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Technical Report

Electromagnetic compatibility and Radio spectrum Matters (ERM); Road Transport and Traffic Telematics (RTTT); Radio equipment to be used in the 77 GHz to 81 GHz band; System Reference Document for automotive collision warning Short Range Radar

Reference

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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).

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 Post and Telecommunications Administrations (CEPT) for the purpose of amending annex 5 (RTTT) of the CEPT/ERC Recommendation 70-03 [1] in order to include 79 GHz Short Range Radars for automotive collision warning.

Introduction

The industry has responded to European Commission programs and has developed new Short Range Radar (SRR) solutions for Road Safety and Intelligent Transport Systems. This is in support of such programs as *e*-Safety, IST, the EU Approach to Road Safety and Intelligent Transport systems (ITS) and RESPONSE, Project TR4022 [4] (see clause 2).

This Systems Reference document relates to a basic element of the IST program for the automotive sector and can be applied in a variety of applications.

The objective and focus of "The EU Approach to Road Safety and Intelligent Transport systems (ITS)" (see bibliography), "Intelligent Vehicle Systems" are defined as "Improve Safety, Security, Comfort and Efficiency in all Transport modes" and "Focusing on Advanced Pilot/Driver Assistance Systems (in support of vision, alertness, manoeuvring, automated driving compliance with the regulations, etc…)".

The presentdocument is needed for the process of implementing the initiated ECC decision and to follow the EC mandate to CEPT to harmonize the SRR spectrum and to facilitate a coordinated EU introduction of SRR, specifically the definition of a permanent frequency for SRR.

ECC bodies have identified the 77 GHz to 81 GHz range for the permanent SRR frequency and an appropriate ECC/CEPT decision is being prepared.

The following information is included in the annexes A, B and C of the present document:

- Annex A: Detailed market information.
- Annex B: Technical information.
- Annex C: Expected compatibility issues.

1 Scope

The present document applies to Short Range Devices (SRD) in the field of Short Range Radars (SRR) operating at a frequency band in the 79 GHz range (within 77 GHz to 81 GHz) for exterior automotive applications for vehicle environmental sensing. It covers integrated transceivers and separate transmit/receive modules:

- transmitters operating in range from 77 GHz to 81 GHz with peak power levels ranging up to 55 dBm;
- receivers operating in the range from 77 GHz to 81 GHz.

The present document applies to low power motion and distance monitoring radars for automotive applications, operating on radio frequencies in the 77 GHz to 81 GHz band, with mean power densities of up to 23,5 dBm.

The remaining elements of the present document concentrate on the technical matters that are required to assist ECC/CEPT working groups FM and SE.

2 References

For the purposes of this Technical Report (TR) the following references apply:

[1] CEPT/ERC Recommendation 70-03 (2003): "Relating to the use of Short Range Devices (SRD)".

[2] Fotis Karamitsos: "The EU approach to Road Safety and Intelligent Transport Systems (ITS), http://www.cordis.lu/en/".

[3] ETSI EN 301 091-1: "ElectroMagnetic Compatibility and Radio Spectrum Matters (ERM); Road Transport and Traffic Telematics (RTTT); Technical characteristics and test methods for radar equipment operating in the 76 GHz to 77 GHz band; Part 1: Technical characteristics and test methods".

[4] IST -19910107, PROTECTOR (Preventive safety for unprotected road users). http://www.cordis.lu/en/.

[5] ITS, Mobile information society, Advanced driver assistance systems.

[6] SRD/MG(03)31, EC Mandate to CEPT to harmonize Spectrum to facilitate a coordinated EU introduction of Automotive Short Range Radar Systems.

[7] ECC Decision (02)01: "ECC Decision of 15 March 2002 on the frequency bands to be designated for the co-ordinated introduction of Road Transport and Traffic Telematic Systems".

3 Definitions, symbols and abbreviations

3.1 Definitions

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

accuracy: degree of conformity of a measured or calculated value to its definition or with respect to a standard reference (see uncertainty)

auto-correlation: measure of the similarity between a signal and a time-shifted replica of itself

bandwidth: range of frequencies, expressed in Hertz (Hz), that can pass over a given transmission channel

NOTE: The bandwidth determines the rate at which information can be transmitted.

Half Power Beam Width (HPBW): in an antenna, the angular sector in degrees of the radiated power pattern at the half-power (3 dB) point

Binary Phase Shift Keying (BPSK): DSB suppressed carrier discrete phase modulation

car parc penetration: proportion of registered cars which are equipped with SRRs

chip: time it takes to transmit a bit or single symbol of a PN code

coherent homodyne detection: synchronous receive process with a local carrier of same frequency and phase

correlator: SS receiver component that demodulates a Spread Spectrum signal; a device that measures the similarity between an incoming signal and a stored replica

cross-correlation: measure of the similarity of two different signals

de-spreading: process used by a correlator to recover narrowband information from a spread spectrum signal

diffraction loss: loss between two antennas caused by the scattering of energy from obstruction in the path

directive gain: in a given direction, 4 pi times ratio of the radiation intensity in that direction to the total power radiated by the antenna

relative gain: ratio of the intensity at any direction to the maximum intensity

drift (frequency): linear (first-order) component of a systematic change in frequency of an oscillator over time drift is due to aging plus changes in the environment and other factors external to the oscillator data symbol.

Direct Sequence Spread Spectrum (DSSS): it can be assumed that the information signal in DSSS transmission is spread at baseband, and the spread signal is then modulated in a second stage

dwell time: continuous time duration a carrier frequency stays within a given frequency channel

FCC NPRM: regulative authority of the United States (FCC) has started a rule making process regarding ultra wideband transmitters which will result into a standard amendment of 47FDR part 15

NOTE: One important document during this process is the 'notice of proposed rulemaking', released in 5/2000.

fractional bandwidth: in a design the ratio of necessary bandwidth divided by the carrier frequency
e.g. 4 GHz / 79 GHz = 5 %

free-space path loss: in an antenna, the loss between two isotropic radiators in free space resulting from the decrease in power density with the square of the separation distance

frequency allocation: band of radio frequencies identified by an upper and lower frequency limit earmarked for use by one or more of the 38 terrestrial and space radio communications services defined by the International Telecommunication Union under specified conditions

frequency assignment: authorization given by a nation's government for a station or an operator in that country to use a specific radio frequency channel under specified conditions

Frequency Shift Keying (FSK): modulation where the data causes the frequency of the carrier to change from one frequency to another on discrete stages

gain, dBd: antenna gain, expressed in decibels referenced to a half wave dipole

gain, dBi: antenna gain, expressed in decibels referenced to a theoretical isotropic radiator

gain, dBic: antenna gain, expressed in decibels referenced to a theoretical isotropic radiator that is circularly polarized

Industrial Scientific, Medical bands (ISM): frequency bands in which non-radio RF emissions can be allocated

NOTE: Generally also allowed for secondary radio services i.e. SRD's.

isotropic radiator: hypothetical, loss less antenna having equal radiation intensity in all directions; used as a zero-dB gain reference in pattern measurements or directivity calculations

K, Ku, Ka bands: frequency band between 18 GHz and 27 GHz, Ku 12 GHz to 18 GHz, Ka 27 GHz to 40 GHz

microwave: signal in the generic frequency range from above 1 GHz to an upper end of perhaps 30 GHz or 40 GHz

NOTE: This is the frequency range where coaxial cabled TEM mode signal propagation is viable.

narrowband: classification for the spectral width of a transmission system

NOTE: Generally considered if the fractional BW is below 1 % of the carrier frequency.

noncoherent detection: envelope receive process without phase coherency to the reference carrier but any subcarrier

occupied BW bandwidth of an emission defined for UWB or alike systems as 10 dB bandwidth of the power spectral density

NOTE 1: The definitions (such as Occupied bandwidth, Necessary Bandwidth, …) related to UWB are currently under study in CEPT and ITU-R Recommendation TG 1/8. Upon completion of this work ETSI will be in a position to update this definition if necessary. Therefore for the time being this definition is not to be added to any ETSI definition database.

NOTE 2: 10 dB definition also according FCC NPRM.

PN Code: a digital bit stream with noise-like characteristics

Power Spectral Density (PSD) (dBm/Hz): some limit specifications prefer a definition of PSD as a power in a certain measurement resolution bandwidth, e.g. -30 dBm in 1 MHz, which is equivalent -90 dBm/Hz

Pulse Desensitization Correction Factor (PDCF): technique used to determine the true pulse amplitude based on measurements taken from a spectrum analyser, which has less resolution bandwidth then the signal to be measured

NOTE: The analysers impulse response is unable to transfer the input pulse shape into an similar narrow output shape but distort the shape magnitude (decrease) as well as the pulse duration (increase).
A pulse desensitization correction factor was designed specifically for measuring the peak output level of pulsed radar transmissions. The PDCF is defined as 20log(B_signal/RBW_analyser) with respect to the peak field strength (see HP application note 150-1 PDCF with regard to amplitude spectrum).

Pseudo Noise (PN): digital signal with noise-like properties

NOTE: Also a wideband modulation which imparts noise-like characteristics to an RF signal.

polarization: in an antenna, the direction in which the electric field vector is aligned during the passage of at least one full cycle

pseudo random binary sequence: pattern of digital data which has a random information content

NOTE: The ITU specifies a variety of sequences with different lengths identified by a PN number.

processing gain: ratio of the bandwidth of a spread spectrum signal to the bandwidth of the baseband signal

Radiation Pattern (RP): graphical representation in either polar or rectangular coordinates of the spatial energy distributions of an antenna

reflection: in an antenna, the redirection of an impinging RF wave from a conducting surface

refraction: bending of an RF wave while passing through a non-uniform transmission medium

resolution: degree to which a measurement can be determined is called the resolution of the measurement

NOTE: The smallest significant difference that can be measured with a given instrument.

return loss: expressed in decibels, Return Loss is a measure of VSWR

scattering: random redirection of RF energy from irregular conducting surfaces

separation: capability to discriminate two different events (e.g. two frequencies in spectrum or two targets over range)

side lobe: in an antenna, a radiation lobe in any direction other than that of the major lobe

synchronization: process of measuring the difference in time of two time scales such as the output signals generated by two clocks

NOTE: In the context of timing, synchronization means to bring two clocks or data streams into phase so that their difference is zero.

uncertainty: limits of the confidence interval of a measured or calculated quantity

NOTE: The probability of the confidence for limits should be specified, preferably as two standard deviations.

Video BandWidth (VBW): video bandwidth of a spectrum analyser. A VBW less the RBW applied results in an averaging of the measured signal

ultra wideband: classification for the spectral width of a transmission system. Considered as a fractional BW greater than 25 % or an absolute BW of more than 1,5 GHz according to FCC NPRM

wideband: classification for the spectral width of a transmission system. Generally considered if the fractional BW is greater than 1 % of the carrier frequency

3.2 Symbols

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

λ	Wavelength
Δr	Range separation
E	Electrical field strength
Eo	Reference electrical field strength
f	Frequency
P	Power
R	Distance
Ro	Reference distance

3.3 Abbreviations

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

ACC	Adaptive Cruise Control
B_{occ}	spectral bandwidth
BPSK	Binary Phase Shift Keying
CW	Continuous Wave
dB	deciBel
dBi	deciBel isotropic
dBm	deciBel milliwatt
DSSS	Direct Sequence Spread Spectrum
EIRP	Equivalent Isotropically Radiated Power
ECC	Electronic Communication Committee (formerly ERC)
ERC	European Radiocommunication Committee
ERP	Effective Radiated Power with respect to dipole
FCC	Federal Communications Commission
FHSS	Frequency Hopping Spread Spectrum
FMCW	Frequency Modulated Continuous Wave
FSK	Frequency Shift Keying
IF	Intermediate Frequency
ISM	Industrial Scientific, Medical
LRR	Long Range Radar
Mbps	one Million bits per second; a data rate
PDCF	Pulse Desensitization Correction Factor
PN	Pseudo Noise
PPM	Pulse Position Modulation
PRF	Pulse Repetition Frequency
PSD	Power Spectral Density (dBm/Hz)

RBW	Resolution BandWidth of a spectrum analyzer
RCS	Radar Cross Section
RF	Radio Frequency
rms	root-mean-square
RPE	Radiation Pattern Envelope
RTTT	Road Transport and Traffic Telematics
Rx	Receiver
SRD	Short Range Device
SRR	Short Range Radar
Tx	Transmitter
VBW	Video BandWidth of a spectrum analyser
VSWR	Voltage Standing Wave Ratio
WGSE	Working Group Spectrum Engineering

4 Executive summary

4.1 Status of the present document

The document is approved by ETSI_ERM for publication

4.2 Technical issues

4.2.1 Introduction

Automotive radar functions cover Long Range Radar (LRR) and Short Range Radar (SRR).

Adaptive Cruise Control (ACC) today uses LRR operating between 76 GHz and 77 GHz with a maximum bandwidth of 1 GHz. It uses distance scanning, which requires an operating range of approximatively 150 m and is used at vehicle velocities not below 30 km/h. One or multiple narrow lobes control or scan the driving path in front of the car to determine the distance to the vehicle driving ahead for maintaining a constant minimum safety distance. The mean power levels (EIRP) are 50 dBm for class 1 and 23,5 dBm for class 2. Peak levels are 55 dBm (see EN 301 091-1 [3]).

4.2.2 Technical characteristics of the SRRs

SRR units operating at 79 GHz (i.e. in the band 77 GHz to 81 GHz) require an operating range from 0 m to 30 m approximately , and are used for a number of applications to enhance the active and passive safety for all kind of road users. Applications which enhance passive safety include obstacle detection, collision warning, lane departure warning, lane change aid, blind spot detection, parking aid and airbag arming. The combination of these functions is referred to in the literature as a "safety belt" for cars.

The 79 GHz SRR is a combination of two functions. It allows on the one hand a precise speed measurement with help of a CW Doppler emission. This speed measurement mode is combined with wideband signals to provide precise radial range information of objects with a high range separation in order of approximately 5 cm to 10 cm. To obtain the required resolution the SRR needs a large bandwidth of 4 GHz for the range measurement.

According to a defined mean PSD EIRP mask. Emissions outside the necessary bandwidth are considered as spurious emissions.

SRR functionality may be integrated with LRR function into one device.

Because of foreseeable saturating interference from LRRs into SRRs (not vice versa) a common band allocation is not feasible. The SRRs would be jammed due to the lack of spatial separation. Therefore a spectral separation in the 79 GHz range according to the following table is necessary.

Table 1 also lists the necessary power levels for the envisaged future applications of second generation's SRR (see clause B.2 for further explanations).

Table 1: Overview of SRR and LRR parameters

	SRR	Present LRR	
		FMCW	Pulsed
Frequency	77 GHz to 81 GHz	76 GHz to 77 GHz	
Worst Case Mean EIRP Spectral Density @ 79 GHz	< -15 dBm/MHz to -3 dBm/MHz		
Mean Power	18 dBm to 30 dBm	50 dBm	23,5 dBm
Worst Case Peak EIRP @ 79 GHz	46,2 dBm to 55 dBm	55 dBm	55 dBm
Operating Distance	30 m	150 m	150 m

5 Conclusions

The present 76 GHz to 77 GHz frequency band as given in the CEPT/ERC Recommendation 70-03 [1], annex 5 is already designated to automotive radar applications. Additional spectrum above 77 GHz is anticipated by the ECC, WGFM and the industry as permanent band for SRR functions.

The 76 GHz to 77 GHz frequency band was designated for vehicular and infrastructure radar systems in CEPT/ERC Recommendation 70-03 [1] and in ECC Decision (02)01 [7]. This frequency band is, however, intended for LRR systems which are not compatible with SRR systems. Thus, a new frequency band of 4 GHz for Ultra Wide Band Automotive SRR is needed within the 79 GHz range (77 GHz to 81 GHz).

The peak power limit for the new SRR allocation from 77 GHz to 81 GHz is required to be from 46,2 up to 55 dBm to achieve road safety goals.

Annex A: Market information

A.1 Applications

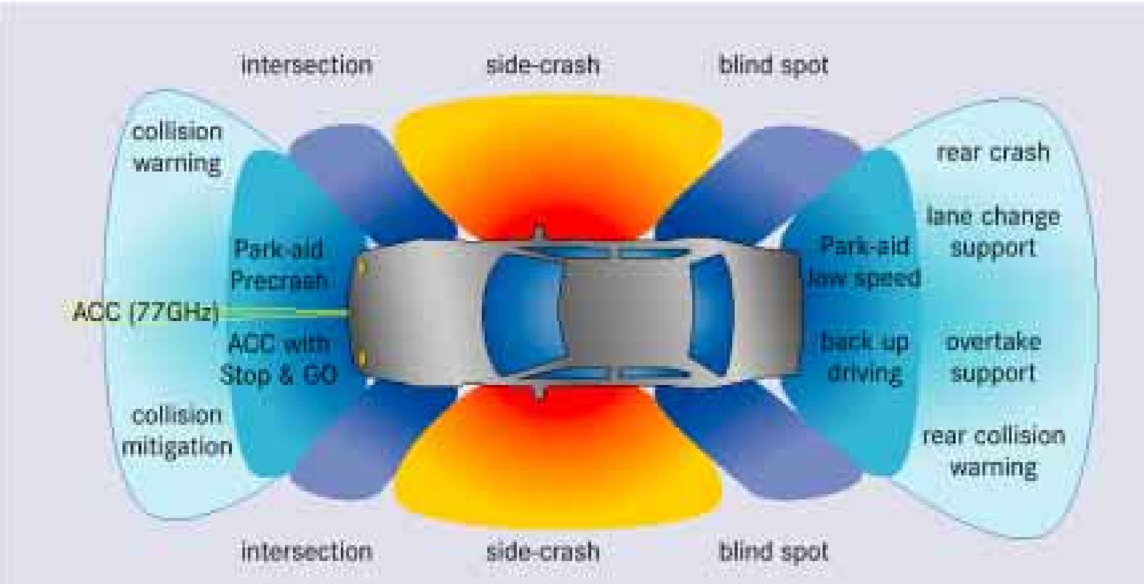

Figure A.1: SRR functions relevant for enhancement of road safety

Figure A.1 shows possible applications for automotive radars (LRR for ACC application is not the subject of the present document).

A.2 Market size and value

CEPT/ECC currently studies a "package solution", which would comprise the long-term frequency band 77 GHz to 81 GHz for SRR plus a possible temporary band around 24 GHz. Industry works towards an early introduction of equipment operating in the long-term band from early on, e.g. 2008 by means of intensive research and development programs. Moreover, given car industry's interest to use the same technology during the lifetime of the model lines (usually 6 years to 7 years in Europe), it is expected that new car lines starting before the sunset date will already use the long-term frequency equipment. This means that the SRR penetration curve saturates before the sunset date.

Possible deployment at 24 GHz would not only be limited in time by the sunset date, but also by the overall car parc penetration is restricted to below 10 % as an outcome of CEPT's compatibility studies. These restrictions do not apply to the 79 GHz permanent band. Therefore the market for 79 GHz systems (which would have started with applications based on 24 GHz SRR) is expected to grow way beyond the limit of 10 %.

Figure A.2 reflect the upper boundaries of the overall market expectations.

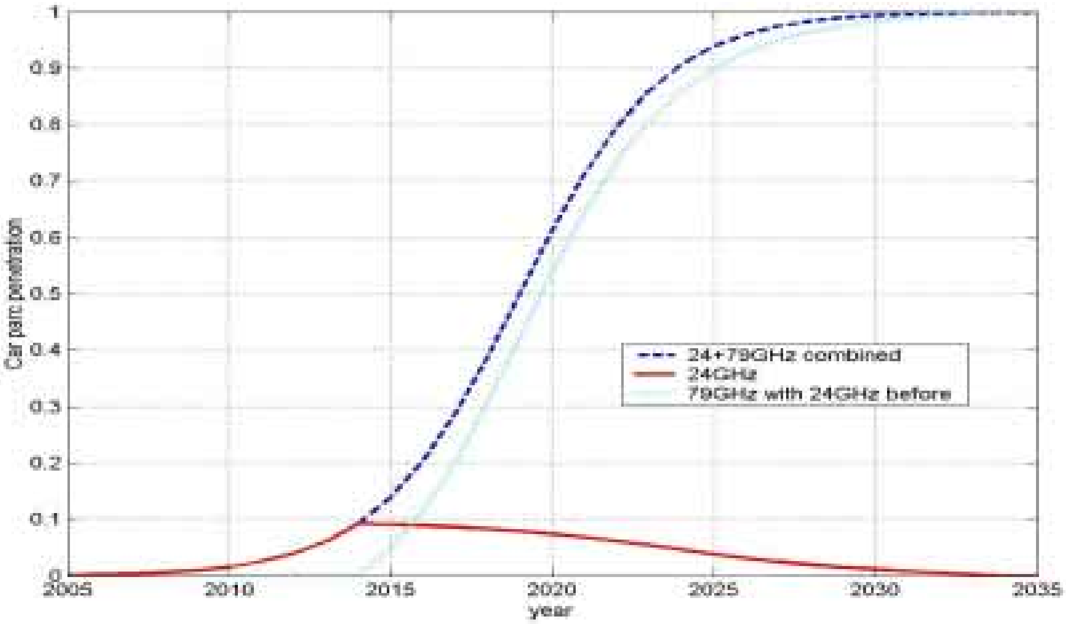

Figure A.2: SRR Car Parc Penetration for SRR comprising 24 GHz and 79 GHz Systems

The business volume is estimated by looking at the production rates of cars in Europe, which is currently around 17 million units per year. This figure is expected to exceed 19 million units in the year 2014.

By then, only 79 GHz SRR technology would be installed in new cars. Assuming that 10 % of new cars would be equipped with SRR with a system cost of around 500 € for the SRR sensors plus control unit, a total size of the market of over 950 million euro would result.

This figure is expected to grow even more as the number of applications grows as well as equipment rates.

Socio-economic benefit

Investigations of the automotive industry were made, which identify the following social economical benefit resulting from road accidents or avoidance thereof (e.g. in Germany 34 Billion €).

The number of cars in Europe is increasing, which leads to a higher traffic density. The average age of drivers is increasing consistent with demographics of the total European population. Every second accident involving vehicles is related to traffic situations in which a faster reaction of the driver could have avoided crashes. Consequently, there is an increased need and appreciation for early obstacle detection systems that operate at day and night (see figure A.2).

SRR is an enabling technology for enhanced active safety systems and in particular the mitigation of front-end crashes thus reducing damages and saving of lives.

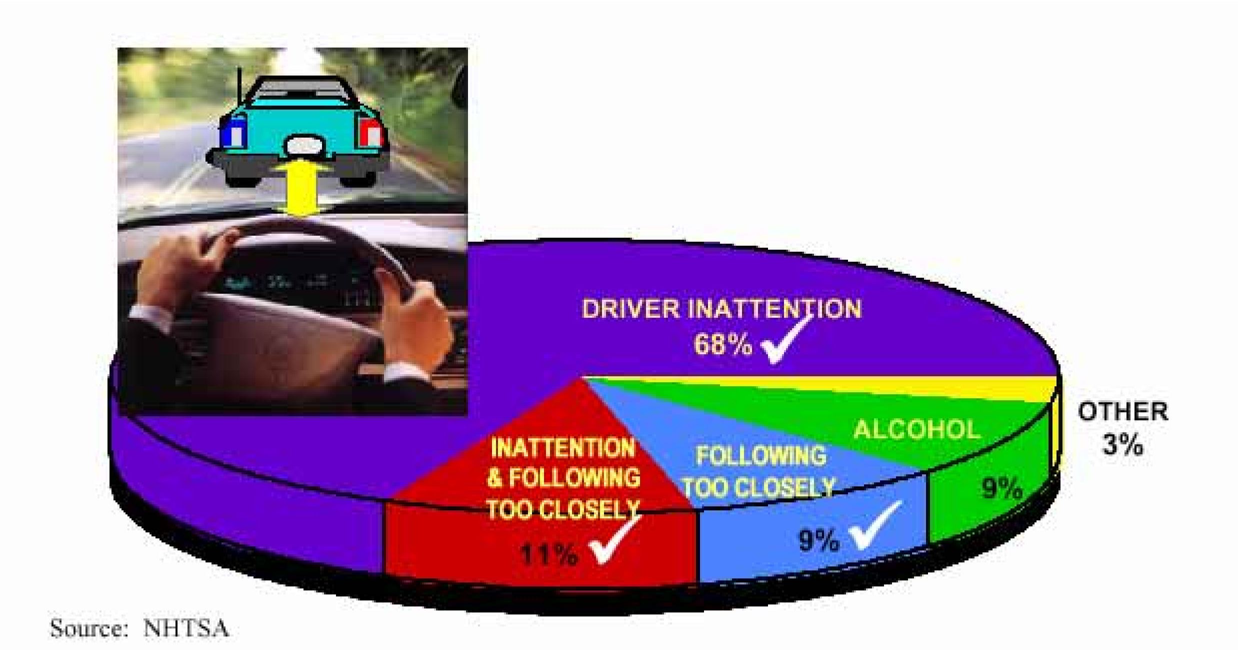

Figure A.3: Potential impact of SRR on causes of rear-front crashes

Annual damage cost caused by accidents in the EU is approximatively 100 Billion euro, which can be potentially avoided or minimized according to the analysis given in "Volkswirtschaftliche Kosten der Personenschäden im Strassenverkehr" (see bibliography).

The amount of damage related to persons injured or death toll is counted for 56 % while the rest of 44 % is related to goods damage.

Furthermore, in connection with Adaptive Cruise Control (ACC), SRR can reduce traffic congestion.

Leading European car manufacturers have chosen improved safety systems as a competitive aspect for the marketing of their cars. The program supports the EU leadership in the automotive industry which has the highest growth rates in the next decades to come.

A.3 Traffic evaluation

The traffic evaluation can be estimated by the number of systems, the average and/or instantaneous emitted power, based on antenna beam width, the installation height and the occupied bandwidth of the modulation.

The power spectral density limit for the transmission is -3 dBm/MHz while the level outside the SRR band, which is below the spurious limit, is not anticipated to cause harmful interference (subject to sharing studies).

Due to the low antenna installation height, the low power density, and the narrow vertical beam width, the potential interference (e.g. with airborne or satellite systems) is anticipated to be very low.

The complete coverage of the surround sensing of the car requires between four and eight SRR devices.

Annex B: Technical information

B.1 Technical description

The SRR devices planned to be used for automotive applications as described in the present document are not developed yet but will have the following characteristics according to present knowledge:

- Mean power limit of 23,5 dBm EIRP (CW Doppler and wideband operation mode).
- Mean EIRP PSD of -15 dBm/MHz to -3 dBm/MHz (wideband operation mode).
- Peak power limit of 46,2 dBm to 55 dBm EIRP (wideband operation mode).
- Wideband operation frequency range: 77GHz to 81 GHz.

Outside the SRR band the average spectral EIRP density is -30 dBm/MHz or -90dBm/Hz respectively.

The TX antenna pattern of the anticipated 79 GHz SRR can range up to 180°C horizontally and 20°C vertically without bumper.

A carrier modulated UWB radar needs a CW narrow band allocation of 500 MHz around 79 GHz in the centre of the 77 GHz to 81 GHz band for the residual carrier of 23,5 dBm EIRP. The same narrow band CW carrier could be used to perform Doppler speed measurements.

If any CW Doppler system should require more power, then the existing 76 GHz to 77 GHz SRD band shall be used. In this band the maximum value of the mean power is 50 dBm EIRP according to the current ERC/REC Recommendation 70-03 [1].

The UWB modulation mode requires a bandwidth of 4 GHz to meet range resolution requirements of approximately 5 cm to 10 cm. There are several wideband modulation technologies as known from spread spectrum technologies, which can be used for short-range radar systems. Possible types of spread spectrum techniques for automotive based radar devices, which also might be combined in hybrid concepts, are:

- Pulse Modulation;
- FHSS;
- BPSK;
- Pulsed FMCW.

A further spreading of a pulse modulated signal can be achieved by additional FM of the carrier during the pulse (e.g. a pulse compression with a linear FM Chirp). The same effect can be obtained by discrete phase shifts of the pulse according to a barker code.

Independent from the modulation scheme, the EIRP of all SRR systems shall be in conformance to the common EIRP mask as to be defined later.

B.2 Technical justification for spectrum

B.2.1 Power

Depending on the requirements of the prevailing application, e.g. speed-oriented information or high precision position determination or a combination of both, SRR devices can operate in both narrow band Doppler mode and wide band modes for 4 GHz).

- The radio devices planned to be used for automotive applications as SRR as described in the present document and for the LRR in EN 301 091-1 [3], may simultaneously operate in LRR and SRR modes (hybrid operation).

A frequency shift from the 24 GHz range to the 79 GHz band requires higher power levels as those for the 24 GHz SRR to get similar performance. The effects of additional losses due to the higher frequency have to be considered in the transmit power.

The main factor in comparing 24 versus 79 GHz SRR system power levels is the medium where the radar has to transmit through i.e. bumper, air and to consider the higher system noise figure.

The value for bumper damping has still to be estimated at this point in time, since there are no accurate data reflecting *in situ* measurements currently available for bumper material losses at 79 GHz. A typical value of 7 dB to 12 dB (for two way propagation) was proposed for the calculation by the automotive and component supplier industry. In the case of SRRs, due to the use multiple sensors, cost, design constraints and bumper functionality, Special windows or specific bumper materials may not be acceptable.

Measurements performed in one independent laboratory indicated that, in case of orthogonal incidence, maximum bumper losses of 1,3 dB are possible (see ERM_RM (03)_MZ33rev1).

NOTE: Bumper damping depends on the exact installation of the sensors in the vehicle and it is therefore possible, that the loss figure could be reduced to an absolute minimum. The regulatory authorities are asked to give guidance with respect to the question on how to deal with the issue of bumper losses. There are two options:

a) A consideration without any losses, (stand-alone sensor);

b) A consideration with an assumed worst case loss figure.

In both cases, the integrator, who installs sensors in the car has to make sure, that a given declaration of conformity (under the R&TTE Directive) with essential requirements concerning spectrum use is still valid, i.e. that the maximum permitted radiated power level is not exceeded in any case. For this reason, a clear guidance on the preferred option from the regulatory authorities is requested.

Due to the higher frequency, the SRR receiver noise will increase by approximatively 5 dB.

Furthermore additional damping effects due to water, ice and spray on the bumper are not available at present. Also the behavior of the reflectivity of pedestrians at 79 GHz will be different as compared to 24 GHz. Finally, safety oriented applications require a reasonable signal to noise ratio. The maximum PSD of -41,3 dBm/MHz, currently discussed for the operation of automotive SRR at 24 GHz, is the absolute lower boundary for current applications. Due to desired enhancement of detection range, especially of targets with low reflectivity, future applications require higher power levels. It should be noted that the SRDoc for 24 GHz did claim a PSD of at least –30 dBm/MHz to cover future applications. Therefore, for a long term band and the needed functionality of SRR above 60 GHz, enhanced Signal-to-Noise-Ratio requirements has to be taken into account.

Tables B.1 and B.2 provides an estimation for the required mean PSD power level considering current knowledge in order to achieve comparable performance at 79 GHz SRR for future applications as compared to 24 GHz.

Tables B.1 and B.2 reflect the above considerations in determining the mean and peak power levels.

Table B.1: Derivation of mean power values for SRR operating at 79 GHz

Parameter	Value	Unit	Note
Reference EIRP Spectral Density Limit, 24 GHz	-30	dBm/MHz	Mean PSD for 5 GHz Bandwidth (-20 dB) This figure includes an increase of the power level to cover future requirements of new applications, i.e. this represents a power increase of 11,3 dB for new applications.
Bumper Damping @79 GHz	see note above, 0 to 12	dB	(Two way propagation)
Noise Figure Increase @79 GHz	+5	dB	Increase in Receiver Noise Figure from 24 GHz to 79 GHz.
Additional Frequency related propagation loss	+10	dB	
Worst case Mean EIRP Spectral Density @ 79 GHz	**-15 to -3**	**dBm/MHz**	

The assumed noise figure increase might be reduced in future as technology improves.

Table B.2: Derivation of peak power values for SRR operating at 79 GHz

Parameter	Value	Unit	Description
Worst case Mean EIRP Spectral Density @ 79 GHz	-15 to -3	dBm/MHz	
Spectral power Spreading for 2 GHz (3 dB bandwidth)	+33	dBm/MHz	
Mean Power	18 to 30	dBm	Over entire BW
Impact of Duty Cycle	+28,2	dB	Typical 24 GHz SRR Duty Cycle (3 MHz PRF, 500 ps Pulse width)
Worst case Peak EIRP @ 79 GHz	**+ 46,2 to 58,2**	**dBm**	

Based on the estimation above, SRRs operating at the 79 GHz range may require the same peak power level of 55 dBm as already specified for the long range pulsed ACC (CEPT/ERC Recommendation 70-03 [1], annex 5).

Outside the 77 GHz to 81 GHz band the average spectral EIRP density is below -30 dBm/MHz or -90 dBm/Hz respectively.

The CW carrier for Doppler measurement is estimated for 23,5 dBm over a bandwidth of 500 MHz to take care of stability, aging, etc.

B.2.2 Frequency bandwidth

The automotive short range radar systems need to determine not only radial range but also lateral positions. This is e.g. needed to decide in-path and out-of-path objects with respect to the driver lane and to predict the direction of impact for precrash systems. The radar system calculates lateral position from triangulation with the radial range information from at least two sensors. The accuracy Δr of the distance reading which is necessary to achieve a lateral accuracy Δy is given by:

$$\Delta r = \Delta y \times b / 2r$$

where b is the distance between the two sensors and r the radial range of the object referred to the baseline between the sensors.

Typical values are:

- Δy = 20 cm;
- b = 1,5 m; and
- r = 10 m.

This results in an accuracy requirement of 1,5 cm. Assuming as a rule of thumb that accuracy can be chosen by a factor of three better than the separation we get an requirement of about 5 cm to10 cm for the separation.

Independent of the accuracy requirement the radar systems need to resolve complex objects with several reflection factors and spots like cars, motorbikes and other objects including pedestrians. Here we also find an separation requirement of about 5 cm to10 cm.

Radar range separation is a function of the modulation bandwidths as shown below. The resolution requirements of about 5 cm to 10 cm lead to modulation bandwidths of 4 GHz as necessary bandwidth.

For simplifying illustration, a 3 dB Bandwidth is used in figure B.1.

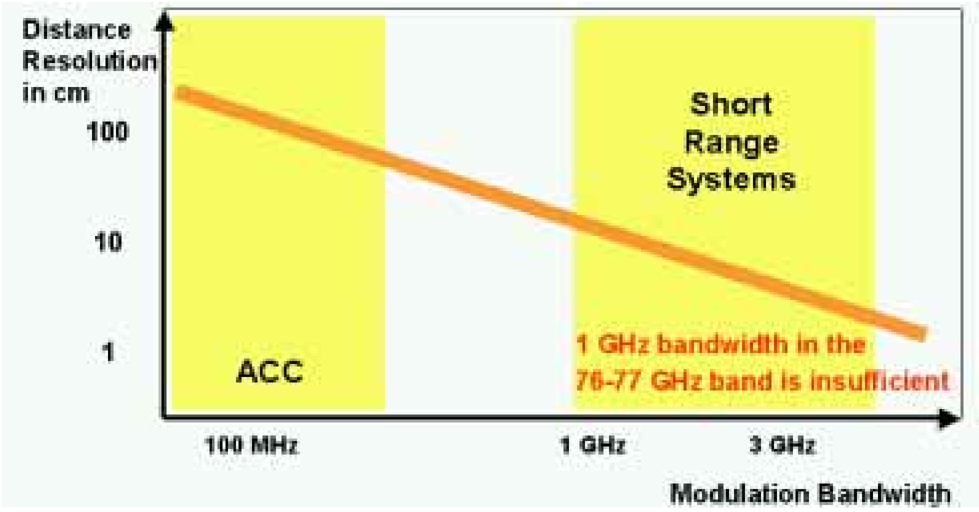

Figure B.1: Potential Impact of SRR on causes of rear-front crashes

Annex C: Expected compatibility issues

C.1 Coexistence studies

Because of likely interference between SRRs and LRRs a common band allocation is not feasible. The SRRs would be jammed due to the lack of spatial separation. Therefore a spectral separation in the 79 GHz range according to the following table is necessary.

Table C.1: Summary of SRR parameters

	SRR	**Present LRR**	
		FMCW	**Pulsed**
Frequency	77 GHz to 81 GHz	76 GHz to 77 GHz	
Worst Case Mean EIRP Spectral Density @ 79 GHz	< -15 dBm/MHz to -3 dBm/MHz		
Mean Power	18 dBm to 30 dBm	50 dBm	23,5 dBm
Worst Case Peak EIRP @ 79 GHz	46,2 dBm to 55 dBm	55 dBm	55 dBm
Operating Distance	30 m	150 m	150 m

Radio amateurs are doing experimental transmissions in the 77,5 GHz to 78 GHz band but there is currently no amateur satellite communication in the band. This may change in future.

The frequency band 76 GHz to 81 GHz is allocated to the Radio Astronomy Service subject to footnote 5.149, but not footnote 5.340. The band is shared on an co-primary basis with the Radiolocation Services.

The LRR Band 76 GHz to 77 GHz for ACC functions has been already in use for a number of years with comparable operating power levels to the SRR systems and surfaced no problems neither with Radio Amateur nor Radio Astronomy services.

No information is available on existing or planned radiolocation services.

C.2 Current ITU allocations

Table C.2: ITU allocations in the range of 76 GHz to 81 GHz (see note)

Frequency band	Allocations	Applications
76 GHz to 77,5 GHz	RADIO ASTRONOMY RADIOLOCATION Amateur Amateur-Satellite Space Research (space-to-Earth)	Radio astronomy (74 GHz to 86 GHz) Amateur (75,5 GHz to 76,5 GHz) Amateur-satellite RTTT Radiolocation (civil) Amateur (76,5 GHz to 77,5 GHz)
77,5 GHz to 78 GHz	AMATEUR AMATEUR-SATELLITE Radio Astronomy Space Research (space-to-Earth)	Radio astronomy (74 GHz to 86 GHz)
78 GHz to 79 GHz	RADIOLOCATION Amateur Amateur-Satellite Radio Astronomy Space Research (space-to-Earth)	Radio astronomy (74 GHz to 86 GHz) Radiolocation (civil) Radiolocation (military) (78 GHz to 81 GHz)
79 GHz to 81 GHz	RADIO ASTRONOMY RADIOLOCATION Amateur Amateur-Satellite Space Research (space-to-Earth)	Radio astronomy (74 GHz to 86 GHz) Radiolocation (military) (78 GHz to 81 GHz) Radiolocation (civil)
NOTE: The frequency band 76 GHz to 81 GHz is allocated to the Radio Astronomy Service subject to footnote 5,149, but not footnote 5,340. The band is shared on an co-primary basis with the Radiolocation Services.		

Annex D: Bibliography

- 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".
- SE24, M19_38R0 Preliminary _SRR Specification for the 77 GHz Band.
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History

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