CEPT ECC
Electronic Communications Committee

ECC Report 350

Radiodetermination equipment for ground based vehicular applications in 77-81 GHz

approved 3 February 2023

0 EXECUTIVE SUMMARY

New operational parameters for automotive radars in the 77-81 GHz band are proposed to represent the evolution of the technology that has taken place. The studies carried out in this Report are based on the technical characteristics of radiodetermination equipment for ground based vehicular applications defined in the ETSI Technical Report TR 103 593 [2].

The envisaged frequency range is already in use by other services or applications in the in-band and the out-of-band domain. Other systems could be in operation on a national basis. The results of studies conducted in the framework of this Report are summarised below.

0.1 SHARING WITH RAS

The single-entry study leads to similar exclusion zones for both NOEMA and SRT, up to approximately 50 km.

Comparing the results of the aggregation study, no significant variations are found for the same location in different scenarios. The terrain seems to play an important role for the exclusion zone size, varying from a few kilometres (Effelsberg) up to almost 70 km (IRAM and Yebes).

It has to be noted that switching off automotive radars in potential exclusion zones has an impact on the reliability for safety relevant driver's assistance functions and autonomous driving. Other mitigation techniques than exclusion zones were not studied.

0.2 SHARING WITH RADIOLOCATION

In 2020, information was provided that no military radiolocation systems are operated by NATO members in the band 77 to 81 GHz. Furthermore, there are no plans to introduce such systems.

There is no other applications of the Radiolocation Service using this band.

0.3 SHARING WITH AMATEUR SERVICE

MCL calculations, taking into account the vertical delta between both automotive radar (AR) and Amateur Service antennas, reveal separation distances between 0 km and 35.7 km. The distance depends highly on transmission level and angular offset between the AR transmitter to the Amateur Radio receiver.

Due to the use of directive antennas the highlighted areas where interference could happen are relatively small. It has to be noted that interference in reality may have a low probability due to following reasons:

- A car/street has to be inside of the relatively small critical area;
- The cars antenna must be directed towards the Amateur Service antenna;
- LOS conditions between automotive radars and the Amateur Service receiver must apply;
- The more vertical separation between both antennas prevails the lower the impact will be;
- The setup of the Amateur Service system is such (e.g. LOS conditions between two Amateur Service stations) that probability of interference is low, but may be assessed case by case.

Aggregation was not taken into account.

0.4 SRD IN THE BAND

It has to be noted that SRDs have no status of being protected from interference from a regulatory point of view. However, the following information about coexistence with automotive radars is provided.

HD-GBSAR systems operating in the band 77-78 GHz avoid interference by implementing detect and avoid techniques.

Information about Security Scanners in the band 60-82 GHz, which may use the band in future, can be found in ECC Report 344 [40].

0.5 COMPATIBILITY WITH THE FIXED SERVICE

The compatibility between vehicle radars and FS has been studied based on a MCL approach. The unwanted emissions for the automotive radar in the bands 71-76 GHz and 81-86 GHz were limited to -30 dBm/MHz e.i.r.p. The highest required separation distance is 4.23 km where the I/N of -20 dB is exceeded at most by 2.5 dB when using a 50 dBi FS antenna gain. The separation distance becomes 2.12 km where the I/N of -20 dB is exceeded at most by 3 dB for an FS antenna gain of 43 dBi. There are limited cases where the radar can potentially cause interference to the fixed service receiver and highly depends on the relative orientation between the vehicular radar and FS Rx. This happens when the vehicle radars fall in the main lobe of the fixed service station. Due to the narrow beamwidth of the FS antenna, the minimum separation distance decreases if the interferer is not in the main lobe. The interference becomes negligible when the vehicular radars are beyond approximately 0.8 degrees in azimuth from the main beam of the FS Rx. These finding are inline also with the results obtained in the studies in Report ITU-R F.2394 [12].

On the topic of possible mitigation techniques, possible options to improve the compatibility between both adjacent services are:

- The avoidance of fixed service links pointed in the azimuth direction near to and parallel to roads;
- Minimise vehicular radar antenna radiation above the horizontal plane, since the goal is to prevent collision with other vehicles or obstacle;
- Use of vehicular radar antennas with higher gain and smaller beamwidths to minimise the occurrence of interference.

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LIST OF ABBREVIATIONS

Abbreviation	Explanation
ACC	Automatic Cruise Control
AEB	Automatic Emergency Breaking
AMSL	Above mean sea level
APA	Automated Parking Assist
AR	Automotive Radar
BW	Bandwidth
CEPT	European Conference of Postal and Telecommunications Administrations
CLC	Corine Land Cover
CW	Continuous wave
DATV	Digital Amateur TV
e.i.r.p.	Equivalent isotropically radiated power
ECA	European Common Allocation
ECC	Electronic Communications Committee
EESS	Earth Exploration Satellite Service
EME	Earth-moon-earth
ETSI	European Telecommunications Standards Institute
FMCW	Frequency Modulated Continuous Wave
GBVR	Ground based vehicular radar
HZAP	Home Zone Automated Parking
LOS	Line-of-sight
LPR	Level Probing Radar
LRR	Long Range Radar
ITU	International Telecommunication Union
MCL	Minimum Coupling Loss
NLOS	Non Line-of-sight
OFDM	Orthogonal Frequency-Division Multiplexing
OOB	Out-of-band
OSM	OpenStreetMap
PSD	Power Spectral Density
RA	Radio Astronomy
RAS	Radio Astronomy Service
RF	Radio Frequency

Abbreviation	Explanation
RLOC	Radiolocation
RT	Radio Telescope
Rx	Receiver
SRR	Short Rang Radar
TLPR	Tank Level Probing Radar
TR	Technical Report (ETSI)
TTT	Transport and Traffic Telematics
Tx	Transmitter
UWB	Ultra Wide Band

1 INTRODUCTION

In 2004, ECC Decision (04)03 [1] was published. It identified the 77-81 GHz band as a long term solution for short- range radars. It also identified the maximum operational parameters as given in Table 1:

Table 1: Existing PSD and e.i.r.p. limits

	Mean PSD - limit (e.i.r.p.)	Peak e.i.r.p. - limit
Single radar (including e.g. bumper attenuation)	-9 dBm/MHz	(not specified)
Single radar (standalone)	-3 dBm/MHz	55 dBm

The European Commission harmonised the use of automotive Short Range radar equipment according to this decision in 2004 [5].

The regulation for the 79 GHz band is untouched since then, but RF technology and signal processing evolved that allows to develop 79 GHz automotive radar sensors that provide more functions and better RF performance than it was foreseen in 2004.

Since 2004, the demand for radar based driver assistance functions increased significantly and the number of radar equipped vehicles is increasing.

In addition, the performance of radar based driver assistance functions evolved. Radar based functions will also be a key technology for highly automated or autonomous driving vehicles [2].

The baseline for studies in this Report is the industry request ETSI TR 103 593 [2] which is expected to lead to regulatory action in Europe to increase safety at vehicle level. More detailed information can be found in ANNEX 1.

New operational parameters are proposed to represent the evolution of the technology that has taken place and to make Mid Range and Long Range Radars also possible in the range 77-81 GHz. The studies carried out in this Report are based on radiodetermination equipment for ground based vehicular applications technical characteristics defined in the ETSI TR 103 593 [2].

2 SYSTEM DESCRIPTION OF GROUND BASED VEHICULAR RADARS IN THE 77-81 GHZ BAND

2.1 SYSTEM DESCRIPTION

To provide different functionalities for driving assistance and increased safety, more and more cars are equipped with different type of radars that are mounted at specific positions on board the vehicle as shown in Figure 1. Front and corner radars are used for applications requiring long and medium range such as automatic cruise control, lane keep, lane change assist, automatic emergency braking, etc.

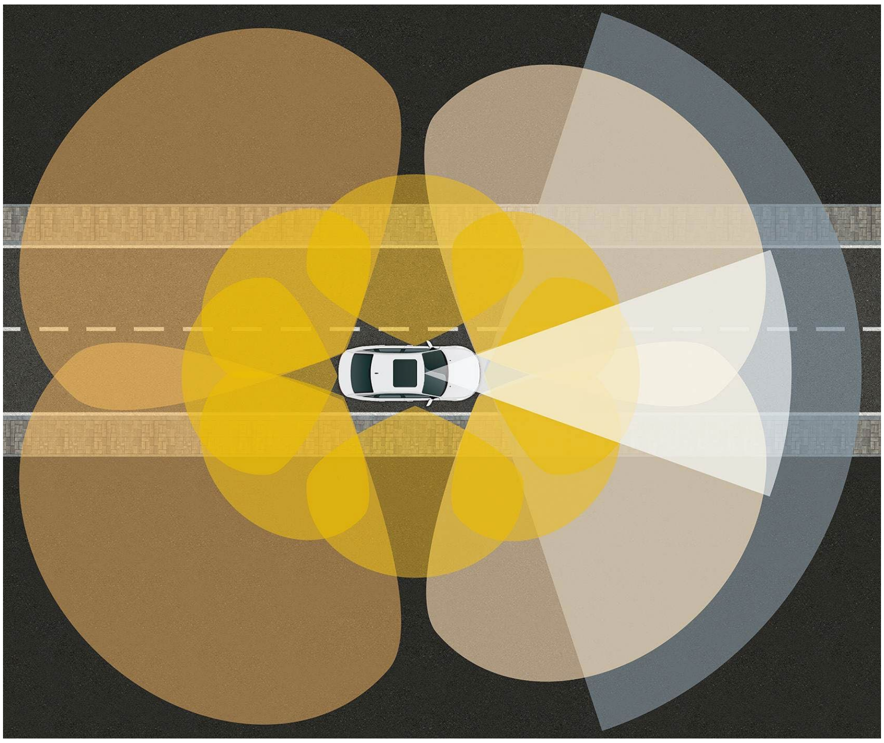


Figure 1: Example for the coverage range of radar sensors at one vehicle to achieve 360 degrees coverage

Future radar based applications providing the vehicle with higher degree of autonomy and enable automated driving require long, short and ultra-short-range radars for front, side and rear-view (see yellow areas in Figure 1), such that 360° sensing is enabled.

New high resolution vehicular radar sensors will besides the already implemented long-range functions allow to obtain a wide field of view (in azimuth) 360 degrees around the vehicle and allow to implement features like e.g. turn assist, intersection assistant, automated parking assistance or autonomous valet parking. A more comprehensive list of functions that depend on high-resolution radars is available in ETSI TR 103 593 [2].

To perform such features, the radars need to be capable to detect a wide range of objects such pedestrian, bicycles, vehicles, etc. Vehicular radar sensors that are capable of detecting small objects such as bicycles, pedestrians and children require an operating bandwidth with up to 4 GHz.

To offer that in as many cars as possible, it is required to extend radio resources and use lower-bandwidth radars also in the band 77-81 GHz and increase the maximum possible transmit power spectral density.

A listing of Advanced Driving Assistance Systems covering the related features & use cases can be found in Table 2. The key system elements including radar are provided.

The list does not claim to be complete and is therefore not restricted to the systems specified. Additional systems and applications may exist or will emerge based on evolving technology.

Table 2: Advanced Driving Assistance Systems

Advanced driver assistant Systems	Key System Elements
Adaptive Light Control	Matrix LED Lighting, Radar, Camera, Localisation
Forward Collision Warning	Radar, Camera
Automatic Emergency Braking	Radar, Camera, Braking Control
Automatic Cruise Control (ACC)	Radar, Camera, Braking Control
Enhanced Blind Spot Monitoring	Radar, Camera
Lane Change Assis	Front Camera, Corner Radar
Traffic Jam Assist	Camera, Radar, Corner Radar, LiDAR, Steering and/or Braking Control
Rear Cross Traffic Alert	Corner Radar, Rear Camera, UPA, SVS, Braking Control
Front Junction-Intersection Assist	Camera, Corner Radar, SVS, UPA, Braking Control
Highway Chauffeur	Front Radar(s), Camera, Driver Monitoring, Steering & Braking Control
Automatic Lane Chang	Camera, 360° Radar, Steering & Braking Control
Automated Parking Assist (APA) (Note 1)	UPA, SVS, Steering Control, Braking Control
Home Zone Automated Parking (HZAP)	Secure Connectivity, UPA, SVS, Radar, Steering & Braking Control
Valet Parking	Secure Connectivity, Camera, 360° Radar, UPA, LiDAR Steering & Braking Control
Highway Pilot	Secure Connectivity, Camera, 360° Radar, UPA, LiDAR, Driver Monitoring, Steering & Braking Control
Note 1: Ultrasonic-only or camera+ultrasonic-fusion automated parking systems	

In ETSI TR 103 593, table 5 and annex A [2] additional information is provided for radar-based functions that could be implemented in a vehicle:

- The implementation of radar-based functions varies for each vehicle type and vehicle platform;
- In a vehicle certain radar-based functions are used and activated only in dedicated situations and are not activated while the vehicle is travelling on the road in normal traffic. For instance, for parking support functions (based on Ultra Short Range Radar) this function is activated only when the vehicle is in a specific situation such as a parking lot or parking garage at slow speed.

2.2 PROPOSAL FOR NEW SYSTEM PARAMETERS

ETSI TR 103 593, section 8, table 8 [2] provides the proposed maximum mean PSD (e.i.r.p.) and maximum mean e.i.r.p. limits for standalone vehicular radar sensors. These limits apply during T_{on} and do not include any consideration of car body losses.

Table 3: Proposed mean PSD (e.i.r.p.) and mean e.i.r.p. limits in the frequency range 77-81 GHz

Radar sensor category	Modulation Bandwidth	max. mean PSD e.i.r.p. (during T_{on})	max. mean e.i.r.p. (during T_{on})
Long Range Radar	Up to 1 GHz	20 dBm/MHz	40 dBm
Mid Range Radar	Up to 2 GHz	7 dBm/MHz	37 dBm

Radar sensor category	Modulation Bandwidth	max. mean PSD e.i.r.p. (during T_{on})	max. mean e.i.r.p. (during T_{on})
Short Range radar	Up to 4 GHz	-3 dBm/MHz	30 dBm
Ultra Short Range Radar	Up to 4 GHz	-3 dBm/MHz	30 dBm

RF loss of a cover above the radar sensor (for example a bumper fascia) is not included in the study, because such covers are not under control of the radar manufacturers [2]. Cover loss might only be considered as additional mitigation in the background.

2.3 GENERAL SYSTEM PARAMETERS

Technical parameters for vehicular radars operating in the frequency range 77-81 GHz are available in ETSI TR 103 593 [2] and Recommendation ITU-R M.2057 [8].

Table 4 provides general parameters extracted from [2] and [8] for vehicular radars operating in the 77-81 GHz band.

Table 4: General parameters of vehicular radars

Parameter	Value
Antenna height above road surface	0.3-1 m typical 0.5 m
Duty cycle	30-50% [2]
Operating Bandwidth	Up to 4 GHz, depending on vehicle speed and scenario
Typical emission type	FMCW, Fast FMCW
Typical sweep time	FMCW: 10000-40000 µs Fast FMCW: 10 -40 µs

Automotive radars may use analogue modulation schemes with linear chirps (see illustration in Figure 2). Chirp durations are in the order of 10 ms for slow chirps or in the order of 10 µs for fast chirps [2].

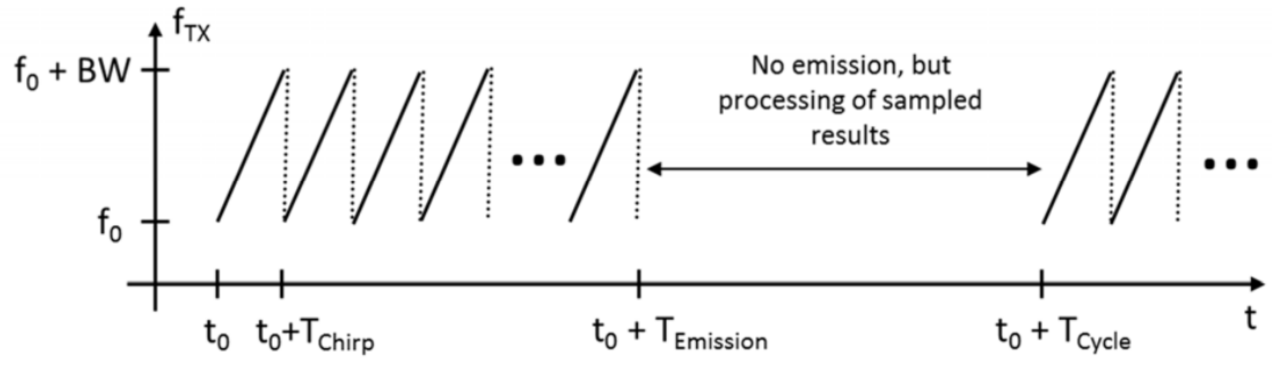


Figure 2: Illustration of analogue modulated radar transmit emission

Automotive radars may use digital modulation schemes, for example with phase modulation or OFDM (see illustration in Figure 3) [2].

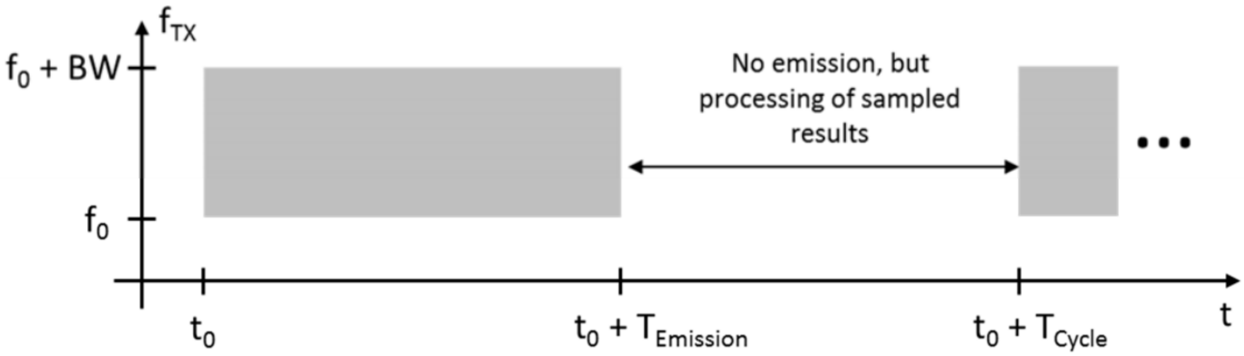


Figure 3: Illustration of digital modulated radar transmit emission

For both modulations the emission follows a periodic cycle to duration T_{Cycle} (in the order of 50 ms) which is subdivided into an active measurement interval of duration $T_{Emission}$ (in the order of 20 ms) and a processing of sampled results (duration T_{Cycle} - $T_{Emission}$) [2].

2.3.1 Operating bandwidth

ETSI TR 103 593 section 7.1.1, table 5 [2] provides the context between the required bandwidth of a vehicular radar sensor and the traffic/ environment situation a vehicle is in.

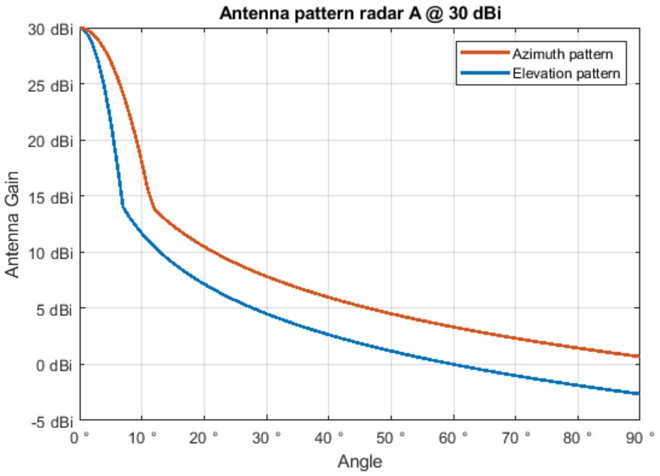
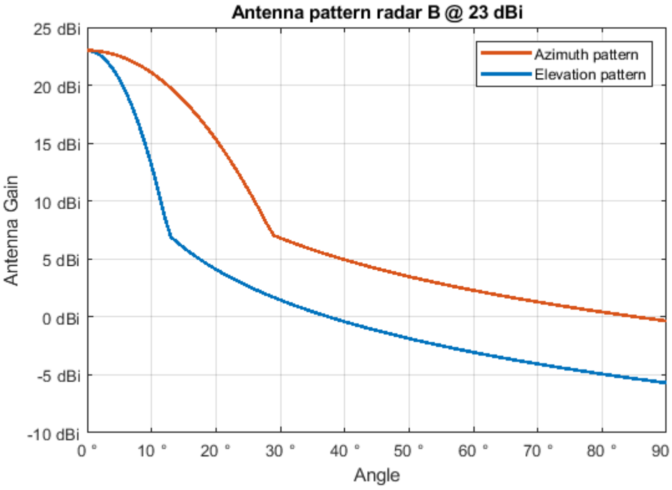
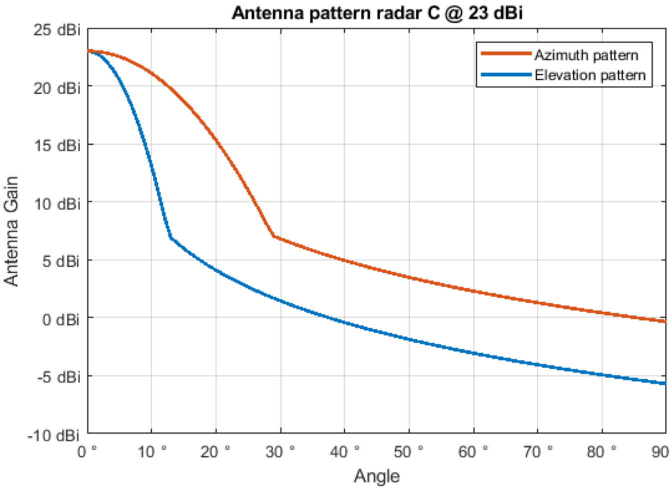
It can be concluded that only in specific situations such as parking scenarios the sensor will use the full 4 GHz bandwidth. In these specific situations the vehicle moves only at low speed.

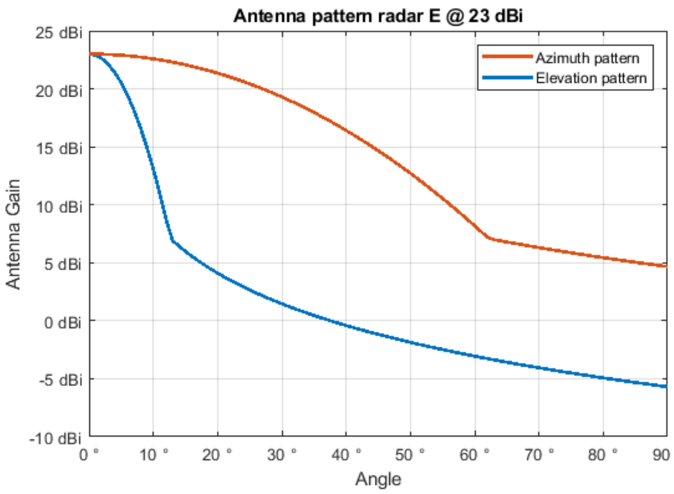
In driving scenarios on highway and standard roads the typical occupied BW is 1-1.5 GHz.

The operating bandwidth of the automotive radar signal is specified by the bandwidth in which -23 dB below the maximum of the radiated power is emitted or equivalent 99% of its radiated power.

ITU-R Recommendation M.2057, table 1 [8] provides the antenna gain assumptions to be used for the 4 types of vehicular radars (see Table 5).

Table 5: Antenna patterns for vehicular radars

Radar use case	Antenna gain (dBi)	Reference Radar Type	Pattern
Long Range Radar	30	Radar A	
Mid Range Radar	23	Radar B	
Short Range Radar	23	Radar C	

Radar use case	Antenna gain (dBi)	Reference Radar Type	Pattern
Ultra Short Range Radar	23	Radar E	

2.3.2 Unwanted Emissions

For compatibility studies with the FS, the unwanted emissions for the automotive radar in the bands 71-76 GHz and 81-86 GHz were limited to -30 dBm/MHz e.i.r.p.

Compatibility studies with AR in the 76-77 GHz were not done.

3 EXISTING BAND USAGE

Given a bandwidth of 4 GHz centred at 79 GHz the in band frequencies are 77 GHz to 81 GHz and the out-of-band frequencies are 69 GHz to 77 GHz and 81 GHz to 89 GHz.

The envisaged frequency range is already in use by other allocations and applications in the in-band and the out-of-band domain. An overview of those is given in the following subsection using information from the ECA table, version April 2022 [4]. Other systems could be in operation on a national basis.

A simplified visualisation (for example MOBILE-SATELLITE is included in MOBILE) of the band in focus can be found in Figure 4. Additional information about the usage of frequency bands of applications can be found e.g. in ERC Recommendation 70-03 [50]. Other applications using the band in addition to the applications given in the ECA Table are for example HD-GBSAR (ECC Decision 21(02) [41]), Rotorcraft Radars in the band 76-77 GHz (ECC Decision(16)01 [42]). At the time of publication of this ECC Report Security Scanners (ECC Report 344 [40]) are under consideration to be allowed for use in the frequency range 60-82 GHz.

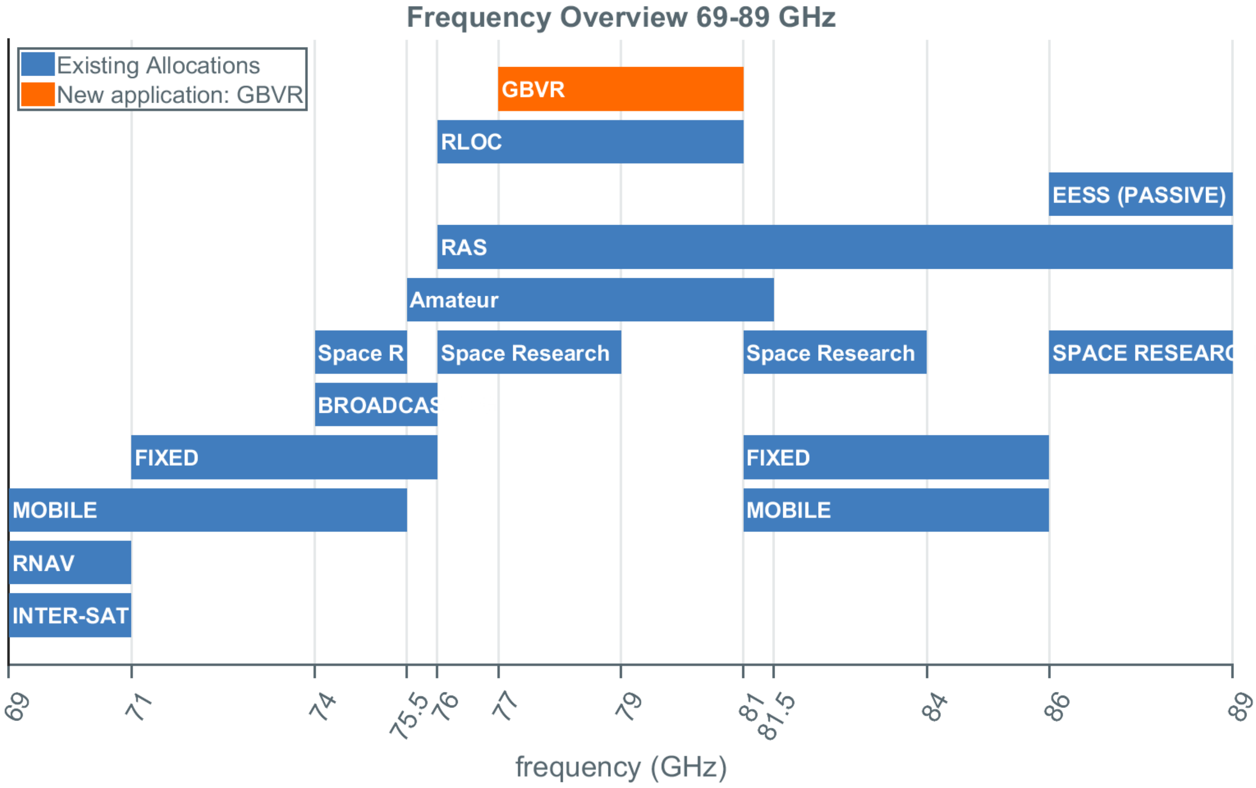


Figure 4: Simplified visualisation of the frequency band 69-89 GHz according to the ECA Table

3.1 ECA ALLOCATIONS INBAND (77-81 GHZ)

Table 6 is an excerpt of the ECA Table [4] for the in band domain.

Table 6: Excerpt of the ECA Table for the in-band domain

Frequency Range	Allocations	Applications
76 GHz - 77.5 GHz	RADIO ASTRONOMY RADIOLOCATION Amateur Amateur-Satellite Space Research (space-to-Earth) 5.149	Amateur Amateur-satellite Radio astronomy Radiodetermination applications Radiolocation (civil) SRR TTT
77.5 GHz - 78 GHz	AMATEUR AMATEUR-SATELLITE RADIOLOCATION 5.559B Space Research (space-to-Earth) 5.149	Amateur Amateur-satellite Radio astronomy Radiodetermination applications SRR
78 GHz - 79 GHz	Amateur Amateur-Satellite RADIOLOCATION Radio Astronomy Space Research (space-to-Earth) 5.149 5.560	Amateur Amateur-satellite Radio astronomy Radiodetermination applications Radiolocation (civil) SRR
79 GHz - 81 GHz	RADIO ASTRONOMY RADIOLOCATION Amateur Amateur-Satellite 5.149	Amateur Amateur-satellite Radio astronomy Radiodetermination applications Radiolocation (civil) SRR

5.149: In making assignments to stations of other services to which the bands: 13 360-13 410 kHz, 25 550-25 670 kHz, 37.5-38.25 MHz, 73-74.6 MHz in Regions 1 and 3, 150.05-153 MHz in Region 1, 322-328.6 MHz, 406.1-410 MHz, 608-614 MHz in Regions 1 and 3, 1 330-1 400 MHz, 1 610.6-1 613.8 MHz, 1 660-1 670 MHz, 1 718.8-1 722.2 MHz, 2 655-2 690 MHz, 3 260-3 267 MHz, 3 332-3 339 MHz, 3 345.8-3 352.5 MHz, 4 825-4 835 MHz, 4 950-4 990 MHz, 4 990-5 000 MHz, 6 650-6 675.2 MHz, 10.6-10.68 GHz, 14.47-14.5 GHz, 22.01-22.21 GHz, 22.21-22.5 GHz, 22.81-22.86 GHz, 23.07-23.12 GHz, 31.2-31.3 GHz, 31.5-31.8 GHz in Regions 1 and 3, 36.43-36.5 GHz, 42.5-43.5 GHz, 48.94-49.04 GHz, 76-86 GHz, 92-94 GHz, 94.1-100 GHz, 102-109.5 GHz, 111.8-114.25 GHz, 128.33-128.59 GHz, 129.23-129.49 GHz, 130-134 GHz, 136-148.5 GHz, 151.5-158.5 GHz, 168.59-168.93 GHz, 171.11-171.45 GHz, 172.31-172.65 GHz, 173.52-173.85 GHz, 195.75-196.15 GHz, 209-226 GHz, 241-250 GHz, 252-275 GHz are allocated, administrations are urged to take all practicable steps to protect the radio astronomy service from harmful interference. Emissions from spaceborne or airborne stations can be particularly serious sources of interference to the radio astronomy service (see Nos. 4.5 and 4.6 and Article 29). (WRC-07)

5.559B: The use of the frequency band 77.5-78 GHz by the radiolocation service shall be limited to short-range radar for ground-based applications, including automotive radars. The technical characteristics of these radars are provided in the most recent version of Recommendation ITU-R M.2057. The provisions of No. 4.10 do not apply. (WRC-15)

5.560: In the band 78-79 GHz radars located on space stations may be operated on a primary basis in the Earth exploration-satellite service and in the space research service.

3.2 ECA ALLOCATIONS OUT-OF-BAND (69-77 GHZ, 81-89 GHZ)

Table 7 is an excerpt of the ECA Table [4] for the lower out-of-band domain.

Table 7: Excerpt of the ECA Table for the lower out-of-band domain

Frequency Range	Allocations	Applications
66 GHz - 71 GHz ()	INTER-SATELLITE MOBILE 5.553 5.558 MOBILE-SATELLITE RADIONAVIGATION RADIONAVIGATION-SATELLITE 5.554	Wideband data transmission systems
71 GHz - 74 GHz	FIXED FIXED-SATELLITE (SPACE-TO-EARTH) MOBILE MOBILE-SATELLITE (SPACE-TO-EARTH)	Fixed
74 GHz - 75.5 GHz	BROADCASTING BROADCASTING-SATELLITE FIXED FIXED-SATELLITE (SPACE-TO-EARTH) MOBILE Space Research (space-to-Earth) 5.561	Fixed Radiodetermination applications Space research
75.5 GHz - 76 GHz	BROADCASTING BROADCASTING-SATELLITE FIXED FIXED-SATELLITE (SPACE-TO-EARTH) Amateur Amateur-Satellite 5.561 ECA35	Amateur Amateur-satellite Fixed Radiodetermination applications Space research
76 GHz - 77.5 GHz	RADIO ASTRONOMY RADIOLOCATION Amateur Amateur-Satellite Space Research (space-to-Earth) 5.149	Amateur Amateur-satellite Radio astronomy Radiodetermination applications Radiolocation (civil) Railway applications SRR TTT

5.149: In making assignments to stations of other services to which the bands: 13 360-13 410 kHz, 25 550-25 670 kHz, 37.5-38.25 MHz, 73-74.6 MHz in Regions 1 and 3, 150.05-153 MHz in Region 1, 322-328.6 MHz, 406.1-410 MHz, 608-614 MHz in Regions 1 and 3, 1 330-1 400 MHz, 1 610.6-1 613.8 MHz, 1 660-1 670 MHz, 1 718.8-1 722.2 MHz, 2 655-2 690 MHz, 3 260-3 267 MHz, 3 332-3 339 MHz, 3 345.8-3 352.5 MHz, 4 825-4 835 MHz, 4 950-4 990 MHz, 4 990-5 000 MHz, 6 650-6 675.2 MHz, 10.6-10.68 GHz, 14.47-14.5 GHz, 22.01-22.21 GHz, 22.21-22.5 GHz, 22.81-22.86 GHz, 23.07-23.12 GHz, 31.2-31.3 GHz, 31.5-31.8 GHz in Regions 1 and 3, 36.43-36.5 GHz, 42.5-43.5 GHz, 48.94-49.04 GHz, 76-86 GHz, 92-94 GHz, 94.1-100

GHz, 102-109.5 GHz, 111.8-114.25 GHz, 128.33-128.59 GHz, 129.23-129.49 GHz, 130-134 GHz, 136-148.5 GHz, 151.5-158.5 GHz, 168.59-168.93 GHz, 171.11-171.45 GHz, 172.31-172.65 GHz, 173.52-173.85 GHz, 195.75-196.15 GHz, 209-226 GHz, 241-250 GHz, 252-275 GHz are allocated, administrations are urged to take all practicable steps to protect the radio astronomy service from harmful interference. Emissions from spaceborne or airborne stations can be particularly serious sources of interference to the radio astronomy service (see Nos. 4.5 and 4.6 and Article 29). (WRC-07)

5.553: In the bands 43.5-47 GHz and 66-71 GHz, stations in the land mobile service may be operated subject to not causing harmful interference to the space radiocommunication services to which these bands are allocated (see No. 5.43). (WRC-2000)

5.554: In the bands 43.5-47 GHz, 66-71 GHz, 95-100 GHz, 123-130 GHz, 191.8-200 GHz and 252-265 GHz, satellite links connecting land stations at specified fixed points are also authorized when used in conjunction with the mobile-satellite service or the radionavigation-satellite service. (WRC-2000)

5.558: In the bands 55.78-58.2 GHz, 59-64 GHz, 66-71 GHz, 122.25-123 GHz, 130-134 GHz, 167-174.8 GHz and 191.8-200 GHz, stations in the aeronautical mobile service may be operated subject to not causing harmful interference to the inter-satellite service (see No. 5.43). (WRC-2000)

5.561: In the band 74-76 GHz, stations in the fixed, mobile and broadcasting services shall not cause harmful interference to stations of the fixed-satellite service or stations of the broadcasting-satellite service operating in accordance with the decisions of the appropriate frequency assignment planning conference for the broadcasting-satellite service. (WRC-2000)

ECA35: In Europe the band is also allocated to the Amateur and Amateur-satellite services.

Table 8 is an excerpt of the ECA Table [4] for the upper out-of-band domain.

Table 8: Excerpt of the ECA Table for the upper out-of-band domain

Frequency Range	Allocations	Applications
81 GHz - 84 GHz	FIXED 5.338A FIXED-SATELLITE (EARTH-TO-SPACE) MOBILE MOBILE-SATELLITE (EARTH-TO-SPACE) RADIO ASTRONOMY Space Research (space-to-Earth) 5.149 5.561A	Amateur Amateur-satellite Fixed Radio astronomy Radiodetermination applications
84 GHz - 86 GHz	FIXED 5.338A FIXED-SATELLITE (EARTH-TO-SPACE) MOBILE RADIO ASTRONOMY 5.149	Fixed Radio astronomy Radiodetermination applications
86 GHz - 92 GHz	EARTH EXPLORATION-SATELLITE (PASSIVE) RADIO ASTRONOMY SPACE RESEARCH (PASSIVE) 5.340	Passive sensors (satellite) Radio astronomy

5.149: In making assignments to stations of other services to which the bands: 13 360-13 410 kHz, 25 550-25 670 kHz, 37.5-38.25 MHz, 73-74.6 MHz in Regions 1 and 3, 150.05-153 MHz in Region 1, 322-328.6 MHz, 406.1-410 MHz, 608-614 MHz in Regions 1 and 3, 1 330-1 400 MHz, 1 610.6-1 613.8 MHz, 1 660-1 670 MHz, 1 718.8-1 722.2 MHz, 2 655-2 690 MHz, 3 260-3 267 MHz, 3 332-3 339 MHz, 3 345.8-3 352.5 MHz, 4 825-4 835 MHz, 4 950-4 990 MHz, 4 990-5 000 MHz, 6 650-6 675.2 MHz, 10.6-10.68 GHz, 14.47-14.5 GHz, 22.01-22.21 GHz, 22.21-22.5 GHz, 22.81-22.86 GHz, 23.07-23.12 GHz, 31.2-31.3 GHz, 31.5-31.8 GHz in Regions 1 and 3, 36.43-36.5 GHz, 42.5-43.5 GHz, 48.94-49.04 GHz, 76-86 GHz, 92-94 GHz, 94.1-100 GHz, 102-109.5 GHz, 111.8-114.25 GHz, 128.33-128.59 GHz, 129.23-129.49 GHz, 130-134 GHz, 136-148.5 GHz, 151.5-158.5 GHz, 168.59-168.93 GHz, 171.11-171.45 GHz, 172.31-172.65 GHz, 173.52-173.85 GHz, 195.75-196.15 GHz, 209-226 GHz, 241-250 GHz, 252-275 GHz are allocated, administrations are urged to take all practicable steps to protect the radio astronomy service from harmful interference. Emissions from spaceborne or airborne stations can be particularly serious sources of interference to the radio astronomy service (see Nos. 4.5 and 4.6 and Article 29). (WRC-07)

5.340: All emissions are prohibited in the following bands: 1 400-1 427 MHz, 2 690-2 700 MHz, except those provided for by No. 5.422, 10.68-10.7 GHz, except those provided for by No. 5.483, 15.35-15.4 GHz, except those provided for by No. 5.511, 23.6-24 GHz, 31.3-31.5 GHz, 31.5-31.8 GHz, in Region 2, 48.94-49.04 GHz, from airborne stations 50.2-50.4 GHz [see No. 5.340.1] , 52.6-54.25 GHz, 86-92 GHz, 100-102 GHz, 109.5-111.8 GHz, 114.25-116 GHz, 148.5-151.5 GHz, 164-167 GHz, 182-185 GHz, 190-191.8 GHz, 200-209 GHz, 226-231.5 GHz, 250-252 GHz. (WRC-03)

5.538A: In the frequency bands 1 350-1 400 MHz, 1 427-1 452 MHz, 22.55-23.55 GHz, 24.25-27.5 GHz, 30-31.3 GHz, 49.7-50.2 GHz, 50.4-50.9 GHz, 51.4-52.4 GHz, 52.4-52.6 GHz, 81-86 GHz and 92-94 GHz, Res. 750 (Rev.WRC-19) applies. (WRC-19)

5.561A: The 81-81.5 GHz band is also allocated to the amateur and amateur-satellite services on a secondary basis. (WRC-2000)

4 SHARING STUDIES

Parameters of victim systems and methodologies have been reused from existing documentation within ECC and ITU. An overview of existing documentation is given in Annex 2.

4.1 SHARING WITH THE RADIO ASTRONOMY SERVICE

4.1.1 Use of the band by RAS and regulatory status

Radio Astronomy Service (RAS) is allocated as a primary service in the 76 GHz to 77.5 GHz and 79 to 81 GHz frequency bands, while 77.5-78 GHz is allocated as secondary. Furthermore, the full frequency range (76-81 GHz) is addressed in the footnote RR No. 5.149 [37] because of the scientific interest in this frequency range. Important detections of molecules in the interstellar medium have been performed with first-class radio telescopes such as the 30 m radio telescope (IRAM Pico Veleta, Spain), the NOEMA interferometer (IRAM Plateau de Bure, France), the Onsala 20 m radio telescope (OSO, Sweden) and the 40 m radio telescope (IGN-Yebes Observatory, Spain) in the 76-81 GHz range.

Many large prebiotic molecules can be detected in this range, such as CH3OH, CH3C5N, and the long carbon chains (HC3N, HC9N, C3N, C5H, etc). Particularly important are some deuterated molecules (DNC, DC3N and mainly N2D+), where the N2D+ J=1-0 line at 77.1 GHz is the best tracer of pre-stellar condensations, particularly in the crucial phase in which stars are ready to be formed, but with the interstellar gas still being cold.

Another field of research in the frequency range of 76-81 GHz is the study of emission of galaxies, observed via the highly redshifted CO lines. The analysis of these lines is required to understand star formation inside galaxies.

According to footnote No. 5.149 of the Radio Regulations, administrations are urged to take all practicable steps to protect the RAS from harmful interference in the 76-86 GHz frequency band. The necessary protection levels are defined in Recommendation ITU-R RA.769-2 [16], whose Table 1 contains threshold levels for the so-called continuum observations (which apply here) for a range of example bands. As no value is provided in that Table for the particular frequency bands studied in this Report, the threshold values provided for 89 GHz are considered.

4.1.2 RAS protection criterion

In Recommendation ITU-R RA.769-2 the protection criterion for continuum observations in the relevant frequency range provides a value of -228 dB (W/m²/Hz), which was also used in existing studies. However, for this Report a power spectral density (PSD) limit is proposed to be calculated from the interference input power limit of -189 dBW which is also given in RA.769-2. This results for a 4 GHz Radar system in -195 dBm/MHz, for a 2 GHz Radar system in -192 dBm/MHz and for a 1 GHz radar system in -189 dBm/MHz.

4.1.3 Parameters used in this Report

For the single interferer study (see section 4.1.4.1), it is assumed that the device under test is a car equipped with a single radar Type A which belongs to the category of Long Range Radar (LRR).

For the aggregation study (see section 4.1.4.2) it is assumed that the device under test is a car equipped with several radar devices.

The technical parameters of a radar device are shown in 2.2. However, the transmitter antenna pattern has to be taken into account for cases where the RAS station is not located close to the boresight of the radar antenna.

The parameters for the radio astronomy station are defined in Recommendation ITU-R RA.769-2 [16] and are shown in Table 9. A list of RAS stations in Europe is included in Table 10.

Table 9: Radio astronomy station parameters

System Parameter	Value	Remarks
Integration time	2000 s	
Side lobe gain, Gr	0 dBi	According to Recommendation ITU-R RA.769-2 [16], only side lobe receptions need to be considered
Duty cycle	30 %	Percentage of time where the signal is active. It reduces the average power
Threshold interference level: Recommended continuum power, P_{lim}	-189 dBW	For continuum observations, extracted from Recommendation ITU-R RA.769-2 [16]
Antenna height, hrx	D/2 m	D is the diameter of the antenna. See column 5 of Table 10
Polarisation loss	0 dB	RAS observations use both polarisations

4.1.4 Interference scenarios and methodologies

In the following, two different scenarios are considered. First, a single-entry worst-case study is performed, in which it is assumed that a car points (one of) its Radar system (type A) towards the RAS station. However, the number of cars in the area will usually be large, which increases the potential power received by the radio telescope significantly. At the same time, not all car Radars will transmit towards the telescope. Therefore, in a second more realistic scenario, a full simulation of a large number of cars is performed. This is based on a realistic road network and takes into account several possible mitigation effects from antenna directions and local clutter on the transmitter side.

The terrain around a radio telescope has an important impact on the study results, which is why, for both scenarios, the propagation model according to ITU-R Recommendation P.452-16 [13] is employed. For the aggregate case, the clutter losses are determined according to the model in P.452-16, as well, which is a correction to the propagation path loss taking into account the end point of the path, only. An explanation of the applicability of model P.452-16 in the frequency range 77-81 GHz is given in Annex 3.

According to Recommendation ITU-R RA.1513 [17], RAS has to accept a maximum data loss of 2%. Therefore, for the propagation model, a time-percent value of 2% is used throughout this section.

Two sites are studied in detail in the following: Plateau de Bure/NOEMA (France) and Sardinia/SRT (Italy), which lead to. 53 km (NOEMA) and 40 km (SRT). Comparing the results of the first three scenarios (A, 4B and A+4B) with the latter three scenarios (B, 4C and B+4B) very similar exclusion zone sizes are required. While the nominal maximum e.i.r.p. of the former is higher, the beam widths of the antennas in the latter compensate for the lower e.i.r.p. in the aggregation calculations. The spread of curves is due to the high number of possible configurations considered. Table 13 and Figure 20 show the summary of necessary exclusion zone sizes for the different radar configurations.

For the other sites only a summary of the results is provided in Table 13 and resulting images are provided attached to this Report. Terrain height profiles are based on Lidar data [18], except for those under Note 1 in Table 10, which are based on SRTM data [19]. Maido (France) and Raege (Portugal) were not studied in aggregate case due to the lack of data for the road maps.

Table 10: List of CEPT radio telescopes (RT) operating in the 77-81 GHz band

Observatory Name	Administration	Longitude I, Latitude (N)	Elevation (m AMSL)	Antenna Height (m)	Geographical characteristics
Plateau de Bure/ NOEMA	France	05°54'28.5″ 44°38'02"	2553	8	Isolated high mountain top in the Alps
Sardinia (SRT)	Italy	09°14′42″ 39°29′34″	600	32	Partially shielded by surrounding mountains
Pico Veleta (IRAM-30 m)	Spain	-03°23'34" 37°03'58"	2850	17	Sierra Nevada Mountain
Onsala (note 1)	Sweden	11°55'04" 57°23'35"	18	10	Waterside, forested. Located at 5 km from the closest urban area (Onsala)
Effelsberg	Germany	06°53'01.0" 50°31'29.4"	369	50	Located in a valley in a mountainous area
Medicina (note 1)	Italy	11°38'49" 44°31'15"	28	16	Flat plain near Bologna
Noto	Italy	14°59'20.51" 36°52'33.78"	90	16	Partially shielded by surrounding mountains
Metsähovi (note 1)	Finland	24°23'36" 60°13'05"	80	7	Flat populated countryside
BEST (note 1)	Hungary	19°31'00" 47°54'00"	240	9	Forested mountainous area
Yebes	Spain	-03°05'13" 40°31'28.8"	980	22	Broad flat plain
Maido (note 2)	France	55°23’01” –21°04’46”	2200	2	Mountain top
RAEGE Santa María (note 2)	Portugal	-25°07′33.2″ 36°59′7.1″	247	9	Island in Azores archipelago

Note 1: Lidar Data are not freely available for these sites, therefore, SRTM data is used.
Note 2: Not studied in aggregate case due to the lack of data for the road maps.

4.1.4.1 Site-specific single-entry scenarios

In the single-entry scenario, only one transmitter is considered, which emits with maximum gain towards the RAS station. Considering only type A radars as transmitter with an average e.i.r.p. of 40 dBm and a duty cycle of 30%, the effective e.i.r.p. is 34.8 dBm. The difference between the transmitter (Tx) e.i.r.p., (Long Range Radar) and the RAS threshold (Table 9) is denoted as the minimum coupling loss (MCL). For the site-specific single-entry scenario, just one transmitter is assumed. The actual difference between the MCL and the determined path propagation loss (following the propagation model in Recommendation ITU P.452-16 [13]) is called the margin. A positive margin means that the received signal strength is below the RAS threshold from Recommendation ITU-R RA.769-2 and thus both applications are compatible with each other. A negative margin indicates a violation of the threshold levels. Therefore, the area enclosed by the zero-margin contour indicates the potential size of an exclusion zone.

In Figure 5 and Figure 6, the left panel shows the path loss map at 77 GHz, while the right panel shows the contour black line at which the margin is zero, thus it identifies the minimum separation distance for the specific site considering the terrain heights. The white circles show distances from the RAS stations in steps of 25 km. As explained above, for the single-entry worst-case study, no clutter attenuation is considered. Likewise, the maximum transmitter antenna gain is assumed.

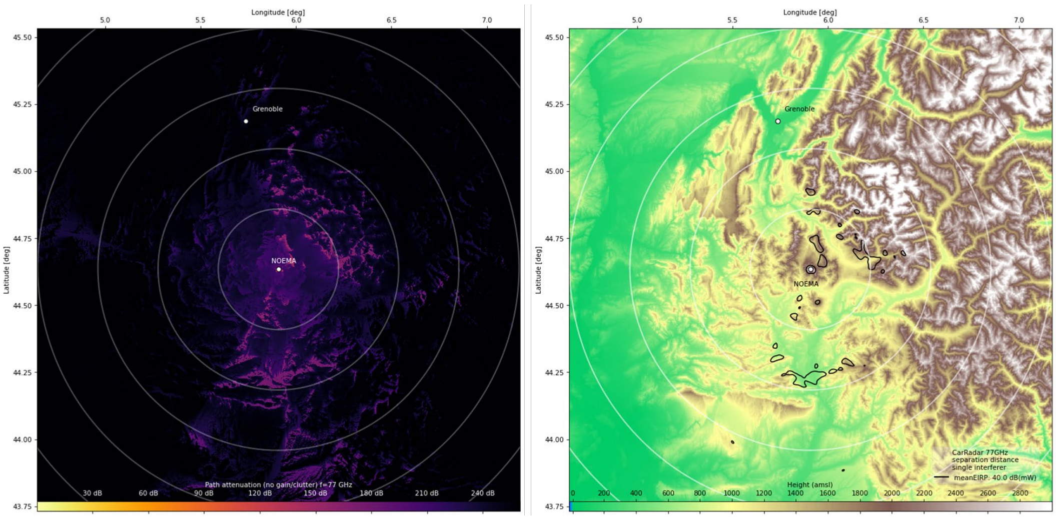


Figure 5: Attenuation map (left) and exclusion zone (right) for the single interference case for NOEMA

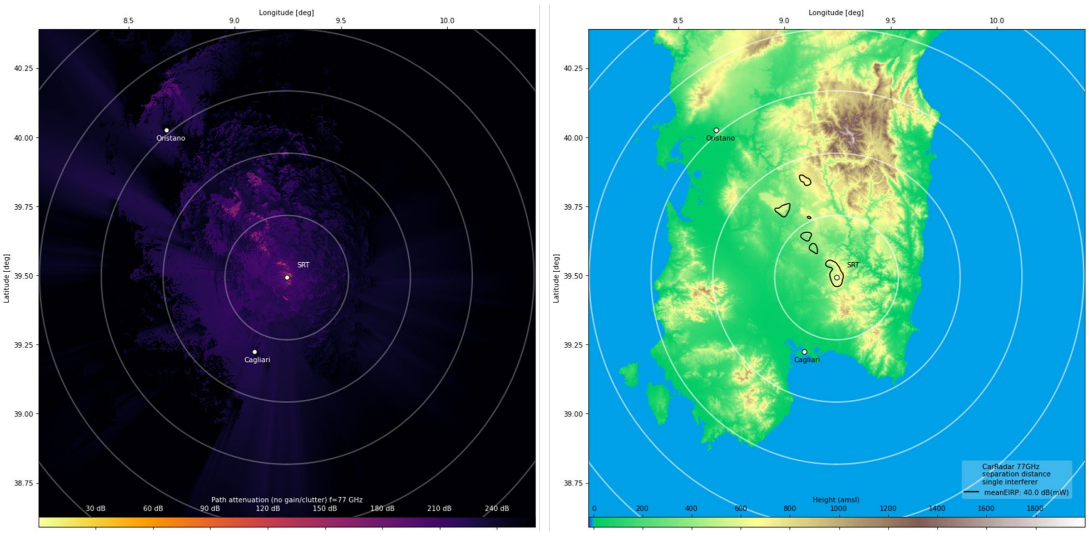


Figure 6: Attenuation map (left) and exclusion zone (right) for the single interference case for Sardinia (SRT)

In both cases, for SRT and NOEMA, the resulting exclusion zones are within a radius of less than 50 km and highly direction-dependent.

4.1.4.2 Site-specific aggregation scenarios

For the aggregation case, a more realistic scenario is assumed, where several vehicles are located randomly on the different roads around the radio telescopes following a statistical distribution (see Table 12).

To simulate a realistic distribution of vehicles, road map data from OpenStreetMap [20] (OSM) is utilised, which is available under Open Database License [21]. For each scenario, road map data within an area of 200x200 km^2 were queried. OSM differentiates between various road types. Table 11 lists the total length of each type of road in the area for the two stations. For simplicity, all road types other than "primary", "secondary", "tertiary" and "residential" were subsumed into a category "other". Motorways and trunk roads are considered as primary roads. Figure 7 shows the average road length in certain distance bins (normalised to the area). When interpreting the numbers, one should consider that different types of roads will have very different traffic statistics. For example, the NOEMA station has more than 6000 km of primary roads on 200x200 km^2 area.

Table 11: Total Road length per road type with 100 km radius centred around the RAS stations. OpenStreetMap contributors

Road Type	Total length of roads (per type) (km)	
	NOEMA	SRT
Primary	7805	3981
Secondary	13000	4130
Tertiary	21372	4858
Residential	21404	9052
Other	49776	10389
All	113357	32410

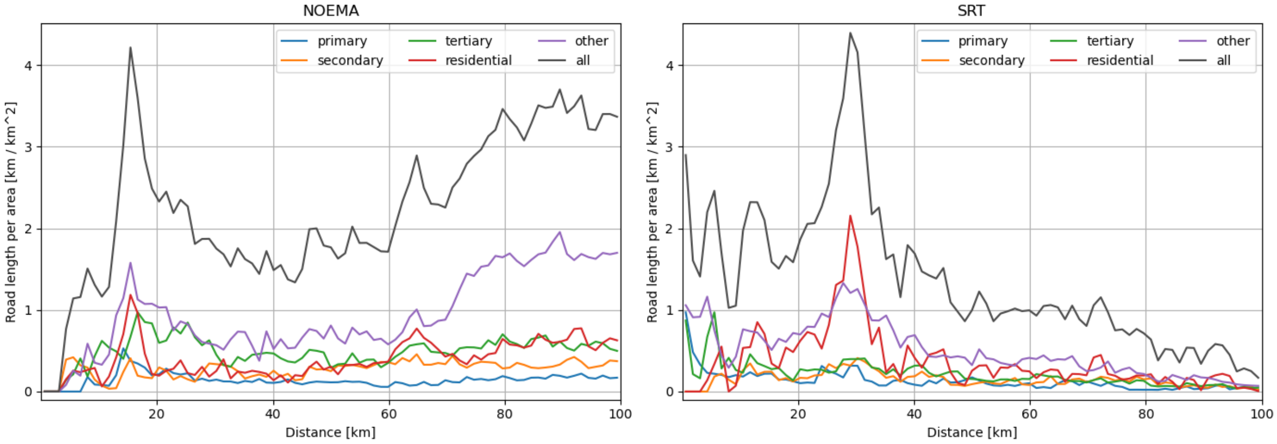


Figure 7: Road length per area per road type in distance bins around the RAS stations. Based on OpenStreetMap

For an aggregation study, one can create samples of vehicles which follow the road distribution and also account for the different types of roads. To acknowledge the fact that traffic can be different during the day (and night) and also from day to day, the overall number of vehicles in such a sample can also be varied. In

Table 12, the deployment parameters are summarised. For each of the road types, a normal distribution with a given mean and standard deviation was used to randomly sample the overall vehicle density for one realisation in the simulation (ECC Report 327, table 61 [49]). As the radar antenna directions play a role in the simulation, the motion vector of the car has to be considered, i.e. cars can usually travel in both directions of a road. In total, the simulation was repeated 100 times to have a fair number of realisations for statistical analyses, e.g. to estimate uncertainties. In each simulation run, vehicles were placed randomly onto the roads according to the desired density distributions. To account for the rather long integration time of 2000 s, which is the basis of the RAS thresholds (compare ITU-R RA.769 [16]), vehicular positions were sampled 200 times each (according to a time resolution of 10 s). The antenna pattern provided in Recommendation ITU-R M.2057 [8] is applied to determine the effective gain of the transmitter into the direction of the RAS station. The azimuthal (offset) angle with respect to the transmitter boresight can be directly computed from the motion vector of the car relative to the direction to the receiving RAS station. The motion vector was derived from the OSM road vectors. The roads are stored as polygons, i.e. the motion vector on a given road piece is entirely determined by the start and end point of the road piece (but can have the anti-parallel direction, of course). The elevation pattern is not purely geometric, as the actual propagation path could also be trans-horizon, in which case the path horizon elevation angle is the angle under which the local (radio) horizon appears. The elevation angles are determined according to the Recommendation ITU-R P.452 [13] model. Antenna patterns are shown in Table 5. Figure 8 and Figure 9 show a realisation of the simulations (the one with the highest overall vehicle density) for each station. The average car density is respectively 5.6 and 2.2 car/km^2 for NOEMA and SRT station. In these maps, transparent lines show road data, while filled dots indicate the vehicle positions. RAS stations are marked with a black square, while grey circles indicate distances from the RAS station in steps of 25 km.

Table 12: Vehicle densities used for the simulation

Road type	Vehicle density (vehicles/km)
Primary	3.6 ± 0.9
Secondary	0.6 ± 0.15
Tertiary	0.2 ± 0.05
Residential	0.1 ± 0.025
Other	0.1 ± 0.025

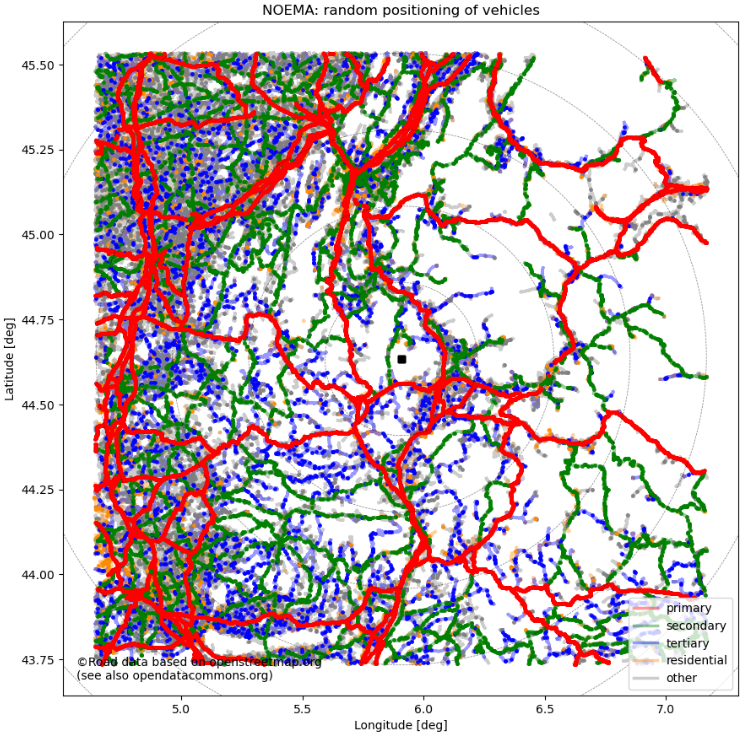


Figure 8: Random vehicle positions from the simulations around NOEMA station

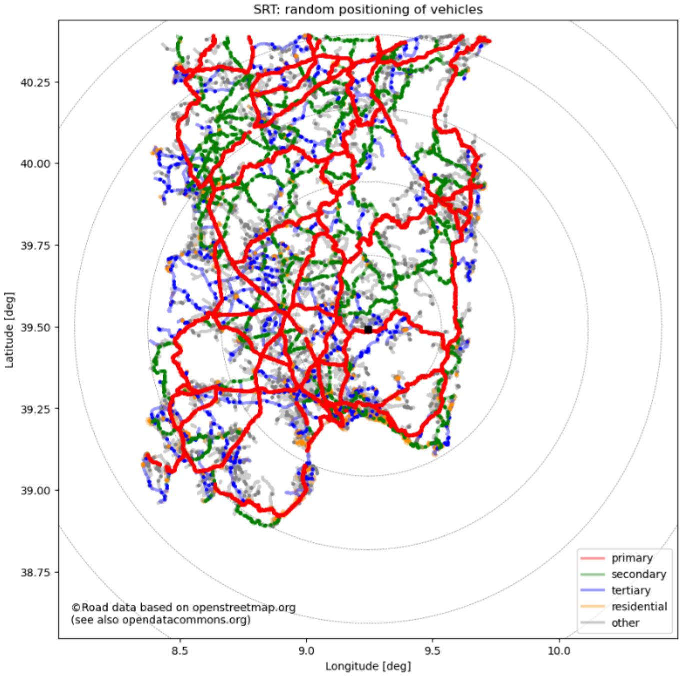


Figure 9: Random vehicle positions from the simulations around Sardinia (SRT) station

Based on the location of vehicles, one can then determine the propagation loss individually. Furthermore, Corine Land Cover (CLC) data [22] was queried to obtain the clutter type zones for each position. Based on the clutter type, the clutter loss model in Recommendation ITU-R P.452 [13], and a Tx height of 0.7 m, the clutter loss could be determined. Figure 10 and Figure 11 show the inferred clutter types around each station.

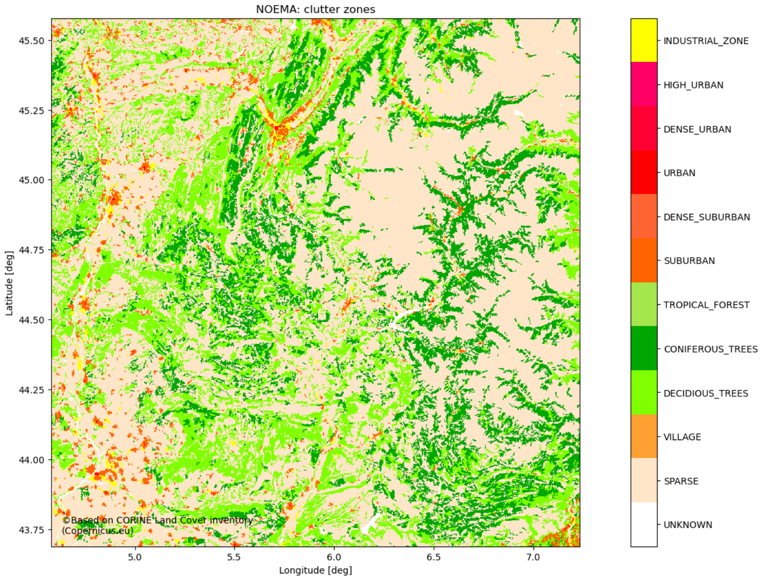


Figure 10: Clutter type zones around NOEMA station

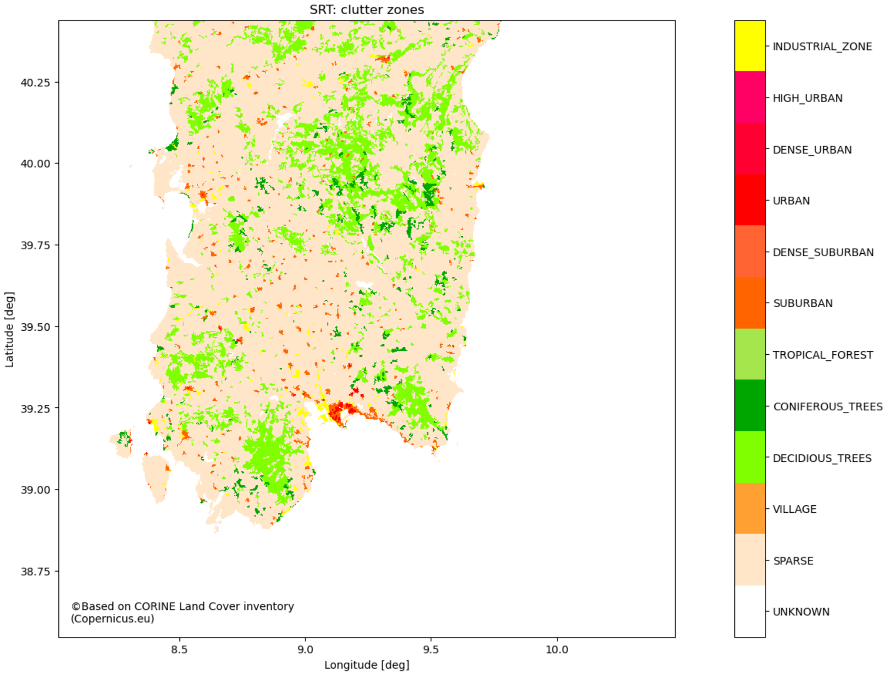


Figure 11: Clutter type zones around SRT station

In reality, each car will have several radars. To properly estimate the total contribution, multiple radars (six different cases) have been considered for each car. In particular, the following scenarios were assessed:

- Scenario A: 1 front radar, type A;
- Scenario 4B: 4 corner radars, type B;
- Scenario A+4B: 1 front radar, type A, and 4 corner radars, type B;
- Scenario B: 1 front radar, type B;
- Scenario 4C: 4 corner radars, type C;
- Scenario B+4C: 1 front radar, type B, and 4 corner radars, type C.

The other radar types considered in this Report have shorter range and will not significantly change the outcome. The resulting antenna patterns of the mixed scenarios, A+4B and B+4C, are shown from Figure 12 to Figure 15.

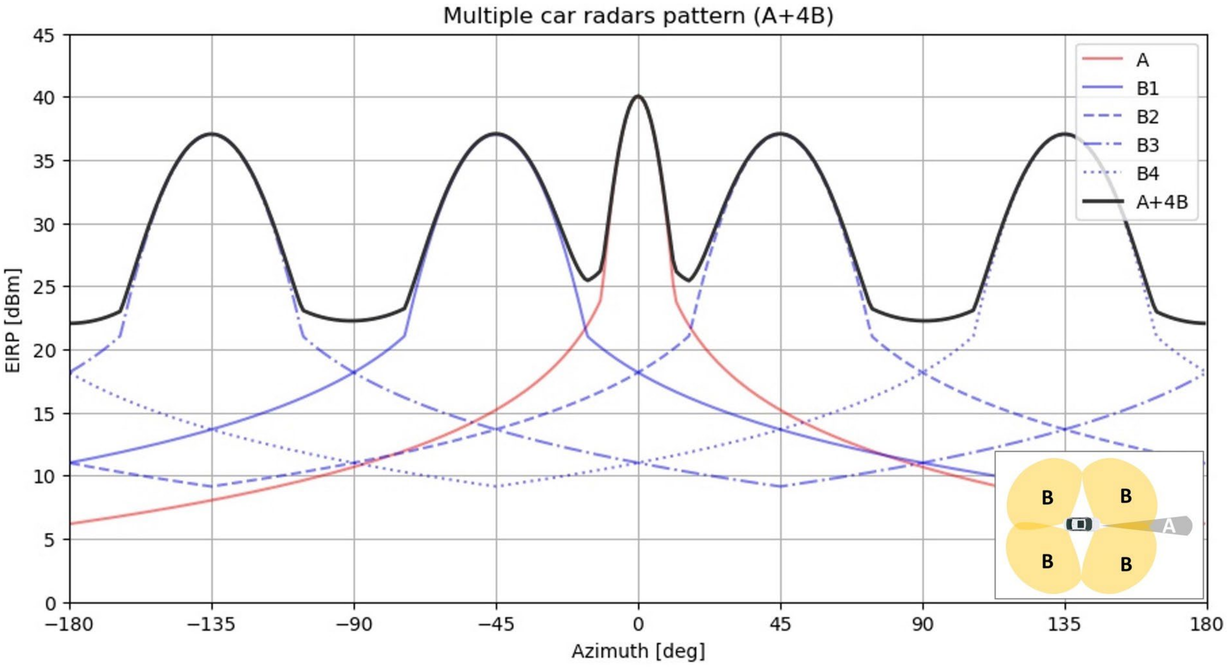


Figure 12: Antenna pattern of multiple radars, type A in the front direction and 4 type B in the corner directions at 0° elevation plane. Bottom right: top view of the radar distribution

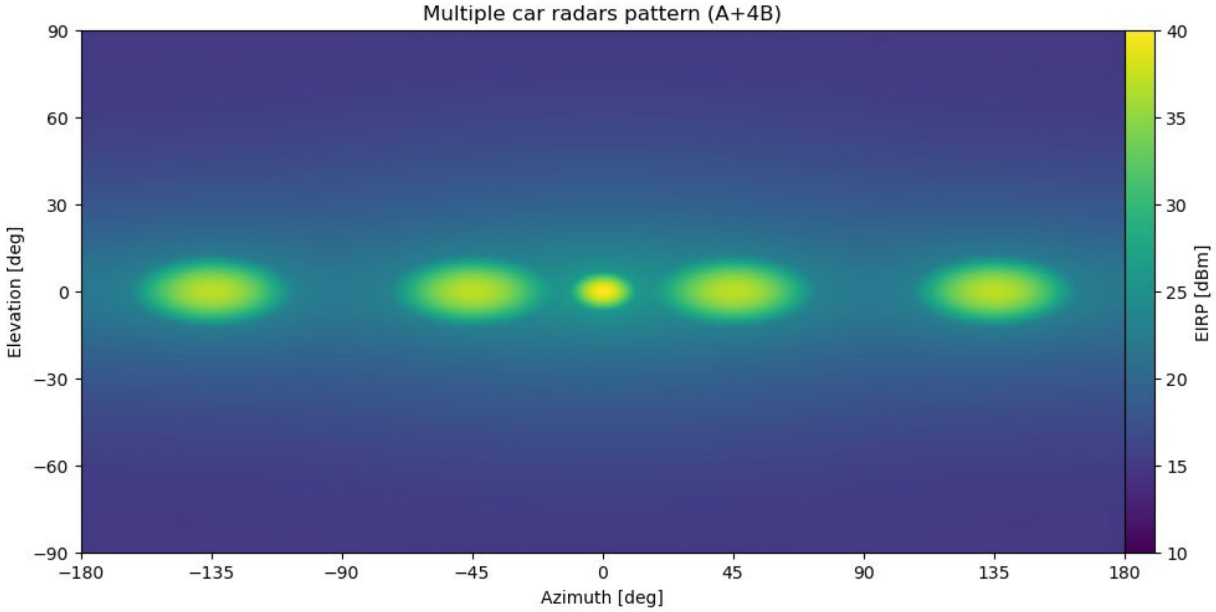


Figure 13: Antenna pattern of multiple radars, type A in the front direction and 4 type B in the corner directions displayed for both azimuthal and elevation planes

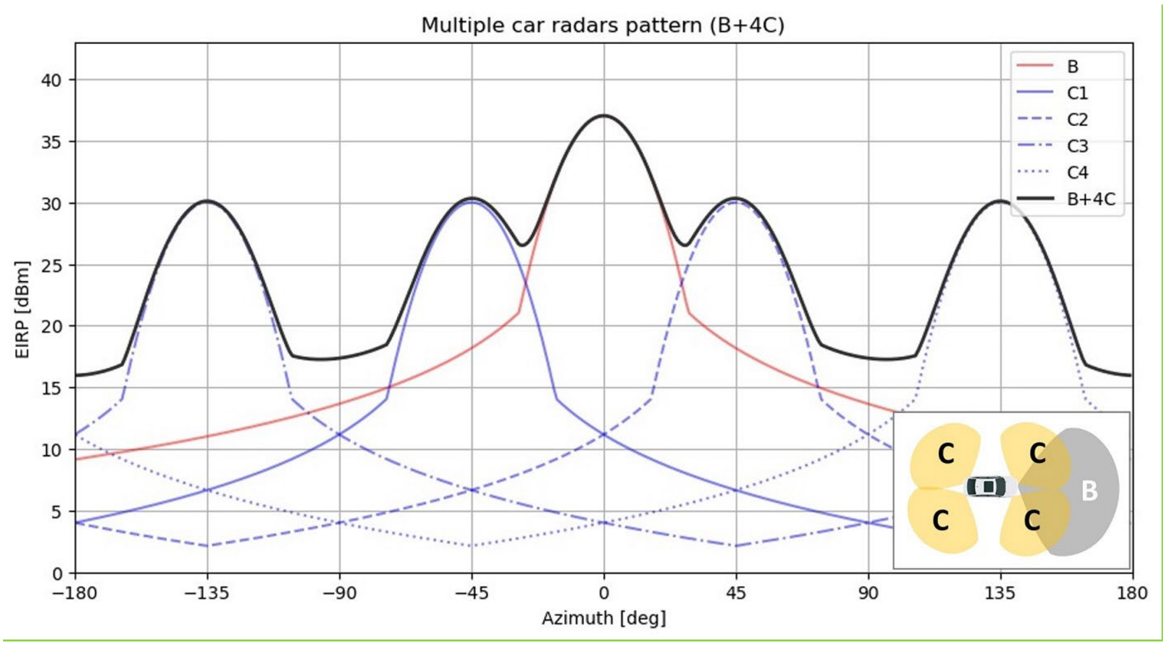


Figure 14: Antenna pattern of multiple radars, type B in the front direction and 4 type C in the corner directions at 0° elevation plane

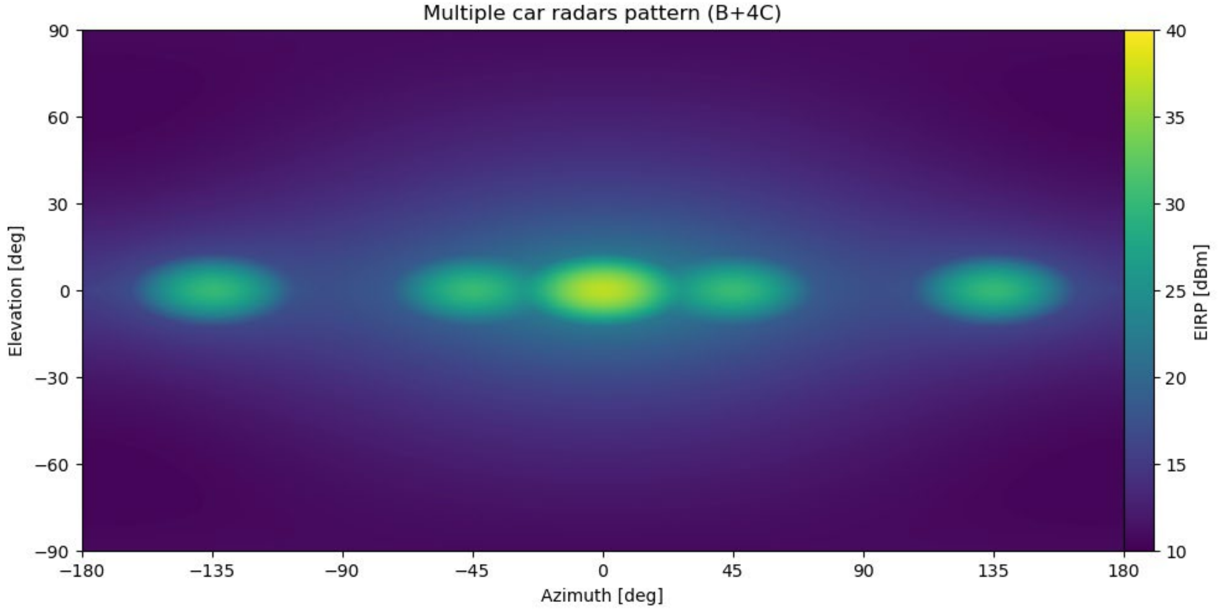


Figure 15: Antenna pattern of multiple radars, type B in the front direction and 4 type C in the corner directions displayed for both azimuthal and elevation planes

The aggregated received power at the RAS station can be determined for each simulation run (averaging the powers of all time steps). As this almost always exceeds the RAS thresholds, the aggregation was repeated for a number of hypothetical exclusion zones, in which no device would be active.

Results

The results are depicted from Figure 16 to Figure 19, which show the received power for the various exclusion zone radii for each iteration and the median for single radar (type A and type B) and multiple radars (4B, A+4B, 4C and B+4C). The exclusion zone radius actually required to comply with the RAS threshold is determined by the intersection of the median curve (black solid line) with the RAS threshold line (red dashed horizontal line).

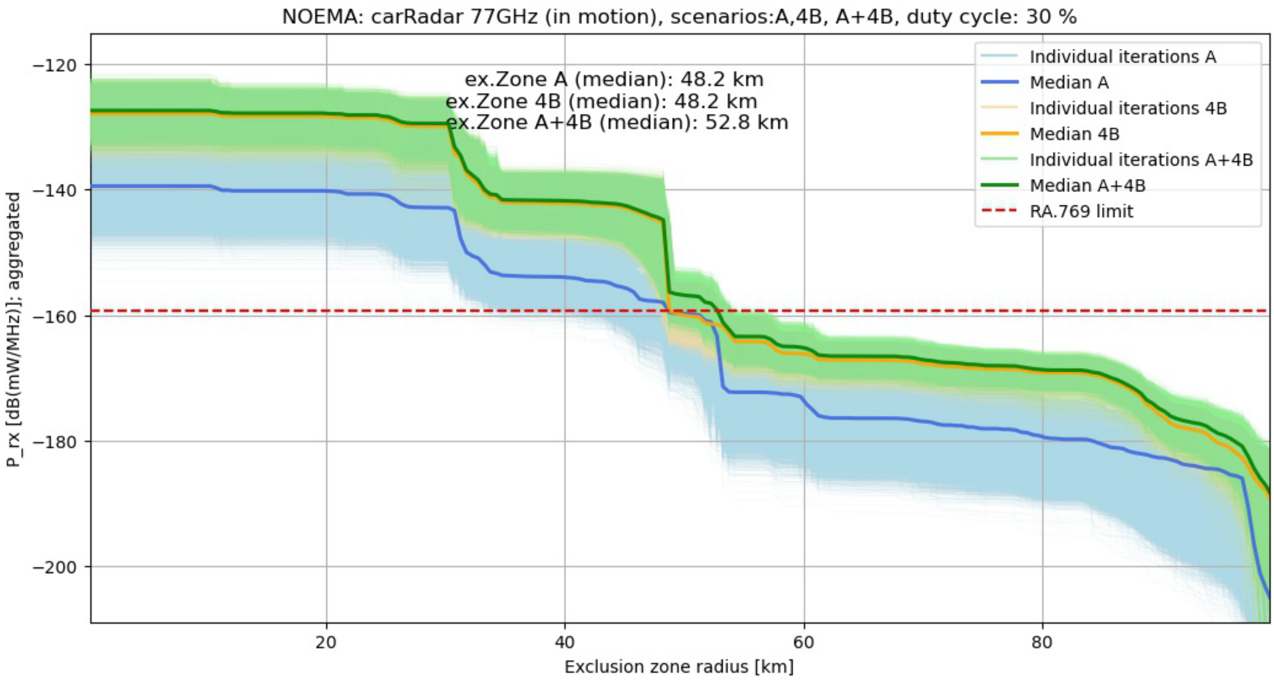


Figure 16: Results of the aggregation calculation of Automotive Radar (type A, type 4B, and type A+4B) in motion around NOEMA station

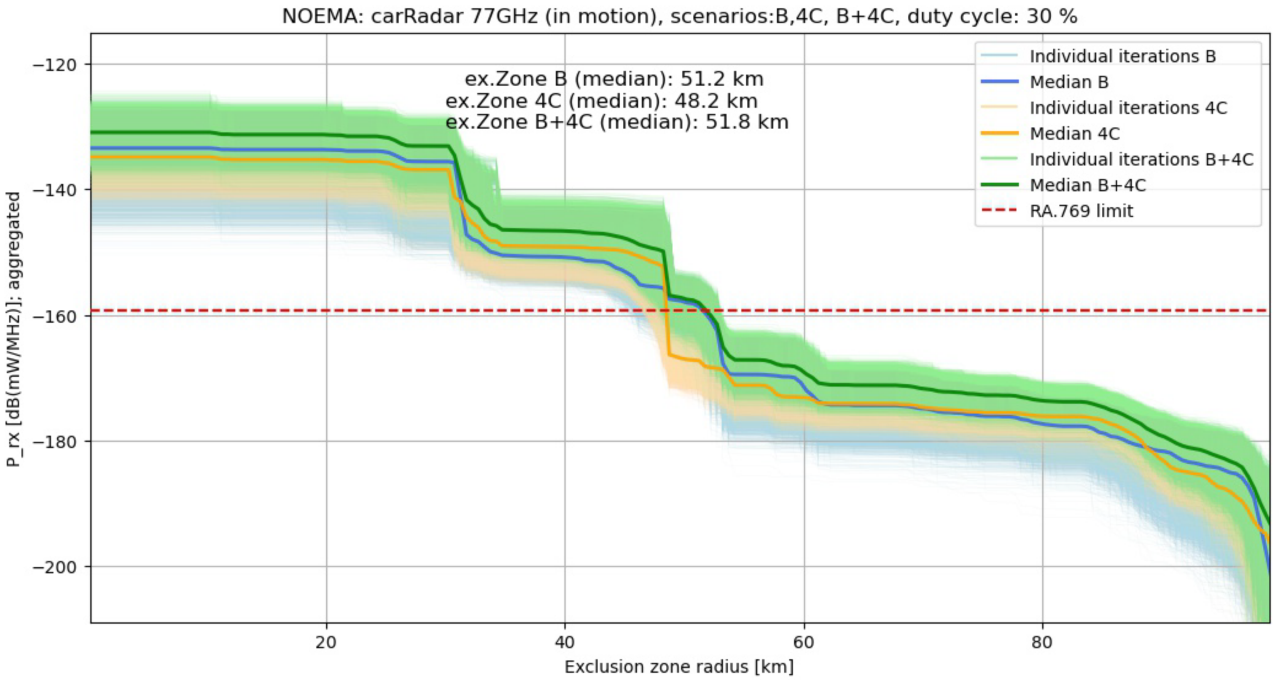


Figure 17: Results of the aggregation calculation of Automotive Radar (type B, type 4C and type B+4C) in motion around NOEMA station

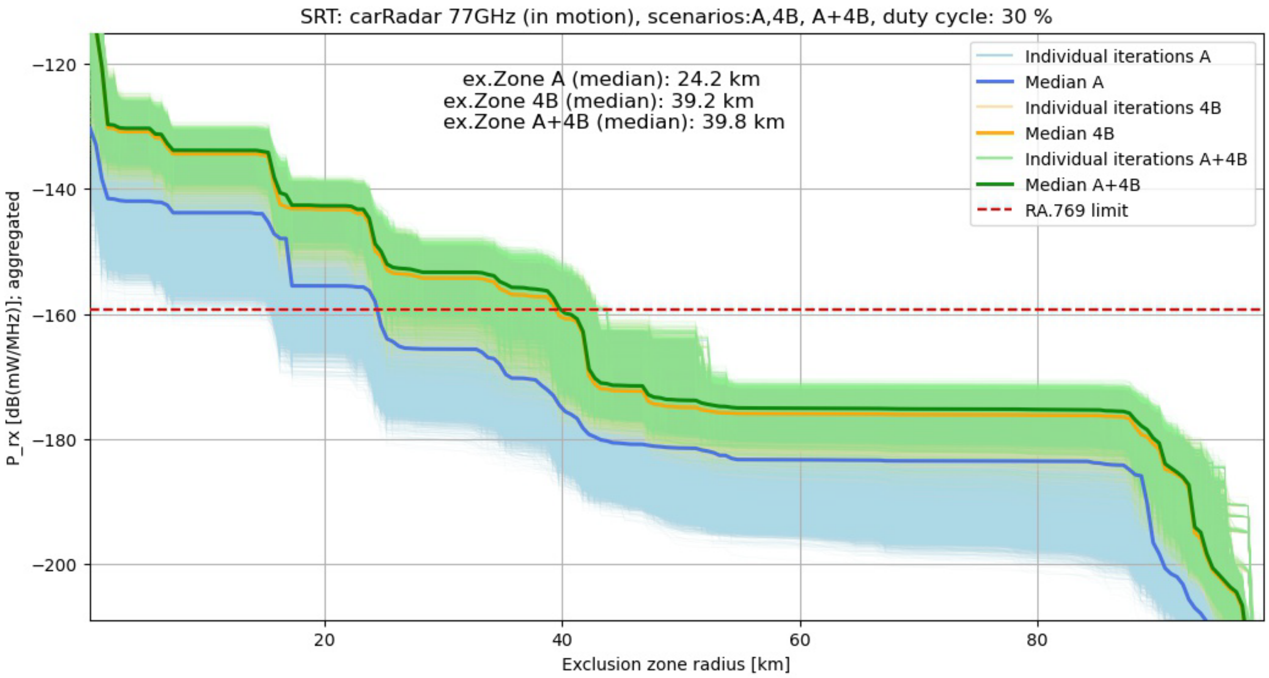


Figure 18: Results of the aggregation calculation of Automotive Radar (type A, type 4B, and type A+4B) in motion around SRT station

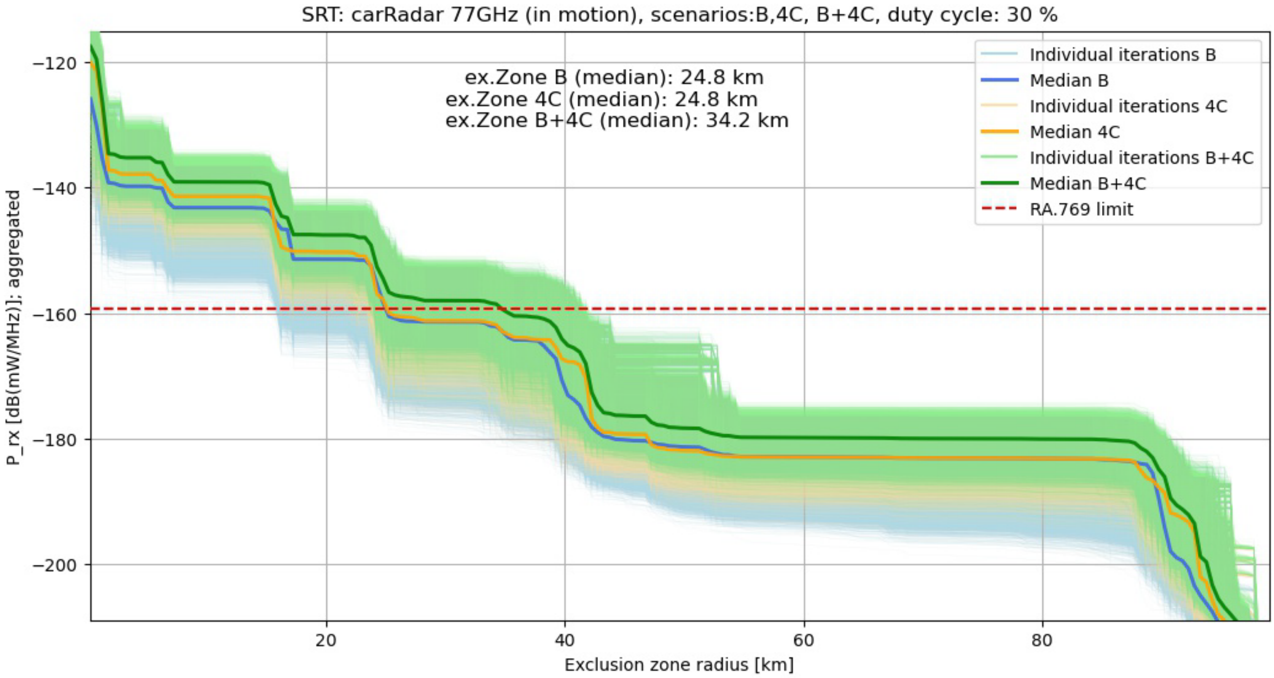


Figure 19: Results of the aggregation calculation of Automotive Radar (type B, type 4C and type B+4C) in motion around SRT station

The results show a range of necessary exclusion zone sizes, depending on the radar configurations and environment of a site. For the type A car radar, compatibility with RAS is achieved with an exclusion zone size of 48 km for the NOEMA station and 24 km for the Sardinia station, respectively, while for the multiple radar (A+4B) case the necessary exclusion zone size increases up to 53 km (NOEMA) and 40 km (SRT). Comparing the results of the first three scenarios (A, 4B and A+4B) with the latter three scenarios (B, 4C and B+4B) very similar exclusion zone sizes are required. While the nominal maximum e.i.r.p. of the former is higher, the beam widths of the antennas in the latter compensate for the lower e.i.r.p. in the aggregation calculations. The spread of curves is due to the high number of possible configurations considered. Table 13 and Figure 20 show the summary of necessary exclusion zone sizes for the different radar configurations.

Table 13: Summary of the exclusion zone radius considering different radar configurations for the CEPT RT

	Required exclusion zone sizes (km) for each scenario					
Observatory Name	**A**	**4B**	**A+4B**	**B**	**4C**	**B+4C**
Plateau de Bure/NOEMA	48.2	48.2	52.8	51.2	48.2	51.8
Sardinia (SRT)	24.2	39.2	39.8	24.8	24.8	34.2
Pico Veleta (IRAM-30m)	60.2	68.2	69.2	62.2	58.8	64.2
Onsala	12.8	20.2	21.2	15.8	18.8	19.8
Effelsberg	1.8	2.2	2.2	1.8	1.8	1.8
Medicina	50.2	63.8	65.2	52.8	51.2	57.8
Noto	13.2	26.8	27.8	13.8	14.8	18.8
Metsähovi	5.8	14.2	15.2	6.2	14.2	14.2
BEST	14.2	16.2	16.2	14.8	15.8	15.8
Yebes	57.8	66.8	67.2	59.8	61.2	64.8

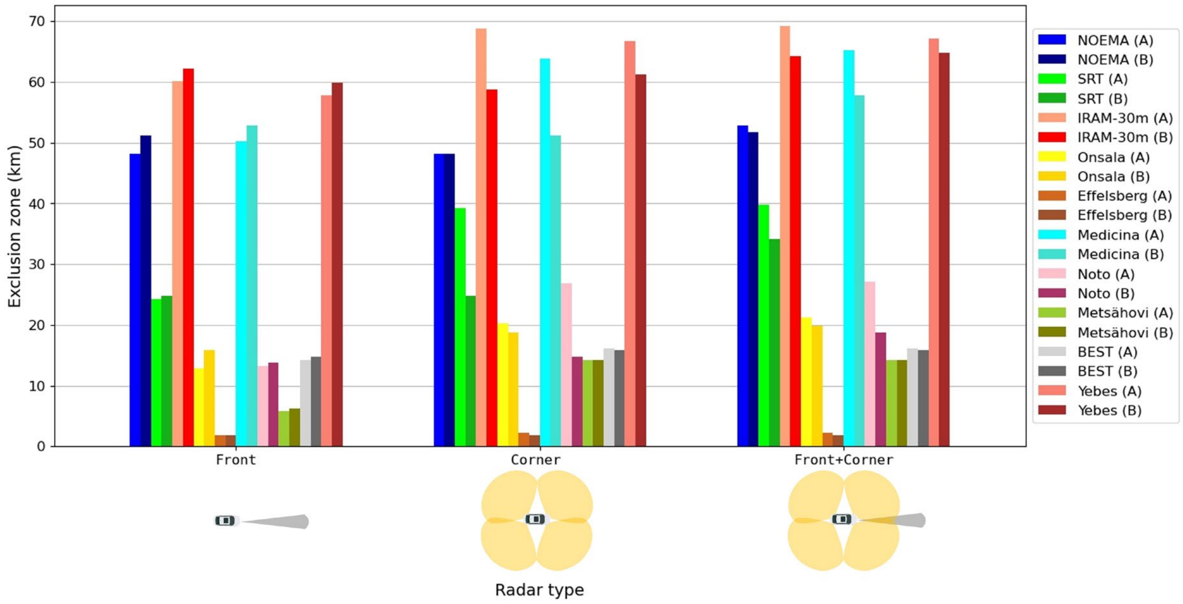


Figure 20: Summary of the exclusion zone radius considering different radar configurations for CEPT RAS stations (#1 refers to type A, 4B or A+4B and #2 refers to type B, 4C or B+4C)

4.1.5 Conclusion

The single-entry study leads to similar exclusion zones for both NOEMA and SRT, up to approximately 50 km.

Comparing the results of the aggregation study, no significant variations are found for the same location in different scenarios. The terrain seems to play an important role for the exclusion zone size, varying from a few kilometres (Effelsberg) up to almost 70 km (IRAM and Yebes) (see Table 13).

4.2 SHARING WITH THE RADIOLOCATION SERVICE

In 2020, information was provided that no military radiolocation systems are operated by NATO members in the band 77 to 81 GHz. Furthermore, there are no plans to introduce such systems.

There is no other application of the Radiolocation Service using this band.

4.3 SHARING WITH THE AMATEUR SERVICE

The amateur and amateur-satellite services have secondary and primary allocations within the range of study between 75.5 and 81 GHz. Whilst past use has been inhibited by equipment availability, 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 non-geostationary amateur satellite transponders);
- Growing use of wider bandwidth modes, such as Digital Amateur TV (DATV) and data links;
- Usage of fixed beacon transmitting stations for propagation research and equipment alignment.

In general, most amateur stations are currently portable low-power highly directional systems. In order to maximise Long Range communications, operation is often from elevated locations where they can achieve terrestrial line of sight contacts up to 50 km. Antennas operate at elevated angles for EME and satellite operations.

4.3.1 Methodology

In the following, single interferer MCL calculations were done for an area around an amateur service receiver which is placed at the position (0,0) and directed to the right. The impact of a single AR interferer (directed towards the Amateur Service antenna in the azimuth) is calculated on each point of the area taking into account the antenna patterns. A schematic view from the top is given in Figure 21.

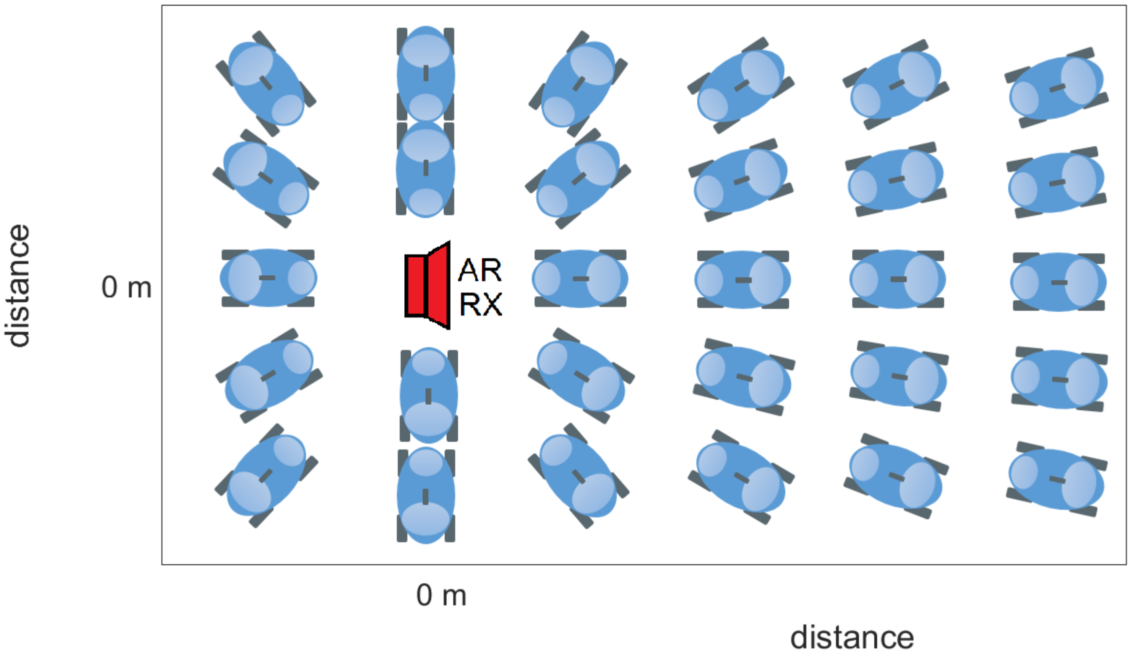


Figure 21: MCL top view

Both antennas are pointing to 0° in elevation. A schematic view from the side is given in Figure 22.

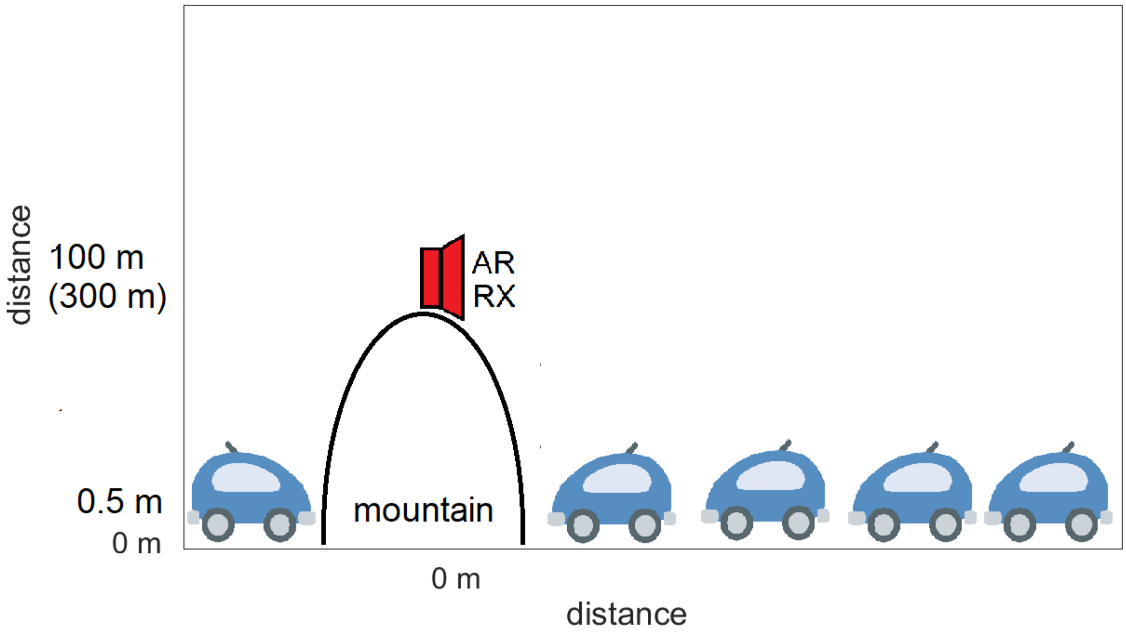


Figure 22: MCL side view

The impact of a single AR interferer is calculated on each point of the area. A red contour highlights the separation distance in each direction. The coloured areas highlight the amount to which the results lie above or below the criterion I/N =-6 dB. The parameters used and also the results are noted on the plots, respectively.

Peak radius results represent the maximum range of interference coming from the height level of the AR, when a constant ground level of 0 m is assumed. This is usually located in the main lobe direction.

Circle radius results represent the minimum range of interference coming from the height level of the AR, when a constant ground level of 0 m is assumed. This is usually located in the back lobe area.

Main beam to main beam results represent the MCL calculation, where no vertical geometry was considered.

4.3.2 Victim parameters

Recommendation ITU-R M.1732-2 [11] provides generic characteristics of stations operating in the amateur service for use in sharing studies. However, they are not very specific for the 75.5-81 GHz frequency range. This Report considers the appropriate amateur and amateur-satellite service characteristics as used in ECC Report 315 [6] and summarised in Table 14.

Terrestrial stations in the amateur and amateur-satellite services have identical technical characteristics, except for the (variable) positive elevation angle of the receiver antenna.

Table 14: Examples of Amateur and Amateur-Satellite Service characteristics in the band 75.5-81 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)	36–42 (typically: 40)	36–42 (typically: 40)	36–42 (typically: 40)	36–42 (typically: 40)
Antenna polarisation	Horizontal, Vertical	Horizontal, Vertical	Horizontal, Vertical	Horizontal, Vertical
Receiver Noise Figure (dB)	3–7 (typically 4)	3–7 (typically 4)	3–7 (typically 4)	3–7 (typically 4)

4.3.3 Operational scenario

For terrestrial operations, amateur stations are usually tripod mounted around 2 to 5 m above ground and are rotatable in azimuth. The operating sites are usually in non-built up locations on high ground with uncluttered visibility. For EME and amateur satellite service activities the antennas will be capable of pointing skyward. Therefore, the height of the receivers will be assumed to be 100 m and 300 m, similar to ECC Report 315 [6].

Parameters of AR were taken from section 2.2.

The propagation model described in Recommendation ITU-R P.452-16 [13] was used to calculate the path loss. Propagation parameters were noted on each plot and were kept constant for all analyses.

4.3.4 Results

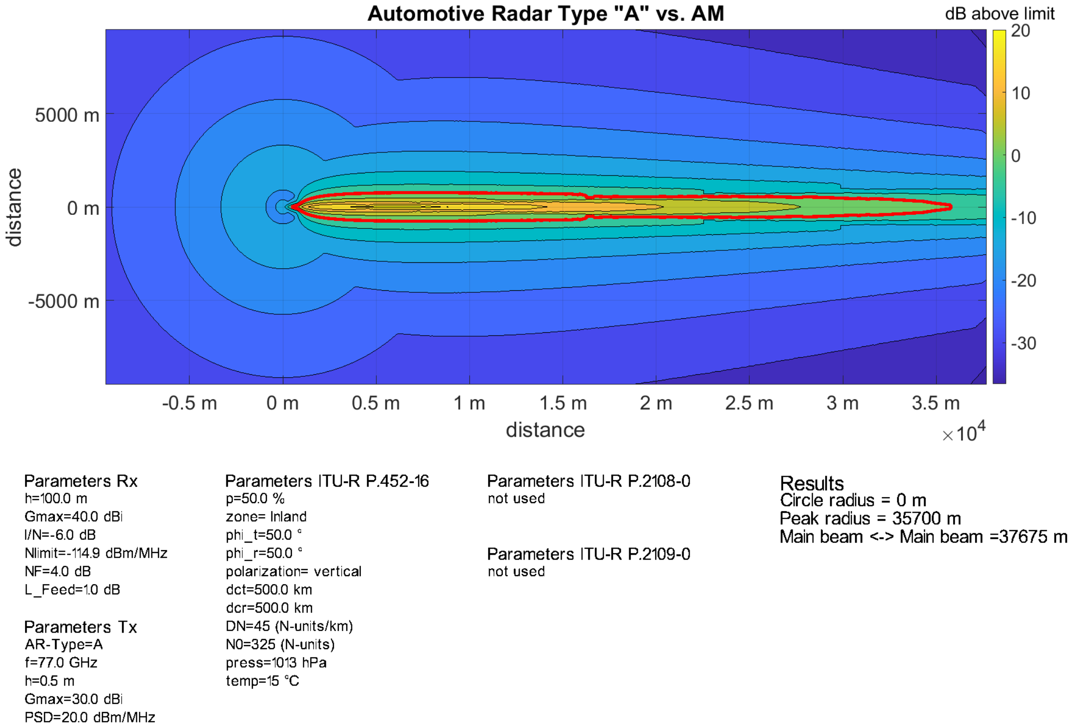
4.3.4.1 Automotive Radar Type ”A” @20 dBm/MHz

The worst-case geometry (main beam to main beam) for the Automotive Radar Type “A” would lead to a separation distance of 37675 m. This scenario is not considered as realistic.

Taking into account the vertical delta of 99.5 m and the respective antenna patterns, this distance was calculated to be 35700 m (see Figure 23).

Taking into account the vertical delta of 299.5 m and the respective antenna patterns, this distance was calculated to be 34100 m (see Figure 24).

In general, the critical area around the amateur radio receiver is limited to small angle around its azimuthal directivity.



Parameters Rx
h=100.0 m
Gmax=40.0 dBi
I/N=-6.0 dB
Nlimit=-114.9 dBm/MHz
NF=4.0 dB
L_Feed=1.0 dB

Parameters Tx
AR-Type=A
f=77.0 GHz
h=0.5 m
Gmax=30.0 dBi
PSD=20.0 dBm/MHz

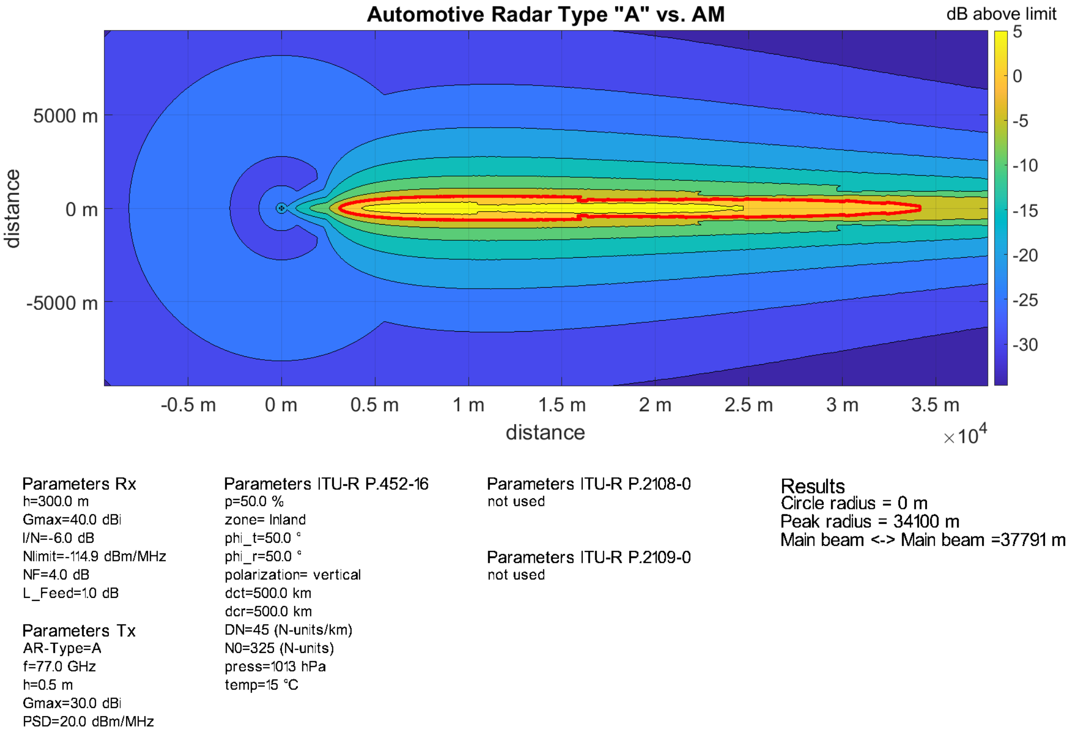
Parameters ITU-R P.452-16
p=50.0 %
zone= Inland
phi_t=50.0 °
phi_r=50.0 °
polarization= vertical
dct=500.0 km
dcr=500.0 km
DN=45 (N-units/km)
N0=325 (N-units)
press=1013 hPa
temp=15 °C

Parameters ITU-R P.2108-0
not used

Parameters ITU-R P.2109-0
not used

Results
Circle radius = 0 m
Peak radius = 35700 m
Main beam <-> Main beam =37675 m

Figure 23: AR ”A” @20 dBm/MHz vs. Amateur Service @100 m



Parameters Rx
h=300.0 m
Gmax=40.0 dBi
I/N=-6.0 dB
Nlimit=-114.9 dBm/MHz
NF=4.0 dB
L_Feed=1.0 dB

Parameters Tx
AR-Type=A
f=77.0 GHz
h=0.5 m
Gmax=30.0 dBi
PSD=20.0 dBm/MHz

Parameters ITU-R P.452-16
p=50.0 %
zone= Inland
phi_t=50.0 °
phi_r=50.0 °
polarization= vertical
dct=500.0 km
dcr=500.0 km
DN=45 (N-units/km)
N0=325 (N-units)
press=1013 hPa
temp=15 °C

Parameters ITU-R P.2108-0
not used

Parameters ITU-R P.2109-0
not used

Results
Circle radius = 0 m
Peak radius = 34100 m
Main beam <-> Main beam =37791 m

Figure 24: AR ”A” @20 dBm/MHz vs. Amateur Service @300 m

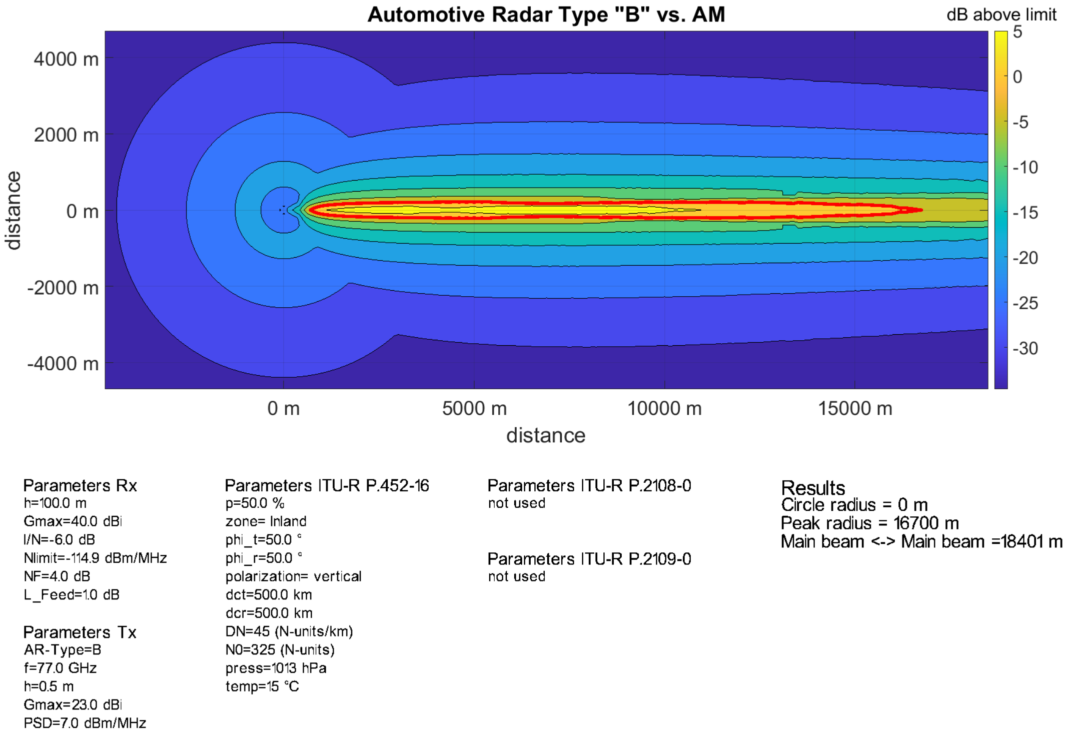
4.3.4.2 Automotive Radar Type ”B” @7 dBm/MHz

The worst-case geometry (main beam to main beam) for the Automotive Radar Type “B” would lead to a separation distance of 18401 m. This scenario is not considered as realistic.

Taking into account the vertical delta of 99.5 m and the respective antenna patterns, this distance was calculated to be 16700 m (see Figure 25).

Taking into account the vertical delta of 299.5 m and the respective antenna patterns, no separation distance would be needed (see Figure 26).

In general, the critical area around the Amateur Radio receiver is limited to small angle around its azimuthal directivity.



Parameters Rx
h=100.0 m
Gmax=40.0 dBi
I/N=-6.0 dB
Nlimit=-114.9 dBm/MHz
NF=4.0 dB
L_Feed=1.0 dB

Parameters Tx
AR-Type=B
f=77.0 GHz
h=0.5 m
Gmax=23.0 dBi
PSD=7.0 dBm/MHz

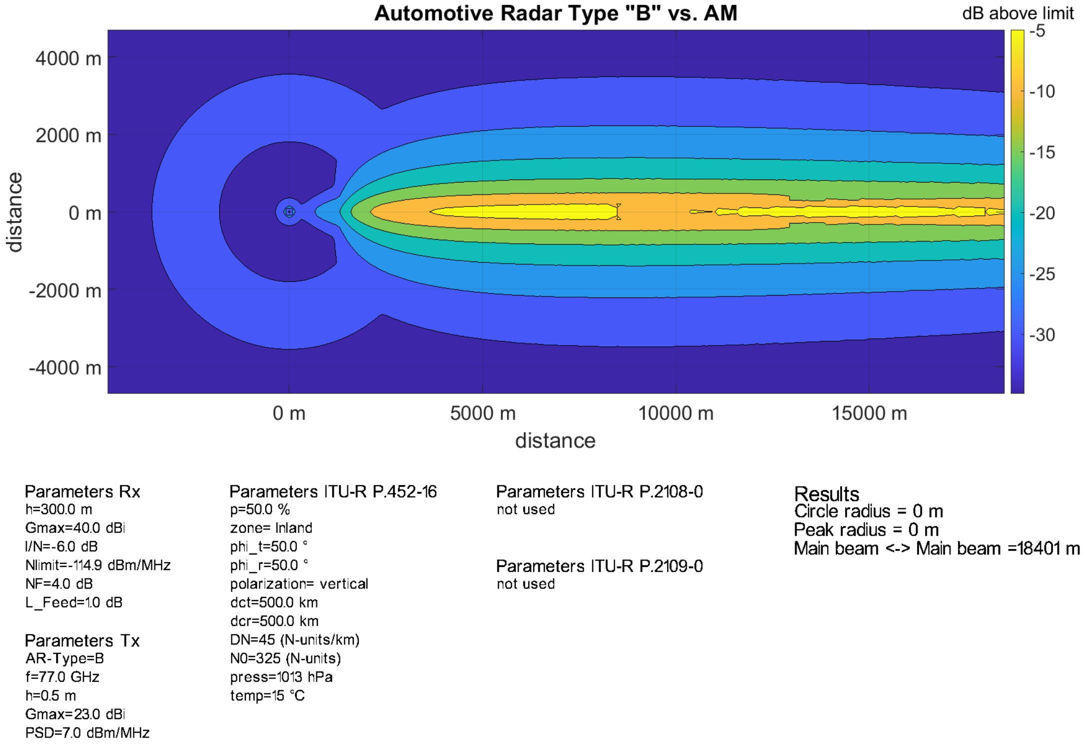
Parameters ITU-R P.452-16
p=50.0 %
zone= Inland
phi_t=50.0 °
phi_r=50.0 °
polarization= vertical
dct=500.0 km
dcr=500.0 km
DN=45 (N-units/km)
N0=325 (N-units)
press=1013 hPa
temp=15 °C

Parameters ITU-R P.2108-0
not used

Parameters ITU-R P.2109-0
not used

Results
Circle radius = 0 m
Peak radius = 16700 m
Main beam <-> Main beam =18401 m

Figure 25: AR ”B” @7 dBm/MHz vs. Amateur Service @100 m



Parameters Rx
h=300.0 m
Gmax=40.0 dBi
I/N=-6.0 dB
Nlimit=-114.9 dBm/MHz
NF=4.0 dB
L_Feed=1.0 dB

Parameters Tx
AR-Type=B
f=77.0 GHz
h=0.5 m
Gmax=23.0 dBi
PSD=7.0 dBm/MHz

Parameters ITU-R P.452-16
p=50.0 %
zone= Inland
phi_t=50.0 °
phi_r=50.0 °
polarization= vertical
dct=500.0 km
dcr=500.0 km
DN=45 (N-units/km)
N0=325 (N-units)
press=1013 hPa
temp=15 °C

Parameters ITU-R P.2108-0
not used

Parameters ITU-R P.2109-0
not used

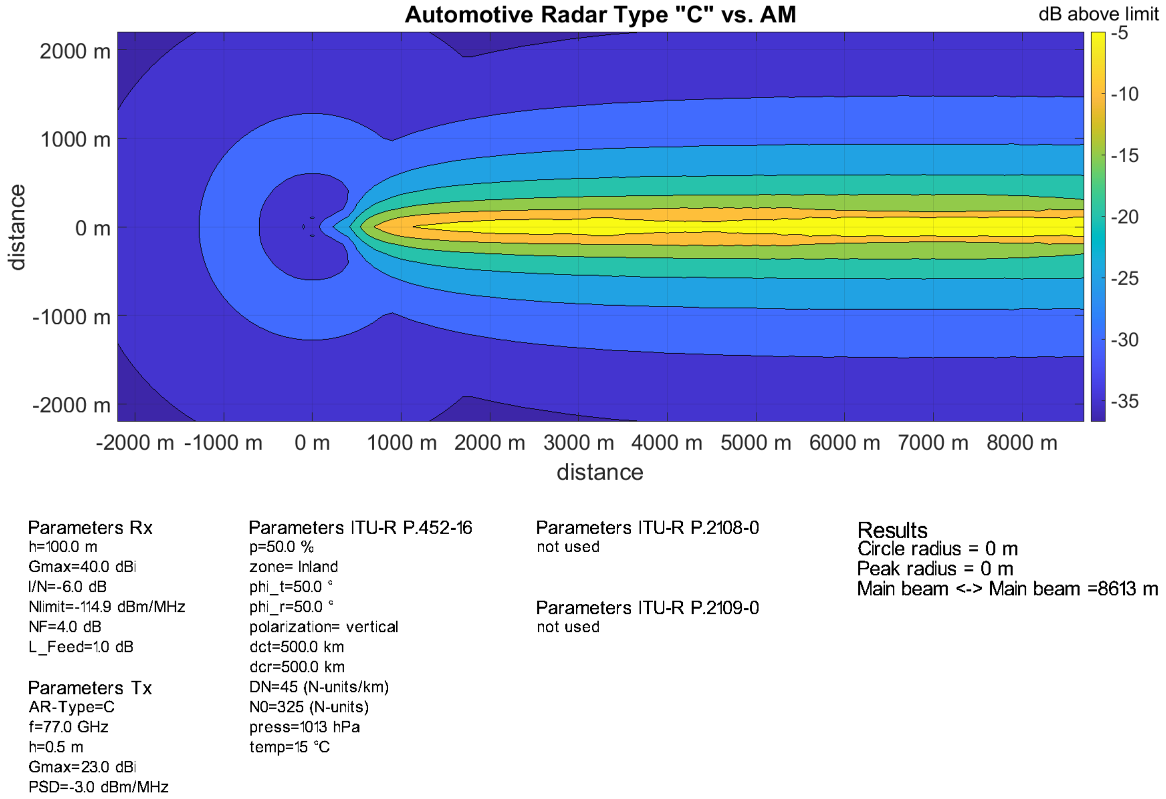
Results
Circle radius = 0 m
Peak radius = 0 m
Main beam <-> Main beam =18401 m

Figure 26: AR ”B” @7 dBm/MHz vs. Amateur Service @300 m

4.3.4.3 Automotive Radar Type ”C” @-3 dBm/MHz

The worst-case geometry (main beam to main beam) for the Automotive Radar Type “C” would lead to a separation distance of 8613 m. This scenario is not considered as realistic.

Taking into account the vertical delta of 99.5 m and the respective antenna patterns, no separation distance would be needed (see Figure 27).



Parameters Rx
h=100.0 m
Gmax=40.0 dBi
I/N=-6.0 dB
Nlimit=-114.9 dBm/MHz
NF=4.0 dB
L_Feed=1.0 dB

Parameters Tx
AR-Type=C
f=77.0 GHz
h=0.5 m
Gmax=23.0 dBi
PSD=-3.0 dBm/MHz

Parameters ITU-R P.452-16
p=50.0 %
zone= Inland
phi_t=50.0 °
phi_r=50.0 °
polarization= vertical
dct=500.0 km
dcr=500.0 km
DN=45 (N-units/km)
N0=325 (N-units)
press=1013 hPa
temp=15 °C

Parameters ITU-R P.2108-0
not used

Parameters ITU-R P.2109-0
not used

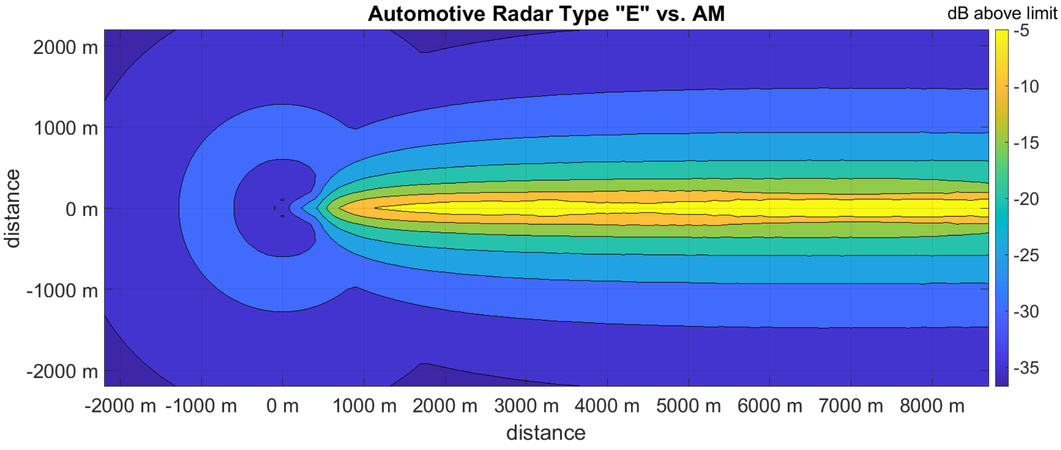
Results
Circle radius = 0 m
Peak radius = 0 m
Main beam <-> Main beam =8613 m

Figure 27: AR ”C” @-3 dBm/MHz vs. Amateur Service @100 m

4.3.4.4 Automotive Radar Type ”E” @-3 dBm/MHz

The worst-case geometry (main beam to main beam) for the Automotive Radar Type “E” would lead to a separation distance of 8613 m. This scenario is not considered as realistic.

Taking into account the vertical delta of 99.5 m and the respective antenna patterns, no separation distance would be needed (see Figure 28).



Parameters Rx
h=100.0 m
Gmax=40.0 dBi
I/N=-6.0 dB
Nlimit=-114.9 dBm/MHz
NF=4.0 dB
L_Feed=1.0 dB

Parameters Tx
AR-Type=E
f=77.0 GHz
h=0.5 m
Gmax=23.0 dBi
PSD=-3.0 dBm/MHz

Parameters ITU-R P.452-16
p=50.0 %
zone= Inland
phi_t=50.0 °
phi_r=50.0 °
polarization= vertical
dct=500.0 km
dcr=500.0 km
DN=45 (N-units/km)
N0=325 (N-units)
press=1013 hPa
temp=15 °C

Parameters ITU-R P.2108-0
not used

Parameters ITU-R P.2109-0
not used

Results
Circle radius = 0 m
Peak radius = 0 m
Main beam <-> Main beam =8613 m

Figure 28: AR ”E” @-3 dBm/MHz vs. Amateur Service @100 m

4.3.5 Conclusion

MCL calculations, taking into account the vertical delta between both AR and Amateur Service antennas, reveal separation distances between 0 km and 35.7 km. The distance depends highly on the transmission level and angular offset between the AR transmitter to the Amateur Radio receiver.

Due to the use of directive antennas the highlighted areas where interference could happen are relatively small. It has to be noted that interference in reality may have a low probability due to following reasons:

- A car/street has to be inside of the relatively small critical area;
- The car´s antenna must be directed towards the Amateur Service antenna;
- LOS conditions between automotive radars and the Amateur Service receiver must apply;
- The more vertical separation between both antennas prevails the lower the impact will be;
- The setup of the Amateur Service system is such (e.g. LOS conditions between two Amateur Service stations) that probability of interference is low, but may be assessed case by case.

Aggregation was not taken into account.

4.4 SRD OPERATING IN THE BAND

It has to be noted that SRDs have no status of being protected from interference from a regulatory point of view. However, the following information about coexistence with automotive radars is provided.

HD-GBSAR systems operating in the band 77-78 GHz avoid interference by implementing detect and avoid techniques.

Information about Security Scanners in the band 60-82 GHz, which may use the band in future, can be found in ECC Report 344 [40].

5 COMPATIBILITY STUDIES

5.1 COMPATIBILITY WITH THE FIXED SERVICE

5.1.1 MCL Methodology

5.1.1.1 Propagation Model

This Report uses the same propagation model as used in Report ITU-R F.2394-0 [12]. This model is described in Recommendation ITU-R P.452 [13] to determine the propagation loss for the automotive radar system's signal, using a smooth circular Earth and a time percentage of 50%.

Reflections and diffraction of an automotive radar signal off surrounding vehicles could potentially increase the interference received by an FS station. However, losses incurred from the reflection of this signal would result in the field strength of this reflected wave at the FS station to be less than the field strength of the wave emitted directly by the automotive radar mounted on the front of the reflecting vehicle (except only in high density traffic conditions where the direct signal of the preceding car is being shielded). Therefore, the overall effect of reflection and diffraction effects from surrounding vehicles are assumed to be negligible and will not be taken into account.

5.1.1.2 Interference scenario model

This Report considers only single-entry interference scenarios. Multiple entry interference scenarios can be considered in another study.

In practice, a vehicle can have any orientation in azimuth with respect to the FS Rx. For the elevation angles, to simplify the analysis, it is assumed that the radar emits towards the horizon and the FS Rx is also pointing towards the horizon, i.e. 0 elevation angles. The top view of the geometric model used to conduct the interference analysis in shown in Figure 29, which consists of an FS receiver and a radar emitter. The azimuth angles α and β are varied and the minimum separation distance is calculated for each pair of angles. The effective antenna gain for both the radar Tx and FS Rx is calculated for each case based on the geometry of the interference scenario. Note that although the radar is placed in the front of the vehicle in Figure 29, this is representative also for radars mounted on the side or in the back, but for simplicity reasons, the illustration shows the radar mounted in the front.

Figure 29: Interference scenario top view

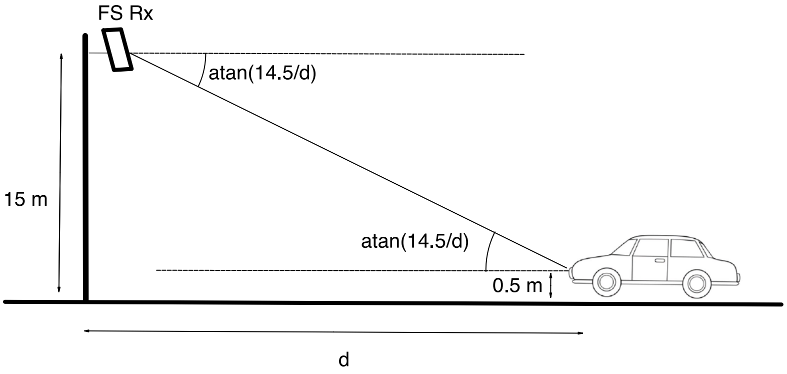


Figure 30: Interference scenario side view

5.1.2 Vehicular Radar Parameters

Table 15 provides a summary of the parameters for vehicular radars used in the MCL study.

Table 15: Used Automotive Radar parameters

Sensor operation/Function	Antenna gain	OOB e.i.r.p.	Notation
Long Range Radar	30 dBi	-30 dBm/MHz	A
Mid Range Radar	23 dBi	-30 dBm/MHz	B
Short Range Radar	23 dBi	-30 dBm/MHz	C
Ultra Short Range Radar	23 dBi	-30 dBm/MHz	D

The height of the radar was considered to be 0.5 m above ground level and the elevation angle was 0 degrees assuming the car radar is pointing towards the horizon.

5.1.3 FS parameters

Table 16 summarises the parameters used for the FS in the MCL study taken from Recommendation ITU-R F.758-7 [15].

Table 16: Used FS parameters [15]

Parameter	Value
Carrier frequency	81 GHz
FS Receiver noise power density typical	-106 dBm/MHz
FS Allowed Long-term interference to noise ratio (I/N)	-20 dB
Antenna height	15 m
Antenna gain	43 dBi and 50 dBi
Antenna elevation angle	0 degrees
Antenna pattern	ITU-R F.699-8 [14]
Feeder/multiplex loss	0 dB

5.1.4 Results

Calculations have been done for all four types of radars in Table 15 and two different FS antenna gains. First contour plots are shown with the minimum separation distance for different azimuth angles for the vehicular radar and the FS receiver. The upper limit represents the worst-case scenario. Second, specific scenarios for azimuth angles of 0 are shown for the vehicular radar and FS, respectively. Third, I/N curves are shown as a function of distance between the vehicular radar and FS receiver for specific scenarios for azimuth misalignment of 0 degrees between both antennas.

5.1.4.1 FS Antenna Gain 43 dBi

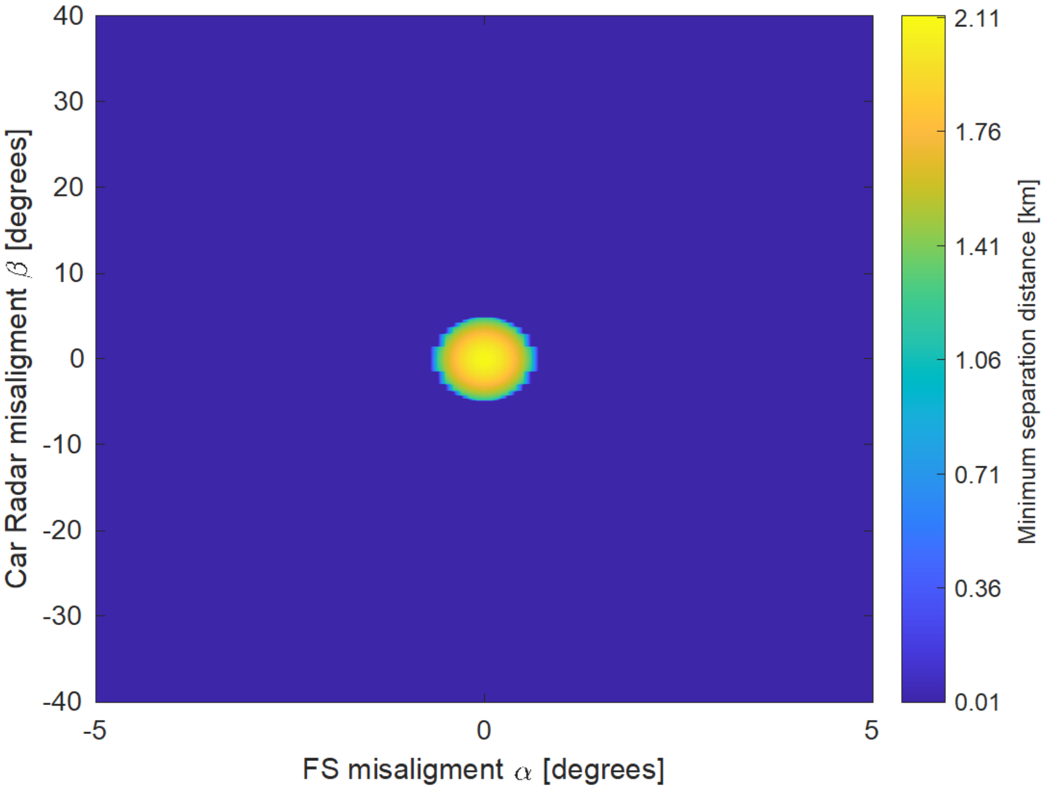


Figure 31: Long Range Radar A

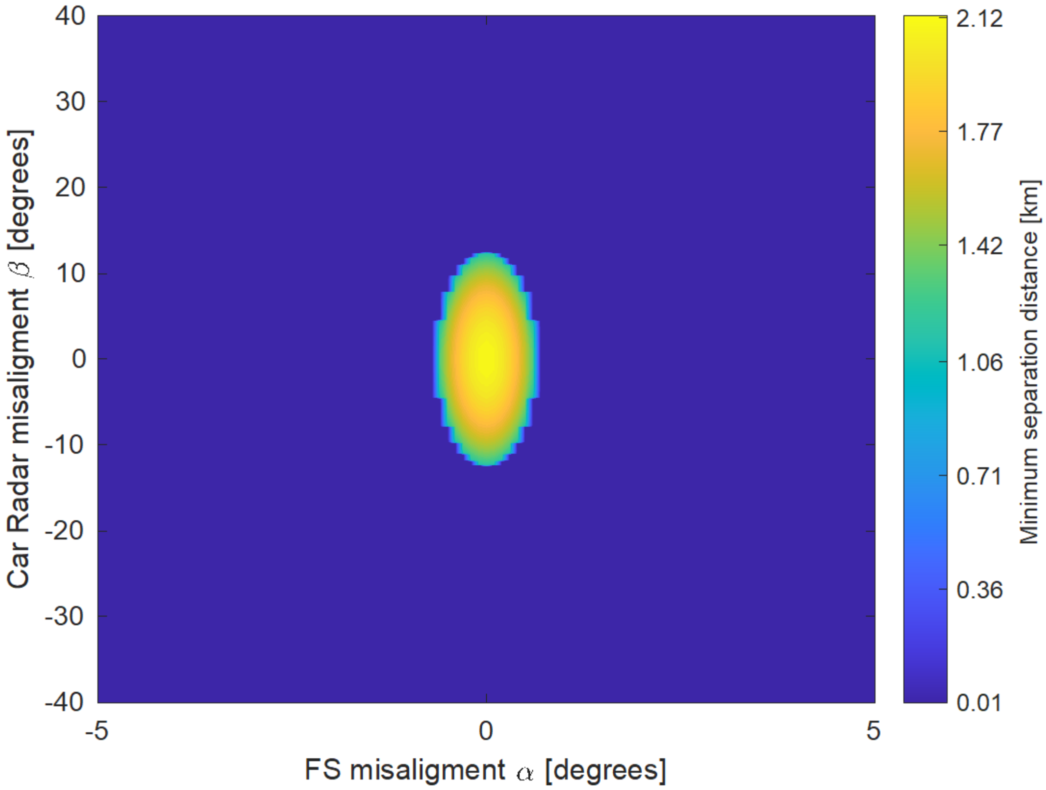


Figure 32: Mid Range Radar B

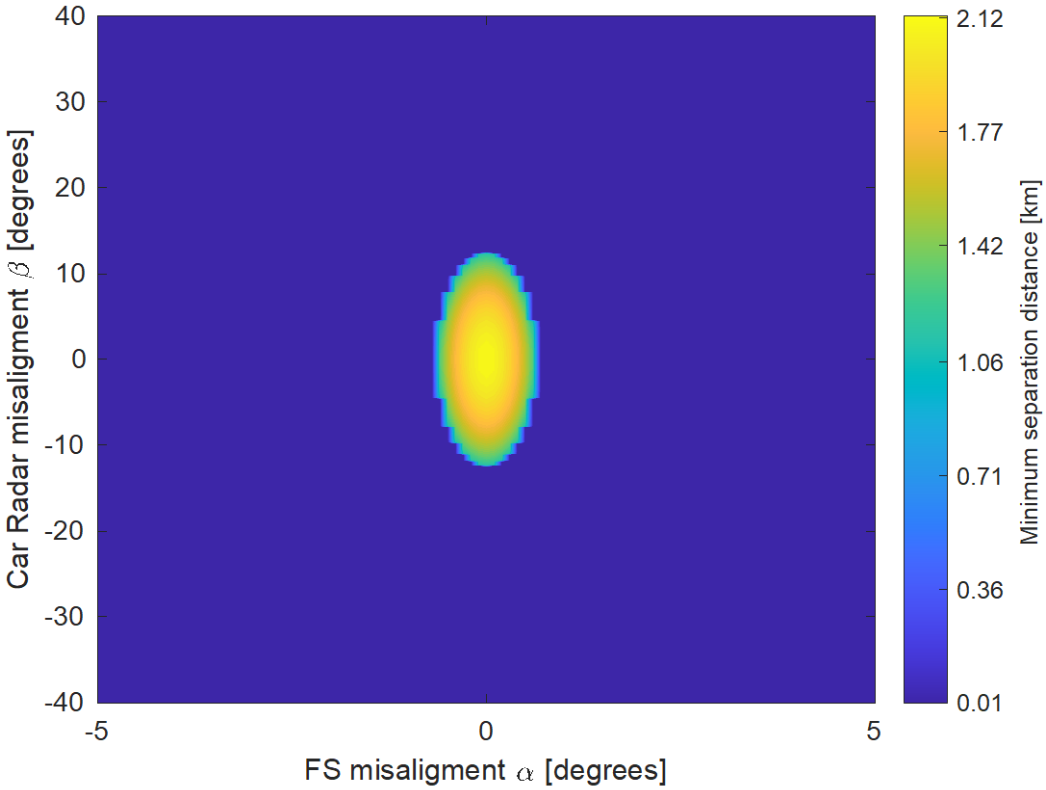


Figure 33: Short Range Radar C

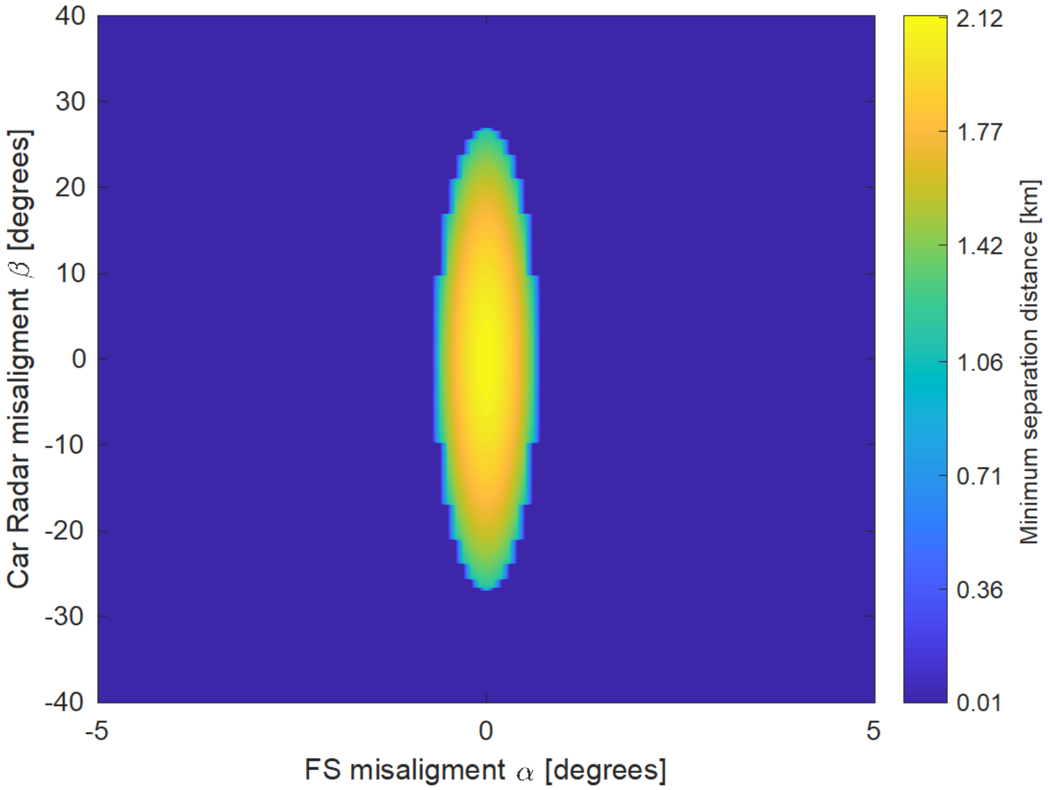


Figure 34: Ultra Short Range Radar D

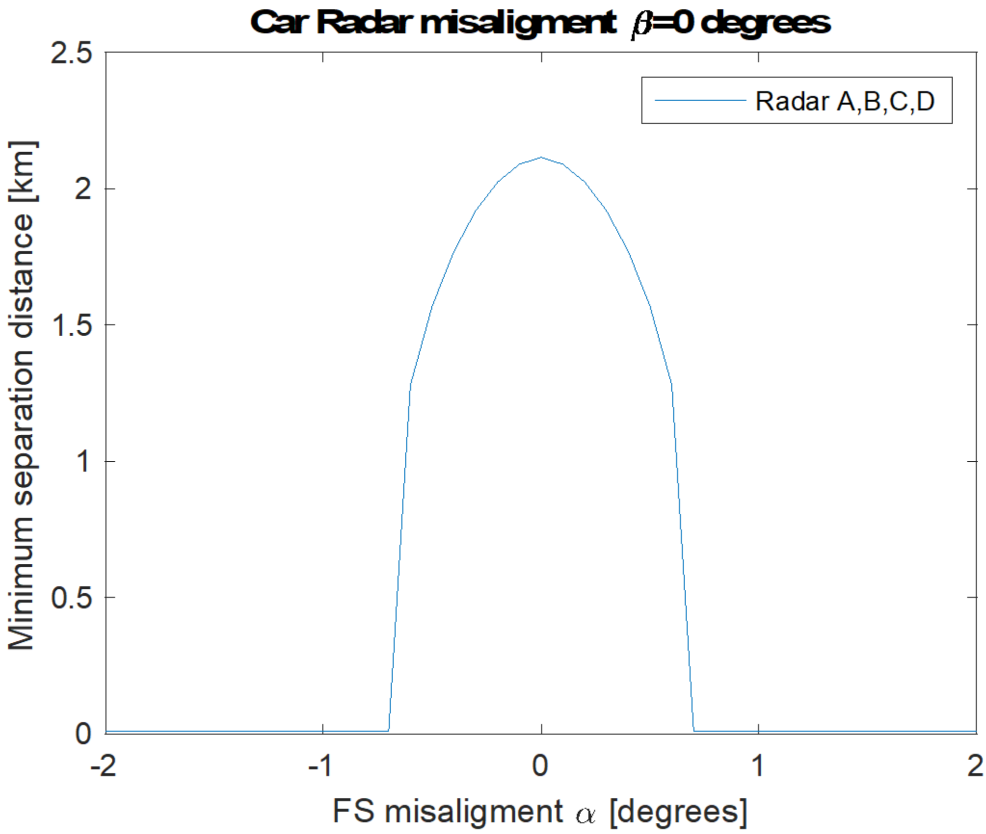


Figure 35: Car radar azimuth β=0 degrees

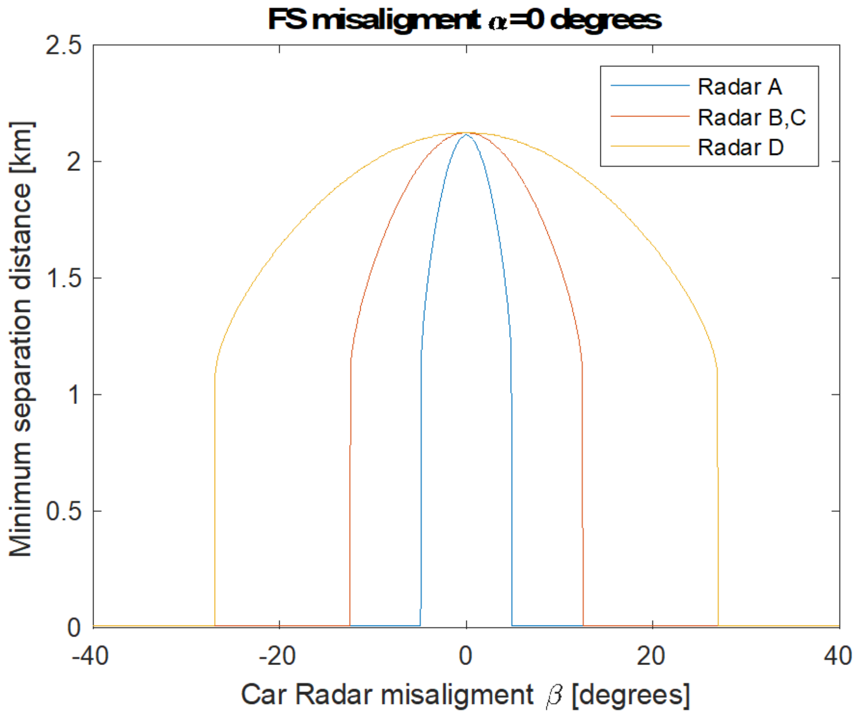


Figure 36: FS azimuth $\alpha = 0$ degrees

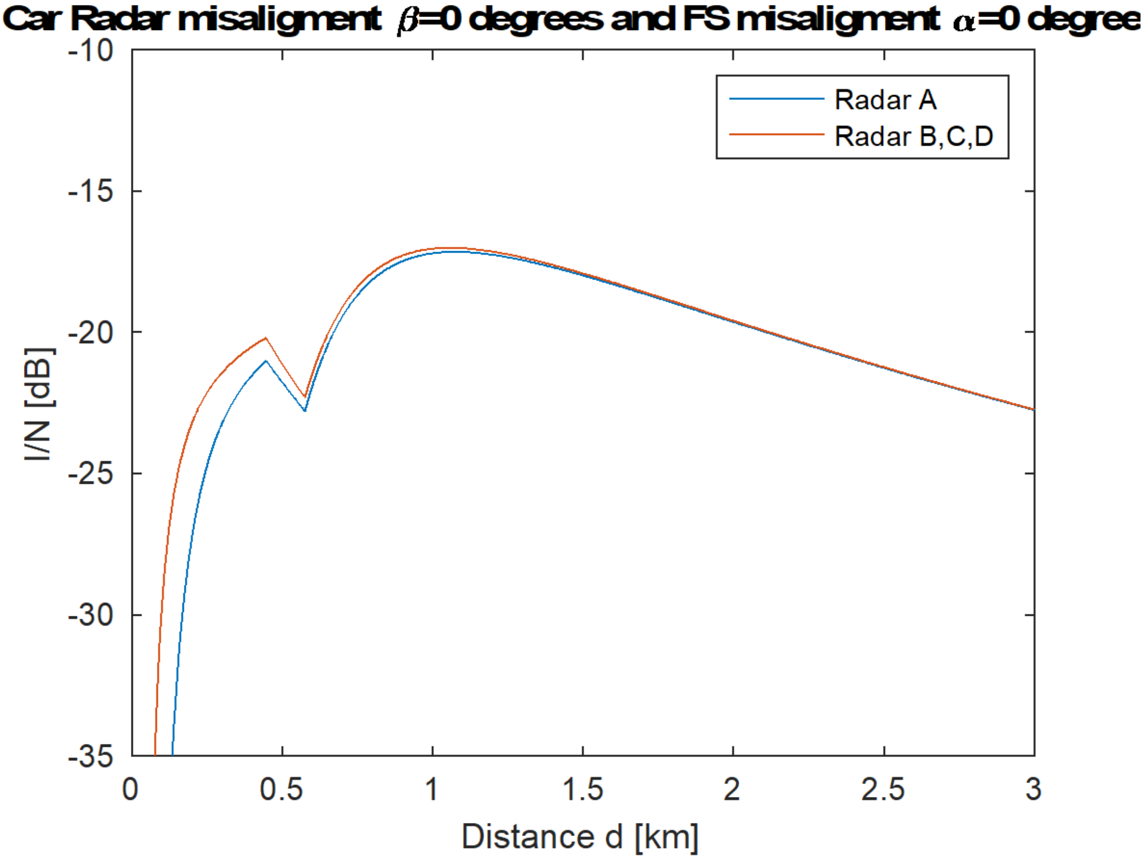


Figure 37: Interference as function of distance for 0 degree misalignment in azimuth (43 dBi FS antenna)

As can be seen in the figures above, all radars have the same maximum required separation distance, i.e. 2.12 km, to fulfil the protection criterion due to same emission level. However, due to the different antenna pattern of the radar, the required separation distance changes differently depending on the relative orientation in azimuth between the FS receiver and the vehicle radar. Long Range radars have a faster decay on the antenna gain, which results in narrower spot where interference is possible. Long Range radars have also a faster day in elevation compared to the other radar types, therefore the interference is lower when comparing the same azimuth orientation, c.f. Figure 32. Mid Range radars have the same results as short-range radars since they share the same antenna pattern. Whereas Ultra Short Range Radars having the broadest gain in azimuth, have also the broadest range for interference, c.f. Figure 30.

Figure 32 shows the interference to noise ratio for the worst-case scenario when the FS receiver and vehicle are aligned in azimuth. The highest I/N value is -17 dB, reached around 1 km, and the criterion of I/N<-20 dB is fulfilled before 0.65 km and after 2.12 km.

5.1.4.2 FS Antenna Gain 50 dBi

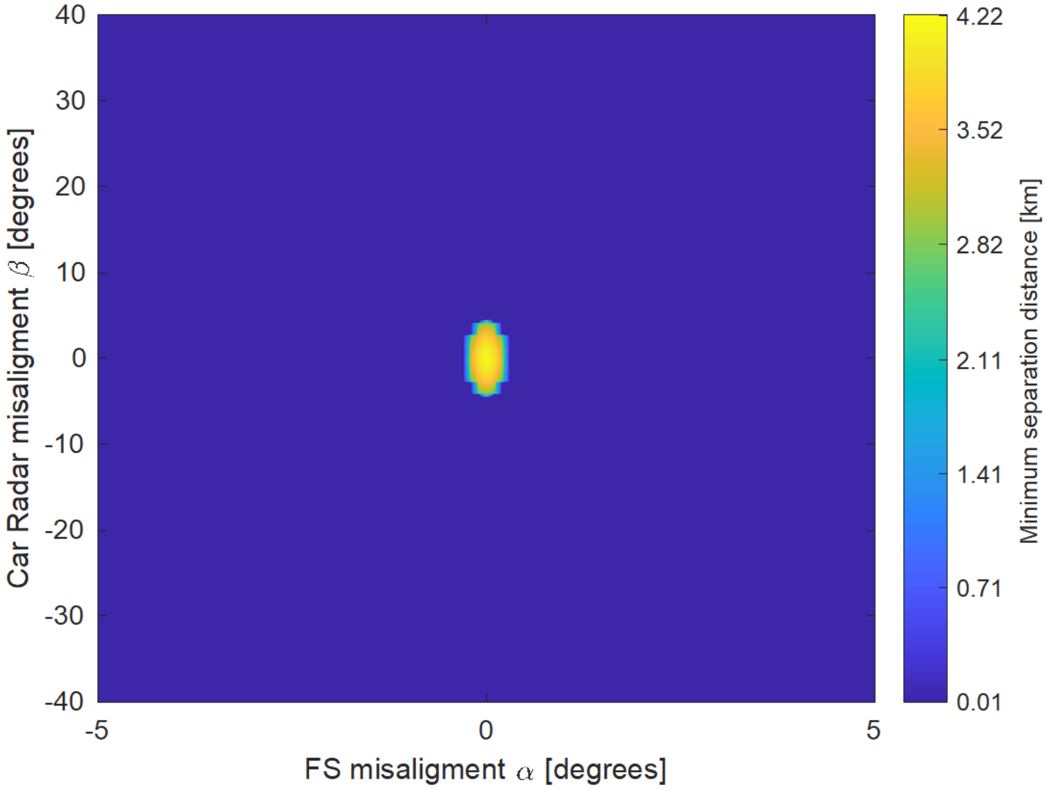


Figure 38: Long Range Radar A

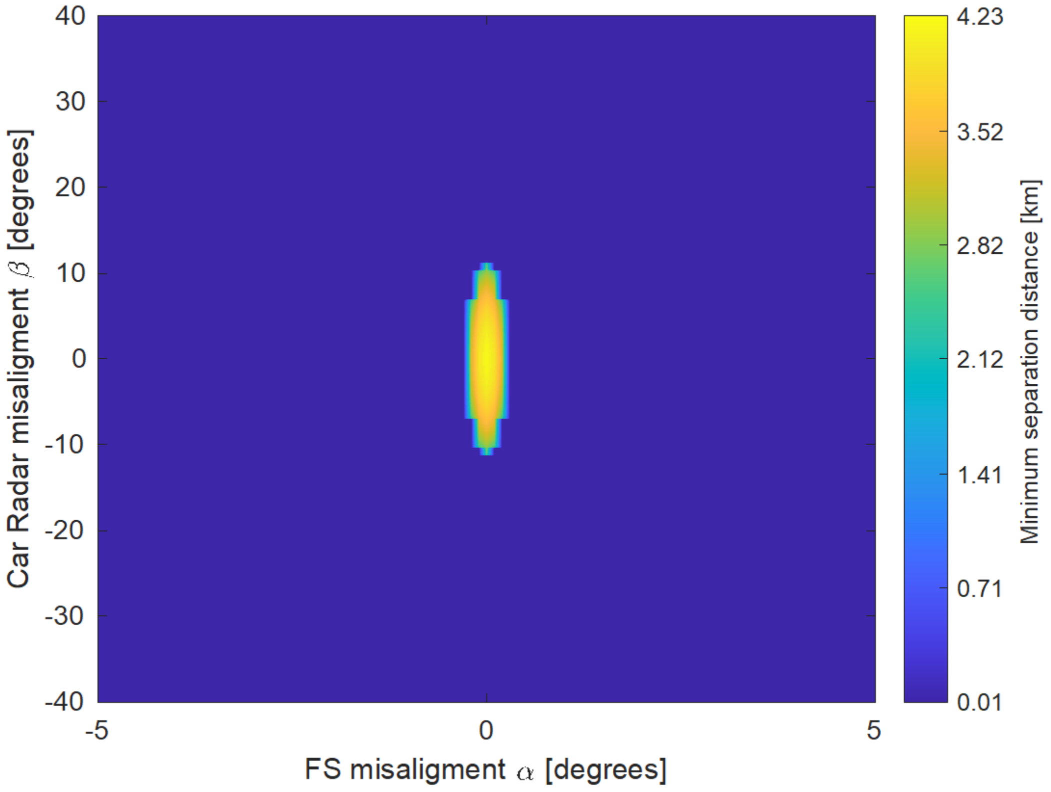


Figure 39: Mid Range Radar B

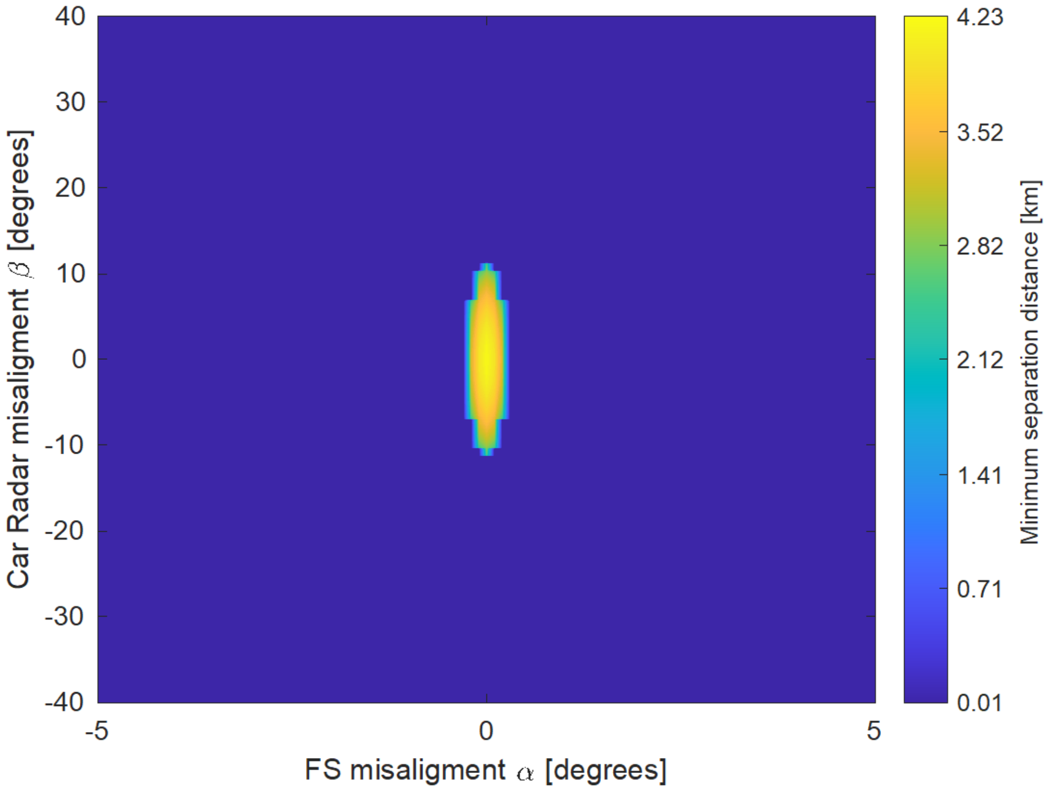


Figure 40: Short Range Radar C

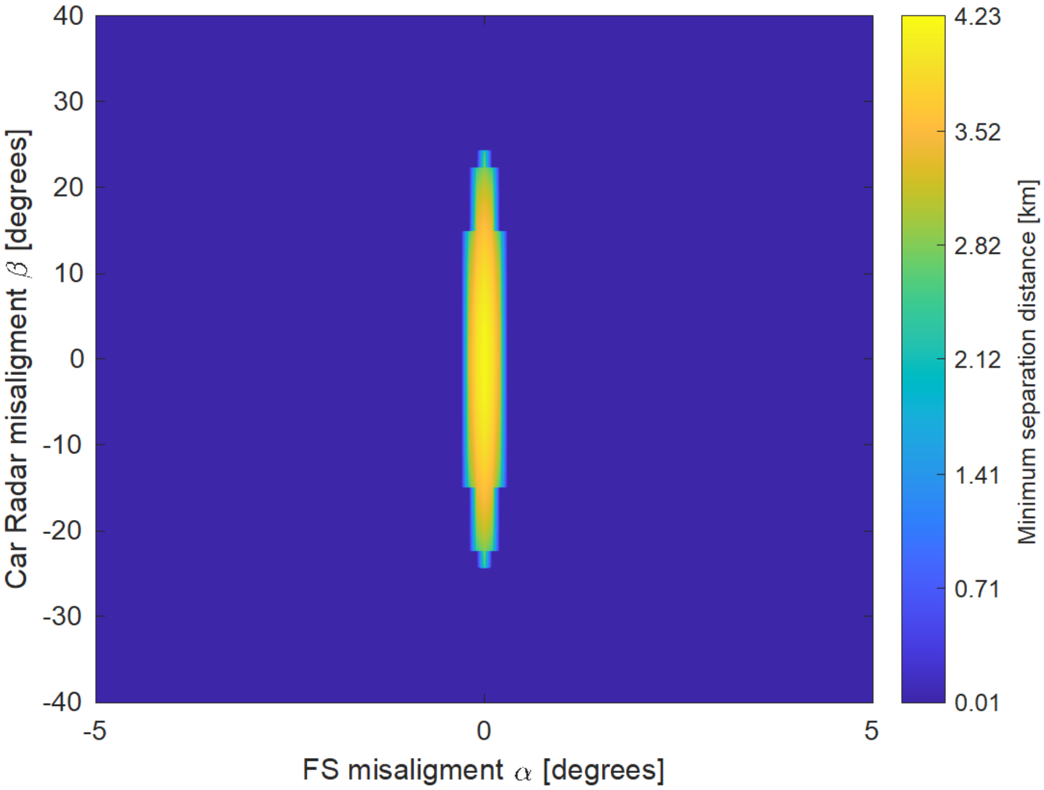


Figure 41: Ultra Short Range Radar D

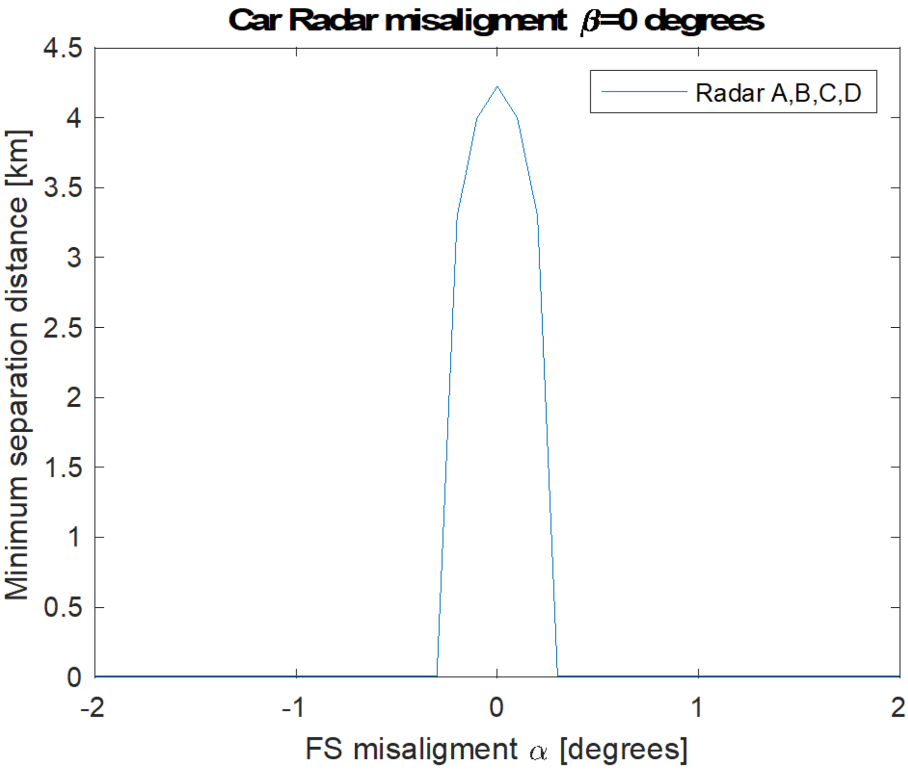


Figure 42: Car radar azimuth $\beta = 0$ degrees

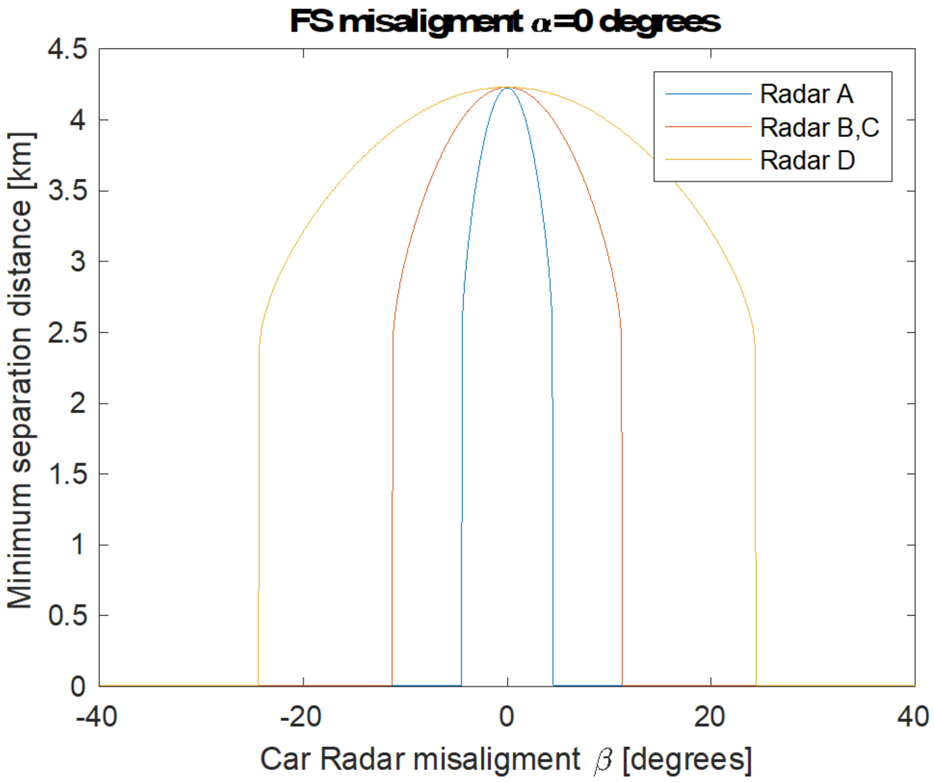


Figure 43: FS azimuth $\alpha = 0$ degrees

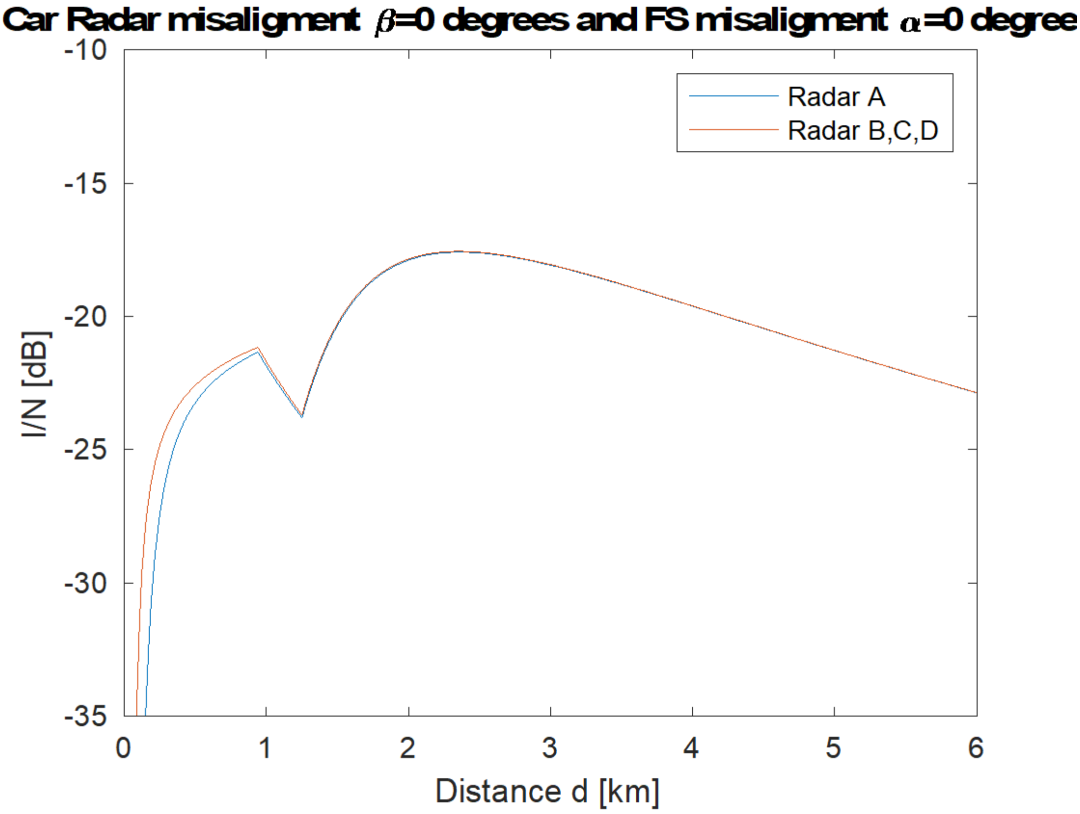


Figure 44: Interference as function of distance for 0 degree misalignment in azimuth (50 dBi FS antenna)

The results obtained for the 50 dBi FS antenna follow the same pattern as the ones for the 43 dBi antenna. The differences result in a narrower interference region with respect to azimuth alignment of the FS antenna and a higher separation distance due to the higher antenna gain.

Figure 41 shows the interference to noise ratio for the worst-case scenario when the FS receiver and vehicle are aligned in azimuth. The highest I/N value is -17.5 dB, reached around 2.3 km, and the criterion of I/N<-20 dB is fulfilled before 1.5 km and after 4.23 km.

5.1.5 Conclusion

The compatibility between vehicle radars and FS has been studied based on a MCL approach. The unwanted emissions for the automotive radar in the bands 71-76 GHz and 81-86 GHz were limited to -30 dBm/MHz e.i.r.p. The highest required separation distance is 4.23 km where the I/N of -20 dB is exceeded at most by 2.5 dB when using a 50 dBi FS antenna gain. The separation distance becomes 2.12 km where the I/N of -20 dB is exceeded at most by 3 dB for an FS antenna gain of 43 dBi. There are limited cases where the radar can potentially cause interference to the fixed service receiver and highly depends on the relative orientation between the vehicular radar and FS Rx. This happens when the vehicle radars fall in the main lobe of the fixed service station. Due to the narrow beamwidth of the FS antenna, the minimum separation distance decreases if the interferer is not in the main lobe. The interference becomes negligible when the vehicular radars are beyond approximately 0.8 degrees in azimuth from the main beam of the FS Rx. These finding are inline also with the results obtained in the studies in Report ITU-R F.2394 [12].

On the topic of possible mitigation techniques, possible options to improve the compatibility between both adjacent services are:

- The avoidance of fixed service links pointed in the azimuth direction near to and parallel to roads;
- Minimise vehicular radar antenna radiation above the horizontal plane, since the goal is to prevent collision with other vehicles or obstacle;
- Use of vehicular radar antennas with higher gain and smaller beamwidths to minimise the occurrence of interference.

6 CONCLUSIONS

6.1 SHARING WITH RAS

The single-entry study leads to similar exclusion zones for both NOEMA and SRT, up to approximately 50 km.

Comparing the results of the aggregation study, no significant variations are found for the same location in different scenarios. The terrain seems to play an important role for the exclusion zone size, varying from a few kilometres (Effelsberg) up to almost 80 km (IRAM and Yebes).

It has to be noted that switching off automotive radars in potential exclusion zones has an impact on the reliability for safety relevant driver's assistance functions and autonomous driving. Other mitigation techniques than exclusion zones were not studied.

6.2 SHARING WITH RADIOLOCATION

In 2020, information was provided that no military radiolocation systems are operated by NATO members in the band 77 to 81 GHz. Furthermore, there are no plans to introduce such systems.

There is no other applications of the Radiolocation Service using this band.

6.3 SHARING WITH AMATEUR SERVICE

MCL calculations, taking into account the vertical delta between both AR and Amateur Service antennas, reveal separation distances between 0 km and 35.7 km. The distance depends highly on transmission level and angular offset between the AR transmitter to the Amateur Radio receiver.

Due to the use of directive antennas the highlighted areas where interference could happen are relatively small. It has to be noted that interference in reality may have a low probability due to following reasons:

- A car/street has to be inside of the relatively small critical area;
- The cars antenna must be directed towards the Amateur Service antenna;
- LOS conditions between automotive radars and the Amateur Service receiver must apply;
- The more vertical separation between both antennas prevails the lower the impact will be;
- The setup of the Amateur Service system is such (e.g. LOS conditions between two Amateur Service stations) that probability of interference is low, but may be assessed case by case.

Aggregation was not taken into account.

6.4 SRD IN THE BAND

It has to be noted that SRDs have no status of being protected from interference from a regulatory point of view. However, the following information about coexistence with automotive radars is provided.

HD-GBSAR systems operating in the band 77-78 GHz avoid interference by implementing detect and avoid techniques.

Information about Security Scanners in the band 60-82 GHz, which may use the band in future, can be found in ECC Report 344 [40].

6.5 COMPATIBILITY WITH THE FIXED SERVICE

The compatibility between vehicle radars and FS has been studied based on a MCL approach. The unwanted emissions for the automotive radar in the bands 71-76 GHz and 81-86 GHz were limited to -30 dBm/MHz e.i.r.p. The highest required separation distance is 4.23 km where the I/N of -20 dB is exceeded at most by 2.5 dB when using a 50 dBi FS antenna gain. The separation distance becomes 2.12 km where the I/N of -20 dB is exceeded at most by 3 dB for an FS antenna gain of 43 dBi. There are limited cases where the radar can potentially cause interference to the fixed service receiver and highly depends on the relative orientation between the vehicular radar and FS Rx. This happens when the vehicle radars fall in the main lobe of the fixed service station. Due to the narrow beamwidth of the FS antenna, the minimum separation distance decreases if the interferer is not in the main lobe. The interference becomes negligible when the vehicular radars are beyond approximately 0.8 degrees in azimuth from the main beam of the FS Rx. These finding are inline also with the results obtained in the studies in Report ITU-R F.2394 [12].

On the topic of possible mitigation techniques, possible options to improve the compatibility between both adjacent services are:

- The avoidance of fixed service links pointed in the azimuth direction near to and parallel to roads;
- Minimise vehicular radar antenna radiation above the horizontal plane, since the goal is to prevent collision with other vehicles or obstacle;
- Use of vehicular radar antennas with higher gain and smaller beamwidths to minimise the occurrence of interference.

ANNEX 1: DESCRIPTION OF FUTURE CAR TECHNOLOGY

Development roadmaps and regulatory requirements foresee further price/performance improvements of a single sensor allowing also new use cases and thus further improvement of road traffic safety.

In part the growth is motivated by governments setting mandatory requirements for car manufacturers to include features like AEB (Automatic Emergency Breaking), Pedestrian Detection (VRU-AEB), or product rating agencies like Euro NCAP assigning higher ratings if safety functions are available as optional or standard equipment (see [23], [24] and [25]).

The European Commission has issued a proposal [23] for the mandatory inclusion of multiple ADAS technologies. In [24], it is stated "The current proposal addresses the main problem of persistent high number of road accidents that in turn leads to a high number of fatalities and severe injuries and provides measures to increase safety at vehicle level so as to either avoid and lower the number of accidents or lower the severity of un-avoided accidents to limit the number of fatalities and severe injuries".

Figure 45: European Commission views on the need to address the main problem of persistent high number of road accidents

The European Commission [24] enforced that from 6 July 2022 on all new models introduced on the market should have several advanced safety features, such as:

- Advanced emergency braking;
- Alcohol interlock installation facilitation (cars, vans, trucks and buses);
- Drowsiness and attention detection (cars, vans, trucks and buses);
- Distraction recognition/prevention (cars, vans, trucks and buses);
- Event (accident) data recorder (cars and vans);
- Emergency stop signal (cars, vans, trucks and buses);
- Intelligent speed assistance (cars, vans, trucks and buses);
- Lane keeping assist (cars and vans);
- Reversing camera or detection system (cars, vans, trucks and buses).

Different countries and regions have already implemented safety functions and new evolved functions are planned. The regional NCAP organizations (e.g. Euro NCAP, US NCAP, etc.) have already developed their road maps for implementing new functions for the next period (see [35], [36] and [38]).

Through fusion of several vehicular perception sensors (e.g. camera, lidar and radar) a sensing performance is on the horizon, powerful enough for automated driving. By additionally using communication between vehicles or infrastructure the data set used by a car to decide on its next actions can be further improved.

The Society of Automotive Engineers (SAE) has defined five levels of autonomous driving. The relevant SAE standard SAE J3016TM that defines the levels of automated driving can be found in [43].

In Germany, currently series production cars up to level 3 are allowed to be used on the roads. Some manufacturers and groups of manufacturers are developing highly and fully automated vehicles (levels 4 and 5). End of 2018, the first robotic taxi service was started in Phoenix (Arizona).

Highly automated autonomous driving level 4 and fully automated cars of level 5 are expected to provide new forms and modes of transportation, changing the way mobility is provided.

In parallel, UNECE and ISO have worked and are working on detail regulations and test standards of assistance functions (see Table 17 and Table 18). Some of these functions can only be supported or provided by radar technology.

Table 17: Examples of UNECE requirements for current driver assistance systems

Regulation	Summary of Content
UNECE regulation 79 [27]	Dealing with vehicle steering, among others covering automatic steering during parking, automatic lane centering and automatic lane change.
UNECE regulation 131 [26]	Dealing with automatic emergency braking for busses and trucks.
UNECE regulation 151 [29]	Dealing with turn assist function for busses and trucks
UNECE regulation 152 [30]	Dealing with automatic emergency braking for passenger cars

Table 18: Examples of ISO standards for driver assistance systems

ISO standards	Summary of Content
ISO 15622:2018 [31]	Describes requirements and test for adaptive cruise control function
ISO17387:2008(E) [32]	Describes requirements and test for blind-spot detection and lane change assist functions
ISO 21202:2020 [33]	Describes requirements and test of partially automated lane change function
ISO 22078:2020 [34]	Describes requirements and test of emergency braking for bicyclists

ANNEX 2: EXISTING STUDIES FOR THE RELEVANT RAS BAND

This Annex includes information about existing studies in the relevant RAS band published in ECC and ITU.

ECC Report 056 (SRR 77-81 GHz) published 2004 [3]

Recommendation ITU-R RA.769 [18] was used to define the protection level to be -222 dBW/($m^2 \cdot$Hz) and the receiving antenna gain to be 0 dBi. Propagation models described in Recommendation ITU-R P.525 [44] and Recommendation ITU-R P.620 [46] were used.

A first study (Annex C, Section 6) was conducted to derive the maximum tolerable e.i.r.p. per SRR device from an aggregated scenario with a separation distance of 30 m to a RAS station.

A second study (Annex C, Section 7) was conducted to derive the separation distance to a RAS station assuming a mean e.i.r.p. power spectral density of -3 dBm/MHz for SRR.

ECC Report 139 (TLPR 75-85 GHz) published 2010 [38]

Recommendation ITU-R RA.769 [18] was used to define the protection level to be -208 dBW/($m^2 \cdot$Hz) and the receiving antenna gain to be 0 dBi. Propagation models described in Recommendation ITU-R P.525 [44].

A MCL study (Section 5.4.1) was conducted to derive the separation distance.

A Monte-Carlo study (Section 6.5) was conducted to derive the probability of interference varying the distance, the Tx antenna gain (random pointing), the activity and the power level.

Unwanted emissions were studied.

A list of relevant RAS stations is given in the Report.

ECC Report 222 (Helicopter Radars 76-79 GHz) published 2014 [7]

Recommendation ITU-R RA.769 was used to calculate the protection level to be -224 and -228 dBW/($m^2 \cdot$Hz) and to define the receiving antenna gain to be 0 dBi. The propagation model described in Recommendation ITU-R P.452 has been used with a time percentage of 50 %.

A MCL study (Section 4.2.2) was conducted to derive the critical separation distance.

The occurrence probability from take-off and landing has been determined in the critical areas to compare it against the maximum data loss value of 2 % (Section 4.2.5).

Unwanted emissions were studied.

A list of relevant RAS stations is given in the Report.

ECC Report 315 (HD-GBSAR 74-81 GHz) published 2020 [6]

Recommendation ITU-R RA.769 was used to calculate the protection level to be -228, -208 and -172 dBW/($m^2 \cdot$Hz) and to define the receiving antenna gain to be 0 dBi. The propagation model described in Recommendation ITU-R P.620 has been used.

A MCL study (Section 5.2.7) was conducted to derive the separation distance. An average Tx antenna was used in combination with an offset of 5° in elevation domain.

Unwanted emissions were studied.

A list of relevant RAS stations is given in the Report.

Report ITU-R RA.2457-0 (2019-06) 76-81 GHz [9]

Recommendation ITU-R RA.769 was used to calculate the protection level to be -228, -208 and -172 dBW/(m^2·Hz) and to define the receiving antenna gain to be 0 dBi. An attenuation coefficient of 0.15 dB/km was used.

A MCL study (Section 4.2) was conducted to derive the separation distance. The propagation models described in Recommendation ITU-R P.525 [44], Recommendation ITU-R P.526 [45], and Recommendation ITU-R P.676 [47] have been used. Line-of-sight (LOS) and non-line-of-sight (NLOS) results were compared.

Site specific MCL (Section 5) studies were conducted to show critical areas taking into account terrain data. The Propagation model described in Recommendation ITU-R P.452 was used. Clutter losses other than terrain heights were not introduced.

LOS-measurements (Section 4.3 and Annex 3) with Rx antenna gains corresponding to the side lobes at two distances between RAS and SRR were undertaken to calculate a zone of avoidance. The propagation models described in Recommendation ITU-R P.525 [45] and Recommendation ITU-R P.676 have been used.

A list of relevant RAS stations is given in the Report.

Report ITU-R M.2322-0 (2014-11) 77.5-78 GHz [10]

Recommendation ITU-R RA.769 was used to calculate the protection level to be -228, -208 dBW/(m^2·Hz) and to define the receiving antenna gain to be 0 dBi. The propagation models described in Recommendation ITU-R P.525 [44], Recommendation ITU-R P.526 [45], Recommendation ITU-R P.620 [46] and Recommendation ITU-R P.676 [47] have been used. Line-of-sight (LOS) and non-line-of-sight (NLOS) cases were considered. An attenuation coefficient of 0.358 dB/km was used.

A MCL study (Section 6.3.4.1) was conducted to derive the separation distance as a function of the density of SRR devices.

LOS-measurements (Section 6.3.4.2) with Rx antenna gains corresponding to the side lobes at two distances between RAS and SRR were undertaken to calculate a zone of avoidance. The propagation models described in Recommendation ITU-R P.525 and Recommendation ITU-R P.676 have been used.

A site specific MCL study (Section 6.3.4.3) was conducted to show critical areas taking into account terrain data.

A list of relevant RAS stations is given in the Report.

Table 19: Summary Table ECC

	ECC Report 56 [3]	ECC Report 139 [38]	ECC Report 222 [7]	ECC Report 315 [6]
Year of Publication	2004	2010	2014	2020
Frequency Band	77-81 GHz	75-85 GHz	76-79 GHz	74-81 GHz
Study type	MCL aggregation	MCL single entry, Monte-Carlo	MCL	MCL
RAS protection level	$-222\ \frac{dBW}{m^2Hz}$	$-208\ \frac{dBW}{m^2Hz}$	$-228\ \frac{dBW}{m^2Hz}$	$-228\ \frac{dBW}{m^2Hz}$
RAS Antenna Gain	0 dBi	0 dBi	0 dBi	0 dBi
Propagation model	<45 km: P.525 >45 km: P.620	P.525	P.452	P.620 “clear air mode”

	ECC Report 56 [3]	ECC Report 139 [38]	ECC Report 222 [7]	ECC Report 315 [6]
Result 1	Maximum e.i.r.p. as function of SRR density (no separation distance)	Separation distance (MCL)	Separation distance	Separation distance
Result 2	Minimum separation distance as function of SRR density (no further e.i.r.p. restriction)	Probability of exceeding the protection level (Monte-Carlo)	Comparison of take-offs/landings with 2% criterion of time	
Sections containing study results	Annex C / Section 6 & 7	Section 5.4.1 Section 6.5	Section 4.2.2 Section 4.2.5	Section 5.2.7
Additional Information	-	list of 7 relevant RAS stations	list of 10 relevant RAS stations	list of 8 relevant RAS stations

Table 20: Summary Table ITU

	Report ITU-R M.2322-0 [10]	Report ITU-R RA.2457-0 [9]
Year of Publication	2014	2019
Frequency Band	77.5-78 GHz	76-81 GHz
Study type	MCL, Measurement	MCL, Measurement
RAS protection level	$-228\ \frac{dBW}{m^2Hz}$	$-228\ \frac{dBW}{m^2Hz}$
RAS Antenna Gain	0 dBi	0 dBi
Propagation model	(I) P.525, P.526, P.676 (II) P.452	(I) P.620, P.526 (II) P.525, P.526, P.676 (III) P.452
Gas coefficient	0.358 dB/km	0.15 dB/km
Result 1	Separation distance (LOS/NLOS)	Separation distance (LOS/NLOS) Minimum separation distance as function of SRR density (no further e.i.r.p. restriction)
Result 2	Separation areas using terrain data Separation distance based on measurements	Separation areas using terrain data Separation distance based on measurements
Sections containing study results	Section 4.2 Section 4.3 & Annex 3 Section 5	Section 6.3.4
Additional Information	List of 18 relevant RAS stations	List of 16 (7 of those are not using the band in 2019) relevant RAS stations

ANNEX 3: APPLICABILITY OF USING RECOMMENDATION ITU-R P.452-16 IN THE BAND 77-81 GHZ

This Annex includes information about the applicability of using Recommendation ITU-R P.452-16 [13] as propagation model in the band 77-81 GHz, although its applicable range is given with maximum 50 GHz. In the process of developing this ECC Report, the following comparison between different models was made.

A3.1 PROPAGATION MODEL

For site specific calculations, path profiles have to be taken into account by the propagation model. Different models were compared, based on Recommendation ITU-R P.452-16 and Report ITU-R M.2322-0 [10]. The model used in Report ITU-R M.2322-0 combines Recommendation ITU-R P.525 [44] and Recommendation ITU-R P.526 [45], which are not restricted in frequency above 30 MHz. Section 4.5 “Method for a general terrestrial path” of P.526-15 was used. A time percentage of 2% was used. It could be observed that the major difference between the models came from the way clutter information was included.

A3.2 CONSIDERATION OF CLUTTER LOSS

Site specific calculations, taking into account terrain heights, lack of nearby clutter information. Antennas are placed above the average surface height, which means that nearby clutter losses are disregarded. Two different ways of taking into account clutter losses are compared, e.g. due to a forest close to an antenna.

One way could be to place an additional obstacle into the terrain path between both antennas (plot b in Figure 47). Following attributes are proposed. The obstacle should have a height of 15 m (Recommendation ITU-R P.1812-5, table 2 [48]) and should be placed at a distance of about 25 m from the antenna, if the antenna is surrounded by a forest. This information could be obtained from Corine Land Cover maps like depicted in Figure 46. In Report ITU-R M.2322-0 [10], clutter heights were taken into account when diffraction was considered.

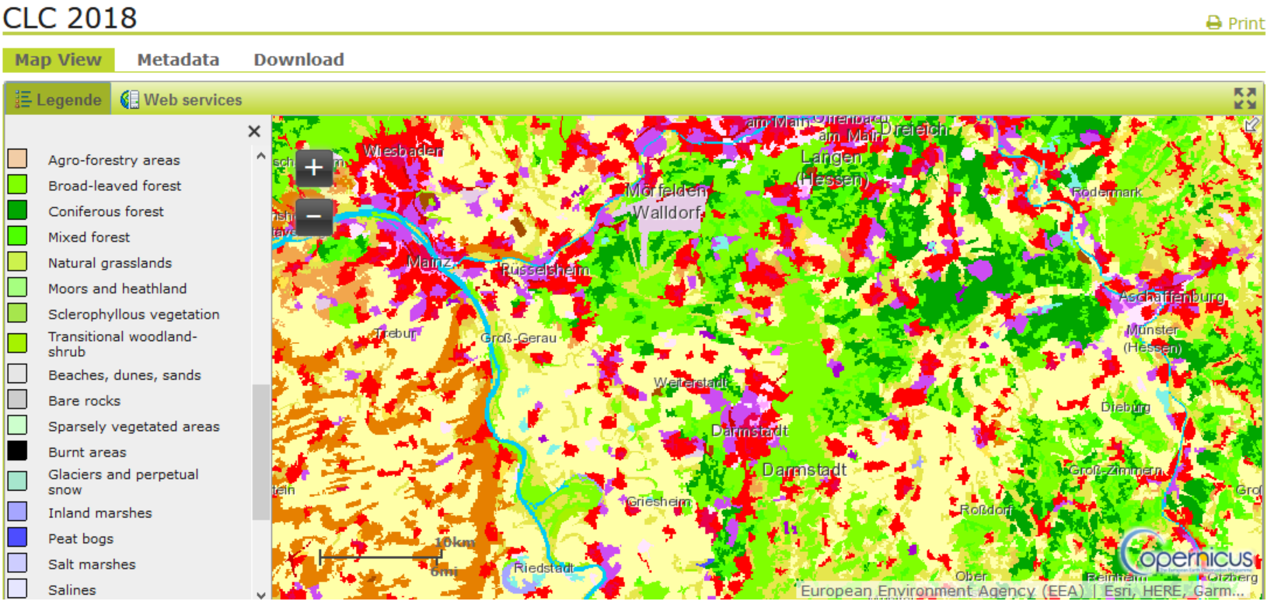


Figure 46: Example of CLC data

The other way to consider clutter losses is described in Recommendation ITU-R P.452-16 (plot c in Figure 47) and will be included in the comparison for the transmitter side. In this model, a wider range of clutter types is available.

In Figure 47, the aforementioned models are compared on a theoretical path with a length of 10 km. The blue curve shows the terrain height. Plots a, d, and e were calculated without taking into account clutter.

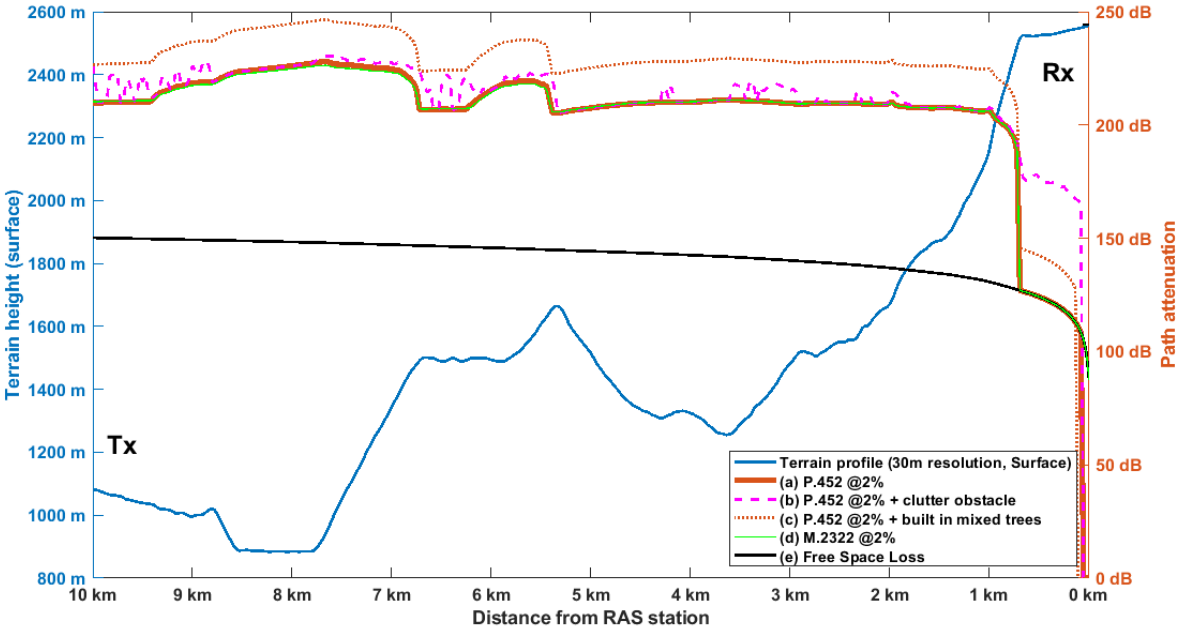


Figure 47: Comparison of path attenuation

Plot b shows that for close LOS conditions the additional loss due to an obstacle can be up to 50 dB, for other conditions the additional loss is up to 10 dB. There are many situations where no additional loss was calculated.

Plot c would give a constant value for additional path loss of about 20 dB for distances greater than 1 km from the receiver Rx. This model seems to be less deterministic, because the resulting terrain angles will be calculated in a statistical approach.

The model described in ITU-R M.2322 [10] without restriction of upper frequency is calculating quite similar values compared to the model ITU-R P.452 [13] without clutter. Therefore, even if model ITU-R P.452 is limited to 50 GHz, it is regarded as a model that can be used in this Report.

ANNEX 4: LIST OF REFERENCES

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[9] Report ITU-R RA.2457-0 (06-2019): “Coexistence between the radio astronomy service and radiolocation service applications in the frequency band 76-81 GHz”

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- Plateau de Bure (NOEMA), F: Institut national de l’information géographique et forestière (IGN): RGE ALTI, DTM 5 m https://geoservices.ign.fr/documentation/diffusion/telechargement-donnees-libres.html https://geoservices.ign.fr/cgu-licences
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