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Fixed Radio Systems; Evaluation of the ElectroMagnetic Field (EMF) radiated by Line-of-Sight (LoS) fixed radio stations using parabolic dish directional antennas

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Foreword

This Technical Report (TR) has been produced by ETSI Technical Committee Access, Terminals, Transmission and Multiplexing (ATTM).

Modal verbs terminology

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Introduction

The protection of the general public and workers from Electromagnetic Fields (EMF) is subject of EU and national regulations.

Basic information is generally taken from ICNIRP guidelines [i.6], while EU regulations setting harmonised exposure limits are provided in Council Recommendation 1999/519/EC [i.2] for general public and 2013/35/EU Directive [i.3] for workers.

EU member states may set more restrictive national limits for the general public, which will prevail on the EU ones; information on such national limits may be found in a European Commission implementation report [i.5].

EU RF exposure limits are expressed in terms of Basic Restrictions (BR, for general public) or Exposure Limitation Values (ELV, for workers); the entity placing the EMF transmitting equipment on the market and the entity putting it into in the affected environment (either with specific field tests or other specific protection measures) are assessing compliance of RF exposure with the limits defined in the above mentioned EU Recommendation and Directive. However, RF exposure assessment based on BR/ELV may be complex, for example when Specific Absorption Rate (SAR) needs to be measured below 10 GHz (for general public) or 6 GHz (for workers); therefore, both EU Recommendation [i.2] and Directive [i.6] have defined limits in terms of Reference Levels (RL, for general public) or Action Levels (AL, for workers) which are more easily tested/calculated Electric field (E) and/or Power density (S); they indicate that, whenever they are satisfied, also the BR/ELV are fulfilled.

One possible approach to the problem, according the EC Non-binding guide [i.4], is to test or calculate a conservative volume (compliance boundary) around the EMF source where the RL/AL limits are certainly respected; therefore, the need for EMF assessment of BR/ELV is limited only inside that volume, if accessible by general public or by workers.

Radio equipment are subject to 2014/53/EU Directive [i.1], which article 3.1a) requires self declared assessment also the "health" of persons; this might include considerations about the evaluation of the impact of the EMF radiated through the connected antenna based on the above RL or AL limits.

Assessment to article 3.1a of the 2014/53/EU Directive [i.1] of equipment in the scope of the present document may be carried on based on harmonised standards CENELEC EN 50385 [i.9] for placing equipment on the market and CENELEC EN 50401 [i.8] for putting them into service. Both harmonised standards rely on CENELEC EN 62232 [i.7] basic standard that provides the appropriate RF exposure assessment methods.

In case the radio equipment is supplied also with the antenna (or the manufacturer specifies the antenna characteristics to be connected to the equipment, as it is often the case for fixed service radio systems) the manufacturer might consider to calculate the above described compliance boundary within the technical documentation in support of the DoC to 2014/53/EU Directive [i.1] as support for the customer's further RF exposure assessment.

The present document describes one methodology for assessing that compliance boundary when the antenna of the fixed service radio system uses conventional passive directional antennas (parabolic dish).

1 Scope

The present document provides guidelines for assessing the compliance of human exposure to established RF exposure limits based on the evaluation of the electromagnetic fields in the main beam emission of fixed service radio (base) stations when operating in line-of-sight (LoS) using directional parabolic (dish) antennas (e.g. in Point to Point applications). The methodology may be applicable also to other fixed radio stations provided that they use similar directional parabolic antenna type (e.g. for some terminals in Point to Multipoint and Multipoint to Multipoint systems).

Fixed radio stations using sector and omni-directional antennas are not in the scope of the present document.

Fixed service radio stations in the scope of the present document may use integral/integrated antennas or dedicated antennas, supplied by the same manufacturer, or stand-alone antennas from different manufacturer, but compliant to radio equipment manufacturer specifications; detailed definition of those antenna types are found in ETSI EN 302 217-1 [i.10].

Article 3.1a of the 2014/53/EU Directive [i.1], provides essential requirement for health and safety. Council Recommendation 1999/519/EC [i.2] (for general public) and Directive 2013/35/EU (for workers) gives recommended limits for exposure to electromagnetic fields based on the ICNIRP guidelines [i.6]. Assessment of compliance to article 3.1a of the 2014/53/EU Directive [i.1] of equipment in the scope of the present document and to the requirements defined in the Directive 2013/35/EU [i.3] (for workers) and Council Recommendation 1999/519/EC [i.2] (for general public) may be carried on based on harmonised standards CENELEC EN 50385 [i.9] for placing equipment on the market and CENELEC EN 50401 [i.8] for putting them into service.

The present document considers these exposure limits for comparison; calculations and measurements are reported. The guidelines presented may be used for calculation of the compliance boundaries as required by CENELEC EN 50385 [i.9] and CENELEC EN 50401 [i.8].

The simplified assessment method described is derived from measurement and calculation techniques defined in clause 8 of CENELEC EN 62232 [i.7] (see note) and may help in the compliance assessment of the above mentioned fixed service radio stations.

Definitions from the above mentioned EN standards are used in the present document where appropriate.

NOTE: CENELEC EN 62232 [i.7] considers a very broad types of radio antennas used in Base Stations (including Fixed Radio Stations) and is presently limited to 100 GHz; however, in specific case of parabolic (dish) antennas, the electromagnetic field generation is dominated by purely geometrical factors (related to the D/λ ratio); therefore, the methodology in the present document is considered applicable also to fixed service stations operating at higher frequency up to 300 GHz.

The maximum electric field or power density evaluation is based on calculations and measurements performed with the most common configurations and the values are tabulated. The measurement and calculation results on real systems that have been used to establish the method are also provided to give an estimation on the accuracy of the method adopted.

2 References

2.1 Normative references

Normative references are not applicable in the present document.

2.2 Informative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

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

The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

[i.1] Directive 2014/53/EU of the European Parliament and of the Council of 16 April 2014 on the harmonisation of the laws of the Member States relating to the making available on the market of radio equipment and repealing Directive 1999/5/EC.

[i.2] Council Recommendation 1999/519/EC of 12 July 1999 on the limitation of exposure of the general public to electromagnetic fields (0 Hz to 300 GHz).

[i.3] Directive 2013/35/EU of the European Parliament and of the Council of 26 June 2013on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (electromagnetic fields) (20th individual Directive within the meaning of Article 16(1) of Directive 89/391/EEC) and repealing Directive 2004/40/EC.

[i.4] Non-binding guide to good practice for implementing Directive 2013/35/EU Electromagnetic Fields: Volume 1 - Practical guide.

NOTE: Available at http://ec.europa.eu/social/main.jsp?catId=738&langId=en&pubId=7845.

[i.5] Report from the Commission on the application of Council Recommendation of 12 July 1999 (1999/519/EC) on the limitation of the exposure of the general public to electromagnetic fields (0 Hz to 300 GHz) - Second Implementation report 2002-2007.

NOTE: Available at http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A52008DC0532.

[i.6] ICNIRP Guidelines for Limiting Exposure to Time-Varying Electric, Magnetic and Electromagnetic Fields (up to 300 GHz), Health Physics April 1998, Volume 74, Number 4:494-522.

[i.7] CENELEC EN 62232 (2017): "Determination of RF field strength, power density and SAR in the vicinity of radiocommunication base stations for the purpose of evaluating human exposure".

[i.8] CENELEC EN 50401 (2017): "Product standard to demonstrate the compliance of base station equipment with radiofrequency electromagnetic field exposure limits (110 MHz - 100 GHz), when put into service".

[i.9] CENELEC EN 50385 (2017): "Product standard to demonstrate the compliance of base station equipment with radiofrequency electromagnetic field exposure limits (110 MHz - 100 GHz), when placed on the market".

[i.10] ETSI EN 302 217-1: "Fixed Radio Systems; Characteristics and requirements for point-to-point equipment and antennas; Part 1: Overview, common characteristics and system-independent requirements".

[i.11] ETSI EN 302 326-2: "Fixed Radio Systems; Multipoint Equipment and Antennas; Part 2: Harmonised Standard for access to radio spectrum".

[i.12] ETSI TR 102 243-1: "Fixed Radio Systems; Representative values for transmitter power and antenna gain to support inter- and intra-compatibility and sharing analysis; Part 1: Digital point-to-point systems".

[i.13] R. C. Hansen; L. F. Libelo: "Rapid Calculation of Near-field Fluence of High Power Microwave Antennas". IEEE Transact. EMC Year: 1992, Volume: 34, Issue: 3.

[i.14] C. Balanis: "Advanced engineering electromagnetics", ISBN: 978-0-470-58948-9.

[i.15] E.V. Jull: "Aperture Antennas and Diffraction Theory". IEEE Electromagnetic Waves Series ISBN: 978-0906048528.

[i.16] R. C. Hansen: "Circular-Aperture Axial Power Density". Microwave Journal (vol. 19, pp. 50-52, February 1976).

[i.17] R. W. Bickmore and R. C. Hansen: "Antenna Power Densities in the Fresnel Region". Proceedings IRE, vol. 47, pp. 2119-2120, 1959.

[i.18] ETSI EG 202 373: "Electromagnetic compatibility and Radio spectrum Matters (ERM); Guide to the methods of measurement of Radio Frequency (RF) fields".

3 Definitions, symbols and abbreviations

3.1 Definitions

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

action level (AL): action levels are provided for practical exposure-assessment purposes to establish boundaries, within which the Exposure Limits Values (ELV) are satisfied

NOTE: AL notation used is used in Directive 2013/35/EU [i.3], while "reference level" (RL) notation is used with similar meaning in Recommendation 1999/519/EC [i.2].

antenna: device that serves as a transducer between a guided wave (e.g. coaxial cable) and a free space wave, or vice versa

antenna gain: ratio of the maximum radiation intensity from an (assumed lossless) antenna to the radiation intensity that would be obtained if the same power were radiated isotropically by a similarly lossless antenna

Base Station (BS): fixed equipment including the radio transmitter and associated antenna(s) as used in wireless telecommunications networks (CENELEC EN 50385 [i.9])

basic restrictions (BR): lawful limit for general public exposure to time-varying electric, magnetic, and electromagnetic fields (EMF) that are based directly on established health effects and biological considerations

NOTE: Basic restriction (BR) notation is used in Recommendation 1999/519/EC [i.2], while "Exposure Limits Values" (ELV) notation is used in Directive 2013/35/EU [i.3] with similar meaning.

compliance boundary: volume outside which any point of investigation is deemed to be compliant with the RL or AL exposure limits

NOTE: Outside the compliance boundary, the exposure levels do not exceed the basic restrictions (BR) or exposure limit values (ELV) irrespective of the time of exposure.

dish antenna: parabolic antenna usually used for radio-relays or point-to-point communications

Electric field strength (*E*): magnitude of a field vector at a point that represents the force (*F*) on a positive small charge (*q*) divided by the charge

NOTE 1: Electric field strength is expressed in units of volt per metre (V/m).

NOTE 2: RL (for general public) and AL (for workers) are defined in term of E limits. Above 10 MHz (for general public) and above 6 GHz (for workers), alternative equivalent S limits are also defined.

Equipment Under Test (EUT): device (such as transmitter, base station or antenna as appropriate) that is the subject of the specific test investigation being described

Equivalent Isotropically Radiated Power (EIRP): product of the power supplied to the antenna and the maximum antenna gain relative to an isotropic antenna

NOTE: EIRP = G * P
where:
P is the emitted power;
G is the maximum gain of the antenna relative to an isotropic antenna.

Exposure Limit Values (ELV): lawful limit for workers exposure to EMF, established on the basis of biophysical and biological considerations

NOTE 1: ELV notation is used in Directive 2013/35/EU [i.3], while "basic restriction" (BR) notation is used in Recommendation 1999/519/EC [i.2] with similar meaning.

NOTE 2: Same as note 2 to the definition of basic restriction (BR) above.

fixed radio station: radio station used for systems in the Fixed Service; typically for PP or Multipoint systems and included in the broader term "Base Station" in CENELEC EN 50385 [i.9]

parabolic antenna: See dish antenna.

Point Of Investigation: location in space at which the value of E-field, H-field, Power flux density or SAR is evaluated

NOTE: This location is defined in cartesian, cylindrical or spherical co-ordinates relative to the reference point on the EUT.

Power flux density (S): power per unit area normal to the direction of electromagnetic wave propagation

NOTE 1: Lawful limits are expressed in S values above 10 GHz (for general public) or above 6 GHz (for workers).

NOTE 2: AL (for workers above 6 GHz) and RL (for general public) are defined in term of S limits. Alternative equivalent E limits are also defined.

Reference Level (RL): reference levels are provided for practical exposure-assessment purposes to establish boundaries, within which the relevant basic restriction (BR) are satisfied

NOTE: reference level (RL) notation is used in Recommendation 1999/519/EC [i.2], while Action Level (AL) notation is used, with similar meaning, in Directive 2013/35/EU [i.3].

Specific Absorption Rate (SAR): time derivative of the incremental energy (dW) absorbed by (dissipated in) an incremental mass (dm) contained in a volume element (dV) of given mass density (ρ)

NOTE 1: $$SAR = \frac{d}{dt}\left(\frac{dW}{dm}\right) = \frac{d}{dt}\left(\frac{dW}{\rho dV}\right)$$

SAR is expressed in units of watt per kilogram (W/kg).

NOTE 2: SAR can be calculated by:

$$SAR = \frac{\sigma E_i^{\,2}}{\rho}$$

where:
E_i is rms value of the electric field strength in the tissue in V/m
σ is conductivity of body tissue in S/m (e.g. ICNIRP [i.6] assumes a typical value of 0,2 S/m)
ρ is density of body tissue in kg/m^3 (typically about 1 000 kg/m^3).

NOTE 3: Lawful limits are expressed in SAR values up to 10 GHz (for general public) or up to 6 GHz (for workers).

3.2 Symbols

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

ξ Normalized variable for the antenna radius $\xi \in (0,1)$

γ	Factor for spatial averaging
λ	Wavelength (m)
η_A	Antenna aperture efficiency (see annex A, equation A.5)
a	Radius of the antenna (m), a=D/2
A	Geometric antenna aperture (m^2)
A_e	Equivalent antenna aperture (m^2)
A_0	Reference area 20 cm^2 for spatial averaging
CD_{los}	Compliance distance (to the AL or in the line of sight
Din	Inner diameter of the antenna (m)
Dout	Outer diameter of the antenna (m)
E	Electromagnetic field (V/m)
E_{lim}	Electromagnetic field limit value (V/m) of AL (for general public) or RL (for workers)
F	Peak to average factor of the power density (S)
G	Antenna gain
m_0	Reference mass 10 g for spatial averaging (expressed in kg)
P	Power transmitted by the antenna
r	Distance between the point of investigation and the antenna

NOTE: Some figures in the annexes the notation "z" is alternatively used and in some phormulas the alternatively notation ρ is alternatively used.

R_{ff}	Far-field distance

NOTE: Some figures in the annexes the notation r_{FAR} is alternatively used.

R_{lim}	Extension of compliance boundary
rms	root mean square
S	Power density (W/m^2) at distance r (m) from the antenna

NOTE: Not to be confused with "S" abbreviation of the unit "Siemens" used as S/m in conductivity (σ).

S_{ff}	Power density at a distance R_{ff} from the antenna
S_{lim}	Power flux density limit value (W/m^2) of AL (for general public) or RL (for workers)
S_{max}	Maximum power density (W/m^2) spatially averaged over 20 cm^2
S_n	Power density normalized to P/D^2
SAR_{lim10g}	Specific Absorption Rate (W/kg) on 10g contiguous tissue; lawful limit value
x	Normalised distance (Ratio of distance to the antenna (r) and Rff)
z	See r

3.3 Abbreviations

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

AL	Action Level
BR	Basic Restriction
BS	Base Station
CAD	Computer Aided Design
EIRP	Equivalent Isotropically Radiated Power
ELV	Exposure Limit Value
EMC	ElectroMagnetic Compatibility
EMF	ElectroMagnetic Field
EUT	Equipment Under Test
FCC	Federal Communications Commission
MMF	Mobile Manufacturers Forum (MMF)

NOTE: From Jan 1st 2017 changed into Mobile & Wireless Forum (MWF).

MoM	Method of Moments

RF	Radio Frequency
RL	Reference Level
SAR	Specific Absorption Rate

4 Some properties of fixed radio systems

4.1 General

4.1.1 Frequency bands

Frequency bands for the fixed radio systems range from about 1,3 GHz up to 86 GHz and beyond. Details are given in ETSI EN 302 217-1 [i.10] and ETSI EN 302 326-2 [i.11].

4.1.2 Transmit power levels

Transmit power levels are in general determined by EIRP restrictions or power flux density restrictions. Thus the restrictions are placed for a combination of both transmit power and antenna gain. Representative values can be found in ETSI TR 102 243-1 [i.12].

Licensed EIRP is generally regulated on link-by-link basis through Remote Transmit Power Control (RTPC) functionality; however, when generic equipment assessment for article 3.1a of the 2014/53/EU Directive [i.1] is concerned (i.e. for placing equipment on the market through application of CENELEC EN 50385 [i.9]) the maximum EIRP delivered by the equipment through the highest foreseen antenna gain may be used for defining the safeguard boundaries valid for all stations.

When put into service (i.e. through application of CENELEC EN 50401 [i.8]) the actual licensed EIRP (including any positive tolerance, if any) could be used; however, the real field conditions should also be considered (e.g. presence of more than one systems in the same location).

4.1.3 Antennas

4.1.3.1 Directive antennas

This class of antennas are generally used to send and/or receive a signal from a single location.

The most common antenna type is a parabolic dish antenna. Prominent characteristics are high directivity and low radiation outside the main beam direction.

For the purpose to calculate the maximum power flux density from these antennas only a few parameters are needed like transmitted power, frequency, antenna diameter, aperture efficiency and antenna gain.

4.1.3.2 Sectorial and omni-directional antennas

Sectorial and omni-directional antennas are not in the scope of the present document.

4.2 Point-to-point fixed radio stations

Point-to-point fixed radio stations , similarly to macro-cells base stations in mobile systems, are installed in towers, masts, on rooftops or in similar locations. The main design criteria consists in having the two corresponding locations in line of sight, so there is no possibility that some building be "crossed" by the radio signal, since, in such case, an attenuation would be produced and the connection would not work properly.

Outdoor units and antennas are normally required to be inaccessible by the general public to prevent intentional or unintentional damage to the equipment or to the radio link.

The above situation establishes a special condition for these systems: unavailability of the radio path for the general public. Nevertheless, care should be taken (see note) when very short links are deployed at street level (i.e. buildings might be immediately beyond the receiver station).

NOTE: In literature, some systems (e.g. high power radars) have an obstruction avoidance mechanism which will immediately (i.e. within less than 1 s) stop the transmission if a person is staying in the main lobe of the antenna. Such mechanism, might also be taken into account when appropriate.

4.3 Multipoint fixed radio stations

Multipoint communication systems are communication systems between multiple (source) terminal stations access points and a single (destination) base station access point for bi-directional asymmetric, bi-directional symmetric, or unidirectional communication.

Base stations for multipoint fixed radio systems, not in the scope of the present document, are installed in towers, masts, on rooftops or in similar locations.

Terminal stations, in the scope of the present document when using directional parabolic-like antennas, are considered similar to point-to-point stations and can be deployed in similar conditions.

5 Antenna properties

5.1 Near-field and Far-field concept

A very common subdivision of the space surrounding an antenna consists in defining two regions of space, called "near-field" and "far-field".

Although there are not sharp boundaries between these regions, the near-field is the region of space nearest to the antenna, where the wave is still nearly plane, like in the aperture. The "far-field" region is assumed to start in a location of the space, where the wave can be considered as a spherical wave and free space conditions can be adopted.

For the parabolic reflector, a common shape of reflector that is frequently met on microwave antennas, the lower boundary of near-field region is situated at a distance R_{nf} from the antenna given by the formula $R_{nf} = D^2/2\lambda$ (called Rayleigh distance), where D, R_{nf} and λ are respectively the antenna diameter, the near-field distance and the wavelength. At this distance the degradation of the main beam is moderate low, but the gain is reduced.

For the same type of reflector, the far-field limit (R_{ff}), is assumed at a distance equal to $R_{ff} = 2D^2/\lambda$, (called Fraunhofer distance) where D, R_{ff} and λ are respectively the antenna diameter, the far-field distance and the wavelength.

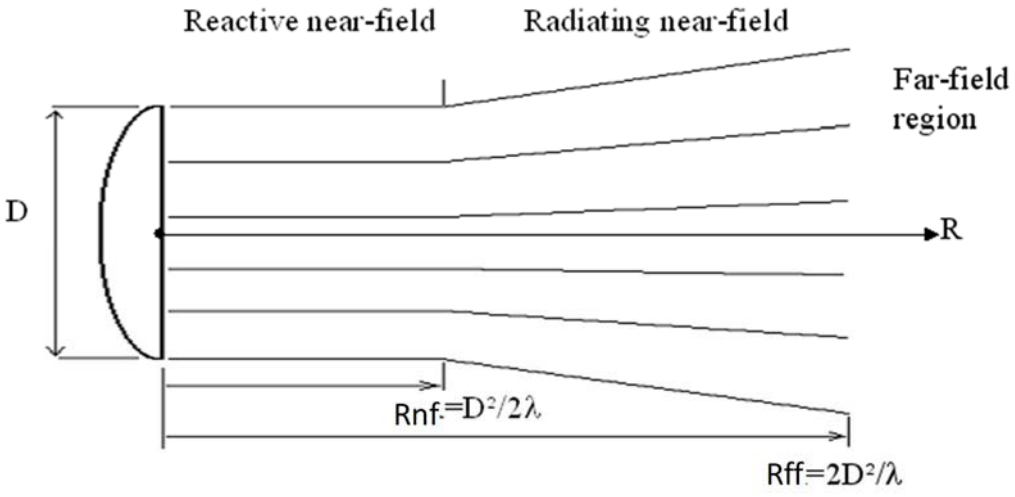

Figure 5.1: Near-field / far-field representation