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Technical mitigation measures to protect RAS against interference from ground based vehicular radars within 77 - 81 GHz to support revision of ECC/DEC/(04)03

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ETSI

650 Route des Lucioles
F-06921 Sophia Antipolis Cedex - FRANCE

Tel.: +33 4 92 94 42 00 Fax: +33 4 93 65 47 16

Siret N° 348 623 562 00017 - APE 7112B
Association à but non lucratif enregistrée à la
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Foreword

This Technical Report (TR) has been produced by ETSI Technical Committee Electromagnetic compatibility and Radio spectrum Matters (ERM).

Modal verbs terminology

In the present document "**should**", "**should not**", "**may**", "**need not**", "**will**", "**will not**", "**can**" and "**cannot**" are to be interpreted as described in clause 3.2 of the ETSI Drafting Rules (Verbal forms for the expression of provisions).

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1 Scope

The present document describes technical interference mitigation measures to protect RAS against interference from ground based vehicular radars (as potential alternatives to protection zones). The present document is based on the existing studies in ECC report 350 [i.12] and is focused on the open question (see LS in ERM(24)083040) on practicality of protection zones raised by the industry during ECC discussions (FM and SRD/MG) on the public consultation comments for revision of ECC/DEC/(04)03 [i.1].

2 References

2.1 Normative references

Normative references are not applicable in the present document.

2.2 Informative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

NOTE: While any hyperlinks included in this clause were valid at the time of publication, ETSI cannot guarantee their long term validity.

The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

[i.1] ECC/DEC/(04)03 (Approved 19 March 2004): "The frequency band 77-81 GHz to be designated for the use of Automotive Short Range Radars".

[i.2] ECC Report 056 (10/2004): "Compatibility of automotive collision warning Short Range Radar operating at 79 GHz with radiocommunication services".

[i.3] ERC Report 025 (most recent inforce version): "The European table of frequency allocations and applications in the frequency range 8.3 kHz to 3000 GHz".

[i.4] Committee on Radio Astronomy Frequencies (CRAF) (web 2024): "List of radio quiet zones around observatories in Europe".

[i.5] ECC Report 351 (02/2023): "UWB radiodetermination applications within the frequency range 116 GHz to 148.5 GHz for vehicular use".

[i.6] Recommendation ITU-R RA.769-2 (05/2003): "Protection criteria used for radio astronomical measurements".

[i.7] Recommendation ITU-R RA.1513-2 (03/2015): "Levels of data loss to radio astronomy observations and percentage-of-time criteria resulting from degradation by interference for frequency bands allocated to the radio astronomy service on a primary basis".

[i.8] ECC Report 222 (09/2014): "The impact of Surveillance Radar equipment operating in the 76 to 79 GHz range for helicopter application on radio systems".

[i.9] Recommendation ITU-R M.2322-0 (11/2014): "Systems characteristics and compatibility of automotive radars operating in the frequency band 77.5-78 GHz for sharing studies".

[i.10] Recommendation ITU-R RA.2457-0 (06/2019): "Coexistence between the radio astronomy service and radiolocation service applications in the frequency band 76-81 GHz".

[i.11] ETSI TR 103 593 (V1.1.1): "System Reference document (SRdoc); Transmission characteristics; Technical characteristics for radiodetermination equipment for ground based vehicular applications within the frequency range 77 GHz to 81 GHz".

[i.12] ECC Report 350 (02/2023): "Radiodetermination equipment for ground based vehicular applications in 77-81 GHz".

[i.13] SRD/MG #91 - SRDMG(24)030: "PC summary draft revision of ECC Decision (04)03".

[i.14] TC ERM - ERM(24)083040: "LSin from WGFM on ground based vehicular radars mitigation measures for the protection of RAS".

[i.15] ERMTGSRR - ERMTGSRR(24)050007: "LSin from WGFM on ground based vehicular radars mitigation measures for the protection of RAS".

[i.16] CEPT WG SE - SE24_WI82: "Ground based vehicular radar mitigations".

[i.17] Committee on Radio Astronomy Frequencies (CRAF) (2005): "CRAF Handbook for Radio Astronomy".

[i.18] ITU (2013) "Handbook on Radio Astronomy".

[i.19] Recommendation ITU-R RA.314-9 (2002): "Preferred frequency bands for radio astronomical measurements".

[i.20] Recommendation ITU-R RA.2126-1 (2013): "Techniques for mitigation of radio frequency interference in radio astronomy".

[i.21] Alessandro Cabras: "Monitoring and Mitigation of RFI in Radio Astronomy Using Artificial Intelligence", 2. Forum della Ricerca Sperimentale e Tecnologica in INAF 2024.

[i.22] Recommendation ITU-R RA.2259-1 (2021): "Characteristics of radio quiet zones".

[i.23] Regulation (EU) 2019/2144 of the European Parliament and of the Council of 27 November 2019 on type-approval requirements for motor vehicles and their trailers, and systems, components and separate technical units intended for such vehicles, as regards their general safety and the protection of vehicle occupants and vulnerable road users, amending Regulation (EU) 2018/858 of the European Parliament and of the Council.

[i.24] ITU-R Radio Regulations: 2024 Edition.

[i.25] Y. X. Gong, R. Mittra, L. Zhen, W. H. Yu, J. T. Jiang and W. Z. Shao: "Edge treatment for sidelobe reduction of parabolic reflector antenna with a two-layer absorber," 2011 IEEE™ International Symposium on Antennas and Propagation (APSURSI), Spokane, WA, USA, 2011, pp. 2184-2186, doi: 10.1109/APS.2011.5996946.

[i.26] P. Lam, Shung-Wu Lee, K. Lang and D. Chang: "Sidelobe reduction of a parabolic reflector with auxiliary reflectors," in IEEE™ Transactions on Antennas and Propagation, vol. 35, no. 12, pp. 1367-1374, December 1987, doi: 10.1109/TAP.1987.1144056.

[i.27] Bo Sun, Jinghui Qiu, Caitian Yang and Lingling Zhong: "Effect of design parameters on sidelobe level of short-focus parabolic reflector antenna," 2008 Asia-Pacific Symposium on Electromagnetic Compatibility and 19th International Zurich Symposium on Electromagnetic Compatibility, Singapore, 2008, pp. 851-854, doi: 10.1109/APEMC.2008.4560009.

[i.28] Recommendation ITU-R SA.509-3 (2013): "Space research earth station and radio astronomy reference antenna radiation pattern for use in interference calculations, including coordination procedures, for frequencies less than 30 GHz".

[i.29] Recommendation ITU-R SA.1811-0 (2007): "Reference antenna patterns of large-aperture space research service earth stations to be used for compatibility analyses involving a large number of distributed interference entries in the bands 31.8-32.3 GHz and 37.0-38.0 GHz".

[i.30] Recommendation ITU-R P.526-15 (2019): "Propagation by diffraction".

[i.31] Recommendation ITU-R RA.1513-1: "Levels of data loss to radio astronomy observations and percentage-of-time criteria resulting from degradation by interference for frequency bands allocated to the radio astronomy on a primary basis".

3 Definition of terms, symbols and abbreviations

3.1 Terms

For the purposes of the present document, the following terms apply:

avoidance zone: Defined in [i.10].

coordination area: Defined in [i.9], and further definition in [i.24].

coordination zone: Defined in [i.5].

exclusion zone: Defined in [i.5] and [i.12].

radio quiet zone: Defined in [i.22].

3.2 Symbols

For the purposes of the present document, the following symbols apply:

λ	wavelength
Θ	elevation angle or polar angle
Φ	azimuth angle
η	antenna efficiency
d_1	Path length from top of barrier to effective center of antenna
d_2	Path length from top of barrier to transmitter
d'1	Actual distance on a straight line between barrier and telescope; approximately d1
d'2	Actual distance on a straight line between barrier and telescope; approximately d2
dB	deciBel
dBi	gain in deciBels relative to an isotropic antenna
dBm	gain in deciBels relative to one milliwatt
D	diameter RAS antenna
f_C	centre frequency
h_a	Height above reference level of the effective center of the antenna
h_b	Height above reference level of the barrier
h_m	Effective height of barrier: approximated by h_b-h_a for $d_2 \gg d_1$
J(v)	Diffraction loss
Ic	compensated interference
Inc	non- compensated interference

3.3 Abbreviations

For the purposes of the present document, the following abbreviations apply:

ADAS	Advanced Driver Assistance System
CEPT	European Conference of Post and Telecommunications administrations
CRAF	Committee on Radio Astronomy Frequencies
ECA	European Common Allocations table
ECC	Electronic Communications Committee
EIRP	Equivalent Isotropic Radiated Power
ERC	European Radiocommunication Committee
EU	European Union
ITU-R	International Telecommunication Union - Radio sector
LOS	Line Of Sight
RAS	Radio Astronomy Service
RF	Radio Frequency
RR	ITU-R Radio Regulations
SRD/MG	Short Range Devices/Maintainance Group
SRR	Short Range Radar

UWB	Ultra Wideband Technology
WG FM	CEPT Working Group Frequency Management
WG SE	CEPT Working Group Spectrum Engineering

4 Regulatory frameworks and other background information

4.1 Spectrum allocations in the range 77 - 81 GHz in CEPT

4.1.1 European Common allocations table

Table 1 provides information about the spectrum allocations in the range 77 - 81 GHz, information is extracted from ERC Report 025 [i.3].

Table 1: Extract from European Common allocations table (Source: ERC Report 025 [i.3])

Frequency band	RR Region 1 Allocation and RR footnotes applicable to CEPT	European Common Allocation and ECA Footnotes
76 GHz - 77,5 GHz	RADIO ASTRONOMY RADIOLOCATION Amateur Amateur-Satellite Space Research (space-to-Earth) 5.149	RADIO ASTRONOMY RADIOLOCATION Amateur Amateur-Satellite Space Research (space-to-Earth) 5.149
77,5 GHz - 78 GHz	AMATEUR AMATEUR-SATELLITE RADIOLOCATION 5.559B Radio Astronomy Space Research (space-to-Earth) 5.149	AMATEUR AMATEUR-SATELLITE RADIOLOCATION 5.559B Space Research (space-to-Earth) 5.149
78 GHz - 79 GHz	RADIOLOCATION Amateur Amateur-Satellite Radio Astronomy Space Research (space-to-Earth) 5.149 5.560	RADIOLOCATION Amateur Amateur-Satellite Radio Astronomy Space Research (space-to-Earth) 5.149 5.560
79 GHz - 81 GHz	RADIO ASTRONOMY RADIOLOCATION Amateur Amateur-Satellite Space Research (space-to-Earth) 5.149	RADIO ASTRONOMY RADIOLOCATION Amateur Amateur-Satellite 5.149

4.1.2 Relevant footnotes

4.1.2.1 Introduction

The texts of the relevant footnotes that are referred to in Table 1, are given below. The text of the footnotes was extracted from ERC Report 025 [i.3].

- Clause 4.1.2.2; ERC Report 025 [i.3], footnote 5.149.
- Clause 4.1.2.3; ERC Report 025 [i.3], footnote 5.559B.
- Clause 4.1.2.4; ERC Report 025 [i.3], footnote 5.560.

4.1.2.2 Footnote 5.149

The following text is a citation from ERC Report 025 [i.3]:

"In making assignments to stations of other services to which the bands: 13360-13410 kHz, 25550-25670 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, 1330-1400 MHz, 1610.6-1613.8 MHz, 1660-1670 MHz, 1718.8-1722.2 MHz, 2655-2690 MHz, 3260-3267 MHz, 3332-3339 MHz, 3345.8-3352.5 MHz, 4825-4835 MHz, 4950-4990 MHz, 4990-5000 MHz, 6650-6675.2 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)"*

4.1.2.3 Footnote 5.559B

The following text is a citation from ERC Report 025 [i.3]:

"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)".

4.1.2.4 Footnote 5.560

The following text is a citation from ERC Report 025 [i.3]:

"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."

4.2 Regulatory framework for ground based vehicular radar operating in 77 - 81 GHz in CEPT

ECC/DEC/(04)03 [i.1] currently states under Considering l) and Decides 2) that automotive radar in 77 - 81 GHz is operating on a non-protection/ non-interference basis.

The current regulation in ECC/DEC/(04)03 [i.1] was developed in 2004 based on the studies provided in ECC Report 056 [i.2]. In the studies in ECC Report 056 [i.2] it was assumed that the parameters of the at that time available 24 GHz UWB radars could also be used for 79 GHz automotive radars, because the envisaged use cases focussed on short range radars. When the regulation was published in 2004 no automotive radar sensors operating in the 79 GHz band were available. ECC/DEC/(04)03 [i.1] has not been revised since then.

Within the last 20 years, RF technology and radar signal processing evolved, so that now 79 GHz automotive radar sensors can be realized that provide more functions and better RF performance than it was foreseen in 2004.

4.3 Regulatory framework for RAS in CEPT

Radio Astronomy Service in the 77-81 GHz frequency range is operating in some portions of the band on a primary basis and in other portions on a secondary basis. The technical and operational characteristics and the RAS observing techniques are provided in the CRAF "Handbook for Radio Astronomy [i.17]. The protection criteria for RAS are provided in Recommendation ITU-R RA.769-2 [i.6] and Recommendation ITU-R RA.1513 [i.7].

RAS with a secondary allocation is still protected under Recommendation ITU-R 5.149 [i.3] and [i.24]: "*…administrations are urged to take all practicable steps to protect the radio astronomy service from harmful interference…*"). Nevertheless, any potential interference criteria for the vehicular radar due to coexistence with RAS should reflect this difference in status.

Therefore, regulatory resolution for a less strict limit in the band 77,5 - 79 GHz could be considered.

4.4 Existing radio quiet zones around RAS sites based on national regulation

In some European Countries there are radio quiet zones established around radio astronomy sites. The radio quiet zones are based on individual national regulation. A list of these radio quiet zones is available on the CRAF website [i.4]. For better reading the information is cited:

"*Usually a radio quiet zone has been established around a radio astronomy station. Within such area motorized traffic is severely restricted or forbidden, and there may be several severe restrictions on the use of electronic equipment and on the existences of e.g. factories, buildings and construction works within that area: i.e. radio-quiet means quiet*".

Table 2: Relevant for ground based vehicular radar are the following radio quiet zones

RAS	Radius of radio quiet zone	Regulatory process
Metsähovi	About 1 km	The radio quiet zone has been established in consultation with the Finnish national regulatory authority
Plateau de Bure	3 km for emitters	Radio quiet zone established by the French national protection zone law since December 2010
Pico Veleta	15 km	Protected by a national law (https://www.boe.es/buscar/pdf/2014/BOE-A-2014-4950-consolidado.pdf)
Yebes	11 km	Protected by a national law (https://www.boe.es/buscar/pdf/2014/BOE-A-2014-4950-consolidado.pdf)

4.5 RAS operation details

Before discussing new proposals for interference mitigation measures in clause 8 operating details of RAS stations in the 77 - 81GHz band are summarized.

According to Recommendation ITU-R RA.314-9 [i.19], Table 1, only one spectral line of interest is located inside the band 77 - 81 GHz, but according to Recommendation ITU-R RA.314-9 [i.19] Table 3, 77 81 GHz falls into one of the preferred ranges for continuum observations. So, for the purpose of the present document only continuum observations are considered.

Based on the available information in the RAS handbooks [i.17] and [i.18] it is assumed that certain regular mitigation measures are already implemented today.

Below follows a summary of the applicability of the mitigation measures (in **bold**) described in Recommendation ITU-R RA.2126-1 [i.20] as they apply to continuum observations (incoherent reception) and interference from ground based radars:

1) The **temporal excision** could apply in case of interference with large temporal peaks and low values otherwise. This hardly applies to ground based vehicular radar interference.

2) And (with some specific geographical situations exempted) since there is no clear singular direction for the ground based vehicular radar interference **spatial excision** also hardly applies, though the observation track planning technique described in clause 8.7 partially falls in this category.

3) **Temporal cancellation** applied to the incoherent detection performed by continuum observations is possible however if multiple antennas are used to measure the desired signal or auxiliary receivers are used to accurately estimate the interference. This is very similar to the technique described in Annex C to the present document.

4) **Post-correlation** cancellation only applies to coherent RAS receivers.

5) **Anti-coincidence** mitigation may have some application to ground based vehicular radar interference, possibly in combination with temporal cancellation.

According to publication [i.21] new interference mitigation methods for RAS using artificial intelligence are under development.

NOTE: It is unclear which RAS mitigation measures from the list above and which mitigation level in dB was included in ECC Report 350 [i.12], and which additional mitigation could be achieved by applying these methods more extensively.

5 Earlier studies that deal with interference of radar operating in 76 - 81GHz or parts thereof into the radio astronomy service

5.1 Introduction

In the CEPT and ITU-R context, the following studies already consider the impact of radar operating in the frequency range 76 - 81 GHz or parts thereof into RAS. For reference, the summary of the relevant clause of each document is provided in the chapters below, for detailed information the full documents should be examined.

Following reports offer former studies:

- Clause 5.2: ECC Report 056 [i.2] - Compatibility of automotive collision warning Short Range Radar operating at 79 GHz with radiocommunication services.
- Clause 5.3: ECC Report 222 [i.8] - The impact of Surveillance Radar equipment operating in the 76 to 79 GHz range for helicopter application on radio systems.
- Clause 5.4: Report ITU-R M.2322 [i.9] - Systems characteristics and compatibility of automotive radars operating in the frequency band 77,5 - 78 GHz for sharing studies.
- Clause 5.5: Report ITU-R RA.2457 [i.10] - Coexistence between the radio astronomy service and radiolocation service applications in the frequency band 76 - 81 GHz.

5.2 Studies in ECC Report 056

The following text is a direct citation from the conclusion clause (clause 4) of ECC Report 056 [i.2].

"The technical feasibility of coexistence between automotive collision warning SRR and the radio astronomy service in the frequency band around 79 GHz is dependent on the aggregated impact of SRR devices transmitting in the direction of a radio astronomy station.

From the results based on the model used, with a maximum e.i.r.p. of -3 dBm/MHz per SRR device around 79 GHz, it is concluded that regulatory measures (e.g. automatic deactivation mechanism close to radio astronomy observatory stations) are necessary to enable the coexistence between SRR and the radio astronomy service.

…

It is further noted that Short Range Devices shall not cause harmful interference to a Radiocommunication service, in particular if operating on a Primary basis".

5.3 Studies in ECC Report 222

The following text of the relevant section is a direct citation from the executive summary of ECC Report 222 [i.8]. from:

"This report presents the results of the compatibility studies performed on the impact of airborne surveillance radar in the 76 to 79 GHz frequency range on radio systems and services.

…

Radioastronomy (co-channel)

Separation distances between 47 km and 98 km are required under worst case assumptions to protect the RAS stations in Europe. The difference between the near field and medium range obstacle detection system is small (near field system 47-98 km, medium range system 57-98 km). The altitude of the helicopter has an essential impact on the separation distance (altitude 300m: separation distance 98 km, altitude 0 m: separation distance 29 km. The above-mentioned distances are derived for an effective antenna height on the radio astronomy site of 50 m. The effect of the terrain can increase the size of the separation distances (e.g. 98 km could increase to 115 km) in case of RAS located in elevated positions (or when the helicopter would fly at greater altitudes) or reduce it when the terrain offer shielding to the radio astronomy site. It will be left to Administrations to identify, where necessary, the size and shape of the exclusion zone to protect radio astronomy sites, by using appropriate digital terrain models.

The occurrence probability has also been analysed in this report. As a limit the data loss value of 2% from Recommendation ITU-R RA.1513-1 maybe applicable as the percentage of lost observation packets each 2000 s period over one day.

The simplest interpretation would be to restrict the helicopter radar activity around the RAS station to fulfil the 2 % per day. This would mean a maximum on-time of 28.8 minutes a day, or about six Take-Offs and Landings per day (assuming 5 minutes transmitter on-time each landing and take-off).

More detailed occurrence probability calculations are provided in addition considering assumptions on helicopter deployment. As a result the occurrence probability shows a huge variance. …

It was not possible in this report to determine a representative result for the occurrence probability and exclusion zone.

Therefore, administrations should decide on a national level on the need for and the size of an exclusion zone.

…

No differentiation has been made between rescue (which is only a fraction of all operations) and non-rescue helicopter missions in the above calculations, because this is seen as outside the scope of this report.

…".

5.4 Studies in Report ITU-R M.2322

The following text is a direct citation from the conclusion section (chapter 8) of Report ITU-R M.2322 [i.9]:

"Theoretical studies and observations indicated that the required separation distance between automotive radars and incumbent services could range from less than 1 km to up to 42+km, depending on the interference scenario and deployment environment. These results were based on worst-case assumptions and did not take into account the effects of terrain shielding, terrain occupation and the implementation of mitigation techniques to reduce the possibility of interference to incumbent services. When these factors are taken into account, the possibility of co-channel interference to incumbent services from automotive radars is sufficiently low and manageable. Therefore, it can be concluded that in the 77.5-78 GHz band, sharing is feasible between automotive radars and incumbent services.

It is expected that any potential cases of interference between automotive radars and incumbent services could be addressed by mitigation factors such as terrain shielding, emission power limits and quiet zones. Some areas of concern remain and may need to be further analysed and dealt with by administrations. It is anticipated that the radio astronomers, radio amateurs and the automotive radar manufacturers will continue their cooperative effort to examine and implement mitigation techniques that can be employed to address potential interference concerns".

5.5 Studies in Report ITU-R RA.2457

The following text is a direct citation from the summary section (chapter 7) of Report ITU-R RA.2457 [i.10]:

"This Report provides sharing and compatibility study results between the radio astronomy service and radiolocation service (automobile radar applications) in the frequency range 76-81 GHz.

The case studies in the Report found the separation distances between a RAS station and a single automotive radar to be up to the order of 100 km. It has also been found that the separation distances strongly depend on the features of the terrain surrounding the RAS site, and local atmospheric characteristics. Indeed, this Report also shows that, if a RAS station is protected by mountains, the separation distance is greatly reduced. Thus, a zone around a RAS station, from which there might be impact from the automotive radars, should be analysed on a case by case basis and may have an irregular shape.

The impact of multiple interferers was not studied in this Report at this stage. Such analysis would require the consideration of the car radar density in road and towns with power aggregation taking into account the particularities of radar transmissions such as modulation type, duty cycle, lack of synchronization between different transmitters, and random orientation of the antennas with respect to the RAS station.

As shown in some compatibility studies, to address the areas of concerns around RAS stations observing in the frequency band 76-81 GHz, administrations operating RAS stations may introduce national regulatory measures to ensure coexistence between the two services. This Report provides examples of regulatory measures adopted by administrations operating RAS stations in its territory. Some administrations have already introduced such measures. Other administrations may refer to this Report towards establishing coexistence between the RAS and automobile radars, when operating or planning to operate RAS stations performing observations in the frequency band 76-81 GHz".

5.6 Summary of the former studies

There are already studies available that examine the impact of ground based vehicular radars operating in 76 - 81 GHz or parts thereof, into radio astronomy stations. Studies were prepared in CEPT as well as in ITU-R.

Depending on the approach and the assumptions that were taken for the individual studies, the following conclusions were drawn. For details, the relevant documents should be consulted:

- Separation distances are required to mitigate the interference from radars operating in the 76 - 81 GHz range into radio astronomy observation sites. The proposed values for the separation distances vary, depending on the study, from some km up to 100 km.
- Exclusion zones would need to be analysed on a case-by-case basis and might have an irregular shape.
- Factors such as terrain shielding, terrain occupation and local atmospheric characteristics might help reduce the required separation distances.
- Other mitigation factors such as emission power limits and quiet zones could be implemented to address potential cases of interference between ground based vehicular radars and incumbent services.
- Administrations operating RAS stations may introduce national regulatory measures to ensure coexistence between ground based vehicular radar and the RAS. Some examples exist where such measures were already implemented.

6 New CEPT study based on information provided in ETSI TR 103 593

6.1 Introduction

In 2018 the European automotive radar manufacturers started to develop a system reference document ETSI TR 103 593 [i.11] in ETSI TG SRR to revise the in-force European Regulation for 77 - 81 GHz ground based vehicular radar in order to enable the use for current and future radar-based applications. ETSI TR 103 593 [i.11] was published in 05/2020.

The key aspects that were addressed in the SRDoc are:

- Evolution of the radar technology since 2004.
- Evolution of legal requirements for vehicle safety.

- Request for technical parameters that also allow the operation of Mid-range Radars and Long-Range Radars in the frequency band.
- Description of the evolving requirements for radar-based driver assistance systems and for highly automated or autonomous driving vehicles.

In 2020 the SRDoc was sent to WG FM and they subsequently tasked WG SE to carry out studies. The studies were conducted in SE 24 and the results are available in ECC Report 350 [i.12] which was approved and published in 2023.

6.2 Summary of the Results from ECC Report 350 regarding interference from vehicular ground based radars into RAS

The following text below is a citation and provides the relevant section that summarizes the results of the sharing studies between vehicular ground based radars and RAS from the executive summary of ECC Report 350 [i.12] is provided:

"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."

NOTE: The exclusion zone of up to 70 km corresponds to an approx. 40 dB too large interference power received by RAS.

6.3 Revision of ECC/DEC/(04)03

Based on the results of the studies in ECC Report 350 [i.12], SRD/MG started the revision of ECC/DEC/(04)03 [i.1]. The revision covered the following points:

- Modification of the title of the decision to "The frequency band 77-81 GHz to be designated for the use of ground based vehicular radars".
- Revision and addition of technical parameters for ground based vehicular radars operating in 77 - 81 GHz.

It is to be noted, that in the revised text of the decision ECC/DEC/(04)03 [i.1] Considering j) states that "*that ground based vehicular radar equipment is not considered as a safety of life service in accordance with the Radio Regulations, therefore it must operate on a non-interference and non-protected basis in accordance with the Radio Regulations*". It is for regulatory consideration to follow WRC-15 decision for the 77,5 - 78 GHz band and designate automotive radars as an application of the Radio Location service as already outlined in ETSI TR 103 593 [i.11].

The elevation in the status of ground based vehicular radar as an application of the Radio Location service would increase the apportionment of the interference attributed to ground based vehicular radar.

The final draft was sent to public consultation. SRD/MG #91 examined the comments that were received during public consultation: a contribution from CRAF was received. CRAF's comments raised the issue that in their view the ECC Report 350 superseded the 2003 studies and that it is necessary to introduce a protection zone for astronomical sites in relation to SRR and a list of the astronomical sites should be attached as an annex of the ECC/DEC/(04)03 [i.1]. All contributions that were received during public consultation of draft revision of ECC/DEC/(04)03 [i.1] are available in SRDMG(24)030 [i.13].

SRD/MG #91 debated the contributions and comments that were made. It was noted that the studies in ECC Report 350 [i.12] only considered exclusion zones as mitigation technique to protect RAS, and that other mitigation measures were not considered. It was decided to inform WG FM that further studies may need to be carried out in relation to exclusion zones and possible other mitigation measures for SRR.

Following the report from SRD/MG to WG FM#107 Liaison statements were sent by WG FM to:

- WG SE with Cc to SE24, the subject of this LS being related to initiating studies to analyse mitigation measures for SRR to ensure protection of RAS, while eliminating or minimizing the exclusion zones.
- ETSI TC ERM, with CC to CRAF and ETSI TGSRR Chair, regarding on possible mitigation measures for SRR to ensure the protection of RAS. The LSin to ERM is available in document ERM(24)083040 [i.14]. The LSin to TG SRR is available in document ERMTGSRR(24)050007 [i.15].

7 Review of the study results from ECC report 350

7.1 Illustration of the RAS exclusion zones based on the results from ECC Report 350

The map in Figure 1 provides an overview illustration of the size and geographical localization of the proposed RAS exclusion zones based on the results from ECC Report 350 [i.12].

Figure 1: RAS exclusion zones based on the results of ECC Report 350 (scenario "A+4B")

The exclusion zones cover approx. 250 000 km² which is approx. 2,3 % of Europe. They touch the larger cities of Madrid, Grenada and Bologna which represent approx. 1 % of the European population.

Outside of those exclusion zones radar sensors would be able to transmit in the range 77 - 81 GHz with the max. allowed power.

Inside of those exclusion zones radar sensors could only transmit in the range 76 - 77 GHz, which would mean a second mode of operation, which would have to be validated and to be homologated, so doubling the radar sensor and vehicle function development effort. That could prevent deployment of ground based vehicular radar in the 77 - 81 GHz band at all.

Alternatively, radar transmission could be completely stopped inside of those exclusion zones which would mean loss of ADAS and safety features for the car user. This aspect is already referred to in ECC report 350 [i.12] and ECC/DEC/(04)03 [i.1].

Therefore, the continuous availability of radar with appropriate technical performance will play a key role in satisfying the related safety regulations. Turning off the radar will reduce or disable the system's performance and features in protecting vulnerable road users. This functionality cannot be replaced by other technical systems, considering the varying operational conditions. See Annex F for more details on the existing General Safety Regulation (EU) 2019/2144 [i.23].

7.2 Used RAS antenna pattern

ECC report 350 uses an omnidirectional 0 dBi antenna for the RAS. This is based on the assumption that all ground based interference will be received through the sidelobes, which is further explained in Recommendation ITU-R RA.769-2 [i.6] §1.3. A reference gain of 0 dBi is selected, which is achieved at an angle of 19,05° for the peak pattern of Recommendation ITU-R SA.509-3 [i.28].

Recommendation ITU-R SA.509-3 [i.28] also contains an aggregate model, which is to be used in aggregate studies, seems more applicable to aggregate studies. This pattern is 3 dB lower than the peak pattern for the same angle.

Recommendation ITU-R SA.509-3 [i.28] is only applicable for frequencies less than 30 GHz. Recommendation ITU-R SA.1811 [i.29] contains an example of RAS aggregate antenna pattern for 31,8 - 32,3 GHz and 37 - 38 GHz. At an angle of 19,05°, this pattern has a gain of -7,7 dBi. Therefore, in view of the applicability to higher frequencies and the more recent basis of the work, the aggregate model from Recommendation ITU-R SA.1811 [i.29] seems like the appropriate model.

Figure 2 shows the comparison of the different RAS antenna models based on the available recommendations ITU-R.

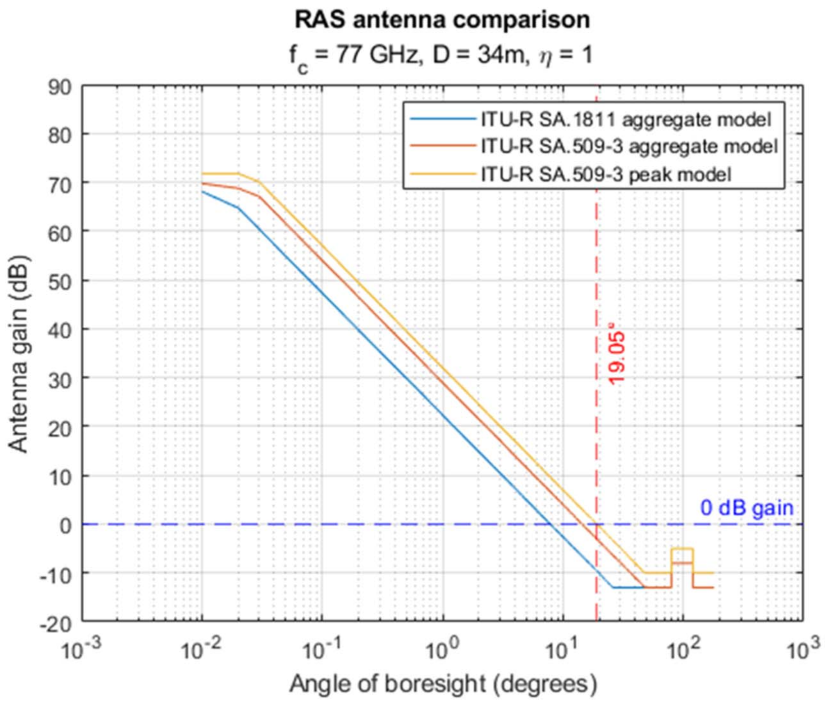

Figure 2: RAS antenna comparison

NOTE: In view of the RAS antenna patterns provided it is proposed to reconfirm the applied RAS antenna model for the frequency range 77 - 81 GHz. Outcome can be that interference power is smaller by approximative 8 dB.

7.3 Traffic density assumptions

In Annex E an apparent mismatch between traffic density assumptions in ECC Report 350 [i.12] and the reported worst case vehicle density in a 200 x 200 km area around two RAS stations in that same report is signaled.

Comment: Resolution of this mismatch is highly desirable.

7.4 Radar transmit power

In ECC report 350 [i.12] it is assumed that all vehicles use the maximum transmit power levels. In reality, a certain power level distribution below the maximum power level would be observed. A rough estimation is a normal distribution with ±3sigma = 3 dB.

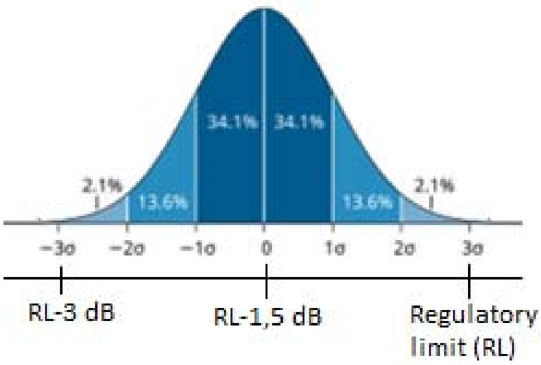

Figure 3: Estimated transmit power distribution for a ground based vehicular radar sensor

NOTE: Considering that would lead to a reduction of interference power in average by 1,5 dB.

7.5 Summary

With the aspects discussed in clauses 7.2 to 7.4 the interference power would be at most reduced by approx. 10 dB, meaning that the exclusion zones would have a smaller radius, but would still be present.

To avoid exclusion zones completely a further reduction of interference power of approx. 40 - 10 = 30 dB is needed.

In clause 8 several mitigation measures other than exclusion zones are discussed for reducing the interference power. Independent of that, the radio quiet zones mentioned in clause 4.4 do still exist.

8 Alternative mitigation measures

8.1 Introduction

This clause lists alternative measures that can be used to mitigate interference from ground based vehicular radars into RAS sites.

Clauses 8.2 to 8.6 provides measures that would be performed by the vehicle system.

Clause 8.7 lists "external" measures outside the vehicle.

8.2 Mitigation in space

Table 3 provides alternative mitigation measures in space.

Table 3: Mitigation measures in space

Measure	Estimated interference power reduction in [dB]	Comments	Assessment
Replace exclusion zones by coordination zones	See Annex A for a first estimate: Coordination zones can probably reduce the area where mitigating measures are needed substantially for most RAS sites. Medicina, Yebes, IRAM and Onsala do not have a very favourable geography, however. Other RAS sites: depending on the geography > 40 dB	Either no transmission inside coordination zone or other mitigation method(s)	Increases complexity in system validation & integration in vehicles. Impacts sensor dependability in car safety and automatic driving systems
Inside coordination zone: Adaptive Tx beam: ground based vehicular radar sensor always produces emission notch in direction of radio astronomy sites	> 6 dB	Bad if from driving point of view in just that direction a large detection range is needed. This type of antenna pattern control is not a common ground based vehicular radar feature. Depends on the implementation of the radar sensor. Not technology neutral	Unrealistic / not feasible
Inside coordination zone: Radar sensor pointing to RAS station will stop transmission in band 77 - 81 GHz	15 - 20 dB		Increases complexity in system validation & integration in vehicles. Impacts sensor dependability in car safety and automatic driving systems

8.3 Mitigation in power

Table 4 provides alternative mitigation measures in power.

Table 4: Mitigation measures in power

Measure	Estimated interference power reduction in [dB]	Comments	Assessment
Inside coordination zone: Reducing vehicular radar duty cycle (in addition to the 30 % duty cycle assumed in ECC Report 350 [i.12]).	A few dB, depending on the permissible detection performance degradation and time-resolution of the sensor.	Will reduce a bit the area of the exclusion zones but will not remove them.	Degrades radar performance in terms of range and latency.
Inside coordination zone: Reduce the proposed increased power levels (as assumed in ECC Report 350 [i.12], table 3).	A few dB, depending on the permissible detection performance degradation and the required range of the sensor. Range is a function of d^4.	Will reduce a bit the area of the exclusion zones but will not remove them.	Degrades radar performance in terms of range.
Inside coordination zone: Step back from request for long range radar category.	Approx. 1 dB if mitigating radar type A (see ECC Report 350 [i.12]).	20 dBm/MHz was planned for front center sensors, but RAS simulation results show that mid-range radars are more relevant.	China so far also does not allow more than 7 dBm/MHz.
Inside coordination zone: Step back from request for long range and mid range radar category.	Approx. 7 dB if mitigating radar type A and type B.		South Korea so far also does not allow more than -3 dBm/MHz.

8.4 Mitigation in frequency

Table 5 provides alternative mitigation measures in frequency.

Table 5: Mitigation measures in frequency

Measure	Estimated interference power reduction in [dB]	Comments	Assessment
Inside coordination zone: Ground based vehicular radars with less than 1 GHz operating bandwidth switch to range 76 - 77 GHz	> 40 dB	Will increase interference in 76 - 77 GHz among ground based vehicular radars	Increases complexity in system validation and integration in vehicles
Inside coordination zone: Ground based vehicular radars do not use 79 - 81 GHz	3 dB	Would worsen the resolution of the radar from 3,75 to 7,5 cm, losing the benefit of the high bandwidth for new higher resolution applications In 77,5 - 79 GHz radio astronomy is not a primary user	Reduced precision of shorter distance radars. Higher contention between radars in the 76 - 79 GHz band. China so far also does not allow 79 - 81 GHz for ground based vehicular radars

8.5 Mitigation in time

Table 6 provides alternative mitigation measures in time.

Table 6: Mitigation measures in time

Measure	Estimated interference power reduction in [dB]	Comments	Assessment
Inside coordination zone: Radio astronomy informs vehicles via mobile internet or other communication technology when radio astronomy measurements are ongoing. During that time radar sensors will only operate in 76 - 77 GHz	> 40 dB	Will increase interference in 76 - 77 GHz among ground based vehicular radars and will exclude higher resolution radar functions	Increases complexity in system validation and integration in vehicles. Impacts wideband sensor dependability in car safety and automatic driving systems in a modest degree

8.6 Mitigation in code

This was investigated, but found to be not applicable, because RAS station in this band use continuum observations (see clause 4.5), and only detect energy.

8.7 Mitigation in propagation

Table 7 provides alternative mitigation measures in propagation.

Table 7: Mitigation measures in propagation

Measure	Estimated interference power reduction in [dB]	Comments	Assessment
Local fixed shielding(s) around radio astronomy sites to protect radio astronomy in most severe propagation paths	> 30 dB, see Annex B for further details	Would need additional interference simulations to find exact dB improvement and best position for shielding measures. Might be a Feasible solution	Will involve costs per RAS site
Road shielding	At most 3 dB (first order estimate: shielding of only primary roads provides covers roughly 50 % of cars)	Provide shielding for roads with significant traffic and good propagation to a RAS site. In practice shielding of other than primary roads will be impractical	Will involve costs per RAS site
Active RAS interference compensation technique to measure interference close to the RAS station and compensating RAS measurements for interference from ground based vehicular radars	Approx. 10 dB (research is needed), see Annex C for further details	It may be possible to compensate the interference of a RAS measurement by subtracting an estimate of that interference from the measurement using specific interference receivers	Research is needed to determine effectiveness
RAS antenna sidelobe reduction	Up to 10 dB, see Annex D for further details	Would need modification to RAS antenna	Effectiveness needs to be investigated
Observation track planning Limitation of operation of elevation and azimuth angle of RAS station possibly in combination with (expected) traffic density	Approx. 6 dB (factor 4) for traffic density. Sidelobe attenuation envelope Recommendation ITU-R SA.1811 [i.29] varies between -8 dB and -13 dB over a large range. I.e. 5 dB mitigation can be achieved maximally by avoiding exposing the worst side	Traffic density scheduling effectiveness is limited by traffic density variation through the day. A factor 4 is assumed here as potentially practical	Adds a constraint to RAS observation planning

9 Mitigation measures and related technical information to be used in the addendum to ECC Report 350

9.1 Background

In September 2024, CEPT WG SE approved a new SE 24 work item 82 [i.16] for the additional studies to be used in the addendum to ECC Report 350 [i.12]. See [i.16] for more detail. This study report serves as input to SE24 WI82.

The results of the present document are summarized in the following clauses.

9.2 Simulation

Some details of the existing RAS simulations in ECC report 350 [i.12] require clarification. Table 8 summarize the necessary clarifications.

Table 8: Parameters of RAS studies in ECC report 350 that require clarification

Detail	Clause	Mitigation	Comment
RAS mitigation measures in signal processing already applied today	4.5	TBD	To be added to simulation?
RAS antenna pattern	7.2	8 - 13 dB	To be corrected in simulation?
Traffic density assumptions	7.3	TBD	To be corrected in simulation?
Radar transmit power distribution	7.4	1,5 dB	To be added to simulation

With clarified details then updated simulations can be run to get updated exclusion zone dimensions and an updated dB target for mitigation measures without exclusion zones.

9.3 Mitigation measures

From the mitigation measures presented in clause 8 those to influence the propagation and coupling to the RAS receiver seem most interesting from the perspective of the automotive industry as shown in Table 9.

Table 9: Mitigation measures

Measure	Clause	Mitigation	Qualification
RAS shielding	8.7	> 30 dB	Costly, depending on permits & existing situation around RAS station
Road shielding	8.7	< 3 dB	
RAS interference compensation	8.7	approx. 10 dB	Requires investigation
RAS sidelobe reduction	8.7	< 10 dB	Requires investigation
Observation track planning - lobe vs. traffic density	8.7	approx. 6 dB	Requires investigation

These measures can also protect against other (future) interferers in adjoining bands. However, the realization of these measures will require a thorough investigation/simulation.

The mitigation measures, presented in clause 8 for realization by the vehicle system, propose to replace "exclusion zone" by "coordination zone" concept and combine this with further measures.

For radars, with an operating bandwidth ≤ 1 GHz, the measures given in Table 10 significantly contribute to interference mitigation:

Table 10: Measures for radars with operating bandwidth ≤ 1 GHz

Measure	Clause	Mitigation	Qualification
Inside coordination zone: Switch all radars to range 76 - 77 GHz.	8.4	> 40 dB	Increases complexity in system validation and integration in vehicles. Will increase interference in 76 - 77 GHz among ground based vehicular radars.
Inside coordination zone: Switch the radar sensor pointing towards the RAS station to range 76 - 77 GHz.	8.2	15 - 20 dB	Increases complexity in system validation & integration in vehicles. Impacts sensor dependability in car safety and automatic driving systems.

For radars with an operating bandwidth > 1 GHz the measures given in Table 11 significantly contribute to interference mitigation:

Table 11: Measures for radars with operating bandwidth > 1 GHz

Measure	Clause	Mitigation	Qualification
Inside coordination zone: Radar sensor pointing to RAS station will stop transmission in band 77 - 81 GHz.	8.2	15 - 20 dB	Increases complexity in system validation & integration in vehicles. Impacts sensor dependability in car safety and automatic driving systems.

It is highlighted that protection or coordination zones cause increased complexity and effort required for radar and vehicle system design. Furthermore, radar functionality needs to be continuously available with appropriate technical performance in order to satisfy the related traffic-safety regulations. Turning off the radar will reduce or disable the system's performance and features in protecting vulnerable road users. This functionality cannot be replaced by other technical systems, considering the varying operational conditions. Safety systems that disable radar sensors do not meet existing General Safety Regulation (EU) 2019/2144 [i.23], see Annex F for more details. Protection- or coordination zones will bring significant negative consequences for the car industry.

Annex A: Coordination zones

A.1 Introduction to ECC Report 351 coordination zones

Coordination zones were introduced first as a concept in ECC Report 351 [i.5]. In ECC Report 351 [i.5] the coordination zones require a reduction of output power to a maximum when inside a given coordination zone. Coordination zones are circular, but not necessarily centred around the RAS station. Coordination zones may overlap. In ECC Report 351 [i.5] the demarcation of coordination zone is defined as a zone where the maximum EIRP for a single interferer limit in the direction of the RAS station is more than the limit of the coordination zone (with the exception of an overlapping area of a nested zone with a lower EIRP limit).

A.2 Coordination zones in the present document

In the present document a much more generic concept of coordination zone is introduced (if applicable it may be called mitigation zone). No specific constraints are imposed (like circle shape or EIRP limit). Simply that it is a "connected" area where a mitigation method is required to ensure no substantial interference is caused to the RAS station. The precise details of the zone shape, location and the mitigation method is not considered in detail at this stage.

A.3 Differences between ECC Report 351 and ECC Report 350

Table A.1: Differences between ECC Report 351 [i.5] and ECC Report 350 [i.12]

Analysis method aspect	Report 350 [i.12]	Report 351 [i.5]
Clutter model	Yes	No
Multi-interference	Aggregate	single-entry
Car orientation	Aligned to road	Worst case
Probability of car in a location	Road network + type of road determines probability	Not considered
Radars creating most interference	corner	front
Other parameters (interference level, radar output power, atmospheric propagation differences, frequency, etc.)	Not compared - see note	
NOTE: These combined differences of these parameters are considered as a combined effect leading to an outer range where mitigation is required.		

A.4 Comparison of exclusion zones in ECC Report 350 and ECC Report 351

In Figures A.1 and A.2 the zero interference margin lines for 9 and 32 dBm EIRP are presented for Noema (France) and IRAM (Spain). Note that the white circles have a radius of 50 and 100 km. The exclusion zones for these examples in ECC report 351 [i.5] were determined at 100 and 70 km respectively.

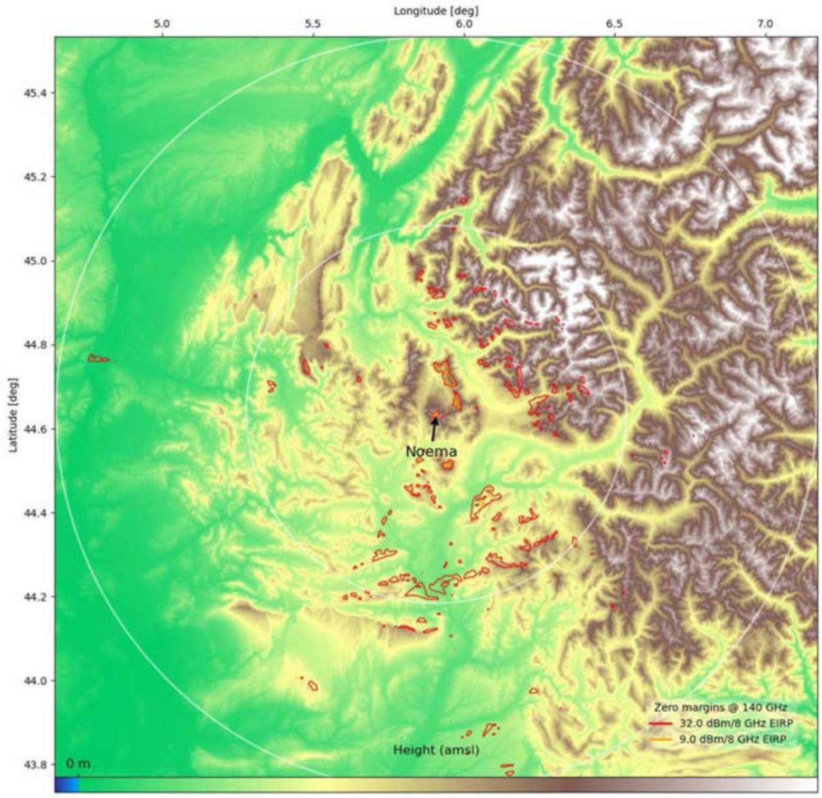

Figure A.1: Eero interference line for NOEMA RAS site (Source: ECC Report 350 [i.12])

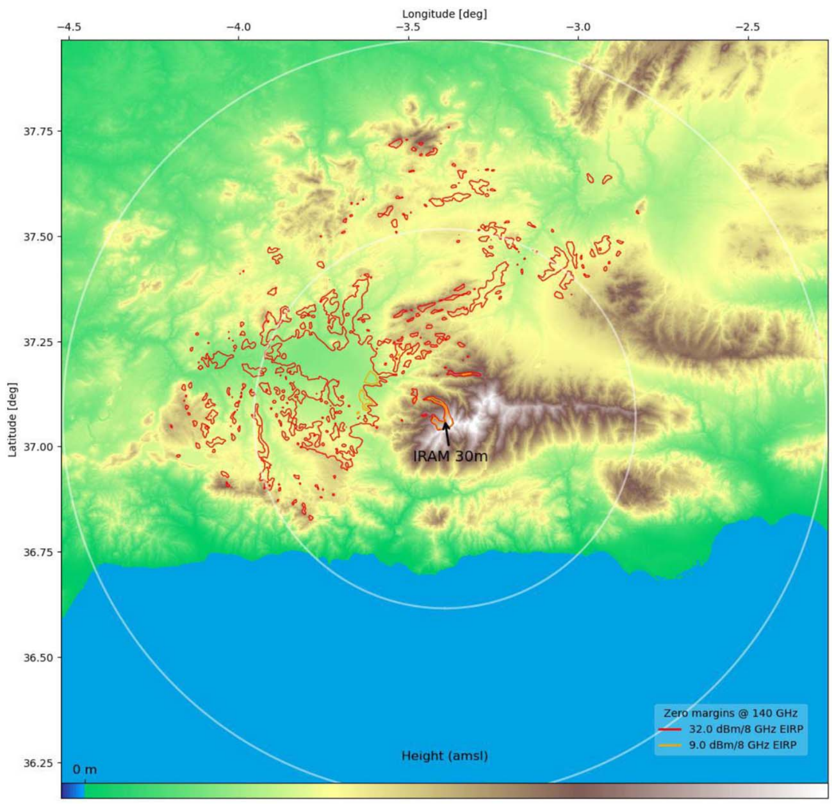

Figure A.2: zero interference line for IRAM RAS site (Source: ECC Report 350 [i.12])

The exclusion zones for Noema and IRAM in ECC report 350 [i.12] were determined as 53 and 70 km:

- both slightly smaller.

A.5 Coordination zones in ECC report 351

The coordination zones in ECC Report 351 [i.5] are indicated below in Figure A.3 and Figure A.4. The IRAM coordination zones are nested, while the NOEMA zones are distributed (also referred to as 'clustered' in ECC Report 351 [i.5]).

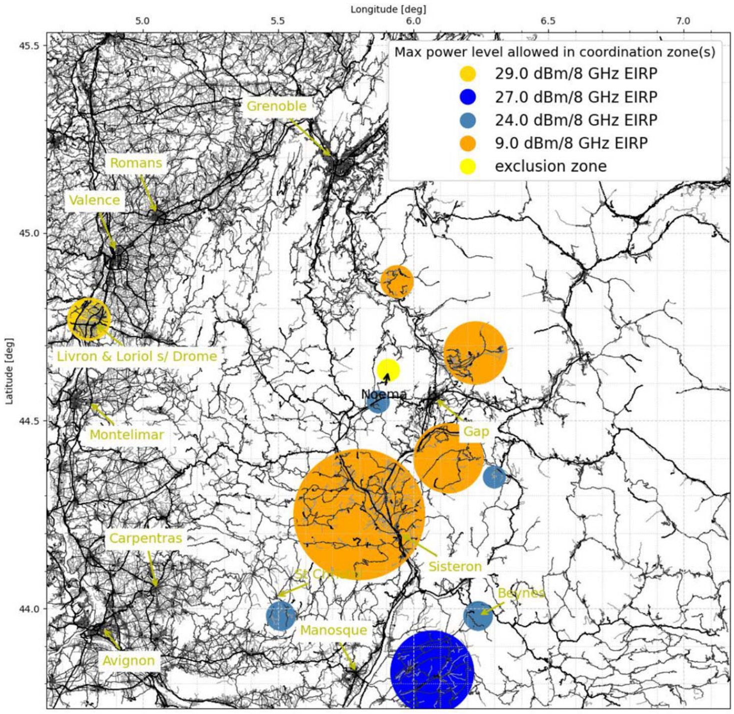

Figure A.3: Coordination zone around NOEMA RAS site (Source: ECC Report 351 [i.5])

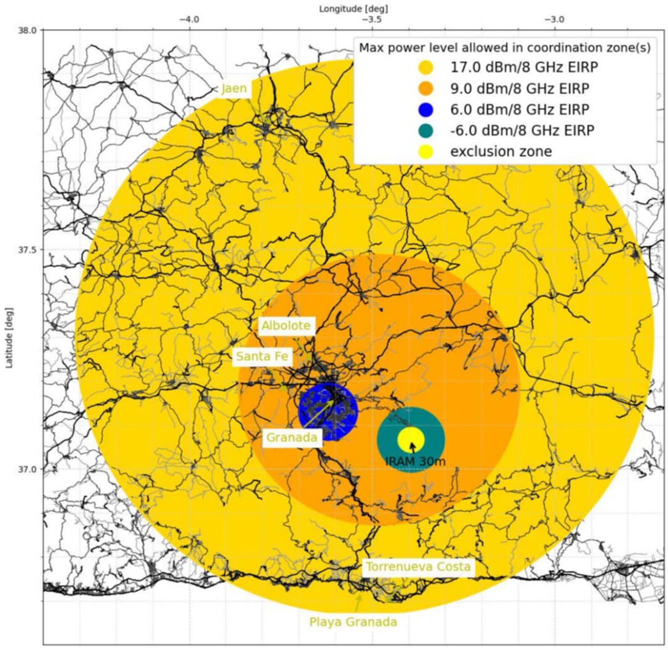

Figure A.4: Coordination zone around IRAM RAS site (Source: ECC Report 351 [i.5])

A.6 Informal assessment of coordination zone effectiveness for all RAS stations

This clause provides a first informal assessment of the potential effectiveness of coordination zones. The reason to provide this informal assessment of all RAS sites is to understand what the end result could likely be, because doing a full analysis is rather labour intensive.

The shape of the exclusion zone graph in ECC Report 350 [i.12] permits a relatively simple assessment at what distance local zones exist and where they end. This is where there is a sudden drop in the exclusion zone radius. Also it is possible to assess if local zones are the exclusive source of interference or if wider areas are causing gradually diminishing interference. This is where there are gradually sloping down sections in the graph. These zones are referred to as "concentric" zones attenuation.

For example, in below Figure A.5 showing NOEMA (France) situation, several sudden drops can be seen for example at ~30 km and ~48 km.

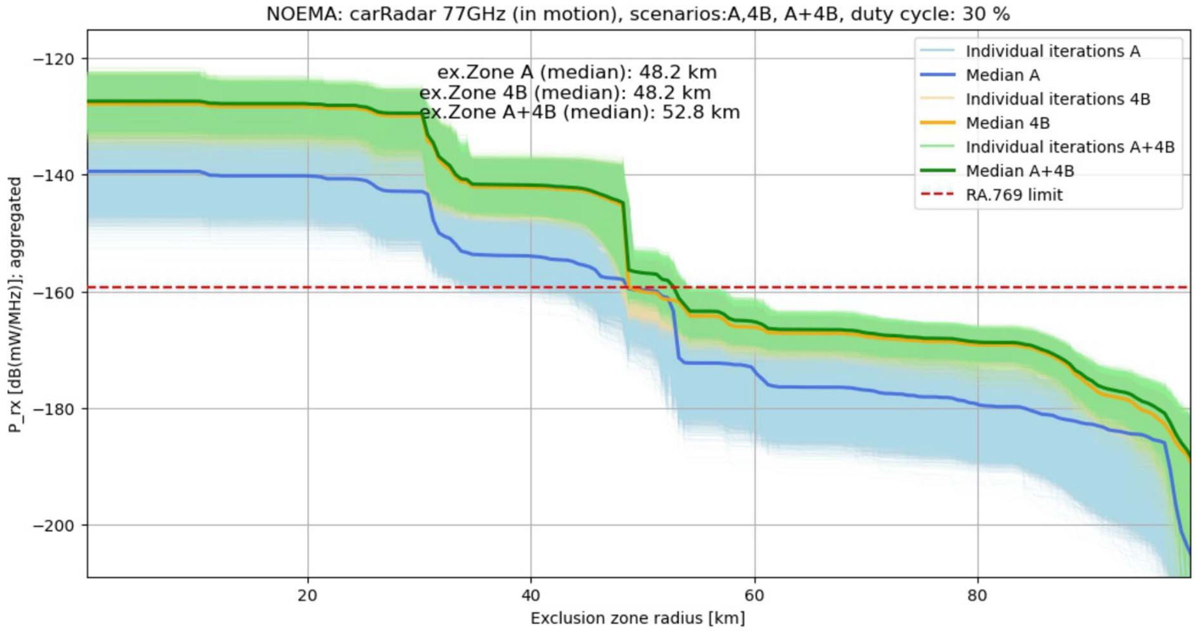

Figure A.5: NOEMA RAS site: power versus distance (Source: ECC Report 350 [i.12])

Table A.2: Results from ECC report 350 [i.12] for the size of exclusion zones around selected RAS sites

Station	A+4B [km]	Local zone(s) ending [km]	Concentric zones of attenuation
NOEMA (FR, Alps)	53	30, 48, 53	none
Sardina (IT)	40	2, 8, 16, 24, 42	none
Pico Veleta (IRAM, SP, Granada)	69	43	37, 70
Onsala (Sweden, east coast)	21	13, 16, 21	10
Effelsberg (Germany)	2.2	2.2	none
Medicina (IT, Bologna)	64	4	65
Noto ("heel of" Italy)	27	6, 15, 19, 27	3
Metsähovi (suburb Helsinki)	15	5, 15	3
BEST	16	17	2
Yebes (SP, Madrid)	67	11, 23, 58, 66	17, 56

A.7 Assessment of potential effectiveness of coordination zones

In 7 of the 11 sites local coordination zones seem to be sufficient to reduce the concentric zone to less than 3 km. In 4 sites there will be a need for larger concentric zones:

- Medicina;
- Yebes;
- IRAM; and
- Onsala.

Specifically Medicina geography is extremely problematic: see ECC Report 350 [i.12] result summary for Medicina in Figure A.6.

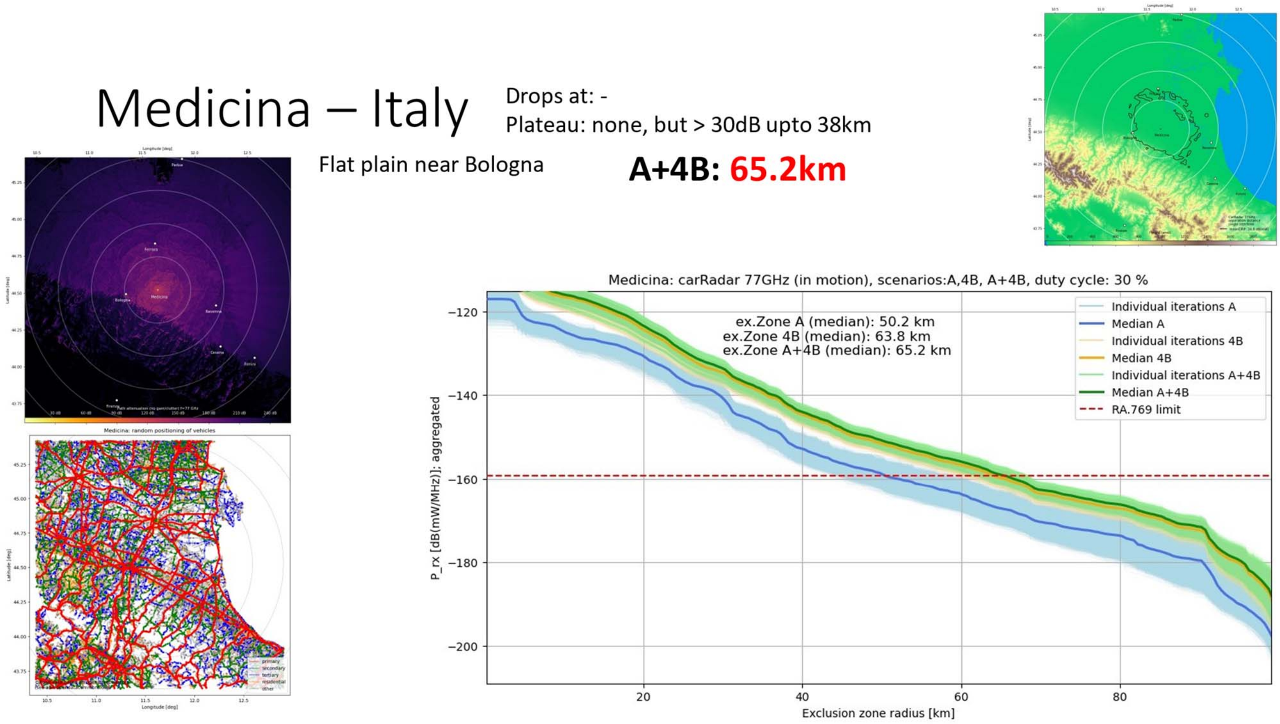

Figure A.6: Situation around Medicina RAS site
(Source: ECC Report 350 [i.12])

A.8 Provisional conclusion

Coordination zones (local zones where ground based vehicular radars take interference mitigating measures) can probably reduce the area where mitigating measures are needed substantially for most RAS sites. Medicina, Yebes, IRAM and Onsala do not have a very favourable geography, however.

Annex B: Effectiveness of local shielding

B.1 Introduction

By adding local shielding (barrier) in the close vicinity of the telescope a significant attenuation can be achieved towards areas which cause significant interference from ground based vehicular radars. For the estimation of the effectiveness of a barrier, knife edge diffraction approximation is used.

NOTE: The calculations and figures in this clause are indicative.

It should be noted that there is a practical limit for high barriers besides cost: it will also limit the visibility of the telescope to the sky if too high or placed too closely.

B.2 Single barrier case

Assume a LOS situation, and a barrier is added. As an approximation, the barrier is modeled as a single knife-edge obstacle as shown in Figure B.1. The explanation of the parameters is given in Table B.1.

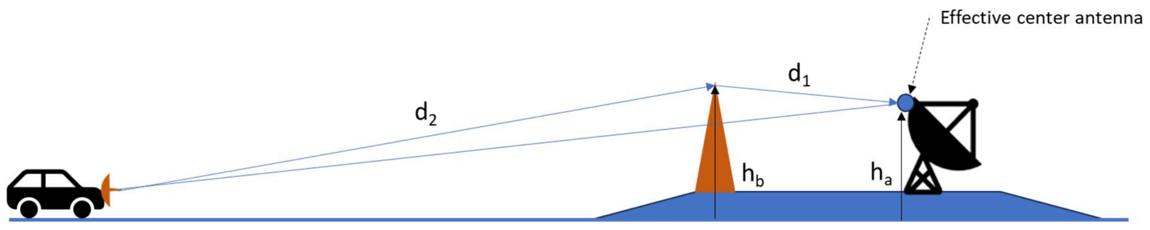

Figure B.1: Representation of the described scenario

Table B.1: Explanation of the parameters used

Symbol	Meaning
h_a	Height above reference level of the effective center of the antenna
h_b	Height above reference level of the barrier
d_1	Path length from top of barrier to effective center of antenna
d_2	Path length from top of barrier to transmitter
h_m	Effective height of barrier: approximated by $h_b - h_a$ for $d_2 \gg d_1$
d'_1	Actual distance on a straight line between barrier and telescope; approximately d_1
d'_2	Actual distance on a straight line between barrier and telescope; approximately d_2
$J(v)$	Diffraction loss

Using equation (26) from Recommendation ITU-R P.526-15 [i.30], section 4.1 the diffraction parameter ν can be calculated as in equation (B.1):

$$\nu = h_m \sqrt{\frac{2}{\lambda}\left(\frac{1}{d'_1} + \frac{1}{d'_2}\right)}. \tag{B.1}$$

The diffraction loss $J(v)$ can be calculated as in equation (B.2):

$$J(v) = -20 \log\left(\frac{\sqrt{[1-C(v)]^2 + [C(v)-S(v)]^2}}{2}\right) \tag{B.2}$$

where $C(v)$ and $S(v)$ are the real and imaginary parts respectively of the complex Fresnel integral $F(v)$, as defined in Recommendation ITU-R P.526-15 [i.30], § 2.7.

For $v > -0{,}78$ $(corresponding\ to\ J(v) > 0\ dB)$ this can be approximated using equation (B.3):

$$J(v) = 6{,}9 + 20\log\left(\sqrt{(v-0{,}1)^2+1} + v - 0{,}1\right) \qquad \text{(B.3)}$$

Warning: The barrier height in the graphs below excludes the height of the effective antenna center.

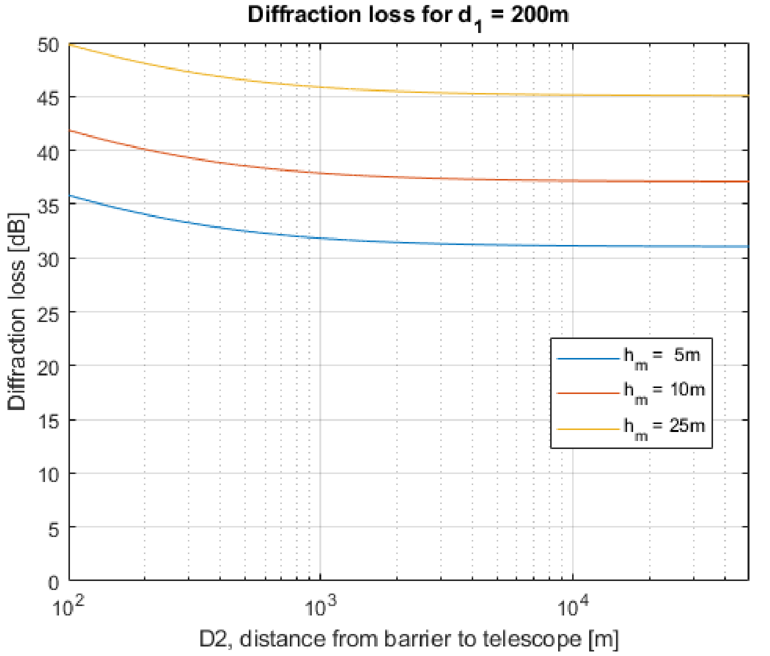

Figure B.2: Diffraction loss for the above-described scenario by varying d_1

Figure B.2 shows that as long as the distance of the car to the barrier is substantially longer than the distance of the barrier to the RAS station, the diffraction loss is practically constant.

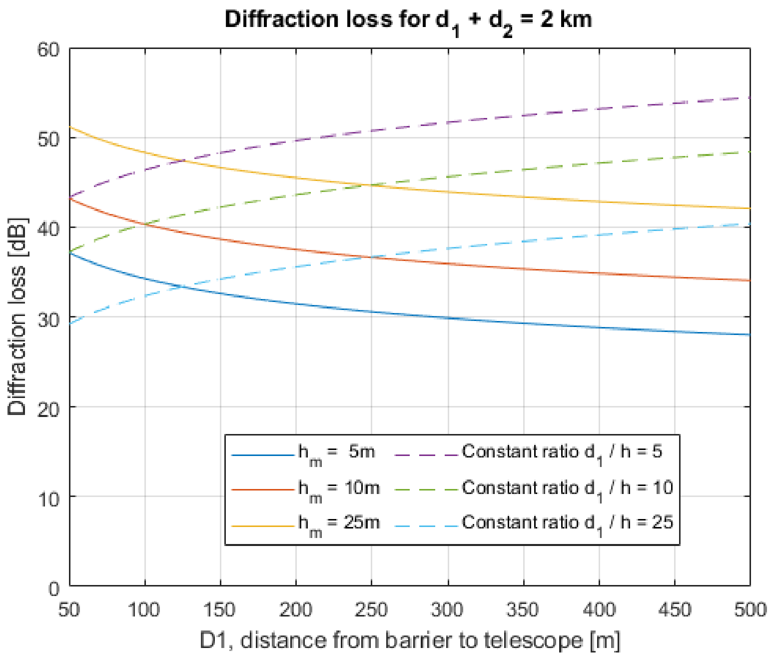

Figure B.3: Diffraction loss for d_1+d_2 = 2 km

Figure B.3 shows that increasing the distance of the barrier to the telescope will decrease the diffraction loss, but by keeping the ratio between *effective* barrier height ($h_m \approx h_b - h_a$) and the distance equal an increase of the diffraction loss can be achieved.

B.3 Provisional conclusion

In locations with RAS station line of sight to traffic, a barrier between 100 m and 1 km from the telescope, slightly higher than the effective height of the radio astronomy antenna can provide 30 - 50 dB diffraction attenuation.

NOTE: For barriers relatively closer to the telescope more complex models may be needed, since there is unlikely to be a distinct effective antenna height.

B.4 Addendum: Extension with clutter loss

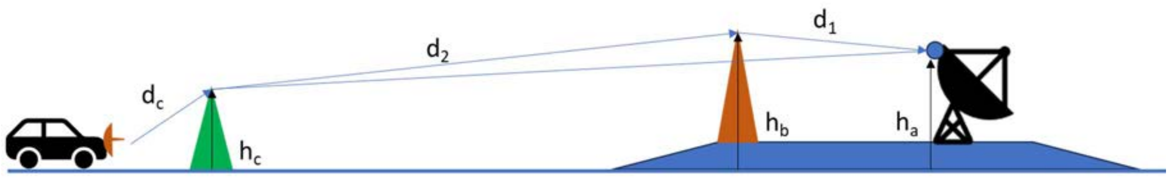

Figure B.4: Model where there is clutter loss the situation is slightly more complex

Assuming the height of the clutter has no significant impact on h'_m the overall diffraction loss is the sum of the diffraction loss of the clutter and the diffraction loss of the barrier according to Deygout method of multiple knife-edge diffraction loss calculations, the ν for the clutter and the ν for the barrier being relatively independent, except when h_c is very high.

Annex C:
Interference compensation

C.1 Introduction

Interference compensation is a system proposed in the present document whereby the RAS measurement of the energy coming from a certain location in the hemisphere to which interference energy is added can be compensated by subtracting an measurement of that interference from the RAS measurement.

The basic principle is indicated below and is relatively simple: the interference is measured as coming from a specific direction. With a known attenuation from the measurement antenna to the RAS antenna a good estimate can be created of the amount of interference received.

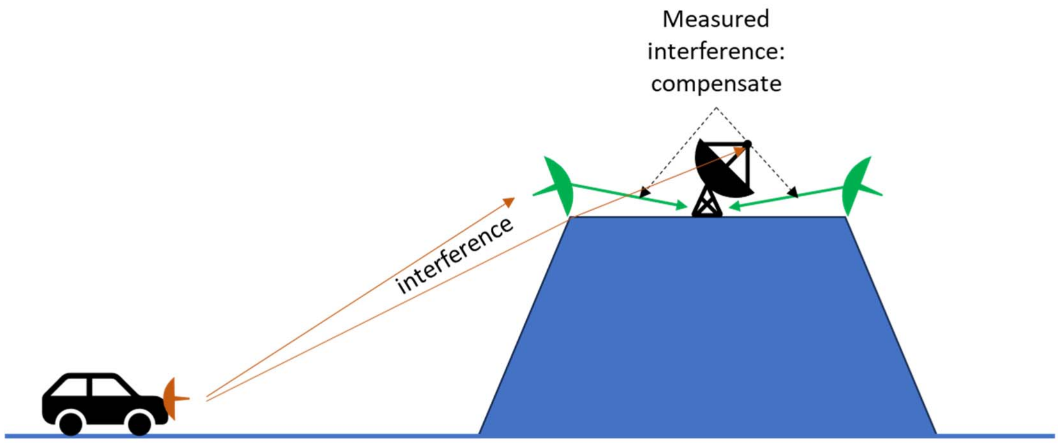

Figure C.1: Basic principle for interference compensation

The precise transfer from incoming interference to the RAS receiver is through sidelobes which may be irregular and thus very RAS antenna-direction dependent. In case the interference is relatively homogeneous in terms of direction such high direction dependency average out. This is true specifically for interference in the azimuth plane. Elevation dependent RAS antenna may require a quite precise determination.

EXAMPLE: With a 90 % compensation accuracy, and the non-compensated interference Inc/N= -3 dB, the compensated interference Ic/N = -13 dB.

C.2 Provisional conclusion

It may be possible to compensate the interference of a RAS measurement by subtracting an estimate of that interference from the measurement using specific interference receivers.

Annex D: Sidelobe reduction for parabolic antennae

D.1 Introduction

In this annex, three literature references are presented that provide techniques to reduce the sidelobes of a parabolic antenna.

D.2 Literature references

D.2.1 Edge treatment for sidelobe reduction of parabolic reflector antenna with a two-layer absorber

Abstract:

In this paper [i.25]: "*we present a method to reduce the sidelobe levels of a given parabolic reflector antenna by coating it with a 2-layer absorber. The absorber is designed by using Genetic Algorithm and an ultra-wideband performance (4,6 - 18 GHz) is obtained. The simulation results show that the sidelobe level can be reduced by coating the edge of the parabola with 2-layer absorber without compromising the gain*".

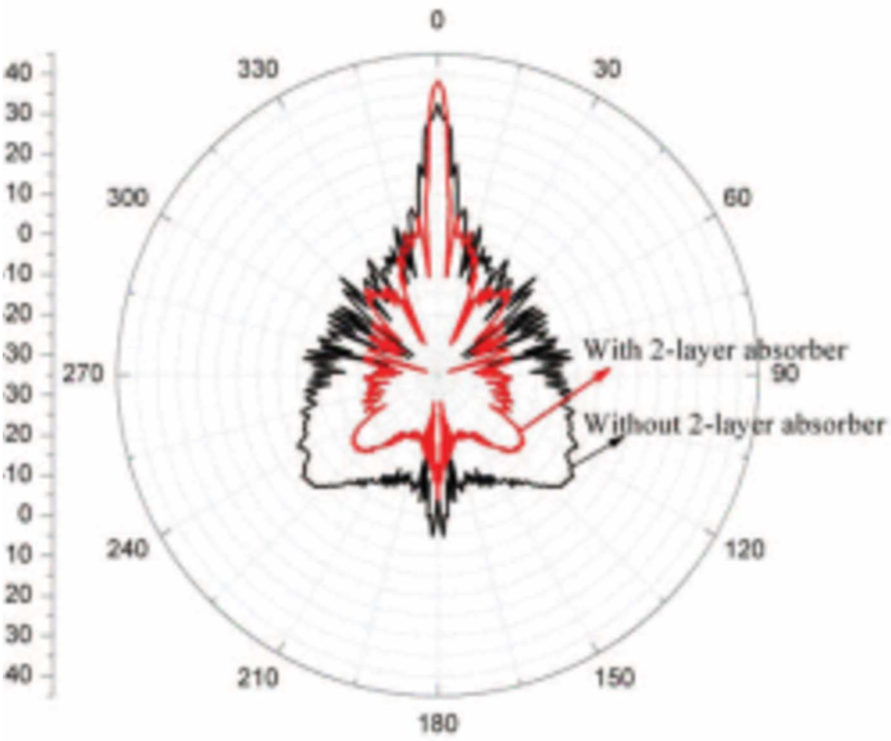

Figure D.1: Side lobe reduction of a parabolic reflector

D.2.2 Sidelobe reduction of a parabolic reflector with auxiliary reflectors

Abstract:

In the paper [i.26] Reducing the sidelobe level of a reflector antenna in a particular direction is desirable in many applications. A simple way of achieving this reduction is to add auxiliary reflectors either internally over the main reflector surface or externally outside the main reflector surface. Design curves are presented on the size of these auxiliary reflectors versus feed taper and F/D to achieve a prescribed sidelobe reduction. Typically, for a 10 dB sidelobe reduction, the diameter of the auxiliary reflector is about a third of the main reflector diameter (10 % in surface area).

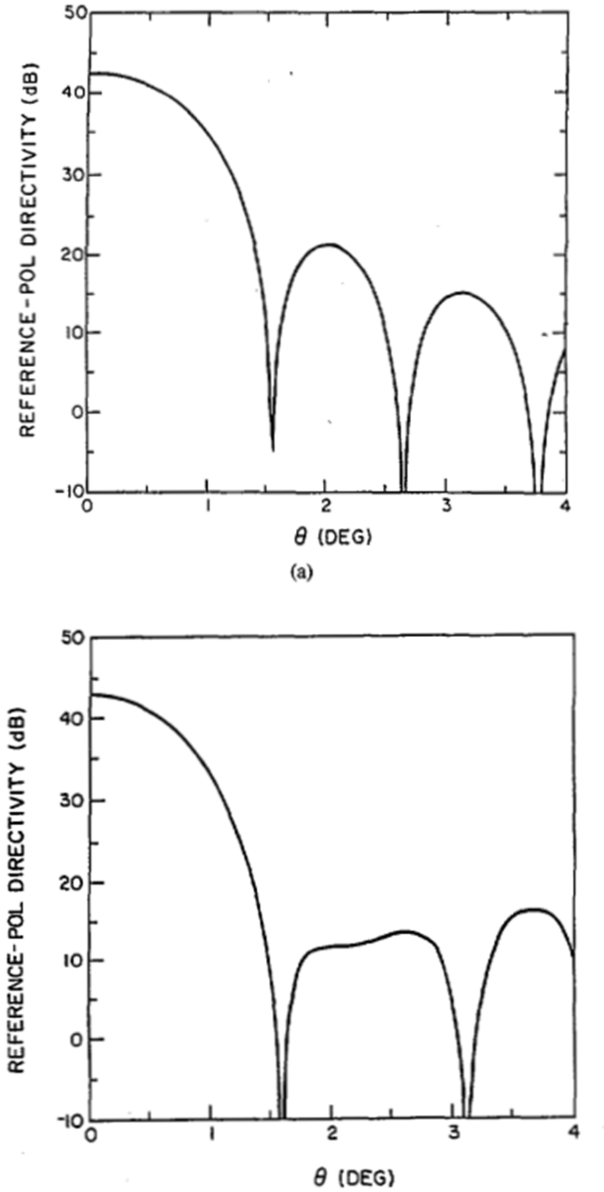

Figure D.2: Sidelobe reduction of the antenna

D.2.3 Effect of design parameters on sidelobe level of short-focus parabolic reflector antenna

Abstract:

In this paper [i.27], a low sidelobe short-focus parabolic reflector antenna fed by a half-wave dipole with a disk secondary reflector is presented. Effect of focal length to diameter ratio and secondary reflector parameters on sidelobe level has been explored. Electromagnetic simulations and theoretical analysis of parameters variation were performed. The tendency and degree of the effect of each parameter on sidelobe level have been given. This low sidelobe short-focus parabolic reflector antenna has the advantages of low cost, small size, simple structure and perfect electrical properties. It can be applied to special occasions as life detection radar systems which in need of low cost and small-size.

D.3 Provisional conclusion

It is possible to reduce the sidelobes of a parabolic antenna using various techniques. The sidelobe reduction may be up to 10 dB.

Annex E: Peak traffic density mismatch

E.1 Introduction

In this annex an apparent mismatch between traffic density assumptions, and the reported worst case vehicle density in a 200 x 200 km area around two RAS stations is provided.

E.2 Traffic Density distribution in ECC Report 350

The traffic density per road type and total length of each road type as used in ECC Report 350 [i.12] for NOEMA and SRT are given in Table E.1 and Table E.2.

Table E.1: Vehicle densities used for the simulation (Source: ECC Report 350 [i.12])

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

Table E.2: Total Road length per road type with 100 km radius centred around the RAS stations - OpenStreetMap contributors" (Source: ECC Report 350 [i.12])

Road type	Total lengths of roads (per type) (km)	
	NOEMA	SRT
Primary	7 805	3 981
Secondary	13 000	4 130
Tertiary	21 372	4 858
Residential	21 404	9 052

E.3 Average car density discrepancy

With reference to Table E.3, the total expected density is 1,18 car/km² for Noema, and 0,49 car/km² for SRT. Also the corresponding standard deviations (σ) are calculated.

Noting the number of iterations for which the simulation was run (200x100), it seems unrealistic that the maximum value of 5,6 car/km^2 for Noema and 2,2 car/km^2 for SRT reported in ECC Report 350 [i.12] correspond to the calculated probability distribution as provided in Table E.3 and Table E.4.

Table E.3: Calculation of average road traffic density distribution

	NOEMA										
Road Type	**Mean car density per road type (car/km)**	**σ car density per road type**	**Total road length per road type**	**Mean total number of cars per road type**	**σ total number of cars per road type**	**Mean total number of cars**	**σ total number of cars**	**Mean cars per [km^2]**	**σ cars per [km^2]**	**Max density in ECC report 350 [i.12] over 20 000 samples**	**P [average car density ≥ 5,6]**
Primary	3,6	0,9	7 805	28 098	7 025	47 290	7491,5	1,1823	0,187	5,6	<<10^{-10}
Secondary	0,6	0,15	13 000	7 800	1 950						
Tertiary	0,2	0,05	21 372	4 274	1 069						
Residential	0,1	0,025	21 404	2 140	535						
Other	0,1	0,025	49 776	4 978	1 244						

Table E.4: Calculation of average road traffic density distribution

	SRT										
Road Type	**Mean car density per road type [car/km]**	**σ car density per road type**	**Total road length per road type**	**Mean total number of cars per road type**	**σ total number of cars per road type**	**Mean total number of cars**	**σ total number of cars**	**Mean cars per [km^2]**	**σ cars per [km^2]**	**Max car density ECC report 350 [i.12] over 20 000 samples**	**P [average car density ≥ 2,2]**
Primary	3,6	0,9	3 981	14 332	3 583	19 725	3660,4	0,4931	0,092	2,2	<<10^{-10}
Secondary	0,6	0,15	4 130	2 478	620						
Tertiary	0,2	0,05	4 858	971,6	243						
Residential	0,1	0,025	9 052	905,2	226						
Other	0,1	0,025	10 389	1 039	260						

Annex F: EU Legal baseline for motor vehicles and driver assistance systems also targeting protection of vulnerable road users

F.1 General safety regulation for new vehicles

The European Union has implemented regulations to enhance vehicle safety, including requirements for brake assist systems. The General Safety Regulation (EU) 2019/2144 [i.23], also known as GSR2, mandates that new vehicles be equipped with various Advanced Driver Assistance Systems (ADAS) to improve road safety.

Key requirements include:

- Autonomous Emergency Braking (AEB): This system automatically applies the brakes to prevent or mitigate collisions.
- Intelligent Speed Assist (ISA): Helps drivers maintain the speed limit.
- Driver Drowsiness and Attention Warning (DDAW): Alerts drivers if they show signs of drowsiness or distraction.
- Emergency Lane Keeping Systems (ELKS): Helps prevent unintentional lane departures.

These regulations aim to reduce accidents and enhance the safety of both vehicle occupants and vulnerable road users like pedestrians and cyclists.

The General Safety Regulation (EU) 2019/2144 [i.23] defines vulnerable road users as including non-motorised road users such as pedestrians and cyclists, as well as users of powered two-wheelers.

The General Safety Regulation (EU) 2019/2144 [i.23] does not specify exact distances for the systems to act to prevent accidents. Instead, it sets performance requirements for various safety systems, such as Autonomous Emergency Braking (AEB), to ensure they can effectively detect and respond to potential collisions in a timely manner.

These systems are designed to operate within a range that allows them to detect obstacles and apply the brakes automatically to avoid or mitigate collisions. The specific performance criteria and testing procedures are detailed in the implementing and delegated acts associated with the regulation.

F.2 Technical aspects in application of radar to cover legal requirements

Radar technology is quite powerful and versatile in vehicle applications. Here are some key strengths:

- Enhanced Safety: Radar systems are crucial for safety features like adaptive cruise control, collision avoidance, and blind-spot detection. They help detect objects and measure their distance, speed, and direction accurately.
- All-Weather Operation: Unlike cameras and optical sensors, radar is not affected by poor lighting, fog, heavy rain, or snow. This makes it reliable in various weather conditions.
- High Precision and Long-Range Detection: Radar can detect objects at long ranges and with high precision.
- Robust Performance: Radar systems provide consistent performance in complex environments, such as urban settings with pedestrians, cyclists, and other vehicles.

Annex G: Bibliography

- Willem A. Baan: "Implementing RFI mitigation in Radio Science", JAI, VOL. 09, No 01, 2019.

Annex H: Change history

Date	Version	Information about changes
September 2024	0.0.1	Initial draft to be submitted to first drafting meeting
September 2024	0.0.2	Output M1 rapporteurs meeting: Clause 4.2 amended Clause 5 rearranged, new clause 5.1 added Clause 6.3 text added, to provide more details on the scope of the revision of the decision Clause 7 new subclause 7.1, 7.2 added Clause 8 material from contribution ERMTGSRR(24)TR1002 added to the relevant subclauses Clause 9.1 added
October 2024	0.0.3	Output M2 rapporteurs meeting: Clause 7.3 added based on material from Doc TR2004 Clause 7.4 added Clause 8.4 added based on material from Doc TR2003 Started to review clause 8.3 and subclauses
October 2024	0.0.4	Output M3 rapporteurs meeting: Full document: editorial improvements based on elements in doc TR3002 Clause 5: subsection for summary of the cited studies added Clause 7: developed further and restructured Clause 8: developed further and restructured Clauses 8.3.1 - 8.3.5 further developed
November 2024	0.0.5	Output M4 rapporteurs meeting: Full document: editorial improvements based on elements in doc TR4003 Clause 5: summary added Clause 7: rearranged Clause 8: Material from doc TR4006 added, Annexes A-D included accordingly
November 2024	0.1.0	Output of drafting session at TG SRR#52 Elements from contribution ERMTGSRR(24)052006 taken on board Clause 4.5 amended Clause 7 reviewed and re-arranged Clause 8 review and rearrangement was started After discussion the Meeting decided to elevate the document to "stable draft"
December 2024	0.1.1	Output of M4bis and M5 rapporteurs meeting Elements from contributions TR4b003 and TR4b004 were included and consolidated Subclauses in clause 8 were restructured Rapporteur´s meeting performed a full run-through the document Full document was editorially reviewed and updated Usage and spelling of terms aligned Clause 9.2 to be finalized
January 2025	0.1.2	Output M6 rapporteurs meeting Elements from contributions TR6003, TR6004, TR6005,TR6006r1 were included and consolidated into the report New Annex F created based on the material provided in TR6004 Full document was editorially reviewed and updated Usage and spelling of terms aligned Figure and table headers and numbering updated Clause 9.2 to be consolidated and finalized
January 2025	0.1.3	Output M7 rapporteurs meeting Elements from contribution TR7004r1 were included and consolidated into the document Clause 9: structure revised and simplified. Already available text proposals (from previous contributions) were reviewed and consolidated Content and structure of table 1 deeply discussed. decision of the meeting: (1)retain table in the document (2)tidy up and simplify the table Text of clause 9 to be finalized Next meeting expected to finalize clause 9

Date	Version	Information about changes
February 2025	0.1.4	Output M8 rapporteurs meeting Editorial improvements throughout the full document TR8004 was discussed in great detail, Proposals from TR8005 were consolidated into the document. Editors note in clause 9.2 added, to reflect that no consensus could be reached on the elements for the conclusion section.
February 2025	0.1.5	Some editorials
February 2025	0.1.6	Outcome TC ERM#85, approved for publication
April 2025	0.1.7	Some editorials
May 2025	1.1.1	First published version

History

Document history		
V1.1.1	May 2025	Publication