World Academy of Science, Engineering and Technology
International Journal of Electronics and Communication Engineering
Vol:4, No:9, 2010

Mitigation of Radiation Levels for Base Transceiver Stations based on ITU-T Recommendation K.70

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***Abstract*—**This essay presents applicative methods to reduce human exposure levels in the area around base transceiver stations in a environment with multiple sources based on ITU-T recommendation K.70. An example is presented to understand the mitigation techniques and their results and also to learn how they can be applied, especially in developing countries where there is not much research on non-ionizing radiations.

***Keywords*—**Electromagnetic fields (EMF), human exposure limits, intentional radiator, cumulative exposure ratio, base transceiver station (BTS), radiation levels.

I. Introduction

According to latest World Health Organization [1] (WHO) and 13 country Interphone [2] study researches, mobile phones can contribute to health deficiency, including the increased risk of brain tumours, eye cancer, salivary glands tumours, testicular cancer, non-Hodgkin's lymphoma and leukaemia [3]; and though so far no study has linked BTS with human health risks, it is better to take preventive measures such as periodic assessments of the electromagnetic emissions at them and even try to mitigate the radiation levels to provide greater protection to general public.

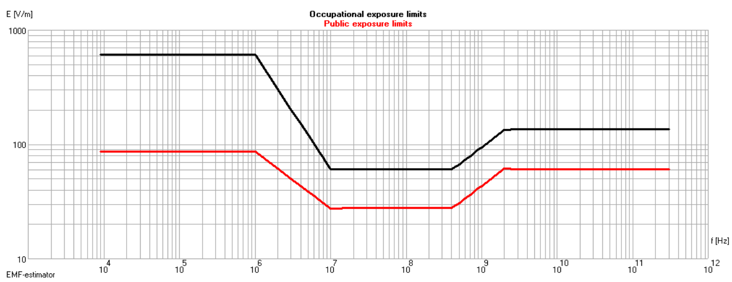
In developing countries, as Ecuador, just scarce or no research on non-ionizing radiation is performed. The telecommunication regulator in Ecuador [4] and the mobile operators must take in account the recommendations released by international entities in order to comply with human exposure levels, it means protect human against non-ionizing radiation.

ITU-T Recommendation K.70 [5] defines techniques which may be used by telecommunication operators to evaluate the cumulative exposure ratio in the vicinity of transmitting antennas and to identify the main source of radiation. It offers guidance on mitigation methods which allow reduction of radiation level in order to comply with exposure limits. It also provides guidance on procedures necessary in the environment in which, in most cases, there is a simultaneous exposure to multiple frequencies from many different sources. Radiating sources may belong to many mobile telephony operators and even may represent different radiocommunication services, as trunking systems, broadcasting, wireless access, etc.

First, the main methods used to evaluate the exposure levels are met with an especial focus on the point source method which is chosen for this study. Then the cumulative (total) exposure ratio will be presented in order to understand how external sources affect the accuracy of the assessment. After that, mitigation techniques will be studied to apply them later in the case of study. This essay finishes with conclusions and recommendations

II. Evaluation of Exposure Levels

To evaluate the human exposure to EMFs [6], basic restrictions based directly on established health effects are defined; calculate them in real situations are used to being very difficult. Reference levels for human exposure to electric, magnetic and electromagnetic fields are derived from the basic restrictions using the realistic worst-case assumption about exposure. If the reference limits are met, then the basic restrictions will also be met; if reference levels are exceeded, that does not necessarily mean that the basic restrictions are exceeded. It means that the demand for the compliance with the reference levels is a conservative approach.



The real source of intentional EMF is the transmitting antenna, not the transmitter itself. Transmitting antenna is the main source that determines EMF distribution in the vicinity of a transmitting station. The radiation emitted by the transmitter enclosure is unintentional radiation. On the other hand, the intentional radiation is that emitted by the transmitting antenna which is most important to assess the exposure and determines radiation levels in areas accessible to people.

The most important step in the exposure assessment is the evaluation of radiation levels in the considered area. In typical

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transmitting and base stations, many operating frequencies are used, so the cumulative exposure assessment is required. Depending on the accessible data, models and methods used for the evaluation, the results have a lower or higher accuracy. In general, more detailed information concerning the radiation sources and more sophisticated methods and models lead to higher accuracy. In some cases, the accuracy of the evaluation is limited because of the lack of appropriate data concerning transmitting equipment (antennas).

Depending on the method used and accessible data concerning radiating sources (antennas) and depending on the needs and required accuracy, in general three approach levels may be applied and may be efficient in cases met in practice [7].

A. Full-Wave Methods

The highest accuracy of calculation of the reference levels will be achieved by the numerical modelling using one of the full-wave methods based on solving Maxwell's equations in frequency or time domain. It includes the method of moments (MoM), finite-difference time domain (FDTD) and many others. Such methods of calculation may be used for any region of the EMF. They use detailed-segmented models of systems – the more detailed-segmented model is used, the better accuracy of the evaluated field distributions is achieved.

The accuracy of the results of calculations strongly depends on the exactness and the range of accessible data concerning a transmitting antenna, which includes antenna geometry and its feeding arrangement. Cellular panels contain a huge number of active radiating elements (up to 256) which are fed with different amplitudes and phases. Without such information, the calculation is impossible or may be used for a general assessment only.

Numerical modeling provide a good opportunity to take into account almost all substantial factors influencing radiation, but they are useful in rather simple cases only, or for near-field regions in which other methods are not sufficiently accurate. This happens so because it is very difficult to collect all the data needed. Additionally, sophisticated software and experience in electromagnetics are required, together with huge computer resources.

B. Synthetic Methods

In this model each antenna is considered to be a set of elementary sources which have identical parameters. This model may be employed for distances beyond the near-field distance calculated with respect to the maximum size of an elementary radiating source.

The model leads to very accurate results, but the accuracy is lower than in numerical modelling because the coupling between radiating sources in neglected. In many cases this assumption is well fulfilled. A disadvantage of this model is that exact information concerning the feeding arrangements of system containing many radiating sources is required.

C. Point Source Model

It is a simple but very effective model which assumes that the transmitting antenna is represented only by one point source, situated in the antenna electric centre and having its radiation pattern. The accuracy of this model depends on the field region and on the antenna gain [reference].

This model is fully applicable in the far-field region; this is, for distances from the transmitting antenna bigger than:

$$d_r = \max\left(3\lambda, \frac{2D^2}{\lambda}\right) \quad (1)$$

Where:

d_r is the distance between the transmitting antenna and the point of investigation

D is the maximum size of the antenna

λ is the wavelength

If the results of calculations are to be accurate, the minimum distance between the point of investigation and the transmitting antenna has to fulfil requirements for the far-field region. This limitation may be substantially decreased by the use of the synthetic model but it requires additional information concerning this transmitting antenna which may be impossible to collect.

A disadvantage of this model is in the immediate vicinity of the antenna, where the dimension of the antenna needs to be taken into account in the exposure assessment.

D.Special Considerations

Some external influences must to be taken in consideration, such as reflections since the radiation patterns are always provided for free space conditions. A reflection from the ground, buildings, fencing and some other structures may lead to an increase in the value of the reference level; this means electric field strength is multiplied by a factor. It should be noted that in a complex environment, with many reflections, only the one with the highest multiplication factor should be considered. In practice, the maximum value of the multiplication factor is 2 for the electric field strength which corresponds to 4 for the power density.

It is necessary to specify the uncertainty of the result when performing a calculation. The calculation of uncertainty with a 95% confidence interval should be done. The expanded uncertainty shall not exceed 3 dB for the power density. If the calculation uncertainty exceeds 3 dB, the limit values should be reduced.

E. Parameters of the Transmitting Stations

The transmitters used in radiocommunication produce electromagnetic waves which, by feeding lines, are delivered to the transmitting antennas and radiated into the environment. The best situation is when the calculation is based on the exact information concerning the radiating sources (the equivalent radiated power ERP, radiation patterns, etc.). In many cases, it is very difficult to obtain such information. Therefore, the general data concerning the transmitting system under consideration may be helpful. General characteristics of the intentional radiation sources (transmitters and transmitting antennas) such as: transmitter power, transmitting antenna radiation patterns, antenna gain, antenna height and EIRP (equivalent isotropically radiated power).

III. CUMULATIVE EXPOSURE RATIO

In most cases, a typical transmitting station contains many transmitting systems operating on many frequencies. In this case, in the area around the antenna structure, the electromagnetic field has a complex structure with many components of different frequencies and different field strengths, varying from point to point.

The exposure assessment in the multiple sources environment [8] requires the calculation of the cumulative exposure W. All the operating frequencies must be considered in a weighted sum, where each individual source is pre-rated according to the limit applicable to its frequency.

For the frequencies range above 100 kHz, in which the thermal effect is dominating the cumulative exposure, the coefficient Wt has the following form:

$$W_t = \sum_{i=100KHz}^{300\,GHz} \left(\frac{E_i}{E_{l,i}}\right)^2 \leq 1 \qquad (2)$$

Where:

Ei is the electric field strength at frequency i
El,i is the reference limit at frequency i

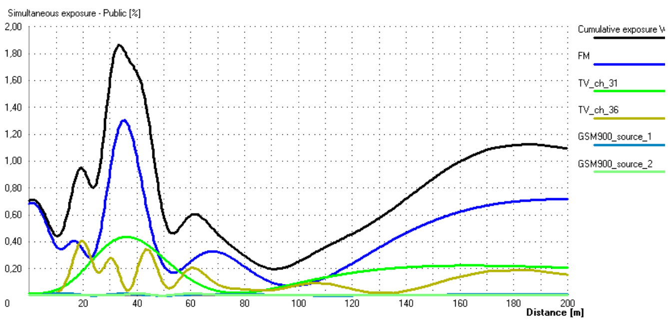

Fig. 2 Example of cumulative exposure ratio Wt and identification of the main source of radiation

For the induced current density and electrical stimulation effect, relevant up to 10 MHz, and electric field strength as the reference level, the coefficient We has the form shown in equation 7-2:

$$W_e = \sum_{i=1Hz}^{10MHz} \frac{E_i}{E_{l,i}} \leq 1 \qquad (3)$$

For compliance with the regulations, both coefficients W of the cumulative exposure should be less than 1. The conditions concerning electrical stimulation effects are important at very short distances from the transmitting antenna, usually with no access for people.

Equations (2) and (3) show that the exposure assessment in the multiple sources environment requires the prediction of the electric field strength for each operating frequency. Such prediction, including calculation of the coefficients W, can be done using methods described in SECTION II.

A. Main Source of Radiation

In the multiple sources environment, at each observation point, the components radiated from all transmitting antennas are present. In most cases, only one component is dominant and has the biggest influence on the total exposure level. Identification of the dominant radiation source is indispensable to consider the possibility of reducing the radiation level.

The main source of radiation may be identified by the calculation of the coefficient Wt in the points of investigation regularly distributed in the area accessible to people. All the points should be at the same height, our case 1.2 m a.t.l. (above the terrain level) with respect to the ground level, uniformly distributed along a line from the antenna tower to the maximum distance considered, usually hundreds of metres. The azimuth angle for such calculation should be on the common maximum of the horizontal radiation patterns (HRP) of all antennas. If, for different antennas, the maxima are at different azimuth angles, then the calculations may be required for all the respective azimuths.

B. Compliance Distances

Considering the exposure limits given by ICNIRP, it is possible to calculate distances to the transmitting antennas at which exposure limits are achieved. Such distances are different for different types of transmitting antennas. Compliance distances [9] are also different for the general public and for the occupational exposure because of different limits for these two types of exposure.

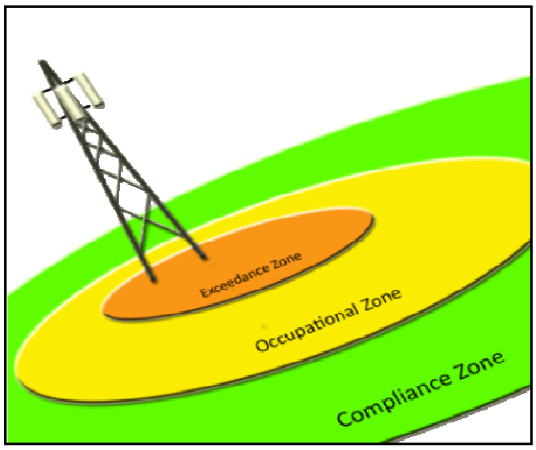

Fig. 3 Exposure zones

Compliance distances may be evaluated in many ways, depending on the accuracy required and on the data available, as seen in SECTION II. It should be always assured that for distances greater than the compliance distance, the radiation level is under the limit. It means that if a lower amount of data concerning a radiating source is available, then the higher overestimation of the compliance distances is required.

The point source model with an isotropic antenna and with the knowledge of the radiation patterns are two useful approaches. In both cases, the compliance distances may be evaluated accurately if numerical methods based on Maxwell's equations are used. The difficulty is that this approach requires very detailed data concerning transmitting antenna, special software and experience in the numerical modelling.

The TABLE I presents a simplified method for the calculation of the compliance distances for radiocommunication transmitter stations operating at radio frequencies above 1 MHz.

IV. Mitigation Techniques

A. Decreasing the Transmitting Power

The simplest method to reduce radiation levels is to reduce transmitter power. Unfortunately, this method leads also to the reduction of the coverage area and for this reason it should be used only if other methods for some reasons cannot be applied.

TABLE I
Simplified Methods to calculate compliance distances

Radio frequency Range	General Public Exposure	Occupational Exposure
1 to 10 MHz	$r = 0.10 * \sqrt{eirp * f}$	$r = 0.0144 * f * \sqrt{eirp}$
10 to 400 MHz	$r = 0.319 * \sqrt{eirp}$	$r = 0.143 * \sqrt{eirp}$
400 to 2000 MHz	$r = 6.38 * \sqrt{eirp/f}$	$r = 2.92 * \sqrt{eirp/f}$
2000 to 300000 MHz	$r = 0.143 * \sqrt{eirp}$	$r = 0.0638 * \sqrt{eirp}$

r is the minimum antenna distance, in metres
f is the frequency, in MHz
eirp is the equivalent isotropically radiated power in the direction of the largest antenna gain, in Watts

B. Increasing the Antenna Height

If the antenna height is increased, then the distances to all points of investigation are increased as well. It means that in this case the radiation level is reduced. This reduction is even greater because at the same time elevation angles to the considered area are moved to another part of the vertical radiation pattern (VRP) of the transmitting antenna. This method can only be applied if a possibility to increase the antenna height exists.

C. Decreasing the VRP Downtilt

The main beam tilt of the vertical radiation pattern of the transmitting antennas is frequently used for performance service reasons. This is because, in the first approximation, in a line-of-sight mode, all the energy radiated above the horizontal plane is lost. This loss can be reduced by narrowing the vertical radiation pattern of the antenna system and tilting the beam downward. In the cellular base stations, the downtilt is also used to limit the coverage area, which increases the possibility of the frequency reuse. Main beam tilt has also an influence on the radiation level in the proximity of the transmitting antenna. It can be generally stated that bigger downtilt gives bigger radiation levels in the proximity of the transmitting antenna. Although the main part of the radiation is emitted in the main beam, the changes in the radiation level appear also in all remaining directions.

D. Increasing the Antenna Gain

The antenna gain corresponds directly to the antenna directivity; this means its ability to radiate more in a desired direction and to limit the radiation in other directions. In a natural way, the antenna directivity is used to decrease the radiation in the direction accessible to people. The antenna directivity is closely related to the HRP and VRP radiation patterns.

The HRP in cellular systems, where a typical cell has three sectors, each sector is served by its own transmitting antenna. Considering the exposure assessment, the radiation components from all sectors have to be combined and the total radiation level is similar to that given by omnidirectional transmitting antenna. If radiation in some directions (azimuths) is attenuated, then the coverage on those azimuths is lower. Therefore, the changes in the transmitting antenna HRP, made to protect people against radiation, always affect the coverage area.

A different situation takes place in the case of the transmitting antenna VRP, which determines the radiation as a function of the distance to the antenna. Higher gain implies narrower main beam width and if the VRP has filled nulls, then there are no losses in the coverage area. Indirectly, the antenna gain is responsible for the division of the radiated energy into two parts: the part which is radiated in the main beam direction and the part radiated to the area under the antenna in close proximity to it. So, it can be seen that the antenna gain (or more precisely the vertical main beam width) may be used to reduce the radiation level in close proximity to the antenna.

E. Changing the HRP

The possibilities of the radiation level reduction by the changes in the HRP are very limited. For cellular base stations, it is possible to reduce the level by replacing panels with a wide horizontal beam by one with a narrower horizontal beam. The panel with the narrower horizontal beam needs lower transmitter power without loss in the radius of the coverage but the transmitter power reduction results in decreasing the radiation level in the area accessible to people.

F. Multiple Methods applied simultaneously

In some cases it can be necessary to apply more than one method to achieve the required reduction of the radiation level. All the methods described above are independent and in many cases they can be applied simultaneously.

V. Case of Study

At Escuela Superior Politécnica del Litoral - ESPOL University (Guayaquil - Ecuador) there are two BTS (belonging to PORTA and MOVISTAR Operators). Some other sources (AM, FM, VHF, UHF, etc.) radiates in the area under study, but are not taken in account for their distance to the observation point, which is located in the Faculty of Electrics and Computation Engineering.

Fig. 4 Satellite view of ESPOL Campus

The main source of radiation is PORTA GSM 850 site, which uses antennas Kathrein dual band sector panels 742266 [10] (height=2516mm, HRP=68, VRP=7.3, Gain=2*16.5dBi) with the following configuration:

TABLE II
SECTORS CONFIGURATION

Parameters	X	Y	Z
Height [m]	24.00	24.00	24.00
Azimuth [°]	0	90	260
Downtilt [°]	4	7	4

The EMF-estimator [11] designed by ITU and Telekomunikacja Polska is the simulator presented in ITU-T Recommendation K.70 and it was the one used in this project. The configuration for the main source was the following:

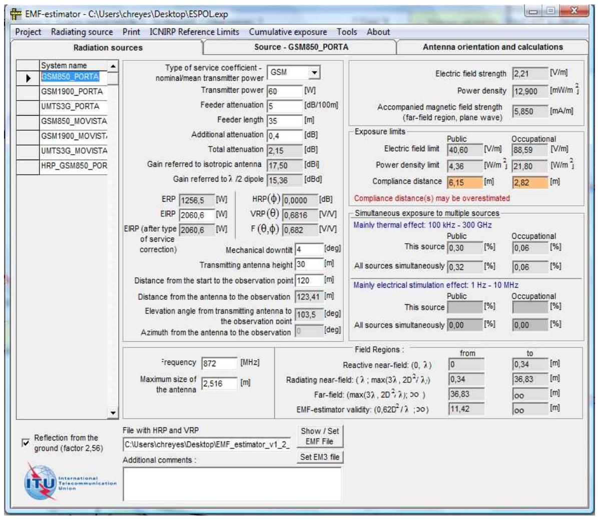

Fig. 5 Configuration of PORTA GSM 850

The resulting curves of exposure levels are presented below:

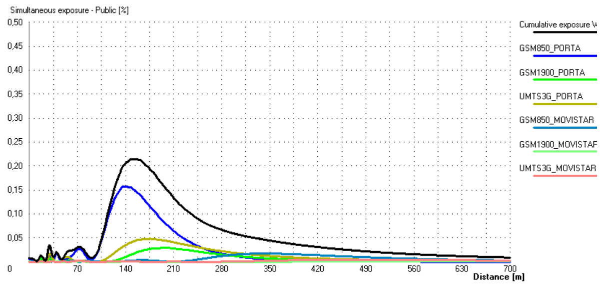

Fig. 6 Coefficient Wt distribution and contribution of each radiating source

The following charts will show the current main source levels and how this could change whether mitigation techniques reviewed in SECTION III are applied (only possible ones).

A. Decrease in Transmitter Power

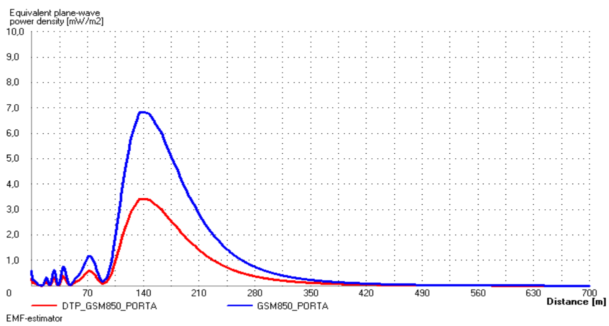

Fig. 7 Exposure levels and Decreased transmitter power

Decrease in transmitter power also decrease exposure levels. However, this could lead to a reduction in the coverage area.

B. Decrease in the VRP Downtilt

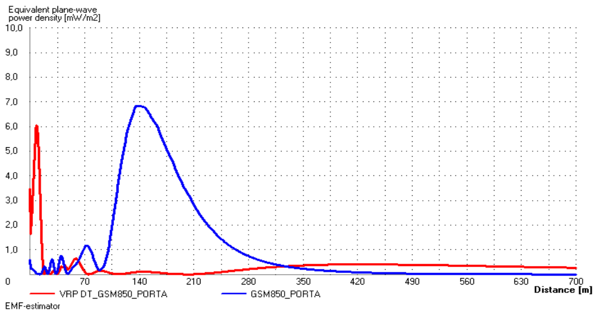

Fig. 8 Exposure levels and Decreased VRP downtilt

This technique decrease exposure levels, but it is required to narrow the VRP beam width for improve the antenna gain. This usually means to change the antennas.

C. Increase in Antenna Gain

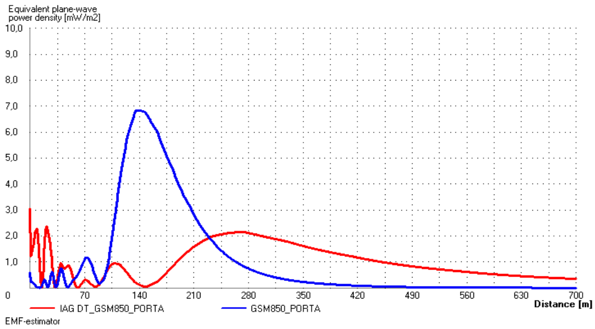

Fig. 9 Exposure levels and Increased antenna gain

Increasing the antenna gain implies to radiate more in the desired direction and limit it in other directions.

This may lead to change the antennas for narrower horizontal and vertical beam antennas.

D. Changes in HRP

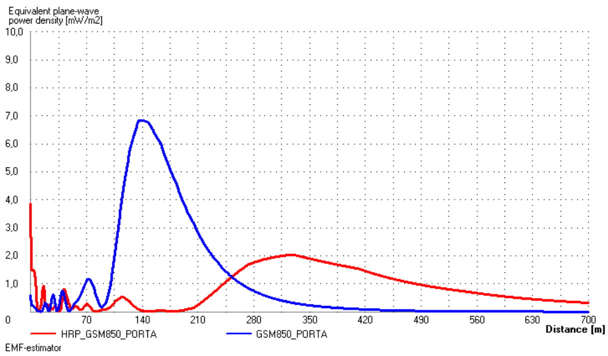

Fig. 10 Exposure levels and Decreased HRP beam width

To decrease the radiation levels it is needed to reduce the HRP beam width, which implies replacing panels by others with narrower horizontal beam width.

E. Multiple Methods applied simultaneously

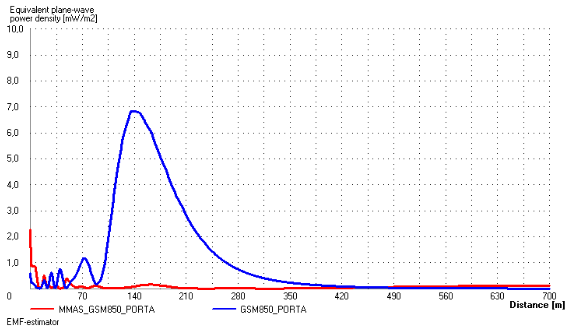

Fig. 11 Exposure levels and Multiple methods applied

Several methods can be applied simultaneously if they are independent of each other. This leads to a notorious reduction in the exposure levels.

VI. Conclusions

The methods presented are intended for use when considering the EMFs in areas around a BTS in order to reduce exposure levels, avoiding risks to human health.

The accuracy of the exposure assessment strongly depends on the data accessible during the evaluation. As the radiation emitted by the transmitting antennas is intentional, the accuracy of the assessment is as good as the data concerning the radiation patterns. Guidance is given concerning the parameters of the typical transmitting antennas and their influence on the radiation levels in the area accessible to people.

The coverage area strongly depends on radiated power ERP (or EIRP). The same value of the ERP can be achieved by the low power transmitter feeding the high gain antenna and by the high power transmitter feeding the low gain antenna. As far as the protection against radiation is concerned, a much better choice is to use the low power transmitter feeding the high gain antenna.

In order to reduce exposure levels, it is practically to decrease the beam widths of the radiation patterns, both VRP and HRP. This is, the narrower the beam width, the higher the antenna gain (higher directivity), improving the main objective.

In practice, the exposure levels around a cellular base station can be decreased by replacing the existing transmitting panel by a panel with higher gain (if such a panel exists). The transmitting panel with higher gain also requires a decrease in the transmitter power in order to sustain the ERP and the coverage area.

Since the VRP is determined by the manufacturer, no changes in this parameter can be performed

Changes in the HRP mean replacing the antenna by one with narrower beam width. This makes an increase in the antenna gain which makes possible a simultaneous decrease in the transmitter power by the same value. The radius of the coverage is preserved in the main direction from the panel. For all the other directions, the radius of the coverage is lower, which is a disadvantage of this method.

VII. Recommendations

Possible technical solutions to the problem when the reference levels are exceeded in the multiple sources environment can be avoided putting in practice the techniques presented in several recommendations made by international entities, such ITU and WHO.

In the case when many operators have radiating sources in the considered area, the proper solution has to be found on the basis of an agreement between all parties. In the case when such an agreement is not possible, the operator who introduces the last change in the installations will be responsible for the appropriate limitation of the exposure level from his source of radiation so as not to exceed the allowed global limit.

The mobile telephony operators should consider seriously this study and ITU-T recommendations, especially K.52, K61 and K70, in order to keep the operation of BTSs in compliance with regulations concerning environmental protection against non-ionizing radiation.

The Ecuadorian government, and government of any other developing country, should motivate the research of non-ionizing radiation in universities and the creation of specialized centres. Also encourage the active participation of the cellular operators and always keep the public informed.

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