ETSI TR 101 982 V1.1.1 (2001-07)

Technical Report

Electromagnetic compatibility and Radio spectrum Matters (ERM); Radio equipment to be used in the 24 GHz band; System Reference Document for Short Range Radar

Reference
DTR/ERM-RM-005

Keywords
Radar, radio, short range

ETSI

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

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

Siret N° 348 623 562 00017 - NAF 742 C
Association à but non lucratif enregistrée à la
Sous-Préfecture de Grasse (06) N° 7803/88

Contents

Intellectual Property Rights

IPRs essential or potentially essential to the present document may have been declared to ETSI. The information pertaining to these essential IPRs, if any, is publicly available for **ETSI members and non-members**, and can be found in ETSI SR 000 314: *"Intellectual Property Rights (IPRs); Essential, or potentially Essential, IPRs notified to ETSI in respect of ETSI standards"*, which is available from the ETSI Secretariat. Latest updates are available on the ETSI Web server (http://www.etsi.org/ipr).

Pursuant to the ETSI IPR Policy, no investigation, including IPR searches, has been carried out by ETSI. No guarantee can be given as to the existence of other IPRs not referenced in ETSI SR 000 314 (or the updates on the ETSI Web server) which are, or may be, or may become, essential to the present document.

Foreword

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

It includes necessary information to support the co-operation under the MoU between ETSI and the European Radiocommunications Committee (ERC) of the European Conference of Post and Telecommunications Administrations (CEPT) for amending annex 5 (RTTE) of the CEPT/ERC Recommendation 70-03 [1].

Introduction

The industry has responded to European Commission programs and has developed new, efficient 24 GHz Short Range Radar (SRR) solutions for Road Safety and Intelligent Transport Systems. This is in support of such programs as IST, the EU Approach to Road Safety and Intelligent Transport systems (ITS) and RESPONSE, Project TR4022 (see bibliography).

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…)".

Further the new 24 GHz Radar system is an essential "building block" of the EU Project RESPONSE, Project TR4022 (see bibliography) Advanced Driver Assistance Systems: "System Safety and Driver Performance".

1 Scope

The present document applies to Short Range Devices (SRD) in the field of SRR operating at very low power levels for exterior automotive applications for vehicle environmental sensing.

These applications require antenna characteristics, which necessitates only narrow elevation antenna beam combined with a limited mounting height.

The document describes the technical characteristics of SRR's, the Radio frequency requirements as a wideband emission mask, for the carrier frequency operating in the 24 GHz SRD as specified in CEPT/ERC Recommendation 70-03 [1]. The devices also use the SRD Band for a movement sensor function implementing a Doppler mode for a target speed measurement function.

The EN 301 091 [3] presents a basis for the new cost efficient and versatile 24 GHz radar technology, which complements 77 GHz Automotive Cruise Control (ACC) functions.

The following information is given in:

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

2 References

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

[1] CEPT/ERC Recommendation 70-03 (1998): "Relating to the use of Short Range Devices (SRD)".

[2] ETSI EN 300 440-1: "Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices (SRD); Technical characteristics and test methods for radio equipment to be used in the 1 GHz to 40 GHz frequency range, Part 1: Transmitter and receiver requirements".

[3] ETSI EN 301 091: "Technical characteristics and test methods for radar equipment operating in the 76 to 77 GHz band".

[4] The "Sensitive" Automobile –Bosch Sensors for Complete Environmental Sensing. Dr. Martin Zechnall, Robert Bosch GmbH. Speech to the 55th International Automotive Press Conference, April 2001 in Boxberg.

[5] 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:

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

Ambiguity: the properties of something that allows it to have more than one possible meaning

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

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

NOTE 1: The bandwidth determines the rate at which information can be transmitted.

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

Binary Phase Shift Keying: DSB suppressed carrier discrete phase modulation

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

Code: a digital bit stream with noise-like characteristics

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

Correlator: the SS receiver component that demodulates a Spread Spectrum signal; a device that measures the similarity of of an incoming signal and a stored reference code.

Cross-correlation: a 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: the loss between two antennas caused by the scattering of energy from obstruction in the path

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

Drift: the 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

Differential Phase Shift Keying: a simplified BPSK where only data transitions are transmitted

NOTE 2: DSPK results when the data changes the phase of the carrier from the phase determined by the previous data symbol.

Direct Sequence Spread Spectrum: 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: the time duration a carrier frequency stays within a given frequency band

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: a 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

GFSK: Gaussian Frequency Shift Keying - FSK where the base-band signal is filtered by a Gaussian filter. The modulation scheme has constant amplitude between symbols

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: modulation where the data causes the frequency of the carrier to change from one frequency to another

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

Gaussian Frequency Shift Keying: FSK where the base-band signal is filtered by a Gaussian filter

NOTE 3: The modulation scheme has constant amplitude between symbols.

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

NOTE 4: Generally also allowed for secondary radio services.

Isotropic Radiator: a 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 Band: the frequency band between 18.5 GHz to 26 GHz

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

NOTE 5: This is the frequency range where coaxial cabled TEM mode signal propagation is viable.

Narrowband: a classification for the spectral width of a transmission system

NOTE 6: Generally considered if the fractional BW is below 1% of the carrier frequency.

Noncoherent detection: envelope receives process with no reference wave

Occupied BW: bandwidth of an emission defined for UWB or alike systems as 10 dB bandwidth

Phased Array: an antenna comprised of multiple identical radiating elements in a regular arrangement and fed to obtain a prescribed radiation pattern

Pulse Desensitization Correction Factor: the pulse desensitization correction factor is a technique used to determine the true pulse amplitude based on measurements taken from a spectrum analyser. The analyser is unable to respond fast enough and is not using sufficient bandwidth to measure all of the energy in the pulsed signal. A pulse desensitization correction factor was designed specifically for measuring the peak output level of pulsed radar transmissions

Pseudo Noise: a digital signal with noise-like properties. 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: a pattern of digital data which has a random information content

NOTE 7: The ITU specifies a variety of sequences with different lengths identified by a PN number.

Processing Gain: the ratio of the bandwidth of a spread spectrum signal to the baseband

Radiation Pattern: a 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: the bending of an RF wave while passing through a non-uniform transmission medium

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

NOTE 8: 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: the random redirection of RF energy from irregular conducting surfaces

Separation: the capability to discriminate two different events (e.g. two frequencies or two targets)

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

Super High Frequency: a signal in the frequency range of from 3 GHz to 30 GHz

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

NOTE 9: In the context of timing, synchronization means to bring two clocks or data streams into phase so that their difference is zero.

Syntonization: relative adjustment of two frequency sources with the purpose of cancelling their frequency difference but not necessarily their phase difference

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

NOTE 10: The probability of the confidence limits should be specified, preferably as two standard deviations.

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

3.2 Symbols

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

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

3.3 Abbreviations

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

ACC	Automotive Cruise Control
B_{occ}	Spectral bandwidth
BPSK	Binary Phase Shift Keying
dB	Decibel
dBi	Decibel, isotropic
dBm	Decibel, milliwatt
DPSK	Differential Phase Shift Keying
DSSS	Direct Sequence Spread Spectrum
eirp	equivalent isotropically radiated power
ERC	European Radio communication Committee
ERP	Effective Radiated Power
FHSS	Frequency Hopping Spread Spectrum
FMCW	Frequency Modulated Continuous Wave
FSK	Frequency Shift Keying
GFSK	Gaussian 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
PRBS	Pseudo Random Binary Sequence
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
RTTT	Road Transport and Traffic Telematics
Rx	Receiver
SHF	Super High Frequency
SRD	Short Range Device
SRR	Short Range Radar
Tx	Transmitter

VBW	Video Bandwidth
VSWR	Voltage Standing Wave Ratio
WGSE	Working Group Spectrum Engineering

4 Executive summary

Automotive radar function covers Long Range Radar (LRR) and SRR. LRR at 77 GHz is used for distance scanning, which requires an operating range of approx 150 m and is used at vehicle velocities above 30 km/h to 50 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.

SRR units operating at 24 GHz provide a number of applications to enhance the active and passive safety for all kind of road users. Applications which enhance passive safety include obstacle avoidance, collision warning, lane departure warning, lane change aid, blind spot detection, parking aid and airbag arming.

Applications which enhance active safety include stop and follow, stop and go, autonomous braking, firing of restraint systems and pedestrian protection.

The combination of these functions is referred to in the literature as a "safety belt" for cars.

The SRR functions allow a significant increase in safety, the saving of lives and avoiding damage of goods which is in the order of 100's Billion EUR/p.a (see bibliography).

The 24 GHz SRR technology provides a high range resolution as well as object separation, the combination with Doppler radar will provide the information of closing speeds. Sensor data fusion can furthermore provide Cartesian object positions, a crash impact point and the closing angle.

24 GHz SRR technology provides the best compromise between using an established producable low-cost design and a frequency that is high enough to keep the product size such that it will fit in the space available and to provide useful range resolution and separation which is needed for Cartesian object tracking.

Such SRR functions cannot be covered by other means or systems operating at other frequencies because only cost-efficient systems will be accepted by the market for use in widespread applications.

SRR operates with carrier frequencies in the 24 GHz SRD band, however the separation requirement demands an occupied bandwidth of approx ± 2,5 GHz for each radar system (e.g. a spread spectrum concept), but at very low emission levels. These emissions out of the existing SRD band are at or below the spurious levels according the defined emission mask. The emissions outside the proposed emission mask are reduced below – 50 dBm.

SR Radar systems can be accommodated under CEPT/ERC Recommendation 70-03 [1], annex 6 "equipment detecting movement or alert" allowing a carrier power of 20 dBm. Alternatively the annex 5, RTTT, can be amended which seems to be more appropriate since this annex deals already with automotive functions.

According to the RTTE Directive, article 5, harmonized standards; article 6 and 7, the placing on the market and putting into service assumes availability of harmonized ETSI standards and availability of the frequencies as published in national Air Interface (and OJ). CEPT/ERC requires harmonization of the frequencies for operation in the ERC countries. The amending of the ETSI harmonized standard EN 301 091 [3] is pursued in parallel to this system reference.

4.1 Status of the System Reference Document

This system reference has been agreed by ETSI ERM #14.

4.2 Technical Issues

Short background information

The 77 GHz LRR autonomous cruise control systems fall short in providing the required functionality as required by the market and as defined by the EU Commission programs for RTTT and alike technology.

The availability of high volume SRR systems is based on cost-effective industry solutions. 24 GHz SRR prototypes designed by a number of manufacturers have demonstrated this.

System description

See annex B1.

Applications

See annex A1.

New technology (if any)

The 24 GHz SRR technology combines several technical features, which can be realized by using different spread spectrum technologies.

These technologies can be accommodated within the requested emission mask, which is valid for all modulation types.

The applications in the various surround-sensing functions provide a "safety belt" around a vehicle, aiming to protect passengers as well as other traffic members like pedestrians.

SRR can only be realized if the technology is accepted resulting in high volume production. A precondition is that the appropriate functionality and a low unit cost is given which can only be realized with established manufacturing technologies.

This in turn requires mature "off the shelf "components available up to K-Band (18,5 GHz to 26 GHz), automated high yield production for the used active and passive devices like resonator and other microwave components which are necessary to meet the target costs.

An additional requirement is the small unit size, the integrated mounting,conformal within the vehicle structure. e.g. bumper of a vehicle. This mounting is invisible, preventing vandalism.

To date, the 24 GHz technology has demonstrated the functionality and it satisfies the cost expectations of the automotive industry.

Short market information:

- Car surround sensing functions requires several individual SRR sensing units per vehicle in the front, rear and sideways with a total number of approx.10 units per vehicle but with limited overlapping beam characteristics.
- The market will develop as soon as cost-effective units are available. Prototypes for characterization are available, pilot units are foreseen in the first half of 2002 with possible volume production start early 2003 or late 2002.
- An essential requirement is the availability of the ETSI standard as well as the amendment of the CEPT/ERC Recommendation 70-03 [1], annex 5.

Market size, forecasts and timing

See clause A.2, Market size and Volume.

Spectrum requirement and justifications

The 24 GHz band is considered as the best compromise for functionality, performance, spectrum efficiency, cost, manufacturability and integration in vehicle structures.

The carrier is allocated inside the 24 GHz SRD band within 24,050 GHz to 24,250 GHz. A level of the modulation spectrum which is located outside of the SRD band is low with emissions at or below the spurious levels.

Considering the high propagation loss at 24 GHz, the directed and narrow beam width (for elevation) as well as the very low power of the modulation sidebands, the system is expected to coexist with all primary users in the range of ± 2,5 GHz.

Both frequency ranges, the 5,8 GHz as well as the 77 GHz frequency band are not suited for the required SRR functionality. The 5,8 GHz range require larger antennas for comparable directivity of the radar beam (e.g. 25 cm instead of 6 cm vertical antenna dimension). This makes integration into bumpers impossible. Other critical factors are that the required fractional bandwidth to support the radar resolution is technically not feasible for carrier based systems (e.g. more then 50 % instead of 13%).

The 77 GHz for SRR has the disadvantage of higher system cost and cost of ownership since automated production is difficult if not impossible, the integration in bumpers is not feasible without increasing the power significantly. (The absorption by the bumper material will increase about 5dB) (see also clause B.2).

Spectrum parameters and radiated power:

See spectral spectrum emission mask is provided in clause B.2.2.

Transmitted bandwidth / Frequency considerations

The width of the 24 GHz SRD band is too narrow to accommodate the required spectrum for SRR operation systems with the needed higher bandwidth were designed. The out-of-band emission levels outside the SRD bands are below the spurious emissions but intentional.

SRR's higher bandwidth is needed for sufficient object radial range discrimination. Δr, which is the capability of a given Radar system to distinguish between two objects with equally ideal reflective behaviour, but which are positioned at a minimum radial distance of Δr.

The range resolution is inverse proportional to the occupied spectral bandwidth Bocc.

$\Delta r = k*c / Bocc$.

The factor k is related to the system approach, (which can be set to $0,5 < k < 1$) and the needed discrimination criteria within the related signal processing, c is equivalent to the speed of light.

A minimum range resolution $\Delta r < 0,05$m is needed, if several targets with multireflective properties in a dynamic vehicle environment have to be detected and tracked, and also if Cartesian position determination via sensor data fusion (2-D triangulation) needs very precise range information.

This necessitates a minimum Bandwidth Bocc in the order of 5 GHz.

Current regulations. (CEPT/ERC Recommendation 70-03 [1], annexes 5 and 6).

Technical and regulatory parameters are defined in the CEPT/ERC Recommendation 70-03 [1] in annex 1 (Generic applications) annex 5 (RTTT) and annex 6 (Movement and Alert).

The SRD ISM bandwidth is 200 MHz (CEPT/ERC Recommendation 70-03 [1], annex 6) and is too narrow to accommodate the SRR modulation spectrum.

5 Excerpt of CEPT/ERC Recommendation 70-03 [1], annex 6

This 24 GHz specification table can be used for CEPT/ERC Recommendation 70-03 [1], annex 5 with an added transmission mask.

Equipment for Detecting Movement and Equipment for Alert

Available ETSI Standard: I-ETS 300 440

Superseded Recommendations: CEPT Recommendation T/R 60-01

Technical and regulatory parameters:

For interpretation of codes, see Appendix 1

	Frequency Band	Power (table 2)	Antenna (table 3)	Channel spacing (table 4)	Licensing requirement (table 5)	Approvals (table 6)	Duty cycle (table 7)
f	24.05-24.25 GHz	11 (100mW)	1 or 2	13	2	1, 2 or 4	-

7 Main conclusions

Business importance and social economic impact

- An automotive Industry group SARA (Short range Automotive Radio frequency Allocation) was recently formed to accelerate the introduction of SRR systems. The timely introduction of the technology is given through the early availability of standards and regulations. This is in fulfilment of the RTTT programs of the EU (see bibliography).
- The industry has made significant investments in the 24 GHz SRR technology and eagerly awaits provision of regulations and availability of radio standards.
- The Automotive Industry and the VDA are actively supporting the SARA activity.

  SARA SRR members are:

  - DaimlerChrysler, BMW, Ford, Opel/GM, Porsche, Volkswagen, Audi, Bosch, Siemens, Valeo, M/A-COM, Hella, A.D.C., Delphi, TRW, SMS, Innosent and others.

Expected timing for products to market

- The market is requesting cost-effective units right now. Prototypes for characterization are available,
- Pilot units are foreseen in the first half of 2002 with volume production to start either late 2002 or early 2003.
- An essential requirement is the availability of the ETSI standard as well as the amendment of the CEPT/ERC Recommendation 70-03 [1] for annex 5.

Requested ERC actions

- Compatibility evaluations and studies for services as defined under clauses C.1 and C.2 of the present document.
- Update of CEPT/ERC Recommendation 70-03 [1], annex 5, specifying an emission mask.

Annex A: Detailed market information

A.1 Range of applications

Short range Radar functions

Collision warning

Precrash sensing,

Firing of restraints, Airbags

Stop, follow and roll,

Recognition of all Traffic members,

Lane departure warning,

Blind spot detection,

Parking aid,

Pedestrian recognition.

A.2 Market size and value

The value can be expressed in the commercial business volume and the social economical benefit and savings.

Table 1

Business volume (EU)

	Year	2003	2004	2005	2010	2015	2020
Car production rate	MU / Y	17	17,5	18,0	18,6	19,1	19,7
Cars using SRR	%	0,06	0,3	5	15	35	60
Cars using SRR	kU	10	53	902	2.786	6.697	11.825
Average units / Car	Units	10	10	8	6	5	4
Price / Sensor unit	EUR	65	55	38	32	20	15
Value / Car incl. others	EUR	845	715	395	250	130	78
Total Value / Car	Billion EU	8.6	38	363	695	870	922

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 68 Billion DM).

The number of cars in Europe is increasing, which leads to a higher traffic density. The average age of European 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 obstacle detection systems that operate at day and night (see figure 1).

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.

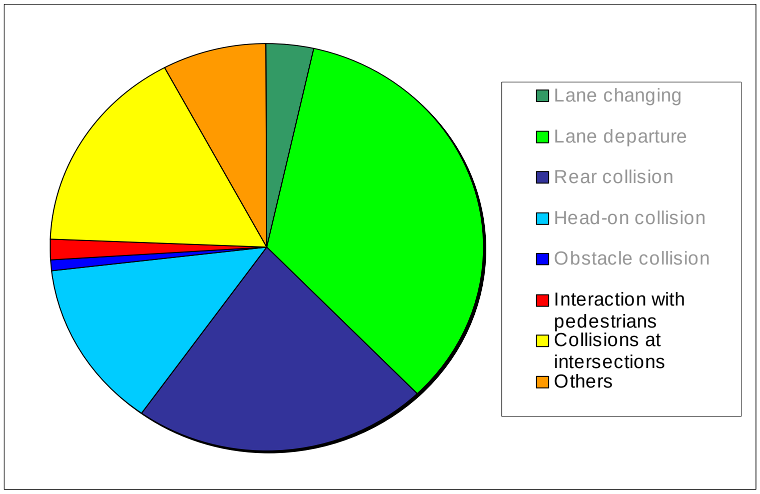

Figure 1: Causes of Accidents in Road traffic outside of Towns (97)

Annual damage cost caused by accidents in the EU is approx. Billion EUR 100 which can be potentially avoided or minimized according to 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.

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

The precrash application could well be an EC-wide mandate, thus every car produced in the EU would have several radar sensors.

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 level for the in band transmission is according to the annex 6 of the CEPT/ERC Recommendation 70-03 [1] is 10 mW peak while the modulation level, which is below the spurious level, 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 ten SRR devices.

Annex B (informative): Technical information

B.1 Detailed technical description

There are several wideband modulation technologies as known from spread spectrum technologies, which can be used for short-range radar systems.

Overview of SS Systems for Automotive Radar

A spread spectrum (SS) signal being "spread" over a large bandwidth can coexist with narrowband signals only adding a slight increase in the noise floor that the narrowband receivers see. As for the spread spectrum receiver, it does not see the narrowband signals since it is listening to a much wider bandwidth at a prescribed code sequence.
There are three basic types of spread spectrum techniques usable for automotive low cost carrier based radar devices, which also might be combined in hybrid concepts:

1) PN--PSK (Pseudonoise coded phase shift keying)

   The carrier phase of the continuously transmitted sinusoidal signal is changed according to a pseudorandom code sequence. The pseudorandom code sequence has a fixed length, which is repeated after a given number of bits. The speed of the code sequence is called the chipping rate, measured in chips per second (cps). The occupied Bandwidth depends upon the chipping rate. At the receiver, the information is recovered by multiplying the signal with a locally generated replica of the code sequence. Due to a finite phase shift precision a certain degree of a residual carrier remains.

2) PN-FHSS (Pseudonoise coded Frequency Hopping Spread Spectrum)

   In frequency hopping systems, the carrier frequency of the transmitted Sinusoidal signal hops over a defined frequency range according o a pseudo random code sequence. The frequency hopping sequences are dictated by the code sequence. The receiver tracks these changes and produces a constant IF signal. The occupied Bandwidth is equal to the total frequency shift utilized by the steps.

3) PN-PPM (pseudonoise Pulse position Modulation)

   The period of a pulsed RF carrier is varied in a pseudorandom manner by a coded sequence. The occupied bandwidth is related to the pulse duration. Due to a finite amplitude modulation, a residual carrier leakage is transmitted between the pulses.

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

All these SS types - including further concepts optimized for communication channels- have the following advantages and disadvantages in common:

Advantages:

- Resists intentional and non-intentional interference of narrowband and to a degree wideband emissions.
- Reduces or eliminates multipath effects
- Improve spectrum efficiency by permitting sharing of the same bands
- Individual sensor privacy due to the pseudo random code sequence (code division multiplexing)

Disadvantages:

- Larger bandwidth (BW) but at lower power densities.
- More complex implementation

The larger or relative bandwidth inefficiency does not really apply for the automotive usage of SS radar systems. This stems from the fact that for range accuracy and target separation capability only the absolute bandwidth (or its reciprocal, the pulse duration) is relevant and not the information rate of the binary message (or the PN code, respectively). Indeed the information transmitted contains only the transmitter-specific pseudo-noise sequence and no varying data messages.

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

The basic transmitter block diagrams and spectral emissions of SRR systems are shown in figures 2 to 5.

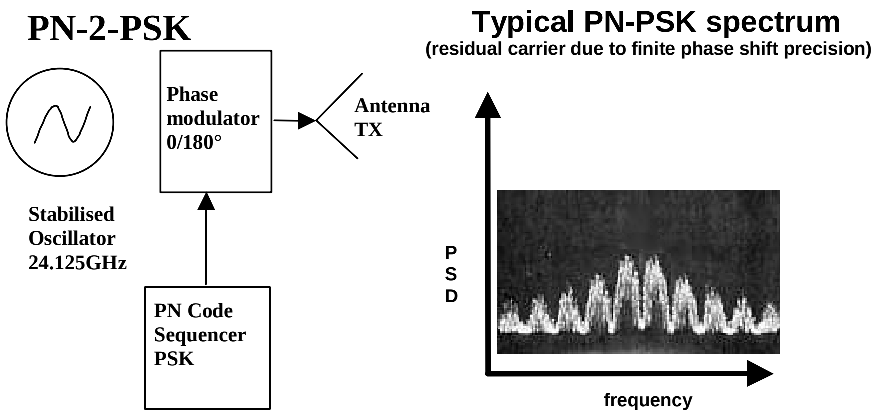

Figure 2

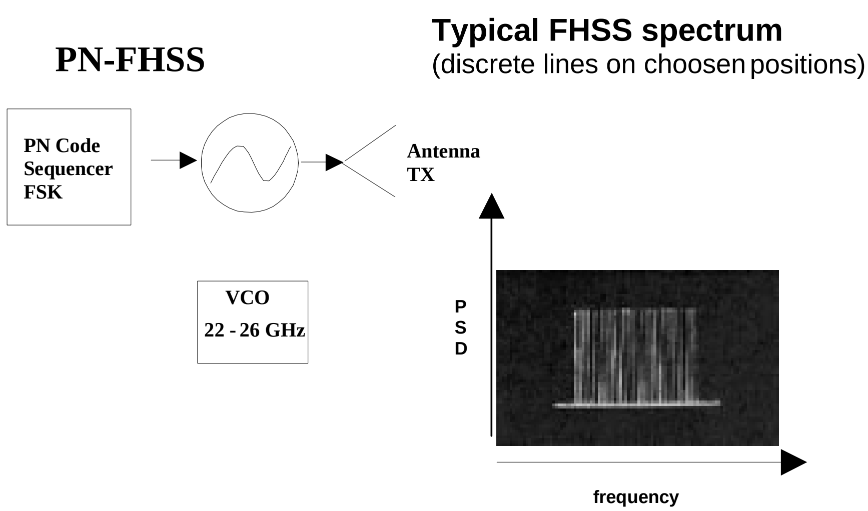

Figure 3

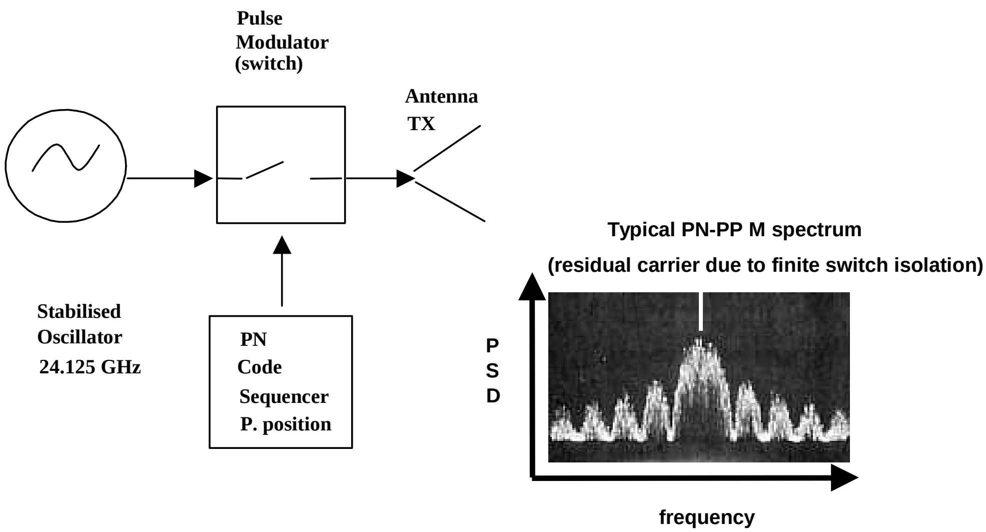

Figure 4

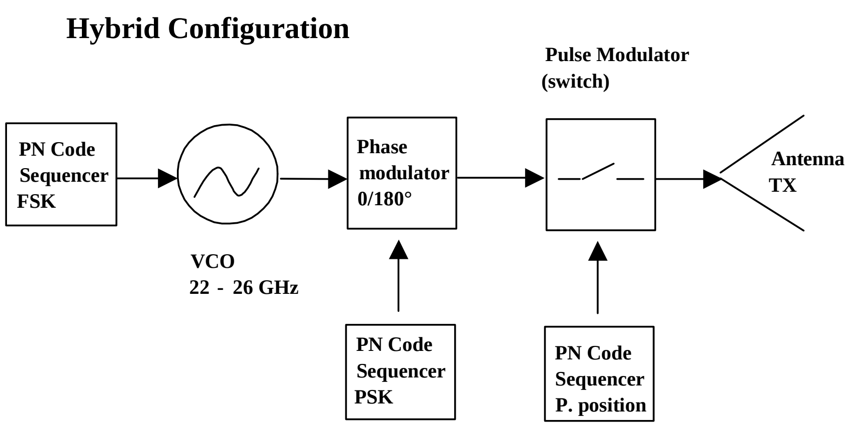

Figure 5

B.2 Technical justifications for spectrum

B.2.1 Power

The peak power level at the nominal carrier frequency of 24,125 GHz is 20 dBm or 100 mW. This is needed to provide the Doppler operation of the SRR.

The average power is in the range of -15 up to 0 dBm depends on the range required by the application.

B.2.2 Frequency (See also spectrum requirements clause 4.2)

The centre frequency is set at 24,125 GHz; with a typical tuning tolerance of +/- 0,05 GHz as determined by cost effective frequency stabilization of the oscillator.

At 24 GHz, the integration of moderate antenna sizes within the vehicle bumpers is feasible. The bumper material allows invisible integration because of the low absorption at this frequency. The technology also allows cost effective solution to meet market needs while providing the needed performance in resolution and operating range

> *(77 GHz systems would have to use an "open" mounting in bumpers, secondly the 77 GHz component availability and component cost as well as the precision mounting of chips itself penalizes production cost, yield)*

B.2.3 Bandwidth and other radio parameters

See figure 6.

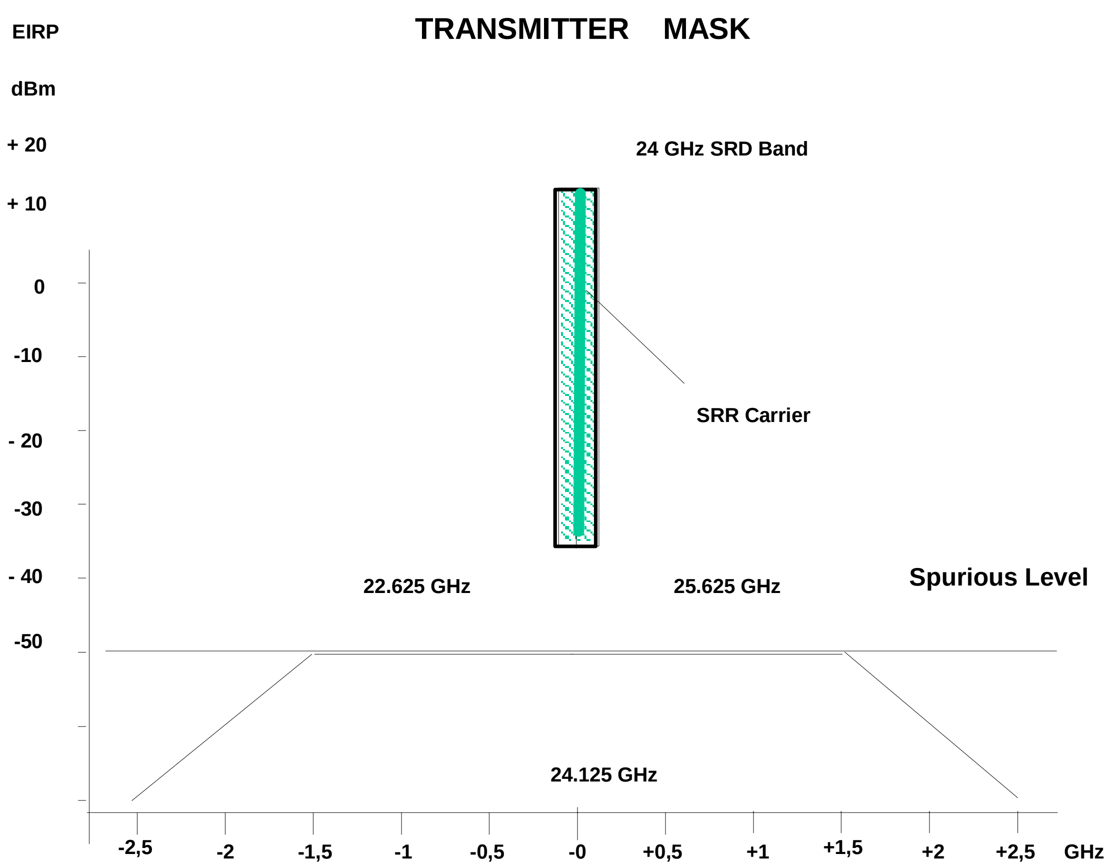

Figure 6

Measured at 100 kHz RBW with maximum dwell times of 10 µsec.*

NOTE: *final approval for measurement specifications to be determined.

The mean PSD defined in the transmitter mask shall be measured with a minimum RBW of 100 kHz.

If the system concept utilizes additional time gating, the minimum VBW is specified to 100 kHz. Furthermore the SA shall be switched into "peak (max) hold" mode. If the system does not utilize further time gating, the minimum VBW is specified to 1 kHz (according to ETSI EN 301 091-1 [3], clause 7.1.3).

Peak behaviour (the following clarification has been added in responses to ETSI-ERM-TM4).

With the measurement conditions proposed (100kHz RBW, 100kHz VBW, "peak max hold") for pulsed or time gated transmitters the spectrum mask effectively describes a mean PSD for wideband victim receiver systems, which utilize channel capacities higher then the measurement bandwidth mentioned above (e.g. fixed services).

The peak power evaluation during the compatibility studies depends on the one hand on properties of the transmitter system (e.g. PEP, pulse duration, duty cycle, freq. hopping position...) and on the other hand on properties of the considered victim receiver (e.g. IF-bandwidth of all stages, data rate, processing gain...).Therefore the evaluations should be performed case by case.

Limitation of vertical antenna characteristic

The vertical antenna pattern shall be limited according table 3 with respect to the maximum antenna gain. The vertical antenna angle is positioned on 0° for a vector direction parallel to ground and on –90° for a vector direction from top to ground. The vertical antenna pattern shall be measured within the azimuth plane of EIRP_max.

Table 2: Limitation of vertical antenna pattern

Vertical antenna angle θ in °	spatial antenna gain
θ < -75° and θ > 45°	G_dBi_max –30 dB
-75° < θ < -30°	G_dBi_max + 0,666 × [dB/°](θ +30°)
-30° < θ < 0°	G_dBi_max
0° < θ < 45°	G_dBi_max – 0,666 × θ [dB/°]

The mounting height is limited to maximum 1,50 m.

(according draft standard ETSI EN 301 091-1 [3], clauses 7.2.3.3 and 7.2.3.4).

B.3 Information on current version of relevant ETSI standard

The EN 301 091 [3] covers RTTT Radar equipment used for 77 GHz Adaptive Cruise Control (ACC) systems.

The standard needs amending to include 24 GHz short-range radar applications and to cover the different technologies for SRR functions.

Annex C (informative): Expected compatibility issues

C.1 Coexistence studies (if any)

Primary Services in the range of 21,625 GHz to 26,625 GHz

- fixed Links;
- Astronomy;
- Space research;
- Inter Satellite;
- Mobile;
- Earth exploration-Satellite.

Secondary services

- SRD's operating in the ISM band
- Amateur radio
- Amateur Satellite

C.2 Current ITU allocations

Same as under clause C.1 of the present document, plus radio navigation

C.3 Sharing issues

Compliance evaluation and studies are to be conducted for sharing with services under C.1 and C.2 of the present document. Especially the fixed link and astronomy services require sharing studies.

Annex D (informative): Item check lists

1. Approval by RP08

    1. Decision - normative annex to EN 300 440-1 [2] or inclusion in EN 301 091[3]

    2. Approval of S.R. by ERM RM

    3. Liaison Statement to SRD MG

    4. Liaison statement to SE

Annex E (informative): Bibliography

The EU Approach to Road Safety and Intelligent Transport systems (ITS), EU Commission Unit INFSO/B/5, Fotis Karamamitsos, http://www.cordis.lu/ist/ka1.

RESPONSE, Project TR4022, Advanced Driver assistance Systems, System safety and driver performance. http://www.cordis.lu/telematics/tap_transport/research/projects/response.html.

Prof. Peter Knoll, Martin Reiche, Robert Bosch GmbH, "Short Range Automotive Radar (SRR) ERO/ERC workshop on regulatory issues regarding introduction of UWB in Europe. 20 March 2001, – RegTP in Mainz http://www.ero.dk/eroweb/srd/SRD-UWB.htm.

Bundesanstalt für Strassenwesen (BAST), "Volkswirtschaftliche Kosten der Personenschäden im Strassenverkehr", Publication of BAST, Issue M102, Jan. 1999, Authors Herbert Baum, K-J Höhnscheid, University of Cologne.

History

Document history		
V1.1.1	July 2001	Publication