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**COMPATIBILITY BETWEEN WIDE BAND LOW ACTIVITY MODE (WLAM)
AUTOMOTIVE RADARS IN THE FREQUENCY RANGE
24.25 GHz TO 24.5 GHz
AND
OTHER RADIOCOMMUNICATION SYSTEMS/SERVICES**

Montegrotto Terme, May 2011

0 EXECUTIVE SUMMARY

Currently in Europe the narrow-band automotive radars operate in the 24.05 - 24.25 GHz band and follow the limits contained in Annex 6 of Rec. 70-03 for movement detection and are also compliant to the ETSI standard EN 300 440. According to ETSI TR 102 892 some radar manufacturers wish to extend the radar emissions up to 24.5 GHz, extending the bandwidth from 200 MHz to 450 MHz. The wider bandwidth will be only activated in specific driving conditions, i.e. for pedestrian safety.

This ECC Report only considers the compatibility between WLAM in the frequency range 24.25 GHz to 24.5 GHz, and other systems/services.

The WLAM systems (Wide band Low Activity Mode) can operate in three different modes:

- Forward facing Radars
 - Calibration mode (Front-permanent mode), which consists in a few low-power CW emissions with -11 dBm in 24.25 – 24.495 GHz and -8 dBm in 24.495 - 24.5GHz.
 - APPS mode (Front Emergency mode) which is a frequency modulated emission in 24.05-24.5 GHz with +20 dBm e.i.r.p., activated for emergency braking support in case of a crash event monitored by a camera, for a vehicle speed above 20km/h.
- Rear facing Radars
 - Rear-parking mode, which is a frequency modulated emission in 24.05 - 24.5 GHz with +16 dBm e.i.r.p., activated only when the vehicle moves back to better discriminate pedestrians.

The following characteristics were considered in the study:

Table 1: WLAM operational characteristics

Mode or Activation event	Peak e.i.r.p.	Modulation bandwidth	DC	Technical conditions of activation
Standard ISM mode	+20dBm	200 MHz (24.05-24.25 GHz)	--	--
Calibration	-11dBm (24.25-24.495GHz) -8dBm (24.495- 24.5 GHz)	450 MHz (24.05-24.50 GHz)	0.25%/s/25 MHz within 24.25-24.495 GHz 1.5%/s within 24.495-24.5 GHz	Gear in forward drive mode Forward looking radar only
Active braking for Pedestrian Protection System (APPS)	+20 dBm	450 MHz (24.05 - 24.50 GHz)	5.6%/s/25MHz during activation within 24.25-24.50 GHz	- V>20km/h, <u>and</u> - Emergency braking flag monitored by a forward looking camera in case of a crash event - Maximum activation time may need to be defined by ETSI
Rear parking	+16 dBm		2.3 %/s/25MHz during activation within 24.25-24.50 GHz	- V<30km/h, <u>and</u> Gear in reversing mode Rear facing radar only

WLAM Standard Mode (Forward facing and Rear facing radars) will operate in the 24.05 - 24.25 GHz band, based on the existing standard (EN 302 858-2), they are compatible with the others services/applications operating in this frequency range.

Standard P-P fixed links and ENG/OB services (temporary fixed links and cordless cameras) have been considered in the compatibility studies. There are no channel arrangements for the Fixed Service established within the ECC for the 24.25-24.5 GHz band. However, in the case where traditional Fixed Service stations are used by some administrations, compatibility studies of this class of stations with WLAM radars may be required on a national basis. The following conclusions were reached considering the impact of WLAM on ENG/OB based on the mean e.i.r.p. values of WLAM (averaged over 1s).

For the **calibration** mode:

- Within the frequency band 24.25-24.495 GHz, the resulting I/N of -26 dB is compliant with the long term and short term criteria.
- Within the frequency band 24.495-24.5 GHz,
 - the I/N of -8 dB is compliant with the short term objective (I/N of 18dB),
 - but not compliant with the long term objective (I/N of -20dB).

In the case of SAP/SAB temporary applications, they are expected to perform a frequency scan before emitting to check if other temporary services are already using the same band limiting the risk of interference. In addition, due to their nature, the deployment of SAP/SAB links will be temporary and any interference resulting from WLAM will be sporadic, limiting the risk of long term interference.

For the **rear parking** mode:

- The short term criterion (I/N of 18dB) is met (see Figure 13).
- The long term criterion is not met, but it is expected that this criterion will not be exceeded for more than 1.67% of the time (for worst case parking scenario - see section 6.3.3). The shadowing effect will decrease this probability. In addition, it is expected that the interference level won't exceed I/N=0dB over more than 0.05% of the locations in urban environment (see Table 13).

For the **APPS** mode with a mean power of -6.5 dBm/MHz/s e.i.r.p., the results can be summarised as follows:

- The short term criterion (+18dB) is met taking into account realistic scenarios.
- The long term criterion is not met. However, due to their nature, the deployment of SAP/SAB links will be temporary and any interference resulting from WLAM used just in emergency situations will be sporadic (0,03s/km per year), limiting the risk of long term interference.

In addition, the following limits are proposed for unwanted emissions falling into the band 23.6-24 GHz in order to protect RAS and EESS:

- -71 dBm/MHz e.i.r.p.
- With an additional average antenna attenuation of at least 20dB above 30° elevation.

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LIST OF ABBREVIATIONS

The following table provides the list of abbreviations and their meaning in this report.

APPS	Active braking for Pedestrian Protection Support
BW	Bandwidth
BWCF	Bandwidth Correction Factor
CW	Continuous Wave
ECA	European Common Allocation
EESS	Earth Exploration Satellite Service
e.i.r.p.	Equivalent Isotropically Radiated Power
ENG/OB	Electronic News Gathering/ Outside broadcast
FMCW	Frequency Modulated Continuous Wave, one of LPR sensing technologies
I/N	Interference-to-Noise ratio
INSEE	Institut National de la Statistique et des Etudes Economiques (France)
ISM	Industrial, Scientific and Medical
LoS	Line-of-Sight
NB	Narrow Bandwidth
NHTSA	National Highway Traffic Safety Administration (US)
ONISR	Observatoire national interministériel de sécurité routière (France)
PMP	Point-to-Multipoint system in Fixed Service
PP	Point-to-Point links in Fixed Service
Rx	Receiver
SAP/SAB	Services Ancillary to Programme making / Services Ancillary to Broadcasting
SRdoc	ETSI System Reference document
SRR	Short Range Radar
TLPR	Tank Level Probing Radar
UWB	Ultra-Wideband technology
WLAM	Wide band Low Activity Mode

**Compatibility between Wide band Low Activity Mode (WLAM)
automotive radars in the frequency range 24.25 GHz to 24.5 GHz,
and other radiocommunication systems/services**

1 INTRODUCTION AND BACKGROUND

Currently in Europe the narrow-band automotive radars operate in the 24.05 - 24.25 GHz band and follow the limits contained in Annex 6 of ERC Rec. 70-03 [1] for movement detection and are also compliant to the ETSI standard EN 300 440 [2] and EN 302 858-2 [3]. According to ETSI TR 102 892 [4] some radar manufacturers wish to extend the radar emissions up to the frequency 24.5 GHz, extending the bandwidth from 200 MHz to 450 MHz. The wider bandwidth will be only activated in specific driving conditions, i.e. for pedestrian safety.

This ECC Report only considers the compatibility between WLAM in the frequency range 24.25 GHz to 24.5 GHz and other systems/services.

2 WLAM APPLICATIONS AND TECHNOLOGY

2.1 WLAM overall characteristics

WLAM systems are automotive radars for short and mid range applications using frequency modulation techniques, like FMCW. These systems are described in ETSI TR 102 892 [4] and operate in the 24.05 – 24.5 GHz band with two modes as described below.

Narrow-Band Regular Mode (200 MHz bandwidth)

System is operating in the frequency range between 24.05 GHz and 24.25 GHz following the limits contained in Annex 6 of ERC Rec. 70-03 [1] for movement detection and compliant to the ETSI standard EN 300 440 [2]. The regular mode is the standard mode.

WLAM mode (450 MHz bandwidth)

The WLAM mode is a low activity mode, activated only a limited percentage of the operation time. In the WLAM mode the operating bandwidth is extended to a maximum of 450 MHz, from 24.05 GHz to 24.50 GHz.

2.2 WLAM systems penetration rate

WLAM 24 GHz radar technology would be based on ACC/Automatic braking system using a single mid range sensor. The WLAM mode will be used for emergency braking systems monitored by a forward facing camera. A 25-50% maximum penetration rate is expected.

A 50% penetration rate has been used for forward facing and rear applications in the present compatibility study.

2.3 WLAM systems characteristics

Table 1 provides characteristics for WLAM systems. In particular, it should be noted that WLAM systems using a wider bandwidth are activated only in specific conditions; therefore, they have a low activity factor as provided in Table 2.

Table 2: Standard mode and WLAM operational characteristics

Mode or Activation event	e.i.r.p.	Modulation bandwidth	DC	Technical conditions of activation	Probability of activation
Standard ISM mode	+20dBm	200 MHz (24.05-24.25 GHz)	--	--	100%
Calibration	-11dBm (24.25-24.495GHz) -8dBm (24.495-24.5 GHz)	450 MHz (24.05-24.50 GHz)	0.25%/s/25 MHz within 24.25-24.495 GHz 1.5%/s within 24.495-24.5 GHz	Gear in forward drive mode Forward looking radar only	100 % (see also section 2.2)
Active braking for Pedestrian Protection System (APPS)	+20 dBm	450 MHz (24.05 - 24.50 GHz)	5.6%/s/25MHz during activation	- V>20km/h, <u>and</u> - Emergency braking flag monitored by a forward looking camera in case of a crash event	Very low 0.03 s/km per year (see also section 6.3.1)
Rear parking	+16 dBm		2.3 %/s/25MHz during activation	- V<30km/h, <u>and</u> Gear in reversing mode Rear facing radar only	0.59 event/km ² for a urban density of 453 veh./km ² (see also section 6.3.2)

2.3.1 WLAM Calibration Mode

A permanent calibration mode is required for the WLAM forward looking radars to activate the WLAM mode.

The permanent calibration mode will use CW tones with the following characteristics

- -11 dBm max e.i.r.p. within 24.25-24.495 GHz, and 0.25% duty cycle in any 25MHz band
- -8 dBm max e.i.r.p. within 24.495-24.5 GHz, and 1.5% duty cycle in this 5 MHz band
- Tone duration is fixed after radar initialization, the duration is in the range of 4 to 10ms depending on the system
- In the 24.25-24.495 GHz band, the frequency of the CW tone f1, f2, f3 is changing between each activation, and spread over 100 MHz or more depending on the systems.

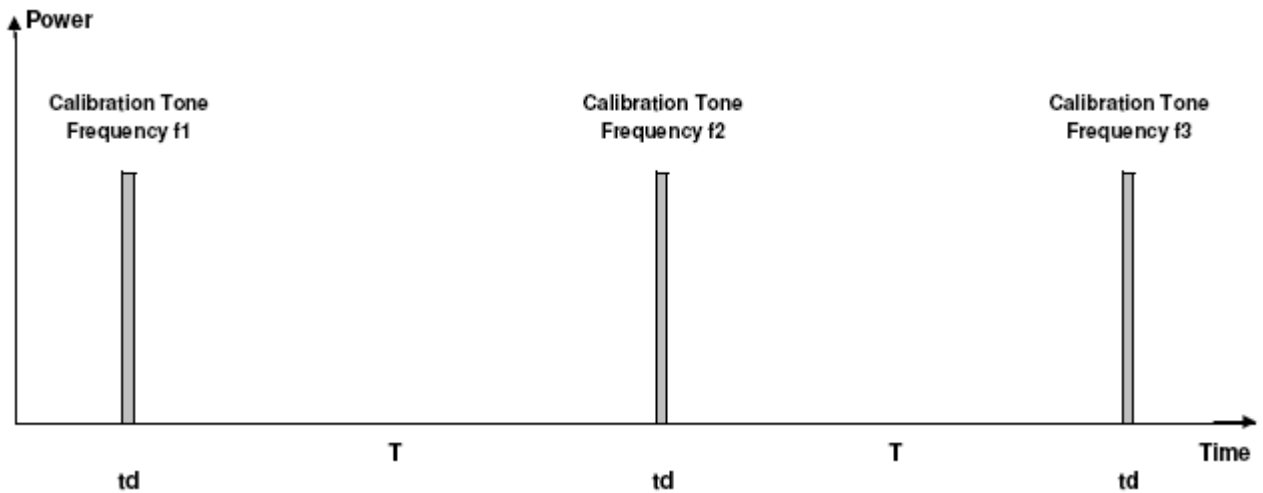


Figure 1: WLAM Calibration Tones Timing Diagram

2.3.2 WLAM – Rear parking

WLAM Rear Parking Mode aims at improving pedestrian detection in rear driving mode during parking manoeuvres.

The WLAM rear radars are side detection radars, not pointing directly to the rear of the cars (0° rear axis), but with a deviation angle A roughly distributed around a $+45^\circ$ axis as shown in Figure 2.

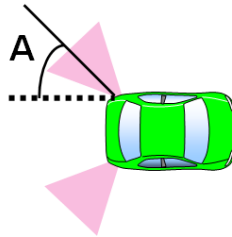


Figure 2: Rear WLAM radars pointing angles

2.4 The radar may be either using a fixed beam or scanning beams

2.4.1 WLAM – APPS Emergency Mode (Active braking for Pedestrian Protection Support)

WLAM in APPS emergency mode will be only activated when the vehicle speed $>20\text{km/h}$ and the input signal (flag) from the vehicle crash assessment system as described below. In normal situations, the driver will start braking before the WLAM activation.

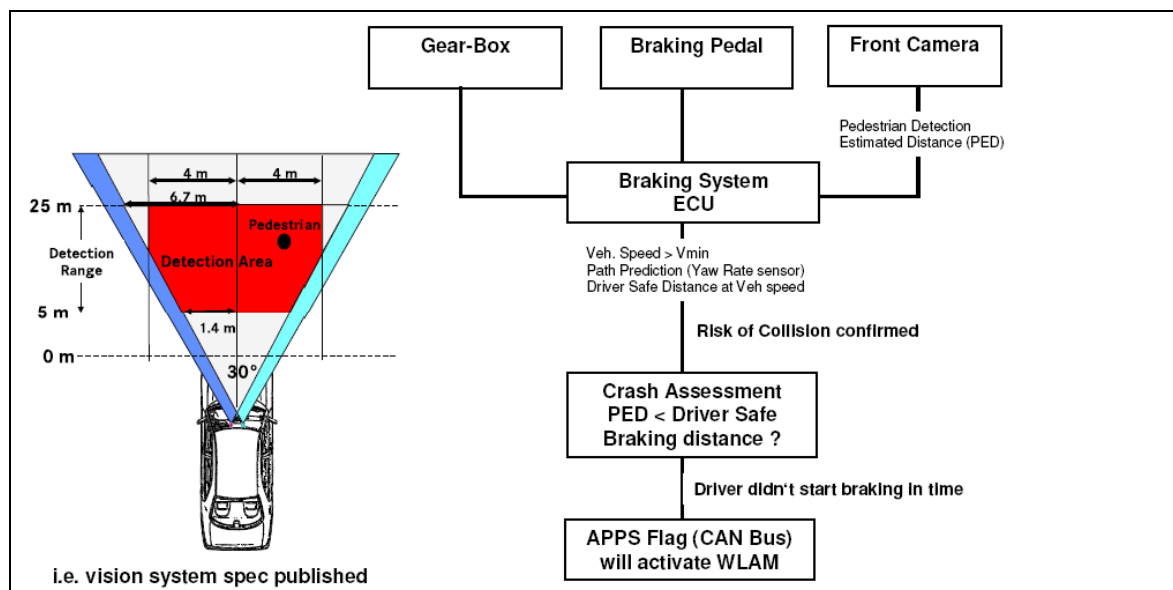


Figure 3: APPS mode detection diagram

The probability of WLAM-APPS activation can be derived from statistics from ONISR [5] which reported 12 791 accidents in 2008 in France over the 1 014 378 km road network.

Table 3: Statistics about accidents in France (2007 - 1 014 378km road network)

Crash events	Accidents with injuries/fatalities	Percentage
One car with a pedestrian	12 791	16.7%
One car with infrastructure	15 888	20.7 %
Two cars – head-on collision	7 567	9.9 %
Two cars – side collision	23 199	30.2 %
Two cars – rear-end collision	8 358	10.9 %
Three cars or more	4 897	6.4%
Other	4 067	5.3%

Thus on a 1 km road segment, there is 0.013 accident per year on average, which is also the probability of detection for WLAM APPS. This value is consistent with the indications from the American NHTSA report [6] (see Annex 1 section A.1.3) which indicates a maximum occurrence of 21.8 crash imminent alerts for 1000 km (or 0.02 event per km) for car speeds between 25 mph and 35 mph. Given that about 40% of cars exceed 25mph (40 km per hour) in cities, the resulting crash imminent alert is about 0.008 event per km (all crash situations), independently of the car speed.

WLAM APPS durations are detailed in the **Error! Reference source not found.** below.

Table 4: WLAM activation duration according to the vehicle speed

WLAM activation time for APPS mode	Key Parameters	30km/h	40km/h	50km/h	60km/h
Host Speed in m/s		8.3 m/s	11.1 m/s	13.9 m/s	16.7 m/s
Braking Time to go down to 0km/h (s) including WLAM activation	0.7 g deceleration	1.8	2.2	2.6	3.0
Distance to complete emergency braking (m)	0.3s Delay to get the braking force	10.1	15.7	22.4	30.2
Distance for a normal braking (m) including a 2m safety distance at stop	0.4 g deceleration	13.3	21.1	30.7	42.4
Time to collision at Camera Prer-crash Alert event (s)	25 m detection range (Ped.)	3.0	2.3	1.8	1.4
WLAM activation delay (s)		0.3	0.3	0.3	0.3
WLAM activation duration (s)		1.8 until a stop	2.2 until a stop	2.6 until a stop	1.5 at impact
Final speed after emergency braking (km/h)_p NB: new bumper designs avoid fatalities for collision speeds below 40km/h (EuroNCAP requirements)		0 km/h No collision	0 km/h No collision	0 km/h No collision	30 km/h Collision

WLAM-APPS is being operated 2.2 s on average per emergency breaking.

2.5 WLAM Antenna Pattern

There are two types of WLAM systems depending on the manufacturers:

- Systems with fixed beams
- Systems with scanning beams

The following tables provide typical antenna attenuation levels in the vertical plan and in azimuth.

Table 5: Vertical antenna gain attenuation

Vertical antenna pattern (attenuation)	Beamwidth angle in °	Beamwidth above the road
-5 dB	35°	+17.5°
-10 dB	40°	+20°
-20 dB	45°	+22.5 °
-23 dB	50°	+25 °
-23 dB	Outside 50°	Above +25 °

Table 6: Horizontal antenna gain attenuation

Horizontal antenna pattern (attenuation)	Half beamwidth angle in °
-8 dB	20°
-20 dB	21°
-30 dB	90°

It has to be noted that for the scanning beams systems, the attenuation levels for the side lobes apply to all individual patterns, the 0dB reference being the most directive beam.

For the scanning radars, the overall field of view covering all the scanning beams in the WLAM mode is 125° at -10dB.

3 INCUMBENT SERVICES/APPLICATIONS

The Table below is an extract from the ECA database [7] between 23.6 GHz and 25 GHz.

Table 7: Use of the spectrum 23.6 to 25.25 GHz

Band (GHz)	ECA	Major utilisation
24.05-24.25	RADIOLOCATION Amateur Earth exploration-satellite (active) Fixed Mobile 5.150	Active sensors (satellite) Amateur Defence systems ISM Non-Specific SRDs Radiodetermination applications SAP/SAB SRR
24.25-24.45	FIXED MOBILE	Radiodetermination applications SAP/SAB SRR Unidirectional fixed links
24.45-24.5	FIXED MOBILE	Radiodetermination applications SAP/SAB SRR Unidirectional fixed links

The standard mode of WLAM is operating in the lower band 24.05-24.25 GHz in conformity with ERC/REC 70-03 Annex 6. Therefore, for this frequency range no additional compatibility studies are needed. Compatibility studies are required only with regard to applications in the new upper band 24.25-24.5 GHz:

- SAP/SAB and ENG/OB temporary fixed links (see sections 5 to 7)
- TLPR operating in the frequency range 24.25-25.25 GHz (see section 9)
- SRR (see section 9).

In addition, section 7 covers the case of the EESS and the RAS operating in the frequency range 23.6-24 GHz.

4 ENG/OB AND SAB/SAP

According to the ECC Report 002 [8] the frequency band 24.25-24.5 GHz is in major use for video SAP/SAB links in Europe, in particular cordless cameras and temporary point-to-point video links, on a tuning range basis. The actual usage varies from country to country.

The usage of this frequency band for SAP/SAB is expected to increase. It is therefore proposed that the whole band should be kept as a tuning range for video SAP/SAB links.

ITU-R Report BT.2069 [9] provides two types of link as follows.

Temporary point-to-point audio link

Temporary link between two points (e.g. part of a link between an OB site and a studio) is used for carrying broadcast quality audio or for carrying service (voice) signals. Link terminals are mounted on tripods, temporary platforms, purpose built vehicles or hydraulic hoists. Two-way links are often required.

Cordless camera

These are handheld or otherwise mounted camera with integrated transmitter, power pack and antenna for carrying broadcast-quality video together with sound signals over short-ranges.

4.1 Basic characteristics

The table below gives some information on typical ENG/OB links (extracted from Table 1 in ERC Report 038 [10]).

Table 8: Information on typical ENG/OB links

Type of Link	Range	Max e.i.r.p.	Min Tx ant. gain	Min Rx ant. gain	Radio Link Path	Suitable Frequency Range	Description
Cordless Camera	<500m	6dBW 13dBW (22 GHz or 47GHz)	0dBi	6dBi	Usually clear line of sight.	Currently \leq 12GHz but future systems at 22GHz and 47GHz may be achievable.	Handheld camera with integrated transmitter, power pack and antenna.
Temporary Point-to-point Link	<80km each hop for links at <10GHz	40dBW	13dBi	17dBi	Usually clear line of sight for OB, but often obstructed for ENG use.	<10GHz for long hops. Hop length at >10GHz limited by precipitation fading.	Link terminals are mounted on tripods, temporary platforms, purpose built vehicles or hydraulic hoists. Two-way links are often required.

4.2 Deployment

Concerning ENG/OB use cases, the indoor SAP/SAB applications are not relevant for compatibility studies with WLAM automotive radars.

Outdoors use-cases that may need to be considered are:

- events which take place on a given location (e.g. sport events, outdoor concerts, news)
- events that take place on the move (e.g. cycling races).

The former scenario is rather common and therefore of a higher priority for compatibility studies.

4.3 Protection criteria

Taking into account that WLAM radar are considered as sort range devices (SRD) and according to ITU-R Recommendation F.758 [11] and F.1094 [12] the long-term protection criterion $I/N = -20$ dB should be used for ENG/OB temporary P-P links in the compatibility studies.

The short-term criteria and associated time percentages should be calculated for required performance and 99.95% availability in compliance with ITU-R Recommendations F.758 [11], SF.1006 [13], and ITU-R Report BT.2069 [9].

ECC Report 023 [14] assumed an I/N value of 15 dB as short term criterion. Since ECC Report 023 assumes a fade margin of 23 dB and ERC Report 038 [10] mentions a fade margin of 26 dB as lower value, an I/N of 18 dB will be conservatively assumed in the studies. This value should not be exceeded for more than 0.05% of time considered suitable for this temporary application.

4.4 SAP/SAB P-P links

At 24 GHz, typical antennas are parabolic dishes:

Table 9: Antenna characteristics

Size	Max gain	3dB beamwidth
0.6m	41 dBi	<1.5°
1.2m	46.4 dBi	<1°

The antenna gains derived from Recommendations ITU-R F.1245 [15] or F.699 [16] are illustrated in figure below.

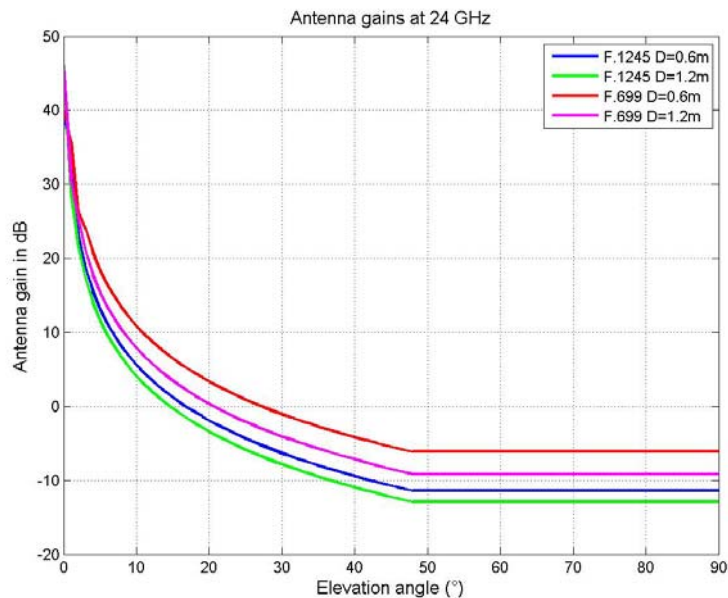


Figure 4: Antenna attenuations at 24 GHz according to ITU-R Recommendations F. 699 and F. 1245

5 COMPATIBILITY BETWEEN SAP/SAB AND WLAM IN CALIBRATION MODE

ECC Report 023 [14] considered the impact assessment on FS which is used as a reference in this ECC Report for compatibility between SAP/SAB and WLAM. The impact of WLAM in the ECC Report 023 worst case scenario is being investigated in this section.

5.1 Worst case scenario ECC Report 023 investigation

The possible interference from WLAM on SAP/SAB temporary fixed links in the worst case scenario described in ECC Report 023 is investigated.

The scenario assumes as worst case a 3 km segment of straight road parallel to the path of a SAP/SAB temporary fixed link,).

The interference from several cars considering one active front radar per car is then investigated with the following input parameters:

- SAP/SAB reception bandwidth : 25 MHz
- Victim noise floor : -168 dBm/Hz (-108 dBm/MHz), or -124 dBW/25MHz
- SAP/SAB antenna height : 10 m
- SAP/SAB antenna offset to road : 10 m
- Car spacing : 20 m
- Rain attenuation : 0.6 dB/km
- Car shielding : see formula in ECC Report 023, § 4.1.1.4.6
- Bumper attenuation : 3 dB

It has to be noted that the SAP/SAB reception bandwidth is set to 25 MHz in order to reflect realistic SAP/SAB receivers.

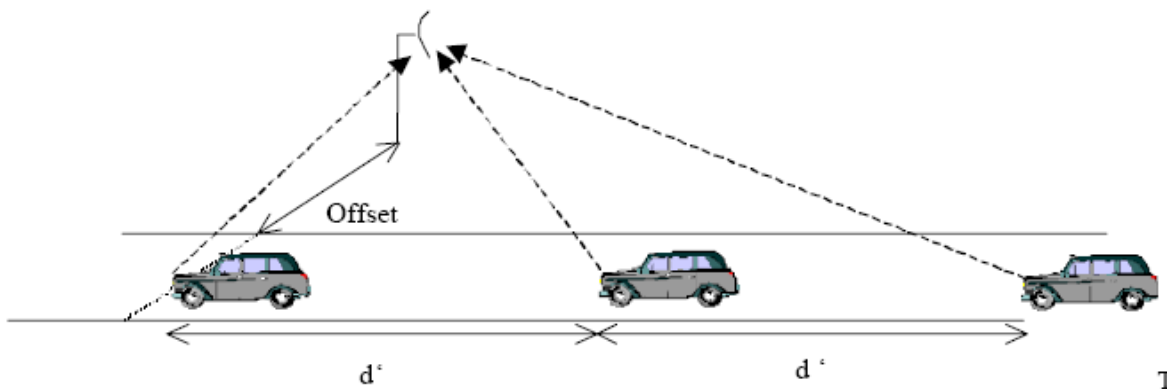


Figure 5: Scenario (extract from ECC Report 023 - Figure 17)

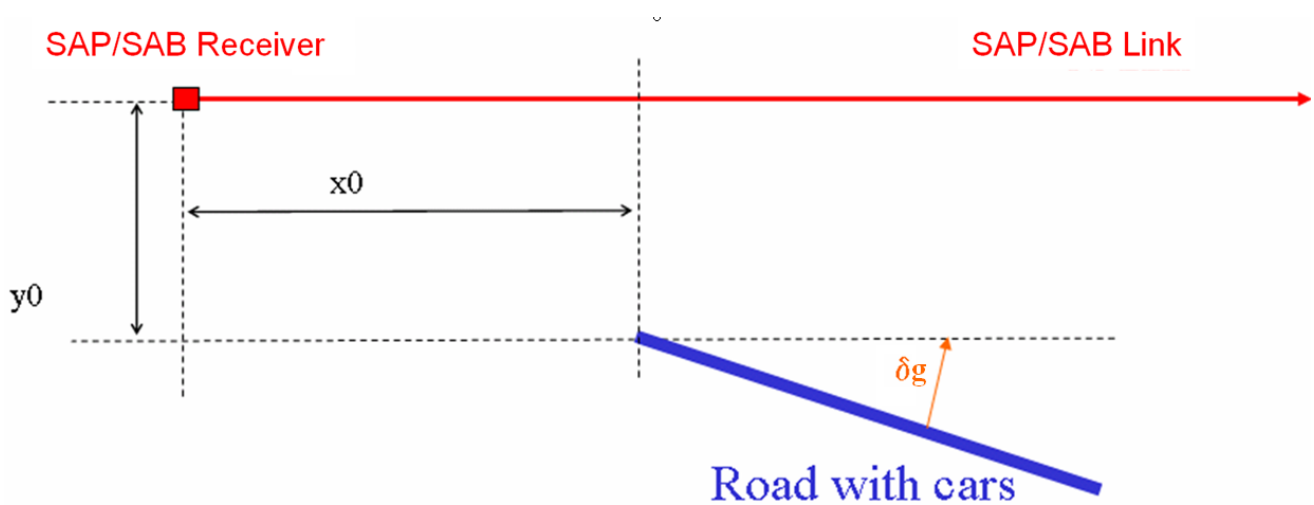
SAP/SAB temporary fixed links and cordless cameras have been considered in the compatibility study. Protection criteria and characteristics are provided in section 4.

The following table provides characteristics for the calibration mode and in particular the mean e.i.r.p. to be used in the calculations.

Table 10: calibration mode characteristics

Calibration mode	Peak e.i.r.p.	DC	Mean e.i.r.p. assuming a instantaneous bandwidth <1MHz (FMCW)
In the 24.25-24.495 MHz band	-11 dBm/ 250MHz	0.25%/ 25MHz/s	-37 dBm/25MHz/s * => -51 dBm/MHz/s **
In the 24.495-24.5 MHz band	-8 dBm/5 MHz	1.5 %/5MHz/s	-26 dBm/5MHz/s = -33 dBm/MHz/s ***
* = -11dBm + 10log(0.25%) ** = -11dBm + 10log(0.25%) + 10log(1MHz/25MHz) *** = -8dBm + 10log(1.5%) + 10log(1MHz/5MHz)			

The interference power (I_{vict}) of a single WLAM transmitter is calculated at the victim receiver on a line with a certain angle to the SAP/SAB link, with variable offset values in X, Y and Z (height) direction.

**Figure 6: SAP/SAB compatibility scenario**

The parameters are:

- e.i.r.p. max: Mean e.i.r.p. in dBm/MHz
- r_{att} : Rain attenuation (0.6dB/km)
- x_0 : Distance to the victim of the first car on the x axis (0 m)
- δg : Deviation angle in regards to road axis (0-20°)
- y_0 : Distance to the victim of the first car on the y axis (0 m)
- h : Difference between antenna heights (10m)
- dc : Distance between cars (20m)
- i : Number of cars in x direction ($i=125$ is used)
- j : Number of lanes (not relevant here, because just one lane is considered; $j=1$ is used)
- D : Antenna diameter of the SAP/SAB receiver (0.6m -> an Antenna pattern is used with 41dBi max gain based on Recommendation ITU-R F.699 [16])

The following function is used and contains the technical parameters of the calculations:

$$I_{vict}(e.i.r.p., \delta g, y_0, h, dc, i, j, D)$$

The max acceptable power level at the SAP/SAB receiver used in ECC Report 023 [14] of -128 dBm/MHz, which is equivalent to the long term objective of I/N -20 dB, is displayed as reference.

- System 1: -11dBm/250MHz, 0.25%/25 MHz, mean e.i.r.p. -51 dBm/MHz/s

- System 2: -8dBm/5MHz, 5% 1.5%/25MHz, mean e.i.r.p. -33 dBm/MHz/s

In the calibration mode a WLAM mean power level of -51 dBm/MHz/s is assumed (see Table 10).

The results with -41 dBm/MHz are shown to give a comparison with the SRR discussions – red line in Figure 7 (4dB objective discrimination with 1 sensor, see ECC Report 158 on 26 GHz SRR [17]).

Figure 7 shows the results of the single entry scenario (inline with the scenarios of ECC Report 023 [14] and ITU-R SM.2057 [18]). The assumed one sensor per car is in LoS to the victim receiver. The blue dotted line shows the results for the calibration mode sensor with parallel road ($\delta g=0^\circ$), while for the green and violet curve the angle is 10° and 20° . The light blue is -128 dBm/MHz, representing the protection criterion of $I/N=-20\text{dB}$.

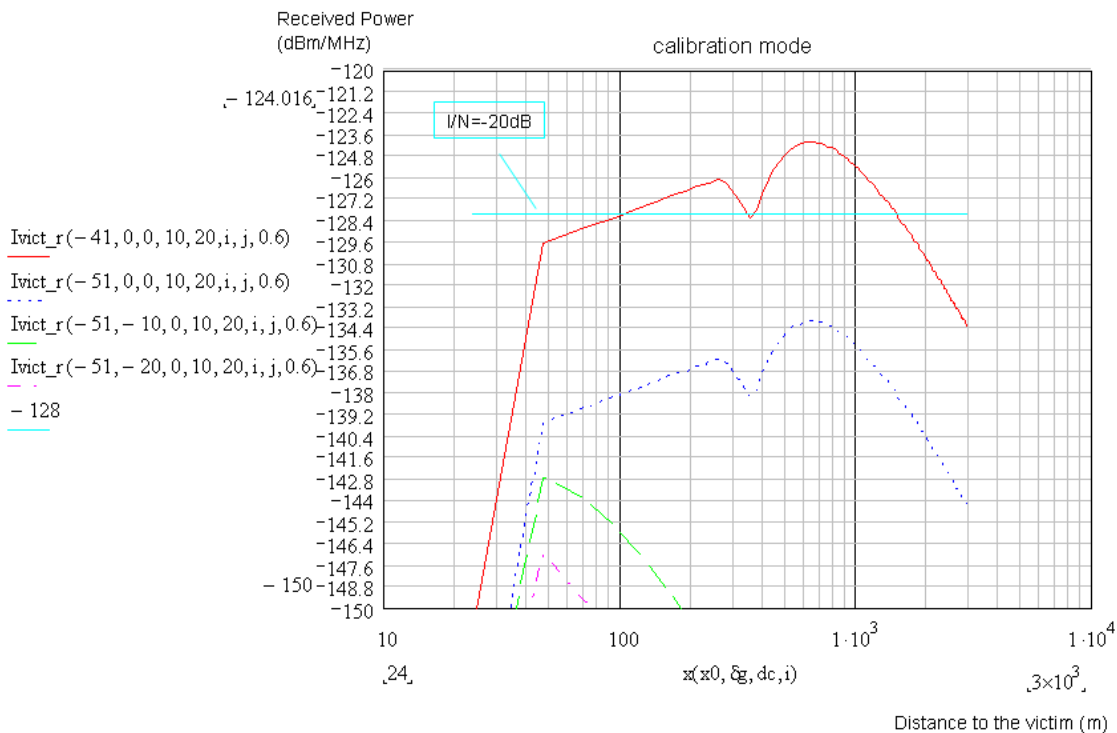


Figure 7: Calibration mode, Single entry scenario without shadowing and with different angles between line and road (red curve is related to SRRs and used as reference)

The -11dBm calibration (-51dBm/MHz/s) mode results in an interfering power of -134dBm/MHz which is compatible with the long term objective of -128 dBm/MHz ($I/N = -20\text{dB}$). This corresponds to $I/N=-26\text{ dB}$.

The -8 dBm WLAM calibration mode in the band 24.495 to 24.5 GHz emits 18dB higher (-33 dBm/MHz/s, see Table 9), thus the interfering power is -116 dBm/MHz which is 12dB above the long term objective. This corresponds to $I/N=-8\text{ dB}$.

5.2 Conclusion for calibration mode

Single entry calculations:

- Within the frequency band 24.25-24.495 GHz, the resulting I/N of -26 dB is compliant with the long term and short term criteria.
- Within the frequency band 24.495-24.5 GHz,
 - the I/N of -8 dB is compliant with the short term objective (I/N of 18dB),
 - but not compliant with the long term objective (I/N of -20dB).

There are no channel arrangements established within the ECC for the 24.25-24.5 GHz band. However, in the case where traditional Fixed Service stations are used by some administrations, compatibility studies of this class of stations with WLAM radars may be required on a national basis..

In the case of SAP/SAB temporary applications, they are expected to perform a frequency scan before emitting to check if other temporary services are already using the same band limiting the risk of interference. In addition, due to their nature, the deployment of SAP/SAB links will be temporary and any interference resulting from WLAM will be sporadic, limiting the risk of long term interference.

6 COMPATIBILITY BETWEEN SAP/SAB AND WLAM APPS OR WLAM REAR PARKING MODES

This section studies an interference scenario between WLAM in APPS and parking modes and SAP/SAB receivers (in particular ENG/OB) inspired from ECC Report 023 “worst case” scenario for FS P-P link.

Section 6.1 addresses the case of high SAP/SAB antenna gain (41dBi) and section 6.2 addresses the case of low SAP/SAB antenna gain (15dBi).

6.1 Scenario of interference between temporary SAP/SAB P-P and WLAM (APPS and rear parking modes)

The scenario is the same as in section 5.1 and considered is the following:

- A SAP/SAB P-P link receiver is located on top of a mast located along a straight road of 3000 m: this scenario quite similar to the FS scenario of ECC Report 023
- the SAP/SAB receiver has a 10m height
- the SAP/SAB receiver is pointing parallel to the straight road

The following table shows the emission characteristics of the APPS and parking modes.

Table 11: APPS and rear parking mode characteristics

Mode	Peak e.i.r.p.	DC	Mean e.i.r.p. assuming a instantaneous bandwidth <1MHz (FMCW)
Active breaking for Pedestrian Protection System (APPS)	20 dBm/ 450 MHz	5.6 % / 25MHz/s within 24.25-24.5GHz	3.4 dBm/25MHz/s => -6.5 dBm/MHz/s *
WLAM Rear parking	16 dBm/ 450 MHz	2.3 % / 25MHz/s within 24.25-24.5GHz	-0.4 dBm/25MHz/s => -14.5 dBm/MHz/s **
* 20dBm + 10log(2%) + 10log(1MHz/25MHz)			
* 20dBm + 10log(5,6%) + 10log(1MHz/25MHz)			
** 16dBm + 10log(2.3%) + 10log(1MHz/25MHz)			

A mean power level of -14.5 dBm/MHz/s is assumed for the single entry calculations for these modes. The aggregation is assumed to be irrelevant for these modes, due to the very low occurrence probability of the aggregated scenario. The same assumptions as in section 5 for the calibration mode are used here.

Figure 8 to 11 show the interfering power at the SAP/SAB receiver for each of the cars on the 3 km long road:

- Figure 8 shows the impact of the angle between link direction and road without shadowing
- Figure 9 shows the impact of the angle between link direction and road with shadowing
- Figure 10 shows the impact of the car separation (5-40m)
- Figure 11 shows the impact of the SAP/SAB antenna diameter (0.1-0.65m).

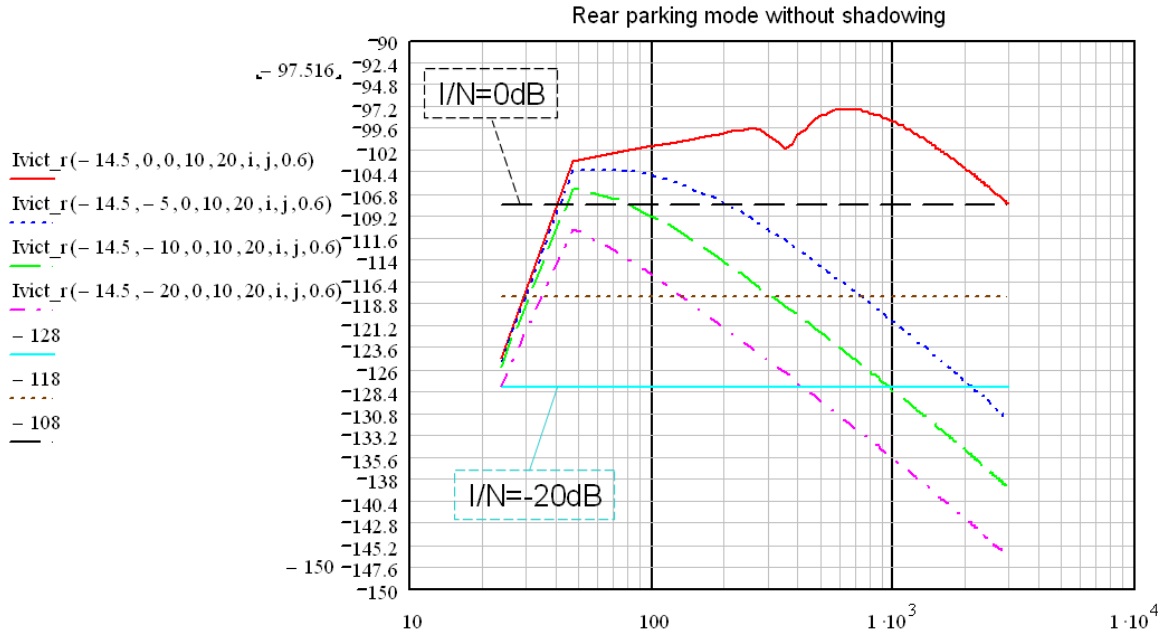


Figure 8: Impact of the deviation angle between link direction and road without shadowing, with a 10m SAP/SAB height, angle δ between 0° and -20°

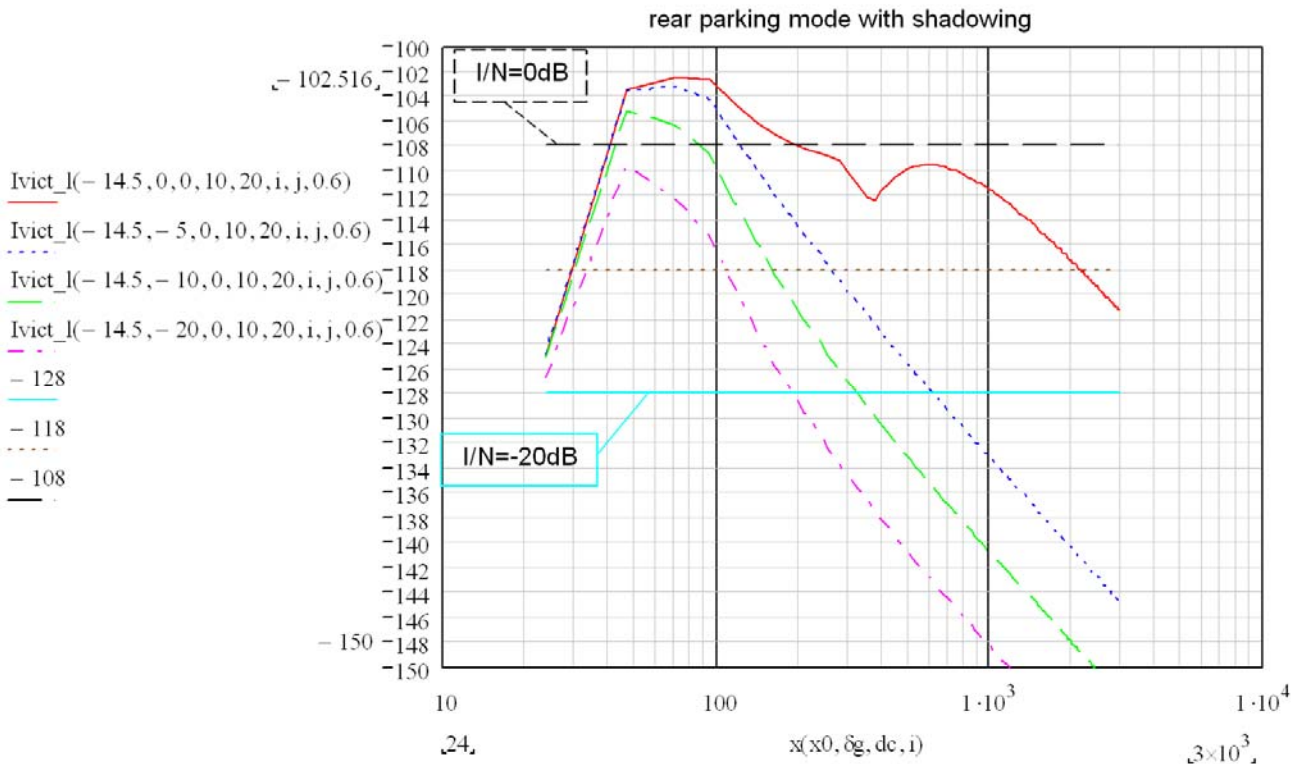


Figure 9: Impact of the angle ($0-20^\circ$) between link direction and road with shadowing (car distance 20m)

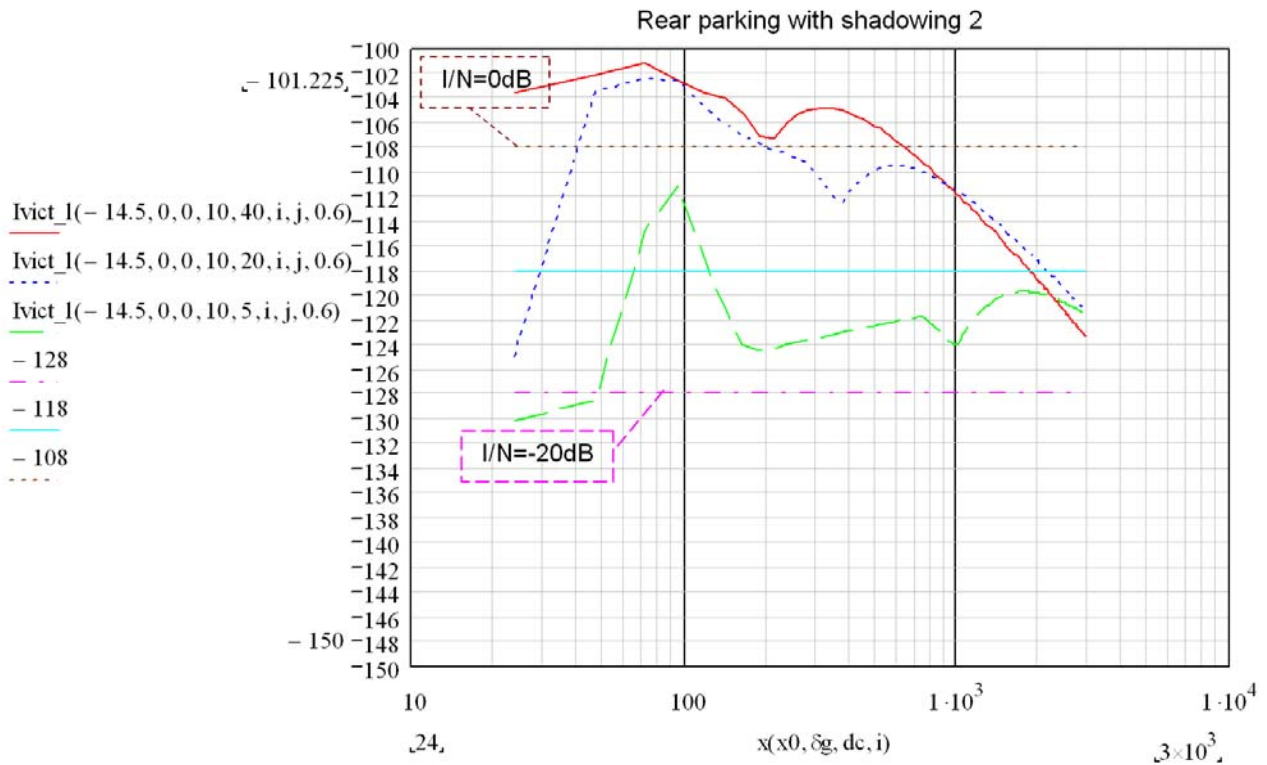


Figure 10: Impact of the car separation (5m, 20m, and 40m)

I/N max of 0dB is achieved with a car separation of 5m (parking lots)

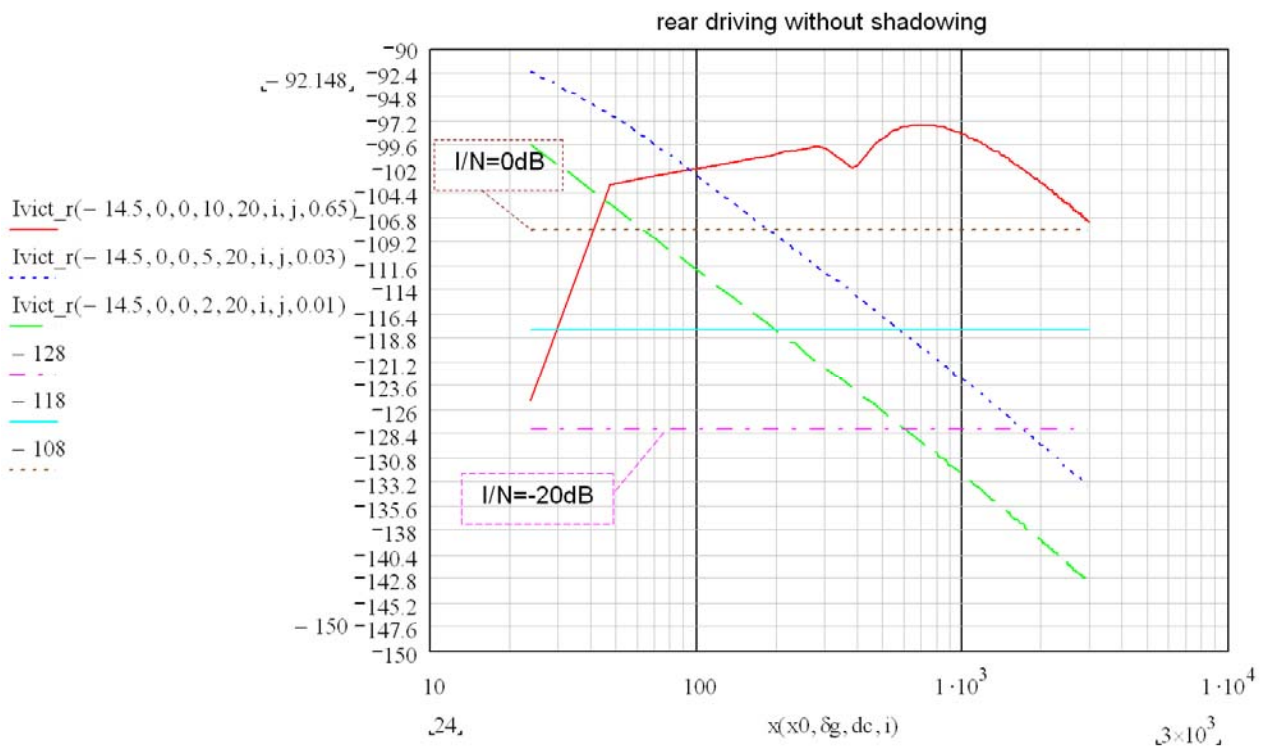


Figure 11: Impact of the SAP/SAB antenna diameter (0.1-0.65m)

6.2 Scenario of interference between ENG/OB (temporal PP links and cordless cameras) and WLAM (APPS and rear parking modes)

Relevant ENG/OB applications in this frequency band are described in ERC Report 38 [10]:

- o Temporary PP links (~15dBi antenna gain)
- o Cordless cameras (~6dBi antenna gain)

The parameters are:

e.i.r.p. max: Mean e.i.r.p. in dBm/MHz (-10,5dBm/MHz) for the APPS mode and -14.5 dBm/MHz for the rear parking mode

r_att: Rain attenuation (0.6dB/km)

x0: Distance to the victim of the first car on the x axis (0 m)

δg: Deviation angle in regards to road axis (0°)

y0: Distance to the victim of the first car on the y axis (0 m)

h: Difference between antenna heights

- o 10m for PP (**red curve**)
- o 5m for ENG/OB temporal links (**blue dotted curve**)
- o 2m for cordless cameras (**green curve**)

dc: Distance between cars (20m)

i: Number of cars in x direction (i=125 is used)

j: Number of lanes (not relevant here, because just one lane is considered; j=1 is used)

D: Antenna diameter of the FS receiver (an ITU-R Rec. F.699 Antenna pattern [16]):

- o Traditional PP links: 0.6m equivalent to 41dBi, (**red curve**)
- o Temporal ENG/OB links: 0.3m equivalent to 15dBi, (**blue dotted curve**)
- o Cordless cameras: 0.1m equivalent to 6dBi) (**green curve**)

The following function is used and contains the technical parameters of the calculations:

$$I_{\text{vict}}(e.i.r.p., \delta g, Y_0, h, dc, I, j, D)$$

The following Figures 11 and 12 show the results for those applications.

Figure 11 shows the results without consideration of shadowing effects:

- Red curve: traditional PP links (10m Antenna height, 41dBi gain)
- Blue curve: temporal ENG/OB links (5m antenna height, 15dBi)
- Green curve: cordless camera (2m antenna height, 6dBi)

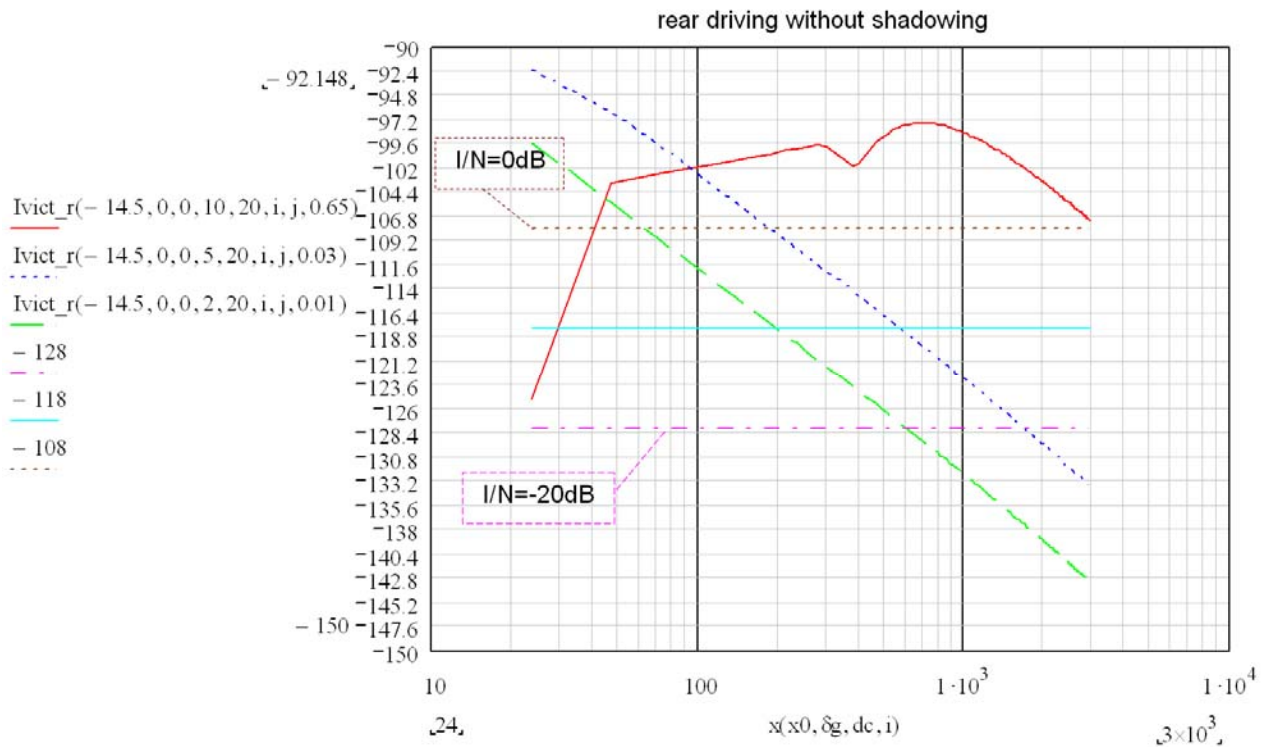


Figure 12: interference power for the rear driving mode without shadowing effects from other cars

Figure 13 shows the results with consideration of shadowing effects according to ECC Report 023 (car separation 20m).

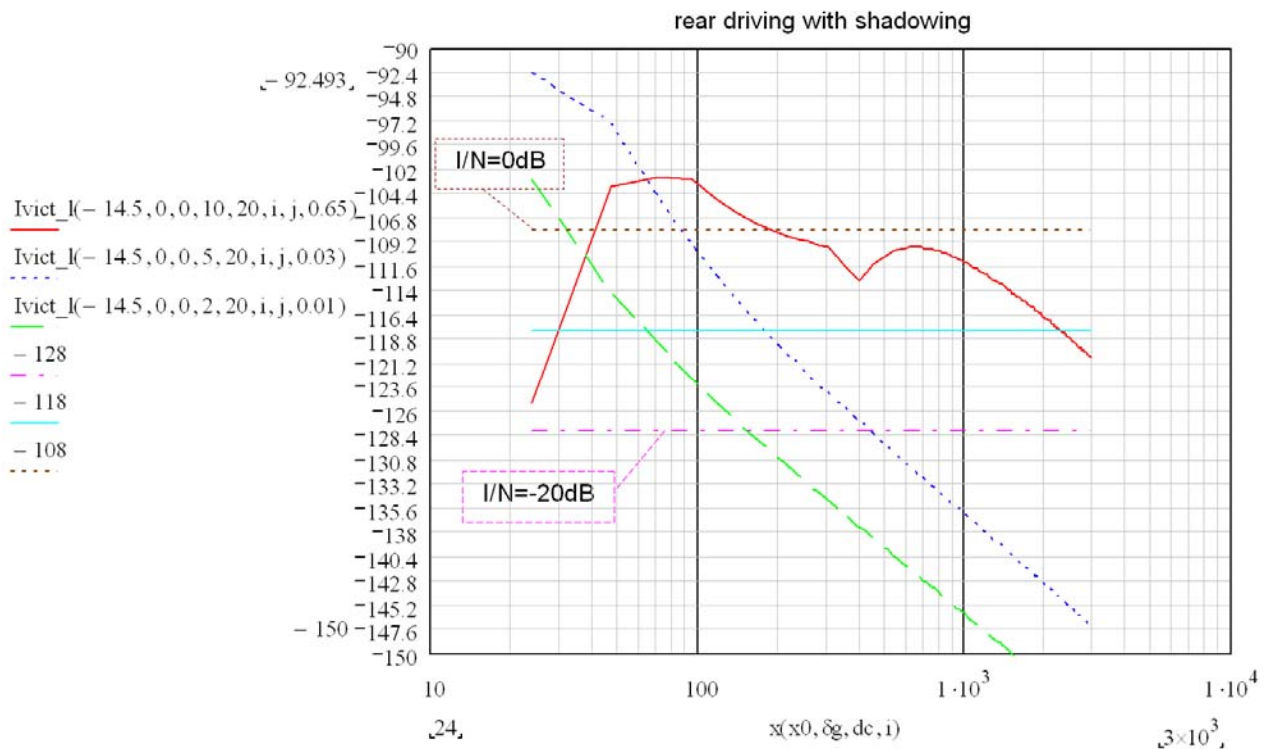


Figure 13: interference power for the rear driving mode with shadowing effects from other cars according to ECC Report 023

The extrapolation of the blue dotted curve (worst case at 5m height) shows that an I/N of 18 dB (short term criterion) is expected to be met.

6.3 Probability of interference between ENG/OB and WLAM (APPS and parking modes)

6.3.1 Probability of interference between ENG/OB and WLAM-APPS

WLAM is activated by a front camera, after a crash assessment procedure as below:

- The front camera has detected a pedestrian in path (the camera is the primary sensor to detect pedestrian since has a higher range than the radar for pedestrians)
- A risk of collision is confirmed comparing the vehicle speed and distance to target
- The driver doesn't activate the brakes in time to operate a normal braking
- Therefore the activation of WLAM and Automatic Braking process is decided

The activation of WLAM-APPS will happen above a minimum speed (20km/h) to avoid the activation at low-speed or in parking conditions.

The duration of the Automatic Braking / WLAM activation has been calculated at different speeds in urban conditions, showing a 1.5 s to 2.6 s activation time depending on the speed of the car.

Impact of the APPS mode on the availability of the ENG/OB:

- The number of accidents with pedestrians in France is estimated to 0.013 /km per year (12.791 accidents for a 1.014.378 km road network [3]), or 0.0065 per year for a 500m road section
- Based on a 2.2 s average activation time, the average WLAM activation on a 1000 m street portion lasts 0.03 s per year (see also section 2.3.3).

This doesn't take into account the probability

- to have a ENG/OB system deployment on that place, on the day of the crash,
- with a pointing direction strictly parallel to the road,
- without any line of sight issue over a 1000 m distance in a city.

Therefore the impact of the APPS front detection mode on the availability of ENG/OB link is expected to be very low.

6.3.2 Probability of interference between ENG/OB and WLAM Rear-parking

6.3.2.1 Aggregated impact of WLAM over a large area

The following table shows the WLAM activity factor calculation for the Rear-parking Mode.

Table 12: WLAM activity factor

	A *	C **	D	E	F
WLAM activation for rear-parking events	Activation per event (s) in average	Activation time per event in % of travel time	Car Density (ECC Report 023)	Penetrationrate %	Number of systems activated
Urban	5.0 (see also Annex 2)	0.26% Veh C= A/(32*60s)	453 vehicles/km ²	50%	0.59 systems/km ² F= C x D xE
Rural	5,0	0.26%	123 veh/km ²	50%	0.16
<p>* Average activation time per rear parking event – see Annex 2 ** Average Travel duration of 32 min (rush hours and all drivers considered) - according to French statistics related to about 18 Millions of French workers, allocated to the different home & work situations in France [19].</p>					

6.3.2.2 Collision Probability in space

The probability for a SAP-SAB to receive a signal with an I/N above 18dB (which assumed to be the threshold for short term effects) has been calculated for different SAP-SAB systems, considering:

- The probability the WLAM system radiates with its main beam toward the victim (worst case of a scanning radar); here it is assumed that this probability is 35% based on an WLAM beam width of 125° (125/360)
- The probability the SAP-SAB receives a WLAM signal above a certain I/N. This is derived from the calculations presented in section 6.1:
 - Figure 8 shows that an I/N of 0dB is not exceeded as long as the angle between Victim and WLAM is 20° and therefore the corresponding probability is 2.3% (20°/360°).
 - Then, the probability for the SAP-SAB to receive a signal above 0dB I/N also depends on the interference area Ai (see Figure 14 below); the protection distance Rp is derived for the high gain antenna from Figure 8 and for the medium and low gain antennas from Figure 12; Rp is the protection distance needed for an I/N of 0dB.
 - This already considers shadowing effects.

A I/N level of 0dB was considered in addition.

The formula for calculating this Probability Pi in a simulation radius of 1km is:

- $P_i = \text{Interference area } A_i / \text{Simulation Area} \times \text{WLAM mainbeam prob}$
- $= A_i / \pi \cdot R_s^2 \cdot \beta / 360 = \alpha / 360^\circ \cdot \pi \cdot R_p^2 / \pi \cdot R_s^2 \cdot \beta / 360^\circ = \alpha / 360^\circ \cdot \beta / 360^\circ \cdot (R_p / R_s)^2$
- With $A_i = \alpha / 360^\circ \cdot \pi \cdot R_p^2$

The following picture illustrates the calculation

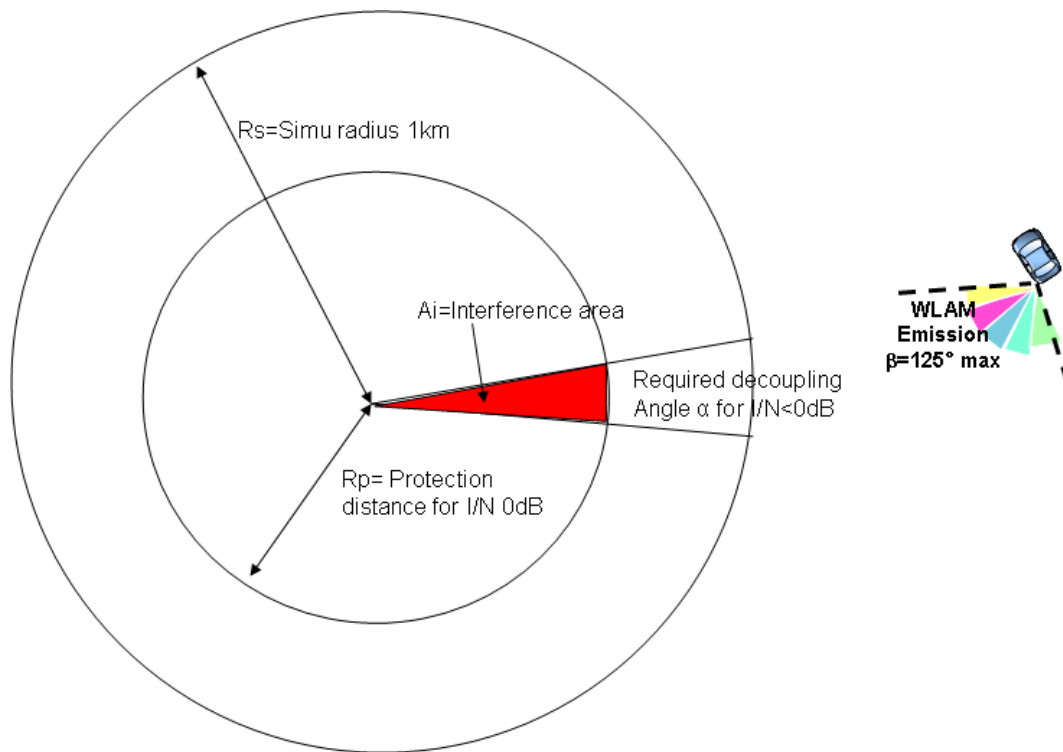


Figure 14: Configuration where the SAP-SAB receives a radar signal such that $I/N > 0\text{dB}$

The following Tables show the probability of exceeding $I/N = 0\text{ dB}$ for three different SAP/SAP systems.

Table 13: probability for SAP-SAB receivers to get a WLAM interfering signal with $I/N > -20\text{dB}$

	High gain antenna	medium gain	low gain antenna
SAP/SAP antenna gain dBi	41	15	6
SAP/SAP antenna height m	10	5	2
decoupling angle alpha °	20	45	90
10dB beamwidth WLAM °	125	125	125
Simulation radius Rs m	1000	1000	1000
Protection distance Rp for $I/N < 0\text{dB}$	200	600	200
Probability of interference Pi %	0,077%	1,563%	0,347%

Table 14: probability for SAP-SAB receivers to get a WLAM interfering signal with $I/N > 0\text{dB}$

	High gain antenna	medium gain	low gain antenna
SAP/SAP antenna gain dBi	41	15	6
SAP/SAP antenna height m	10	5	2
decoupling angle alpha °	20	45	90
10dB beamwidth WLAM °	125	125	125
Simulation radius Rs m	1000	1000	1000
Protection distance Rp for $I/N < 0\text{dB}$	50	100	40
Probability of interference Pi %	0.005%	0.043%	0.014%

The table above shows that the probability of receiving WLAM signals from the rear parking mode with $I/N > 0\text{dB}$ is below 0.043% in the worst case with scanning radars.

For non scanning radars, due to the smaller beamwidth (divided by three), the probabilities will be divided by three.

6.3.3 High Density Parking Scenario

A high density parking scenario has been considered based on a SAP/SAB receiver pointing parallel to a 500 m straight street in a city, with 100 parking slots in its field of view along the 500 m distance.

A 30% rotation per hour for the parking slots has been assumed. This means 30 parking manoeuvres per hour on the 500m portion or one parking operation every 2 minutes.

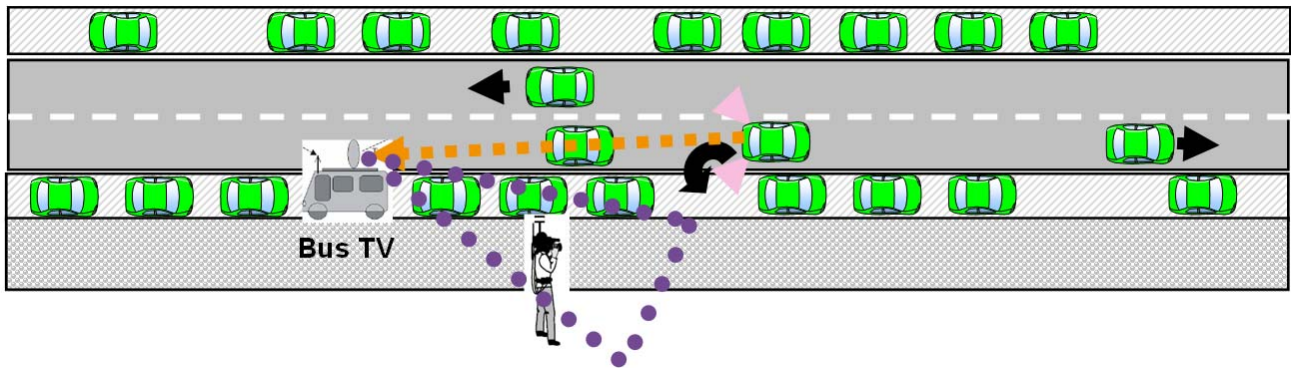


Figure 15: High density parking scenario

The characteristics used for rear parking manoeuvre are the following:

- The total duration of each parking manoeuvre is assumed to be 15 s based on the automatic parking specifications of one car manufacturer, and the **rear driving portion of this manoeuvre is 12 s**.
- Only part of the parking manoeuvre will be pointing toward the victim since the car is changing its direction several times: **a line of sight factor of 33 % has been used**.

The following tables show the calculation of the probability of interference for single entry and high density parking scenarios

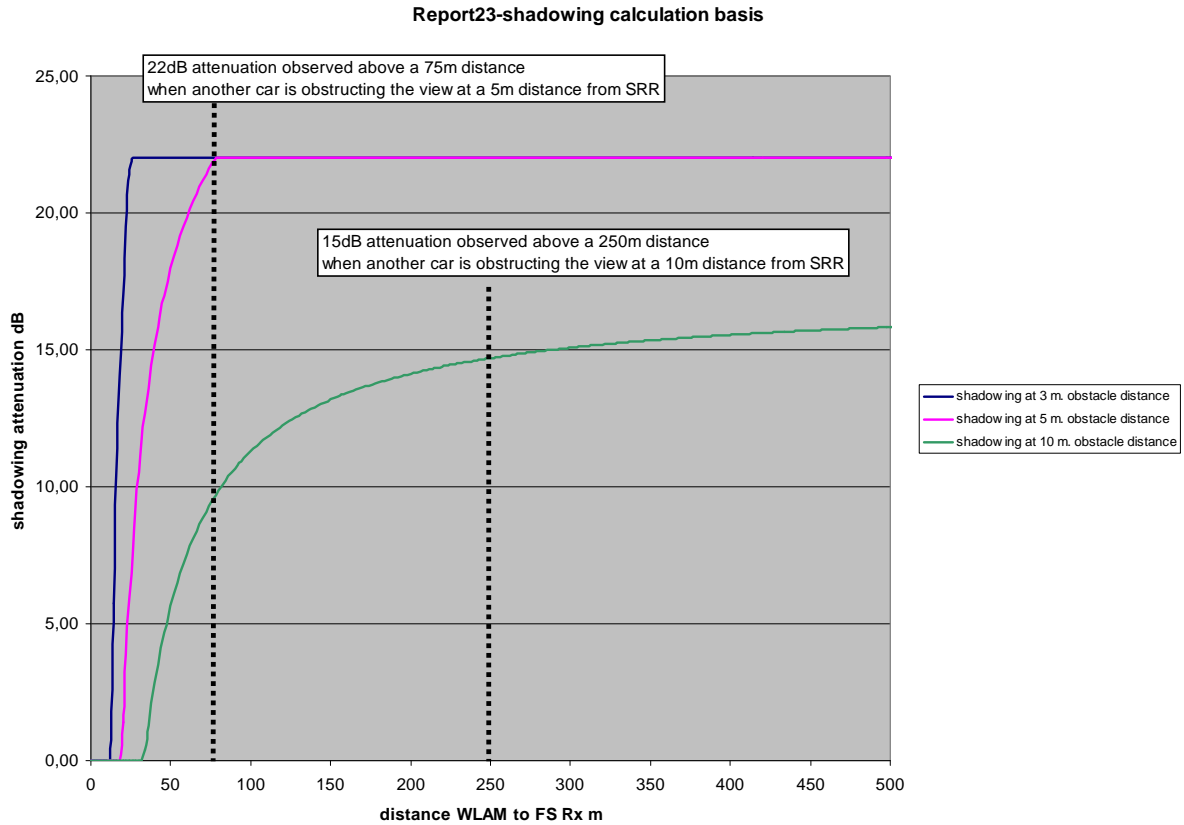
Table 15: Interference calculation in the high density parking scenario

number of parking events per hour (1 event every 2 minutes along 500m)	30
penetration rate	50%
manoeuvre duration per event (4s toward victim)	4
Probability of a parking event per hour	1,67%

In the above described parking scenario the probability that the SAB/SAP receiver sees a WLAM is about 1.67% per hour or in other words: there are 15 events each 4s long.

A 10dB shadowing effect not considered in this section will be noticed for cars emitting at a distance >25m, when a 1.5m height obstacle (other car parked) is obstructing the view at a distance of less than 5m – see Figure 16.

With manoeuvres every 2 minutes, the traffic will be frequently interrupted, and many cars performing a manoeuvre will have another car standing still behind them at a 5m distance.



**Figure 16: Shadowing attenuation depending on the distance between WLAM & victim
Scenarios based car obstructing the view at 3, 5 and 10m distance from WLAM**

6.4 Conclusion for emergency braking (APPS) and rear parking modes

For the rear parking and APPS modes, the following results were achieved:

For the **rear parking** mode:

- The short term criterion (I/N of 18dB) is met (see Figure 13).
- The long term criterion is not met, but it is expected that this criterion will not be exceeded for more than 1.67% of the time (for worst case parking scenario - see section 6.3.3). The shadowing effect will decrease this probability.- In addition, it is expected that the interference level won't exceed I/N=0dB over more than 0,05% of the locations in urban environment (see Table 13).

For the **APPS mode** with a mean power of -6.5 dBm/MHz/s e.i.r.p, the results can be summarised as follows:

- The short term criterion (+18dB) is met taken into account realistic scenarios.
- The long term criterion is not met. However, due to their nature, the deployment of SAP/SAB links will be temporary and any interference resulting from WLAM used in emergency situation will be sporadic (0.03s/km per year), limiting the risk of long term interference.

The issue of synchronization loss was not investigated since it was considered not necessarily.

7 COMPATIBILITY WITH EESS (PASSIVE) AND RADIOASTRONOMY AT 23.6-24 GHZ

The unwanted emissions in the out-of-band domain in the frequency band 23.6 GHz to 24 GHz are proposed to be consistent with the specifications defined for the SRR 26 GHz-UWB to achieve co-existence with the passive services [17].

The unwanted emissions in the out-of-band domain in the frequency band 23.6 GHz to 24 GHz for the 24 GHz Short Range Radar are:

- Direct emission limit in the main beam will not exceed -73 dBm/MHz e.i.r.p.
- Additional average antenna attenuation above 30° elevation to be separately measured will be at least 20 dB.

This was based on 4 radars per car in average.

Provided that, for WLAM, there would be only 1.5 radars per car in average, the proposed specification is -68.5 dBm/MHz and antenna average attenuation >20dB above 30° elevation (antenna pattern to be measured separately) in order to protect EESS.

In addition, Decides-5 of ECC/DEC/(04)10 for 24 GHz SRR defines a level of -74 dBm/MHz for the protection of the RAS without the necessity for a deactivation mechanism. Therefore, in addition to the constraint given in (b), the limit for the direct emissions was set to -74 dBm/MHz for the band 23.6-24 GHz to protect EESS passive and the RAS. In the case of WLAM, 1 radar will be visible instead of 2, resulting in a level of -71 dBm/MHz.

Therefore, the following is proposed:

- -71 dBm/MHz and
- an additional average antenna attenuation above 30° elevation to be separately measured will be at least 20 dB.

Radio compatibility issues between WLAM and the radio astronomy service (RAS) in the band 23.6-24 GHz were not studied in detail, because it has been assumed that the limit derived for the protection of the earth exploration-satellite service (passive), would also be sufficient for the protection of the RAS.

8 COMPATIBILITY WITH SRR AND TLPR DEVICES IN 24 250-24 500 MHZ

Today, 24 GHz SRRs already share the band 24.05-24.25 GHz with 24GHz narrow band automotive radars operating at 20dBm e.i.r.p.

The introduction of WLAM won't significantly increase the risk of interference: WLAM systems are designed to use the standard 24.05-24.25 GHz mode most of the time and the bandwidth extension will be used with a very low activity factor.

Finally, the regulation framework for SRR at 24 GHz specifies a deployment on a time limited basis.

For TLPR, it is expected that they will be deployed in specific locations, installed inside metallic tank only and therefore are not going to be interfered.

9 GENERAL CONCLUSIONS

The following conclusions were reached considering the impact of WLAM on ENG/OB based on the mean e.i.r.p. values of WLAM (averaged over 1s).

For the **calibration** mode:

- Within the frequency band 24.25-24.495 GHz, the resulting I/N of -26 dB is compliant with the long term and short term criteria.
- Within the frequency band 24.495-24.5 GHz,
 - the I/N of -8 dB is compliant with the short term objective (I/N of 18dB),
 - but not compliant with the long term objective (I/N of -20dB).

In the case of SAP/SAB temporary applications, they are expected to perform a frequency scan before emitting to check if other temporary services are already using the same band limiting the risk of interference. In addition, due to their nature, the deployment of SAP/SAB links will be temporary and any interference resulting from WLAM will be sporadic, limiting the risk of long term interference.

For the **rear parking** mode:

- The short term criterion (I/N of 18dB) is met (see Figure 13).
- The long term criterion will not be met, but it is expected that this criterion will not be exceeded for more than 1.67% of the time (for worst case parking scenario - see section 6.3.3). The shadowing effect will decrease this probability.- In addition, it is expected that the interference level won't exceed I/N=0dB over more than 0.05% of the locations in urban environment (see Table 13).

For the **APPS** mode with a mean power of -6.5 dBm/MHz/s e.i.r.p, the results can be summarised as follows:

- The short term criterion (+18dB) is met taken into account realistic scenarios.
- The long term criterion is not met. However, due to their nature, the deployment of SAP/SAB links will be temporary and any interference resulting from WLAM used in emergency situation will be sporadic (0,03s/km per year), limiting the risk of long term interference.

In addition, the following limits are proposed for unwanted emissions falling into the band 23.6-24 GHz in order to protect RAS and EESS:

- -71 dBm/MHz e.i.r.p.
- With an additional average antenna attenuation of at least 20dB above 30° elevation.

ANNEX 1: CRASH ALERT OCCURRENCE OF FORWARD COLLISION WARNING SYSTEMS

The following is an extract of Evaluation of an automotive rear-end collision avoidance system (ACAS) by the NHTSA [18], and shows a maximum occurrence of 21,8 crash imminent alerts for 1000km (or 0,02 events per km) for car speed between 25 mph and 35mph. Given that about 40% of cars exceed 25mph (40km/h) in cities, the resulting crash imminent alert is about 0,008 event per km independently of the car speed.

“

This Report presents the results of an independent evaluation by the Volpe Center to assess an automotive rear-end crash avoidance system built by General Motors and Delphi Electronics for light-vehicle applications.

According to the 2002 National Automotive Sampling System/ General Estimates System (NASS/GES) crash database, light vehicles were involved in approximately 1.8 million police-reported rear-end crashes in the United States or about 29 percent of all light-vehicle crashes. These rear-end crashes resulted in about 850,000 injured people.

System Description

This rear-end crash avoidance system is known as the Automotive Collision Avoidance System (ACAS), which consists of both forward crash warning (FCW) and adaptive cruise control (ACC) functions. The FCW detects, assesses, and alerts the driver of a potential hazard in the forward region of the host vehicle.

The FCW is automatically functional when the host vehicle speed exceeds 25 mph (40 km/h), and becomes inactive when the speed falls below 20 mph (32km/h).

The ACC uses automatic brake and throttle to maintain speed and longitudinal headway control. The maximum braking authority of ACC is 0.3g. Cautionary alerts are visually presented by means of a color head-up display (HUD).

Crash imminent alerts consist of both a flashing visual display (HUD) and an auditory alert from a speaker embedded in the dashboard, which occur simultaneously. The driver can set the gap headway of ACC between 1 and 2 seconds.

The ACC possesses a warning capability that takes into account the braking ACC can provide. In integrating FCW and ACC functions, the ACAS is intended to improve automotive safety by assisting drivers to avoid rear-end crashes.

Description of Field Operational Test

The ACAS underwent a field operational test (FOT) that was conducted with 10 equipped vehicles from March 2003 to November 2004. 96 subjects were selected from the State of Michigan as FOT participants, 66 of which were exposed to the final version of the ACAS that was evaluated in this report.

Each subject drove the ACAS-equipped vehicle as his or her own personal car for a test period of four weeks, unsupervised and unrestricted. The first week was dedicated to collecting baseline driving data, i.e., *without* the assistance of the ACAS. During this week, FOT subjects drove with manual control and also had the option of using conventional cruise control (CCC). During the remaining three weeks, driving was performed *with* the assistance of the ACAS. In that period, subjects drove the FOT vehicles with either manual control or manual control augmented with the FCW function, and they also had the option of engaging ACC. It should be noted that FOT subjects could not disable the FCW function during ACAS-enabled test period. Two hours of training were provided for FOT participants prior to starting the FOT.

Independent Evaluation Goals

Goals of the independent evaluation of ACAS were to: characterize ACAS performance and capability; achieve a detailed understanding of ACAS safety benefits; and determine driver acceptance of ACAS. The independent evaluation sought to address these 3 goals to support the decision process in the deployment of crash avoidance systems.

System Capability & Alert Occurrence

The analysis of 8-second video episodes triggered by the auditory crash-imminent alerts revealed the following:

Subjects received 6.2 crash-imminent alerts per 1,000 km travelled overall during the FOT.
However, this alert rate was 21.8 crash-imminent alerts per 1,000 km travelled between 25 and 35 mph.

ANNEX 2: REAR PARKING SCENARIO

A2.1 Time per rear parking manoeuvre

The rear parking duration taken into account depends on the type of parking manoeuvres:

Parallel parking on road side :

- 12s reversing time out of 15s for a complete manoeuvre
- 12s to drive backwards + turn into the slot + reversing into the slot
- 3s to complete the manoeuvre by moving forward again

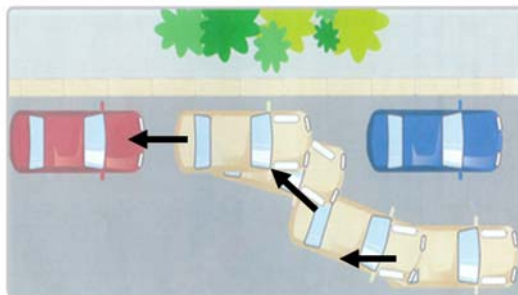


Figure 17: The 3 phases of a parking manoeuvre

Orthogonal Parking : 8 s reversing manoeuvre (simpler manoeuvre)

Front Parking : 0 s reversing manoeuvre (no reversing operation)

The average Rear-parking timing considered in the compatibility study is provided in the following table:

Table 16: Average parking event duration

Rear Parking Duration	IN	OUT	%
road side parking	12	2	50%
car park - backing manoeuvre	8	0	25%
car park - forward manoeuvre	0	4	25%
Average	8,0	2,0	100%
Average time per event (s)	5,0		

A2.2 Dimensions of Parking Lots (reference for the shadowing effect)

The following Figure 18 provides typical dimensions of parking lots in Europe.

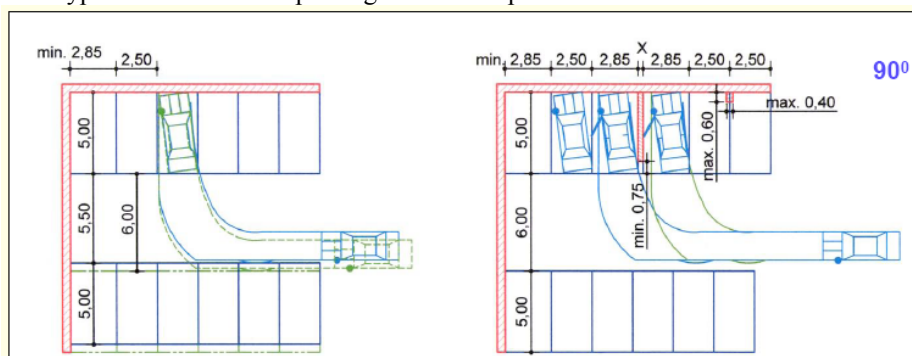


Figure 18: Usual dimensions of parking lots

ANNEX 3: LIST OF REFERENCES

- [1] ERC/REC 70-03: Relating to the use of Short Range Devices (SRD)
- [2] ETSI EN 300 440: Short range devices; Radio equipment to be used in the 1 GHz to 40 GHz frequency range
- [3] EN 302 858-2: DEN/ERM-TGSRR-051-2 EN for NB SRR at 24 to 24.250 GHz band
- [4] ETSI TR 102 892: SRdoc for SRD radar equipment using a WLAM Mode (Wideband Low Activity Mode) in the 24,05 - 24,50 GHz range
- [5] Source ONISR-2007 / Observatoire National Interministériel de Sécurité Routière - France
- [6] NHTSA report dated Mar2006 – Evaluation of an automotive rear-end collision avoidance system (ACAS) - Ref DOT-VNTSC-NHTSA-06-01 / DOT HS 810 569
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