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IMPACT OF LEVEL PROBING RADARS USING ULTRA-WIDEBAND TECHNOLOGY ON RADIOCOMMUNICATIONS SERVICES

Rottach-Egern, February 2010

0 EXECUTIVE SUMMARY

This Report considers co-existence of the proposed generic Level Probing Radar (LPR) applications with various radiocommunications services operated in the LPR candidate bands or in adjacent bands, which were identified as possible victims of interference from LPR operation. The concept and technical specifications of LPR devices were communicated to CEPT with appropriate request for authorisation of use of spectrum, by ETSI SRDoc TR 102 601 [1].

LPR devices represent one of the specific applications of Ultra-Wide-Band (UWB) technology. They are professional applications to which installation and maintenance are performed by professionally trained individuals only.
LPR are used in many industries concerned with process control to measure the amount of various substances, mostly liquids or granulates. The ETSI SRDoc TR 102 601 [1] proposed that LPR are allowed to be operated in the following frequency bands:

- 6.0-8.5 GHz,
- 24.05-26.5 GHz,
- 57-64 GHz, and
- 75-85 GHz.

The evaluation of maximum interference ranges from LPR devices was carried out in section 5 using MCL deterministic approach, by applying worst-case of a single nearest LPR installation to victim receiver and related assumptions (direct LOS and main-beam coupling, Free Space Loss model, no clutter/roof/wall losses, etc).
In addition to MCL-based analysis, detailed probabilistic analysis was carried out in section 6 to evaluate the probability of interference for identified critical cases, as well as the impact of aggregation of LPR devices.

Some conservative assumptions were considered in the study, among others, the following are to note:

(A) Studies of this assumed interference from outdoor LPR installations, although they are expected to quote only 10% of market share [1]. The remaining 90% of indoor installations, benefiting of additional shielding attenuation in the range of 10 dB to 25 dB (depending on the operational frequency) were not considered. As a result, all calculated interference impacts will represent the most conservative estimates, which in many real life cases will be further reduced due to aforementioned shielding attenuation.

(B) The use of deterministic MCL simulation for terrestrial path was based on interference from a single nearest LPR installation to victim receiver. This view is justified by the fact that LPR is a fixed installation special-purpose industrial device that is normally installed at very low densities (see Table 2.1). Therefore this Report evaluated the worst-case interference range from single LPR device, i.e. the maximum impact range beyond which an LPR should not be at all discernible by the concerned victim receiver station.

(C) For the case of victim FS PP link receiver, a worst case of mutual placement was assumed with LPR installation positioned within the main beam of FS antenna leading to separation distances of up to 4 km. However the likelihood of such occurrence is extremely low given the very small beamwidth of PP FS antennas. In the side lobe case, the separation distances are of the order of 20 m.

(D) Although the ETSI SRDoc TR 102 601 [1] indicates certain market grow up to 2015 resulting in a Maximum expected LPR density per km^2 of 0.00034, in the present Report, it was agreed to use for possible interference to Earth Exploration Satellite Service a very conservative figure of two/four time folds, however still showing a good margin as final result.

The findings of this Report include the following proposals in order to ensure compatibility between LPR and incumbent radiocommunications services in subject bands:

1. LPR devices have to operate only with dedicated/integrated certified antennas, as specified in the following Table 0.1 (Column C) below,
2. LPR device (complete unit of transmitter with dedicated/integrated antenna) should comply to Mean e.i.r.p. spectral density and Peak e.i.r.p. (both within main beam), as specified in the following Table 0.1 (Columns A and B). Results of experimental tests have shown that it is impractical to perform radiated measurements on the half sphere (see §2.9), while it was shown that both radiated and conducted power measurements in the main beam of LPR are possible and thus represent the only practical solution,
3. Compliance to the main beam limit above is expected to correspond to maximum mean e.i.r.p. spectral density values emitted to the half sphere around the LPR installation (see Table 0.1, Column D) according to the present investigations in the Report.

4. Strict downwards orientation of LPR antennas is an essential installation requirement (LPR must naturally follow this rule otherwise its operational measurement sought performances cannot be achieved);,
5. Automatic Power Control (APC) with a dynamic range of about 20 dB, as proposed in the ETSI SRDoc TR 102 601 [1], is able to reduce the probability of interference and therefore APC should be considered as an essential technical requirement for license exempt regulation all considered bands.

   In addition to APC, the RAS stations (a list of presently known sites is provided in Annex 3) should be additionally protected as follows:

   a. From 0 km to 4 km radius around any RAS station, installation of LPR devices operating in 6.6 GHz, 24 GHz and 75 GHz bands should be prohibited unless a special authorisation has been provided by the responsible national administration.
   b. Between 4 to 40 km around any RAS station, the antenna height of a LPR installation should not exceed 15 m height.
6. Without the APC requirement, indoor LPR installation may be allowed on a licence-exempt basis provided they comply with the same requirement for protection of RAS stations as in clauses 5.a and 5.b above.

   For outdoor installations of LPR without APC, some additional administrative safeguards will need to be implemented in order to guarantee their interference-free operation, for example on-line site clearance and database registration as a part of a "light-licensing" regime, which would be designed to ensure the compliance with the sufficient separation distances as established by studies in this Report. A separation distance of 2 km was found to be sufficient for all the bands and for all services, except the RAS which is 4 km as outlined in clause 5.a above.

Frequency band *(Note 1)*	**Maximum Mean e.i.r.p. spectral density (dBm/MHz)** *(Notes 2 and 6)*	**Maximum peak e.i.r.p. (dBm measured in 50 MHz)** *(Notes 3 and 6)*	**Maximum antenna beamwidth, deg** *(Note 4)*	**Guidance for maximum mean e.i.r.p. spectral density on half-sphere (dBm/MHz)** *(Notes 5 and 6)*
	A	**B**	**C**	**D**
6.0-8.5 GHz	-33	+7	12	-55
24.05-26.5 GHz	-14	+26	12	-41.3
57-64 GHz	-2 (Note 7)	+35 (Note 7)	8	-41.3
75-85 GHz	-3 (Note 7)	+34 (Note 7)	8	-41.3

Table 0.1: Essential technical requirements for LPR devices

Notes:

(1) Operational frequency band for UWB emissions defined by the -20 dBc level.

(2) Mean e.i.r.p. density, within mainbeam, means the mean power measured with a 1 MHz resolution bandwidth, a root-mean-square (RMS) detector and an averaging time of 1 ms or less.

(3) Peak e.i.r.p. density, within mainbeam, means the peak level of transmission contained within a 50MHz bandwidth centred on the frequency at which the highest mean radiated power occurs. If measured in a bandwidth of x MHz, this level is to be scaled down by a factor of 20log(50/x) dB.

(4) Defined by -3 dB level. In ETSI TR102 601 [1] expressed as ± HalfBeamWidth (here as total opening angle). The antenna gain in the elevation angles above 60 degrees from the main beam direction has to fulfil a maximum value of -10 dBi.

(5) The maximum mean e.i.r.p. spectral density limits on half sphere accounts for both the LPR antenna side-lobe emissions and any reflections from the measured material/object, as illustrated in section 3.2 (Figure 3.1). Here the LPR antenna side-lobe gain was assumed as -10 dBi at elevation above 60° from the main beam and the reflection was simulated with a reflection loss of 13 dB (fine dry sand with an angle of repose of 33° in direction of the victim receiver). Compliance with these limits is expected to be fulfilled as long as LPR devices comply with measured Mean/Peak e.i.r.p. spectral density limits within main beam (Table 0.1, Columns A and B) and use the prescribed antenna (see note 4 above).

(6) The related limits in unwanted emissions domain radiated by LPR are those as listed in Table 4.1 for the LPR operating in 6.0-8.5 GHz band. For LPR operating in other bands the unwanted emissions e.i.r.p density should be at least 20 dB less than the in-band limits specified in Table 0.1 (Columns A, B and D). For LPR operating in the 24 GHz band, the unwanted emissions in the 23.6 to 24.0 GHz "passive band" should be 30 dB less than the in-band limits specified in Table 0.1 (Columns A, B and D), as additional cautionary measure in respect to RAS.

(7) Mean and peak power within the LPR main beam, operated in frequency bands 57-64 GHz and 75-85 GHz, are increased compared the values originally requested by TR 102 601 [1] in order to meet the identified operational requirements of higher power at these high frequencies, while still respecting the generally established safe equivalent maximum mean e.i.r.p. density on half-sphere (Table 0.1, Column D). For further details see sections 5.3.1, 5.4.1 and Annex 5 of the Report.

Finally is worth to note that simulations and calculations made were supported by one specific actual (field) test. This test was performed using commercial PP FS and LPR equipment in 24-26.5 GHz band, with LPR being placed at close range near to the main beam of PP FS antenna, as reported in Annex 4. These tests showed no occurrences of interference as long as LPR antenna was directed strictly downwards.

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LIST OF ABBREVIATIONS

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

APC	Adaptive Power Control
BW	Bandwidth
BWA	Broadband Wireless Access
BWCF	Bandwidth Correction Factor
CO	Continuum Observations, a type of Radio Astronomy observations
CS	Central Station (of BWA)
ECA	European Common Allocations
EESS	Earth Exploration Satellite Service
e.i.r.p.	Effective isotropically radiated power
EMF	Electromagnetic Field
FLANE	Fixed Local Area Network Extension, sub-set of MGWS, a kind of very high bit rate PP FS link
FMCW	Frequency Modulated Continuous Wave, one of LPR sensing technologies
FSL	Free Space Loss propagation model
I/N	Interference-to-Noise ratio
ITS	Intelligent Transport System
LOS	Line-Of-Sight
LPR	Level Probing Radar
MCL	Minimum Coupling Loss method
MGWS	Multiple Gigabit Wireless System, very high speed wireless application in 60 GHz range
NLOS	Non-Line-Of-Sight
PMP	Point-to-Multipoint system in Fixed Service
PP	Point-to-Point links in Fixed Service
PRF	Pulse Repetition Frequency
RA	Radio Astronomy
RAS	Radio Astronomy Service
RSU	Road Side Unit of ITS
Rx	Receiver
SEAMCAT	Spectrum Engineering Advanced Monte-Carlo modelling Tool, a software tool, see: www.seamcat.org
SLO	Spectral Line Observations, a type of Radio Astronomy observations
SPFD	Spectral Power Flux Density
SRDoc	ETSI System Reference Document, e.g. TR 102 601 for LPR applications
TLPR	Tank Level Probing Radar, a device installed inside a fully enclosed tank, a sub-set of LPR family
TS	Terminal Station (of BWA)
UWB	Ultra-Wideband technology

Impact of Level Probing Radars (LPR), using Ultra-Wideband Technology on Radiocommunications Services

1 INTRODUCTION AND BACKGROUND

The use of Tank Level Probing Radars (TLPR) for gauging level of liquids within closed metallic tanks has been well established on the market since decades. TLPR were standardised through ETSI EN 302 372 [2] and the appropriate radio spectrum access rules were established by CEPT in ERC Recommendation 70-03 [3]. Extension of the same concept and principles of unlicensed operation to a broader range of level gauging applications, i.e. not necessarily enclosed inside metallic tanks, has been proposed by ETSI as a generic Level Probing Radar (LPR) application in System Reference Document (SRDoc) TR 102 601 [1].

This Report therefore considers co-existence of the proposed generic LPR applications with various radiocommunications services that might be impacted by LPR operation. Though LPR use a similar radar sensing technology as TLPR, however due to different installation conditions that allow installation in open spaces (even though true outdoor/open installations will be but a very small portion of all LPR installations – see 2.7.) and the resulting co-existence issues, it is envisaged that LPR will call for different technical requirements in the eventual Harmonized Standard.

LPR are professional (industrial) applications to which installation and maintenance are performed by professionally trained individuals only.

Today LPRs are already used as individually coordinated installations in many industries concerned with process control to measure the amount of various substances, mostly liquids or granulates. LPR is often the preferred measurement tool in such applications for the following reasons:

- due to the requirement of having non-contact measurement means because of large level variations, aggressive substances or extreme temperature/conditions,
- since other alternative solutions (e.g. ultra-sonic or optical) are too sensitive to contamination or other process conditions,
- since metallic coating of enclosure structure is not possible (e.g. plastic or glass tanks) because of chemical reactions by aggressive substances.

The ETSI SRDoc TR 102 601 [1] proposes that LPR be operated in one or more of the following frequency bands:

- 6.0-8.5 GHz,
- 24.05-26.5 GHz,
- 57-64 GHz, and
- 75-85 GHz.

The lower band 6.0-8.5 GHz has been chosen due to the fact, that this band is already used for UWB applications (technology available) and due to gathered manufacturing experience with existing TLPR systems in the neighbouring frequency ranges 4.5-7 GHz and 8.5-10.6 GHz.

The 24 GHz band is today widely used for TLPR and therefore is attractive for possibility to re-use existing design technology and manufacturing base and materials (e. g. components, antennas).

The advantage of the 57 GHz band is the higher available bandwidth compared to the lower bands which directly translates into higher obtainable resolution. This band also provides for more efficient and compact designs thanks to lower wavelength, allowing using highly directional yet compact antennas, etc. Another special advantage with the 57 GHz band is the high atmospheric attenuation due to oxygen absorption over most of the band (in the order of 10dB/km). This should be providing for more favourable co-existence conditions.

The 75-85 GHz band is important for future developments and has similar advantages to those of the 57 GHz band.

2 LPR APPLICATIONS AND TECHNOLOGY

2.1 Typical LPR applications

Typical examples of LPR applications will include:

- Liquid level measurements inside tanks made of glass, plastic or similar “EMF transparent” materials. The walls of such tanks will provide some attenuation of radar signal (i.e. in the range of 10 dB to 25 dB depending the operational frequency), however to a lesser degree than that provided by metallic tanks in case of TLPR. Typical tanks in this application would be in the order of 5 m tall and placed at ground level in an industrial cluttered environment,
- Water/liquid pool level measurements in water processing/sewage plants, chemical plants, etc. In such applications LPR would be mounted some 1-3 m over ground level with low gain antennas and low RF output power. Typical water processing plant might contain dozens of such low power LPRs, enclosed by a typical industrial plant clutter.

  However in such rare occurrences of high concentration of LPR devices, impact to victim radiocommunications services (i.e. FS PP link) should be mitigated to a certain extent by effectual “time spreading” of interference due to fact that all LPR units work independently, i.e. not synchronised in time domain, with non-coherent emission bursts (i.e. not operating on same phase). The specifics of such very rare scenario are discussed in section 6.3 of this Report.
- Water level measurements in natural basins as rivers, lakes, by the dams. Such application would contain a possibly large number of LPR dispersed over large areas. Typically LPR would be installed 2-10 m over normal water level, often under a bridge or similar overarching structure/building,
- Piles of solid/granulate substances stored in open warehousing environment, such as coal, iron ore, wood pellets, etc. In such applications LPR would be typically mounted at some 5-30 m over ground level, but the number of LPRs would be low both per plant and over wider area due to typical remoteness of such open warehousing plants.

Typical examples of LPR installations are illustrated below in Figure 2.1.

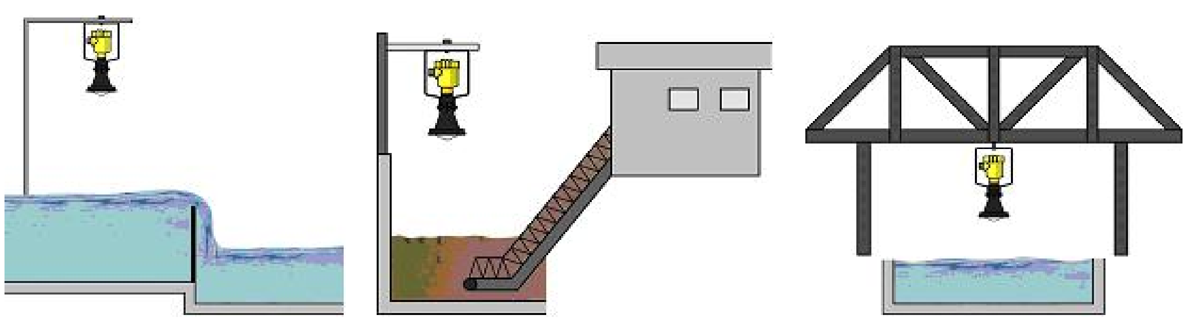

Figure 2.1: Typical examples of LPR installations [1]

It is foreseen that being a strictly professional (industrial) application, all LPRs are expected to be installed by installation requirements as follows:

- LPR are required to be installed at a permanent fixed position pointing in a downwards direction, otherwise will not achieve its operational goal of a proper and precise measurement.
- Installers have to ensure that there are no obstacles in the downwards radiating beam of the LPR to minimize unwanted reflections otherwise (once again) it will not achieved its operational goal of a proper and precise measurement.
- Installation and maintenance of the LPR equipment should be performed by professionally trained individuals only.

Equipment provider will be required to inform the users and installers of LPR equipment about the installation requirements and, if applicable, any additional special restrictions to be observed (to be clearly specified in the installation and operational manual respectively, also according to 99/5/EC (R&TTE) Directive [4]). This opens, for example, opportunity for proper regulation if necessary.

The ETSI SRDoc TR 102 601 [1] projects the number of LPR devices to reach 36000 units over Europe by 2015. Given the European area of 10.5×10^6 km^2, this translates to the average density of 0.0034 LPR devices/km^2. Anticipated split of LPR devices between different bands is given below in Table 2.1.

The numbers quoted below from ETSI SRDoc TR 102 601 [1] were derived by ETSI based on the current number of LPR devices deployed in European countries (based on manufacturer's information), which was extrapolated taking into account future market forecasts. Since TR 102 601 was developed in 2007, before onset of the current economic downturn, it might be safely considered that market forecasts made at that time should by all means represent overly optimistic forecasts that are rather unlikely to be matched in the current depressed state of industrial growth. This context should be seen as providing an additional re-assurance to the credibility of provided estimates, although even on many previous instances of developing System Reference Documents for new applications ETSI was credited with giving sufficiently reliable market estimates.

Frequency band	**% of total**	**Devices**	**Devices/km^2**
6.0-8.5 GHz	10	3600	0.00034
24.05-26.5 GHz	70	25200	0.00238
56-64 GHz	10	3600	0.00034
75-85 GHz	10	3600	0.00034
Total for all bands	100	36000	0.0034

Table 2.1: Projected number of LPR devices for different candidate bands

It may be seen from the numbers given above, that the projected average density of LPR devices will be extremely low, as provided for by their industrial type of use and specific nature of applications. This however does not exclude cases of certain plants, where multiple LPR devices could be used in near proximity. But given their very low duty cycles, even in such cases any aggregation effects may be considered unrealistic.

It should be further noted that it is expected that the majority proportion of LPRs will be actually installed indoor (e.g. inside roofed industrial areas, such as warehouses) or will have similar topping/cover reducing level of emissions outside the installation, e.g. LPR installed inside non-metal tank, providing some shielding, or other kind of overhead structures, see examples in Figure 2.2.

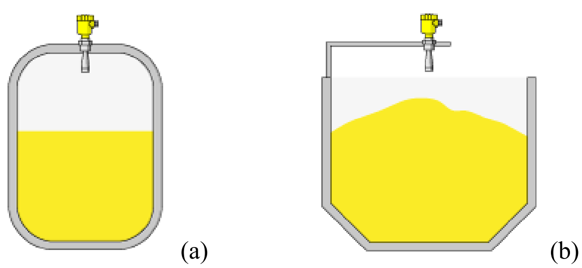

Figure 2.2: Illustration of typical LPR installations that provide natural shielding of outward emissions: (a) measurements in non-metal tanks (plastic, glass), (b) measurements of solids in bunkers

2.2 Percentage indoor/outdoor use

Less than 10 % of all LPR Installations are expected to be outdoors. In most cases the LPR equipment are used in open storage halls, bunkers with roof and in buildings.

The proposal for aggregated scenarios is as follows: 10 % outdoor, 90 % indoor with an additional wall attenuation of 10 dB at 7 GHz, 15 dB at 24 GHz, 20 dB at 57 GHz, 25 dB at 75 GHz. This may be taken into account when performing the probabilistic analysis and aggregation effects.

However, in order to implement the philosophy of worst-case critical simulations of LPR interference, no additional natural shielding was considered in MCL calculations of this Report, i.e. all MCL simulations were performed for the worst case of LPR being placed outdoor and without any natural shielding. As a result, all calculated interference impacts will represent the most conservative estimates, which in many real life cases will be further reduced due to aforementioned natural shielding.

2.3 Types of LPR

There are presently two basic radar types used in LPR applications, namely FMCW (Frequency Modulated Continuous Wave and pulsed radars.

FMCW radar sweeps its entire operational frequency range within a period of time to obtain the signal bandwidth required by the measurements. The bandwidth is 1 GHz or more and the bandwidth is inversely proportional to the precision of discriminating between received echoes. The signal reflected from the object surface will be mixed with a fraction of the transmitted signal to result in a very low “beat frequency” – the frequency difference between the transmitted and instantaneously received signal). Beat frequency corresponds to the distance between LPR antenna and surface of the observed object. The distance (and its derivative – the surface level of observed liquid/substance) is therefore obtained by measuring in LPR the frequency difference between the received and the transmitted signal.

Another type is called pulsed LPR which transmits a train of short pulses towards to the object. The distance (surface level of observed object) is obtained by measuring the time difference between the received and the transmitted pulses. The pulse width is normally 1 ns or less in order to achieve a good range resolution and the required bandwidth for such narrow pulses corresponds to the FMCW bandwidth and the need for resolution. The minimum pulse repetition frequency for pulsed LPR technology is 500 kHz.

2.4 Proposed limits for LPR technical specifications

The initially proposed essential limits for LPR technical specifications have been extracted from those proposed by ETSI SRDoc TR 102 601 [1] as shown below in Table 2.2. However it should be immediately noted that the limits given in the table represent those initially anticipated in TR 102 601 and may need to be adjusted, clarified and augmented with some additional conditions as a result of this study.

Frequency band (Note 1)	Peak e.i.r.p., dBm (Note 2)	Mean e.i.r.p., dBm (Note 3)	Maximum antenna beamwidth, deg (Note 4)
6.0-8.5 GHz	24	1	12
24.05-26.5 GHz	43	20	12
57-64 GHz	43	23	8
75-85 GHz	43	23	8

Table 2.2: ETSI TR 102 601 proposed limits for technical specifications of LPR devices

Notes:
(1) Operational frequency band for UWB emissions defined by the -20 dBc level,
(2) The peak power is derived from the measured mean power value by taking into account modulation/Duty Cycle parameters of particular type of LPR device,
(3) The mean power is determined as the conducted power measured with a true RMS power meter (e.g. bolometer, etc), under normal operating conditions. The measured value is then adjusted by adding known maximum gain of LPR antenna,
(4) Defined by -3 dB level. In TR 102 601 [1] expressed as ±HalfBeamWidth, here as total opening angle.

Some other additional requirements were proposed in TR 102 601 [1] such as Duty Cycle limit of 0.5-1% and APC – Adaptive Power Control, with typical dynamic range of 20 dB. However the worst case conservative approach, adopted throughout this Report, made to suggest that it is unnecessary to consider these secondary parameters in this study from the beginning, as these factors might effectively constitute certain mitigation.

It should be noted that the technical specifications given above are generic in a sense that they would be applicable to any LPR irrespective of its type (FMCW or pulsed).

When considering prospects for future enforcement of the eventual LPR regulations, it may be noted that the compliance with the essential limits proposed above in Table 2.2 should be very easy to check even for the kind of low power UWB devices that LPRs represent. This because when the limits are defined at the output of device they could be easily measured. For example, maximum e.i.r.p. could be evaluated by, first, determining output power with the measurement device being directly attached to waveguide output of LPR and, then, adding maximum LPR antenna gain, which could be independently verified using standard antenna testing setups (as mentioned in Note 3 under the Table 2.2).

2.5 LPR antenna example

An example of radiation pattern for horn antenna, based on source [2], which might be suitable for LPR devices, is shown below in Figure 2.3. The relationship between antenna diameter *d*, gain *G* and main lobe angle $\pm\theta_{-3dB}$, could be according to [2] expressed in the E-plane by following expressions:

$$\pm\theta_{-3dB} \approx 38° \cdot \lambda / d$$

$$\frac{G}{dB} \approx 4 + 20\log\frac{d}{\lambda} \approx 4 + 20\log\frac{38°}{\pm\theta_{-3dB}}$$

By using these equations, a set of reference antenna parameters was generated for the purpose of this study, and is given in Table 2.3 below. However it should be noted, that these parameters should be referred to only as indicative reference values, as they might not correspond precisely to the real values exhibited by practical antenna designs.

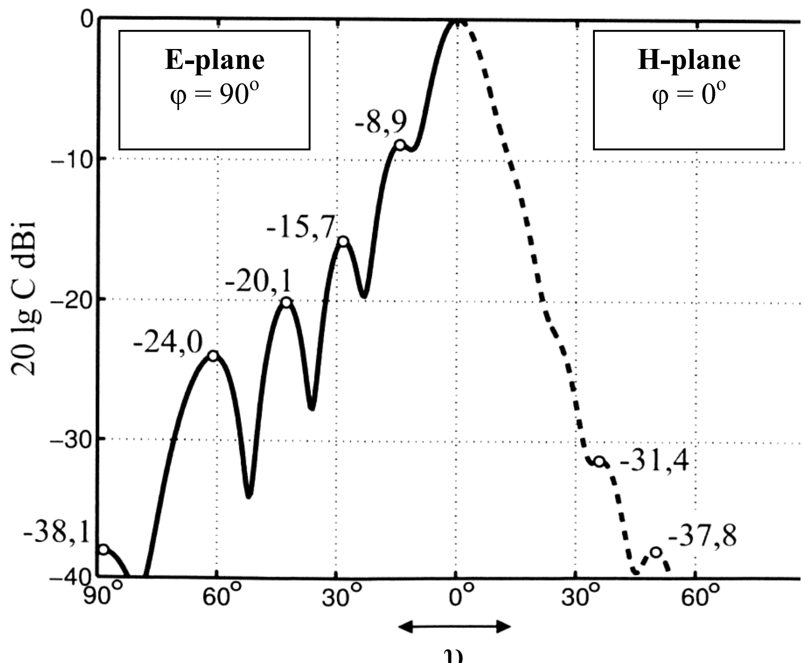

Figure 2.3: An example of radiation pattern for 23 dB gain horn antenna (-3 dB beamwidth = ± 5.3° (E-plane)) [5]

When analysing information given in Table 2.3, it should be remembered that LPR antenna's main beam will always point downwards, at normal angle to ground surface, thus LPR antenna's side-lobe angles larger than 60° shall define radiation from LPR in horizontal plane along the ground surface.

Frequency band	Antenna diameter, mm	-3dB beam width	Gain range, dBi	Side-lobe gain >60°, dBi
6.0 – 8.5 GHz	250	12°	18 - 21	-10
24.05 – 26.5 GHz	75	12°	20 - 24	-10
	100	8°	23 - 27	-10
	250	4°	31 - 33	-10
57 – 64 GHz	100	4°	34	-10
75 – 85 GHz	100	3°	30 - 35	-10

Table 2.3: Simulated reference antenna parameters

As mentioned above, the parameters given in Table 2.3 represent theoretically simulated parameters. In particular this is important for consideration of gain in side-lobes. The values of side-lobe gain quoted in Table 2.3 should be therefore understood as being only initial reference values for simulations. The eventual ETSI harmonised standard for LPR may establish requirements for side-lobe gain based on results of these studies as well as practical measurement results.

2.6 Typical LPR parameters

Some indicative typical parameters for the two types of LPR devices have been provided by industry and are given below in Tables 2.4 and 2.5.

a	**Frequency range**	**6.0-8.5 GHz**	**24.05-26.5 GHz**	**57-64 GHz**	**75-85 GHz**
b	APC	0-25dB	0-20 dB	-	-
c	Conducted peak power	-15 to 10 dBm	-10 to 10 dBm	10 dBm	10 dBm
d	Pulse width	1 ns	1.2 ns	1.2 ns	1.2 ns
e	PRF	1MHz	1.8 MHz	1.8 MHz	1.8 MHz
f	Conducted Mean PSD	-75 to -50 dBm/MHz	-66 to -46 dBm/MHz	-46 dBm/MHz	-46 dBm/MHz
g	Conducted Peak power within 50MHz	-41 to -16 dBm	-35 to -15 dBm	-15 dBm	-15 dBm
h	Antenna gain mainbeam (see Table 2.3)	18 dBi	27 dBi	29 dBi	32 dBi
i	Mean e.i.r.p. mainbeam (i=f+h)	-57 to -32 dBm/MHz	-39 to -19 dBm/MHz	Max -3 dBm	Max -3 dBm
j	Peak e.i.r.p. within 50MHz mainbeam (j=g+h)	-23 to +2 dBm	-8 to +12 dBm	Max +55 dBm	Max +55 dBm
k	Antenna gain >60° (see Table 1)	-10 dBi	-10 dBi	-10 dBi	-10 dBi
l	Mean e.i.r.p. >60° (l=f+k)	-85 to -60 dBm/MHz	-76 to -56 dBm/MHz	Max -56 dBm/MHz	Max -56 dBm/MHz
m	Peak e.i.r.p. within 50MHz >60° (m=g+k)	-51 to -26 dBm	-45 to -25 dBm	Max -25 dBm	Max -25 dBm

Table 2.4: Typical parameters for Pulsed type of LPR devices

Frequency ranges	6.0-8.5 GHz	24.05-26.5 GHz	57-64 GHz	75-85 GHz
APC	typical 0-25 dB			
Conducted carrier peak power	-15 dBm to +10 dBm			
Used bandwidth for sweep	1000-2500 MHz	1000-2450 MHz	1000-7000 MHz	1000-10000 MHz
Dwell time	Between 1-100 µs/MHz			
Conducted Peak power within 50 MHz	= conducted carrier peak power = -41 dBm to -15 dBm			
Conducted Mean PSD dBm/MHz	= conducted peak power + 10log(dwell time/1ms/MHz) = -57 to -32			
Typical antenna gain mainbeam (see Table 1)	15 dBi	20 dBi	25 dBi	29 dBi
Peak e.i.r.p. within 50MHz, mainbeam	-12 to +13 dBm	-7 to +18 dBm	-2 to +23 dBm	+2 to +27 dBm
Mean e.i.r.p. dBm/MHz, mainbeam	-42 to -17 dBm	-37 to -12 dBm	-32 to -7 dBm	-28 to -3 dBm
Antenna gain >60°	- 10 dBi	- 10 dBi	- 10 dBi	- 10 dBi
Peak e.i.r.p. within 50MHz, >60°	-37 to -12 dBm	-37 to -12 dBm	-37 to -12 dBm	-37 to -12 dBm
Mean e.i.r.p. dBm/MHz >60°	-67 to -42 dBm	-67 to -42 dBm	-67 to -42 dBm	-67 to -42 dBm

Table 2.5: Typical parameters for FMCW type of LPR devices

For FMCW systems using step-frequency waveforms, the wideband signal is formed by transmitting a sequence of discrete frequencies each having a Dwell Time (DT). The length of the total sequence is referred to as the Scan Time (ST). The Scan Time is identical to the Cycle Time in frequency hopping systems, and it is the interval between each time the transmitter is hopping back to the first frequency in the sequence.

2.7 LPR Duty Cycle and Activity Factor

The Duty Cycle and Activity Factor are the terms used to describe different activity levels of LPR devices. In this Report, these factors are defined as follows (for illustration see Figure 2.4):

- Duty Cycle (DC) – is the ratio of transmitter activity, i.e. $Tx_{on}/(Tx_{on}+Tx_{off})$, defined over one active measurement period (Notes 1, 2);
- Activity Factor (AF) – is the ratio of active measurement periods (bursts, sweeps, scans) within the overall repetitive measurement cycle, i.e. T_{meas}/T_{meas_cycle} (Note 3), sees Figure 2.4.

Note 1: DC defined here is also sometimes referred to as "DC resulting from modulation" in some sources dealing with UWB devices;
Note 2: DC is important for defining relation between mean and peak power of transmitter,
Note 3: AF defined here is also sometimes referred to as "DC resulting from user" in some sources dealing with UWB devices.

The requirements of DC/AF for unlicensed LPR devices may be therefore included in a future harmonized ETSI standard.

Further illustration of realistic transmission cycle of a Pulsed LPR system is given below in Figure 2.5.

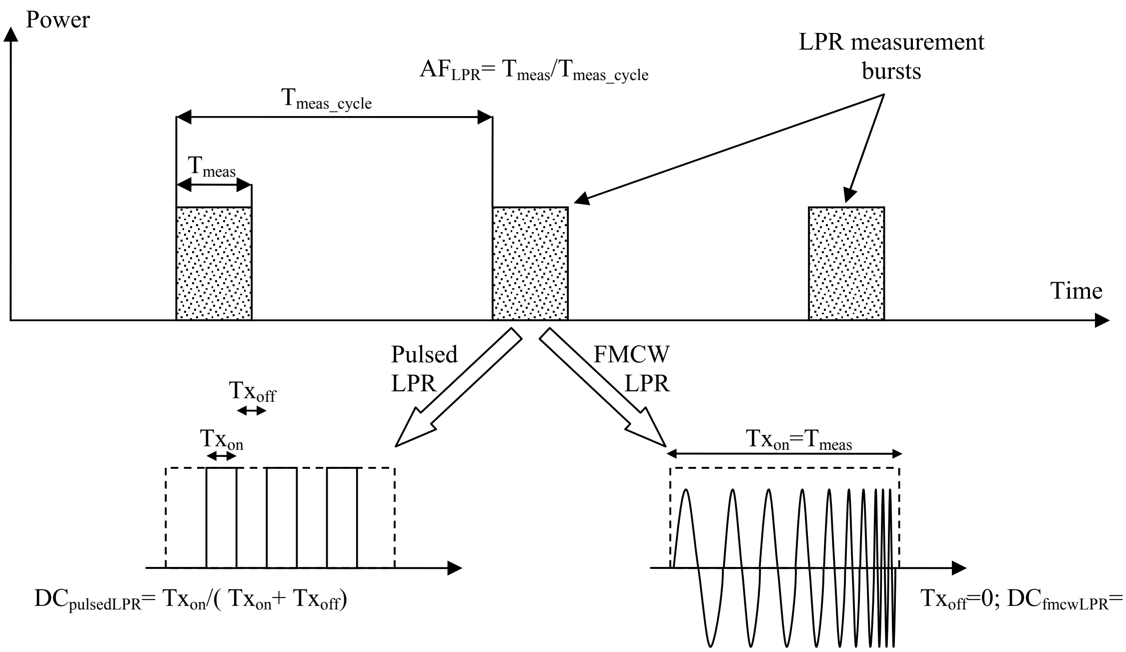

Figure 2.4: Illustration of definitions of LPR Duty Cycle and Activity Factor

It should be clear from the above definitions that DC is dependant on modulation technology employed by LPR device (i.e. differs between Pulsed LPR and FMCW LPR), whereas AF does not depend on modulation and pulse forming technology as such but rather on overall design objectives of measurement device. It is therefore used to describe overall activity of LPR emissions over longer time periods.

Examples of DC and AF values for various types of previously existing LPR devices are shown below in Table 2.6.

	Pulsed LPR	FMCW LPR
DC, %	0.05-1	100
AF, %	0.5-50	0.5-35

Table 2.6: DC/AF examples for various LPR types

It may be noted that the choice of AF for Pulsed/FMCW LPR is often determined depending on power supply restrictions.

Some applications are severely restricted in power supply consumption and have to use smaller AF values. When power supply is not an issue the AF may run up to 35-50%.

The following Figure 2.5 shows a further realistic example of pulse train sequencing for Pulsed LPR application.

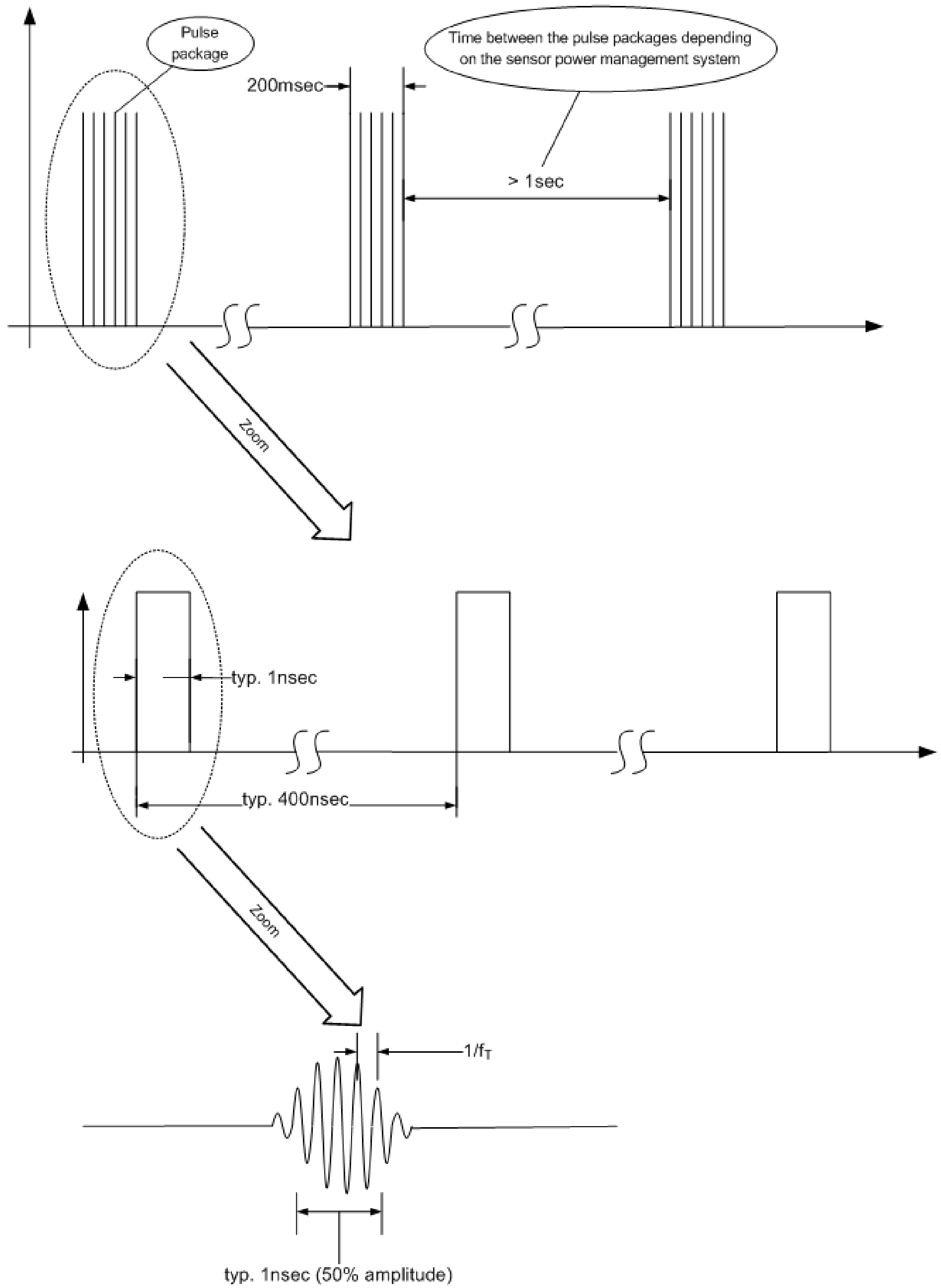

Figure 2.5: Real example of activity cycles of Pulsed LPR

Figure 2.5 shows a particular example of a Pulsed LPR system with AF=17% (200 ms measurement burst with a measurement cycle of 1.2 s) and DC=0.25% (1 ns burst to 400ns single measurement period).

2.8 Height of LPR installation above ground

Based on current experience on the market and some forecasted market trends for various types of LPR uses, it is anticipated that 90% of all outdoor LPR applications are installed 2.0 m to 15.0 m above ground, and remaining 10% are installed 15 m to 50 m above ground.

It is therefore proposed to use the above estimates for aggregated scenarios.

2.9 Practical measurements on LPR

Practical measurements with real LPR equipment were carried out in two phases in order to obtain a better understanding of operational circumstances and emanating emissions from LPR devices as well as gain some first hand experience with performing the controlling measurements on LPR.

The first set of measurements was carried out at BNetzA test facilities at Kolberg, Germany (testlab of the Federal Network Agency), on 8-9 April 2009. LPR equipments under test, operating in 6.0-8.5 GHz and 24.05-26.5 GHz, were provided by LPR manufacturing companies. The initial tests attempted to use a typical setup with measuring antenna installed at 3 m off the downward looking LPR device, see Figure 2.6. Later the distance was reduced down to 0.2 m trying to achieve better measurements.

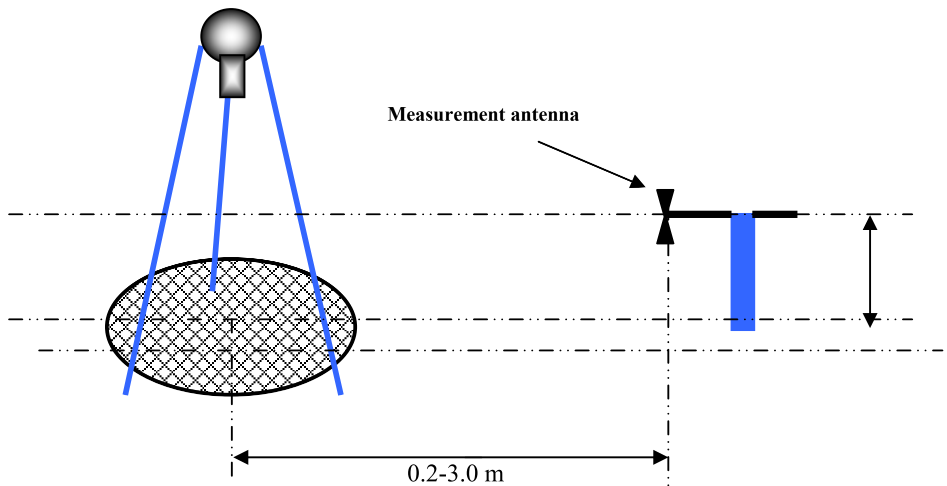

Figure 2.6: Initial setup for LPR measurements

The tests however revealed that the initial setup shown in Figure 2.3 was not practical as the emanating LPR emissions measured at 3 m from LPR were below or very close to the sensitivity levels of state of art measuring equipment. Even with a distance of 0.2 m the signal was approaching the noise floor of state of the art test equipment (for a case with absorbing foam on the floor). When a metal target was placed in stead of the foam, some signals were detected as reflections from edges of the target. Only in the lowest range (6.0-8.5 GHz) was it possible at all to discern the LPR emissions properly, however the signal-to-noise ratio was very low.

One important conclusion could be therefore made from the first testing phase, namely that the concept of "half-sphere" around LPR device (originally proposed in TR 102 601 [1]with the very purpose of aiding practical on-site controlling measurements) was not fulfilling its objectives as the only meaningful measurements of LPR emissions could be carried only with the measuring device placed directly in the main beam of LPR antenna. Based on that observation, the further analysis in this Report has disregarded the concept of "half-sphere" and treated LPR as a normal emitter having certain output power and specific radiation pattern defined by its antenna.

Another important observation from initial tests was that scattering of identified emissions was mainly caused by edges of surfaces illuminated by LPR, not the in-beam surface itself. This suggests recommending that strict vertical downward alignment of LPR antennas should be seen of primary importance to reducing "spill-over" reflections of LPR emissions from illuminated edges of the monitored surface (e.g. edges of water tank, etc).

After the above reported first round of testing where inadequateness of the "half-sphere" measurements was shown, a second round of measurements was carried out at the same Kolberg facility on 29-30 June 2009. This was done in order to establish the alternative approaches to practical measurements of LPR devices.

Having performed measurements of several provided real samples of LPR devices, this measurement campaign reached the following results.

- It was confirmed that it is possible and practical to perform both radiated and conducted power measurements in the main beam of LPR only.
- Practical recommendations were made with regards to measurement of peak powers.
- Several examples of practical measurement set-ups were provided.

- It was confirmed that it is possible and practical to measure radiation patterns of antennae for LPR.

According to these findings, this Report further considered developing recommendations of power limits and limits on antenna radiation pattern. The limits on the antenna pattern are needed in order to reduce the spill-over" reflections of LPR emissions at the edges of the monitored surface.

3 VICTIM SERVICES AND INTERFERENCE SCENARIOS

3.1 Victim services for different frequency bands

European Common Allocations (ECA) table in ERC Report 025 [6] defines a very broad range of primary and secondary allocations to various radiocommunications services in all candidate LPR bands. In order to limit the amount of addressed co-existence considerations to a practical degree, and not repeat some of the work done previously, it was proposed to limit these studies for this frequency range to the following list of representative victim applications:

Band 6.0-8.5 GHz:

- Point-to-Point (PP) fixed links (civil and military systems),
- Satellite links (space-to-Earth, 7250-8400 MHz, including military systems),
- Radio Astronomy – Spectral line observations (6650-6675.2 MHz, RR 5.149),
- Military radars (terrestrial and airborne) in adjacent band 8.5-10 GHz.

Band 24.05-26.5 GHz:

- PP fixed links (civil and military systems),
- Point-to-Multipoint (PMP) Broadband Wireless Access (BWA) systems:
  - Central Stations,
  - Terminal Stations,
- Passive Earth Exploration Satellite Service (EESS passive) in adjacent band 23.6-24.0 GHz (RR 5.340),
- Radio Astronomy Service observations in adjacent band 23.6-24.0 GHz (RR 5.340).

Band 57-64 GHz:

- PP fixed links in 57-59 GHz, with chosen critical example of broadband Multiple Gigabit Wireless System / Fixed Local Area Network Extension (MGWS/FLANE) application, which have channel bandwidths up to 2.5 GHz,
- Radars in 59-63 GHz,
- EESS (passive) in 57-59.3 GHz,
- Road Side Unit (RSU) of Intelligent Transport Systems (ITS) in 63-64 GHz.

Band 75-85 GHz:

- PP fixed links,
- Radio Astronomy Service , in certain segments of 76-92 GHz (RR 5.149 and RR 5.340),
- EESS (passive) in adjacent band 86-92 GHz.

The above list corresponds to the critical victim services or applications identified in their respective frequency ranges in prior co-existence studies:

- generic UWB applications below 10.6 GHz, ECC Report 064 [7],
- Automotive Short Range Radars at 24 GHz, ECC Report 023 [8],
- MGWS applications in 57-66 GHz, ECC Report 114 [9],
- Intelligent Transport Systems in 63-64 GHz, ECC Report 113 [10],

- Fixed Service in 71-76 GHz and 81-86 GHz, ECC Report 124 [11].

When considering the range of identified above victim services, it may be suggested to divide the possible interference scenarios into two broad categories:

- Interference over terrestrial paths,
- Interference to EESS (passive) satellite receivers.

3.2 Terrestrial interference scenario

Scenario when interference signal propagates along terrestrial path will be most typical case. It will be relevant when evaluating co-existence of LPR devices with these victim services as:

- Fixed Service links (PP and BWA),
- FSS Earth Station receivers,
- Radio Astronomy Service.

In such case, LPR installation might be having impact on the victim stations through emissions emanating in horizontal plane along the Earth surface. The studies in this Report have considered two equally important components of such radiation – emissions from LPR antenna side lobes as well as a power of signal reflected from measured surface. As the resulting interfering signal is obtained by power summation of these two components, see Figure 3.1, it is important that both these components are expressed by worst case estimates.

It may be therefore suggested that the reasonable worst case interference scenario for this case might be described as LPR installed in open air environment over a slope of a pile of solid bulk material, such as sand.

There is a wide variety of bulk materials but only a few of them could be normally stored outdoors for the reasons of needing to protect from weather influences, i.e. to prevent deterioration on purity and dryness.

Another important factor to consider here is the granularity of the solid bulk material. When the material is sufficiently fine to form a flat and smooth reflective surface (compared to the wavelength of radar), then LPR's antenna beam is reflected without scattering and will retain its original directivity shape.

When the material is coarser and forms uneven reflective surface (on the scale of the radar wavelength), the reflection will be scattered to a large degree resulting in broadly dispersed signal and low reflection. Reflection level of radar signals is dependent on dielectric constant and electromagnetic conductivity.

A close look at a wide range of outdoor bulk products leads to the conclusion that dry fine sand could be the worst case material for the applications. It has a fine granular structure and being in effect the mixture of sand granules and air, the effective composite dielectric constant of 2.38. Materials with better reflectivity have much coarser granularity, leading to aforementioned case of uneven reflective surfaces.

An important characteristic of fine material heaps is that they all have a certain maximum angle of repose. For fine dry sand this is 33 degrees. When wet sand is heaped, it could show larger angles of repose but also the shape gets much coarser which leads to scattering and lower e.i.r.p. of the reflections. Measurements on fine dry sand show a reflection loss of about 13-14.5 dB, which is largely independent on angle of incidence[1], as shown in Annex 2.

The configuration of such considered worst case of interference along terrestrial path is illustrated below in Figure 3.1. It shows that both the reflected and side-lobe components of emissions escaping from LPR are taken into account by first calculating them separately and then performing power summation.

[1] An exception is incidence of a parallel polarized wave along or close to the Brewster angle for which most of the signal is transmitted into the material (i.e. more reflection loss and not worst case).

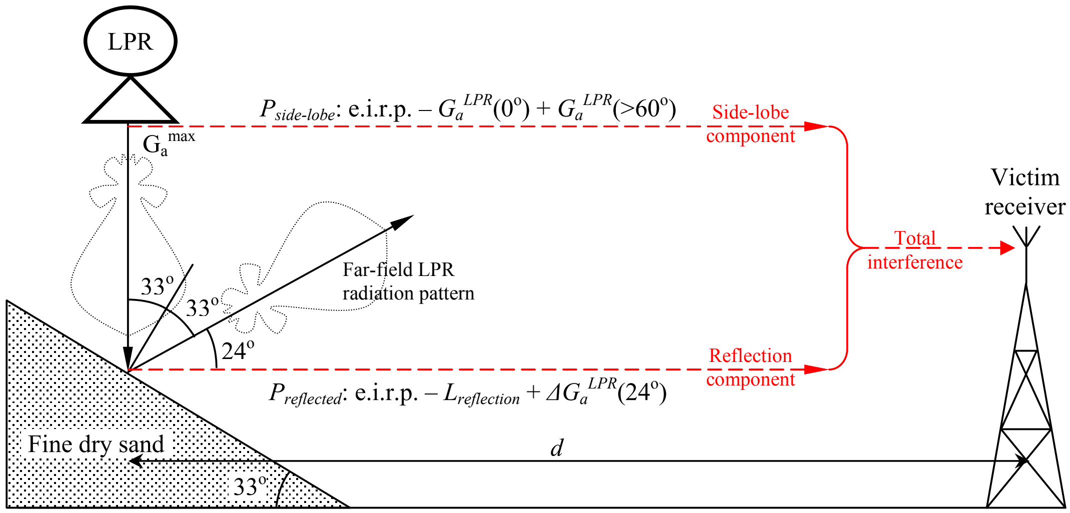

Figure 3.1: Configuration of considered worst case of LPR interference along terrestrial (horizontal) paths

Note that in this case a large portion of emitted signal energy may be reflected outside of the LPR operational area. Therefore APC may not be relied upon to detect the reflection correctly and limit the output power. As a result, the effect of APC should be disregarded in this worst case, which represents another very pessimistic assumption as it discounts APC as mitigation technique in the MCL calculations.

In this connection it may be reminded, that the APC mechanism proposed for LPR would function as any traditional power control mechanism, i.e. the receiver evaluating the strength of received signal and if it exceeds a certain threshold, the output power being reduced in steps until either the received signal drops below the threshold or the dynamic range of power control mechanism has been exhausted (20 dB foreseen for ETSI SRDoc TR 102 601 [1]). The impact of APC as interference mitigating factor may be considered as part of statistical simulations.

Note also that for initial worst case simulations it would be reasonable to assume direct Line-of-Sight (LOS) coupling between LPR reflected beam and victim station. This means that Free Space Loss model could be applied to model propagation of interfering signal over flat Earth path. This, in turn, makes it unnecessary to consider heights of interferer's reflecting point and victim station's antenna. However, this initial simplification should be later re-evaluated in the light of calculated interference range.

For example, if calculated interference distance for a given co-existence case would be clearly exceeding estimated radio horizon, this would clearly mean Non-LOS propagation conditions leading to requirement to apply different propagation model and unavoidable reduction of actual interference range.

3.3 Scenario of interference to satellite receivers

In case of interference to satellite receivers, the relevant radiation direction would be in vertical plane above LPR, and the worst conceivable case could be described as open air LPR installation over calm (ripple-free) water surface. Calm water surface would produce non-scattered reflection with a very low reflection loss. In this case, the studies reported in this Report will consider both the direct radiation component from LPR antenna's back-lobe as well as LPR signal reflected from illuminated surface at a right angle to Earth, i.e. in vertical plane towards zenith, see Figure 3.2 below.

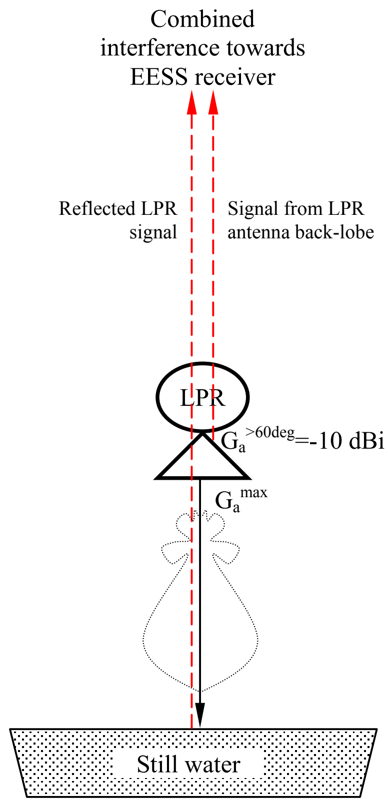

Figure 3.2: Configuration of considered worst case of LPR interference towards satellite receivers

Note that in this case, it is important whether LPR installations are installed indoors or have any other similar over-structure blocking direct path towards sky. Therefore calculations shall assume that 90% of all LPRs are actually installed indoors (see section 2.7) and they will be apportioned appropriate building attenuation: 15 dB at 24 GHz, 20 dB at 57 GHz and 25 dB at 75 GHz.

3.4 MCL-based calculation method for terrestrial paths

As a departing point, it may be considered that primary interference mechanism over terrestrial paths will be interference from single nearest LPR installation to victim receiver. This view is justified by the fact that LPRs the special-purpose industrial devices that will be normally installed at very low densities (see Table 2.1). Therefore this Report will first use MCL-based methods to evaluate the worst-case interference range from single LPR device, i.e. the maximum impact range beyond which an LPR should not be at all discernible by the concerned victim receiver station.

If then the obtained interference ranges will be sufficiently large to warrant consideration of aggregation effects from multiple LPR devices, this aggregated impact may be considered through second part of co-existence studies so that the present Report could be completed.

In order to evaluate maximum interference range of single LPR device to particular victim receiver, this Report uses the methodology proposed in §6.3.3.2 of ECC Report 064 [7]. This methodology applies MCL-based principles for calculating compliance with I/N criteria. Using I/N criteria has a distinct advantage that there is no need to consider entire victim system for calculating useful received carrier signal (which would be necessary if using C/I-based methods). When using I/N criteria, it is sufficient to consider just the fundamental parameters of victim receiver, such as reference bandwidth and noise figure/temperature, whereas interfering signal could be considered as component degrading the noise floor level of victim receiver.

The method described in ECC Report 064 importantly considers specifics of impact from UWB emissions by making distinction between dithered and non-dithered UWB emissions and taking into account Pulse Repetition Frequency (PRF) of interfering UWB device. Prior to being used in ECC Report 064, the same method was employed in UWB co-existence studies in the U.S. and Canada.

This study applies the method by following steps:

Step 1: Evaluation of noise floor and I/N interference threshold of victim receiver

Evaluation of noise floor is done by applying the following expressions, derived from fundamental equation of thermal noise:

- When victim receiver's noise is defined through noise figure:

$$N_{Rx}[dBm] = -113.83 + 10 \cdot \lg\left(BW\ [MHz]\right) + NF[dB],$$

- When victim receiver's noise is defined through system noise temperature:

$$N_{Rx}[dBm] = -138.6 + 10 \cdot \lg\left(BW_{Rx}[MHz]\right) + 10 \cdot \lg(T_S[^O K]).$$

The interference threshold is then obtained by referring to I/N objective. Expressed as power level at victim receiver antenna:

$$I_{MAX}[dBm] = N + I/N - G_a^{Rx} + L_{feeder},$$

where:

- G_a^{Rx} – gain of victim receiver antenna, dBi, in the direction of interferer,
- L_{feeder} – feeder losses, dB.

Step 2: Evaluation of MCL

Minimum Coupling Loss is evaluated as path loss isolation that is necessary to shunt interfering signal to below interference threshold identified in step 1. This condition may be expressed as follows:

$$MCL = e.i.r.p._{mean}^{LPR \to Victim} - I_{MAX} + BWCF_{mean},$$

where:

- $e.i.r.p._{mean}^{LPR \to Victim}$ – mean e.i.r.p. of LPR interferer in the direction of victim. Given that TR 102 601 [1] specifies maximum e.i.r.p., rather than output power and maximum antenna gain, and noting the developed worst case reference interference scenario (see Figure 3.1) this composite parameter could be expressed by using relative discrimination of antenna gain between main beam and the direction towards victim as well as taking into account a relevant reflection loss:

$$e.i.r.p._{mean}^{LPR \to Victim} = e.i.r.p._{mean}^{LPR} - L_{reflection} + \Delta G_a^{LPR \to Victim}$$

- $BWCF_{mean}$ – bandwidth correction factor expressed for mean power of LPR's UWB emission as conditional function of its PRF as follows[2]:

$$BWCF_{mean} = \begin{cases} 10 \cdot \lg\left(PRF / BW_{LPR}\right), \text{when } BW_{Victim} \le PRF \text{ and } BW_{LPR} \ge PRF, \\ 10 \cdot \lg\left(BW_{victim} / BW_{LPR}\right), \text{when } BW_{Victim} > PRF \text{ and } BW_{LPR} \ge PRF. \end{cases}$$

Step 3: Evaluation of interference range

The final evaluation of interference range is done by solving the inverted Free Space path loss model for previously obtained MCL value:

$$d_{\max}[km] = 10^{\frac{MCL - 32.44 - 20 \cdot \lg\left(F[MHz]\right)}{20}}.$$

The above formulas had been programmed into an Excel spreadsheet and used for MCL-based calculations referred later in this Report. The relevant Excel file with a copy of the used spreadsheet is attached to this Report for possible reference.

[2] ECC Report 064 (§6.3.3.2) gives two more cases for calculating $BWCF_{average}$, which are not reproduced here as being not relevant to the case of LPR (they address cases when $PRF > BW_{UWB}$).

3.5 Calculation of interference to EESS (passive) satellite sensors

The purpose of the analysis is to compute the amount of radiated energy reached at the satellite passive sensor. This energy is composed of two components which are added:

$$E = E_d + E_s \quad (1)$$

where:

- E_d = energy directly radiated by the LPR. However, due to the fact that the LPR is looking downwards, the radiated energy is derived from the side-lobe of the LPR. Therefore, it is necessary to take into account the value of the value of the antenna back-lobe.
- E_s = scattered energy derives from the reflection of the direct LPR waveform (main beam) according to the formula:

$$Scattered\_energy = \frac{P_t G_t}{4\pi D^2}\frac{\sigma}{Losses} \quad (2)$$

where:

P_t is the transmit power of the transmitter

G_t is the antenna gain of the transmitter (main beam),

D= distance LPR-tank,

σ = radar cross section seen by the main beam of the LPR,

Losses= additional losses within the transmitter (5 dB in the LPR case).

In many cases (for example the SRR at 24 GHz), this scattered energy is substantially higher than the e.i.r.p. directly radiated to the satellite through the side-lobes.

Radar cross section is the measure of a target's ability to reflect radar signals in the direction of the radar receiver, i.e. it is a measure of the ratio of backscatter power in the direction of the radar (from the target) to the power density that is intercepted by the target. σ is the area of an ideal "mirror" that reflects that amount of power back to the source.

For the case of a flat plate which is a case representative for LPR:

$$\sigma = 4\pi\left(\frac{ab}{\lambda}\right)^2 \quad (3)$$

where:

a and *b* represent the width and the length of the flat plate. This formula holds true if the target is perpendicular to the direction of the wave of the radar.

Within the ETSI SRDoc TR 102 601 [1], it is explicitly stated that:
"*The radar equation for LPR is quite different from the classic radar equation in that the large reflecting surface exhibits increased radar reflection at large distances (h) giving a distance dependence of h^{-2} rather than the h^{-4} in the classic radar equation. This can simply be described as follows in the case of a flat liquid surface (or a flat solid surface).*"

$$P_R = P_T L^2 \left(\frac{G\lambda\rho}{8\pi h}\right)^2 \quad (4)$$

where:

P_T = transmit power of the radar,
h = distance between the radar and the target,
G = antenna gain of the radar,
L = losses = -5 dB
ρ = dielectric reflection factor as a function of ε which is the relative dielectric constant of the target material. We have:

$$\rho = \frac{\sqrt{\varepsilon}-1}{\sqrt{\varepsilon}+1} \quad (5)$$

where:

ε ranges from 1.6 to 80 for liquids, which means that ρ varies from 0.1 to 0.8.

According to information provided by manufacturers (see Annex 2), for the purpose of this calculation one may take ρ = 0.8 (ε = 80) = -0.95 dB. This is a worst case material (valid for normal incidence only) for liquids. For sand material, the appropriate value is ρ = -6.5 dB.

However, for the purpose of the compatibility analysis, it is necessary to compute the amount of energy reached at the satellite passive sensor. Equation (4) provides the amount of energy reached at the radar receiver after the antenna. Therefore, in order to get the energy radiated after the reflection of the incident wave on board the satellite, it is necessary to take out the receiver radar antenna gain within (4), to subtract the path loss between the target and the radar, and to add the path loss between the target and the satellite sensor.

Therefore, the computation of the energy at the antenna port of the satellite passive sensor may be expressed as follows:

$$E_s = P_T L^2 \left(\frac{G\lambda\rho}{8\pi h}\right)^2 \frac{1}{G}\left(\frac{4\pi h}{\lambda}\right)^2 \left(\frac{\lambda}{4\pi d}\right)^2 = GP_T L^2 \left(\frac{\lambda\rho}{8\pi d}\right)^2 = eirp.L^2.\left(\frac{\lambda\rho}{8\pi d}\right)^2 \qquad (6)$$

where:

d is the distance between the target and the satellite, e.i.r.p. is the LPR's e.i.r.p.

Note that due to the fact that equation (4) had a dependence of h^{-2}, the distance *h* between the LPR radar and the target (i.e. height of LPR installation over measured surface) cancels itself out in composite equation and does not appear in final expression (6).

3.6 Radio Astronomy Service related considerations

In CEPT, the RA stations are located in rural or sub-urban areas, where the existence of e.g. water canals, lakes, dams or grains deposits are the ideal potential places to install LPR devices.

During an observation, a radio astronomy telescope points towards an astronomical radio source with a specific azimuth and elevation at a certain moment in time. The pointing direction of the telescope is continuously adjusted to compensate for the rotation of the Earth. The direction of the antenna includes low elevation angles.

However, for generic theoretical studies the Recommendation Rec. ITU-R RA.769 [12] assumes that the interference is received in a sidelobe of the antenna pattern, i.e. at a level of 0 dBi at 19º from boresight (see also Recommendation ITU-R SA.509 [13]).

The probability of LPR interference to RAS stations may not be excluded, considering the previous studies as presented in section 4.1.2.1 of ECC Report 023 [8] and the possibility that LPR installations are installed outdoor at heights ranging from 2.0 m to 15.0 m for 90% of installations with the remaining 10% ranging from 15 m to 50 m.. Especially the LPR installations at height above 15 m might represent a risk for RAS, but thanks to low percentage of such installation cases, at the very end the probability of them being positioned next to RAS stations is really low. Nevertheless, the studies presented in this Report used the Free Space path loss model which represents the most critical case, regardless of actual height of LPR installation.

Figure 3.3: Radio Astronomy telescope at low elevations
(note the surrounding low profile vegetation)

The findings for the protection of radio astronomy may be summarised as follows:

- 6.6 GHz: the Rec. ITU-R RA.769 [12] limit for spectral line observation is fulfilled with the proposed limit (-55 dBm/MHz e.i.r.p. on the sphere) in a distance of more then 3.5 km (see Table 5.1); this is considered although the 6.6 GHz band is not mentioned in current Rec. ITU-R RA.769-2; the limit was extrapolated from the 4.83 GHz limits for spectral line observation.
- 23.6-24.0 GHz: the Rec. ITU-R RA.769 [12] limit for continuum observation is fulfilled with the proposed limit (-41-20=-61 dBm/MHz e.i.r.p. on the sphere) in a distance of more then 3.5 km (see Table 5.4);
- based on the above assumptions and applying the worst case MCL calculations as described in section 5 of this Report, there seems to be an agreement for a exclusion zone of about 4 km around all RAS stations, even for the license exempt option with APC.

For the above mentioned reasons, LPR installations outside the exclusion zone of 4 km can just have a harmful impact on RAS if LPR were to appear in the main beam of RAS antenna, because the protection criteria of Rec. ITU-R RA.769 are assuming a RAS antenna gain of 0 dBi. However, the practical risk of such cases (assuming the protection area of 4 km around the RAS installations) would be low considering that:

- the RAS main beam direction is not fixed,
- the LPR emission can be assumed to be time variant (e.g. due to reflections on changing material and due to APC);
- seen LPR will be operated in the near field of the RAS telescope.

Based on these observations, the findings of this Report were formulated with the requirement of 4 km protection area around RAS installations in mind. This would provide the necessary precautionary measure to avoid interference from LPR into RAS, and would also reduce the risk of high mounted LPR devices appearing within main beam of RAS antennas.

As an additional precautionary measure in the 23.6-24.0 GHz RAS band, the LPR Out Of Band emissions within this band may be further reduced by 30 dB compared to the main beam e.i.r.p.

4 RESULTS OF COMPARATIVE ANALYSIS

In order to set the stage for detailed analysis of LPR co-existence with radiocommunication services, first a simple preliminary comparison between existing ECC studies and regulations in one hand and LPR parameters and values on the other hand was made. . In particular, such analysis could be helpful in order to derive Unwanted Emissions (in previous studies also referred to as Out-Of-Band emissions) limits for LPR devices, based on similar requirements previously derived for generic UWB and some other kinds of UWB-based applications.

4.1 LPR 6.0-8.5 GHz operations and unwanted emissions in adjacent bands

To evaluate requirements applicable to LPR operations in band 6.0-8.5 GHz, it was considered ECC Report 123 [14] which investigated all bands below 10.6 GHz.

A simple comparison of existing UWB regulations and existing studies are provided in the following:

- **Generic UWB**: the max limit of -41 dBm/MHz e.i.r.p. from ECC/DEC/(06)04 [15] is not applicable to LPR, because this ECC Decision is not applicable to *'devices and infrastructure used at a fixed outdoor location or connected to a fixed outdoor antenna'* (decides 3a of ECC/DEC/(06)04 revised July 2007). A detailed analysis to this can be found in CEPT Report 009.
- **Generic UWB, road and rail vehicles**: ECC/DEC/(06)04 allows the usage of UWB installations within cars with max -41 plus TPC (12dB dynamic) or low duty cycle or -53 (see a detailed analysis in Annex 2 of CEPT Report 017 [16])
- **BMA/ODC**: amended ECC/DEC/(07)01 [17] allows a limit for BMA of -50 dBm/MHz e.i.r.p. and -55 dBm/MHz total radiated power. In addition movement detector + wall contact are regulated too. For Material sensing devices (ODC) power limit is -50 dBm/MHz e.i.r.p.. In addition integrated on the tool + running sensors and wall contact (application B) are regulated too.
- **Fixed outdoor**: In **Document TG3#23_21-A4** the results of studies of ECC TG3 in relation to generic UWB fixed outdoor installation are contained. Although it is mentioned that a maximum mean e.i.r.p. densities of —55 dBm/MHz in the band 6 – 8.5 GHz would protect the FS P-P against interference from fixed outdoor generic UWB installations, ECC TG3 has concluded to maintain the prohibition of fixed outdoor installations within the generic framework of UWB.

The limits for unwanted emissions from LPR operated in 6.0-8.5 GHz band are determined as shown below in Table 4.1.

Frequency range	Max. e.i.r.p. unwanted emission density limit, dBm/MHz (on half sphere)	Max. e.i.r.p. unwanted emission density limit, dBm/MHz (in the antenna mainbeam) (Note)
Below 1.73 GHz	-85	-63
1.73-2.7 GHz	-80	-58
2.7-5 GHz	-70	-48
5-6 GHz	-65	-43
8.5-10.6 GHz	-65	-43
Above 10.6 GHz	-85	-63

Table 4.1: Limits of unwanted emissions for LPR operated in 6.0-8.5 GHz band

Note: these values are based on the limits on the half sphere with a typical LPR antenna pattern.

4.2 LPR 24.05-26.5 GHz in-band operations

References

- ECC Report 023 [8]: impact of UWB SRR on RAS, EESS and FS
- ECC/DEC/(04)10 [18] permits in this frequency range -41 dBm/ MHz as Short Range Radars (but time limited until 2013 and also with a limited penetration of 7% for automotive SRR).
- the studies of ITU-R Report SM.2057 [19] and ITU-R Recommendation SM.1757 [20].

Radioastronomy 23.6-24.0 GHz

The following table shows results of Recommendation Rec. ITU-R SM.1757 [20] and Report ITU-R SM.2057 [19]:

Service/ Applications	Frequency bands	Victim station characteristics	Protection criteria used in study	Interference scenario	UWB e.i.r.p. density (dBm/MHz)	Comments
RAS Continuum observations (broadband)	23.6-24.0 GHz	Single-dish Antenna gain = 0 dBi	Rec. ITU-R RA.769	Aggregate, (100 active SRR/km^2) (Note 1)	−109.2	(Note 2)
RAS Continuum observations (broadband)	~79 GHz	Single-dish Antenna gain = 0 dBi	Rec. ITU-R RA.769	Aggregate, (100 active SRR/km^2) (Note 1)	−97.4	(Note 2)
NOTE 1 – Analyses used the summation methodology (R_1 = 30 m R_o = 500 km), path loss calculated with Recommendation ITU-R P.452 with a percentage of time of 10%, and 2% fraction of data loss due to interference.						
NOTE 2 – Results assume all devices using UWB technology to be active simultaneously.						

Table 4.2: Results of Recommendation ITU-R SM.1757 and Report ITU-R SM.2057 for the Radioastronomy in the band 23.6-24.0 GHz

The aggregated scenario of LPR seems to be neglect table compared to the SRR assumptions of Report ITU-R SM.2057:

- LPR has a average active density at 24GHz of 0.00238/km² (100 / 0.0024 = 46dB).

The worst case of one active LPR installed next to a RA station would be imaginable, but seems to be unrealistic given that RA stations usually have a de-facto certain protective area around them (quiet zone) where no industrial activities and radio transmitting devices are expected.

ECC/DEC/(04)10 [18] defines a limit of less then -74 dBm/MHz e.i.r.p. as criterion for SRR without the need for a automatic deactivation.

Fixed Service 21-23.6 GHz, 24.25-29.5 GHz

The following table shows the results of ITU-R SM.1757 [20] and ITU-R SM.2057 [19]:

Service/ applications	Frequency bands	Victim station characteristics	Protection criteria used in study	Interference scenario	UWB e.i.r.p. density (dBm/MHz)	Comments
FS/P-P and P-MP	21-23.6 GHz 24.25-26.5 GHz 27.5-29.5 GHz	NF = 6 dB Minimum feeder loss = 0 dB P-P antenna gain = 41 dBi FWA sectorial antenna gain = 18 dBi	Rec. ITU-R F.1094 and WP 9A liaison statement (*I*/*N* = −20 dB assuming 0.5% apportionment for SRR)	Aggregate short range radar along a main road parallel to FS link: 4 active sensors (2 front 2 rear) per car; up to 4 lanes in each direction). Free space plus shielding effects. Two different studies on the same methodology but using different parameters, impact of mitigation factors and SRR activity factor of either 0 or 7 dB	Study 1 −50 to −60 (Note 1) Study 2 −41.3 (even with positive margin) (Note 2)	Wideband peak protection limit in 50 MHz bandwidth was evaluated 42 dB above e.i.r.p. limit (from actual tests)

Table 4.3: Results of Recommendation ITU-R SM.1757 and Report ITU-R SM.2057 for the Fixed Service in the bands 21-23.6 GHz, 24.25-29.5 GHz

NOTE 1 – Appropriate for countries where the deployment of P-P links, with low FS receiver antenna height and are frequently located along high traffic density roads combined with extensive use of these bands of FS links in mobile network infrastructure; an average SRR e.i.r.p. density limit of at least −50 dBm/MHz is necessary. However, where the joint concurrence probability of the more severe deployment situations (i.e., lower FS antenna heights closer to a road) are considered, an e.i.r.p. density limit of –60 dBm/MHz is necessary for long-term coexistence.

NOTE 2 – Appropriate for countries, where less stringent infrastructural requirements regarding the FS receiver height and distance to the road might exist, the SRR e.i.r.p. density limit of –41.3 dBm/MHz may be considered appropriate, when other mitigation factors (unpredictable but possibly present) are taken into account. However, this higher e.i.r.p. density increases the risk of interference from SRR to the FS in case where those mitigation factors may not be present.

Comparing this with the FS studies in the band 6.0-8.5 GHz, then a limit of -50 dBm/MHz e.i.r.p. for fixed LPR in-band operation may be also here appropriate for protection of FS. It is assumed that the higher path loss at 24 GHz compared to 7 GHz is balanced by the lower antenna height of FS station at 24 GHz compared to 7 GHz. Higher levels may require a kind of authorisation procedure (to be further analysed later in this Report).

5 RESULTS OF DETERMINISTIC MCL-BASED ANALYSIS

5.1 Frequency band 6.0-8.5 GHz

Following the preliminary comparative analysis of previous generic UWB studies shown in Section 4 above, this section takes a closer look at specific LPR co-existence with identified possible victim services, by performing a dedicated MCL analysis with reference to critical worst-case scenarios of single LPR installation nearest to victim, according to methodology described in Section 3 above.

The results of MCL calculations for the case of identified critical victim services in the frequency band 6.0-8.5 GHz are given below in Table 5.1. A copy of used Excel spreadsheet is provided in separate file.

The relevant parameters of victim services are mostly taken from previous studies reported in ECC Report 064 [7]. The emission power of LPR interferers are taken as proposed in TR 102 601 (see Table 2.2) [1] and other parameters are derived as described elsewhere in this Report. For example, important value of antenna discrimination (ΔG_a, expressed relative to maximum antenna gain) for the first side-lobe, which corresponds to 24^o off-axis angle identified in critical interference scenario as shown in Figure 2.3.

Note that for the case of victim FS PP link receiver, a worst case of mutual placement was assumed with LPR installation positioned within the main beam of FS antenna. The probability of such occurrence will be considered later in this Report.

For the case of victim Radio Astronomy station, the tolerable interference field for the band 6650-6675.2 MHz is given in ITU-R Recommendation RA.769 [12] as maximum spectral power flux density of -230dBW/m^2/Hz. In order to convert this value to the equivalent dBm power units, we assumed that isotropic aperture at 6650 MHz (wavelength of 4.5 cm) is equal to:

$$A_i = \lambda^2/4\pi = 1.62*10^{-4} = -37.9 \text{ dB(m}^2)$$

Referring to this, and also noting that ITU-R Recommendation RA.769 prescribes using RAS antenna side-lobe gain of 0 dBi for evaluating interference arriving along terrestrial paths, we could express maximum RAS tolerable power outside antenna as -267.9 dBW/Hz or -177.9 dBm/MHz. This maximum tolerable interference power could then be used in reported calculations as is, i.e. without needing to correct it further by I/N criteria. List of European Radio Observatories working in this frequency band is provided in Annex 3.

Victim:	PP FS receiver	FSS ES Rx	RA station
Operating frequency, MHz	7000	7500	6650
Bandwidth (IF), MHz	40	72	1
System noise temperature, degK		100	N/A
Receiver noise figure, dB	4		
I/N objective, dB	-20	-20	N/A
Ga (in the direction of Interferer), dBi	41	0	0
Feeder (insertion) loss, dB	3	0	0
Receiver thermal noise, dBm:	**-93.81**	**-100.03**	**N/A**
Interference threshold at receiver input, dBm:	**-113.81**	**-120.03**	**N/A**
Interference threshold before antenna, dBm:	**-151.81**	**-120.03**	**-177.90**
LPR Interferer:			
Main-beam mean e.i.r.p. limit (ref. TR 102 601), dBm (in the reference bandwidth)	1	1	1
Mean e.i.r.p density, dBm/MHz	*-32.98*	*-32.98*	*-32.98*
Peak e.i.r.p density, dBm/50 MHz	*7.01*	*7.01*	*7.01*
Antenna main-lobe gain, dBi	18	18	18
DeltaGa (first side-lobe, offset angle 20-30 deg), dB	-15.7	-15.7	-15.7
Antenna side-lobe gain >60 deg, dBi	-10	-10	-10
Reflection loss, dB	13	13	13
Pulse Repetition Frequency, MHz	1	1	1
Reference bandwidth, MHz	2500	2500	2500
Reflected e.i.r.p. in the direction of Victim, dBm	**-27.7**	**-27.7**	**-27.7**
Side-lobe e.i.r.p. in the direction of Victim, dBm	**-27**	**-27**	**-27**
Total interfering power towards Victim, dBm	**-24.33**	**-24.33**	**-24.33**
Horizontal power density check, dBm/MHz (e.i.r.p)	*-58.31*	*-58.31*	*-58.31*
Conditional BW Correction Factor, dB	**-17.96**	**-15.41**	**-33.98**
Impact range calculation:			
Minimum Coupling Loss balance, dB	**109.52**	**80.29**	**119.59**
Impact range with FSL model, km	**1.021**	**0.033**	**3.427**

Table 5.1: Calculated LPR interference ranges to victim services in 6.0-8.5 GHz band

Looking at the results of calculations reported in Table 5.1, the following conclusions could be made regarding LPR's co-existence prospects in the frequency band 6.0-8.5 GHz:

- Co-existence with FSS Earth Stations should not pose any concerns if separation distance of some 30 m could be observed. This small impact range makes unnecessary to consider any LPR aggregation effects.
- Co-existence with FS PP receivers was studied here assuming absolute worst case, i.e. with LPR installation being positioned within the main beam of FS antenna. For such case MCL simulations, reported above, show that impact range is up to 1 km in 6 GHz frequency band. However the likelihood of such occurrence is extremely low given the very small beam width of PP FS antennas (1-3^o). For example, a simple geometric consideration will suggest that likelihood of LPR falling within the angular opening of 3^o is equal to relationship of areas of 3^o-width sector to the entire 360^o circle area, which is 1/120 or roughly 1%.
- Co-existence with Radio Astronomy stations would require observation of a separation of LPR installation from RA site, in the order of 3.5 km, to overcome some very unlikely interference cases (very low probability) – see section 3.6.

5.1.1 Military satellite stations in the frequency band 6.0-8.5 GHz

The European Common Allocation table [6] shows that there are Defence systems operating within the frequency band 7250-8400 MHz, designated as a harmonised military band for satellite systems. These bands are currently used by the military to deploy the various terrestrial satellite stations. Table 5.2 below details the characteristics of military stations with receiving stations filed in ITU:

		Operational bandwidth	**Channel bandwidth**	**Noise T°**	**Gain**	**Beamwith**	**C dBW**	**C/I* (6%)**
Syracuse	7250-7750	50 MHz	100 kHz	170	61	0.15	-135	22.2
		50 MHz	100 kHz	200	40	1.87	-156	22.2

** the protection criterion used in satellite studies is C/I corresponding to a temperature increase of 6% (ΔT/T)*

Table 5.2: Military satellite stations in 6.0-8.5 GHz

The Syracuse systems are GSO receiving station. Table 5.3 details MCL interference calculations between LPR and Siracuse stations listed above. The interfering signal from the LPR is the result of the direct emission from the LPR side lobe and the reflected signal on a pile of dry sand with an angle of repose of 33°. The antenna gain in the side lobes is -10dB, and the reflection loss is 13 dB.

The interference level from the LPR is estimated in the side-lobes of victim satellite stations with following assumptions:

In the case of GSO receiving station, the elevation could be as low as 10° to catch the geostationary satellite, therefore antenna gain discrimination at 10° off-set angle was applied, resulting in antenna gains:

- Syracuse 1: applying antenna gain discrimination of 54 dB, i.e. the effective antenna gain in horizontal plain = 7 dBi;
- Syracuse 2: applying antenna gain discrimination of 30 dB, i.e. the effective antenna gain is 10 dBi,
- Note that the radiation pattern of actual antennas can be found in Appendix 8 of the RR.

Besides, the feeder loss value depends on the deployment configuration: for fixed systems, the feeder loss is 3dB, whereas for transportable systems (where the receiver input is close to the antenna) the feeder loss is 1 dB.

Victim:	Syracuse 1	Syracuse 2
Operating frequency, MHz	7500	7500
Bandwidth (IF), MHz	0.1	0.1
Satellite e.i.r.p, dBW	5	5
Propagation attenuation loss 36000 km, dB	201	201
Ga (in the direction of Interferer) (10° off-set), dBi	7	10
Ga main beam, dBi	61	40
C/I protection criterion, dB	22.2	22.2
C, dBW	-135	-156
Max interference level at receiver input, dBm	-127.2	-148.2
Max interference level at receiver input, dBm/MHz	**-117.20**	**-138.20**
Feeder (insertion) loss, dB	3	1
LPR Interferer:		
Mainbeam mean e.i.r.p limit, dBm	1	1
Reference bandwidth, MHz	2500	2500
Mainbeam mean e.i.r.p limit, dBm/MHz	**-32.98**	**-32.98**
Ga main beam, dBi	18	18
Antenna input power level, dBm/MHz	-50.98	-50.98
DeltaGa (first side-lobe, offset angle 20-30°), dB	-15.7	-15.7
Reflection loss, dB	13	13
Ga side lobes (>60°) gain, dBi	-10	-10
e.i.r.p towards the victim, reflection component, dBm/MHz	-61.68	-61.68
e.i.r.p towards the victim, sidelobe component, dBm/MHz	-60.98	-60.98
Total interfering power towards Victim, dBm/MHz	**-58.31**	**-58.31**
Impact range calculation:		
Minimum Coupling Loss balance, dB:	**62.89**	**88.89**
Impact range with FSL model, km	**0.00**	**0.09**

Table 5.3: MCL calculations between LPR and military satellite stations in 6.0-8.5 GHz

The maximum LPR impact ranges to GSO-satellite receiving stations are nearly zero for the Syracuse-1 and just about 90 m for the Syracuse-2. This very low range clearly shows no concern for co-existence between LPR and military FSS Earth Stations.

5.1.2 Military radar systems in the adjacent band 8.5-10 GHz

Military airborne and ground based radars are currently deployed in the adjacent band 8.5-10 GHz. Co-existence of these systems with proposed LPR usage has been considered in this study, however it was confirmed that assuming the LPR's unwanted emissions level of -20 dBc (to be confirmed by provisions in the ETSI harmonised standard), and additional mitigation due to antenna discrimination of airborne radars (that are normally aligned with the aircraft flight direction, thus giving significant gain discrimination in direction toward ground).

It was therefore concluded that there is no significant danger of interference from LPRs to such systems.

5.2 Frequency band 24.05-26.5 GHz

5.2.1 Interference over terrestrial paths

The results of MCL calculations for the case of identified critical victim services in the frequency band 24.05-26.5 GHz, and Radio Astronomy in adjacent band 23.6-24.0 GHz are given below in Table 5.2. A copy of used Excel spreadsheet is provided in separate file.

The relevant parameters of victim services are mostly taken from previous studies reported in ECC Report 023 [8]. The emission power of LPR interferers are taken as proposed in TR 102 601 and other parameters are derived as described elsewhere in this Report. Relative antenna discrimination for first side-lobe (near 24^{o} offset angle identified in critical interference scenario) is derived from simulated 25 GHz LPR antenna pattern shown below in Figure 5.1. This simulated pattern was verified to be in compliance with radiation pattern measurements on real antennas.

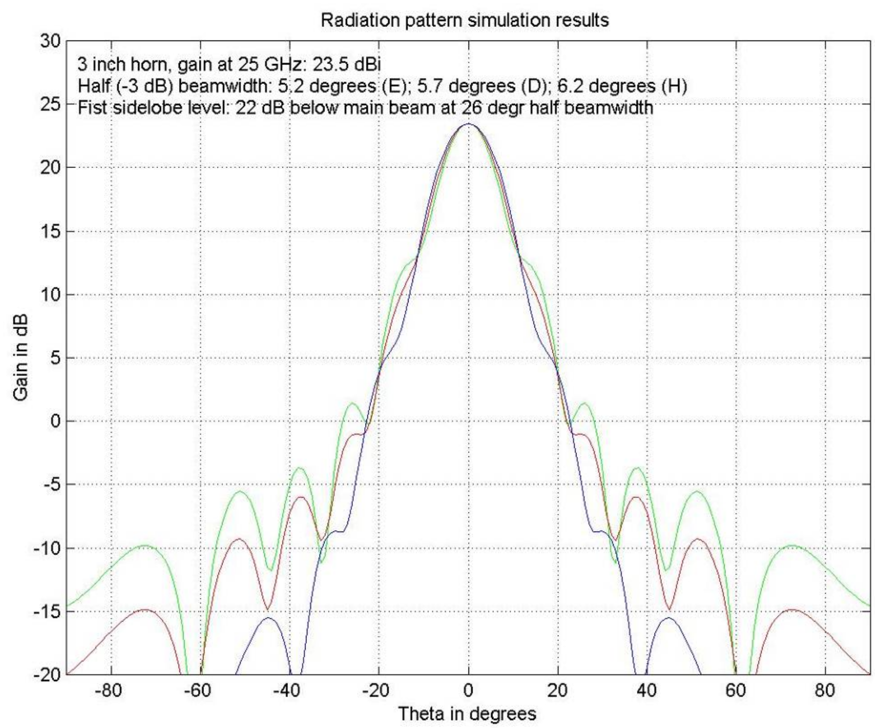

Figure 5.1: Simulated radiation pattern for 25 GHz Ø75 mm LPR antenna

Note that for the case of victim FS PP and PMP receivers, a worst case of mutual placement was assumed with LPR installation positioned inside the main beam of FS antenna, as in 6 GHz band. For the case of victim Radio Astronomy station in adjacent band 23.6-24.0 GHz, the tolerable interference field for this band is given in ITU-R Recommendation RA.769 [12] as maximum spectral power flux density (SPFD) of -215 dB(W/m^2/Hz) for spectral line observations (narrow band) or -233 dB(W/m^2/Hz) for continuum observations (broad band). For analysis in this Report, the value of -233 dB(W/m^2/Hz) is used for broad band (1 MHz) observations. Similarly as was done previously for 6 GHz band, it first should convert this SPFD value to the equivalent dBm power units. The isotropic aperture at 24 GHz (wavelength of 1.25 cm) is equal to:

$$A_i=\lambda^2/4\pi=1.24*10^{-5}=-49.1 \text{ dB(m}^2\text{)}$$

Therefore the maximum tolerable power outside Radio Astronomy observatory antenna may be expressed as -282.1 dBW/Hz or -192.1 dBm/MHz. This maximum tolerable interference power could then be used in reported calculations as is, i.e. without needing to correct it further by I/N criteria. Since in this case LPR will be affecting Radio Astronomy station through unwanted emissions in adjacent band, the equivalent power of LPR emissions was reduced by 30 dB (in the same reference bandwidth), while TR 102 601 requires -20 dB LPR power reduction in OOB domain, the value of -30 dBc was suggested for additional protection of critical passive band 23.6-24.0 GHz). List of European Radio Observatories working on this frequency band is provided in Annex 3.

Victim:	PP FS (civil)	PP FS (military)	PMP BS Rx	PMP TS Rx	RAS
Operating frequency, MHz	25000	25000	25000	25000	25000
Bandwidth (IF), MHz	28	28	28	28	1
Receiver noise figure, dB	6	4.5	6	6	N/A
I/N objective, dB	-20	-20	-20	-6	N/A
Ga (in the direction of Interferer), dBi	41	47.4	18	0	0
Ga (sidelobes), dBi	0	0			
Feeder (insertion) loss, dB	0	1	3	0	0
Receiver thermal noise, dBm	**-93.36**	**-94.86**	**-93.36**	**-93.36**	**N/A**
Interference threshold at receiver input, dBm	**-113.36**	**-114.86**	**-113.36**	**-99.36**	**N/A**
Interference threshold before antenna, dBm	**-154.36**	**-161.26**	**-128.36**	**-99.36**	**-192.10**
Interference threshold PP FS side-lobes, dBm	**-113.36**	**-113.86**	**N/A**	**N/A**	**N/A**
LPR Interferer:					
Main beam mean e.i.r.p. limit (ref. TR 102 601), dBm (in the reference bandwidth)	20	20	20	20	-10*
Mean e.i.r.p density, dBm/MHz	*-13.89*	*-13.89*	*-13.89*	*-13.89*	*-43.89*
Peak e.i.r.p density, dBm/50 MHz	*26.10*	*26.10*	*26.10*	*26.10*	*6.10*
Antenna main-lobe gain, dBi	20	20	20	20	20
DeltaGa (first side-lobe, offset angle 20-30 deg), dB	-22	-22	-22	-22	-22
Antenna side-lobe gain >60 deg, dBi	-10	-10	-10	-10	-10
Reflection loss, dB	13	13	13	13	13
Pulse Repetition Frequency, MHz	1.8	1.8	1.8	1.8	1.8
Reference bandwidth, MHz	2450	2450	2450	2450	2450
Reflected e.i.r.p. in the direction of Victim, dBm	**-15**	**-15**	**-15**	**-15**	**-45**
Side-lobe e.i.r.p. in the direction of Victim, dBm	**-10**	**-10**	**-10**	**-10**	**-40**
Total interfering power towards Victim, dBm	**-8.81**	**-8.81**	**-8.81**	**-8.81**	**-38.81**
Horizontal power density check, dBm/MHz(e.i.r.p)	*-42.70*	*-42.70*	*-42.70*	*-42.70*	*-72.70*
Conditional BW Correction Factor, dB	**-19.42**	**-19.42**	**-19.42**	**-19.42**	**-31.34**
Impact range calculation:					
Minimum Coupling Loss balance, dB	**126.13**	**133.03**	**100.13**	**71.13**	**121.95**
Impact range with FSL model, km	**1.935**	**4.282**	**0.097**	**0.003**	**1.196**
Impact range calculation (in PP FS side-lobes):					
Minimum Coupling Loss balance, dB	**85.13**	**85.63**	**N/A**	**N/A**	**N/A**
Impact range with FSL model, km	**0.017**	**0.018**	**N/A**	**N/A**	**N/A**

Table 5.4: Calculated LPR interference ranges to victim services in and near 24.05-26.5 GHz band

(*) This value is not contained in TR 102 601 but was considered in the studies for the unwanted emissions level falling into the RAS band.

Table 5.4 shows the protection distances required for both FS systems based on simple MCL calculations for LPR in the FS main lobe as well as in the side lobe with a 0dBi gain, which is suitable for offset angle more than 20-30° depending on the antenna directivity.

Considering the results provided in Table 5.4 it may be concluded that LPR co-existence situation will be broadly similar to 6 GHz band case as in section 5.1 above:

- Co-existence with FS PMP systems requires separation distance of some 100m to PMP Base Station, when LPR is placed within the main beam of PMP BS receiver antenna. Further statistical evaluation of this scenario is made later in this Report (i.e. section 6.2).
- Co-existence with FS PP receivers was studied here assuming worst case, i.e. with LPR installation positioned within the main beam of FS antenna. For such case MCL simulations reported above show that impact range is up to 2 km (civil) and up to 4 km (military) in 24 GHz band. However the likelihood of such occurrence is extremely low given the very small beam width of PP FS antennas (1-3^o). For example, a simple geometric consideration will suggest that likelihood of LPR falling within the angular opening of 3^o is equal to relationship of areas of 3^o-width sector to the entire 360^o circle area, which is 1/120 or roughly 1%. In the side lobe case, the separation distances are of the order of 20 m.
- Co-existence with Radio Astronomy stations requires separation of LPR installation from RA site, in the order of 3.5km, unless some suitable mitigation of interference is applied.

5.2.2 Interference to EESS (passive) in adjacent band 23.6-24.0 GHz

Interference criterion for protecting operation of EESS (passive) in the band 23.6-24.0 GHz is given by Recommendation ITU-R RS.1029 [23] as -166 dBW in 200 MHz reference bandwidth. This is described as a maximum interference level from all sources. The number of measurement cells where interference threshold can be exceeded must not be more than 0.01% of pixels in all service areas for any kind of EESS sensor.

In addition, the above criterion represents the maximum level of aggregate interference from all possible sources and therefore a suitable part of it needs to be apportioned for UWB devices. Previous references (information from ITU-R WP7C) have suggested apportioning 1% to 5% of the total interference criteria to UWB emissions. This corresponds to reduction of interference criterion by 13-20 dB, that is to say using interference threshold of -179…-186 dBW/200 MHz.

Simulation of EESS and LPR co-existence is done by calculating the amount of radiated LPR emission as it reaches satellite passive sensor. However it should be remembered that the EESS is operated in adjacent band, therefore it is unwanted emissions of LPR that could potentially affect the EESS sensor receivers. For this reason it is assumed that LPR's unwanted emissions are described as uniform flat wideband emissions with the power level of -20 dBc. The mean in-band e.i.r.p. of LPR operated in the band 24.05-26.5 GHz is fixed by ETSI SRDoc TR 102 601 [1] at +20 dBm in 2500 MHz reference bandwidth, i.e. -13.9 dBm/MHz. It could be then deducted that LPR's mean e.i.r.p. for unwanted emissions will be -33.9 dBm/MHz.

The interference scenario for worst case vertical LPR emissions was described in Figure 3.2. Therefore calculation of link budget is based on the assumptions described in that scenario.

The following Table 5.3 provides calculated link budgets for conical scan EESS sensors and Table 5.4 provides similar budget for Nadir sensors.

Parameter	**MEGHA TROPIC**	**EOS AMSR-E**	**CMIS**
Frequency, GHz	23.80	23.80	23.80
LPR e.i.r.p. (main beam), dBm/MHz	**-33.90**	**-33.90**	**-33.90**
Direct e.i.r.p. sent to the tank, dBW/MHz	-63.90	-63.90	-63.90
Gain of the transmit LPR antenna, main beam, dBi	25.00	25.00	25.00
LPR power spectral density, dBW/MHz	**-88.90**	**-88.90**	**-88.90**
Gain of the transmit LPR antenna side lobe, dBi	-10.00	-10.00	-10.00
Direct e.i.r.p. component sent to the satellite, dBW/MHz	-98.90	-98.90	-98.90
Additional losses for the scattered component, dB	-5.00	-5.00	-5.00
Dielectric reflection factor, dB	-0.95	-0.95	-0.95
Distance LPR - EESS sensor in km	1336.00	1229.00	1336.00
Space attenuation in dB	182.49	181.76	182.49
Scattered e.i.r.p. component received at the antenna port of the satellite, dBW/MHz	**-264.31**	**-264.31**	**-264.31**
Direct e.i.r.p. received at the satellite antenna port, dBW/MHz	**-281.39**	**-281.39**	**-281.39**
Total e.i.r.p. received at the antenna port of the satellite, dBW/MHz	**-264.23**	**-264.23**	**-264.23**
EESS antenna gain, dBi	40.00	46.00	52.00
Atmospherical loss (Rec. ITU-R P.676), dB	1.60	1.70	1.70
Received power at the EESS sensor in a 1 MHz bandwidth, dBW	-225.83	-219.93	-213.93
Corresponding received power at the EESS in a bandwidth of 200 MHz for one single LPR, dBW	-202.82	-196.92	-190.92
EESS interference threshold in a reference bandwidth of 200 MHz: application of revised Rec. ITU-R SA 1029-1, dBW	-166.00	-166.00	-166.00
EESS interference threshold in a reference bandwidth of 200 MHz: application of Rec. ITU-R SA 1029-2 with 1% apportionment, dBW	-186.00	-186.00	-186.00
Pixel surface, km²	1926.00	425.00	264.00
Maximum expected LPR density per km²	0.005	0.005	0.005
Total number of LPR within an EESS pixel	9.63	2.13	1.32
Percentage of indoor LPR, %	90.00	90.00	90.00
Attenuation indoor/outdoor, dB	15.00	15.00	15.00
Corresponding total number of outdoor active (100% of the time) LPR devices within an EESS pixel	1.24	0.27	0.17
Corresponding received power at the EESS in a bandwidth of 200 MHz for active LPR within an EESS pixel, dBW	-201.89	-202.55	-198.62
Margin with ref. to Rec. ITU-R RS.1029-2, dB	**35.89**	**36.55**	**32.62**
Corresponding required LPR e.i.r.p. (main beam), dBm/MHz	**1.99**	**2.65**	**-1.28**
Margin with ref. to RS 1029-2 with 1% apportionment, dB	**15.89**	**16.55**	**12.62**
Corresponding required LPR e.i.r.p. (main beam), dBm/MHz	**-18.01**	**-17.35**	**-21.28**

Table 5.5: Calculation of LPR impact to Conical Scan EESS sensors in adjacent band 23.6-24.0 GHz

Note: although the ETSI SRDoc TR 102 601 [1] indicates certain market grow up to 2015 resulting in a Maximum expected LPR density per km^2 of 0.00238, in the present Report's table 5.5 it was agreed to use a very conservative figure of 0.005, however still showing a good margin as final result.

Parameter	Push-Broom	AMSU-A	ATMS
Frequency, GHz	23.80	23.80	23.80
LPR e.i.r.p. (main beam), dBm/MHz	**-33.90**	**-33.90**	**-33.90**
Direct e.i.r.p. sent to the tank, dBW/MHz	-63.90	-63.90	-63.90
Gain of the transmit LPR antenna, main beam, dBi	25.00	25.00	25.00
LPR power spectral density, dBW/MHz	**-88.90**	**-88.90**	**-88.90**
Gain of the transmit LPR antenna side lobe, dBi	-10.00	-10.00	-10.00
Direct e.i.r.p. component sent to the satellite, dBW/MHz	-98.90	-98.90	-98.90
Additional losses for the scattered component, dB	-5.00	-5.00	-5.00
Dielectric reflection factor, dB	-0.95	-0.95	-0.95
Distance LPR - EESS sensor, km	850.00	850.00	850.00
Space attenuation, dB	178.56	178.56	178.56
Scattered e.i.r.p. component received at the antenna port of the satellite, dBW/MHz	**-260.38**	**-260.38**	**-260.38**
Direct e.i.r.p. received at the satellite antenna port, dBW/MHz	**-277.46**	**-277.46**	**-277.46**
Total e.i.r.p. received at the antenna port of the satellite, dBW/MHz	**-260.30**	**-260.30**	**-260.30**
EESS antenna gain, dBi	45.00	36.00	31.00
Atmospheric loss (Rec. ITU-R P.676), dB	1.00	1.00	1.00
Received power at the EESS sensor in a 1 MHz bandwidth, dBW	-216.30	-225.30	-230.30
Corresponding received power at the EESS in a bandwidth of 200 MHz for one single LPR, dBW	-193.29	-202.29	-207.29
EESS interference threshold in a reference bandwidth of 200 MHz: application of revised Rec. ITU-R SA 1029-1, dBW	-166.00	-166.00	-166.00
EESS interference threshold in a reference bandwidth of 200 MHz: application of Rec. ITU-R SA.1029-2 with 1% apportionment, dBW	-186.00	-186.00	-186.00
Pixel surface, km²	206.00	1842.00	4542.00
Maximum expected LPR density per km^2	0.005 (Note 1)	0.005 (Note 1)	0.005 (Note 1)
Total number of LPR within an EESS pixel	1.03	9.21	22.71
Percentage of indoor LPR, %	90.00	90.00	90.00
Attenuation indoor/outdoor, dB	15.00	15.00	15.00
Corresponding total number of outdoor active (100% of the time) LPR devices within an EESS pixel	0.13	1.18	2.92
Corresponding received power at the EESS in a bandwidth of 200 MHz for active LPR within an EESS pixel, dBW	-202.07	-201.56	-202.64
Margin with ref. to Rec. ITU-R RS.1029-2, dB	**36.07**	**35.56**	**36.64**
Corresponding required LPR e.i.r.p. (main beam), dBm/MHz	**2.17**	**1.66**	**2.74**
Margin with ref. to Rec. ITU-R RS.1029-2 with 1% apportionment, dB	**16.07**	**15.56**	**16.64**
Corresponding required LPR e.i.r.p. (main beam), dBm/MHz	**-17.83**	**-18.34**	**-17.26**

Table 5.6: Calculation of LPR impact to Nadir EESS sensors in adjacent band 23.6-24.0 GHz

Note 1: although the ETSI SRDoc TR 102 601 [1] indicates certain market grow up to 2015 resulting in a Maximum expected LPR density per km^2 of 0.00238, in the present Report's table 5.6 it was agreed to use a very conservative figure of 0.005, however still showing a good margin as final result.

Looking at the results provided in Tables 5.5 and 5.6 it becomes clear that even in most critical scenarios LPR unwanted emissions will not exceed their apportioned 1% interference objectives to any of the considered EESS systems. These largely demonstrated margins also ensure by themselves a sufficient safety against possible future growth of LPR numbers in the long-term future, beyond the time frame for which forecasts were given in ETSI SRDoc TR 102 601 [1].

5.3 Frequency band 57-64 GHz

5.3.1 Interference over terrestrial paths

Results of simulating maximum terrestrial interference ranges to protect identified victim services in the band 57-64 GHz are reported below and the spreadsheet used for these calculations is included in the attached separate Excel file. Note that the frequency band 57-64 GHz has a very high specific atmospheric absorption due to oxygen resonance, which may be in the order of 10 dB/km and above. Therefore results of MCL calculations derived by using Free Space Loss model need to be adjusted for oxygen absorption.

The relevant parameters of victim services were for the most part taken from previous studies reported in ECC Report 114 [9]. The emission power of LPR interferers was increased to the level, which would correspond to equivalent horizontally emitted power density of -41.3 dBm/MHz. This was done in order to affording LPR devices higher power for reliable level measurements in this very high frequency band. It was assumed that as long as the horizontally emitted power complies with the aforementioned generally established limit all over the three higher sought bands, the impact on the victim services should be tolerable, as investigated by calculations reported in Table 5.7 level. LPR antenna discrimination for offset angles near 24^{o} identified in critical interference scenario was taken as -30 dB to maximum antenna gain. For this frequency band it was assumed that LPR antenna of 100 mm diameter will be used, with maximum gain of 34 dBi. These values correspond to generic antenna radiation pattern specified in ITU-R Recommendation F.699 [22].

Note that for the case of victim FS PP (MGWS/FLANE) receivers, a worst case of mutual placement was again assumed with LPR positioned along the main beam of FLANE antenna.

Results of simulations for terrestrial paths are given below in Table 5.7.

Victim:	**PP FLANE Rx**	**Radar Rx**	**ITS RSU Rx**
Operating frequency, GHz	59	63	64
Bandwidth (IF), MHz	2500	100	120
Receiver noise figure, dB	10	6	8
I/N objective, dB	-20	-20	-20
Ga (in the direction of Interferer), dBi	38	38	23
Feeder (insertion) loss, dB	0	5	0
Receiver thermal noise, dBm	**-69.85**	**-87.83**	**-85.04**
Interference threshold at receiver input, dBm	**-89.85**	**-107.83**	**-105.04**
Interference threshold before antenna, dBm	**-127.85**	**-140.83**	**-128.04**
LPR Interferer:			
Mainbeam mean *e.i.r.p* limit (ref. TR 102 601), dBm (in reference bandwidth)	**37**	**37**	**37**
Mean e.i.r.p density, dBm/MHz	***-1.45***	***-1.45***	***-1.45***
Peak e.i.r.p density, dBm/50 MHz	***35.54***	***35.54***	***35.54***
Antenna main-lobe gain, dBi	34	34	34
DeltaGa (first side-lobe, offset angle 20-30 deg), dB	-30	-30	-30
Antenna side-lobe gain >60 deg, dBi	-10	-10	-10
Reflection loss, dB	13	13	13
Pulse Repetition Frequency, MHz	1.8	1.8	1.8
Reference bandwidth, MHz	7000	7000	7000
Reflected e.i.r.p in the direction of Victim, dBm	**-6**	**-6**	**-6**
Side-lobe e.i.r.p in the direction of Victim, dBm	**-7**	**-7**	**-7**
Total interfering power towards Victim, dBm	**-3.46**	**-3.46**	**-3.46**
Horizontal power density check, dBm/MHz (e.i.r.p)	*-41.91*	*-41.91*	*-41.91*
Conditional BW Correction Factor, dB	**-4.47**	**-18.45**	**-17.66**
Impact range calculation:			
Minimum Coupling Loss balance, dB	**119.92**	**118.92**	**106.92**
Impact range with FSL model, km	0.401	0.335	0.083
Oxygen absorption, dB/km	10	11	10
Impact range adjusted for oxygen absorption, km	**0.29**	**0.245**	**0.075**

Table 5.7: Calculated LPR interference ranges to victim services in 57-64 GHz band

Calculation results shown in Table 5.7 demonstrate moderate ranges of possible impact from LPR to radiocommunications services in the band 57-64 GHz, though much smaller than was obtained in lower frequency bands for services like PP FS with similar worst case scenarios, including direct beam-to-beam coupling with highly directional antennas of victim services such as PP FS links and radars. The complementary statistical SEAMCAT simulations for this frequency band are reported in section 6.

5.3.2 Interference to EESS (passive) in the band 57-59.3 GHz

ITU-R Recommendation RS.1029 [23] requires that for future EESS (passive) systems interfering power at passive sensor should not exceed the level of -169 dBW/100 MHz. Following the same logic as described for EESS study in the 24 GHz range (ref. section 5.2.2), this level should be further reduced to reflect the apportionment of 1% to interference arriving from considered LPR applications. Therefore the equivalent interference threshold of -189 dBW/100 MHz will be used for calculations.

Aforementioned high oxygen absorption in this frequency band also has impact on interference signals propagating towards zenith, with particular values of oxygen attenuation in zenith direction given in ITU-R Recommendation P.676 [23] On average, total average zenith attenuation across considered 57-59.3 GHz band may be conservatively estimated at 90 dB, the value used in recent similar studies for the subject band [9].

Regarding the LPR parameters, they are taken with reference to requirements outlined in TR 102 601 [1] for this frequency band, i.e. mean e.i.r.p. of +23 dBm over reference bandwidth of 7000 MHz. This results in LPR e.i.r.p. density of -15.5 dBm/MHz. Other parameters having impact on vertical emission chosen according to identified critical scenario, which was described in Figure 3.2.

Results of calculations for typical Nadir sensing systems used or planned in the band 57-59.3 GHz are provided in Table 5.8.

Parameter	**Push-Broom**	**AMSU-A**	**ATMS**
Frequency, GHz	58.00	58.00	58.00
LPR e.i.r.p. (main beam), dBm/MHz	**-15.50**	**-15.50**	**-15.50**
Direct e.i.r.p. sent to the tank, dBW/MHz	-45.50	-45..50	-45.50
Gain of the transmit LPR antenna, main beam, dBi	34.00	34.00	34.00
LPR power spectral density, dBW/MHz	**-79.50**	**-79.50**	**-79.50**
Gain of the transmit LPR antenna side lobe, dBi	-10.00	-10.00	-10.00
Direct e.i.r.p. component sent to the satellite, dBW/MHz	-89.50	-89.50	-89.50
Additional losses for the scattered component, dB	-5.00	-5.00	-5.00
Dielectric reflection factor, dB	-0.95	-0.95	-0.95
Distance LPR - EESS sensor, km	850.00	850.00	850.00
Space attenuation, dB	186.30	186.30	186.30
Scattered e.i.r.p. component received at the antenna port of the satellite, dBW/MHz	**-249.72**	**-249.72**	**-249.72**
Direct e.i.r.p. received at the satellite antenna port, dBW/MHz	**-275.80**	**-275.80**	**-275.80**
Total e.i.r.p. received at the antenna port of the satellite, dBW/MHz	**-249.71**	**-249.71**	**-249.71**
EESS antenna gain, dBi	45.00	36.00	41.00
Atmospheric loss (Rec. ITU-R P.676), dB	90.00	90.00	90.00
Received power at the EESS sensor in a 1 MHz bandwidth, dBW	-294.71	-303.71	-298.71
Corresponding received power at the EESS in a bandwidth of 100 MHz for one single LPR, dBW	-274.71	-283.71	-278.71
EESS interference threshold in a reference bandwidth of 100 MHz: application of revised Rec. ITU-R SA 1029-1, dBW	-169.00	-169.00	-169.00
EESS interference threshold in a reference bandwidth of 100 MHz: application of Rec. ITU-R SA 1029-2 with 5% apportionment, dBW	-182.01	-182.01	-182.01
Pixel surface, km²	201.00	1885.00	804.00
Maximum expected LPR density per km²	0.001	0.001	0.001
Total number of LPR within an EESS pixel	0.20	1.89	0.80
Percentage of indoor LPR, %	90.00	90.00	90.00
Attenuation indoor/outdoor, dB	20.00	20.00	20.00
Corresponding total number of outdoor active (100% of the time) LPR devices within an EESS pixel	0.02	0.21	0.09
Corresponding received power at the EESS in a bandwidth of 100 MHz for active LPR within an EESS pixel, dBW	-291.30	-290.58	-289.28
Margin with ref. to Rec. ITU-R RS.1029-2, dB	**122.30**	**121.58**	**120.28**
Margin with ref. to Rec. ITU-R RS.1029-2 with 5% apportionment, dB	**109.29**	**108.57**	**107.27**

Table 5.8: Calculation of LPR impact to Nadir EESS sensors in the band 57-59.3 GHz

Note: although the ETSI SRDoc TR 102 601 [1] indicates certain market grow up to 2015 resulting in a Maximum expected LPR density per km^2 of 0.00034, in the present Report's table 5.6 it was agreed to use a very conservative figure of 0.001, however still showing a good margin as final result.

Results of calculations provided in Table 5.8 clearly demonstrate that LPR will not cause any interference concern to current or future EESS (passive) systems in the band 57-59.3 GHz.

5.4 Frequency band 75-85 GHz

5.4.1 Interference over terrestrial paths

Results of MCL calculations for the case of identified critical victim services PP FS in 76 GHz frequency band and Radio Astronomy in 76-77.5 GHz and 85-93 GHz are given below in Table 5.7. A copy of used Excel spreadsheet is provided in a separate file.

The relevant parameters of victim services were for the most part taken from previous studies reported in ECC Report 124 [11]. The emission power of LPR interferers was increased to the level, which would correspond to equivalent horizontally emitted power density of -41.3 dBm/MHz. This was done in order to affording LPR devices higher power for reliable level measurements in this very high frequency band. It was assumed that as long as the horizontally emitted power complies with the aforementioned generally established limit all over the three higher sought bands, the impact on the victim services should be tolerable, as also re-confirmed by the results of calculations reported in Table 5.8. LPR antenna discrimination for offset angles near 24^{o} identified in critical interference scenario was taken -32 dB to maximum antenna gain. For this frequency band it was assumed that LPR antenna of 100 mm diameter will be used, with maximum gain of 35 dBi.

As in all other bands, the worst case of main beam coupling was assumed for victim FS PP receivers.

Regarding the Radio Astronomy observations, two cases were studied for this band. One case would address in-band interference to narrow-band Spectral Line Observations (SLO) in the band 76-77.5 GHz. Another case would address impact of unwanted LPR emissions to broadband Continuum Observations (CO) in adjacent channel above 85 GHz (the RAS CO measurements in the upper band are centred on 89 GHz with measurement bandwidth of 8 GHz, see e.g. ECC Report 124 for more detailed explanation of RAS use in this band). With reference to protection requirements described in ITU-R Recommendation RA.769, this study used the same interference power threshold values as those used in previous study in ECC Report 124 [11]: -209 dBW for SL observations in 1 MHz reference bandwidth, and -189 dBW for continuum observations in 8 GHz reference bandwidth. List of European Radio Observatories working in this frequency band is provided in Annex 3.

Victim:	**PP FS receiver**	**RAS SLO**	**RAS CO adjacent**
Operating frequency, GHz	76	77	89
Bandwidth (IF), MHz	1250	1	8000
Receiver noise figure, dB	10	N/A	N/A
I/N objective, dB	-20	N/A	N/A
Ga (in the direction of Interferer), dBi	38	0	0
Feeder (insertion) loss, dB	0	0	0
Receiver thermal noise, dBm	**-72.86**	**N/A**	**N/A**
Interference threshold at receiver input, dBm	**-92.86**	**N/A**	**N/A**
Interference threshold before antenna, dBm	**-130.86**	**-179.00**	**-159.00**
LPR Interferer:			
Main beam mean e.i.r.plimit (ref. TR 102 601), dBm	**37**	**37**	**17**
Mean e.i.r.pdensity, dBm/MHz	***-3.00***	***-3.00***	***-23.00***
Peak e.i.r.p density, dBm/50 MHz	***33.99***	***33.99***	***13.99***
Antenna main-lobe gain, dBi	35	35	35
DeltaGa (first side-lobe, offset angle 20-30 deg), dB	-32	-32	-32
Antenna side-lobe gain >60 deg, dBi	-10	-10	-10
Reflection loss, dB	13	13	13
Pulse Repetition Frequency, MHz	1.8	1.8	1.8
Reference bandwidth, MHz	10000	10000	10000
Reflected e.i.r.p in the direction of Victim, dBm	**-8**	**-8**	**-28**
Side-lobe e.i.r.p in the direction of Victim, dBm	**-8**	**-8**	**-28**
Total interfering power towards Victim, dBm	**-4.99**	**-4.99**	**-24.99**
Horizontal power density check, dBm/MHz (e.i.r.p)	*-44.99*	*-44.99*	*64.99*
Conditional BW Correction Factor, dB	**-9.03**	**-37.45**	**-0.97**
Impact range calculation:			
Minimum Coupling Loss balance, dB	**116.84**	**136.56**	**133.04**
Impact range with FSL model, km	**0.218**	**2.088**	**1.204**

Table 5.9: Calculated LPR interference ranges to victim services in 75-85 GHz band

Calculation results shown in Table 5.9 are consistent with findings for other frequency bands in that only Radio Astronomy would require observation of a separation of LPR installation from RA site, in the order of 2km, to overcome some very unlikely interference cases (very low probability) – see section 3.6.

5.4.2 Interference to EESS (passive) in adjacent band 86-92 GHz

ITU-R Recommendation RS.1029 [24] requires that interfering power at passive sensors in this frequency band should not exceed the level of -169 dBW/100 MHz. Following the same logic as described for EESS study in the 24 GHz and 57 GHz ranges (ref. sections 5.2.2 and 5.3.2), this level should be further reduced to reflect the apportionment of 1% to interference arriving from considered LPR applications. Therefore the equivalent interference threshold of -189 dBW/100 MHz will be used in calculations for this frequency band.

Regarding the LPR parameters, they are taken with reference to requirements outlined in ETSI SRDoc TR 102 601 [1] for the frequency band 75-85 GHz (i.e. mean e.i.r.p. of +23 dBm over reference bandwidth of 10000 MHz) and further adjusted by -20 dB to reflect that interference will be occurring from unwanted emissions of LPR. This results in LPR unwanted emissions' e.i.r.p. density of -37 dBm/MHz. Other parameters having impact on emissions towards EESS are chosen according to identified critical scenario, which was described in Figure 3.2.

Results of calculations for typical Conical Scan and Nadir EESS (passive) systems used or planned in the band 86-92 GHz are provided in Table 5.10. and 5.11 respectively. The choice of considered systems was made with reference to similar studies in ECC Report 124 [11].

Parameter	MEGHA TROPIC	EOS AMSR-E	CMIS
Frequency, GHz	88.00	88.00	88.00
	.	.	.
LPR e.i.r.p. (main beam), dBm/MHz	**-37.00**	**-37.00**	**-37.00**
Direct e.i.r.p. sent to the tank, dBW/MHz	-67.00	-67.00	-67.00
Gain of the transmit LPR antenna, main beam, dBi	33.00	33.00	33.00
LPR power spectral density, dBW/MHz	**-100.00**	**-100.00**	**-100.00**
Gain of the transmit LPR antenna side lobe, dBi	-10.00	-10.00	-10.00
Direct e.i.r.p. component sent to the satellite, dBW/MHz	-110.00	-110.00	-110.00
Additional losses for the scattered component, dB	-5.00	-5.00	-5.00
Dielectric reflection factor, dB	-0.95	-0.95	-0.95
Distance LPR - EESS sensor, km	1336.00	1229.00	1336.00
Space attenuation, dB	193.85	193.12	193.85
Scattered e.i.r.p. component received at the antenna port of the satellite, dBW/MHz	**-278.77**	**-278.77**	**-278.77**
Direct e.i.r.p. received at the satellite antenna port, dBW/MHz	**-303.85**	**-303.85**	**-303.85**
Total e.i.r.p. received at the antenna port of the satellite, dBW/MHz	**-278.75**	**-278.75**	**-278.75**
EESS antenna gain, dBi	50.00	60.50	56.00
Atmospherical loss (Rec. ITU-R P.676), dB	2.00	2.00	2.00
Received power at the EESS sensor in a 1 MHz bandwidth, dBW	-230.75	-220.25	-224.75
Corresponding received power at the EESS in a bandwidth of 100 MHz for one single LPR, dBW	-210.75	-200.25	-204.75
EESS interference threshold in a reference bandwidth of 100 MHz: application of revised Rec. ITU-R SA 1029-1, dBW	-169.00	-169.00	-169.00
EESS interference threshold in a reference bandwidth of 100 MHz: application of Rec. ITU-R SA 1029-2 with 1% apportionment, dBW	-189.00	-189.00	-189.00
Pixel surface, km²	131.00	18.00	115.00
Maximum expected LPR density per km2	0.001 (Note 1)	0.001 (Note 1)	0.001 (Note 1)
Total number of LPR within an EESS pixel	0.13	0.02	0.12
Percentage of indoor LPR, %	90.00	90.00	90.00
Attenuation indoor/outdoor, dB	25.00	25.00	25.00
Corresponding total number of outdoor active (100% of the time) LPR devices within an EESS pixel	0.01	0.00	0.01
Corresponding received power at the EESS in a bandwidth of 100 MHz for active LPR within an EESS pixel, dBW	-229.46	-227.58	-224.03
Margin with ref. to Rec. ITU-R RS.1029-2, dB	**60.46**	**58.58**	**55.03**
Margin with ref. to Rec. ITU-R RS.1029-2 with 1% apportionment, dB	**40.46**	**38.58**	**35.03**

Table 5.10: Calculation of LPR impact to Conical EESS sensors in the adjacent band 86-92 GHz

Parameter	**AMSU-A**	**AMSU-B**	**ATMS**
Frequency, GHz	88.00	88.00	88.00
Wavelength, m	.	.	.
LPR e.i.r.p. (main beam), dBm/MHz	**-37.00**	**-37.00**	**-37.00**
Direct e.i.r.p. sent to the tank, dBW/MHz	-67.00	-67.00	-67.00
Gain of the transmit LPR antenna, main beam	33.00	33.00	33.00
LPR power spectral density, dBW/MHz	**-100.00**	**-100.00**	**-100.00**
Gain of the transmit LPR antenna side lobe, dBi	-10.00	-10.00	-10.00
Direct e.i.r.p. component sent to the satellite, dBW/MHz	-110.00	-110.00	-110.00
Additional losses for the scattered component, dB	-5.00	-5.00	-5.00
Dielectric reflection factor, dB	-0.95	-0.95	-0.95
Distance LPR - EESS sensor, km	850.00	850.00	850.00
Space attenuation, dB	189.92	189.92	189.92
Scattered e.i.r.p. component received at the antenna port of the satellite, dBW/MHz	**-274.84**	**-274.84**	**-274.84**
Direct e.i.r.p. received at the satellite antenna port, dBW/MHz	**-299.92**	**-299.92**	**-299.92**
Total e.i.r.p. received at the antenna port of the satellite, dBW/MHz	**-274.83**	**-274.83**	**-274.83**
EESS antenna gain, dBi	34.40	47.00	37.90
Atmospherically loss (Rec. ITU-R P.676), dB	2.00	2.00	2.00
Received power at the EESS sensor in a 1 MHz bandwidth, dBW	-242.43	-229.83	-238.93
Corresponding received power at the EESS in a bandwidth of 100 MHz for one single LPR, dBW	-222.43	-209.83	-218.93
EESS interference threshold in a reference bandwidth of 100 MHz: application of revised Rec. ITU-R SA 1029-1, dBW	-169.00	-169.00	-169.00
EESS interference threshold in a reference bandwidth of 100 MHz: application of Rec. ITU-R SA.1029-2 with 1% apportionment, dBW	-189.00	-189.00	-189.00
Pixel surface, km²	1500.00	170.00	1000.00
Maximum expected LPR density per km2	0.001 (Note1)	0.001 (Note 1)	0.001 (Note 1)
Total number of LPR within an EESS pixel	1.50	0.17	1.00
Percentage of indoor LPR, dBW/MHz	90.00	90.00	90.00
Attenuation indoor/outdoor, dB	25.00	25.00	25.00
Corresponding total number of outdoor active (100% of the time) LPR devices within an EESS pixel	0.15	0.02	0.10
Corresponding received power at the EESS in a bandwidth of 100 MHz for active LPR within an EESS pixel, dBW	-230.54	-227.40	-228.81
Margin with ref. to Rec. ITU-R RS.1029-2, dB	**61.54**	**58.40**	**59.81**
Margin with ref. to Rec. ITU-R RS.1029-2 with 1% apportionment, dB	**41.54**	**38.40**	**39.81**

Table 5.11: Calculation of LPR impact to Nadir EESS sensors in the adjacent band 86-92 GHz

Note 1: although the ETSI SRDoc TR 102 601 [1] indicates certain market grow up to 2015 resulting in a Maximum expected LPR density per km^2 of 0.00034, in the present Report's table 5.10 and 5.11 it was agreed to use a very conservative figure of 0.001, however still showing a good margin as final result.

Results in Table 5.10 and 5.11 clearly demonstrate that also in this band EESS (passive) operations will be completely unaffected by operation of industrial LPR devices.

6 RISK ASSESSMENT THROUGH STATISTICAL SIMULATION OF CRITICAL SCENARIOS

6.1 Using Monte-Carlo simulations for LPR interference studies

Whereas MCL simulations allow establishing just the maximum range of interference, the statistical simulation methods, such as the Monte-Carlo method implemented by CEPT software tool SEAMCAT, can be used for evaluating realistic probability of interference from LPR devices. However, in order for these simulations to be meaningful, it is important to discern which parameters of interference scenario can be subject to variation.

Traditionally, Monte-Carlo method was conceived and widely used for simulating interference in scenarios that involve mobile services, as their randomness in terms of both place and time of operation submits easily and intuitively to being modelled as a combination of random statistical processes. However, there are many more elements that are random in each and every radio link, which makes possible applying statistical simulation methods also to other services and scenarios, such as the scenario of interference from LPR to fixed services, in which both the interferer and the victim are stationary.

In such essentially stationary environment, the following elements of interference scenario and link budgets may be subject to random variations and could be thus modelled by statistical simulations, using SEAMCAT tool, as follows:

- Non-coherent activity periods of pulsed transmissions of LPR devices – this variation could be modelled by setting the random activity of LPR interferers, with probability of active transmission corresponding to activity factor of LPR devices set to AF=25%, which would correspond to average value for various types of LPR devices, see Table 2.6;
- Varying reflection losses towards the victim receiver – this variation will have an effect that the entire signal emanating from LPR installation (sum of side-lobe component and reflected component) will vary. It is proposed to model this situation in SEAMCAT by defining LPR interferer as a transmitter with zero gain omni-directional antenna and the output power varying within the limits describing the aforementioned sum of side-lobe and reflected component. It is proposed to vary the reflection loss by ±5 dB from the value used in MCL calculations (13 dB), which would correspond to total power emitted in horizontal plane towards victim changing:
    - for LPR operating in 6.0-8.5 GHz band (see Table 5.1 and associated Excel file with MCL simulations): the value of total interfering power towards victim is -24.33 dBm with default static reflection loss of 13 dB. If reflection loss where to be reduced to 8 dB, this would result in total interfering power towards victim of -21.33 dBm; if reflection loss were increased to 18 dB, the interfering power towards victim would become -25.96 dBm. Thus the interfering power range assumed in these SEAMCAT simulations where chosen to be between -21.3…-26 dBm;
    - for 24.05-26.5 GHz band(see Table 5.4 and associated Excel file with MCL simulations): the value of total interfering power towards victim is -8.81 dBm with default static reflection loss of 13 dB. If reflection loss where to be reduced to 8 dB, this would result in total interfering power towards victim of -6.99 dBm; if reflection loss were increased to 18 dB, the interfering power towards victim would become -9.59 dBm. Thus the interfering power range assumed in these SEAMCAT simulations where chosen to be between -7…-9.6 dBm;
- Varying random fading in the propagation path loss for interfering signal, which at longer distances can result in situation when deeper fades can render the interfering station and its signal "invisible" to victim – this could be modelled by a standard randomised fading component of the SEAMCAT's in-built propagation path loss models.

Taking the above factors into account, the rest of this section describes several possible approaches of statistical modelling of, respectively, a scenario with LPR being randomly scattered over wider area, the very rare scenario with a set of closely positioned interferers, or a scenario with LPR being placed stationary within the main beam of FS antenna.

6.2 Scenario with randomly scattered LPR devices

The most typical scenario of LPR interference would be the case when a particular victim receiver is surrounded by an unspecified number of LPR devices, randomly scattered over wider area around the victim. Although each particular LPR device, once installed, becomes stationary and the victim is stationary, it is still reasonable to apply statistical modelling given the variability of factors described in 6.1 above.

Additional random factor which would manifest itself in this case is the height of LPR device above ground, which could vary from 2 m to 50 m, as described previously in section 2.8. Accordingly, the LPR antenna height could be defined in SEAMCAT as random parameter with distribution shown in Figure 6.1.

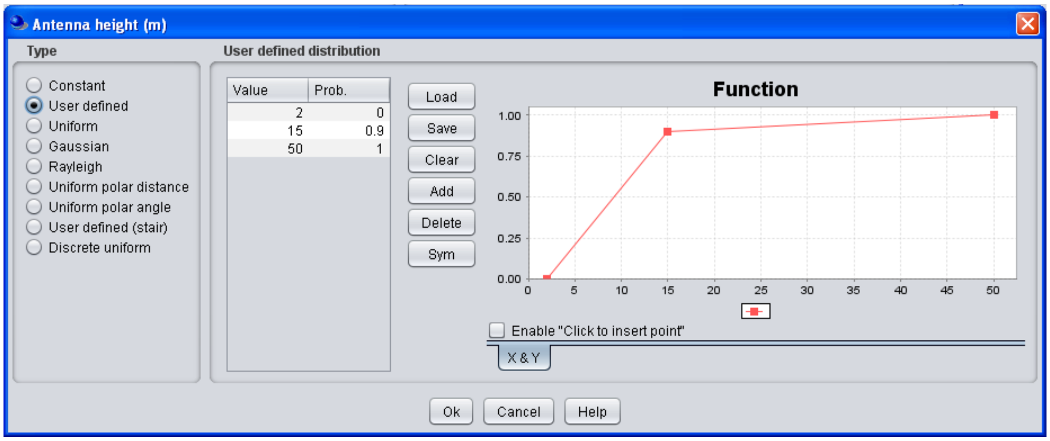

Figure 6.1: Cumulative Distribution Function for LPR antenna height in SEAMCAT simulations

As mentioned in preceding section, the power of LPR could be also modelled as a random parameter, with its values and distribution corresponding to product of the actual total e.i.r.p. reflected in horizontal plane towards victim and the fluctuating ON-OFF time to model the activity factor. The distribution for LPR power used in SEAMCAT is shown in Figure 6.2, see first and second bullet points in section 6.1:

1) the first bullet point gives justification for the 75-25% of time inactivity/activity split (with 75% of inactivity time modelled by a "dummy" power of -100 dBm);

2) the second bullet point describes the reasoning for the actual power levels within LPR activity period (-9.6...-7 dBm values for the 25% of time).

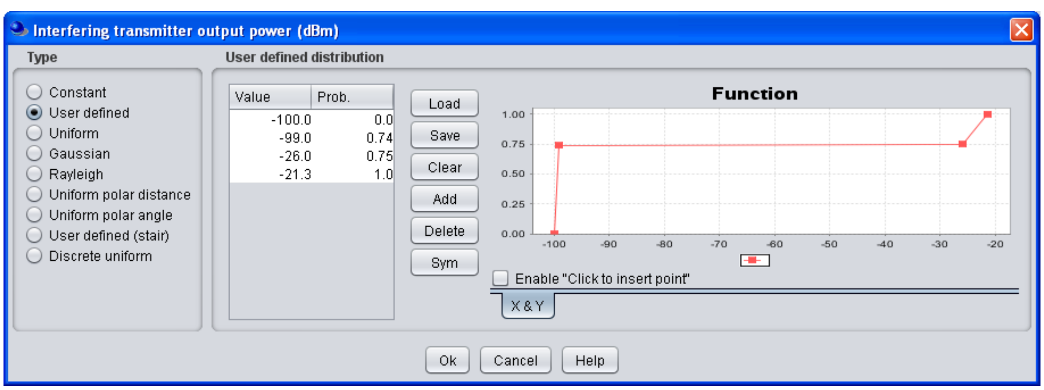

Figure 6.2: Cumulative Distribution Function for LPR total (reflected+side-lobe) e.i.r.p. in SEAMCAT simulations

In order to establish the number of LPR devices to be used in simulations, the reference could be made to estimated densities of LPR devices in different frequency bands, as reported in Table 2.1. For simulations reported here a radius of 30 km around victim FS PP receiver was used, in order to obtain the area of sufficient size that would contain on average more than one LPR device. The graphical outlook of the simulated scenario is shown in Figure 6.3.

Technical parameters of LPR devices and victim PP FS receivers were in accordance with assumptions used previously in MCL calculations reported in section 5, with the following exceptions or additions:

- The propagation modelling on interference path was still done using the Free Space model, given the high probability of line-of-sight conditions for the considered critical scenario. However in these simulations the fading variations were activated as discussed above;

- Height of victim FS antenna was set to 10 m, again to represent the worst case for this kind of FS installations in rural areas;
- Radiation pattern for FS antennas was modelled using ITU-R Recommendation F.699 [22];
- The interference criterion was chosen to be I/N, which again represents worst case by disregarding possible advantage provided in cases of sufficient C/I margins on real links.

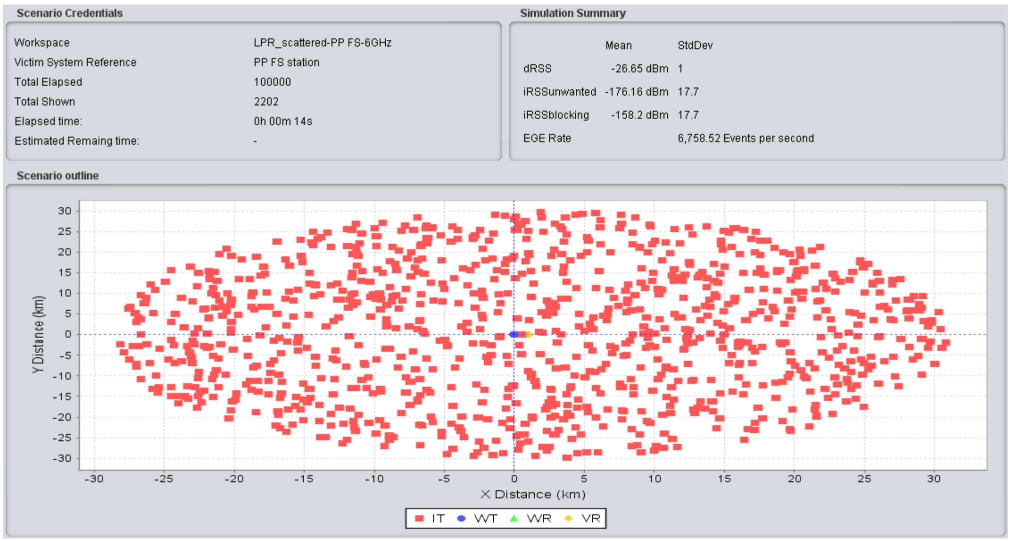

Figure 6.3: Simulated scenario (6.0-8.5 GHz band) with randomly scattered LPRs around the victim PP FS link

The results of simulations in terms of probability of interference (measured using I/N criterion) are reported below in Table 6.1.

Frequency band	LPR density, 1/km^2	Number of LPR devices in area of 30 km radius	Probability of interference to victim (I/N=-20 dB)
6.0-8.5 GHz	0.00034	1	0…$1 \cdot 10^{-5}$
6.0-8.5 GHz	0.0034 (Note 1)	10	$5 \cdot 10^{-5}$
24.05-26.5 GHz	0.00238	7	$1.5 \cdot 10^{-4}$
24.05-26.5 GHz	0.0238 (Note 1)	70	$9 \cdot 10^{-4}$

Table 6.1: Results of simulating scenario with randomly scattered LPRs around the victim PP FS link

Note 1: projected density of LPR devices increased ten-folds compared with values estimated by ETSI (see [1] and Table 2.1) to test the sensitivity of interference potential to possible very long term future growth of LPR market. These, even unrealistic, high numbers were used in order to alleviate any doubts regarding the interference risk of future developments.

It may be noted from the results in Table 6.1 that in all considered cases and frequency bands the probability of interference to victim radiocommunications receiver such as PP FS links remains extremely low.

6.3 Scenario with Multiple Close-range Interferers

In order to establish the extreme limits of probability of interference, a very rare scenario could be considered that was previously mentioned in section 2.1, such as an example of industrial water processing plant with large number of LPR devices installed in an open area of limited size. This could be, for example, a sewage water treatment plant with multiple water tanks (called “sedimentation tanks”) regularly spaced throughout the plant area, each tank being equipped with an LPR device for monitoring water level.

Let us consider that a mast is being erected nearby to host the antennas of a base station of mobile network, which would use PP FS link for backhaul connection to the main network. This scenario is schematically depicted in Figure 6.4, even in this case showing some worst case assumption, namely that the PP FS antenna would be facing the water plant.

The minimum separation distance of 100 m was chosen as it was shown by MCL simulations reported in previous section that such distance may be recommended as a safe separation distance to be respected by all LPR installations. It could be also imagined that such distance would be still within the control of entity operating the facility that employs LPR devices, therefore it should be easy to oversee respecting this distance also for future new radio sites, i.e. some third party asking for erection of new radio site on the water plant territory would be advised by the plant owner that LPRs are being used on the facility so that the safe separation distance could be respected.

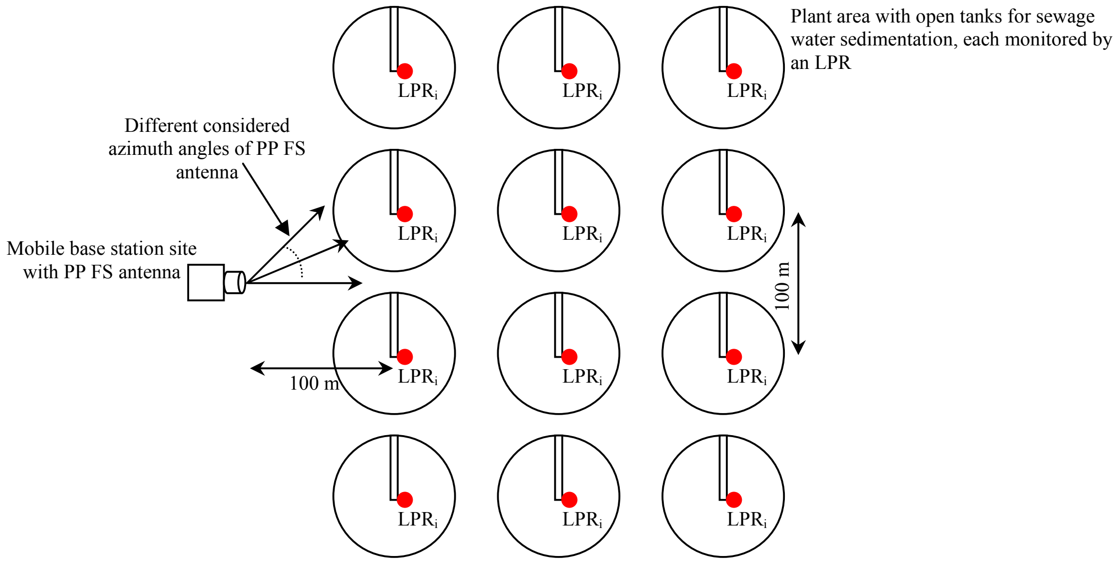

Figure 6.4: Modelled scenario of FS PP antenna facing sewage water treatment plant with multiple LPR devices

It should be recognised that the size of the modelled plant and the number of sedimentary tanks is but just one example. However it was believed that the chosen values would reasonably well represent a real water treatment plant and possible occurrence of worst case configuration of victim antenna with regard to interferers.

Most of technical radiocommunications parameters (frequency, channel sizes, victim antenna gain, etc) for this interference scenario were the same as those originally used in relevant MCL simulations reported in section 5 and in the scenario with randomly scattered LPR devices reported in section 6.2. The only exception to the latter was that the height of interfering LPR devices was set to constant 2 m (which is considered suitable for this type of application where water tanks are mounted in the ground and water level could not become much higher than the ground level) while the height of victim FS receiver was increased to 50 m corresponding to installation on a top of the mast or chimney, as is often the case for mobile base stations installed in industrial environment.

As previously, the SEAMCAT scenario files used for simulations are attached to this Report. The graphic outline of scenario simulated in SEAMCAT is shown in Figure 6.5.

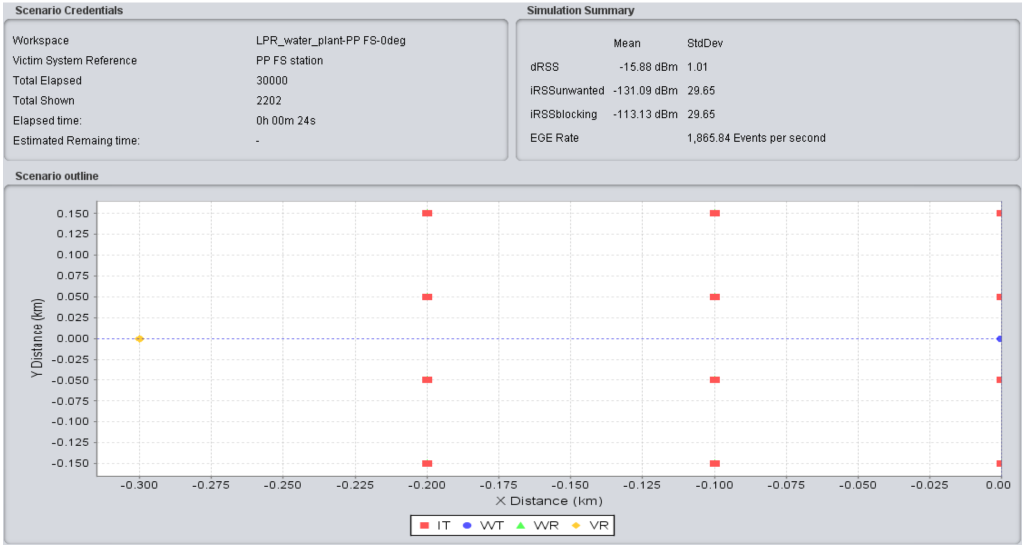

Figure 6.5: Simulated scenario with multiple LPRs at a water plant close to victim PP FS link

The results of simulations for LPRs operating in the band 6.0-8.5 GHz may be summarised in illustrative manner in the following Figure 6.6 that shows calculated probability of interference for different exposure angles of PP FS antenna.

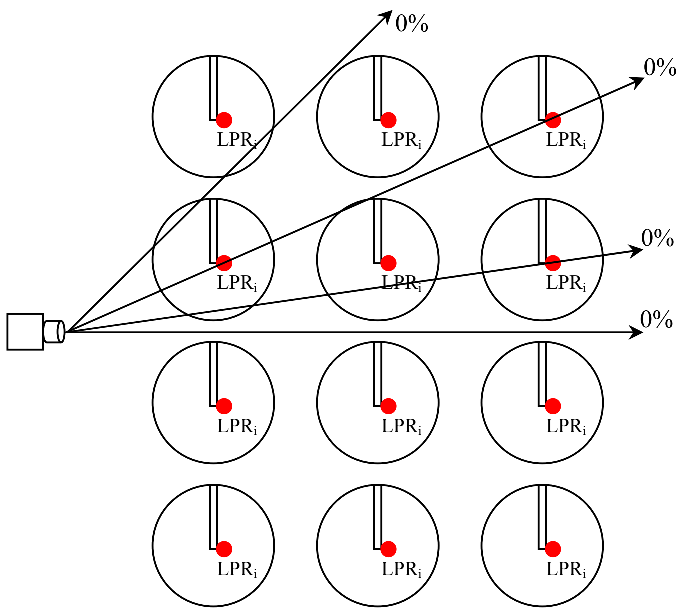

Figure 6.6: Results of statistical simulations in 6.0-8.5 GHz band of FS PP antenna facing water treatment plant, for various orientation angles of FS antenna with regard to LPR pattern

The results of simulations reported above show that interference from LPR in a typical worst case static scenario is very unlikely. In this case it could be explained by the fact that signal from LPR devices positioned closely to the highly directional victim antenna will be reduced by vertical discrimination of victim antenna. Condition of direct line of sight inherently required by FS link installation rules will mean that no obstacles (including LPR installation structures) are likely to be positioned in the main beam of FS antenna.

6.4 Scenario with LPR in the main beam of FS receiver antenna

Another critical case identified by MCL studies in section 5 is the case when LPR would be placed in the main beam of the PP FS receiver antenna. MCL calculations have shown that in such case the maximum interference range may be reaching up to 1.0-1.9 km under worst case conditions. The simulations reported in this sub-section therefore looked at the statistical probability of interference in such critical scenarios.

The departing point for this simulation was observation that the proposed limit for LPR radiation in horizontal plane at 26 GHz is -41 dBm/MHz e.i.r.p.; this limit seems to be required for worst case LPR configurations and reflections. Due to the high directivity of LPR antennas it can be assumed that this maximum limit on the outside of LPR installation can just be reached in small parts of the virtual half-sphere surrounding the LPR installation, or in other words: the -41dBm/MHz can not be assumed for all parts of the half-sphere simultaneously. It is unrealistic worst case to assume the max e.i.r.p. value as an isotropic radiator.

To take this effect into account the following simulation was proposed with SEAMCAT:

- Both, the FS link and the LPR installation were fixed with antenna heights of 10m and LPR being in the main beam of victim FS antenna at distances between 200 m and 1km,
- a fixed FS antenna with 41dBi maximum gain from ITU-R F.699 (elevation and azimuth fixed to 0°) [22],
- the “unwanted/undesired emissions” of the LPR installation were simulated as transmitter with a directional antenna (25dBi maximum gain, see radiation pattern in Figure 6.7), which transmits -41dBm/MHz e.i.r.p. in the main beam,
- the pointing of the “unwanted” LPR antenna was randomly changed within the angular limits of half-sphere with the centre at LPR device.

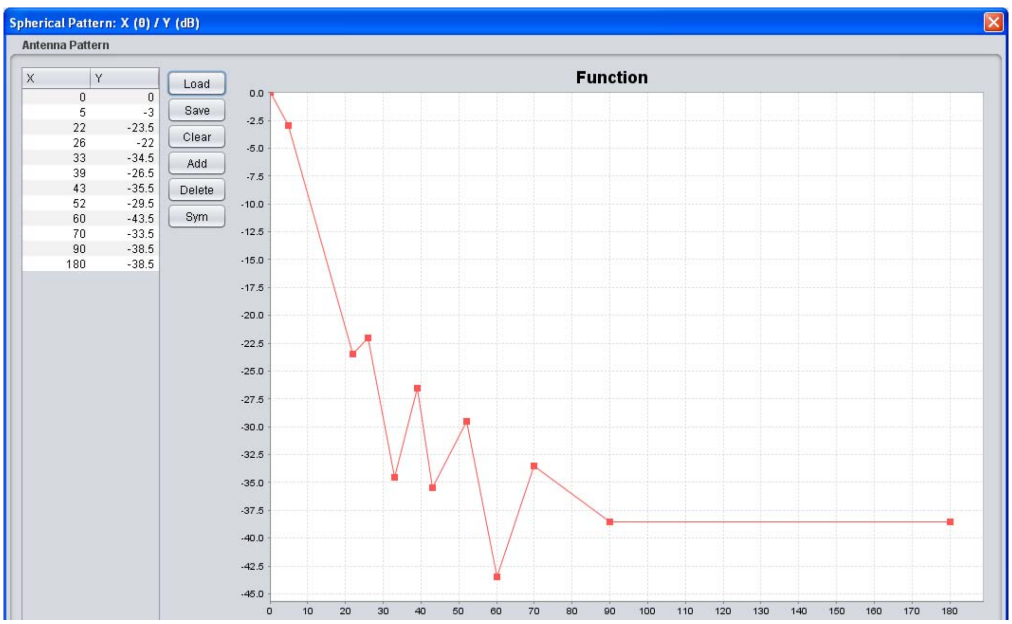

Figure 6.7: Radiation pattern for realistic 24 GHz LPR antenna

In addition to the above assumptions, also the impact of Adaptive Power Control (APC) was modelled for interfering LPR device in order to evaluate its impact on probability of interference in this critical co-existence scenario.

All important parameters of simulated scenarios along with their respective probabilities of interference, as simulated by SEAMCAT, are reported in Table 6.2 (without APC).

SEAMCAT input	Parameters	Unit	Simulated cases					
			A	B	C	D	E	F
X	FS antenna gain	dBi	41					
X	FS antenna pattern		F.699					
X	FS antenna height	m	10					
X	FS elevation	Deg	0					
X	**Distance LPR – FS**	**km**	**1**	**0.5**	**0.2**	**0.1**	**0.1**	**0.1**
	LPR max power towards victim (e.i.r.p.)	dBm/MHz	-41.3					
	APC range	dB	0 (i.e. no APC)					
X	LPR antenna height	m	**10**	**10**	**10**	**8**	**6**	**10**
X	LPR antenna maximum gain	dBi	25					
X	LPR antenna pattern		Envelope of pattern in Figure 6.7					
X	LPR simulated power	dBm/MHz	-66					
X	Interference criterion (Note 1)	dBm/MHz	-128					
X	LPR antenna elevation		0-90					
X	LPR antenna azimuth	Grad	0-360					
RESULTS	Mean iRSS	dBm/MHz	-156	-149.5	-141.5	-135.5	-139.5	-151
RESULTS	**Probability of interference**	**%**	**0.4**	**1.3**	**3.3**	**8.9**	**4.4**	**1.2**

Table 6.2: Parameters and results of statistical simulation of LPR without APC

Note 1: Interference criterion is set as acceptable noise level: (kTBF for B=1 MHz) – 20 dB, which corresponds to I/N=-20 dB objective.

In addition, simulations were conducted assuming 20 dB APC. The results are provided in Table 6.3.

SEAMCAT input	Parameters	Unit	Simulated cases					
			A’	B’	C’	D’	E’	F’
X	FS antenna gain	dBi	41					
X	FS antenna pattern		F.699					
X	FS antenna height	m	10					
X	FS elevation	Deg	0					
X	Distance LPR – FS	km	1	0.5	0.1	0.1	0.1	0.2
	LPR max power towards victim (e.i.r.p.)	dBm/MHz	-41.3					
	APC range	dB	20					
X	LPR antenna height	m	10	10	10	8	6	10
X	LPR antenna maximum gain	dBi	25					
X	LPR antenna pattern		Envelope of pattern in Figure 6.7					
X	LPR simulated power	dBm/MHz	-66 to -86					
X	Interference criterion (Note 1)	dBm/MHz	-128					
X	LPR antenna elevation		0-90					
X	LPR antenna azimuth	Grad	0-360					
RESULTS	Mean iRSS	dBm/MHz	-165	-159	-151.5	-145	-149	-145
RESULTS	**Probability of interference**	**%**	**0.09**	**0.3**	**1.2**	**2.6**	**1.70.3**	**0.3**

Table 6.3: Parameters and results of statistical simulation of LPR with APC

The SEAMCAT simulations show that the probability of interference from LPR to the FS may be critical for distance of less then 100m. It shows additionally that APC with a dynamic range of 20dB (as proposed by the ETSI SRDoc TR 102 601 [1]) is able to reduce the probability of interference essentially. Those conclusions may be applied also in other bands in order to reduce the requested separation distance (i.e. for RAS and GEO FSS at 6 GHz). This is analysed in following sub-section 6.5.

Looking at the results of simulations reported in Table 6.3 it may be concluded that, when LPR with APC is placed in the main beam of PP FS receiver, the simulated probability of interference is up to 2.6%, depending on configuration of technical parameters. However again it should be stressed, that this modelled scenario was in itself a rare occurrence of LPR being placed within the main beam of PP FS antenna. It is worth to say that the very small beamwidth of PP FS antennas (1-3°) –see table 5.1 and 5.4 footnote- may lead to a simple geometric consideration suggesting that likelihood of LPR falling within the angular opening of 3° is equal to relationship of areas of 3°-width sector to the entire 360° circle area, which is 1/120 or roughly 1%(=0.01) with the probability of producing interference estimated as 2.6%(=0.026) i.e. table 6.3. Thus the cumulative total probability is 0.026x0.01=0.00026=0.026%.

Since this scenario was one of the identified critical co-existence cases, some additional testing of real-life interference was done by using commercial off-the-shelf PP FS and LPR equipment in the same configuration with LPR being placed in the main beam of PP FS receiver. Results of this testing are reported in Annex 4 of this Report, which clearly show no danger of interference from LPR placed at close ranges within main beam of PP FS antenna, as long as LPR is mounted with downward antenna orientation. The latter should not be a problem since antenna orientation rule is to be included within the proposed set of LPR installation requirements and also if LPR were installed by violating this rule then it could not meet operational level measurement by which LPR is designed for and expected to provide.

6.5 Scenario with LPR within impact range of RAS

Following on the realistic modelling case with LPR being placed at close range to PP FS victim receiver, the similar study was performed for the assumed worst-case occurrence of LPR being placed within the impact range (i.e. the maximum possible LPR impact range calculated through MCL simulations reported in section 5) of RAS stations. These calculated maximum impact ranges for victim RAS receiver are (in-band interference to narrowband single line observations) – 3427 m in 6 GHz band, 1196 m in 24 GHz band, and 3012 m in 75 GHz range.

The set-up for SEAMCAT simulations was identical to the one used in previous study reported in sub-section 6.4, with the following changes required to reflect different nature of victim stations:

- Since for the RAS case the interfering signal is coupled to victim receiver via victim antenna side-lobes, the victim antenna gain was set accordingly and no antenna pattern was set;
- The noise floor was adjusted to correspond to the values relevant to RAS victim stations.

Note that the Recommendation ITU-R RA.769 [12] prescribes using RAS antenna side-lobe gain of 0 dBi for evaluating interference arriving along terrestrial paths.

No changes were made to the definition of LPR interferer; both cases with and without APC were considered just as was done for the study within PP FS main beam.

The results of simulations for the case of placing LPR within impact range of RAS are reported in Tables 6.4-6.5 for RAS in 6 GHz range, Tables 6.6-6.7 for RAS in 24 GHz range, and Tables 6.8-6.9 for RAS in 77 GHz range. In each pair of tables the first table shows results without APC on LPR device and second table showing results with APC employed.

SEAMCAT input	Parameters	Unit	Simulated cases					
			A	B	C	D	E	F
X	RAS antenna gain (side lobes)	dBi	0					
X	RAS antenna height	m	10					
X	RAS elevation	deg	0					
X	**Distance LPR – RAS**	**km**	**3.5**	**3**	**2**	**1**	**0.5**	**0.1**
	LPR max power towards victim (e.i.r.p.)	dBm/MHz	-55					
	APC range	dB	0 (i.e. no APC)					
X	LPR antenna height	m	**10**					
X	LPR antenna maximum gain	dBi	18					
X	LPR antenna pattern		Envelope of pattern in Figure 6.7					
X	LPR simulated power	dBm/MHz	-73 (Note 1)					
X	Interference criterion	dBm/MHz	-177.9					
X	LPR antenna elevation		0-90					
X	LPR antenna azimuth	Grad	0-360					
RESULTS	Mean iRSS	dBm/MHz	-209.4	-208	-204.5	-198.5	-192.5	-178.5
RESULTS	**Probability of interference**	**%**	**0.095**	**0.24**	**0.5**	**1.4**	**2.8**	**35.6**

Note 1: LPR power derived with reference to horizontal emissions limit and LPR antenna gain: $EIRP_{limit} – G_a^{LPR}$=-55-18=-73 dBm.

Table 6.4: Parameters and results of statistical simulation of LPR within impact range of RAS station at 6650 MHz, <u>without</u> APC

SEAMCAT input	Parameters	Unit	Simulated cases					
			A’	B’	C’	D’	E’	F’
X	RAS antenna gain (side lobes)	dBi	0					
X	RAS antenna height	m	10					
X	RAS elevation	deg	0					
X	**Distance LPR – RAS**	**km**	**3**	**2**	**1**	**0.5**	**0.2**	**0.1**
	LPR max power towards victim (e.i.r.p.)	dBm/MHz	-55					
	APC range	dB	20					
X	LPR antenna height	m	**10**					
X	LPR antenna maximum gain	dBi	18					
X	LPR antenna pattern		Envelope of pattern in Figure 6.7					
X	LPR simulated power	dBm/MHz	-73…-93 (Note 1)					
X	Interference criterion	dBm/MHz	-177.9					
X	LPR antenna elevation		0-90					
X	LPR antenna azimuth	Grad	0-360					
RESULTS	Mean iRSS	dBm/MHz	-218	-214.5	-208.5	-202.4	-194.6	-188.4
RESULTS	**Probability of interference**	**%**	**0.035**	**0.06**	**0.3**	**1.1**	**2.9**	**9.4**

Note 1: Upper limit for LPR power range derived with reference to horizontal emissions limit and LPR antenna gain: $e.i.r.p._{limit} – G_a^{LPR}$=-55-18=-73 dBm. Lower limit obtained by applying APC effect of maximum 20 dB.

Table 6.5: Parameters and results of statistical simulation of LPR within impact range of RAS station at 6650 MHz, <u>with</u> APC

Analysis of results of simulations of LPR interference to RAS in 6 GHz range illustrates the importance of APC for reducing the interference potential. When employing APC the fixed LPR installation as close as 100 m from RAS the statistical probability of interference will be nearly 10%, and below 3% for separation distance of 200 m, the distance which is also within the “visibility awareness limit”.

7 CONCLUSIONS

The evaluation of maximum interference ranges from LPR devices deployed in different candidate bands was carried out using MCL deterministic approach, by applying worst-case of a single nearest LPR installation to victim receiver and related assumptions (direct LOS and main-beam coupling, Free Space Loss model, no clutter/roof/wall losses, etc). The results of this analysis for identified critical victim incumbent radiocommunications services in respective bands are summarised below in Table 7.1.:

Victim incumbent radiocommunications service	**MCL worst-case** **Maximum interference range from a single LPR device, meters**
Frequency band 6000-8500 MHz	
Point-to-Point (radio relay link) FS receiver	1021
FSS Earth Station receiver	33
Military FSS ES receiver (Syracuse-2 type)	90
Radio Astronomy Station	3427
Frequency band 24.05-26.5 GHz	
PP FS receiver	1935(civil) / 4282(military)
PMP Base (Central) Station receiver	97
PMP Terminal Station receiver	3
Radio Astronomy Station	1196
Frequency band 57-64 GHz	
PP FS receiver (MGWS/FLANE)	290
Radar	245
ITS Road Side Unit receiver	75
Frequency band 75-85 GHz	
PP FS receiver	315
Radio Astronomy Station	2088

Table 7.1: Maximum interference ranges of LPR devices under worst-case conditions (direct LOS, etc. – see comments below) using MCL evaluation method.

Looking at table 7.1 it may be concluded that other than for RAS, in most practical cases the interference range from a single LPR device is limited to below 100 m even under worst possible assumptions. The longer impact ranges might have been possible only for LPR devices placed directly within the main beam of PP FS links; however the spatial likelihood of such occurrence is by itself extremely low, given the very narrow beam widths of PP FS antennas (1-3^{o}) –see table 5.1 and 5.4 footnote. Similarly, it is highly unlikely to have military radars operating at distances like 245 m from civil buildings and industrial sites.

Regarding the interference to in-band and adjacent band EESS (passive) services, in all considered bands analysis has shown that aggregated LPR emissions from pan-European deployment do not exceed interference objectives by sufficient margin.

In addition to MCL-based analysis, detailed probabilistic risk analysis was carried out to evaluate the probability of interference for identified critical cases only, as well as impact of aggregation of LPR devices. The analysis reported in section 6 confirmed or even made better the overall findings of MCL analysis. The results of statistical SEAMCAT simulations show that LPR with active Automatic Power Control (APC) with a dynamic range of 20 dB, as proposed in the ETSI SRDoc TR 102 601 [1], is able to reduce the probability of interference.

LPR with APC may be deployed as close as around a hundred meters from victim FS or RAS receiver without posing significant risk of interference, see summary of results of simulations in Table 7.2.

Therefore APC should be considered as an essential technical requirement for license exempt regulation in the bands 6.0-8.5 GHz, 24.05-26.5 GHz and 75 – 85 GHz. For a licensing solution APC may not be required, but the LPR locations would need to be coordinated with FS, RAS and FSS earth stations.

Victim	Probability of interference at distance, %		
	500 m	200 m	100 m
PP FS (LPR within main beam) in 24 GHz band	0.3	1.2	2.6
RAS in 7 GHz band	1.1	2.9	9.4
RAS in 24 GHz band (adjacent band interference)	0.6	1.7	5.1
RAS in 77 GHz band	0.4	1.3	3.0

Table 7.2: Probabilistic risk assessment for identified critical scenarios for LPR with APC activated

These statistical simulations were validated by an additional real-life testing of interference using commercial PP FS and LPR equipment in 24-26.5 GHz band, with LPR being placed at close range in the main beam of PP FS antenna, as reported in Annex 4. These tests showed no occurrences of interference as long as LPR antenna was directed strictly downwards. The compliance with latter requirement should not cause any concerns because:

- antenna orientation rule is to be included within the set of LPR installation requirements, and
- more importantly, if LPR were installed by violating this rule then it simply could not fulfil its intended operational function of measuring level variations of a material/surface underneath the device.

The findings of this Report include the following proposals in order to ensure compatibility between LPR and incumbent radiocommunications services in subject bands:

1. LPR devices have to operate only with dedicated/integrated certified antennas as specified in the following Table 0.1 (Column C) below,
2. LPR device (complete unit of transmitter with dedicated/integrated antenna) should comply to Mean e.i.r.p. spectral density and Peak e.i.r.p. (both within main beam), as specified in the following Table 0.1 (Columns A and B). Results of experimental tests have shown that it is impractical to perform radiated measurements on the half sphere (see §2.9), while it was shown that both radiated and conducted power measurements in the main beam of LPR are possible and thus represent the only practical solution,
3. Compliance to the main beam limits above is expected to correspond to maximum mean e.i.r.p. spectral density values emitted to the half sphere around the LPR installation (see Table 0.1, Column D) according to the investigations in the present Report,
4. Strict downwards orientation of LPR antennas is an essential installation requirement (LPR must naturally follow this rule otherwise its operational measurement sought performances cannot be achieved);
5. Automatic Power Control (APC) with a dynamic range of 20 dB, as proposed in the ETSI SRDoc TR 102 601 [1], is able to reduce the probability of interference and therefore APC should be considered as an essential technical requirement that allows license-exempt deployment of LPR in all considered bands.

   In addition to APC, the RAS stations (a list of presently known sites is provided in Annex 3)should be additionally protected as follows:

   a. From 0 km to 4 km radius around any RAS station, installation of LPR devices operating in 6.6 GHz, 24 GHz and 75 GHz bands should be prohibited unless a special authorisation has been provided by the responsible national administration.
   b. Between 4 to 40 km, the antenna height of a LPR installation should not exceed 15 m height.

6. Without the APC requirement, indoor LPR installation may be used on a licence-exempt basis provided they comply with the same requirement for protection of RAS stations as in sections 5.a and 5.b clauses above.

   For outdoor installations of LPR without APC, some additional administrative safeguards will need to be implemented in order to guarantee their interference-free operation, for example on-line site clearance and database registration as a part of a “light-licensing” regime, which would be designed to ensure the compliance with the sufficient separation distances as established by studies in this Report. A separation distance of 2 km was found to be sufficient for all the bands and for all services, except the RAS which is 4 km as outlined in clause 5.a above.

Frequency band *(Note 1)*	**Maximum Mean e.i.r.p. spectral density (dBm/MHz)** *(Notes 2 and 6)*	**Maximum peak e.i.r.p. (dBm measured in 50 MHz)** *(Notes 3 and 6)*	**Maximum antenna beamwidth, deg** *(Note 4)*	**Guidance for maximum mean e.i.r.p. spectral density on half-sphere (dBm/MHz)** *(Notes 5 and 6)*
	A	**B**	**C**	**D**
6.0-8.5 GHz	-33	+7	12	-55
24.05-26.5 GHz	-14	+26	12	-41.3
57-64 GHz	-2 (Note 7)	+35 (Note 7)	8	-41.3
75-85 GHz	-3 (Note 7)	+34 (Note 7)	8	-41.3

Table 7.3: Essential technical requirements for LPR devices

Notes:

(1) Operational frequency band for UWB emissions defined by the -20 dBc level.

(2) Mean e.i.r.p. density, within mainbeam, means the mean power measured with a 1MHz resolution bandwidth, a root-mean-square (RMS) detector and an averaging time of 1 ms or less.

(3) Peak e.i.r.p. density, within mainbeam, means the peak level of transmission contained within a 50MHz bandwidth centred on the frequency at which the highest mean radiated power occurs. If measured in a bandwidth of x MHz, this level is to be scaled down by a factor of 20log(50/x) dB.

(4) Defined by -3 dB level. In ETSI TR102 601 [1] expressed as ± HalfBeamWidth (here as total opening angle). The antenna gain in the elevation angles above 60 degrees from the main beam direction has to fulfil a maximum value of -10 dBi.

(5) The maximum mean e.i.r.p. spectral density limits on half sphere accounts for both the LPR antenna side-lobe emissions and any reflections from the measured material/object, as illustrated in section 3.2 (Figure 3.1). Here the LPR antenna side-lobe gain was assumed as -10 dBi at elevation above 60° from the main beam and the reflection was simulated with a reflection loss of 13 dB (fine dry sand with an angle of repose of 33° in direction of the victim receiver). Compliance with these limits is expected to be fulfilled as long as LPR devices comply with measured Mean/Peak e.i.r.p. spectral density limits within main beam (Table 0.1, Columns A and B) and use the prescribed antenna (see note 4 above).

(6) The related limits in unwanted emissions domain radiated by LPR are those as listed in Table 4.1 for the LPR operating in 6.0-8.5 GHz band. For LPR operating in other bands the unwanted emissions e.i.r.p density should be at least 20 dB less than the in-band limits specified in Table 0.1 (Columns A, B and D). For LPR operating in the 24 GHz band, the unwanted emissions in the 23.6 to 24.0 GHz "passive band" should be 30 dB less than the in-band limits specified in Table 0.1 (Columns A, B and D), as additional cautionary measure in respect to RAS.

(7) Mean and peak power within the LPR main beam, operated in frequency bands 57-64 GHz and 75-85 GHz, are increased compared the values originally requested by ETSI SRDoc TR 102 601 [1] in order to meet the identified operational requirements of higher power at these high frequencies, while still respecting the generally established safe equivalent maximum mean e.i.r.p. density on half-sphere (Table 0.1, Column D). For further details see sections 5.3.1, 5.4.1 and Annex 5 of the Report.

Finally is worth to note that simulations and calculations made were supported by one specific actual (field) test. This test was performed using commercial PP FS and LPR equipment in 24-26.5 GHz band, with LPR being placed at close range near to the main beam of PP FS antenna, as reported in Annex 4. These tests showed no occurrences of interference as long as LPR antenna was directed strictly downwards.

ANNEX 1: LIST OF REFERENCES

[1] ETSI SRDoc TR 102 601 ERM System reference document: Level Probing Radar (LPR)-sensor equipment operating in the frequency bands 6 GHz to 8.5 GHz; 24.05 GHz to 26.5 GHz; 57 GHz to 64 GHz and 75 GHz to 85 GHz. Version 1.1.1 (2007-12)

[2] ETSI EN 302 372: Short Range Devices (SRD);Equipment for Detection and Movement;Tanks Level Probing Radar (TLPR) operating in the frequency bands 5,8 GHz, 10 GHz, 25 GHz, 61 GHz and 77 GHz

[3] ERC Recommendation 70-03: Short Range Devices (SRD)

[4] Directive 99/5/EC (9 march 1999) of the European Parliament and of the Council relating radio equipment and telecommunications terminal equipment and the mutual recognition of their conformity

[5] Klaus Kark, Antennen und Strahlungsfelder (Figure 14.9) , Vieweg, 2006

[6] ERC Report 025 The European table of frequency allocations and utilisations in the frequency range 9 kHz to 3000 GHz (September 2008)

[7] ECC Report 064 on Protection Requirements of Radiocommunications Systems Below 10.6 GHz from Generic UWB Applications (February 2005)

[8] ECC Report 023 on Compatibility of Automotive Collision Warning Short Range Radar Operating at 24 GHz with FS, EESS, and Radio Astronomy (May 2003)

[9] ECC Report 114 on Compatibility studies between Multiple Gigabit Wireless Systems in frequency range 57-66 GHz and other services and systems (except ITS in 63-64 GHz) (September 2007)

[10] ECC Report 113 on Compatibility studies around 63 GHz between Intelligent Transport Systems (ITS) and other systems (September 2007)

[11] ECC Report 124 on Coexistence between Fixed Service operating in 71-76/81-86 GHz and the passive services (September 2008)

[12] ITU-R Recommendation RA.769 on Protection criteria used for radio astronomical measurements

[13] Recommendation ITU-R SA.509: Space research earth station and radio astronomy reference antenna radiation pattern for use in interference calculations, including coordination procedures

[14] ECC Report 123: The impact of Object Discrimination and Characterization (ODC) applications using Ultra-Wideband (UWB) technology on radio services

[15] ECC/DEC/(06)04 on the harmonised conditions for devices using UWB technology in bands below 10.6 GHz

[16] CEPT Report 017 Report from CEPT to the European Commission in response to the Mandate to: identify the conditions relating to the harmonised introduction in the European Union of radio applications based on Ultra-WideBand (UWB) technology (2007)

[17] ECC/DEC(07)01 on specific Material Sensing devices using Ultra-Wideband (UWB) technology (amended 26 June 2009)

[18] ECC/DEC/(04)10 on the frequency bands to be designated for the temporary introduction of Automotive Short Range Radars (SRR) (2004/545/EC) and (2005/50/EC) amended 5 September 2007

[19] ITU-R Report SM.2057: Studies related to the impact of devices using ultra-wideband technology on radiocommunication services

[20] ITU-R Recommendation SM.1757: Impact of devices using ultra-wideband technology on systems operating within radiocommunication services

[21] Decision 2006/771/EC on the harmonisation of the radio spectrum for use by short-range devices

[22] ITU-R Recommendation F.699 on Reference radiation patterns for fixed wireless system antennas for use in coordination studies and interference assessment in the frequency range from 100 MHz to about 70 GHz

[23] ITU-R Recommendation P.676 on Attenuation by atmospheric gases

[24] ITU-R Recommendation RS.1029 on Interference criteria for satellite passive remote sensing

ANNEX 2: EVALUATING REFLECTION LOSSES FOR MATERIALS MEASURED BY LPR

A2.1 Introduction

This annex provides explanation of the basic theory of reflectivity as well as supporting results of practical measurements that are relevant to establishing the levels of scattered emissions generated from operation of LPR devices. It therefore provides reasoning and justification for the reflection levels that have been used in interference calculations provided in this Report.

A2.2 Theoretical consideration of overall reflection losses in LPR measurement scenarios

A2.2.1 Reflection losses due to reflection coefficient

In various text books the theory of reflection has been described. Two cases are studied for ideally smooth half spaces with incident electromagnetic waves. The reflection coefficients for E-wave parallel to surface of incidence as well as for case of perpendicular incidence are given by the following formulae[3]:

$$\rho_{parallel} = \frac{-\frac{\varepsilon_2}{\varepsilon_1}\cos(\theta_i) + \sqrt{\frac{\varepsilon_2}{\varepsilon_1} - \sin^2(\theta_i)}}{\frac{\varepsilon_2}{\varepsilon_1}\cos(\theta_i) + \sqrt{\frac{\varepsilon_2}{\varepsilon_1} - \sin^2(\theta_i)}} \qquad (1)$$

$$\rho_{perpendicular} = \frac{\cos(\theta_i) - \sqrt{\frac{\varepsilon_2}{\varepsilon_1} - \sin^2(\theta_i)}}{\cos(\theta_i) + \sqrt{\frac{\varepsilon_2}{\varepsilon_1} - \sin^2(\theta_i)}} \qquad (2)$$

where:

ε – is the relative dielectric constant of given propagation media,
θ – is the angle of incidence from normal.

In case of incident waves, i.e. falling perpendicular to the surface, which arrive from the air (ε_{air}=1), equations (1-2) may be simplified to:

$$|\rho| = \frac{|1-\sqrt{\varepsilon_2}|}{|1+\sqrt{\varepsilon_2}|} \qquad (3)$$

Reflection loss may be then determined from the reflection coefficients by:

$$RL = 20\log_{10}(|\rho|) \qquad (4)$$

For instance, in the case of normal angles of incidence, the theoretical reflection loss of calm water surface (ε_{water} = 81) will be 1.9 dB, which may be used to evaluate the reflected energy radiated in vertical plane (e.g. towards satellite receivers).

The value of relative dielectric constant is obviously very important factor in above calculations, however establishing it is not always straightforward. It may be established with certainty only for the homogenous media, such as air (ε=1) or water (ε=81). For the stone-like materials the inherent ε is normally in the range of 4-7, however in the considered cases of LPR applications, what is normally measured is some kind of finely granulated "flow-able" mixtures, such as sand. In this case the composite dielectric constant is affected by the fact that a certain proportion of air is present between the granules, the proportion which naturally depends on the size and shape of the granules. For such composite mixtures, the "effective dielectric constant" could be expressed using a Maxwell-Garnets law[4], which states that for the mixture having a proportion μ of certain dielectric material (own dielectric constant ε) with the air, the effective dielectric constant would be:

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[3] Kraus J.D., Fleisch D.A., *Electromagnetics with applications*, McGraw-Hill 1999 5th Ed. NY USA
[4] Ari Shivola, *Electromagnetic mixing*, IEE 1999

$$\varepsilon_{eff} = 1 + \frac{3\mu(\varepsilon - 1)}{2 + \varepsilon - \mu(\varepsilon - 1)} \quad (5)$$

Numerically within a wide range of ε the equation (5) can be expressed as a decrease of 6 dB if μ is 0.5 and a decrease of 4 dB for μ=2/3. For instance ε=80 and μ=0.5 will give ε_{eff}=3.8 illustrating the dominating influence of the dielectric material (air) with the lowest ε. ε_{eff}=3.8 gives reflection ~-10 dB. For more typical stone-like granulated materials with ε~ 4-7 the effective reflection will be around -12 dB.

It may be however noted that obtaining analytically precise value of mixture proportion (μ) should be very difficult for the typical "irregular" mixtures that are subject to LPR measurements, such as sand, coal, etc, and therefore the practical measurements would often offer the only practical alternative. It has been thus established (and verified by measurements reported below in this annex) that for the fine dry sand the typical ε_{eff}=2.38, which would correspond to a "solid ε" of 6.2 and filling factor μ=0.5.

The reflection loss curves obtained using equations (1-2) and (4) for dry sand with ε_{eff}=2.38 are shown in Figure A2.1 below.

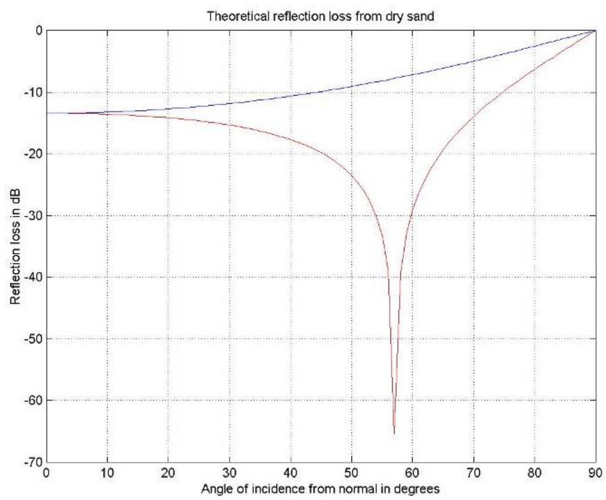

Figure A2.1: Theoretical reflection losses due to reflection coefficient for dry sand with ε_{eff}=2.38 (blue curve for perpendicularly polarised waves, red curve for parallel polarised waves)

An important characteristic of fine material heaps is that they all have a certain maximum angle of repose. For fine dry sand this is 33º (which then also equals to the incidence angle, since the LPR beam is directed vertically downwards). When wet sand is heaped, it could show larger angles of repose but also the shape gets much coarser which leads to scattering and lower e.i.r.p. of the reflections.

From Figure A2.1 it can be determined that at 33 degrees of incident angle the worst case reflection loss over sand with ideally flat and even surface would be about 11.5 dB. For the case of normal incidence to the flat bed of sand using equation (4) would produce theoretical worst case of reflection loss for fine sand of 13.4 dB.

However the above assumptions of ideal surfaces are difficult to apply for practical scenarios, therefore the following two sections discuss the impact of surface unevenness and the varying macro-shape of practical formations of measured solids.

A2.2.2 Impact of surface unevenness as related to granularity of reflecting material

The reflection from a smooth or rather smooth surface can be thought of as a "specular reflex" (mirror reflex) that produces a scattered beam containing all power which was not absorbed by the material (i.e. main beam minus reflection loss due to reflection coefficient as discussed in previous section A2.2.1). The imperfection (unevenness) of the reflecting surface will result in scattering of the reflected beam, which may be described as a dispersion of amplitude in a given particular direction towards interferer. This will have an effect of additional loss due to imperfection of reflecting surface.

The amplitude of the specular reflex can simply be estimated if assuming a reflective surface with normally distributed "amplitude" with standard deviation σ. A stochastic average of reflected power with regard to the phase can be estimated as $\exp(-(4\pi\sigma/\lambda)^2)$. If arbitrarily regarding 3σ as a typical peak-to-peak (ptp) value (noting that ±1.5σ contain 87% of the normally distributed values) the assumed expression will produce that a ptp roughness of 0.2λ will additionally attenuate the reflected signal by 3 dB while a roughness of λ/3 will attenuate it by 10 dB.

For example, for LPR operating in the 6 GHz band (wavelength 50 mm) the unevenness of surface in the order of 10 mm will produce additional loss of 3 dB, while unevenness of around 15 mm scale will result in 10 dB of extra loss. For LPR operating in 25 GHz band (wavelength 12 mm) the unevenness of the reflecting surface should not be more than 2-4 mm to achieve the meaningful reflection with 3-10 dB attenuation.

For an inclined surface (such as the considered case of sand pile reposed at 33º angle), the σ in the above expression should be replaced by σcos(α) making the surface to appear a bit smother (i.e. 19% more of unevenness σ could be tolerated at 33° inclination for the same attenuation of reflected signal).

Looking on the grain-size gives another view on the possible smoothness. If each grain is λ/3 or bigger (~1 wavelength or more as circumference) then each grain gives a fair reflection by itself so the surface has a diffuse reflection even if it should appear to be very smooth. That implies that there is very little specular reflection but instead a scattering of the incoming wave and by the grain-size already the estimation above implies a small specular reflex (i.e. reflection loss of more that 10 dB). By this effect a shorter wavelength is a clear advantage for measurements of solids.

From practical experience it takes small grains (dry sand) or very similar grains (wheat etc) to form a smooth surface with just a few mm ptp roughness. With that kind of grains smooth surfaces can surely be observed but to form a good reflection the flat part of the surface must be sufficiently large too, as considered in the following section.

A2.2.3 Impact of size and macro-shape of reflecting surface

To form a good "mirror" matching the antenna beam the flat reflecting surface have to be sufficiently large to include the entire footprint of the antenna's main beam. For instance a typical 100 mm diameter (8º beam width) antenna of LPR device operating at 25 GHz and mounted at 5 m above the measured surface will have a footprint covering a more or less circular area of around 0.6 m diameter.

Under lab conditions a flat surface is the easiest shape to form, but under real conditions where container is usually filled by material falling from above a conical shape appears to be the regular shape which is most likely to be formed. The LPR is usually located on the side of the material's cone in order not to disturb the filling of material, but it is preferably located where there will always be material (i.e. closest possible to the filling conveyor/pipe, usually near centre of container). The cone may point downwards too when the container/tank is being emptied by opening discharge valve at the bottom, but in that case scattering will be effectively "enclosed" inside the downward cone and scattering around the pile is unlikely.

An ideal smooth surface with a convex shape can be described by two radiuses of curvature (R_1 and R_2) in two orthogonal planes and if a plane wave is incident it will be diverging after the reflection[5]. The power density in the reflected wave will by physical optics have a power density at the distance r from the surface which can be written as:

$$S_{reflected} = \frac{r^{-2}}{(r^{-1} + R_1^{-1})(r^{-1} + R_2^{-1})} S_{incident} \qquad (6)$$

It can be noted that for small r (close to the surface) the factor equals to 1 (i.e. ideal reflection) and the same is the case when the radius of curvature are much larger than r (i.e. a flat or nearly plate). In the opposite case where r is much bigger than R_1 and R_2 , it will produce a diverging wave where the factor is R_1R_2/r^2 . The equation (6) can also be seen as a simple expression for energy conservation. For a cone one R will be rather small (smaller than r) while the other R is big ("∞").

Taking an ideal smooth cone as the practical worst case of surface shape, let us consider an example of a cone of sand with 10 m base diameter measured from 5 m distance (height) at a centre-off-set point at half the radius of the pile. Probably the device should be measuring height of the pile throughout its different levels of filling, thus the LPR should be located rather close to the centre of the cone. In most cases such scenario would produce rather small distances and small footprints of the main beam, but when the measurement distance is largest it would require a big flat surface too to really achieve the supposed mirror effect. Thus it may be proposed as one example take R_1=2.5 m, R_2 =∞ and d=5 m, and this would result in 5 dB attenuation at the diverging reflection.

The full range of geometries for such considered case of LPR mounting of sand pile may be hard to justify but the considered example of a practically very flat surface indicates that the reflection is clearly lower than from the mathematically flat surface used in the preliminary estimations. Looking on practical cases the example above seems realistic while storage in a silo-like structure typically will be smaller measures. However it should be noted that in silo the wall will give additional attenuation.

Another dependence of geometry is that the reflection will increase (at least for worst case polarization) when the incidence deviates from normal. As the system itself only use the diffuse reflection (at inclined surface) it might be possible to use the polarisation giving the least reflection.

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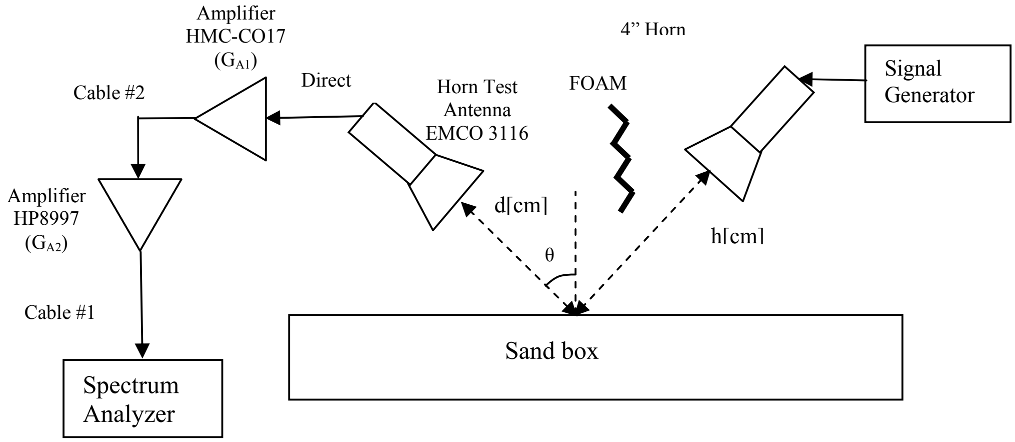
5 Eugene Knott, *Radar Cross Section*. Artech House, 1985.

There is a vast practical experience of which inclinations we can get not the least from building industry. The 33º stated previously in this annex can be regarded as a well established worst case for dry specimens of a uniform grain size. Wet substances and granulates with irregular shape may get more complicated surface shapes (including partly steeper inclined ones) but they do not form the extremely flat surface required to get a type of "mirror" with a flatness in the mm range.

A2.3 Results of lab measurements

In order to verify the above described theoretical considerations, some practical measurements have been carried out at SIEMENS facility using fine dry sand as reference reflective material.

The set-up of measurements is depicted in Figure A2.2.



(a)

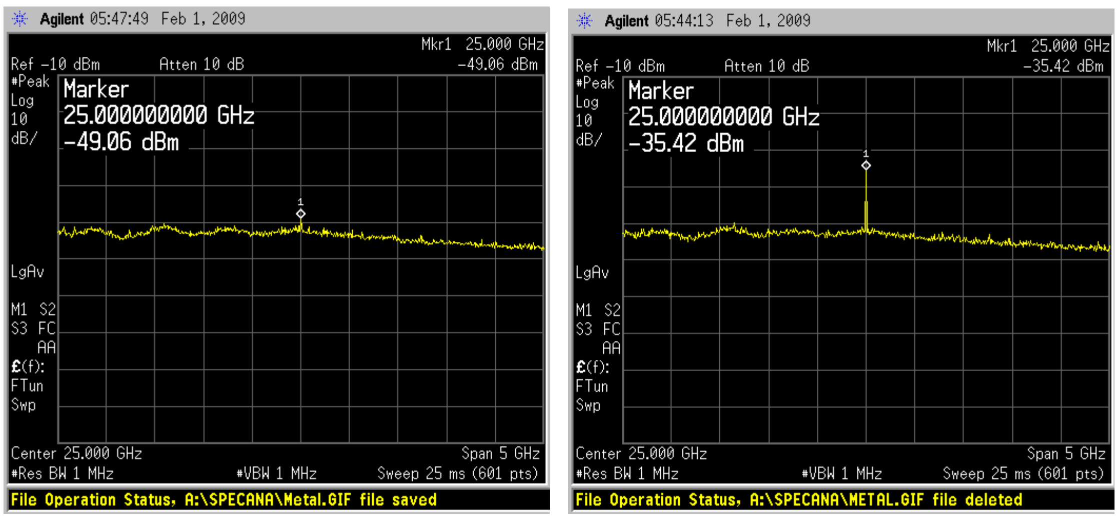
(b)

Figure A2.2: Measurement set-up for evaluating reflection properties of fine dry sand: (a) functional scheme, (b) photograph of a practical set.

A signal generator with -48 dBm output power (measured with a power meter) at a fixed frequency of 25GHz was connected to a 100 mm diameter horn transmitting antenna having gain of 23dBi.

The receiving (test) and transmitting antennae were fixed at distances *d* and *h* to the reflection point, at an angle of incidence θ, which was varied by turning and lowering/raising antennas appropriately. It is notable that original set up had foreseen using fixed antennas against the pile of sand which angle of repose is changed, however after first trials it become clear very quickly that it was very difficult if at all possible to form a uniform flat surface of sand reposed at angles anywhere near assumed maximum of 33°. It was therefore decided to use a flat sand bed but vary incidence angles by operating antennas instead. Tests could be thus performed for a wide range of incidence angles, including angles beyond 33° in order to obtain the most complete picture of reflectivity losses as a function of incidence angle.

At first a large, thin, bare metal plate was placed on top of the sand and the test antenna was adjusted to get maximum signal at the reflected main beam. Reading on the spectrum analyzer's screen was -35 dBm, see Figure A.2.3 (a). The metal plate was removed and the signal strength dropped to -49 dBm, see Figure A.2.3 (b). For this first experiment the angle of incidence was set to 45 degrees. Both antennas have been rotated for an incidence polarization that leads to maximum reflection on the sand bed. It may be thus concluded that total signal loss due to reflection from sand was 14dB.



(a) (b)

Figure A2.3: Screen shots of spectrum analyser readings during measurements: (a) with ideal reflector (metal plate), (b) with fine-sand bed

With the following data the e.i.r.p. budget of the initial setup and the sand pile loss can be analysed:

1) Straight calculation. e.i.r.p. = -48dBm + 23dBi = -25dBm
2) The total gain (link budget), at 25 GHz, between test antenna and spectrum analyzer is:

   $G_{Tot} = G_{A1} + L_2 + G_{A2} + L_1 = 17.4 – 4.5 + 34.5 – 1.6 = 45.8dB$

When using metal plate, P1 at the test antenna connector:

$$P1 = P_{SA} – G_{Tot} = -35 – 45.8 = -80.8dBm$$

The power at the test antenna input plane is: $P_{in} = P1 - G_r$

$$P_{in} = -80.8dBm – 12dBi = -92.8dBm$$

e.i.r.p. at distance D=1.6m is:

$$\text{e.i.r.p.} = P_{in}[dB] – 20\log\left(\frac{\lambda}{4\pi D}\right) = -92.8 – (-64.5) = -28\,\frac{dBm}{MHz}$$

When signal being reflected over sand bed, P1 at the test antenna connector:

$$P1 = P_{SA} – G_{Tot} = -49 – 45.8 = -94.8dBm$$

$$P_{in} = -94.8dBm – 12dBi = -106.8dBm$$

e.i.r.p. at distance D=1.6m is:

$$\text{e.i.r.p.} = P_{in}[\text{dB}] - 20\log\left(\frac{\lambda}{4\pi D}\right) = -106.8 - (-64.5) = -42.3\ \frac{dBm}{MHz}$$

This corresponds to introduced difference due to reflection loss over sand of 14.3dB.

Similarly the reflection loss over sand was derived for different angles of incidence θ (maintaining constant link path distance (*d*+*h*)=180 cm, and fixed CW power incident at the transmit antenna):

θ°	**P_{SA}[dBm]**
20	-45.8
30	-45.7
40	-45.8
45	-45.2
50	-45.3
60	-49.6

The results reported in the above table show that the reflected power was practically independent on the angle of incidence. This may be seen as confirming the theoretical considerations (ref. section A2.2.2) that for granulate materials significant portion of reflection loss may be generated by scattering due to surface finish.

The larger difference noted for the incidence angle at 60° was probably due to the fact that this is very close to the Brewster angle: arc tan $\sqrt{\frac{\varepsilon_2}{\varepsilon_1}} = 57°$, where ε_1=1 (air), $\varepsilon_2 \approx$ 2.38 (dry sand), as measured at 25GHz.

A2.4 Conclusions

It may be seen from the discussion presented in this annex that evaluating the overall reflection losses for various materials and measurement scenarios that could be encountered by LPR application is a complex matter. Some simplified estimation for ideally flat and smooth surfaces produce results in the order of:

- $L_{reflection}$=1.9 dB for calm water with 0° angle of incidence;
- $L_{reflection}$=11.5-13.4 dB for solid granular materials as dry sand, at angles of incidence 0-33°.

However it may be further considered, that for the realistic scenarios of measuring piles of solid granular materials, the overall reflection loss may be higher due to impact of scattering by surface unevenness (surface finish) and irregularity of macro-shape (i.e. reflecting surface being not flat or of sufficient size to contain the entire footprint of antenna).

The results of lab measurements reported here showed that for the considered case of fine dry sand (measured under conditions of its natural surface coarseness, yet formed in a flat bed as opposed to conical shape that would be more suitable for natural conditions) the reflection loss was in around 14 dB and little dependant on the angle of incidence.

It was therefore decided to use for compatibility studies in this Report the representative value of 13 dB for reflection loss of solid granular materials, which was seen as a fair compromise between idealistic estimates and the results of lab measurements. Additional losses that may be introduced by scattering effects were left out of further consideration, but should be kept in mind as additional natural mitigation factor that further reduces interference potential from LPR devices.

ANNEX 3: LIST OF EUROPEAN RADIO ASTRONOMY SITES TO BE PROTECTED FROM LPR

The following list of Radio Astronomy Stations that may need to be protected from LPR emissions was compiled from information tables provided by CRAF (www.craf.eu).

This list was compiled at the moment of drafting this Report, the possible omission of stations for certain frequency ranges does not mean that future use of these frequency ranges is excluded.

List of RAS operating in 6.7 GHz frequency band:

- Effelsberg Radio Observatory, Germany
- Sardina Radio Observatory, Italy
- Onsala Radio Observatory, Sweden
- Westerbork Radio Observatory, The Netherlands
- Torun Radio Observatory, Poland
- Kayseri Radio Observatory, Turkey
- Jodrell Bank Radio Observatory, UK

List of RAS operating in 23.6-24.0 GHz band:

- Effelsberg Radio Observatory, Germany
- Plateau de Bure Radio Observatory, France
- Medicina Radio Observatory, Italy
- Sardina Radio Observatory, Italy
- Robledo Radio Observatory, Spain
- Yebes Radio Observatory, Spain
- Onsala Radio Observatory, Sweden
- Cambridge, UK
- Darnhall, UK
- Jodrell Bank, UK
- Knockin, UK
- Pickmere, UK

List of RAS operating in 76/86 GHz bands:

- Effelsberg Radio Observatory, Germany
- Bordeaux Radio Observatory, France
- Plateau de Bure Radio Observatory, France
- Sardina Radio Observatory, Italy
- Pico Veleta Radio Observatory, Spain
- Yebes Radio Observatory, Spain
- Onsala Radio Observatory, Sweden

ANNEX 4: MEASUREMENTS OF COMPATIBILITY BETWEEN LPR AND FS IN 24 GHZ BAND

A measurement campaign initiated by BNetzA, E-Plus network operator and SARA was designed so as to give confidence to the FS community by checking compatibility of planned 24-26.5 GHz LPR applications under real world scenarios. The measurements took place at a test track in Papenburg (North West Germany). The test used a temporary installed FS link operating in the 26 GHz band. The interfering sources have been placed on the test track parallel to the microwave link. LPR transmitters from two manufacturers were investigated.

A4.1. Test setup

The microwave link was installed on an automotive test track in Papenburg, Germany. As shown in Figure A4.1, antenna A of the link was installed at a steep turn of the test track and antenna B on a bridge crossing the test track area. The total link length between antenna A and B has been 2.26 km.

Figure A4.1: Automotive test track in Papenburg, Germany with FS link

The measurement setup is shown in Figure A4.2. The path attenuation of the microwave link was increased (using the wave guide attenuators on location B) until the link reached a BER of 10^{-6}. This was done to simulate a microwave link at its operational limit and thus make it vulnerable for interference. It should be noted that a FS link is planned to operate at a link budget level which is set 10dB above the threshold used in this test plus additional 10dB ATPC.

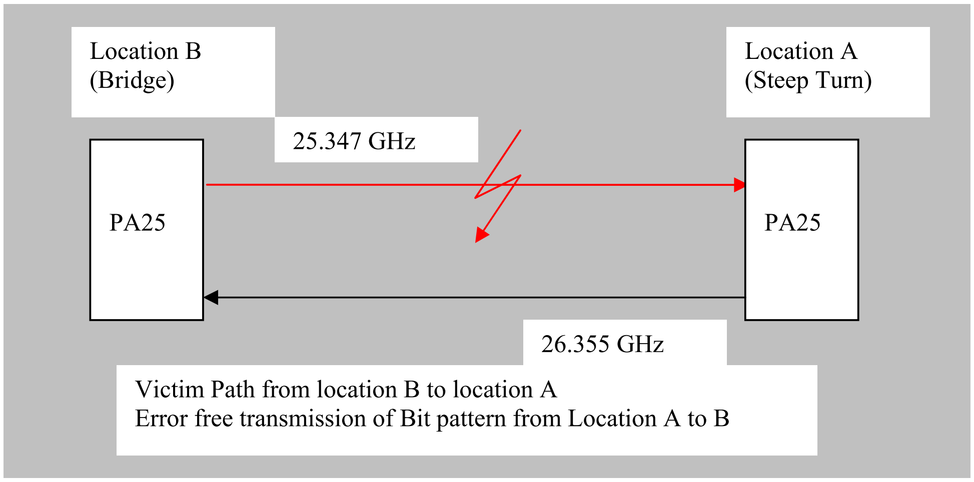


Figure A4.2: FS link setup

Photographs of the microwave link and the LPR setup are shown below in Figures A4.3-A4.9.

			
Figure A4.3: FS link A at steep turn	**Figure A4.4:FS antenna A at steep turn**	**Figure A4.5: Measurement equipment at FS link A**	**Figure A4.6: FS link B at bridge**

		
Figure A4.7:FS antenna B at bridge	**Figure A4.8: Measurement equipment at FS link B**	**Figure A4.9: The LPR test setup**

A4.2. FS Link Data

The test FS link had the following parameters:

- Lower Band: Center Frequency 25347 MHz (Rx at position A, steep turn)
- Upper Band: Center Frequency 26355 MHz
- Channel Band Width: 28 MHz (+- 14 MHz)
- Modulation Method: QPSK
- Error Correction Method: FEC (not used for measurements)
- RX Antenna Diameter: 0,6 m (on RX location only)
- RX Antenna height above ground: 10 m (Site A - TX), 12 m (Site B - RX)
- RX Elevations angle (0° = horiz.): Site A: 0,12° up; Site B: 0,13° down
- FS Link length: 2.26 km

The RX/TX antenna pattern and gain are shown in Figure A4.10.

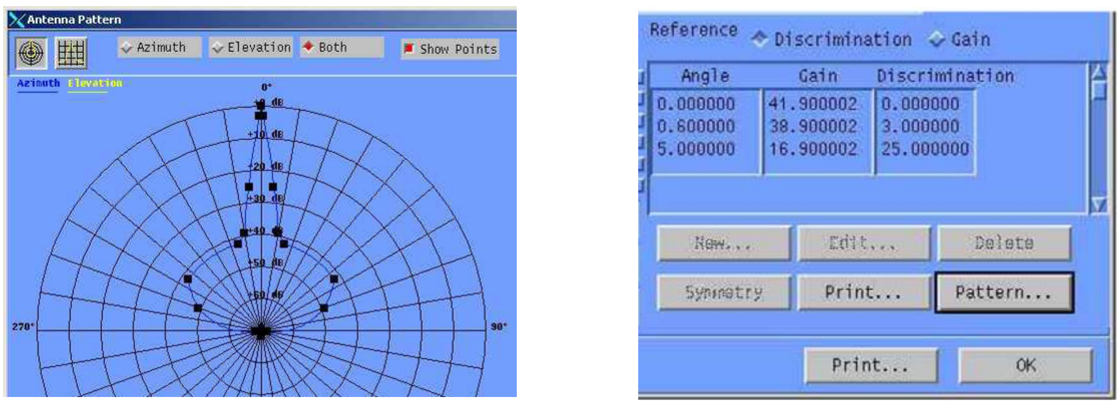


Figure A4.10: Antenna pattern of FS antenna A (60cm dish)

To assure that the link from location A to location B was undisturbed during the whole measurement time, the link output power in location A was set to +18dBm (maximum output power) and location B was set to +13 dBm. With this setup one direction of the link was running with the desired bit error rate of 10^{-6} while the other direction was running error-free (see Figure A4.2).

A4.3. LPR parameters

The description of the VEGA LPR system is embedded as a separate file below:

LPR_Vega_descriptio
n_2009_412-1.doc

A4.4. Test results

With the LPR antenna placed at a distance of 500 m to the FS receiver and transmitting downwards over a flat reflection area (height of the LPR transmitter over ground 3-8m, no ground reflections assumed in direction of the FS receiver) there was no discernible impact on the operation of FS link.

However, when in one test case the LPR antenna was tilted 90 degrees upwards to transmit horizontally in the direction towards the FS receiver, the operation of FS link (in most sensitive mode) was disrupted totally.

The complete test report from Alcatel Lucent is embedded as a separate file below:

Alcatel-Lucent_26GH
z_test report_2009_4

ANNEX 5: EIRP LIMITS FOR LPR OPERATING IN 57-64 GHz and 75-85 GHz

A5.1 Introduction

During the prototype development and testing phase, the LPR manufacturers became convinced that the originally envisaged emissions limits for LPR in the two upper bands 57-64 GHz and 75-85 GHz are not sufficient for ensuring practical implementation of LPR applications. This is in particular due to much higher absorption of LPR signals in these high frequency bands, as well as due to less developed RF technology (e.g. less efficient receivers) in those high bands, which has significant impact on the precision and range of LPR measurements.

At the same time, already in the initial phase of developing this Report, the MCL simulations (see chapter 5 of this Report) showed around 14 dB of positive margin in worst-case MCL interference scenarios for bands 57-64 GHz and 75-85 GHz. This means that the power of LPR emissions within main beam of strictly downward looking antennas could be increased by 14…17 dB, while still not exceeding the generally accepted safe emission limits of -41.3 dBm/MHz on the half-sphere around LPR installation.

The rest of this annex shows how utilising the 14 dB of extra margin into higher limits of LPR emissions power could enable achieving the intended operating range of LPR (maximum of 50 m above low-level point of measured surface) in the bands 57-64 GHz and 75-85 GHz.

A5.2 Example link budget for LPR devices in 57-64 GHz and 75-85 GHz bands

A5.2.1 Using conventional link budget calculations

For the band 57-64 GHz:

Assumptions:

LPR EIRP (TR 102 601 original):	-15 dBm/MHz;
LPR antenna gain:	34 dBi
Thermal noise (Rx Nf=6 dB):	-108 dBm/MHz
Rx sensitivity (**$(S/N)_{min}$=15 dB**):	-93 dBm/MHz
Reflection from sand (see Annex 2):	12 dB

Maximum path loss: -15 dBm/MHz -(-93 dBm/MHz) + 34 dBi -12 dB = 100 dB

Note that in this calculation the initial power is expressed as EIRP, which already accounts for transmitting antenna gain, therefore only the receiving antenna gain should be accounted additionally.

Resulting maximum path with Free Space Loss:	40 m
Maximum height of LPR above surface:	**20 m**
Required maximum height objective:	**50 m**

If increasing the output power by 14 dB of available positive margin identified by the MCL calculations in this Report, the tolerable path loss increases to 114 dB, which results in maximum 200 m of measurement path obtained with FSL, or ca. 160 m when corrected for specific oxygen absorption loss in this band of 10dB/km. This results in sufficient design margin to ensure maximum LPR installation height of 50 m.

For the band 75-85 GHz:

Assumptions:

LPR EIRP (TR 102 601 original):	-17 dBm/MHz
LPR antenna gain:	35 dBi
Thermal noise (Rx Nf=6 dB)	-108 dBm/MHz
Rx sensitivity (**$(S/N)_{min}$=15 dB**)	-93 dBm/MHz
Reflection from sand (see Annex 2):	12 dB

Maximum path loss: -17 dBm/MHz -(-93 dBm/MHz) + 35 dBi -12 dB = 99 dB

Note that in this calculation the initial power is expressed as EIRP, which already accounts for transmitting antenna gain, therefore only the receiving antenna gain should be accounted additionally.

Maximum path with Free Space Loss:	27 m
Maximum height of LPR above surface:	**14 m**
Required maximum height objective:	**50 m**

If increasing the output power by 14 dB of available positive margin identified by the MCL calculations in this Report, the tolerable path loss increases to 113 dB, which results in maximum 130 m of measurement path obtained with FSL. This results in sufficient design margin to ensure maximum LPR installation height of 50 m.

A5.2.2 Using "radar equation"
Alternatively to the above calculations, the so called "radar equation" could be used for evaluating the link budget of LPR. However, given the specifics of LPR operational configuration, with very close large reflecting dielectric surface as opposed to faraway linearly small targets monitored by traditional radars, the traditional radar equation should be modified, as discussed in depth in section B.2.1 of TR 102 601. According to material there (see Eq. B.2.2), the modified radar equation suitable for LPR under "calm surface" conditions could be expressed as follows on decibel scale:

$$P_{rx} = P_{tx} + 2G_a + 20\lg(\lambda/8\pi h) - L_{ant} - L_{reflection}$$

where:
P_{tx}: transmitter output power, dBm or dBW,
G_a: LPR antenna gain, dBi,
λ: wave length, m;
h: LPR measurement range (height above target surface), m;
L_{ant}: LPR antenna contamination loss, e.g. dirt build-up on antenna surface or foam on measured liquid etc, experiments show: L_{ant}=5 dB as an optimistic value, 10 dB more realistic (see B.2 in TR 102 601);
$L_{reflection}$: reflection loss from measured material.

When using this LPR-modified radar equation, the calculation results are as follows (see the attached Excel file for details):

F, GHz	60	80
Ptx, e.i.r.p (original TR 102 601 value), dBm/MHz	-15.5	-17
Ga, dBi	34	35
Antenna contamination loss, dB	5	5
Reflection loss, dB	12	12
Radar range: h, m	50	50
Wavelength, m	0.005	0.00375
Received power at receiver input, "calm surface" formula, dBm/MHz:	**-106.50**	**-109.50**
Compares with:		
LPR receiver noise floor, dBm/MHz	-108	-108
RX sensitivity (S/Nmin=15 dB), dBm/MHz	-93	-93
Margin (calm surface), dB:	**-13.50**	**-16.50**

A5.3 Special considerations regarding FMCW type of LPR

Realisation of FMCW systems in the 60/80 GHz bands is even more sensitive to the power limitations than in the case with pulsed LPR. Because a pulsed LPR system can operate with ca 20…30 dB lower power level than the power level required by FMCW systems, since pulsed LPR is a "true" UWB system with a large signal bandwidth, allowing to have "system gain" as a result of processing of UWB signal.

The FMCW is the opposite of this with a very narrow instantaneous bandwidth and is "punished" in the spectrum analyzer measurement which is narrowband.

This is the reason why higher limits are wished for the higher bands especially by FMCW LPR applications, as they would provide right margin for viable implementation of these comparatively narrowband systems.

At the same time it should be noted that FMCW methods are currently the only possible way at present to utilize the entire available bandwidth of 7/10 GHz in subject bands, since pulsed system would need to use sub-nanosecond pulses to achieve the resolution that the large bandwidth permits.

So whereas the requested increase of power limits originally specified in TR 102 601 would be necessary for pulsed LPR systems as a matter of reaching the specified measurement range (as exemplified by preceding calculations), for FMCW LPR system the increased power limit is a matter of nothing less than the principal viability of their practical implementation.