ECC REPORT 23

Electronic Communications Committee (ECC)
within the European Conference of Postal and Telecommunications Administrations (CEPT)

COMPATIBILITY OF AUTOMOTIVE COLLISION WARNING SHORT RANGE RADAR OPERATING AT 24 GHZ WITH FS, EESS AND RADIO ASTRONOMY

Cavtat, May 2003

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EXECUTIVE SUMMARY

This report considers the impact of automotive Short Range Radars (SRR) on allocated radiocommunication services operating in the frequency range 21 to 27 GHz, as given in Annex A. The study does not consider the impact of radiocommunication services on SRR or automotive EMC issues.

The study has focused on the following 3 specific primary services to which SRR 24 GHz is considered likely to present a high interference potential:

- Fixed Service (FS)
- Earth Exploration Satellite Service (EESS)
- Radio Astronomy Service (RAS).

There are also other primary services, listed in section 3, which are likely to be affected.

ITU-R footnote 5.340 applies to the passive frequency band 23.6 to 24 GHz, which states that "All emissions are prohibited".

The conclusions of this report are summarised in the following Tables 1A and 1B (NB: No = sharing not feasible, Yes = sharing feasible):

SRR e.i.r.p. levels (dBm/MHz)	RAS	EESS	Fixed
-30	No, see note 1	No	No
-41.3	No, see note 1	No	No
-50	No, see note 1	No	See note 2A
-60	No, see note 1	Yes	Yes

Table 1A: Summary of co-existence (assuming 100% of vehicles within visibility of the victim service are equipped with SRR)

Note 1: If all of the possible mitigation factors such as local terrain, clutter loss, car density are applicable and if this leads to sufficient reduction in interference level, then sharing between the SRR at 24 GHz and radio astronomy could be possible in some cases.

Note 2A: If the protection criteria of –20 dB I/N is to be met in all cases, sharing is not feasible. However, sharing is considered to be feasible if an excess of the protection criteria by 10 dB (up to –10 dB I/N) in worst case scenarios can be accepted.

SRR e.i.r.p. levels (dBm/MHz)	RAS	EESS	Fixed
-30	No, see note 1	No	No
-41.3	No, see note 1	Yes	See note 2B
-50	No, see note 1	Yes	Yes

Table 1B: Summary of co-existence (assuming 10%, or less, of vehicles within visibility of the victim service are equipped with SRR)

Note 1: If all of the possible mitigation factors such as local terrain, clutter loss, car density are applicable and if this leads to sufficient reduction in interference level, then sharing between the SRR at 24 GHz and radio astronomy could be possible in some cases.

Note 2B: If the protection criteria of –20 dB I/N is to be met in all cases, sharing is not feasible. However, sharing is considered to be feasible if an excess of the protection criteria by 10 dB (up to –10 dB I/N) in worst case scenarios can be accepted.

It is to be noted that it is not clear how to relate the percentage of vehicles equipped with SRR in a specific area, as used in the sharing scenarios, with market penetration figures.

Radio Astronomy

The sharing study between the SRR application at 24 GHz and the Radio Astronomy Service was done on the assumption of a mean e.i.r.p. per SRR device of –90 dBm/Hz.

It shows that compatibility is not feasible, with a calculated negative margin in the order of 70 dB for spectral line observations and 90 dB for continuum observations, with a device density of 100 devices per km² that are transmitting into the direction of the radio astronomy station.

If all of the possible mitigation factors such as local terrain, clutter loss, car density are applicable and if this leads to sufficient reduction in interference level, then sharing between the SRR at 24 GHz and radio astronomy could be possible in some cases.

EESS

Using the assumptions that SRR e.i.r.p. is –41.3 dBm/MHz with a 100% percentage of vehicles equipped with SRR devices in the EESS pixel , then protection criteria for all types of EESS sensors (according to ITU-R Rec SA.1029-2 to be adopted in February 2003) will be exceeded by up to 10.8 dB. All the data derived from those measurements will be corrupted in corresponding EESS observations (cities, roads or motorways).

The above reasons lead to the conclusions that SRR with 100% cars equipped cannot share the band with the EESS (passive) in the band 23.6-24 GHz.

It should be noted that a percentage of vehicles equipped with SRR devices in the EESS pixel lower than 100 % provides a decrease of the aggregate power, e.g. around 10 dB for a percentage limited to 10 %.

For the case of SRR radars with very low horizontal e.i.r.p. (-50 dBm/MHz), sharing with all types of EESS sensors would still result in a negative margin. This would be up to –2.1 dB for current requirements (for which the Recommendation SA 1029 has been recently revised), and up to –9.1 dB for future instruments in the long term, i.e. by year 2020.

Fixed Service

It was recognised that being the SRR deployment assumed on a “no harmful interference” basis, it might be difficult in practice to apply counter-measures to stop possible interference, once the SRR deployed in full.

On this basis, and taking into account the protection requirements of the FS, the long-term compatibility scenario with SRR (with an e.i.r.p density level of –41.3 dBm/MHz) with 100% percentage of cars equipped with SRR devices in visibility of the FS receiver was studied. Due to the complex sharing scenario, a number of assumptions had to be made. For simplification, the simulations were restricted to two scenarios (1 lane and 4 lanes scenarios) with 2 active forward sensors per car. Important factors such as the FS antenna height and distance from the road (offset), distance between cars and different models for the rain attenuation, which could heavily influence the results of the study were varied in order to be able to compare their effects.

Due to the complexity of the compatibility scenario, a simplified propagation model was chosen. In this model, propagation effects such as spray due to preceding cars, clutter losses (except from other cars) and reflections of SRR transmissions from the road or other cars were not taken into account, since it was uncertain whether or not and to what extent (in dBs) these effects influence the sharing situation.

The results of the studies with all assumptions described above show that the protection criteria of the FS is exceeded by 0 to 20 dB depending on the scenario and on the combination of the factors.

Considering that the SRR devices are to be operated on a non-interference basis, it is concluded that SRR deployed in the 24 GHz band operating at a –41.3 dBm/MHz e.i.r.p density are not compatible with FS in the long-term.

However, on the basis of the whole range of calculation results, it can be concluded that with an e.i.r.p. density of -60 dBm/MHz the FS protection criteria (–20 dB I/N) for all scenarios considered in these studies is respected, whilst with an e.i.r.p. density of –50 dBm/MHz, this protection criteria would be met in most scenarios. Some administrations are of the opinion that is it necessary that SRR meets the –20 dB I/N protection criteria in all cases. Some other administrations are of the opinion that an excess of the protection criteria by 10 dB, which still corresponds to an I/N of –10 dB, is acceptable.

In addition, on a short-term basis, it was concluded that an e.i.r.p. mean power density of –41.3 dBm/MHz associated with an e.i.r.p peak limit of 0dBm/50 MHz could be sufficient to protect the FS as far as the percentage of cars equipped with SRR devices in visibility of the FS receiver is limited to less than 10% or less than few percent depending on whether the protection criteria is to be met in all cases; 10 % is equivalent to a 10 dB decrease of the aggregate power. Finally, even though the studies have been limited to the 23 and 26 GHz FS bands, the calculation results and conclusions are still valid in the 28 GHz FS band and have also to be taken into account for the 32 GHz band.

1 INTRODUCTION

The European Commission has a number of programmes focusing on Road Safety and Intelligent Transport Systems. The EU approach to this is:

> "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…)".

EU Project - RESPONSE, Project TR4022 Advanced Driver Assistance Systems: "System Safety and Driver Performance" is one such project.

The automotive industry has developed Short Range Radar (SRR) operating in the 24 GHz band as part of the solutions for Road Safety and Intelligent Transport Systems. The SRR operates at very low power levels for exterior automotive applications, sensing the environment immediately around the vehicle. These applications require antenna characteristics, which necessitates only narrow elevation antenna beam combined with a limited mounting height. These devices are also used as a movement sensor function implementing a narrow band Doppler mode for a target speed measurement function.

The automotive industry proposal is intended to present the basis for the new cost efficient and versatile SRR technology, which complements 77 GHz Automotive Cruise Control (ACC) functions, realised with Long Range Radar (LRR).

ETSI has initiated a work program to amend the current EN 301 091 to include the industries requirements for the 24 GHz SRR. The amended draft Standard has been used as a basis for this study and additional technical information considered necessary for the study have been provided by the contributing manufacturers.

The intended emissions of the SRR developed by the automotive component manufacturers spreads outside the Short Range Devices (SRD) allocation given in Recommendation 70-03 Annex 1 for General SRDs. Although the intended emissions from the SRR are relatively low outside of the 24 GHz SRD allocation, the Allocated radio services in the band 21 to 27 GHz must be protected.

This report looks at the effects of SRR on allocated radiocommunication services operating in the frequency range 21 to 27 GHz, as given in **ANNEX A**. The study does not look at interference from radiocommunication services into SRR or automotive EMC issues.

This study does not consider the effect of co-channel or adjacent channel authorised radio services on the SRR devices. The onus for use of these bands for SRR applications is solely the responsibility of the SRR/Vehicle manufacturer.

2 SHORT RANGE RADAR

2.1 Description

SRR units operating at 24 GHz require an operating range of up to 30 metres and used for a number of applications to enhance the active and passive safety for all kind of road users. Applications that enhance passive safety include obstacle avoidance, collision warning, lane departure warning, lane change aid, blind spot detection, parking aid and airbag arming. SRR 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 also referred to as a "safety belt" for cars.

The SRR functions are intended to allow for 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.

The 24 GHz SRR is a combination of two functions:

- a high resolution distance measurement to provide speed information of an approaching object using Doppler radar. This necessitates a narrow band +20 dBm peak signal with a mean power level of 0 dBm. All wanted emissions associated with the necessary bandwidth are inside the SRD band (24.05 to 24.25 GHz), as given in CEPT Recommendation 70-03.

- a wide band radar to provide information of the position of objects with a high resolution of approximately 10-15 cm and requires an average spectral power density of -30 dBm/1MHz or -90 dBm/Hz, spread approximately ± 2.5 GHz centred on the SRD band at 24 GHz. Emissions outside of this mask are at least a further 20 dB down i.e. -50 or -110 dBm respectively.

The proposed 24 GHz SRR technology allows a low-cost design and to keep the product size small enough to fit in the space available while providing useful range resolution and object separation which is needed for Cartesian object tracking. The processing of the data from the Sensors provides Cartesian object positions and can predict a possible crash impact point and the closing angle. With this information the system can alert the driver or the system can do counter measures to prevent collisions or to circumvent obstacles autonomously.

Such SRR functions at present are not covered by other means or systems because of installation, manufacturing and cost constraints.

2.2 Technical considerations

Car surround sensing functions requires several individual SRR sensing units per vehicle, in the front, rear and sideways with an approximate number of 10 units per vehicle but with limited overlapping beam characteristics.

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

The carrier of the SSR signal is allocated inside the 24 GHz SRD band within 24.050 GHz to 24.250 GHz. The level of the modulation spectrum which is located outside of the SRD band is given in Draft EN 301 091

In selecting the 24 GHz band, manufacturers have taken the following factors into consideration; 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.

SRR's higher bandwidth is needed for sufficient object radial range separation. 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 separation is inverse proportional to the occupied spectral bandwidth Bocc:

$$\Delta r = k{*}c / B_{occ.}$$

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 the speed of light.

A minimum range separation $\Delta r < 0.05$m is needed, if several targets with multi-reflective 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 B_{occ} in the order of 5 GHz (@ - 20 dB).

2.3 Technical parameters (- taken from Draft EN 301 091 V1.2.1 2001 07)

2.3.1 Operating frequency range

Narrow band	Wide band
24.05 GHz to 24.25 GHz (Note 1)	22.65 GHz to 25.65 GHz
Note 1 : according to CEPT/ERC Recommendation 70-03, annex 1 or 6	

Table 2: Operating frequency range

2.3.1.1 Frequency shift

It has to be ensured by the regulations in the draft standard EN 301 091 that also in the case of ageing and time variant drift that the mean power spectral density are below -30 dBm/MHz at all frequencies below 24.05 GHz.

2.3.2 Modulation types

2.3.2.1 PN PPM (Pseudonoise Pulse Position Modulation)

Table 3: Limits for pulse position modulation

Parameter	**Minimum**	**Maximum**
Mean Power(e.i.r.p.) (note 1)		0 dBm
Peak Power(e.i.r.p.)		20 dBm (note 2)
PRF	No limit	100 MHz
PRI	10 ns	No limit
Equivalent pulse power duration	400 ps	10 µs No limit, if carrier fixed within 24.05 GHz to 24.25 GHz
Average output power	No limit	0 dBm
Peak output power	No limit	20 dBm 0 dBm without duty cycle limit
Duty cycle	No limit	10 % if carrier allocated within 24.05 GHz to 24.25 GHz 1 % if carrier located within wideband 22.625 GHz to 24.625 GHz
AM degree (switch isolation)	No limit	-20 dB
Average spectral power density (e.i.r.p.) within B $_{FHSS}$ (c.f. emission mask, w.o. blanking)	no limit	-30 dBm @MHz -90 dBm/Hz
Occupied Bandwidth (DSB $_{-10dB}$) including FM/PM	No limit	5 GHz

NOTE 1: The maximum average time for mean power measurements shall be limited to 50 msec.

NOTE 2: The increase of the peak power limit by 20 dB above the mean power limit for time gated or pulsed systems (PM, IPSK, IFSK, IFHSS) is only allowed under the following conditions:

a) the carrier location is positioned within the SRD Band 24.05 GHz to 24.25 GHz and the time or carrier duty cycle is less then 10 %;

b) the carrier location is positioned within the wideband 22.625 GHz to 25.625 GHz and the time- or channel duty is less then 1 %.

No further limits apply to the parameters defined as long as the resulting signal spectrum satisfies the requirements defined in the other clauses of the present document.

2.3.2.2 PN FH (Pseudo noise coded Frequency Hopping)

Table 4: Limits for FHSS modulation

Parameter	Minimum	Maximum
Mean Power(e.i.r.p.) (note 2)		0 dBm
Peak Power(e.i.r.p.)		0 dBm (note 1)
Number of slots $n_{slot\ per\ frame}$	2^{3} (within SRD band (CEPT/ERC Recommendation 70-03)) 2^{6} (within B_{FHSS})	no limit
Dwell time per slot T_{dw}	no limit	10 µs
Hopping frequency f_{hop}	$1/T_{dw}$	no limit
Frame time period T_{fr}	no limit	10 ms
Equivalent pulse power duration T_{pw}	400 ps	10 µs no limit, if carrier fixed within SRD band at 24.05 GHz to 24.25 GHz
Duty cycle for pulse train	no limit	10 %, if carrier allocated within 24.05 GHz to 24.25 GHz 1 %, if carrier allocated within wideband 22.625 GHz to 25.625 GHz
Blank Time period T_{blk}	no limit	10 ms
Occupied Bandwidth B_{FHSS} (DSB $_{-10\ dB}$)	no limit	5 GHz
slot interleave bandwidth Δf_{I}	100 kHz	no limit
Average spectral power density (e.i.r.p.) within B_{FHSS} (c.f. emission mask without blanking)	no limit	30 dBm @MHz -90 dBm/Hz
Peak output power	No limit	20 dBm, 0 dBm without duty cycle limit
Average output power (e.i.r.p.) without blanking)	no limit	-0 dBm
NOTE 1: Peak power is equivalent CW power, if no further switching or time gating is applied on the CW systems PN-PSK and PN-FHSS. NOTE 2: The maximum average time for mean power measurements shall be limited to 50 msec.		

2.3.2.3 PN-BPSK (Pseudo noise Binary coded Phase Shift Keying)

Table 5: Limits for PN-BPSK Modulation

Parameter	Minimum	Maximum
Mean Power(e.i.r.p.) (note 2)		0 dBm
Peak Power(e.i.r.p.)		0 dBm (note 1)
Chip period T c	400 ps	no limit
PN-sequence period (L □T c)	No limit	10 µs
Occupied Bandwidth B (DSB - 10dB)	No limit	5 GHz
Average output power w.o. blanking	No limit	0 dBm
Peak output power	No limit	20 dBm, 0 dBm without Duty cycle limit
Average spectral power density (e.i.r.p.) within B FHSS (c.f. emission mask) without blanking	No limit	-30 dBm/MHz -90 dBm/Hz
Duty cycle	No limit	10 %, if carrier allocated within 24.05 GHz to 24.25 GHz 1 %, if carrier allocated within wide-band 22.625 GHz to 25.625 GHz

NOTE 1: Peak power is equivalent CW power, if no further switching or time gating is applied on the CW systems PN-PSK and PN-FHSS.

NOTE 2: The maximum average time for mean power measurements shall be limited to 50 msec.

2.3.3 Alternative spectral power density

An alternative SRR output spectral power density of –41dBm/MHz (-101 dBm/Hz) has also been considered in order to determine to which extent it could improve the compatibility with existing services.

It represents an 11 dB decrease compared to the spectral power density described in the previous section.

2.3.4 Vertical antenna pattern

The vertical discrimination antenna pattern for 24 GHz SRR is given according to table 6 below 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 e.i.r.p._max.

Vertical antenna angle θ in °	Spatial antenna gain
$\theta < -70^\circ$ and $\theta > 40^\circ$	Gmax (dBi)–26.66 dB
$-70^\circ < \theta < -30^\circ$	Gmax (dBi)+ 2/3× (θ +30°)[dB/°]
$-30^\circ < \theta < 0^\circ$	Gmax (dBi)
$0^\circ < \theta < 40^\circ$	Gmax (dBi) – 2/3 × θ [dB/°]

Table 6: Limitation of vertical antenna pattern

As a possible mean of improving the compatibility with other services, an alternative antenna pattern (as proposed by the FCC for the year 2014) as also been considered and is given in table 7 below.

Vertical antenna angle θ in °	**Spatial antenna gain**
θ < -70°	Gmax (dBi)–26.66 dB
-70° < θ < -30°	Gmax (dBi)+ 2/3× (θ +30°)[dB/°]
-30° < θ <0°	Gmax (dBi)
0° < θ < 30°	Gmax (dBi) – 7/6× θ [dB/°]
θ > 30°	Gmax (dBi)–35 dB

Table 7: Alternative limitation of vertical antenna pattern

These 2 vertical discrimination patterns are described in the following figure 1.

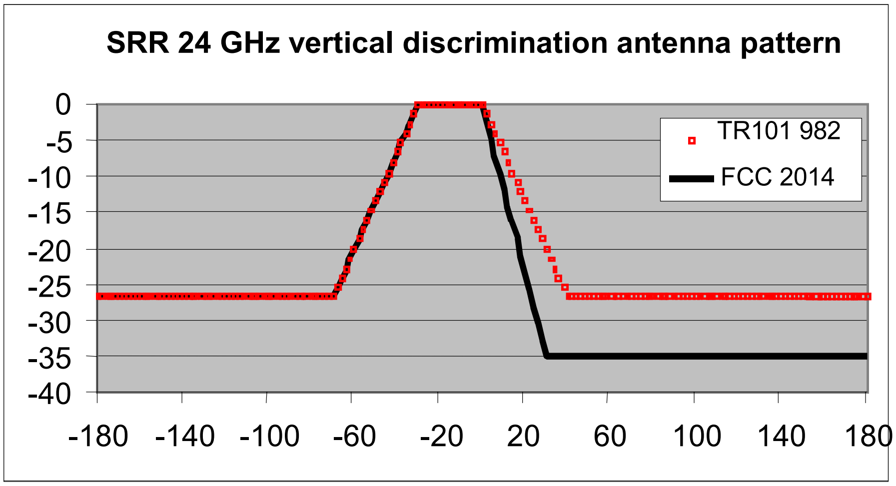


Figure 1

2.3.5 *Antenna mounting height*

The mounting height from 24 GHz SRR is limited to maximum 1.5 m. However, the typical mounting height for forward and rearward facing sensors is bumper height (about 0.5 m for cars).

2.3.6 *Percentage of vehicles equipped with SRR devices*

The percentage of vehicles equipped with SRR in a specific area will be growing with the market penetration. Figures in ETSI TR 101 982 are extended up to year 2020 (40% penetration).

On the other hand, a comparison can be made with the development of Air Bags and Anti-Blocking Systems (ABS). This equipment at the beginning was only installed in the luxury cars andnowadays every car, even the cheapest one, have air bags and ABS as standard equipment, since a 95 % equipment rate is reported.

Therefore, this report being a technical long-term study, market penetration figures are difficult to estimate and 100% of vehicles equipped with sensors have been assumed.

In short-to-medium term, the percentage of vehicles equipped with SRR devices will be lower than 100%. However, it is not clear how to relate market penetration figures (i.e., an "average" situation over a continental area such as Europe) and the percentage of vehicles equipped with SRR in a specific area as considered in the sharing scenarios.

2.3.7 Additional Mitigation Factors

Due to various impacts of bumpers, mainly metallic paint, a bumper loss of – 3 dB has been considered.

Other mitigation factors specifically related to the sharing scenarios with each service that may have been considered are described in section 4.1 below.

3 VICTIM RADIOCOMMUNICATION SERVICES

Annex A gives the current allocations in the Radio Regulation (edition 2001) and shows that the following services are found in the range 21 – 28.5 GHz:

- Fixed Service
- Mobile Service
- Broadcasting Satellite Service
- Fixed Satellite Service
- Mobile Satellite Service
- Standard frequency and time signal satellite service
- Earth Exploration Satellite Service
- Inter-Satellite Service
- Space Research Service
- Radio Astronomy Service
- Amateur and Amateur Satellite Service
- Radiolocation Service
- Radionavigation Service.

A number of those services were not considered in the study since SRR 24 GHz was not assumed to present interference potential. However, this has not been validated by technical studies. This was mainly due to the fact that the corresponding band was adjacent to the currently declared wanted emission of the SRR (e.g. for space-to-Earth satellite services) or because the compatibility scenarios were obviously positive with regard to the compatibility (e.g. for Earth-to-space satellite services) or, finally, that the compatibility conditions were similar to another service, as for Fixed and Mobile services.

On this basis, the study has focused on the following 3 specific services to which SRR 24 GHz that were considered as likely to present a high interference potential:

- Fixed Service
- Earth Exploration Satellite Service
- Radio Astronomy Service.

3.1 Fixed service

3.1.1 Frequency bands

In the range 21.625 - 26.625 GHz, Fixed Service is allocated in the 21.2 - 23.6 GHz and 24.25 - 27 GHz bands (See annex A for details).

Within CEPT, the 23 and 26 GHz bands are both currently heavily used by FS.

3.1.1.1 23 GHz band (22-23.6 GHz)

The 23 GHz band is heavily used throughout Europe for digital FS systems with low/medium and high capacity PP links. In many cases this is used for the provision of regional telecommunication infrastructure (e.g. for Public Mobile Telephony Networks), but also for multi-purpose RRL, such as private FS networks.

The number of links has more than doubled between 1997-2001 and is now higher than 37000 links. That makes this band one of the more important frequency band for Mobile Telephony Networks infrastructure.

In most countries the channel arrangement follows Annex A of CEPT Recommendation T/R 13-02, with actually used channel widths of 3.5/7/14/28 MHz. In few countries 56 MHz channels are also in use. The average recorded hop length in this frequency band is 7 km.

3.1.1.2 26 GHz band (24.5-26.5 GHz)

With a fast growing tendency (from 500 links in 1997 to about 13000 in 2001), the 26 GHz band is heavily used throughout CEPT for FS in accordance with the channel arrangements in Annex B of CEPT Recommendation T/R 13-02. This encompasses the FS applications for the provision of regional telecommunication infrastructure (e.g. for Public Mobile Telephony Networks) using digital point-to-point, but also point-to-multipoint fixed links. The capacity of the links ranges between low, medium and high.

This band is also one of the preferred bands for Fixed Wireless Access (FWA) introduction in Europe, in accordance with its identification in ERC/REC 13-04. Assignment of channels for FWA also follows arrangements given in T/R 13-02. Together with the band 3400–3600 MHz this band (or parts of it) constitutes the most widely used band for the provision of FWA within CEPT. The average length of reported (PP) links in this band is 6 km.

3.1.2 Protection Criteria

Recommendation ITU-R F.1094 provides the apportionment of the total degradation of an FS link as:

- 89 % for the intra service interference
- 10% for the co-primary services interference
- 1% shared between the secondary service interference, the unwanted emissions and the unwanted radiation.

These percentages do not relate to the total time of operation but apply to the performance objectives. In addition, this degradation allowance is not given for a single transmitter, but to the aggregation of the whole secondary service transmitters and unwanted signals.

Performance of FS links are controlled by two different factors:

- Availability (or unavailability),
- Error performance objectives (EPO) as given in Recommendations ITU-R F.1397 and F.1491.

In the bands where the fading is controlled by rain (higher than around 17 GHz), the design of the FS links is based on availability (with typical values of 99.99% or 99.999% depending on the type of application and the operator requirements) applying Recommendation ITU-R P.530 to determine the appropriate fade margin.

Long-term interference (more than 20% of the time) leads to a margin and availability degradation. In order to limit this degradation to a maximum of 0.5% (the 1% degradation of the Rec. ITU-R F.1094 is to be shared with secondary services), it was shown that the noise increase due to long term interference shall be limited to 0.04 dB. **This is equivalent to a long-term criteria expressed as I/N = –20 dB**.

Even though short-term scenarios were not considered as being predominant, short-term criteria were determined on the principle that the whole fade margin (20 dB typical was assumed) can be given to interference:

for Point to Point (P-P) systems :

- for ES (G.828) : I/N = 15 dB not to be exceeded for more than 0.0016 % of the time
- for ES (G.826) : I/N = 15 dB not to be exceeded for more than 0.006 % of the time
- for SES : I/N = 19 dB not to be exceeded for more than 0.00016 % of the time

for Fixed Wireless Access (FWA) systems :

- for ES (G.828) : I/N = 5 dB not to be exceeded for more than 0.0016 % of the time
- for ES (G.826) : I/N = 5 dB not to be exceeded for more than 0.006 % of the time
- for SES : I/N = 9 dB not to be exceeded for more than 0.00016 % of the time

It can be noted that these long-term and short-term criteria are consistent with those defined within ITU-R for similar sharing scenarios.

3.1.3 FS characteristics

The following FS parameters necessary for the completion of the compatibility studies have been used:

- Antenna gain and pattern
- Noise figure and noise floor
- Feeder losses

3.1.3.1 Antenna gain and pattern

For FWA access terminals and P-P links, typical antenna gain of 41 dBi (0.6 m diameter) has been considered, recognising that 47 dBi (1.2 m) (or even 50 dBi (1.8 m)) antennas are also deployed in 23 or 26 GHz networks.

The antenna pattern described in Recommendation ITU-R F.699 has been used in the calculations. The following figure 2 compares this antenna pattern an the one from ETSI 300 833 standard (class 2) and shows that F.699 represents a best case with regards to compatibility and also provides values in the main lobe (i.e. below 5°) which is not the case of the ETSI standard.

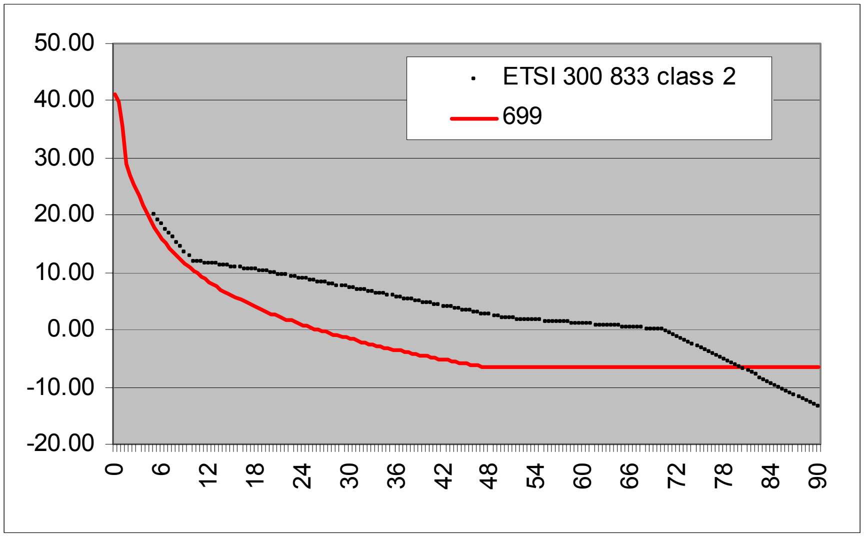


Figure 2

For the FWA Central stations, a 90° sector antenna of 18 dBi maximum gain has been considered as typical, associated with the antenna pattern given in ETSI 301 215-2 standard and described in figure 3 below. It has to be noted that in order to ensure an adequate coverage of the FWA cells, CS station antennas are down-tilted. A 2° downtilt has been considered in the present study.

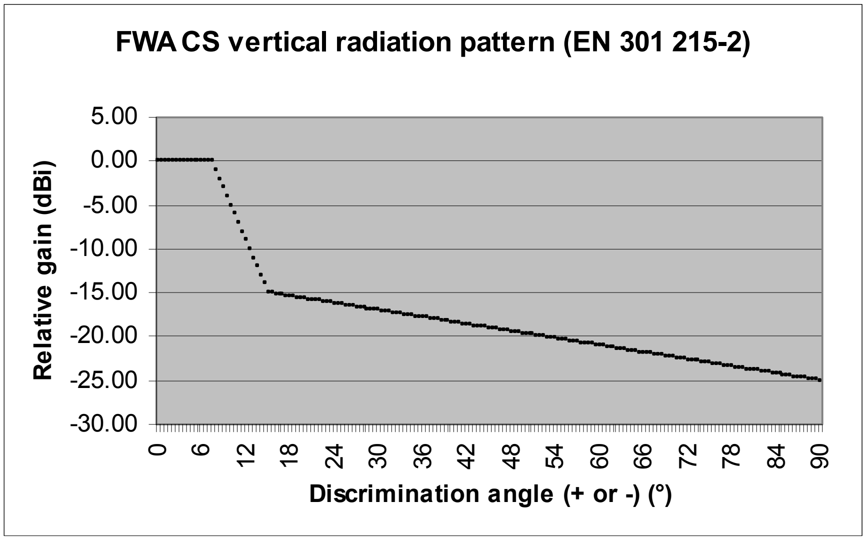


Figure 3

3.1.3.2 Noise figure and noise floor

For all types of FS systems (P-P or FWA), a 6 dB noise figure has been taken into account, that leads to a noise floor of –168 dBm/Hz.

It can be noted that this value does not represent a worst case since up to date equipment present 3 or 4 dB noise figure.

3.1.3.3 Feeder losses

For the typical systems in the 23 and 26 GHz bands as described above, the radio receivers are generally implemented close to the antennas, which implies that the feeder losses are negligible.

3.2 Earth Exploration-Satellite Service

According to Annex A, EESS (passive) is allocated in the bands 21.2-21.4 GHz, 22.21-22.5 GHz, 23.6-24 GHz and 24.05-24.25 GHz

ITU-R footnote 5.340 applies to the frequency band 23.6 to 24 GHz, which states that “All emissions are prohibited”.

The passive band 23.6-24 GHz is of primary interest to measure water vapour and liquid water.

3.2.1 Required protection criteria

The following three documents establish the interference criteria for passive sensors:

- Recommendation ITU-R SA.513-3, Frequency bands and bandwidths used for satellite passive services
- Recommendation ITU-R SA.1028-1, Performance criteria for satellite passive remote sensing.
- Recommendation ITU-R SA.1029-1, Interference criteria for satellite remote sensing.

It should be emphasized that operational applications which are routinely operating microwave passive sensors rely heavily on background scientific activities aiming at a better understanding and knowledge of the complex land/ocean-atmosphere machinery.

For that reason, the required performance parameters and interference criteria which are contained in the recommendations ITU-R SA.1028 and 1029 must be regularly updated to reflect such improvements, and to take advantage of the technological advances. These recommendations were recently revised (ITU-R WP7C, February 2002).

The revised interference criteria are the following.

- The interference threshold of the passive sensor is −166 dBW in a reference bandwidth of 200 MHz. This is a maximum interference level from all sources. Such a threshold corresponds to a measurement sensitivity of 0.05 K.
- The number of measurement cells where the interference threshold can be exceeded must not be more than 0.01% of pixels in all service areas for any kind of instrument.

It is to be noted that the above interference criteria represent the maximum acceptable contribution of the interferer to the error budget.

3.2.2 Operational characteristics

Details of the operational characteristics for the earth exploration satellites are given in Annex D.

3.3 Radio Astronomy

The ITU Radio Regulations identify the following frequency bands to the Radio Astronomy Service:

- 22.21-22.5 GHz: primary allocation to radio astronomy: footnote 5.149 applies.
- 22.81-22.86 GHz: notification of use for radio astronomy: footnote 5.149 applies.
- 23.07-23.12 GHz: notification of use for radio astronomy: footnote 5.149 applies.
- 23.6-24.0 GHz: primary allocation to radio astronomy: footnote 5.340 applies.

Footnote 5.149, which urges Administrations to take all practicable steps to protect the radio astronomy service from harmful interference, applies to the bands 22.21-22.5 GHz, 22.81-22.86 GHz and 23.07-23.12 GHz.

Footnote 5.340, which states that all emissions are prohibited, applies to the band 23.6-24.0 GHz.

European radio astronomy stations where observations are currently made in the frequency range 22-24 GHz are found in France, Germany, Italy, Spain, Sweden and the United Kingdom.

4 COMPATIBILITY STUDY

4.1 Theoretical

4.1.1 FIXED SERVICE

In this section the possible coexistence of UWB SRR automotive applications operating in the 24 GHz with FS are explored, focusing on the compatibility with Point-to-point FS systems. The FS performance criteria, receiver characteristics and coexistence scenarios are defined and numerical evaluations are carried out. Also, based on some practical measurements carried out (see Annex C), limits for possible coexistence of 24 GHz UWB SRR devices with FS systems in neighbouring 23 GHz and 26 GHz bands are proposed.

4.1.1.1 Frequency bands

In the range 21.625 - 26.625 GHz, Fixed Service is allocated in the 21.2 - 23.6 GHz and 24.25 - 27 GHz bands (See annex A for details).

Within CEPT, the 23 and 26 GHz bands are both currently heavily used by FS.

4.1.1.1.1.1 23 GHz band (22-23.6 GHz)

The 23 GHz band is heavily used throughout Europe for digital FS systems with low/medium and high capacity PP links. In many cases this is used for the provision of regional telecommunication infrastructure (e.g. for Public Mobile Telephony Networks), but also for multi-purpose RRL, such as private FS networks.

The number of links has more than doubled between 1997-2001 and is now higher than 37000 links. That makes this band one of the more important frequency band for Mobile Telephony Networks infrastructure.

In most countries the channel arrangement follows Annex A of CEPT Recommendation T/R 13-02, with actually used channel widths of 3.5/7/14/28 MHz. In few countries 56 MHz channels are also in use. The average recorded hop length in this frequency band is 7 km.

4.1.1.1.2 26 GHz band (24.5-26.5 GHz)

With a fast growing tendency (from 500 links in 1997 to about 13000 in 2001), the 26 GHz band is heavily used throughout CEPT for FS in accordance with the channel arrangements in Annex B of CEPT Recommendation T/R 13-02. This encompasses the FS applications for the provision of regional telecommunication infrastructure (e.g. for Public Mobile Telephony Networks) using digital point-to-point, but also point-to-multipoint fixed links. The capacity of the links ranges between low, medium and high.

This band is also one of the preferred bands for Fixed Wireless Access (FWA) introduction in Europe, in accordance with its identification in ERC/REC 13-04. Assignment of channels for FWA also follows arrangements given in T/R 13-02. Together with the band 3400–3600 MHz this band (or parts of it) constitutes the most widely used band for the provision of FWA within CEPT. The average length of reported (PP) links in this band is 6 km.

4.1.1.2 FS interference criteria

The common ITU-R rule for interference from unwanted emissions from sources other than FS or Services sharing the same band on primary bases is reported in Recommendation ITU-R. F.1094. Recommendation ITU-R F.1094 provides the apportionment of the total degradation of an FS link due to interferences as:

- 89 % for the intra service interference
- 10% for the co-primary services interference
- 1% for the aggregation of the following interferences:
  a) Emissions from radio services which share frequency allocations on a non-primary basis;

  b) Unwanted emissions (i.e. out-of-band and spurious emissions such as energy spread from radio systems, etc.) in non-shared bands;

  c) Unwanted radiations (e.g. ISM applications);

These percentages are not related to the total time of operation but apply to the performance objectives such as given in Recommendations ITU-R F.1397 and F.1491. In addition, this degradation allowance is not given to a single transmitter but to the aggregation of the whole secondary service transmitters and unwanted signals.

Moreover, F.1094 recommends that no impairment, due to interference, on system availability (generally requested less than 0.01% of the time) be allowed (i.e. propagation attenuation only is to be considered); FS system availability requirements are defined in ITU-R Recommendation F.695.

This criteria is considered applicable also for the SRR emissions interference (that are considered among the a) case above).

From the above principle ITU-R has defined interference criteria as described the following paragraphs.

4.1.1.2.1 Long-term criteria

It is generally agreed, such as in Recommendation F.758, that, on a long-term basis (20% of the time), a margin degradation of 0.5 dB (equivalent to an I/N= –10dB) implies a performance degradation of 10 % and hence yield to an I/N= –10dB long-term criteria for co-primary sharing.

For secondary service interference and unwanted emissions, Recommendation ITU-R F.1094 specifies that the performance degradation shall not exceed 1%. This obviously means that the level of interference should be much lower than the I/N= –10dB agreed for the co-primary case. In addition, Recommendation ITU-R F.758 stipulates that the interference from secondary service interference and unwanted emissions should not degrade the availability of the FS links. This means that the margin degradation should be limited to the lowest possible.

Performance of FS links are controlled by two different factors :

- Availability (or unavailability),
- Error performance objectives (EPO) as given in Recommendations ITU-R F.1397 and F.1491

In the bands where the fading is controlled by rain (higher than around 17 GHz), the design of the FS links is based on availability (with typical values of 99.99% or 99.999% depending on the type of application and the operator requirements) applying Recommendation ITU-R P.530 to determine the appropriate fade margin.

Long-term interference (more than 20% of the time) leads to a margin and availability degradation. In order to limit this degradation to a maximum of 0.5% (the 1% degradation of the Rec. ITU-R F.1094 is to be shared with secondary services), it is shown that the noise increase due to long term interference shall be limited to 0.04 dB. **This is equivalent to a long-term criteria expressed as I/N = –20 dB**.

As an example, the last meeting of ITU-R WP 9A had to cope with the definition of interference criteria to protect the fixed service from aeronautical mobile satellite stations operating on a secondary basis. For such secondary service, WP 9A concluded that an I/N=–20 dB for 20% of the time is the adequate criteria.

It should be considered that this is a generic objective assuming that the interference will have similar spectral emission characteristic of the noise. In SRR case, due to the pulsed characteristic of most applications, separate considerations would be needed for both average (rms) and peak (within FS receiver bandwidth) interference objectives.

4.1.1.2.2 Short-term criteria

Short–term criteria, also reported by ITU-R F.758, is an additional criteria that gives allowance, for very short percentage of time (e.g. in the order of 0.0001 % of the time), for a positive I/N ratio to happen. This could be related to possible coherent sum of many SRR devices of the same kind; the statistical behaviour of the aggregate power (referred as Amplitude Probability Distribution (APD) in NTIA studies) depends on the actual characteristic of the SRR emission or mixture of different emissions.

The particular elements taken into consideration in the definition of the short-term criteria (20 dB fade margin for P-P and Error performance objectives related to “Access” or “short-haul inter-exchange” parts of the network) are representative of the existing FS links in both 23 and 26 GHz band.

Therefore, based on indications from WGPT SE19 liaison statement, the following short-term protection criteria should be used in the compatibility studies between SRR 24 GHz and FS and which could affect in particular the aggregate peak limitation of the SRR:

for P-P systems :

- for ES (G.828) : I/N = 15 dB not to be exceeded for more than 0.0016 %
- for ES (G.826) : I/N = 15 dB not to be exceeded for more than 0.006 %
- for SES : I/N = 19 dB not to be exceeded for more than 0.00016 %

for FWA systems :

- for ES (G.828) : I/N = 5 dB not to be exceeded for more than 0.0016 %
- for ES (G.826) : I/N = 5 dB not to be exceeded for more than 0.006 %
- for SES : I/N = 9 dB not to be exceeded for more than 0.00016 %

However, this study being generic and not focused to a specific SRR emission, these criteria have not been considered at this stage and would need a case by case consideration with the definition of a representative aggregate APD statistics.

4.1.1.3 FS characteristics

The following FS parameters necessary for the completion of the compatibility studies have been used:

- Antenna gain and pattern
- Noise figure and noise floor
- Feeder losses
- Antenna height and horizontal offset

4.1.1.3.1 Antenna gain and pattern

For FWA access terminals and P-P links, typical antenna gain of 41 dBi (0.6 m diameter) has been considered, recognising that 47 dBi (1.2 m) (or even 50 dBi (1.8 m)) antennas are also deployed in 23 or 26 GHz networks.

The relevant ETSI standard for this frequency bands is EN 300 833. However, it only represents an envelope of pattern and does not give pattern for the main lobe (i.e. below 5°). On the other hand, Recommendation ITU-R F.699 is generally used for international sharing studies and hence seems preferable to be used for UWB compatibility.

The following figure 4 compares this antenna pattern an the one from ETSI 300 833 standard (class 2) and shows that F.699 represents a best case with regards to compatibility and also provides values in the main lobe (i.e. below 5°) which is not the case of the ETSI standard.

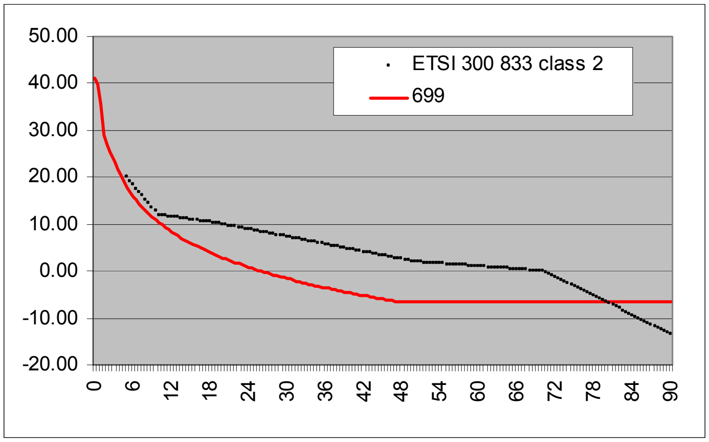


Figure 4

In addition ITU-R F.1245 gives an additional radiation pattern that presents attenuation based on average values of side lobes, to be used for aggregate interference studies. Figure 5 gives a comparison between the antenna pattern from Recommendations F.699 and F.1245.

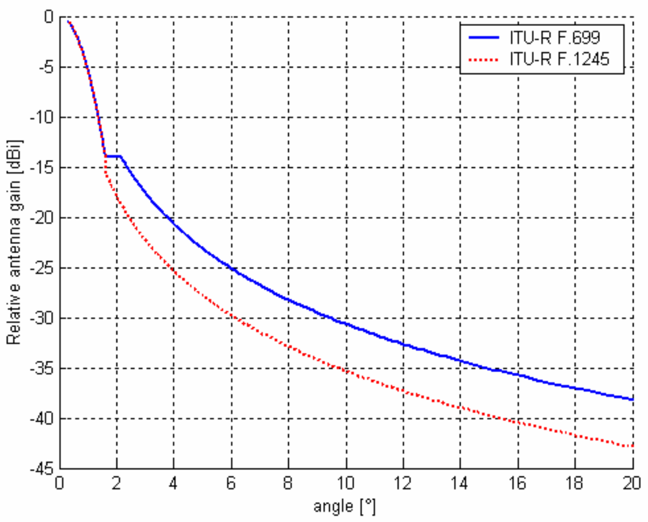


Figure 5

For the FWA Central stations, a 90° sector antenna of 18 dBi maximum gain has been considered as typical, associated with the antenna pattern given in ETSI 301 215-2 standard and described in figure 6 below. It has to be noted that in order to ensure an adequate coverage of the FWA cells, CS stations are down tilted. A 2° down tilt has been considered in the present study.

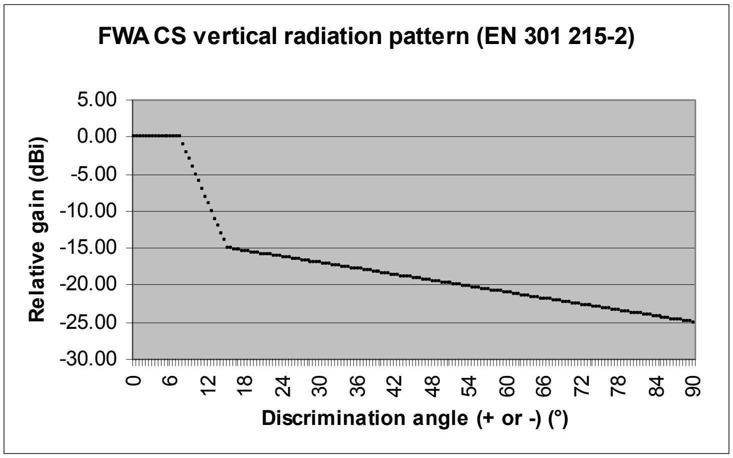


Figure 6

As a summary, the following antenna parameters have been used in the compatibility studies:

- According to ITU-R F.699 for single entry evaluation with P-P (see figure 4)
- According to F.1245 for aggregate scenarios with P-P (see figure 5)
- According to EN 301 215 for scenarios with FWA (see figure 6)
- P-P Antenna Gain = 41 dBi
- FWA CS Antenna Gain = 18 dBi
- P-P Tilt = 0°
- FWA Tilt = 2° down

4.1.1.3.2 Noise figure and noise floor

For all types of FS systems (P-P or FWA), a 6 dB noise figure has been taken into account that leads to a noise floor of –168 dBm/Hz.

It can be noted that up–to-date equipment has a 4 dB noise figure, whereas Recommendation ITU-R F.758 specifies a 5-12 dB range for this parameter.

4.1.1.3.3 Feeder losses

For the typical systems in the 23 and 26 GHz bands as described above, the radio receivers are generally implemented close to the antennas, which implies that the feeder losses are negligible. A 0 dB feeder loss has hence been considered in the calculations.

4.1.1.3.4 FS antenna height and horizontal offset

The vertical and horizontal location of the antennas and their decoupling with regard to the road play a fundamental role, as shown in Figure 7.

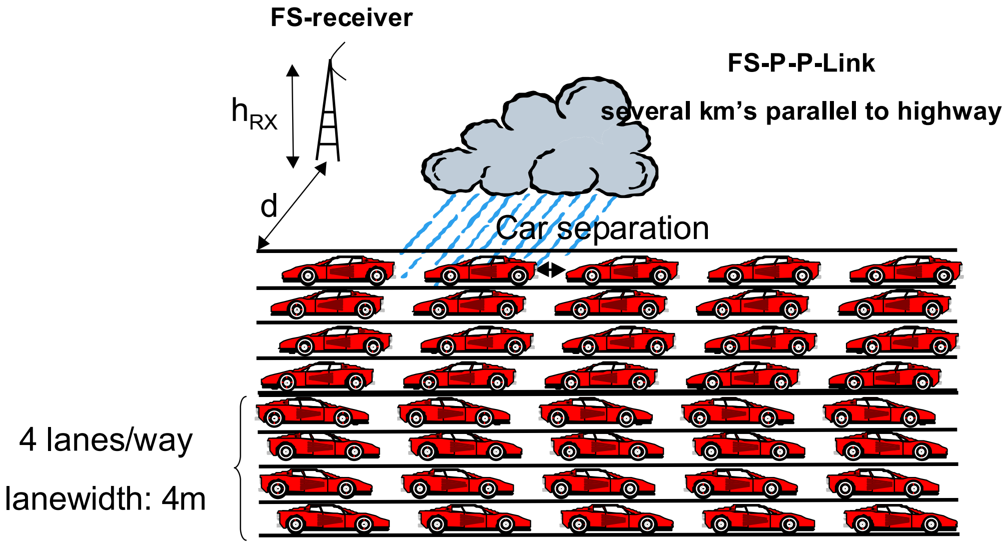


Figure 7: Vertical/horizontal planes scenario

The antenna height plays significant role; worst case is expected with the lower FS antenna location. For FWA CS higher locations are sought for enhancing cell coverage.

For P-P links, on the contrary, the lowest possible height, consistent with link line-of-sight conditions, is chosen for cost-effective deployment and frequency reuse. Examples were given for an Italian operator network, where standard antenna poles 18m height are used wherever possible; same typical 15-18 m pole height seems in use by Germany operators. UK however presented typical data including lower height (10 m) above the road plane.

It was hence agreed to explore three different heights: 10, 18 and 25 m

Also the horizontal offset from the road border will affect the results: the greater is the offset, the lower is the expected aggregated interference. Various figures have been presented ranging from 10 m (possibly more appropriate for normal roads (e.g. with 1 lane only) up to 30 m (possible when large highways are concerned).

Also in this case both values 10 and 30 m have been evaluated

4.1.1.4 Additional parameters for interference calculations

4.1.1.4.1 Number of active SRR device per car

Initial ETSI TR 101 982 indicate that up to 10 sensor/car might be used, but does not give additional information about their use, number and location of contemporarily operated ones.

Industry produced more detailed information, giving location/purpose activation/deactivation criteria of the sensors related to environ characteristic (e.g. car speed and road type, possibly connected to GPS positioning).

On the basis of this document it was assumed that a maximum of 4 active sensors per car are representative of a long term situation, two pointing frontward and two backward. The following figure 8 below summarises all possible situations of cars relative to an FS station.

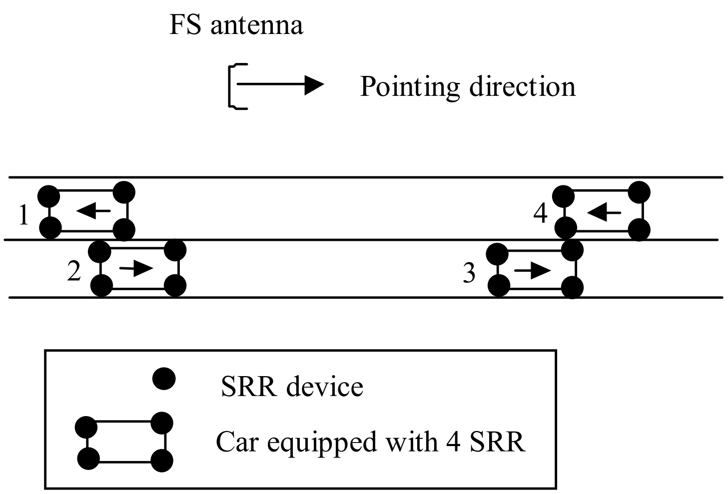


Figure 8: description of all different possible SRR locations

For car situations N° 1 and 2, the radars will interfere in the back lobe of the FS antenna and have not been taken into account.

Similarly, the contribution of car situation N°3 (farthest lanes from the FS location) was expected to be negligible and has also not been taken into account.

Finally, only the 2 frontward radars from car situation N° 4 were considered in the studies.

It can be noted that side's radars were not considered in the studies. However, it was assumed that they could increase the interference potential to FS station in the vicinity of the road.

In this case it is also worth noting the comparison with the current development of Air Bags and Anti-Blocking Systems (ABS), see section 2.3.6.

4.1.1.4.2 SRR e.i.r.p. levels and directional characteristics (present and evolution)

ETSI TR 101 982 presently gives the following e.i.r.p. density values:

- E.i.r.p. density (rms) = –30 dBm/MHz
- E.i.r.p. density (peak) = No limit (only the overall e.i.r.p. peak of +20 dBm for SRD is considered.

However, according the recently released FCC rules, SRR sensors would operate at lower power:

- E.i.r.p. density (rms) = –41.3 dBm/MHz
- E.i.r.p. density (peak) = 0 dBm/50MHz

On this basis, these latter e.i.r.p. levels were agreed for use in the calculations.

In addition, FCC rule specifies different antenna patterns for SRR sensors that would be more stringent in elevation compared with the ETSI standard as shown in Figure 9. However, it was shown that its impact on compatibility with FS is negligible.

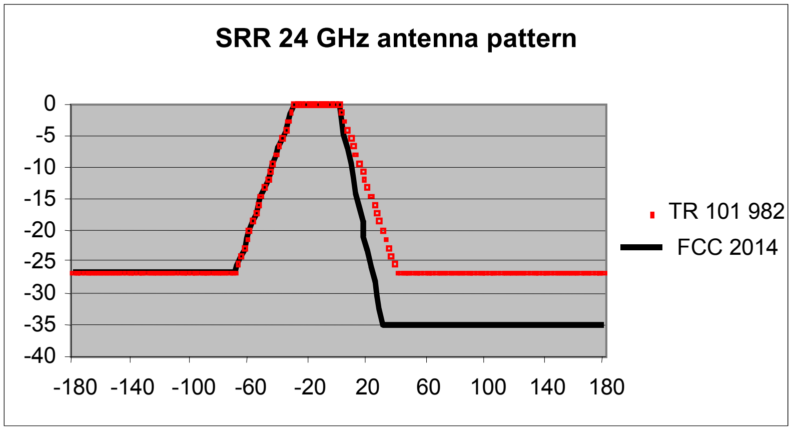


Figure 9: Present ETSI SRdoc and FCC objective for year 2014

4.1.1.4.3 Bumper loss

Since SRR sensors would be commonly mounted behind bumpers, their attenuation has to be taken into account because regulatory levels would be set for SRR "bare" sensors only.

A typical bumper has a depth of about 4mm to meet the mechanical requirements and consists of the recyclable plastic PBT (**P**oly **B**uthylen **T**erephtalat). The commonly used plastic has transmission losses of about 3dB that further slightly increases if humidity is absorbed by the plastic. The painting of the bumpers causes a further loss that depends on the paint that is used. Metallic paints cause the highest noted losses.

Tests have been carried out and the results are given on Figure 10 below showing that the typical or average loss of the bumper is higher than the assumed 3dB.

To reproduce the real case, the bumper damping was measured with a SRR using UWB technology placed behind a piece of bumper in an anechoic environment. The transmitted mean power was measured by using a power meter connected to a pick up horn at bore sight of the TX antenna.

It can be noted that the uppermost light blue curve relates to a SRR device without bumper and that the relative SRR TX PSD is measured versus azimuth angle.

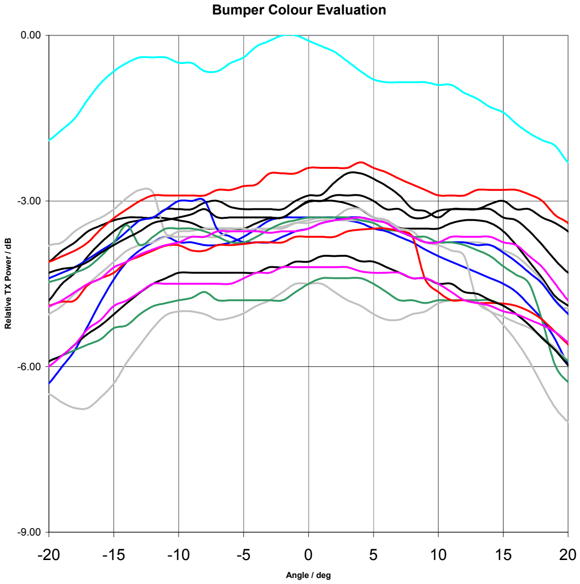


Figure 10: Losses caused by the bumper measured with different bumper colours

On this basis, an 3 dB additional loss has been used in the compatibility studies.

However, considering that it is not possible to foresee technology and "styling" evolution in automotive market, the ETSI EN standard should mention the fact that SRR mounting is behind a bumper or similar. In case of "bare" mount of the sensor, the e.i.r.p. would have to be reduced accordingly.

4.1.1.4.4 SRR sensor height

As the height of the SRR sensors mounting increases, the expected interference is assumed to increase, due in particular to the loss of shielding given by preceding vehicles.

Initial ETSI TR 101 982 indicate a maximum height of 1.5m. However this only seems suitable for trucks, while for cars, representing the majority of all vehicles, an average 0.5m is more appropriate.

More detailed requirement would be needed in the ETSI EN standard.

4.1.1.4.5 Rain correlation and water spray attenuation

Since long-term criterion as defined in section 3.1.2 above is justified by a margin degradation in rainy conditions (that controls the FS availability), it was determined that attenuation due to rain on the FS link path would also result in a lower attenuation due to rain on the interfering path between the radar and the FS receiver.

Based on Recommendations ITU-R P.452 and P.530 which give statistics on rain distributions and rain cell sizes, and comparing the typical hop length of the FS link ~5to 7 km to the cell rain size for various rain zones. It was determined that a specific attenuation ranging from 0.6 dB/km to 3 dB/km on the interfering path might be considered in the simulations.

In addition, a possible additional attenuation due to water spray caused by preceding vehicles has also been evaluated.

It was reported that during rain period, the attenuation of SRR radiation due to spray from preceding cars might be much stronger than the attenuation due to the rain itself. Usually, during rain showers with precipitation rates of the order of 28mm/h, the area in front of the radar sensors has such high water concentration that even SRR-operation is jeopardised or impossible due to the strong water attenuation.

On the other hand, it was also noted that new anti-spray pavement is becoming more and more popular on high traffic density roads for the same life-saving reasons that ask for SRR to be introduced.

Due to the lack of technical evidence on numerical value of such impact (a value of ~2 dB was suggested), it was not possible to determine to which extent it would improve the compatibility with FS.

However, it was agreed that such effect could be neglected in cases where the distance between cars is higher than 50 m. For lower distances, it was agreed to consider this effect as a safeguard margin.

4.1.1.4.6 Car shielding

When vehicles, queuing on roads become closer, the proceeding car/van acts as shielding towards the FS victim antenna.

Tests have been carried out and additional attenuation has been evaluated, as a function of the clearance or obstruction angle shown in Figures 11 and 12.

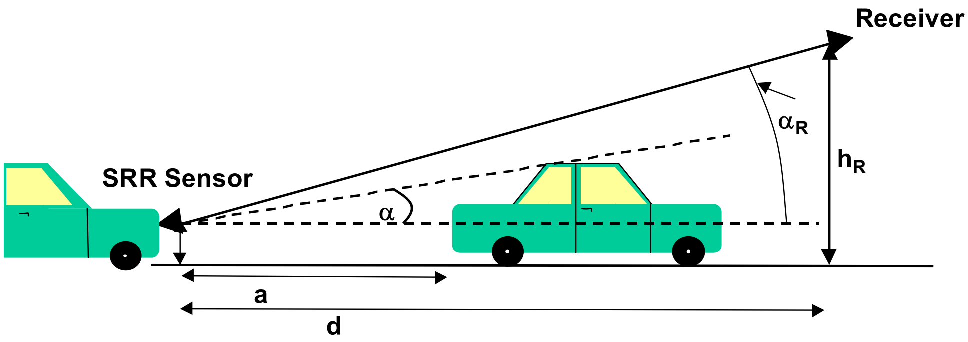


Figure 11: Sketch of a LOS-connection between SRR and receiver.

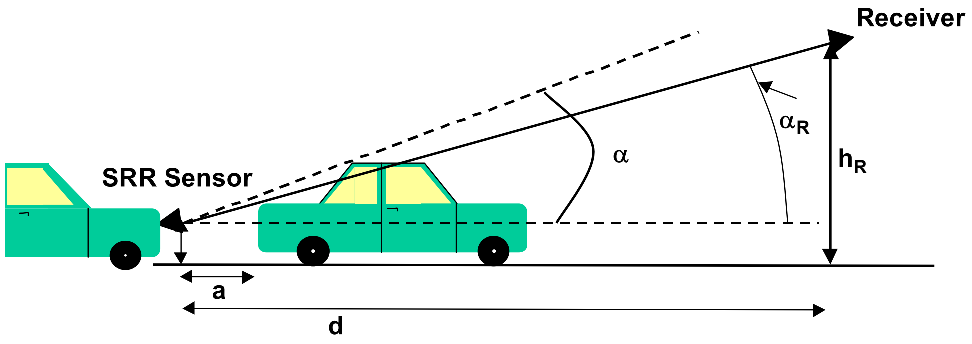


Figure 12: Sketch of an NLOS-connection between SRR and receiver.

The measured attenuation and the assumed linear model for the attenuation are shown in Figure 13, which shows relative shielding loss L_S as function of the difference between the elevation angle α to the top of shielding vehicle and the LOS-angle a_R. The shielding loss is normalised with regard to received power in the absence of any shielding object between transmitter. The red curve gives a simplified shielding model to be used in the calculations:

$L_S = 0$ for $a\text{-}a_R < -2$

$L_S = 2.2*(a\text{-}a_R) + 4.4$ for $-2 < (a\text{-}a_R) < 8$

$L_S = 22$ for $(a\text{-}a_R) > 8$.

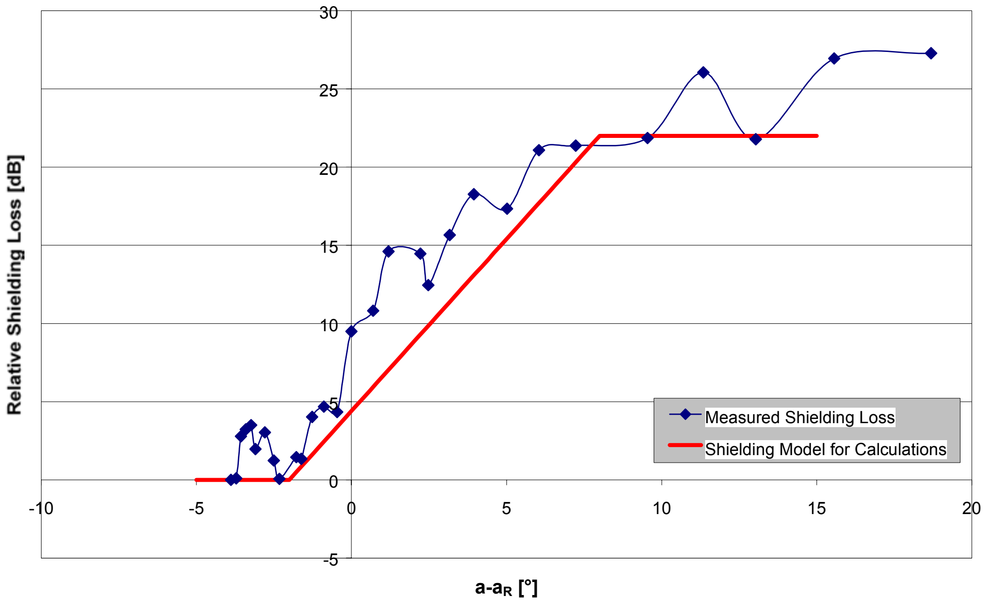


Figure 13: Results of shielding measurement

Note: the reference for evaluating the angle given in the above figure 13 is the mounted height of the SRR device (i.e. 0.5 m as described in sections above).

The angle α depends on both the separation of vehicles and the height of the preceding car, for which a value of 1.4m has been assumed. This value is certainly valid for majority of cars, but not for trucks, buses, or vans. In order to account for vehicles other than cars, a stochastic approach would have been necessary that would have likely led to an additional attenuation. However, since the car variance is difficult to assess and varies from day to day (working days, weekend (no trucks), etc.), it would have posed very difficult burden to the mathematical model. On the other hand, it was also acknowledged that the radars are likely to be mounted higher on trucks and vans and hence would experience less shielding.

In addition to shielding due to preceding vehicles, the shielding by vehicles on adjacent lanes has also been considered. Recognising that when the FS station is placed in off-set distance from the road boarder, no shielding may occur for some SRR devices, it was considered in the study, as a mean of simplification, that all emissions from adjacent lanes except the outermost one would be shielded.

Finally, the calculations have applied the above described shielding effect only with regards to the vertical plane. The same shielding model might have been considered in the horizontal plane, but would have led to complex calculations. However, some example calculations performed with this additional mitigation factor report that it could result in an aggregate interference decrease from 10 dB, when the distance between cars is 10 metres, to 3 dB, when the distance between cars is 30 metres, which could hence allow assuming that it is likely to vanish for higher distances between cars.

4.1.1.4.7 Clutter loss

Besides shielding due to other vehicles, clutter loss due to shielding by objects such as traffic signs, bridges, trees, guardrails, buildings may have to be taken into account in the interference calculations.

Even if a potential of around 5 dB attenuation was proposed, it was difficult to quantify these effects without evidence, recognising that it can vary depending on the considered location.

Therefore no attenuation due to clutter loss has been taken into account recognising, however, that it could be retained as a safeguard margin.

4.1.1.4.8 Reflection/diffraction from surrounding vehicles

The reflection/diffraction caused by surrounding vehicles has the potential to increase the interference from SRR to the FS stations.

As an example, the backward SRR device emissions may reflect on the front of the following vehicle and be redirected towards the victim antenna and hence add to the aggregate interference from direct path.

However, this effect is also difficult to assess even though it is likely that it would be more important in high traffic density situations. Therefore, it has not been taken into account in the calculations, recognising that it would balance other mitigation factors that have also not been considered, such as clutter losses or horizontal shielding.

4.1.1.4.9 Polarisation decoupling

It was suggested that SRR might use vertical or horizontal polarisation and was proposed that ~50% (i.e. 3 dB) of devices would transmit on different polarisation than that used by the FS victim station. In addition, also for the co-polarised devices, the imprecision of mounting and the road plane differences would also rotate the copular emission of some random angle giving an un-predictable decoupling.

On the other hand, it was also considered that, the propagation characteristics are more effective using vertical polarisation at 24 GHz.

Finally, it was also noted that Recommendation ITU-R F.1245 (see section 3.1.3.1 above) only consider a potential polarisation gain for "circular-polarised" interferer in main beam to main beam scenario.

Therefore, no polarisation decoupling has been taken into account in the calculations in these studies.

4.1.1.4.10 Gating

In practice, all SRR sensors would be idle for a period, necessary to the receiver to elaborate the backward signal. Regulators would not consider this fact and are expected to consider limits with continuous emission only. The FCC regulation that requests an e.i.r.p. density limit of –41 dBm/MHz asks for assessment without considering any gating.

Therefore, no gating improvement has been considered in the calculation studies.

4.1.1.5 Methodology and Scenarios

4.1.1.5.1 Introduction

As usual, the interfering scenario for Fixed Service is different from the typical probabilistic approach for Point-to-area mobile communications (such as GSM, GPS, 3G and various safety services). It is expected that large number of UWB SRR interfering sources will be spread, often in deterministic way, within a small area covered by a single FWA or P-P receiver.

The stochastic approach used for mobile or space located victim receivers is no longer correct for Fixed Service covering a relatively small area and often in urban environment (the bands 23 and 26 GHz are largely used for GSM (and now for UMTS) infrastructure support links. The possible car concentration nearby FS stations is often experienced (anybody who commutes each morning and evening is well aware of that) and has to be taken into account.

Consequently two typical cases have been assumed:

1. **SRR aggregate interference due to vehicles queuing for traffic lights or traffic jamming on avenues converging to a city central square (Figure 14) (FWA case)**

   The Fixed Wireless Central Station (CS) is placed on a medium-height location (e.g. 30m height might be commonly assumed) on a building where some large streets converge. It was assumed that 3 of those streets, with 3 lanes per street, would generate interference.
   The CS would have a typical sector antenna with 90º horizontal (equal gain) beam width, and a slight down-tilt (e.g. 2°) as common engineering rule for enhanced coverage, placed on a medium-height building overlooking the square.
   The number of active SRR devices (from TR 101 982 and other SRR introductory documents) and other mitigation factors (e.g. shielding from preceding vehicles), leading to additional interference mitigation and data, as discussed in section 4.1.1.3.2, were used in the numerical evaluation of the expected interference.
   The length of the cueing has to be assumed at ~100 m (~15-20 vehicles in a line).

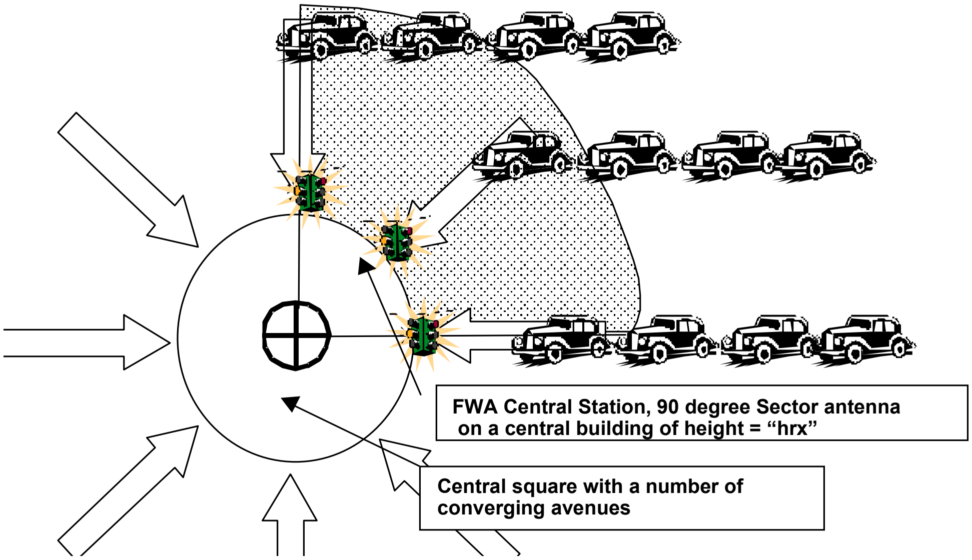


Figure 14: The Central Square scenario (plan projection)

2. **SRR aggregate interference due to vehicles driving (or queuing, in rush hours) on road or highway within FWA CS sector coverage or parallel to a P-P link (Figure 15).**
   In this case, the length of the lines might be much longer (e.g. few km) than the first case. The number of active SRR devices (from TR 101 982 and other SRR introductory documents) and other mitigation factors (e.g. shielding from preceding vehicles), leading to additional interference

mitigation and data, as discussed in section 4.1.1.3.2, were used in the numerical evaluation of the expected interference.

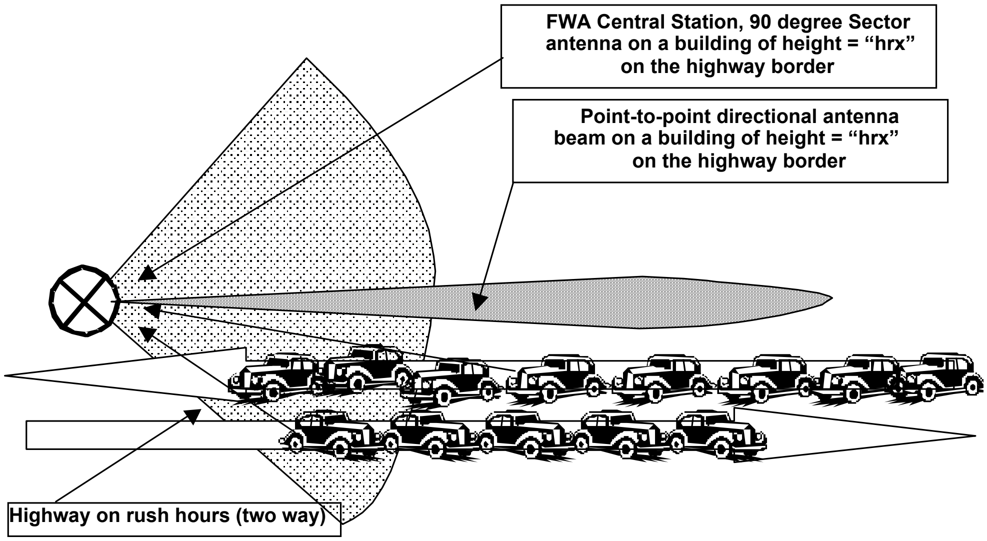


Figure 15: The road or highway scenario (plan projection)

Initial evaluations have shown that the second scenario for Point-to-point links is considered worst than for FWA CS. Therefore only the P-P case has been fully explored as representative of the compatibility issue

On this basis, the considered scenarios were based on a typical case of an FS station located in the vicinity (at a given distance, called offset) of a road or a highway, as described in figure 16 below.

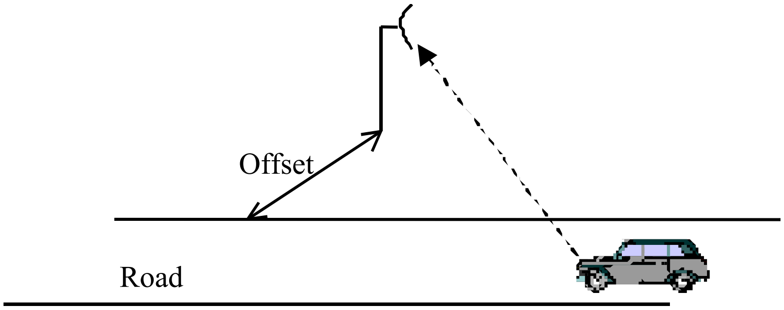


Figure 16

The I/N produced by one radar is calculated as follows:

$$\frac{I}{N} = P_{rad} - Gat - A_{bump} + Discri_{rad} - FSL - A_{rain} + Gain_{FS} - kTBF ,$$

with: P_{rad} = Power of the radar (dBm/Hz)

Gat = Gating ratio of the radar (dB)

A_{bump} = Attenuation due to bumpers (dB)

$Discri_{rad}$ = discrimination of the radar in the direction of the FS receiver (dB)

FSL = free space losses (dB), function of the distance

A_{rain} = attenuation due to rain (dB), function of the distance

$Gain_{FS}$ = Gain of the FS in the direction of the radar (dBi)

kTBF = Noise floor of the FS (dBm/Hz)

2 different studied scenarios have been considered for a separation distance between cars of 20, 50, 100 and 150 metres:

Scenario 1: Aggregation of multiple cars on 1 lane (Road), with 2 radars per car

Scenario 2: Aggregation of multiple cars on 4 lanes (Highway), with 2 radars per car.

4.1.1.5.2 Scenario 1: Aggregation of multiple cars on 1 lane (Road)

This scenario proposes to calculate the aggregate interference from multiple cars with 2 frontward radars per car (the assumed 2 backward radars have not been considered). The distance between cars is d' (see figure 17 below).

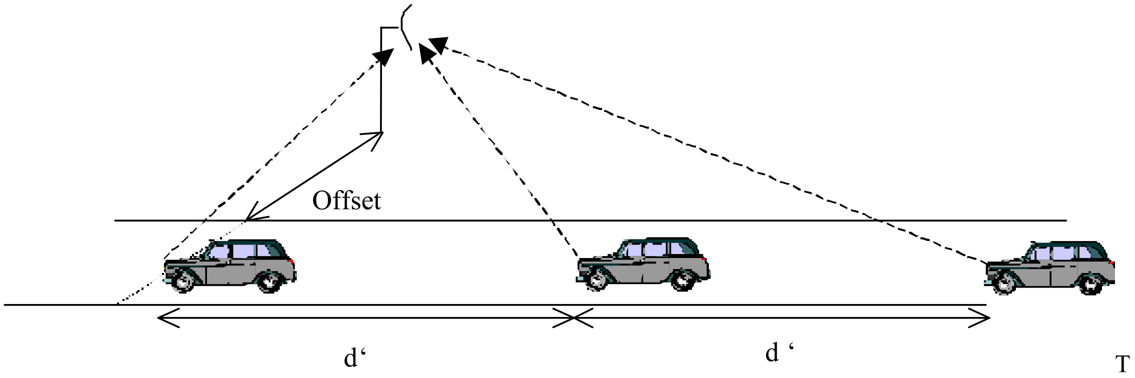


Figure 17

The 2 radars are implemented frontward, 1 on the right, and the second on the left of the car.

Due to the fact that the FS station is offset from the road, no shielding due to preceding car is taken into account for the right hand radar.

For the left hand radar, the shielding due to preceding car as described in figure 17 above is taken into account if, approximately, $\frac{(Offset + l)}{d} < \frac{l}{d' - L}$ (see figure 18 below).

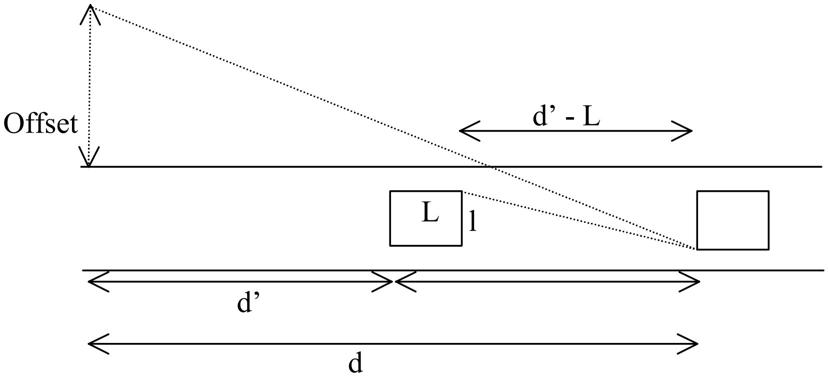


Figure 18

Where: d' = distance between cars

d = distance from the considered car and the FS receiver

l = width of the car

L = length of the car

Offset = offset of the FS receiver from the road

In other cases, no shielding is considered. It can be noted that in situations where the offset is relatively small, the shielding on the left hand radar is considered in almost all cases.

4.1.1.5.3 Scenario 2: Aggregation of multiple cars on 4 lanes (Highway)

This scenario proposes to calculate the aggregate interference from multiple cars on a 4 lane highway with 2 frontward radars per car. The distance between cars is d'.

For the right lane, the scenario is similar to Scenario 1 above.

For the 3 other lanes, even though in many cases the interference from radars will not be attenuated, it has been considered that the shielding due to preceding cars applies to all radars, which represents obviously a best case for the SRR.

4.1.1.6 Calculation results

Based on the above, calculations have been performed for all variations of the following parameters:

- rain attenuation: 0.6 dB/km and 3 dB/km
- FS antenna height: 10 m, 18 m and 25 m
- FS antenna offset: 10 m and 30 m
- Distance between cars: 20 m, 50 m, 100 m and 150 m

The whole set of results is given in Annex B.

In all figures, the input parameters used for each simulation are given using the following simple convention:

"0.6p-25h-10off-20m",

which in this example means that the rain attenuation was 0.6 dB/km, the FS antenna height 25m, the offset 10 metres and the distance between cars 20 m.

The figures B.1, B.12, B.13 and B.24 from the Annex B are reproduced below and show the extreme cases for the 2 considered scenarios. These figures show that even using the lower e.i.r.p. density from the FCC regulations, the interference exceeds the FS protection criteria (I/N = -20 dB), by 0 to 20 dB depending on the scenario and on the combination of the factors.

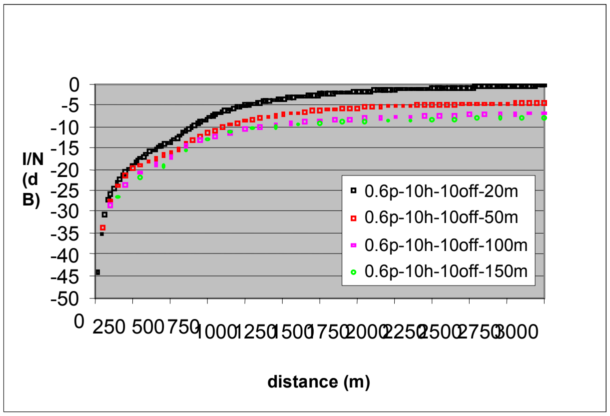


Figure B.1: 1 lane scenario (0.6p-10h-10off)

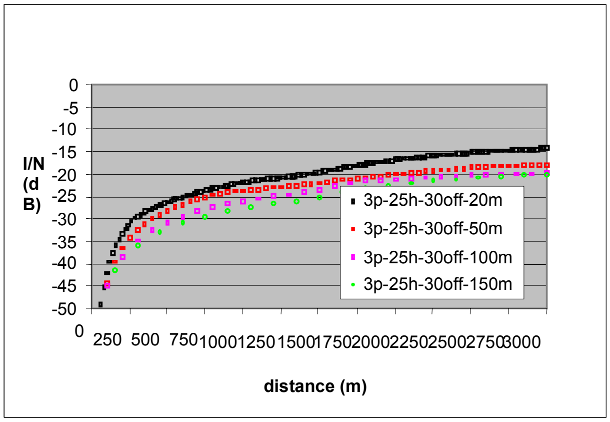


Figure B.12: 1 lane scenario (3p-25h-30off)

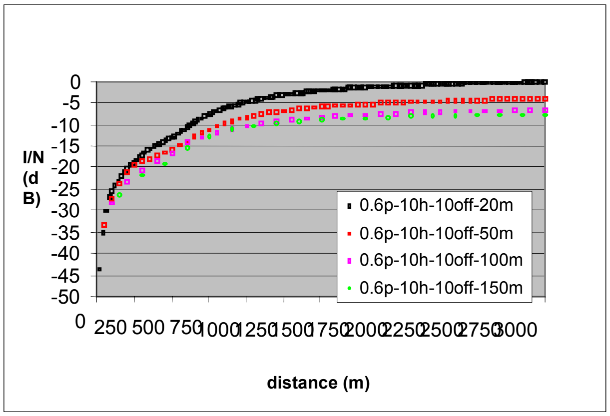


Figure B.13: 4 lanes scenario (0.6p-10h-10off)

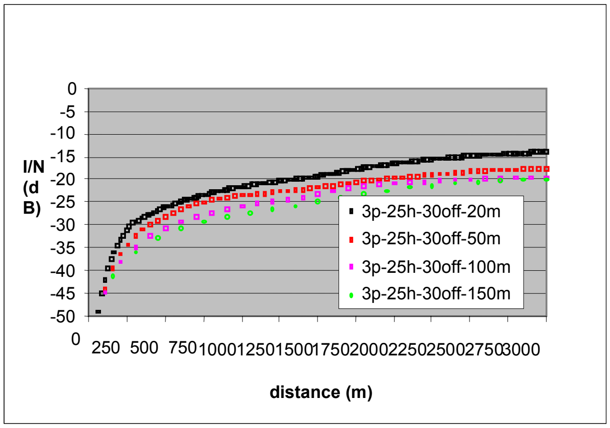


Figure B.24: 4 lanes scenario (3p-25h-30off)

In addition, figures B.25 to B.28 from the annex B are reproduced below to provide a comparison of the effect of variation of each independent input parameter. With this respect, it is interesting to note on figure B.28 that the interference for scenario 1 (1 lane) and scenario 2 (4 lanes) are almost similar which means that due to shielding effect, the interference is mainly due to the vehicles on the near-side lane.

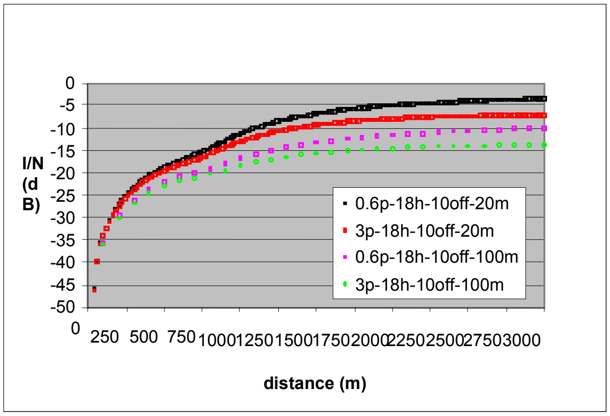


Figure B.25: 1 lane scenario (Rain comparison)

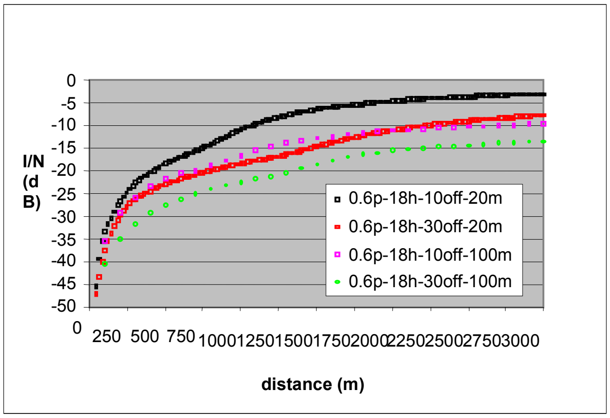


Figure B.26: 4 lanes scenario (Offset comparison)

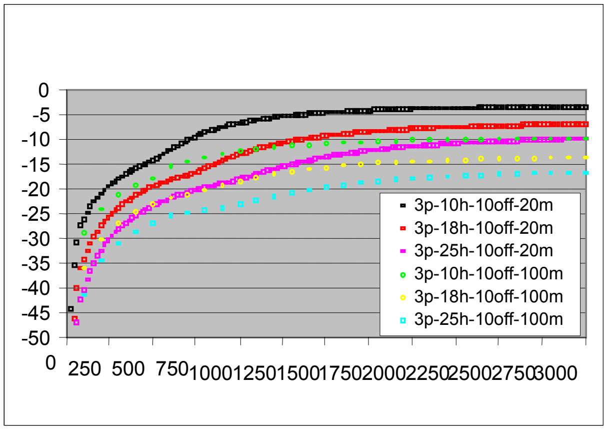


Figure B.27: 1 lane scenario (FS antenna height comparison)

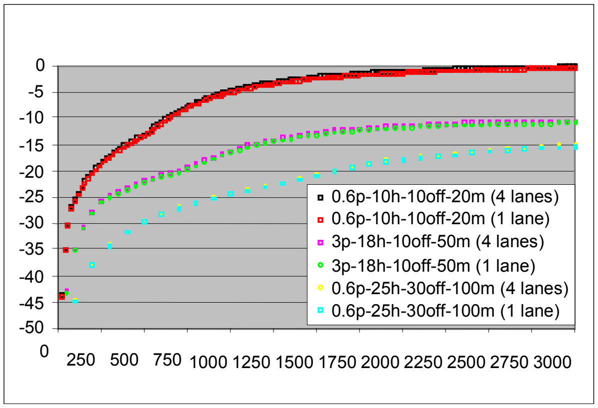


Figure B.28: 1 lane and 4 lanes scenarios comparison

On this basis, it is obvious that the compatibility between 24 GHz SRR and FS can not be ensured and that a reduction in power or percentage of cars equipped with SRR devices in vicinity of the FS receiver would be necessary.

On the basis of the whole range of calculation results, it can be concluded that with an e.i.r.p. density of -60 dBm/MHz the FS protection criteria (–20 dB I/N) for all scenarios considered in these studies is respected, whilst with an e.i.r.p. density of –50 dBm/MHz, this protection criteria would be met in most scenarios. Some administrations are of the opinion that is it necessary that SRR meets the –20 dB I/N protection criteria in all cases. Some other administrations are of the opinion that an excess of the protection criteria by 10 dB, which still corresponds to an I/N of –10 dB, is acceptable.

In addition, on a short-term basis, it was concluded that an e.i.r.p. mean power density of –41.3 dBm/MHz associated with an e.i.r.p peak limit of 0dBm/50 MHz could be sufficient to protect the FS as far as the percentage of cars equipped with SRR devices in visibility of the FS receiver is limited to less than 10% or less than few percent depending on whether the protection criteria is to be met in all cases; 10 % is equivalent to a 10 dB decrease of the aggregate power.

4.1.1.7 Tests Results

Summary of a test campaign to determine the effect of 24 GHz SRR on the Error performance objectives (mainly Bit Error Ratio) of FS receiver is given in Annex C.

These results have in particular allowed determining that the peak interference power from the SRR devices should also be limited to a value 42 dB higher than the mean interference limit within 1 MHz.

Therefore, for a –41.3 dBm/MHz e.i.r.p. mean density limit, the peak interference power density limit, according to the coexistence objectives, should be:

$$I_{peak/50MHz} \leq -116 \text{ dBW/50MHz}$$

4.1.1.8 Summary of required modifications of EN 301 091 for FS coexistence

The use of UWB SRR in the 24.050-24.250 GHz band depends on the final decision from CEPT WG FM. In any case, this use would require the following modifications of the ETSI EN standard :

- Correlation formula(s) for deriving dBm/50 MHz peak values (worst case) from SA test at lower resolution bandwidth (e.g. 3 MHz)
- Sensor height limited to 1.5m for trucks, less than 0.75 m for private cars
- Requirement for mounting behind a bumper (otherwise additional shielding in front of the sensor or reduced e.i.r.p. is required).

In the case where WG FM would allow a short-term deployment of such devices in the 24.050-24.250 GHz band, the following e.i.r.p. density limits shall be considered:

- Spectrum mask (rms) level outside 24.050-24.250 GHz ≤ -41.3 dBm/MHz
- Spectrum mask (peak) level outside 24.050-24.250 GHz ≤ 0 dBm/50 MHz.

These levels are valid for SRR device to be mounted behind additional enclosures that would provide an additional shielding (e.g. bumpers). In the event additional shielding is supplied from the SRR device itself (i.e.: no further bumper shielding provided), these e.i.r.p. limits shall be decreased by 3 dB.

Finally, should CEPT decide to allow a long-term deployment of SRR in this band, these e.i.r.p. densities would need to be reduced to in accordance with the conclusions of this report.

4.1.1.9 Conclusions

It was recognised that the SRR deployment being assumed on a "no harmful interference" basis, it might be difficult in practice to apply counter-measures to stop possible interference, once the SRR are deployed in full.

On this basis, and taking into account the protection requirements of the FS, the long term compatibility scenario with SRR (with an e.i.r.p density level of –41.3 dBm/MHz) with 100% percentage of cars equipped with SRR devices in vicinity of the FS receiver was studied. Due to the complex sharing scenario, a number of assumptions had to be made. For simplification, the simulations were restricted to two scenarios (1 lane and 4 lanes scenarios) with 2 active forward sensors per car. Important factors such as the FS antenna height and distance from the road (offset), distance between cars and different models for the rain attenuation, which could heavily influence the results of the study were varied in order to be able to compare their effects.

Due to the complexity of the compatibility scenario, a simplified propagation model was chosen. In this model, propagation effects, such as spray due to preceding cars, clutter losses (except from other cars) and reflections of SRR transmissions from road or other cars were not taken into account since it was uncertain whether or not and to what extent (in dB) these effects influence the sharing situation.

The results of the studies with all assumptions described above show that the protection criteria of the FS is exceeded by 0 to 20 dB depending on the scenarios and on the combination of the factors. Considering that the SRR devices are to be operated on a non-interference basis, it is concluded that SRR deployed in the 24 GHz band operating at a –41.3 dBm/MHz e.i.r.p density are not compatible with FS in the long-term.

However, on the basis of the whole range of calculation results, it can be concluded that with an e.i.r.p. density of -60 dBm/MHz the FS protection criteria (–20 dB I/N) for all scenarios considered in these studies is respected, whilst with an e.i.r.p. density of –50 dBm/MHz, this protection criteria would be met in most scenarios. Some administrations are of the opinion that is it necessary that SRR meets the –20 dB I/N protection criteria in all cases. Some other administrations are of the opinion that an excess of the protection criteria by 10 dB, which still corresponds to an I/N of –10 dB, is acceptable.

In addition, on a short-term basis, it was concluded that an e.i.r.p. mean power density of –41.3 dBm/MHz associated with an e.i.r.p peak limit of 0dBm/50 MHz could be sufficient to protect the FS as far as the percentage of cars equipped with SRR devices in visibility of the FS receiver is limited to less than 10% or less than few percent depending on whether the protection criteria is to be met in all cases; 10 % is equivalent to a 10 dB decrease of the aggregate power.

Finally, even though the studies have been limited to the 23 and 26 GHz FS bands, the calculation results and conclusions are still valid in the 28 GHz FS band and have also to be taken into account for the 32 GHz band.

4.1.2 Radio Astronomy

4.1.2.1 General scenario

During an observation, a radio astronomy telescope points towards a celestial radio source at a specific right ascension and declination, corresponding with a specific azimuth and elevation at a certain moment in time. During this observation the pointing direction of the telescope is continuously adjusted to compensate for the rotation of the Earth. It is assumed that interference from a terrestrial transmitter is generally received through the sidelobes of the radio astronomy antenna. Thus 24 GHz SRR will have impact on radio astronomy operations in the frequency range 22-24 GHz. The allocation status for radio astronomy in these bands is given in Table 9.

The ITU-R Recommendations taken as a basis for the compatibility study carried out are:

> ITU-R RA.769: "*Protection Criteria used for Radioastronomical Measurements*";
>
> ITU-R RA.1513: "*Levels of data loss to radio astronomy observations and percentage-of-time criteria resulting from degradation by interference for frequency bands allocated to the radio astronomy on a primary basis*".

ITU-R P.452: “*Prediction procedure for the evaluation of microwave interference between stations on the surface of the Earth at Frequencies above 0.7 GHz*”

Recommendation ITU-R RA.769 assumes that the interference is received in a sidelobe of the antenna pattern, i.e. at a level of 0 dBi at 19° from boresight (see also Recommendation ITU-R SA.509). It should be noted that a radio telescope is an antenna with a very high gain, typically in the order of 70 dB. If interference is received via the main lobe of the antenna pattern, this high gain should also be taken into account. However, Recommendation ITU-R RA.769 assumes that the chance that the interference is received by the main lobe of the antenna is low, and therefore uses the level of 0 dBi in the calculation of the levels of detrimental interference given in this Recommendation.

It is considered that the interference received at the radio telescope antenna shall not exceed the levels of detrimental interference given in Recommendation ITU-R RA.769.

Depending on the relative location of the interferer and the telescope, the interference occurs in the near field or the far field of the telescope. The far field area, or Fraunhofer area, lies beyond a distance of $2D^2/\lambda$, where D is the diameter of the telescope and λ the wavelength. For the frequency of ~24 GHz, this distance is of the order of 625 km for a radio telescope of 50 metre diameter. A diameter of 50 metre can be considered as representative for radio telescopes in Europe operating in the frequency range 22-24 GHz; the largest have a diameter of 100 metre.

For the assumptions considered in Recommendation ITU-R RA.769, it is irrelevant whether the interferer is in the near field or in the far field of a radio telescope. The near field/far field issue is relevant only for studies that need to consider the signal path from the interfering transmitter to the receiving antenna.

4.1.2.2 Protection requirements

As noted above, the protection requirements for radio astronomy observations are given Recommendation ITU-R RA.769.

The protection criteria for the frequency bands between 22 and 24 GHz are given in Table 9. For the frequencies between 22 and 23.6 GHz, radio astronomy observing programs are dedicated to spectral line or narrow band observations. The band 23.6-24.0 GHz is also used for continuum or broadband observations. Spectral line and continuum observations have different protection requirements.

Frequency band (MHz)	**ITU-RR Allocation status**	**Protection level (Rec. ITU-R RA.769) (dB(Wm^{-2}Hz^{-1}))**
22 010 - 22 210	RR No. 5.149	-216 [1]
22 210 - 22 500	Primary (RR No. 5.149)	-216 [1]
22 810 - 22 860	RR No. 5.149	-216 [1]
23 070 - 23 120	RR No. 5.149	-215 [1]
23 600 - 24 000	Primary - passive exclusive (RR No.5.340)	-215 [1], -233 [2]

Table 9: Frequency bands allocated to the Radio Astronomy Service in the frequency range 22-24 GHz and their protection requirements (Recommendation ITU-R RA.769)

Note 1: spectral line observations (narrow band)

Note 2: continuum observations (broadband).

Footnote 5.149 states for the identified frequency bands that "administrations are urged to take all practicable steps to protect the radio astronomy service from harmful interference. Emissions from spaceborne or airborne stations can be particularly serious sources of interference to the radio astronomy service (see Nos. 4.5 and 4.6 and Article 29)”.

Footnote 5.340 states for the identified frequency bands that "all emissions are prohibited".

From these regulations it is assumed that for the frequencies between 22 and 23.6 GHz, radio astronomy needs to be protected to a level of –216 dB($Wm^{-2}Hz^{-1}$), while the protection criteria in the band 23.6-24.0 GHz apply to *unwanted* emissions only (because of the regulatory conditions for this band).

4.1.2.3 Methodology used to determine the maximum tolerable e.i.r.p. per SRR device

ERC Report 26 describes the methodology for calculating separation distances between a radio astronomy observatory and transmitting stations in the mobile services, in which the interfering signal received at a radio astronomy observatory is assumed to be the sum of the contributions of users located in concentric rings of 10 km width, each centred on the radio astronomy station. Inversely, this methodology can also be used to estimate the tolerable transmission power of an SRR device, for given separation distance, protection criteria and some additional necessary parameters.

Clear-air propagation models given in Recommendation ITU-R P.452 were used. This involves several propagation mechanisms: Line-of-Sight propagation; spherical-earth diffraction and tropospheric scatter:

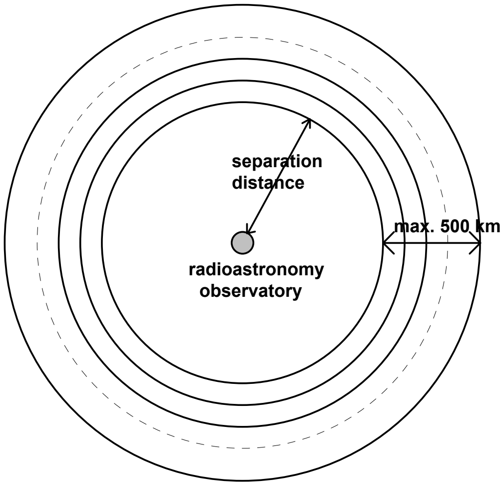
- For a time percentage of 10% and distances greater than approximately 100 km, the tropospheric scatter mechanism is typically dominant.
- For distances between 20 and 100 km, the spherical-earth diffraction is typically dominant.
- For distances shorter than 20 km Line-of-Sight dominates.

The assumptions for the protection of the radio astronomy service as used in Recommendation ITU-R RA.769 apply to the calculations presented here.

A fraction of data-loss due to interferences of 2% is taken, which is considered to be the maximum acceptable percentage of time for data loss to radio astronomy from an aggregate of interfering devices of a single system, like SRR radars (see Recommendation ITU-R RA.1513*)*.

The density of users is integrated in the calculation of the total interfering signal by summing (in power) the total power coming from concentric rings 10 km wide, starting at the minimum separation distance between an SRR device and the radio astronomy station, taken to be 30 m.

The number of rings taken into account in the calculation is determined by the software and covers an area with a radius of up to the minimum separation distance + 500 km



The required e.i.r.p. level is calculated for interference experienced during a certain percentage of the time.

If P_t is the average power emitted by a single transmitting device, the power received at the radio astronomy observatory coming from the ring number *i*, Pr_i is then:

$$\Pr_i = P_t - L(d_i, p_i) + 10 * \log(N_i)$$

where: -*d* : required separation distance (km)

- d_i : distance between the transmitter and the radio astronomy observatory : $d_i = d + 10(i - 1)$

- $L(d_i,p_i)$: propagation attenuation between the ring i and the radio astronomy observatory for interference during p_i% of time.

- N_i : number of users in ring number i : $N_i = \pi * n\,[d_{i+1}^2 - d_i^2]$

- n : density of transmitters per km^2

The total interfering power at the radio astronomy site is then, in dBW:

$$\mathrm{Pr} = 10 * \log\left(\sum_{i=1}^{N_r} 10^{\frac{\mathrm{Pr}_i}{10}}\right)$$

where: N_r - number of rings used for the simulations (default: 50 rings of 10 km width each).

Using a uniform density of users, and taking into account the probability of interference in the radio astronomy band, this leads to an e.i.r.p. which dependent directly on the density of SRR devices.

The assumption of a uniform distribution of users does not have a significant impact on the results of the calculations, however, as experiences with previous calculations of similar situations have shown.

4.1.2.4 Results of calculations

For compatibility studies applicable to all European radio astronomy telescopes, it must be assumed that a radio telescope can point to all directions in the sky, i.e. its azimuth can vary between 0º and 360º and its elevation can vary between 0º and 90º. For terrestrial interferers, in the interference scenario an elevation of 0º is assumed.

With the input parameters given in Table 10 the maximum tolerable e.i.r.p. per SRR device as a function of the density of SRR devices per km^2 has been estimated.

Maximum permissible spectral power flux density (for radio astronomy spectral line observations)	-215 dB(Wm^{-2}Hz^{-1})
Radio astronomy antenna gain	0 dBi
Frequency	22 GHz
Reference bandwidth	1 MHz
Height radio astronomy antenna	50 metre
Elevation angle	0°
Height SRR transmitter	0.5 metre
Measurement distance used to receiving antenna / minimum separation distance	30 metre [1]
Sea level refractivity	320
Fraction of data-loss due to interference	2%
Maximum distance for calculations	500 km

Table 10: Input parameters

Note 1: The smallest distance between a radio telescope and the edge of the territory of a radio astronomy station. For European radio astronomy stations this ranges from about 30 metres to a few hundred metres. To ensure protection for all European radio astronomy stations a typical value of 30 metre was taken.

The maximum possible spectral power flux density has been taken for spectral line observations, in order to reflect adequately the radio astronomy interest in this frequency domain.

The radio astronomy antenna gain was taken as 0 dBi, since this is assumed in Recommendation ITU-R RA.769.

As height of a radio astronomy antenna a value was taken which is considered representative for the instruments currently operating at ~22 GHz. An elevation angle of 0° was used to lead to a result applicable to all radio telescopes under all observing conditions.

Radio astronomy must be protected for all distances of the transmitting device to a radio telescope antenna, i.e. for SRR devices everywhere outside the extent of the radio astronomy station territory, while SRR devices are not equipped with a facility to determine their position. Results are given for a measurement distance of 30 metre.

It is considered that the values for the refractivity and the fraction of data-loss due to interference are representative values for Europe and in compliance with Recommendation ITU-R RA.1513.

The maximum distance of 500 km used in ERC Report 26 was adopted, to derive a result representative for the impact from a large geographic area and to reduce the dependence of the results on fluctuations in the local density of SRR devices.

The results of the calculations are given in figure 19.

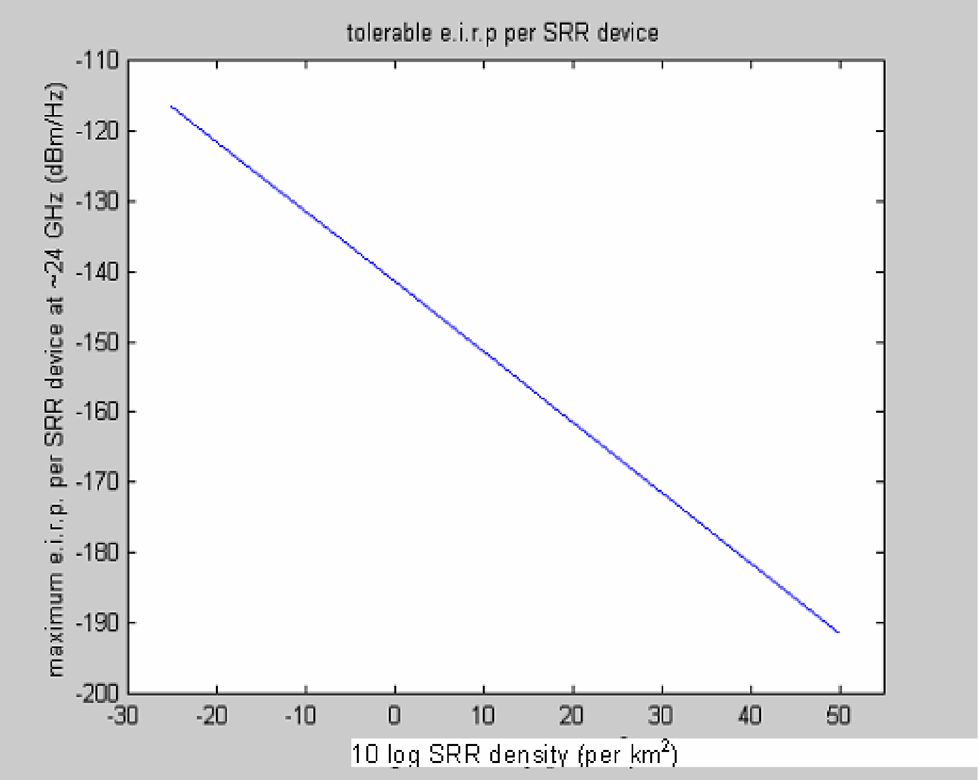


Figure 19: Maximum tolerable e.i.r.p. at a frequency of ~22 GHz per SRR device operating at 24 GHz as a function of SRR density in order not to exceed the protection criteria for radio astronomy for spectral line observations

These results lead to the following analytical expression for the maximum permissible e.i.r.p. per SRR device at frequencies ~22 GHz that will not exceed the protection criteria for spectral line radio astronomy observations:

$$\text{e.i.r.p.}_{max} = -10^{*} \log \rho - 141.5 \qquad \text{dBm/Hz}$$

where: ρ = number of SRR devices per km^2 operating at ~24 GHz from which emission is received by a radio astronomy station.

For continuum observations, the constant in the formula should be changed to 159.5 instead of 141.5. Table 9 shows that the protection criteria for radio astronomy between 22 and 24 GHz are rather frequency independent.

If cars equipped with SRR will not have a facility to determine their position with sufficient accuracy nor with an ‘off’-switch for their SRR device(s), any specific separation distance for radio astronomy is irrelevant, since enforcement of such a condition is not possible.

It may be noted that these results apply to the aggregate of SRR transmitting devices in a geographic area of large dimensions, which can easily cover entirely one or more European countries. Such large areas will include both the remote areas where radio astronomy stations are assumed to be as well as urban areas.

For practical reasons it is assumed that all SRR devices have the same transmitting power. Obviously, the results apply only for those SRR devices transmitting towards a radio astronomy station. This would imply, for example, that the total number of transmitting SRR devices is probably at least about 4 times larger than ρ per km^2, if a radio astronomy station 'sees' emission from only ¼ of the transmitting SRR devices. It was not possible to estimate the density of SRR devices to be used in practice because of the possible mitigation factors that might be taken into account in the conversion of ρ to this number.

These results indicate that the e.i.r.p. value of –90 dBm/Hz currently considered by the SRR industry can be achieved for a density below about 7×10^{-6} per km^2 and a minimum separation distance of 30 metre. Noting the estimate that in 2015 the average number of SRR devices will be about 1 per car, the expected density exceeds the tolerable density by several orders of magnitude, regardless of possible mitigation factors.

4.1.2.5 Conclusions

The calculated maximum tolerable e.i.r.p. per SRR device at ~24 GHz is several orders of magnitude below the currently considered e.i.r.p. per SRR device of –90 dBm/Hz. It is noted that this difference depends strongly on the aggregated impact of SRR devices emitting towards a radio astronomy antenna operating in the frequency range 22 - 24 GHz; for densities that may be considered as realistic in areas with a radio observatory site (e.g. 100 devices per km^2) the difference between the currently considered and the maximum tolerable e.i.r.p. per SRR device emitting to a radio astronomy station would be in the order of 70 dB for spectral line observations and about 90 dB for continuum observations.

From these results, based on the model used, it may be concluded that 24 GHz SRR and radio astronomy facilities operating between 22 and 24 GHz are incompatible.

In practical scenarios, consultation with Administrations concerned may lead to the inclusion in the coordination process of mitigation elements, such as local terrain, clutter loss, car density, that are specific to the radio astronomy station(s). These elements could be included in the determination of separation distances adequate to protect the radio astronomy site under consideration. These distances could result in the definition of exclusion zones where the operation of the SRR should be switched off.

If all of the possible mitigation factors are taken into account and lead to sufficient reduction in interference level, then sharing between the short range radar at 24 GHz and radio astronomy may be possible.

4.1.3 EESS

4.1.3.1 Introduction

The EESS (passive) currently operates two types of passive sensors:

- Conically scanned sensors around the nadir direction, which are designed to measure two-dimensional surface (land and ocean) parameters;
- Cross-track nadir sensors, which are designed to measure three-dimensional atmospheric parameters.

4.1.3.1.1 EESS (passive) frequency allocation status

4.1.3.1.1.1 General considerations

Spaceborne microwave passive sensors are operated by the EESS for the purpose of weather forecast and climatology to measure geophysical data worldwide, which describe the status of the complex atmosphere/oceans/land surface machinery.

In recognition of:

- the extreme vulnerability to interference of microwave passive sensors which are designed to measure very faint natural emissions,
- and the catastrophic consequences that interference may have on operational and scientific applications which rely on microwave passive measurements,

exclusive status has been granted to most passive allocations, in particular to those which are used for 3D atmospheric measurements, to the exception of frequency bands where the natural atmospheric attenuation provides sufficient shielding to prevent interference (for instance, in the O_2 absorption spectrum around 60 GHz).

4.1.3.1.1.2 The 23.6-24 GHz frequency band

- The 23.6-24 GHz frequency band is allocated to the EESS (passive) with an exclusive status where the footnote 5.340 is applicable.
- The ITU RR footnote 5.340 stipulates that all emissions are prohibited in these frequency bands.
- According to the Rules of Procedures of the ITU Radio Regulation Board, it is impossible to notify any system in the bands listed in footnote 5.340.

The table 11 summarizes the frequency allocation around 24 GHz.

Services in lower allocated bands		**Passive band**	**Service in upper allocated band**
22.55-23.55 GHz	23-23.6 GHz	23.6-24 GHz	24-24.05 GHz
FIXED INTER-SATELLITE MOBILE	FIXED MOBILE	EARTH EXPLORATION-SATELLITE (Passive) RADIO ASTRONOMY SPACE RESEARCH (Passive) 5.340	AMATEUR AMATEUR-SATELLITE 5.150

TABLE 11: Adjacent band allocations

NOTE – The Inter-satellite allocation could be used for GSO and non-GSO systems.

It should be emphasized that, despite the fact that interference may be suffered by the passive sensor near the lower and upper edges of the allocated passive band due to out-of-band emissions from active services allocated in adjacent bands, the exclusive status of the allocation essentially guarantees the cleanliness of the passive band, thus preserving the potential improvement of this sensing technique.

4.1.3.1.2 Service and use of the band 23.6-24 GHz

4.1.3.1.2.1 General interest of the band 23.6-24 GHz

The band 23.6-24 GHz is of primary interest by itself to measure water vapour and liquid water. It is used by both conically scanned and cross-track nadir sensors. The total water vapour content from the ground to the satellite is best measured in this frequency band and, it is not possible to find any equivalent frequency band having this same characteristic in the whole electromagnetic spectrum.

4.1.3.1.2.2 Auxiliary parameter for 3D vertical atmospheric temperature sensing

Three dimensional atmospheric temperature measurements of utmost importance for operational meteorology (numerical weather forecasting models) and climate studies and monitoring are performed in the oxygen absorption spectrum around 60 GHz. Temperature is also essential to retrieve passive measurements of other atmospheric gases which play a major role in energy transport (water vapour) and photo-chemistry processes (O_3, CH_4, NO_2…).

Besides these primary measurements, auxiliary parameters are simultaneously measured because they are mandatory to decontaminate the primary measurements from unwanted effects due to atmospheric moisture (water vapour and liquid water).

Auxiliary parameters are obtained in three radiometric channels:

- Around 23.8 GHz for the total water vapour content ;
- Around 90 GHz for the liquid water (precipitations) ;
- Around 31.5 GHz, which is the optimum « window » in the « valley » resulting from the combination of the oxygen and water-vapour absorption curves (see the channel 2 (A) on the figure 20 below), and which serves as a reference for all other measurements.

These auxiliary measurements must have radiometric and geometric performances consistent with those of the primary measurements, and must receive similar protection against interference. It is noted that the non-availability of only one auxiliary channel totally invalidates the complete data set.

These frequencies are indicated on the atmospheric O_2 and H_2O absorption curves presented on figure 20, where « channels 1(A) and (B), 2(A) and (B), 3(A) and (B)… » refer to the AMSU-A and B vertical sounders which are currently deployed on operational meteorological satellites.

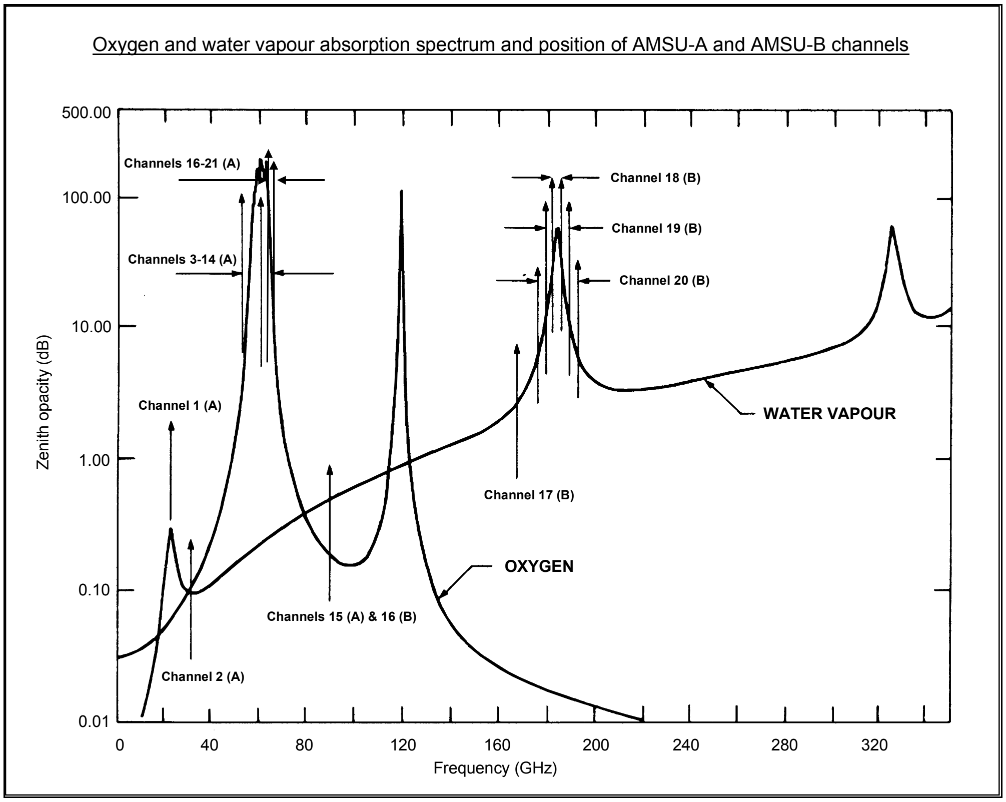


FIGURE 20: Frequencies for 3D passive atmospheric sounding

It must be emphasized that besides the numerical weather prediction, many applications relying on these measurements are strongly life and property-safety related. It was demonstrated that they can be severely hampered by any interference exceeding the internationally agreed threshold. These applications are in particular:

- Detection and signalisation of potentially hazardous meteorological events. The augmentation of these hazardous events, even at mid latitudes, raise serious concerns in the scientific community ;
- Air and sea traffic routing and safety in the vicinity of airports ;
- Off-shore activities and in general out-door industrial activities.

The fulfilment of these tasks requires:

- The most accurate models of the atmosphere/oceans/land surface system;
- Routinely acquired worldwide data which describe the status of the atmosphere/oceans/land surface system;
- The most powerful computers able to run the models and to assimilate the increasing volume of data.

Because the atmosphere/oceans/land surface system is extremely complex, the operational tasks must be supported by important background scientific activities aiming at a better understanding and the consequential better modelling of this system.

In addition to that, concerning the band 23.6-24 GHz, it is important to note that this is the unique band in the whole electromagnetic spectrum where it is possible to retrieve with a good quality the total vertical water vapour content.

Therefore, it is essential to preserve such a frequency band for undisturbed EESS observations.

4.1.3.1.3 Required protection criteria

The following three documents establish the interference criteria for passive sensors.

1) Recommendation ITU-R SA.513-3, Frequency bands and bandwidths used for satellite passive services
2) Recommendation ITU-R SA.1028-1, Performance criteria for satellite passive remote sensing.
3) Recommendation ITU-R SA.1029-1, Interference criteria for satellite remote sensing.

It should be emphasized that operational applications which are routinely operating microwave passive sensors rely heavily on background scientific activities aiming at a better understanding and knowledge of the complex land/ocean-atmosphere machinery.

For that reason, the required performance parameters and interference criteria which are contained in the recommendations ITU-R SA.1028 and 1029 must be regularly updated to reflect such improvements, and to take advantage of the technological advances. These recommendations were recently revised (ITU-R WP7C, February 2002).

The revised interference criteria are the following:

- The interference threshold of the passive sensor is –166 dBW in a reference bandwidth of 200 MHz. This is a maximum interference level from all sources. Such a threshold corresponds to a measurement sensitivity of 0.05 K.
- The number of measurement cells where the interference threshold can be exceeded must not be more than 0.01% of pixels in all service areas for any kind of instrument.

It is to be noted that the above interference criteria represent the maximum acceptable contribution of the interferer to the error budget.

4.1.3.1.4 Operational characteristics

The operational characteristics are contained in Annex D.

4.1.3.2 Characteristics of the 24 GHz automotive radar

The requirements as described in the “US Federal Communications Commission rules regarding Ultra-Wideband Transmission systems” (Revision of Part 15 of the Commission’s Rules Regarding Ultra Wideband transmission Systems Released April 22, 2002) were used in these studies.

4.1.3.2.1 Transmit carrier frequency

The transmit carrier frequency is within the range 24.05-24.25 GHz.

According to RR No. 5.150, the band 24-24.25 GHz (centre frequency 24.125 GHz) is designated for industrial, scientific and medical (ISM) applications. ISM equipment operating in this band is subject to the provisions of article 15.13.

ITU RR No. 15.13 stipulates that Administrations shall take all practical and necessary steps to ensure that radiation from equipment used for industrial and medial applications is minimal and that, outside the bands designated for use by this equipment, radiation from such equipment is at level that does not cause harmful interference to a radiocommunication service (…).

4.1.3.2.2 24 GHz automotive radar density

The expected density of vehicles is taken to be 123 vehicles/km^2 for the highway scenario outside urban/suburban areas and up to 330 vehicles/ km^2 for urban/suburban areas.

4.1.3.2.3 Limitation of vertical antenna characteristic

The FCC rules give for the frequency band between 23.6 GHz to 24.0 GHz the following limitations of vertical antenna pattern for the car radars at greater than 30 degrees elevation above the horizontal plane:

25 dB attenuation by January 1, 2005
30 dB attenuation by January 1, 2010
35 dB attenuation by January 1, 2014

For this analysis only the 3rd (more stringent) pattern has been used, since it would correspond to the situation that would develop in the long term.

4.1.3.2.4 Power spectral density

The FCC Part 15 general emission limit is –41.3 dBm/MHz for the specification regarding SRR at 24 GHz.

4.1.3.2.5 Bumper loss

The mounting of 24 GHz SRR devices behind metallic painted vehicle bumpers does not pose problems due to size and attenuation by the bumper material. In addition to that, concerning the application capability, it is stated that simulation and experiments suggest that SRR devices at 24 GHz can operate with these application requirements. According to information provided by ETSI, the following compatibility analysis will take into account a loss of 3 dB due to bumper attenuation at 24 GHz.

4.1.3.2.6 Scattering effects

The US meteorological administration (NOAA) has made a study that analyses the impact of the radar signal scattering. One of the most probable coupling scattering mechanisms between mobile vehicle radar and a satellite radiometer is a reflection of the main lobe of the radar by another directly-illuminated vehicle toward the main lobe of the radiometer. This study has shown that the reflection generated by the rear part of the car in front of the transmitting radar would create a coupling ranging from –10 to –30 dB with respect to the EESS radiometers within the range of look angles.

This study considers reflections from other cars only and takes into account the reflections due to the curvature of the window (characterised by an effective radius of curvature), the glass thickness and the distance between the two cars. Both cases of vertical and horizontal polarisation have been considered. The figures are the following for a glass thickness of 0.5 cm and for a radius of curvature of 10 m.

⇨ Cars with a separation distance of less than 10 m: about 5% of cars and a scatter gain of – 15 dB.

⇨ Cars with a separation distance of less than 30 m and more than 10 m: about 45% of cars and a scatter gain of – 18 dB.

⇨ Cars with a separation distance of more than 30 m: about 50% of cars and a scatter gain of – 25 dB.

Therefore, the averaged car scattering gain becomes:

$$car\_scattering\_gain = 10 * \log 10\left[0.05 * 10^{-1.5} + 0.45 * 10^{-1.8} + 0.5 * 10^{-2.5}\right] = -19.8\,\mathrm{dB}$$

The resulting scattered power is –71.3 (half power) -19.8 (scattering gain) –3 (bumper attenuation) = -94.1 dBW/MHz.

Automotive industry representatives informed CEPT that some field tests were done at JRC in Ispra(I) to measure the scattering effects at 24 GHz. The results, indicate that a further 4.7 dB should be deducted to take into account the hemispherical distribution of the scattering.

The resulting total scattered power per transmitter was therefore assumed: –94.1 –4.7= -98.8 dBW/MHz

It must be noted that the above analysis does not include considerations about the ground scattering and any additional power scattered by secondary reflections. This could increase the interference level, in particular in the urban scenario. At this stage, given the margin levels calculated in the interference assessment below, it was felt that the additional study effort is not required. In case it is needed, the work of ITU-R Study Group 3 could provide some guidance for the part relevant to the secondary reflections contribution.

4.1.3.3 Interference assessment

The general methodology used in this report is to compute the margin given for a certain expected vehicles density. According to the applicable ETSI document, several automotive radars are planned for each car, but they are not all operated simultaneously. According to information provided by ETSI, the basis is 4 SRR per car that are supposed to be in operation simultaneously. However, for the specific case of the conical scan instruments, because of their geometry, it is assumed a mitigation of factor of 25% due to random car directions.

4.1.3.3.1 Conically scanned EESS instruments

Parameter	MEGHA-TROPIC	EOS AMSR-E
Maximum e.i.r.p. (power spectral density)	-41.3 dBm / MHz	-41.3 dBm / MHz
Bumper attenuation	-3 dB	-3 dB
Gating effect	0 dB	0 dB
Radar antenna gain to be substracted (2014 mask)	35 dBi	35 dBi
Direct power component	-109.3 dBW/MHz	-109.3 dBW/MHz
Total scattered power component (asphalt scattering dominant)	-98.8 dBW/MHz	-98.8 dBW/MHz
Total power	-98.4 dBW/MHz	-98.4 dBW/MHz
Distance radar - EESS sensor in km	1336	1229
Space attenuation in dB	182.5 dB	181.7
EESS antenna gain in dBi	40	46
Atmospherical loss (ITU-R P.676)	-1.0 dB	-1.0 dB
Received power at the EESS in a 1 MHz bandwidth	-241.9 dBW	-235.1 dBW
Corresponding received power at the EESS in a bandwidth of 200 MHz for one single radar.	-218.9 dBW	-212.1 dBW
EESS interference threshold in a reference bandwidth of 200 MHz: application of revised ITU-R SA 1029-1	-166 dBW	-166 dBW
Number of radars in order to reach the EESS threshold	52.9 dB (194984 radars)	46.1 dB (40738 radars)
Number of active radars per car	4	4
Mitigation factor due to random car directions (25%)	- 6 dB	- 6 dB
Size of the EESS pixel: diameter in km	35.4	17.6
Maximum car density per km^2 corresponding to the above number of cars in the EESS pixel	$194984 \Big/ \pi\left(35.4/2\right)^2 = 198$ or 23 dB (cars) per km^2	$40738 \Big/ \pi\left(17.6/2\right)^2 = 167$ or 22 dB (cars) per km^2
Expected car density per km^2	123/ Km^2 (Highway) (20.9dB) 330/Km^2 (Urban/suburb.) (25.2dB)	123/ Km^2 (Highway) (20.9 dB) 330/ Km^2(Urban/suburb.) (25.2 dB)
Margin in highway scenario	**+2.1 dB**	**+1.1 dB**
Margin in urban/suburban scenario	**-2.2 dB**	**-3.2 dB**

Table 12: Compatibility analysis between automotive radars at 24 GHz and MEGHA-TROPIC, EOS AMSR-E

The margin for both instruments is negative for the urban/suburban scenario.

It is to be noted that the analysis is based on the FCC emission mask that will be in operation by the year 2014. Taking into account the earlier, less stringent masks would increase the negative margin.

4.1.3.3.2 Cross-track nadir EESS sensors

Parameter	Push-Broom	AMSU-A
Radar e.i.r.p. density in main lobe	-41.3 (dBm/MHz)	-41.3 (dBm/MHz)
Bumper attenuation	-3dB	-3dB
Gating effect	0 dB	0 dB
Direction of interfering path	Zenith	Zenith
Radar antenna gain to be substracted (2014 mask)	35	35
Radar e.i.r.p. density to zenith: direct power component	-109.3 dBW/MHz	-109.3 dBW/MHz
Total scattered power component	-98.8 dBW/MHz	-98.8 dBW/MHz
Total power	-98.4 dBW/MHz	-98.4 dBW/MHz
Distance radar - passive sensor (km):	850	850
Space loss at 23.8 GHz in dB	178.6	178.6
Atmospherical loss (ITU-R P.676)	-1.0 dB	-1.0 dB
EESS antenna gain in dBi	45	36
Power density received by the sensor from one single radar	-233 dBW/MHz	-242 dBW/MHz
Corresponding received power at the EESS in a bandwidth of 200 MHz for one single radar.	-210 dBW	-219 dBW
EESS interference threshold in a reference bandwidth of 200 MHz: application of revised ITU-R SA 1029-1	-166 dBW	-166 dBW
Number of radars in order to reach the EESS threshold	44 dB (25118 radars)	53 dB (199526 radars)
Number of radars active per car	4	4
Size of the EESS pixel: diameter in km	16	48
Maximum car density per km^2 corresponding to the above number of cars in the EESS pixel	$6279 \Big/ \pi\left(16/2\right)^2 = 31.2$ or 14.9 dB (cars) per km^2	$49881 \Big/ \pi\left(48/2\right)^2 = 27.5$ or 14.4 dB (cars) per km^2
Expected car density per km^2 (as from SARA forecast)	123/ Km^2 (Highway) (20.9dB) 330/Km^2 (Urban/suburb.) (25.2dB)	123/ Km^2 (Highway) (20.9 dB) 330/Km^2(Urban/suburb) (25.2dB)
Margin in highway scenario	**- 6 dB**	**- 6.5 dB**
Margin in urban/suburban scenario	**- 10.3 dB**	**- 10.8 dB**

Table 13: Compatibility analysis between automotive radars at 24 GHz and nadir sensors

The margin for both instruments and for both car density scenarios is heavily negative.

It is to be noted that the analysis is based on the FCC emission mask that will be in operation by the year 2014. Taking into account the earlier less stringent masks would increase the negative margin.

If also the effects of the expected evolution in the sensors design technology by the year 2020 were to be considered as indicated in following sections, the negative margins given above would be even more negative by 7 dB.

4.1.3.4 Future protection criteria

4.1.3.4.1 Permissible interference based on operational weather forecast and climate monitoring

Today, the required deltaT is 0.05 K, which is needed for surface remote sensing and assimilation in the numerical weather forecasts (NWP). It is to be noted that, at the time of completion of the SRR deployment scenario, the required radiometric sensitivity of the passive sensor will be well below 0.05 K. A reasonable hypothesis by the year 2020 for this value is 0.01 K, which will be needed for global climatic change monitoring and global change survey. It is therefore to be expected that a future revision of Recommendation 1029 will have a –173 dBW/200 MHz threshold value for this band around the year 2020. The sharing analysis conducted in this document uses the official figures contained in Recommendation SA.1029 and its revised version, but the sensor evolution should be kept in mind when analysing the results. These expected requirements explain why this band is designated as “purely passive” in the ITU regulations. It is of utmost importance that the « cleanliness » of the exclusive passive sensor allocations is preserved, in order not to unduly limit the improvement potential of the applications that rely on these passive measurements.

4.1.3.4.2 Permissible interference based on the technological evolution of the passive sensors

Taking into account the technological evolution of the on spaceborne passive sensors, it is expected that the cross track nadir sensors will be able to reach a sensitivity measurement of 0.01K.

4.1.3.4.3 Review of the margins

The following table provides the updated margins taking into account the above future threshold requirements of –173 dBW/200 MHz.

Type of EESS sensor	Highway scenario	Urban/suburban scenario
Pushbroom	Margin = - 13 dB	Margin = - 17.3 dB
AMSU-A	Margin = - 13.5 dB	Margin = - 17.8 dB

Table 14: Resulting margins of the EESS (passive) sensors due to the interference caused by the automotive radars at 24 GHz using the measurement sensitivity requirement of 0.01 K (future evolutions of cross track nadir sensors by the year 2020)

4.1.3.5 Other aspects in the sharing analysis

Although the above compatibility analysis can be used to draw conclusions on the sharing feasibility, the following factors have not been yet considered. It is worth noting that each of the following effect is able to create additional negative margins, resulting into a compatibility situation even worse.

4.1.3.5.1 Scattering effects (secondary reflections and ground scattering)

It must be noted that the scattering analysis in this document does not include considerations about the additional power scattered by secondary reflections. This could add a significant interference level, in particular in the urban scenario. At this stage, given the margin levels calculated in the sharing analysis (see section 4.1.3.3), it is felt that the additional study effort is not required. In case it is needed, the work of ITU-R Study Group 3 could provide some guidance.

Also the ground scattering effect has not been evaluated at this stage, since the car scattering appears to be dominant. Nevertheless the ground scattering contribution can be calculated in the future if required.

4.1.3.5.2 Apportionment

Since this band is exclusively allocated to the EESS (passive), interferences near the lower and upper limits of the allocated band are to be expected only due to unwanted emissions from active services allocated in the adjacent bands (see table 11 for the current allocated services). The concept of “apportioning” the interference threshold among the various interferers (which are actually the adjacent services) is under discussion within ITU-R (TG1/7).

4.1.3.6 Interference assessment for SRR with lower horizontal e.i.r.p.

This section analyses the sharing scenario for the case of SRR radars with very low horizontal e.i.r.p. (-50 dBm/MHz). This analysis is made for the case of nadir sensors, since this type of sensors has been shown to be more critical than the conical scanning sensors.

Parameter	Push-Broom	AMSU-A
Radar e.i.r.p. density in main lobe	-50 (dBm/MHz)	-50 (dBm/MHz)
Bumper attenuation	-3dB	-3dB
Gating effect	0 dB	0 dB
Direction of interfering path	Zenith	Zenith
Radar antenna gain to be substracted (2014 mask)	35	35
Radar e.i.r.p. density to zenith: direct power component	-118 dBW/MHz	-118 dBW/MHz
Total scattered power component	-107.5 dBW/MHz	-107.5 dBW/MHz
Total power	-107.1 dBW/MHz	-107.1 dBW/MHz
Distance radar - passive sensor (km):	850	850
Space loss at 23.8 GHz in dB	178.6	178.6
Atmospherical loss (ITU-R P.676)	-1.0 dB	-1.0 dB
EESS antenna gain in dBi	45	36
Power density received by the sensor from one single radar	-241.7 dBW/MHz	-250.7 dBW/MHz
Corresponding received power at the EESS in a bandwidth of 200 MHz for one single radar.	-218.7 dBW	-227.7 dBW
EESS interference threshold in a reference bandwidth of 200 MHz: application of revised ITU-R SA 1029-1	-166 dBW	-166 dBW
Number of radars in order to reach the EESS threshold	52.7 dB (186208)	61.7 dB (1479108 radars)
Number of radars active per car	4	4
Size of the EESS pixel: diameter in km	16	48
Maximum car density per km^2 corresponding to the above number of cars in the EESS pixel	$^{46552}\!/_{\pi\left(^{16}\!/_{2}\right)^2} = 231.6$ or 23.6 dB (cars) per km^2	$^{369777}\!/_{\pi\left(^{48}\!/_{2}\right)^2} = 203.8$ or 23.1 dB (cars) per km^2
Expected car density per km^2 (as from SARA forecast)	123/ Km^2 (Highway) (20.9dB) 330/Km^2 (Urban/suburb.) (25.2dB)	123/ Km^2 (Highway) (20.9 dB) 330/Km^2(Urban/suburb) (25.2dB)
Margin in highway scenario	**2.7 dB**	**2.2 dB**
Margin in urban/suburban scenario	**- 1.6 dB**	**- 2.1 dB**

Table 15: Compatibility analysis between very low power automotive radars at 24 GHz and nadir sensors

The above results show that, with the current sensitivity levels for EESS (passive) sensors, the highway scenario shows a small positive margin, while the urban/suburban scenario still shows a negative margin, although reduced with respect to the case of FCC emission limits.

Taking into consideration what indicated in section 4.1.3.5 about future protection criteria, if this analysis is applied to the year 2020, the following negative margins would result.

Margin in highway scenario	-4.3 dB	-4.8 dB
Margin in urban/suburban scenario	**- 8.6 dB**	**- 9.1 dB**

Table 16: Resulting margins of the EESS (passive) sensors due to the interference caused by the very low power automotive radars at 24 GHz using the measurement sensitivity requirement of 0.01 K (future evolutions of cross track nadir sensors by the year 2020)

It is to be noted that the results above do not take into account the other aspects listed in this section. These elements may add to the already negative margins.

4.1.3.7 Conclusion

Using the assumptions that SRR e.i.r.p. is –41.3 dBm/MHz with a 100% percentage of vehicles equipped with SRR devices in the EESS pixel, then protection criteria for all types of EESS sensors (according to ITU-R Rec SA.1029-2 to be adopted in Feb 2003) will be exceeded by up to 10.8 dB. All the data derived from those measurements will be corrupted in corresponding EESS observations (cities, roads or motorways).

The above reasons lead to the conclusions that the SRR with 100% cars equipped cannot share the band with the EESS (passive) in the band 23.6-24 GHz.

It should be noted that a percentage of vehicles equipped with SRR devices in the EESS pixel lower than 100 % provides a decrease of the aggregate power, e.g. around 10 dB for a percentage limited to 10 %.

For the case of SRR radars with very low horizontal e.i.r.p. (-50 dBm/MHz), sharing with all types of EESS sensors would still result in a negative margin (up to –2.1 dB for current requirements (for which the Recommendation SA 1029 has been recently revised), and up to –9.1 dB for future instruments in the long term i.e. year 2020).

It is to be noted that ITU-R footnote 5.340 does not allow any emission in the band 23.6-24 GHz and that, according to the Rules of Procedures of the ITU-R Radio Regulation Board, it is impossible to notify any system in the bands listed in footnote 5.340.

4.1.3.8 Viewpoint from the industry

The following margin calculation summarise the view of some ETSI members and is based on the unrealistic worst case scenario, that 33000 cars in an area of 200 km^2 have a distance of ≤ 10 m and further 33000 cars have a distance of about 30 m to each other and 100 % of cars are equipped with SRR.

It was calculated with the method presented by several ETSI members and based on Table 12 and 13 of this report but it was used a hemispherical averaging factor of –6 dB instead –4.7 dB and a 3 dB polarisation loss.

	Existing satellites	**ITU recommendations**		
		Current	**upcoming**	**2020**
Radiom. accuracy	0.6 K			0.2 K
Radiom. resolution	0.5K	0.2 K	0.05 K	0.01 K
Protection criteria in dBW/200 MHz	-156	-160	-166	-173
margin in uninhabited area (< 1car / km^2)	**+28 dB**	**+22 dB**	**+18 dB**	**+11 dB**
margin in rural area (< 10 car / km^2)	**+18 dB**	**+12 dB**	**+8 dB**	**+1 dB**
margin in high traffic area (< 100 car / km^2)	**8 dB**	**4 dB**	**-2 dB**	**-9* dB**
margin big cities (< 330 car / km^2)	**3 dB**	**0 dB**	**-7* dB**	**-14* dB**

Table 17: Summary of alternative margin calculation

* value not applicable due to the coverage effect, caused by man made interferences, that are much higher than the SRR emissions.

The margins in the table above will be enlarged by about +8 dB if typical averaged car distances of about 50 m are used.

Industry feels that these calculations show a more realistic view that the margin will be about 0 dB with reference to the upcoming corresponding ITU-R Recommendation.

5 GENERAL CONCLUSION

This report considered the impact of SRR on allocated radiocommunication services operating in the frequency range 21 to 27 GHz, as given in Annex A. The study did not consider the impact of radiocommunication services on SRR or automotive EMC issues.

The study has focused on the following 3 specific primary services, to which SRR 24 GHz is considered likely to present a high interference potential:

- Fixed Service (FS)
- Earth Exploration Satellite Service (EESS)
- Radio Astronomy Service (RAS).

There are also other primary services, listed in section 3, which are likely to be affected.

ITU-R footnote 5.340 applies to the passive frequency band 23.6 to 24 GHz, which states that “All emissions are prohibited”.

The conclusions of this report are summarized in the following Tables 18A and 18B (NB: No = sharing not feasible, Yes = sharing feasible):

SRR e.i.r.p. levels (dBm/MHz)	RAS	EESS	Fixed
-30	No, see note 1	No	No
-41.3	No, see note 1	No	No
-50	No, see note 1	No	See Note 2A
-60	No, see note 1	Yes	Yes

Table 18A: Summary of co-existence (assuming 100% of vehicles within visibility of the victim service are equipped with SRR)

Note 1: If all of the possible mitigation factors such as local terrain, clutter loss, car density are applicable and if this leads to sufficient reduction in interference level, then sharing between the SRR at 24 GHz and radio astronomy could be possible in some cases.

Note 2A: If the protection criteria of –20 dB I/N is to be met in all cases, sharing is not feasible. However, sharing is considered to be feasible if an excess of the protection criteria by 10 dB (up to –10 dB I/N) in worst case scenarios can be accepted.

SRR e.i.r.p. levels (dBm/MHz)	RAS	EESS	Fixed
-30	No, see note 1	No	No
-41.3	No, see note 1	Yes	See note 2B
-50	No, see note 1	Yes	Yes

Table 18B: Summary of co-existence (assuming 10%, or less, of vehicles within visibility of the victim service are equipped with SRR)

Note 1: If all of the possible mitigation factors such as local terrain, clutter loss, car density are applicable and if this leads to sufficient reduction in interference level, then sharing between the SRR at 24 GHz and radio astronomy could be possible in some cases.

Note 2B: If the protection criteria of –20 dB I/N is to be met in all cases, sharing is not feasible. However, sharing is considered to be feasible if an excess of the protection criteria by 10 dB (up to –10 dB I/N) in worst case scenarios can be accepted.

It is to be noted that it is not clear how to relate the percentage of vehicles equipped with SRR in a specific area, as used in the sharing scenarios, with market penetration figures.

5.1 Radio Astronomy

The sharing study between the SRR application at 24 GHz and the Radio Astronomy Service was done on the assumption of a mean e.i.r.p. per SRR device of –90 dBm/Hz.

It shows that compatibility is not feasible, with a calculated negative margin in the order of 70 dB for spectral line observations and 90 dB for continuum observations, with a device density of 100 devices per km² that are transmitting into the direction of the radio astronomy station.

If all of the possible mitigation factors such as local terrain, clutter loss, car density are applicable and if this leads to sufficient reduction in interference level, then sharing between the SRR at 24 GHz and radio astronomy could be possible in some cases.

5.2 EESS

Using the assumptions that SRR e.i.r.p. is –41.3 dBm/MHz with a 100% percentage of vehicles equipped with SRR devices in the EESS pixel, then protection criteria for all types of EESS sensors (according to ITU-R Rec SA.1029-2 to be adopted in February 2003) will be exceeded by up to 10.8 dB. All the data derived from those measurements will be corrupted in corresponding EESS observations (cities, roads or motorways).

The above reasons lead to the conclusions that the SRR with 100% cars equipped can not share the band with the EESS (passive) in the band 23.6-24 GHz.

It should be noted that a percentage of vehicles equipped with SRR devices in the EESS pixel lower than 100 % provides a decrease of the aggregate power, e.g. around 10 dB for a percentage limited to 10 %.

For the case of SRR radars with very low horizontal e.i.r.p. (-50 dBm/MHz), sharing with all types of EESS sensors would still result in a negative margin (up to –2.1 dB for current requirements (for which the Recommendation SA 1029 has been recently revised), and up to –9.1 dB for future instruments in the long term i.e. year 2020).

5.3 Fixed Service

It was recognized that the SRR deployment being assumed on a “no harmful interference” basis, it might be difficult in practice to apply counter-measures to stop possible interference, once the SRR deployed in full.

On this basis, and taking into account the protection requirements of the FS, the long term compatibility scenario with SRR (with an e.i.r.p density level of –41.3 dBm/MHz) with 100% of vehicles equipped with SRR devices in visibility of the FS receiver was studied. Due to the complex sharing scenario, a number of assumptions had to be made. For simplification, the simulations were restricted to two scenarios (1 lane and 4 lanes scenarios) with 2 active forward sensors per car. Important factors such as the FS antenna height and distance from the road (offset), distance between cars and different models for the rain attenuation, which could heavily influence the results of the study were varied in order to be able to compare their effects.

Due to the complexity of the compatibility scenario, a simplified propagation model was chosen. In this model, propagation effects such as spray due to preceding cars, clutter losses (except from other cars) and reflections of SRR transmissions from the road or other cars were not taken into account since it was uncertain whether or not and to what extent (in dBs) these effects influence the sharing situation.

The results of the studies with all assumptions described above show that the protection criteria of the FS is exceeded by 0 to 20 dB depending on the scenarios and on the combination of the factors.

Considering that the SRR devices are to be operated on a non-interference basis, it is concluded that SRR deployed in the 24 GHz band operating at a –41.3 dBm/MHz e.i.r.p density are not compatible with FS in the long-term.

However, on the basis of the whole range of calculation results, it can be concluded that with an e.i.r.p. density of -60 dBm/MHz the FS protection criteria (–20 dB I/N) for all scenarios considered in these studies is respected, whilst with an e.i.r.p. density of –50 dBm/MHz, this protection criteria would be met in most scenarios. Some administrations are of the opinion that is it necessary that SRR meets the –20 dB I/N protection criteria in all cases. Some other administrations are of the opinion that an excess of the protection criteria by 10 dB, which still corresponds to an I/N of –10 dB, is acceptable.

In addition, on a short-term basis, it was concluded that an e.i.r.p. mean power density of –41.3 dBm/MHz associated with an e.i.r.p peak limit of 0dBm/50 MHz could be sufficient to protect the FS as far as the percentage of cars equipped with SRR devices in visibility of the FS receiver is limited to less than 10% or less than few percent depending on whether the protection criteria is to be met in all cases; 10 % is equivalent to a 10 dB decrease of the aggregate power.

Finally, even though the studies have been limited to the 23 and 26 GHz FS bands, the calculation results and conclusions are still valid in the 28 GHz FS band and have also to be taken into account for the 32 GHz band.

ANNEX A: EXTRACT FROM ITU RADIO REGULATIONS: 2001– 21 TO 28 GHZ

A.1 Extract from the Table of Frequency Allocations

<table>
<tr><th colspan="3">Allocation to services</th></tr>
<tr><th>Region 1</th><th>Region 2</th><th>Region 3</th></tr>
<tr><td colspan="3">20.2-21.2
FIXED-SATELLITE (space-to-Earth)
MOBILE-SATELLITE (space-to-Earth)
Standard frequency and time signal-satellite (space-to-Earth)
5.524</td></tr>
<tr><td colspan="3">21.2-21.4
EARTH EXPLORATION-SATELLITE (passive)
FIXED
MOBILE
SPACE RESEARCH (passive)</td></tr>
<tr><td>21.4-22
FIXED
MOBILE
BROADCASTING-SATELLITE 5.530</td><td>21.4-22
FIXED
MOBILE</td><td>21.4-22
FIXED
MOBILE
BROADCASTING-SATELLITE 5.530
5.531</td></tr>
<tr><td colspan="3">22-22.21
FIXED
MOBILE except aeronautical mobile
5.149</td></tr>
<tr><td colspan="3">22.21-22.5
EARTH EXPLORATION-SATELLITE (passive)
FIXED
MOBILE except aeronautical mobile
RADIO ASTRONOMY
SPACE RESEARCH (passive)
5.149 5.532</td></tr>
<tr><td colspan="3">22.5-22.55
FIXED
MOBILE</td></tr>
<tr><td colspan="3">22.55-23.55
FIXED
INTER-SATELLITE
MOBILE
5.149</td></tr>
<tr><td colspan="3">23.55-23.6
FIXED
MOBILE</td></tr>
<tr><td colspan="3">23.6-24
EARTH EXPLORATION-SATELLITE (passive)
RADIO ASTRONOMY
SPACE RESEARCH (passive)
5.340</td></tr>
</table>

<table>
<tr><th>Region 1</th><th>Region 2</th><th>Region 3</th></tr>
<tr><td colspan="3">24-24.05
AMATEUR
AMATEUR-SATELLITE
5.150</td></tr>
<tr><td colspan="3">24.05-24.25
RADIOLOCATION
Amateur
Earth exploration-satellite (active)
5.150</td></tr>
<tr><td>24.25-24.45
FIXED</td><td>24.25-24.45
RADIONAVIGATION</td><td>24.25-24.45
RADIONAVIGATION
FIXED
MOBILE</td></tr>
<tr><td>24.45-24.65
FIXED
INTER-SATELLITE</td><td>24.45-24.65
INTER-SATELLITE
RADIONAVIGATION
5.533</td><td>24.45-24.65
FIXED
INTER-SATELLITE
MOBILE
RADIONAVIGATION
5.533</td></tr>
<tr><td>24.65-24.75
FIXED
INTER-SATELLITE</td><td>24.65-24.75
INTER-SATELLITE
RADIOLOCATION-SATELLITE (Earth-to-space)</td><td>24.65-24.75
FIXED
INTER-SATELLITE
MOBILE
5.533 5.534</td></tr>
<tr><td>24.75-25.25
FIXED</td><td>24.75-25.25
FIXED-SATELLITE (Earth-to-space) 5.535</td><td>24.75-25.25
FIXED
FIXED-SATELLITE (Earth-to-space) 5.535
MOBILE
5.534</td></tr>
<tr><td colspan="3">25.25-25.5
FIXED
INTER-SATELLITE 5.536
MOBILE
Standard frequency and time signal-satellite (Earth-to-space)</td></tr>
<tr><td colspan="3">25.5-27
EARTH EXPLORATION-SATELLITE (space-to Earth) 5.536A 5.536B
FIXED
INTER-SATELLITE 5.536
MOBILE
Standard frequency and time signal-satellite (Earth-to-space)</td></tr>
<tr><td>27-27.5
FIXED
INTER-SATELLITE 5.536
MOBILE</td><td colspan="2">27-27.5
FIXED
FIXED-SATELLITE (Earth-to-space)
INTER-SATELLITE 5.536 5.537
MOBILE</td></tr>
</table>

Region 1	Region 2	Region 3
27.5-28.5	FIXED 5.537A FIXED-SATELLITE (Earth-to-space) 5.484A 5.539 MOBILE 5.538 5.540	

A.2 Relevant RR Footnotes

5.149 In making assignments to stations of other services to which the bands:

13 360-13 410 kHz,
25 550-25 670 kHz,
37.5-38.25 MHz,
73-74.6 MHz in Regions 1 and 3,
150.05-153 MHz in Region 1,
322-328.6 MHz*,
406.1-410 MHz,
608-614 MHz in Regions 1 and 3,
1 330-1 400 MHz*,
1 610.6-1 613.8 MHz*,
1 660-1 670 MHz,
1 718.8-1 722.2 MHz*,
2 655-2 690 MHz,
3 260-3 267 MHz*,
3 332-3 339 MHz*,
3 345.8-3 352.5 MHz*,
4 825-4 835 MHz*,
4 950-4 990 MHz,
4 990-5 000 MHz,
6 650-6 675.2 MHz*,
10.6-10.68 GHz,
14.47-14.5 GHz*,
22.01-22.21 GHz*,
22.21-22.5 GHz,
22.81-22.86 GHz*,
23.07-23.12 GHz*,
31.2-31.3 GHz,
31.5-31.8 GHz in Regions 1 and 3,
36.43-36.5 GHz*,
42.5-43.5 GHz,
42.77-42.87 GHz*,
43.07-43.17 GHz*,
43.37-43.47 GHz*,
48.94-49.04 GHz*,
72.77-72.91 GHz*,
93.07-93.27 GHz*,
97.88-98.08 GHz*,
140.69-140.98 GHz*,
144.68-144.98 GHz*,
145.45-145.75 GHz*,
146.82-147.12 GHz*,
150-151 GHz*,
174.42-175.02 GHz*,
177-177.4 GHz*,
178.2-178.6 GHz*,
181-181.46 GHz*,
186.2-186.6 GHz*,
250-251 GHz*,
257.5-258 GHz*,
261-265 GHz,
262.24-262.76 GHz*,
265-275 GHz,
265.64-266.16 GHz*,
267.34-267.86 GHz*,
271.74-272.26 GHz*

are allocated (* indicates radio astronomy use for spectral line observations), administrations are urged to take all practicable steps to protect the radio astronomy service from harmful interference. Emissions from spaceborne or airborne stations can be particularly serious sources of interference to the radio astronomy service (see Nos. **4.5** and **4.6** and Article **29**). (WRC-97)

5.150 The following bands:

13 553-13 567 kHz	(centre frequency 13 560 kHz),
26 957-27 283 kHz	(centre frequency 27 120 kHz),
40.66-40.70 MHz	(centre frequency 40.68 MHz),
902-928 MHz	in Region 2 (centre frequency 915 MHz),
2 400-2 500 MHz	(centre frequency 2 450 MHz),
5 725-5 875 MHz	(centre frequency 5 800 MHz), and
24-24.25 GHz	(centre frequency 24.125 GHz)

are also designated for industrial, scientific and medical (ISM) applications. Radiocommunication services operating within these bands must accept harmful interference which may be caused by these applications. ISM equipment operating in these bands is subject to the provisions of No. **15.13**.

5.340 All emissions are prohibited in the following bands:

1 400-1 427 MHz,	
2 690-2 700 MHz,	Except those provided for by Nos. **5.421** and **5.422**,
10.68-10.7 GHz,	Except those provided for by No. **5.483**,
15.35-15.4 GHz,	Except those provided for by No. **5.511**,
23.6-24 GHz,	
31.3-31.5 GHz,	
31.5-31.8 GHz,	In Region 2,
48.94-49.04 GHz,	From airborne stations,
50.2-50.4 GHz2,	Except those provided for by No. **5.555A**,
52.6-54.25 GHz,	
86-92 GHz,	
105-116 GHz,	
140.69-140.98 GHz,	From airborne stations and from space stations in the space-to-Earth direction,
182-185 GHz,	Except those provided for by No. **5.563**,
217-231 GHz.	(WRC-97)

5.484A The use of the bands 10.95-11.2 GHz (space-to-Earth), 11.45-11.7 GHz (space-to-Earth), 11.7-12.2 GHz (space-to-Earth) in Region 2, 12.2-12.75 GHz (space-to-Earth) in Region 3, 12.5-12.75 GHz (space-to-Earth) in Region 1, 13.75-14.5 GHz (Earth-to-space), 17.8-18.6 GHz (space-to-Earth), 19.7-20.2 GHz (space-to-Earth), 27.5-28.6 GHz (Earth-to-space), 29.5-30 GHz (Earth-to-space) by a non-geostationary-satellite system in the fixed-satellite service is subject to application of the provisions of No. **9.12** for coordination with other non-geostationary-satellite systems in the fixed-satellite service. Non-geostationary-satellite systems in the fixed-satellite service shall not claim protection from geostationary-satellite networks in the fixed-satellite service operating in accordance with the Radio Regulations, irrespective of the dates of receipt by the Bureau of the complete coordination or notification information, as appropriate, for the non-geostationary-satellite systems in the fixed-satellite service and of the complete coordination or notification information, as appropriate, for the geostationary-satellite networks, and No. **5.43A** does not apply. Non-geostationary-satellite systems in the fixed-satellite service in the above bands shall be operated in such a way that any unacceptable interference that may occur during their operation shall be rapidly eliminated. (WRC-2000)

5.524 *Additional allocation:* in Afghanistan, Algeria, Angola, Saudi Arabia, Bahrain, Bangladesh, Brunei Darussalam, Cameroon, China, the Congo, Costa Rica, Egypt, the United Arab Emirates, Gabon, Guatemala, Guinea, India, Iran (Islamic Republic of), Iraq, Israel, Japan, Jordan, Kuwait, Lebanon, Malaysia, Mali, Morocco, Mauritania, Nepal, Nigeria, Oman, Pakistan, the Philippines, Qatar, the Dem. Rep. of the Congo, Syria, the Dem. People's Rep. of Korea, Singapore, Somalia, Sudan, Tanzania, Chad, Togo and Tunisia, the band 19.7-21.2 GHz is also allocated to the fixed and mobile services on a primary basis. This additional use shall not impose any limitation on the power flux-density of space stations in the fixed-satellite service in the band 19.7-21.2 GHz and of space stations in the mobile-satellite service in the band 19.7-20.2 GHz where the allocation to the mobile-satellite service is on a primary basis in the latter band. (WRC-2000)

5.530 In Regions 1 and 3, the allocation to the broadcasting-satellite service in the band 21.4-22 GHz shall come into effect on 1 April 2007. The use of this band by the broadcasting-satellite service after that date and on an interim basis prior to that date is subject to the provisions of Resolution **525 (WARC-92)**.

5.531 *Additional allocation:* in Japan, the band 21.4-22 GHz is also allocated to the broadcasting service on a primary basis.

5.532 The use of the band 22.21-22.5 GHz by the Earth exploration-satellite (passive) and space research (passive) services shall not impose constraints upon the fixed and mobile, except aeronautical mobile, services.

5.533 The inter-satellite service shall not claim protection from harmful interference from airport surface detection equipment stations of the radionavigation service.

5.534 *Additional allocation:* in Japan, the band 24.65-25.25 GHz is also allocated to the radionavigation service on a primary basis until 2008.

5.535 In the band 24.75-25.25 GHz, feeder links to stations of the broadcasting-satellite service shall have priority over other uses in the fixed-satellite service (Earth-to-space). Such other uses shall protect and shall not claim protection from existing and future operating feeder-link networks to such broadcasting satellite stations.

5.536 Use of the 25.25-27.5 GHz band by the inter-satellite service is limited to space research and Earth exploration-satellite applications, and also transmissions of data originating from industrial and medical activities in space.

5.536A Administrations installing Earth exploration-satellite service earth stations cannot claim protection from stations in the fixed and mobile services operated by neighbouring administrations. In addition, earth stations operating in the Earth exploration-satellite service should take into account Recommendation ITU-R SA.1278. (WRC-2000)

5.536B In Germany, Saudi Arabia, Austria, Belgium, Brazil, Bulgaria, China, Korea (Rep. of), Denmark, Egypt, United Arab Emirates, Spain, Estonia, Finland, France, Hungary, India, Iran (Islamic Republic of), Ireland, Israel, Italy, Jordan, Kenya, Kuwait, Lebanon, Libya, Liechtenstein, Lithuania, Moldova, Norway, Oman, Uganda, Pakistan, the Philippines, Poland, Portugal, Syria, Slovakia, the Czech Rep., Romania, the United Kingdom, Singapore, Sweden, Switzerland, Tanzania, Turkey, Viet Nam and Zimbabwe, earth stations operating in the Earth exploration-satellite service in the band 25.5-27 GHz shall not claim protection from, or constrain the use and deployment of, stations of the fixed and mobile services. (WRC-97)

5.537 Space services using non-geostationary satellites operating in the inter-satellite service in the band 27-27.5 GHz are exempt from the provisions of No. **22.2**.

5.537A In Bhutan, Indonesia, Iran (Islamic Republic of), Japan, Maldives, Mongolia, Myanmar, Pakistan, the Dem. People's Rep. of Korea, Sri Lanka, Thailand and Viet Nam, the allocation to the fixed service in the band 27.5-28.35 GHz may also be used by high altitude platform stations (HAPS). The use of the band 27.5-28.35 GHz by HAPS is limited to operation in the HAPS-to-ground direction and shall not cause harmful interference to, nor claim protection from, other types of fixed-service systems or other co-primary services. (WRC-2000)

5.538 *Additional allocation:* the bands 27.500-27.501 GHz and 29.999-30.000 GHz are also allocated to the fixed-satellite service (space-to-Earth) on a primary basis for the beacon transmissions intended for up-link power control. Such space-to-Earth transmissions shall not exceed an equivalent isotropically radiated power (e.i.r.p.) of +10 dBW in the direction of adjacent satellites on the geostationary-satellite orbit. In the band 27.500-27.501 GHz, such space-to-Earth transmissions shall not produce a power flux-density in excess of the values specified in Article **21**, Table **21-4** on the Earth's surface.

5.539 The band 27.5-30 GHz may be used by the fixed-satellite service (Earth-to-space) for the provision of feeder links for the broadcasting-satellite service.

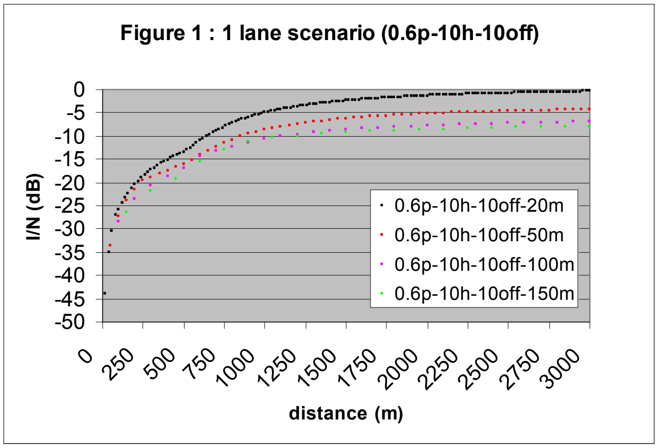
5.540 *Additional allocation:* the band 27.501-29.999 GHz is also allocated to the fixed-satellite service (space-to-Earth) on a secondary basis for beacon transmissions intended for up-link power control.

ANNEX B: FS CALCULATION RESULTS

In all figures below, the variable input parameters are reflected using the following simple convention, as for example:

"0.6p-25h-10off-20m"

which, for this example means that the rain attenuation is 0.6 dB/km, the FS antenna height is 25m, the offset is 10 metres and the distance between cars is 20 m.



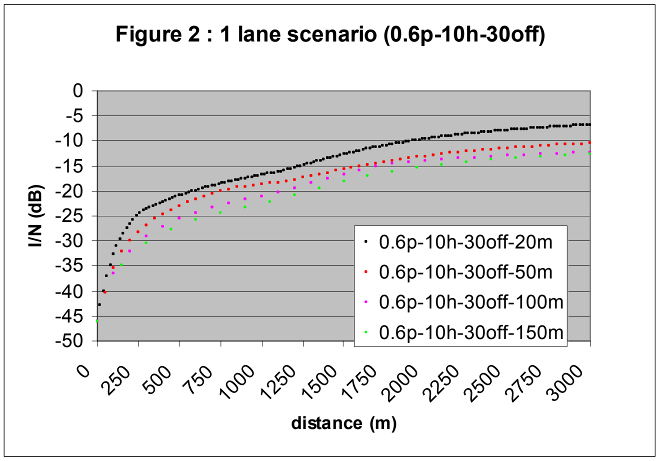


Figure 3 : 1 lane scenario (0.6p-18h-10off)

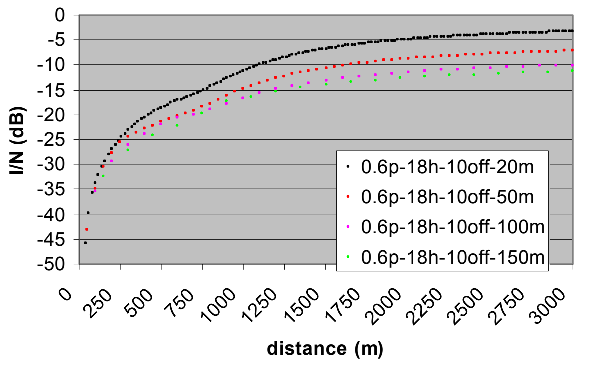


Figure 4 : 1 lane scenario (0.6p-18h-30off)

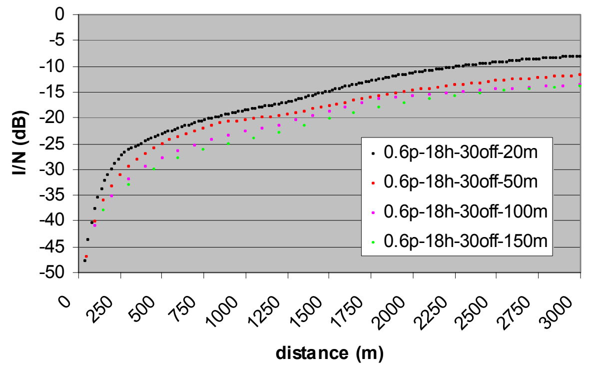
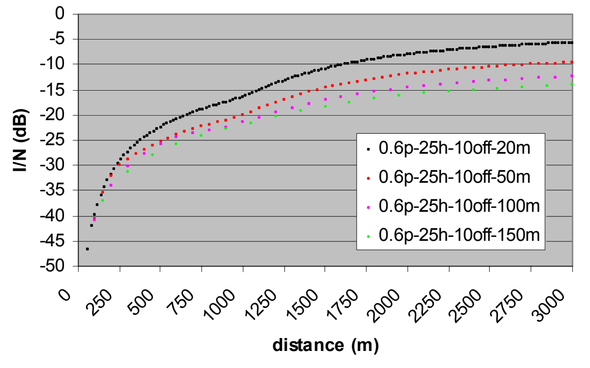


Figure 5 : 1 lane scenario (0.6p-25h-10off)



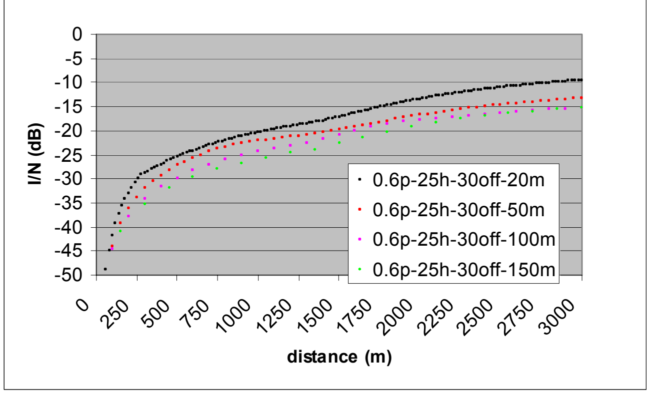


Figure 6 : 1 lane scenario (0.6p-25h-30off)

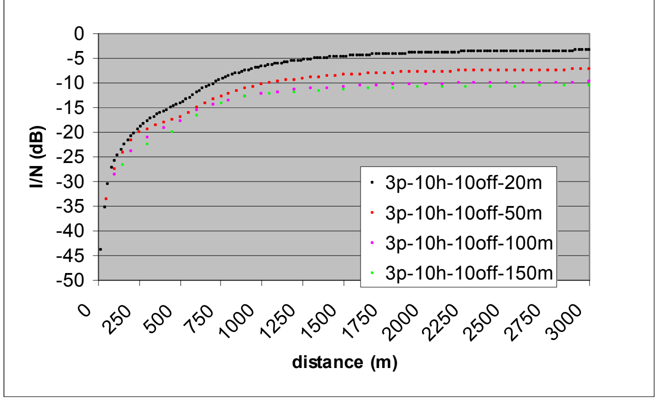


Figure 7 : 1 lane scenario (3p-10h-10off)

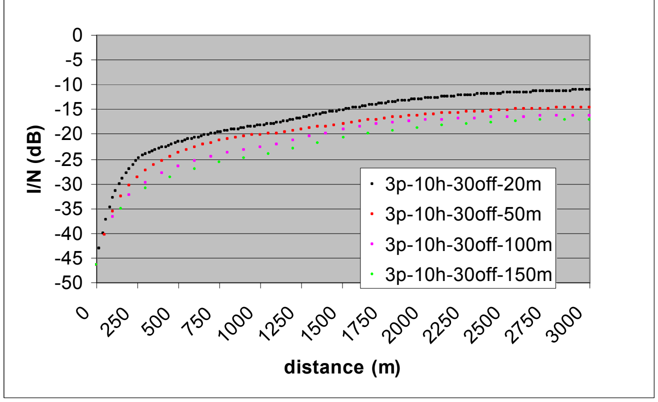


Figure 8 : 1 lane scenario (3p-10h-30off)

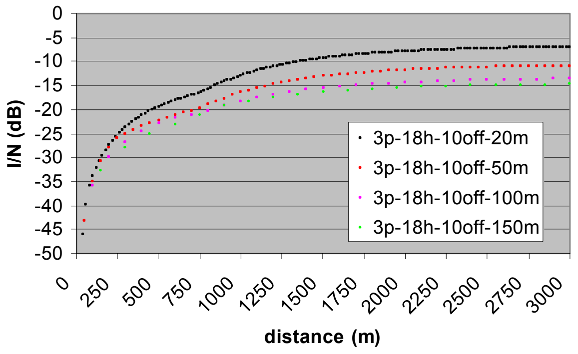


Figure 9 : 1 lane scenario (3p-18h-10off)

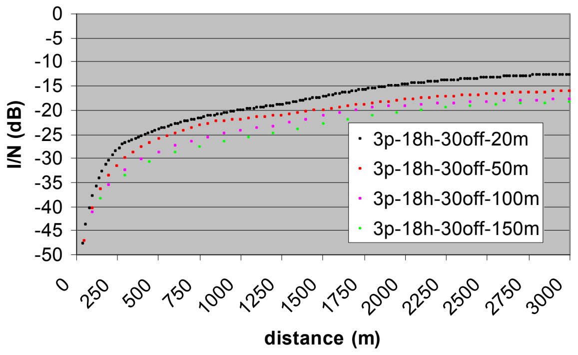


Figure 10 : 1 lane scenario (3p-18h-30off)

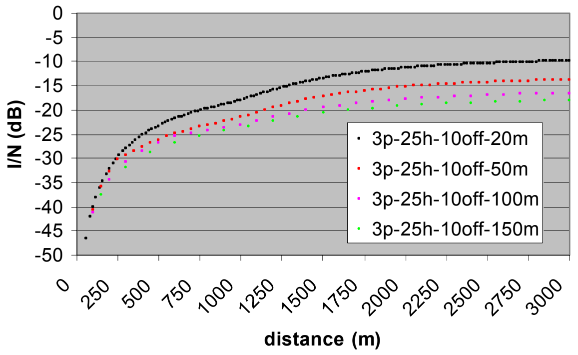


Figure 11 : 1 lane scenario (3p-25h-10off)

Figure 12 : 1 lane scenario (3p-25h-30off)

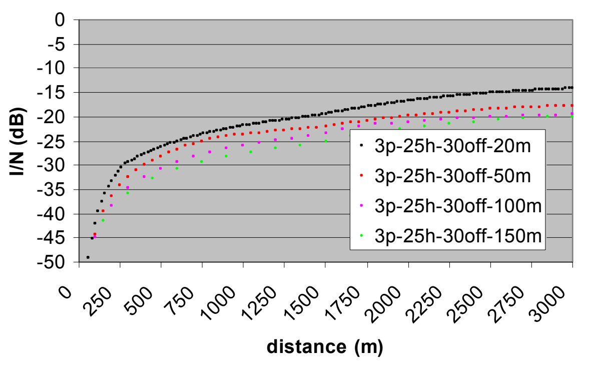


Figure 13 : 4 lanes scenario (0.6p-10h-10off)

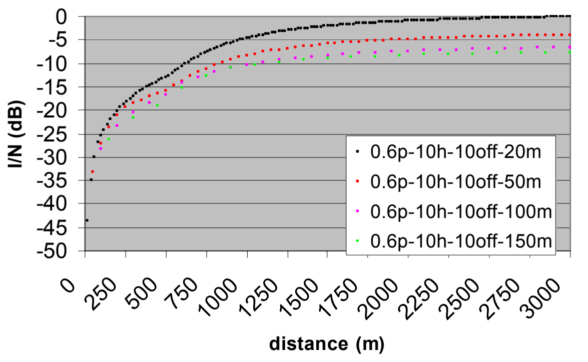


Figure 14 : 4 lanes scenario (0.6p-10h-30off)

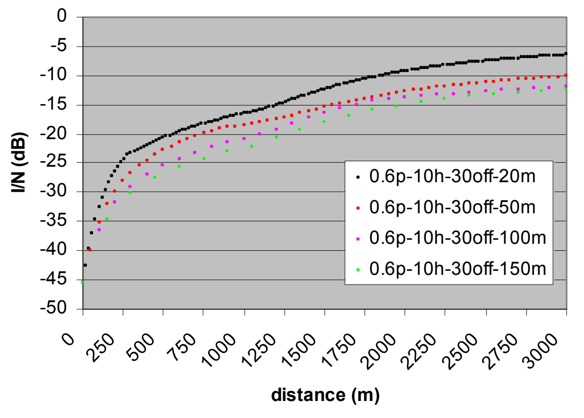


Figure 15 : 4 lanes scenario (0.6p-18h-10off)

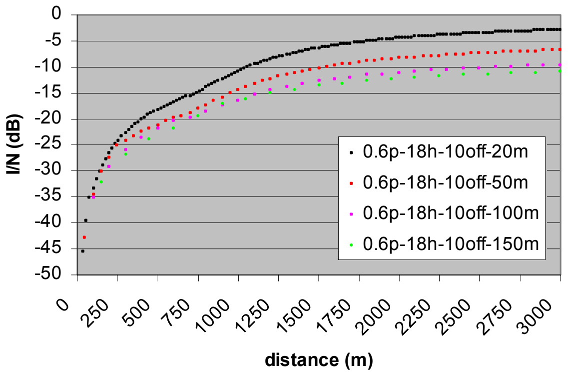


Figure 16 : 4 lanes scenario (0.6p-18h-30off)

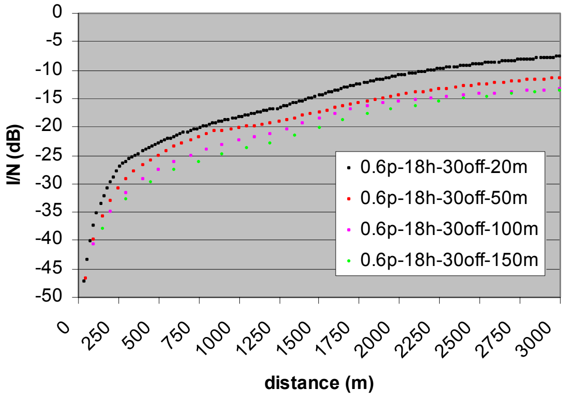


Figure 17 : 4 lanes scenario (0.6p-25h-10off)

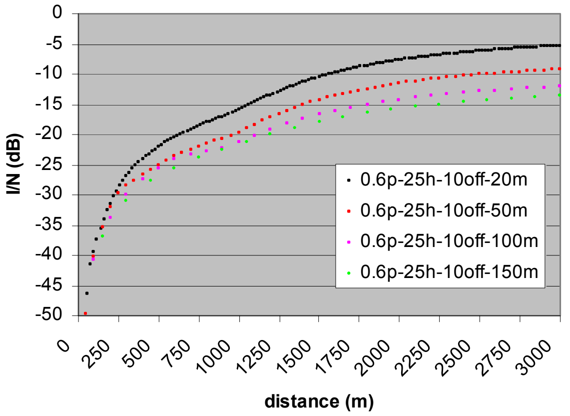


Figure 18 : 4 lanes scenario (0.6p-25h-30off)

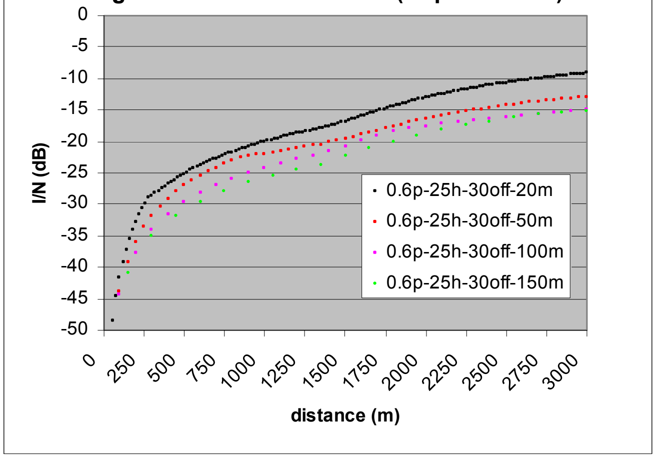


Figure 19 : 4 lanes scenario (3p-10h-10off)

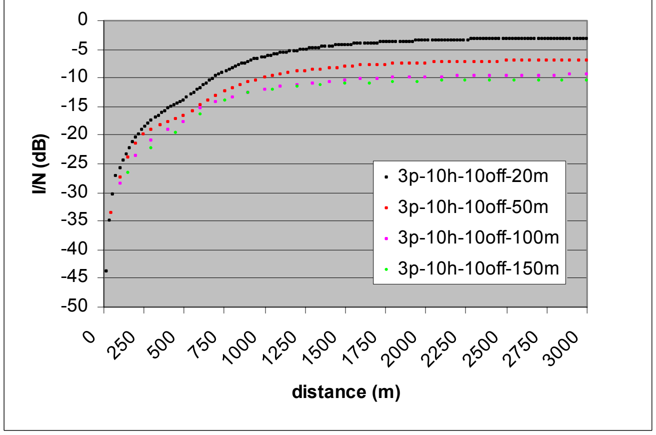


Figure 20 : 4 lanes scenario (3p-10h-30off)

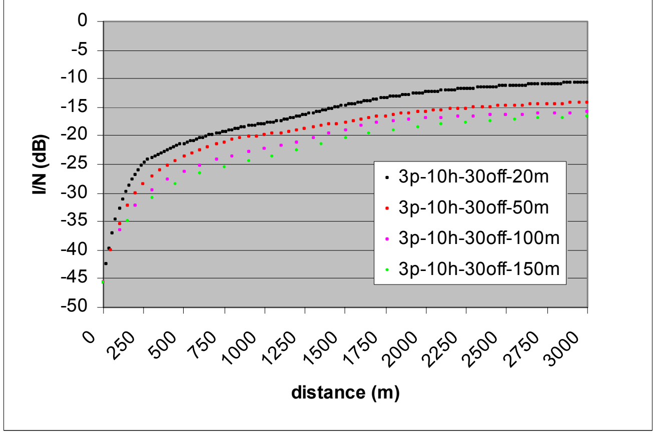


Figure 21 : 4 lanes scenario (3p-18h-10off)

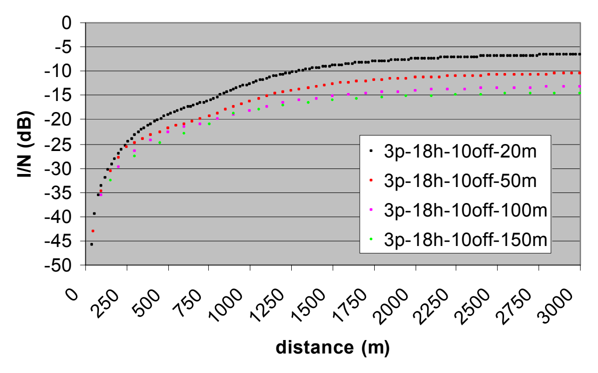


Figure 22 : 4 lanes scenario (3p-18h-30off)

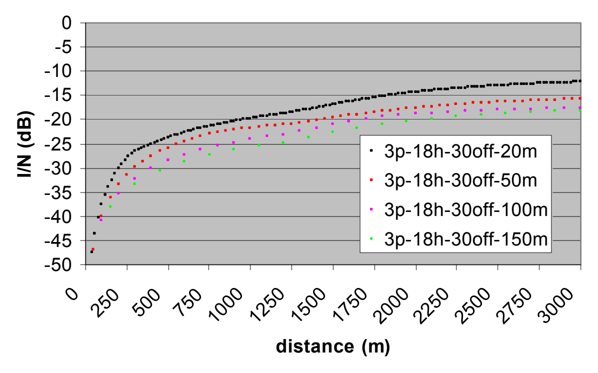


Figure 23 : 4 lanes scenario (3p-25h-10off)

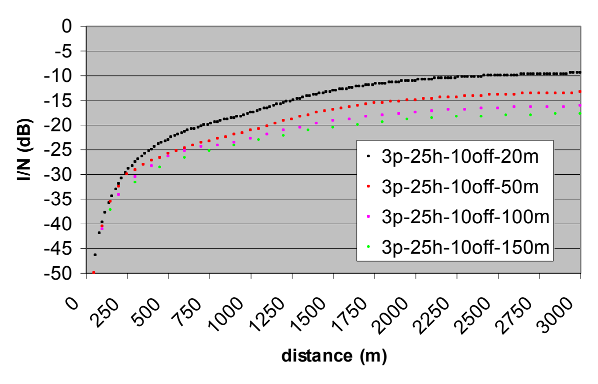


Figure 24 : 4 lanes scenario (3p-25h-30off)

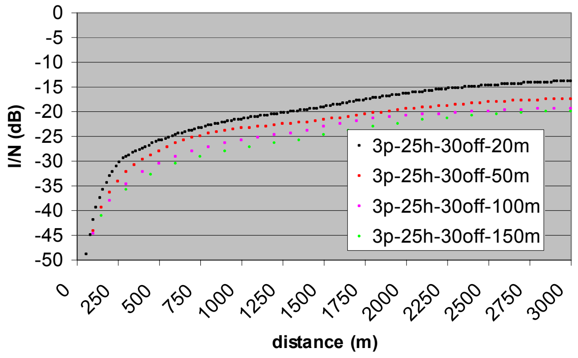


Figure 25 : 1 lane scenario (Rain comparison)

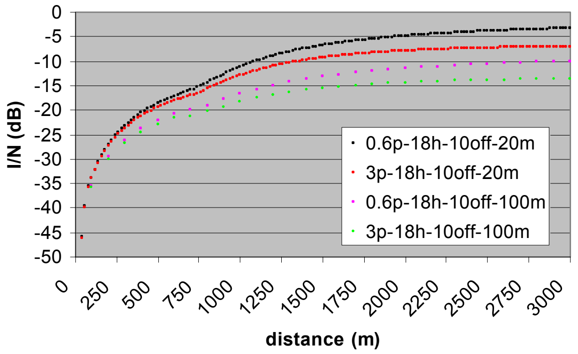
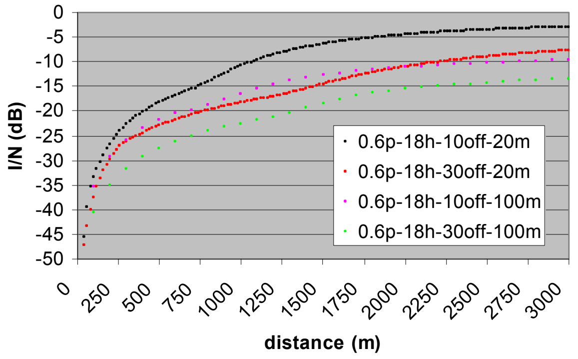


Figure 26 : 4 lanes scenario (Offset comparison)



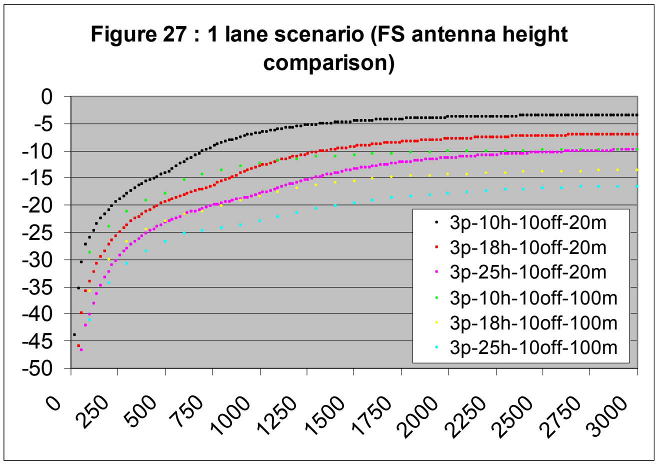


Figure 27 : 1 lane scenario (FS antenna height comparison)

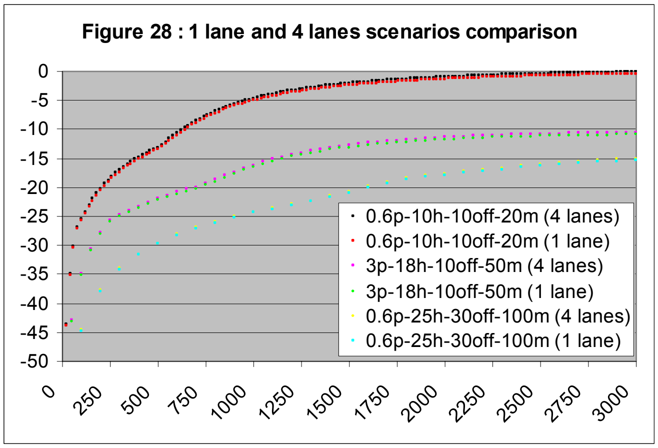


Figure 28 : 1 lane and 4 lanes scenarios comparison

ANNEX C: FS TEST CAMPAIGN RESULTS

Tests were performed at R&D labs of Fixed MW dept. - Siemens MN (Milan-Italy) and were attended, besides the representative of four different SRR manufacturers also by some representatives of European Administrations as independent witnesses.

C.1 Scope

The main target of the tests was to determine and specify the relevant SRR parameters (e.g. maximum peak and/or mean interference level) which lead to coexistence regarding the FS link budget.

Being the spectral characteristics of SRR quite different from thermal receiver noise it has been considered important to compare actual FS BER threshold degradation caused by a CW co-channel interference (on which preliminary assumption were based) and by the various kind of SRR signals presently foreseen in ETSI proposal. This would give more confidence to both SRR and FS parties on the objectives to be considered for defining final ECC regulations.

In particular the FS system selected was of “wide-band” kind (i.e. receiver Bw~41 MHz) being expected that peak SRR contribution to FS degradation is more affecting as far as the receiver Bw increases. Due to the kind of coded modulation (error correction) of the FS system used for the test, the results may be assumed as representative of current wide-band FS technology for presently deployed systems. The band is close to the 50 MHz assumed in FCC regulations (difference from 50MHz wide-band peak to rms ratio is less than 1 dB).

Representative characteristics of FS receiver under test are reported in Appendix 1 attached to this Annex.

The four types of SRR, presented to the test, were representative of all those described in ETSI System Reference Document TR 101 892, where detailed characteristics may be found

It should be noted that the actual e.i.r.p. limit for SRR devices was beyond the scope of the test; it should be set comparing the objectives derived from the test results with the aggregate interference values coming from numerical evaluation of the representative scenarios. However this is a necessary step forward in the comprehension of the physical phenomena in order to set more technically sound and fair objectives for coexistence.

Tentative practical objectives for both rms and peak I/N objectives are derived from the tests.

C.2 Test setup

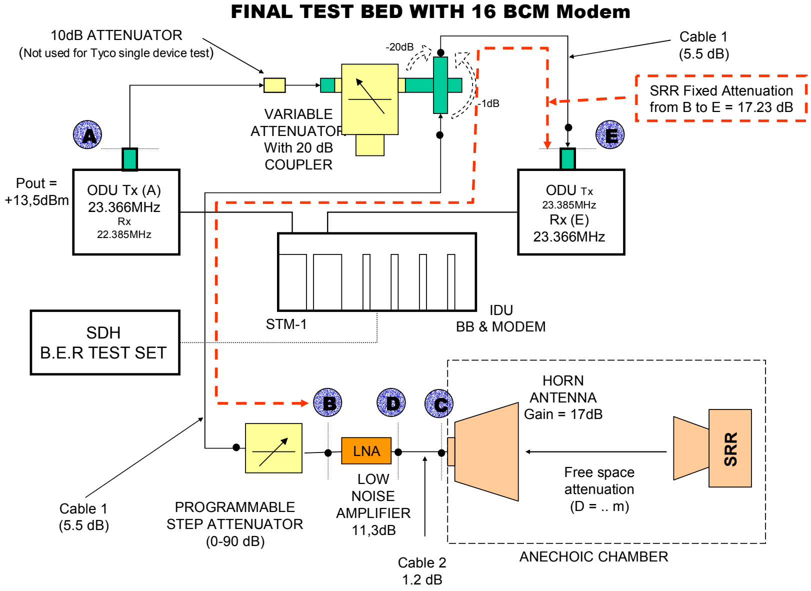


Figure C.1: Final set-up for SRR tests for improved sensitivity.

A CW signal generator was also used for a reference I/N degradation test.

C.3 Test results

Data of FS RSL degradations for BER thresholds 10^{-6} and 10^{-8} versus SRR rms and peak power has been carried on and data recorded on Excel file and SA readings for further elaboration.

It should be noted that some tests (in particular for Tyco and Delphi devices and also for Siemens VDO aggregate), while still giving evident degradation to the FS receiver, the reference levels of SRR devices at reference point C were very close to the SA noise floor (SNR<3dB!). In those cases it was expected that the actual SRR levels would be quite lower than the reading. For reducing the possible errors the SA noise floor was taken into account and correction of the actual SRR spectrum readings, nevertheless a potential error of few dB has been considered and errors bars appears in the final graphs.

The following SRR devices/Mode of operation have been tested for BER10^{-6} and 10^{-8} threshold degradation:

Interfering signal (CW or SRR Type and mode of operation)	
CW interference	**Delphi** (single mode)
Tyco dithered mode no FM	**Siemens** VDO Mode 1 (PRF 200 kHz - DC = 20dB)
Tyco undithered mode no FM	**Siemens** VDO Mode 2 (PRF 2 MHz – DC = 10 dB)
Tyco undithered mode + slow FM	**Aggregate** of up to 3 Tyco devices dithered
Bosch undithered mode	**Aggregate** of up to 3 Siemens VDO devices (Mode 1)
Bosch dithered mode	

It was considered that data and conclusions were affected by:

- errors due to somehow insufficient sensitivity of the spectrum analyser used for defining the reference levels of interfering sources
- tests made on a single type of FS receiver; therefore different behaviour might be expected from other receivers. However the group was of the opinion that, when limited to very low interference degradation (as given by the coexistence objective considered), those differences should be quite limited.

In particular the peak objective is proposed, being clear from the tests, that an rms limit only would not be technically sufficient for guaranteeing suitable and balanced criteria.

From the set of tests produced, the following considerations are relevant.

C.3.1 Aggregation of multiple devices

Tests have been made with up to three SRR devices from Tyco and Siemens (Mode 1) in order to have more confidence on the assumed 10logN adding law provisionally assumed in the coexistence study.

Results are not enough conclusive due to the far insufficient sensitivity in the tests however qualitative results might be summarised as:

- Tyco aggregate tests seems to fit the 10log adding law (aggregate devices behaviour is close to a single device with the same aggregate power)
- Siemens Mode 1 results are inconclusive, due to the discovered power drop of one device that does not allows actual levels comparisons. However there was no evidence or feeling that might contradict Tyco results.

C.3.2 FS Thresholds degradations at different BER:

Tests have been made for both BER 10^{-6} and 10^{-8} FS thresholds degradations in order to evaluate possible non-linear behaviour of the interference impact.

No significant difference have been found between BER 10^{-6} and BER=10^{-8}

Therefore only BER 10^{-6} data are described here.

C.3.3 Measured BER Threshold degradation versus I/N

C.3.3.1 General

Figures C.2and C.3 are directly derived from the data of the tests and show the FS BER 10^{-6} threshold degradation as function of I/N rms ratio in 1 MHz bandwidth and Ipeak/Nrms ratio in the FS signal bandwidth of 41 MHz. Figure C.4 shows the measured $I_{peak@41}/I_{rms@1}$ ratio of the SRR devices; the theoretical noise graph is shown for reference.

In all figures potential error bars have been added to show the levels of assumed confidence.

For comparison, the CW interference test is shown. For this purpose, an $I_{CW\text{-}rms}$ “density” value, being the receiver bandwidth flat along its assumed to be:

$$I_{CW\text{-}rms} = I_{CW} - 10\log 41$$

while $I_{CW\text{-}peak}$ was assumed to be:

$$I_{CW\text{-}peak} = I_{CW} + 3\text{dB}.$$

The tentative proposed I/N practical objectives are also indicated as discussed later in this section.

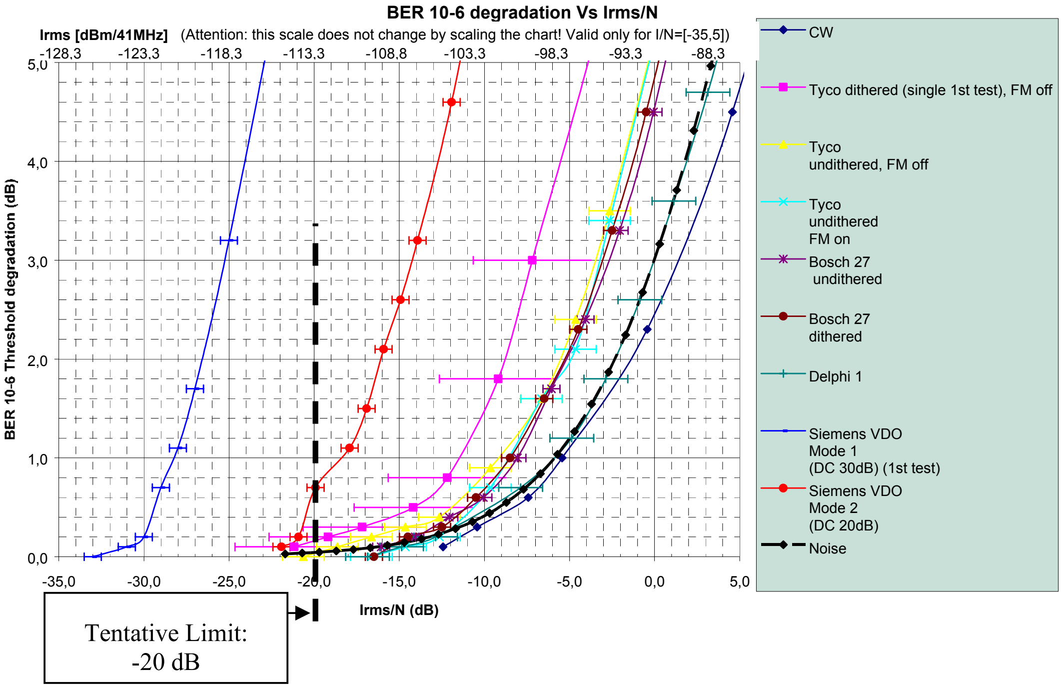


Figure C.2: SRR rms impact on BER $^{10\text{-}6}$ FS threshold degradation

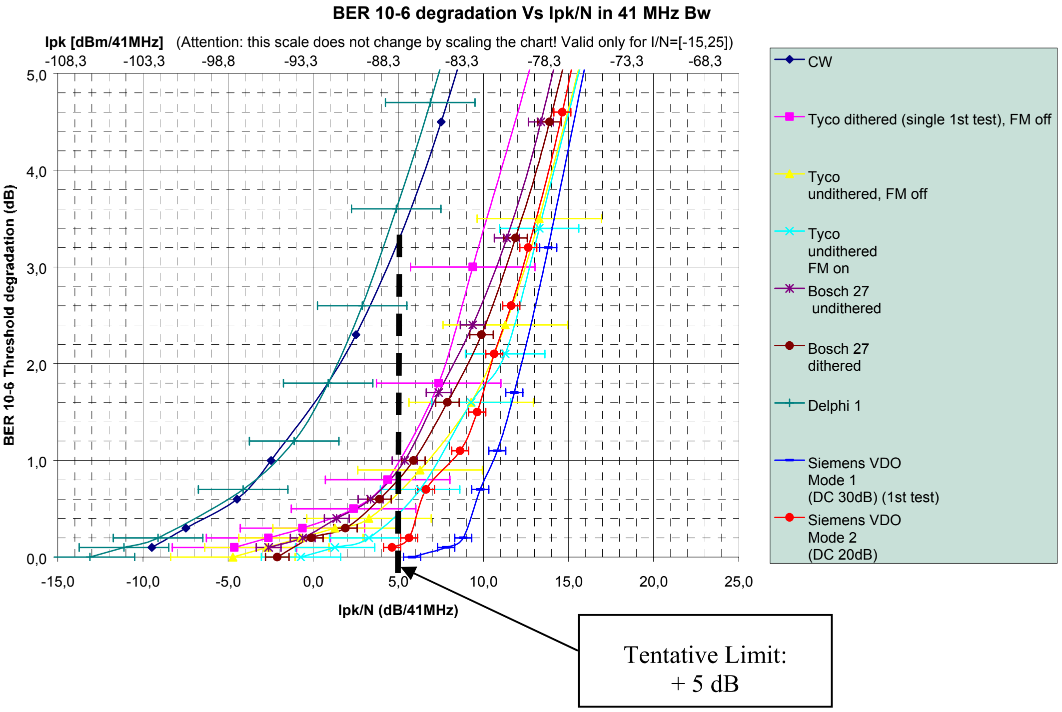


Figure C.3: SRR peak impact on BER $^{10-6}$ FS threshold degradation

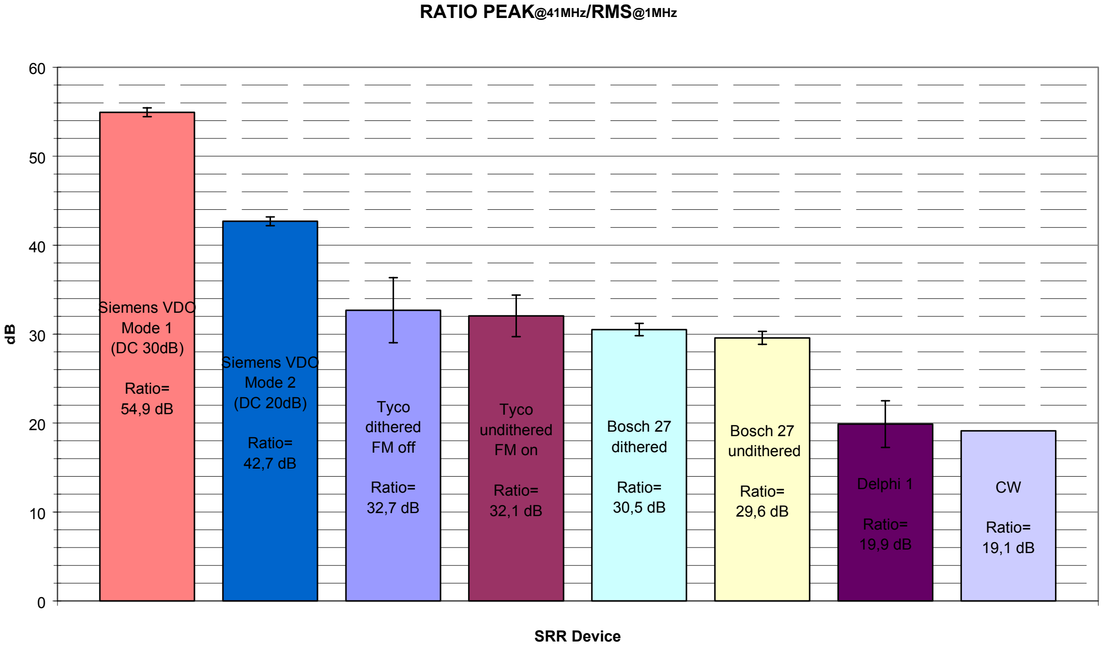


Figure C.4: $I_{PK@41}/I_{rms@1}$ ratio for tested SRR devices

C.3.3.2 Analysis of the FS receiver behaviour in term of I_{rms}/N_{rms} and I_{PK41}/N_{rms41} ratios

CW interference is slightly better than noise theory, however the difference is within the possible measurement errors.

It seems clear that FS receiver degradation is generated by two different contributions; one related to interferer rms power and another related to its peak power falling in the victim receiver band. The triggering level where degradation starts is obviously related to the peak to rms characteristic of the SRR device (see Figure C.4).

- For high peak to rms emissions (Siemens FH sensors) the BER degradation is initially caused by peak interference only and the degradation versus rms looks artificially worse.
- Unfortunately while the difference in function of Siemens DC seems linear in the rms case, for the peak such linearity is not seen. This might be due to contribution of the rms phenomena that for Siemens mode 2 (DC=10dB) is not negligible; it might be interesting having an additional test with even lower DC (e.g. DC=30dB)
- For low peak to rms ratio devices (Delphi and CW), on the contrary, it is the BER degradation versus peak that looks artificially worse because errors are initially caused by rms contribution only.
- For intermediate cases such as Bosch and Tyco (that in Figure C.4 appears to have very close characteristics), the two contributions to BER degradation seems activated contemporarily.
- The crossover value between the two phenomena appears to be close to an $I_{PK41}/I_{rms1} \cong 30\text{-}32$ dB, that, by the way is consistent with initial FCC studies assumptions (−41dBm/MHz and −10dBm/50MHz) before the peak limit is raised to 0dBm/50MHz in the final rule.

C.3.3.3 Setting tentative objectives

In Figure C.2 and C.3 tentative limits are shown in agreement with the proposal made for the UWB below 6 GHz and 24 GHz SRR.

→ **$I_{rms}/N \leq -20$ dB within 1MHz:** rms densities ratio within 1MHz are in line with ITU-R and ECC WGPT SE19 views

→ **$I_{PK}/N \leq +5$ dB within 41(or 50) MHz:** I_{peak} to N_{rms} ratio within 41(or 50) MHz giving interference peak below noise peak for a probability $p > \sim 4\%$.

Analysing these values it might be noticed that:

- For Siemens devices, for which the Irms/N objective would need to be tighter, would in any case limited by the peak limit to keeping the rms lower than the maximum allowed.
- For Delphi device the situation is opposite, it would be bounded by Irms/N an I_{PK}/N will be far lower than the limit.
- Bosch and Tyco are in intermediate situations and seems to be bounded by rms limit, however the peak limit is very close and actual final implementation would manage between those limits
- The difference with possible peak limit in 50 MHz band is in the worst case $20\log(50/41) - 10\log(50/41) \cong 0.85$ dB and is in the order of the potential errors. Therefore the same values might be assumed as proposed for 50 MHz bandwidth regulation.

C.3.3.4 Note on possible regulatory framework

The problem of Peak evaluation within 50 MHz band was noted during the actual tests and further elaboration of the data; this needed to be clarified / rectified further in order to create a clear and balanced regulatory framework. In the initial phase, when specific test equipment is not available, some difficulty for assessing it might be present.

A contribution to the study suggested that limits, drawn for 50 MHz bandwidth, be transformed into 3 MHz or even 1 MHz bandwidth assuming that the 20log (50/Bres) is the worst case possible.

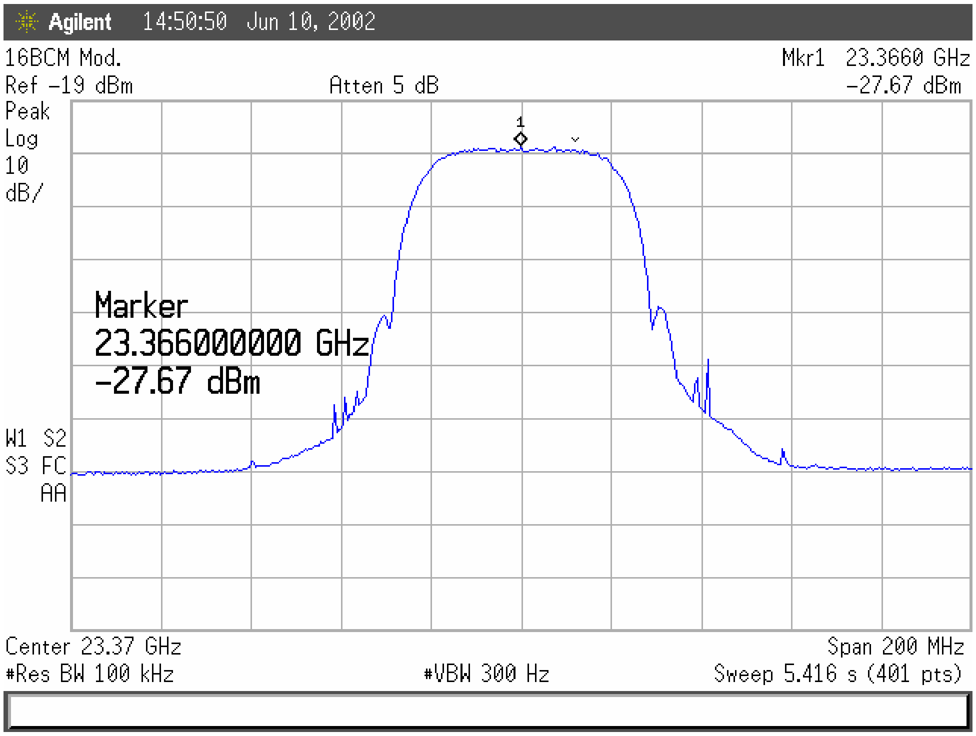
However, the absence of technical background for known examples, where that law is not theoretically true, led to some initial misinterpretation of the measurements (made at 3 MHz and transformed numerically to 41 MHz) for two type of devices:

- For Siemens FH sensors there was an overestimation of the true 41 MHz peak due to the pulse bandwidth that was less (~20MHz) than the 41MHz and a corrected formula had to be used for correct evaluations.
- For Delphi sensor there was an even higher overestimation because of its continuous and pseudorandom phase modulation that fit into a “noise-like” behaviour of 10log(41/Bres) also for the peak power.

Having so wide difference in technology used for SRR it might be important that, to avoid future misunderstandings between manufacturers, test houses, regulatory bodies and other persons related to R&TTE Directive product assessment, to describe at least such known cases as examples given in ETSI ENs, even if the 20 *log* law is maintained as general rule. Such examples might be of help if introduced in ECC report.

APPENDIX 1 TO ANNEX C: FIXED SERVICE TEST RECEIVER CHARACTERISTICS

FS system spectral emission



Test conditions: Transmitter Pout = +13.5 dBm
SA input Power (after cable loss and -6dB fixed att) = -0.5 dB

Other Relevant System characteristics:

- Payload capacity: STM-1 (155.52 Mbit/s SDH hierarchy)
- Physical modulation format: 16 QAM
- Coded modulation: 16 BCM (Block coded modulation, 16/15 block redundancy)
- S_R (Symbol rate) = 1/4 * 155.52 *16/15 = 41.472 Mbd/s (continuous transmission)
- Block code duration: $16*1/S_R \cong 386$ nS
- Noise Figure measured at Section E of test set-up (Rx antenna port) = 4.5 dB
- Noise rms power density at section E: $N_{RMS} = -114 + NF = -109.5(dBm/MHz)$
- Received Signal Level (RSL) for BER=10^{-6} :$\cong -74.2$ dBm
- Received Signal Level (RSL) for BER=10^{-8} : $\cong$–72.7 dBm
- S/N (normalised to the symbol rate bandwidth) derived according the formula:

$$S/N = RSL - (-114 + NF + 10\log S_R) = RSL + 93.3$$

ANNEX D: OPERATIONAL CHARACTERISTICS FOR THE EARTH EXPLORATION SATELLITE (PASSIVE) SERVICE

D.1 Operational characteristics

D.1.1 Operational characteristics of conical scan instruments

The following table D1 provides characteristics of conically scanned sensors.

Channel 23.6 – 24 GHz	MEGHA-TROPIC	EOS-AMSR-E
Channel bandwidth	400 MHz	400 MHz
Pixel size across track	35.4 km	17.6 km
Beam efficiency	96 %	97%
Incidence angle i at footprint centre	52.3°	55°
Half cone offset angle	44.5°	47.5°
Useful scan angle	130°	122°
Altitude of the satellite	817 km	705 km
Maximum antenna gain	40 dBi	46 dBi
Reflector diameter	650 mm	1.6 m
Half power antenna beamwidth θ_{3dB}	1.65°	0.9°

Table D1: Preliminary specifications for microwave radiometric applications using conically scanned sensors

The pixel size across track is computed from the –3 dB contour of the antenna pattern taking into account the satellite altitude and the incidence angle of the beam boresight.

It is important to note that this kind of EESS sensor is not a nadir satellite, but an EESS sensor having a conical scan configuration centered around the nadir direction. It is important for the interpretation of surface measurements to maintain a constant ground incidence angle along the entire scan lines. The in orbit configuration of conically scanned instruments is described in the figure D.1. The rotation speed of the instrument (and not the satellite) is w = 20 revolutions per minute (rpm) for MEGHA-TROPIC and 40 rpm for EOS AMSR-E. At its altitude, the conical scan radiometer measures the upwelling scene brightness temperatures over an angular sector (useful scan angle in Figure D.1).

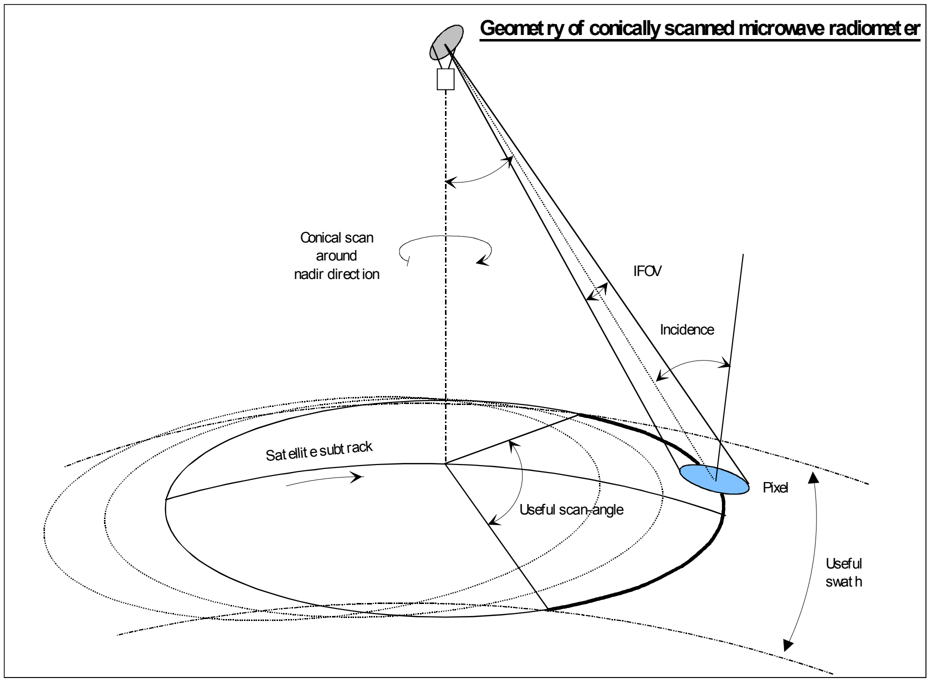


Figure D.1: Configuration of conically-scanned passive microwave radiometers

The typical geometrical parameters of this kind of instruments are the following (for an altitude of about 850 km).

- Ground incidence angle i at footprint centre: around 50°.
- EESS offset angle to the nadir or half cone angle α to the nadir direction: about 44°.
- Useful swath of about 1600 km.
- The scanning period is chosen in order to ensure full coverage and optimum integration time (radiometric resolution).

The figure D.2 shows the relative antenna gain pattern of the MEGHA-TROPIC satellite below the maximum gain.

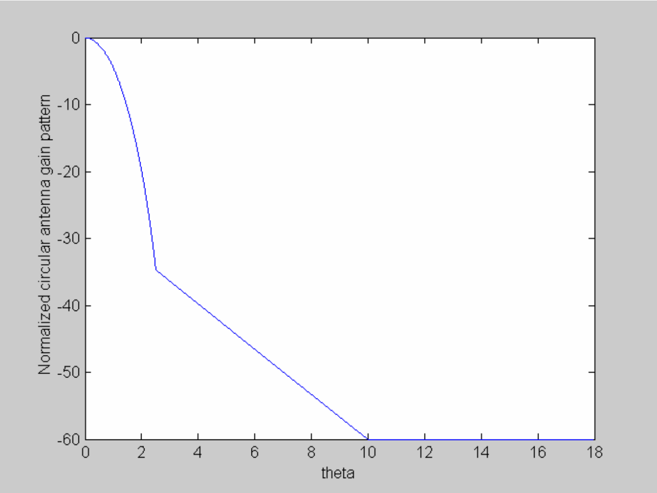


Figure D.2: Antenna gain pattern of the MEGHA-TROPIC satellite

The figure D.3 shows the relative antenna gain pattern of the EOS AMSR-E satellite below the maximum gain.

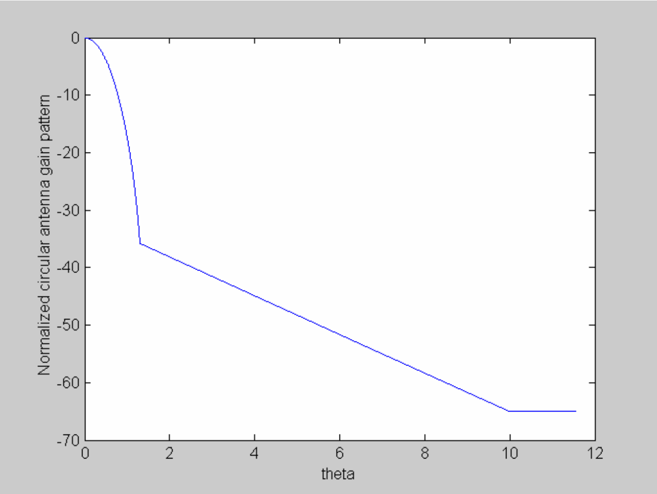


Figure D.3: Antenna gain pattern of the EOS AMSR-E satellite

D.1.2 Operational characteristics of cross-track nadir sensors

The cross-track nadir sensors retained for this analysis are the AMSU and the “push-broom”. They both scan in a vertical plane containing the nadir direction, normal to the velocity vector of the satellite.

The AMSU (Advanced Microwave Sounding Unit) is a mechanically scanned instrument, where the pixels are acquired sequentially. The cold-space calibration is implemented once per scan revolution by the main antenna, when looking in the cold space direction. The AMSU instrument contains 20 channels and is comprised of two major components, AMSU-A and AMSU-B. The 23.6-24 GHz band is contained within the AMSU-A instrument (module AMSU A2).

The « push-broom » is a purely static instrument with no moving parts, where all pixels in a scan-line are acquired simultaneously, enabling to significantly increase the integration time and the achievable radiometric resolution. The push-broom incorporates one fixed data acquisition antenna pointing in direction of nadir and one dedicated cold space calibration antenna.

The main characteristics of these sensors are given in Table D2.

Parameter	**AMSU**	**Push-broom**
Main antenna gain (dBi)	36	45
Antenna Back Lobe Gain (dBi)	-12	–12
IFOV (Instantaneous Field Of View) at -3 dB in °	3.3	1.1
Total FOV (Field Of View) cross/along-track (°)	96.66/3.3	100/1.1
Pixel size (km)	48	16
Number of pixels per line	30	90
Sensor Altitude (km)	850	850
Cold calibration antenna gain (dBi)	36	35
Cold Calibration Angle (re.satellite track)	90	90
Cold Calibration Angle (re. nadir direction)	83	83
Type of Scan	Mechanical	Electronic

Table D2: Cross-track nadir sensors characteristics

The in-orbit configurations of the AMSU and the “push-broom” sensors are described on the figures 4 and 5 respectively.

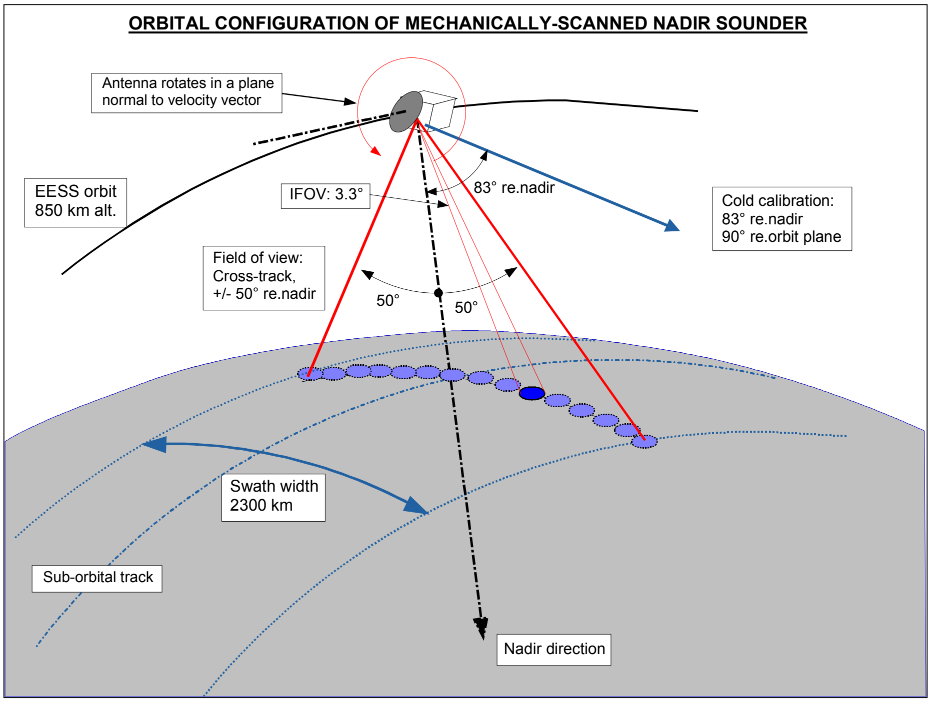


Figure D.4: Geometry of a nadir scan passive microwave radiometer

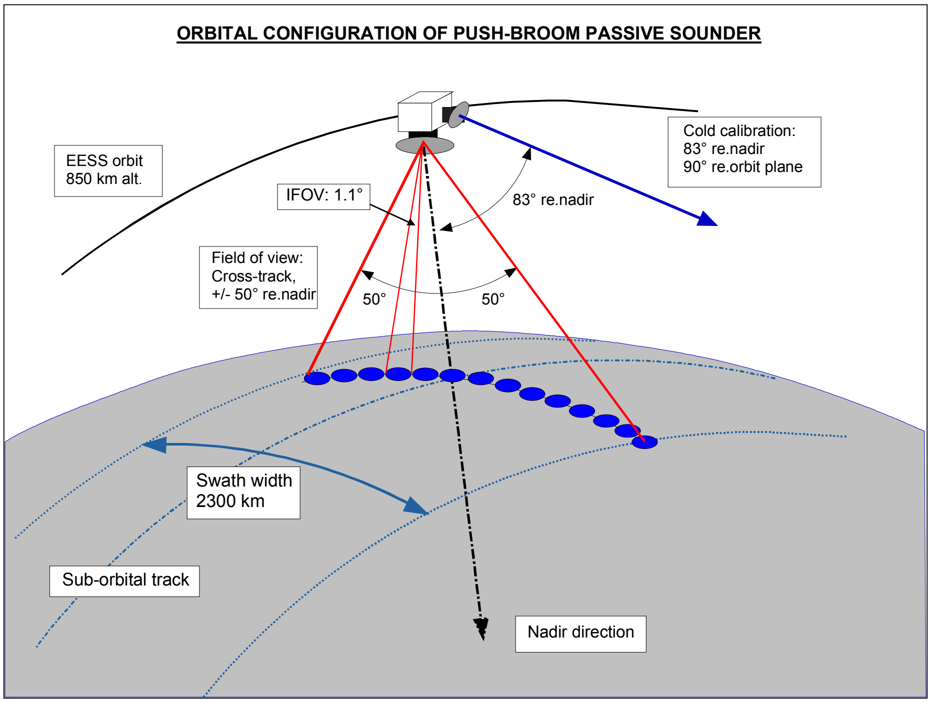


Figure D.5: Orbital configuration of the push-broom sensor