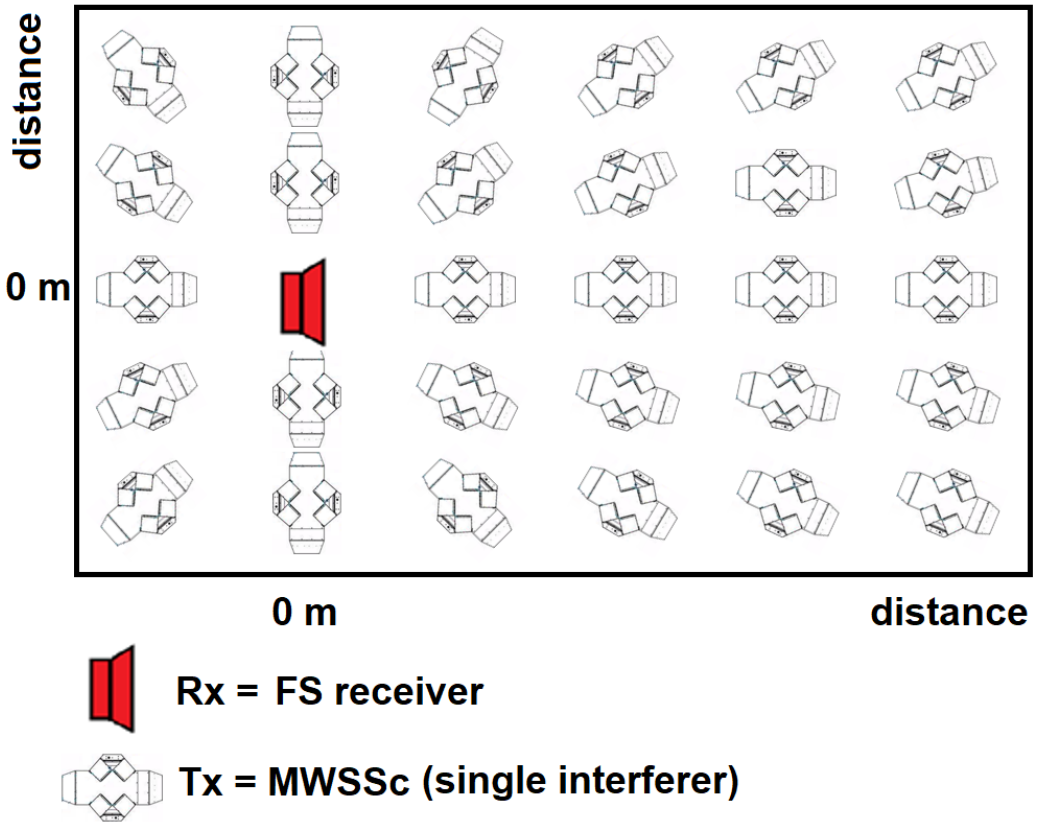


Figure 31: MCL scenario top view

The FS antenna is pointing to 0° in elevation. The MWSSc antenna is assumed at a height of 2 m. A schematic view from the side is given in Figure 32.

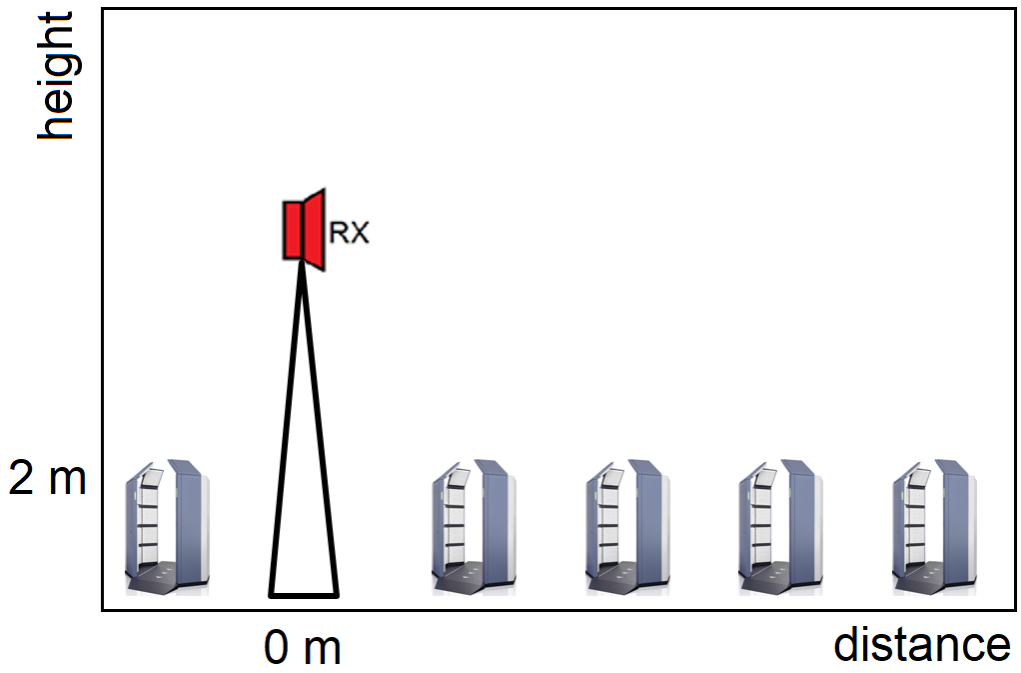


Figure 32: MCL with elevation scenario side view

The impact of a single interferer is calculated on each point of the area. The coloured areas in the resulting plots highlight the amount of exceedance of the protection criterion. A red contour highlights the potential area where the protection criterion is exceeded. The parameters used and also the results are noted on the plots, respectively. Maximum and minim separation distances found are noted as “Circle radius” and “max. separation”.

The resulting maximum received *e.i.r.p.* level found on the plot and its corresponding distance is noted as "max. exc.".

Main beam to main beam results represent the MCL calculation, where no vertical nor horizontal geometry was considered.

The calculations are repeated for different heights of the FS receiver and for outdoor SSc and indoor SSc scenarios. Table 28 gives an overview of the scenarios studied.

Table 28: SSc vs FS - scenarios

Scenario	FS height	Building entry loss
Outdoor MWSSc	15 m / 55 m / 110 m	-
Indoor traditional MWSSc – worst case	15 m / 55 m / 110 m	Traditional building p = 50% angles calculated

Taking into account the outdoor SSc scenarios, for the worst-case scenario with -50 dBm and -55 dBm areas in the FS azimuthal directivity could be found where interference seem to be possible. The maximum distance found was at 250 m where the clutter is taken into account for the calculation (see Figure 33). Without clutter / with LOS conditions the distance is up to 7.2 km (see Figure 35). The angle of interference is very narrow.

The maximum received *e.i.r.p.* level was found to be about 5 dB above the limit at a distance of 250 m in the scenario with a FS antenna height of 15 m and PSD of -50 dBm/MHz.

For a PSD of -60 dBm/MHz the maximum received *e.i.r.p.* level was found to be about 7 dB below the limit at a distance of 250 m in the scenario with a FS antenna height of 15 m. Even under LOS conditions no interference could be found.

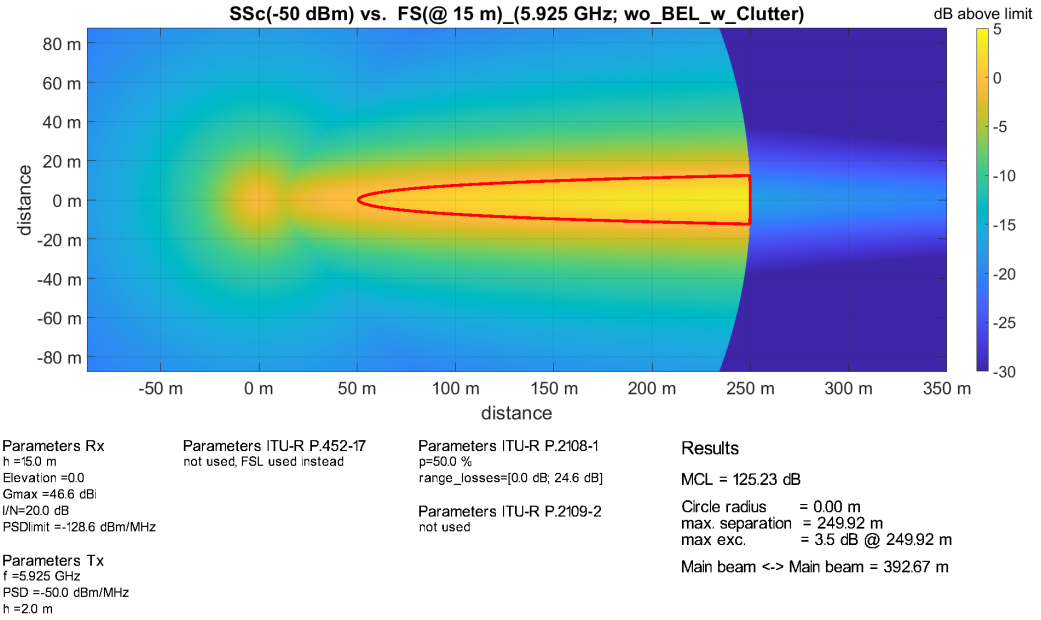


Figure 33: Results for outdoor SSc vs. Fixed Service @15 m height and -50 dBm/MHz

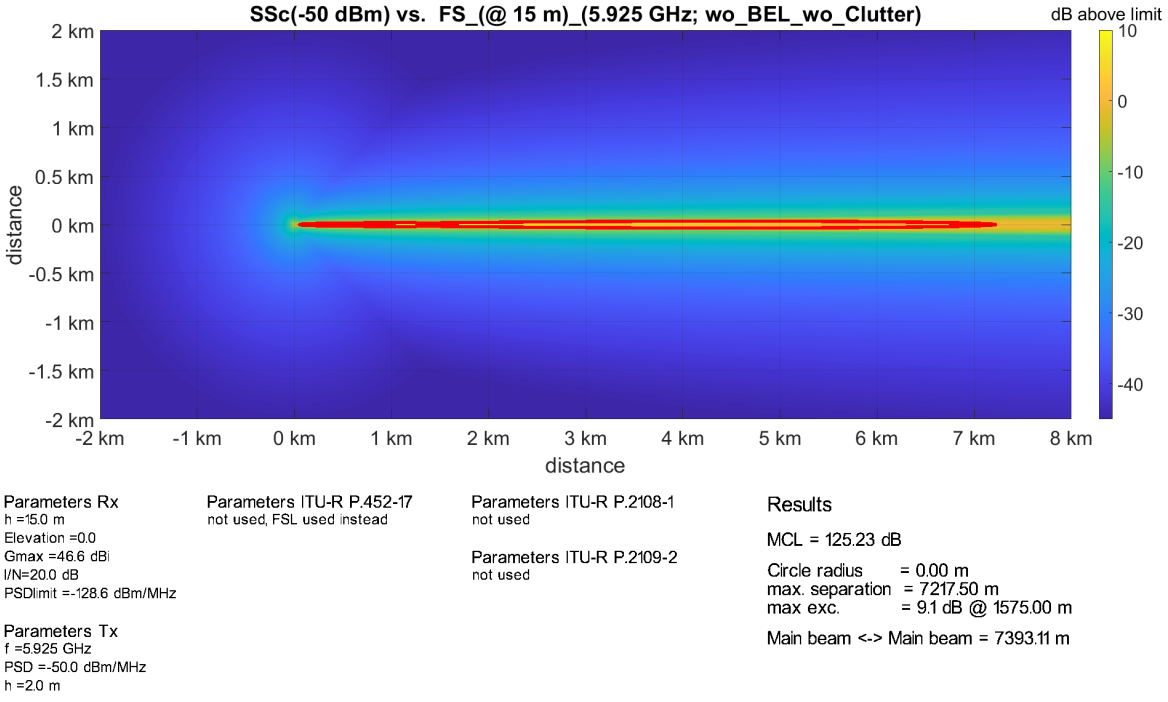


Figure 34: Results for outdoor SSc vs. Fixed Service @15 m height and -50 dBm/MHz

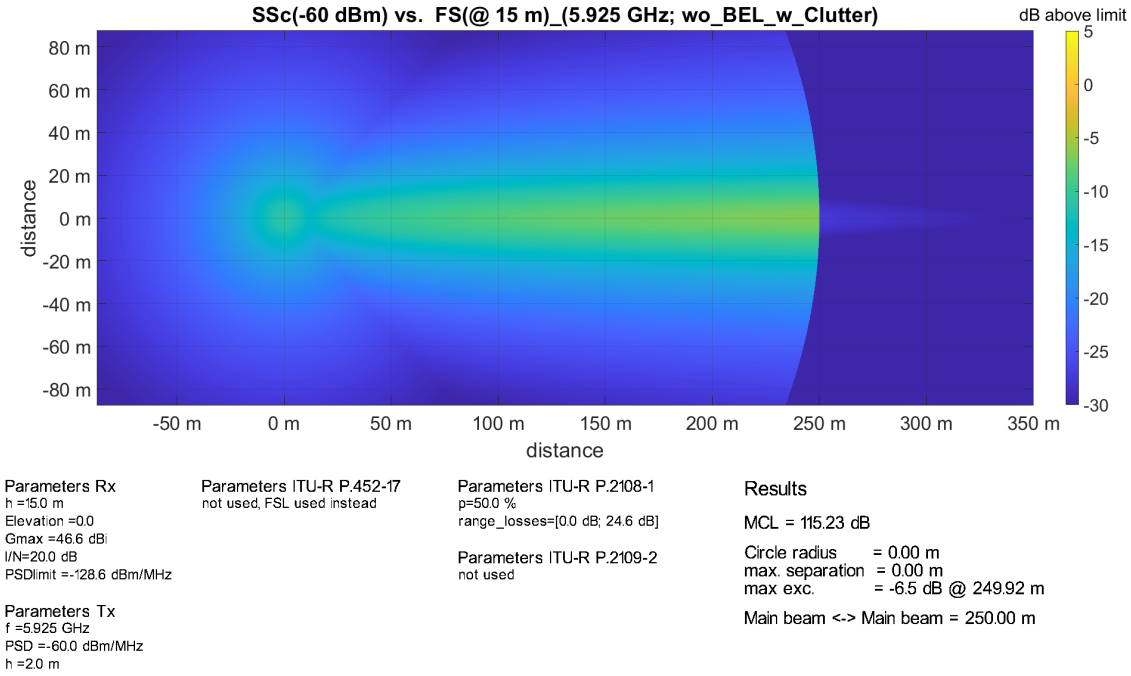


Figure 35: Results for outdoor SSc vs. Fixed Service @15 m height and -60 dBm/MHz

Considering the indoor SSc scenarios for traditional buildings, no separation distance could be found for all studied FS antenna heights and different PSD (-50, -55, -60 dBm/MHz).

Considering the indoor scenario where MWSSc operates with PSD = 41.3 dBm/MHz, and a FS antenna height of 15 m, the separation distance could be found in an area between ~1200 m – 2362 m, displayed in Figure 36. For other antenna heights no separation distance could be found (Figure 7). Furthermore, when applied clutter, no separation distance will be found for indoor scenario.

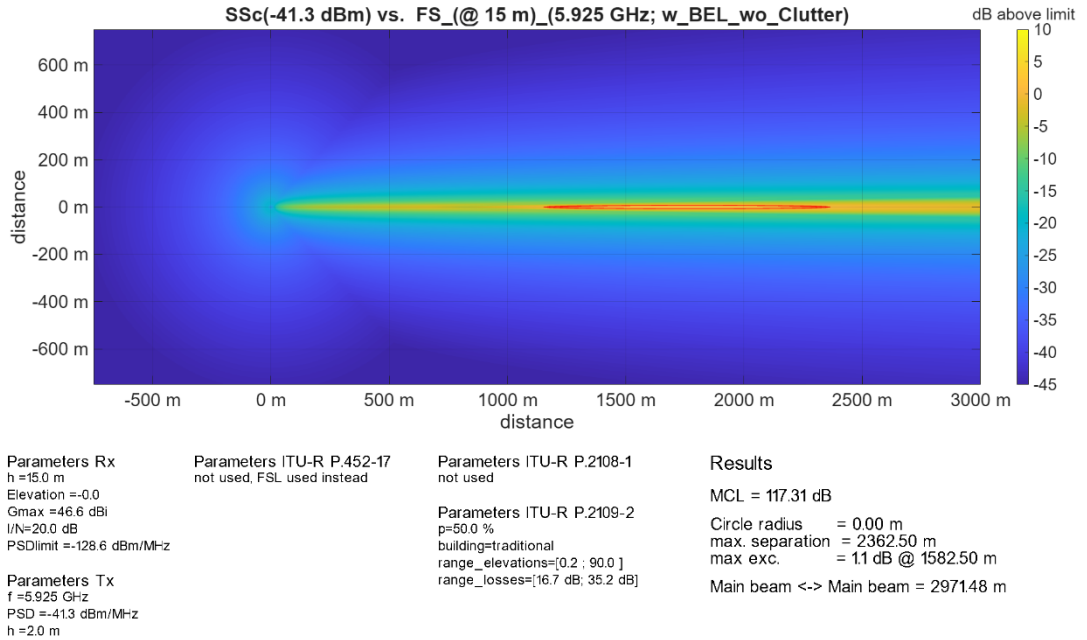


Figure 36: Results for indoor SSc vs. Fixed Service @15 m height and -41.3 dBm/MHz

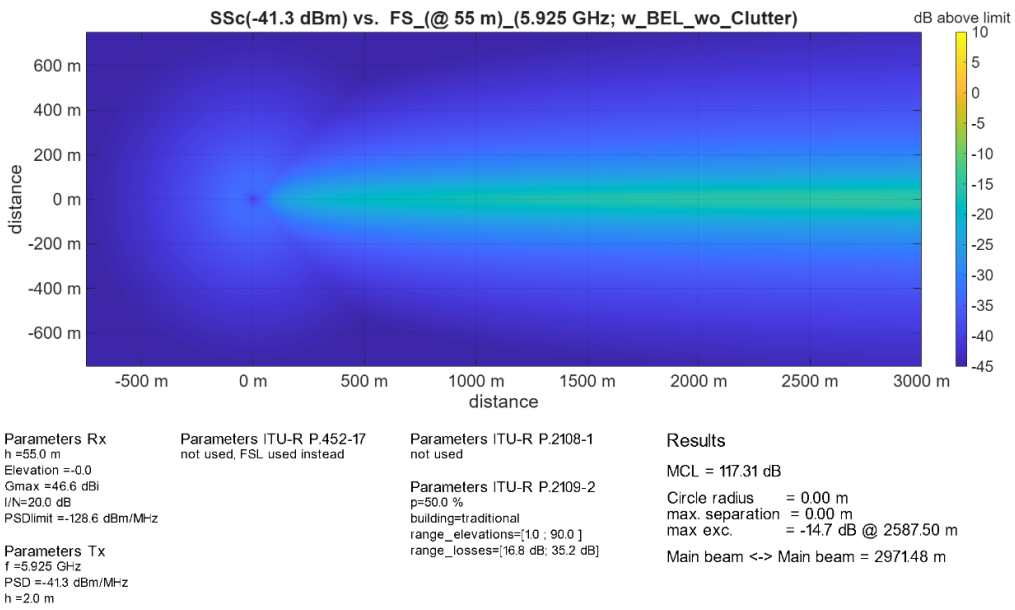


Figure 37: Results for indoor SSc vs. Fixed Service @55 m height and -41.3 dBm/MHz

Table 29: SSc vs FS - summary of results for MCL Interference Intensity study

Scenario	FS height	Separation distance (PSD = -41.3 dBm/MHz)	Separation distance (PSD = -50 dBm/MHz)	Separation distance (PSD = -55 dBm/MHz)	Separation distance (PSD = -60 dBm/MHz)
Outdoor MWSSc	15 m	Not applicable	250 m (Recommendation ITU-R P.2108 [14] limitation) 7200 m (no clutter)	0 m 3800 m (no clutter)	0 m 0 m (no clutter)
	55 m	Not applicable	0 m 0 m (no clutter)	0 m 0 m (no clutter)	0 m 0 m (no clutter)
	110 m	Not applicable	0 m 0 m (no clutter)	0 m 0 m (no clutter)	0 m 0 m (no clutter)
Indoor traditional MWSSc	15 m	0 m 1200 m - 2362 m (no clutter)	0 m 0 m (no clutter)	0 m 0 m (no clutter)	0 m 0 m (no clutter)
	55 m	0 m 0 m (no clutter)	0 m 0 m (no clutter)	0 m 0 m (no clutter)	0 m 0 m (no clutter)
	110 m	0 m 0 m (no clutter)	0 m 0 m (no clutter)	0 m 0 m (no clutter)	0 m 0 m (no clutter)

4.3.3 Conclusions on sharing with the Fixed Service

MCL studies for indoor MWSSc at -50, -55 and -60 dBm/MHz indicate no risk of interference towards the FS, even under LOS conditions.

MCL studies for indoor MWSSc at -41,3 dBm/MHz indicate a risk of interference towards FS receivers, exceeding the protection criterion by 1.1 dB. Interference could than happen between 1200 m and 2362 m distance from the FS and within a small angle of the FS pointing direction. For greater FS antenna heights above 55 m no risk of interference is expected.

MCL studies for outdoor MWSSc at -60 dBm/MHz indicate no risk of interference towards the FS, even under LOS conditions.

MCL studies for outdoor MWSSc at -50 and -55 dBm/MHz indicate a risk of interference towards FS receivers, exceeded the protection criterion by up to 9.1 dB. Interference could then happen up to 7.5 km distance from the FS and within a small angle of the FS pointing direction. For greater FS antenna heights above 55 m no risk of interference is expected. The calculated 250 m of possible interference for the cluttered scenario only occurs due to Recommendation ITU-R P.2108 [14] being not applicable up to 250 m, which led to LOS conditions in the clutter scenario, which is not correct.

4.4 EESS (ACTIVE) IN THE 9.2-10.4 GHZ BAND

4.4.1 Technical and operational characteristics

Recommendation ITU-R RS.2105-3 [24] provides the “Typical technical and operational characteristics of Earth exploration-satellite service (active) systems using allocations between 40 MHz and 238 GHz”. The list of sensors operating in the frequency range 9200-10400 MHz is showed below in Table 30.

Table 30: Characteristics of EESS (active) missions in 9200-10400 MHz band

Parameter	SAR-F1	SAR-F2	SAR-F3	SAR-F4	SAR-F5	SAR-F6	SAR-F7	SCAT-F8
Sensor type	SAR	SAR	SAR	SAR	SAR	SAR	SAR	Scatter meter
Type of orbit	Circular, SSO	Circular, SSO	SSO	SSO	SSO	Circular, SSO	Circular	Circular
Altitude (km)	514	620	512	620	514	514	650..850	835
Inclination (degrees)	97.4	97.8	97.9	97.8	97.44	97.4	97..99	98.85
Ascending node LST	18:00	06:00	06:00	06:00	18:00	18:00	N/A	19:30
Repeat period (days)	11	16	5	16	11	11	–	–
Antenna type	Active phased array	Planar array	Offset linear array fed reflector	Planar array	Active phased array	Active phased array	Phased array	Phased array
Number of beams	1	1	1	1	1	1	1	1
Antenna (Transmit and Receive) peak gain (dBi)	45.5	45.5	46	46.8	43.4	47	45.6	39.5/38.5

Parameter	SAR-F1	SAR-F2	SAR-F3	SAR-F4	SAR-F5	SAR-F6	SAR-F7	SCAT-F8
Polarisation	Linear VV	Linear HH	Linear VV, VH	Linear HH	Linear HH, VV	Linear HH, VV	Linear HH, VV	Linear, VV
Azimuth scan rate (rpm)	0	0	0	0	0	0	0	0
Antenna beam look angle (degrees)	15-60	21-44	30-40	37.8	15-45	18-50	15-55	90
Antenna elev. beamwidth (degrees)	2.54	1.32	1.5	1.34	2.5	1.13	1-1.2	26
Antenna az. beamwidth (degrees)	0.37	0.32	0.5	0.32	0.4	0.53	0.4-0.45	0.13
RF centre frequency (MHz)	9650	9600	9600	9500	9650	9800	9600	9623.275
RF bandwidth (MHz)	150, 300	41-118	10	40-300	5-300	1 200	600	0.5
Transmit Pk pwr (W)	2000	7600	3000	7600	2260	7000	1800	1600
Transmit Ave. pwr (W)	400	836	270	836	452	2 100	–	–
Pulse width (µs)	47	18-31	20-30	18-31	47	50	36	2
Pulse repetition frequency (Hz)	2000-6500	2850-3230	1000-3000	1000-3000	3000-6500	6000	–	–
Chirp rate (MHz/µs)	3.2, 6.8	3.81	0.5-0.67	3.81-9.7	0.85-6.38	24	16.6	N/A
Transmit duty cycle (%)	20	7-11	2-9	7-11	20	30	Variable, max. 15%	Variable, max. 15%
Max. 15%	2.9	1.0	3	1.0	5.0	3	4	4

In addition, Recommendation ITU-R RS.2043-0 [29] also provides complementary information on the "Characteristics of synthetic aperture radars (SARs) operating in the Earth exploration-satellite service (active) around 9 600 MHz" and how SAR systems operate in general. The description of this complex EESS (active) application is given in the Annex of the Recommendation.

In this study, the characteristics to consider for the Earth Exploration Satellite Service (EESS) (active) satellite are the ones corresponding to the sensor SAR-F6 illustrated in Table 30.

The antenna Beam Look Angle (BLA, equivalent to off-nadir angle) of the SAR satellite is between 18 and 50 degrees. The SAR F6 uses a spotlight mode of operation as defined in Recommendation ITU-R RS.2043. The most common pointing practice is having the satellite spotlight pointing orthogonally to the satellite track. In other words, in the case of a highly inclined orbit with a ground track from south to north, the SAR satellite would point eastward or westward. The following figure provides an illustration of such a mode of operation:

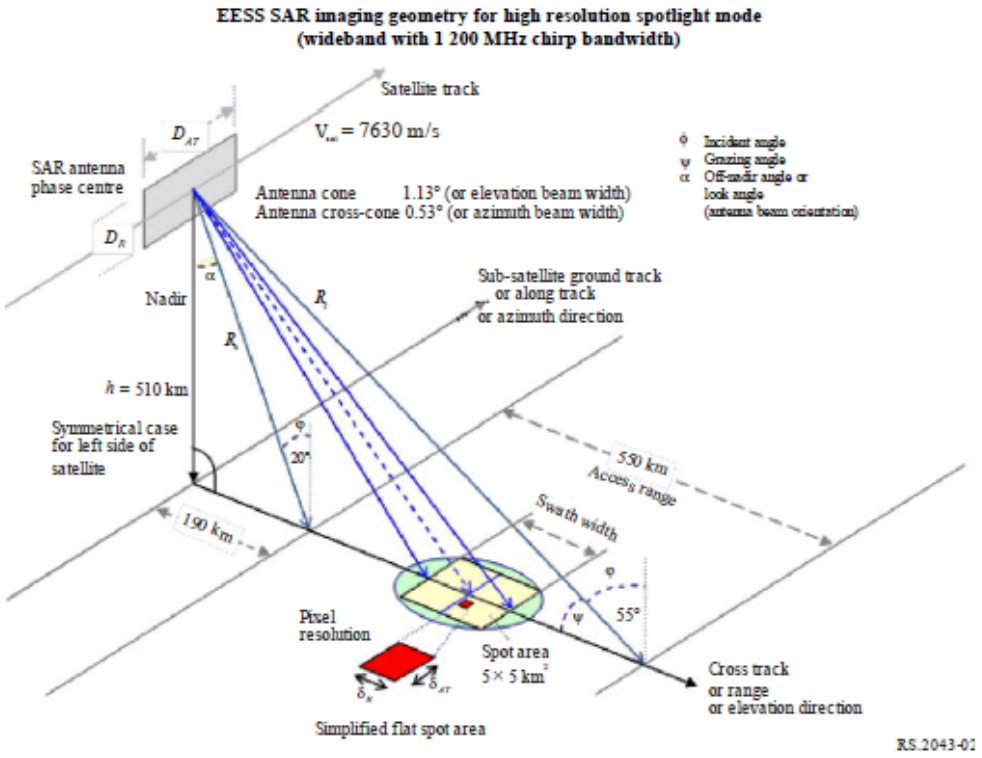


Figure 38: SAR Satellite mode of operation

4.4.2 Protection criteria

Recommendation ITU-R RS.1166-6 [30] provides “Performance and interference criteria for active spaceborne sensors” in the EESS (active) allocations between 40 MHz and 238 GHz.

Table 31 under recommends 2 of Recommendation ITU-R RS.1166-6 [30] provides “the interference and data availability criteria given in Table 2 be applied for instruments used for active sensing of the Earth’s aquifers, ice sheets, land, oceans and atmosphere”. For SAR systems, it is as follows:

Table 31: Interference and data availability criteria for EESS (active) missions (Source: Recommendation ITU-R RS.1166-6, table 2)

Sensor type	Interference criteria		Data availability criteria (%)	
	Performance degradation	I/N (dB)	Systematic	Random
Synthetic aperture radar	10% degradation of standard deviation of pixel power Snow Water Equivalent (SWE) retrieval radar: 10% error on minimum SWE retrieved	–6	99	95

It has to be emphasised that the interference criteria given in Recommendation ITU-R RS.1166-6 [30] represent the total interference levels admissible by EESS (active) sensors from all sources (aggregate interference). Hence, when addressing multiple potential sources of interference to EESS (active) sensors in a given band, the total allowable interference level needs to be apportioned among these sources (various Services and number of transmitters). Considering that the apportionment factors are typically in the range between 1 and 5%, equivalent to 13 to 20 dB, the apportionment of 13 dB has been used for the relevant studies in this Report, so the maximum interference-to-noise level with apportionment, taking in due account other services and systems in operation, is an I/N of -19 dB.

4.4.3 Compatibility study between MWSSc and EESS (active)

In the compatibility studies, the characteristics to consider for the Earth Exploration Satellite Service (EESS) (active) satellite are the ones corresponding to the sensor SAR-F6 illustrated in Recommendation ITU-R RS.2105-3 [24]. The study is done for the two extreme beam look angles (BLA), 18 and 50 deg.

Table 32: Characteristics of EESS (active)

SAR-F6 - EESS (active)		
Parameter	**Value**	
Frequency [GHz]	9.8	
Satellite height [km]	514	
Max antenna gain [dBi]	47	
Noise figure [dB]	3	
	BLA 50 deg	**BLA 18 deg**
Elevation angle (from the ground) [deg]	34.1	72.0
Slant range [km]	851.7	538.3
Free space loss [dBi]	170.9	166.9

4.4.3.1 Single entry study – outdoors scenario

In this scenario, the assumption is that the MWSSc is operating outdoors (worst-case scenario) so no building entry loss is considered. Table 33 contains the maximum peak *e.i.r.p.* SD considered outdoors and which correction factors are to be considered in this scenario, based on the correction factors presented in Table 4. Overall, the calculation of the MWSSc spectral power density is as follows:

Table 33: Characteristics and applicable correction factors of the MWSScs for the single-entry study

UWB Scanners	
Parameter	**Value**
Antenna max peak *e.i.r.p.* SD [dBm/50 MHz]	-15.0
CF BW [dB]	17.0
CF ANT v [dB]	3
CF_GEO_v [dB]	5.2

System max peak *e.i.r.p.* SD (outdoors) [dBm/MHz] = Antenna max peak *e.i.r.p.* SD [dBm/50 MHz] – CF BW [dB] – CF ANT v [dB] – CF GEO v [dB] = -15.0 - 17 - 3 - 5.5 = -40.2 dBm/MHz

Note that for the correction factor due to the antenna gain, it has been considered the worst-case gain towards the satellite. At a BLA of 50 deg, the elevation angle is approximately 34 deg above the horizon, which is more or less the point at which the antenna of the vertical panel is at 3 dB below the maximum gain as can be seen in Figure 4. Therefore, this correction factor has been set to 3 dB.

The resulting I/N for the single-entry scenario, for both extremes of the BLA range (50 deg and 18 deg) is presented in Table 34.

Table 34: Resulting I/N for single entry interference from MWSSc to an EESS (Active) receiver

Scenario for ONE scanner	BLA 50 deg	BLA 18 deg
Peak power SD at receiver [dBW/MHz] (After antenna)	-194.12	-190.14
Thermal noise [dBW/MHz]	-140.93	-140.93
I/N peak at receiver [dB]	-53.19	-49.2

The single-entry interference scenario from MWSSc towards EESS (active) sensors shows that there is a total margin with regards to the EESS (active) protection criteria of 29 dB for the BLA 50 deg case and of 25 dB for the BLA 18 deg case.

It shows that even in the case where the worst-case scenario has been considered, it's expected that a single-entry MWSSc will not cause harmful interferences to the SAR satellites.

4.4.3.2 Aggregate study – outdoors scenario

In this case, the study aims to evaluate the aggregate scenario. For that, the maximum peak *e.i.r.p.* value is transformed into a maximum mean *e.i.r.p.* value. Table 35 contains the maximum peak *e.i.r.p.* SD considered outdoors and which correction factors are to be considered in this scenario. Overall, the calculation of the aggregated MWSSc spectral power density is as follows:

Table 35: Characteristics of the MWSScs for the aggregate study

UWB Scanners	
Antenna max peak *e.i.r.p.* SD [dBm/50 MHz]	-15.0
CF BW [dB]	17.0
CF PRF [dB]	28.0
CF ANT v [dB]	3
CF GEO [dB]	5.2
Number of scanners in cluster NB_SC_IN_CLUSTER [dB] *	10 10
Note: This considers a worst-case where the 10 scanners are perfectly synchronised	

System max. mean e.i.r.p. SD (outdoors) [dBm/MHz] = Antenna max peak e.i.r.p. SD [dBm/50 MHz] – CF BW [dB] – CF PRF [dB] – CF ANT v [dB] – CF GEO v [dB] + NB_SC_IN_CLUSTER [dB] = -58.2 dBm/MHz

Table 36: Resulting I/N for interference from cluster of MWSSc to an EESS (Active) receiver

Scenario for cluster of MWSSc	BLA 50 deg	BLA 18 deg
Peak power SD at receiver [dBW/MHz]	-212.12	-208.14
Thermal noise [dBW/MHz]	-140.93	-140.93
I/N peak at receiver [dB]	-71.19	-67.2

Table 37: Maximum MWSSc cluster density in satellite visibility

Scenario for cluster of MWSSc	BLA 50 deg	BLA 18 deg
I/N peak at receiver [dB]	-71.19	-67.2
Protection criteria - max I/N [dB]	-19	-19
Margin [dB]	52.19	44.78
Footprint size [km^2]	185.30	44.78
Max number of scanner clusters in footprint	165476	66112
Scanner cluster density [scanner clusters/km^2]	893.02	1476.37

For one single cluster, the results show a considerable margin. But it's important to also look at the density of scanners to be deployed in an area. The results show that for densities lower than ~893 clusters/km^2 the SAR satellites should not receive harmful interferences. This is higher than the expected density for this type of scanners.

4.4.4 Conclusion

This analysis focused on the outdoor scenario, which is the worst-case scenario. Both studies show that MWSScs are not expected to cause harmful interferences towards the EESS (active) satellites.

The single-entry study shows that one single MWSSc is not going to interfere the SAR satellite and the aggregate study shows that as long as the deployment density of this type of scanners does not exceed ~893 clusters/km^2, the SAR satellites will most likely not be interfered by the MWSScs.

4.5 RADARS AND MILITARY SYSTEMS IN THE 5.25-5.85 GHZ AND THE 8.5-10.6 GHZ FREQUENCY BANDS

4.5.1 Technical characteristics

4.5.1.1 Radars in the 5.25-5.85 GHz frequency band

The characteristics of the radars studied in the 5.25-5.85 GHz frequency band are derived from Recommendation ITU-R M.1638-1 [25] and Recommendation ITU-R M.1849-3 [19]. The radars considered correspond to Recommendation ITU-R M.1638-1, entries 19 and 22 and Recommendation ITU-R M.1849-3, radars 14, 17 and 21.

Table 38: Radar characteristics operating in the 5.25-5.85 GHz range

	Radar 19 from Recommendation ITU-R M.1638-1	Radar 22 from Recommendation ITU-R M.1638-1
Type	Fixed radar	Tactical radar
Maximum antenna gain	44.5 dBi	35 dBi
Horizontal Beamwidth	1°	2°
Vertical Beamwidth	1°	2°
Side Lobe Level	-25 dB	-25 dB

	Radar 19 from Recommendation ITU-R M.1638-1	Radar 22 from Recommendation ITU-R M.1638-1
Antenna pattern	Recommendation ITU-R M.1851-2, equation (4) [26] Recommendation ITU-R F.1245 [33]	Recommendation ITU-R M.1851-2, equation (4) [26] Recommendation ITU-R F.1245 [33]
Antenna diameter	4 m	2.1 m
Elevation angle	0°	0°
Antenna height	10 m	10 m
Noise Factor	3 dB	5 dB

In accordance with Recommendation ITU-R M.1638, a protection criterion of I/N = -6 dB is recommended. This criterion is an aggregated protection criterion that takes into account desensitization from all radio systems.

Table 39: Meteorological radar characteristics operating in the 5.42-5.725 GHz range

	Radar 17 from Recommendation ITU-R M.1849-3	Radar 21 from Recommendation ITU-R M. 1849-3
Type	Ground based	Ground based
Output device	Magnetron	Solid state
Maximum antenna gain	45 dBi	45 dBi
Antenna pattern	Pencil beam	Pencil beam
Antenna vertical scan type	-2° to +90°	-2° to +90°
Antenna side-lobe levels	-26 dB	-28 dB
HPBW	0.95°	0.5° - 1.0 °
Antenna height	10 m - 40 m	5 m - 45 m
Receiver IF 3 dB bandwidth	1.2 MHz	20 MHz
Noise Factor	2 dB	2.5 dB

Table 40: Meteorological radar characteristics operating in the 5.35-5.47 GHz range

	Radar 14 from Recommendation ITU-R M.1849-3
Type	Ground based
Output device	Magnetron
Maximum antenna gain	45 dBi
HPBW	1°
Antenna vertical scan type	-0.2° to 40°
Antenna side-lobe levels	- 28 dB SL suppression

	Radar 14 from Recommendation ITU-R M.1849-3
Antenna height	5 m - 45 m
Receiver IF 3 dB bandwidth	2.5 MHz
Noise Factor	1.8 dB

The radiation pattern of the radars is calculated according to Recommendation ITU-R M.1851-2 [26] using the values obtained for the peak pattern mask. In Figure 39, a graphical representation of the antenna radiation pattern is shown.

Additionally, studies are conducted using radar antenna pattern data obtained from measurements of an operating C-band meteorological radar. This measured radiation pattern shows lower side lobe suppression than the pattern calculated according to Recommendation ITU-R M.1851-2 [26]. The main lobe of both patterns are nearly identical with only minor differences, which are expected to affect the calculated margin by less than 0.5 dB. These differences are shown in Figure 40.

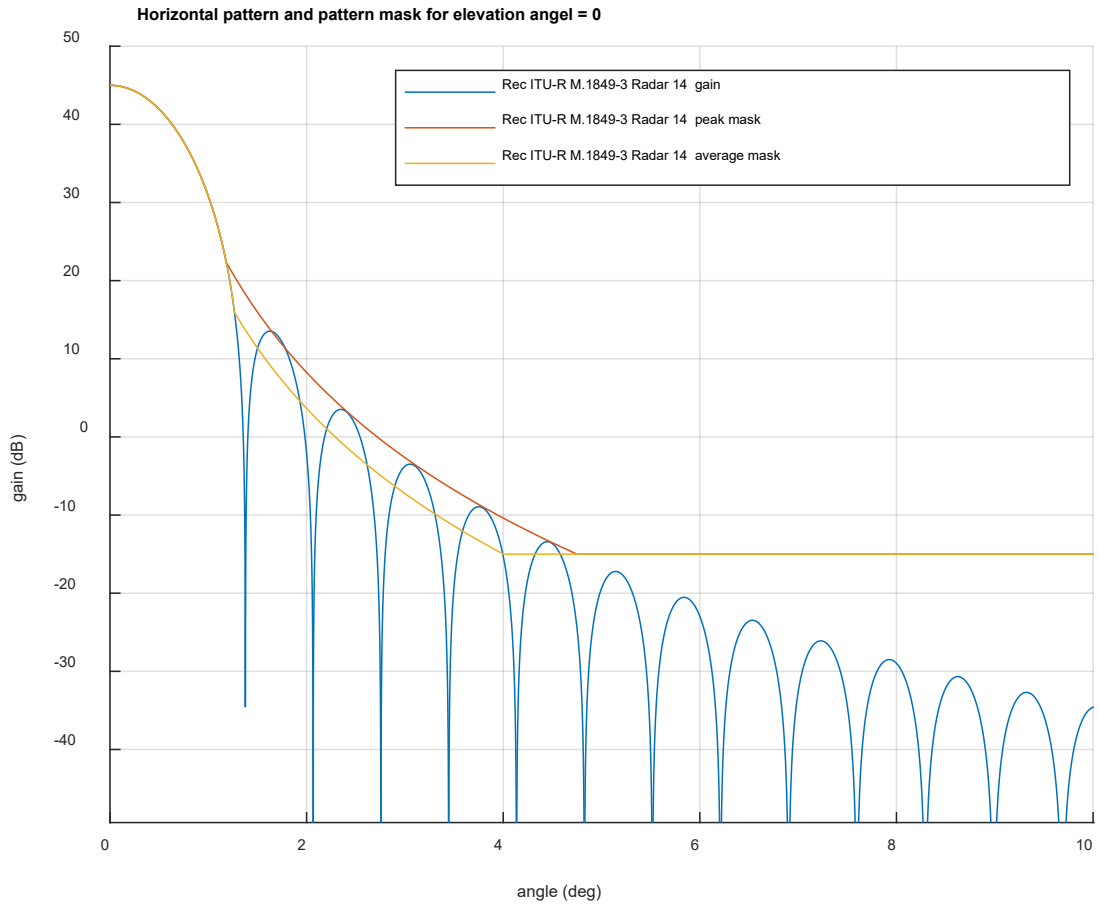


Figure 39: Recommendation ITU-R M.1849-3 Radar 14 radiation pattern. Blue line showing pattern, red line showing peak pattern and yellow line showing average pattern

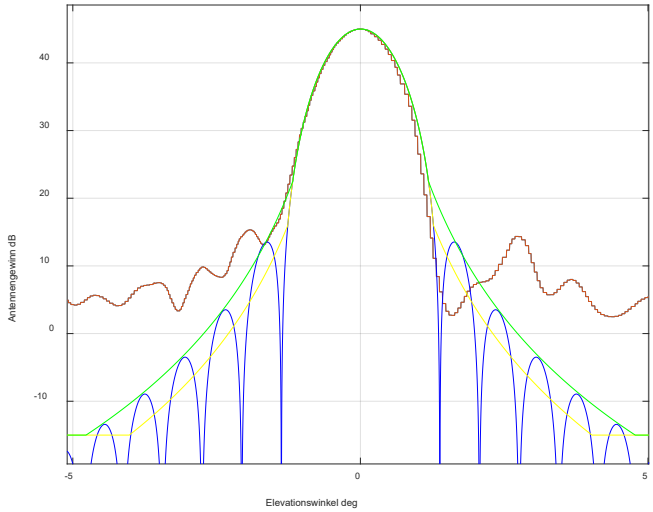


Figure 40: C-band meteorological radar antenna pattern. Red line showing pattern of a measured antenna, blue line showing pattern, green line showing peak pattern and yellow line showing average pattern according to Recommendation ITU-R M.1851-2 [26]

For the meteorological radars, the protection criterion I/N = -10-apportionment dB is used based on the I/N = -10 dB as given in Recommendation ITU-R M.1849-3 [19] which is an aggregate protection criterion from all radio sources.

4.5.1.2 Radars in the 8.5-10.6 GHz frequency band

The characteristics of the radars studied in the 8.5-10.6 GHz frequency band are derived from Recommendation ITU-R M.1796-3 [31]. The radars considered correspond to of ITU-R M.1796-3, entries G4, G5 and G14 [31] .

Table 41: Radar characteristics operating in the 8.5-10.6 GHz range

	Radar G4 from Recommendation ITU-R M.1796-3 **[31]**	**Radar G5 from** Recommendation ITU-R M.1796-3 **[31]**	**Radar G14 from** Recommendation ITU-R M.1796-3 **[31]**
Type	Tactical radar	Approach and landing radar	Fixed radar
Maximum antenna gain	42.2 dBi	40 dBi	43 dBi
Horizontal beamwidth	1 °	1 °	1 °
Vertical beamwidth	1 °	1 °	1 °
Side lobe level	-25 dB	-25 dB	-23 dB
Antenna pattern	Recommendation ITU-R M.1851, equation (4) [26]	Recommendation ITU-R M.1851, equation (4) [26]	Recommendation ITU-R M.1851, equation (4) [26]
Antenna diameter	1.4 m	2 m	1 m
Elevation angle	0°	0°	-3°
Antenna height	5 m	5 m	50 m
Noise Factor	3.4 dB	3 dB	3.5 dB

In accordance with Recommendation ITU-R M.1461 [32] , a protection criterion of I/N = -6 dB is recommended. This criterion is an aggregated protection criterion that takes into account desensitization from all radio systems.

Meteorological radars in the 9.3-9.5 GHz frequency band

Table 42: Meteorological radar characteristics operating in the 9.3-9.5 GHz range

Parameter	Value
Type	Ground based
Maximum antenna gain	45 dBi
Antenna pattern	Pencil beam
Antenna vertical scan type	-2° to +90°
Antenna side-lobe levels	-26 dB
Minimum antenna height	10 m
Receiver IF 3 dB bandwidth	1.2 MHz
Antenna diameter	1.8 m
Noise Factor	2 dB
3 dB beamwidth	0.9°

Similar approach is considered for the meteorological radars regarding the protection criterion of I/N = -10-X dB based on the I/N = -10 dB given in Recommendation ITU-R M.1849-3 [19] which is an aggregate protection criterion from all radio sources.

The (atmosphere) volume scanning performed by a weather radar results from the detection and the measurement of the hydrometeor intensities as well as their radial velocities. The horizontal and vertical coverage required for a volume scan to produce a horizontal sweep, is achieved by rotating the antenna in the horizontal plane at a constant elevation angle. The antenna elevation is modified by a pre-set amount after each horizontal sweep. The vertical scan provides the range of these elevation angles. Negative tilt is operated for meteorological radars deployed in high altitude i.e. when they are installed in mountains, hills to retrieve information on precipitation at lower altitudes.

The current study assumes two different radar locations in France (among all French weather radars operating in this band) that have the same minimum elevation angle to be 0.4° for the vertical scanning and two different antenna height (6 m for Nice aerodrome and 12 m for Roissy Charles-de-Gaulle).

Meteorological radar antenna pattern

The computation of the radiation pattern is performed using:

- Recommendation ITU-R F.1245-3, rec 2.2.2 [33] as $D/\lambda \leq 100$;
- Recommendation ITU-R M.1851-2 [26] with a circular aperture antenna model to account the circular nature of the aperture of a parabolic antenna used by the weather radar.

For a modelling of the radiation pattern, one could consider the different levels on the edges of the antenna pedestal C as well as bandwidth factor K using Recommendation ITU-R M.1851-2, table 10. Theoretical directivity approach is considered (Equation 33) from Recommendation ITU-R M.1851-2 to build the radiation pattern $G(\theta,\varphi)$.

Figure 41 exhibits the plot of the antenna pattern using Recommendation ITU-R F.1245 and Recommendation ITU-R M.1851 [26]. It should be noted that the main lobe from Recommendation ITU-R F.1245 model is wider than the one from Recommendation ITU_R M.1851 which seems to be in accordance with the note from Recommendation ITU-R M.1849 [19] Although representative of parabolic antennas, the first three Recommendations [whose Recommendation ITU-R F.1245 [33] is one of the representant] tend to

overestimate the beamwidth of a pencil beam antenna pattern, similar to that generally used by meteorological radars.

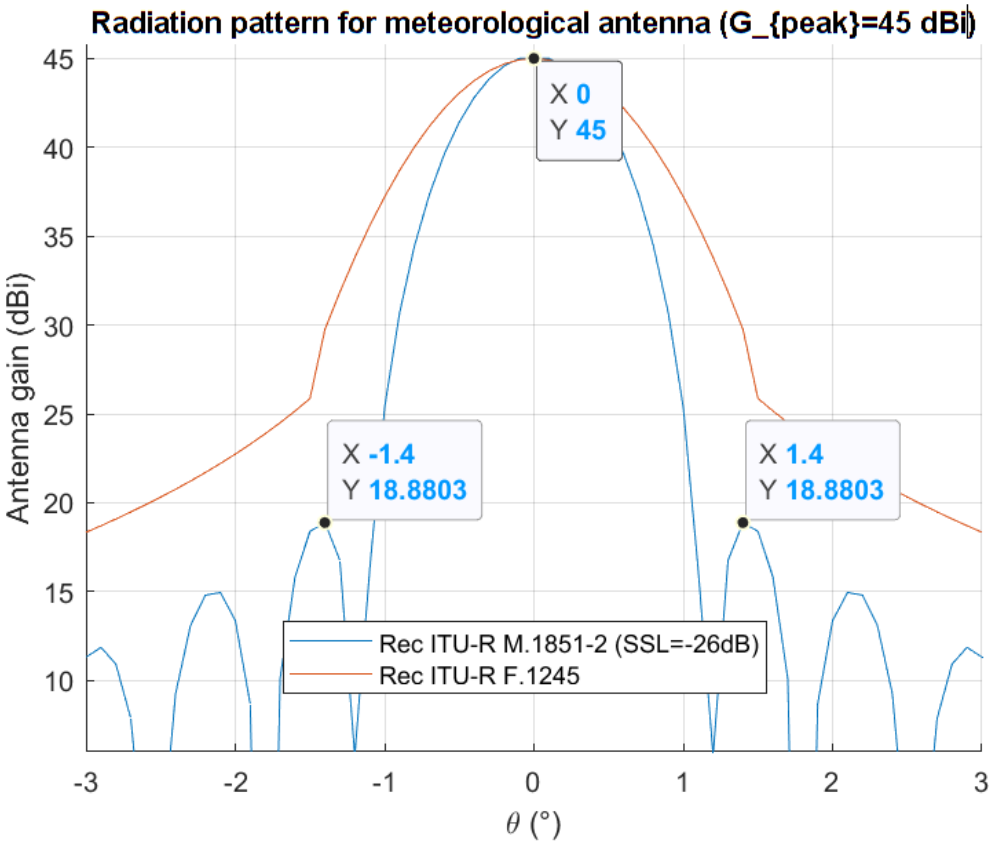


Figure 41: Plot of the pattern for radar with radial symmetry

Deployment of meteorological radars

As indicated by Recommendation ITU-R M.1849 [19], Ground-based meteorological radars are used for operational meteorology and weather prediction, atmospheric research, and aeronautical and maritime navigation, and play a role in the immediate meteorological and hydrological alert processes. To cover these missions, these radars operate over different frequency ranges (S-band, C-band and X-band) and cover the whole territory. If the performance of the radar systems is pretty similar in S-band and C-band (200-250 km), their deployment in X-band in generally performed to fill hole in the coverage area left from systems operating in 2700-2900 MHz and in 5250-5725 MHz. In addition to this requirement, meteorological radars in X-band offer additional functionality such wind shear detection which is particularly useful for some airports where strong variations require their prediction for the airline pilot during the approach and landing.

4.5.1.3 Military aeronautical mobile systems in the 4.4-4.99 GHz frequency band

The characteristics of the military aeronautical mobile system studied in the 4400-4990 MHz frequency band is derived from Recommendation ITU-R M.2116, system 1 [34].

Table 43: Military aeronautical mobile systems characteristics operating in the 4400-4990 MHz range

	System 1 from Recommendation ITU-R M.2116 [34]		
Type	**Airborne**	**Ground**	
Maximum antenna gain	3 dBi	19 dBi	31 dBi

	System 1 from Recommendation ITU-R M.2116 [34]		
Horizontal beamwidth	360°	16°	3.3°
Vertical beamwidth	90°	16°	3.3°
Side Lobe Level	n/a	-13 dB	-13 dB
Antenna pattern	Omni	Recommendation ITU-R M.1851, equation (3) [26]	
Minimum elevation angle	n/a	5°	
Antenna height	n/a	5 m	
Noise factor	3.5 dB	3 dB	

In accordance with Recommendation ITU-R M.2116, a protection criterion of I/N = -6 dB is recommended. This criterion is an aggregated protection criterion that takes into account desensitization from all radio systems.

4.5.2 Propagation model

For all types of radars, the propagation loss depends on the interferer and receiver antenna heights as well as the path profile separating them (terrain, clutter). Accounting those characteristics and assuming low separation distances (e.g. less than 1 km) where diffraction (due to the curvature of the Earth, to terrain/clutter) can be neglected, free space attenuation model (Recommendation ITU-R P.525-4 [16]) is considered for most radar systems.

Additionally, a clutter loss, further described in Recommendation ITU-R P.2108 [14], is factored in for certain radars to account deployment in populated area.

The building entry loss, further described in Recommendation ITU-R P.2109 [9], is also considered in scenarios where indoor MWSSc are involved.

The propagation parameters are summarised in the following table:

Table 44: Propagation parameters

	4.8-6 GHz band		8.5-10.6 GHz band		
	Radar 19	Radar 17, 21, 22	Radar G4 Meteorological radar	Radar G5	Radar G14
Free Space	✓	✓	✓	✓	✓
Clutter Loss	✓	No (Note 1) (Note 2)	No (Note 1) (Note 2)	✓	No (Note 3)
Building Entry Loss	16 dB (Indoor scenarios only)	16 dB (Indoor scenarios only)	17 dB (Indoor scenarios only)	17 dB (Indoor scenarios only)	17 dB (Indoor scenarios only)

Note 1: Given the flexible deployment options of this tactical radar, a rural environment represents the most challenging configuration. Consequently, the propagation loss calculations do not take into account for clutter loss.
Note 2: Regarding meteorological radars, they are usually implemented in such a way that clutter will not apply, in particular at relatively short distance. The radar protection has to ensure the protection of all single radial measurements from the radar. Application of clutter being purely statistical, it is not possible to guaranty any value of clutter losses that would apply 360° around the radar. On the contrary, applying any clutter distribution will always depict several radials where no clutter would apply. Hence, for meteorological radars, no clutter loss is to be taken into account.
Note 3: In light of the radar antenna height (50 m), the propagation loss is calculated without taking clutter loss into account.

4.5.3 Study A - Weather Radars in the 9.3-9.5 GHz frequency band

4.5.3.1 Methodology

Performance and calibration of a weather radar

Weather radar data results from the signal processing of the echoes received by the radar receiver (that have been previously sent) over the same direction. Any kind of reflective surface due to terrain profile or due to clutter (buildings, facilities…) may be at the origin of these echoes. These echoes from non-precipitating objects may severely affect radar performance by concealing reflections from targets of interest as they typically exhibit large reflectivity, near-zero Doppler shift, small spectrum width, and are consistently localised. For a quantitative precipitation estimation and a capability of forecasting a high data quality, it's then important to address these issues before putting into service a meteorological radar dedicated to the "coverage" of a given area. Such measures are possible during the calibration phase once the radar station has been installed. This period takes months for the radar to acquire knowledge about its geodetic environment by collecting information on terrain/clutter profile for every sampled/discrete orientation of the antenna beam when scanning all azimuths at different elevation angles.

Why are cluttered paths not used to forecast the weather?

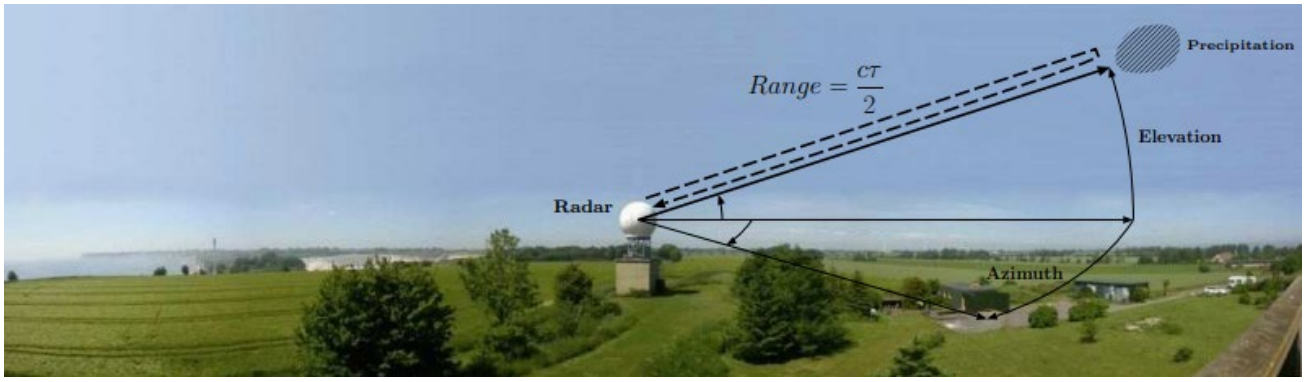


Figure 42: Driving parameters and visibility for radar (atmosphere) volume scanning

Since the weather radar is generally mounted on a high location (high tower/building) to avoid blockage of the radar rays by near-by buildings, trees and other obstacles to enable the detection of a target (computed from the round-trip time τ and the speed of light c), cluttered path profiles will be ignored by the radar antenna whatever the different situations:

When the obstacle is not very close to the radar antenna facility, burst of pulses are generated by the radar but their echoes won't be processed by its receiver chain.

When the obstacle is very close to the radar antenna facility, there is a risk that it causes reflections resulting in a high magnitude echoes (due to high power of the radar system) exceeding the overloading threshold of the radar receiver. In such case, blanking sector is generally triggered by the radar system i.e. no pulses are transmitted by the radar for those azimuths at the associate elevation angles (subject to lack of visibility).

This means that the detection of precipitation is only possible when the main beam of the meteorological antenna is radiated by means of a terrain clearance angle at its vicinity. This results for the radar in not detecting anything behind an obstacle (building, relief) located at a given azimuth from the radar station causing the non-line of sight. This does not mean that the radar is unable to detect anything within this azimuth as any increase of its elevation angle pointing will progressively clear the antenna from any obstruction (within the same azimuth subject to obstruction) allowing the radar could detect precipitation in those azimuths when no clutter infringing the visibility of the main beam antenna.

In summary, for meteorological radars, no clutter loss is to be taken into account.

Free Space Model vs Recommendation ITU-R P.452

Recommendation ITU-R P.452 [13] is suitable for the assessment of pathloss of any point-to-point terrestrial path as it accounts multiple physical mechanisms other than line-of-sight affecting the attenuation of a wave radiated from an emitter to a receiver. While some of them can be assumed to be neglected for small separation distances under study (tropospheric scattering) or for not small percentage of time (anomalous phenomena: ducting, hydrometeor scatter…), other are of great importance like spherical-Earth diffraction (as a long path depends on the Earth curvature) or diffraction related to the path profile when any obstruction (due to clutter or terrain) component arises between transmitter and receiver. If there are cases where the terrestrial path separating the meteorological radar from the security scanners contain obstructions components such as clutter or relief, these paths are not considered by the meteorological radar to cover its missions (e.g. to determine the radial velocity of the precipitation particles) for the reasons expressed in the previous sections. That's why there is no need to consider any clutter or relief in the terrestrial path separating the weather radar from the security scanner for an interference assessment. Thus, for distances shorter than the LoS distance where the path clearance is equal or lower to a fraction of the first Fresnel zone radius (as this covers the ellipsoidal space where the direct LoS passes through), diffraction does not take part in the propagation mechanisms of the interference from Microwave Security Scanners. According to Recommendation ITU-R P.526, section 2.3 [35], this threshold is assumed 60% of the first Fresnel zone.

One can conclude that Free-space loss model (Recommendation ITU-R P.525 [16]) is sufficient for the prediction of the pathloss towards the radar system.

Aggregation factor

In accordance with the functionalities of MWSSc, it is understood that their usage, if local, won't prevent their deployment to several units. For such case, multiple devices would occupy a given area dedicated to specific needs and would not turn to uniform deployment. For example, in airport, multiple MWSSc would be aligned to process simultaneously flow of passengers with their belongings and mitigate traffic congestion. Since the meteorological radar operates with highly directive antenna, sidelobes levels are sufficiently low (at least 26 dB lower) with respect to the peak value of the main beam) not to contribute to the received aggregate interference. Hence, MWSScs located within the 3 dB beamwidth of the weather radar antenna are considered in the computation of the aggregate interference.

Their positioning (depicted by a blue cross) with respect of the victim receiver antenna main beam could be roughly summarised by the following scenarios:

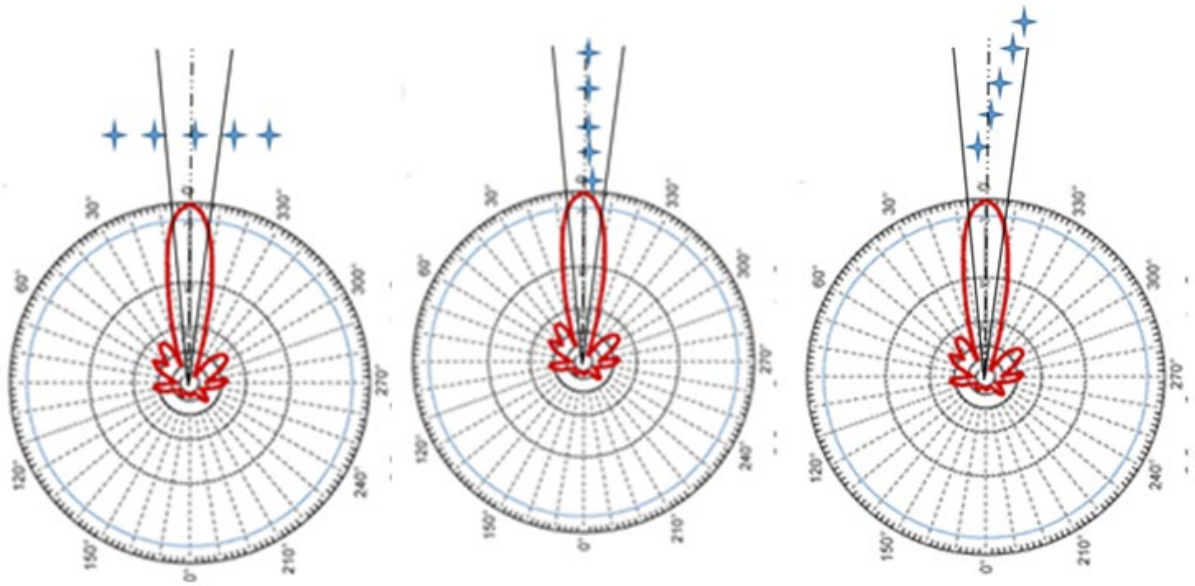


Figure 43: Geometry of the receiver antenna main beam and MWSSc positionings

Cases 1, 2, 3 respectively depict the left, middle and right side above figures representing the main beam of the receiver antenna (plotted in red) with respect to the MWSScs. For these cases, MWSScs always remain aligned, but the positioning of the receiver antenna main beam is different.

For the first case, the number of MWSScs within the main beam will be derived based on the size of the device, the gap between two adjacent devices and the beamwidth. For the second case, even though all MWSScs are within the beamwidth of the receiver antenna, most of them are shaded by the first ones which would result in an additional attenuation by the scanners behind the first one in the interference calculation. For the third case, all MWSScs are within the beamwidth of the receiver antenna and they are not shaded each other. However, for this configuration, the main beam won't be able to see an integer number of strips composing every scanner and radiating without additional attenuation. To capture that idea, multiple MWSScs are drawn in the below left picture and rays were plot from the victim receiver (blue cross) to capture what it could see from every MWSSc. For example, to enable green rays departing from the victim receiver antenna to see a full strip (i.e. not a portion of the strip/side of the scanner) of the « third scanner », this one should be shifted to the right side. But when doing that, it would leave the main beam of the victim receiver. This observation would also apply for the purple ray crossing one strip of the « second scanner ».

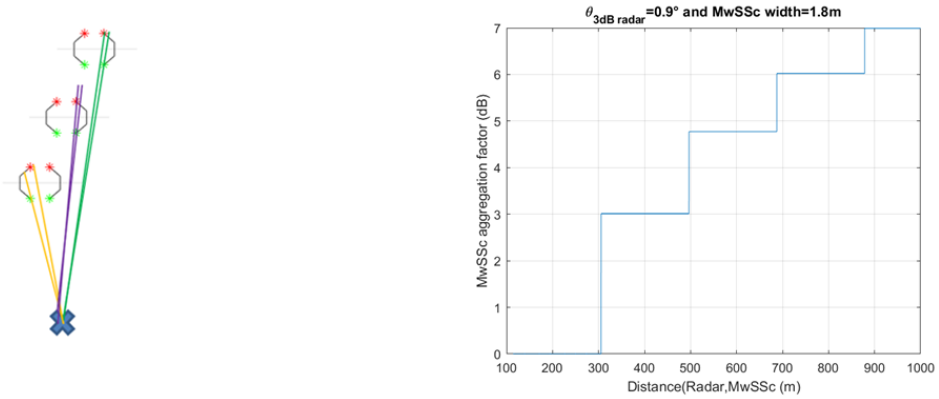


Figure 44: (left) panels from 3 MWSScs in visibility of a radar (right) Aggregation factor of MWSScs

From the above analysis, case #1 appears to be the worst case from the highest aggregation factor. Thus, it will be retained for the scenario to be investigated in the sharing studies. The aggregation factor (depicted in right side figure above) is determined based on the 3 dB beamwidth of the victim receiver antenna, the MWSSc size (1.8 m), the gap between devices (assumed to be 1.6 m) as well as the separation distance between the victim receiver the closest.

Recognising that multiple MWSScs would generally operate unsynchronised, there would be no synchronization between radiating antenna from multiple MWSSc i.e. even though they may simultaneously radiate, their LoS conditions towards a victim receiver would not necessarily match it other. However, noting that the integration time of the victim receiver is close (or smaller) than the period of the radiation of any antenna of the scanner[2], the probability that multiple scanners simultaneously radiate in visibility to the victim receiver becomes smaller with this number. For the sake of not worsening the studied case assuming only LoS conditions between MWSSc and ground weather radar, it would be wise to calculate the distribution of the aggregation factor and take the average value of this statistic. Such procedure can be run in different steps as follows:

- Time integration T of the victim receiver (equal to the inverse of the receiver bandwidth)<1μs;
- Set a given number of N interferers/security scanners;
- As burst of pulses emitted by a single antenna (e.g. 1.25 μs) last more than T seconds, one single cycle of interference sample per event is considered;
- Generate for every interferer i=1..N, if the transmitting antenna is in visibility with the victim receiver with p probability (i.e. 1-p probability no to be in visibility);
- Weighting the visible antenna with 1 coefficient (full power), the non-visible antenna with a reduction power (e.g. 1/10) from the full power to capture the additional attenuation due to shadowing loss,

[2] <1µs for the radar and 1.25µs for MwSSc.

Such approach results in plotting the distribution of the aggregation factor depending on the total number of MWSScs in Figure 45 (left side).

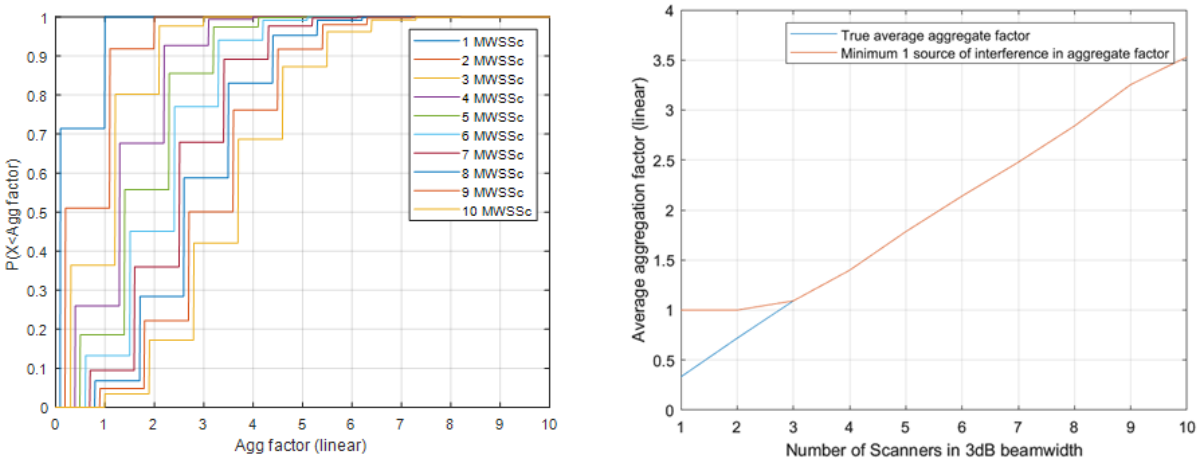


Figure 45: Aggregation factor

Considering an average value of the aggregate factor (as exhibited in the right above figure) would result in listing all combinations of aggregation factor i.e. where a fraction of the interferers visible from the victim receiver is very low (could be 1 among N or even 0 over N for several samples). The mean aggregate factor slowly increases with the number of scanners within the 3 dB beamwidth. Two different ways to perform this average were implemented:

the strict computation of the average of the aggregate factor enabling lower value than 1 to capture cases with 1 security scanner within 3 dB beamwidth of the receiver antenna that is not in visibility of the radar (blue curve). Even for two scanners, it is possible not to achieve the full interference level in configuration with LoS between the scanner and the victim receiver (when they are NLoS).

Another computation with a minimum of 1 interferer (red curve).

The relevant approach to calculate the aggregate interference (the second one) is based on a non-null number of interferers.

A maximum of 10 MWSScs collocated in the same area and deployed at the entrance of the terminals would not be in visibility of the ground weather radar generally located at the edge of the aircraft runway because the terminal would behave as an obstacle. However, it's possible that MWSSc can be deployed outdoor at another entrance corresponding to the airport staff (aircraft crew, sellers in duty-free shops, cleaning staff). This entrance might be located within the same side as an aircraft runway but would not require as many MWSScs as for the passenger traffic (tens/hundreds of thousands per day) e.g. two could be sufficient to enable such control. Based on the above picture, one consequence of the average aggregation factor behaviour for 2 MWSScs results in no aggregation for the sharing analysis, corresponding to single-entry interference. If the aggregate-entry interference scenario is considered for a small number of sources of interference, the aggregate factor should not be computed on an average basis. That is why for 2 MWSScs, results are presented on a single-entry (average aggregation factor) and multi-entry (non-average aggregation factor) basis.

Apportionment factor of the aggregate interference

As previously highlighted, for the aggregate protection criteria for ground-based meteorological radars an interference-to-noise ratio (I/N) of −10 dB should be used. This means that this protection criterion is aggregate for all sources of interference allocated on a primary, secondary basis or without specific status (for SRD) in the same band as well as in adjacent band.

Apportionment needs to account the visibility area of the victim receiver in order to justify aggregating stations from multiple services (either primary or secondary or with no status like SRD). Visibility area for aeronautical or satellite stations is sufficiently large to deal with multiple services. This is not the case for ground station (whether it's from terrestrial or satellite services) unless a significant antenna height is considered.

Moreover, as suggested in ECC Report 334 [12] for similar issue[3], the apportionment induced by other UWB applications which would operate within the same frequency band and over the same area should also be accounted. Such measure would be applicable to both indoor or/and outdoor environments. Assuming a minimum of two different UWB applications sharing the same band 9300-9500 MHz in any environment (outdoor/indoor), the resulting minimum apportionment would then equate: 3 dB.

Calculation of aggregate interference received by the radar

Interference received by the meteorological radar can be theoretically expressed as follows:

$$P_R = P_T + \mathrm{G_T} + \mathrm{Agg} + G_R - PL - BEL \quad (3)$$

where:

- P_R: the power received by the meteorological radar receiver (dBm/MHz);
- P_T: the transmitter power (dBm/MHz) in the radar band;
- G_R: the gain of the radar in the direction of the transmitter (i.e. MWSSc);
- $\mathrm{G_T}$: the gain of the transmitter in the direction of the radio receiver;
- Agg: the aggregation factor from multiple MWSScs;
- PL: Path propagation loss;
- BEL: Building Entry Loss (according to Recommendation ITU-R P.2109-1 [9]) for an indoor deployment of MWSSc only.

From this equation, one could notice that:

- the collocation of MWSSc devices for this study justifies using a single value of pathloss PL (unlike the typical approach used to compute aggregate interference per single radio-link) as well as the aggregate factor term,
- the above analytical formula is typical from radio-interference problem with continuous emission of power which is not the case for MWSSc using pulse compression technology (with burst of pulses).

That is the reason why its radiated power should not be expressed using P_T and $\mathrm{G_T}$ parameter but through mean(*e.i.r.p.*) metric in order to capture the radiation averaged over a given duration. This duration depends on the time window of the victim receiver. As mean(*e.i.r.p.*) input parameter is provided over 1 ms and because *e.i.r.p.* measured at any location outside the MWSSc will vary because different antenna (from different panels from different strips) radiate towards this location with varying Line of Sight (LoS) conditions, a conversion of this metric to the integration time (denoted T) of the meteorological radar is needed. In addition, the fact that the protection criterion of the radar receiver is expressed in terms of (Interference to Noise) power ratio allows to express the interference level through its power spectral density (PSD). Based on these observations, equation (3) can be rewritten as follows:

$$P_R(\mathrm{dBm\ /MHz}) = Mean_T(E.I.R.P.)(\mathrm{dBm/MHz}) + \mathrm{Agg} + G_R - PL - BEL \quad (4)$$

4.5.3.2 Results

Based on methodology described in the previous section, the results are presented in terms of difference between received I/N and the protection criterion I/N=-13 dB (corresponding to 3 dB apportionment, captured in ordinates axis) as a function of the separation distance (for the abscissa axis) between the victim receiver

[3] Although it is recognised that ECC Report 334 [12] applies for the protection of passive service operating in adjacent bands of UWB radiodetermination applications in different frequency ranges, there is no reason to apply similar rationale.

and the cluster of scanners. A positive gap for the ordinates refers to an exceedance of the protection criterion while a negative one would correspond to a coexistence margin.

Two scenarios have been investigated for this study: one meteorological radar notified and located in Roissy Charles-de-Gaulle airport (with an antenna height equal to 12 m whose results in the next figures are captured in blue curve) and another one put in service in Nice aerodrome (with the lowest antenna height being 5.4 m captured in red curve for the next figures) as depicted in Figure 46. Both operate with pencil beam pointing above the horizon with a 0.4° minimum elevation angle.

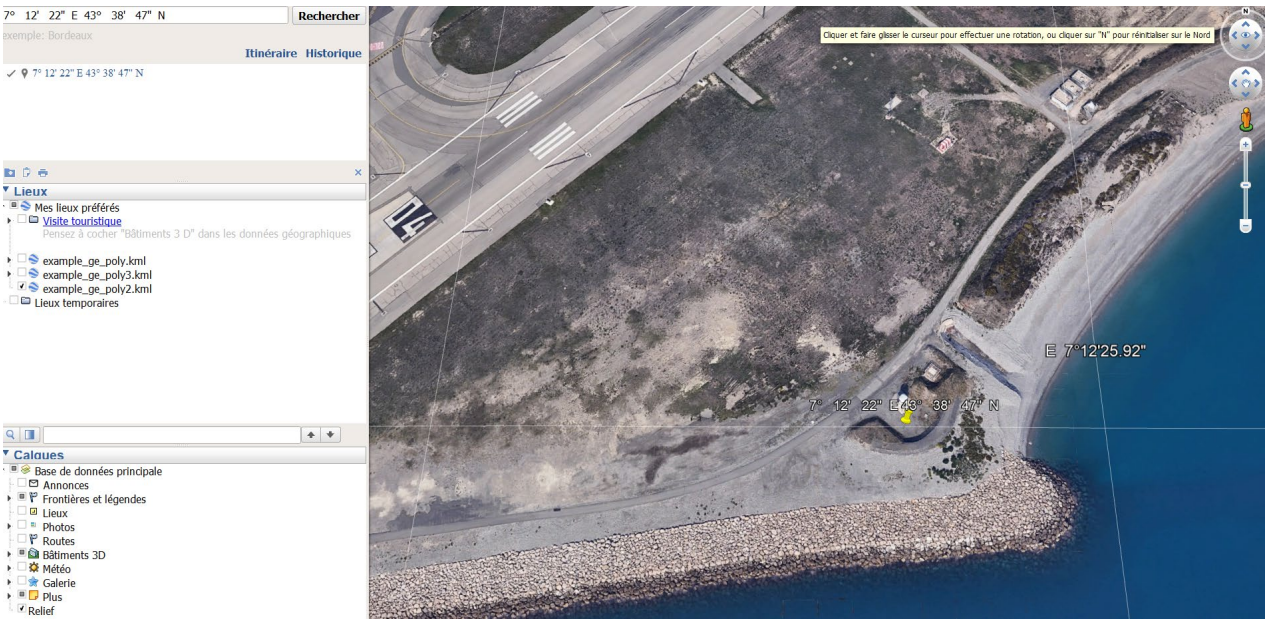


Figure 46: Notified radar in Nice aerodrome (43°38'47"N 7°12'22"E)

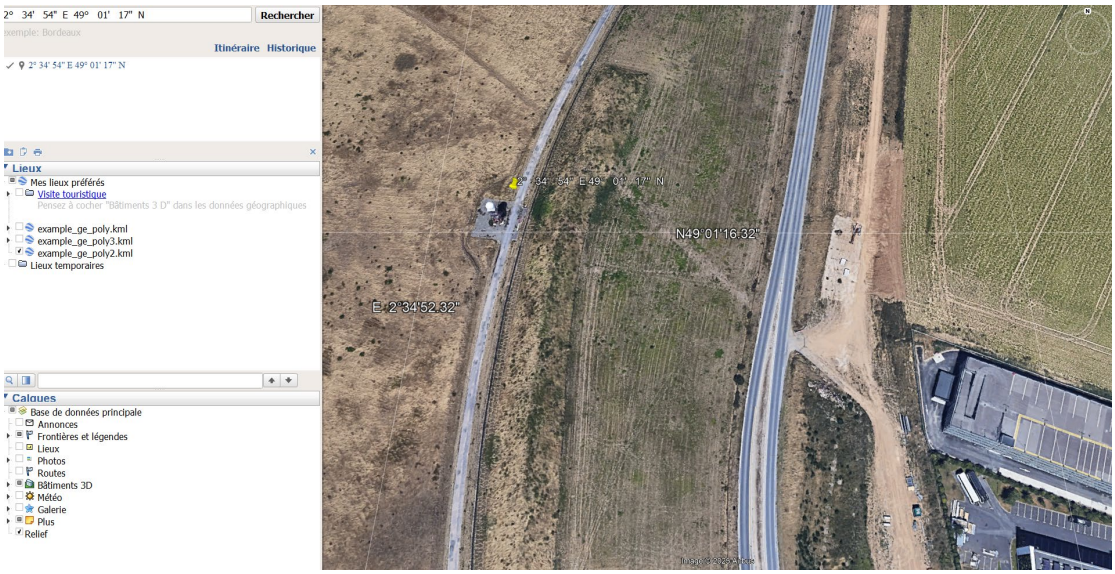


Figure 47: Notified radar in Roissy Charles-de-Gaulle airport (49°01'17"N 2°34'54"E)

Outdoor deployment

As previously indicated, when computing the aggregate interference, the retained path separating the victim receiver and the cluster of MWSScs is free from obstacles affecting the visibility of the mean beam of the radar antenna. Based on the methodology described in the previous section, gap between the aggregate interference noise to ratio I/N and the protection threshold (=-13 dB) is plotted for different distance(radar, MWSSc) in Figure 48 and Figure 49 for the single-entry scenario (average aggregate interference). The

maximum exceedance achieved after few meters away from the radar system (based on the zoom of the picture) is around 5.4 dB for an implementation of Recommendation ITU-R F.1245 [33] model, probably because of a wider beamwidth of the pattern. This means that under -60 dBm/MHz mean(*e.i.r.p.*) (average over 1 ms) and with a 5.4 dB geometrical factor, the meteorological radar could be interfered with an exceedance level of the protection criterion up-to 5.4 dB for Recommendation ITU-R F.1245 [33] implementation. A minimum of 5.4 additional reduction of the mean(*e.i.r.p.*) would be needed to solve the coexistence issue, resulting in -65.4 dBm/MHz max(mean(*e.i.r.p.*)) averaged over 1 ms.

For the aggregate-entry scenario (non-averaged aggregate factor), a 3 dB shift of every curve (red for h_{radar}=12 m, blue for h_{radar}=6 m) to the upper part of the graphic reflects the corresponding results. This results in achieving -68.4 dBm/MHz mean(*e.i.r.p.*) (average over 1 ms).

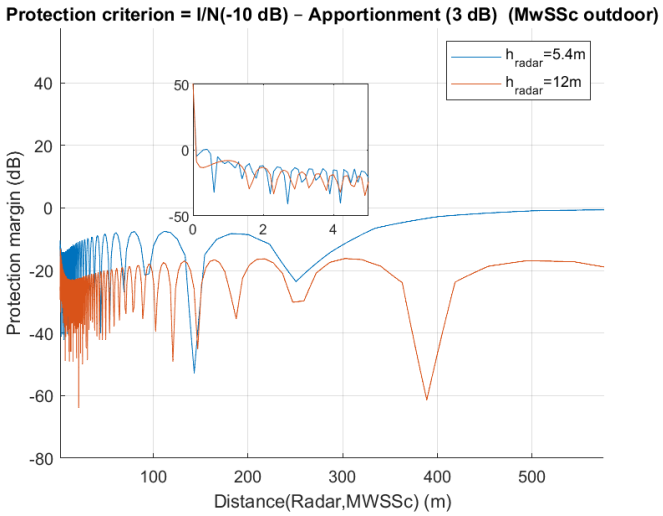


Figure 48: Using Recommendation ITU-R M.1851-2 model

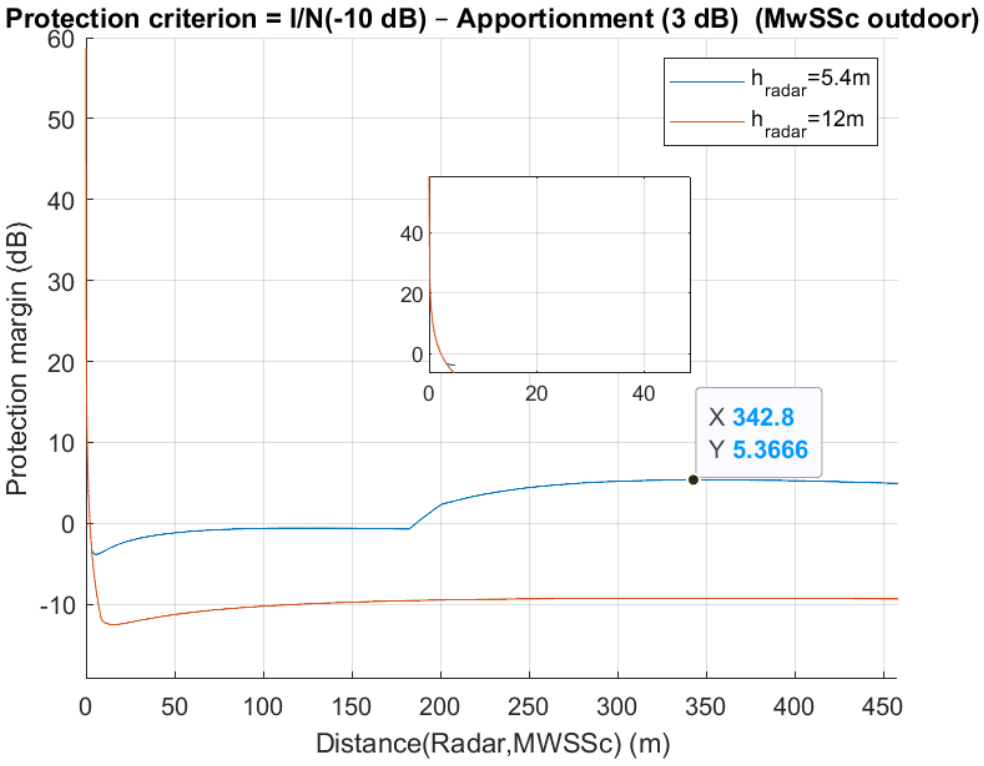


Figure 49: Using Recommendation ITU-R F.1245-3

Accidental outdoor

For an indoor deployment of MWSScs, it would be relevant to consider building entry loss in the computation of the aggregate interference potentially affecting the radar system. However, such assumption would lead to conclude that the cluster of MWSScs would not be in visibility of the meteorological radar. In light of the operability of the meteorological radar (only in visibility of the main beam), this case cannot be part of the scenario where the protection of the radar is addressed. The only relevant scenario would then be with MWSSc indoor but with some of them being in visibility of the radar receiver. This would be the case when the MWSSc is deployed close to the entrance of the building. In such configuration, one could assume that a very few amount of the indoor MWSScs could remain in visibility of the radar. If the remaining MWSScs would not be in visibility to the weather radar, they won' take part in the interference of interest affecting the radar and should then be disregarded. The number of those MWSScs would depend on multiple factors: the angular sector departing from the cluster in line of sight with the outside of the building but also the orientation of the radar receiver with respect to the building hosting those MWSScs. Given the constraint of opening within a building as well as ideal positioning configuration of victim receiver, a single MWSSc indoor in line of sight of the radar receiver is assumed for the study.

Such assumption would lead to no aggregation factor, similarly to what was achieved for the outdoor deployment scenario. Compatibility results would then be the same as for the outdoor case presented in the previous section.

Typical indoor

In case where there is no visibility between MWSScs and radar receiver, building entry loss needs to be accounted in the interference calculation. It can be computed using Recommendation ITU-R P.2109 with 0° elevation angle of the path at the building façade at 9.3 GHz. For a traditional building (around 17.5 dB for the median value), the protection criterion of the ground weather radar is always met in light of the exceedance observed for outdoor case (5.4 dB for a single interferer based on Figure 49 and 8.4 dB for an aggregated MWSScs) is largely balanced with building entry loss when MWSSc operates with -60 dBm/MHz mean(*e.i.r.p.*) (average over 1 ms).

If MWSSc operates with -41.3 dBm/MHz mean(*e.i.r.p.*) (average over 1 ms), the protection criterion of the meteorological radar will be exceeded:

- For single entry by 6.6 dB for a median value of building entry loss;
- For cluster of two scanners by 9.6 dB for a median value of building entry loss.

4.5.3.3 Conclusion

Sharing studies between meteorological radar and Microwave Security Scanners (MWSSc) operating in 9300-9500 MHz have been undertaken for different scenarios involving radiolocation systems currently operating in France (Nice and Roissy Charles-de-Gaulle) with a cluster of MWSSc deployed indoor and outdoor. The aggregation factor generated by the cluster of MWSSc was limited to the 3 dB beamwidth of the radar receiver antenna and accounted the unsynchronised nature of those scanner by considering the average aggregation factor, resulting in 0 dB.

The results show that the coexistence between meteorological radar and MWSScs for outdoor deployment of MWSScs is feasible when max(mean(*e.i.r.p.*) =-65.4 dBm/MHz averaged over 1 ms for single-entry use case scenario and -68.4 dBm/MHz averaged over 1 ms for multi-entry use case scenario

The results show that the coexistence between meteorological radar and MWSScs for indoor deployment (entry loss of 17.5 dB assumed) of MWSScs is feasible when max(mean(*e.i.r.p.*) =-47.9 dBm/MHz averaged over 1 ms for single-entry use case scenario and -50.9 dBm/MHz averaged over 1 ms for multi-entry use case scenario.

It should be noted that these results were achieved assuming a specific geometry of the UWB device (MWSSc), resulting in around 5.4 dB gap between max(mean(*e.i.r.p.*)) averaged over 1 ms and max(mean(*e.i.r.p.*)) averaged over the signal repetition time corresponding to the burst of pulses for the same antenna with the highest magnitude (i.e. the antenna is in visibility of a receiver located outside the MWSSc).

This gap illustrates the non-constant nature of the envelope of the MWSSc emissions level during the signal repetition time.

As indicated in ETSI EN 303 883 [1], the procedure to average the *e.i.r.p.* spectral density is described either for 1 ms (ETSI EN 303 883, section 5.3.2.4) or a for a shorter duration corresponding to the signal repetition time (ETSI EN 303 883, section 5.3.2.5).

If UWB device with a lower dynamic between max(mean(*e.i.r.p.*)) averaged over 1 ms and averaged over the signal repetition time with the highest magnitude than 5.4 dB is considered, under the max(mean(*e.i.r.p.*)) (averaged over 1 ms) conditions stated above (e.g. -65.4 dBm/MHz averaged over 1 ms for outdoor deployment of MWSSc in case of single-entry scenarios), the coexistence between meteorological radar and MWSScs is met. However, if the dynamic between max(mean(*e.i.r.p.*)) averaged over 1 ms and averaged over the signal repetition time with the highest magnitude exceeds 5.4 dB, the coexistence between meteorological radar and MWSScs is not met anymore.

Considering the agnostic nature of ECC Decision (06)04 [3] regarding the technology used for the design of any UWB device, technological neutrality is assumed, that's why it would be relevant to set the max(mean(*e.i.r.p.*)) condition for the signal repetition time with the highest magnitude to ensure all categories of UWB MWSScs protect the meteorological radars in 9300-9500 MHz. In such a case, coexistence between meteorological radar and MWSScs for outdoor deployment would be feasible when max(mean(*e.i.r.p.*))=-65.4+5.4=-60 dBm/MHz for single-entry and max(mean(*e.i.r.p.*))=-68.4+5.4=-63 dBm/MHz for multi-entry over the signal repetition time with highest magnitude level. For the indoor deployment would be feasible when max(mean(*e.i.r.p.*))=-47.9+5.4=-42.5 dBm/MHz for single-entry and max(mean(*e.i.r.p.*))=-50.9+5.4=-45.5 dBm/MHz for multi-entry over the signal repetition time with highest magnitude level.

4.5.4 Study B - Weather Radars (Monte Carlo)

In the generic case study, a simplified single entry coupling loss analysis between MWSSc and X-band Meteo Radar was performed.

MWSSC are deployed to protect secure zones - such as in airports, government buildings, or other critical infrastructure - are typically installed indoors, often within reinforced structures, walls, and complex indoor environments. These environments have substantial additional signal attenuation, beyond what is accounted for in large-scale outdoor propagation models such as Recommendation ITU-R P.452 [13], Recommendation ITU-R P.1546 [17] or Recommendation ITU-R P.1812 [18].

The clutter loss described in ITU-R P.2108-1 [14] provides a statistical model for local environmental attenuation caused by buildings, walls, vegetation, and other obstructions in the vicinity of the transmitter or receiver. It is specifically designed to be used in conjunction with other propagation models to account for near-field environmental effects not resolved by terrain-based models.

MWSSC are deployed inside buildings, where the building structure itself significantly attenuates emissions. The additional environment makes this a case for the application of P.2108-1 [14], which was developed for such scenarios.

Omitting clutter loss would result in an overestimation of the interference potential to sensitive services. Applying only free-space or terrain-based models without clutter loss would assume a clear line-of-sight from the MWSSC to the receiver station, which is a physically artificial scenario in most cases (unlike Study A addressing the remaining cases).

For a more detailed analysis a Monte Carlo simulation workspace using SEAMCAT (Spectrum Engineering Advanced Monte Carlo Analysis Tool) V 5.5.0 was setup. Even though MWSSc are considered to operate indoor, the simulation considers an outdoor case with a potential transmit power of -50 dBm/MHz to be in align with the MCL calculations.

The simulation was performed with the following parameters:

- Time variance;
- Recommendation ITU-R P.2108-1 [14] variable percentage of location (1-99%);

- Recommendation ITU-R P.525 [16] (Free Space);
- Position / distance;
- Antenna patterns (Recommendation ITU-R F.1245-3 Meteo radar peak gain 45 dBi, dish size 1.8 m / MWSSC according to Table 3;
- Direction of Antenna pattern;
- Number of iterations = 20000;
- Antenna height (Meteo Radar 5..12 m (unif. distributed), SSC = 2 m);
- Meteo Radar IF 1.2 MHz;
- Frequency 9.375 GHz;-Scenario: Outdoor;
- MWSSC Power level: -50 dBm/MHz.

The scenario is depicted in Figure 50. The Meteo Radar station is facing one (1) and ten (10) MWSSc respectively in different scenarios which are outlined in further detail below.

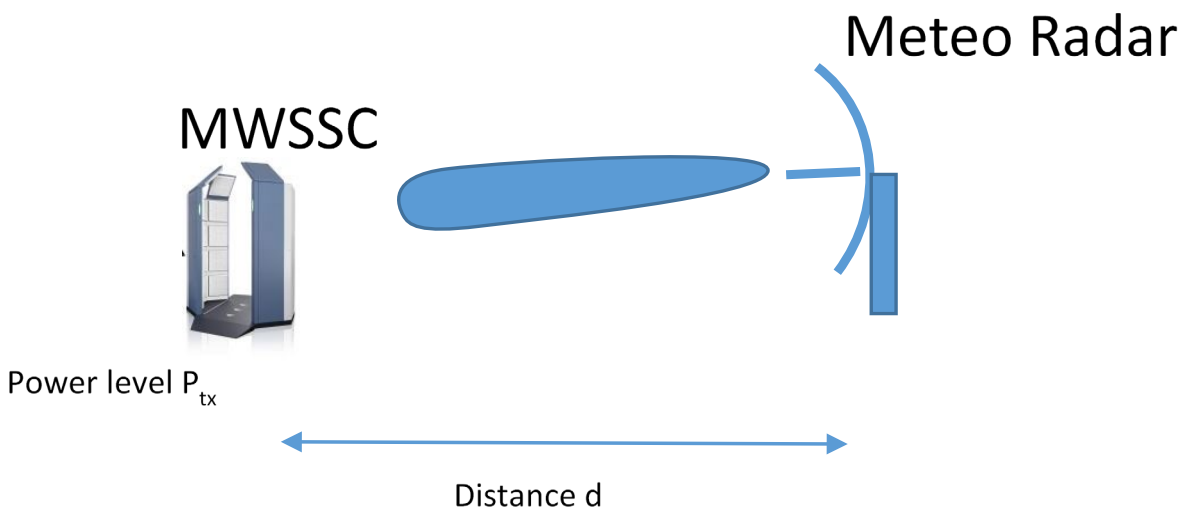


Figure 50: Sketch of Scenario setup

It should be noted that the simulation does not consider the rotation of the Meteo Radar antenna but pointing towards the MWSSc continuously in order to protect the radar performance in every angular scanning direction it operates. It calculates power levels at the radar receiver just like single entry studies, but considers additional parameters and the variation of these parameters according to statistics as mentioned in the list above.

Two scenarios have been simulated. One scenario with a single MWSSC at certain distances as outlined “Scenario 1” and a second scenario with 10 MWSScs that transmit at the same time. This scenario is named “Scenario 2”. It should be noted that transmitters of multiple MWSSC are not synchronised. Therefore, the power increase from one to ten MWSScs is not linear, but has been considered in this Monte Carlo for simplicity and as worst-case assumption.

4.5.4.1 Scenario 1

In scenario 1 a single MWSSC is considered to be in a distance of 1 km to 3 km away from the Meteo X-band radar. The transmit power of the single MWSSC is -50 dBm/MHz. The antenna of the Meteo X-band radar is pointing towards the MWSSC as shown in Figure 51.

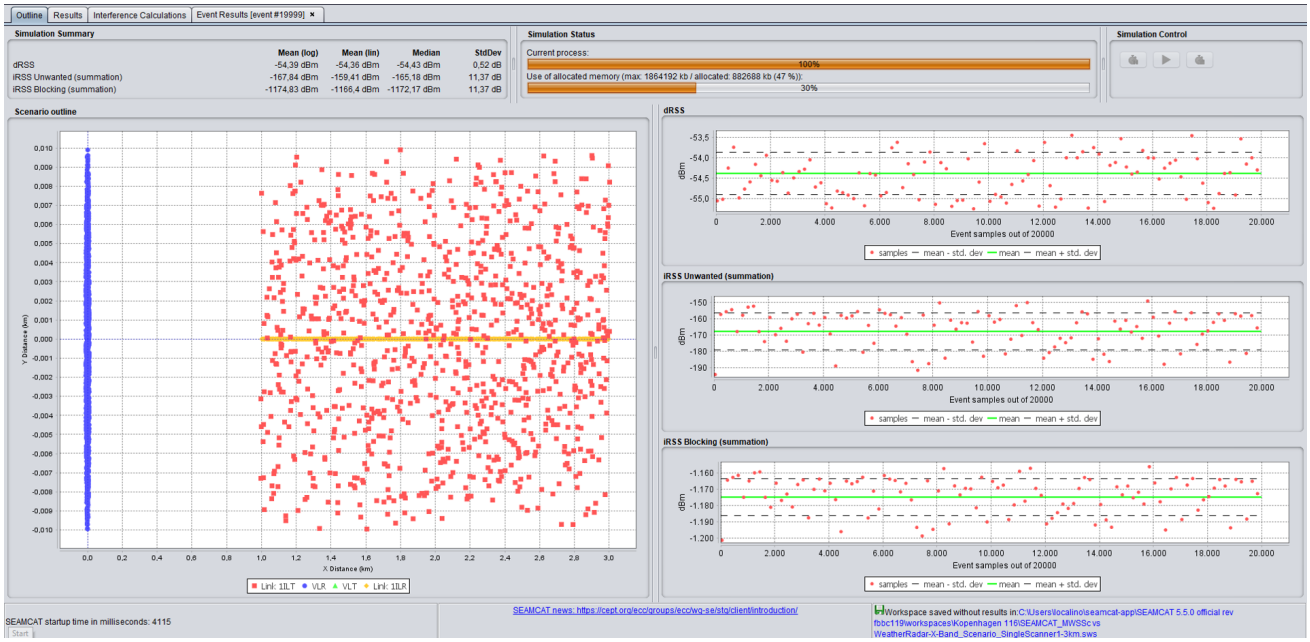


Figure 51: SEAMCAT Simulation

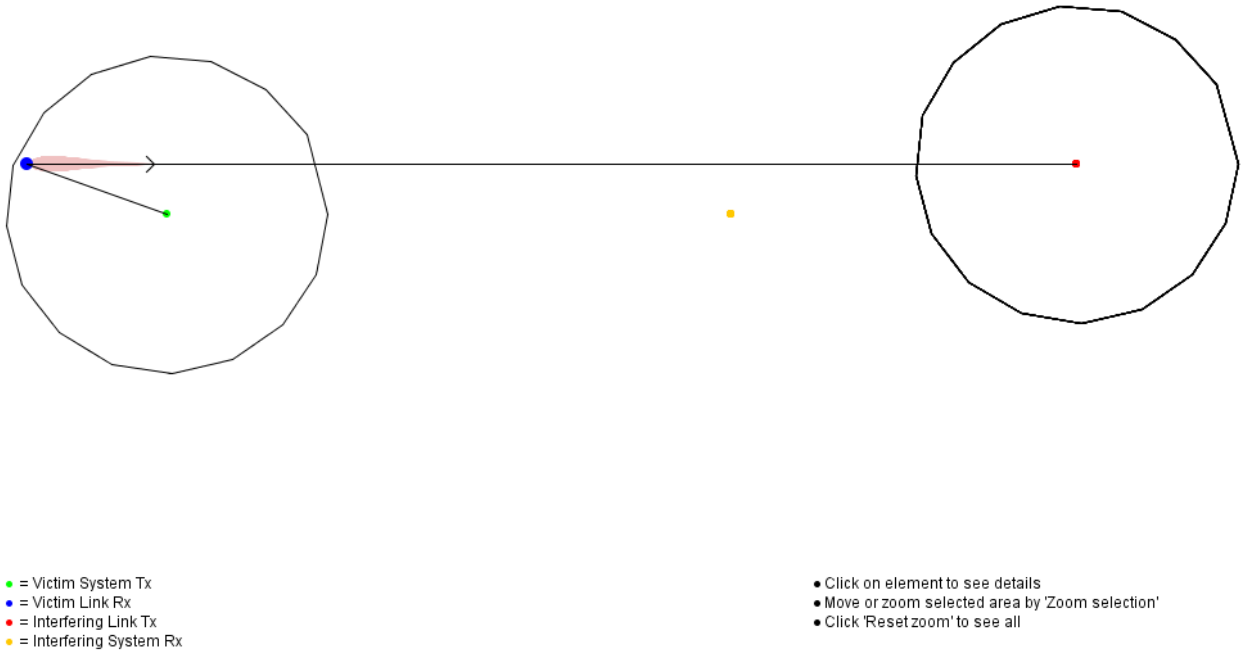


Figure 52: Meteo X-band radar antenna beam pointing towards MWSSC

The iRSS unwanted as cumulative distribution function (CDF) was calculated and is shown in Figure 53. The max iRSS value is -142.45 dBm. With an acceptable 2% value the iRSS power value results in -155 dBm and the margin increases by an additional 13 dB.

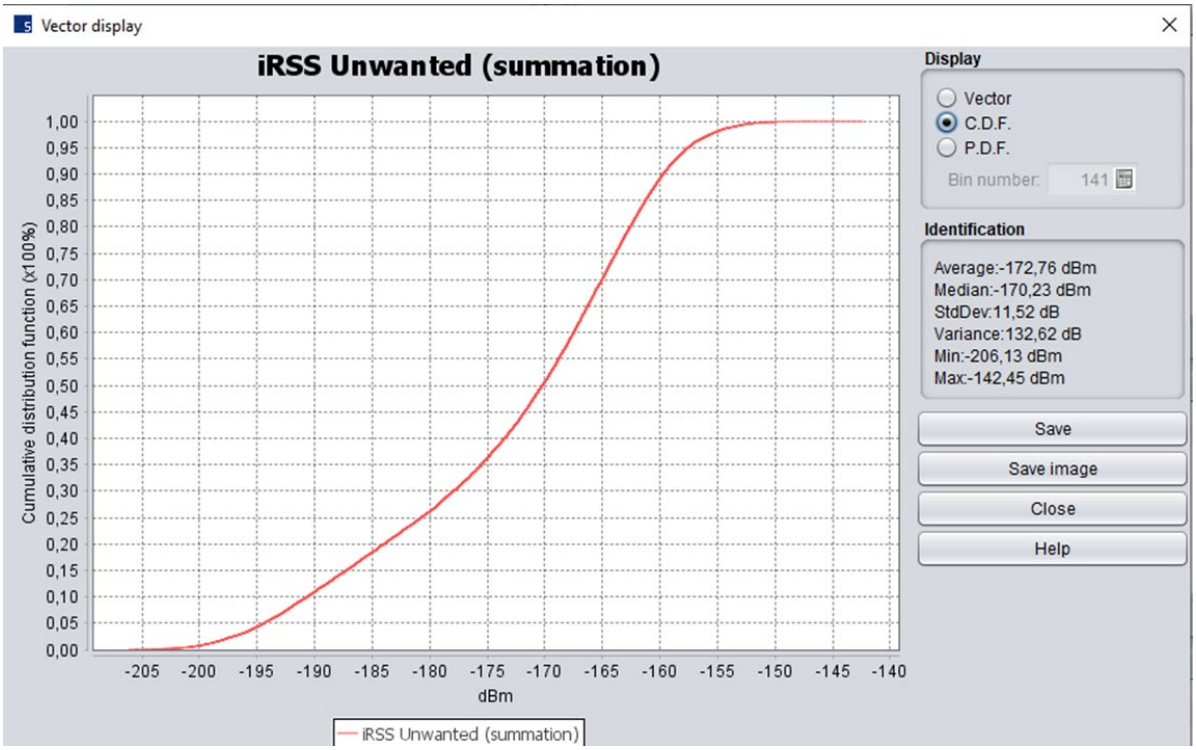


Figure 53: CDF of iRSS at the Meteo X-Band receiver

4.5.4.2 Scenario 2

In a second scenario a number of ten MWSSC are considered to be deployed at a site in Munich airport. The transmit power of each MWSSC is -50 dBm/MHz. No building entry loss is considered.

In Figure 54, the Meteo X-band radar at the parking deck P2 can be seen.

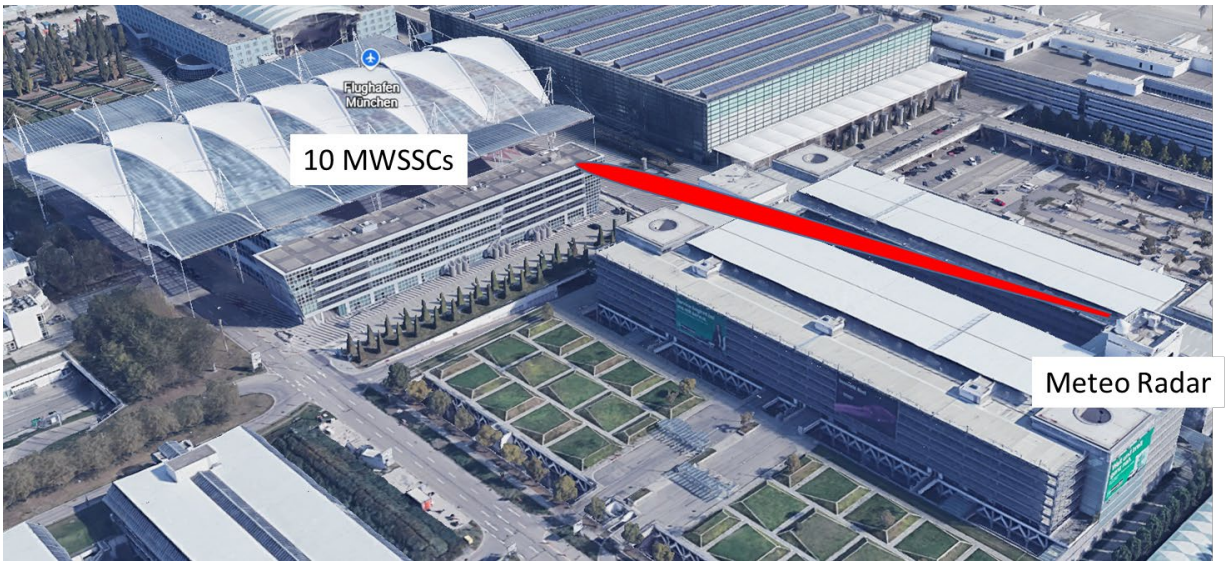
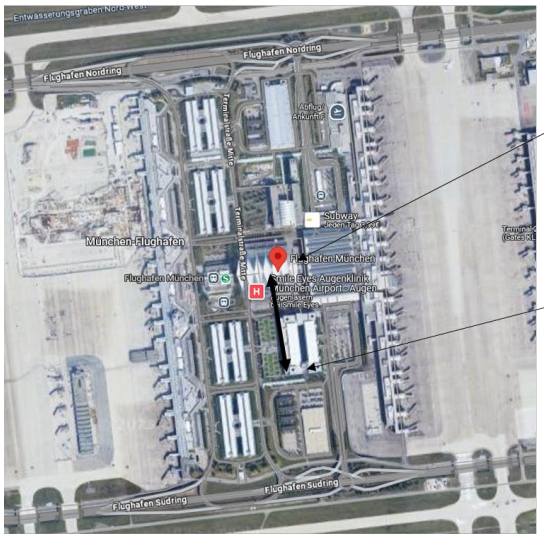


Figure 54: Meteo Radar at Munich Airport



Potential MWSSc inside at security check

Simulation parameters:
Horizontal distance between Radar and MWSSc: 300m – 400m
Antenna height: 2m above ground
TX power: -50 dBm/MHz
10 MWSSc outdoor

X-Band meteo radar on parking P20

Simulation parameters:
Antenna height at top level parking lot: 23,9m
Gain: 42.4 dBi ITU-R F-1245-2

Technical specification according to DWD:

Operating Frequency	9.375 GHz
Pulse Width	2 us
Sensitivity	-113…-103dBm
Antenna scan angle elevation	1°– 90° (1.3° 3dB bandwidth, mechanical scan)
Antenna Gain	42.4 dBi

Figure 55: Technical parameters of Scenario 2

The resulting iRSS CDF is shown in Figure 56. The maximum value results in -143.81 dBm, while a 2 % value would result in approximately -147 dBm. One can see that the iRSS CDF gets steeper compared to the iRSS CDF from Figure 53 where a single MWSSC is considered. However, the maximum power level in these scenarios is in the same range and would not exceed the sensitivity level of an X-band Meteo Radar.

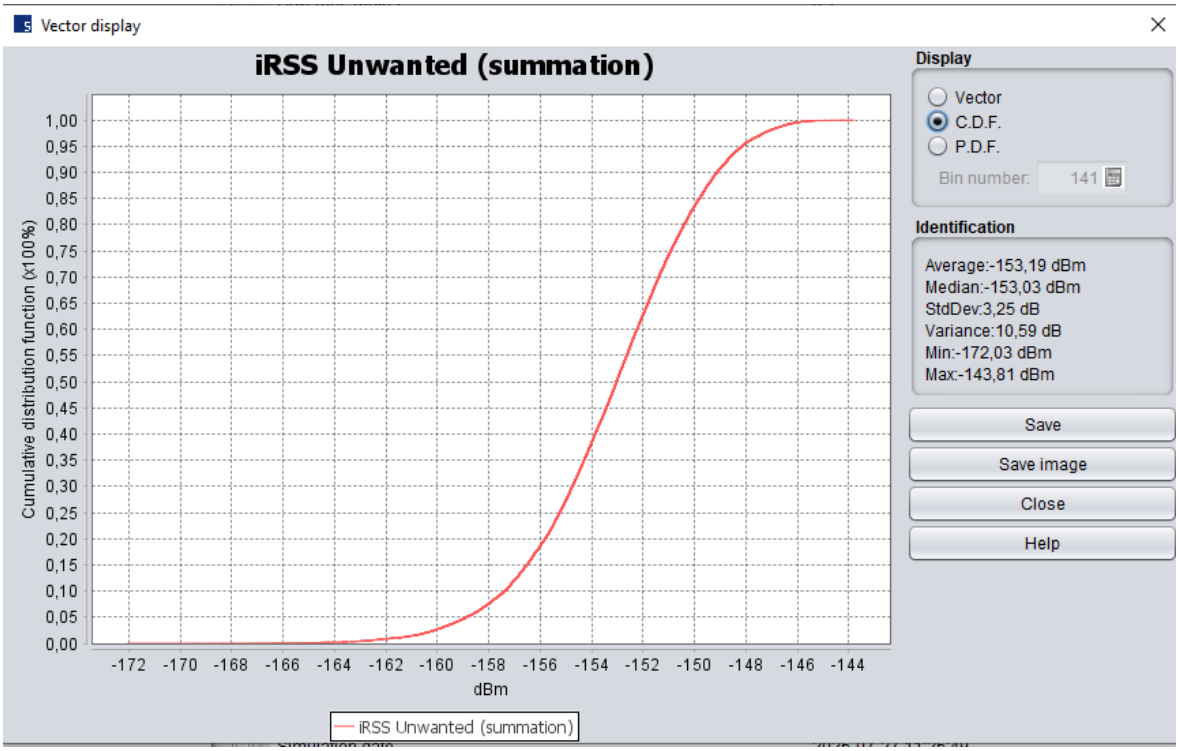


Figure 56: Scenario 2 iRSS CDF

4.5.4.3 Conclusion

Sharing studies for Meteo Radars in X-Band with the radar characteristics of study A (Table 35) have been undertaken in a single interferer scenario with a range of 1 km to 3 km and a dedicated scenario with 10 MWSSC in a cluster similar to the airport in Munich. Considering the 1.2 MHz IF Bandwidth thermal noise will

be at -113.2 dBm. Including the noise figure of 2 dB the noise floor results at -111.2 dBm. According to the description in study A, an I/N of -10 dB is taken into account. This results in an iRSS unwanted value of - 121.2 dBm which should not be exceeded.

In the 10 MWSSC Scenario the radar will observe -145 dBm iRSS and in the single MWSSC scenario in a range from 1 to 3 km the radar will observe -151 dBm at the 2% value. Both values do not exceed the - 121.2 dBm and show a margin of 23.8 to 29.9 dB.

4.5.5 Study C - Weather Radars

4.5.5.1 Generic assumptions for the interference studies with meteorological C-band radars

The compatibility studies for meteorological radars focus on worst-case scenarios, which can be encountered in practice under reasonable assumptions. These assumptions include, for example, unobstructed line of sight propagation between MWSSc and radars antennas when MWSSc are deployed outdoor or at building entrances. Another case considered is the simultaneous operation of up to two independent MWSSc (which operate in an asynchronous manner) in a deployment, within a cluster of up to ten MWSSc deployed indoors, where interference can still propagate over the terrain on an unobstructed LoS path to the radar.

Indoor clusters of multiple MWSSc may be present in locations such as airports or public buildings. Conversely, scenarios with outdoor MWSSc clusters operating in the vicinity of meteorological radars with LoS conditions are unrealistic. In addition, the studies also consider typical deployment situations rather than worst-case ones.

A summary of all these assumptions can be found in Table 45 and Table 46, reflecting the view that only a limited number of permanently installed units is realistic. It can be further noted, that MWSSc are not densely deployed and, unlike mobile devices, cannot generate unpredictable temporary radiation hot spots with a high number of active devices. An apportionment is intended to take account cases in which interference from an MWSSc occurs simultaneously with interference from a transmitter of any other service, including another SRD. Considering all possible scenarios, an apportionment of 3 dB is appropriated for the protection of the X-Band radars, while for C-band radars no apportionment is taken into account. This means that if a MWSSc and any other system interferes simultaneously with the radar, the protection criterion remains satisfied when considering the combined power of both interference sources.

For C-band ground-based radar having a pencil beam antenna pattern of 1° HPBW and operating at elevation angle below 1°[4], the likelihood of receiving two additional independent interfering signals simultaneously is negligible. Although C-band radars share frequencies with other systems that could potentially cause interference, such cases are only possible when the radar operates at elevation angles above 1°. Therefore, an apportionment of 3 dB can be considered a reasonable worst-case assumption for X-Band radars, where the frequency band is shared with different services and the simultaneous reception from two independent sources is more plausible. Given the narrow beamwidth of the radar antenna, interference signal aggregation from MWSSc is likely to occur only within MWSSc clusters. Considering the device size (1.8 m), the assumed spacing between devices (1.6 m) and the distance over which interference can occur within the radar antenna' s HPBW, an aggregation factor of 3 dB can be considered a reasonable worst-case assumption.

Table 45: Deployment parameters considered in the studies for C-band ground based radars

Scenario	Deployment parameters			
	BEL	Clutter loss	Apportionment factor	Aggregation factor
Worst-case indoor	16.5 dB	0 dB	0 dB	3 dB
Worst-case outdoor	0 dB	0 dB	0 dB	0 dB
Generic indoor	16.5 dB	P.2108 [14], p=95%	0 dB	3 dB

[4] Compatibility analysis show, that MWSSc interference is possible only at radar antenna elevation angles below 1°.

Scenario	Deployment parameters			
	BEL	Clutter loss	Apportionment factor	Aggregation factor
Generic outdoor	0 dB	P.2108 [14], p=95%	0 dB	0 dB

Table 46: Deployment parameters considered in the studies for X-Band ground based radars

Scenario	Deployment parameters			
	BEL	Clutter loss	Apportionment factor	Aggregation factor
Worst-case indoor	16.5 dB	0 dB	3 dB	3 dB
Worst-case outdoor	0 dB	0 dB	3 dB	0 dB
Generic indoor	16.5 dB	P.2108 [14], p=95%	3 dB	3 dB
Generic outdoor	0 dB	P.2108 [14], p=95%	3 dB	0 dB

4.5.5.2 Propagation model

The exceedance of the radar protection criterion as well as the minimum required separation distance for compatibility are calculated assuming a flat terrain over distances ranging from 0.1 km to 5 km. It can be shown, based on the first order Fresnel ellipse calculation, that the free space propagation model cannot be applied for the above-described scenarios. Instead, a propagation model which takes into account diffraction losses, such as the model provided in Recommendation ITU-R P.452-16 [37] must be used.

This study is based on the propagation model in Recommendation ITU-R P.452-16 without clutter loss. The clutter loss taken into account in the studies is based on Recommendation ITU-R P.2108 [14] configured with the parameter value p=0.95.

4.5.5.3 C-band weather radars

Protection margin for C-band meteorological radars when using an average power spectral density of - 60 dBm/MHz

The MWSSc is assumed to radiate electromagnetic energy with an average power spectral density of - 60 dBm / MHz, over a 40 µs duration, with a periodicity of 280 µs and a PRF of 12 MHz.

In this study, the radars are assumed to operate at their minimum antenna elevation angle, as this configuration represents their most vulnerable state to interference from MWSSc signals. According to Recommendation ITU-R M.1849-3 [19], each type of radar is associated with a range of possible antenna heights. To account for this, interference calculations are performed across these height ranges using 5 m increments. Specifically, radar 14 considers 3 antenna heights, radar 17 considers 7, and radar 21 considers 9, resulting in a total of 19 distinct antenna height configurations for all scenario types (worst-case indoor, worst-case outdoor, generic indoor, and generic outdoor).

Each configuration yields a different separation distance and interference margin. Those results are shown graphically in Figure 57 to Figure 62 as cumulative distribution functions (cdf), where the vertical axis indicates the relative number of scenarios (*rnos*) (i.e. sets of parameter configurations) for which a separation distance or margin undershoot occurs, where the vertical axis indicates the relative number of parameter configurations used in the calculations.

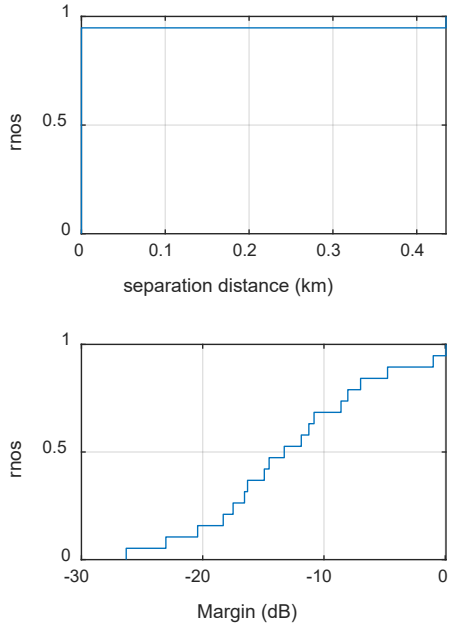


Figure 57: Worst-case outdoor

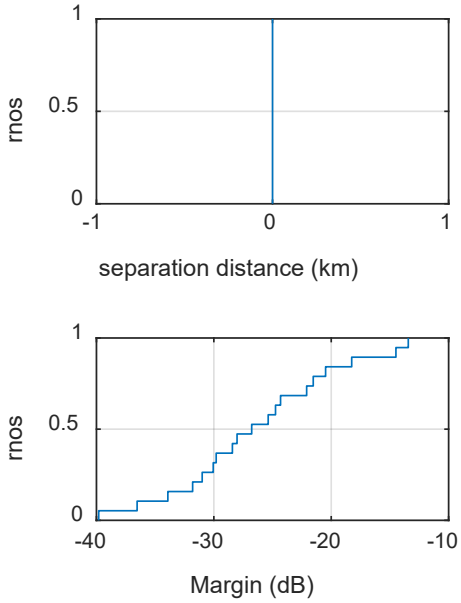


Figure 58: Worst-case indoor

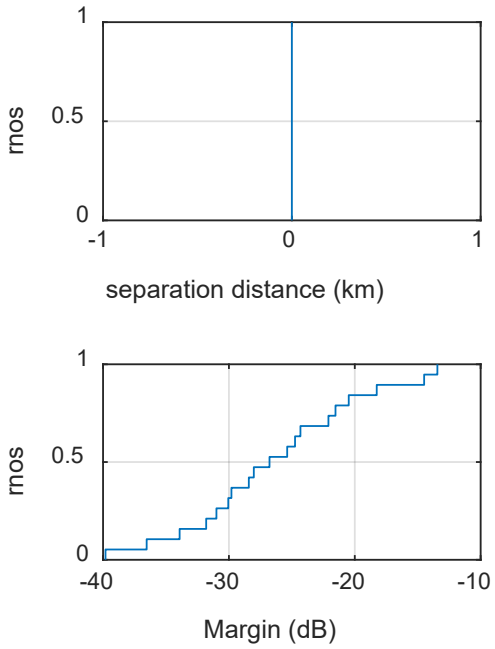


Figure 59: Worst-case indoor

Figure 57 shows, that under Worst-case outdoor assumptions, coexistence is possible for 85% of the parameter settings (18 out of 19). A detailed analysis shows, that for radar 14, when operated with an antenna height of 5 m, coexistence is not achievable. As shown in Figure 57, in this case a separation distance of about 450 m is needed. For the scenarios "Worst-case indoor", "generic indoor" and "generic outdoor" coexistence is achievable, as shown in Figure 59 to Figure 61. Details on the analysis results for the scenario "Worst-case outdoor" can be found in the Annex 3. All these results are based on calculations taking into account the radiation pattern specified in Recommendation ITU-R M.1851-2 [26].

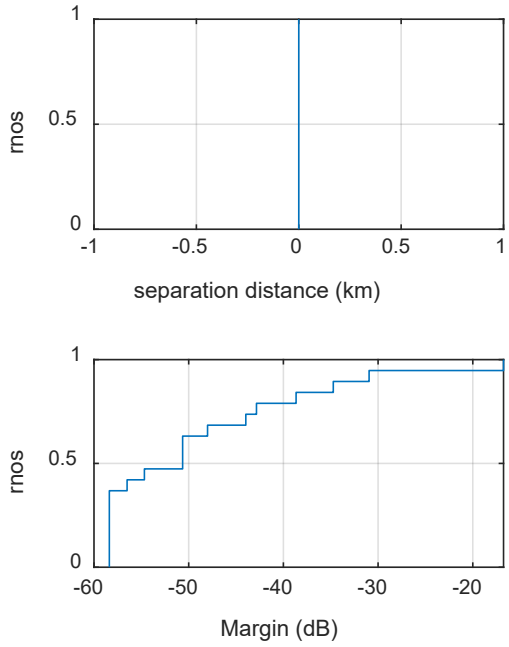


Figure 60: Generic case indoor

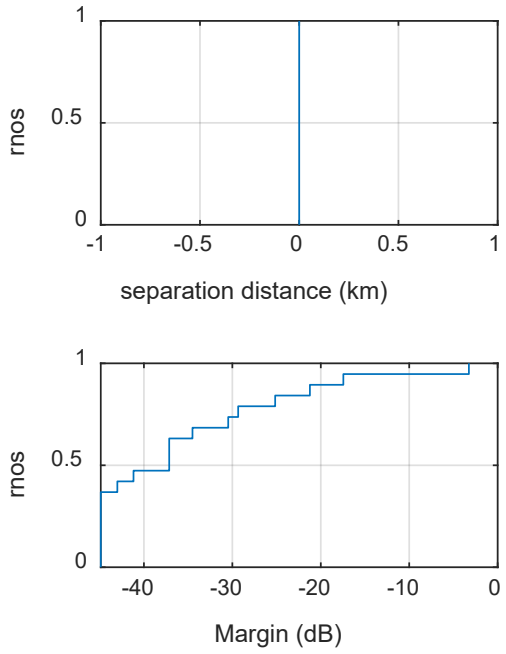


Figure 61: Generic case outdoor

Maximum acceptable e.i.r.p. for coexistence with C-band meteorological radars

The separation distance and margin are calculated taking into account the radiation pattern data measured from an operating C-band meteorological radar, the results are presented in Figure 62.

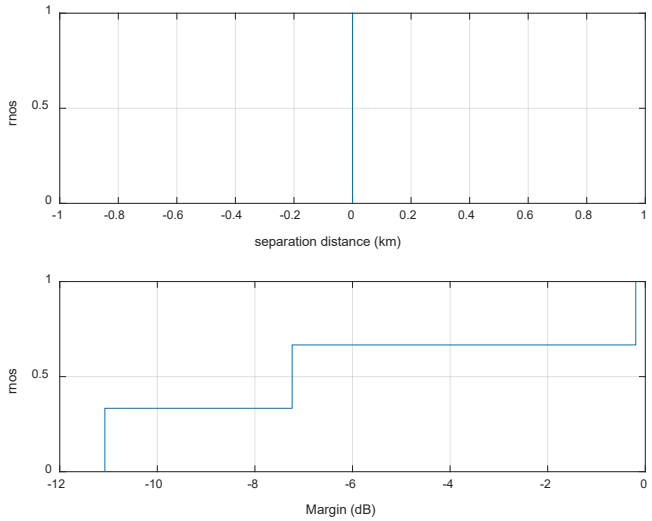


Figure 62: Worst-case outdoor

It can be concluded that, given the deployment scenarios and characteristics of the MWSSc under consideration, the data from the measured radiation pattern of an existing C-band meteorological radar station has no significant influence on the results of the compatibility calculation.

Table 47: Maximum PSD levels for coexistence with C-band radars

Scenario	Mean *e.i.r.p.* spectral density (t = Rx averaging time)	Mean *e.i.r.p.* spectral density (t = 1 ms)
Worst-case indoor	-46.5 dBm/MHz	-52 dBm/MHz
Worst-case outdoor	-60.1 dBm/MHz	-65.6 dBm/MHz
Generic indoor	-43.2 dBm/MHz	-48.7 dBm/MHz
Generic outdoor	-56.7 dBm/MHz	-62.2 dBm/MHz

It may seem surprising that the limit for the "generic outdoor" scenario is only 5.25 dB higher than for the "Worst-case outdoor" scenario. This is due to the fact, that at distance of about 250 m from the radar operating at an elevation angle of 0°, the antenna gain approaches its maximum value. Additionally, for distances below 250 m, the model defined in Recommendation ITU-R P.2108 [14] does not account for clutter loss, which further reduces the difference between the two scenarios.

Conclusions

Maximum permissible radiation mean *e.i.r.p.* spectral density for MWSSc to protect meteorological C-band radars are shown in Table 47.

4.5.5.4 X-band radars

Protection margin for X-Band radars when using an average power spectral density of -60 dBm/MHz

The MWSSc is assumed to radiate electromagnetic energy with an average power spectral density of -60 dBm / MHz, radiated during a time period of 40 µs with a periodicity of 280 µs and a PRF of 12 MHz.

In this study, the radars are assumed to operate at their minimum antenna elevation angle, as this configuration represents their most vulnerable state to interference from MWSSc signals. For the four scenario types (Worst-

case indoor, Worst-case outdoor, generic indoor and generic outdoor) are analysed. Each configuration yields a different result for the required separation distance and interference margin Those results are shown graphically in Figure 63 to Figure 66, where the vertical axis indicates the relative number of parameter configurations used in the calculations.

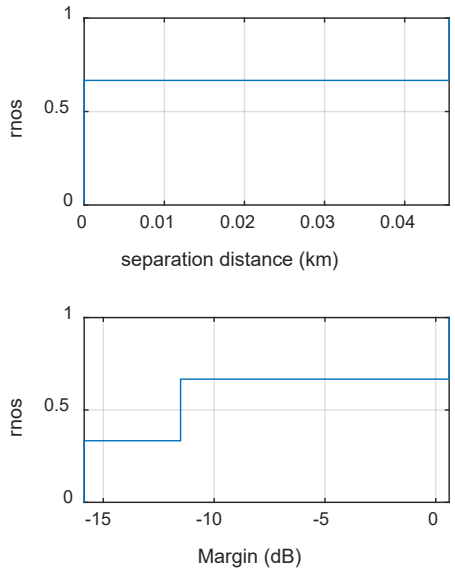


Figure 63 Worst-case outdoor

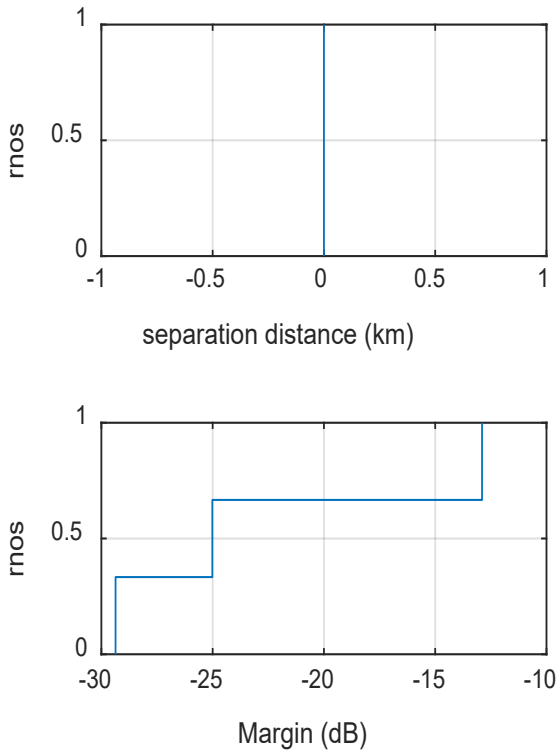


Figure 64: Worst-case indoor

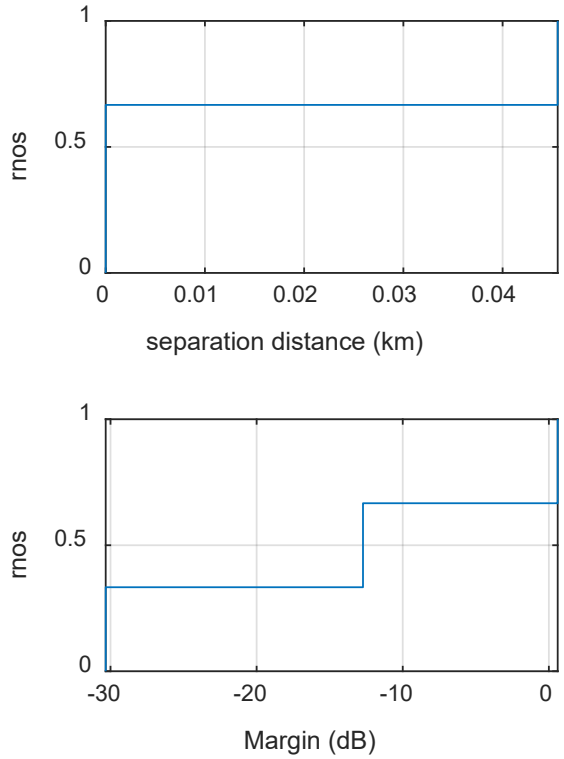


Figure 65 Generic case indoor

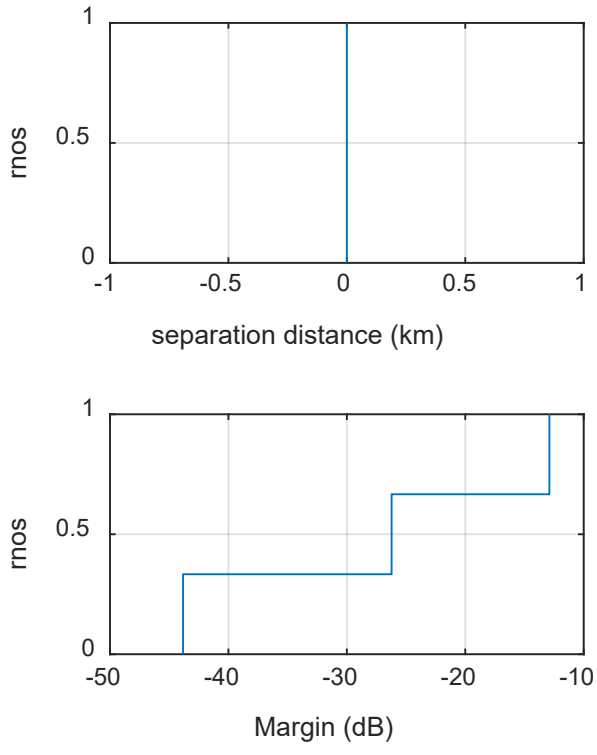


Figure 66: Generic case outdoor

Maximum acceptable *e.i.r.p.* for coexistence with X-band radars

Table 48: Maximum PSD levels for coexistence with X-band radars

Scenario	Average PSD	Average PSD measured over 1 ms
Worst-case indoor	-47.1 dBm/MHz	-52.6 dBm/MHz
Worst-case outdoor	-60.4 dBm/MHz	-65.9 dBm/MHz
Generic indoor	-43.2 dBm/MHz	-48.7 dBm /MHz
Generic outdoor	-47.1 dBm/MHz	-52.6 dBm /MHz

Conclusions

Maximum permissible radiation mean *e.i.r.p.* spectral density for MWSSc to protect meteorological X-band radars are shown in Table 48.

4.5.6 Study D - Weather Radars (Measurement)

4.5.6.1 Introduction

Microwave Security Scanners (MWSSc) using Ultra-Wideband (UWB) technology operate in a range from 3.6 GHz to 10.6 GHz.

The targeted deployment sites at airports, public events, public transportation, and shopping malls indicate possible widespread indoor and outdoor use.

Considering the current UWB ECC regulations, in particular the ECC Decision (06)04 [3], the operating range of meteorological radars in C-band and X-band is safeguarded with very low levels of maximum emissions (-70 dBm/MHz) for UWB applications.

In light of the ongoing interference to meteorological radars caused by RLAN devices operating in Europe, it is of paramount importance to Deutscher Wetterdienst (DWD, German Meteorological Service) and EUMETNET that the introduction of MWSSc UWB technology does not give rise to additional interference concerns.

To assess the compatibility between MWSSc and meteorological radars operating in the C-band and to determine the necessary conditions for coexistence in real-world scenarios, DWD and Rohde & Schwarz, with support from BNetzA, conducted measurements for MWSSc using UWB technology.

Different waveforms were generated at varying power levels and transmitted towards the radar system to simulate the potential impact of an MWSSc. The radar was operated in different operational configurations and recorded data for further post-processing and analysis. The setup was repeated at two locations to obtain line-of-sight results at two different distances from the radar.

The measurements took place on 5 and 6 November 2024.

4.5.6.2 Setup

Technical specifications of meteorological radar

The measurements took place using the DWD Hohenpeißenberg radar (MOHp) in the southern region of Germany. The technical specifications are given in Table 49.

Table 49: MOHp Parameters

Characteristic	MOHp
Operating frequency	5640 MHz
Antenna pattern type	Pencil
Antenna type	Parabolic
Antenna polarisation	Horizontal and vertical
Antenna main beam gain	45 dBi
Antenna side lobe gain	25 dBi
Antenna elevation beam width	0.9°
Antenna azimuthal beam width	0.9°
Transmitter (Tx) output power	500 kW (Magnetron)
Duty cycle	0.12%
Pulse width	0.4-3.0 us
PRF	200-2400 Hz
Receiver IF filter bandwidth	1.0 - 2.5 MHz (depending on pulse width)
Receiver Path Losses	2.74 dB
Minimum detectable signal (MDS)	Approximately. -115 dBm (LNA Input) @ 0.8µs

The parabolic antenna used by meteorological radars are usually well described by the antenna pattern given in Recommendation ITU-R F.1245 [33].

In addition to these parameters, meteorological radars present a number of specificities in term of operational conditions, such as volumetric scanning strategy and use of schemes mixing different pulse width and PRF, and in particular the use of fixed, staggered or interleaved PRF (i.e. different PRF during a single scheme).

In the operational DWD scan strategy, the antenna rotates continuously in azimuth and changes elevation angle between 0.5° and 25° in an interleaved pattern. This procedure is repeated every 5 minutes and results in a volume scan. Additionally, a dedicated terrain-following precipitation scan at an elevation angle low above the horizon, and a scan at 90° elevation is performed. At each elevation, the antenna rotates 360° in azimuth before moving to the next elevation. These scans are extended by a “staring” time scan in the direction of a distinct scatterer with fixed azimuth and elevation.

For the measurement campaign eight time-scans in a fixed direction were followed by three plane position indicator (PPI) scans. For the fixed scans, the radar antenna was pointed with the main lobe in direct line of sight to the interfering signal source and neither moved in azimuth nor elevation. The PPI scans used the fixed elevation angle.

The scanning scheme is presented in Table 50.

Table 50: Scanning Scheme Radar

No.	Type	PRF [Hz]	PW [us]	Range avg.	Other
1	Fixed scan	1000	0.8	-	1024 samples per ray, 4 seconds
2	Fixed scan	1000	0.8	10	1024 samples per ray, 4 seconds
3	Fixed scan	1000	0.4	-	1024 samples per ray, 4 seconds
4	Fixed scan	1000	0.4	10	1024 samples per ray, 4 seconds
5	Fixed scan	1000	0.8	-	30 samples per ray, 4 seconds
6	Fixed scan	1000	0.4	-	30 samples per ray, 4 seconds
7	Fixed scan	1000	0.8	-	60 samples per ray, 4 seconds
8	Fixed scan	1000	0.4	-	60 samples per ray, 4 seconds
9	PPI	600	0.8	10	12°/s
10	PPI	800/600	0.8	10	12°/s
11	PPI	2410	0.4	10	30°/s

Additionally, to the scan scheme given in Table 50 a raster scanning was selectively added, in which the radar antenna moved in a relatively fine azimuth and elevation grid centred on the interfering signal. The settings are provided in Table 51.

Table 51: Raster scan settings

Type	PRF [Hz]	PW [us]	Other
Raster Scan (Parking Lot)	3000	0.4	Azimuth: 85° - 105°, Elevation: -2° - 5°, Az-Speed 2.5°/s, El-Step 0.2°, Az-Step 0.2°
Raster Scan (Auerberg)	1200	0.8	Azimuth: 240° - 260°, Elevation: -2° - 5° Az-Speed 2.0°/s, El-Step 0.2°, Az-Step 0.2°

Parameters, signals and equipment

As it was not feasible to use an actual MWSSc antenna tile or to simulate its signal in the testing environment, it was agreed to use four representative signal types to assess potential interference effects on the radar system. To reflect different spectral characteristics, two narrowband signal types - continuous wave (CW) and rectangular pulsed - and two broadband signal types - additive white Gaussian noise (AWGN) and orthogonal frequency-division multiplexing (OFDM) - were selected. The CW and AWGN signals serve as well-reproducible reference cases, while the pulsed and OFDM signals represent realistic, application-relevant examples.

The selected signals and their parameters are summarised in Table 52. All signals were centred on the radar operating frequency of 5640 MHz.

Table 52: Parameters Interfering Signals

Waveform	Parameters
CW	Continuous wave 5640 MHz
Pulsed	Rectangular 5590-5690 MHz, fp = 12 MHz
AWGN	Signal bandwidth 10 MHz
OFDM	Signal bandwidth 20 MHz

The interfering signal was generated using the Rohde & Schwarz SMBV100B vector signal generator connected to an Rohde & Schwarz HF907 double-ridged waveguide horn antenna.



Figure 67: Horn antenna on extendable mast (left) and signal generator (right) setup

Measurement setup

The measurements were carried out at two sites at different distance to the radar site.

Table 53: Sites

Site	Coordinates	Distance to MOHp	Free space losses
Radar MOHp	47.8015 N, 11.0092 E	-	-
Parking Lot	47.8012 N, 11.0150 E	432 m	100.18 dB
Auerberg	47.7359 N, 10.7365 E	21630 m	134.17 dB

At each site, the radar antenna and the horn antenna transmitting the interfering signal were aligned to face each other directly. Both locations offered a clear line-of-sight, with minor obstructions limited to the lower hemisphere of the propagation path.



Figure 68: Distance Auerberg – Radar Hohenpeißenberg, Bavaria, Germany

For each of the four signal types, a complete dataset was processed and recorded by the radar signal processor, using the scan scheme outlined in Table 50 and the radar's operational settings. Measurements were conducted at three different power levels of the interfering source. These power levels were adjusted to achieve signal-to-noise ratios (SNR) at the radar of approximately 20 dB, 0 dB, and –5 dB (i.e., near the detection threshold). The appropriate settings were determined in real time by monitoring the radar signal processor's live data display, specifically the SNR over range plot in the horizontal channel, while incrementally adjusting the signal generator output.

Due to the short distance of only 432 meters at the parking lot, the radar transmitter was not activated during measurements at this location in order to avoid potential damage to the interfering equipment. Furthermore, boresight alignment of the radar antenna with the horn antenna was not possible, as the horn was positioned below the radar pedestal's lower elevation limit. This misalignment is evident in the SNR contour plot from a raster scan conducted at the Parking Lot site, shown in Figure 69. The signal originating from the horn antenna appears slightly to the left of 95° azimuth and does not reach the expected maximum intensity.

This observation was further substantiated by a link budget analysis, which revealed higher-than-anticipated path losses for the Parking Lot configuration.

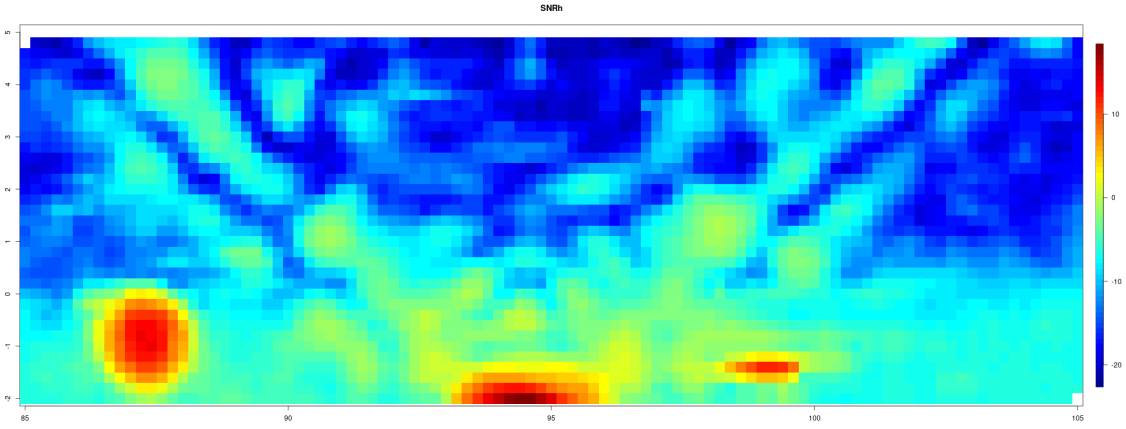


Figure 69: Raster Scan Parking Lot, CW, SNR 20 dB, Tx off

At the Auerberg site most measurements were conducted with the radar transmitter turned on, offering a more representative operational scenario. An overview of the measurements included in the evaluation is provided

in Annex 4. As a result, the Auerberg site - offering full line-of-sight, proper alignment, and active transmission - is used as the primary reference scenario for the evaluation.

4.5.6.3 *Measurement data*

Overview

Data analysis was performed on the measurement data obtained from the fixed scans, using the processed SNR values from the horizontal receiver channel, as provided by the radar signal processor.

The signal processor estimates the SNR as:,

$$SNR = 10 * \log_{10}\left(\frac{T_0 - N}{N}\right) \quad (5)$$

where:

- T_0 is the unfiltered signal power at the digital receiver input (including the noise);
- N is the noise power determined through noise sampling.

The received signal strength — measured at the input of the Low Noise Amplifier (LNA), i.e., prior to down-conversion to intermediate frequency (IF), digitisation, and further processing — can be estimated based on the radar antenna gain, receiver path losses (as provided in Table 49) and the free-space-loss, as follows:

$$\mathrm{LNAinput} = \mathrm{PTSG} - \mathrm{Losscable} + \mathrm{Ghorn_antenna} - \mathrm{Lossfree-space} + \mathrm{GRadar} - \mathrm{LossRX} \quad (6)$$

Since the gain of the horn antenna is approximately 11 dBi and the cable loss between the signal generator and the horn antenna mounted on the extendable mast is approximately 10.9 dB, the equivalent isotropic radiated power (*e.i.r.p.*) at the horn antenna can be estimated by subtracting the cable loss from the signal generator output power and then adding the antenna gain. Therefore, the *e.i.r.p.* at the horn antenna is nearly equal to the output power of the signal generator (PTSG).

In the evaluation, the SNR is used as the primary reference for the received signal power at the radar, as direct measurements of the input power at the LNA is not feasible during operation. Furthermore, such a measurement would not reflect the characteristics of the receiver electronics, including the down-converter, digitizer, and signal processing chain the relation between signal power at the LNA and the observed SNR is not strictly linear, particularly at low SNR levels. Nevertheless, the SNR provides a reliable indicator of the detection threshold and the impact of interference on radar data quality.

The fixed scans provide data points over both range (per ray) and time (across sequential rays). Time sampling per ray and range sampling are configurable parameters of the signal processor and are detailed in Table 50.

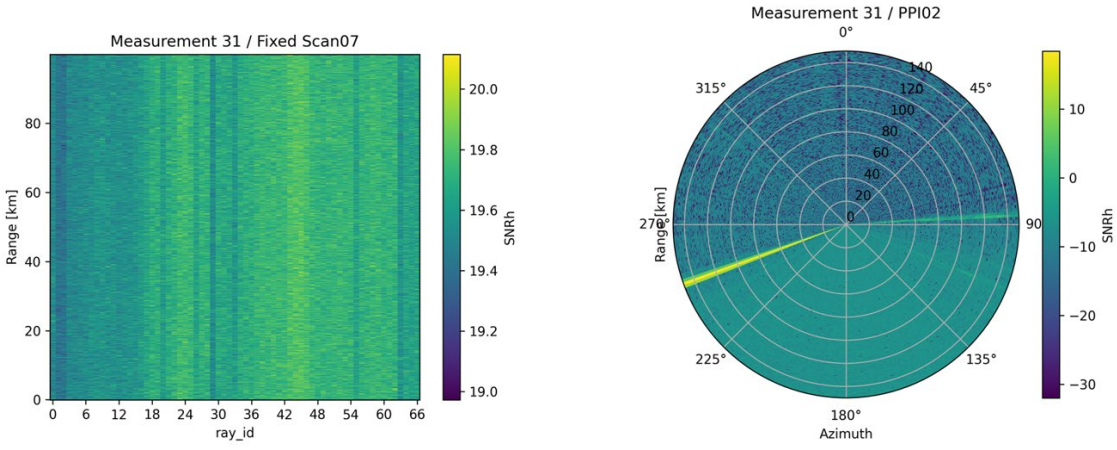


Figure 70: Example Visualisation of Data, Measurement 31, Fixed Scan 07 and PPI 02

A ray consists of the processed data in discrete range bins in a single direction. In operational scanning, the number of pulses used to form a ray depends on the pulse repetition frequency (PRF) and antenna rotation speed. For time-fixed scans, this number can be selected freely. Each operational radar ray at DWD spans approximately 1° in azimuth and extends up to 180 km in range, covering an area of approximately 283 km² per ray.

Interference signals typically affect an entire ray, necessitating its exclusion from operational processing. For subsequent analysis, the SNR values from all rays within a fixed scan are averaged to yield a single representative SNRh value corresponding to the specific signal type and power level of the interfering source.

Initial evaluation of the datasets under different scan settings is conducted using boxplots.

Data analysis Auerberg site

Clutter correction

At the Auerberg site, data was recorded for the CW and AWGN signals with the radar transmitter both switched on and off, while for the pulsed and OFDM signals data was only recorded with the radar transmitter on.

When the radar transmitter is active, the recorded data include backscatter from the Earth's surface, commonly referred to as ground clutter. As this clutter in not relevant for the interference analysis, affected range gates were excluded based on the signal processor's clutter detection. This ensures that the remaining data contain only noise and the interfering signal. Weather conditions during the measurement were ideal (blue sky with minimal cloud cover), and as a results, no weather echoes were present in the data.

Figure 71 shows a representative comparison of the PPI scans with and without clutter removal. It is evident that the radar transmitter is consistently switched off in the azimuth sector between 80° and 110°, due to safety constraints. Additionally, elevated background noise is observed between 80° and 250° azimuth, attributed to reflections from the Alpine terrain.

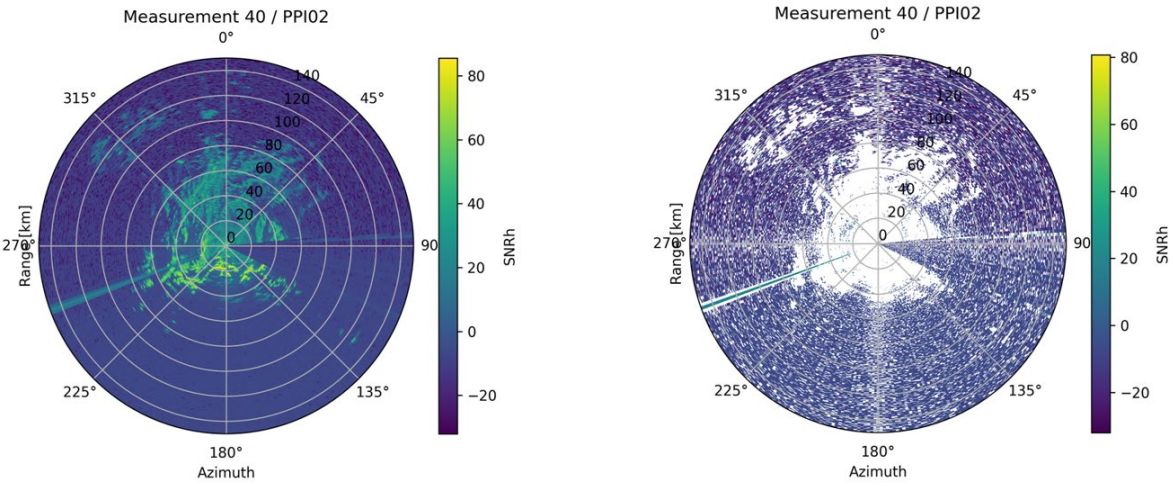


Figure 71: PPI Plots, Auerberg, Tx On, CW, with clutter (left), clutter removed (right)

A comparison of the datasets for AWGN and CW - measured with the transmitter off and the transmitter on but clutter removed - shows comparable median values, as illustrated in the boxplots in in Table 54, Figure 72 and Figure 73. Only at the lowest signal power level, close to an SNR of -5 dB, a slight reduction in sensitivity of approximately 1 dB is observed. This is attributed to the presence of the transmitted radar pulse. This deviation remains well within the overall measurement uncertainty.

Table 54: Comparison of median values of CW and AWGN datasets (Auerberg)

Signal Type	Signal Power Spectrum Density (PSD) [dBm/MHz]	Tx Off [dB]	Tx On (clutter removed) [dB]
CW	3	19.66	19.82
CW	-18	-1.15	0.11
CW	-23	-4.87	-3.59
AWGN	7.1	20.21	20.34
AWGN	-13.9	-0.08	0.03
AWGN	-15.9	-2.62	-1.65

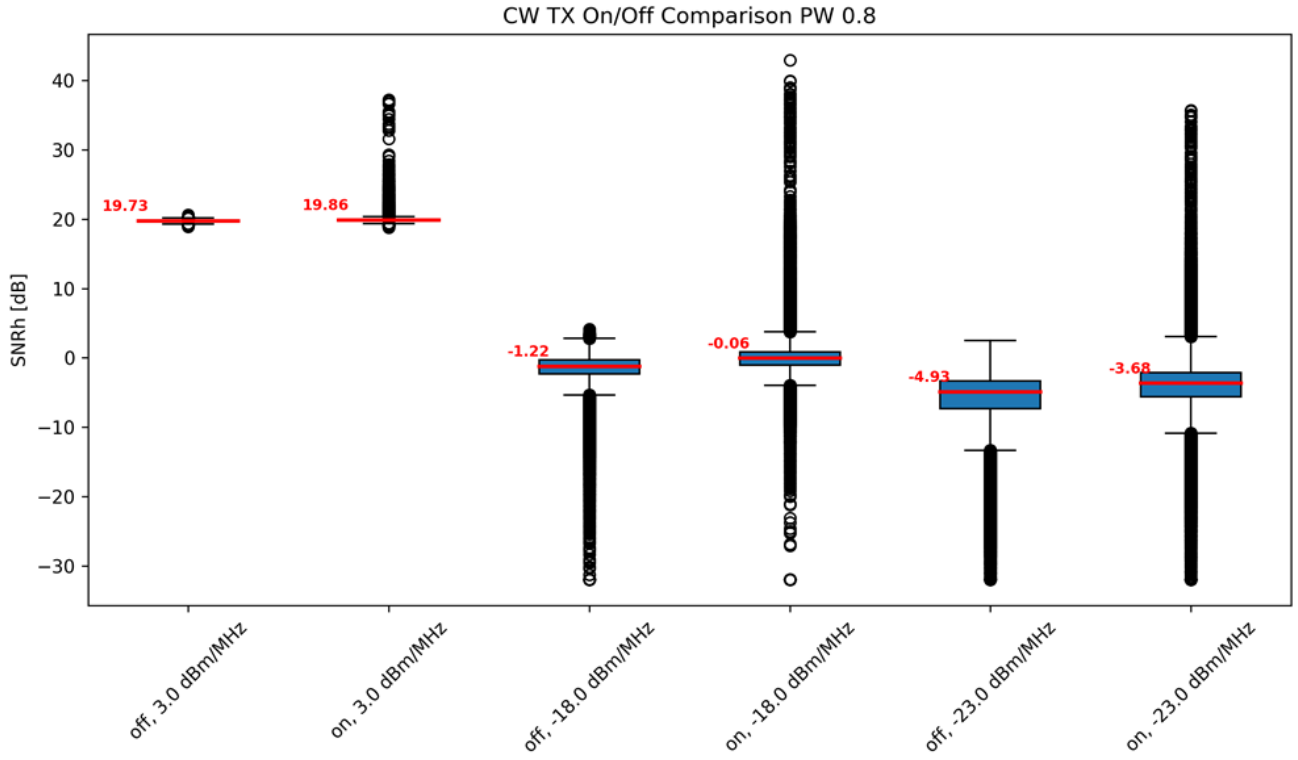


Figure 72: Comparison of datasets for TX Off and TX On (clutter corrected), CW, Auerberg

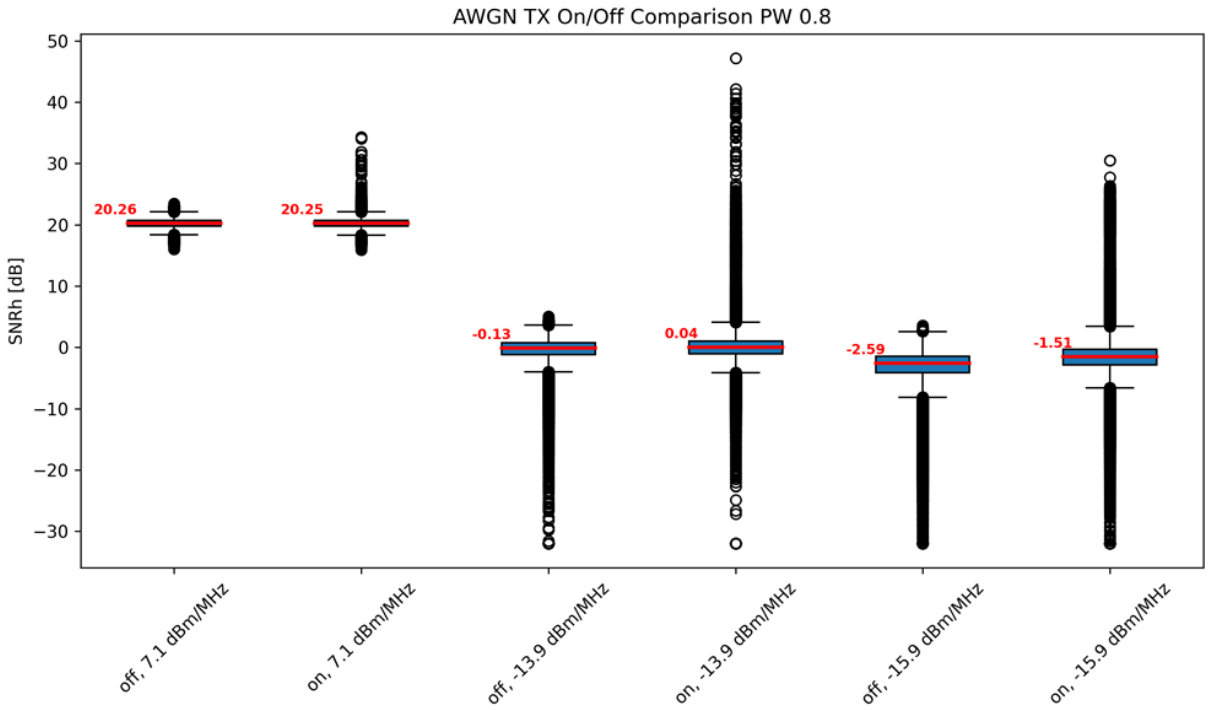


Figure 73: Comparison of datasets for TX Off and TX On (clutter corrected), AWGN, Auerberg

The comparison demonstrates the effectiveness of the clutter removal procedure.

Signal Type

A comparison of the datasets for the four signal types reveal a significant dependency on the radar pulse width.

The pulse width used for the radar signal directly influences the filter bandwidth of the receiver. In case of DWD radars, 0.4 and 0.8 µs are operationally used, however other European countries use values of up to 2 µs for magnetron systems.

In Figure 74, a comparison between the measured SNR of the different signal types sorted by the used pulse width is shown. For the CW and pulsed signal, the median of the SNRh for a 0.4 µs pulse width is noticeably lower (-1.52 dB/ -0.54 dB) than for the 0.8 µs pulse width (-0.06 dB/ 1.18 dB). For the AWGN and OFDM signals no noticeable difference can be seen.

An explanation for this is, that the bandwidth of the receiver matched filter is inversely proportional to the pulse width (BW ~ 1/PW). Hence, longer pulses require less bandwidth which reduces the received noise power. For narrowband signals, this will result in an increased SNR. For the broadband signals considered here, the signal bandwidth is much than the filter, and changing pulse width will equally change signal and noise power.

This is important to consider for narrowband signals, as an additional safety margin may be necessary for other meteorological services that operate with pulse widths of up to 2 µs. These are significantly longer than the 0.4 µs and 0.8 µs used by DWD, and result in higher receiver sensitivity - making such systems more susceptible to this type of interference.

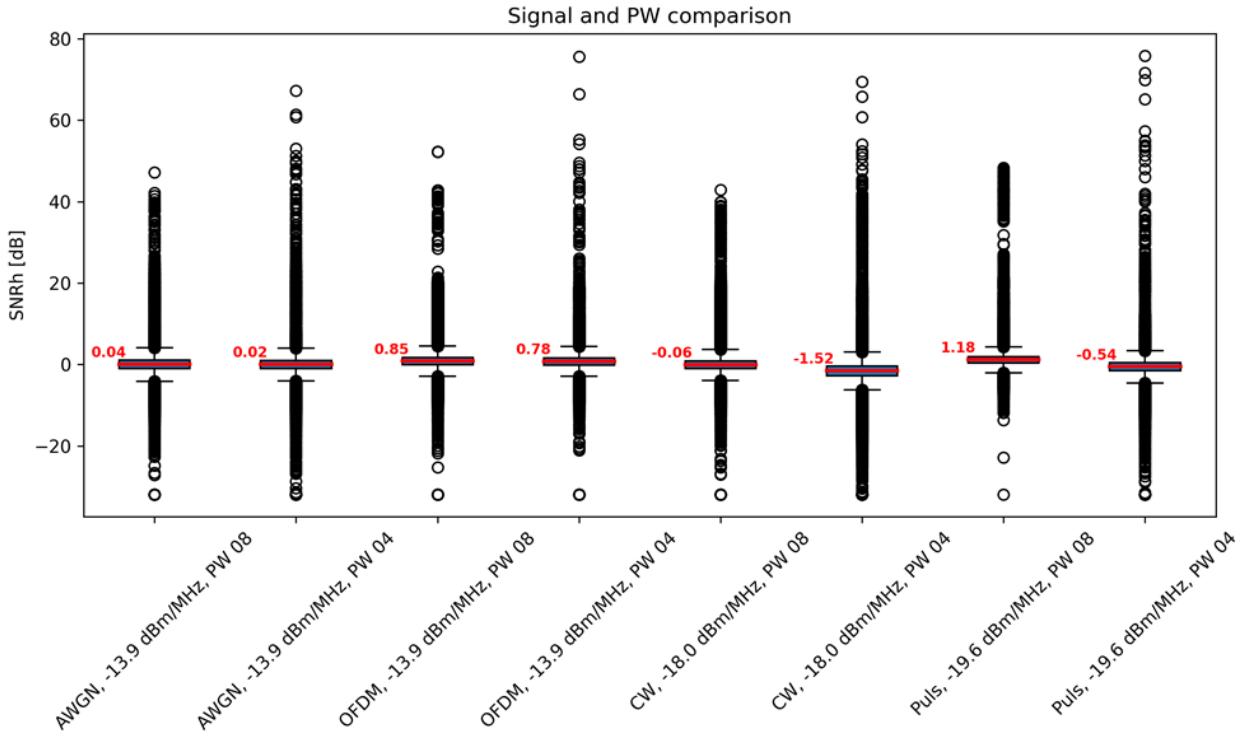


Figure 74: Comparison of datasets for different Signal Types sorted by Pulse Width, Auerberg

Comparison to Minimum Detectable Signal

To gain a better understanding of the relationship between receiver input power at the LNA and the SNR as calculated by the signal processor (see Eq. (1)) and to determine the detection threshold at the minimum detectable signal (MDS) an additional measurement is carried out. A high-quality internal signal generator (iTSG) inside the radar is used to generate a CW signal and inject it into the LNA. The iTSG features a well-calibrated and adjustable power output.

During the measurement, the output power of the iTSG was gradually reduced until the radar's PPI display began to show missing data points - an indication that the detection threshold had been reached. This occurred at approximately –5 dB SNR. For each power setting, the average SNR was recorded.

To replicate conditions similar to the interference measurements, the radar antenna was pointed toward the Auerberg site, ensuring a comparable background noise level. The radar signal processor was configured using the same fixed-scan settings, with both 0.4 µs and 0.8 µs pulse widths.

Figure 10 presents the iTSG measurement results in comparison with the CW datasets obtained at Auerberg, separated by pulse width and transmitter state. For the 0.8 µs pulse width, the observed minimum detectable signal corresponds to approximately –116 dBm at an SNR of –5 dB.

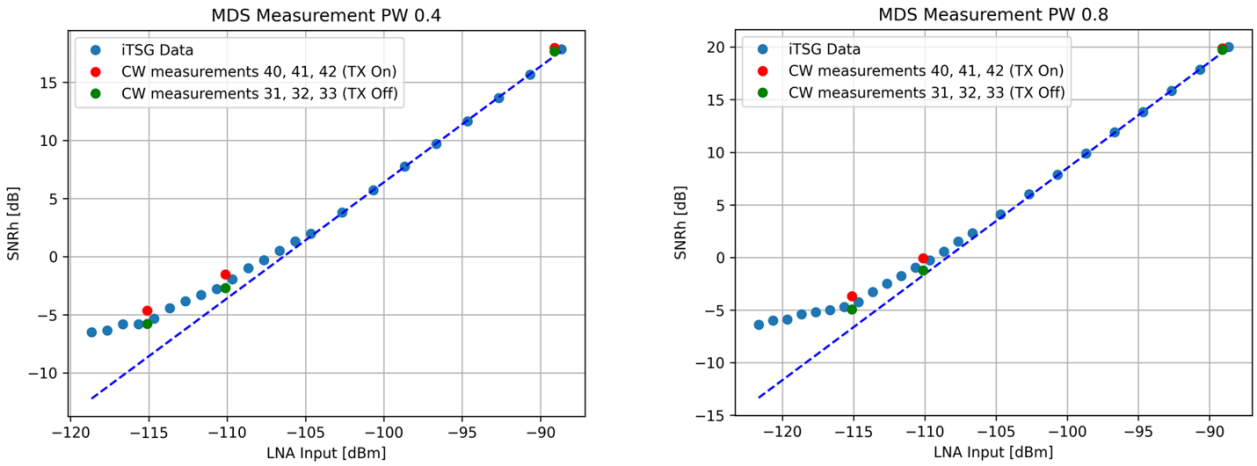


Figure 75: MDS measurements including CW datasets (Auerberg) for TX On and TX Off. Separated by scans with pulse width 0.4 µs (left) and 0.8 µs (right).

Overall, they show good a good fit to the internal measurements with the data for the transmitter on being elevated as explained in the section on "clutter correction".

Data Analysis Parking Lot site

As discussed in section 2.3, the Parking Lot site exhibits certain limitations. However, due to its close proximity to the radar, it allowed for the use of more realistic power spectral density (PSD) levels at the interference source levels that are representative of the anticipated MWSSc emission limit of –41.3 dBm/MHz. The resulting SNR values from the fixed scans conducted with a pulse width of 0.8 µs are presented as boxplots in Figure 76 and summarised in Table 56. Given the site-specific uncertainties, these results are not used to draw definitive conclusions regarding compatibility.

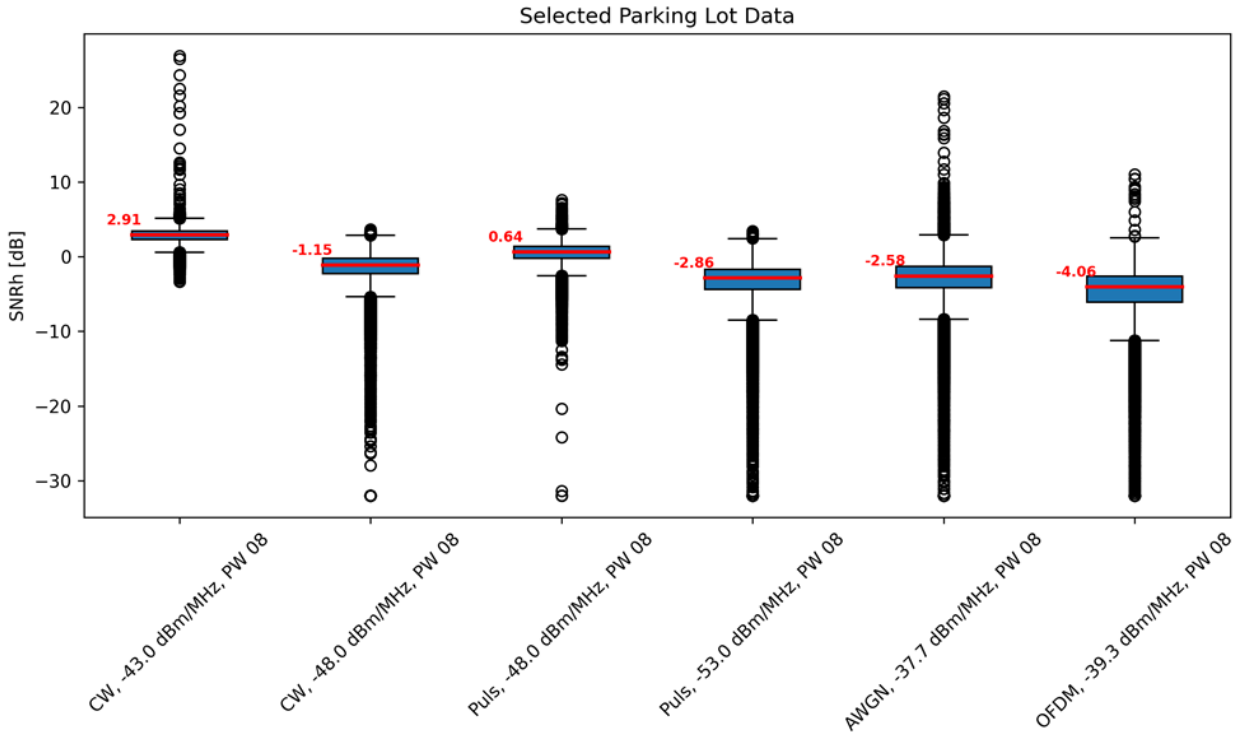


Figure 76: Datasets plotted for Table 56, Parking Lot

Table 55: Selected Measurements Parking Lot, Transmitter Off

No.	Signal	Signal Power TSG (dBm)	Signal PSD (dBm/MHz)	SNR [dB]
02	CW	-43	-43	2.91
03	CW	-48	-48	-1.15
08	Pulsed	-27	-48	0.64
09	Pulsed	-32	-53	-2.86
18	AWGN	-36	-37.7	-2.58
29	OFDM	-43	-39.3	-4.06

Nonetheless, CW and Pulsed measurements were conducted with signal PSDs below –41.3 dBm/MHz and measurements No. 02 and 08 still resulted in SNR values clearly exceeding the detection threshold of –5 dB. This indicates that such signals would cause detectable interference at the radar receiver. Despite the inherent limitations of the Parking Lot site, the data provides a strong indication that outdoor operation of MWSSc devices at PSD levels up to –41.3 dBm/MHz would likely be incompatible with the protection requirements of meteorological radar systems.

4.5.6.4 Minimum separation distance estimation

Since no direct measurements were conducted at the power spectral densities (PSDs) of –60, –55, –50, and –41.3 dBm/MHz as studied in CEPT SE24, the datasets from the Auerberg site were used to extrapolate a minimum required separation distance based on free-space path loss.

Only the data acquired with the radar transmitter on and from fixed scans using a pulse width of 0.8 µs were considered, as this represents the most realistic operational scenario—using the narrowest filter settings typically employed by DWD.

During the measurements, the PSD of the interference source was adjusted such that the radar observed a signal-to-noise ratio (SNR) of approximately 20 dB. These PSD values were significantly higher than the PSDs foreseen for MWSSc operation. Therefore, the PSD difference (PSD_diff) between the measured PSD at TSG and each target PSD level was calculated. In addition, the clutter-removed average SNR was computed. These values are summarised in Table 56.

Table 56: PSD levels at the Auerberg site to achieve ~20 dB SNR at the radar

Signal	PSDmeas at source	Target PSD [dBm/MHz]	PSDdiff [dB]	Averaged SNR
CW	3.0 dBm/MHz	-60/-55/-50/-41.3	63.0/58.0/53.0/44.3	19.9 dB
Pulse	0.4 dBm/MHz	-60/-55/-50/-41.3	60.4/55.4/50.4/41.7	19.9 dB
AWGN	7.1 dBm/MHz	-60/-55/-50/-41.3	67.1/62.1/57.1/48.4	20.3 dB
OFDM	7.1 dBm/MHz	-60/-55/-50/-41.3	67.1/62.1/57.1/48.4	20.9 dB

The required separation distance to avoid interference is estimated based on the results from Table 56, under the assumption that the difference in signal-to-noise ratio (SNR) is directly proportional to the difference in power spectral density and (through the relation given in Eq. (7) power difference at the LNA input at the radar receiver (i.e. SNRdiff = PSDdiff = LNAdiff).The resulting SNR at the radar as a function of separation distance r is then calculated as:

$$\mathrm{SNR(r)} - \mathrm{SNRavg,meas} = \mathrm{PSDtarget} - \mathrm{PSDmeas} = \mathrm{PSDtarget} - \mathrm{LossfreeSpace\,(r)} - \mathrm{PSDmeas} + \mathrm{LossfreeSpace\,(Auerberg)} \quad (7)$$

$$\mathrm{SNR(r)} = \mathrm{SNRavg,meas} - \mathrm{PSDdiff} + \mathrm{LossfreeSpace\ (Auerberg)} - \mathrm{LossfreeSpace\ (r)} \quad (8)$$

where:

- *SNR(r)* is the SNR to be calculated for the Target PSD at range r;
- *SNRavg,meas* is the measured average SNR at Auerberg;
- *PSDdiff* is the difference between measured PSD at the TSG and the target PSD (PSDmeas - PSDtarget);
- *LossfreeSpace (Auerberg*) is the free-space loss corresponding to the distance between radar and the Auerberg site;
- *LossfreeSpace (r*) is the free-space loss at the separation distance r.

To ensure compatibility, the resulting SNR must remain below –5 dB (the detection threshold at the minimum detectable signal). Figure 77 illustrates the calculated SNR versus distance for the CW signal, with and without building entry loss (BEL). The red line denotes the –5 dB threshold.

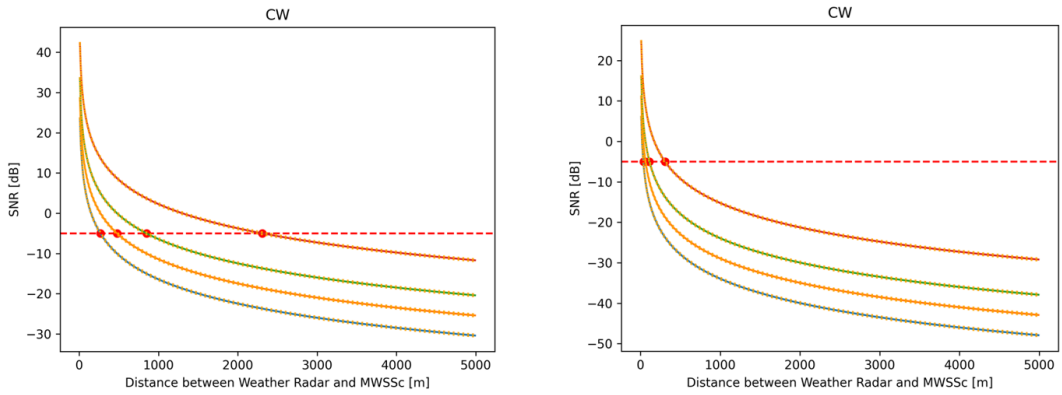


Figure 77: Minimum Separation Distance Estimation, no BEL (left) and BEL = 17.5 dB (right)

Caveat: This extrapolation assumes a linear relationship between the SNR and the PSD of the interfering signal. As this might be theoretically correct, considering hardware limitations and imperfect noise sampling, it does not hold true in reality. As discussed, it can be seen in the section "comparison to minimum detectable signal", this holds for higher SNRs but becomes less accurate near the detection threshold (around 0 dB and below). As illustrated in Figure 78 for both CW and AWGN signals, some deviation is evident; however, the error is relatively small and considered acceptable for this evaluation.

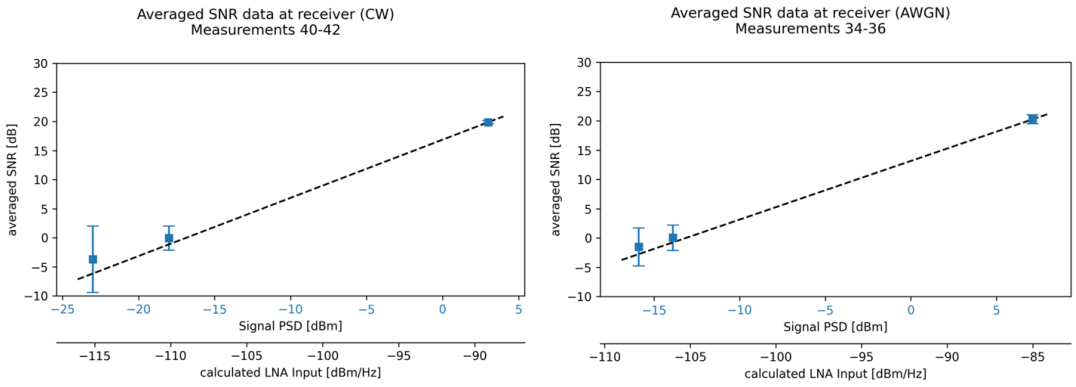


Figure 78: Average SNR and signal power relation with line (slope 1) through SNR around 20 dB, CW (left) and AWGN (right)

The resulting minimum separation distances for various PSD values, both with and without a BEL of 17.5 dB (averaged value for mostly traditional buildings based on Recommendation ITU-R P.2109-2 [9]), are summarised in Table 57.

Table 57: Minimum Separation Distance Estimations (with BEL = 17.5 dB in brackets)

PSD [dBM/MHz]	CW	AWGN	Pulsed	OFDM
-60	270 m (40 m)	170 m (20 m)	360 m (50 m)	190 m (30 m)
-55	480 m (60 m)	310 m (40 m)	650 m (90 m)	330 m (40 m)
-50	850 m (110 m)	550 m (70 m)	1150 m (150 m)	590 m (80 m)
-41.3	2310 m (310 m)	1510 m (200 m)	3130 m (420 m)	1620 m (220 m)

Additional plots for the remaining signal types are provided in Annex 2.

4.5.6.5 Overview measurements Auerberg

Table 58: Overview Measurements Auerberg

No.	Location	Tx	Tx State	Signal	Signal Power TSG (dBm)	Signal PSD (dBm/MHz)	Avg. SNR [dB] for PW 0.8/0.4 µs
31	Auerberg	Mag	off	CW	3	3	19.73/17.66
32	Auerberg	Mag	off	CW	-18	-18	-1.22/-2.69
33	Auerberg	Mag	off	CW	-23	-23	-4.93/-5.77
34	Auerberg	Mag	on	AWGN	10	-7.1	20.25/20.29
35	Auerberg	Mag	on	AWGN	-11	-13.9	0.04/0.02
36	Auerberg	Mag	on	AWGN	-13	-15.9	-1.51/-1.56
37	Auerberg	Mag	on	OFDM	14	7.1	20.88/20.61
38	Auerberg	Mag	on	OFDM	-7	-13.9	0.85/0.78
39	Auerberg	Mag	on	OFDM	-12	-18.9	-2.85/-2.81
40	Auerberg	Mag	on	CW	3	3	19.86/17.94
41	Auerberg	Mag	on	CW	-18	-18	-0.06/-1.52
42	Auerberg	Mag	on	CW	-23	-23	-3.68/-4.64
43	Auerberg	Mag	on	Pulsed	22	0.4	19.90/19.01
44	Auerberg	Mag	on	Pulsed	2	-19.6	1.18/-0.54
45	Auerberg	Mag	on	Pulsed	-3	-24.6	-2.00/-3.35
46	Auerberg	Mag	off	AWGN	10	7.1	20.26/20.29
47	Auerberg	Mag	off	AWGN	-11	-13.9	-0.13/0.03
48	Auerberg	Mag	off	AWGN	-14	-15.9	-2.59/-2.43

4.5.6.6 Estimated Minimum Separation Distance Plots

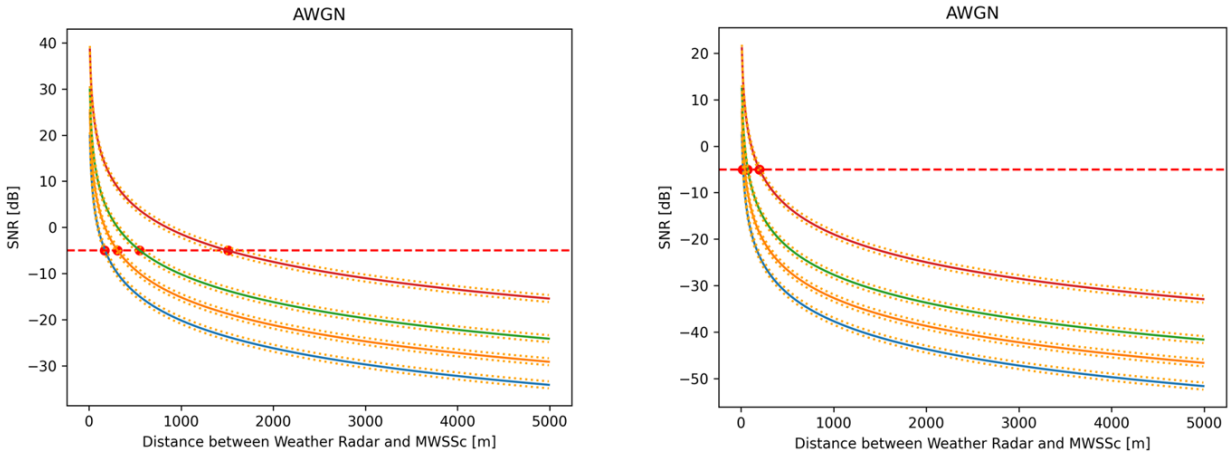


Figure 79: AWGN - Minimum Separation Distance Estimation, no BEL (left) and BEL = 17.5 dB (right)

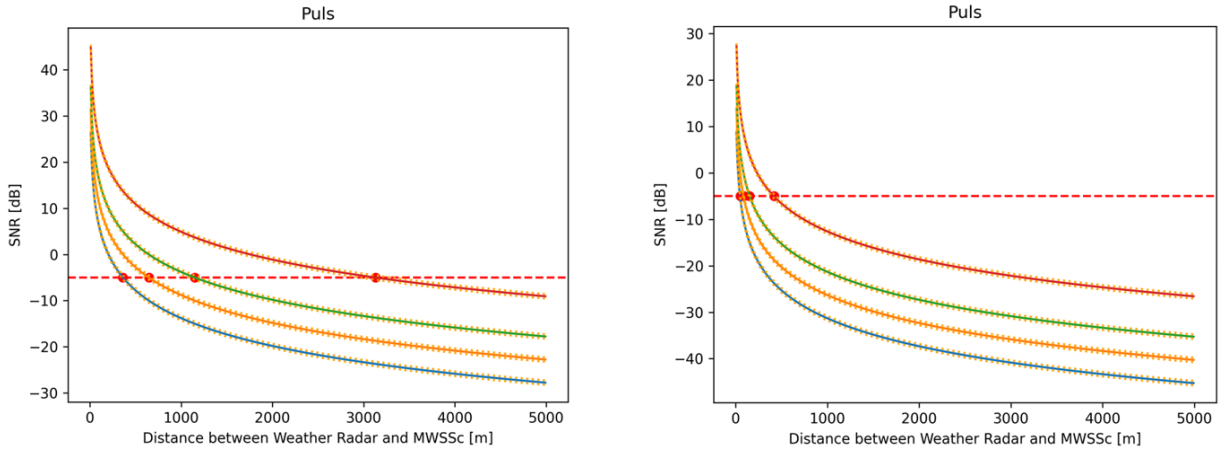


Figure 80: Pulsed Signal - Minimum Separation Distance Estimation, no BEL (left) and BEL = 17.5 dB (right)

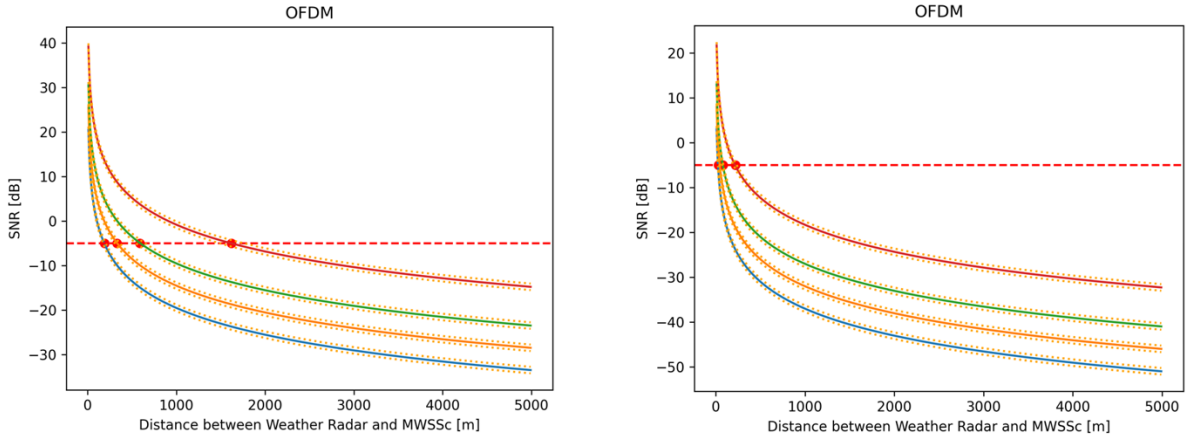


Figure 81: OFDM Signal - Minimum Separation Distance Estimation, no BEL (left) and BEL = 17.5 dB (right)

4.5.6.7 Conclusion on Study D

The data from this measurement campaign was analysed and extrapolated to assess the potential compatibility between MWSSc and meteorological radars operating in the C-band frequency range.

An estimation of the minimum separation distance was derived from clutter-corrected datasets. To represent a relatively sensitive radar configuration, the 0.8 µs pulse width operationally used by DWD was selected for evaluation. It is important to note that some meteorological services operate with longer pulse widths (e.g. 2 µs), which increases receiver sensitivity by approximately 4 dB. This must be considered when interpreting the results, as such systems may be more susceptible to interference.

Indoor use is generally less problematic. At the highest considered power spectral density (PSD) of −41.3 dBm/MHz interference cannot be completely ruled out in worst-case scenarios.

For the outdoor case, more care is required. DWD defines a radar safety zone of 300 m without obstruction, typically free of buildings. Under these conditions, a PSD of −60 dBm/MHz or lower appears to be a reasonable limit for outdoor use without causing interference.

These results are limited to line-of-sight (LOS) scenarios, which represent a conservative, worst-case setup. Aggregation effects from multiple simultaneous interferers were not considered.

It is critical to emphasise that the results are based on measurements from a single C-band weather radar operating at 5640 MHz, and may not be representative of other radar systems. Radar-specific characteristics—such as antenna gain, receiver noise figure, and signal processing—can significantly affect interference susceptibility. Other radars may be either more or less robust under similar conditions.

Additionally, the study considers only a single interfering source. In real-world deployments, multiple devices could emit simultaneously, potentially resulting in constructive aggregation and significantly higher interference power at the radar receiver.

No additional I/N margin was applied in this study. As such, even small changes in environmental or system parameters could lead to interference. Therefore, to ensure robust compatibility, applying a protection criterion, as suggested in Recommendation ITU-R M.1849-3, is recommended and should be a feasible and prudent guideline.

4.5.7 Study E - Military systems in the 4.4-4.99 GHz, 5.25-5.85 GHz and 8.5-10.5 GHz frequency bands

4.5.7.1 Introduction

This study aims to assess the impact of introducing Microwave Security Scanners (MWSSc):

- in band 4200-4800 MHz where military aeronautical mobile systems operate in the range 4400-4990 MHz (worldwide);
- in band 4800-6000 MHz where military radars operate in the range 5250-5850 MHz (worldwide);
- in band 8500-10600 MHz where military radars operate in the range 8500-10500 MHz (worldwide).

This study was carried out by using Max(Mean(*e.i.r.p.*)) metric averaged over 1 ms and equal to -60 dBm/MHz for MWssc outdoor deployment and -41.3 dBm/MHz for MWSSc indoor deployment. Aggregated deployment scenarios are considered.

4.5.7.2 Methodology

The level of interference received by the victim system can be theoretically expressed as follows:

$$P_R = P_T + \mathrm{G_T} + \mathrm{Agg} + G_R - PL - BEL \qquad (9)$$

where:

- P_R: the power received by the victim receiver (dBm/MHz);

- P_T: the transmitter power (dBm/MHz) in the radar band;
- G_R: the gain of the victim in the direction of the transmitter (i.e. MWSSc);
- $\mathrm{G_T}$: the gain of the transmitter in the direction of victim;
- Agg:: the aggregation factor from multiple MWSSc;
- PL: the Path propagation Loss;

From this equation, one could notice that:

the collocation of MWSSc devices for this study justifies to use a single value of pathloss PL (unlike the typical approach used to compute aggregate interference per single radio-link) as well as the aggregate factor term,

the above analytical formula is typical from radio-interference problem with continuous emission of power which is not the case for MWSSc using pulse compression technology (with burst of pulses).

That's the reason why its radiated power should not be expressed using P_T and $\mathrm{G_T}$ parameter but through Mean(*e.i.r.p.*) metric in order to capture the radiation averaged over a given duration. This duration depends on the time window of the victim receiver. As Mean(*e.i.r.p.*) input parameter is provided over 1 ms and because *e.i.r.p.* measured at any location outside the MWSSc will vary because different antenna (from different panels from different strips) radiate towards this location with varying Line of Sight (LoS) conditions, a conversion of this metric to the integration time (denoted T) of the victim is needed. In addition, the fact that the protection criterion of the radar receiver is expressed in terms of (Interference to Noise) power ratio allows to express the interference level through its power spectral density (PSD). Based on these observations, the below equation can be rewritten as follows:

$$P_R(\mathrm{dBm\ /MHz}) = Mean_T(e.i.r.p.)(\mathrm{dBm/MHz}) + \mathrm{Agg} + G_R - PL - BEL \qquad (10)$$

4.5.7.3 Propagation assumptions

For all types of victims, the propagation loss depends on the interferer and receiver antenna heights as well as the path profile separating them (terrain, clutter). Accounting those characteristics and assuming low separation distances (e.g. less than 1 km) where diffraction (due to the curvature of the Earth, to terrain/clutter) can be neglected, considering than the first Fresnel ellipsoid is clear from obstacle, free space attenuation model (ITU-R P.525-4 [16]) is considered for most victims.

Additionally, a clutter loss, in line with Recommendation ITU-R P.2108 [14], is factored in for certain victims to take into account deployment in populated area.

For indoor deployment scenarios of MWSSc, the building entry loss is also taken into consideration in accordance with Recommendation ITU-R P.2109 [9] as follows:

- Some of the indoor MWSSc may be within the line of sight of the receiver (for example, when the MWSSc is positioned near the building entrance), and therefore, they are not impacted by the building entry loss. The number of MWSSc would depend on a number of factors, including the angular sector departing from the cluster in line of sight with the outside of the building, as well as the orientation of the radar receiver with respect to the building housing the MWSSc. Given the constraints of opening within a building and the ideal positioning configuration of the victim receiver, the study assumes a single MWSSc in line of sight of the radar receiver;
- The other remaining MWSSc are affected by Building Entry Loss.

In order to compute the aggregated transmitted power, it is necessary to consider the building entry loss exclusively for MWSSc that are not within the receiver's line of sight. The following equation can be used to express the aggregated transmitted power by the MWSSc:

$$P_T^{Aggregated} = 10.\log_{10}\left(10^{\frac{P_T}{10}} + (N-1) \times 10^{\frac{P_T - BEL}{10}}\right)$$

where:

- $P_T^{Aggregated}$: aggregated transmit power (dBm/MHz);
- P_T : Transmit power by a single MWSSc;
- BEL : Building Entry Loss, computed according to the Recommendation ITU-R P.2109 [9];
- N : Number of MWSSc in the 3 dB beamwidth of the victim receiver (see section 4.5.7.5).

The following values are considered for the Building Entry Loss, according to the ITU-R P.2109 [9]:

Table 59: Building Entry Loss

Band	Building Entry Loss
4400-4990 MHz	16 dB
5250-5850 MHz	16 dB
8500-10500 MHz	17 dB

Note: Knowing that the military systems can be deployed in various environments where all types of buildings can be met, the BEL is computed considering traditional buildings method.

The propagation parameters are summarised in Table 60:

Table 60: Propagation parameters

	4400-4990 MHz band		5250-5850 MHz band		8500-10500 MHz band		
	Airborne	Ground	Radar 19	Radar 22	Radar G4	Radar G5	Radar G14
Free Space	✓	✓	✓	✓	✓	✓	✓
Clutter Loss	No (Note 1)	No (Note 2)	✓	No (Note 2)	No (Note 2)	✓	No (Note 3)
Building Entry Loss	Yes (indoor scenario)	Yes (indoor scenario)	Yes (indoor scenario)	Yes (indoor scenario)	Yes (indoor scenario)	Yes (indoor scenario)	Yes (indoor scenario)

Note 1: The path between the airborne AMS and the MWSSc is considered free from obstacle.
Note 2: Given the flexible deployment options of this system, a rural environment represents the most challenging configuration. Consequently, the propagation loss calculations do not take into account for clutter loss.
Note 3: In light of the radar antenna height (50 m) and the typical rural environment for its deployment, the propagation loss is calculated without taking clutter loss into account from the radar side. Moreover, from the MWSSc side, it is assumed that any buildings are located behind the scanners and do not interfere with the radio path, allowing not to consider the clutter loss neither.

4.5.7.4 Maximum number of collocated MWSSc in the same area

The maximum number of collocated MWSSc in the same area depends on the considered environment in the scenarios.

In scenarios involving military systems in urban or suburban environments, a maximum of 10 collocated MWSSc is assumed. Indeed, in urban environments, it is considered that places where MWSSc could be deployed would be able to welcome a large number of people. This would imply the need for a significant number of MWSSc at the security checks of these places.

In scenarios involving military systems in rural environments, it is assumed that a maximum of 2 collocated MWSSc will be required. Indeed, in rural environments, the number of people present at places where MWSSc could be deployed would be lower than in urban environments. Consequently, fewer MWSSc would be required at the security checks of these places.

As illustrated in Table 61, the number of collocated MWSSc for the different military systems under study is shown.

Table 61: Number of collocated MWSSc for the military systems studied

	4400-4990 MHz band		5250-5850 MHz band		8500-10500 MHz band		
	Airborne	Ground	Radar 19	Radar 22	Radar G4	Radar G5	Radar G14
Number of collocated MWSSc	10	2	10	2	2	10	2

4.5.7.5 Aggregation factor (AF)

In accordance with the functionalities of MWSSc, it is understood that their usage, if local, won't prevent their deployment to several units. For such case, multiple devices would occupy a given area dedicated to specific needs and would not turn to uniform deployment. For example, in airport, multiple MWSSc would be aligned to process simultaneously flow of passengers with their belongings and mitigate traffic congestion.

When the victim system operates with omnidirectional antenna (for example the airborne antenna of the AMS system 1 in 4400-4990 MHz), all the MWSSc are considered in the computation of the aggregate interference.

When the victim system operates with highly directive antenna, sidelobes levels are sufficiently low with respect to the peak value of the main beam not to contribute to the received aggregate interference. Hence, only the MWSSc which are located within the 3 dB beamwidth of the victim antenna are considered in the computation of the aggregate interference.

Assuming a linear deployment of MWSSc, their positioning (depicted by a blue cross ✦) with respect of the victim receiver antenna main beam could be roughly summarised by the following scenarios:

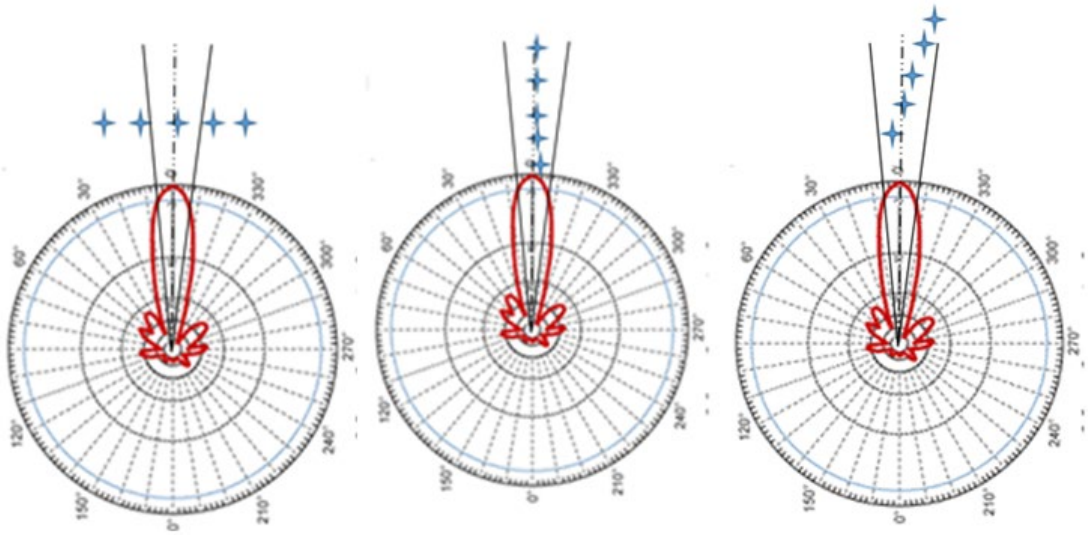


Figure 82: Geometry of the receiver antenna main beam and MWSSc positionings

Cases 1, 2, 3 respectively depict the left, middle and right side above figures representing the main beam of the receiver antenna (plotted in red) with respect to the MWSSc. For these cases, MWSSc always remain aligned, but the positioning of the receiver antenna main beam is different:

- For the first case, the number of MWSSc within the main beam will be derived based on the size of the device, the gap between two adjacent devices and the beamwidth;
- For the second case, even though all MWSSc are within the beamwidth of the receiver antenna, most of them are shaded by the first ones which would result in an additional attenuation by the scanners behind the first one in the interference calculation;
- For the third case, all MWSSc are within the beamwidth of the receiver antenna and they are not shaded each other. However, for this configuration, the main beam won't be able to see an integer number of strips composing every scanner and radiating without additional attenuation. To capture that idea, multiple MWSSc are drawn in the below left Figure 83 and rays were plot from the victim receiver (blue cross) to capture what it could see from every MWSSc. For example, to enable green rays departing from the victim receiver antenna to see a full strip (i.e. not a portion of the strip/side of the scanner) of the « third scanner », this one should be shifted to the right side. But when doing that, it would leave the main beam of the victim receiver. This observation would also apply for the purple ray crossing one strip of the « second scanner ».

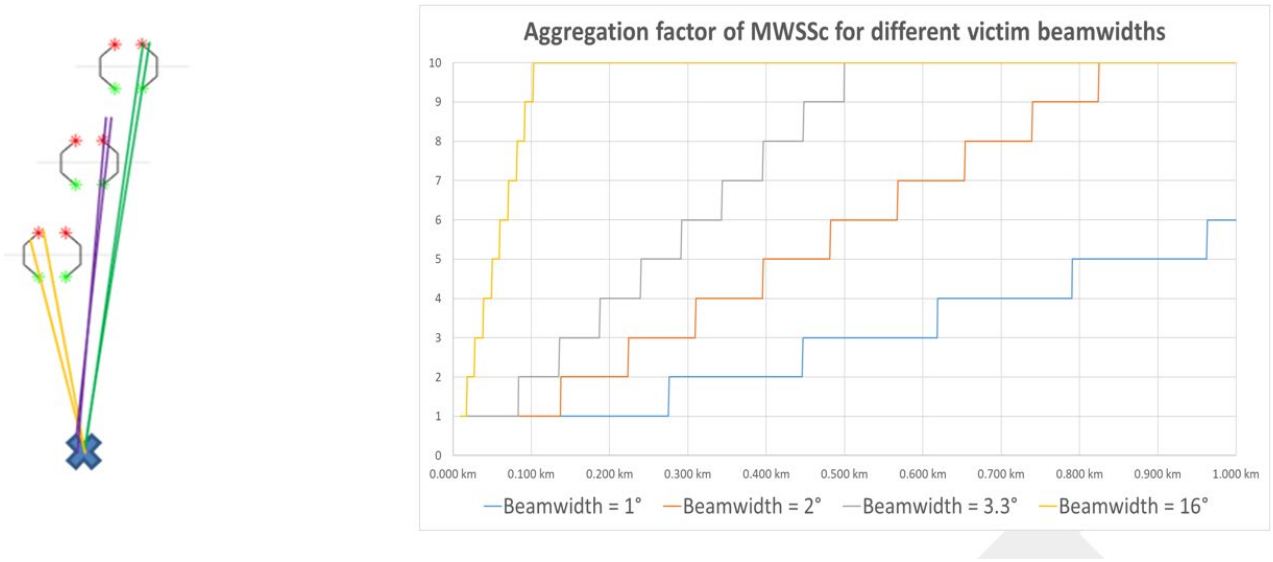


Figure 83: (left) panels from 3 MWSSc in visibility of a radar (right) Number of MWSSc in the 3 dB beamwidth of the victim receiver (with an example of a maximum of 10 collocated MWSSc)

From the above analysis, case #1 appears to be the worst case from the highest aggregation factor (AF). Thus, it will be retained for the scenario to be investigated in the sharing studies when victim system has a directive antenna. The number of MWSSc located in the 3 dB beamwidth of the victim receiver antenna depends on the distance between two MWSSc (assumed to be 3 m) as well as the separation distance between the victim receiver: it is depicted in right side figure above. The maximum number of collocated MWSSc in the same area is discussed in section 4.5.7.4. One consequence of the AF behaviour is its increase with the separation distance.

Finally, one cannot consider that every MWSSc located in the 3 dB beamwidth of the victim receiver are transmitting in visibility. This section provides a calculation of the AF. It has to be noted that the calculation of the AF in this section assumes the particular design of the Rohde & Schwarz MWSSc (i.e. the percentage of antennas from the scanner that radiates in visibility of the victim receiver), whereas the conclusions of this Report should remain agnostic of the design. On the other hand, ignoring MWSSc leads to conservative results. Consequently, caution should be taken so that the consideration of MWSSc design in the aggregation factor calculation does not adversely bias the conclusion of this Report (see section 6).

Let's consider the probability that N unsynchronised security scanners simultaneously radiate interference in visibility of a victim receiver. It should be also noted that the probability that all of the scanners simultaneously radiate in visibility of the victim receiver reduces when the number of interferers increases. The MWSSc can impact a victim receiver especially when the radiating antenna is in visibility of the receiver. This probability

corresponds to the number of antennas radiating in visibility of a point outside the scanner over the total number of antennas).

To calculate this percentage, the geometry of the security scanner is provided hereafter.

Table 62: Number of transmitting antennas according to Rohde & Schwarz MWSSc geometry

Parameters	Value
Number of strips	6
Number of tiles/panels per strip	5 for 4 strips 4 for 2 strips
Number of transmitting antennas per tile/panel	8
Total number of transmitting antennas per scanner	(5x4+4x2)x8=224

Noting that there are only two short strips that can be in visibility of an spectrum analyser, this would lead to 4x2/(5x4+4x2)≈28.6%=p of antennas that are in visibility of a victim receiver.

Increase the aggregation factor to n interferers would lead to 0.286n x 100 percent.

To get an aggregation factor with higher probability, it would be wise to calculate the distribution of the aggregation factor and take an average or a median value of this statistic. To do, let's find out the parameters needed to compute the simulation of this random variable "aggregation factor":

- Time integration T of the victim receiver (equal to the inverse of the receiver bandwidth) less than 1 µs;
- Set a given number of N interferers/security scanners;
- As burst of pulses emitted by a single antenna (1.25 µs) last more than T seconds, one single cycle of interference sample per event is considered;
- Generate for every interferer i=1...N if the transmitting antenna is in visibility with the victim receiver with p probability (i.e. 1-p probability no to be in visibility);
- Weighting the visible antenna with 1 coefficient, the non-visible antenna with a lower 1/10 coefficient (than 1) to capture the additional attenuation due to shadowing loss;
- Derive the aggregation factor (in linear scale) for every event.

From this, one could plot the distribution of the aggregate factor according to the number of security scanners in the 3 dB beamwidth of the victim receiver:

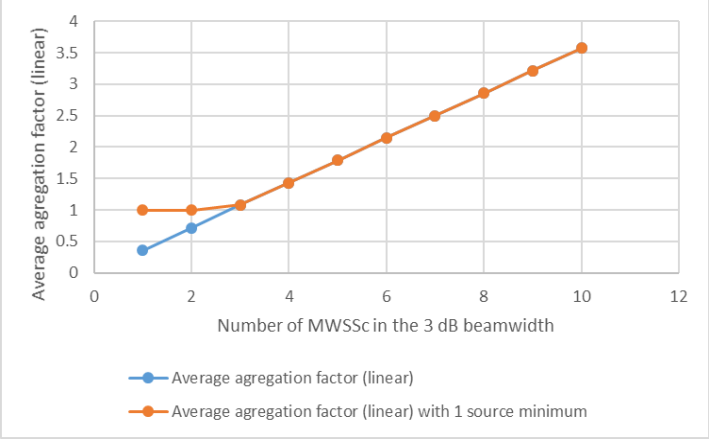


Figure 84: Average aggregation factor according to the number of MWSSc in the 3 dB beamwidth of the victim receiver

Considering an average value of the aggregate factor (as exhibited in the above figure) would result in listing all combinations of aggregation factor i.e. where a fraction of the interferers visible from the victim receiver is very low (could be 1 among N or even 0 over N for several samples). The mean aggregate factor slowly increases with the number of scanners within the 3 dB beamwidth. Two different ways to perform this average were implemented:

- the strict computation of the average of the aggregate factor enabling lower value than 1 to capture cases with 1 security scanner within 3 dB beamwidth of the receiver antenna that is not in visibility of the radar (blue curve). Even for 2 scanners, it is possible not to achieve the full interference level in configuration with LoS between the scanner and the victim receiver (when they are NLoS);
- Another computation with a minimum of 1 interferer (orange curve).

The relevant approach to calculate the aggregate interference (the second one) is based on a non-null number of interferers.

In the particular case of scenarios involving only 2 MWSSc (see section4.5.7.4), the approach is to consider the number of MWSSc which are located in the 3 dB beamwidth of the victim receiver. Indeed, the computation of the average aggregate factor would lead to consider only 1 MWSSc (according to Figure 1), which would not be in phase with the multi-entry scenario considered.

The aggregation factor taken into account in the study is summarised in Table 63:

Table 63: Aggregation factor assumptions

	4400-4990 MHz band		5250-5850 MHz band		8500-10500 MHz band		
	Airborne	Ground	Radar 19	Radar 22	Radar G4	Radar G5	Radar G14
Number of collocated MWSSc	10	2	10	2	2	10	2
Aggregation Factor (AF)	Averaged AF	10.log(N) (Note 1)	Averaged AF	10.log(N) (1)	10.log(N) (Note 1)	Averaged AF	10.log(N) (Note 1)
Note 1: N is the number of MWSSc located in the 3 dB beamwidth of the victim receiver.							

4.5.7.6 Apportionment factor of the aggregate interference

As previously highlighted, the aggregate protection criteria used for the victims is an interference-to-noise ratio (I/N) of −6 dB. This means that this protection criterion is aggregated for all sources of interference allocated on a primary, secondary basis or without specific status (for SRD) in the same band as well as in adjacent band.

Apportionment needs to account the visibility area of the victim receiver in order to justify aggregating stations from multiple services or applications. Visibility area for aeronautical stations is sufficiently large to deal with multiple services. This is not the case for ground station unless a significant antenna height is considered. That would sort the victim receiver into two categories:

- Scenario involving ground deployment for the victim receiver: ground radar or terrestrial station of the aeronautical mobile systems. No apportionment among multiple services is expected i.e. 0 dB;
- Scenario involving airborne deployment for the victim receiver: as the airborne stations of the aeronautical mobile systems considered in this study evolve at low altitude (≈100/200 m), no apportionment among multiple services is taken into account..

Moreover, as suggested in ECC Report 334 [12] for similar issue[5], the apportionment induced by other UWB applications operating within the same frequency band and over the same area should also be considered. Such measure would be applicable to both indoor or/and outdoor environments:

- In the 4400-4990 MHz band: since no other new UWB application is sharing this band as MWSSc, no apportionment is considered (i.e. 0 dB).
- In the 5250-5850 MHz band: since no other new UWB application is sharing this band as MWSSc, no apportionment is considered (i.e. 0 dB);
- In the 8500-10500 MHz band it is assumed that a minimum of two different UWB applications will be sharing the band when the victim system operates in urban or suburban environment. In such a scenario, 3 dB should be added to the initial apportionment expressed above. If the victim system operates in rural environment, no apportionment is taken into account.

This lead to take into account the following value of apportionment in the studies:

Table 64: Apportionment values

Band	Apportionment
4400-4990 MHz – Airborne station	0 dB
4400-4990 MHz – Terrestrial station	0 dB
5250-5850 MHz	0 dB
8500-10500 MHz	Radar G5 : 3 dB (suburban or urban) Radar G4 and G14: 0 dB (rural)

4.5.7.7 MWSSc Mean e.i.r.p.

It was observed that the geometry of MWSSc would affect the value of the max(mean(*e.i.r.p.*)) depending on the window time. On one hand, when every antenna of MwSSC radiates during the 1 ms, max(mean(*e.i.r.p.*)) value would cover the geometrical factor by accounting the Line of Sight (LoS) rate of the radiating antenna towards the device used to perform the (*e.i.r.p.* spectral density) measurement (spectrum analyzer). On the other hand, when the averaging time is smaller in a way that the LoS rate of radiating antenna is different (higher) than the one achieved for 1 ms[6], max(Mean(*e.i.r.p.*)) value would be higher.

That's why it was recognised the need to adjust the max(Mean(*e.i.r.p.*)) to the integration time of the victim receiver for the sharing and compatibility studies.

4.5.7.8 Summary of assumptions

Table 65 summarises the assumptions discussed on the previous chapters.

[5] Although it is recognised that ECC Report 334 [12] applies for the protection of passive service operating in adjacent bands of UWB radiodetermination applications in different frequency ranges, there is no reason to apply similar rationale.

[6] or a period of transmission of every antenna of the MwSSc

Table 65: Summary of assumptions

		4400-4990 MHz band		5250-5850 MHz band		8500-10500 MHz band		
		Airborne	Ground	Radar 19	Radar 22	Radar G4	Radar G5	Radar G14
Propagation	Free Space	✓	✓	✓	✓	✓	✓	✓
	Clutter Loss	No	No	✓	No	No	✓	No
	Building Entry Loss	Yes (indoor scenario)	Yes (indoor scenario)	Yes (indoor scenario)	Yes (indoor scenario)	Yes (indoor scenario)	Yes (indoor scenario)	Yes (indoor scenario)
Maximum number of collocated MWSSc		10	2	10	2	2	10	2
Aggregation factor (note 1)		Averaged AF	10.log(N) (1)	Averaged AF	10.log(N) (1)	10.log(N) (1)	Averaged AF	10.log(N) (1)
Apportionment factor		0 dB	0 dB	0 dB	0 dB	0 dB	3 dB	0 dB
MWSSc Mean *e.i.r.p.*					max(Mean(*e.i.r.p.*)) adjusted to the integration time of the victim receiver			
Note 1 : N is the number of MWSSc located in the 3 dB beamwidth of the victim receiver.								

4.5.7.9 Results

Based on methodology described in the previous section, the results are presented in terms of difference between received I/N and the protection criterion (I/N=-6 dB plus the apportionment given in Table 65 for each frequency band) as a function of the separation distance between the victim receiver and the cluster of scanners.

A positive gap for the ordinates refers to an exceedance of the protection criterion while a negative one would correspond to a coexistence margin.

The distances shown on the x-axis of the graphs below are:

- Horizontal distances for ground stations (ground stations of the AMS and ground radars);
- Slant distances pour aeronautical stations. For the aeronautical stations, under the assumption of a minimum altitude of 150 meters, the following results are not displayed for distances lower than 150 meters.

Outdoor deployment



Figure 85: Separation distance for Military AMS (outdoor MWSSc)

The protection criterion is respected with a minimum margin of 4.4 dB. This means that under -60 dBm/MHz Mean(*e.i.r.p.*) (average over 1 ms) and with a 5.4 dB geometrical factor, the military AMS in 4400-4990 MHz could coexist with MWSSc.

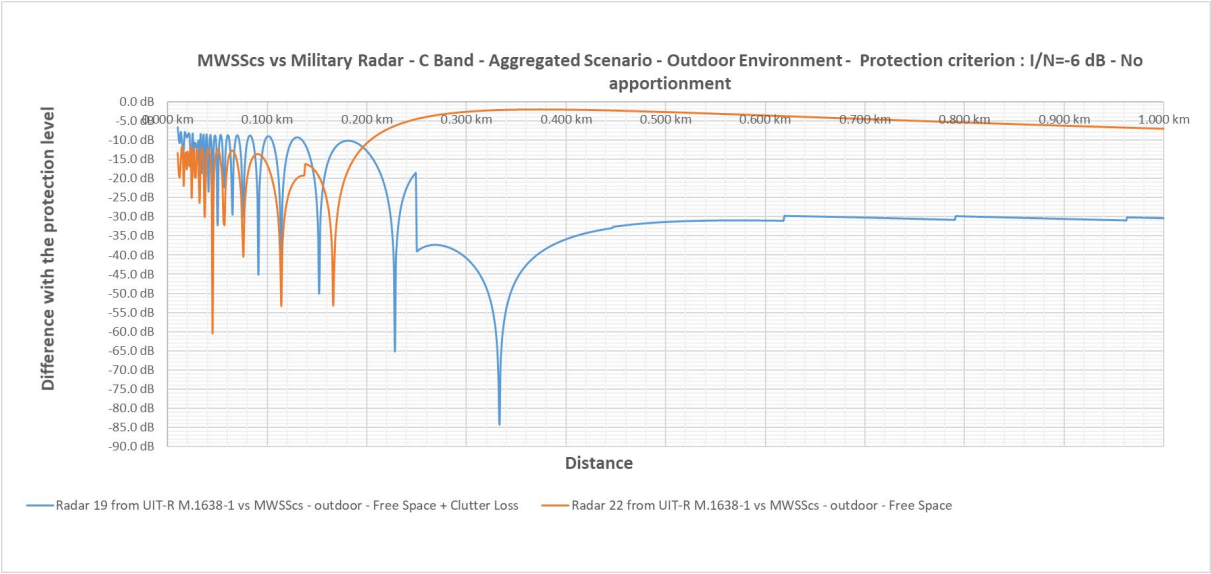


Figure 86: Separation distance for C-band military radar (outdoor MWSSc)

The protection criterion is respected with a minimum margin of 2 dB. This means that under -60 dBm/MHz Mean(*e.i.r.p.*) (average over 1 ms) and with a 5.4 dB geometrical factor, the military radar in 5250-5850 MHz could coexist with MWSSc.

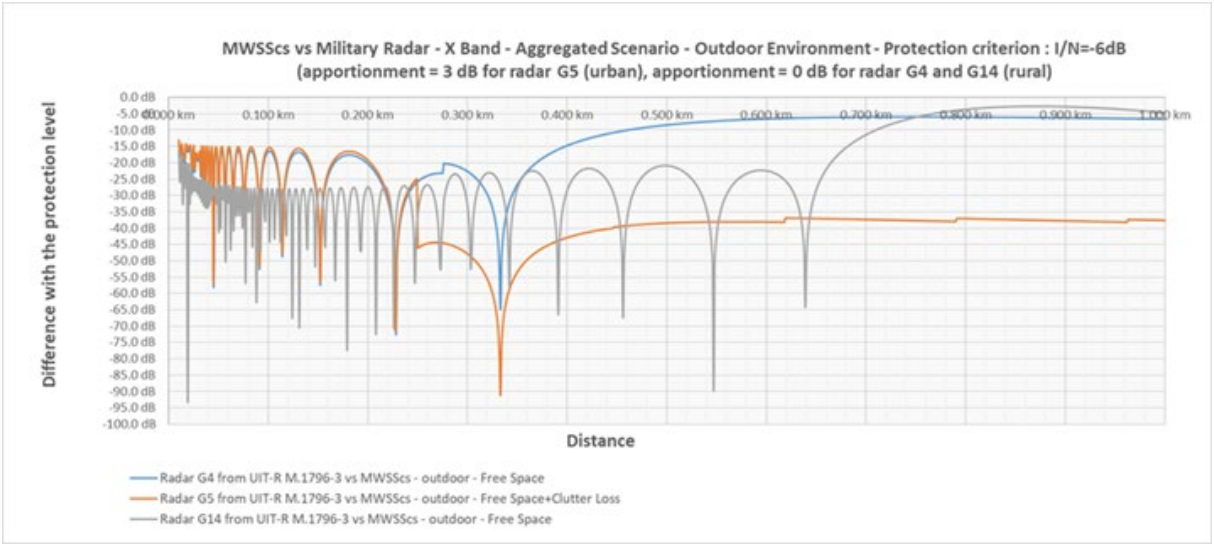


Figure 87: Separation distance for X-band military radar (outdoor MWSSc)

The protection criterion is exceeded with a maximum deficit of 0.2 dB. This means that under -60 dBm/MHz Mean(*e.i.r.p.*) (average over 1 ms) and with a 5.4 dB geometrical factor, the military radar in 8500-10500 MHz could coexist with MWSSc.

Indoor deployment



Figure 88: Separation distance for Military AMS (indoor MWSSc)

The maximum exceedance of the protection criterion is around 11.3 dB. This means that under -41.3 dBm/MHz Mean(*e.i.r.p.*) (average over 1 ms) and with a 5.4 dB geometrical factor, the military AMS in 4400-4990 MHz could be interfered with an exceedance level of the protection criterion up to 11.3 dB. A minimum of 11.3 dB additional reduction of the mean(*e.i.r.p.*) would be needed to solve the coexistence issue.

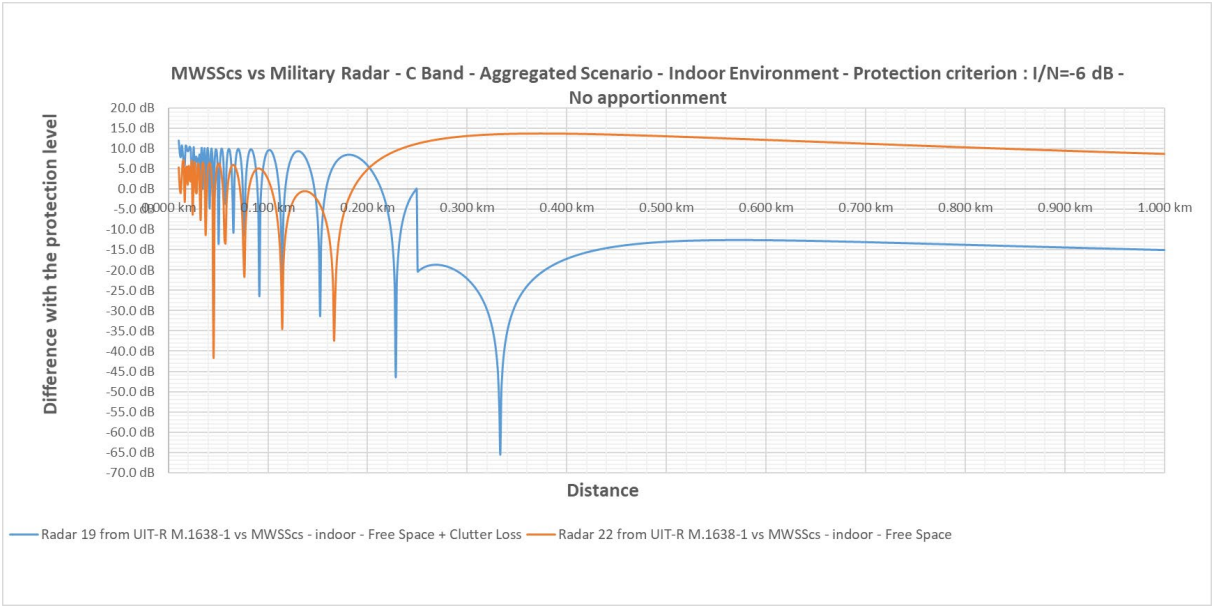


Figure 89: Separation distance for C-band military radar (indoor MWSSc)

The maximum exceedance of the protection criterion is around 13.7 dB. This means that under -41.3 dBm/MHz Mean(*e.i.r.p.*) (average over 1 ms) and with a 5.4 dB geometrical factor, the military AMS in 4400-4990 MHz could be interfered with an exceedance level of the protection criterion up to 13.7 dB. A minimum of 13.7 dB additional reduction of the mean(*e.i.r.p.*) would be needed to solve the coexistence issue.

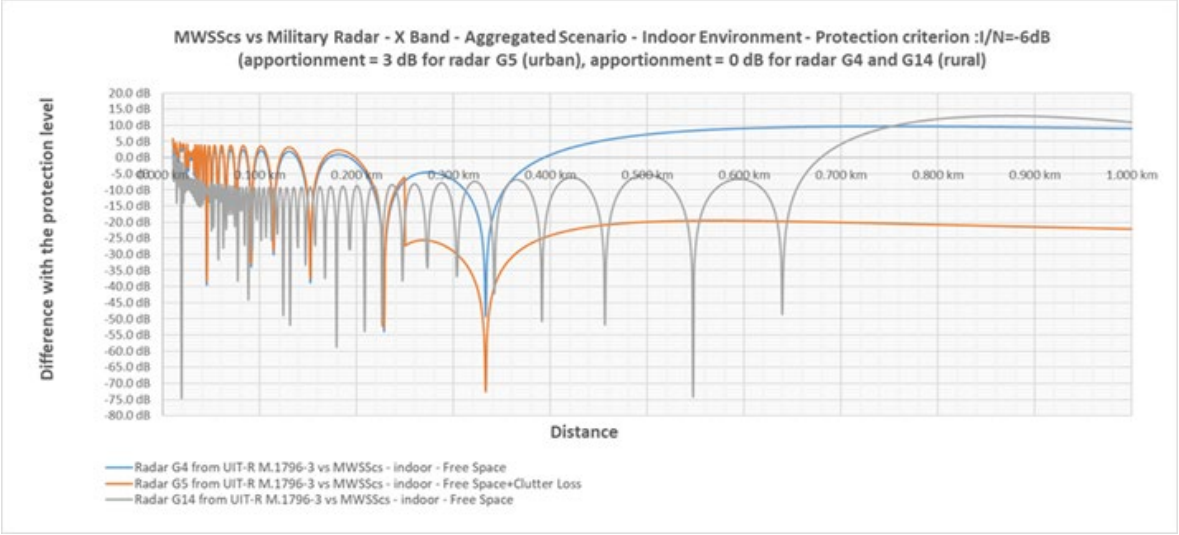


Figure 90: Separation distance for X-band military radar (indoor MWSSc)

The maximum exceedance of the protection criterion is around 12.9 dB. This means that under -41.3 dBm/MHz Mean(*e.i.r.p.*) (average over 1 ms) and with a 5.4 dB geometrical factor, the military AMS in 4400-4990 MHz could be interfered with an exceedance level of the protection criterion up to 12.9 dB. A minimum of 12.9 dB additional reduction of the mean(*e.i.r.p.*) would be needed to solve the coexistence issue.

4.5.7.10 Conclusions

Considering the agnostic nature of ECC Decision (06)04 [3] regarding the technology used for the design of any UWB device, technological neutrality is assumed, that's why it would be relevant to set the Max(Mean(*e.i.r.p.*)) condition for the signal repetition time with the highest magnitude to ensure all categories of UWB MWSSc protect the military systems. In such a case, coexistence between outdoor MWSSc and

military aeronautical mobile systems operating in 4400-4990 MHz, ground military radars operating in 5250-5850 MHz and ground military radars operating in 8500-10500 MHz would be feasible when max(mean(*e.i.r.p.*))=-60+5.4=-54.6 dBm/MHz averaged over the signal repetition time with highest magnitude level. This would correspond to mean(*e.i.r.p.*)=-60 dBm/MHz averaged over 1 ms. Coexistence between indoor MWSSc and military aeronautical mobile systems operating in 4400-4990 MHz, ground military radars operating in 5250-5850 MHz and ground military radars operating in 8500-10500 MHz would be feasible when max(mean(*e.i.r.p.*))=-41.3+5.4-12.9=-48.8 dBm/MHz averaged over the signal repetition time with highest magnitude level. This would correspond to mean(*e.i.r.p.*)= -54.2 dBm/MHz averaged over 1 ms.

4.6 AERONAUTICAL RADIONAVIGATION SERVICE (ARNS), AERONAUTICAL MOBILE (ROUTE) SERVICE (AM(R)S) AND AERONAUTICAL MOBILE SATELLITE (ROUTE) SERVICE (AMS(R)S) USED BY CIVIL AVIATION

Civil aviation has several applications in the 3.6-10.6 GHz band which are part of the ARNS, AM(R)S and AMS(R)S services. This section introduces these applications and provide their technical characteristics which are needed to conduct the compatibility studies.

Table 66 ARNS, AM(R)S, and AMS(R)S applications in the 3.6-10.6 GHz band

Service	Frequency band	Application
ARNS	4.2-4.4 GHz	Radio Altimeter
AM(R)S	4.2-4.4 GHz	WAICs
AMS(R)S	5000-5150 MHz	Satellite-based C2 Link
AM(R)S	5030-5091 MHz	Terrestrial based C2 Link
AM(R)S	5091-5150 MHz	Aeromacs
ARNS	5350-5470 MHz	On-board weather radar
ARNS	9-9.2 GHz	Airport surface detection equipment (ASDE)
ARNS	9.3-9.5 GHz	On-board weather radar

4.6.1 Technical characteristics

4.6.1.1 ARNS systems

This section provides the technical characteristics of ARNS systems needed to conduct sharing and compatibility studies.

Civil aviation on-board radars

Table 67 contains technical characteristics of civil aviation on-board radars.

Table 67: Technical characteristics of ARNS on-board radars

	Radio altimeter	On-board weather radar @ 5.35-5.47 GHz	On-board weather radar @ 9.3-9.5 GHz
Type	On-board radar	On-board radar	On-board radar
Maximum antenna gain	10	34	34.4 dBi
Antenna pattern	(Eq 1)	Pencil	Pencil
Vertical beamwidth	NA	3.5°	3.5°

	Radio altimeter	On-board weather radar @ 5.35-5.47 GHz	On-board weather radar @ 9.3-9.5 GHz
Vertical scan	NA	Typically +-15° (TBC)	Typically +-15° (TBC)
Side lobe	NA	3 dBi	3.4 dBi
Noise Factor	6-10 dB	5 dB	4 dB
Safety margin	6 dB	6 dB	6 dB
Reference	Recommendation ITU-R M.2059 [36]	Recommendation ITU-R M.1638 [25]	Recommendation ITU-R M.1796 [31]

The Radio Altimeter antenna pattern is given by (11), in accordance with Report ITU-R M.2319.

$$G_{RA}(\theta) = G_{RA,max} - 12\left(\frac{\theta}{\theta_{3dB}}\right)^2 \quad (11)$$

The $G_{RA,max}$ is the maximum Radio Altimeter antenna gain, θ is the elevation with respect to the aircraft Radio Altimeter, and $\theta_{3dB} = 60°$ is the 3 dB Radio Altimeter beamwidth.

In accordance with Recommendation ITU-R M.2059 [36], Recommendation ITU-R M.1638 [25] and Recommendation ITU-R M.1796 [31], a protection criterion of I/N = -6 dB is recommended. This criterion is an aggregated protection criterion that takes into account desensitization from all radio systems. Given the regulatory status of UWBs, an X dB apportionment margin(X>0) should be included in the criterion, resulting in I/N=-6-X dB.

Civil aviation ground-based radar

Table 68 contains technical characteristics of civil aviation ground-based radar.

Table 68: Technical characteristics of ARNS ground based radars

	ASDE @ 9-9.2 GHz		
Type	Ground-based radar		
Maximum antenna gain	35 dBi	37.6 dBi	37.6 dBi
Antenna pattern	Inverse csc²	Inverse csc²	Inverse csc²
Antenna height	30 - 100 m	10 - 100 m	10 - 100 m
Tilt angle (note 1)	Typical -2° to -0.5°	Typical -2° to -0.5°	Typical -2° to -0.5°
Elevation beamwidth	19°	9.91°	9.91°
Azimuth beamwidth	0.35°	0.35°	0.35°
Azimuth scan	360°	360°	360°
Noise Factor	5.56 dB	5.25 dB	5 dB
Side lobes in elevation	20 dBi	9.15 dBi	9.15 dBi
Polarisation	RHCP	RHCP	RHCP
IF bandwidth	36 MHz	50 MHz	180 MHz
Safety margin	6 dB	6 dB	6 dB
Reference	ITU-R M.1796 System G8	ITU-R M.1796 System G18	ITU-R M.1796 System G19
Note 1: Based on settings of ASDE deployed in France.			

Regarding the protection criterion, similar approach than for civil aviation on-board radars is considered for the I/N = -6-X dB based on the I/N = -6 dB from Recommendation ITU-R M.1796-3 [31] which is an aggregate protection criterion from all radio sources.

4.6.1.2 AM(R)S systems

Table 69 contains technical characteristics of civil aviation AM(R)S systems needed to conduct compatibility studies where I/N=-6 dB protection criterion is assumed. This criterion is an aggregated protection criterion that takes into account desensitization from all radio systems. Given the regulatory status of UWBs, a X dB apportionment margin(X>0) should be included in the criterion, resulting in I/N=-6-X dB.

Table 69: Technical characteristics of AM(R)S systems

	WAICs	Terrestrial based C2 Link		Aeromacs	
Type	On-board system	On-board Rx	Ground Rx	On-board Rx	Ground Rx
Maximum antenna gain	0 dBi	2	20	6 dB	15 dB
Antenna pattern	Omni	Omni	TBD	TBD	TBD
Antenna height	Aircraft altitude	Aircraft altitude	2 m to 50 m Typically 10 m	Aircraft height (up to 10 m)	2 m to 50 m Typically 10 m
Noise Factor	8 dB	7 dB	7 dB	7 dB	8 dB
Polarisation	TBC	Vertical	Vertical	Vertical	Vertical
Safety margin	6 dB	6 dB	6 dB	6 dB	6 dB

4.6.1.3 AMS(R)S systems

Table 70 contains technical characteristics of civil aviation AMS(R)S systems needed to conduct compatibility studies

Table 70: Technical characteristics of AMS(R)S systems

	Satellite based C2 Link
Type	On-board Rx
Maximum antenna gain	3 dBi
Antenna pattern	Omni
Noise Factor	7 dB
IF bandwidth	20 to 140 kHz
Polarisation	RHCP
Safety margin	6 dB

Regarding the protection criterion, similar approach than for AM(R)S is considered for the AMS(R)S systems and I/N = -6-X dB based on the I/N = -6 dB from Recommendation ITU-R M.1796-3 which is an aggregate protection criterion from all radio sources.

4.6.2 General methodology

The interference power coming from N MWSSc and received by a civil aviation receiver can be expressed by:

$$I_{Rx}(\boldsymbol{x}_{aircraft}, \boldsymbol{x}_{MWSSc}) = \sum_{i=1}^{N} \alpha_i(\boldsymbol{x}_{aircraft}, \boldsymbol{x}_{MWSSc}) P_{Tx} G_{TX}(\theta_{MWSSc,i}, \varphi_{MWSSc,i}) G_{Rx}(\theta_{MWSSc,i}, \varphi_{MWSSc,i}) PL(\boldsymbol{x}_{aircraft}, \boldsymbol{x}_{MWSSc}) BEL \quad (12)$$

where:

- P_{Tx}: MWSSc power as measured outside of the MWSSc, averaged over the integration time of the victim receiver;
- α_i: For each MWSSc, $\alpha_i \in \{0.1; 1\}$ is a random variable whose objective is to take into account the shielding effect of the scanner. As a matter of fact, the radiating section of the MWSSc is not always in visibility of the victim receiver. As a consequence, let's denote p the probability that the radiating element is in visibility of the victim receiver. This parameter p depends on the design of the MWSSc, as well as its the relative position with respect to the victim receiver. When a radiating element is shielded by a strip of the MWSSc (therefore not visible by the victim receiver), the power that reaches the victim receiver is significantly reduced e.g. 10% of the total power to account for leakage, reflection, etc, therefore, $\alpha_i = 0.1$. When the radiating element of the MWSSc is in visibility of the impacted receiver, $\alpha_i = 1$. Assumptions to derive this probability p are described later;
- G_{Tx}: MWSSc antenna gain discrimination (see Figure 4). MWSSc antenna gain discrimination in azimuth and elevation are discussed on a case by case basis for the different scenarios;
- G_{Rx}: Civil aviation receiver antenna pattern;
- PL: propagation losses;
- BEL: building entry losses. Equal to 0 dB for MWSSc outdoor deployment;
- $\boldsymbol{x}_{aircraft}$: vectors with the 3D position of the aircraft;
- $\boldsymbol{x}_{MWSSc}$: vector with the 3D position of the N MWSSc;
- $\theta_{MWSSc,i}$: elevation angle between MWSSc i and the aircraft;
- $\varphi_{MWSSc,i}$: azimuth angle between MWSSc i and the aircraft.

This study assumes that the ***e.i.r.p.*** averaged over the signal repetition time with highest magnitude level, therefore upper bounding P_{Tx}, is:

- for indoor deployment: -59.6 dBm/MHz;
- for outdoor deployment: -65.8 dBm/MHz

Considering the Rohde & Schwarz MWSSc design and a geometrical factor of 5.4 dB, the above limits can be translated to power averaged over 1 ms of:

- -65 dBm/MHz for indoor deployment (radiating elements in visibility of the victim receiver).
- -71.2 dBm/MHz for outdoor deployment (radiating elements in visibility of the victim receiver).

The average value of the random variable $I_{Rx}(\boldsymbol{x}_{aircraft}, \boldsymbol{x}_{MWSSc})$ can be expressed as in (13.

$$\mathbb{E}\left(I_{Rx}(\boldsymbol{x}_{aircraft}, \boldsymbol{x}_{MWSSc})\right) = \sum_{i=1}^{N} P_{Tx} \mathbb{E}\left(\alpha_i(\boldsymbol{x}_{aircraft}, \boldsymbol{x}_{MWSSc})\right) G_{TX}(\theta_{MWSSc,i}, \varphi_{MWSSc,i}) G_{Rx}(\theta_{MWSSc,i}, \varphi_{MWSSc,i}) PL(\boldsymbol{x}_{aircraft}, \boldsymbol{x}_{MWSSc}) BEL \quad (13)$$

This average approach is valid provided that the number of MWSSc impacting the affected receiver is sufficiently high (typically higher than 5). When this number is lower, the maximum aggregation should be considered.

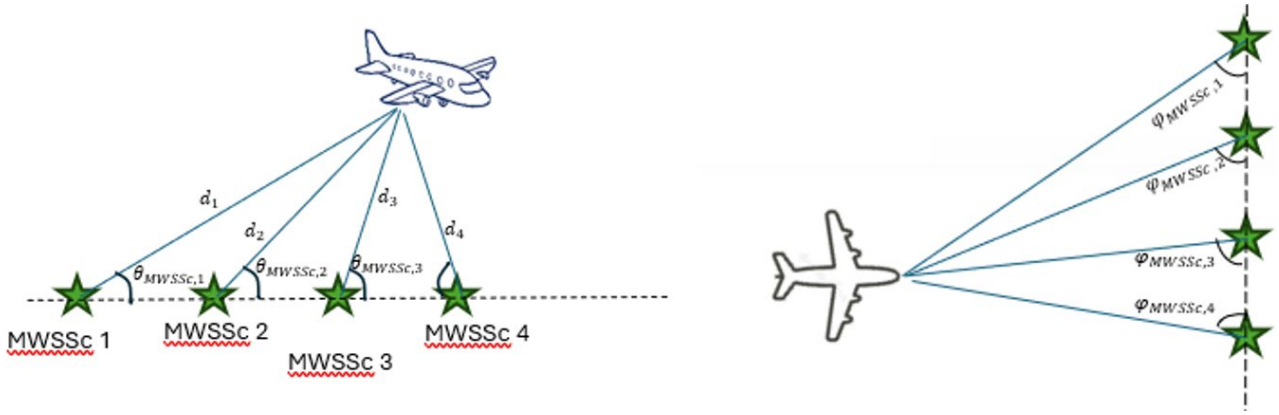


Figure 91: Deployment of MWSScs with respect to the aircraft

4.6.2.1 Description of scenarios

Landing configuration

For on-board systems, it is anticipated that the maximum impact occurs when the aircraft is close to the ground. As a consequence, only the final approach phase when the aircraft is below 1000 ft is investigated, as illustrated in Figure 92.

After the edge of the runway, it is assumed that MWSSc cannot be deployed over a distance of 150 m, corresponding to the strip length (60 m) and to the runway end safety area (90 m). It has to be noted that some runway can have a shorter runway end safety area. These aeronautical servitudes follow the recommendations of ICAO Annex 14.

Typically, the aircraft approach angle is around 3°, with instrument and aircraft trajectory error up to +-0.375°. Therefore in this study, an approach angle of 2.625° is taken into account, and the aircraft height at the runway threshold is 15 m (50 ft). Only the impact of MWSSc when the aircraft is close to the ground is analysed, and a maximum aircraft height of 1000 ft (around 305 m) is assumed. That results in a maximum (horizontal) distance of (1000*0.3048-15)/tan(2.625°)=6321 m from the aircraft with respect to the runway threshold (denoted dmax in Figure 92).

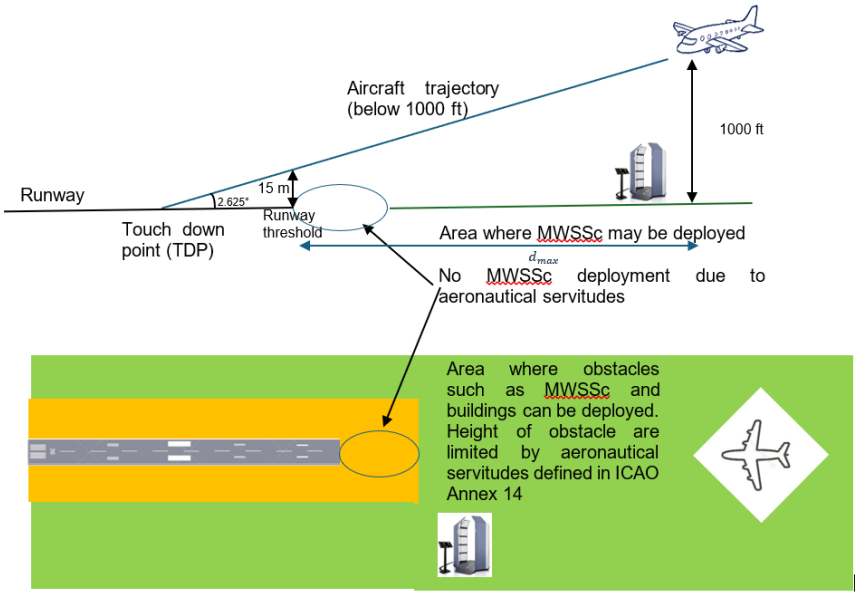


Figure 92: Aeronautical servitudes and aircraft trajectory for landing configuration

Take off-configuration

ICAO Annex 14 defines a runway strip of 140 m along runway as illustrated in Figure 93. Deployment of MWSSc is precluded in these strips. In addition, ICAO Annex 14 defines area free from obstacle after runway edge, as illustrated in Figure 93. According to constraints imposed by ICAO Annex 14, it is not likely to have MWSSc deployed in continuation of the runway, so MWSSc in continuation of the runway are not considered for take off scenarios.

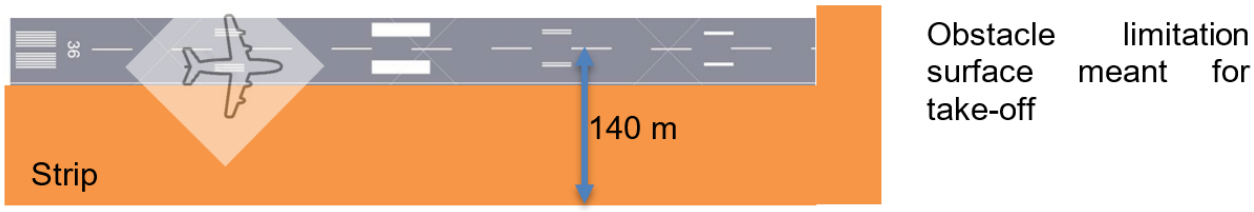


Figure 93: Obstacle limitation surface for take-off (ICAO)

However, most airports operate with a higher area in which no obstacle like MWSSc are deployed. For this study, an obstacle free area with a width of 200 m (instead of 140 m) is taken into account.

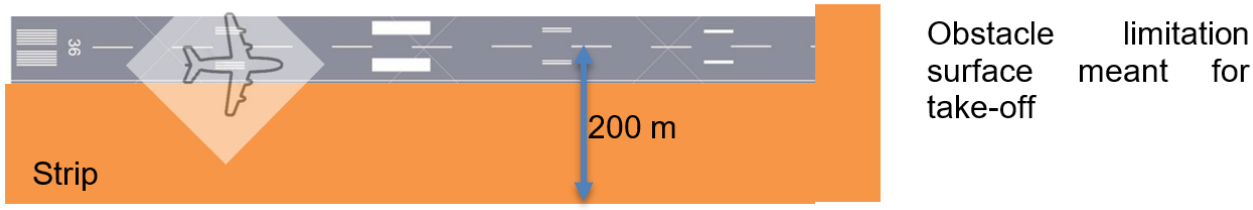


Figure 94: Obstacle limitation surface for take-off for this study

4.6.3 Compatibility study with Radio Altimeters

4.6.3.1 Description of the aircraft trajectory

Aircraft trajectory and aeronautical servitudes described in section 4.6.2.1 for landing configuration are considered when analysing the impact of MWSSc on Radio Altimeter.

4.6.3.2 Impact of MWSSc on Radio Altimeter

Antenna patterns

Radio Altimeter antenna pattern does not depend on the azimuth, and the equation is given in section 4.6.1, (15). For simplification, let's denote $G_{Rx}(\theta,\varphi) = G_{Rx}(\theta)$. Likewise, assuming the 10 MWSSc azimuth directions are pointing toward the aircraft, let's denote $G_{Tx}(\theta) = \max_{\varphi} G_{Tx}(\theta,\varphi)$ (no diminution is accounted for in azimuth direction). As a consequence, G_{Tx} only varies with the elevation according to Figure 4. For example, a reduction of 17 dB is taken into account when the aircraft is above the MWSSc ($G_{Tx}(\theta = 90°) = -17\ dB$).

Apportionment factor of the aggregate interference

The protection criteria (I/N=-6 dB) corresponds to the aggregation of all interference sources affecting the system to be protected. It is also understood that in light of their status, UWB devices cannot claim protection and should not cause harmful interference to services allocated on higher status (i.e. primary or secondary) in the same band. Even though the duration during which MWSSc has a non-negligible impact on Radio Altimeter is typically below 1 s, any disruption or corruption of Radio Altimeter, even of short duration, negatively affect the safety of flight and must not be tolerated.

A 3 dB apportionment is applied in order to take into account other services that operate into the same band than the Radio Altimeter. In particular, WAICs are deployed on-board aircraft and operate in the 4.2-4.4 GHz band during all phases of flight. Whereas the coexistence between WAICs and Radio Altimeter is carefully addressed during aircraft certification, and since it has a primary allocation, WAICs impact cannot be assumed lower than the impact of MWSSc. In this study, no additional apportionment is taken into account for UWB application sharing. As a matter of fact, the most dimensioning situation occurs at low altitude where the visibility area of the Radio Altimeter is limited. As a consequence, it is not expected that the Radio Altimeter antenna will receive interference from MWSSc and other collocated UWB source transmitting in the 4.2-4.4 GHz band simultaneously.

Interference threshold

Resulting maximum MWSSc interference threshold for Radio Altimeter is derived as follows:

$$I_{max,RA} = \left(\frac{I}{N}\right)_{prot} - App + NF - 114\ dBm/MHz \quad (14)$$

$\left(\frac{I}{N}\right)_{prot} = -6\ dB$ is the Radio Altimeter protection threshold, $NF = 6\ dB$ is the noise factor (see Table 67), and $App = 3\ dB$ is the apportionment to MWSSc interference sources. That results in an interference threshold of $I_{max,RA} = -117\ dBm/MHz$.

Propagation model

Radio Altimeters are mounted on-board aircraft and operate from ground level up to the maximum aircraft operational altitude. Airports environment is free from any obstacles where the aircraft operate. As a consequence, no clutter losses are taking into account in the study. Free space loss model (Recommendation ITU-R P.525 [16]) is applied when analysing the impact of MWSSc on radioaltimeter. Building entry loss are taken into account for indoor MWSSc deployment with $BEL = -16\ dB$ according to Recommendation ITU-R P.2109 (traditional buildings) [9].

Aggregation

For the landing configuration, results are given with N=2 and N=10 MWSSc potentially impacting the radioaltimeter, each one with a probability p which depends on the MWSSc design and relative position between the aircraft and the MWSSc. This probability p is determined by identifying, for a given position of the aircraft with respect to the MWSSc, the percentage of surface of the MWSSc in visibility of the receiver. Figure 95 Figure 95 illustrates this probability p, considering an aircraft height of 25 m (only for the illustration), with two designs of MWSSc: hexagonal shape and crossbar-like shape.

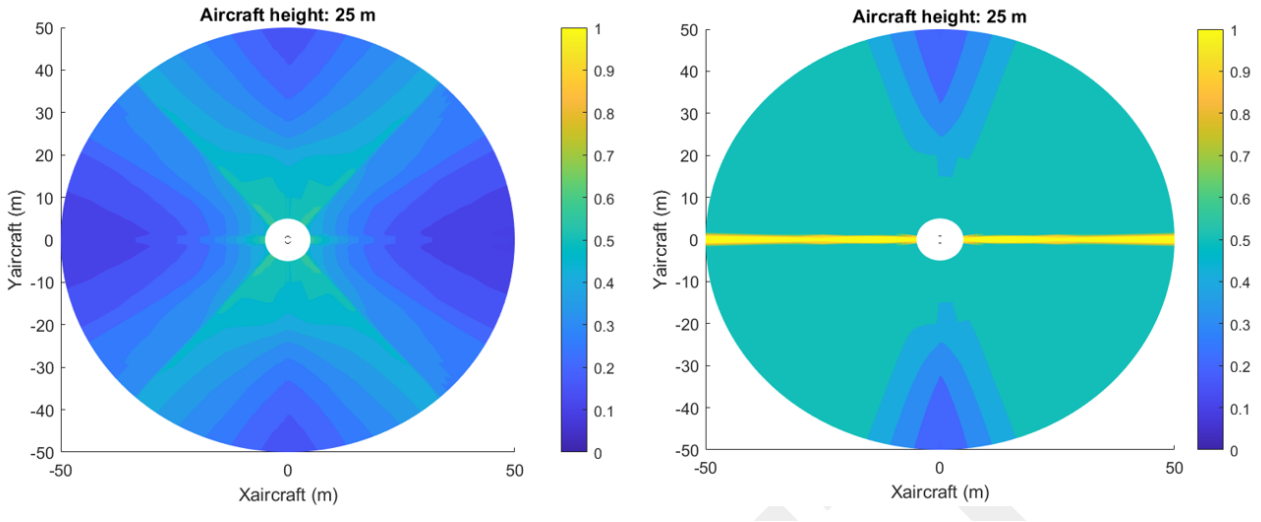


Figure 95: Probability of visibility for two designs of MWSSc: hexagonal (left) and crossbar-like (right)

With the above assumptions, (13) can be reduced to (15).

$$\mathbb{E}\left(\boldsymbol{I_{Rx}}\left(\boldsymbol{x_{aircraft}}, \boldsymbol{x_{MWSSc}}\right)\right) \tag{15}$$
$$= \boldsymbol{P_{Tx}}\, \boldsymbol{BEL} \sum_{i=1}^{N} \mathbb{E}\left(\boldsymbol{\alpha_i}\left(\boldsymbol{x_{aircraft}}, \boldsymbol{x_{MWSSc}}\right)\right) \boldsymbol{G_{TX}}\left(\boldsymbol{\theta_{MWSSc,i}}\right) \boldsymbol{PL}\left(\boldsymbol{x_{aircraft}}, \boldsymbol{x_{MWSSc}}\right)$$
$$= \boldsymbol{P_{Tx}}\, \boldsymbol{BEL}\, \boldsymbol{G_{Rx}} \sum_{i=1}^{N} (\boldsymbol{0.1 + 0.9p}) \boldsymbol{G_{Rx}}\left(\boldsymbol{\theta_{MWSSc,i}}\right) \boldsymbol{G_{TX}}\left(\boldsymbol{\theta_{MWSSc,i}}\right) \boldsymbol{PL}\left(\boldsymbol{x_{aircraft}}, \boldsymbol{x_{MWSSc}}\right)$$

When N=2, since the number of MWSSc is not sufficient so that the average value of the received power is representative, results considering the maximum aggregation are also provided ($\alpha_1 = \alpha_2 = 1$).

Figure 96 illustrates $\min_{x_{aircraft}} \left[I_{max,RA} - SM - \mathbb{E}\left(I_{Rx}\left(\boldsymbol{x_{aircraft}}, \boldsymbol{x_{MWSSc}}\right)\right)\right]$ as a function of the position of the MWSSc $\boldsymbol{x_{MWSSc}}$, taking into account all positions $\boldsymbol{x_{aircraft}}$ along the approach trajectory when the aircraft is below 1000 ft. $SM = 6\ dB$ safety margin is taken into account.

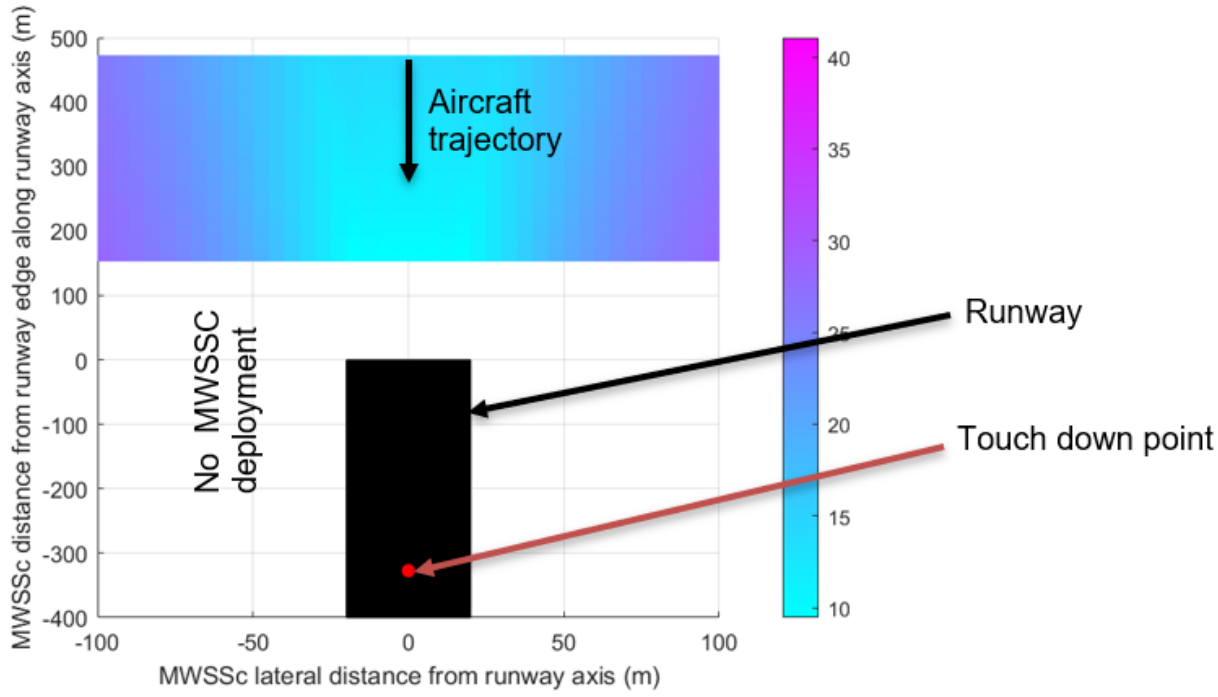


Figure 96: Link budget margin (Outdoor, 10 MWSSc with crossbar design, averaged aggregation)

4.6.3.3 Results

As a consequence, the maximum MWSSc power tolerated to ensure the protection of on-board weather radar during take-off is summarised in Table 71. For outdoor, two values are given when considering 2 MWSSc: the first one corresponds to the max aggregation. The second value is given for information and corresponds to the average aggregation; this situation leads to an underestimation of the interfering power on the on-board weather radar of around 2.6 dB with a probability 0.25, which is too high when it comes to the protection of service safety

Table 71: MWSSc *e.i.r.p.* limits to protect Radio Altimeters during landing (dBm/MHz)

Radio Altimeters in 4.2-4.4 GHz band					
		N=2		N=10	
		Rohde & Schwarz design	Crossbar design	Rohde & Schwarz design	Crossbar design
Indoor	max(mean(*e.i.r.p.*)) averaged over the signal repetition time with highest magnitude level	NA	NA	-37.4	-37.4
	mean(*e.i.r.p.*) averaged over 1 ms	NA	NA	-42.8	-42.8
Outdoor (note 1)	max(mean(*e.i.r.p.*)) averaged over the signal repetition time with highest magnitude level	-49.4/ -46.5	-49.4/ -46.9	-53.4	-53.4
	mean(*e.i.r.p.*) averaged over 1 ms	-54.8/ -51.9	-54.8/ -52.3	-58.8	-58.8
Note 1: For outdoor, two values are given: the first one corresponds to the max aggregation. The second value is given for information and corresponds to the average aggregation, considering MWSSc; this situation leads to an underestimation of the interfering power on the Radio Altimeter of around 2.6 dB with a probability 0.25, which is too high when it comes to the protection of safety service.					

4.6.3.4 Conclusion on Radio Altimeters

The result of indicates that the maximum *e.i.r.p.* averaged over the signal repetition time with highest magnitude level of MWSSc to protect Radio Altimeter in the frequency band 4200-4400 MHz are:

- -37.4 dBm/MHz for indoor;
- -53.4 dBm/MHz for outdoor.

The *e.i.r.p.* limits averaged over 1 ms depend on the MWSSc design. For the Rohde and Schwarz design, *e.i.r.p.* limits averaged over 1 ms are:

- -42.8 dBm/MHz for indoor;
- -58.8 dBm/MHz for outdoor.

As an important assumption, these results assume that emission towards the sky benefit from attenuation due to antenna directivity. The hypothesis on the elevation attenuation due to the MWSSc radiating element directivity is reminded in Table 72, as well as the associated *e.i.r.p.* limits.

Table 72: *e.i.r.p.* limits for protecting Radio Altimeters

Elevation (note 1)	Assumed attenuation (dB)	Corresponding *e.i.r.p.* limit for indoor (dBm/MHz)	Corresponding *e.i.r.p.* limit for outdoor (dBm/MHz)
0°	0	-42.8	-58.8
10°	0.21	-43.01	-59.01
20°	2.11	-44.91	-60.91
30°	3.61	-46.41	-62.41

Elevation (note 1)	Assumed attenuation (dB)	Corresponding *e.i.r.p.* limit for indoor (dBm/MHz)	Corresponding *e.i.r.p.* limit for outdoor (dBm/MHz)
40°	6.11	-48.91	-64.91
50°	8.11	-50.91	-66.91
60°	13.11	-55.91	-71.91
90°	17.11	-59.91	-75.91
Note 1: 90° elevation refers to the zenith from MWSSc. 0° elevation refers to the horizon from MWSSc			

4.6.4 Compatibility study with on-board weather radars

4.6.4.1 Description of the aircraft trajectory

Aircraft trajectory and aeronautical servitudes described in section 4.6.2.1 are considered when analysing the impact of MWSSc on on-board weather radar.

For this take-off configuration, the on-board weather radar may be affected by MWSSc located in front of the aircraft but outside the area in the vicinity of the take-off runway where clutter (buildings, object) is prohibited. Indeed, depending on the location of MWSSc, they might impact the main lobe of the on-board weather radar antenna, as illustrated in Figure 97.

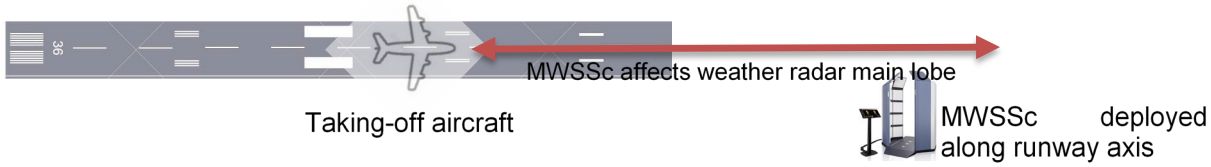


Figure 97: On-board weather radar - take off configuration

Considering the 30° scanning of on-board radars and the assumed 200 m of obstacle free area from the runway edge, the minimum separation between MWSSc and on-board weather radar during take-off is 400 m.

Landing: During landing phases, it is assumed that the weather radar has a down tilt angle in order to detect adverse weather and windshear along the aircraft landing trajectory. In this configuration, it is unlikely that MWSSc will be in the main lobe of the on-board weather radar, therefore, only the impact of MWSSc on secondary lobes of the on-board weather radar is analysed.

4.6.4.2 Take-off configuration

Antenna patterns

The on-board weather radar main lobe points toward the MWSSc. As a consequence, the weather radar antenna pattern gain is constant and equal to:

- $G_{Tx} = 34\ dBi$ in the 5.35-5.47 GHz band;
- $G_{Tx} = 34.4\ dBi$ in the 9.3-9.5 GHz band.

The MWSSc antenna gain discrimination is taken as $G_{Tx} = 0\ dB$.

Apportionment factor of the aggregate interference

The protection criteria (I/N=-6 dB) corresponds to the aggregation of all interference sources affecting the system to be protected. It is also understood that in light of their status, UWB devices cannot claim protection and should not cause harmful interference to services allocated on higher status (i.e. primary or secondary) in the same band.

Apportionment needs to account for:

- The number of services and systems operating in the same frequency band than the on-board weather radar, as well as the visibility area of the victim receiver, since a narrow beamwidth may limit the number of interferers simultaneously seen by the victim receiver.
- The number of UWB applications operating in the same frequency band than the on-board weather radar.

As a consequence, the following approach is proposed to compute the apportionment factor:

- Since a flying aircraft can see a wider area than an aircraft taking off on a runway, a 3 dB factor is assumed for service sharing in the landing scenario and a 0 dB factor is taken into account for take-off configuration;
- The 9.3-9.5 GHz frequency band is also targeted by applications under the scope of WI-79. As a consequence, a 3 dB factor is added for sharing between UWB applications in the compatibility analysis with on-board weather radars operating in the 9.3-9.5 GHz. A 0 dB factor is taken into account for UWB sharing in the 5.35-5.47 GHz band;
- The resulting apportionment factor is summarised in Table 73.

Table 73: Apportionment factor for compatibility studies between MWSSc and on-board weather radars (take-off configuration)

Scenario	5.35-5.47 GHz	9.3-9.5 GHz
On-board weather radar (take-off scenario)	0 dB	3 dB

Interference threshold

Resulting maximum MWSSc interference threshold for Radioaltimeter is derived as follows:

$$I_{max,WR} = \left(\frac{I}{N}\right)_{prot} - App + NF - 114\ dBm/MHz$$

$\left(\frac{I}{N}\right)_{prot} = -6\ dB$ is the on-board weather radar protection threshold, $NF = 5\ dB$ in the 5.35-5.47 GHz band and $NF = 4\ dB$ in the 9.3-9.5 GHz band corresponds to the noise factor (see Table 69), and $App = 3\ dB$ (9.3-9.5 GHz band) / $App = 0\ dB$ (5.35-5.47 GHz band) is the apportionment to MWSSc interference sources. That results in an interference threshold of:

- $I_{max,WR} = -115\ dBm/MHz$ in the 5.35-5.47 GHz band and
- $I_{max,WR} = -119\ dBm/MHz$ in the 9.3-9.5 GHz band.

Propagation model

On-board weather radars are mounted on-board aircraft and operate from ground level up to the maximum aircraft operational altitude. Airports environment is free from any obstacles where the aircraft operate. As a consequence, no clutter losses are taking into account in the study. Free space loss model is applied when analysing the impact of MWSSc on on-board weather radar. Building entry losses are taken into account for indoor MWSSc deployment with $BEL = -16\ dB$ in the 5.35-5.47 GHz band and $BEL = -17\ dB$ in the 9.3-9.5 GHz band, according to Recommendation ITU-R P.2109 (traditional buildings) [9].

Aggregation

This analysis assumes that only the MWSSc impacting the on-board weather radar main lobe are significant. The number of MWSSc impacting the main lobe of is derived from the beamwidth of the on-board weather radar main lobe and from the distance between the weather radar and the MWSSc, as illustrated in Figure 98.

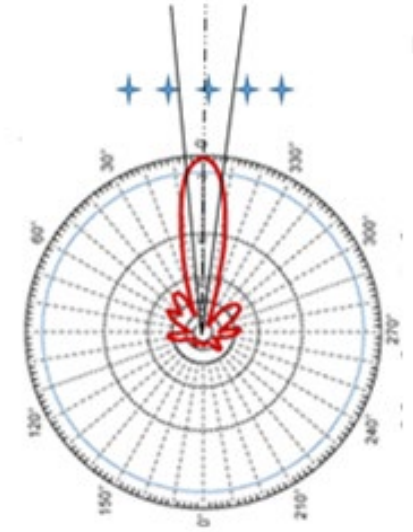


Figure 98: Illustration of aggregation factor calculation

For take-off configuration, the following assumption is taken into account regarding the maximum number of MWSSc deployed on a given site to be considered:

- 10 colocalised MWSSc for indoor deployment (e.g. to represent airport scanners deployed indoor for passengers' control);
- 2 colocalised MWSSc in visibility of the aircraft for outdoor deployment.

The number for outdoor deployment is reduced compared to the indoor deployment because the use cases of outdoor MWSSc (e.g. for airport crew control, whose flow is less important than passenger) directly in visibility of the runways generally require less MWSSc.

Considering a 3.5° beamwidth, a 1.8 m scanner width and a 1.6 m inter scanner distance and a maximum of 10 MWSSc on the same site, the number of MWSSc impacting the main lobe of the on-board weather radar is represented in Figure 99 as a function of the distance between the MWSSc and the on-board weather radar. Since the azimuth beamwidth is identical for on-board weather radar operating in 5.35-5.47 GHz band and 9.3-9.5 GHz band, the number of MWSSc impacting the main lobe of the on-board weather radar is independent of the band.

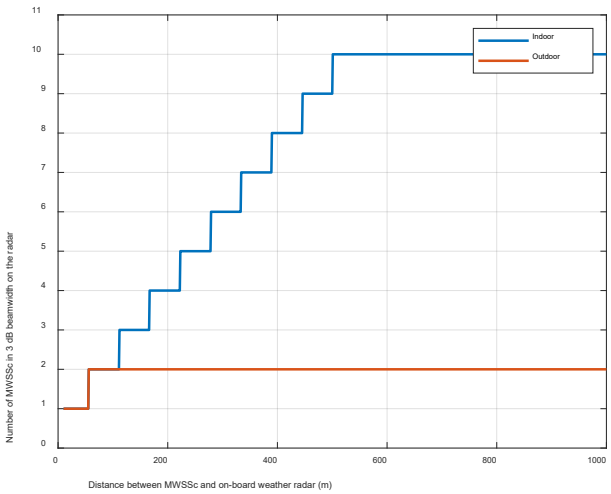


Figure 99: Number of MWSSc in the 3 dB beamwidth of on-board weather radar for take-off configuration

From the above hypothesis, and assuming that the propagation losses are the same for the different MWSSc impacting the on-board weather radar main lobe, (16.

$$\mathbb{E}\left(I_{Rx}\left(\boldsymbol{x}_{aircraft}, \boldsymbol{x}_{MWSSc}\right)\right) = G_{TX}G_{Rx}PL\ BEL\ P_{Tx}\ \mathbb{E}\left(\sum_{i=1}^{N}\alpha_i\left(\boldsymbol{x}_{aircraft}, \boldsymbol{x}_{MWSSc}\right)\right) = G_{TX}G_{Rx}PL\ BEL\ P_{Tx}\ \mathbb{E}(Agg) \quad (16)$$

$Agg = \sum_{i=1}^{N}\alpha_i\left(\boldsymbol{x}_{aircraft}, \boldsymbol{x}_{MWSSc}\right)$ is the aggregation factor.

The aggregate factor, taking into account the shielding effect of the MWSSc, is computed as follows:

Consider that N MWSSc are within the 3 dB beamwidth of the victim receiver.

Consider that the probability that the radiating element is not shielded by a face of the MWSSc (therefore visible by the main beam of the receiver) is p.

Consider that when a radiating element is shielded by a face of the MWSSc (therefore not visible by the victim receiver), the power that reaches the victim receiver is 10% of the total power to account for leakage, reflection, etc.

The aggregation factor is a random variable given by (17) .

$$Agg = \sum_{i=1}^{N}(0.1 + 0.9\,\tilde{\alpha}_i) = 0.1\,N + 0.9\sum_{i=1}^{N}\tilde{\alpha}_i \quad (17)$$

where:

- $\tilde{\alpha}_i$ is a Bernoulli random variable with parameter p. $\tilde{\alpha}_i = 1$ when the radiating antenna of MWSSc i is not shielded
- $\alpha_i = 0$ when the radiating antenna of MWSSc i is shielded.

When the MWSSc radiated powers are uncorrelated, (α_i) are independent from each other and $\sum_{i=1}^{N}\tilde{\alpha}_i$ is a binomial random variable with parameters (N, p).

The average value of the aggregation factor random variable is given in (18) .

$$\mathbb{E}(Agg) = \mathbb{E}\left(0.1\,N + 0.9\sum_{i=1}^{N}\tilde{\alpha}_i\right) = 0.1\,N + 0.9\,N\,p = N(0.1 + 0.9p) \quad (18)$$

The average value of the aggregation factor is represented in Figure 100 as a function of the number of MWSSc in the 3 dB beamwidth of the victim receiver, for several values of p.

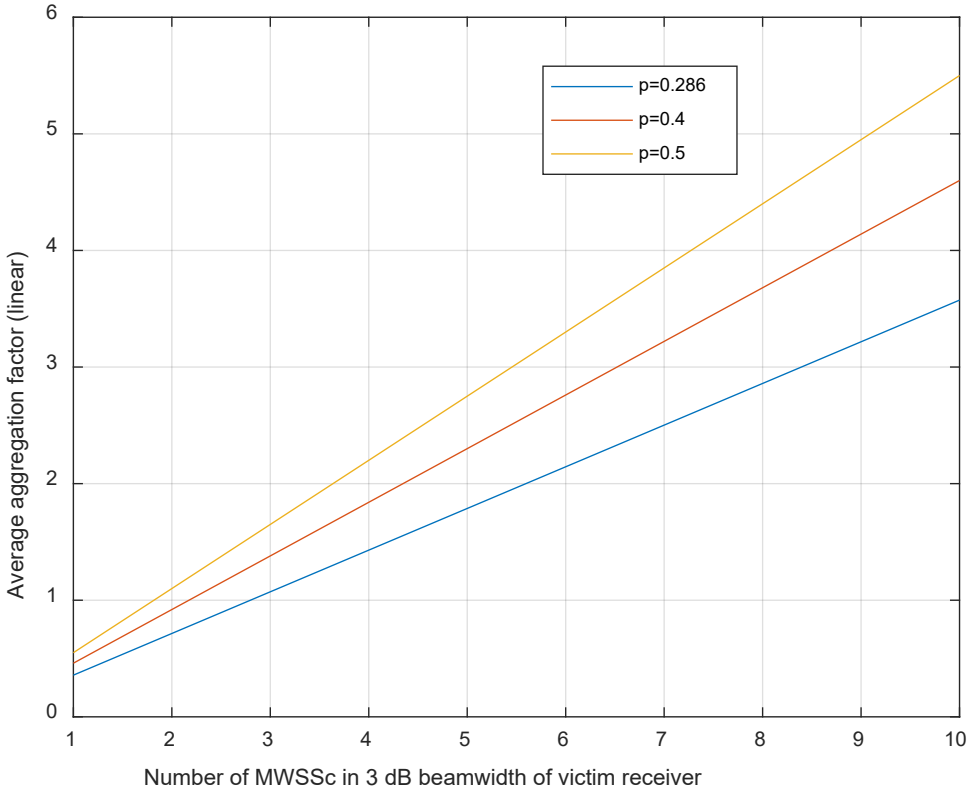


Figure 100: Average aggregation factor for different values of p

In order to remain agnostic of the MWSSc design (to be technology neutral), the aggregation factor is computed by the average value of the random variable Agg with different probability MWSSc antenna element radiates in visibility of the victim receiver, i.e. p=0.5, p=0.4 and p=0.286. In the following study, the average aggregation factor is bounded to 1 in order to at least cover the single entry case.

It has to be noted that for outdoor MWSSc deployment, the number of deployed MWSSc is limited to 2. The probability that the 2 MWSSc radiate is visibility of the victim receiver is 0.25 (when p=0.5), whereas the average aggregation factor is 1.1. This situation leads to an underestimation of the interfering power on the on-board weather radar of around 2.6 dB with a probability 0.25, which is too high when it comes to the protection of the aeronautical radionavigation service which is a safety service. As a consequence, this study also provide the results using a non-averaged aggregation factor for outdoor MWSSc deployment (2 MWSSc considered), corresponding to multi-entry (interference) case.

Results

Taking into account the above assumptions, (16) can be rewritten in log scale as a function of the distance between the on-board weather radar and the MWSSc $d_{MWSSc-WR}$ as follows:

$$I_{Rx,WR}(d_{MWSSc-WR}) = P_{Tx} + G_{Tx} + G_{Rx} + 20\log\left(\frac{c}{4\pi f\, d_{MWSSc-WR}}\right) + \mathbb{E}(Agg) + BEL \quad (19)$$

The associated margin (in dB) is computed by:

$$M_{Rx}(d_{MWSSc-WR}) = I_{max,WR} - SM - I_{Rx,WR}(d_{MWSSc-WR}) \quad (20)$$

$I_{Rx,WR}$ and M_{Rx} are represented in (19) and (20), respectively, as a function of $d_{MWSSc-WR}$, with $P_{Tx} = -65.8\, dBm/MHz$ and outdoor deployment (BEL=0 dB) and $P_{Tx} = -59.6\, dBm/MHz$ for indoor deployment (BEL=17 dB). SM=6 dB is taken into account.

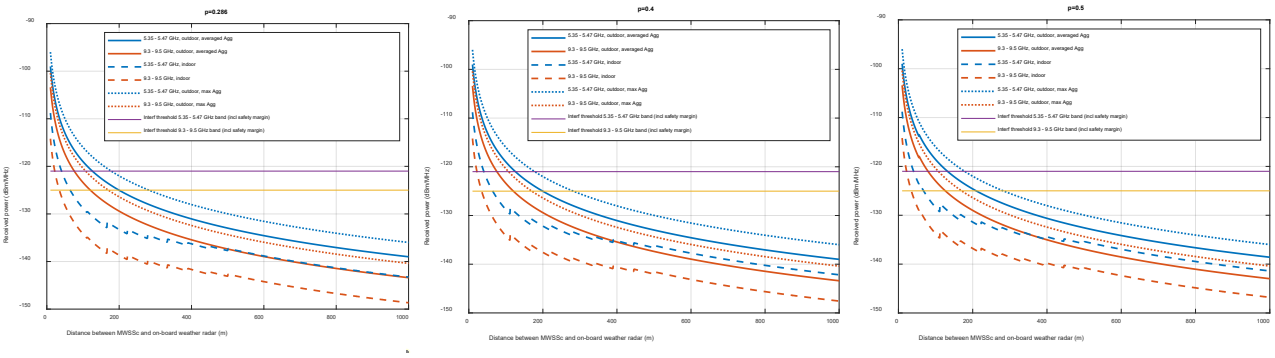


Figure 101: Received interference power by on-board weather radar (take off scenario)

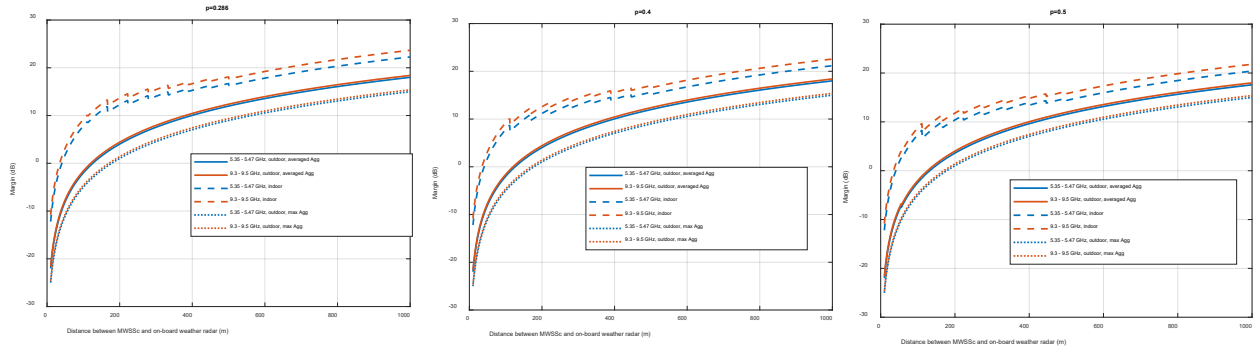


Figure 102: Link budget margin for on-board weather radar (take off scenario)

Difference of results between indoor and outdoor scenarios are explained by the variation of BEL and MWSSc transmitted power. Results appear to be very similar for X-band and C-band, although some parameters are different (propagation losses, apportionment, interference threshold). Eventually, the steps in the curves that are visible in Figure 101 and Figure 102 are due to the discontinuous variation of the aggregation factor with the separation distance.

Interpretation of results

Figure 102 shows:

- For indoor MWSSc deployment, the minimum separation distances required to protect the airborne radar are inferior to the minimum practical separation distance between MWSSc and the aircraft (400 m). Consequently, on-board weather radar is assumed to be protected with the considered assumptions, and can tolerate a relaxation of the *e.i.r.p.* limit assumed in this study, in order to meet the required separation distance of 400 m;
- For outdoor MWSSc deployment, the minimum separation distances required to protect the airborne radar (less than 200 m) are inferior to 400 m for on-board weather radar operating in the C-band and X-band respectively. That allows a relaxation of the *e.i.r.p.* limit assumed in this study, in order to meet the required separation distance of 400 m.

As a consequence, the maximum MWSSc power tolerated to ensure the protection of on-board weather radar during take-off is summarised in Table 74. For outdoor, two values are given: the first one corresponds to the max aggregation. The second value is given for information and corresponds to the average aggregation, considering 2 MWSSc. This situation leads to an underestimation of the interfering power on the on-board weather radar of around 2.6 dB with a probability 0.25, which is too high when it comes to the protection of service safety.

Table 74: MWSSc average *e.i.r.p.* limits to protect weather radars during take-off (dBm/MHz)

		On-board weather radar in 5.35-5.47 GHz band			On-board weather radar in 9.3-9.5 GHz band		
		p=0.5	p=0.4	p=0.286	p=0.5	p=0.4	p=0.286
Indoor	max(mean(*e.i.r.p.*)) averaged over the signal repetition time with highest magnitude level	-46.2	-45.5	-44.6	-44.8	-44.1	-43.2
	mean(*e.i.r.p.*) averaged over 1 ms	-51.6	-50.9	-50	-50.2	-49.5	-48.6
Outdoor (Note 1)	max(mean(*e.i.r.p.*)) averaged over the signal repetition time with highest magnitude level	-58.8/-56.2	-58.8/-55.8	-58.8/-55.8	-58.4/-55.8	-58.4/-55.4	-58.4/-55.4
	mean(*e.i.r.p.*) averaged over 1 ms	-64.2/-61.6	-64.2/-61.2	-64.2/-61.2	-63.8/-61.2	-63.8/-60.8	-63.8/-60.8
Note 1: For outdoor, two values are given: the first one corresponds to the max aggregation (2 MWSScs multi-entry use case). The second value is given for information and corresponds to the average aggregation, resulting in a single-entry use case; this situation leads to an underestimation of the interfering power on the on-board weather radar of around 2.6 dB with a probability 0.25, which is too high when it comes to the protection of safety service.							

4.6.4.3 Landing scenarios

Antenna Pattern

For the landing scenario, is it expected that the interfering MWSSc would not hit the main lobe of the on-board weather radar antenna. As a consequence, the impact on the side lobe is only investigated here, therefore, the receiver antenna gain G_{Rx} does not depend on the azimuth nor elevation angle.

$G_{Rx} = 3\ dBi$ in 5.35-5.47 GHz band

$G_{Rx} = 3.4\ dBi$ in 9.3-9.5 GHz band

The MWSSc antenna discrimination assumed in the landing configuration is illustrated in Figure 4.

Apportionment factor of the aggregate interference and interference threshold

For the landing configuration, the same apportionment factor than for the take-off scenario is assumed. The resulting apportionment factor and interference thresholds for landing configuration are given in Table 75.

Table 75: Apportionment factor for compatibility studies between MWSSc and on-board weather radars (landing configuration)

Parameter		5.35-5.47 GHz	9.3-9.5 GHz
On-board weather radar (landing configuration)	Apportionment factor	0 dB	3 dB
	Interference threshold	-115 dBm/MHz	-119 dBm/MHz

Propagation model

The assumptions for the take-off configuration apply.

Aggregation

For the landing configuration, results are given with N=2 and N=10 MWSSc potentially impacting the on-board weather radar, each one with a probability p which depends on the MWSSc design and relative position between the aircraft and the MWSSc. This probability p is determined by identifying, for a given position of the aircraft with respect to the MWSSc, the percentage of surface of the MWSSc in visibility of the receiver.

Figure 103 illustrates this probability p, considering an aircraft height of 25 m (only for the illustration), with two designs of MWSSc: hexagonal shape and crossbar-like shape[7].

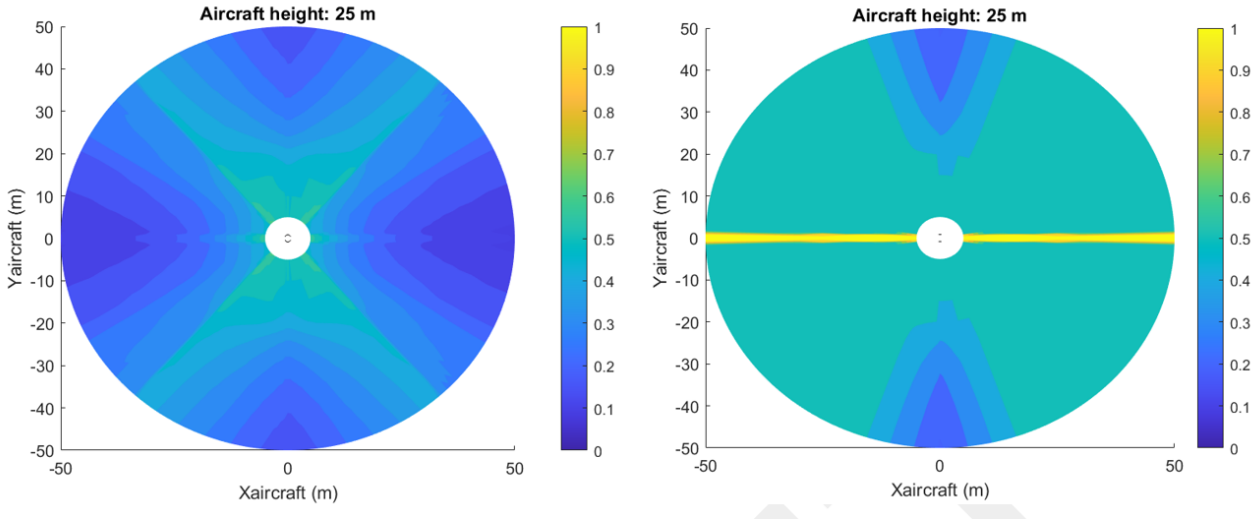


Figure 103: Probability of visibility for two designs of MWSSc: hexagonal (left) and crossbar-like (right)

With the above assumptions, (16) can be reduced to equation (21).

$$\mathbb{E}\left(I_{Rx}(\boldsymbol{x}_{aircraft},\boldsymbol{x}_{MWSSc})\right) \quad (21)$$
$$= P_{Tx}\ BEL\ G_{Rx} \sum_{i=1}^{N} \mathbb{E}\left(\alpha_i(\boldsymbol{x}_{aircraft},\boldsymbol{x}_{MWSSc})\right) G_{TX}(\theta_{MWSSc,i}) PL(\boldsymbol{x}_{aircraft},\boldsymbol{x}_{MWSSc})$$
$$= P_{Tx}\ BEL\ G_{Rx} \sum_{i=1}^{N} (0.1 + 0.9p) G_{TX}(\theta_{MWSSc,i}) PL(\boldsymbol{x}_{aircraft},\boldsymbol{x}_{MWSSc})$$

When N=2, since the number of MWSSc is not sufficient so that the average value of the received power is representative, results considering the maximum aggregation are also provided ($\alpha_1 = \alpha_2 = 1$).

Figure 103 illustrates $\min_{\boldsymbol{x}_{aircraft}} \left[I_{max,WR} - SM - \mathbb{E}\left(I_{Rx}(\boldsymbol{x}_{aircraft},\boldsymbol{x}_{MWSSc})\right)\right]$ as a function of the position of the MWSSc $\boldsymbol{x}_{MWSSc}$, taking into account all positions $\boldsymbol{x}_{aircraft}$ along the approach trajectory when the aircraft is below 1000 ft. $SM = 6\ dB$ safety margin is taken into account.

7 https://www.rohde-schwarz.com/fr/produits/aerospatiale-defense-securite/scanner-de-securite/qps201-security-scanner_63493-332676.html

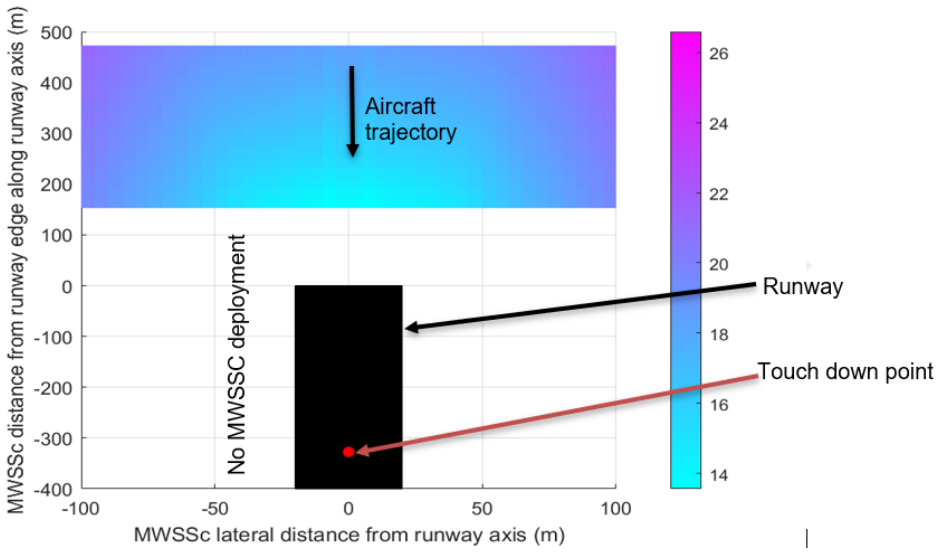


Figure 104: Link budget margin (Outdoor, 10 MWSSc with crossbar design, averaged aggregation, X-band)

As a consequence, the maximum MWSSc power tolerated to ensure the protection of on-board weather radar during take-off is summarised in Table 76. For outdoor, two values are given when considering 2 MWSSc: the first one corresponds to the max aggregation. The second value is given for information and corresponds to the average aggregation; this situation leads to an underestimation of the interfering power on the on-board weather radar of around 2.6 dB with a probability 0.25, which is too high when it comes to the protection of service safety.

Table 76: MWSSc *e.i.r.p.* limits to protect weather radars during landing (dBm/MHz)

		On-board weather radar in 5.35-5.47 GHz band				On-board weather radar in 9.3-9.5 GHz band			
		N=2		N=10		N=2		N=10	
		Rohde & Schwarz design	Cross bar design	Rohde & Schwarz design	Crossbar design	Rohde & Schwarz design	Crossbar design	Rohde & Schwarz design	Crossbar design
Indoor	max(mean(*e.i.r.p.*)) averaged over the signal repetition time with highest magnitude level	N/A	N/A	-31.7	-33	N/A	N/A	-30.3	-31.6
	mean(*e.i.r.p.*) averaged over 1 ms	N/A	N/A	-37.1	-38.4	N/A	N/A	-35.7	-37.0
Outdoor (Note 1)	max(mean(*e.i.r.p.*)) averaged over the signal repetition time with highest magnitude level	-45/ -41.7	-45/42.3	-47.7	-49	-44.7/ -41.3	-44.7/ -41.9	-47.3	-48.6
	mean(*e.i.r.p.*) averaged over 1 ms	-50.4/ -47.1	-50.4/ -47.7	-53.1	-54.4	-50.1/ -46.7	-50.1/ -47.3	-52.7	-54

Note 1: For outdoor, two values are given: the first one corresponds to the max aggregation. The second value is given for information and corresponds to the average aggregation, considering MWSSc; this situation leads to an underestimation of the interfering power on the on-board weather radar of around 2.6 dB with a probability 0.25, which is too high when it comes to the protection of safety service.

4.6.4.4 Conclusion

The results of Table 75 indicate that the maximum *e.i.r.p.* averaged over the signal repetition time with highest magnitude level of MWSSc to protect on-board weather radars are:

- In the 5.35-5.47 band: -46.2 dBm/MHz for indoor, -58.8 dBm/MHz for outdoor;
- In the 9.3-9.5 GHz band: -44.8 dBm/MHz for indoor, -58.4 dBm/MHz for outdoor.

The *e.i.r.p.* limits averaged over 1 ms depend on the MWSSc design. For the Rohde and Schwarz design, *e.i.r.p.* limits averaged over 1 ms are:

- In the 5.35-5.47 band: -51.6 dBm/MHz for indoor, -64.2 dBm/MHz for outdoor;
- In the 9.3-9.5 GHz band: -50.2 dBm/MHz for indoor, -63.8 dBm/MHz for outdoor.

4.6.5 Compatibility study with ASDE Radars in the 9.0-9.2 GHz frequency band

4.6.5.1 Antenna patterns

ASDE radars rotate in the horizontal plane with a rotation rate around 1 rotation per second. This analysis investigates the impact of MWSSc on ASDE considering it points on a given direction (azimuth). As a consequence, only the elevation angle between MWSSc and ASDE antenna has an impact on and no reduction in azimuth is accounted, assuming the ASDE points in the MWSSc direction. For simplification, let's denote:

$G_{Tx}(\theta) = \max_{\varphi} G_{Tx}(\theta, \varphi)$. $G_{Tx}(\theta)$ is derived from Figure 4.

$G_{Rx}(\theta, \varphi) = G_{Rx}(\theta)$. $G_{Rx}(\theta)$ is shown in Figure 105 for characteristics of system G8 reported in section 4.6.1, assuming a down tilt angle of -2°.

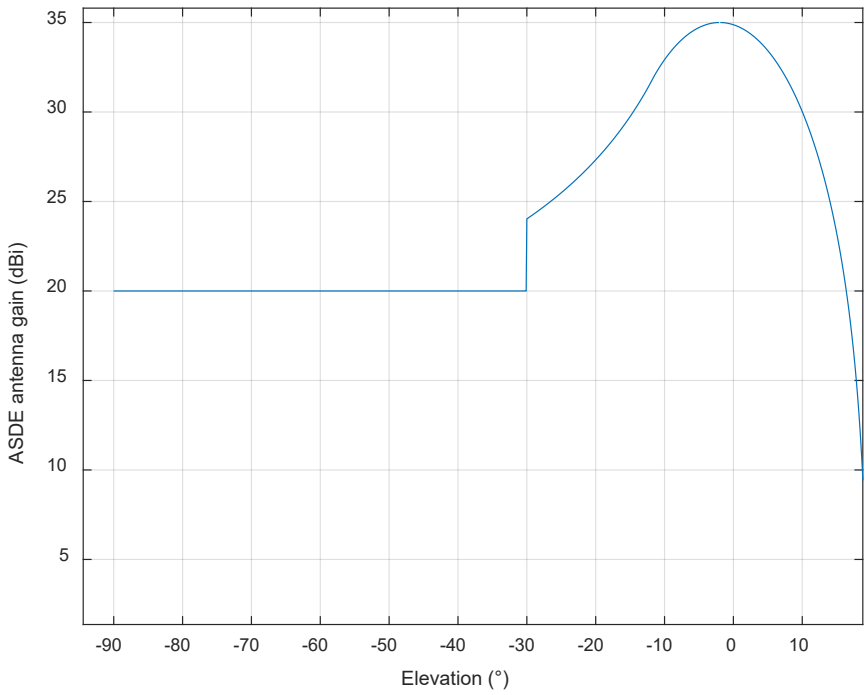


Figure 105: ASDE antenna pattern

4.6.5.2 Apportionment factor of the aggregate interference

Noting the narrowbeam of ASDE radars, it is assumed that the radar will not be affected by several services simultaneously. Noting that the UWB parts needs to be shared with other applications in the 9000–9200 MHz band, a 3 dB apportionment is taken into account.

4.6.5.3 Interference threshold

Resulting maximum MWSSc interference threshold for ASDE is derived as follows:

$$I_{max,ASDE} = \left(\frac{I}{N}\right)_{prot} - App + NF - 114\ dBm/MHz$$

$\left(\frac{I}{N}\right)_{prot} = -6\ dB$ is the ASDE protection threshold, the noise factor NF is given in Table 69, and $App = 3\ dB$ is the apportionment to MWSSc interference sources. That results in an interference threshold of:

- -117.44 dBm/MHz for system G8;
- -117.75 dBm/MHz for system G18;
- -118 dBm/MHz for system G19.

4.6.5.4 Propagation model

ASDE radars operate on airport in area that are free from obstacle. As a consequence, no clutter losses are taking into account in the study. Free space loss model is applied when analysing the impact of MWSSc on ASDE.

4.6.5.5 Aggregation

The number of MWSSc impacting the main lobe of is derived from the azimuth beamwidth of the ASDE radar main lobe and from the distance between the ASDE radar and the MWSSc, as illustrated in the below figure.

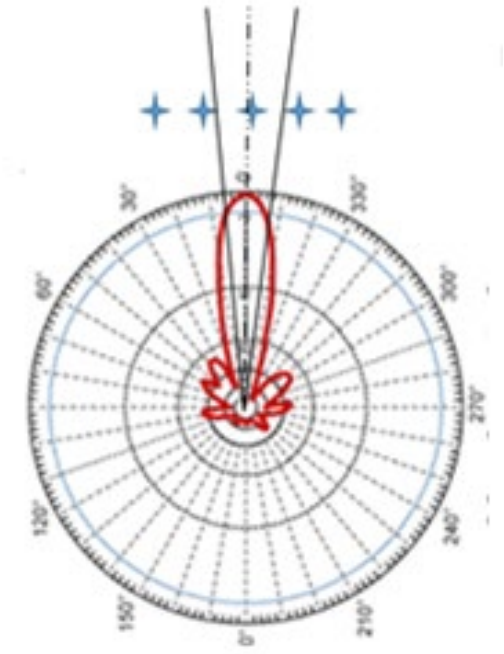


Figure 106: Illustration of aggregation factor calculation

Considering a 0.35° beamwidth, a 1.8 m scanner width and a 1.6 m inter scanner distance and a maximum of 10 MWSSc on the same site, the aggregation factor is represented in Figure 107 as a function of the distance between the MWSSc and the ASDE radar.

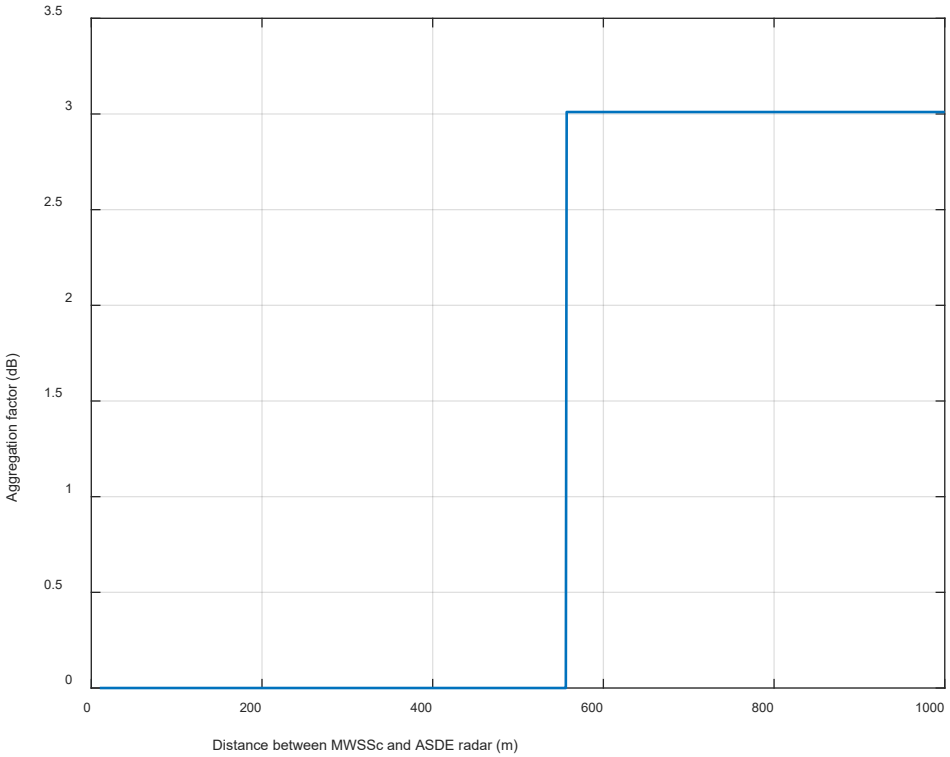


Figure 107: Aggregation factor for ASDE radars

4.6.5.6 Results

Taking into account the above assumptions, the equation (12) can be rewritten in log scale as a function of the distance between the ASDE radar and the MWSSc $d_{MWSSc-WR}$ as follows:

$$I_{Rx,ASDE}(d_{MWSSc-ASDE}) = P_{Tx} + G_{Tx}(\theta(d_{MWSSc-ASDE})) + G_{Rx}(\theta(d_{MWSSc-ASDE})) + 20\log\left(\frac{c}{4\pi f d_{MWSSc-ASDE}}\right) + Agg + BEL \quad (22)$$

With $\theta(d_{MWSSc-ASDE}) = \text{atan}\left(\frac{h_{MWSSc}-h_{ASDE}}{d_{MWSSc-ASDE}}\right)$

h_{ASDE} is the height of the ASDE radar given in Table 68, and $h_{MWSSc} = 2.5\ m$ is the height of the MWSSc.

The associated margin (in dB) is computed by:

$$M_{Rx}(d_{MWSSc-ASDE}) = I_{max,ASDE} - SM - I_{Rx,WR}(d_{MWSSc-ASDE}) \quad (23)$$

A 6 dB safety margin is taken into account.

$I_{Rx,WR}$ and M_{Rx} are represented in Figure 108 and Figure 109, respectively, as a function of $d_{MWSSc-WR}$, with $P_{Tx} = -65.8\ dBm/MHz$ and outdoor deployment (BEL=0 dB) for the ASDE radars G8 in Table 68. Table 77 represents the minimum link budget margins for the different hypothesis, taking into account a minimum separation distance between the ASDE radar and the MWSSc of at least 150 m.

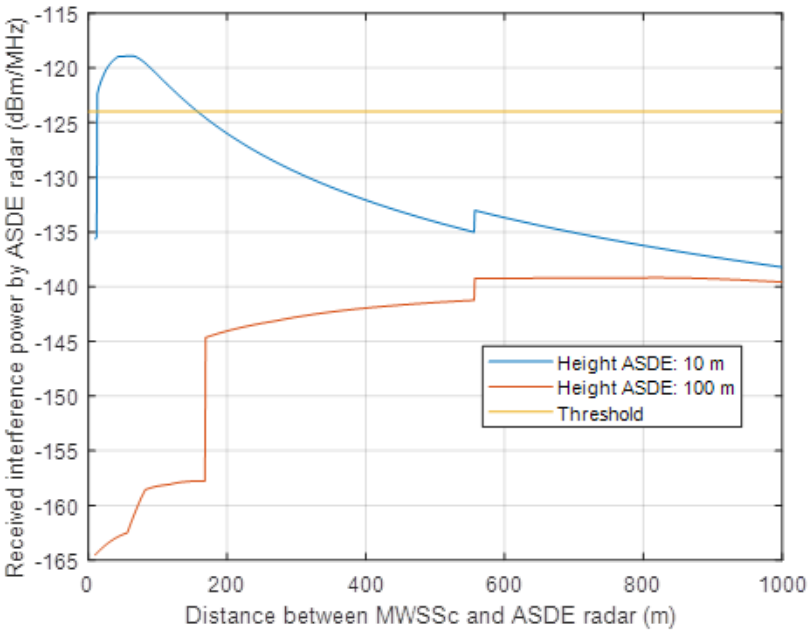


Figure 108: Received interference power by ASDE radar

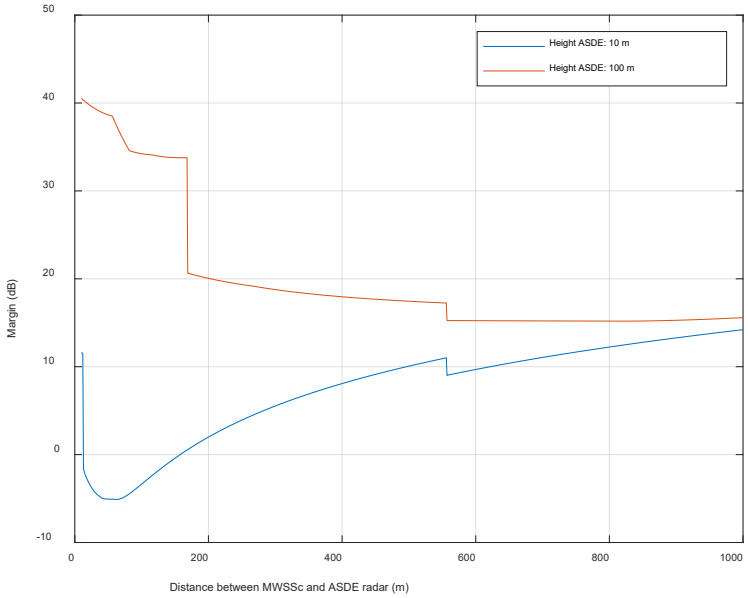


Figure 109: Link budget margin for ASDE radar

Table 77: Link budget margin (in dB) for ASDE radar protection

	G8		G18		G19	
	H = 30 m	H = 100 m	H = 10 m	H = 100 m	H = 10 m	H = 100 m
Indoor	16.1	25.1	10.6	26.3	10.3	26
Outdoor	5.3	14.3	-0.2	15.5	-0.5	15.2

Table 78 shows for indoor deployment, relaxation of the *e.i.r.p.* limit by 10.3 dB is possible. For outdoor MWSSc deployment, since the negative link budgets indicate the necessity to have to stronger *e.i.r.p.* limits.

The maximum tolerable MWSSc *e.i.r.p.* limits to protect ASDE radars are then summarised in Table 78.

Table 78: Maximum tolerable MWSSc *e.i.r.p.* limits for ASDE protection

		G8		G18		G19	
		H = 30 m	H = 100 m	H = 10 m	H = 100 m	H = 10 m	H = 100 m
Indoor	MWSSc *e.i.r.p.* averaged over the signal repetition time with highest magnitude level	-43.5	-34.5	-49	-33.3	-49.3	-33.6
	MWSSc *e.i.r.p.* averaged over 1 ms for R&S design	-48.9	-39.9	-54.4	-38.7	-54.7	-39
Outdoor	MWSSc *e.i.r.p.* averaged over the signal repetition time with highest magnitude level	-60.5	-51.5	-66	-50.3	-66.3	-50.6
	MWSSc *e.i.r.p.* averaged over 1 ms for R&S design	-65.9	-56.9	-71.4	-55.7	-71.7	-56

4.6.5.7 Conclusions on ASDE

The results of Table 77 indicate that the maximum *e.i.r.p.* averaged over the signal repetition time with highest magnitude level of MWSSc to protect ASDE radar in the frequency band 9000-9200 MHz are:

- -49.3 dBm/MHz for indoor;
- -66.3 dBm/MHz for outdoor.

The *e.i.r.p.* limits averaged over 1 ms depend on the MWSSc design. For the Rohde and Schwarz design, *e.i.r.p.* limits averaged over 1 ms are:

- -54.7 dBm/MHz for indoor;
- -71.7 dBm/MHz for outdoor.

One measurement for a specific airport ASDE radar in Munich, given in Annex 5 indicated no visual target at the radar, although these results cannot be generalised.

4.7 AERONAUTICAL TELEMETRY IN THE BAND 5091-5150 MHZ / 5150-5250 MHZ

4.7.1 Description of the system

Telemetry is the real-time transmission of information collected by the test installation from an aircraft to the ground. Telemetry is an essential part of the Flight tests Instrumentation as it participates in flight safety and contributes towards optimizing the test campaigns by a real time study of the flights by specialists.

Telemetry is a key instrument for commercial aircraft that enable

- live testings to guarantee safety of flight in providing key information such as structural integrity, flight operational, propulsion data when aircraft is flying;
- performing diagnostics. Telemetry data are often the only source of diagnostic information to support accident investigation. But telemetry measures are also used in expanding tests sequences when validating aircraft performances.

- optimising productivity. Major test programs for new commercial aircraft, for example, are placing more and more emphasis on real-time availability and evaluation of data. Consistent with safety, the purpose is to accelerate test schedules, thereby reducing or at least controlling the huge, escalating costs of testing, and accelerating time-to-market.

The system operates in the C-band w-thin 5091-5250 MHz frequency band. It consists in few terrestrial stations that are usually deployed in Airport area and the communication is established between the ground and the aeronautical station to perform open-air test campaign. A ground monitoring centre is able to manage until 5 simultaneous connections but on different channels. . One ground station could only track one aircraft at a given time but alternatively, the ground station could stop tracking one aircraft and could switch to another one at a different location on a different channel. Several ground stations could track the same aircraft. The ground station is equipped with a mechanical tracking antenna (and not electronic tracking with phase array technology). Typical channel bandwidth is 8 MHz.

Telemetry signals are received by a high performance receiving station. Sensitive directional receiving antennas are required due to limitations on transmitted power and transmit antenna performance. State-of-the-art feed assemblies and low noise amplifiers are used to achieve the greatest possible performance. They acquire initial signal track prior to take-off and track the vehicle throughout each flight.

4.7.2 Spectrum Regulation

The existing allocations in the frequency band 5091-5150 MHz / 5150 MHz-5250 MHz are listed in following Table 79 according to RR Article 5 TABLE 1

Table 79: Frequency allocations in the frequency band 5091-5150 MHz / 5150-5250 MHz

Region 1	Region 2	Region 3
5091-5150 MHz	AERONAUTICAL RADIONAVIGATION AERONAUTICAL MOBILE 5.444B 5.367 5.444 5.444A	
5150 5250 MHz	AERONAUTICAL RADIONAVIGATION FIXED SATELLITE (Earth to space) 5.447A MOBILE except aeronautical mobile 5.446A 5.446B 5.446 5.446C 5.447 5.447B 5.447C	

WRC-07 allocated 5091-5150 MHz frequency band to the aeronautical mobile service (AMS) on a primary basis subject to No. 5.444B and 5150-5250 MHz frequency band to the AMS through footnote No. 5.446C which recognises an allocation to the aeronautical mobile service on a primary basis, limited to aeronautical telemetry transmissions from aircraft stations in accordance with Resolution 418 (Rev.WRC-19). (WRC-19).

4.7.3 Technical and operational performances and protection criteria

Table 80 provides the aeronautical mobile telemetry transmitting and receiving stations characteristics relevant for performing sharing analysis with other services in co-frequency noting that the system is operating one-way from the mobile station to the ground station.

Table 80: Aeronautical mobile telemetry characteristics

	Aeronautical mobile telemetry system
Transmitter (onboard aircraft)	
Frequency range (MHz)	5090-5150 MHz / 5150-5250 MHz
Channel bandwidth (MHz)	8

	Aeronautical mobile telemetry system
Modulation	Single Carrier-SOQPSK or COFDM-QPSK
Maximum transmit power (dBW)	13
Aircraft antennas location	One antenna on the bottom of the aircraft and another antenna on the top of the aircraft
Tx antenna gain (dBi)	0
Cable loss (dB)	2
Aircraft altitude (m)	0-15000
Aircraft deployment	Typical: 3 Aircraft in flight at the same time but not co-frequency and not simultaneously (each aircraft use different channels) Maximum: 4 Aircraft in flight at the same time but not co-frequency and not simultaneously (each aircraft use different channels)
Receiver (on ground)	
Antenna pattern	Mechanical steering parabolic antenna Recommendation ITU-R S.580
Receiver antenna gain (dBi)	40
Noise figure (dB)	9
Receiver bandwidth (MHz)	8
Antenna polarisation	Circular
Receiver altitude from ground level (m)	Between 6 and 40
Receiver antenna elevation range (degree)	Between −5 and 90 (99% of time the elevation is between −2° and 5°)

Figure 110 shows the antenna pattern to be used, in accordance with Recommendation ITU-R M.1459, for the purpose of computing interference to an AMT ground station.

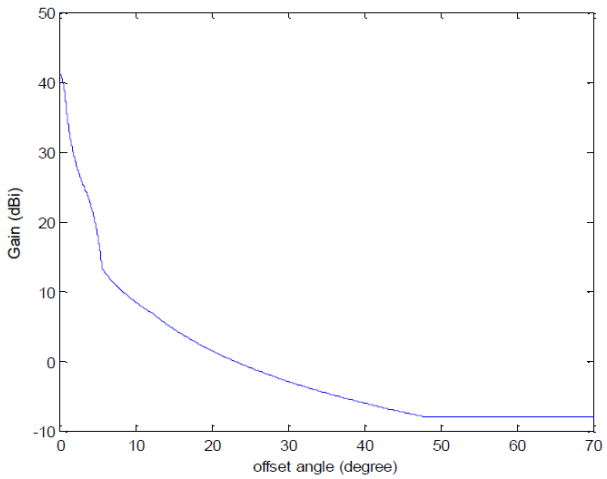


Figure 110: Aeronautical mobile telemetry receiver antenna pattern (Source: Recommendation ITU-R M.1459)

Recommendation ITU-R M.2122 [38] recommends that the aggregate interference protection criterion for ground AMT receiving stations of I/N of −6 dB should be used. Given the regulatory status of UWBs, a X dB apportionment margin(X>0 TBD) should be included in the criterion, resulting in I/N=-6-X dB.

The protection criterion for the aeronautical telemetry ground station is derived assuming the aircraft is at its maximum separation distance of 300 km.

4.7.4 Sharing studies between MWSSc and Telemetry system

4.7.4.1 Interference scenario

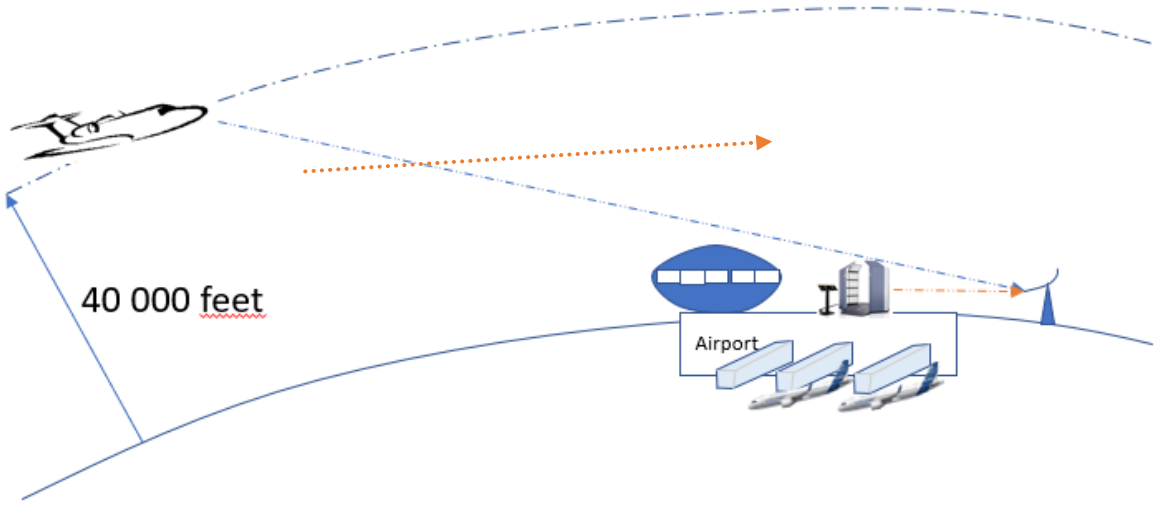


Figure 111: Typical interference scenario

The envisaged interference scenario considered the impact from MWSSc emission on the reception of signal from the Aircraft station at the ground station that is located at the limit of AMT network coverage (approx.. 300 km far away). This is considered as the worst-case situation where the useful signal from the AMT aircraft station is received with a very low level. As a first step, considering an MCL approach the minimum separation distance that should be observed between the AMT ground station and the MWSSc to satisfy the protection criteria that needs to be fulfilled to protect AMT operation will be evaluated through an MCL approach considering a single MWSSc equipment. Taking into consideration that one the prime envisaged scenario is the use of multiple scanners in Airports, a second step consist in evaluating the aggregated impact of those multiple equipment noting that AMT ground station are installed in Airport area.

4.7.4.2 Single entry MCL approach

The MCL calculation is performed for both indoor and outdoor operation of the scanners.

Considering that the basis is to consider the AMT aircraft station is located at limit of its service area, it is assumed that AMT ground station antenna elevation angle is supposed to be very low as it is directed to the aircraft station. As a consequence, for both situations, it is considered that AMT ground station is pointing directly to the MWSSc.

In order to consider a worst-case scenario, Clutter losses are not taken into account. Even if that doesn't reflect the full reality (e.g. excluding consideration on obstacle mask or additional infrastructure attenuation other than the agreed BEL), the principle relies on evaluating if there is the least risk of interference resulting in telemetry performance degradation.

Based on agreed hypothesis, the UWB MWSSc average power is considered to be taken with a value of -60 dBm/MHz and the correction factors that are included in Table 80 are taken into account:

Table 81: Correction factors applied

Correction factor	Value	Description
CF_GEO_V	-5.4 dB	Vertical geometrical correction factor
BEL	-16.5 dB	Building entry loss for the indoor scenario

As a result of the calculation taking into account the above correction factors, the MCL calculation will consider the following mean *e.i.r.p.*:

Preceived(dBm/MHz)= Mean *e.i.r.p.*(dBm/MHz)+ CF_GEO_V + BEL (indoor)

MCL budget link calculation to evaluate the minimum separation distance to be observed between telemetry ground station and a single MWSSc for different I/N values when UWB radiation is aligned with the max AMT gain antenna.

4.7.4.3 AMT characteristics and performances to be take into account in MCL calculations

Table 82: AMT characteristics (single entry)

Parameters	Values
AMT Receiver bandwidth	8 MHz
AMT Receiver Noise floor (Thermal noise in 8 MHz)	-104.97 dBm
AMT Noise figure	9 dB
AMT Receiver noise level	-95.97 dBm/8 MHz
	-105 dBm/MHz
AMT Antenna gain	40 dB
Interference threshold @antenna input (w/o consideration on protection criteria)	-145 dBm/MHz

Taking into account that the I/N of -6 dB is an aggregate interference protection criterion for ground AMT receiving stations that includes the contribution of all emission from different sources in the band, the X dB apportionment due to the only emission of the UWB MWSSc is represented on the graphic below.

When considering the apportionment factor to the overall interference acceptable for the aeronautical telemetry, a reasonable methodology consists in limiting the interference power from a single secondary service category to 10 % of the total acceptable interference. This approach considers a max 10 dB apportionment factor that leads to consider a max specific I/N of -16 dB to evaluate the compatibility between UWB MWSSc and telemetry systems.

Considering a X ranging from 0 to 10 dB, graphics below illustrate the minimum required separation distance depending on the I/N varying from -6 to -16 dB.

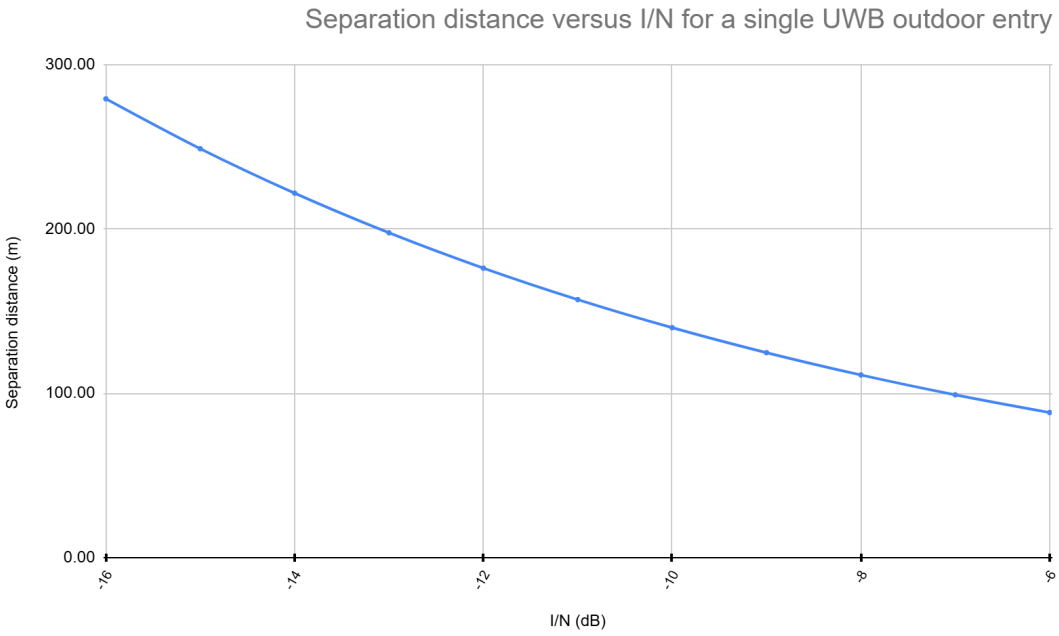


Figure 112: Separation distance (outdoor MWSSc)

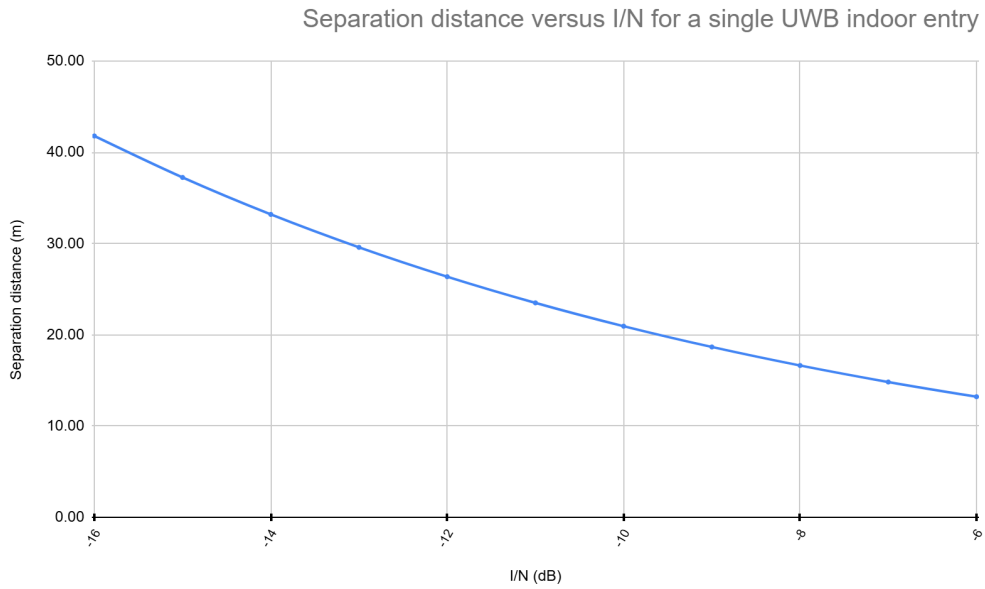


Figure 113: Separation distance (indoor MWSSc)

The equivalent I/N is ranging from -6 to -16 dB. This corresponds to a minimum separation distance with the telemetry ground station between 13 to 42 m for an indoor single UWB entry and from 88 to 279 m for an outdoor single UWB entry.

4.7.4.4 Aggregated impact

In order to evaluate the aggregated impact of UWB scanners on telemetry, ITU-R Recommendation on Telemetry system provide an aggregated interference criteria I/N of -6 dB. Considering the above apportionment leading to an I/N varying from -6 to -16 dB, the interference threshold at the antenna varies as follows:

Table 83: AMT characteristics (aggregation)

Parameters	Values
AMT Receiver bandwidth	8 MHz
AMT Receiver Noise floor	-104.97 dBm
AMT Noise figure	9 dB
AMT Receiver noise level	-95.97 dBm
	-105 dBm/MHz
AMT Protection criteria (I/N)	-6 to -16 dB
Max interference power @AMT receiver entry	-111 to -121 dBm/MHz
AMT Antenna gain	40 dB
Interference threshold at antenna	-151 to -161 dBm/MHz

This basic calculation focus on evaluating the impact simultaneously on the telemetry operation from multiple UWB MWSSc emitting simultaneously.

$P_{uwb-Total}(dB) = P_{uwb-Unit}(dB) + 10\log(n)$

- n being the number of considered scanner
- Puwb-Total being the total power spectral density from the all considered scanners
- Puwb-Unit being the power spectral density from the one single scanner

For I/N of -6 dB, the following results are obtained:

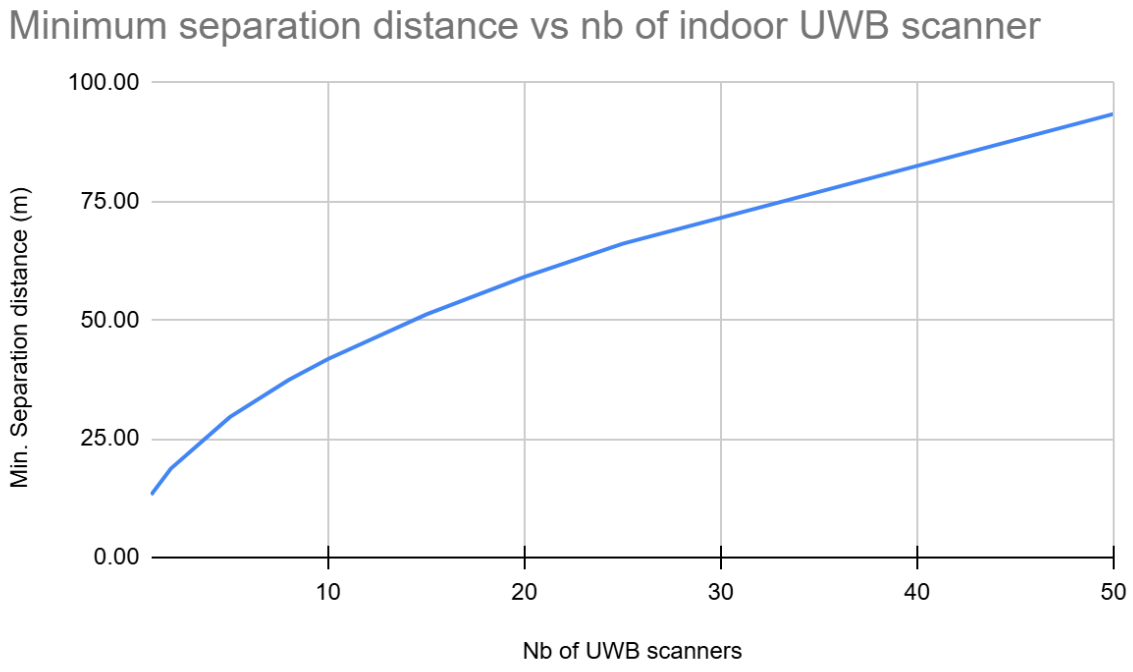


Figure 114: Separation distance (indoor aggregation, I/N=-6 dB)

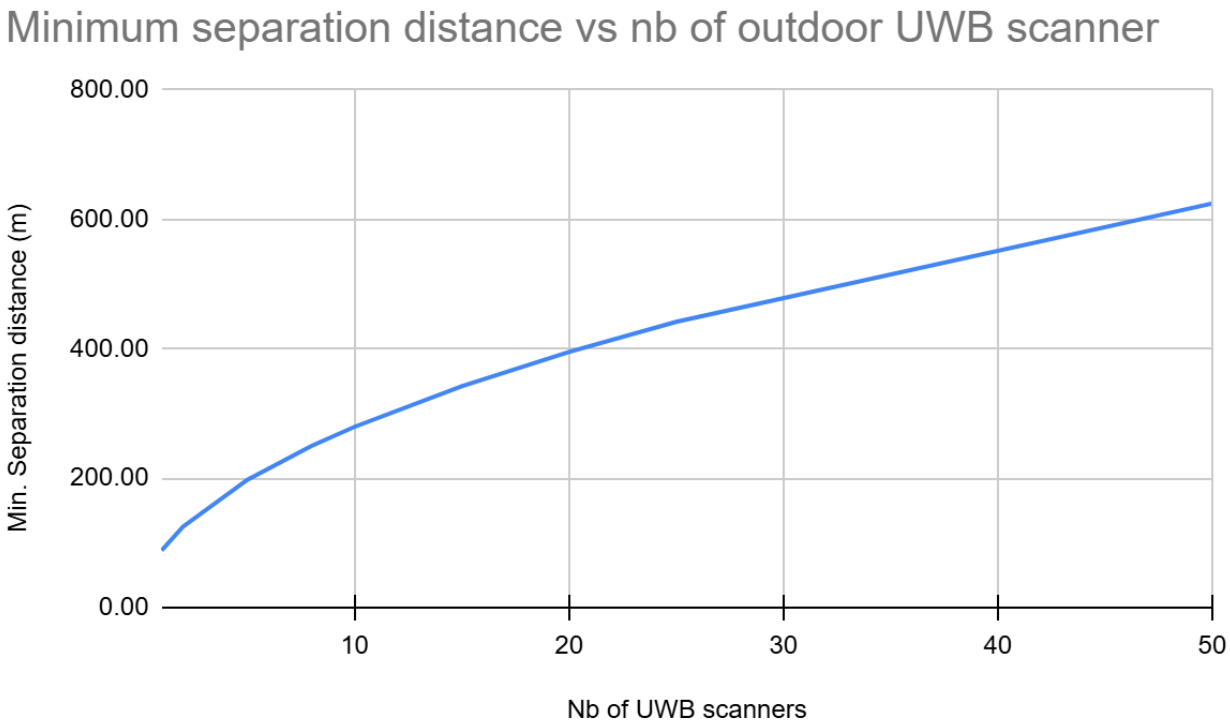


Figure 115: Separation distance (outdoor aggregation, I/N=-6 dB)

For I/N of -16 dB, the following results are obtained:

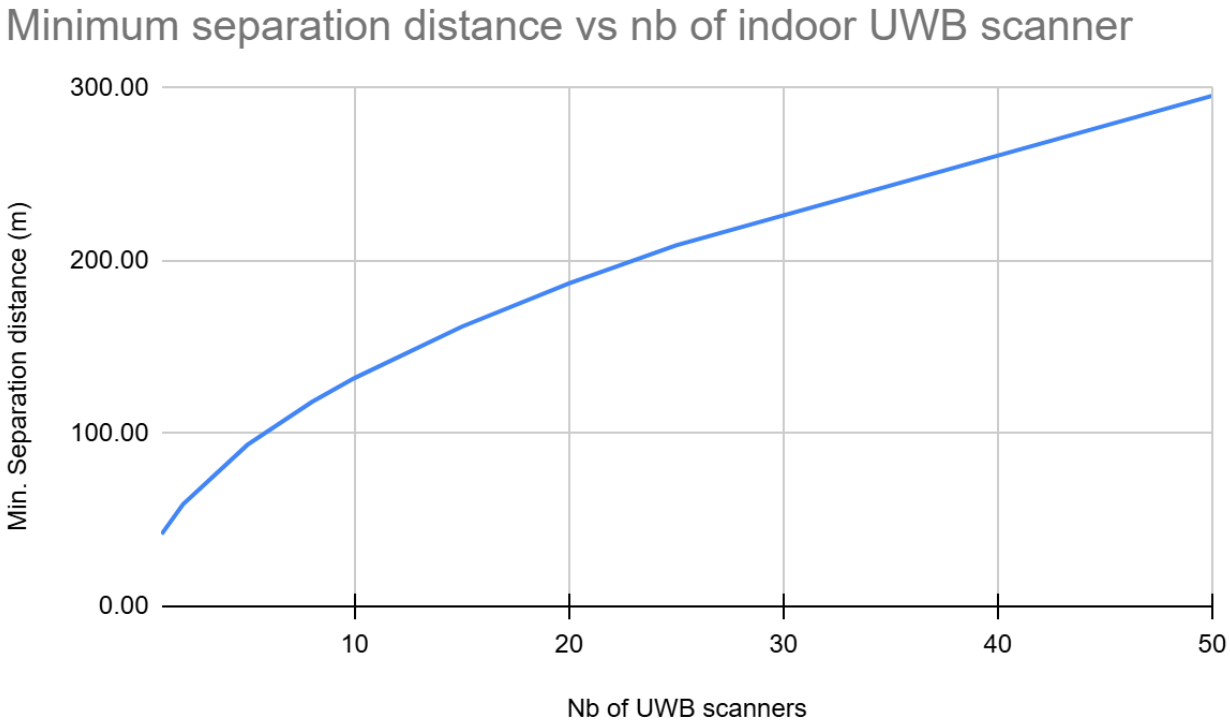


Figure 116: Separation distance (indoor aggregation, I/N=-16 dB)

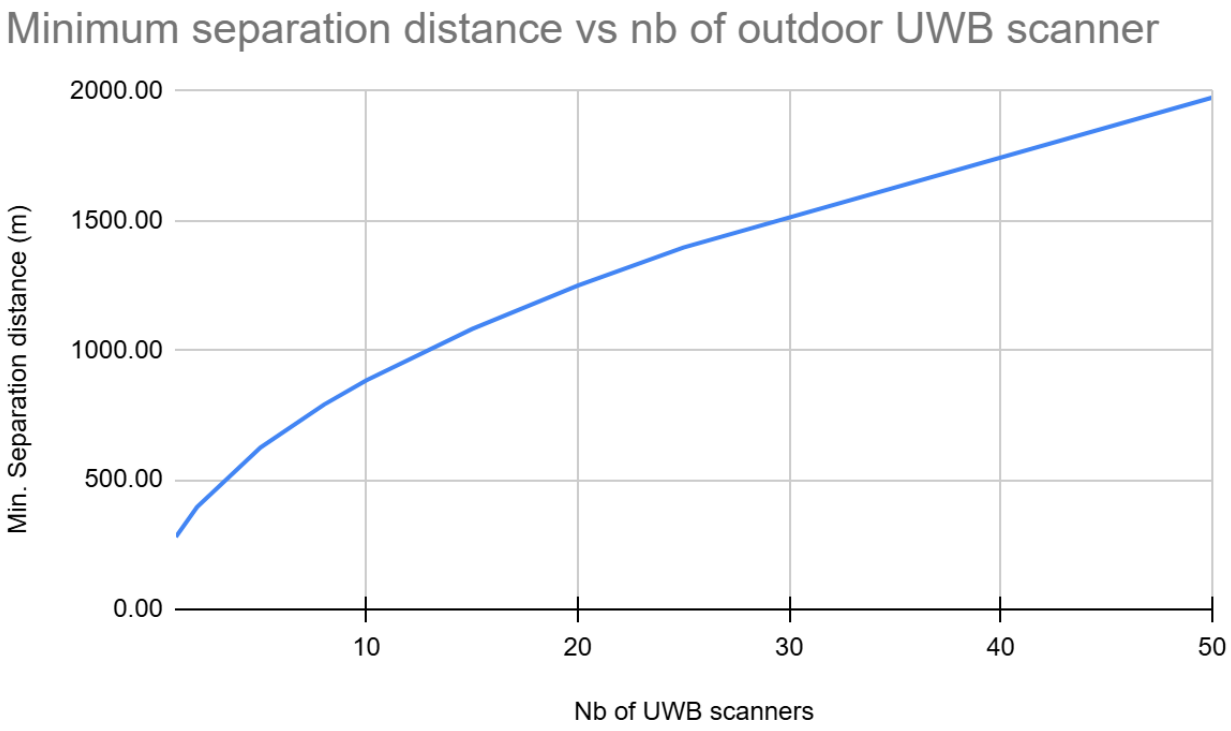


Figure 117: Separation distance (outdoor aggregation, I/N=-16 dB)

Taking into account a deployment scenario of 10 Scanners that represent a common deployment in Airport, the previous figures show that

- For a scanner indoor deployment, a minimum separation distance with the telemetry ground station between 42 to 132 m should be observed;
- For a scanner outdoor deployment, a minimum separation distance with the telemetry ground station between 279 and 883 m should be observed.

Those results reflect the possible impact from a simultaneous emission from the 10s UWB system. It is worth noting that UWB MWSSc operation are not synchronised and as a consequence 10 simultaneous emission can only occur when much more equipment are installed.

4.7.5 Conclusions

The analysis concludes on the possible risk of interference from scanner using a mean *e.i.r.p.* of -60 dBm/MHz mean *e.i.r.p.:*

- Single entry considerations : for an I/N value from -6 to -16 dB, a minimum separation distance with the telemetry ground station between 13 to 42 m for an indoor single UWB entry and from 88 to 279 m for an outdoor single UWB entry should be observed;
- As a result of the aggregated impact from 10 UWB MWSSc, for an I/N value from -6 to -16 dB, a minimum separation distance with the telemetry ground station between 42 to 132 m for indoor aggregate UWB scanners and from 279 and 883 m for an outdoor single UWB entry should be observed.

This study is only a pure mathematical RF analysis considering a non-cluttered environment to only provide some order of magnitude for the possible interference. This simple analysis assumes an unrealistic line-of-sight, main-beam aeronautical telemetry receiver based on its I/N criterion.

Further to this study, taking into account

- that the installation of ground telemetry stations are most of the case, not in immediate vicinity of any infrastructure and preferably around highest height above ground (30 m);
- that the low probability of any single device being in the telemetry antenna's main beam means that the aggregate contribution is from devices seen through lower-gain sidelobes and that 10° offset, gain drops from 40 dBi to ~10 dBi;
- building Entry Loss is the most powerful mitigator, as it applies to the path from every indoor UWB device, fundamentally limiting the total interference power that can reach the telemetry receiver.

It could be concluded that sharing is feasible.

5 COMPATIBILITY STUDIES BELOW 3.6 GHZ AND ABOVE 10.6 GHZ

5.1 EESS (PASSIVE) IN THE BAND 10.6-10.7 GHZ

5.1.1 Victim parameters

The technical characteristics of EESS (passive) sensors operating in the 10.6-10.7 GHz band are given in Recommendation ITU-R RS.1861-1, section 6.3 (Table 5). The elements required for assessing the compatibility between EESS(passive) and UWB devices are replicated below. The Copernicus Imaging Microwave Radiometer (CIMR), one of the Copernicus Expansion missions is captured as Sensor C8.

Table 84: EESS (passive) sensor characteristics in the 10.6-10.7 GHz frequency band

System Parameter	Sensor C1	Sensor C4	Sensor C5	Sensor C6
Sensor type	Conical scan	Conical scan	Conical scan	Conical scan
Altitude (km)	817	835	699.6	830
Maximum beam gain (dBi)	36	33,7	44.1	38.7
Polarisation	H, V	H, V	H, V	H, V
Instantaneous field of view (km)	56 × 30	82 × 196	42 × 24	56 × 133
Off-nadir pointing angle (degree)	44.3	53.3	47.5	53.3
Incidence angle at Earth (degree)	52	65	55	65
Sensor antenna pattern	Recommendation ITU R RS.1813	Recommendation ITU R RS.1813	Recommendation ITU R RS.1813	Recommendation ITU R RS.1813
Channel bandwidth	100 MHz	100 MHz centred at 10.65 GHz	100 MHz centred at 10.65 GHz	100 MHz centred at 10.65 GHz

Table 85: EESS (passive) sensor characteristics in the 10.6-10.7 GHz frequency band

System Parameters	Sensor C7	Sensor C8	Sensor C9	Sensor C10	Sensor C11
Sensor type	Conical scan	Conical scan	Conical scan	Conical scan	Conical scan
Altitude (km)	407	820	407	970	665.96
Maximum beam gain (dBi)	39.6	50.5	40.6	37	44.1
Polarisation	H, V	H, V	H/V	V, H	H, V

System Parameters	Sensor C7	Sensor C8	Sensor C9	Sensor C10	Sensor C11
Instantaneous field of view (km)	30 × 18	19 × 11	32.1 × 19.4	56 × 93	22 × 38
Off-nadir pointing angle (degree)	48.6°	46.5°	48.5°	44°	47.7°
Incidence angle at Earth (degree)	53°	55°	52.8°	53°	55°
Sensor antenna pattern	Recommendation ITU-R RS.1813		Recommendation ITU-R RS.1813	Recommendation ITU-R RS.1813	Recommendation ITU-R RS.1813
Channel bandwidth	100 MHz centred at 10.65 GHz	100 MHz centred at 10.65 GHz	100 MHz centred at 10.65 GHz	100 MHz	100 MHz centred at 10.65 GHz and 500 MHz centred at 10.25 GHz

Interference criteria applicable to EESS (passive) are given in Recommendation ITU-R RS.2017-0. For the band 10.6-10.7 GHz, it specifies an aggregate maximum interference level of -166 dBW/100 MHz not to be exceeded for more than 0.1% of the time or area.

Being aggregate, it needs to be apportioned and, consistently with previous analysis related to UWB applications with EESS (passive)(see Report ITU-R SM.2057), a 5% apportionment of the interference criteria is needed (i.e. 13 dB).

5.1.2 Initial calculations

On a general basis, it is possible to calculate the maximum emission level from interferers on the ground within the EESS (passive) sensor footprint. The same calculation applies to both WI76 and WI 79.

Table 86: Maximum emission level from interferers into EESS (passive) sensor footprints

System Parameter	Sensor C1	Sensor C4	Sensor C5	Sensor C6
Frequency (GHz)	10.65	10.65	10.65	10.65
Orbit altitude (km)	817	835	699.6	830
Nadir angle (°)	44.3	53.3	47.5	53.3
Slant path distance (km)	1222	1622	1114	1610
Free space losses (dB)	174.7	177.2	173.9	177.1
Elevation at ground (°)	38.0	24.9	35.1	25.0
Atmospheric losses (dB)	0.1	0.1	0.1	0.1
Antenna gain (dBi)	36	33.7	44.1	38.7
Protection criterion (dBW/100 MHz)	-166	-166	-166	-166
Apportionment (dB)	13	13	13	13
Max. interference at the ground (dBW/100 MHz)	-40.2	-35.4	-49.1	-40.5

System Parameter	Sensor C1	Sensor C4	Sensor C5	Sensor C6
Footprint area length (km)	56	196	42	133
Footprint area width (km)	30	82	24	56
Footprint area (km²)	1319	12623	792	5850

Table 87: Maximum emission level from interferers into EESS (passive) sensor footprints

System Parameter	Sensor C7	Sensor C8	Sensor C9	Sensor C10	Sensor C11
Frequency (GHz)	10.65	10.65	10.65	10.65	10.65
Orbit altitude (km)	407	820	407	970	665.96
Nadir angle (°)	48.6	46.5	48.5	44	47.7
Slant path distance (km)	643	1292	642	1462	1062
Free space losses (dB)	169.2	175.2	169.1	176.3	173.5
Elevation at ground (°)	37.1	35.0	37.2	36.8	35.2
Atmospheric losses (dB)	0.1	0.1	0.1	0.1	0.1
Antenna gain (dBi)	39.6	50.5	40.6	37	44.1
Protection criterion (dBW/100 MHz)	-166	-166	-166	-166	-166
Apportionment (dB)	13	13	13	13	13
Max. interference at the ground (dBW/100 MHz)	-49.4	-54.2	-50.4	-39.6	-49.5
Footprint area length (km)	30	19	32.1	56	22
Footprint area width (km)	18	11	19.4	93	38
Footprint area (km²)	424	164	489	4090	657

These calculations will then have to be used for aggregate interference from a population of interferer within the Footprint area.

As an example, for system C1, the aggregation of the whole density of Scanners within the 1319 km² footprint should not exceed -40.2 dBW/100 MHz, considered at ground. This value corresponds to -30.2 dBm/MHz within the 1319 km² and -51.4 dBm/MHz within 10 km² (approximately the area of an airport).

No harmful interference towards EESS (passive) is expected from unwanted emissions of indoor MWSSc operating at -41.3 dBm/MHz measured within 1 ms, considering the additional attenuation of a building.

No harmful interference towards EESS (passive) is expected from unwanted emissions of outdoor MWSSc operating at -60.0 dBm/MHz measured within 1 ms, considering the limited density of devices expected.

5.2 RADIO ASTRONOMY IN THE BAND 10.6-10.7 GHZ

In the 10.6-10.7 GHz band, the RAS has primary status, with the 10.68–10.7 GHz portion designated as a passive band under Radio Regulation Note 5.340. Furthermore, potential interference in the 10.68–10.7 GHz OOB range is expected to be lower than that observed in the in-band studies conducted for the 5 GHz and 6

GHz bands (see section 4.1). Therefore, no compatibility studies are carried out in the adjacent scenario between RAS and MWSSc.

6 CONCLUSIONS

6.1 SHARING WITH THE RAS

In terms of sharing with the Radio Astronomy Service, the results of single-entry generic studies indicate that outdoor MWSSc operating at mean *e.i.r.p.* of -60 dBm/MHz (average over 1 ms) requires a minimum separation distance of 13.8 km. For the indoor case, this reduces to 1.7 km. Site-specific studies for five RAS sites (Table 14 shows the results) indicate that those distances are ranging from 8.8 km to 13.4 km (outdoor) and 1.4 km to 1.7 km (indoor). No site-specific scenarios with different power spectral densities, rather than -60 dBm/MHz, are provided.

A generic site Monte Carlo simulation considering urban and suburban scenarios indicated that a minimum separation distance of 1 km is required if the mean spectral power is -60 dBm/MHz, increasing to 7.5 km when the mean spectral power is -41.3 dBm/MHz.

6.2 SHARING WITH THE AMATEUR AND AMATEUR SATELLITE SERVICE

MCL studies for indoor MWSSc at -50, -55 and -60 dBm/MHz indicate minimum risk of interference towards the AS. Separation distances are lower than 100 m and restricted to a small angle within the AS pointing direction. Clutter losses were not considered. This result indicates that sharing is possible due to a low probability of both services operating within the separation distance.

MCL studies for outdoor MWSSc at -60 and -55 dBm/MHz indicate a risk of interference towards the AS up to a separation distance of 100 m and 200 m, restricted to a small angle within the AS pointing direction. Clutter losses were not considered. Those results indicate that sharing is possible due to a low probability of both services operating within the separation distance.

MCL studies for outdoor MWSSc at -50 dBm/MHz indicate an increased risk of interference towards the AS up to a separation distance of 700 m under LOS conditions, restricted to a small angle within the AS pointing direction. Due to the relatively large separation distance no conclusion can be drawn for this scenario. Similar results are expected for the 10 GHz band, because the constant increase in free space loss (~5 dB) and the increase of the typical AS antenna gain (~6 dB) will cancel out each other. In addition, due to the higher antenna gain, the beam width becomes smaller which decreases the angle of the interference area in comparison with the 5 GHz results

6.3 SHARING WITH THE FIXED SERVICE

MCL studies for indoor MWSSc at -50, -55 and -60 dBm/MHz indicate no risk of interference towards the FS, even under LOS conditions.

MCL studies for indoor MWSSc at -41,3 dBm/MHz indicate a risk of interference towards FS receivers, exceeding the protection criterion by 1.1 dB. Interference could than happen between 1200 m and 2362 m distance from the FS and within a small angle of the FS pointing direction. For greater FS antenna heights above 55 m no risk of interference is expected.

MCL studies for outdoor MWSSc at -60 dBm/MHz indicate no risk of interference towards the FS, even under LOS conditions.

MCL studies for outdoor MWSSc at -50 and -55 dBm/MHz indicate a risk of interference towards FS receivers, exceeded the protection criterion by up to 9.1 dB. Interference could then happen up to 7.5 km distance from the FS and within a small angle of the FS pointing direction. For greater FS antenna heights above 55 m no risk of interference is expected. The calculated 250 m of possible interference for the cluttered scenario only occurs due to P.2108 being not applicable up to 250 m, which led to LOS conditions in the clutter scenario, which is not correct.

6.4 SHARING WITH THE EESS (ACTIVE)

This analysis focused on the outdoor scenario, which is the worst-case scenario. Both studies show that MWSSc are not expected to cause harmful interferences towards the EESS (active) satellites.

The single-entry study shows that one single MWSSc is not going to interfere the SAR satellite and the aggregate study shows that as long as the deployment density of this type of scanners does not exceed ~893 clusters/km2, the SAR satellites will most likely not be interfered by the MWSScs.

6.5 SHARING WITH RADARS AND MILITARY SYSTEMS

6.5.1 Study A - Weather Radars in the 9.3-9.5 GHz frequency band

Sharing studies between meteorological radar and Microwave Security Scanners (MWSSc) operating in 9300-9500 MHz have been undertaken for different scenarios involving radiolocation systems currently operating in France (Nice and Roissy Charles-de-Gaulle) with a cluster of MWSSc deployed indoor and outdoor. The aggregation factor generated by the cluster of MWSSc was limited to the 3 dB beamwidth of the radar receiver antenna and accounted the unsynchronised nature of those scanner by considering the average aggregation factor, resulting in 0 dB.

The results show that the coexistence between meteorological radar and MWSScs for outdoor deployment of MWSScs is feasible when max(mean(*e.i.r.p.*) =-65.4 dBm/MHz averaged over 1 ms for single-entry use case scenario and -68.4 dBm/MHz averaged over 1 ms for multi-entry use case scenario

The results show that the coexistence between meteorological radar and MWSScs for indoor deployment (entry loss of 17.5 dB assumed) of MWSScs is feasible when max(mean(*e.i.r.p.*) =-47.9 dBm/MHz averaged over 1 ms for single-entry use case scenario and -50.9 dBm/MHz averaged over 1 ms for multi-entry use case scenario.

It should be noted that these results were achieved assuming a specific geometry of the UWB device (MWSSc), resulting in around 5.4 dB gap between max(mean(*e.i.r.p.*)) averaged over 1 ms and max(mean(*e.i.r.p.*)) averaged over the signal repetition time corresponding to the burst of pulses for the same antenna with the highest magnitude (i.e. the antenna is in visibility of a receiver located outside the MWSSc). This gap illustrates the non-constant nature of the envelope of the MWSSc emissions level during the signal repetition time.

As indicated in ETSI EN 303 883 [1], the procedure to average the *e.i.r.p.* spectral density is described either for 1 ms (ETSI EN 303 883, section 5.3.2.4) or a for a shorter duration corresponding to the signal repetition time (ETSI EN 303 883, section 5.3.2.5).

If UWB device with a lower dynamic between max(mean(*e.i.r.p.*)) averaged over 1 ms and averaged over the signal repetition time with the highest magnitude than 5.4 dB is considered, under the max(mean(*e.i.r.p.*)) (averaged over 1 ms) conditions stated above (e.g. -65.4 dBm/MHz averaged over 1 ms for outdoor deployment of MWSSc in case of single-entry scenarios), the coexistence between meteorological radar and MWSSc is met. However, if the dynamic between max(mean(*e.i.r.p.*)) averaged over 1 ms and averaged over the signal repetition time with the highest magnitude exceeds 5.4 dB, the coexistence between meteorological radar and MWSScs is not met anymore.

Considering the agnostic nature of ECC Decision (06)04 [3] regarding the technology used for the design of any UWB device, technological neutrality is assumed, that's why it would be relevant to set the max(mean(*e.i.r.p.*)) condition for the signal repetition time with the highest magnitude to ensure all categories of UWB MWSScs protect the meteorological radars in 9300-9500 MHz. In such a case, coexistence between meteorological radar and MWSScs for outdoor deployment would be feasible when max(mean(*e.i.r.p.*))=-65.4+5.4=-60 dBm/MHz for single-entry and max(mean(*e.i.r.p.*))=-68.4+5.4=-63 dBm/MHz for multi-entry over the signal repetition time with highest magnitude level. For the indoor deployment would be feasible when max(mean(*e.i.r.p.*))=-47.9+5.4=-42.5 dBm/MHz for single-entry and max(mean(*e.i.r.p.*))=-50.9+5.4=-45.5 dBm/MHz for multi-entry over the signal repetition time with highest magnitude level.

6.5.2 Study B - Weather Radars (Monte Carlo)

Sharing studies for Meteo Radars in X-Band with the radar characteristics of study A (Table 34) have been undertaken in a single interferer scenario with a range of 1 km to 3 km and a dedicated scenario with 10 MWSSC in a cluster similar to the airport in Munich. Considering the 1.2 MHz IF Bandwidth thermal noise will be at -113.2 dBm. Including the noise figure of 2 dB the noise floor results at -111.2 dBm. According to the description in study A, an I/N of -10 dB is taken into account. This results in an iRSS unwanted value of -121.2 dBm which should not be exceeded.

In the 10 MWSSC Scenario the radar will observe -145 dBm iRSS and in the single MWSSC scenario in a range from 1 to 3 km the radar will observe -151 dBm at the 2% value. Both values do not exceed the - 121.2 dBm and show a margin of 23.8 to 29.9 dB.

6.5.3 Study C - Weather Radars

Maximum permissible radiation mean *e.i.r.p.* spectral density for MWSSc to protect meteorological C-band radars are shown in Table 46.

Maximum permissible radiation mean *e.i.r.p.* spectral density for MWSSc to protect meteorological X-Band radars are shown in Table 47.

6.5.4 Study D - Weather Radars (Measurement)

The data from this measurement campaign was analysed and extrapolated to assess the potential compatibility between MWSSc and meteorological radars operating in the C-band frequency range.

An estimation of the minimum separation distance was derived from clutter-corrected datasets. To represent a relatively sensitive radar configuration, the 0.8 µs pulse width operationally used by DWD was selected for evaluation. It is important to note that some meteorological services operate with longer pulse widths (e.g. 2 µs), which increases receiver sensitivity by approximately 4 dB. This must be considered when interpreting the results, as such systems may be more susceptible to interference.

Indoor use is generally less problematic. At the highest considered power spectral density (PSD) of −41.3 dBm/MHz interference cannot be completely ruled out in worst-case scenarios.

For the outdoor case, more care is required. DWD defines a radar safety zone of 300 m without obstruction, typically free of buildings. Under these conditions, a PSD of −60 dBm/MHz or lower appears to be a reasonable limit for outdoor use without causing interference.

These results are limited to line-of-sight (LOS) scenarios, which represent a conservative, worst-case setup. Aggregation effects from multiple simultaneous interferers were not considered.

It is critical to emphasise that the results are based on measurements from a single C-band weather radar operating at 5640 MHz, and may not be representative of other radar systems. Radar-specific characteristics—such as antenna gain, receiver noise figure, and signal processing—can significantly affect interference susceptibility. Other radars may be either more or less robust under similar conditions.

Additionally, the study considers only a single interfering source. In real-world deployments, multiple devices could emit simultaneously, potentially resulting in constructive aggregation and significantly higher interference power at the radar receiver.

No additional I/N margin was applied in this study. As such, even small changes in environmental or system parameters could lead to interference. Therefore, to ensure robust compatibility, applying a protection criterion, as suggested in Recommendation ITU-R M.1849-3, is recommended and should be a feasible and prudent guideline.

6.5.5 Study E - Military systems in the 4.4-4.99 GHz, 5.25-5.85 GHz and 8.5-10.5 GHz frequency bands

Considering the agnostic nature of ECC Decision (06)04 [3] regarding the technology used for the design of any UWB device, technological neutrality is assumed, that's why it would be relevant to set the max(mean(*e.i.r.p.*)) condition for the signal repetition time with the highest magnitude to ensure all categories of UWB MWSSc protect the military systems. In such a case, coexistence between outdoor MWSSc and military aeronautical mobile systems operating in 4400-4990 MHz, ground military radars operating in 5250 - 5850 MHz and ground military radars operating in 8500-10500 MHz would be feasible when max(mean(*e.i.r.p.*))=-60+5.4=-54.6 dBm/MHz averaged over the signal repetition time with highest magnitude level. This would correspond to mean(*e.i.r.p.*)=-60 dBm/MHz averaged over 1 ms. Coexistence between indoor MWSSc and military aeronautical mobile systems operating in 4400-4990 MHz, ground military radars operating in 5250-5850 MHz and ground military radars operating in 8500-10500 MHz would be feasible when max(mean(*e.i.r.p.*))=-41.3+5.4-12.9=-48.8 dBm/MHz averaged over the signal repetition time with highest magnitude level. This would correspond to mean(*e.i.r.p.*)= -54.2 dBm/MHz averaged over 1 ms.

6.6 SHARING WITH THE AERONAUTICAL SERVICE

This section computes the maximum *e.i.r.p.* limits of MWSSc in order to protect safety systems used by civil aviation, for indoor and outdoor MWSSc.

The MCL studies assume the MWSSc design as specified in ETSI TR 103 730 [2]. For this scanner design, it founds that the MWSSc *e.i.r.p.* averaged over 1 ms must not exceed:

- For the protection of Radio Altimeters: -42.8 dBm/MHz for indoor MWSSc and -58.8 dBm/MHz for outdoor MWSSc. These limits are valid provided that the MWSSc emission upward are limited as follow;
- For indoor MWSSc: -46.4 dBm/MHz @ 30°, -55.9 dBm/MHz @ 60°, -59.9 dBm/MHz @ 90°, where 90° is at the zenith;
- For outdoor MWSSc: -62.4 dBm/MHz @ 30°, -71.9 dBm/MHz @ 60°, -75.9 dBm/MHz @ 90°, where 90° is at the zenith;
- For the protection of C-band on-board weather radar: -51.6 dBm/MHz for indoor MWSSc, -64.2 dBm/MHz for outdoor MWSSc;
- For the protection of X-band on-board weather radar: -50.2 dBm/MHz for indoor MWSSc, -63.8 dBm/MHz for outdoor MWSSc;
- For the protection of ASDE radars: -54.7 dBm/MHz for indoor MWSSc, -71.7 dBm/MHz for outdoor MWSSc;
- For other aviation systems in the band 3.6-10.6 GHz: -41.3 dBm/MHz for indoor MWSSc, -58.3 dBm/MHz for outdoor MWSSc.

In case the MWSSc design differ from the one specified in ETSI TR 103 730, MWSSc deployment may require additional precautions to ensure that aeronautical systems remain free from harmful interference.

Any relaxation of the MWSSc *e.i.r.p.* power limits for indoor MWSSc can only be done by ensuring that sufficient attenuation protect incumbent services. Measures allowing additional attenuation include

a) Orientation of the MWSSc such that the radiating antennas of MWSSc are not visible from affected receiver.

b) Use of building material with better building entry losses compared to traditional buildings as characterised in Recommendation ITU-R P.2109 [9].

c) Increase of separation distance between MWSSc and the possible location of victim receivers.

One measurement for a specific airport ASDE radar in Munich, given in ANNEX indicated no visual target at the radar, although these results cannot be generalised.

6.7 SHARING WITH AERONAUTICAL TELEMETRY

The analysis concludes on the possible risk of interference from scanner using a mean *e.i.r.p.* of -60 dBm/MHz mean *e.i.r.p.*:

- Single entry considerations : for an I/N value from -6 to -16 dB, a minimum separation distance with the telemetry ground station between 13 to 42 m for an indoor single UWB entry and from 88 to 279 m for an outdoor single UWB entry should be observed;
- As a result of the aggregated impact from 10 UWB MWSSc, for an I/N value from -6 to -16 dB, a minimum separation distance with the telemetry ground station between 42 to 132 m for indoor aggregate UWB scanners and from 279 and 883 m for an outdoor single UWB entry should be observed.

This study is only a pure mathematical RF analysis considering a non-cluttered environment to only provide some order of magnitude for the possible interference. This simple analysis assumes an unrealistic line-of-sight, main-beam aeronautical telemetry receiver based on its I/N criterion.

Further to this study, taking into account:

- that the installation of ground telemetry stations are most of the case, not in immediate vicinity of any infrastructure and preferably around highest height above ground (30 m);
- that the low probability of any single device being in the telemetry antenna's main beam means that the aggregate contribution is from devices seen through lower-gain sidelobes and that 10° offset, gain drops from 40 dBi to ~10 dBi;
- building Entry Loss is the most powerful mitigator, as it applies to the path from every indoor UWB device, fundamentally limiting the total interference power that can reach the telemetry receiver.

It could be concluded that sharing is feasible.

6.8 COMPATIBILITY WITH THE EESS (PASSIVE) ABOVE 10.6 GHZ

As an example, for system C1, the aggregation of the whole density of Scanners within the 1319 km² footprint should not exceed -40.2 dBW/100 MHz, considered at ground. This value corresponds to -30.2 dBm/MHz within the 1319 km² and -51.4 dBm/MHz within 10 km² (approximately the area of an airport).

No harmful interference towards EESS (passive) is expected from unwanted emissions of indoor MWSSc operating at -41.3 dBm/MHz measured within 1 ms, considering the additional attenuation of a building.

No harmful interference towards EESS (passive) is expected from unwanted emissions of outdoor MWSSc operating at -60.0 dBm/MHz measured within 1 ms, considering the limited density of devices expected.

6.9 COMPATIBILITY WITH THE RAS ABOVE 10.6 GHZ

Potential interference in the 10.68–10.7 GHz OOB range is expected to be lower than that observed in the in-band studies conducted for the 5 GHz and 6 GHz bands (see section 4.1.1). Therefore, no compatibility studies are carried out in the adjacent scenario between RAS and MWSSc.

ANNEX 1: EXISTING ECC REPORTS

Microwave Security Scanners are intended to operate in the 3.6-10.6 GHz band. This envisaged frequency range has been studied for similar systems and services in the past.

A condensed (but not limited to) list of ECC reports that are technically close to the studies in WI76 is shown below and shall be considered in the study.

Table 88: List of ECC Reports that are technically close to the studies in WI76

Date of issue	Report number	Title/description of the ECC Reports
2021-10-01	ECC Report 327	Technical studies for the update of the Ultra Wide Band (UWB) regulatory framework in the band 6.0 GHz to 8.5 GHz
2018-04-27	ECC Report 278	Specific UWB applications in the bands 3.4-4.8 GHz and 6.0-8.5 GHz: Location tracking and sensor applications (LTA) for vehicular access systems
2016-04-29	ECC Report 251	The impact of UWB applications on board aircraft in the band 6-8.5 GHz on FS links used around airports and on EESS earth stations
2015-05-08	ECC Report 234	Analyses of LDC UWB mitigation techniques with respect to incumbent radiocommunication services within the band 3.1 to 3.4 GHz
2012-04-11	ECC Report 175	Co-existence study considering UWB applications inside aircraft and existing radio services in the frequency bands from 3.1 GHz to 4.8 GHz and from 6.0 GHz to 8.5 GHz
2011-10-31	ECC Report 170	Specific UWB applications in the bands 3.4 - 4.8 GHz and 6 - 8.5 GHz Location Tracking Applications for Emergency Services (LAES), location tracking applications type 2 (LT2) and location tracking and sensor applications for automotive and transportation environments (LTA)
2008-07-10	ECC Report 120	Technical requirements for UWB DAA (Detect and Avoid) devices to ensure the protection of radiolocation services in the bands 3.1 - 3.4 GHz and 8.5 - 9 GHz and BWA terminals in the band 3.4 - 4.2 GHz
2006-12-14	ECC Report 094	Technical requirements for UWB LDC devices to ensure the protection of FWA systems
2005-02-25	ECC Report 064	The protection requirements of radiocommunications systems below 10.6 GHz from generic UWB applications
2022-10-07	ECC Report 346	Technical studies on sharing between weather radars in part of 5365-5470 MHz and EESS (active)
2022-05-23	ECC Report 340	Receiver selectivity performance of satellite Earth stations in the band 3800-4200 MHz
2021-11-05	ECC Report 331	Efficient usage of the spectrum at the border of CEPT countries between TDD MFCN in the frequency band 3400-3800 MHz
2019-05-29	ECC Report 302	Sharing and compatibility studies related to Wireless Access Systems including Radio Local Area Networks (WAS/RLAN) in the frequency band 5925-6425 MHz
2018-01-26	ECC Report 272	Earth Stations operating in the frequency bands 4-8 GHz, 12-18 GHz and 18-40 GHz in the vicinity of aircraft
2017-01-27	ECC Report 259	Sharing and compatibility studies between MBR in the 5850-5900 MHz frequency band and other systems

ANNEX 2: RELATION BETWEEN PEAK AND AVERAGE PSD FOR DIFFERENT UWB PRF

Based on ECC Decision (06)04 [3], two distinct limits for UWB emission are specified in order to ensure coexistence between incumbent services/applications and UWB applications. These two limits namely the average spectral power and the spectral peak power received in a specific bandwidth compatibility studies dealing with UWB systems, In this report, the spectral peak power received within a bandwidth of 50 MHz is provided as an input parameter and the average spectral power is to be derived from it.

As described in this Report, UWB signal radiated by the MWSSc consists of several pulse packets, with 1/12 MHz Pulse Repetition Interval, resulting in a of 1.25 µs duration for the burst of 15 pulses. The pulses are not modulated. Each antenna built into the MWSSc transmits exactly one pulse packet one after the other. Figure 118 shows pulse packet of 15 pulses described above.

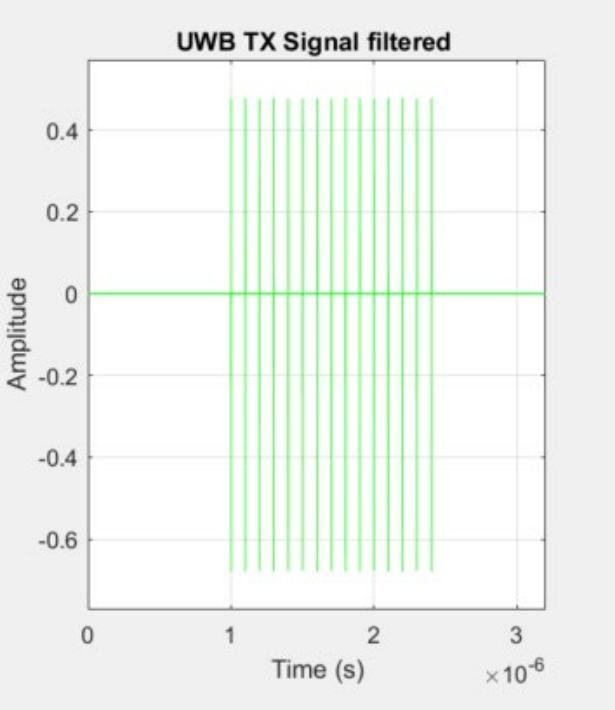


Figure 118: UWB Pulse shape filter response of 15 pulses

An infinitely long sequence of Dirac pulses has an infinitely wide frequency spectrum consisting of an infinite number of Dirac pulses. It is assumed that in the time domain, the pulses are emitted regularly at identical time intervals, which are determined by the so-called pulse repetition frequency PRF. Such UWB signal are called non-dithered signal from Recommendation ITU-R SM.1757 [21] (see section 2.4.2). The Dirac pulses in the frequency domain are then separated by the PRF. The Dirac pulses in the frequency domain can be understood as harmonic components of the fundamental wave with a frequency of PRF and contribute to the total average power of the UWB signal. Technical justification of UWB signal properties are provided below.

Due to the band-limiting of a UWB signal, in this case the MWSSC operates within a 3 dB bandwidth of 3.6 - 10.6 GHz, resulting in achieving a finite number of harmonic components in the frequency domain. Their number can be approximated as follows:

$$N_{UWB} = \frac{BW_{UWB}}{PRF_{UWB}} \quad (24)$$

where:

- N_{UWB}: Number of harmonic components in the frequency domain;
- BW_{UWB}: Bandwidth of the UWB signal, in this case 7 GHz;
- PRF_{UWB}: Pulse repetition frequency of the UWB signal.

It is important to note that all harmonic components have almost identical amplitude within the 3 dB of UWB bandwidth and thus also an almost identical power.

To obtain the mean *e.i.r.p.* from the peak *e.i.r.p.* different factors need to be taken into account. Compared to many other radio signals, the MWSSc signal has some particular interference characteristics. Because this UWB signal is periodic, the spectrum of the MWSSc signal within its 3 dB bandwidth contains harmonic components and because this UWB signal is not modulated, these components are of the same magnitude. The frequency separation between the harmonic spectral components corresponds to the Pulse Repetition Frequency (PRF) of the MWSSc UWB signal, which is 12 MHz.

Victim systems can be interfered by the UWB signal with greatly varying intensity depending on their operating central frequency $f_{c\,Rx}$ and their receiver bandwidth. Figure 119aims to capture different interference scenarios in the spectral domain. The blue curve from Figure 119 depicts the normalised power spectrum of a radiated MWSSc pulse packet transmitter, while the red curves represent the frequency response of two different receiver filters at different $f_{c\,Rx}$:

- one over narrow bandwidth 2 MHz at $f_{c\,Rx}$ matching one harmonic component of the UWB spectrum (Case 1);
- one over narrow bandwidth 2 MHz at $f_{c\,Rx}$ not matching any harmonic component of the UWB spectrum (Case 2);
- one over a larger bandwidth 50 MHz (Case 3).

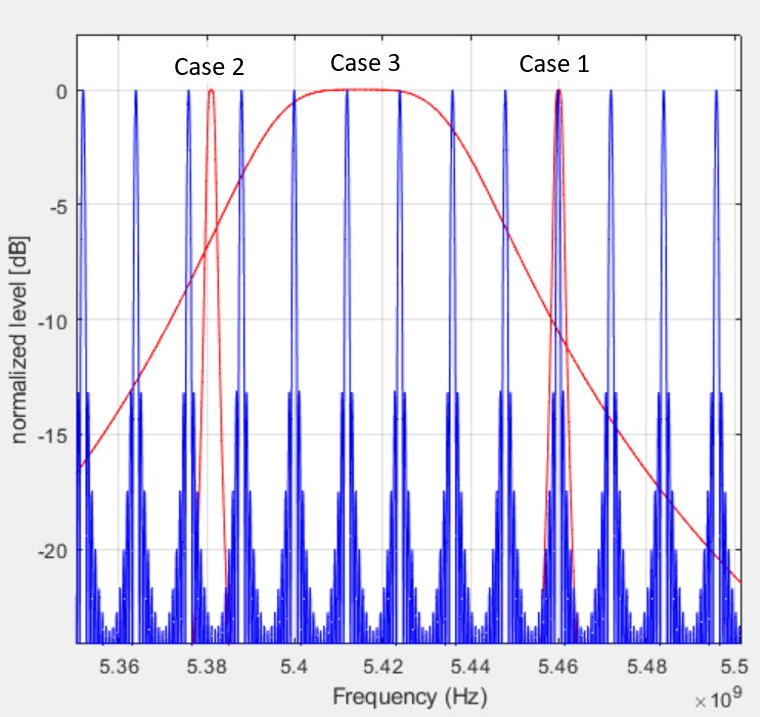


Figure 119: Example cases two victim receiver selectivity (red curves) operating with 2 MHz bandwidth and a victim receiver selectivity operating with 50 MHz bandwidth in the presence of a radiated MWSSc pulse packet (blue signal) of PRF equal to 12 MHz

As can be seen from Figure 120, both the tuning frequency of the victim receiver and its bandwidth determine the interference potential of the UWB signal in a particular way:

If the victim receiver is operating with a bandwidth that is narrower than the PRF (Case 1 and Case 2), the victim receiver experiences a large amount of interference when tuned to a central frequency that coincides with the frequency of a harmonic component of the UWB signal (Case 1). If the victim receiver is tuned to a central frequency that does not coincide with a harmonic component of the UWB signal (Case 2), the victim receiver will only be disturbed to a small extent.

if the victim receiver has a bandwidth that is significantly larger than the PRF of the MWSSc signal (Case 3), then the interference intensity of the UWB signal for this receiver is independent of its operating frequency as it will always contain around the same number of spectral lines power component contributing to the interference power. It should be noted, that in this case the interference power cannot be calculated in a common manner by integrating the interference power density over the victim receiver bandwidth.

Aside from those variations of UWB interference power, it's interesting to compare peak and average power values. It can be shown that in the former case, where the receiver bandwidth is significantly smaller than the UWB PRF, the peak and average values of the interference power in the receiver are identical. In that case, the interference power is also independent on the receiver bandwidth. For the latter case, where receivers with a wider bandwidth are interfered, the value of the peak interference power is always greater than the average interference power and the interference power depends on the receiver bandwidth as it will overlap with a number of UWB spectral lines.

However, in the following studies, the cases where the victim receiver do not operate at the same frequency as a UWB signal harmonic are not considered.

All of the above-described issues are addressed by the calculation methodology for peak and average interference power shown in Recommendation ITU-R SM.1757 [21] for non-dithered UWB signals. Following this methodology, the spectral energy density of a single UWB pulse Ep can be calculated as a baseline for the derivation of the average power measured within a given bandwidth. To calculate the spectral energy density based on the peak power measured within 50 MHz bandwidth, the second equation from page 85 of Recommendation ITU-R SM.1757 should be used, because the bandwidth related to the peak power (50 MHz) is larger than the PRF (12 MHz). It can be assumed, that the peak power of -15 dBm measured within a 50 MHz bandwidth is constant in the frequency range 3.6-9.6 GHz (3.6-10.6 GHz). The equation mentioned above is given below.

$$P_P(B_M) = 5.254\, E_P(B_M)^2 \tag{25}$$

Based on that calculation the spectral energy density is calculated as shown below

$$E_P = \frac{P_P(B_M)}{5.254\ (B_M)^2} = \frac{10^{\frac{-15dBm-30dB}{10}}}{5.254\ \ (\,50.10^6\ Hz)\ ^2} = 2.408\ 10^{-21}\frac{J}{Hz} \tag{26}$$

For the case of victim receivers operating with a bandwidth smaller than the PRF, the average power within this bandwidth is calculated as follows

$$P_A(B_M) = \ E_P(PRF)^2 = \text{-34.6 dBm} \tag{27}$$

As already noted above, if the receiver bandwidth is much smaller than the PRF of the UWB signal, the peak and average powers are independent of the bandwidth. This comes from the fact, that for the condition BRX< PRF only a single "spectral line" or harmonic component within the receiver bandwidth is received and that any bandwidth variation of BRX within a range of BRX<PRF does not change the number of harmonic components within the bandwidth. Of course that behaviour can only be observed, as long as the Victim receiver is tuned to a frequency equal to a frequency of a harmonic component of the UWB signal +/- BRX/2 For the sake of completeness, a graphical representation shows the dependency of the peak and average power density on the receiver bandwidth when applying the methodology of Recommendation ITU-R SM.1757 [21].

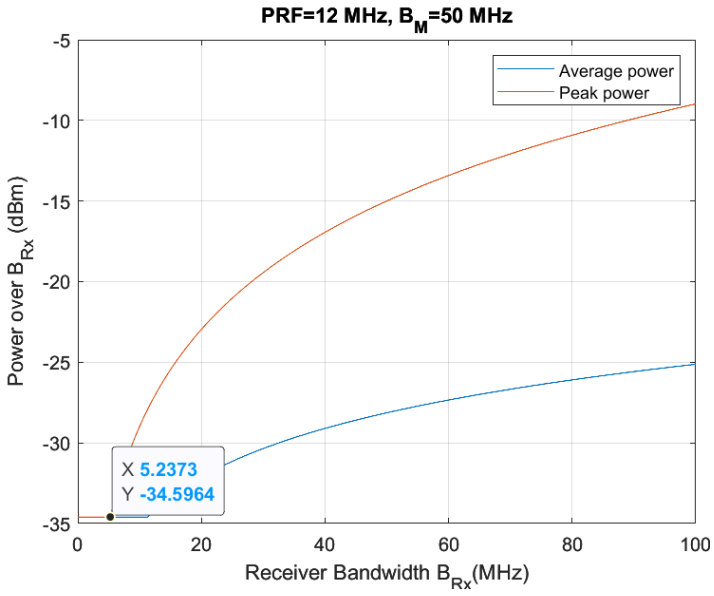


Figure 120: Average and peak powers when receiving the UWB MWSSc signal

Average and peak power calculation from ECC Report 64

When the victim receiver has an IF bandwidth (BIF) different from the reference measurement bandwidth of the *e.i.r.p.* of the UWB transmitter (BREF), a bandwidth correction factor (BWCF) could also be considered to normalise the average (rms) power level in a 1 MHz bandwidth, and to provide a correction for the UWB signal average (rms) power level (BWCFA) or peak power level (BWCFP) at the victim receiver IF output in dB. This approach was considered in ECC Report 64 [27] to assess interference from a single UWB emitter (see ECC Report 64, section 6.3.3.2). It was assumed that UWB transmitter emissions are uniform across the victim receiver bandwidth.

BWCFA/P for non-dithered UWB signals

For non-dithered UWB emissions, the BWCF for average power, BWCFA, in dB, is given by the following expressions, where PRF≥10 kHz:

BWCFA = 0, for BRX ≤ PRF and BREF < PRF;

BWCFA = 10 log (PRF/BREF), for BRX ≤ PRF and BREF ≥ PRF;

BWCFA = 10 log (BRX/PRF), for PRF ≤ BRX and BREF < PRF;

BWCFA = 10 log (BRX /BREF), for PRF ≤ BRX and BREF ≥ PRF.

For non-dithered UWB emissions, the BWCF for peak power, BWCFP, in dB, is given by the following expressions:

BWCFP = 0, for BRX ≤ 0.45 PRF and BREF < PRF;

BWCFP = 10 log (PRF/BREF), for BRX ≤ 0.45 PRF and BREF ≥ PRF;

BWCFP = 20 log [BRX/(0.45 PRF)], for 0.45 PRF ≤ BRX and BREF < PRF;

BWCFP = 10 log [(BRX)2/(0.2 PRF BREF)], for 0.45 PRF ≤ BRX and BREF ≥ PRF.

It should be noted that in any case, these formulae are defined with respect to an average power at the reference bandwidth $P_A(B_{ref})$.

When assuming an average power of –34.8 dBm within a reference bandwidth of 1 MHz, a PRF of 12 MHz and applying the bandwidth correction factor according ECC Report 64 [27], then receiver bandwidth dependent peak and average power levels are calculated as shown in Figure 121.

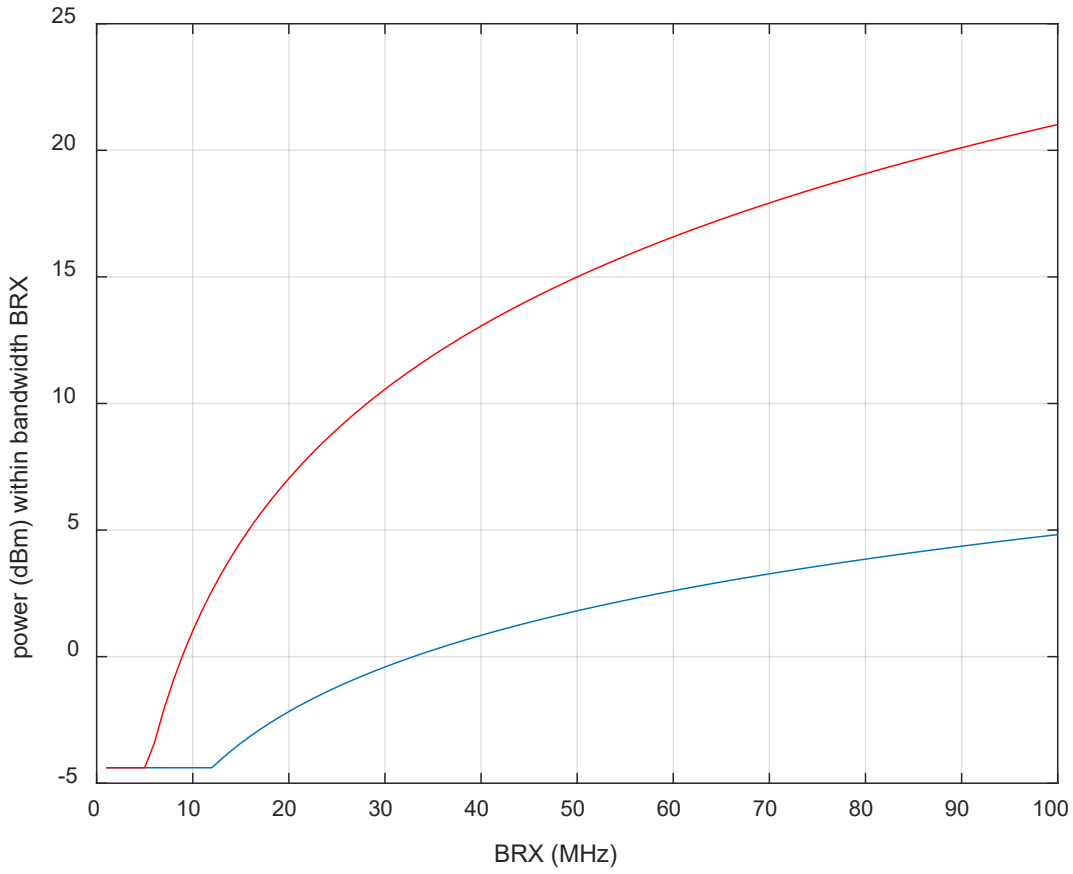


Figure 121: Peak power (red line) and average power (blue line) within Bandwidth BRX for PRF = 12 MHz and peak power = -15 dBm, respectively average power of -28.4 dBm within a bandwidth of 50 MHz

When comparing the results calculated based on ECC Report 64 [27], a good agreement to calculation results based on the approach of Recommendation ITU-R SM.1757 [21] can be concluded, confirming that this method has been already used in CEPT for some studies in previous WIs dealing with UWB emissions.

A more detailed view on UWB signal as interference

When carrying out compatibility studies between UWB MWSSc and other services for WI76, either Peak or Average Power at the victim receiver can be used as input parameter. Depending on which one is selected, the methodology described in previous sections should be followed:

If Peak power is taken as input parameter (this Report assumes -15 dBm/50 MHz), any calculus of average power spectral density at the receiver should be derived based on the approach presented in this input contribution i.e. from Recommendation ITU-R SM.1757 and used in some studies from ECC Report 64 [27]. This approach accounts the non-linear specificities of the UWB signal with respect to the dynamic of peak/average power as a function of the receiver bandwidth while the calculation method currently defined in the working document does not.

If the average power radiated from the MWSSc (averaged over time window of the victim receiver) is taken as input parameter, the interference calculation follows a generic approach (radio link budget with consideration of propagation loss and any antenna gain at the receiver) not considering any formula from Recommendation ITU-R SM.1757 [21].

Overview of UWB signal in time and frequency domains

What is a burst of pulses?

A pulse is a short-time signal whose pattern is output by a pulse shaping filter: rectangular, sinusoidal, sinc… When pulses are emitted at fixed time intervals, the resulting signal is called non-dithered. Π is the pattern of the pulse. The burst of pulses of non-dithered signal is featured with constant Pulse Repetition Interval (PRI) = T, and a length of the burst signal T_{Burst} as follows:

$$s(t) = \Pi(\mathrm{t}) * \sum_{k=1}^{\infty} \delta(t - kT) \times rect\left(\frac{t}{T_{Burst}}\right) \quad (28)$$

where:

- $rect\left(\frac{t}{T_{Burst}}\right) = 1\ if\ |t| < \frac{T_{Burst}}{2}, 0\ otherwise.$

i.e. this periodic signal s is built by duplication of the pattern of the pulse Π at regular (time) interval T.

Figure 122 illustrates the burst of rectangular (left side figure) and sinc pulses (right side figure) in the time domain for different values of pulse characteristic (PRI and amplitude).

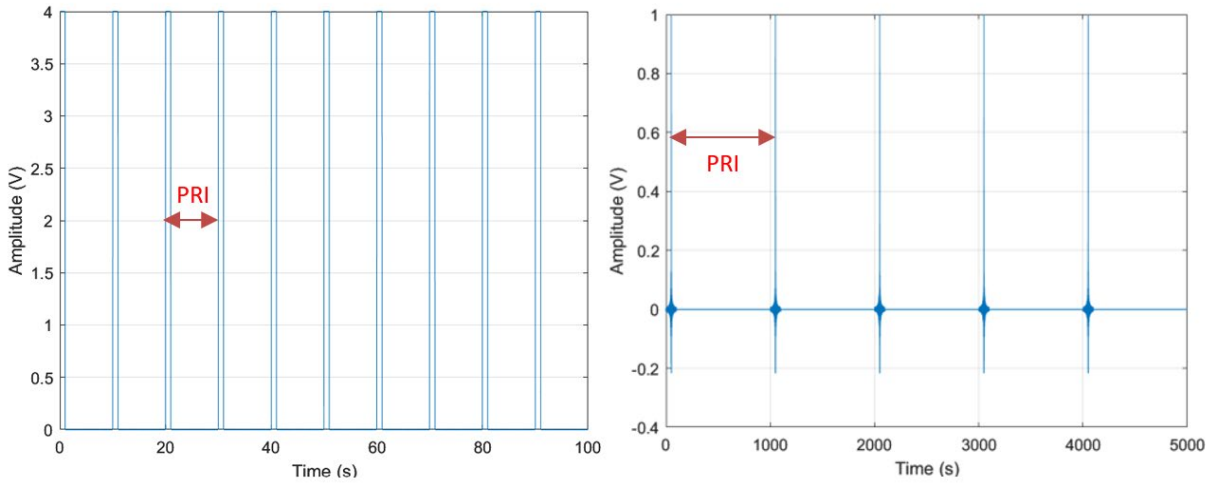


Figure 122 : Burst of rectangular (left side figure) and sinc pulses (right side figure) in the time domain

Since any burst of pulses for non-dithered signal s is periodic (with T period), its spectrum S can be expressed as follows:

$$\mathcal{F}(s) = \mathcal{F}\left(\Pi(\mathrm{t}) * \sum_{k=1}^{\infty} \delta(t - kT) \times rect\left(\frac{t}{T_{Burst}}\right)\right) = \mathcal{F}(\Pi) \times \mathcal{F}\left(\sum_{k=1}^{\infty} \delta(t - kT)\right) * \left(T_{Burst} sinc(\nu T_{Burst})\right)$$

$$\mathcal{F}(s) = \mathcal{F}(\Pi) \times T_{Burst} \frac{1}{T} \sum_{k\epsilon\mathbb{Z}} \delta_{\frac{k}{T}}(\nu) * sinc(\nu T_{Burst}) = \mathcal{F}(\Pi) \times \frac{T_{Burst}}{T} \sum_{k\epsilon\mathbb{Z}} sinc\left(\left(\nu - \frac{k}{T}\right) T_{Burst}\right)$$

As any periodic signal s, its spectrum $|\mathcal{F}(s)|$results in a combination of spectral lines in frequency domain. Every spectral line at frequency $\nu_k = \frac{k}{T}$ is weighted by the power component of the UWB signal, corresponding to the squared module of its Fourier coefficients. As defined, Fourier coefficients relate to the component of the averaged power and they are equally spaced with $\frac{1}{T} = PRF$ Hz. Summing all spectral lines in the frequency domain results in achieving the total average power of the UWB signal, as depicted in Figure 123.

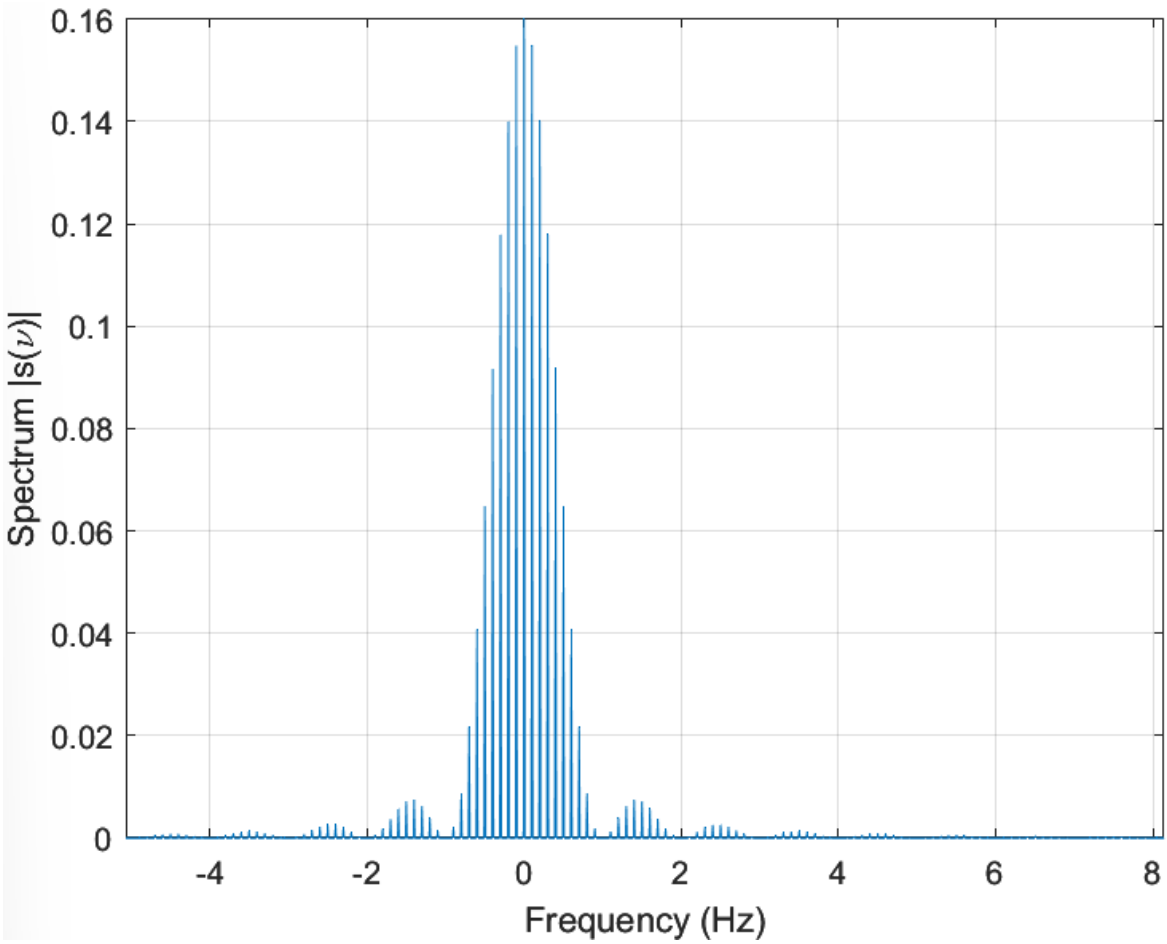


Figure 123: Spectrum of burst of pulses

ANNEX 3: ANALYSIS RESULTS FOR C-BAND METEOROLOGICAL RADARS FOR THE WORST-CASE OUTDOOR SCENARIO

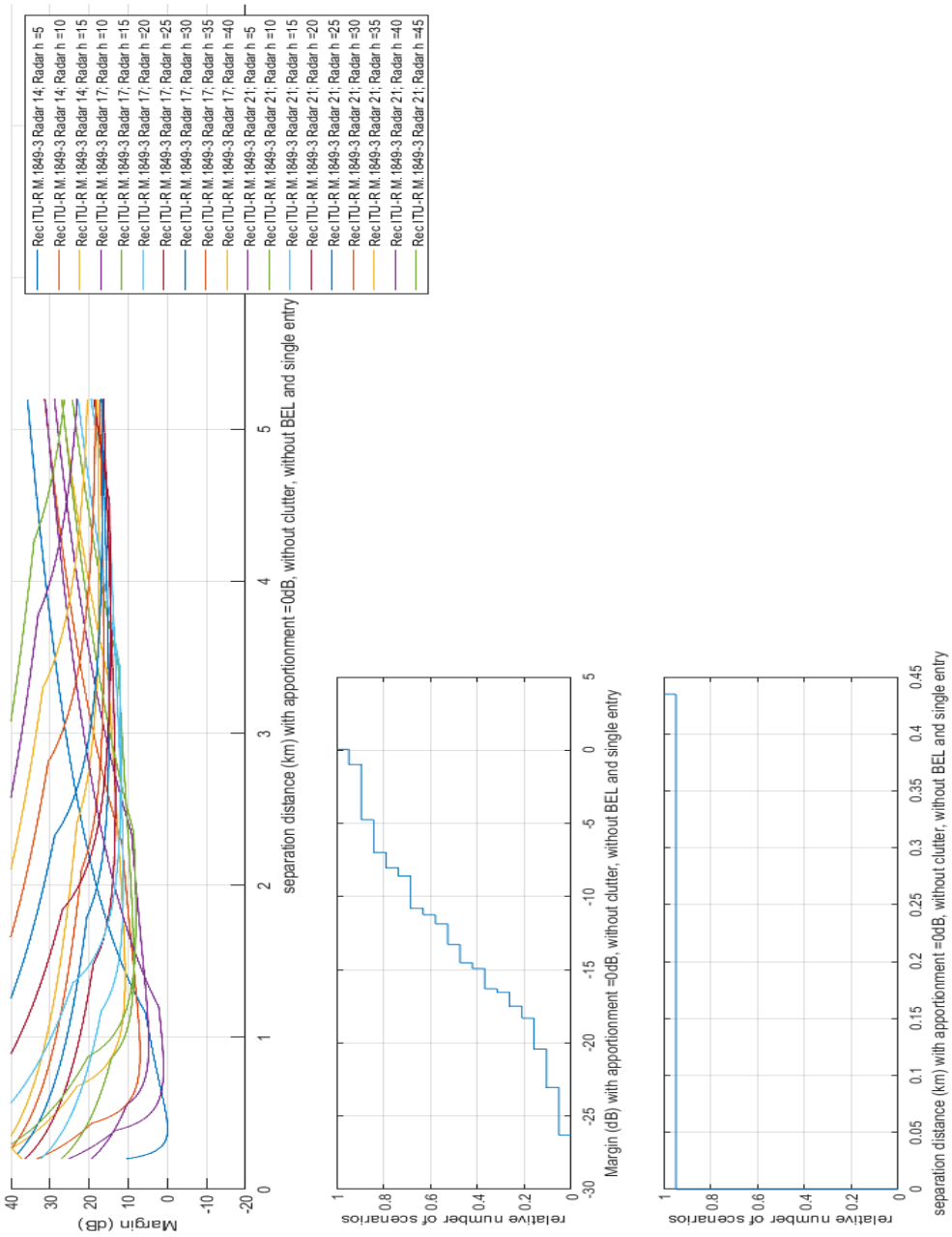


Figure 124: Results for C-band meteorological radars

ANNEX 4: INTERFERENCE MEASUREMENTS BETWEEN MWSSC AND X-BAND ASR

A4.1 INTRODUCTION

This section describes the measurement campaign and shows results with a state of the art airport surveillance radar in x-band.

To assess the compatibility of this airport surveillance radars with representative UWB security scanner waveforms, a broad spectrum of generic waveforms, as well as representative signal of the R&S security scanner, operating in the band from 3.6-10.6 GHz are tested. These measurements illustrate the impact on some observables of the tested signals with a particular airport radar technology.

It should be noted that this section describes a measurement campaign on a specific ASDE radar installed on the airport in Munich. The absence of some technical information (e.g. modulation, signal processing, RF architecture and amplifier dynamic, ASDE radar signal processing algorithm) does not allow to generalise the results to all ASDE radars installed in other airports, in particular miss-detection probability or false detection probabilities - which are usual radar performance metrics - cannot be calculated. In this measurement campaign, results are based on visual criteria described later in this section. In this measurement campaign, it should also be noted that the radar configuration, the signal processing and the signal type of interference affect the level of interference.

The static target that was generated was set 6 dB higher than the detection threshold (i.e. the power level that is needed to be plotted as a target).

Because this measurement campaign was carried out on one particular ASDE system in a very specific configuration, the results cannot be conclusive on the absence of risk on interference.

A4.2 DESCRIPTION OF THE MEASUREMENT SETUP

The used measurement setup is given in Figure 125 and a picture of the scenario in Figure 126. The airport surveillance radar is hereby represented by the tower.

To test the radar a target was generated using a Radar Echo Generator (REG) allowing maximum flexibility. The REG consists of an IQ-analyzer that generates the baseband IQ signal of the received radar signal in real-time, which is then sent to a vector signal generator. The vector signal generator can modulate the digitalised signal with, for example, fading, and thus, according to the hereby added group delay to the signal phase, generate virtual targets in a configurable range of distance from the tower. After the modulation of the signal, it is transmitted back to the radar and the generated, virtual target is plotted as a real target in the chosen range.

For the scenario given here we created a static target at a place where no other objects were detected. To make sure that the radar is not interfered by random interference in the environment but mainly by our injected interference signals, we set the REG power level 6 dB higher than the power level that is needed to be plotted as a target, and therefore, observable by the air traffic controller.

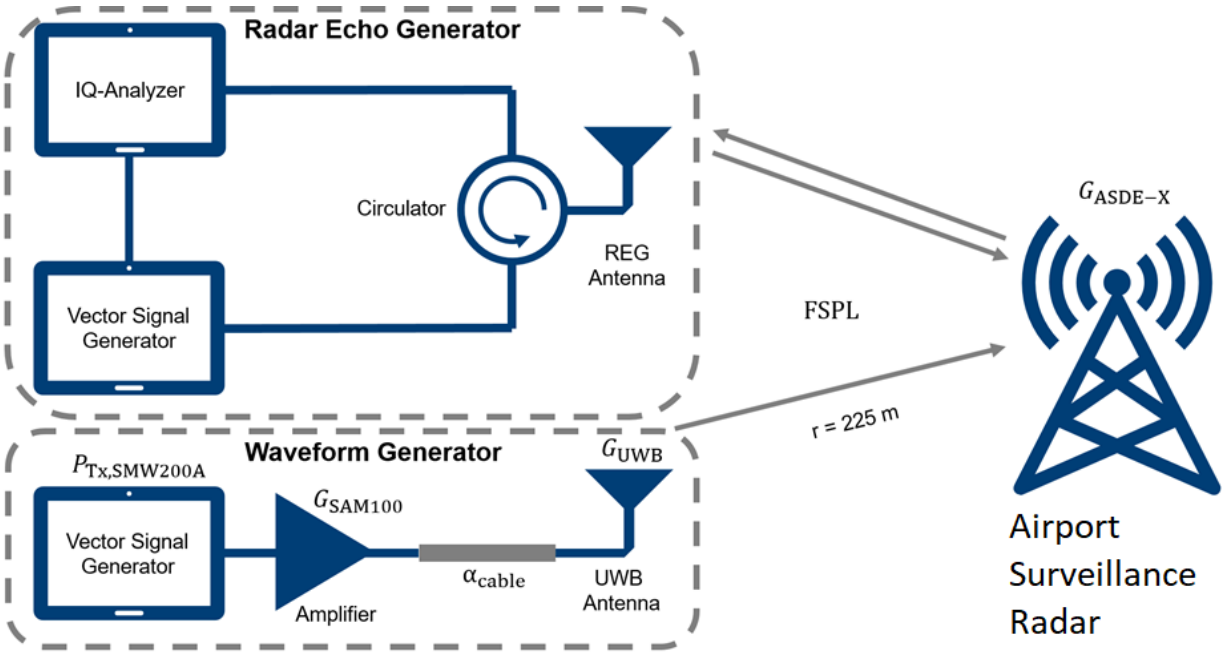


Figure 125: Radar test measurement setup

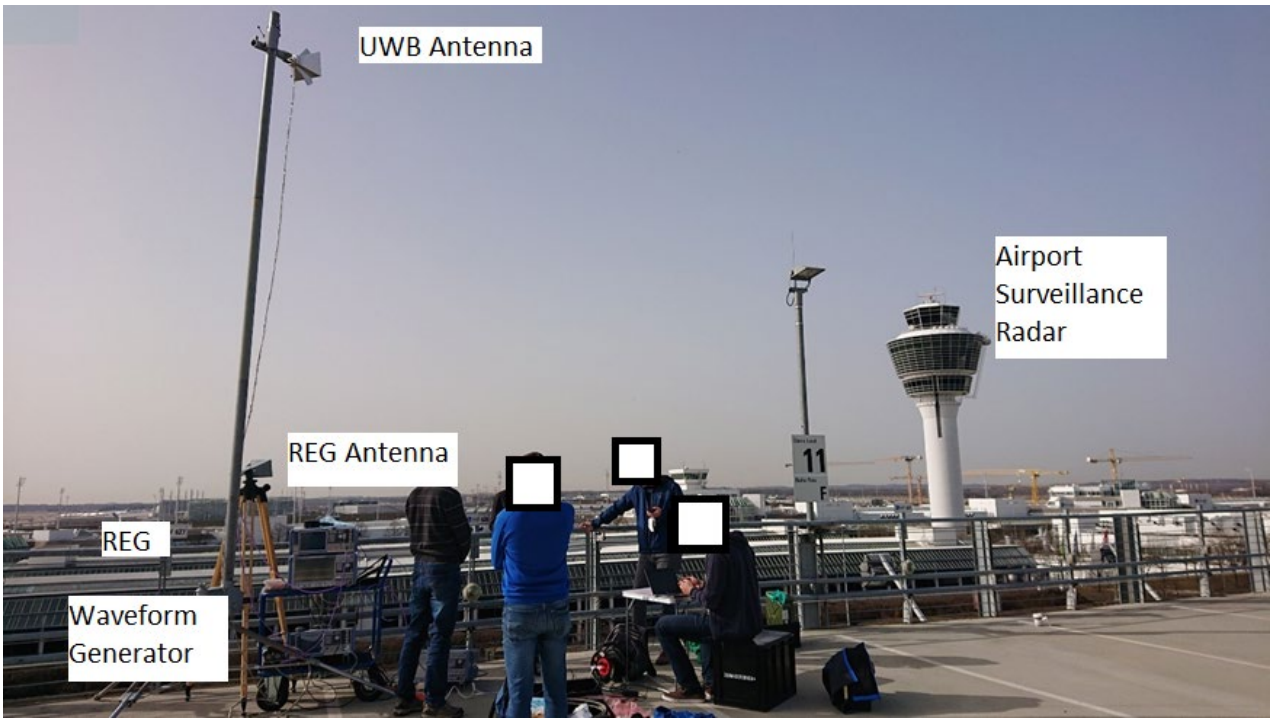


Figure 126: Radar measurement scenario at the airport Munich MUC

To interfere with the radar a typical UWB radar localization and radar imaging waveforms with a vector signal generator, which are first amplified and then transmitted directly towards the radar antenna.

Further, a security scanner signal was used instead of the vector signal generator to observe the impact of the real security scanner signal. This signal was amplified, too, to reach power levels that are high enough to interfere the radar at all, as their resulting power levels are much higher than the noise level of the radar.

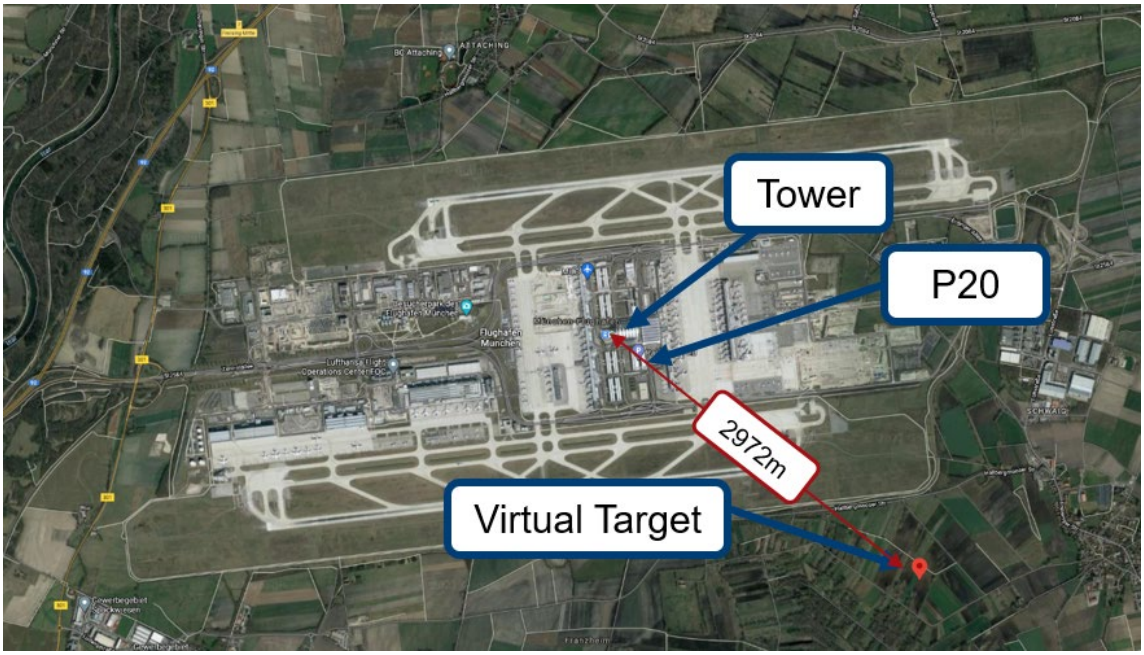


Figure 127: Airport area

With this approach to interfere the radar while transmitting a reference target power levels can be compared.

While radars are used to observe point targets, like airplanes, in space at some distance from the radar itself, weather radars are used to observe distributed targets such as rain, hail, windshear or other atmospheric conditions. According to the different functionality, there are different criteria to be considered.

The radar antenna is on the top of the tower at a height of 78 m, while the interference setup is located on the parking deck P20 at a height of about 27.7 m including the antenna mast. The distance from the parking deck to the tower is about 225 m. The REG setup is operating on the parking deck, too, at a height of about 24.2 m. Using this measurement setup all real-world influences are included, like the gain and inverse cosec² antenna pattern of the radar antenna as well as the system bandwidth.

The two criteria are dependent on the signal shape as well as the increase of the power level.

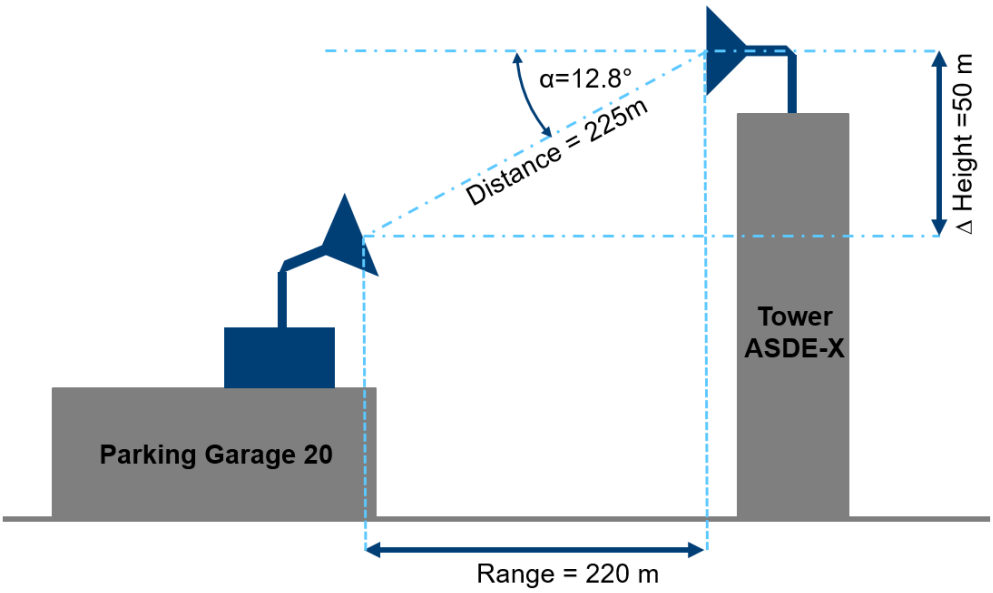


Figure 128: Geometric relationships of the measurement setup

There are two criteria that can be observed for the radar:

- Loss of plotted target: A plotted target is defined as a target that is reported to the air traffic. To be plotted as a real target the power of the incoming signal must at least be higher than a set threshold and the target must be within a specified area around the airport, else the software does not report this target as a real target. Our generated, virtual, static target was set 6 dB higher than the threshold and observed by the air traffic controller, whether it got lost when interfering the radar or not;
- Visual effects observable but not plotted as target: We observed the video signal and watched for visual effects that could occur when interfering with our specified radar signals;

A4.3 INTERFERENCE SIGNALS AND RESULTS

The following table summarises used waveforms and power levels for interference test:

Table 89: Tested interference waveform

Waveform	Bandwidth	Duty cycle	PRF	PRI	Chirp rate (MHz/us)	Chirp/pulse width	Max possible PSD (dBm/MHz)
Pulse 1	1 GHz	0.012	12 MHz	83.33 ns		1 ns	-0.9
Pulse 2	1 GHz	0.006	6 MHz	166.6 ns		1 ns	-6.9
Chirp 1	1 GHz	0.003	1 kHz	1 ms	300.3	3.33 us	15.6
Chirp 2	1 GHz	0.2	2 MHz	500 ns	10000	100 ns	21.1
Chirp 3	1 GHz	0.005	1 kHz	1 ms	200	5 us	16.8
Chirp 4	1 GHz	1	3.03 MHz	330 ns	3030.30	330 ns	13.7
Chirp 5	1 GHz	1	625 kHz	1.6 us	625	1.6 us	12.9
SFCW	1 GHz	0.5	500 kHz	2 us	1000	1 us	20.7
SSC	>10 GHz	0.001	12 MHz	83.33 ns		0.1 ns	-3.9
AWGN	1 GHz	1	-	-	-	-	-6.75

We set the power of our virtual, static target 6 dB higher than the minimum threshold for plotting targets. The REG output power level was therefore set to 0 dBm at the vector signal generator.

We distinguish between the visual output, where a target is visible, and the plotted output, whereas only the plotted output is observed by the air traffic controller.

The power levels are chosen in a way, that either a false target was already observed or the maximum PEP of about +40 dBm at the amplifier output was reached, which is the level before saturation effects occurred. The following table shows the results, while the power PSD is in dBm/MHz and corresponds to the ERP after the interfering setup's transmit antenna.

Table 90: Power levels at which the signals became visible

Signal	PSD	Detection	Visible	Plotted
Pulse 1	-2.9	Level at which interference became visible; not plotted as target	Yes	No

Signal	PSD	Detection	Visible	Plotted
Pulse 2 Pulse 2	-9.9 -6.9	Level at which interference became visible; not plotted as target Max output: still no target plotted	Yes Yes	No No
Chirp 1	15.6	Level at which interference became visible; not plotted as target	Yes	No
Chirp 2 Chirp 2	-3.9 4.1	Level at which interference became visible; not plotted as target Level at which interference became plotted as target	Yes Yes	No Yes
Chirp 3	8.8	Level at which interference became visible; not plotted as target	Yes	No
Chirp 4 Chirp 4	-12.3 -2.3	Level at which interference became visible; not plotted as target Level at which interference is plotted as target	Yes Yes	No Yes
Chirp 5 Chirp 5	-23.1 -12.1	Level at which interference became visible; not plotted as target Level at which interference is plotted as target	Yes Yes	No Yes
SFCW 1 SFCW 1	-8.3 -5.3	Level at which interference became visible; not plotted as target Level at which interference is plotted as target	Yes Yes	No Yes
SSC	-3.8	Nothing detected at the radar	No	No
AWGN1	-6.75	Target not visually indistinguishable from noise	Yes	No

A4.4 OBSERVATIONS

The PSD where a visual output became observable is very dependent on the waveform.

In general, the evaluated type of radar is very resistant against interference and a target is only plotted for continuous wave-like signal shapes.

The worst-case signal tested was Chirp5 where a PSD of -23.1 dBm/MHz was enough to generate a visual output.

The security scanner signal, however, is a pulse signal that is very similar to the tested signal Pulse1, but has a greater bandwidth. It is most noteworthy, that, while for a PSD of -2.9 dBm/MHz (Pulse1) a visual output was just detected, the Security Scanner standalone pulse signal with a -0.9 dB lower PSD, that is -3.8 dBm/MHz, did not generate a visual output. Even for these high PSDs no target was plotted for pulse signals.

According to the measurement results the worst-case waveform generates only a visual output, no plotted target, at a PSD of -23.1 dBm/MHz, while the security scanner signal like waveform needs a PSD of -2.9 dBm/MHz to cause any visual effects (no visual effect observed for -3.8 dBm/MHz).

These measurements for a specific airport ASDE radar in Munich show that a MWSSC is compatible even in outdoor line of sight scenarios and show that higher power levels are required to generate a visual signal at the radar.

ANNEX 5: LIST OF REFERENCES

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