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Technical Report

Electromagnetic compatibility and Radio spectrum Matters (ERM); System Reference document (SRdoc); Technical characteristics of Radio equipment to be used in the 76 GHz to 77 GHz band; Short-Range Radar to be fitted on fixed transport infrastructure

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Contents

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Foreword

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

EC Decision 2011-829-EU [i.9] obliges EU Member States to allow the use of the 76 GHz to 77 GHz band for Road Transport an Telematics for *terrestrial vehicles and infrastructure systems*.

This EC Decision is subject to an update process. CEPT Report 44 [i.10] is the recommendation from CEPT for the 5th update cycle. In this it is recommended to broaden the category of Road Transport and Traffic Telematics (RTTT) to Transport and Traffic Telematics (TTT), and to change the usage restriction on 76 GHz to 77 GHz band to *ground based vehicle and infrastructure systems only*.

The draft revised Decision [i.11] indicates that these recommendations are being adopted.

Accordingly, the present document describes fixed infrastructure radar systems in a range of transport applications.

A previously published ETSI System Reference Document, TR 102 704 [i.7], discusses the use of 76 GHz to 77 GHz band by radars mounted on ground based vehicles other than automobiles.

The purpose of the present document is to provide details of how fixed infrastructure radar are used within the transportation sector, and to indicate the parameters under which these systems operate.

Modal verbs terminology

In the present document "**shall**", "**shall not**", "**should**", "**should not**", "**may**", "**may not**", "**need**", "**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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Executive summary

The present document provides information about fixed surveillance radar installations in the 76 GHz to 77 GHz band.

The majority of the systems described here are high value infrastructure systems serving functions of safety and efficiency in the transport field. Typical uses are for surveillance of critical highway situations such as tunnels and large road intersections. There is a requirement in the EU for Automatic Incident Detection in road tunnels which have a control room and are 500 m or longer [i.1].

Other users of the 76 GHz to 77 GHz band include vehicle radars and the Radio Astronomy Service. The important sharing scenarios are therefore a large number of vehicle radars with a small number of fixed radars and with the RAS conducting measurements from 8 sites in Europe.

The 76 GHz to 77 GHz band is designated for both fixed and vehicle radars by 2011-829-EU (the EC Decision on Short Range Devices) [i.9]. Currently there is a harmonised standard for vehicle radars, EN 301 091-1 [i.8], but fixed radars are outside its scope. The fixed radars described here operate with the same signal parameters as vehicle radars - they are in fact compliant with the technical requirements of EN 301 091-1 [i.8].

It should be noted that the fixed radars described do not constitute a new proposal. They represent an established application with a significant installed base. Systems are currently being installed in many European countries (Annex B), but by their nature as high capital cost infrastructure systems they cannot be expected to become massively deployed items.

The present document also examines the sharing scenarios. An acceptable arrangement with the RAS is a small exclusion zone around each millimetre wave observatory site (Annex E). An initial study shows that probability of a scanning infrastructure radar interfering with a vehicular radar is even less than that of a vehicular radar interfering with another vehicular radar (Annex D).The purposes of the present document include:

1) To provide information to CEPT, EC and other bodies to assist studies and regulatory decisions.

2) To pave the way for ETSI to develop a harmonised standard for fixed surveillance radars.

The present document concentrates on applications for surveillance radars in the transport field. The proponents of the SRdoc also note that there are applications in other fields and these are described in clause B.3.

Introduction

The present document has been developed to support the co-operation between ETSI and the Electronic Communications Committee (ECC) of the European Conference of Post and Telecommunications Administrations (CEPT).

The European Commission Decision on harmonisation of the radio spectrum for use by short-range devices 2006/771/EC sets out the harmonised frequency bands as well as the technical usage conditions under which SRDs can be used across Europe. Last updated in December 2011 under EC Decision 2011/829/EU [i.9], the decision sets the usage scope for this band as "terrestrial vehicle and infrastructure systems".

The 76 GHz RTTT Standard EN 301 091-1 [i.8] defines the technical characteristics and test methods for radar equipment operating in the 76 GHz to 77 GHz band. Early versions of EN 301 091-1 [i.8] define the scope as covering both fixed radar installations, and mobile. Subsequent versions of EN 301 091-1 [i.8] have limited the scope to road vehicles only. Other than the definition of the scope, the fixed radar systems presented are fully compliant with the latest versions of EN 301 091-1 [i.8].

The 76 GHz to 77 GHz band is highly versatile and can be used also for safety relevant radar applications which operate either as part of a fixed transport installation, or on a mobile vehicle. These safety related fixed transport installations are the subject of the present document.

The main benefits of using the 76 GHz to 77 GHz frequency band for these applications are that overall radar sensor package sizes can be made of a reasonable size without overly large or cumbersome antenna. These are suitable for roadside installation. With high operating frequency, high resolution range measurements are possible. In addition componentry is readily available in this band. These advantages are further discussed within.

1 Scope

The present document describes the application of fixed transport surveillance radar systems in the 76 GHz to 77 GHz band. Short Range Radars operating in this band are used in a variety of applications, the majority of which are safety related.

The present document includes in particular:

- market information for applications apart from road vehicles;
- technical information regarding the typical radar installations;
- regulatory issues and interference studies whilst considering other band users.

2 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.

Referenced documents which are not found to be publicly available in the expected location might be found at http://docbox.etsi.org/Reference.

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

2.1 Normative references

The following referenced documents are necessary for the application of the present document.

Not applicable.

2.2 Informative references

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. For non-specific references, the latest version of the referenced document (including any amendments) applies.

[i.1] L167/39: "Directive 2004/54/EC of the European Parliament and of the Council of 29 April 2004 on minimum safety requirements for tunnels in the Trans-European Road Network".

[i.2] WN 96W0000071: "The Impact of Rapid Incident Detection on Freeway Accident Fatalities".

[i.3] Rail Safety and Standards Board: "Half-year safety performance report 2012/13".

[i.4] Network Rail: "Strategic Business Plan for England & Wales January 2013".

[i.5] European Railway Agency: "Railway safety performance in the European Union 2012".

[i.6] European Commission: "Mobility and Transport, Road Safety, Level Crossings".

NOTE: Available at: http://ec.europa.eu/transport/road_safety/topics/infrastructure/level_crossing/index_en.htm.

[i.7] ETSI TR 102 704 (V1.2.1) (2010-12): "Electromagnetic compatibility and Radio spectrum Matters (ERM); System Reference Document; Short Range Devices (SRD); Radar sensors for non-automotive; ground based vehicular applications in the 76 GHz to 77 GHz frequency range".

[i.8] ETSI EN 301 091-1 (V1.3.3): "Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices; Road Transport and Traffic Telematics (RTTT); Radar equipment operating in the 76 GHz to 77 GHz range; Part 1: Technical characteristics and test methods for radar equipment operating in the 76 GHz to 77 GHz range".

[i.9] EC Decision 2011-829-EU: Commission Implementing Decision of 8 December 2011 amending Decision 2006/771/EC on harmonisation of the radio spectrum for use by short-range devices.

[i.10] CEPT Report 44 (11/03/2103): In response to the EC Permanent Mandate on the "Annual update of the technical annex of the Commission Decision on the technical harmonisation of radio spectrum for use by short range devices".

[i.11] RSCOM13-05 (6th March 2013). European Commission Communications Networks Content & Technology Directorate-General. Radio Spectrum Committee: Draft Implementing Decision for the coordinated revision of Decision 2006/771/EC on SRD and the repeal of Decision 2005/928/EC on the169 MHz band.

[i.12] CEPT/ERC/Recommendation 70-03: "Relating to the use of Short Range Devices (SRD)". Annexes 4 and 5.

[i.13] ERC Report 25: "The European Table of Frequency Allocations and Applications in the Frequency Range 8.3 kHz to 3000 GHz (ECA TABLE)". Approved February 2013.

[i.14] MOSARIM: "MOre Safety for All by Radar Interference Mitigation".

NOTE: Available at: http://ec.europa.eu/information_society/activities/esafety/doc/rtd_projects/fact_sheets_fp7/mosarim.pdf.

[i.15] UK Highways Agency: Results published in March 2011 in the UK Highways Agency's three-year safety report into the pilot Managed Motorway scheme on the M42.

NOTE: Available at: http://www.highways.gov.uk/our-road-network/managing-our-roads/improving-our-network/managed-motorways/.

[i.16] ETSI EN 301 783 (all parts): "Electromagnetic compatibility and Radio spectrum Matters (ERM); Land Mobile Service; Commercially available amateur radio equipment".

[i.17] ETSI EN 302 264 (all parts): "Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices; Road Transport and Traffic Telematics (RTTT); Short Range Radar equipment operating in the 77 GHz to 81 GHz band".

[i.18] ETSI EN 302 372 (all parts): "Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices (SRD) ;Equipment for Detection and Movement; Tanks Level Probing Radar (TLPR) operating in the frequency bands 5,8 GHz, 10 GHz, 25 GHz, 61 GHz and 77 GHz".

[i.19] ETSI EN 302 729 (all parts): "Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices (SRD); Level Probing Radar (LPR) equipment operating in the frequency ranges 6 GHz to 8,5 GHz, 24,05 GHz to 26,5 GHz, 57 GHz to 64 GHz, 75 GHz to 85 GHz".

[i.20] ECC/DEC/(04)03: "ECC Decision of 19 March 2004 on the frequency band 77-81 GHz to be designated for the use of Automotive Short Range Radars".

[i.21] ECC/DEC/(11)02: "ECC Decision of 11 March 2011 on industrial Level Probing Radars (LPR) operating in frequency bands 6 - 8.5 GHz, 24.05 - 26.5 GHz, 57 - 64 GHz and 75 - 85 GHz".

[i.22] ERC/REC 74-01: "Unwanted Emissions in the Spurious Domain".

[i.23] Recommendation ITU-R RA.769-2: "Protection criteria used for radio astronomical measurements".

[i.24] Recommendation ITU-R P.452-1: "Prediction procedure for the evaluation of microwave interference between stations on the surface of the Earth at frequencies above about 0.7 GHz".

[i.25] Recommendation ITU-R P.525: "Calculation of free-space attenuation".

3 Definitions, symbols and abbreviations

3.1 Definitions

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

all lane running: permanent use of the hard shoulder or emergency lane as a running lane

antenna boresight: optical axis of a directional antenna, along which the peak antenna gain is found

duty cycle: ratio of the area of the beam (measured at its 3 dB point) to the total area scanned by the antenna (as measured at its 3 dB point)

managed motorways: controlled use of the hard shoulder as a running lane during periods of high vehicle flow or incidents

operating frequency: nominal frequency at which the equipment is operated

radome: external protective cover which is independent of the associated antenna, and which may contribute to the overall performance of the antenna

3.2 Symbols

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

Δf	frequency shift between any two frequency steps
F	frequency
R	distance to target
R_x	received signal
T	frequency step repetition frequency
T_x	transmitted signal

3.3 Abbreviations

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

AID	Automatic Incident Detection
CCTV	Closed Circuit TeleVision
CFAR	Constant False Alarm Rate
CRAF	Committee on Radio Astronomy Frequencies
e.i.r.p	effective isotropic radiated power
EC	European Commission
ECC	Electronic Communications Committee
FM	Frequency Modulation
FMCW	Frequency Modulated Carrier Wave
IRAM	Institut de Radioastronomie Millimétrique
LPR	Level Probing Radar
PTZ	Pan, Tilt, Zoom
RAS	Radio Astronomy Service
RF	Radio Frequency
RPU	Remote Processing Unit
RR	Radio Regulations
RSSB	Rail Safety and Standards Board
RTTT	Road Transport and Traffic Telematics
SEAMCAT	Spectrum Engineering Advanced Monte Carlo Analysis Tool
TEN	Trans-European Transport Network

TEN-T	Trans-European Transport Network
TLPR	Tanks Level Probing Radar
TTT	Transport and Traffic Telematics
WRC	World Radio communications Conference

4 Comments on the System Reference Document

No ETSI members raised any comments.

5 Fixed Transport Infrastructure Radar

This clause contains a brief summary of infrastructure radar and its applications. More comprehensive information together with example installations can be found in Annex B.

5.1 System Description

Fixed Radar systems provide an Automatic Incident Detection capability, for use on motorways and other strategic roads, bridges and tunnels. By continually measuring and tracking vehicles, people and debris using high frequency radar the system is able to generate incident alerts, whilst maintaining extremely low nuisance alarm rates.

5.2 Use Cases and Deployment Scenarios

5.2.1 Surveillance radar for traffic incident detection and prevention

Wide area surveillance of roads, to detect events that are highly likely to lead to incidents, is a valuable way of improving the safety of European road networks. These might include early detection of stopped vehicles, reversing vehicles, personnel or animals on a road carriageway, debris on a carriageway due to a lost load. Europe's major highways are increasingly congested; managed motorways are becoming more prevalent so extra capacity from emergency lanes without the associated costs of extra civil works; reduced Carbon to provide extra road network capacity; these roads do need a rapid detection system though to alert approaching driver in fast moving traffic to a stranded vehicle in a live traffic lane, particularly at night time or in poor visibility.

5.2.2 Surveillance radar for traffic enforcement and safety

Enforcing unsafe behaviour of vehicles, unsafe close following of the vehicle ahead, unsafe overtaking or crossing of the central white lines, illegal behaviour at yellow box junctions leading to congestion as busy intersections become congested, enforcing and thereby discouraging dangerous driving manoeuvres such as illegal U-Turns, enforcement where dangerous driving behaviour can lead to loss of life around intersections with other modes of transport, for example, at railway crossings.

5.2.3 Road-Railway Crossings

Two types of surveillance radar systems are proposed for increasing safety at road-railway crossings, also known as level crossings.

5.2.3.1 Railway network based

Railway based radars function as obstacle detectors for use only when the crossing is operated as a railway. Generally they are fixed rather than scanning beam and oriented so as to illuminate the crossing area and the railway track. These would fall under Annex 4 of Rec 70-03 [i.12]. ETSI intends to introduce a new harmonised standard EN 301 091-3 to cover this application.

5.2.3.2 Road network based

Fixed radars can provide a more extensive surveillance of the crossing area and detect illegal or dangerous behaviour by vehicles, for instance turning along the railway track, failing to stop for the warning lights, driving round the barriers. More details of such systems is given in clause B.2.2.

5.2.4 Airport Ground Movements

Fixed radars are used for monitoring ground movements at airports and landing strips, for the purposes of Air Traffic Control and for security. More details of such systems are given in clause B.2.3.

5.2.5 Non-Transport Applications

Applications outside the field of transport are also possible and currently permitted in some countries, such as the UK. Some of these are described in clause B.3.

6 Market Size and Societal Benefits

This clause is a brief summary. Comprehensive market information for existing and projected installations is given in clause B.2.

6.1 Automatic Incident Detection

Managed motorway programs are currently in operation within the UK, Sweden, Netherlands and Germany, each maintaining between 200 km to 300 km. Casualties per billion vehicle miles travelled have reduced by just under two-thirds (61 %) since hard shoulder running was introduced [i.15]. Managed motorways offer increased capacity, at a fraction of the cost, and can be delivered in a much shorter timeframe.

Fatal Incidents within tunnels in particular have raised concerns about current safety systems, and within EC law, it is mandatory in all tunnels longer than 500 m to install automatic incident detection and/or fire detection [i.1].

The Trans-European Transport Network (TEN- T) is set to encompass 90 000 km of motorway and high-quality roads by 2020 and the EU will eventually have a role in the safety management of these roads.

6.2 Traffic Enforcement

Enforcement, leading to behaviour change of drivers and pedestrians, is an important part of the regulators' strategy to reduce the number of fatalities at level crossings and other intersections. Fixed radar systems, tracking vehicles as they drive towards the crossing after red warning lights have been illuminated, are an important tool to improve safety. Some 200 initial sites have been identified by Network Rail in the UK as requiring railway crossing enforcement systems.

7 Technical information

7.1 Detailed technical description

The radar systems described in the present document use a continuous transmission with frequency modulation. The operating principle is described in detail in Annex A.

Annex B shows a number of existing installations.

The systems are compliant with the technical parameters of EN 301 091-1 [i.8]. Further technical information is also given in Annexes C, D and E.

7.2 Technical parameters and implications on spectrum

Table 1 lists the typical parameters of a mechanically scanned infrastructure radar system.

See clauses 7.2.2 and 7.2.3 for further information.

Table 1: Summary of typical technical parameters

Frequency Range	76,2 GHz to 76,8 GHz
Range of Sensor	500 m
Field of View coverage	full coverage (for scanning systems)
Peak Power	37,5 dBm
Average Power	15 dBm (according to the formula in clause 7.2.3.2. of EN 301 091-1 (V1.3.3) [i.8])
Occupied RF Bandwidth	600 MHz
Rotation and transmission rate (scanning systems)	nominal 2 rps, through 360 degrees 1 000 ms sweep time leading to 900 measurements per second (450 per rotation)
Beam width in azimuth	2 degrees
Duty Cycle	0,5 %
Mounting Height	Typically 5 m above ground level
Deployment of infrastructure radar	Typical separation of 700 m to 1 000 m

7.2.1 Status of technical parameters

7.2.1.1 Current ITU and European Common Allocations

The following table is reproduced from ERC Report 25, February 2013 [i.13].

Table 2: 76 GHz to 77 GHz entry in European Common Allocation table

RR Region 1 Allocation and RR footnotes applicable to CEPT	European Common Allocation	ECC/ERC harmonisation	Applications	Standard	Notes
76 GHz to 77,5 GHz					
RADIO ASTRONOMY	RADIO ASTRONOMY		Amateur	EN 301 783 [i.16]	
RADIOLOCATION	RADIOLOCATION		Amateur Satellite		
Amateur	Amateur	ECC/DEC/(04)03 [i.20]	SRR		
Amateur-satellite	Amateur-satellite		Radiolocation (civil)	EN 302 264 [i.17]	
Space research (S/E)	Space research (S/E)		Radio astronomy		Continuum and spectral line observations
5.149	5.149 EU2	ERC/REC 70-03 [i.12] ECC/DEC/(11)02 [i.21]	Radio determination applications	EN 302 372 [i.18] EN 302 729 [i.19]	Within the band 75 GHz to 85 GHz for TLPR and LPR applications
		ERC/REC 70-03 [i.12]	RTTT	EN 301 091-1 [i.8]	Within the band 76 GHz to 77 GHz Radar. Road Transport and Traffic Telematic
			Railway applications	EN 301 091-1 [i.8]	Obstruction/vehicle detection at level crossings

7.2.2 Transmitter parameters

7.2.2.1 Transmitter Output Power/Radiated Power

The typical peak power is +38 dBm e.i.r.p on the antenna boresight.

The typical mean power is +15 dBm e.i.r.p.

See also clause E.2.1 for further details of calculations of the peak and mean power.

7.2.2.1a Antenna Characteristics

Roadside infrastructure radars typically have a beam width in azimuth of 2 degrees with a spread vertical beam pattern.

The antennas are typically mounted well above the carriageway. The infrastructure radar beam boresight is directed at the road surface at a distance of approximately 200 m , reducing the chance that fixed and vehicular radar should interfere with each other. The vertical inclination of the boresight towards the road surface is approximately 1,5 degrees below the horizontal.

Low power lobes are directed off the boresight, towards the road surface in the foreground. At distances less that 100 m from the radar lower antenna gain and hence power is needed at the road surface, in order to detect objects of interest. Detection performance can be maintained because there is reduced attenuation from spherical spreading when closer to the infrastructure radar device.

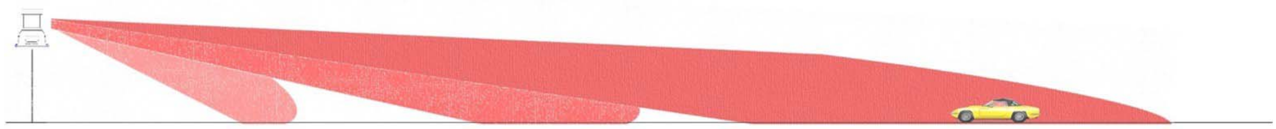
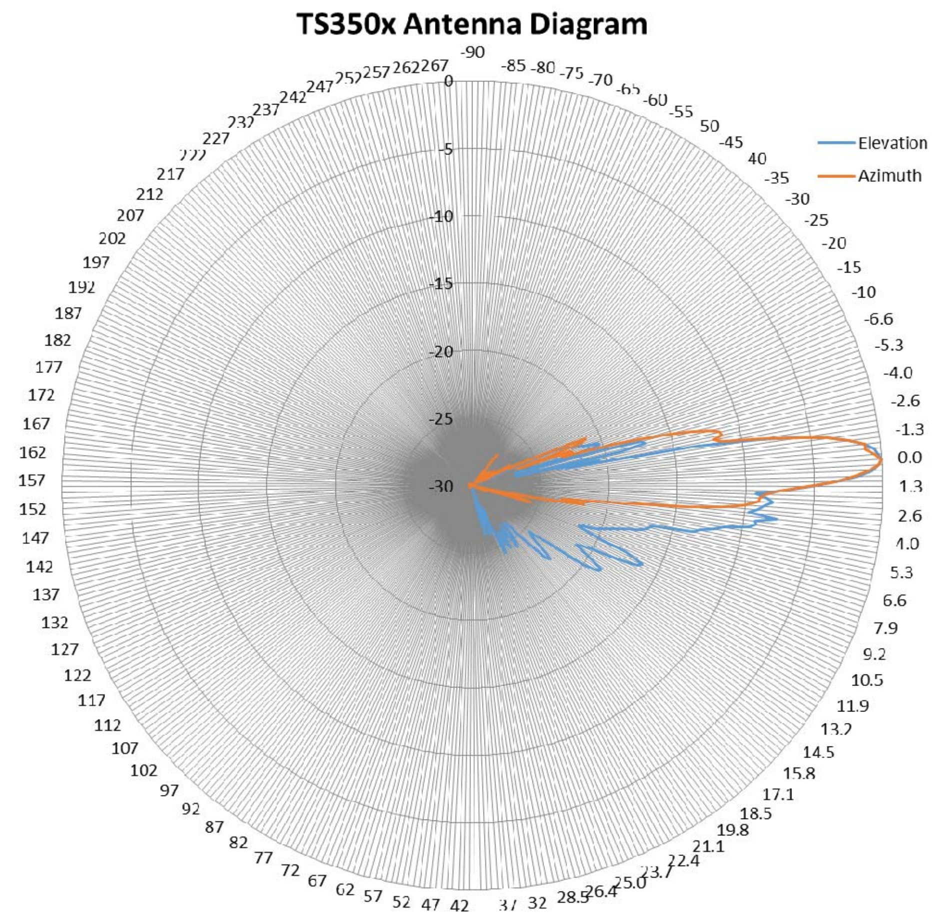


Figure 1: Illumination of surveillance area by spread vertical beam of the radar antenna

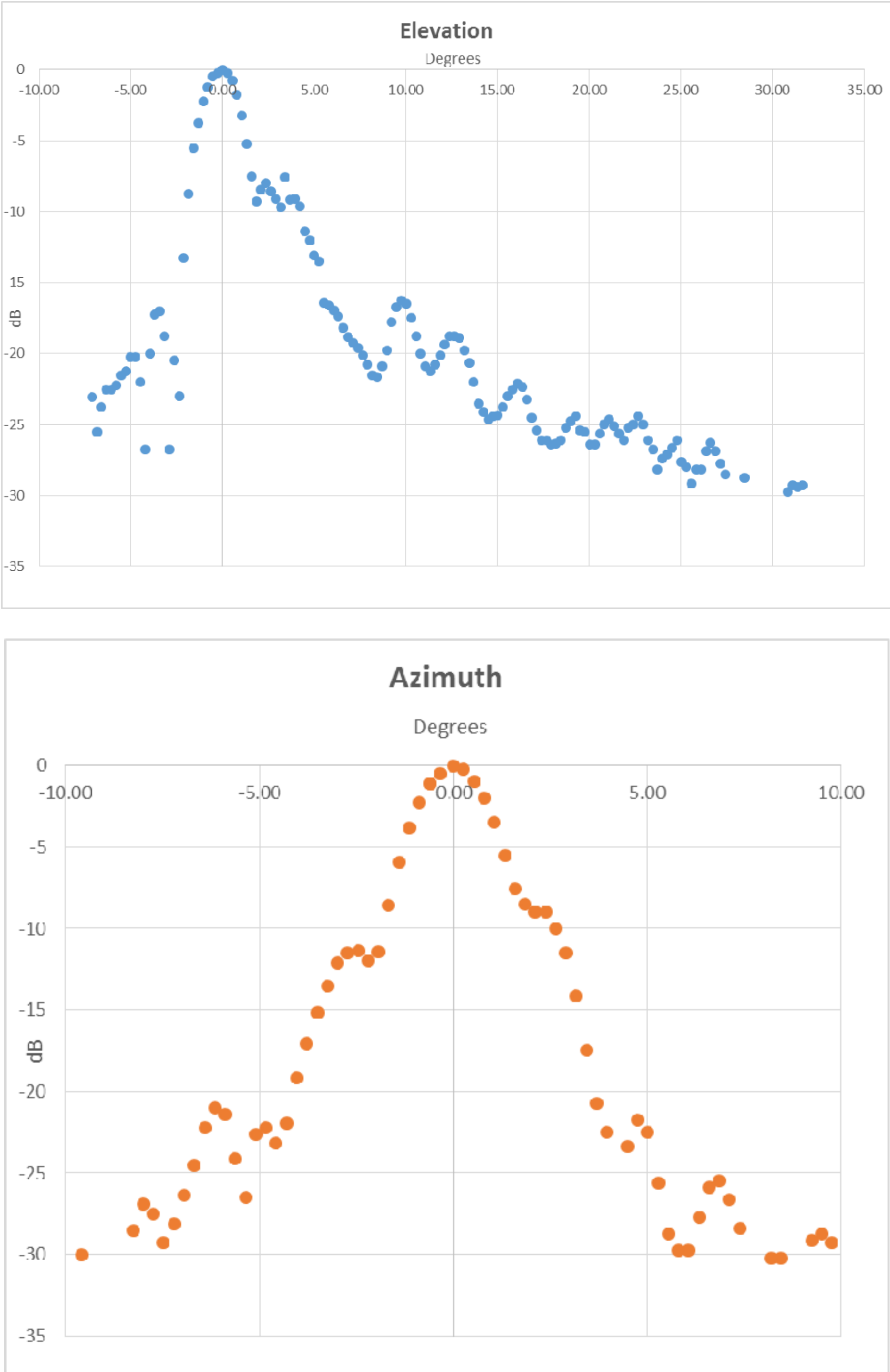
7.2.2.1b Beam Profiles

Antenna beam profiles measured on an example radar system are shown in Figures 2 and 3.



NOTE: Note that the antenna is mechanically scanned through 360 degrees.

Figure 2: Infrastructure radar combined antenna beam



NOTE: The antenna is mechanically scanned through 360 degrees

Figure 3: Infrastructure radar elevation and azimuth antenna beam plots

7.2.2.2 Operating Frequency

The current operating frequency is in the band 76 GHz to 77 GHz.

7.2.2.3 Bandwidth

The overall bandwidth is defined by the FM sweep pattern. This may range from 500 MHz to 800 MHz. A typical sweep is 600 MHz in 1 ms. The instantaneous system bandwidth is 5 MHz.

7.2.2.4 Unwanted emissions

Unwanted emissions are within the limits specified by EN 301 091-1 [i.8], which is aligned with ERC/REC 74-01 [i.22].

7.2.2.5 Duty Cycle/Mechanical Scanning

It is only necessary to illuminate a given target area intermittently, and at a very low duty cycle. One method of achieving this is with a mechanically scanned antenna. The radar boresight scans a horizontal plane parallel to the road surface. The actual duty cycle depends on the antenna beam width in azimuth and is typically 1 in 200. Typically scan rate is 2 times per second.

7.2.3 Receiver parameters

The infrastructure radar includes a single antenna for transmit and receive channels. The radar receiver includes an active mixer that converts the Radio Frequency signal into an Intermediate Frequency or Video range which covers 50 kHz to 5 MHz. The receiver Noise Figure is typically 10 dB at 1 MHz.

7.3 Information on relevant standard(s)

EN 301 091-1 [i.8] defines the technical characteristics and test methods for radar equipment operating in the 76 GHz to 77 GHz band . Early versions of this document define the scope as covering both fixed radar installations, and mobile. Subsequent versions of the standard have limited the scope to road vehicles only. Other than the definition of the scope, the fixed radar systems presented are fully compliant with the latest versions of EN 301 091-1 [i.8].

EN 301 091 is a multi-part deliverable and ETSI is currently developing a new part, EN 301 091-3 for radar systems for rail-road crossings. See clause 5.2.3.1.

7.4 Sharing and Compatibility Studies

The primary services in the 76 GHz to 77 GHz band are the Radio Astronomy Service (RAS) and Radiolocation. The band is also used by vehicular radars using similar technology to infrastructure radars.

The interference mechanism between fixed infrastructure radar and vehicular based radar should be less problematic than between different vehicular radars. In particular, when multiple vehicles approach each other, vehicular radars are located at the same vertical height and are able to mitigate any interference effects successfully. In such a situation, where many vehicles are densely packed on small sections of road, the opposing vehicles are said to not interfere by the radar manufacturers.

Previous study work by the MOSARIM Consortium as well as two investigations conducted in the development of the present document are reported below.

7.4.1 MOSARIM

The MOSARIM project [i.14] was an investigation and assessment of mutual vehicular radar interference and the definition and elaboration of effective automotive radar interference counter-measure and mitigation techniques.

The main objectives of the MOSARIM project were:

1) Development and implementation of comprehensive and realistic simulation models regarding radar interference at different levels and locations. With ray-tracing principles and complex backscattering models a realistic and accurate representation of the real scenarios could be achieved in simulation. A deep insight to the prevailing interference mechanisms and the key parameters that influence the mutual interference effects and strength was achieved.

2) Identification, classification and rating of commonly applicable interference countermeasures to reduce mutual radar interference for several automotive safety applications

3) Development of recommendations and guidelines for vehicular mutual radar interference mitigation.

Only as a side aspect as it was not directly covered by the project scope, was the interference potential from incumbent frequency users, e.g. fixed road side surveillance radar or radar speed meters, into vehicular radars investigated. The effort spent to assess the interference potential from these incumbent frequency users was rather limited and not exhaustive.

7.4.2 SEAMCAT

An initial SEAMCAT study is reported in Annex D. This considered vehicular radars as victims and both infrastructure and vehicular radars as interferers. Initial results indicate that probability of a scanning infrastructure radar interfering with a vehicular radar is less than that of a vehicular radar interfering with another vehicular radar.

The interactions between these types of radars are, however, more complex than could be captured in this analysis. This initial study will benefit from further development. It may also be useful in this case to augment SEAMCAT with other analysis tools.

7.4.3 Radio Astronomy Service

The results of initial discussions and analysis with CRAF (representing the interests of the RAS) are presented in Annex E.

There are 8 RAS sites in Europe that are potentially affected. The initial analysis indicates that an exclusion zone around each one of 40 km radius will protect the RAS.

Mitigation techniques such as sector blanking have the capability of reducing the exclusion zone to 10 km radius.

The proposal is that the installation requirements for infrastructure radars contain a requirement that any installation within 40 km of one of a set of listed locations will require special consideration.

In addition it can be noted that an important application of infrastructure radars is in tunnels and that such installations are unlikely to pose an interference threat to the RAS.

7.4.4 Sharing and compatibility issues still to be considered

One area of interest identified is the interaction between fixed infrastructure and vehicular radars. They operate with similar parameters and similar technology; they both have safety implications; they are both established applications with an installed base and current continuing deployment.

For this reason, continuing work can be expected within both CEPT and ETSI.

8 Radio spectrum request and justification

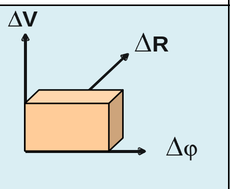
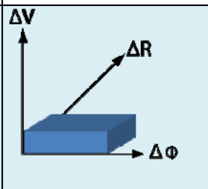
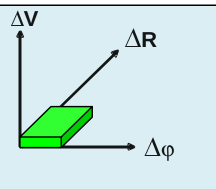
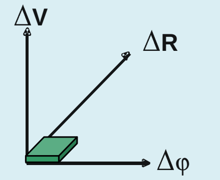
The 76 GHz to 77 GHz band has been designated for vehicle and fixed infrastructure radar usage on the road network since 1998. Devices operating at this frequency have several advantages for Transport and Traffic Telematics. These include:

- Allowing high resolution measurements to be made, without overly large or cumbersome antenna. Only with high resolution can the location of vehicles on a highway be accurately made. Antenna size increases as the operating frequency decreases and whilst operation at lower frequencies is technically possible, because the practical radar housing size is constrained in many cases a lower frequency of operation leads to poorer azimuth resolution. This would limit the usefulness of infrastructure radar in several of the applications mentioned.
- Components are widely available and furthermore they have been packaged into subsystems that can be easily adapted and application engineered for the infrastructure radar applications presented in the present document. This means that the advantages of these products can be made available without an excessive price tag associated.
- Devices operating in this band do not suffer from severe atmospheric attenuation. This means that measurements can be made over several hundred meters and fewer installed devices are needed (figure 4).

- The band offers 1 GHz of bandwidth, allowing high resolution measurements to be made and accurate measurement of the detected objects can be used to track their progress over time. High bandwidth is also available in other bands but there are further disadvantages to these that have already been highlighted.

A summary of the characteristics of the operating bands that have been identified are included in table 3.

Table 3: Comparison of different operating frequencies for short range radar devices

Frequency range (see note 1)	**61 GHz - 61,5 GHz**	**63 GHZ - 64 GHz**	**76 GHZ - 77 GHz**	**122 GHZ -123 GHz**
Designation	Non specific SRDs 100 mW e.i.r.p.	RTTT Comms links 40 dBm e.i.r.p.	RTTT Vehicle and Infrastructure 50 dBm mean e.i.r.p.	Non specific SRDs 100 mW e.i.r.p.
Sensor **performance for proposed applications** (summary of all three parameters / resolutions) (see notes 1 and 2)	0	+	+++	0
ΔV: Velocity Axis Δφ: Angle Axis ΔR: Range Axis				
Bandwidth	500 MHz	1 GHz	1 GHz	1 GHz
Regulated output power	0	+	+++	0
Radar Cross Section influence	+	+	++	+++
Atmospheric Attenuation	0	0	++	+
Technology available	+	+	+++	+ technology 0 for sensor realization

NOTE 1: The smaller the cubic, the better the radar performance.
NOTE 2: For a given aperture, the resolution increases with frequency. Angular resolution is directly related to antenna aperture.

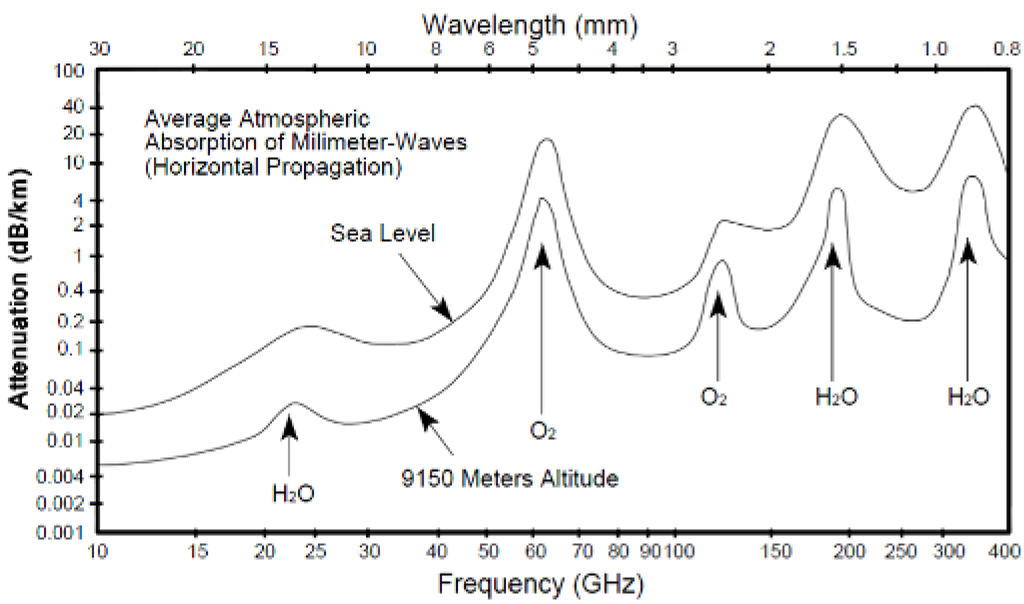


Figure 4: Atmospheric absorption of millimetre waves

The 76 GHz band lies in a region of low attenuation, avoiding the oxygen absorption peaks at 60 GHz and 120 GHz. These add respectively about 20 dB/km and 3 dB/km of attenuation, which limits detection capability for small objects such as people and debris on the highway. Detection of both of these are required for an effective Automatic Incident Detection system to operate.

In addition, the 60 GHz and 122 GHz bands as potential alternative bands for operation were discussed within TGSRR, but considered to be not appropriate.

It is important to avoid frequencies with high atmospheric attenuation; the reduction in radar range is more significant than any benefits that might arise from re-use of frequencies or isolation between installations.

In the 60 GHz and 122 GHz band no mature RF components for radar sensors are available. RF components at 60 GHz are focused on communication applications. At 122 GHz only components at research level exist.

122 GHz might have the attraction of smaller antennas or better resolution but the regulations do not permit sufficient transmit power.

9 Regulations

9.1 Current regulations

Under the EC decision 2011-829-EU [i.9] the restrictions below currently apply in bands that might be considered for infrastructure radar systems.

Table 4: Regulatory environment for short range Radar devices

Frequency Band	Type of Short range device category	Transmit Power limit	Additional Parameters	Other usage restrictions
61 GHz - 61.5 GHz	Non-specific short range devices	100 mW e.i.r.p		
63 GHz - 64 GHz	Road Transport and Traffic Telematics	40 dBm e.i.r.p		This set of usage conditions is available to vehicle-to-vehicle, vehicle-to-infrastructure and infrastructure-to-vehicle systems only
76 GHz - 77 GHz	Road Transport and Traffic Telematics	55 dBm peak e.i.r.p. and 50 dBm mean e.i.r.p. and 23,5 dBm mean e.i.r.p. for pulse radars		This set of usage conditions is available to terrestrial vehicle and infrastructure systems only
122 GHz - 123 GHz	Non-specific short-range devices	100 mW e.i.r.p.		

Note that under current proposals [i.11] this will be updated so that Road Transport and Traffic Telematics becomes Transport and Traffic Telematics (TTT), and the usage restriction on 76 GHz to 77 GHz becomes *ground based vehicle and infrastructure systems only*.

The 76 GHz to 77 GHz band has the advantage of 50 dBm e.i.r.p transmit power being available, and is designated currently for infrastructure system usage.

9.2 Proposed regulation and justification

ETSI proposes continuing the use of the 76 GHz - 77 GHz band for fixed infrastructure radars.

The proponents of hte present document also propose removing the restriction to the TTT category in order to allow use outside the transport sector. It is not expected that the sharing and compatibility issues outside the transport sector will be significantly different to those within it.

Annex A: FMCW Radar - Technical Details

A.1 Principle of operation

Fixed infrastructure radar are typically frequency modulated continuous wave (FMCW) transceivers, with an associated signal processing system. The radar itself measures power in range bins, at incremental steps from the antenna. These are sampled and processed, before being presented to a Tracking process.

The Tracker is sophisticated, following the movement of numerous objects over time, against pre-registered behavioural conditions. However, it is the business rules is a subsequent processing stage to the tracker that ultimately make sense of the radar data for the system users.

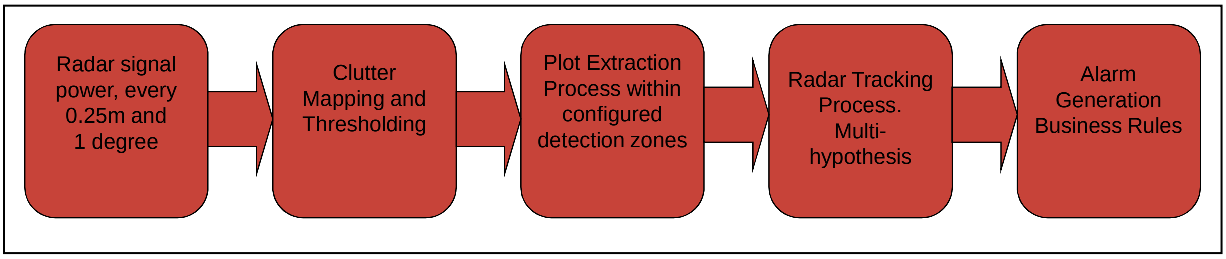


Figure A.1: Radar signal processing chain

A.1.1 Underlying FMCW radar and tracking technology

For traffic applications, a typical radar sensor has a maximum useful detection range coverage of 500 metres in radius, and is typically mounted 5 metres above the street level.

For a scanning radar system, inside the radome, an antenna of 2 degree beam width in azimuth and a spread beam in elevation spins around 360 degrees twice per second, so any one point within the sensor coverage is revisited every 500 ms.

During the rotation, 900 azimuth measurements are taken sweeping in 1 ms and typically 600 MHz bandwidth, though other bandwidth usage is configurable. The measured range resolution achieved is 0,25 m. The radar collects signal power in range and bearing and sends these data over an Ethernet interface to a remote processing unit (RPU).

Hosted on the RPU, a software tracking package excludes the measurements of static infrastructure - known as clutter - and then detects moving targets with the radar field of view using a dynamic threshold process (CFAR). Once a target has been detected a multi hypothesis algorithm associates its movements in order to generate a track. Each track has information on it location (range and bearing), speed, direction of travel and size of the object. Based on the track properties and behaviour, specific alarms can then be generated according to the operators needs.

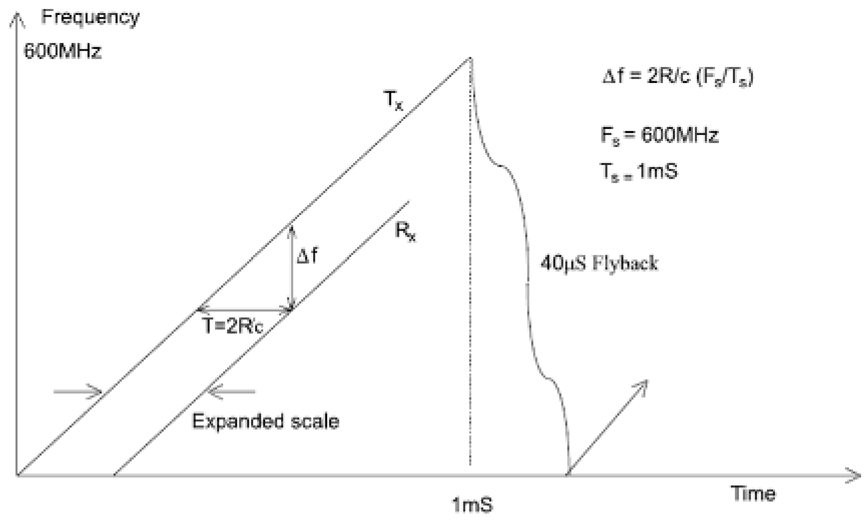


Figure A.2: Typical modulation scheme for a fixed infrastructure radar

A.1.2 Processing for incident detection

An automatic incident detection system operates to reveal dangerous situations for the road user. Traffic operators can configure different rules within the software according to the scenario and their requirements. These rules are typically focused on the generation of alarms for stopped, slow or reversing cars, people and debris. The rules editor allows the operator to apply specific settings such as the threshold speed, classification and how quickly to generate an alarm. Furthermore, in order to reduce nuisance alarms in queue situations, the software can detect a high density of traffic to limit the alarms in these conditions.

Once an alarm is raised the operator can either process it through the signal processing software or interface it with the existing traffic management system. Management software is able to control a fixed CCTV or a PTZ camera to point towards the incident location for the operator to confirm the alarm. In addition to that the operator can update the road message signs to limit the speed or close a lane in case of high risk, thus preventing further accidents.

With a radar incident detection system, the operator can be made aware of a slow or stopped vehicle, or pedestrian, or lost-cargo, within 10 seconds to 15 seconds. His response can then be to alert upcoming road users via the motorway messaging system. Because he is informed by a radar based system, the alert alarms are reliable and rapid, even in conditions of poor visibility, when an AID system is of most benefit to drivers.

A.1.3 Processing for enforcement

Business rules within radar signal processing software can be used also for enforcement purposes. In this case, dangerous road user behaviour can be detected and offenders prosecuted, with the aim of discouraging poor driving habits.

Based on the radar track information, the software can detect if a vehicle is changing lane where illegal, following too close to the vehicle in front or crossing a railway junction when the red light is on.

For lane change enforcement, the software measures the track position within a lane on the carriageway. When the vehicle is detected to have changed lane an alarm is generated and the evidence captured using a camera. This will form the basis of a subsequent enforcement notice. Similarly, for close following enforcement the software compares, within the enforcement area, the distance between two vehicles in the same lane.

Finally, for the red light enforcement on a level crossing the software manages an external input to know the state of the traffic light and enforce only when it is required. In this configuration, an enforcement notice can be served on drivers who ignore the red lights at a level crossing, or avoid the half barriers that protect the crossing from road users.

For enforcement systems a fixed camera is usually used to capture the evidence of the infringement. In this case, the camera points to the area that has been setup in the software for detection of the enforcement event. When the alarm is generated, the software triggers the camera to capture the picture.

A.2 Interference Mechanisms

For a single radar operating in the 76 GHz band to interfere with another, various criteria are to be met. The radar antennas are to be aligned so that the victim's antenna captures a proportion of the interferer's output; the FMCW chirp of interferer and victim are to be aligned in such a fashion so as couple unwanted energy into the receiver. If these criteria are met, then techniques are employed within the signal processing stages to remove any effects of a single interfered radar chirp.

Annex B:
Fixed Radar Installations at 76 GHz to 77 GHz

B.1 Existing Installations

B.1.1 South Link Tunnel, Stockholm, Sweden

Figure B.1
(courtesy of Navtech Radar Ltd)

Tunnels in Stockholm form a key part of the overall urban road network and are instrumental in enabling vehicles to move quickly and safely around the capital. Scanning radar installed in the South Link Tunnel provide reliable Automatic Incident Detection (AID) for stopped vehicles, unauthorized pedestrians, lost cargo and debris.

B.1.2 Bolte Bridge, Melbourne, Australia

Figure B.2
(courtesy of Navtech Radar Ltd)

Fixed infrastructure radar provide early warning detection of unauthorised pedestrians and cyclists in order to prevent accidents and attempted suicides.

B.1.3 E4 Highway, Stockholm, Sweden

Figure B.3
(courtesy of Navtech Radar Ltd)

A system of 33 fixed infrastructure scanning radar installed on the E4 Highway in Stockholm provides rapid Automatic Incident Detection in challenging, environmental conditions of snow, rain and fog. Road operators are to be alerted to incidents of stopped and reversing vehicles, congestion, pedestrians and debris as soon as possible after they occur to notify approaching motorists, via motorway message signs, to avoid network disruption.

B.1.4 E73 Highway, Stockholm, Sweden

Figure B.4
(courtesy of Navtech Radar Ltd)

Following the success of the radar systems installed in the South Link Tunnel and on the E4 Highway, the Swedish highways agency selected scanning radar to provide AID on the E73.

B.1.5 Hindhead Tunnel, London, UK

Figure B.5
(courtesy of Navtech Radar Ltd)

The twin bore Hindhead Tunnel is 1,8 km long. The UK Highways Agency required an AID system to detect traffic incidents, in order to respond quickly and provide assistance for people and vehicles stranded in the tunnel, and to detect slow/stopped vehicles and lost debris events escalating into a major incident as other road users become involved.

B.1.6 Tunnel, Slovenia

Figure B.6
(courtesy of Navtech Radar Ltd)

Fixed infrastructure scanning radar selected after a video detection system produced too many false alarms in the 600 m Golovec Tunnel. A trial system was installed to provide AID coverage for a section of one tunnel. After a successful evaluation, with events being rapidly detected and less than one false alarm per 24 hours, further radars are being installed.

B.1.7 Motorway, Munich, Germany

Figure B.7
(courtesy of Navtech Radar Ltd)

In 2010 a pilot project was run on the A8 in Southern Germany, to evaluate the effectiveness of radar for detecting slow and stopped vehicles on the hard shoulder, as a part of Germany's wider managed motorways program. Further work is underway to enhance the ability of the technology to detect small items of debris at long range. Spare wheels, exhaust pipes and lost cargo are very difficult to detect with CCTV camera based systems, especially during the night or in poor weather. Nevertheless, the hard shoulder is not safe to open as a running lane if such items are present.

B.1.8 Mastrafjord and Tunnel, Norway

Figure B.8
(courtesy of Navtech Radar Ltd)

Mastrafjord tunnel is a subsea road tunnel, 4,4 km long and is part of the European trunk road network. It is currently being fitted with an infrastructure radar Automatic Incident Detection system. Norway has over 900 road tunnels, including the world's longest road tunnel at 24 kms. Monitoring such an extensive tunnel network from a limited number of control rooms requires reliable detections systems with very low false alarm rates.

B.1.9 Autostrada A14, Bologna, Italy

Figure B.9
(courtesy of Navtech Radar Ltd)

Scanning radar has been installed on highway A14 in Bologna, Italy, in a pilot scheme to provide automatic incident detection. Due to the frequent fog, snow and rain, camera technologies were not effective for a continuous monitoring of several strategic highways in Italy. The radar has provided constant performance and thanks to this successful installation more radar systems will be delivered as primary AID technology in other areas of the country.

B.2 Market size

B.2.1 For Automatic Incident detection

B.2.1.1 On Managed Motorways

Managed motorway programs are currently in operation within the UK, Sweden, Netherlands (approximately 200 km) and Germany (approximately 300 km). These schemes operate by converting an existing emergency lane, on a multilane highway, into a running lane. The Highways Agency in the United Kingdom have some 160 km of hard shoulder running either currently in service or under construction. A further 220 km are to be delivered.

In some implementations the lane change is temporary and the emergency lane is opened for peak hour traffic and reverts to use as an emergency lane at other times. In other cases, the emergency lane is made into a permanent running lane - so called 'all lane running'. In both scenarios, if a vehicle breaks down in a live lane, or if debris is dropped, or a pedestrian enters onto the carriageway, approaching drivers need to be warned quickly.

Managed motorways offer increased capacity, at a fraction of the cost of building extra carriageway. Results published in March 2011 in the UK Highways Agency's three-year safety report into the pilot Managed Motorway scheme on the M42 show that accidents involving personal injury reduced by more than half (56 %), with zero fatalities. Casualties per billion vehicle miles travelled have reduced by just under two-thirds (61 %) since hard shoulder running was introduced [i.15].

A short-term period monitoring hard shoulder running on sections of the 'Birmingham Box' between Junction 16 of the M40 and Junction 5 of the M6 shows an average daily saving of about 2 minutes per vehicle for a return journey in peak periods. Two thirds (66 per cent) of road users surveyed report that using the hard shoulder as an additional lane had improved the 'Birmingham box' motorway sections of the M40, M42 and M6.

Out-turn cost of the initial M42 deployment has been given as £100 million, with delivery inside a couple of years. By comparison, just to increase capacity by an additional lane in the same geographical location would have cost £500 million even before the addition of any of the technology which operation of a modern motorway requires. Going outside the current Highways Agency land boundaries, compulsory purchases of land and public consultations could have taken upwards of a decade even before construction started.

Figure B.10: Hard shoulder in use as a running lane, Netherlands
(courtesy of Rijkswaterstaat)

Figure B.11: Radar installed for all lane incident detection in the UK
(courtesy of Navtech Radar Ltd)

B.2.1.2 In Tunnels

Fatal Incidents within tunnels in particular have raised concerns about current safety systems. During the 1999 Mont Blanc Tunnel fire for example, reliable incident detection systems and an improved inter agency response could have helped avert loss of life. Legislators have responded by recommending the wider use of the available detection technologies, in tunnels over 500 meters long [i.1]. Although these are not mandated to be radar based, radar incident detection does offer several advantages including low maintenance, very low false alarm rates - which mean that the operators continue to heed the alerts raised - and low maintenance, which means maintenance staff are in no danger around the roadside equipment.

Within EC law, long tunnels are defined as those with a length of more than 500 meters. Equally, automatic incident detection and/or fire detection is mandatory in all tunnels longer than 500 m. See European Directive on minimum safety requirements for tunnels in the Trans-European Road Network [i.1]. In Germany alone there are over 150 road tunnels.

The Trans-European Transport Network (TEN- T) is set to encompass 90 000 km of motorway and high-quality roads by 2020. The EU will eventually have a role in the safety management of the roads belonging to TEN through safety audits at the design stage and regular safety inspections of the network.

The Hindhead tunnel in the UK sees on average 35 000 vehicles per day. A radar based AID system has been installed since July 2011, operating continuously. 12 fixed radar sensors provide overlapping and redundant coverage of the tunnel. There have been no reported harmful interactions with the vehicle based radar system in this tunnel, despite some 20 million vehicles passing through the tunnel in that period. Other tunnels on the TEN-T handle much higher traffic volumes, up to 100 000 vehicles per day.

Research conducted for the Federal Highways agency in the United States (see The Impact of Rapid Incident Detection on Freeway Accident Fatalities [i.2]) shows that the typical time for the emergency services to be alerted of an incident, on Urban Freeways, is typically 5 minutes and, in general, it takes 6 minutes for the emergency services to arrive, after which time first aid is administered by qualified paramedics. On these urban freeways some 4 112 fatalities were recorded in a single year. The report went on to show that if the incident detection time could be reduced from 5 minutes to 2 minutes, then some 652 of these lives could have been saved, with an associated cost saving of US $1,3 b. Typical incident detection times for fixed radar installation on urban motorways and other strategic roads is 10 seconds to 15 seconds.

B.2.2 For traffic enforcement

Collisions between trains and road vehicles at level crossings are classified as train accidents. Collisions at level crossings account for around 42 % of all of the Precursor Indicator Model's train accident risk to passengers, members of the public and workers.

The graph shown in figure B.14 illustrates the lack of any significant reduction in level crossing risk over the previous eleven years to 2009 with regard to train accident risk (and whole system risk). This has meant that the proportion of train accident risk attributable to level crossings has grown substantially.

Further figures from the Rail Safety and Standards Board (RSSB) in the UK show that in 2009/10 there were 13 fatalities amongst members of the public around level crossing. In 2008/09 there were 12 fatalities, and in 2010/11 there were 6 fatalities. See RSSB Half-year safety performance report 2012/13 [i.3], page 33.

Enforcement of red light violations on railway crossing has been identified as an important tool for discouraging dangerous driving activity. Drivers will often attempt to pass a red light or closing barrier and become stranded on the railway tracks in the crossing area when the train passes.

Fixed radar systems, operating outside of the confines of the crossing area and tracking vehicles as they drive towards the crossing after red warning lights have been illuminated, are an important tool to improve rail safety. They can be more easily, and therefore more quickly, installed than systems that lie within the confines of the level crossing area, and no special interface to the existing railway crossing control system is necessary.

Some 200 initial sites have been identified by Network Rail as requiring railway crossing enforcement systems. See Strategic Business Plan for England & Wales January 2013 [i.4]. A further 1 000 sites are anticipated over the following 3 years

Safety in EU railways differs between member states with a ten-fold difference between the most and least safe states. Overall, there were 2 401 significant railway accidents with 2 500 casualties in 2010; 1 256 killed and 1 236 seriously injured. 60 % were third party victims, i.e. these were people not meant to be on the railway premises.

In addition, there were over 2 743 suicides in 2010; more than 50 per week. Evaluation for 2011 continues but figures show 221 investigations of serious accidents, the highest number since 1996. However, the number of serious accidents investigated is only a small part of the total number of serious accidents. See Railway safety performance in the European Union 2012 [i.5].

The EC web site, says in relation to level crossings: "In most cases, the primary causation of fatalities at level crossings is the inappropriate behaviour of road users (bad evaluation of risk, lack of attention, and misunderstanding of road signs). Eliminating accidents at level crossings is a shared responsibility for both road and rail operators." See European Commission Transport website [i.6].

We can conclude that the number of fatalities on European level crossings is unacceptably high. Furthermore, enforcement systems that lead to improved driver and pedestrian behaviour at level crossings will lead to a reduction in these figures. Enforcement, leading to behaviour change, is an important part of the regulators' strategy. Statistics are available on the type of protection assured by active level crossings at European level.

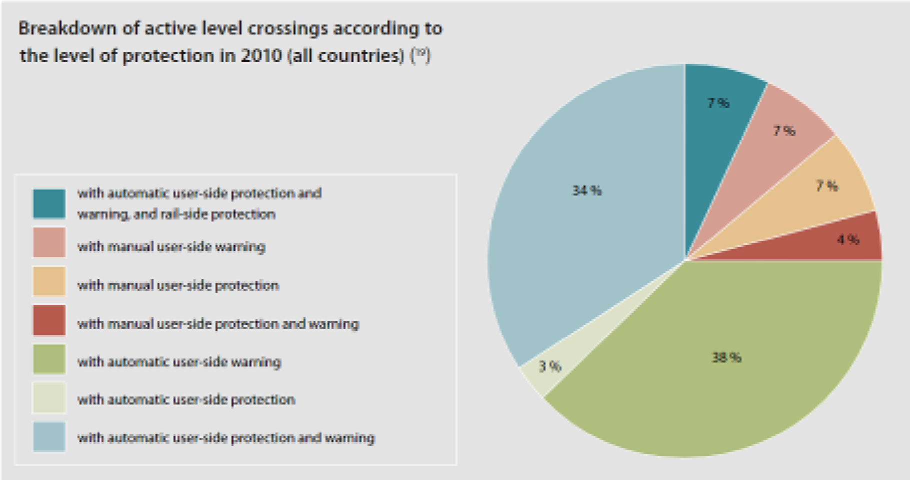


Figure B.12: Breakdown of active level crossings according to the level of protection in 2010,
(source: Rail Safety and Standards Board)

In figure B.12 the data for 24 countries show that level crossings with automatic user-side warning (typically flashing lights) are the most common type of active crossings (38 %), closely followed by the level crossings with automatic user-side protection and warning (barriers with lights) (34 %).

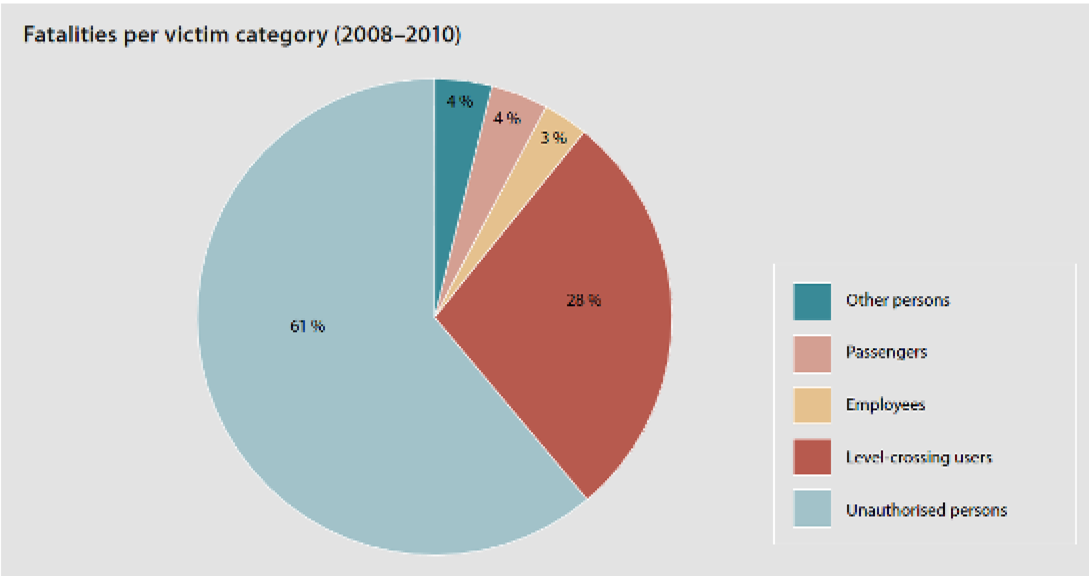


Figure B.13: Fatalities per victim category (2008-2010),
(source: Rail Safety and Standards Board)

Figure B.13 clearly shows that the majority of fatalities are unauthorised persons. Level-crossing accidents account for 28 % of fatalities, whereas passenger fatalities make up less than 5 % of the total number of deaths on railways.

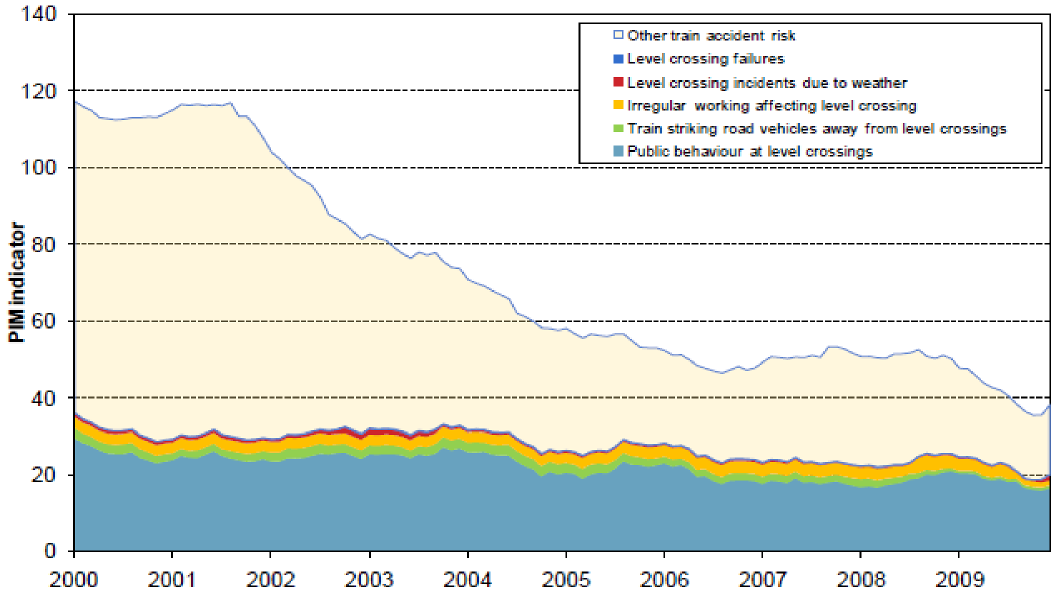
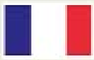


Figure B.14: The graph illustrates the lack of any significant reduction in level crossing risk over the previous eleven years to 2009
(courtesy of Network Rail)

Network Rail figures that show poor public behaviour in and around level crossings has improved little over the last 10 years. See Strategic Business Plan for England & Wales January 2013 [i.4].



Event: *Level-crossing accident*
Date, time: *12 October 2011, 17:17*
Location: *Saint-Médard sur Ille, France*
Outcomes: *3 fatalities, 5 serious injuries*

A regional passenger train hit a truck on a level crossing situated near Saint-Médard sur Ille station, close to Rennes. The semi-trailer truck was blocked on the level crossing between the barriers. The train was travelling at a speed of about 110 km/h; the driver applied the brakes at the last moment so that the speed of the train was only slightly lower on impact. All casualties were train passengers.

The line is double track and there are no side tracks at the station. The level crossing has a particular geometric design which may not be best adapted to the heavy-duty vehicle traffic.

Image 8 _ Level-crossing accident at Saint-Médard sur Ille station.
Source: French NIB.

A similar accident occurred at the same place in 2007 and was investigated by the French NIB who recommended that some improvements be made to the geometry of the road. Unfortunately, these improvements had not yet been carried out.

Figure B.15: Fatal Accident report from a Railway Crossing,
(source: French National Investigation Body)

Figure B.16: Yellow box at traffic junction

Enforcing yellow box junction traffic rules at intersections improves traffic throughput, reduces congestion and consequentially also carbon emissions.

B.2.3 Airports and Landing Strips and Air Traffic Control

Figure B.17: Installation at airport,
(courtesy of Navtech Radar Ltd)

With a detection range capability of 1 200 meters - 1 600 metres radius from the sensor over 360 degrees, radar solutions are ideal for airfield surveillance. Multiple radars can be networked back to a single base station and one display. Reference sites include Alghero Airport in Sardinia, Katowice Airport in Poland, and UK International Airports.

Figure B.18: Surface Movement Radar Installation at airport,
(courtesy of Navtech Radar Ltd.)

In 2003 East Midlands Airport (UK) introduced an airport ground surface movement system using 76 GHz millimetre wave radar. The radar sensor provides aircraft tracking on the runway, taxiways and apron and acts as an aid to the Air Traffic controllers in poor visibility.

B.3 Non Transport Applications

The title and scope of the present document refer to transport applications of fixed surveillance radar. The proponents of the present document wish to provide further information about existing and possible applications outside the field of transport, noting that:

1) Such applications are permitted and already in use in some countries, such as the UK. EC Decision 2011-829-EU [i.9] designates the 76 GHz to 77 GHz band for radars for RTTT terrestrial vehicles and infrastructure systems only. EU Member States are obliged to allow such use but may also be more liberal and permit other uses.

2) The compatibility scenarios for fixed radars are likely to be the same whether or not the application is for transport.

B.3.1 For Industrial detection and automations

TR 102 704 (V1.2.1) [i.7] has reported on the use of radar system for mobile vehicle use, away from roads. Some further examples are provided here of equipment in service.

Figure B.19: Anti-collision system for Ship to Shore cranes
(courtesy of Navtech Radar Ltd)

Prior to installation of a radar anti-collision system at Southampton docks in the UK, two crane boom collapses occurred. In the most recent, the crane driver received life threatening injuries.

The general market for Crane based radar anti-collision systems has been estimated in TR 102 704 (1.2.1) [i.7] and shown in figure 20. More general applications for the same technology are discussed in the same reference.

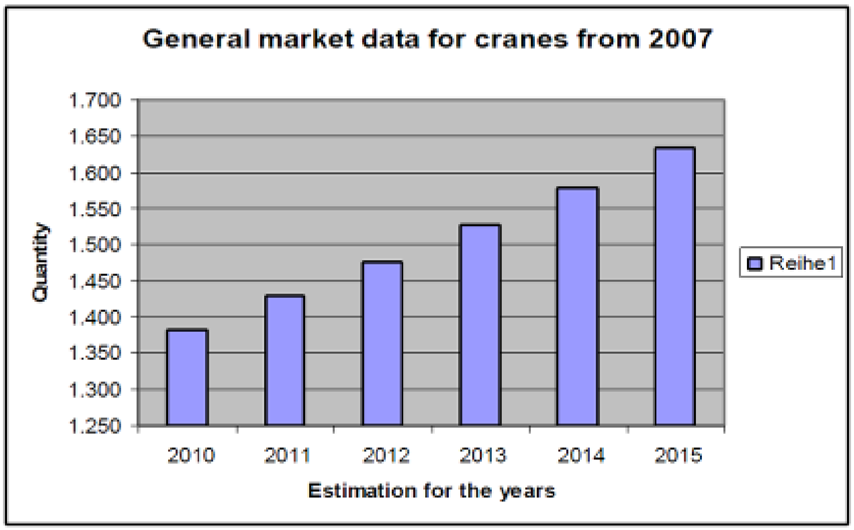


Figure B.20: General market data for cranes from 2007

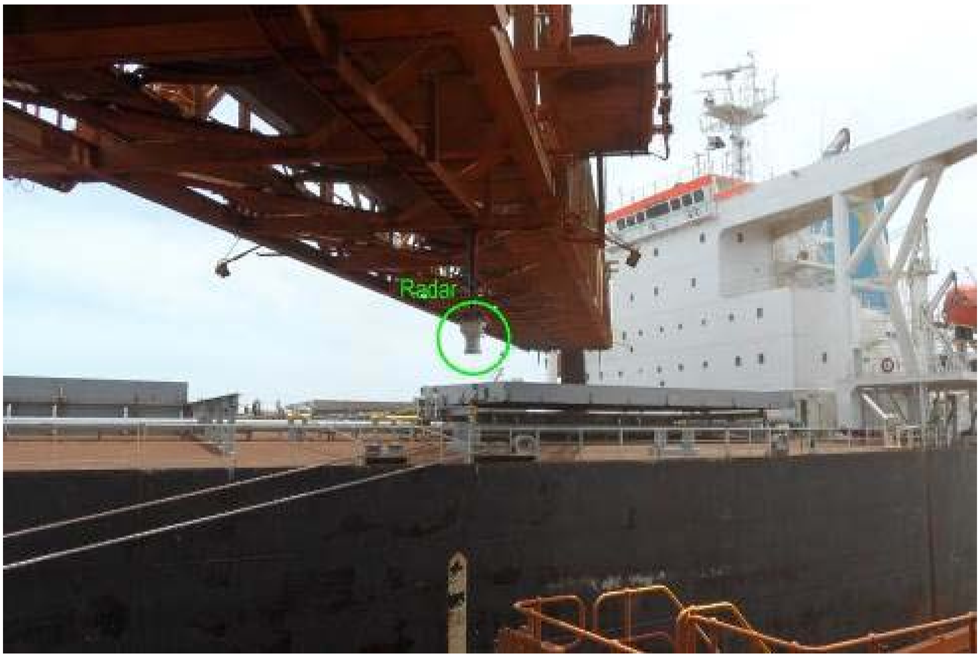


Figure B.21: Anti-collision system for bulk loader

Bulk loading of Ore is a dangerous process. The noise and dust caused by loading the materials serve to make the drivers of these machines less aware of the relative location of ship and loader. In these conditions, collisions between ship and loader are inevitable, and in some of the larger ports can occur 3 or 4 times a year.

For a 9 000 Tonnes per hour machine loading Iron Ore, even a few hours of lost loader time due to a collision can cost over US $ 1 m per hour. A recent accident in Queensland Australia saw a loading boom damaged in a collision with the ship; this could not be repaired in situ and a replacement was needed. The total machine down-time was approximately 3 months.

B.3.2 Prison Buildings

Figure B.22: Typical prison

Fixed infrastructure Radar solutions are ideal for Prison buildings as there is a large expansive area around them. The radar can offer effective detection of escapees and people approaching the perimeter, thus preventing the launch of packages into the courtyard so they cannot be collected by inmates.

B.3.3 Power Stations and Reservoirs

Figure B.23: Installation at power station

Millimetre wave radar systems work over open ground, as well as over water, where other technologies may struggle. Fixed infrastructure radar solutions are being installed at separate nuclear power locations, including one in Finland to protect the approach to the plant over a sea inlet.

B.3.4 Data Centers and Commercial Property

Figure B.24: Data centre

Scanning Radar delivers reliable 24 hour technology solutions for high security commercial sites like data centres. The solutions avoid reliance on manned guarding or physical barriers.

Annex C: Installation details for road surveillance

Roadside surveillance radars are typically mounted on existing highway infrastructure, either gantries or on CCTV posts. In some cases, dedicated radar posts are installed if no suitable mounting locations exist on current infrastructure.

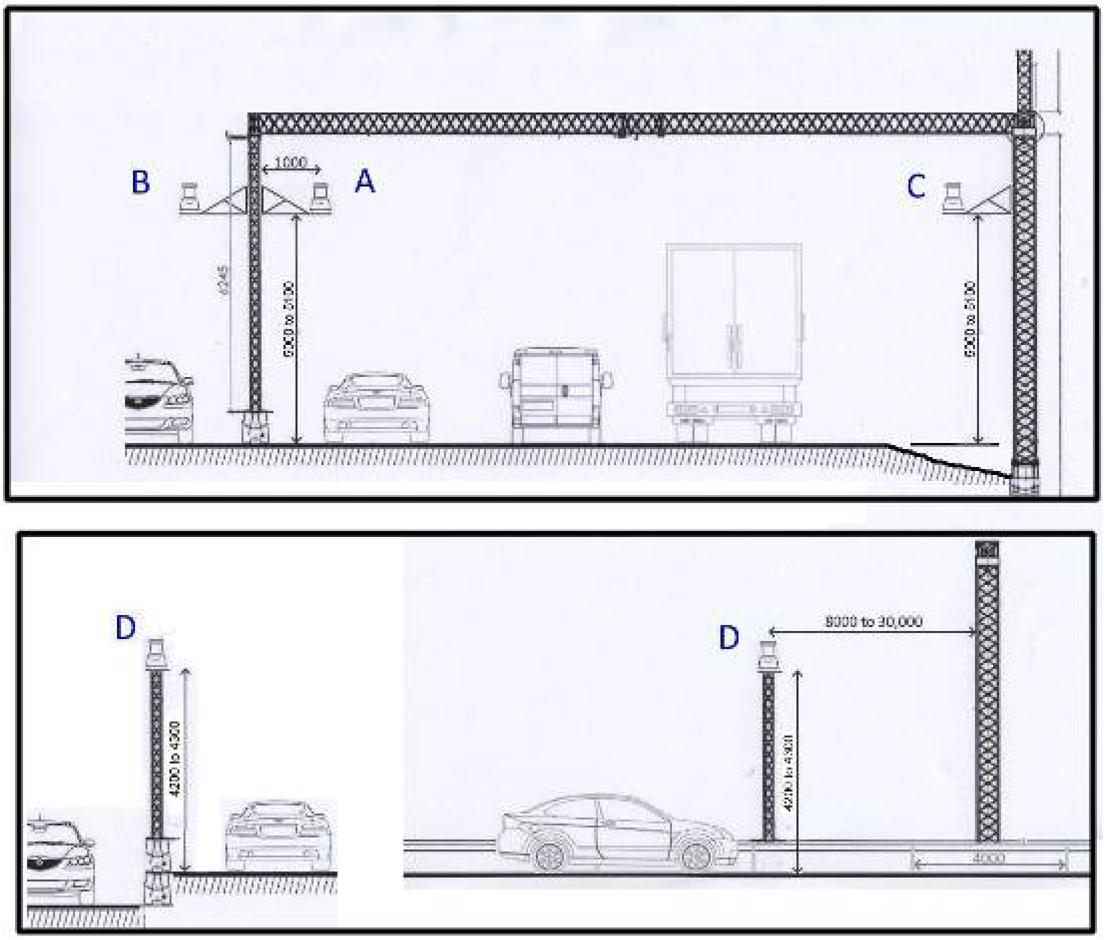


Figure C.1: Example radar sensor locations,
(courtesy of Navtech Radar Ltd)

The typical mounting height for fixed infrastructure radar is approximately 5 meters above the road surface. Radar are always mounted on threaded studs, and adjusted during the installation procedure so as to scan parallel to the road surface Figures C.1 and C.2.

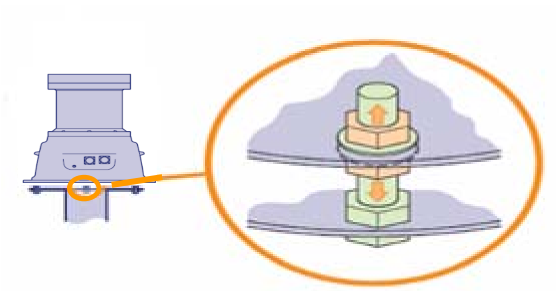


Figure C.2: Levelling adjustment on threaded mounting bolts

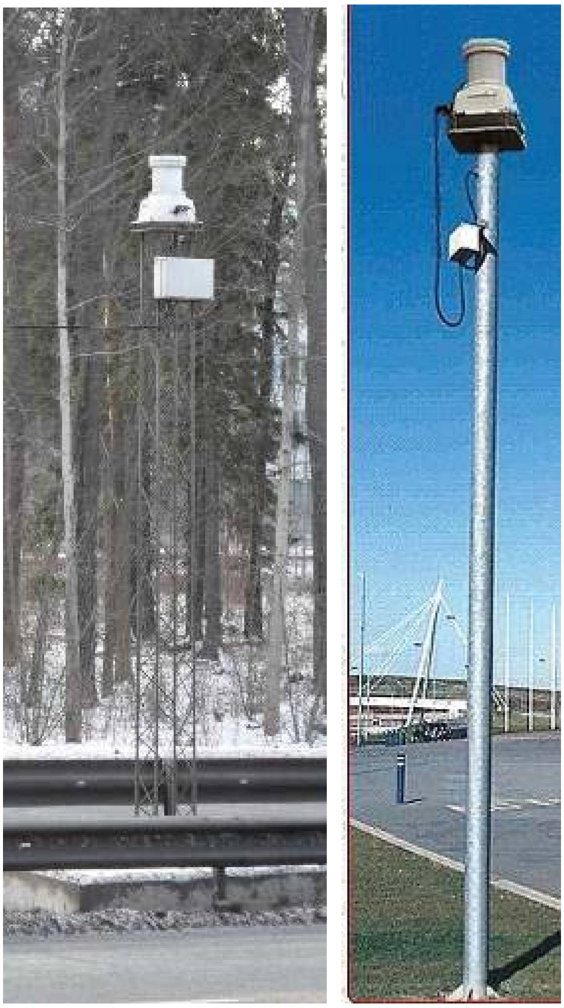


Figure C.3: Radar mounting posts
(courtesy of Navtech Radar Ltd)

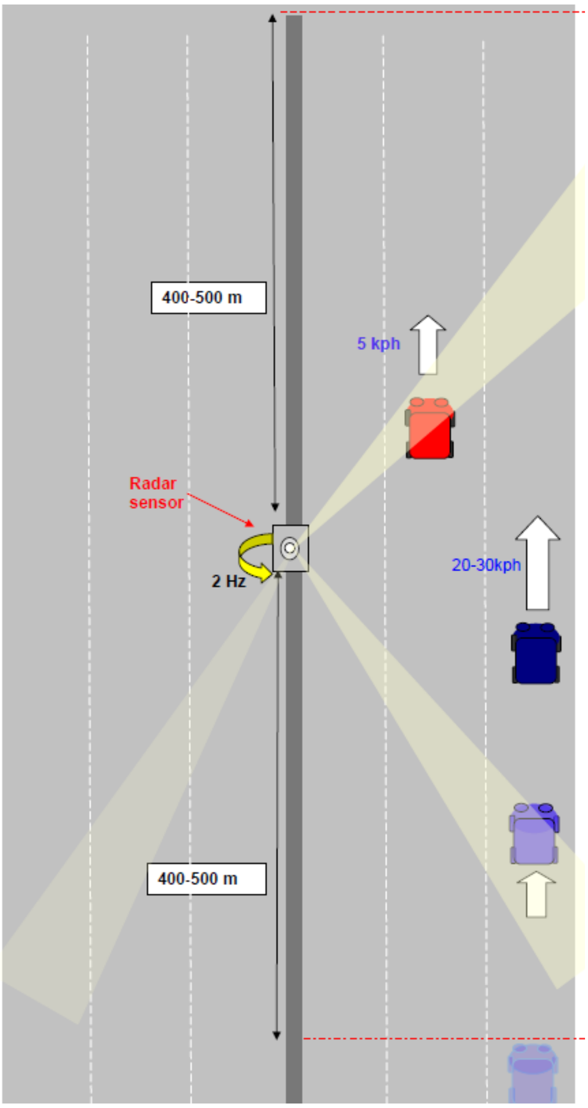


Figure C.4: Diagram showing radar scanning road

The scanner is rotating at 2 Hz, thus illuminating any point on the road twice per second.

Annex D: SEAMCAT Study - Fixed and Vehicular Radars

This is an initial study performed by Navtech Radar Ltd and is intended to provide a preliminary assessment of the risk of interference.

A statistical modelling of the interference between a typical infrastructure radar and vehicular radar, hereafter referred to as SRR, has been performed with a Monte-Carlo simulation method using Seamcat. The software evaluates the probability of interference due to the signal (I) generated by an Interferer and compares this to the noise level (N) of the victim receiver. The criterion used is I/N to be lower than 0 dB, i.e. that the interference is seen as normal noise.

To prepare the simulation it is required to provide the characteristics of the potential interferer (the infrastructure radar) and the victim receiver (the vehicular radar). For each of those, the main information required are the antenna pattern, the emitted power and the position and pointing. The antenna characteristics of the infrastructure radar have been investigated and are discussed in D.1 Radar Antenna Specs , whilst the SRR characteristics were obtained from the Mosarim No. 248231 D1.7 report [i.14]. Further characteristics are included from EN 301 091-1 [i.8].

Two different scenarios were simulated: in one case the interferer is infrastructure radar mounted at 5 metres and victim SRR receivers are distributed up to 500 metres in range and 10 metres in azimuth. The scenario is shown in figure D.1.

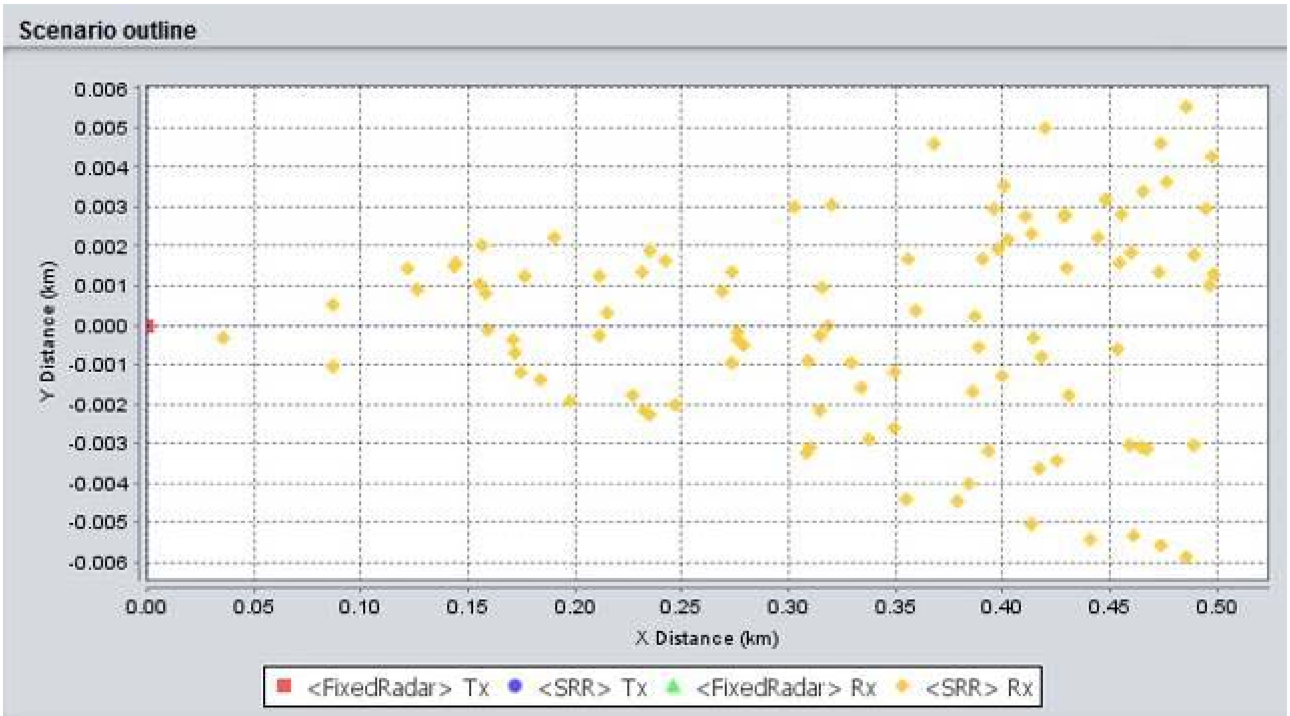


Figure D.1: Scenario outline of the simulation

The interfering signal from the fixed radar is simulated (figure D.2) and compared to the noise floor of the victim receiver. The unwanted signal mean value is -125 dBm, below the victim noise level (KTBN) which is typically -95 dBm - considering a noise floor of 12 dB as per Mosarim No. 248231 D1.7 report [i.14] - leading to a resulting probability of interference lower than 0,02 %.

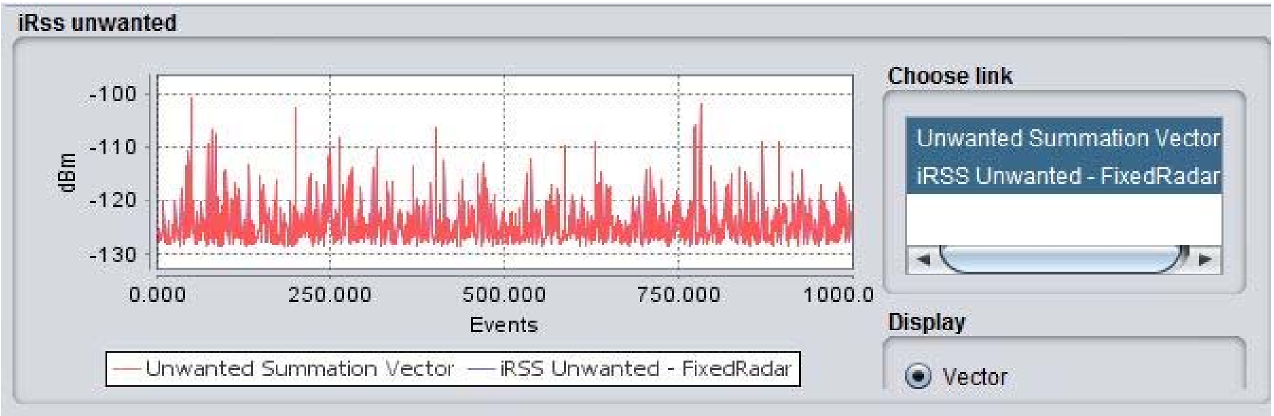


Figure D.2: Simulated interfering signal from the fixed radar

Figure D.2 shows the interfering signal power level received at the victim for each of the Monte Carlo events. For every event a victim receiver is positioned randomly in the simulation area (500 m range × 10 m in azimuth) and the radar is pointing towards the centre of the area. This represents the worst case scenario, whereby the antenna is not considered to be scanning. In this case the transmitted power is the peak power of 37,5 dBm. For the scanning sensor the actual e.i.r.p. is reduced to 15 dBm, according to the formula in clause 7.2.3.2 of EN 301 091-1 V1.3.3 [i.8], leading to a negligible interference at the victim.

As a comparison, the same simulation was performed using a vehicular radar as the interferer source. In this case, the probability of interference registered was similar, around 0,06 %. However, since the maximum range of a vehicular radar is 200 metres, it is more accurate to reduce the maximum range of the simulation. In this case the interference probability raises to 0,2 %.

It is important to note that automotive installed radar also provides important safety related functions that benefit vehicle user, passengers and pedestrians. Potential interference in a critical situation, for emergency braking for example, needs to considered and mitigated.

D.1 Radar Antenna Specs

The antenna gain of an aperture antenna is given by the standard equation

$$G=10\log [\eta 4\pi A/\lambda^2]$$

Where:

- η is the antenna efficiency, typically 0,5 for millimetric frequencies (Papageorgiou, 2012)
- λ is the wavelength in air, 3,9 mm at 76,5 GHz
- A is the aperture area

The antenna diameter of a typical infrastructure radar is 150 mm, thus the maximum theoretical gain achievable is ~ 38,5 dBi. However, the beam is spread in the vertical dimension with a secondary antenna, thereby reducing the gain. To analyse the actual antenna peak gain an empirical measurement is required.

The e.i.r.p. of a typical infrastructure has been measured to be, in the worst case, 37,5 dBm at a particular instance, or 14,9 dBm e.i.r.p. if account is made for the fact that the antenna is rotating.

NOTE 1: Using the formula in clause 7.2.3.2 of EN 301 091-1 (V1.3.3) [i.8].

The e.i.r.p. is linked with the antenna gain G and the transmitted power Pt with the well-known relation:

$$e.i.r.p. = Pt + G - L$$

Where L are the sensor losses, which can be neglected or of the order of few dB. Knowing the transmitted power of 10 mW (10 dBm) it is possible to derive the overall gain of 27,5 dBi at the radar boresight.

The antenna gain off the boresight is then reduced according to the beam profile in horizontal and vertical dimension.

NOTE 2: Antenna beam patterns are shown in clause 7.2.2.1b.

D.2 Conclusions

The antenna characteristics and the emitted power are key factors in the potential interference between an infrastructure radar and a vehicular radar. Given the study on the antenna, the e.i.r.p. measured and this initial simulation performed using SEAMCAT, it appears that the probability of a scanning infrastructure radar interfering with a vehicular radar is less than that of a vehicular radar interfering with another vehicular radar.

It should be noted that this is an initial simulation only and does not exactly represent the real world situation. In particular:

- The automotive radars are not necessarily distributed randomly in the simulation area, either in position or orientation. In the real world they would generally be along parallel axes representing the lanes of a road.
- The use of Recommendation ITU-R P.525 [i.25] (free space propagation) may not accurately represent the real world scenario. Ideally, additional elements representing the low mounting height, reflections from the road surface, additional clutter and other vehicles need to be taken into account. A special propagation model reflecting the usage and operation scenario for automotive radar is currently being developed at ITU level to be used in the studies related to WRC-15 AI1.18.

Annex E:
Radio Astronomy Service

This is an initial study to assess the situation. It was performed by Great Circle Design in conjunction with the European Committee on Radio Astronomy Frequencies (CRAF).

E.1 Locations of Millimetre Wave Observatories

There are 8 sites in Europe where RAS observations are made in the 76 GHz to 77 GHz band.

Table E.1: ITU-R Region 1 RAS sites operating in the 76 GHz - 77 GHz frequency band

Name	Host country	W. Longitude (degrees)	Latitude (degrees)	Description of situation
ITU-R Region 1				
NOEMA 10 m x 15 m Array, Plateau de Bure, France	France	-5,9072222	44,633611	Isolated high mountaintop in line-of-sight to various public facilities
100 m, Effelsberg,	Germany	-6,8833333	50,525556	Broad flat plain exposed to nearby roads
IRAM 30 m, Pico de Veleta	Spain	3,392777	37,06611	Mountainside overlooking nearby ski resort, line of sight to city of Granada
Robledo	Spain	4,2491660	40,427222	Broad flat plain exposed to roads
Yebes 40 m	Spain	3,0894444	40,524167	Broad flat plain exposed to roads
Noto 32 m	Italy	-14,989167	36.876111	Flat exposed plain
Sardinia Radio Telescope 64 m, Sardinia	Italy	-9,261111	39,497222	High exposed plain
Onsala 20 m	Sweden	-11,926389	57,395833	Waterside, forested, relatively isolated, Gotheborg 40 km N

E.2 Coupling Calculations

Recommendation ITU-R RA.769-2 [i.23] gives guidance as to the acceptable limits for unwanted signals at RAS sites. These are expressed as total power and as spectral power density; the choice of which limit applies depends on the bandwidths of the unwanted signal and of the observation being conducted.

RAS observations are integrated over periods of typically 2 000 seconds. This is longer than the scan time of radar systems so it is the average power in the direction of the RAS site that is important, provided the peak power is within the linearity range of the equipment.

An initial compatibility study was done in two steps. First the details of the signal radiated by the radar transmitter were calculated using a spreadsheet. Secondly, CRAF calculated the required separation distance using the preferred propagation model.

E.2.1 Radiated signal details

Infrastructure Radar Signal			
Parameters			
Main Beam Power	38	dBm	eirp
Scan Period	500	ms	
Beamwidth	2	degrees	
Peak Sidelobe level	-16	dB	
Average Sidelobe level	-22	dB	
Bandwidth	800	MHz	
Clutter Scattering coefficient	-10	dB	
Derived parameters			
Pulse rate	2	Hz	
Pulse Width	2.78	ms	
Duty cycle	0.0056		
Sidelobe factor	0.00631		
Sidelobe radiation	16	dBm	eirp
Beamwidth illuminating clutter	0.03491	Steradians	
Power illuminating clutter	12.4	dBm	
Scattering factor	0.00028		
Scattered radiation	2.4	dBm	eirp
Without Sector Blanking			
Radiation towards RAS site from main beam, sidelobes and scattering			
Peak Power	38	dBm	eirp
Pulse Width	2.78	ms	
Duty cycle	0.0056		
Average power	18.8	dBm	eirp
Spectral power density	-100	dBW/Hz	
With Sector Blanking			
In blanked sector: no radiation towards RAS site			
Out of blanked sector: radiation by scattering of main beam from ground clutter			
Angle of blanked sector	90	degrees	
Peak Power	2.4	dBm	eirp
Pulse Width	375	ms	
Duty Cycle	0.75		
Average Power	1.2	dBm	eirp
Spectral power density	-118	dBW/Hz	

E.2.2 Separation distance calculation

Infrastructure Radars

Mean e.i.r.p.: 18 dBm

Bandwidth: $\Delta\nu := 800 \cdot MHz$

Transmitter power spectral density (dBm/MHz): $P_{out\_dBmMHz} := 18.8 - 10 \cdot \log(800)$

sector blanking gives a reduction of mean e.i.r.p. of 17,6 dB

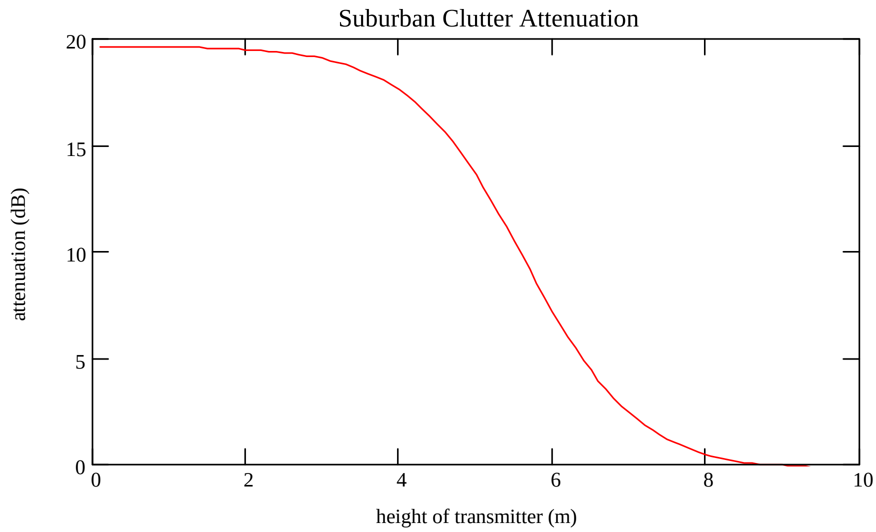
transmitting height: $h_{tr} := 5 \cdot m$

Mean topography (according to the ITU-R P. 452 [i.24] section 4.6.3 height gain model)

with $h_{ar} := 9 \cdot m$ $d_{kt} := 0.025$ (suburban conditions assumed)

and with

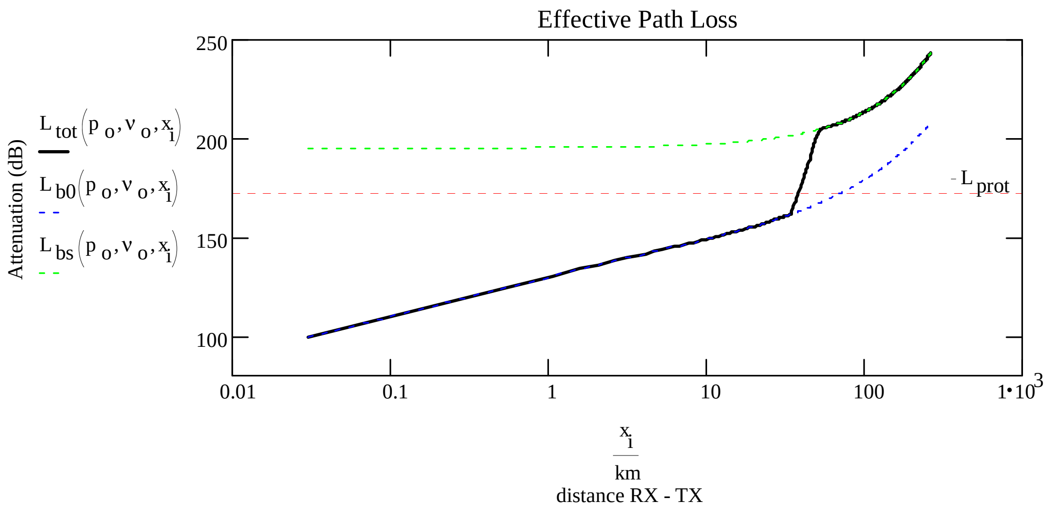
$A_{ht} := 10.25 \cdot e^{-d_{kt}} \cdot \left[1 - \tanh\left[6 \cdot \left(\frac{h_{tr}}{h_{ar}} - 0.625\right)\right]\right] - 0.33$ gives a clutter attenuation of $A_{ht} = 13.607$ dB



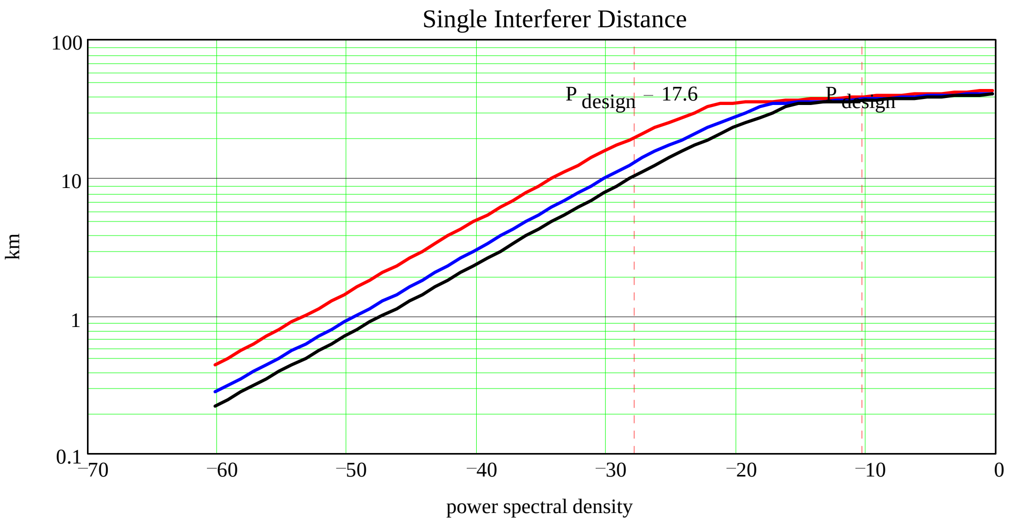
by 4 dB to $A_{ht}(4 \cdot m) = 17.609$ dB and for 2 m by 6 dB to $A_{ht}(2 \cdot m) = 19.506$ dB.

required attenuation(5 m transmitter height):

$L_{prot} := dB(S_{prot}, S_{tx}) - G_M + G_{topo}$ => $L_{prot} = -173.019$ dB



Separation distance: $d_{min} := \text{wurzel}\left(L_{tot}\left(p_o, v_o, y\right) + L_{prot}, y\right)$ => $d_{min} = 38.64 \cdot km$



red: transmitter at 5 m above ground, blue, transmitter at 4 m above ground, black: transmitter 2 m above ground.

without sector blanking $d_{SE}\left(P_{design}\right) = 38.64 \cdot km$, for 4 m and 2 m, this does not change significantly:

$d_{SE}\left(P_{design} - 4\right) = 37.052 \cdot km$

$d_{SE}\left(P_{design} - 6\right) = 36.259 \cdot km$

Sector blanking does make a difference though:

with sector blanking $d_{SE}\left(P_{design} - 17.6\right) = 19.743 \cdot km$

and $d_{SE}\left(P_{design} - 6\right) = 36.259 \cdot km$ for transmitters 4 m above ground level

$d_{SE}\left(P_{design} - 17.6 - 6\right) = 10.345 \cdot km$ for transmitters 2 m above ground level

NOTE: The initial result of this study is that, in the absence of mitigation techniques, a separation distance of 38,64 km is required between an infrastructure radar at 5 m height and a RAS mm-wave observatory.

E.3 Sector Blanking

A simple mitigation technique of sector blanking was included in the compatibility study. Sector blanking involves interrupting the radar beam as it scans through a certain azimuth range. For the radar systems considered here blanking would be achieved be mechanical screening rather than electronic switching.

Sector blanking eliminates main beam radiation in the required direction, but allowance is to also be made for reflections and scattering from the main beam as it scans through the unblanked sector.

This was modelled by calculating the total energy illuminating the scattering objects - the ground clutter - and assuming the clutter then re-radiates this energy isotropically with a scattering efficiency, or albedo, of 10 %.

Under these assumptions the required separation distance falls from 38,6 km to 19,7 km. There is, however, a further effect in that the scattered energy is radiated from ground level instead of the top of a mast. If the scattered energy is assumed to be from 2 m height instead of 5 m, then the required separation distance falls further to 10,3 km.

E.4 Conclusions

There are 8 mm wave observatories in Europe, approximately half of which are in remote locations.

Initial studies indicate that for infrastructure radars at heights up to 5 m and more than 40 km from any of these locations, there is no likelihood of interference to RAS observations.

A solution acceptable to both the RAS and the manufacturers of infrastructure radars would be a requirement that any installation within 40 km of one of the listed sites could only be made if mitigation techniques were shown to be effective. For instance:

- The use of sector blanking could allow operation at separations down to 19 km or 10 km depending on the conditions.
- Installations in tunnels could be considered within the 40 km range.

Note that this study considers the effect of a single radar system. Cumulative effects from a large number of installations have not been considered.

Annex F: Bibliography

Papageorgiou, I. (2012). "Investigation and design of high gain, low sidelobes, compact antennas at E - band". Gothenburg, Sweden: Chalmers University of Technology.

History

Document history		
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