Simulation of Electromagnetic Radiation Levels for some Radiocommunication Systems

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Abstract: In this paper an analysis is carried out of the possible approaches to the problem of the theoretical determination of the electromagnetic fields emission levels and some primary solutions are proposed considering different situations. We will focus our attention on Radiocommunications Systems, in concrete Mobile Communications, leaving apart the other services. Some procedures are provided to determine: theoretically, using simulation programmes, and empirically, taking measures, the emitting values and then, to compare them with the reference level.

Key-Words: - Electromagnetic radiation, Simulation, Propagation models, Radiocommunication, Antennas.

1 Introduction

During the last few years, certain scientific studies have suggested that the exposure to electromagnetic fields could have harmful effects on health. This has caused more and more concern about the possible biological effects and dangers to health produced by the non-ionizing radiation owing to artificial sources. In the beginning, they low frequency electromagnetic fields (ELF), produced by the power lines and the electrical appliances have caused certain alarm. Actually, and due to the fast expansion of the Radiocommunications Systems, especially to the explosion of the mobile communications facilities, the radiofrequency emissions and microwaves have woken up reticence.

Due to this situation, a high number of organizations such as scientific and normalization ones, have developed recommendations and standards on the acceptable limits concerning to the electromagnetic fields exposure. [1-3].

These studies usually try to identify the effects and the exposure parameters, which depend on the frequency, as well as the most appropriate measure procedure in order to obtain those parameters. Many carried out studies do not end up being normative but rather they remain as recommendations. However, entities like CENELEC [1-3] in Europe, FCC in United Estates and the Ministry of Science and Technology in Spain develops obligated normative fulfilment.

Therefore it is necessary to establish mechanisms in order to determine the radiation levels caused by different systems and electromagnetic fields sources with the purpose of checking that the established limits are completed.

Basically, two procedures exist for that evaluation; on one hand by means of theoretical calculations and on the other hand carrying out wide measures campaigns. Some organizations have also established evaluation and measure procedures of levels produced by different sources of electromagnetic fields. [4-5].

The theoretical procedure to determinate the existing electromagnetic emission levels, in an area, can consist on solving analytically by means of simple models or by means of simulation, using more complex models. The high number of sources and their different spectral characteristics, the spatial scattering, and the complexity of the environment, must be considered.

In this paper it is carried out an analysis about possible approaches to the theoretical determination of the electromagnetic fields emission levels and some primary solutions are proposed considering different situations.

We will focus our attention on the electromagnetic emissions related to the Radiocommunication Systems. In this Radiocommunication Systems, the sound and TV broadcasting systems, the radio link point to point, the radionavegation and the mobile communication systems can be pointed out. All of them operate between 100kHz and 100GHz.

2 Electromagnetic Radiation levels

2.1 Exposure parameters

The electromagnetic fields are characterized for the electric field strength E (V/m) and the magnetic field strength H (A/m). Depending on the emitting frequency and the distance to the emitting source, these magnitudes are more or less related in a complex way. When an electromagnetic wave impacts on a live tissue, a portion of that wave is reflected and the rest is absorbed. This effect produce different consequences but the most common one is the heating of those live tissues.

The interaction between the electromagnetic waves and the different parts of the tissues or cells is complex and depends on a high number of parameters, so much physical as biological, (frequency, power, intermittence, dielectric properties, etc.)

With the purpose of characterizing the exposure to electromagnetic fields, different parameters are used depending upon the field frequency: current density (J), Specific Energy Absorption (SA), Specific Energy Absorption Rate (SAR) or Power density (S). Using these parameters, the basic restrictions are set up, distinguishing between the occupational exposure and general public. The SAR is the most useful parameter on Radiocommunication Systems. This parameter is defined as radioelectric power per live tissue mass unit, expressed in W/Kg.

$$SAR = \frac{m \cdot \sigma \cdot E^2}{\rho} \qquad (1)$$

where m y ρ are the mass and the body density, σ is the electric conductivity and E (V/m) is the electric field strength value over the organic tissue. However these parameters are not easily assessment. Reference Levels are provided for practical exposure purposes and applying some margins of security. These are expressed by means of electric field strength (E), magnetic field strength (H), magnetic flux density (B), or power density (S), values. These reference levels are easier to measure or simulate and in most situations there are a relation between them.

All these values have been picked up in different standards and normative with very few differences among them. Level references given by the ICNIRP are included in table 1.

Frequency	Density power, S(W/m^2)
10-400 MHz	2
400-2000 MHz	f/200
2-300 GHz	10

Table 1. Exposure limits for public.

2.2 Procedures to obtain the levels.

There are basically two procedures to determine if the facilities of a Radiocommunications System, well in a isolate way or well together with others of the same or different service, fulfil the imposed limits in the before mentioned normative, or also to determinate the electromagnetic emission levels in a more or less spread area. The first procedure consists on the measurements fulfilment and the second one on a theoretical, analytic or simulated approach. Anyway, the possibility of having a map with the emitting levels of each point in a sufficiently wide area can be only carried out by means of simulation or interpolating the measures taken.

This first procedure is more accurate but requires expensive equipments, careful measure techniques and takes long time when the number of facilities is very high or the measure area is much spread.

In the following figure, the emitting levels corresponding to different Radiocommunication services and therefore different frequencies and their comparison with the reference levels before exposed, are shown.

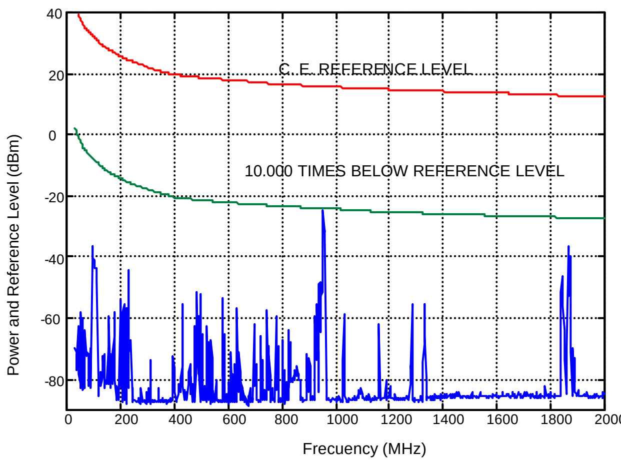

Figure 1. Measurement and Reference Levels for different services.

In a primary approach the second procedure is simpler. Although it is less accurate, it requires different models for different situations: near field, far field; different frequency bands and so different propagation basic mechanisms; etc. In addition it is necessary to verify the models used and the results got.

3 Radiation models for Radio Systems

Since the Radiocommunications started, a large amount of propagation models have been developed: simple theoretical models (Free Space, Surface Wave, Flat Terrain), empiric-statistical models specially obtained for broadcasting and mobile communications (UIT-R, Okumura Hata, etc) and recently deterministic models based on Ray-tracing and Ray-launching, that use electromagnetic approach by geometric-optics and the Uniform theory of diffraction. These models are employed in the design and planning of several Radiocommunication systems and they use to include some considerations about the received signal variability in order to take account fading effects.

To obtain the emitting levels using the mentioned models it is necessary to consider some specific circumstances such as the number and location of the different emitting sources, the high range of frequencies depending on the offered service, etc.

The free space approach is a simple model suitable to all systems and almost the entire range of frequencies. In this case, the power density from one particular transmitter can be calculated, in spherical coordinates, as the following expression indicates:

$$S(d,\theta,\phi) = \frac{EIRP}{4\pi d^2} F(\theta,\phi) \qquad (2)$$

where EIRP, equivalent isotropic radiated power, d distance from the source and F(θ,ϕ) the relative radiation pattern. The model above mentioned is only appropriate in far-field conditions. The most commonly accepted definition for far-field in communications is $d = 2D^2/\lambda$, where D is the largest dimension in the antenna, λ is the wavelength and both must be in the same units. However, in emitting measurements it can be considered that the field is almost formed from $d=\lambda$.

When near-field measurements are made, other approaches can be used, for example an uniform distribution of the emitted power in the transmitter area. Anyway, the free space condition can be adopted as a top limit.

In figure 2 the emitting levels produced by a typical 3-sector base station for mobile communications are shown, in horizontal and vertical plane and taking the free space expression as propagation model.

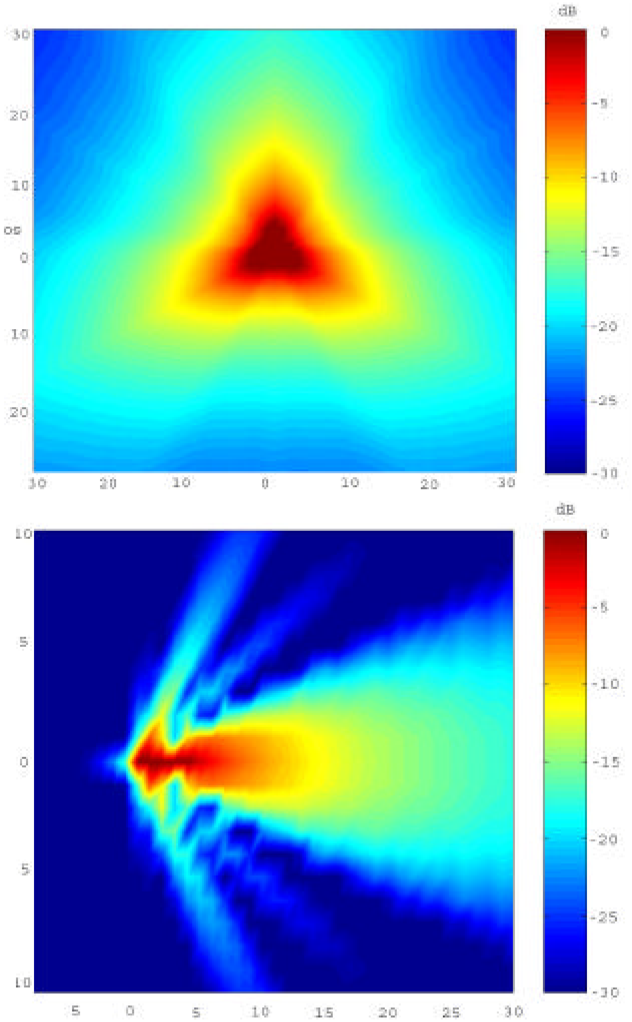

Figure 2. Power density levels, in horizontal and vertical plane, related to Reference Levels (PIRE = 1KW).

When several sources are considered, the density power in any point can be calculated using the expression:

$$S = \sum_{k=1}^{N} \frac{EIRP_k}{4\pi d_k^2} F_k(\theta_k, \phi_k) \qquad (3)$$

where N is the total number of transmission antennas, $EIRP_k$ is the total EIRP of the k-antenna, d_k is the distance between the considered point and the k-antenna, and F_k the radiation pattern from k-antenna which depends on its relative azimuth and elevation.

If the reflection on surfaces and the presence of obstacles are taken account, the propagation conditions are modified. This situation can be modelled as the result of multiple rays for each transmitting source

$$S=\sum_{k=1}^{N}\frac{EIRP_k}{4\pi}\left(\sum_{i=1}^{L}\frac{\rho_{ki}}{d_{ki}}\exp(j\varphi_{ki})F_{ki}^{1/2}(d_{ki},\theta_{ki},f_{ki})\right)^2 \quad (4)$$

where ρ_{ki} is the reflection coefficient of each component, related to the direct ray ($\rho_{k1}=1$); φ_{ki} is the phase of each component. This model requires a detailed knowledge about the environment, locations and electrical characteristics of all components. This could make impossible the study of wide areas with multiple sources. So that, a good approach for this model is the assumption of only two rays per source: direct and reflected rays.

$$S=\sum_{k=1}^{N}\frac{EIRP_k}{4\pi}\left(\frac{1}{d_{k1}}\exp(j\varphi_{k1})F_{k1}^{1/2}+\frac{\rho_k}{d_{k2}}\exp(j\varphi_{k2})F_{k2}^{1/2}\right)^2 \quad (5)$$

For the measurement of exposure levels, it is interesting to establish the maximum level. The worst situation, in this case, occurs when both components have the same phase and amplitude. If multiple rays are taken account, a statistical approach can be considered. Now, the worst case takes place when the amplitudes of all components are similar and it can be modelled as a Rayleigh distribution. As this distribution indicates, the probability of overcoming a value 10 times superior to the value obtained from only one component (free space model) is lower than $1\cdot10^{-4}$.

According to this approach, the worst situation can be assumed as the free space situation, multiplying the obtained value by a factor that ranges between 1 and 10, so that the multiple rays effect were included.

The previous method is a good approximation when we are at near distances from the transmitters, but due to the presence of the earth and its curvature, the interposed obstacles and their own limited coverage designs, a better approach consist of using a theoretic-empirical two-slopes model, n_1 until the break point (or turning point) is reached and the second slope n_2 from this point.

$$S=M_K\sum_{k=1}^{N}\frac{EIRP_k}{4\pi d_k^{n_1}}F_k(\theta_k,f_k) \qquad (d_k\le bp_k)$$

$$S=M_K\sum_{k=1}^{N}\frac{EIRP_k}{4\pi d_k^{n_2}}\frac{bp_k^{n_2}}{bp_k^{n_1}}F_k(\theta_k,f_k) \qquad (d_k\le bp_k)$$

(6)

where bp_k is the break point for each one of the emitting sources.

In figure 3 we show the levels for different models as a distance function. The emitting source corresponding to a Base Station in 900 MHz and 1 KW of EIRP transmitted.

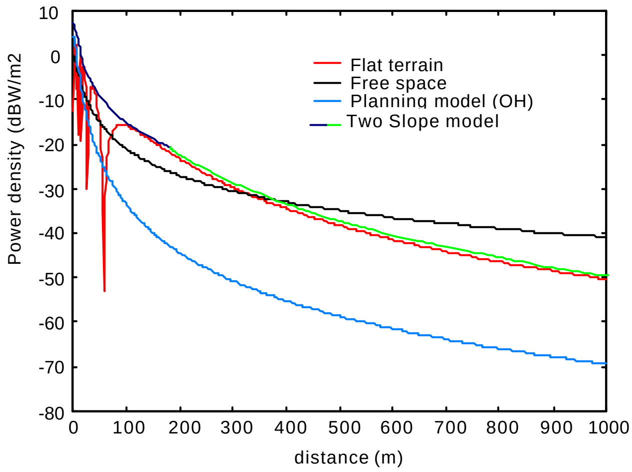

Figure 3. Level for different models.

It is important to consider that the reference levels depend on the frequency, so it is necessary to study the contribution from each frequency band to the exposition limits.

4 Results

Considering the application of the past models, They have been carried out some approaches for different environments, so it have been developed a software where we can place the emitting stations with their parameters and where the applicable models can be selected.

An area corresponding to a big city with a high number of emitting stations appears in figure 4.

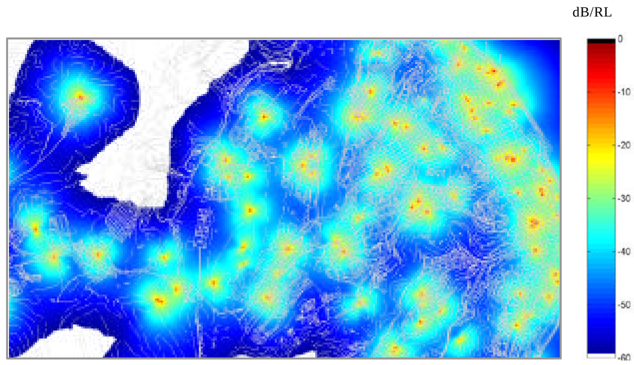

Figure 4. Simulation of a city with a high number of emitting sources.

In last figure it is observed that in bigger population's areas there is a high number of emitting stations which are transmitting with medium power to provide services to more users. For rural areas there are less stations transmitting with a higher power since the number of users is lower.

After that, it is made a comparison between the simulated results and the measures taken from a medium city.

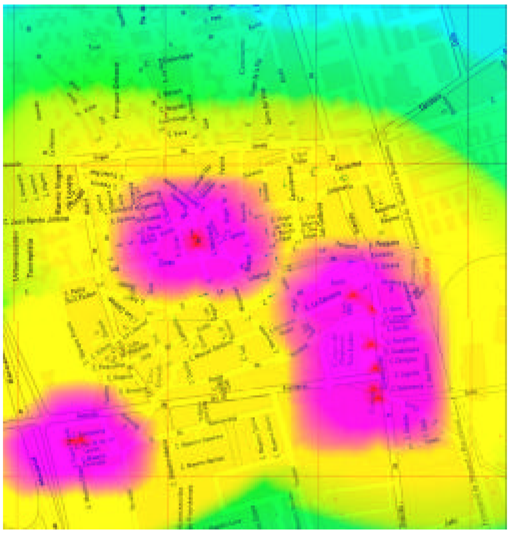

Figure 5. A simulation of emitting levels in a medium size city.

Figure 6. Measurements results taken from the before city

We can observe, in the before figures, a good agreement between the theoretical results and the measurements.

5 Conclusion

In this paper are shown some solutions for establish the emitting levels that affect to a concrete area. The study using the designed software could be a good first-approach, since it lets to obtain theoretically the electromagnetic field in all points. Depending on the chosen propagation model, it is possible to know the field strength for several situations and compare it with the reference levels in order to verify that comply with the standards. This study can be as accurate as are desired, however, when the accuracy increases the number of required parameters increase too and, as a result, the analysis is much more complex. On the other hand it is possible to obtain the electromagnetic field making measures. This solution requires the physical presence of qualified personnel and equipment on the area to evaluate. In addition to the economic inconvenience, these measurements are limited to existing systems, while theoretical study could be used to future situations in planning.

In conclusion, it is purposed to reach a compromise between the two mentioned solutions. In the first place a theoretical study must be carried out, and then take measures only in those places where the levels obtained theoretically are critical.

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