PREDICTION FORMULAS FOR RF ENERGY COMPLIANCE ASSESSMENTS IN THE VICINITY OF CELLULAR BASESTATION ANTENNAS

Quirino Balzano (1), Renato Cicchetti (2), and Antonio Faraone (3)

(1)Motorola Florida Research Labs, Corporate EME Research Lab, 8000 West Sunrise Boulevard,
Fort Lauderdale, Florida, USA; E-mail: eqb001@email.mot.com

(2)University of Rome "La Sapienza", Department of Electronics Engineering,
Via Eudossiana 18, I-00184 Rome, Italy; E-mail: cicchetti@die.uniroma1.it

(3)As (1) above, but E-mail: antonio.faraone@motorola.com

ABSTRACT

The assessment of RF safety compliance near basestation antenna has traditionally required on site measurements, which can be expensive and time consuming. This paper presents in a comprehensive framework a simple methodology that can be employed to perform compliance assessments even in the near field of basestation array antennas. The methodology is based on the analytical characterization of the array near field in both its average and peak power density levels, and the derivation of simple prediction formulas, whose parameters are readily available to personnel engaged in site installation and maintenance, or compliance assessments with respect to the RF exposure limits.

INTRODUCTION

The most widely adopted international RF safety guidelines are those issued by the IEEE [1] and by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) [2]. In both cases, the primary dosimetric quantity for assessing the human exposure to electromagnetic fields is the *specific absorption rate* (SAR), i.e., the time-rate of RF energy absorption per unit mass [3]. The IEEE C95.1-1999 Standard further establishes so called *maximum permissible exposure* (MPE) limits for free-space quantities such as the *rms* electric and magnetic fields, and the equivalent power density. The rationale is that meeting MPE limits ensures SAR compliance as well, thus enabling the choice of simpler free-space field measurements rather than far more complex SAR measurements [4] for compliance assessments. The ICNIRP Standard follows essentially the same approach by defining "reference limits" for the free-space incident field. Both standards also differentiate between controlled (occupational) and uncontrolled (general public) environment by introducing a five-fold limit reduction for the latter. MPE limits have been adopted by the FCC (Federal Communication Commission) in the United States, as well as by regulatory agencies in other countries. Many other nations have adopted the ICNIRP guidelines for their respective RF safety standards.

Except for minor differences in exposure thresholds, IEEE and ICNIRP standards differ in the way the exposure level is assessed: *average* over the bystander's height for IEEE, *peak* for ICNIRP. This distinction does not make a significant difference in the antenna far field. However, the profile of the antenna near field can be highly irregular, so average and peak power density are different near the arrays used in cellular basestations.

In this contribution, simple prediction formulas for the estimation of the peak and average power density in the near field of cellular basestation array antennas are presented. The theoretical background of these formulas is derived by the theoretical analysis of collinear arrays near field character, including a uniform asymptotic expansion of the field radiated by the arrays [5]-[8]. Verification has been carried out by an extensive computational analysis of different classes of base station antennas, as well as measurements. Said prediction formulas depend on readily available parameters and can be employed for the estimation of compliance distances with respect to RF safety guidelines issued by IEEE or ICNIRP without requiring measurements of the antenna near field, thus enabling substantial cost savings during the infrastructure deployment.

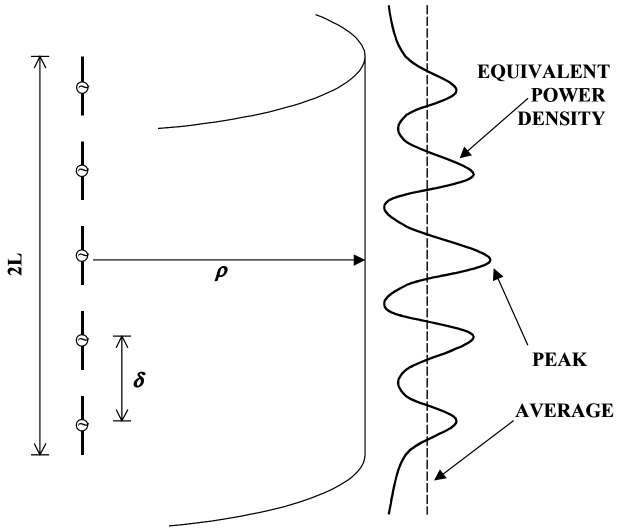

Fig. 1. A collinear array of half-wave dipoles. The cylindrical surface associated with the prediction model is sketched.

PREDICTION OF THE AVERAGE POWER DENSITY

Theoretical analysis of the character of the average power density generated by a collinear array of half-wave resonant dipoles, which is representative of most basestation antennas, allowed to determine simple formulas that allow the prediction of the near-field exposure with remarkable accuracy [6]. Figure 1 illustrates the reference geometry, comprising a vertical (*z*-directed) array. The average power density is defined as

$$\overline{P}_d(\rho;L)=\frac{1}{2L}\int_{-L}^{L}\mathrm{Re}\left\{\frac{1}{2}E_z(\rho,z)H_\phi^*(\rho,z)\right\}dz\,, \tag{1}$$

where $E_z(\rho,z)$ and $H_\phi(\rho,z)$ are the relevant electric and magnetic field components contributing to real power flow. The averaging is carried out over a line parallel to the array axis, at the radial distance ρ. Based on the analysis carried out in [6], the average power density can be predicted, at a distance ρ from the array, using the following formula

$$\overline{P}_d(\rho;L)=\frac{P_{rad}}{2\pi\rho\cdot 2L\sqrt{1+\left(\dfrac{\rho}{\rho_0}\right)^2}}\quad,\quad \rho_0=G_A L\,, \tag{2}$$

where G_A is the array gain and P_{rad} is the radiated power. The corresponding prediction formula for sector arrays, i.e., arrays that feature a directive horizontal beam, is as follows

$$\overline{P}_d\left(\rho;L,\overline{\phi}\right)=\frac{P_{rad}\,2^{-\left(\frac{\phi}{\overline{\phi}}\right)^2}}{\sqrt{2\pi}\gamma L\rho\sqrt{1+\left(\dfrac{\rho}{\rho_0}\right)^2}},\quad \rho_0=\frac{\gamma}{\sqrt{8\pi}}G_A L\,, \tag{3}$$

where $2\overline{\phi}$ is the antenna 3-dB beamwidth in azimuth, while 2γ is the angle of the illuminated sector, which can be approximated with the aperture of the sector array back-plane (typically equal to 180-degrees).

As shown in [6], the expressions (2) and (3) provide an accurate estimation of the average power density near the arrays.

PREDICTION OF THE PEAK POWER DENSITY

In [8], a simple relationship between *peak* and *average* power density was established based on a computational analysis of the near field of a representative set of omnidirectional and sector arrays. This result allowed to use modified versions of the cylindrical model formulas presented earlier to predict the *peak* equivalent power density. These formulas are provided below for omnidirectional and sector arrays

$$P_{d_{PEAK}}\left(\rho;L\right)=\frac{\xi P_{rad}}{2\pi\rho\cdot 2L\sqrt{1+\left(\xi\rho/\rho_0\right)^2}},\quad \rho_0=G_A L, \tag{4}$$

$$P_{d_{PEAK}}\left(\rho;L,\bar{\phi}\right)=\frac{\xi P_{rad}\ 2^{-\left(\frac{\phi}{\bar{\phi}}\right)^2}}{\sqrt{2\pi}\gamma L\rho\sqrt{1+\left(\xi\rho/\rho_0\right)^2}},\quad \rho_0=\frac{\gamma}{\sqrt{8\pi}}G_A L, \tag{5}$$

where

$$\xi=\max_{\rho>\lambda}\left\{\frac{P_{PEAK}\left(\rho,L\right)}{\bar{P}\left(\rho,L\right)}\right\}\simeq 2. \tag{5}$$

Figure 2 shows the typical behavior of the ratio between peak and average power density for two sector arrays. Except for distances within the near field of the array elements ($\rho<\lambda$), the ratio peaks just at the transition region where the behavior of the field changes from cylindrical to spherical. This result is consistent with the prediction of the uniform asymptotic methodology applied to the analysis of arrays in [8].

The expressions (4)-(5) yield an overestimation of the peak power density in the array near field (see Fig. 3). Choosing higher values for ξ can increase the degree of overestimation, which is a built-in confidence margin.

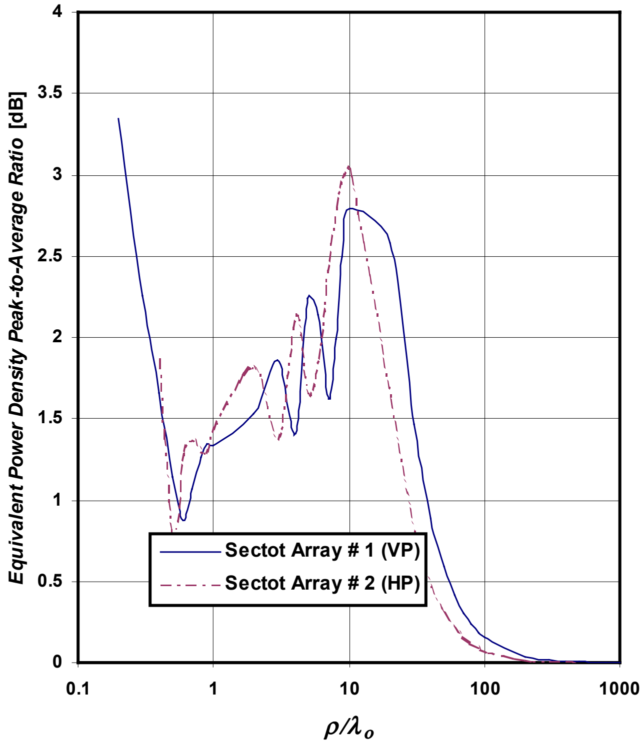

Fig. 2. Dependence of the *peak-to-average* power density ratio on the broadside distance from the back-reflectors for two sector arrays, one vertically polarized (VP) and the other horizontally polarized (HP).

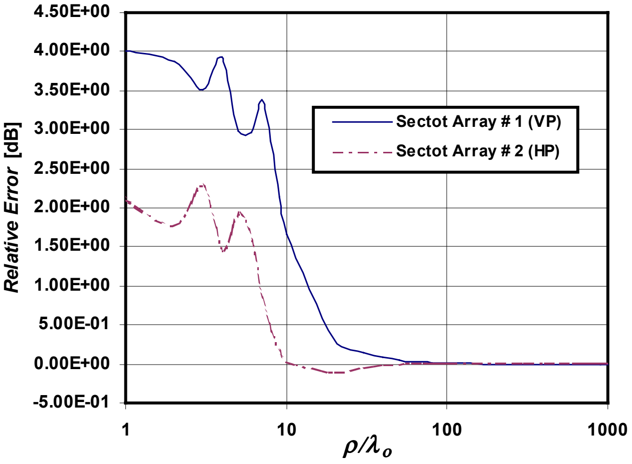

Fig. 7. Relative error between the prediction formula (2) and the computed *peak* power density for the considered sector arrays. Positive dB difference indicates overestimation.

CONCLUSIONS

The prediction formulas presented in this contribution can be very helpful in reducing the costs and efforts involved in the assessment of radio and cellular basestation sites, with respect to both IEEE and ICNIRP RF safety guidelines. They are based on a cylindrical propagation model of the array near-field [6], which was rigorously demonstrated for collinear arrays and extensively verified also for arbitrarily polarized sector arrays by means of numerical simulations. In particular, the results show that not only the *average* but also the *peak* equivalent power density could be accurately predicted by means of simple formulas, whose parameters are readily available. The prediction formulas can have a sufficient built-in margins in order to yield an overestimation of the true exposure levels, which is desirable for compensating any perturbation of the assumed free-space array field due to the surrounding environment, e.g., floor reflections. The formulas are applicable to broadside arrays regardless of the feeding profile of its elements. Furthermore, upon minor modifications [6], it is possible to use the prediction formulas even for arrays whose radiation beam is electrically or mechanically down-tilted.

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