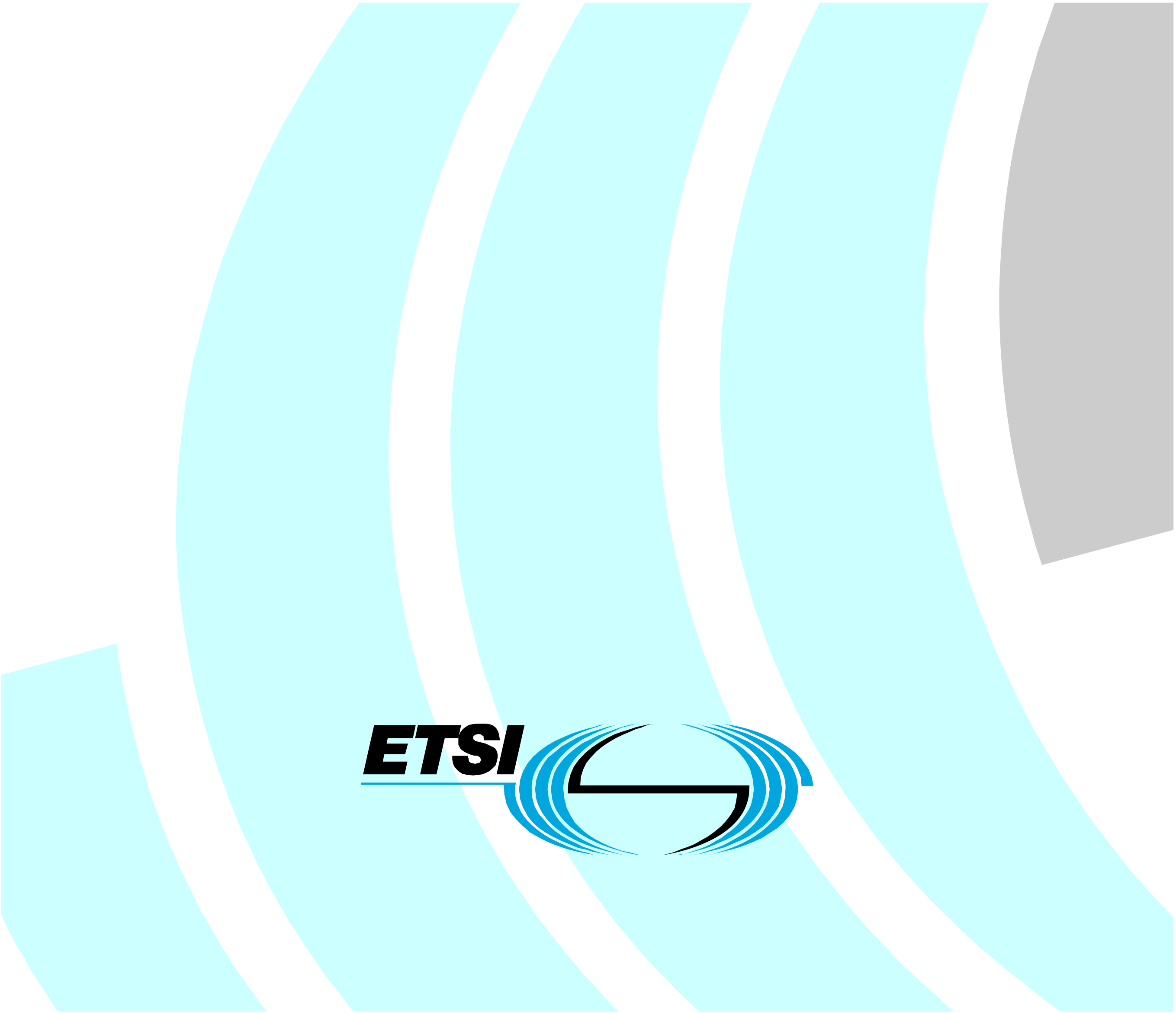
ETSI TR 102 601 V1.1.1 (2007-12)

Technical Report

Electromagnetic compatibility and Radio spectrum Matters (ERM); System reference document; Short Range Devices (SRD); Equipment for Detecting Movement using Ultra Wide Band (UWB) radar sensing technology; 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



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Foreword

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

Introduction

The request for harmonized European spectrum for tank level probing radars (TLPR) as defined in TR 102 347 [4] has resulted in an addition of identified frequencies for TLPR in CEPT/ERC Recommendation 70-03 [1], annex 6. ETSI, in parallel, has published the Harmonized European Standard EN 302 372 [2] for TLPR. ITU-R Recommendation SM.1538 [3] also covers TLPR.

The present document covers the request for harmonized European spectrum for Level Probing Radar-sensors (LPR) applications not installed in closed metallic or similar (e.g. concrete) enclosure structures. LPR use a similar technology as TLPR, however due to the different installation conditions, different technical requirements are envisaged for the Harmonized Standard.

Commercially, sales of LPR are currently limited due to lack of a Harmonized Standard and regulation. License exempt European harmonized conditions for the availability and use of radio spectrum for LPR could lead to an increase of the total addressable market for TLPR and LPR applications.

NOTE: From a regulatory point of view, TLPR may not be considered a subset of LPR. Since the majority of radar level sensor products currently on the market are TLPR, and LPR is closely technology related, TLPR are mentioned in the present document mainly for marketing clarifications (see annex A).

Status of pre-approval draft

The present document has been created and approved by ERM_TG TLPR. The document has been revised and approved by TG TLPR. It has been sent to ERM for approval.

Final approval for publication as ETSI Technical Report was achieved at ERM#33 (26-30 Nov. 2007).

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1 Scope

The present document provides information on the intended applications, the technical parameters and the radio spectrum requirements for LPR proposed to be operated in one or more of the following frequency bands:

- 6,0 GHz to 8,5 GHz;
- 24,05 GHz to 26,5 GHz;
- 57 GHz to 64 GHz; and
- 75 GHz to 85 GHz.

LPR covered by the present document are always installed in a fixed position and pointing downwards to achieve maximum reflection. They use highly directive antennas and the antenna footprint can be defined accurately, i.e. the area of their emissions is well defined, and any reflections outside of the area can be controlled to not exceed a maximum limit by using Adaptive Power Control (APC).

The present document describes LPR devices that measure substance levels via short ranges with an accuracy in the millimeter range. LPR use carrier-based Ultra Wide Band technology for this purpose.

The present document provides information to aid in the development of general, non-individual, preferably licence exempt European harmonized conditions for the availability and use of radio spectrum for level probing radar (LPR) sensor systems.

Additional information is given in the following annexes:

- Annex A: Detailed market information;
- Annex B: Detailed technical information;
- Annex C: Expected sharing and compatibility issues.

2 References

References are either specific (identified by date of publication and/or edition number or version number) or non-specific.

- For a specific reference, subsequent revisions do not apply.
- Non-specific reference may be made only to a complete document or a part thereof and only in the following cases:
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  - for informative references.

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NOTE: While any hyperlinks included in this clause were valid at the time of publication ETSI cannot guarantee their long term validity.

2.1 Informative references

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

[2] ETSI EN 302 372 (parts 1 and 2): "Electromagnetic compatibility and Radio spectrum Matters (ERM); 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] ITU-R Recommendation SM.1538: "Technical and operating parameters and spectrum requirements for short range radiocommunication devices".

[4] ETSI TR 102 347: "Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices (SRD); Equipment for Detecting Movement; Radio equipment operating around e.g. 5,8 GHz, 10 GHz, 25 GHz, 61 GHz, 77 GHz; System Reference Document for Tank Level Probing Radar (TLPR)".

[5] CEPT/ECC Report 64: "The protection requirements of radiocommunications systems below 10.6 GHz from generic UWB applications".

[6] CEPT/ECC Report 23: "Compatibility of automotive collision warning Short Range Radar operating at 24 GHz with FS, EESS and Radio Astronomy".

[7] CEPT/ECC Report 56: "Compatibility of automotive collision warning Short Range Radar operating at 79 GHz with radiocommunication services".

[8] CEPT/ERC Report 25: "The European table of frequency allocations and utilisations covering the frequency range 9 kHz to 275 GHz" Lisboa January 2002 - Dublin 2003 - Turkey 2004 - Copenhagen 2004 - Nice 2007.

[9] CEPT/ECC Report 114: "Compatibility studies between multiple GIGABIT wireless systems in frequency range 57-66 GHz and other services and systems".

[10] EC/EFTA Mandate M/407: "Ultra-Wideband Equipment".

[11] Andrzej Kraszewski: "Microwave Aquametry" from IEE press 1994.

[12] ETSI EG 201 788 (V1.2.1): "Electromagnetic compatibility and Radio spectrum Matters (ERM); Guidance for drafting an ETSI System Reference Document".

3 Definitions and abbreviations

3.1 Definitions

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

beat frequency: frequency difference between the transmitted and instantaneously received signal in FMCW

duty cycle: total accumulated transmitter activity time within one hour within any specific bandwidth of 1 MHz

FMCW radar: carrier- based radar system using a frequency modulated continuous wave

pulse radar: carrier- based radar system transmitting and receiving short RF pulses

range resolution: ability to resolve two targets at different ranges

3.2 Abbreviations

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

APC	Adaptive Power Control
CEPT	European Conference of Post and Telecommunications
dB	decibel
dBc	decibel relative to carrier power
e.i.r.p.	equivalent isotropically radiated power
EC	European Commission
ECC	Electronic Communications Committee
ERC	European Radiocommunications Committee
ETSI	European Telecommunications Standards Institute
FMCW	Frequency Modulated Continuous Wave
ITU	International Telecommunications Union
LPR	Level Probing Radar-sensor for use outside metallic and similar shielding tanks
LR	Level Radar category including both LPR and TLPR
RF	Radio Frequency
SRD	Short Range Device
SRDoc	System Reference Document
TLPR	Tank Level Probing Radar-sensor
UWB	Ultra Wide Band

4 Comments on the System Reference Document

No statements have been received on the present document after the ETSI ERM correspondence approval procedure.

5 Executive summary

5.1 Background information

LPRs are used in many industries concerned with process control to measure the amount of various substances (mostly liquids or granulates). LPRs are used for a wide range of applications such as process control, custody transfer measurement (government legal measurements), water and other liquid monitoring, spilling prevention and other industrial applications. The main purposes of using LPRs are:

- to increase reliability by preventing accidents;
- to increase industrial efficiency, quality and process control;
- to improve environmental conditions in production processes.

LPRs are the preferred measurement tool to achieve the above goals 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.

5.2 Market information

There is already an established LPR market and certain level measurements cannot be performed by other means than LPR.

LPR represent an industrial niche market and should not be considered as a mass market. They cannot be used for communications purposes. An economic benefit results from the introduction of LPR devices in industrial processes.

From a marketing point of view, the Level Radar (LR) market consists of both LPR and TLPR. Sales of LPR are low at this moment since certification is a major problem due to lack of both an appropriate harmonized standard and regulation. Therefore, there is an increase of about 20 % of the total European addressable market for level probing radars, if suitable European harmonized conditions for the availability and use of radio spectrum for LPR could be found in Europe. A harmonized approach would greatly facilitate installation of LPR throughout Europe.

As Level Radar (LR) is a non-contacting level measurement technology, it has proven to be a robust, reliable and accurate in many industrial environments. For this reason, Level Radar is replacing traditional contacting level measurement technology at a rapid pace. The world wide market in 2005 for Level Radar was Euro 250 million and is projected to grow to Euro 660 million by 2015 (approximately 450 000 units). It is expected that Europe comprises 40 % of the worldwide market. Additionally, LPR will be 10 % to 20 % of the total market. In 2015 the installed base of LPR units covered by the present document is projected to be approximately 36 000 units.

Detailed market information is given in annex A.

5.3 Radio Spectrum requirements and justification

Currently, there are no European harmonized conditions for availability and use of radio spectrum for LPR. So far, LPR have been operated under individual licence and notifications (article 6.4 of the R&TTE Directive).

The applications for LPR are very diverse. From a radar signal reflection point of view, it ranges from highly absorptive low dielectric granulates to well reflective liquids such as water. The application circumstances vary from smooth surfaces to very rough and scattering surfaces. Therefore, the wide variety of applications demands the use of several frequency bands. From a radar sensor resolution and accuracy point, a wide frequency band is required. This results in the request of use for LPR of the following 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.

Detailed technical information is given in annex B.

5.4 Current Regulations

The current general position on the common spectrum designation for TLPR for countries within the CEPT is given by CEPT/ERC Recommendation 70-03 [1], annex 6. However, for LPR, no current European harmonized conditions for availability and use of radio spectrum are in existence.

So far, LPR have been operated under individual licence and notifications which vary from country to country, if possible at all in a specific country. So far, no reported cases of interference to other spectrum users are known.

6 Foreseen limits in the Harmonized Standard

Under all circumstances LPR-sensors are expected to be designed to meet the emission limits proposed in this clause and to reduce the risk of interference with other spectrum users by use of Adaptive Power Control to match the highly variable application circumstances and in essence always are pointed downwards. Additionally, the duty cycle is extremely low, and an aggregation effect of LPR-sensors is unlikely.

6.1 Radiated power (e.i.r.p.) in the LPR main lobe

The radiated power (e.i.r.p.) is defined as the downwards emitted power of the LPR including antenna gain. The limits in table 6.1 for radiated power (e.i.r.p.) in the LPR main lobe (i.e. in front of the LPR antenna) are planned to be added to the ETSI Harmonized Standard:

Table 6.1: Radiated peak and mean power limits in the LPR main lobe

Frequency band of operation (see note 1)	Peak radiated power (e.i.r.p.) (see note 3)	Mean radiated power (mean e.i.r.p.) (see note 2)
6 GHz to 8,5 GHz	+24 dBm	+1 dBm
24,05 GHz to 26,5 GHz	+43 dBm	+20 dBm
57 GHz to 64 GHz	+43 dBm	+23 dBm
75 GHz to 85 GHz	+43 dBm	+23 dBm
NOTE 1: -20 dBc bandwidth. NOTE 2: The mean power is determined as the conducted power (dBm) as measured with a true RMS power meter, (e.g. bolometer etc), during normal operating conditions. The measured value is corrected by adding the LPR antenna peak gain (dB). NOTE 3: The peak power is determined by adding the duty cycle factor 10 log (1/D_X) to the measured mean power value.		

NOTE: Notes 2 and 3 in table 6.1 are assuming that the LPR is designed for use in petrochemical, chemical or gas industry hazardous atmospheres. The design therefore meets an intrinsic safety specification which includes a power supply made for very low currents only. In this case it is not possible to disable the duty cycle of the equipment.
However, in cases where the hardware allows the duty cycle to be disabled (i.e. continuous transmitter signal) the peak power can be measured with disabled duty cycle.

6.2 Maximum Emission (e.i.r.p.) outside a defined half sphere area

Due to huge variations in the environment, it is envisaged that the Harmonized Standard will include requirements to control the LPR emission levels by an Adaptive Power Control (APC) to avoid interference to other services and applications. This concept allows for coexistence with radio services and applications by controlling the maximum interference levels by using a geometry defined in figure 6.1 in combination of an adaptive power control.

The effective power level limits in the different bands that are needed for reliable radar operation with state of the art technology are summarized in table 6.2.

Table 6.2: Proposed parameters outside the half sphere

Frequency band (-20 dB bandwidth)	Maximum -3 dB antenna beam-width	Adaptive Power Control (APC)	Max Duty cycle	Max. emission (power spectral density) outside the half sphere area in 1 MHz bandwidth (mean e.i.r.p.) (see note)
6 GHz to 8,5 GHz	± 15°	Yes	0,5 %	-41,3 dBm
24,05 GHz to 26,5 GHz	±8°	Yes	0,5 %	-41,3 dBm
57 GHz to 64 GHz	±4°	Yes	1 %	-41,3 dBm
75 GHz to 85 GHz	±4°	Yes	1 %	-41,3 dBm
NOTE: The reference point for the limit includes: a) The reflected power spectral density from the target. b) Emitted side lobes through the virtual boundary see figure 6.1.				

These limits are based on the concept that LPRs are always installed in a fixed position and pointing in a downwards direction maximizing operational reflection to the LPR while minimizing risk of interference in a horizontal direction. The emission outside the half sphere area (both reflected power from the target and emitted side lobes) can be controlled to not exceed a maximum emission (mean e.i.r.p.) power spectral density limit by using adaptive power control (APC). The APC is controlled by the received energy within the total LPR receiver bandwidth.

A dynamic range for the APC should be at least 20 dB and incremental steps should be 5 dB or less.

The operational bandwidth of the LPR equipment is determined by the lowest and highest frequencies occupied by the power envelope where the output power falls to -20 dB below the maximum power.

Figure 6.1 illustrates test geometry of the half sphere concept.

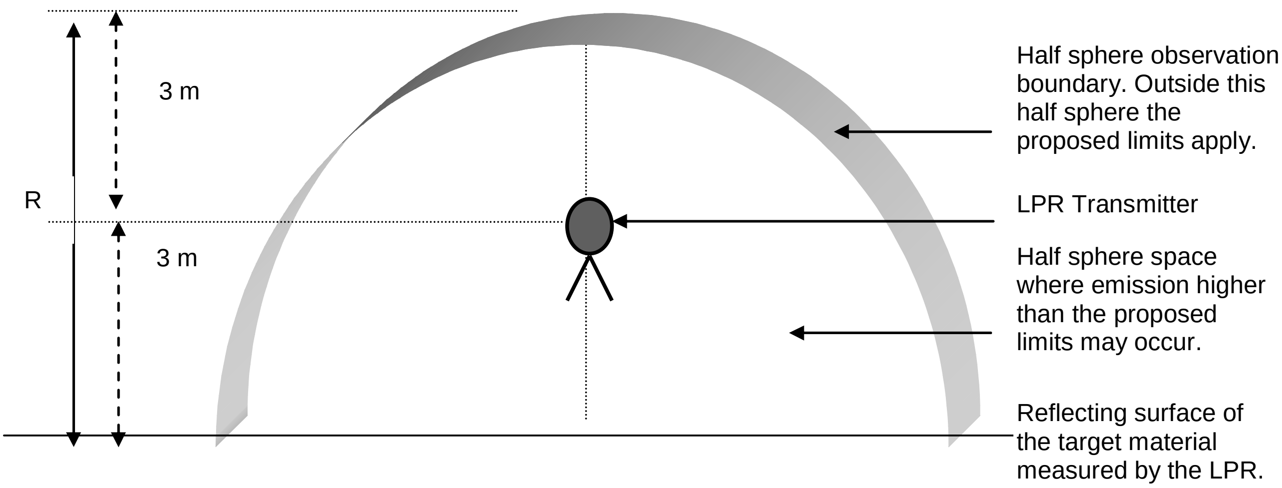

Figure 6.1: Half sphere concept

The radius, R, of the dome (half sphere area) in figure 6.1 is determined by the following:

$$R = 3m + 3m$$

3m is considered to include the far field condition in most cases. For special cases the far field condition can be assessed to determine measurement tolerances. A measurement distance of 3 m is a distance commonly used in similar test set-ups and is easy to implement in a test environment e.g. in an anechoic chamber.

6.3 Antenna considerations

The technical requirement is to meet the limit described in clause 6.2. It is generally known by industry that this can be achieved by using a suitable antenna. Depending on the application this will result in different sidelobe attenuation. This knowledge should be considered by the manufacturer when the antenna and the transmitter are designed to meet the specified limits.

7 Expected ETSI Actions

ETSI ERM TG TLPR is going to create a new Harmonized European Standard for LPR equipment, which is expected to fall under mandate M/407 [10] for Harmonized European Standards for UWB. See also clause 6.

LPRs do not communicate any information via the radar signal to any other equipment; therefore no protocol communications standard is required for these systems.

8 Requested ECC Actions

Harmonized European conditions for the availability and use of the radio spectrum for preferably license free operation for LPR (in for example CEPT/ERC Recommendation 70-03 [1], annex 6) by the middle of 2008 are requested. The desired frequency bands are listed in clause 1. It would also be helpful to know if any restrictive conditions (e.g. geographical restrictions for use) are foreseen.

The present document describes the spectrum request for Level Probing Radars that technologically are closely related to Tank Level Probing Radars but mainly operate outside closed tanks. Being closely related to TLPR, LPR logically should also be handled as Short Range Devices.

Annex A:
Detailed market information

A.1 Range of applications

Today the use of radar (electromagnetic waves) for level measurement is state-of-the-art technology and in many applications the most reliable level measuring technique. This development has been supported by the evolution of microwave technology over the last 15 years. From a marketing point of view, TLPR can be considered a subset of LPR.

LPR is a non-contact level measuring technology that has proven to be robust against various environmental conditions and properties of the measured product. Such environmental conditions and product properties that are detrimental to other measuring techniques include temperature, dust, air turbulence, corrosive properties of substance, viscosity, mechanical forces (e.g. tensile forces), interference with other mechanical structures in the tank (e.g. agitators), etc. Over time, LPR have proven superior to any other known level measuring technology to achieve the two objectives listed above.

Due to different chemical or physical properties of different liquids or solids, LPR are installed in a large number of different storage, processing or transportation containers including:

- metallic tanks or similar (tankers, concrete silos etc.);
- non-metallic tanks (plastic, glass);
- open air (dams, pools, piles, rivers, etc.).

In many of these installations, LPR provide process- safety critical, real-time information to protect humans, equipment and the environment. Examples of process- safety critical applications include:

- hydrological services (river or dam levels, wave height, tides, etc.);
- storing or processing hazardous substances (flammables, acids, corrosives, etc.);
- storing solids in piles (e.g. coal).

In other applications, accurate level measuring helps improving quality of the end product, and conserving the environment by allowing for more efficient use of natural resources. Examples of such applications include:

- exact dosing of liquids in a chemical or pharmaceutical plant;
- measuring on piles of solids (e.g. coal, building materials, iron ore, etc.).

Major use of LPR can be found in the following industries:

- chemical plants;
- petrochemical plants, e.g. refineries, fuel depots;
- pharmaceutical plants;
- food and beverage plants;
- power plants (oil, coal, woodchips, hydro, etc.);
- building industry;
- water and sewage treatment;
- hydrological services (river monitoring, wave height monitoring, etc.).

Examples of LPR installations are shown in figure A.1.

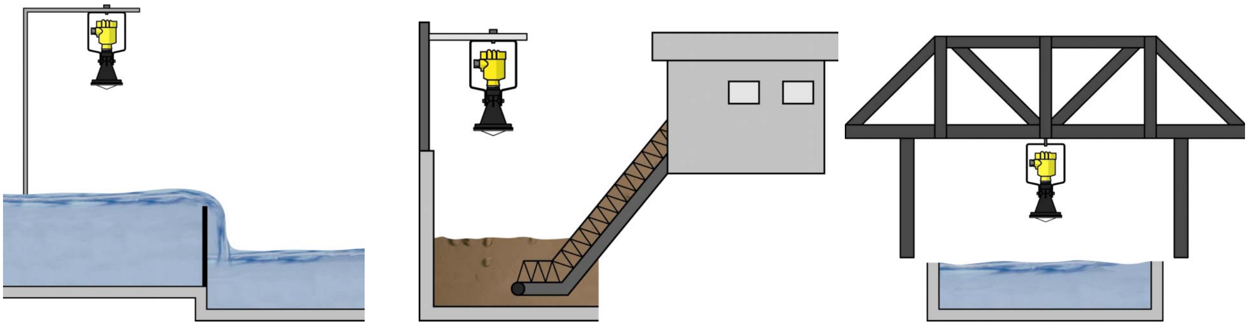

Figure A.1: Examples of LPR Applications

Some of the main advantages of the LPR are:

- not sensitive to products that are corrosive, high temperature, sticky, etc. (due to non-contact with product);
- not affected by environmental conditions such as dust, air turbulence, noise, etc.;
- high measuring accuracy;
- high repeatability;
- high reliability;
- minimum maintenance requirements and wear as result of no moving parts;
- easy installation;
- high long-term stability resulting from self-calibration since the device has a highly stable internal reference.

All these factors combine to provide a level measuring solution that over time has proved to bring an improvement in environmental protection and human safety as well as better use of natural resources and higher quality chemical products.

A.2 Expected market size and value

Over the last 30 years, the total Level Radar (LR) sales have grown substantially. (The category LR includes both TLPR and LPR). By 2015 LR will make up approximately 2/3 of all level measuring instruments sold world wide.

Figure A.2 shows the total level instrument sales during the period 1970 to 2015. It also shows the increasing sales of LR in this market and it can clearly be seen that LR are rapidly replacing other technologies. The total worldwide market for LR products in 2005 was Euro 250 million and is projected to grow to more than Euro 660 million by 2015 (source: industry data). The corresponding number of units in 2015 is estimated to be 450 000 units world-wide. In 2015, it is expected that Europe will represent 40 % of the total world-wide LR market. It is expected that somewhere in the range 10 % to 20 % of all LR units will be sold for applications outside closed metallic tanks or similar attenuating materials. This part of the market is classified as LPR in the present document. This results in an installed base of approximately 36 000 LPRs covered by the present document in 2015 for Europe.

Equipment to be operated in the 60 GHz and 80 GHz range does not exist today but is planned for future use.

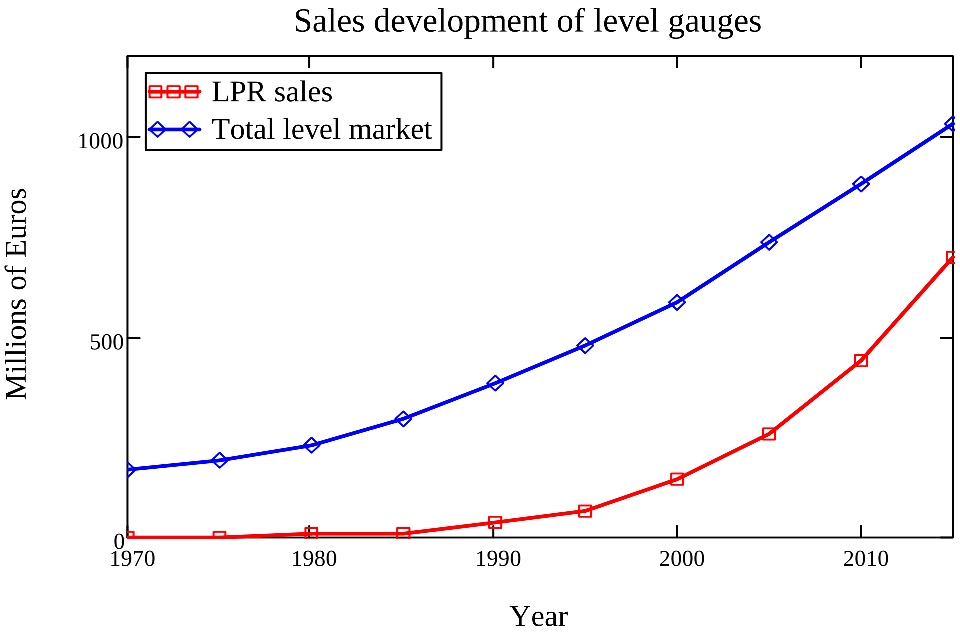

Figure A.2: Total level instrument sales (all technologies) and LR sales (source: industry data)

A.3 Deployment

LPR equipment within the scope of the present document is essentially a professional system strictly for commercial usage that is installed and maintained by professionally trained individuals. Their use is associated with new industrial construction and in retrofitting existing industrial facilities.

Due to the external dimensions of applications that are not in closed metallic tanks, the average number of LPR units per square kilometre will be low. In addition, taking into account the overall transmitter activity at a given frequency of LPR, it can be assumed that aggregation effects from LPR are highly unlikely.

Annex B:
Detailed technical information

B.1 Detailed technical description

B.1.1 Principles

The functional concept of LPR is the same as for TLPR, i.e. the measurement of attributes of the incoming reflections from object surfaces within the footprint of the LPR transmitter. The major difference is the application of the so-called half sphere concept as depicted in figure 6.1.

LPRs are always installed in a fixed position and pointing downwards to achieve maximum reflections. They use highly directive antennas and consequently, the antenna footprint can be defined accurately. The area of their emissions is well defined and any reflections outside of it can be controlled to not exceed a maximum power spectral density limit by using Adaptive Power Control (APC). The APC basically regulates the transmitter power to control emissions.

B.1.2 LPR Types

A LPR comprises three main architectural blocks:

1) The antenna that functionally emits microwaves and transmits them downwards to the surface of the measured material, and receives reflected signals from the surface and leads these back to the electronics. The antenna focuses the microwave energy in the desired downward direction, hence minimizing radiation in unwanted directions.

2) The electronics generate and receive microwaves on a desired frequency. After receiving the microwaves the analogue signal is processed to generate a process parameter or other desirable output. The output is then provided to the user by use of a display or one of several different types of standard communication means. There are strict requirements on the electronics from a safety aspect to eliminate any risk of initiating an explosion should there be a volatile gas or dust in the environment.

3) The housing contains and protects the electronics from the environment. It may have explosion proof properties, is water tight and enable the user to easily install and maintain the LPR.

There are presently two basic radar types used in LPR applications, namely FMCW and pulsed radars. FMCW stands for frequency modulated continuous wave and sweeps a certain 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 determines how close a radar echo the system can separate. 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, which corresponds to the distance between the antenna and the surface of the object. The distance is therefore obtained by measuring 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 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.

B.2 Technical justification for spectrum

The first LPRs were developed around 10 GHz since this had been established as the optimum frequency for use in large storage tanks combining robustness to condensation and contamination with a reasonable antenna beam. A narrow antenna beam is desirable in the storage tanks with large measuring distances (up to 50 m) to avoid interference from structures, walls, etc., that exist inside the tank. Later developments (during the 1990s) produced LPRs first at 6 GHz and later 26 GHz. This development was primarily driven by applications in the process industry where the tanks are typically shorter, but the conditions (structures, foaming, contamination, etc.) inside the tanks more extreme than in the large storage tanks - thus requiring a slightly different optimization of the LPR. For future developments, it is predicted that higher frequencies between 57 GHz to 64 GHz or 75 GHz to 85 GHz will be employed. There are several advantages of higher frequencies including a narrow antenna beam, the possibility to increase the bandwidth, which will contribute to accuracy and ability to resolve echoes in the tank, and the potential to reuse low cost components from other applications (e.g. automotive).

A short summary of advantages and disadvantages of the frequencies bands covered by the present document are shown in table B.2.

Table B.2: Advantages and disadvantages of different frequency bands

Frequency bands (GHz)	Advantages	Disadvantages
6 to 8,5	Effective performance on severe foam, condensation, contamination, turbulent applications (see also clause B.2.2).	Setup requires efforts, needs fine optimization after installation, narrow antenna beams difficult to realize. Bigger dimensions.
24,05 to 26,5	Smaller antenna beam-width, easier setup, wide variety of applications, relative compact design.	Less effective on foam, condensation, contamination, turbulent applications.
57 to 64 and 75 to 85	Ability to increase bandwidth (i.e. better range resolution), small openings, easier to seal, lower cost of mechanics, smallest beam-width. Very effective in applications with limited access.	Less effective on severely contaminated or turbulent applications. High-frequency parts: production is more difficult and costly.

B.2.1 Principle link budget considerations for LPR

In each radar the microwave power is subject to path loss on the 2-way trip from transmitter to receiver. In order to evaluate data from the received signal, its power is to be larger than the noise floor at the receiver input and the required margin that is conventionally denoted as the signal to noise ratio, S/N. High accuracy systems are likely to require a higher S/N. The noise floor increased by S/N is referred to as the sensitivity limit (lowest measurable signal, typically given in dBm) and will for a specific system depend slightly on the distance.

In all LPRs used today, the transmitter- and receiver signal are closely tied together so tests with conventional noise figure meters or similar equipment are generally less reliable than measurements where the transmission path is substituted by a cable length plus a variable attenuator or something similar. Such a measurement will give the path loss limit which should give the difference between transmitter power and sensitivity limit. The path loss limit is closely tied to (and the need easily estimated from) the actual combination of parameters such as antenna size, distance etc. but when it comes to emission the transmitter power is the most important parameter. To evaluate the parameter space within which a good radar function can be combined with low emission (i.e. below a certain limit), the combined set of equations/limitations is to be investigated. Here this is done for some cases only to point out critical points.

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):

$$P_R = P_T L^2 \left[\frac{G\lambda\rho}{8\pi h} \right]^2 \qquad \text{(B.2.1)}$$

For mechanically large antennas, a near field correction term should be included in (B.2.1).

Where:

P_R : Received power in watt for a flat surface reflection;

P_{RT} Received power in watt for a turbulent surface reflection;

P_T : Transmitted power in [W];

G : Gain of the transmit and receive antenna;

λ : Wavelength in [m];

h **:** Distance between the radar and the target level in [m];

$\rho(\varepsilon)$: Dielectric reflection factor; $\rho(\varepsilon) = \dfrac{\sqrt{\varepsilon}-1}{\sqrt{\varepsilon}+1}$

(assuming the wavefront hits the reflector under a 90 degree angle).

Metal has $\rho(\varepsilon)$ = 1 while $\rho(\varepsilon)$ for various liquids are in the range 0,1 to 0,8. ε is the relative dielectric constant of the target material. The dielectric constant for liquids is between 1,6 and 80. Granulates can have lower ε as they are a mixture of solid and air. A typical reduction of ρ is 6 dB for a granulate compared to the same material in solid shape.

L : a factor including losses for antenna contamination, foam on the surface and other losses such as absorption losses in steam and dust between the radar and surface etc. L is the power loss one way through the foam layer on the surface or dirt layer on the antenna surface. -5 dB (L = 0,32) can be taken as an optimistic value just to cover variations of temperature and other parameters. It should be noted that 10 dB less is not an extreme case (see clause B.2.2).

Practical calculations are often done in dB and then equation (B.2.1) can be rewritten for the calm surface:

$$10\log(P_R) = 10\log(P_T) + 20\log(G) + 20\log(\frac{\lambda}{8\pi h}) + 20\log(L) + 20\log(\rho(\varepsilon)) \qquad \text{(B.2.2)}$$

The critical case for high path loss is in many cases turbulence which has two implications. There will be a stochastic variation of amplitude and apparent distance of the turbulent surface of the target. Considering this fact, a correction factor 8/G, which is determined semi-empirically, should be added.

The resulting average received power will be:

$$P_{RT} = P_T L^2 \left[\frac{G\lambda\rho}{8\pi h}\right]^2 \frac{8}{G} \qquad \text{(B.2.3)}$$

With a high gain antenna the loss by turbulence is easily 20 dB but much less for a small low gain antenna. The notation for P_{RT} is used to distinguish from a flat surface. One interesting feature is that P_{RT} is not explicitly dependent on λ which means that the higher antenna gain achieved at a higher frequency is destroyed by the turbulence.

The factor containing λ and h is usually referred to as "free space loss". In case of a turbulent liquid surface a term 8/G should be added, which modifies (B.2.2) to:

$$10\log(P_{RT}) = 10\log(P_T) + 10\log(8G) + 20\log(\frac{\lambda}{8\pi h}) + 20\log(L) + 20\log(\rho(\varepsilon)) \qquad \text{(B.2.4)}$$

It should be noted that the transition region from "calm surface" to "turbulent surface" is very small: in practical LPR case less than λ/2 peak to peak ripple. Therefore, the attenuation caused by turbulence can in most cases be treated binary (i.e. calm or turbulent).

Following figure B.2.1.1, the modified radar equation for radar level gauging (B.2.2) can be deduced from the Friis transmission formula.

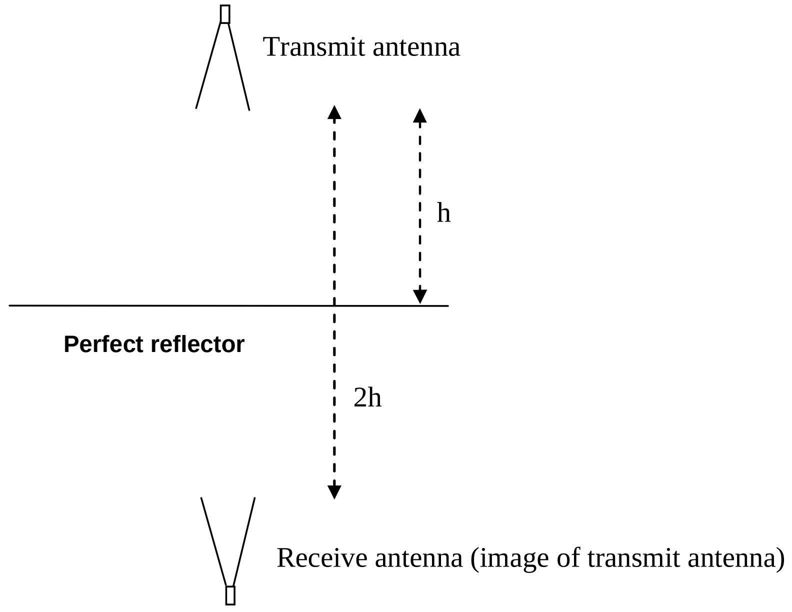

Figure B.2.1.1: Level measurement signal propagation

In the case that an LPR operating at 25 GHz measures through an ideal environment (no vapour damping, no foam, no antenna contamination), the level of plastic granulate with efficient dielectric constant of 1,3 (and by its nature "turbulent"), at a distance of 10 meters, then "free space loss" ($20\log(\frac{\lambda}{8\pi h})$) and reflective loss ($20\log(\rho(\varepsilon))$) can exceed 110 dB. Under the limit for the emission, the transmitted power should be adjusted by so-called APC techniques in order to reach the required signal to noise ratio.

Using the formulas given in this clause, examples for two-way attenuation are calculated in figure B.2.1.2. The results are compared to the acceptable pathloss limits of -70 dB and -95 dB for actual LPR designs.
The acceptable pathloss is defined as the maximum attenuation between the transmitter and the receiver antenna ports under which the equipment is still operating (measured without antennas).

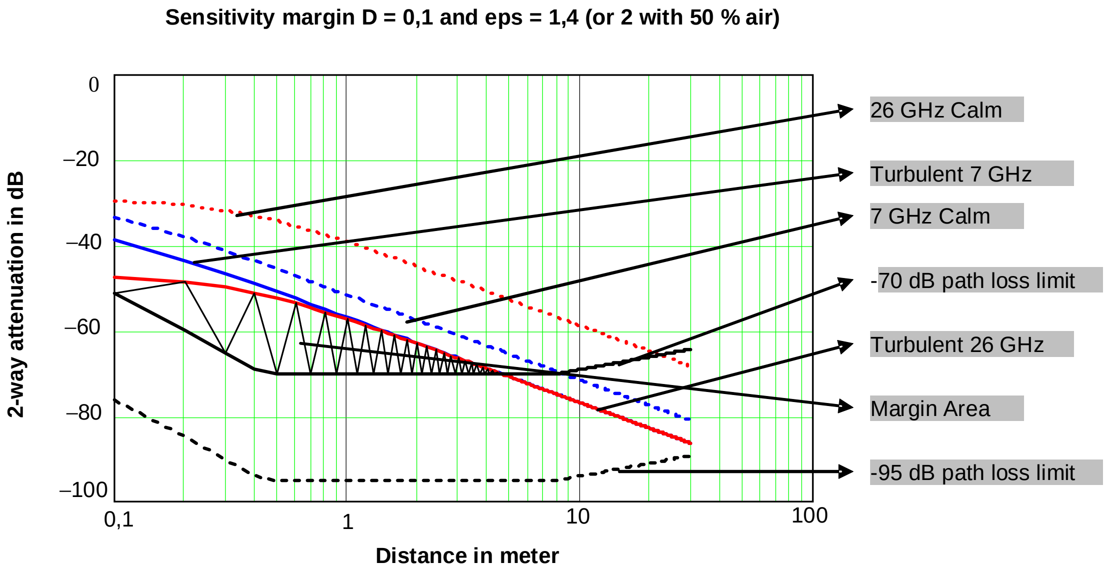

Figure B.2.1.2: Path loss diagram

The shadowed area is a margin which is very small and already before the calculated path loss has been decreased by a standard margin (temperature variations etc.) of 6 dB to 10 dB.

B.2.2 Degradations factors

Beside the degradation factors that were already inherent in the equations above (e.g. various dielectric constants, turbulent environment, antenna sizes etc. used for calculations of the "standard path losses") there are other degradation factors that limit sensitivity of the LPR systems such as dirt of antenna, foam, steaming, dust and solids. The available margins illustrated can be compared to possible extra "degradations", in order to judge how many of them may be acceptable during various known circumstances like distance, antenna size, etc.

Dirt on the antenna is a most typical LPR challenge (actually not described in any of the standard antenna handbooks) and many times associated with wet dirt adhering to the antenna due to splashing, condensation etc.
A 2-way degradation of 10 dB is considered as a normal degradation. However, sometimes a degradation as much as 40 dB to 50 dB has been noted. High frequencies are much more affected (decreased) than low frequencies. A few tenths of a mm of antenna contamination layer may already decrease the function considerable. To illustrate the influence of a wet layer on the dielectric part of an antenna (such as the sealing plug of a horn antenna), the attenuation has been calculated for water forming a layer which is well described in the literature [11], see figure B.2.2.

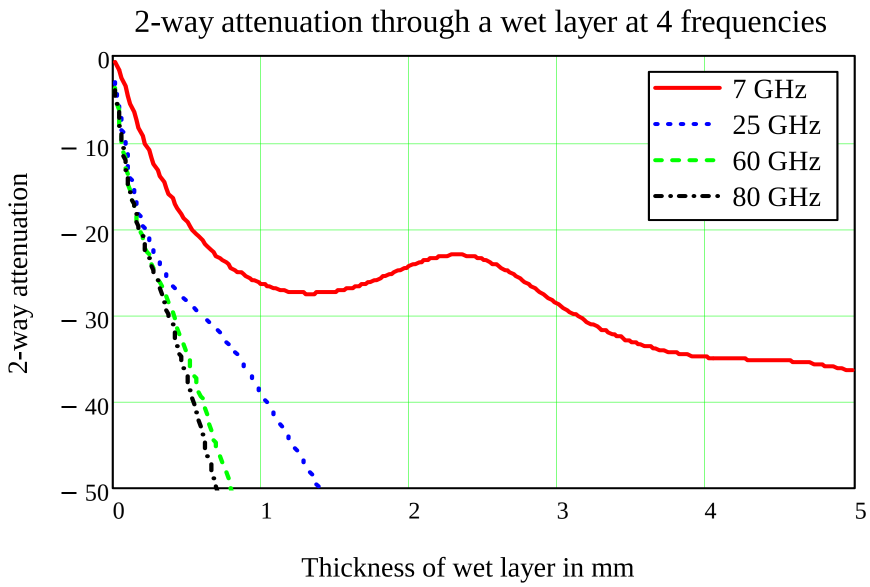

Figure B.2.2: 2-way attenuation as a result of contamination (wet layer) of antenna

There is a big difference for different frequencies and specially for frequencies above 20 GHz. Already one or two tenths of a mm thick layer on the antenna may completely stop the function if a high frequency is used. If, on the other hand, a low frequency is used and there is a good sensitivity margin, a layer of several mm can be accepted. From the diagram it is obvious that the dependence on the thickness is far from linear and especially the strong increase for thin layers is remarkable, mainly due to reflection rather than attenuation (which on the other hand dominates for high frequencies).

Foam on the surface has similar influence as dirt on the antenna, and a 40 dB to 50 dB or more 2-way degradation may occur. Certain liquids are known to be worse (e.g. oil of vegetable or animal origin). This is due to a water content of a few % or more in the liquids while other substances never have foam problems. Foam has a similar dependence as dirt on antenna (if the accumulated water content is used for layer thickness) but as foam can be very different and the liquid forming foam normally has an unknown water content, it is very difficult to make general statements. From experience it is known that already a few cm foam is able to stop the measurement unless the available margin is quite large.

Steaming of the liquid may contribute up to 10 dB degradation of the signal.

Dust_build up from target material will have a similar influence as dirt on an antenna and can cause a signal attenuation of up to 10 dB.

Solids will give a decrease discussed above but solids will also need a certain extra margin of at least 10 dB as the amplitude sometimes (due to the Rayleigh statistics) is low while the surface level may be constant. Solids with a constantly moving surface may not need this margin.

B.2.3 Influence of Turbulence

This clause demonstrates that planned emission limits (see clause 6.2) will be met under all perceivable field conditions the LPRs are expected to encounter. Specifically, the discussion is focusing on turbulent conditions – which from a microwave point of view – behave differently from flat surfaces.

Turbulence is a comprehensive term used to characterize various surface states which are clearly different from the smooth liquid surface. Examples of turbulent surfaces include boiling liquids and liquids that are moved by a rotating agitator. Furthermore, solid material (gravel, grain, pellets etc.) will form a similar surface but generally with slower movements.

When the radar beam hits a turbulent surface, three things happen:

1) Less power is reflected back to the LPR.

2) The amplitude of the reflection is fluctuating over time in a stochastic manner (generally with Rayleigh distribution).

3) Some of the reflected power is scattered away from the vertical line.

The design of the LPR in combination with the laws of physics during turbulent conditions will ensure that limits on emission levels (clause 6.2) will always be met. When turbulence increases, power received by the LPR will decrease and the rest of the power is scattered. However, during all conditions (including turbulence) the highest density will be reflected in the direction of the LPR. Thus, the measurement of the power received by the LPR is a representative measure of the e.i.r.p. of the total reflection. Due to the stochastic variation of the received power, it is a requirement that the peak received power is used to control the APC. Hence, compliance with the limits on emission levels is ensured.

At fully developed turbulence, the average reflected power is multiplied by 8/G (where G is the peak antenna gain) which gives an estimate for the need of dynamic range. There is a direct emission from the antenna as well and that emission will increase with the transmitter power. The maximum transmitter power allowed in a specific system may be determined by the antenna side-lobe attenuation from the horizontal plane to the vertical direction in order to guarantee that emitted power in the worst direction is compatible with the e.i.r.p. limit under the full range of APC conditions.

B.2.4 A conceptual test set-up

A conceptual set-up for the emission test is presented in figure B.2.4. In this set-up, the LPR is mounted above a surface that simulates the reflective properties of the material being measured. Emissions are measured along the half-sphere boundary defined in clause 6.2. Using the maximum recorded value of the emitted signal over that half-sphere, the e.i.r.p. is calculated.

The specific test method is to be defined in a future standard. It is expected that it will include a case where the reflection from the measured surface is good (i.e. flat metal forcing the APC to be at its maximum attenuation), and a case where the APC has its minimum attenuation. In the latter case, the test will show that the antenna side-lobes are sufficiently low with regard to the transmitted power.

Within the range of possible types of LPRs, some will have very low maximum power and correspondingly low requirements on side-lobe level and they will be restricted to be used in applications that have short measuring distances and good reflection (e.g., water treatment etc.). Other types will have higher power and longer possible measuring range but will need more advanced antennas with high side-lobe suppression.

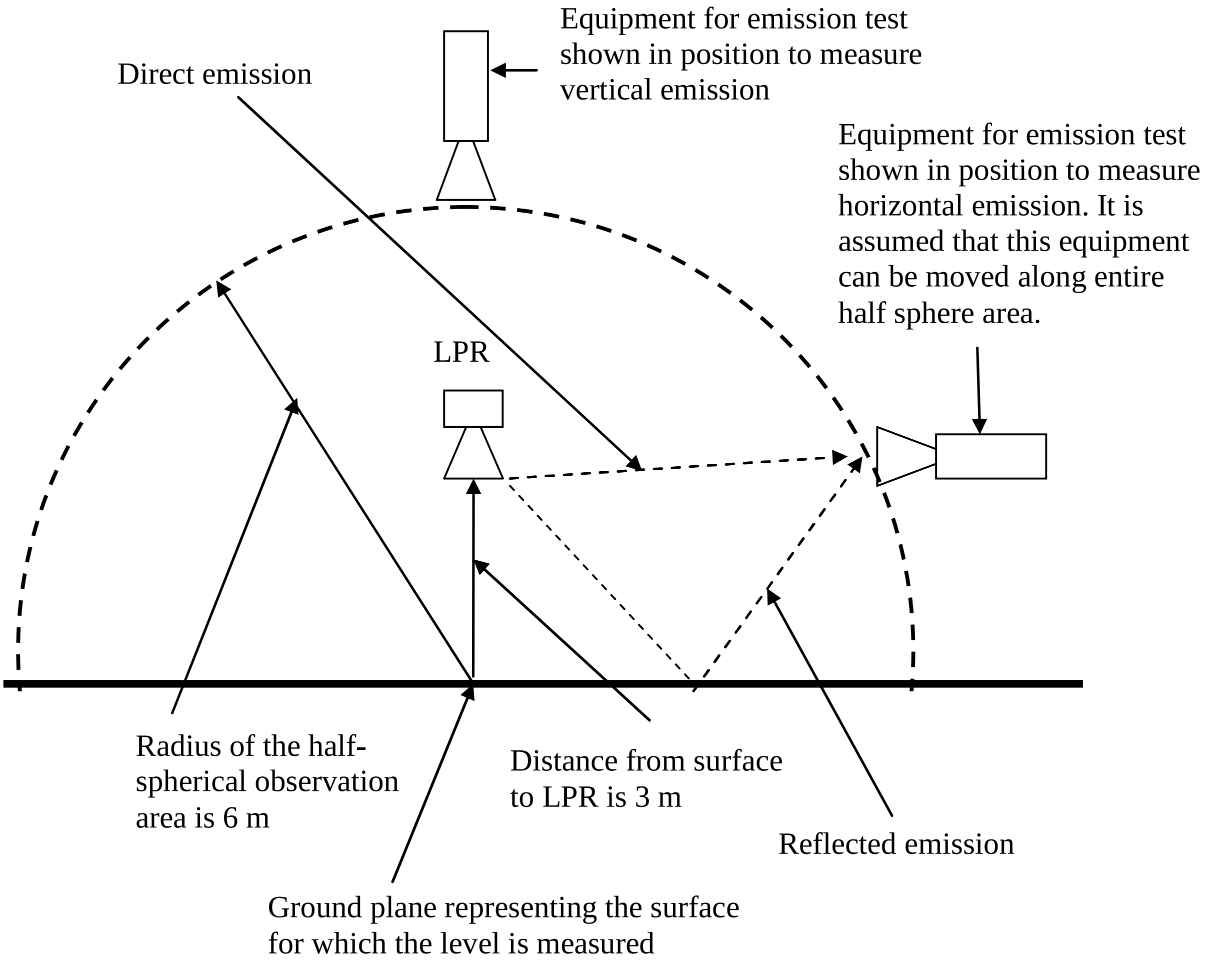

Figure B.2.4: Half-spherical observation area used for verification of emission levels under various surface conditions below the LPR

B.2.5 Bandwidth requirement

The ability to accurately resolve the measured distance is determined by the width of radiated pulse or in the case of FMCW sweep bandwidth. To achieve the required measurement performance, closely adjacent echoes is to be resolved (e.g. adjacent echoes which are one to a few hundred mm or less apart is to be resolved). The technical difficulty is to obtain an accurate measurement of the signal propagation time from the moment it is emitted via an antenna to the moment an echo is received after reflection.

Current systems have a 1 GHz to 2 GHz wide sweep or 0,5 nanosecond to 1 nanosecond pulses. A pulse width of typically 1 nanosecond pulse (depending on the pulse shape) corresponds to at least 1 GHz bandwidth. This bandwidth gives in practice around 300 mm resolution which is insufficient for the user today. For future systems there is demand for a substantial improvement in many applications. The higher the bandwidth, the shorter the pulses. With shorter pulses the echo resolution becomes better, and it is therefore easier to distinguish between two echoes that are close to each other.

Consequently, a wider bandwidth such as 6 GHz to 8,5 GHz in future systems is required. A larger bandwidth will give a considerable improvement in resolution, i.e. up to 20 mm resolution. One typical need for wide bandwidth is to distinguish echoes from items that are close together such as liquid surface and a flat bottom if the liquid is transparent to microwaves. A target at a shallow depth can be distinguished if the time interval δt for the signal to travel between the system and the substance level is greater than the pulse width. Thus, as the distance between the system and the material whose level is to be measured is reduced, the pulse duration needs also to be reduced which means a larger bandwidth of the system is required.

Accuracy is very important, and some applications require an accuracy below 1 mm. Today typical requirements for accuracy are 2 mm over 20 m or 0,01 % which also can be expressed in time as 13 picoseconds. An application example where very high measurement accuracy is needed due to a legal requirement (for example, an accuracy of better than 1 mm). The accuracy is more or less closely related to the bandwidth which is easier to obtain at higher frequencies.

The high measurement accuracy is partly a consequence of a high measurement resolution. Large bandwidth LPRs have a high resolution capability which enables moderating the influence of the disturbing echoes and makes it possible for a system to measure substance level more accurately. If two echoes are mixed up, the accuracy will be destroyed. To avoid mixing echoes, high resolution is required and a wide bandwidth is the only robust method to improve separation. For example, in a pulsed LPR system mixing of echoes can be seen as irregularities in the pulse shape which are a fraction of the pulse length. Such irregularities decrease the ability of finding the top of the pulse and in that way reduce measurement performance accuracy.

In order to meet a high accuracy and high resolution demand of the market, an extremely wide frequency bandwidth should be available, which is only possible at higher frequencies.

B.2.6 Measurement principle for the LPR limit values

Measurements in the new ETSI standard for LPR will be conducted over a semi-sphere along the cylindrical area defined in figure 6.1. This will be necessary to also cover sidelobe emissions.

A measurement to assess the APC performance will be defined using a highly reflective (e.g. metallic) footprint surface (worst case).

B.2.7 Frequency mask

Unwanted emissions outside of the operating frequency range are limited to -20 dBc.

B.3 Installation requirements of Level Probing Radar (LPR) Equipment

This clause provides the information for LPR equipment manufacturers and installers to design the equipment and the installation in such a way, that the technical requirements as stated in clause6.2, are fulfilled.

The following installation requirements are foreseen:

a) LPR are required to be installed at a permanent fixed position pointing in a downwards direction;

b) Installers have to ensure that there are no obstacles in the downwards radiating beam of the LPR to minimize unwanted reflections;

c) installation and maintenance of the LPR equipment should be performed by professionally trained individuals only.

The provider is required to inform the users and installers of LPR equipment about the installation requirements and, if applicable, the additional special mounting instructions (e.g. by putting it in the product manual).

Annex C: Expected sharing and compatibility issues

C.1 Current ITU allocations

There is no current ITU-R allocation corresponding to these devices. The present document assumes operation according to a provision of the Radio Regulations (RR4.4) that does not require any new allocation (i.e. on a non-protected basis and causing no harmful interference).

Due to the broad range of frequencies covered, an excerpt of the European Common Allocation Table [8] is not reproduced here. Please see CEPT/ERC Report 25 [8] for further details.

C.2 Coexistence issues

The limits in clause 6 for the respective frequency bands are considered to be in line with the results of CEPT/ECC Report 64 [5], CEPT/ECC Report 23 [6], CEPT/ECC Report 56 [7] and CEPT/ECC Report 114 [9].

Coexistence is further supported by the maximum duty cycle limit of 1 % which can also be used as a mitigation factor.

Aggregation effects towards radio services and applications are considered to be highly unlikely (see clause A.3).

C.3 Sharing issues

Due to the proposed low emission levels in clause 5 and the special installation requirements, sharing issues are not expected.

History

Document history		
V1.1.1	December 2007	Publication