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CORRELATION BETWEEN THE RF SIGNAL LEVEL AND ELECTROMAGNETIC FIELD PARAMETERS OF A SINGLE BASE STATION OVER THE AREA OF COVERAGE

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Abstract

An unavoidable problem in modern life is the electromagnetic background, a result of the operation of wireless and mobile networks. The question is how accurately the quantitative estimates of the real influence of electromagnetic fields in the vicinity of base stations on other radiocommunication and telecommunication networks correspond to the specified restrictive standards while ensuring the quality of telecommunication services. This article presents a study of the characteristics and parameters of the electromagnetic field in the coverage area of a certain base station, as well as the strength of the radio signal at several different points inside a residential building in order to create a sufficiently reliable probabilistic correlation between the measured quantities.

Keywords: electromagnetic field parameters, RF Environment, RF signal measurements.

INTRODUCTION

Electromagnetic radiation, standardized by the term “electromagnetic power flux density”, is measured as the radiant flux incident on a unit area of a given surface. The SI unit of radiation is the watt per square meter (W/m2). The same physical phenomenon caused by the radio link infrastructure in telecommunications networks is called radio frequency power flux density and is measured in μW/m2 or μW/cm2. This is the main measured parameter for assessing the safety of the living environment around and inside the home. The remaining parameters subject to specialized measurement are: electric field intensity (V/m) and magnetic induction or magnetic flux density. (μT). [1, 2, 5, 7]

The effective value of the radio-frequency power of radio signals with a certain carrier frequency is also an important parameter, easily measured with commonly available radio equipment. In most cases, it is measured in logarithmic units dBm, which is usually the unit set by default in the instruments. For specific purposes, this physical quantity can also be measured in units derived from watts. - "μW", "nW, pW, fW". [3, 4]

Human health safety is extremely important and the restrictions in global and local regulations must be observed unconditionally.

At the same time, radio communications, widely used in modern telecommunications services, require high-quality and very fast data transmission, which can be provided by a radio frequency signal with sufficient power. Achieving a satisfactory compromise is a difficult optimization task.

Mobile service providers often allow themselves settings that lead to exceeding the legal limits of the signal level emitted by the transmitters in a base station, usually one that is in an unfavorable position

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relative to parts of the coverage area when it is impossible to provide sufficient height for the installation of antennas in the presence of tall surrounding buildings. When the signal propagated by the transmitting antenna is stronger than permitted, the signal level in the area covered by that cell will also be above legal limits and this violation could, in the long term, cause health problems for people living under that radio frequency signal coverage, or interference in radio channels used by other communication systems. [5, 6].

In order to measure a standardized quantity correctly, a spectrum analyzer is an absolutely indispensable tool for analyzing radio frequency signals.

In addition to strictly specialized instruments for measuring the power flux density, spectrum analyzers are precise instruments for measuring radio frequency radiation, although not so convenient for direct manipulation. They provide simultaneously results for the power level of each radio signal that forms the spectrum of the studied frequency range, and which frequencies from this range have a significant contribution to the level of the values of the electromagnetic field parameters in the signal coverage area. At the expense of the less convenient manipulation of these instruments, they provide the possibility of detailed data exchange with a computer resource through a practical and reliable communication interface.

Different standards have been established for the RF power flux density limit in different countries in Europe and around the world.

The aim of this study is to investigate the correlation between the signal level of a given base station and the RF power flux density in the coverage area and to find the optimal RF signal level at the imaginary boundary of the coverage area in order to meet the restrictions specified in the regulatory framework.

EXPERIMENTAL SETUP AND MEASUREMENT RESULTS

Two specialized instruments were selected for the characterization of components, systems and signals in the radio frequency (RF) ranges.

For the measurements of the radio frequency power flux density, a high-frequency analyzer HFE35C (Fig. 1) was used, designed for a frequency range from 27 MHz to 2.7 GHz and equipped with three types of receiving antennas.

The measurements of the radio frequency power flux density are performed with a portable instrument HF Analyzer HFE35C (Fig. 1).

To create a suitable simulation model, each individual measurement is recorded separately after testing for HF exposure levels at different locations inside a residential building.

Part of the electromagnetic radiation is reflected or absorbed, therefore the permeability of construction materials to HF radiation is taken into account. Wood, plasterboard and wooden or plastic window frames are “transparent” to radio frequency signals fragments of the building.



Fig. 1. *Portable high-frequency analyzer HF Analyzer HFE35C*

Radio waves are either vertically or horizontally polarized. With an attached antenna, the meter measures the vertically polarized component if the display is horizontal. The corresponding change in the plane of polarization is done by rotating the instrument around its longitudinal axis.

The peak value of the high-frequency radiation is considered to be a critical measurement of the human body and should be compared with the recommended safety limits.

The average value ("RMS") of the signal power density is usually a very small fraction of the peak value, although in practice it forms the basis of most safety regulations.

The spectrum of RF signals is measured using a portable TinySA ULTRA spectrum analyzer, which has the ability to accurately capture RF signals from 100 kHz to 7.3 GHz and has a very convenient software interface for transferring measurement data to a computer in real time and/or as files formatted for convenient word processing.

The effective radiated power (ERP) is an IEEE-standardized definition of the directional radio frequency (RF) power equivalent to that radiated by a radio transmitter. It is the total radio frequency power in watts that would have to be radiated by a half-wave dipole antenna to obtain the same power flux density (W/m2) as the actual antenna of a remote receiver located in the direction of the antenna's strongest beam. ERP measures the combination of the power radiated by the transmitter and the antenna's ability to direct that power in a given direction. It is equal to the input power to the antenna multiplied by the antenna gain. It serves to quantify the "apparent" power of a radio station perceived by receiving stations in its coverage area.

RF sources such as wireless routers, cordless phones, etc. are turned off and removed from the room where the measurements are being made. For higher accuracy of the measurement, it is necessary to mark and take into account all areas of the ceiling, floor and walls, including doors and windows, through which the RF flux penetrates. [5, 6, 8]

The effective isotropic radiated power (EIRP) is a more appropriate parameter that measures the ratio between the power radiated by the transmitter and the ability of the antenna to direct this power in a given direction, as ERP does, but EIRP provides a comparison with the performance of a theoretical isotropic antenna. It is given by the following equation:

$$EIRP = 4\pi r^2 S \quad (1)$$

where S is the currently measured RF power flux density in μW/m2. [3, 5, 8]

The isotropic gain is given by:

$$G\,(dBi) = 10\log_{10}\left(\frac{S_{max}}{S_{max,\ iso}}\right) \quad (2)$$

where and are the maximum and isotropic power densities of the radio frequency signal, respectively, measured in μW/m2. [2, 4]

On the other hand:

$$EIRP\,(dBW) = P_{in}\,(dBW) + G\,(dBi) \quad (3)$$

The other goal of the study is to find a suitable way to calculate the radio-frequency power flux density using a spectrum analyzer, i.e. to convert the readings of the measuring instrument into the radio-frequency power levels of the spectral components of the signal. [7, 8, 9, 10]

The radiation intensity created at a certain point above the earth's surface (according to the technical specifications of the antenna) and distant from the vertical axis of the antenna is calculated in μW/m2 by the formula [3]:

$$S = 2650 \sum_{i=1}^{n} \frac{\left[K_Z K_H F_i(\Delta) F_i(\varphi) \sqrt{30 P_i G_i \eta_i}\right]^2}{(x-x_i)^2 (y-y_i)^2 (z-z_i)^2} \quad (4)$$

where n is the number of antennas in the base station, KZ is a coefficient taking into account the unevenness of the terrain and the effect of reflecting surfaces in the settlement (depending on the location and density of above-ground objects, it varies from 1.3 to 1.15); KH is a coefficient reflecting the unevenness of the antenna directional pattern in the horizontal plane

(takes values from 1.26 to 1.41); Fi(Δ) is the directivity coefficient of the vertical antenna pattern; Fi(φ) is the directivity coefficient of the horizontal antenna pattern; Pi is the transmitter radio frequency power in W; Gi is the antenna gain in dBi. x, y and z are the coordinates of the measurement point. [3]

To measure the power flux density inside the building, a shielded log-periodic antenna is used, directed about 10 degrees below the radiating source being measured to avoid most distortions in the transient sensitivity zones. The antenna is positioned in the direction of the raised base station mast mounted on the roof of a nearby building.

The measurements were made at four different locations inside the building (Fig. 2).

It can be seen that the maximum radio frequency power flux density does not exceed 900.

Measurements in the frequency range from 27 MHz to 2.7 GHz were made at four different locations in the house using the portable spectrum analyzer TyniSA ULTRA, at the same points as the measurements with the high-frequency analyzer HFE35C.



Fig. 2. *Measured radio frequency power flux density at four different points inside the building*

The same log-periodic antenna of the analyzer from Fig. 1 was used for four (4) consecutive measurements, carried out within approximately 1 minute.

The spectrum analyzer is set to display the RF power in units derived from the watt – μW, nW, pW, so that the readings from the two instruments can be compared.

The spectrum analyzer setup allows for up to eight (8) signal level markers to be used simultaneously. The software automatically selects the 8 strongest RF signals and displays their values in a tabular format. The remaining peaks can be measured using a manually controlled marker as an internal functionality of the instrument.

The RF range from 27 MHz to 2.7 GHz displays the dBm levels of the strongest RF signals in this range using a 1000-point scan.

The measured power scan data in instantaneous values and in the frequency domain are saved in *.csv format, and the power is automatically summed after processing the files in a spreadsheet. The total RF signal power is shown after each of the following figures.

Each individual measurement presents a unique spectral pattern that is never repeated, but the signals with the highest power remain in their places along the frequency axis. For higher accuracy of the measured total radio frequency power at the measurement location, it is measured sequentially for 8, 1000 and 10000 frequency values (scan points), located within the studied frequency range 27MHz – 2.7 GHz.

The screen of the measurement at the first point in the building is shown in Fig.3.

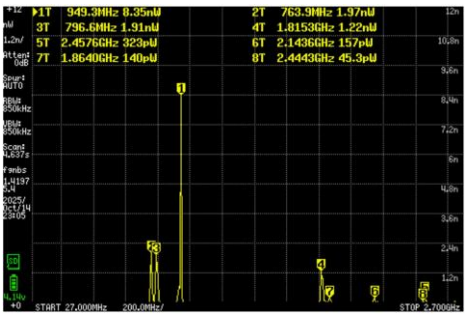


Fig. 3. *RF power of each of the eight (8) strongest intercepted frequencies at the first point*

The measurement screen at the second point in the building is shown in Fig. 4.

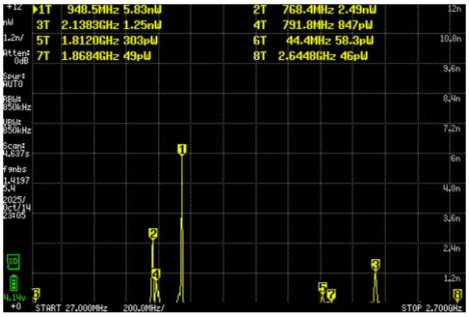


Fig. 4. *RF power of each of the eight (8) strongest intercepted frequencies at the second point*

The measurement screen at the second point in the building is shown in Fig.5.

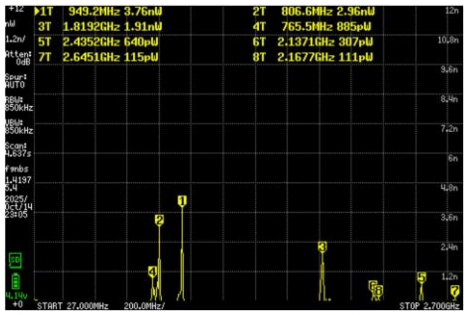


Fig. 5. *RF power of each of the eight (8) strongest intercepted frequencies at the third point*

The measurement screen at the second point in the building is shown in Fig.6.

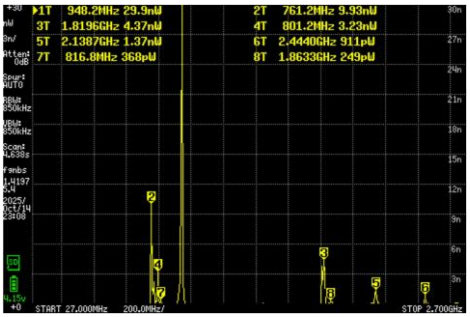


Fig. 6. *RF power of each of the eight (8) strongest intercepted frequencies at the third point*

An expected increase in total power is observed with increasing number of scan frequency points. Including more spectral components increases the total RF power in the studied frequency range 27 MHz - 2.7 GHz.

The signal spectrum picture looks similar in each of the screenshots above, with the shape and main images of the signal clearly recognizable, but the values of the extrema after the measurements are slightly different after each specific measurement. This is inevitable with the measurement methodology used, i.e. the same antenna used by both instruments. The manipulation of changing the instruments and disconnecting and connecting the SMA connector of the log-periodic antenna to the corresponding measuring instrument takes less than a minute, but this is a significant time interval and cannot guarantee high accuracy of the comparison between the readings of the two instruments.

After equating the RF power unit to microwatts when measuring with both devices, it seems at first glance that only the unknown value of the area over which the power is measured makes the main difference in the readings. In reality, however, many more factors have an influence, and since they cannot be measured directly, mathematical tools must be applied. In order to derive a mathematical correlation between the HFE35C and TinySA ULTRA readings, a second log-periodic antenna with exactly the same geometry and electrical parameters is required to perform simultaneous real-time measurements. A large number of final measurements must be made in order to collect sufficient statistical data that can be processed using an appropriate mathematical algorithm to derive a functional relationship between the signal power measured by the spectrum analyzer and its density.

Deriving such a relationship could turn any portable spectrum analyzer into a highly accurate RF signal power flux density meter.

CONCLUSION

The measurement of the power flux density of radio frequency signals allows to estimate the electromagnetic radiation from antennas for mobile and other telecommunications systems. The correctly chosen methodology for measurement, simulation and analysis allows to quantitatively estimate in advance the electromagnetic fields caused by the telecommunications radio frequency background, as well as to visually determine any place or area where the electromagnetic radiation exceeds the established limiting standards. The described analysis helps to control the values of the frequencies of radio frequency and high-frequency signals in general, in order to be able to take timely measures for radio frequency signal power density levels exceeding standardized health limits, but also to force mobile service providers to maintain the transmission power from base stations at optimal values, while ensuring the quality of services - connections, data transfer speed, etc.

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REFERENCES

[1] N. Ida, “Antennas and Electromagnetic Radiation. In Engineering Electromagnetics”, 4th ed.; Springer: Cham, Switzerland, 2021; pp. 915–991.

[2] D.Lingvay, A.Bors, A.G.Borş, “Electromagnetic pollution and its effects on living matter”, Electroteh. Electron. Autom. 2018, 66, 5–11

[3] R.Buckus, A.Chlebnikovas, B.Strukcinskiene, R.Stukas, D.Austys, J.Caban, M.Bogucki, A.Sidlauskiene, V.Seleviciene, A.Kilikevicius, J.Matijošius, K.Kilikeviciene and D.Vainorius, “Simulating the Dispersion of the Energy Flux Density of the Electromagnetic Field Generated by Antennas for Mobile Communications.”, Electronics 2022, 11, 2431. https://doi.org/10.3390/electronics11152431

[4] M. Muhibbullah, A. Abdel Haleem, Y. Ikuma, “An Equation of Energy Flux Density of the Electromagnetic Wave”. 2015. Available online: https://www.researchgate.net/publication/272355066_An_Equation_of_Energy_Flux_Density_of_the_Electromagnetic_Wave (accessed on 10 April 2022)

[5] E. Garaio, P. La Roca, C. Gómez-Polo, V. Sánchez-Alarcos, V. Recarte, I. Pérez-Landazábal, J. Martensitic “Transformation Controlled by Electromagnetic Field: From Experimental Evidence to Wireless Actuator Applications”, Mater. Des. 2022, 219, 110746.

[6] H. Kim, Y. Lee, H. D. Choi, A.K. Lee, S. Jeon, J. K. Pack, N. Kim, Y. Ahn, “Effect of Exposure to a Radiofrequency Electromagnetic Field on Body Temperature in Anesthetized and Non-Anesthetized Rats”, Bioelectromagnetics 2020, 41, 104–112.

[7] L. van Wel, I. Liorni,; A. Huss, A.Thielens, J. Wiart, W. Joseph, M. Röösli, M. Foerster, A. Massardier-Pilonchery, M. Capstick, “Radio-frequency electromagnetic field exposure and contribution of sources in the general population: An organ-specific integrative exposure assessment” J. Expo. Sci. Environ. Epidemiol. 2021, 31, 999–1007.

[8] G. Mihaylov, T. Iliev, T. Bikov, E. Ivanova and I.Stoyanov, "Test cases and challenges for mobile network evolution from LTE to 5G", 2018 41st International Convention on Information and Communication Technology, Electronics and Microelectronics (MIPRO), DOI: 10.23919/MIPRO.2018.8400085

[9] T. Iliev, G. Mihaylov, E. Ivanova and I.Stoyanov, "Power control schemes for device-to-device communications in 5G mobile network",2017 40th International Convention on Information and Communication Technology, Electronics and Mi-croelectronics (MIPRO), DOI: 10.23919/MIPRO.2017.7973460

[10] C. Shannon, “Communication in the Presence of Noise, Proceedings of the IRE”, vol. 37, no. 1, pp. 10 – 21, Jan. 1949.