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Electromagnetic Radiation Measurements at Aperture Antennae installation Sites

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Abstract: This paper presents and analyses measurements as well as theoretical calculations of the electromagnetic radiation emitted by aperture antennae installation of the Greek incumbent Telecom Operator (OTE). These antennae are used mainly for radiolinks operating at frequencies from 2 to 23GHz. The radiation emitted by these installations when worst case scenarios were applied, was well bellow the limits set by European Community legislation, as well as national law.

Key-Words: Electromagnetic Radiation, Electromagnetic Emissions, Microwave Antennae, Aperture Antennae, RF Safety Measurements, Radiation Exposure Limits.

1. Introduction

Aperture antennae are mainly used by telecoms operators, for point to point communications, enabling both high transmission capacities at long relatively distances and low power consumption, Radiolinks, are low cost telecom infrastructures, requiring relatively sort period for installation and testing, and therefore very attractive for rapid deployment of both core and access telecom networks.

The scope of this study is to demonstrate that the radiation levels from aperture antennae installations, used as radiolinks, are below the limits set both by the European Community and National Legislations.

Safety was not the main issue for the designer engineer of radiolinks some years ago. Public awareness due to the expansion of mobile telephony, obliged the operators to look very carefully on this matter, asking expertise help from the academia [1] and [13].

These obligations are imposed to telecom operators through European and national legislation [6], [7].

In this paper four representative installation sites are measured and analysed. In particular: (a) an ad-hoc radio unite, (b) the satellite station of Nemea, (c) the radio station of Neo Heraklion, located in Athens and (d) the radio of Darditsa, located in Peloponnesus.

2. Transmission site radioLink characteristics

Paraboloidal antennae are of highly directional nature and, the likelihood of significant exposure to RF radiation is considerably reduced.

Factors that should be taken into account in assessing the potential for exposure are: main-beam orientation, antenna height above ground, location relative to where people live or work and the operational procedures followed at the facility, as well as factors such as the feeding power and the operating frequency.

Table 1 below summarizes the radiation characteristics of the antennae under test, at the various installation sites, mentioned in the previous section.

Table 1: Antennae radiation characteristics

	ad-hoc radio link	Dar-ditsa Radio	Nemea Radio I	Nemea Radio II	OTE head-quarters
Power [dBm]	28,7	32	31,7	22,5	22
Frequency [GHz]	8	6	6,5	13	13
Antenna diameter [m]	1,2	3	1,8	1,8	0,6
Antenna height [m]	2	4	14	16	1,6
Take-off angle [deg]	0	-0,8	2,6	2,6	0
Trans-mission type	CW	SDH	PDH	SDH	SDH

In compliance of national and EU legislation the Greek Atomic Energy Commission has published in 2001 guidelines for the calculation of EM field from microwaves paraboloidal antennas [3], [4], [9].

3. Power density calculations

The reference levels set by national legislation, for microwave frequencies between 2 and 300 GHz, is 53 V/m and 8 W/m^2 [7]. These values are 20% less than those set in E.U. level [6] and internationally [12].

Aperture antennas have parabolic surfaces and many have circular cross section.

Power density at the antenna aperture can be approximated by the following equation:

$$S_0 = \frac{4P}{A} \qquad (1)$$

where: S_0 = power density at the antenna surface
P = power fed to the antenna
A = π*(D/2)^2 physical area of the aperture antenna and D is the antenna diameter

The field in front of a paraboloidal antenna may be divided into 3 main regions:

- Near Field or Fresnel region
- Transition region
- Far Field or Fraunhofer region

There are no sharp dividing lines between the 3 regions, and the somewhat limits set for each region are based on the way in which energy spreads as the distance from a paraboloidal antenna increases.

The following analysis is refereed on the scenario depicted in the next fig. 1.

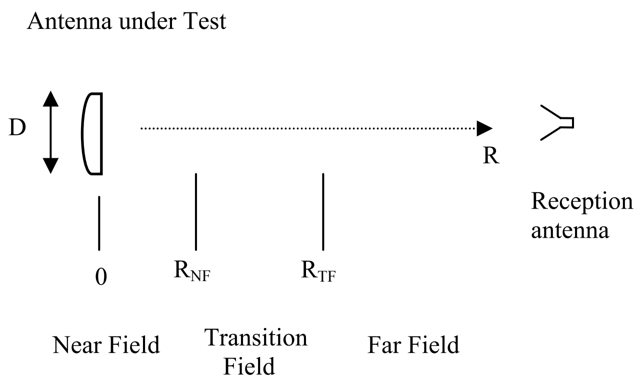

Fig.1: Near, transition and far fields notation

Different equations for the calculation of the limits of the three field regions and the power density within them are given [2], [8], [9] and [11].

3.1 Near-Field Region.

In the near-field region of the antenna the energy is largely confined within a cylindrical pattern of diameter D.

Near field extends up to a distance R_{nf} described by the following equation [11]and [14]:

$$R_{nf} = \frac{D^2}{2 * \lambda} \qquad (2)$$

In [8] and [9] the distance of the near field is given by the equation:

$$R_{nf} = \frac{D^2}{4 * \lambda} \qquad (3)$$

where, R_{nf} the extent of near field
D diameter of antenna
λ wavelength

The corresponded maximum value of the power density is given in [8] by the following equation:

$$S_{nf} = \frac{16 * n * P_{in}}{\pi * D^2} \qquad (4)$$

and in references [9] and [11] by

$$S_{nf} = \frac{16 * P_{in}}{\pi * D^2} \qquad (5)$$

where, S_{nf} power density in the near field
Pin power at the input of antenna
n aperture efficiency in equation (4) between 0.5 and 0.75
D diameter of antenna
λ wavelength

In equation (3b) the aperture efficiency is taken equal to 1.

3.2 Transition Region.
The transition region extents from the end R_{nf} of the near field up to the beginning of the far field R_{ff}. The distance R_{ff} is calculated by [8]:

$$R_{ff} = \frac{0.6 * D^2}{\lambda} \qquad (6)$$

and in references [2], [9] and [11]:

$$R_{ff} = \frac{2 * D^2}{\lambda} \qquad (7)$$

where, R_{ff} beginning of far field
D diameter of antenna
λ wavelength

The power density is given in [8] and [9] by the following equation:

$$S_{tr} = \frac{S_{nf} * R_{nf}}{R} \qquad (8)$$

where, S_{tr} power density in the near field
R_{nf} the extent of near field
R distance to point of calculation

3.3 Far-Field Region.
Far-field region extents for distances $R > R_{ff}$.
The power density is given by the equation (2), [8], [9], [11]:

$$S_{ff} = \frac{P_{in} * G}{4 * \pi * R^2} \qquad (9)$$

where, S_{ff} power density in the far field (W/m^2)
Pin power at the input of antenna
G antenna gain
R distance to point of calculation (m)

It is worth mentioning that national regulation in Greece, takes into account the principal of public protection, and follows worst case scenarios when calculating the electromagnetic field of antennas in microwave point-to-point radio links and satellite earth stations. For example, national regulation, calculates the near field power density from eq. 5, rather than eq. 4, arbitrating with the value of coefficient n, to be 100%.

4. Measurements campaign

Power strength measurements were recorded for each individual antenna installation of Table 1,

These values of the power density were then compared to reference level set by the Greek national law, of 8 W/m^2, and the one of the relevant EU recommendation of 10W/m^2.

Electromagnetic radiation measurements were executed with the aid of a suitable spectrum analyzer [7].

The basic characteristics of the instrument are given in next table 2.

Table 2. Reception measurements instrument basic characteristics

Spectrum analyzer	
Manufacturer	Hewlett Packard
Model	8564E
Frequency Range	30Hz – 40GHz

Reception antenna	
Manufacturer	Hewlett Packard
Type	Horn
Model	11966P
Frequency Range	1GHz – 18GHz

The experimental set-up is depicted in fig. 2. The horn antenna was based at 2m height from the ground level. For each measurement power vs frequency were recorded.

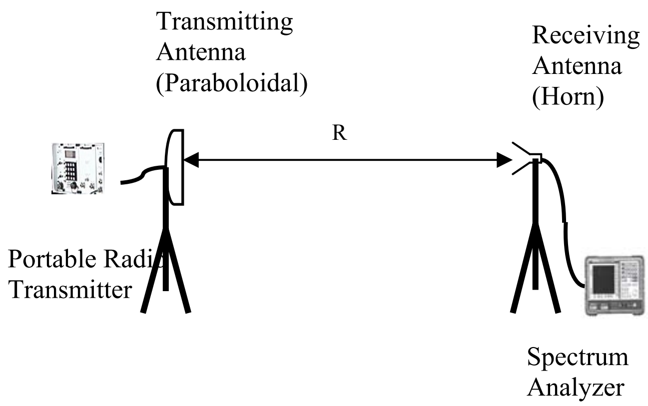

Fig.2: Measurement set-up

In practical working situations the environment may appreciably affect the measured radiation levels. The most common environments have buildings, metal structures and vehicles and the nature and location of some objects may vary from day to day due to the other activities being undertaken. Few sites are without such buildings and structures where there may be interaction with whatever objects are around and the ground may often be far from being flat.
An open area site, without any source of reflection, gives countable and reliable measurements, as there is no need to elaborate de-embedding techniques.

For the ad-hoc radiolink, an open areas it was selected where no buildings or any other obstacles exist in an area of several hundreds meters in order to avoid multiple reflections. The portable transmitter was set to the parameters shown in table 1. The transmitted signal was not modulated. Measurements were performed accordingly, following the set-up of fig. 2.

The receiving measurement instrument was placed at four different points at distances from 10 to 220 meters from the transmitting antenna. At each point the transmitting and receiving antennas were aligned.

Furthermore, measurements were carried out for various angles of the transmitting antenna at the azimuth plane, as well. Fig. 3 depicts a top view of the measurement campaign scenario that includes the measurement points.

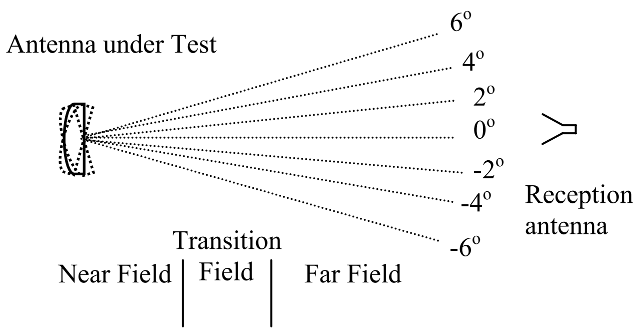

Fig.3: Top-view of measurement campaign set-up

The total power that reaches the reception antenna at the different test points is:

$$P_T = P_f + P_l \qquad (10)$$

Where, P_f is the measured power at the spectrum analyzer and,
P_l, represents the total losses in cables and adaptors

The power density at the measurement point is given by eq. 1,

5. Results

Following the scenario of fig. 3, described in the previous section, the received power in dBm vs distance from the antenna under test, are shown inn both in tabular and graph forms, in table 2 and fig. 4 respectively.

Table 2: Ad-hoc antenna measurements following fig. 3 set-up

R (m)	Power in dBm for various azimuth angles			
	0^o	2^o	4^o	6^o
12,5	2,7	-4,0	-17,0	-16,0
42	-6,5	-20,0	-30,0	-28,5
82,5	-11,8	-23,0	-35,3	-30,5
218	-20,0	-35,0	-43,0	-39,5

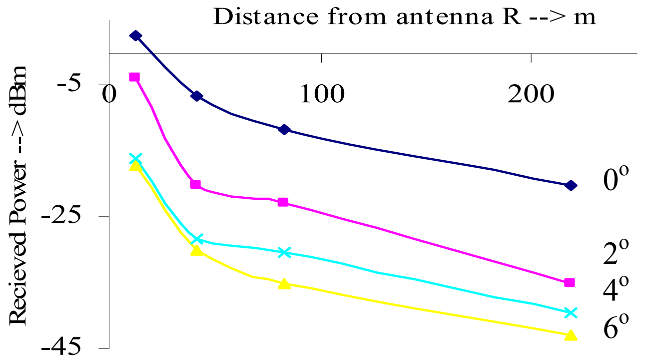

Fig. 4. Power vs distance from the ad-hoc radio antenna, for various angles

The corresponded to the power levels power densities, calculated from eq. 1, for 12,5 m distance form the ad-hoc radiator are depicted in next table 3. The results are compared to theoretical once, taken from eq. 4. The off - bore site theoretical input power to the antenna, is taken form the ITU radiation pattern curves [4]. Considering a worst case scenario, two reflection coefficients were taken into account.

Table 3. Power density vs angle of incidents, for 12,5 m distance form the ad-hoc radiator

Θ deg	Power density – W/m^2		
	Measure-ments	Calculations (eq. 4)	
		single reflection	dual reflection
0	1.282E+00	1.58E+00	3.150E+00
2	2.761E-01	1.90E-01	3.790E-01
4	1.384E-02	6.00E-02	1.200E-01
5	8.730E-03	3.46E-02	6.920E-02
6	1.742E-02	2.20E-02	4.390E-02
7	8.730E-03	1.50E-02	2.99E-02

The corresponded diagram of the next fig. 5, shows the direct comparison between measured and calculated results.

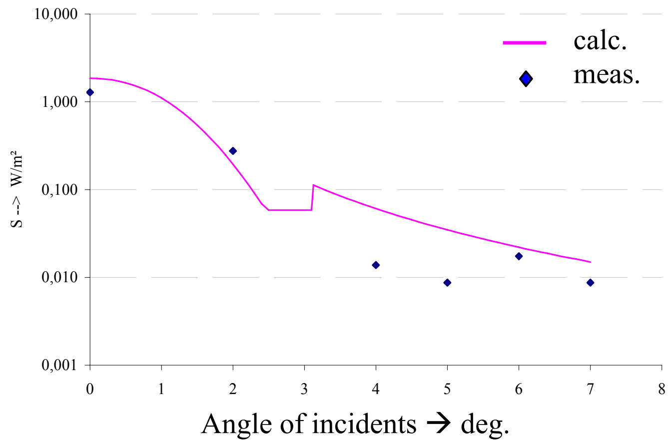

Fig. 5. Measured -vs- calculated results for the figures of table 3.

Experimental figurers are much less below the exposure radiation limit of 8 W/m^2, compared to the calculated. This is due to the fact that worst case scenario are applied for calculating the EM field power density.

Similar results were found for the other antennae installations. In particular, at Darditsa radio station, the following measurements show that at bore site the power density is at least 84.000 times below the limit of 8 W/m^2.

Table 4: Power density measurements at Darditsa radio, at 1,5m below the antenna axis

F (GHz)	**Distance m**	**P (dBm)**	**S ($\mu W/m^2$)**
6,28	3	-36	95
	5	-38	73
6,23	3	-37	86
	5	-37	83

Moreover, measurements at the top floor of OTE headquarters gave 20 times below the limit at a distance of 3,5 m from the antenna, at bore site. At Nemea radio, power density measurements maximum figure, at 38m away from and 8 m below of the antennae was 0,4 $\mu W/m^2$.

6. Conclusions

The results of this work, show that, based on worst case scenario, the values of the electromagnetic field are well below the limits set by the European Community Law, as well as national legislation. In all cases, except when measuring at bore site at distances shorter that 3m, the power density was measured to be thousands of times below the limit. Nevertheless, regardless the exposure distance from antennae, as the political will is to designed for maximum protection of the public. Theoretical calculations, over predict the values of power density in all cases.

In conclusion, aperture antennae installations, when follow all required specifications, fulfil all European and national regulations related to possible hazards from electromagnetic radiation.

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