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**Electromagnetic compatibility
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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**

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Foreword

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

The present document includes necessary information to support the co-operation under the MoU between ETSI and the Electronic Communications Committee (ECC) of the European Conference of Postal and Telecommunications Administrations (CEPT).

Executive summary

The present document describes the radar based surveillance applications in the 76 GHz to 77 GHz for non-automotive ground based vehicular / mobile applications which in most cases are safety related.

A high number of accidents in the public transportation area (trains and trams) or with construction/off road vehicles need an increase in the safety in these areas. Information on accidents is described in annex A.

The 76 GHz radar technology as realized in EN 301 091 [i.1] is also suitable for applications in rail, maritime, construction, agriculture, leisure vehicles, unmanned vehicles and ground transportation. The automotive radars provide safety features and have reached a high penetration. The penetration will further increase significantly with the introduction of radars not only in higher but also in lower class cars.

The coexistence for all mobile ground based vehicular applications in the 76 GHz to 77 GHz can be based on the mitigation / sharing mechanisms between automotive radars. Such automotive mitigation techniques are studied in a European funded project, called MOSARIM [www.mosarim.eu]. The results of the project and the automotive industries implementation of mitigation / sharing techniques for their systems will be reflected in an future update of the related ETSI standards, like EN 301 091 [i.1].

Introduction

ETSI has created a number of Harmonized Standards under the R&TTE Directive [i.19] for automotive radar systems for different applications e.g. for the frequency bands of 24 GHz, 5,8 GHz, 63 GHz, 76 GHz and 79 GHz.

The 76 GHz RTTT Standard EN 301 091 [i.1], defining the technical characteristics and test methods for radar equipment operating in the 76 GHz to 77 GHz band, was among the first ones and published in June 1998. Its scope limits the application to automotive radar equipment.

The 76 GHz to 77 GHz automotive range radar technology is very versatile and can be used also for safety relevant applications e.g. non-road applications which are the subject for the present document.

The main benefits of using the 76 GHz to 77 GHz frequency band are lower weight, more precise measurement results (e.g. range and doppler resolution) and reduced box volumes for new equipment. Better velocity resolution will be achieved because of the very short wavelength and high range resolution due to high bandwidth in connection with a simplified technical design when using e.g. FMCW modulation. This motivates to use the frequency band for many types of applications for short range radar systems.

The new planned applications for short range radar for surveillance radars operating in the 76 GHz to 77 GHz band need to be evaluated with regard to their compatibility to the present 76 GHz to 77 GHz vehicle radars operating on the roads in many countries world-wide.

1 Scope

The present document describes the spectrum requirements, technical characteristics and application scenarios for ground based mobile and radio surveillance applications in the frequency range of 76 GHz to 77 GHz.

The present document provides a proposal for the introduction of the planned applications for surveillance radar for non - automotive ground based vehicle applications operating in the 76 GHz to 77 GHz band and defines characteristics and operation modes in order not to impair the operation of the existing automotive vehicle SRRs operating in the same frequency range as well as for applications in adjacent bands.

The present document excludes radar sensor for level and tank level probing [i.8].

The present document also analyses the current ECC decision ECC(02)01 [i.2] and proposes to revise the ECC framework for sharing the new intended surveillance radar application with the EN 301 091 [i.1] type equipment in same frequency band.

The present document includes in particular:

- market information;
- technical information;
- regulatory issues.

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 reference 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.

[i.1] ETSI EN 301 091 (parts 1 and 2): "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".

[i.2] ECC/DEC/(02)01: "ECC Decision of 15 March 2002 on the frequency bands to be designated for the coordinated introduction of Road Transport and Traffic Telematic Systems".

[i.3] SCI Verkehrs GmbH.

NOTE: See www.sci.de.

[i.4] YARDS book 2008.

[i.5] CEPT/ERC REC 70-03:"Relating to the Use of Short Range Devices (SRD)".

[i.6] Merill Ivan Skolnik, Radar Handbook.

NOTE: See ISBN 0-07-057908-3 at http://de.wikipedia.org/wiki/Spezial:ISBN-Suche/0070579083.

[i.7] Merill Ivan Skolnik, Introduction to Radar Systems 2nd Edition, McGraw-Hil, Inc 1980.

NOTE: See ISBN 0-07-288138-0 at http://de.wikipedia.org/wiki/Spezial:ISBN-Suche/0072881380.

[i.8] 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.9] VDMA report 2005.

[i.10] European Railway Agency.

NOTE: See www.era.europa.eu.

[i.11] CENELEC EN 50413: "Basic standard on measurement and calculation procedures for human exposure to electric, magnetic and electromagnetic fields (0 Hz - 300 GHz)".

[i.12] CENELEC EN 62311: "Assessment of electronic and electrical equipment related to human exposure restrictions for electromagnetic fields (0 Hz -300 GHz) (IEC 62311:2007, modified)".

[i.13] CENELEC EN 50371: "Generic standard to demonstrate the compliance of low power electronic and electrical apparatus with the basic restrictions related to human exposure to electromagnetic fields (10 MHz - 300 GHz) - General public".

[i.14] Council Recommendation 1999/519/EC of 12 July 1999 on the limitation of exposure of the general public to electromagnetic fields (0 Hz to 300 GHz).

[i.15] ISO 11898: "Road vehicles -- Controller area network (CAN)".

[i.16] div. deliverables from www.mosarim.eu; MOre Safety for All by Radar Interference Mitigation; European funded Project to study the interference between and from other applications to an automotive radar sensor.

- D1.7 - Estimation of interference risk from incumbent frequency users and services
- D2.2 - Generation of an interference susceptibility model for the different radar principles

[i.17] ECC Report 139: "Impact of level probing radars using ultra-wideband technology on radiocommunications services"; February 2010.

[i.18] Commission Decision of 30 June 2010 amending Decision 2006/771/EC on harmonisation of the radio spectrum for use by short-range devices.

[i.19] Directive 1999/5/EC of the European Parliament and of the Council of 9 March 1999 on radio equipment and telecommunications terminal equipment and the mutual recognition of their conformity.

3 Definitions, symbols and abbreviations

3.1 Definitions

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

antenna cycle: one complete sweep of a mechanically or electronically scanned antenna beam along a predefined spatial path

antenna scan duty factor: 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)

assigned frequency band: frequency band within which the device is authorized to operate

associated antenna: antenna and all its associated components which are designed as an indispensable part of the equipment

average time: time interval on which a mean measurement is integrated

blanking period: time period where no intentional emission occurs

duty cycle: ratio of the total on time of the "message" to the total off-time in any one hour period

dwell time: accumulated amount of transmission time of uninterrupted continuous transmission within a single given frequency channel and within one channel repetition interval

Equipment Under Test (EUT): radar sensor including the integrated antenna together with any external antenna components which affect or influence its performance

equivalent isotropically radiated power (e.i.r.p.): total power or power density transmitted, assuming an isotropic radiator

NOTE: e.i.r.p. is conventionally the product of "power or power density into the antenna" and "antenna gain". e.i.r.p. is used for both peak or average power and peak or average power density.

equivalent pulse power duration: duration of an ideal rectangular pulse which has the same content of energy compared with the pulse shape of the EUT with pulsed modulation or time gating

far field measurements: measurement distance should be a minimum of $2d^2/\lambda$, where d = largest dimension of the antenna aperture of the EUT and λ is the operating wavelength of the EUT

mean power: supplied from the antenna during an interval of time sufficiently long compared with the lowest frequency encountered in the modulation taken under normal operating conditions

NOTE: For pulsed systems the mean power is equal the peak envelope power multiplied by the time gating duty factor. For CW systems without further time gating the mean power is equal the transmission power without modulation.

on-off gating: methods of transmission with fixed or randomly quiescent period that is much larger than the PRF

operating frequency (operating centre frequency): nominal frequency at which equipment is operated

NOTE: Equipment may be able to operate at more than one operating frequency.

operating frequency range: range of operating frequencies over which the equipment can be adjusted through switching or reprogramming or oscillator tuning

NOTE 1: For pulsed or phase shifting systems without further carrier tuning the operating frequency range is fixed on a single carrier line.

NOTE 2: For analogue or discrete frequency modulated systems (FSK, FMCW) the operating frequency range covers the difference between minimum and maximum of all carrier frequencies on which the equipment can be adjusted.

peak envelope power: mean power (round mean square for sinusoidal carrier wave type) supplied from the antenna during one radio frequency cycle at the crest of the modulation envelope taken under normal operating conditions

Power Spectral Density (PSD): ratio of the amount of power to the used radio measurement bandwidth

NOTE: It is expressed in units of dBm/Hz or as a power in unit dBm with respect to the used bandwidth. In case of measurement with a spectrum analyser the measurement bandwidth is equal to the RBW.

Pulse Repetition Frequency (PRF): inverse of the Pulse Repetition Interval, averaged over a time sufficiently long as to cover all PRI variations

Pulse Repetition Interval (PRI): time between the rising edges of the transmitted (pulsed) output power

quiescent period: time instant where no emission occurs

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

spatial radiated power density: power per unit area normal to the direction of the electromagnetic wave propagation

NOTE: It is expressed in units of W/m^2.

spread spectrum modulation: modulation technique in which the energy of a transmitted signal is spread throughout a relatively large portion of the frequency spectrum

spurious emission: emission on a frequency or frequencies which are outside the necessary bandwidth and the level of which may be reduced without affecting the corresponding transmission of information

NOTE: Spurious emissions include harmonic emissions, parasitic emissions, intermodulation products and frequency conversion products, but exclude out-of-band emissions.

steerable antenna: directional antenna which can sweep its beam along a predefined spatial path

NOTE: Steering can be realized by mechanical, electronically or combined means. The antenna beamwidth may stay constant or change with the steering angle, dependent on the steering method.

3.2 Symbols

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

λ	wavelength
1/P	repetition rate of the modulation wave form
ac	alternating current
B	bandwidth
d	largest dimension of the antenna aperture
D	antenna scan duty factor
D_{fb}	distance between ferrite beads
dB	decibel
dBi	gain in decibels relative to an isotropic antenna
df	spectral distance between 2 lines with similar power levels
Δfmax	maximum frequency shift between any two frequency steps
Δfmin	minimum frequency shift between any two frequency steps
E	field strength
E_o	reference field strength
G	blank time period
P	period of time during in which one cycle of the modulation wave form is completed
P_a	mean power within the BW
P_L	power of an individual spectral line
P_{rad}	radiated power
R	distance
R_o	reference distance
τ	pulse width

T_c	chip period

3.3 Abbreviations

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

AC	Anti-Collision
ACC	Automotive Cruise Control
ADC	Analog Digital Converter
AIS	Automatic Identification System
ASIC	Application Specific Integrated Circuit
CAN	Controller Area Network
CEPT	Conference of Postal and Telecommunications Administrations
CW	Continuous Wave
DAC	Digital to Analog Converter
DC	Duty Cycle
e.i.r.p.	equivalent isotropically radiated power
ECC	Electronic Communications Committee
EMF	Electro Magnetic Field Limits (Human Exposure)
ERC	European Radio communication Committee
EUT	Equipment Under Test
FM	Frequency Modulation
FMCW	Frequency Modulated Continuous Wave
FSK	Frequency Shift Keying
IF	Intermediate Frequency
ISM	Industrial, Scientific and Medical
PLL	Phase Lock Loop
PRF	Pulse Repetition Frequency
PRI	Pulse Repetition Interval
PSD	Power Spectral Density
R&TTE	Radio and Telecommunications Terminal Equipment
RBW	Resolution Bandwidth
RCS	Radar Cross Section
RF	Radio Frequency
RTTT	Road Transport and Traffic Telematics
SiGe	Silicon Germanium
SRD	Short Range Device
SRR	Short Range Radar
UWB	Ultra WideBand
VCO	Voltage Controlled Oscillator
VDMA	Verbands Deutscher Maschinen- und Anlagenbau

4 User defined clause(s) from here onwards

The present 76 GHz to 77 GHz radar technology is the basis for the intended surveillance applications.

The broad range of applications however requires different antenna systems and operation modes tailored to the specific installations to achieve the intended performance.

To meet higher requirements on range and velocity resolution for a radar sensor, the frequency band 76 GHz to 77 GHz has been identified as an eligible choice for a new type of short range surveillance radars. According to the ERC/REC 70-03 [i.5], annex 5 this frequency band is allocated to vehicle and to infrastructure radar systems. The main benefits by using the 76 GHz to 77 GHz frequency band are lower weight and reduced size for new equipment. Better velocity resolution will be achieved because of the very short wavelength and high range resolution in connection with a simplified technical design e.g. FMCW modulation.

Depending on the antenna configurations and the installation position, the proposed surveillance radar can cover ranges up to 1 600 m. The range resolution can be down to approximately 0,2 m with a beam width of 1,5° in azimuth and 5° to 6° in elevation, depending on the antenna characteristics.

4.1 Surveillance radar applications and scenarios

There is a wide range of applications, which can be put into the following categories.

- Rail and general transportation.
- Construction vehicle, rubber tired gantry, portal gantries on wheels, ship-to-shore applications, reclaimers, lorry, machinery, agriculture.
- Unmanned vehicles, ground non-public transportation.
- Leisure vehicles, power sports.

More information can be found in clause A.2.

5 Market information

The main applications for non-automotive ground based vehicular applications are:

- Rail applications with a total number of locomotives, railcars and trams in the field amount to 400 000 (worldwide). Ca. 40 % of the worldwide market is in Europe, which means 160 000 (in EC). There are approximately 15 000 (world) and 6 000 (EC) new devices/year being deployed (source: SCI Verkehrs GmbH, www.sci.de [i.3]).
- Water/ship applications with a total number of professional/industrial ships in the field of: 100 000 (in EC) with approximately 500 to 1 000 new devices/year. (source: YARDS book 2008 [i.4]).
- Sensor applications in heavy vehicles with a total number of construction and agriculture devices in the field of: 37 000 000 (worldwide) and ca. 34 % in EC = 12,580 000 and with approximately 19 000 (worldwide) and 6 460 (EC) new devices/year. (source: VDMA report 2005 [i.9]).

These numbers lead to an estimation of a market size in EC of 250 000 surveillance sensor systems for non-automotive vehicles in 2033; see Figure 5.1 (with the assumption that in 10 years, each new vehicle application will implement such surveillance sensors).

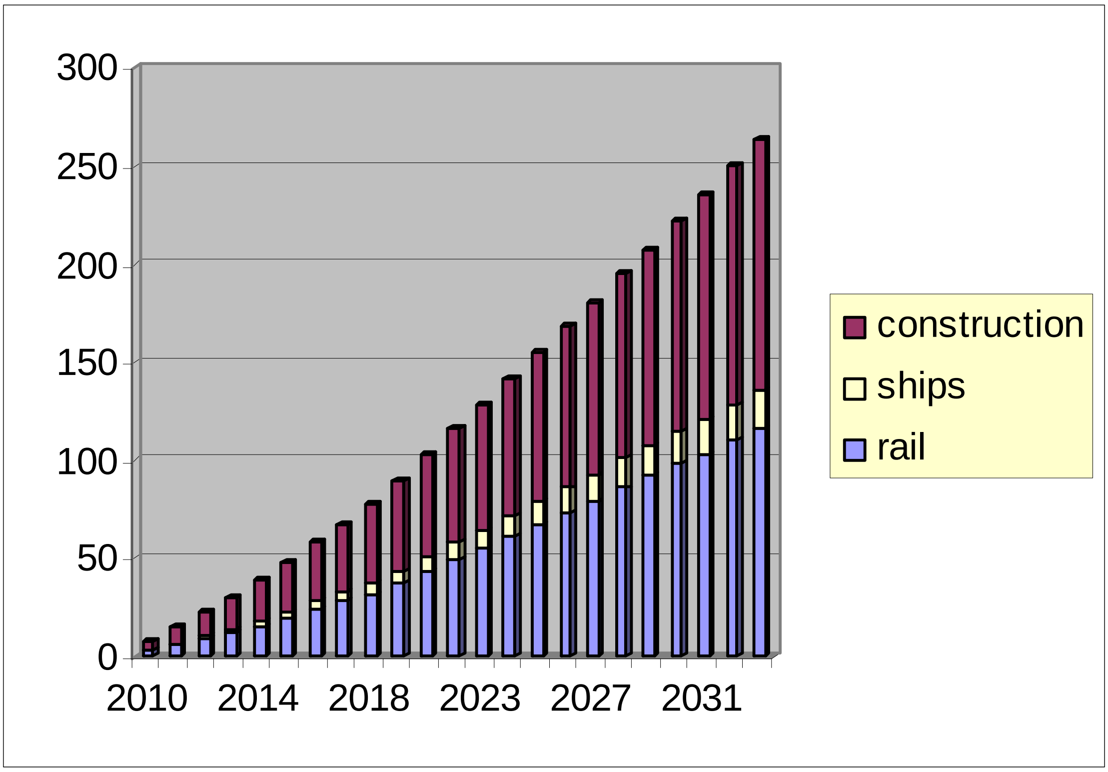


Figure 5.1: Total estimated number of thousands of vehicles (non-automotive) with surveillance radar sensor systems

6 Technical information

6.1 Detailed technical description

6.1.1 Systems overview

6.1.1.1 Vehicular sensor system overview

A systems overview and operational parameters with technical descriptions is given in Figure 6.1.1.1.1.

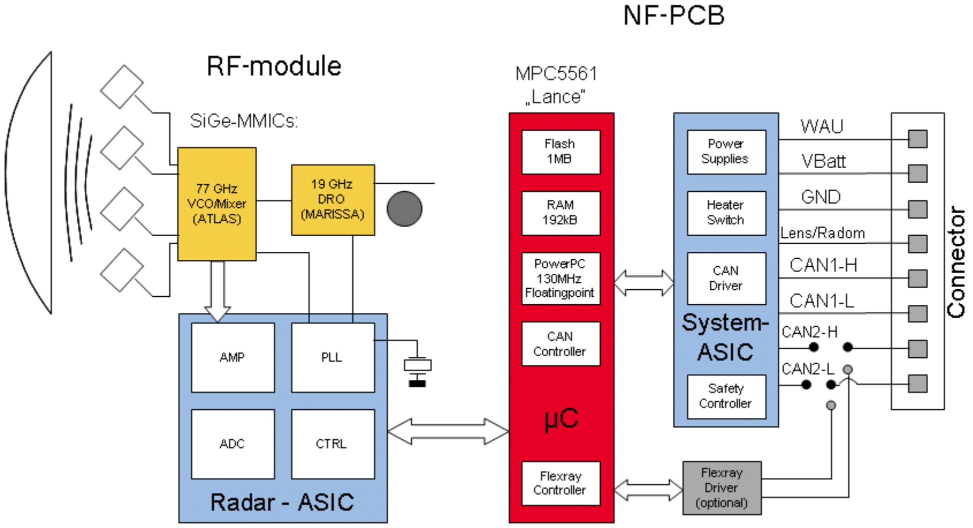


Figure 6.1.1.1.1: Top level diagram of a typical SRR for the applications

In normal installation, one sensor/per direction will be installed. The communication between sensor and the onboard units will be realized via CAN protocol.

A typical vehicular sensor may consist of:

- 76,5 GHz-millimetre wave front end with SiGe MMICs (VCO with four active mixers and reference oscillator with dielectric resonator);
- radar ASIC with 4 channel base band amplifier and DAC, Sigma-Delta ADC, triple PLL and control sequencer;
- system ASIC with switchable power supplies for the millimetre wave module, Radar ASIC and interfaces, physical CAN drivers acc. ISO 11898 [i.15], low side heater switch for lens or external radome and safety controller;
- housing with lens (opt. with heating structure), electrical car connector with integrated pressure compensation element.

6.1.2 Installation considerations

6.1.2.1 Ground based vehicular applications

The SRR should be delivered with an application-specific sensor bracket, which is used to attach the sensor to the mounting position in the vehicular or fixed application.

The points where the bracket is attached in its mounting position for a train, lorry, machinery, etc., can be selected carefully to ensure a very stable mounting of the sensor relatively to the vehicle longitudinal axis.

Please note that the bracket needs some space in the near surrounding of the sensor. The overall dimensions of the sensor with bracket have to be discussed together with the customer.

The sensor bracket also enables horizontal and vertical adjustment of the SRR radar beam to the vehicle longitudinal axis.

Mounting conditions are summarized in table 6.1.2.1.1.

Table 6.1.2.1.1: Mounting conditions

Mounting conditions	min. 2 fixing points on the vehicle
	no relative movement between the fixing points at the vehicle
	long-term stability between the fixing points and relative to the vehicle longitudinal axis

6.2 Technical parameters and implications on spectrum

6.2.1 Status of technical parameters

6.2.1.1 Current ITU and European Common Allocations

6.2.1.1.1 Current 76 GHz to 77 GHz automotive radar applications

The development of the automotive radar systems in the industry predates 1995, and the corresponding ETSI standard EN 301 091 [i.1] (V1.1.1) was published in 1998 and the latest amendment was published in November 2006 as version EN 301 091 [i.1] (V1.3.3). The application of the EN 301 091 [i.1] is restricted to equipment for road vehicles.

These applications include Automotive Cruise Control (ACC), Collision Warning (CW), Anti-collision (AC) systems, obstacle detection, Stop and Go, blind spot detection, parking aid, backup aid and other automotive applications.

There are two classes defined: class 1 (e.g. FM, CW or FSK) and class 2 (pulsed Doppler radar only). The difference between the two class numbers is the permitted average power level. EN 301 091 [i.1] covers integrated transceivers and separate transmit/receive modules.

The equipment is used with either fixed or steerable antennas; the latter can use either electronical or mechanical means. Integral antennas are to be used.

For fixed antennas, the class 1 allows up to 50 dBm mean power and 50 dBm peak power e.i.r.p. whereas class 2 permits up to 23,5 dBm mean power and 55 dBm peak power e.i.r.p. For steerable antennas, the power limits are:

Table 6.2.1.1.1.1: Limits for transmitted power (for steerable antenna only)

	Class 1		Class 2	
maximum antenna signal dwell time (see note 1)	t < 100 ms	t > 100 ms	t < 100 ms	t > 100 ms
Mean Power (e.i.r.p.) (see note 2)	55 dBm + 10 log(D) or 50 dBm (whichever is the smaller)	50 dBm	55 dBm + 10 log(D) or 23,5 dBm (whichever is the smaller)	23,5 dBm
Peak Power (e.i.r.p.)	55 dBm	55 dBm	55 dBm	55 dBm
NOTE 1: t is the largest dwell time at any angle. NOTE 2: D is the ratio of the area of the beam (measured at its 3 dB points) to the total area scanned by the antenna. The power is averaged across one antenna cycle. As D is smaller than 1 (i.e. 100 %), the log (D) value is negative and leads to a reduction of the 55 dBm value.				

These automotive radar systems reference the ERC/REC 70-03 [i.5] for SRDs annex 5 and ECC/DEC/(02)01 [i.2].

6.2.1.2 Sharing and compatibility issues still to be considered

Particular attention needs to be given to restrict the application in the 76 GHz to 77 GHz to surveillance ground based vehicular radar applications and not allow applications for installations to fixed sites or certain mobile installations in order to ensure compatibility. In addition, future UWB SRR systems in the adjacent band 77 GHz to 81 GHz have to be protected as result of the compatibility studies. The most critical potential interference aspect for general surveillance radar applications is that this kind of application may overlap in the direction of automotive SRRs on public roads. In such scenarios, the surveillance radars potentially blind automotive radars operating in the same frequency and area [i.16].

Most of the proposed ground based vehicular surveillance radar applications are in addition safety related and can prevent damage and harm to human beings. Coexistence with the explained ground based vehicular surveillance systems likewise noted in this document may possibly be solved in a similar way implemented in automotive radar sensors. Studies are ongoing in a European funded project called "MOSARIM" to be finalized end of 2012 [i.16]

The new planned applications for surveillance radars operating in the 76 GHz to 77 GHz band need to be evaluated with regard to their compatibility to systems in shared and adjacent bands. In particular, the present 76 GHz to 77 GHz vehicle radars operating on the roads in many countries world-wide as well as future SRR-applications in the adjacent band 77 GHz to 81 GHz.

There is also a need to investigate the compatibility of the automotive radar system within the 76 GHz to 77 GHz band with reference to the defined types of different scenarios for the surveillance application and define appropriate installation guides.

Therefore the only new consequence that might occur is an interference situation between the automotive radar application and the proposed new surveillance application. Depending on what type of scenario, the amount of interference will vary but the basic will be the mitigation techniques between automotive radar systems.

Typical sensor parameters for non automotive surveillance applications are given in table 6.2.1.2.1.

Table 6.2.1.2.1: Typical sensor parameters for non-automotive surveillance applications

Parameter	Application	
Frequency band	76 GHz to 77 GHz / no channelling	
Transmitter output power	0 dBm	
Antenna gain	30 dBi	
Modulation	FMCW, DC 35 %	
Instrumented range/Distance	0,5 m … 250 m Accuracy: 0,1 m	
Range resolution	0,5 m	
Relative speed measurement	-75 m/s … +60 m/s Accuracy: 0,12 m/s	
Horizontal opening angle (Azimuth)	30° (-6 dB)	
Vertical opening angle (Elevation)	5° (-6 dB)	
Operation temperature	-40 °C …+85 °C	
Power consumption / sensor	4 W	
Interfaces	Vehicle system depended	
Additional remarks	Multi beam technique	
Targets	Typical objects to detect are human beings, vehicles, and with typical radar cross sections within 1 m^2 to 100 m^2	

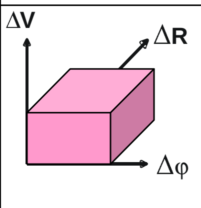
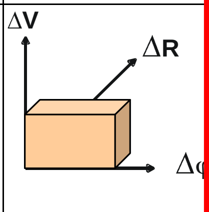
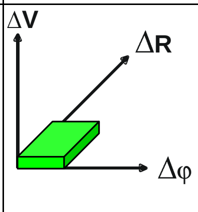
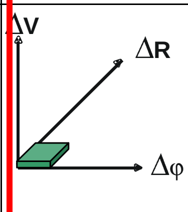
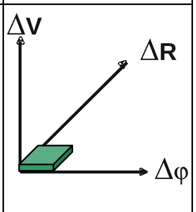
6.3 Information on relevant standard(s)

For the deployment of surveillance radars, a future regulation and Harmonized standard in the 76 GHz to 77 GHz band should make sure that surveillance radars coexist with automotive radars in the same frequency range. A future ETSI Harmonized Standard for surveillance applications will contain mandatory mitigation techniques.

7 Radio spectrum request and justification

Table 7.1 gives a comparison of other radar allocations and the proposed applications.

Table 7.1: Radar performance overview and evolution of systems (automotive and non-automotive allocations)

Frequency range (see note 1)	**Narrowband 24 GHz**	**24 GHz/26 GHz UWB**	**76 GHz**	**79 GHz**	**122 GHz ISM**
Sensor **performance for proposed applications** (summary of all three parameters / resolutions) (see notes 2, 3 and 4)	0	+	++	+++	+++
ΔV: Velocity Axis Δφ: Angle Axis ΔR: Range Axis					
Bandwidth	200 MHz	> 2 GHz	1 GHz	4 GHz	1 GHz
Regulated output power	++	0	++	+	
Radar Cross Section influence (cooperative contribution)	+	+	++	++	+++
Technology available	++	++	++	++	+ technology 0 for sensor realization

NOTE 1: Other frequency ranges below 24 GHz were not taken into account, because of possible/reachable sensor performance for the proposed applications.
NOTE 2: The smaller the cubic, the better the radar performance.
NOTE 3: Doppler resolution of object distance is RF frequency dependent, Higher RF frequency enables better Doppler resolution.
NOTE 4: For a given aperture, the resolution increases with frequency. Angular resolution is directly related to antenna aperture.

So based on actual information in table 7.1 and [i.6], [i.7], it is possible to conclude in general for all applications in the present document that:

- 76 GHz to 77 GHz sensors have a factor 3 to 5 times better object separation by distance compared to 24 GHz narrow band solutions due to higher useable bandwidth of 1000 MHz vs. typical available bandwidth of 200 MHz for 24 GHz narrow band sensors.
- 76 GHz to 77 GHz sensors have a factor 3 times better accuracy in measurement of relative velocity compared to 200 MHz narrowband solutions due to better Doppler resolution at higher carrier frequency.
- 76 GHz to 77 GHz sensors have a factor 1/3 smaller size of antenna structure compared to 24 GHz solutions at equal field of view (opening angle/detection range) due to necessary antenna aperture size.
- With higher frequencies it is possible to use the better RCS factor of a target/object.

With e.g. $RCS = \frac{4 * \pi * a^4}{3 * \lambda^2}$;

and a = dimension of the target/object, in this case radar corner reflector + $\lambda = \frac{c_0}{f}$.

- The power level is sufficient to reach the application requirements in the max. measurable object distance under actual regulatory framework. The possible power in the actual broader (frequency range) 24,25 GHz to 26,65 GHz and 77 GHz to 81 GHz UWB regulations is not sufficient.
- 76 GHz to 77 GHz sensors are, from the performance point of view, very close also to possible radar sensors in 122 GHz to 123 GHz ISM band. The reason in this case is for the 76 GHz to 77 GHz.
  - Hardware solution/realization: 76 GHz to 77 GHz is state of the art and not as cost sensitive than the higher 122 GHz range. In the 122 GHz range, there are a lot of mechanical problems.
  - The power problem: The additional advantage is the higher free space attenuation and the max. possible power on actual realizable systems on chip solutions in the 122 GHz range.

More technical background information is available in [i.6] and [i.7].

8 Regulations and standardization

8.1 Current regulations

Actual the current regulation ERC/REC 70-03 [i.5] and ECC/DEC (02)01 [i.2] is under revision.

The proposed new annex 5 of ERC/REC 70-03 and the plan to withdrawn ECCC/DEC (02)01 is overlapping with the work in ETSI.

Proposed new ERC/REC 70-03 [i.5], annex 5:

Scope of Annex

This annex covers frequency bands and regulatory as well as informative parameters recommended for Road Transport and Traffic Telematics (RTTT) including radar system installations to be ***used in ground based vehicles***.

d	76-77 GHz	55 dBm peak e.i.r.p.	No requirement	No spacing	ECC/DEC/(02) 01	50 dBm average power - 23.5 dBm average power for pulse radar only for Vehicle radars

Commission Decision of 30 June 2010 amending Decision 2006/771/EC [i.18] on harmonisation of the radio spectrum for use by short-range devices.

8.2 Proposed regulation and justification

8.2.1 CEPT/ERC REC 70-03

Implement the proposed changes in ERC/REC 70-03 [i.5], annex 5.

ETSI will support the withdrawal of ECC/DEC (02)01 [i.2], providing the new annex 5 of the ERC/REC 70-03 [i.5] is implemented.

ETSI will not support to change or amend annex 6 of ERC/REC 70-03; "Radiolocation Applications" ETSI has the view that additional fixed radar applications close to roadside will increase the interference potential for automotive applications very dramatic, see clause 8.2.5 and [i.16].

Harmonized Standards (see clause 8, expected ETSI actions).

- EN 301 091 [i.1].

8.2.2 proposed ETSI actions

ETSI intends to amend the Harmonized Standard EN 301 091 [i.1] for the proposed new ground based vehicular surveillance application.

A common Harmonized Standard which incorporates all ground based vehicle applications will make it easier and effective for new safety related applications to be implemented. This will also increase the total amount of 76 GHz systems. This increases the volume and thus enabling manufacturers to provide lower price for the customer. This will be an incentive to invest in security systems even for less imperative reasons.

8.2.3 Other

ECC/DEC/(02)01 [i.2] specifies the 76 GHz to 77 GHz band for RTTT applications as vehicular and infrastructure radar. Based on the planned revision of ERC/REC 70-03 [i.5], annex 5 and the implementation in the ECC member countries ETSI can support the actual ECC plan to withdraw the ECC/DEC(02)01 [i.2]. In addition and based on the results from MOSARIM [i.16] (see chapter 8.2.4), the outcome of the ECC studies for level probing radars [i.17] and the importance of the radar technology for the EC safety strategy for the automotive industry (e.g. EC law in 2012 for emergency brake systems for lorries; ETSI is not proposing any kind of generic or fixed outdoor surveillance radar applications in the frequency range 76 GHz to 77 GHz.

8.2.4 EMF limits

Based on the limits for the human exposure [i.14] and the relevant measurements [i.11], [i.12] and [i.13] following technical context has to be taken into account.

The human exposure limit is given a power density with 10 W/m² or 40 dBm/m² (over an averaging time of 6 min).

With some technical combinations it could be possible that with the proposed regulation this human exposure limit can be reached in a distance r from the sensor.

The power density of a radiated signal is given in a distance r with:

$$S = \frac{P_{ei}}{4\pi \cdot r^2} \; [\frac{W}{m^2}]$$

And in addition with:

$$P_{ei}[W] = e.i.r.p[W] \cdot d_i = P_{t0}[W] \cdot g_i$$

And:

Pei: radiated power.

e.i.r.p.: equivalent isotropic radiated power.

d: sensor antenna directivity.

P_{t0}: antenna feeding point power / transmitter output power.

The minimum protection distance for a human versus the radar sensor can be calculated with:

$$r = \sqrt{\frac{P_{t0} \cdot g_i}{S \cdot 4\pi}} = \sqrt{\frac{e.i.r.p \cdot d_i}{S \cdot 4\pi}}$$

In addition following points has to be also taken into account:

- Averaging time of 6 min for the human exposure.

- The sensor scenario and the point if it is possible that a human can be closer than the protection distance at the sensor and longer than 6 min.

As an example: With the values from clause for a mobile sensor (Table 6.2.1.2.1).

P_{to}: 0dBm and an antenna gain of 30 dBi

→: the minimum protection distance for a human is r 0,09 m

8.2.5 Potential interference from fixed applications to automotive radar

The first interference results from simulation studies in the MOSARIM project [i.16].

8.2.5.1 Simulation Scenario

The first results were based on following scenario (Figure 8.2.5.1.1).

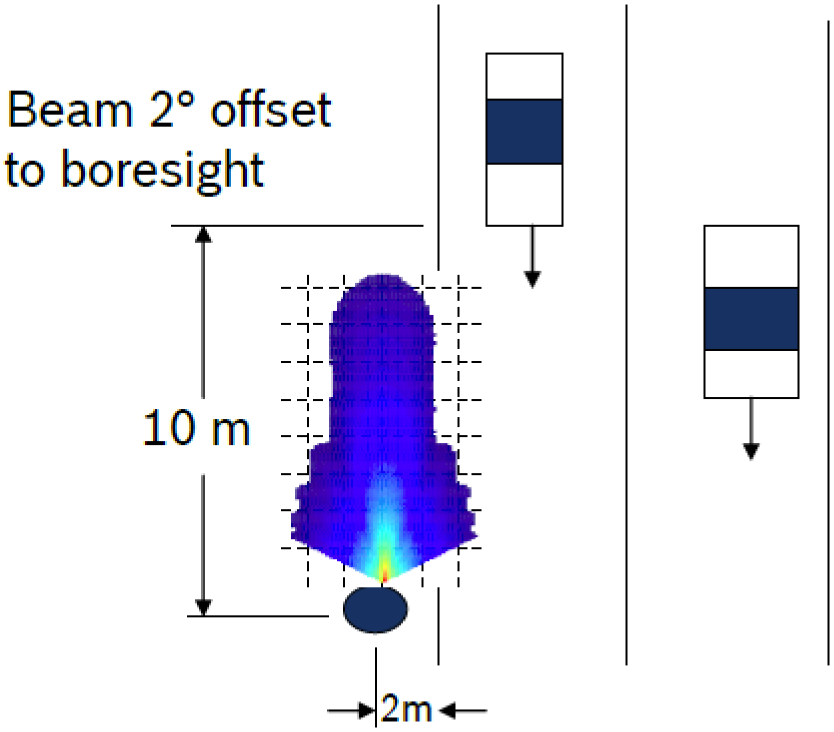


Figure 8.2.5.1.1: Interference scenario "fixed radar close to road" versus automotive radar

Interferer: "fixed outdoor" / "traffic monitoring system"

- Center frequency: 76,5 GHz, transmit power: 45 dBm e.i.r.p.
- Antenna: Beam width: ±1° (azimuth and elevation)
- 1st sidelobe attenuation: 20 dB
- Interferer positioning "automotive radar":
  - 2° with respect to driving lane, (see Figure 8.2.5.2.1, for 1° see Figure 8.2.5.2.2)
  - 2 m besides driving line, 10 m in front of car
  - Height: 1 m above driving lane

Victim

- Forward looking radar, receiver with 10 dB noise figure
- Antenna: beam with 14° azimuth / 5° elevation, 1st side lobe at: 20 dBc
- 17 dBi gain
- Mounting: 0,5 m above driving lane

Environment

- Width of driving lane 7 m (= 2 x 3,5 m), material: Asphalt
- Without guardrails

8.2.5.2 First Results

The first interference simulations results are shown in Figures 8.2 and 8.3.

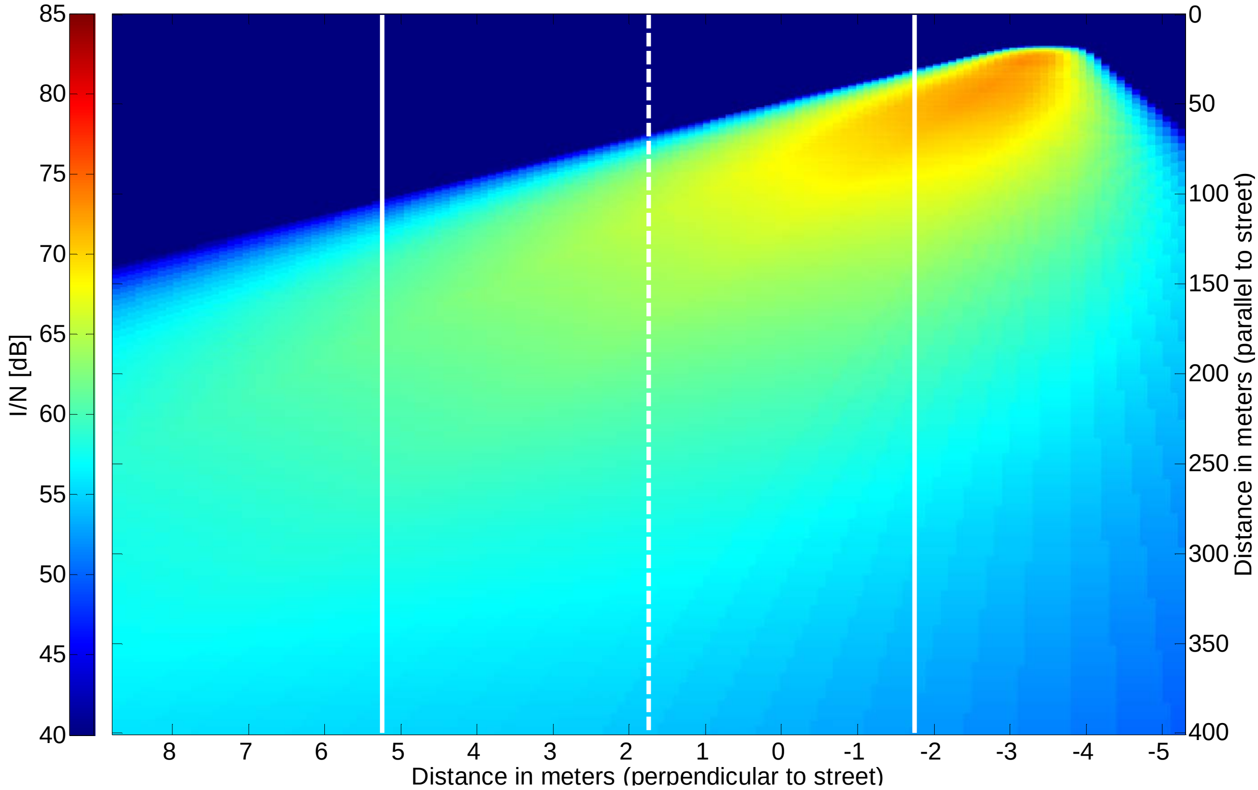


Figure 8.2.5.2.1: Simulation results for a scenario described in Figure 8.2.5.1.1, with interference 2° respect to driving lane

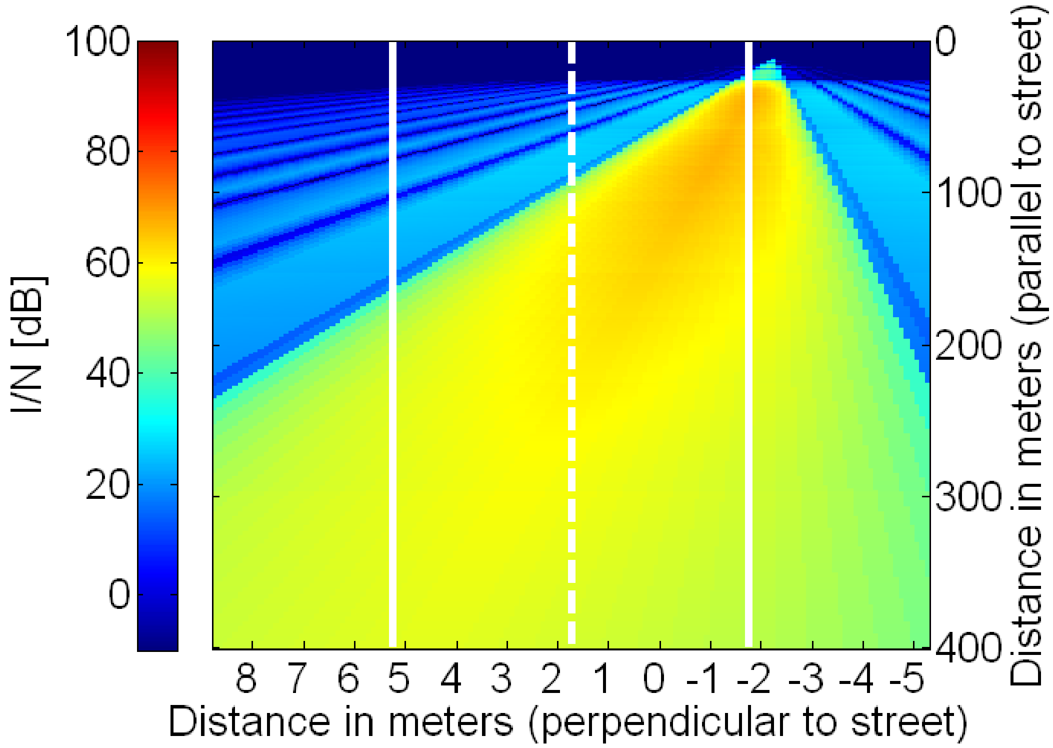


Figure 8.2.5.2.2: Simulation results for a scenario described in Figure 8.2.5.1.1, with interference 1° respect to driving lane

Summary of simulation results:

- Simulation results show a significant interference potential from fixed 76 GHz to 77 GHz installations to automotive radar sensors operating in the same band.
- A possible interference power with +45 dBm e.i.r.p. is up to 75 dB above the noise floor of the 76 GHz to 77 GHz automotive radar sensor. Such a strong interference cannot be mitigated in the radar sensor.
- In contrast, interference between different automotive radar sensors and / or other ground based vehicle applications can be mitigated by interference mitigation effects (e.g. antenna polarization,…). These mitigation techniques can be mandated in the related ETSI standards for ground based vehicle applications. First possible and realizable mitigations techniques are described in [i.16].

Annex A: Detailed application information

A.1 Overview of categories for surveillance radar applications

Figure A.1.1 shows the groups of ground-based vehicular applications, namely:

- rail and general transportation; including rail-based gantries at industrial sights;
- construction vehicles lorry, machinery, agriculture;
- sea port, and other freight on/off-loading vehicles, e.g. wheel based gantries or fork lifts;
- maritime and ship to shore;
- leisure vehicles, power sports;
- and unmanned vehicles, ground transportation automatic emergency brake.

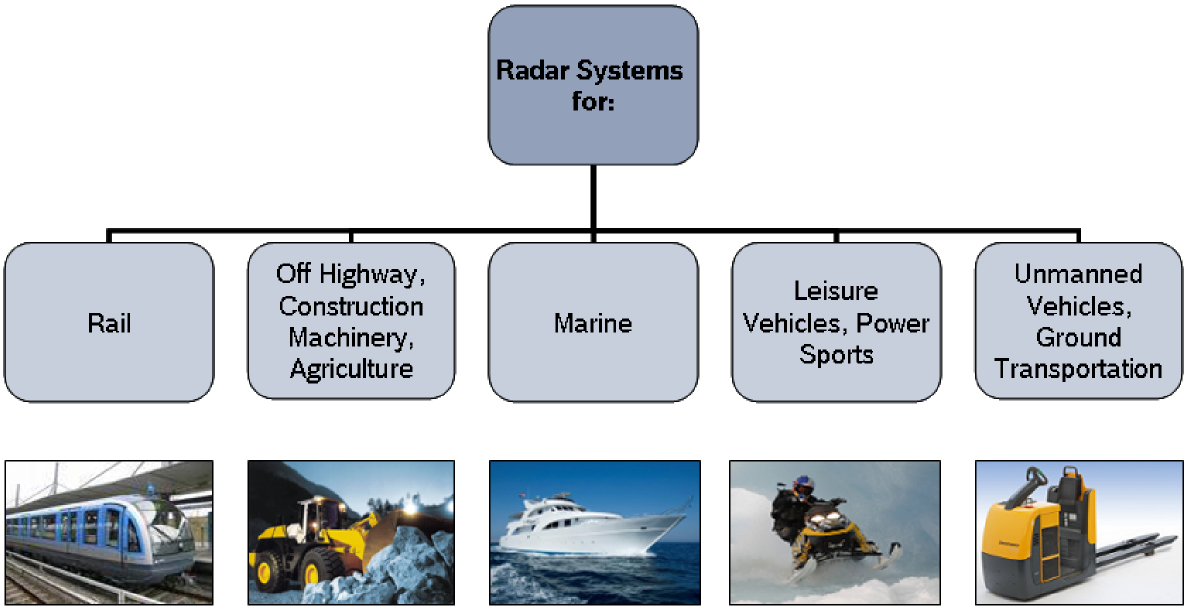
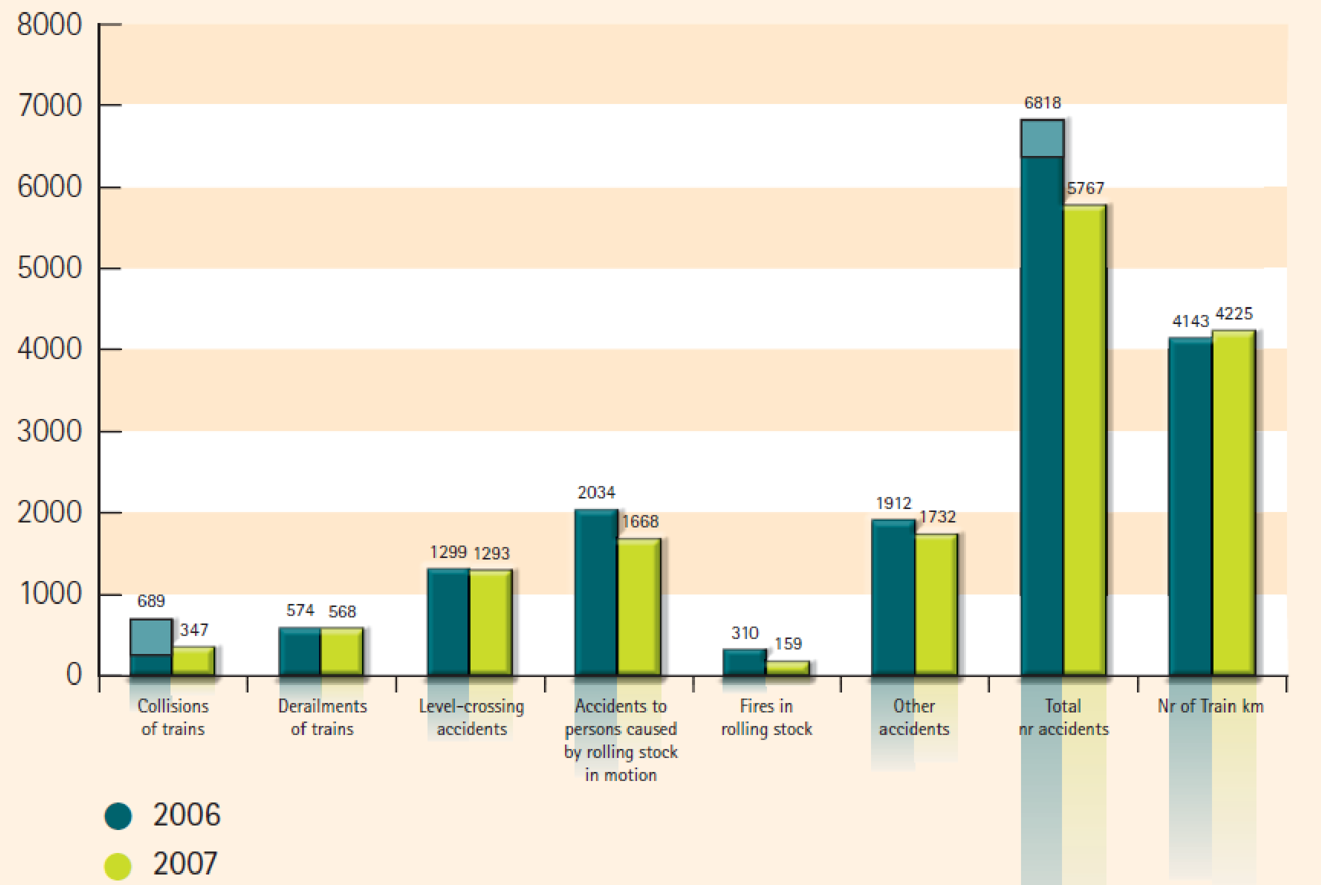


Figure A.1.1: Overview of ground-based vehicular applications

A.1.1 Rail and general transportation

A.1.1.1 Background information and motivation

The main reason to use such radar sensors is to decrease the number of accidents in the area of "rail" applications. The number of accidents with trains in Europe in the years 2006 and 2007 is shown in Figure A.1.1.1.2.



NOTE: Source: European Railway Agency, www.era.europa.eu [i.10].

Figure A.1.1.1.1: Number of accidents with trains in Europe in the years 2006 and 2007

Figure A.1.1.1.2 shows some situations in the public area of accidents between trams and other traffic participants (persons, cars, other trams, etc.).

Figure A.1.1.1.2: Typical cases of accidents involving with trains or trams with road vehicles

In the area of train applications, the accidents of Figure A.1.1.1.2 and other possible situations lead to the following applications or usage scenarios if no sensors are employed.

Safety application: Track clearance for trains and trams, see Figures A.1.1.1.2 to A.1.1.1.8.

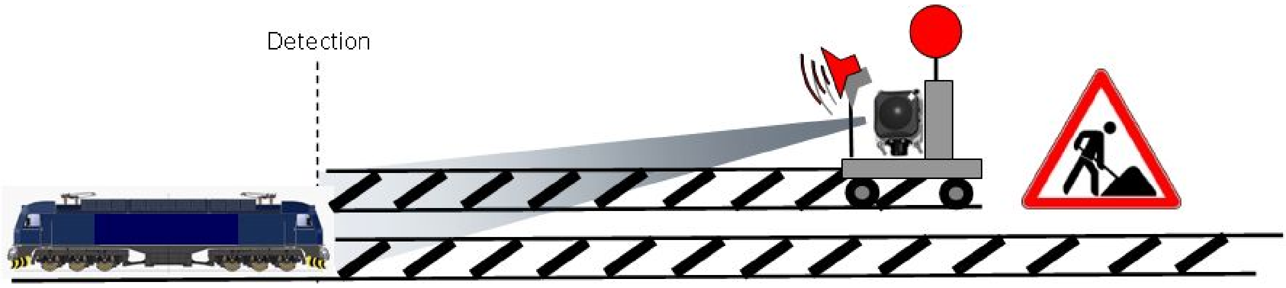


Figure A.1.1.1.3: Sensor applications for track clearance

The main goal of this application is to increase the safety in the train and tram environment, e.g.:

- if trams or trains approach stations (detect person at crossings, official track transitions or if people waiting are too close to the tracks);
- if trams approach the road or rail (train) crossings;
- or clearance status of own tracks, e.g.:
  - potential suicide detection and prevention or persons attempting to cross the tracks at forbidden transitions;
  - construction site safeguard/increase of the safety of constructions in the track areas or in the track environment.

The problem here is that based on the simultaneous workflow and the ongoing traffic, often critical situations are developed, see Figures A.1.1.1.4 and A.1.1.1.5.

Figure A.1.1.1.4: Typical track area work situation

- Or avoid accidents between railway equipment in heavy traffic situations.
- Or collision avoidance between railway equipment and infrastructure (e.g. on a ferry), see Figure A.1.1.1.5.

Figure A.1.1.1.5: Collision avoidance locomotive or wagon to crash element e.g. on a ferry

An additional benefit of surveillance sensors in train or trams applications is increase of track efficiency by reducing the distance between the trains (more tram throughput or traffic on the same track).

In train platooning (see Figure A.1.1.1.6), this application will then also allow independent speed termination.

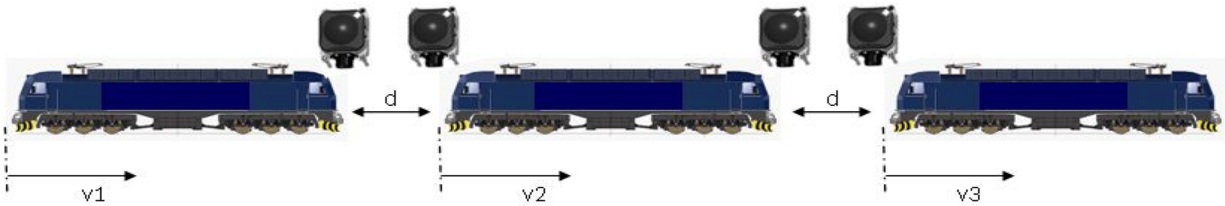
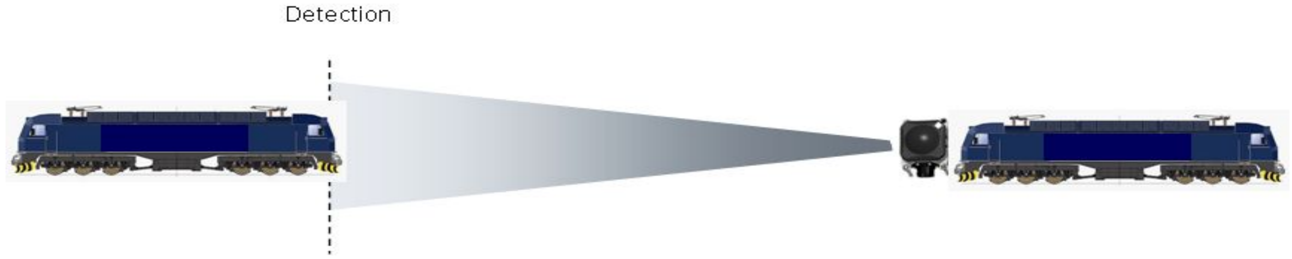


Figure A.1.1.1.6: Phases of track free detection, example for 2 locomotives and platooning

The track free application can be split into the three phases shown in Figure A.1.1.1.7.

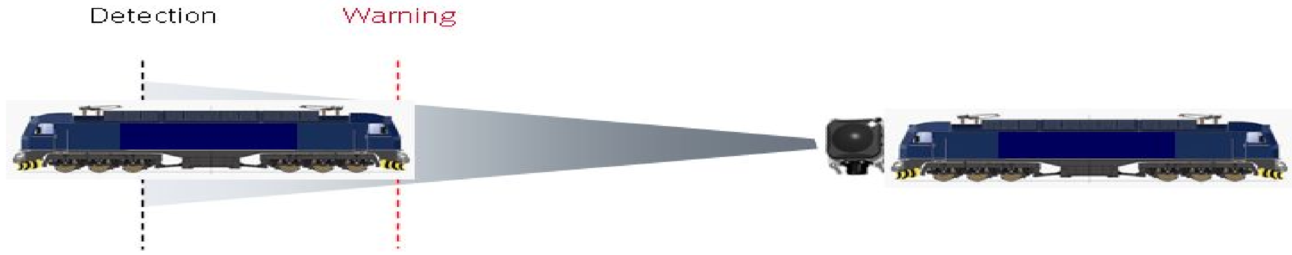
Phase 1:

- safe drive-off after emergency-brakes and stops;
- increase safety for unmanned and automatically run trains and trams.



Phase 2:

- acoustic or optical warning by time to collision less than default.



Phase 3:

- avoid collisions in low speed range;
- accident mitigation by reducing velocity and kinetic energy.

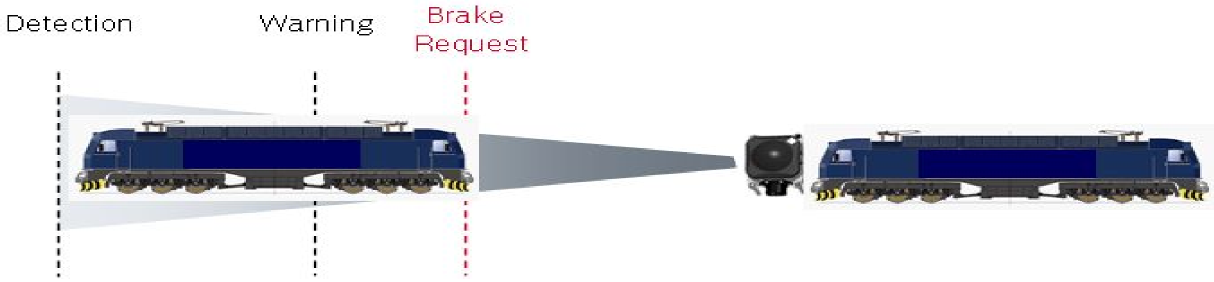


Figure A.1.1.1.7: Phases of track free detection, example for 2 locomotives and platooning

The track free application allows, as an additional benefit, a coupling assistance function for freight cars, see Figure A.1.1.1.8, which:

- reduces the kinetic energy of the freight car before the coupling process;
- protects workers in the coupling process;
- reduces the risk for transportation of hazardous goods.

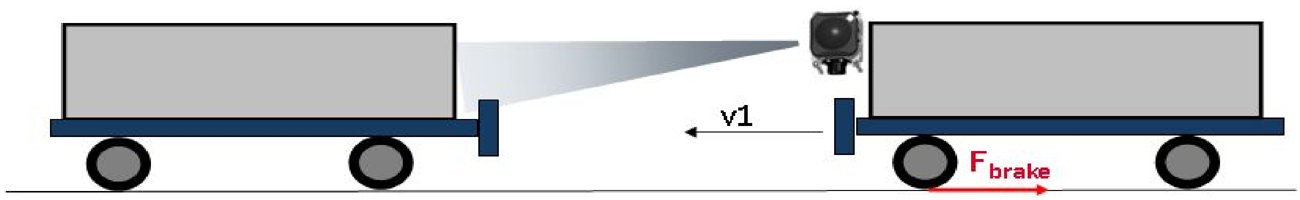


Figure A.1.1.1.8: Coupling assistance for freight cars

A.1.1.2 Typical usage time and travel evaluation of such railway device

In public transportation/tram, the typical average usage time of a tram is 15 hours. During this time a tram is typically 3 hours in a station, therefore a tram is travelling 12 hours/day. This leads to an activity of a surveillance sensor/day in a tram of maximum 12 hours (the sensor is only active if the tram is travelling).

Typically a tram has the possibility to travel in two directions. It is estimated that only the sensor in the travel direction is active for typically 6 hours activity/day = 25 % activity/day. The typical average speed of such tram is 15 m/s.

For railway, in general:

- only the sensor in the travel direction is active;
- there is one sensor per direction;
- the average travel speed is between 50 km/h to 150 km/h;
- the sensor is inactive if the travel speed is v = 0 m/s, which occurs on average 1,5 hours/day;
- for an average usage time of 18 hours/day, the active sensor time is 16,5 hours/day. Thus, each sensor is active for 8,25 hours/day (with an estimation of 50 % travel in each direction), the activity/day is 34 %.

A.1.2 Construction, lorry, machinery and agriculture devices

Under this subcategory, the following vehicles can be seen:

1) construction vehicles;
2) mining and land mover vehicles as in Figures A.1.2.1, A.2.2.2 and A.1.2.3;
3) farming vehicles see Figures A.1.2.4 and A.1.2.5;
4) sea port, and other freight on/off-loading vehicles, Figure A.1.2.6.

Figure A.1.2.1: Mining vehicles

Figure A.1.2.2: Mining vehicles

Figure A.1.2.3: Land mover vehicles

Figure A.1.2.4: Harvester Combines

Figure A.1.2.5: Farming vehicles

Figure A.1.2.6: Freight on/off load vehicle

A.1.2.1 Application examples: safety applications and performance improvement

Some examples of safety applications and performance improvement for these devices are:

- track clearance detection;
- construction site safeguard;
- automatic and/or optimization of positioning;
- (semi) autonomous driving, see Figure A.1.2.1.1.

Figure A.1.2.1.1: Off- Highway construction

A.1.2.2 Justification

Pedestrian traffic and small vehicle use may be high in these areas. Working pedestrians are typically focused on performing tasks and can easily be diverted from awareness of a dangerous situational. In addition, hazardous objects or valuable equipment may be located at unexpected places in the working environment since clearly defined roadways in non-public areas often do not exist.

Increased safety is the most important result of using these surveillance radar devices to help to avoid collisions, damage, injury and death. Table A.1.2.2.1 summarizes accident relevant statements with corresponding weblinks.

Table A.1.2.2.1: Accident relevant statements with sources

Statement	Source
"… half the fatalities involving construction equipment occur while the equipment is backing."	http://www.cdc.gov/niosh/mining/pubs/pdfs/edpce.pdf
"… between 1986 and 1996 nearly 5 000 people (pre-sumably in the U.K.) were killed or injured as a result of being struck by moving vehicles. Twenty-five percent of these accidents occurred while the vehicle was reversing."	http://www.nonoise.org/resource/construc/construc.htm
"Between 1990 and 1998, there were 133 accidents involving 23 fatalities as a result of collisions of off-highway trucks with other objects-vehicles, or people in open-pit mines. In 1998 alone, 13 fatalities occurred in metal/non-metal and open-pit coal mines when off- highway trucks ran over smaller vehicles or people not visible to the truck operator."	https://filebox.vt.edu/users/anieto/web/
"Over 40 % - nearly half - of the fatalities for roadway construction workers occur when workers are run over or struck by moving vehicles, trucks, or equipment. Over half of the fatalities are caused by construction vehicles and equipment in the work area."	http://www.betterroads.com/
"Vehicles and mobile heavy equipment caused 213 deaths on construction sites out of 1,228 construction deaths (17,3 % in 1999). Trucks were involved in 39 % of the deaths, mobile heavy equipment in 37 %, and forklifts in 7 %."	http://www.cdc.gov/elcosh/docs/d0100/d000038/pdfs/page%2039.pdf

A.1.2.3 Traffic evaluation

By far the most prevalent use of sensors is for vehicles in reverse motion. This is when the drivers of these large vehicles suffer the most significant visual impairment. This is also the most vulnerable situation for pedestrians in the vicinity of these vehicles who may not be focused on observing the vehicle and thus may not expect the change in vehicle direction.

The use or on-time of these sensors while the vehicle is in normal motion allows an activity factor which may be numerically estimated as follows:

- A typical operational vehicle is assumed to be moving in front motion on average approximately 80 % of the time the vehicle is actually in motion.
- Observations at industrial work sites also reveal that the typical industrial vehicle is idle (standing still, no motion) a great deal of the time. Therefore a typical operational vehicle is assumed to be actually in motion about 40 % of the total time the vehicle is in use.
  - This gives an effective in-use activity factor of 0,4 × 0,8 = 0,32.
  - The in-use activity factor is ≈ 32 %.
- Additionally, a typical industrial vehicle may be assumed to be operational for about 8 hours to 10 hours per working day.
  - This gives an additional daily operational factor of about 0,33 to 0,42.
  - The daily activity factor is ≈ 11 % to 13 % over 24 hours.
  - The normal motion average activity factor is ≈ 13 %.

The use or on-time of these sensors while the vehicle is in reverse motion allows a low effective activity factor which may be numerically estimated as follows:

- A typical operational vehicle is assumed to be moving in reverse motion on average approximately 20 % of the time the vehicle is actually in motion.
- Observations at industrial work sites also reveal that the typical industrial vehicle is idle (standing still, no motion) a great deal of the time. Therefore a typical operational vehicle is assumed to be actually in motion about 40 % of the total time the vehicle is in use.
  - This gives an effective in-use activity factor of 0,4 × 0,2 = 0,08.

- In Use Activity Factor ≈ 8 %.

- Additionally, a typical industrial vehicle may be assumed to be operational for about 8 hours to 10 hours per working day.
  - This gives an additional daily operational factor of about 0,33 to 0,42.
  - The Net Daily Activity Factor ≈ 2,6 % to 3,3 % over 24 hours.
  - The reverse motion average activity factor of ≈ 3,2 %.

If both possible directions are taken into account: such device will transmit with an activity factor of ≈ 16 %.

The likely modes of deployment and activity factors of such applications in this clause can be summarized as follows:

- The user devices will be limited to non-automotive industrial vehicle use and will operate in non-public areas. As a result, the expected total number of object detection devices in any localized area will be low. The worst-case numbers of active devices used in previous compatibility studies for automotive devices will never be approached by this kind of systems.
- The distance to public victim receivers is typically much larger due to the remote locations of typical industrial vehicle sites. Therefore interference is unlikely to occur.

A.1.3 Marine, coastal and harbour supervision

Some examples are:

- automation and/or optimization of positioning, see Figure A.1.3.1;
- platooning;
- lock procedure (to speed up the lock procedure with the additional feature: anti collision avoidance), see Figure A.1.3.2;
- front blind spot detection (to protect private/non-metallic ships), collision avoidance.

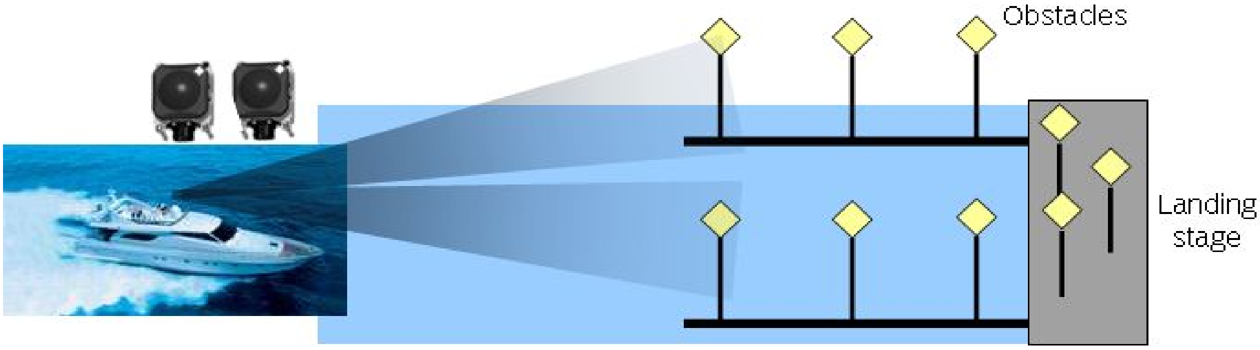


Figure A.1.3.1: Coastal, harbour supervision examples

Figure A.1.3.2: Lock examples

A.1.4 Unmanned vehicles, ground transportation and automatic emergency brake

Examples of safety applications are:

- automatic emergency brake;
- track free detection;
- coupling assistance;
- collision warning.

Examples of performance improvement are:

- automation and/or optimization of positioning;
- platooning applications.

Figure A.1.4.1: Load manoeuvring

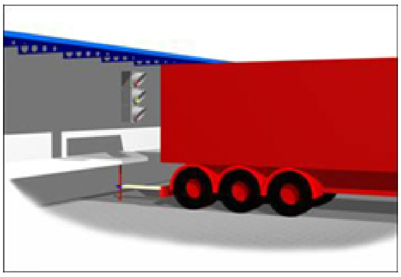


Figure A.1.4.2: Approach lorries to loading ramps

A.1.4.1 Traffic evaluation

For such devices, the estimated usage activity factor is comparable with construction, lorry, machinery and agriculture devices, see clause A.1.1.2.

In the normal travel direction, the activity factor is ≈ 13 %.

In the reverse travel direction, the activity factor is ≈ 3 %.

A.2 Conclusion

Performance

Most recent technologies and innovative algorithms introduced into the sensor allow the integration into safety systems and offer:

- robustness;
- precise measurement even in harsh environment (e.g. dust, fog, vapour);
- reliability;
- standardized manufacturing processes and the selection of fully automotive qualified components and suppliers;
- guaranteed robust and reliable sensor are ready for high volume production.

Annex B: Detailed market information

Detailed market information is available:

- for railway applications under: www.sci.de.
- for the construction equipment: www.vdma.org.

Annex C: Bibliography

- Commission Decision 2004/545/EC of 8 July 2004 on the harmonisation of radio spectrum in the 79 GHz range for the use of automotive short-range radar equipment in the Community.
- EC SPEECH/02/181: "Towards a comprehensive eSafety Action Plan for improving road safety in Europe", High level meeting on Safety Brussels 25 April 2002, Erkki Liikanen.
- ETSI EN 302 288-1 (V1.4.1): "Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices; Road Transport and Traffic Telematics (RTTT); Short range radar equipment operating in the 24 GHz range; Part 1: Technical requirements and methods of measurement".
- ETSI TR 101 982: "Electromagnetic compatibility and Radio spectrum Matters (ERM); Radio equipment to be used in the 24 GHz band; System Reference Document for automotive collision warning Short Range Radar".
- Choose ESC, Choose Life.

NOTE: See http://ec.europa.eu/information_society/activities/esafety/doc/2008/choose_esc_speech_vr.pdf.

- CEPT/ERC Report 25: "European Common Allocation Table (ECA)".
- ETSI TR 102 664: "Electromagnetic compatibility and Radio spectrum Matters (ERM); Road Transport and Traffic Telematics (RTTT); Short range radar to be used in the 24 GHz to 27,5 GHz band; System Reference document".

History

Document history		
V1.1.1	December 2010	Publication
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