

Implications of EMF Exposure Limits on Output Power Levels for 5G Devices above 6 GHz

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Abstract—Spectrum is a scarce resource, and the interest for utilizing frequency bands above 6 GHz for future radio communication systems is increasing. The possible use of higher frequency bands implies new challenges in terms of electromagnetic field (EMF) exposure assessments since the fundamental exposure metric (basic restriction) is changing from specific absorption rate (SAR) to power density. In this study, the implication of this change is investigated in terms of the maximum possible radiated power (P_{\max}) from a device used in close proximity to the human body. The results show that the existing exposure limits will lead to a non-physical discontinuity of several dB in P_{\max} as the transition is made from SAR to power density based basic restrictions. As a consequence, to be compliant with applicable exposure limits at frequencies above 6 GHz, P_{\max} might have to be several dB below the power levels used for current cellular technologies. Since the available power in uplink has a direct impact on the system capacity and coverage, such an inconsistency, if not resolved, might have a large effect on the development of the next generation cellular networks (5G).

Index Terms—EMF exposure limits, device output power, 5G

I. INTRODUCTION

In [1], work is ongoing to lay the foundation for the fifth generation mobile communication systems (5G), to meet the requirements of the future on traffic volume, data rates and accommodation of new types of devices and services [2]. A key issue is to explore the possibility of extending the communication spectrum to include frequency bands above those used today for mobile and wireless communication systems (typically located below 6 GHz).

A measurement campaign in urban environments has

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recently been conducted in the 28 GHz and 38 GHz bands to provide a better understanding of the propagation characteristics in the millimeter wave (mmW) frequency range [3]. Other papers have been focusing on various implementation aspects and application scenarios for high frequency bands [4]. Several questions, however, still need to be addressed to understand the opportunities and limitations of cellular radio access in this frequency range.

An important aspect for wireless technologies is the maximum available output power for the user devices (mobile phones, tablets, laptops, etc.). This factor has a direct impact on the system capacity and coverage. It is therefore important to evaluate the implications that existing radio frequency (RF) electromagnetic field (EMF) exposure regulations may have on the maximum allowed output power of devices operating in the mmW frequency range.

To prevent from elevated tissue temperatures resulting from absorption of energy during exposure to RF EMF, safety guidelines have been published by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) [5]. The ICNIRP limits have been adopted in regulations in the EU and in most countries worldwide. In the US, the limits provided by the Federal Communication Commission (FCC) are applicable [6]. A more recent set of exposure limits have been proposed by IEEE [7, 8], but these have not yet been adopted in any regulatory requirements. In the frequency range commonly used for mobile communications, the fundamental exposure metric is the specific absorption rate (SAR). At frequencies above 3 GHz (IEEE), 6 GHz (FCC) and 10 GHz (ICNIRP), the exposure limits change from SAR (measured in W/kg) to free-space power density (PD, measured in W/m²). A substantial amount of research has been conducted over the years to characterize exposure in the current cellular bands, but for higher frequencies information is scarcer (see [9]).

In this paper, the implications that compliance with the EMF exposure limits above 6 GHz (and up to 70 GHz) has on the maximum possible radiated power from a device used in close proximity of the human body, are investigated. This study provides relevant input to standardization of the next generation mobile networks (5G) and adds value in general for wireless communications at ‘high frequencies’. It also provides input to organizations responsible for setting EMF exposure limits.

II. METHOD

The localized SAR limits applicable for user equipment (UE) are to be averaged over a mass of 1 g (FCC) or 10 g (ICNIRP and IEEE) of body tissue. The PD limits are considered for an averaging area of 20 cm² for ICNIRP and as the peak value for FCC (see Table 1). For IEEE, the averaging area is frequency dependent at and below 30 GHz, while it is 100 cm² above 30 GHz. The ICNIRP and IEEE guidelines also specify spatial peak PD limits for localized exposure which for ICNIRP is taken as an average over 1 cm², see Table 1.

TABLE I
GENERAL PUBLIC BASIC RESTRICTIONS VALID BELOW AND ABOVE CERTAIN TRANSITIONS FREQUENCIES, f_{tr} . (S.P. = SPATIAL PEAK, AV. = AVERAGED OVER, λ = WAVELENGTH IN FREE SPACE, f = FREQUENCY IN GHZ).

	FCC	ICNIRP	IEEE
f_{tr} (GHz)	6	10	3 ^a
PD limit (W/m ²) $f \geq f_{tr}$	10 (S.P.)	10 (Av. 20 cm ²)	10 ($f \leq 30$ GHz \Rightarrow Av. 100 λ^2) ($f \geq 30$ GHz \Rightarrow Av. 100 cm ²)
		200 (Av. 1 cm ²)	18.56 $f^{0.699}$ ($f \leq 30$ GHz, S.P.) 200 ($f \geq 30$ GHz, S.P.)
Localized SAR limit (W/kg) $f \leq f_{tr}$	1.6 (Av. 1g)	2 (Av. 10 g)	2 (Av. 10 g)

^aTo provide a transition in the frequency range 3 GHz to 6 GHz, compliance with IEEE C95.1 may be demonstrated by evaluation of either incident power density or local SAR.

The maximum radiated power, P_{max} , to be compliant with the EMF exposure limits in Table 1 has been determined in a frequency range from 1 GHz to 70 GHz for a canonical half-wave dipole. P_{max} is dependent on the distance from the antenna at which the compliance assessment is made. In this work P_{max} was determined to reflect realistic compliance assessment setups for an intended usage distance of 2 cm [10].

The assessments were made using numerical simulations with the commercial electromagnetic solver FEKO (Altair Development S.A. Ltd, Stellenbosch, South Africa). The SAR simulations modelled a real SAR measurement setup, which include a flat body phantom consisting of a lossy tissue-simulating material and a 2 mm thick phantom shell with a relative permittivity of 4. The dielectric properties of the lossy dielectric material were set to equal the tissue equivalent liquid specifications in [10]. The electrically large finite box-shaped phantom, normally used for measurements, was approximated with a layered half-space and the fields were assessed utilizing a planar Green's function. This was done in order to reduce the computational requirements by avoiding discretization of a large 3D volume. SAR was averaged over a cube of 1 g or 10 g mass depending on the considered EMF exposure restrictions (see Table 1). In the range of frequencies for which SAR is the relevant exposure metric, P_{max} corresponds to the radiated power providing a localized SAR

value equal to 1.6 W/kg (for FCC) or 2 W/kg (for ICNIRP and IEEE). At higher frequencies P_{max} was obtained by means of simulations of the PD for the dipole in free-space. For compliance with ICNIRP the power density was spatially averaged over 20 cm² and 1 cm² according to Table 1, and the lowest obtained P_{max} was selected. A similar approach was also followed for compliance with the IEEE standard using the relevant exposure limits and averaging areas (see Table 1). ICNIRP and IEEE have not specified the shape of the averaging area. In this work, a square-shaped area was assumed for simplicity.

Since the use of more directive antennas for the UE may be desirable when going up in frequencies, results for P_{max} were also determined for an antenna array model with 4 x 4 elements operating at 15 GHz. The dipole length as well as the separation distance between each element was half a wavelength. The reflector, in the shape of a metal square of size 2λ , was surrounded along the sides by metallic walls with a height of $\lambda/5$. The distance between the reflector and the dipoles was $\lambda/4$. The elements were excited with voltage sources of equal amplitude and phase placed in the center of each dipole. The antenna gain for the array was 17.1 dBi.

All simulations were conducted by modeling the antennas as perfect electric conductors and for a total radiated power of 1 W. P_{max} was then obtained by scaling the SAR or PD results obtained for 1 W to the limit values of Table 1. The limits provided by the standards were applied on numerically simulated results; compliance assessment implications that could potentially arise during measurements were not considered.

III. RESULTS

In Fig.1, P_{max} is provided in the frequency range investigated for the single dipole to meet compliance at a separation distance of 2 cm. It is shown that at the transition frequency from SAR to PD limits, P_{max} drops about 5.5 dB for FCC and 6.5 dB for ICNIRP. Within the current cellular bands, P_{max} is larger or similar to what is specified today for the existing technologies (e.g. 23 dBm for Long Term Evolution (LTE)). Above 6 GHz for FCC and 10 GHz for ICNIRP this number is reduced to about 15 dBm and 18 dBm, respectively. With increased the frequency, the far-field distance of the dipole is reduced which explains why P_{max} approaches a steady value as the frequency increases.

The somewhat oscillatory behavior in P_{max} for lower frequencies where the basic restrictions are given in terms of localized SAR, and most noticeable for the ICNIRP exposure limits, may be attributed to a combination of several factors. As the frequency is increases, the electrical distance to the phantom increases and a smaller fraction of the power is absorbed. On the other hand, an increased frequency also implies more superficial energy absorption and a reduced antenna size, which will result in a larger fraction of the absorbed power within the applicable SAR averaging volume.

For IEEE, P_{max} at the transition frequency (3 GHz) presents a considerably smaller discontinuity (about 1 dB), but the

latest revision of this standard [7, 8] have not yet been adopted by any regulatory authority.

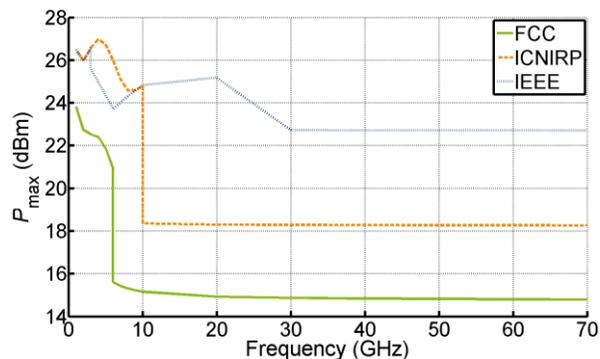


Fig. 1. Maximum output power for a half-wavelength dipole to meet compliance at a distance of 2 cm with FCC, ICNIRP and IEEE EMF exposure.

Fig. 2 shows P_{\max} for the 4x4 antenna array described in the previous section as a function of the test separation distance, d (from 5 mm up to 20 cm). In the reactive near field of the antenna where the peak power density oscillates, P_{\max} has been determined to decrease monotonically with decreasing distance, i.e. $P_{\max}(d) \leq P_{\max}(d')$ for $d < d'$. In this way, the provided P_{\max} will ensure compliance for separation distances equal to or larger than d . This explains why P_{\max} for the FCC limits is relatively constant for low values of d . This effect is also visible in the curve corresponding to the IEEE limits, where for small separation distances the peak power density is the limiting quantity for P_{\max} . Such an effect is not visible when ICNIRP limits are applied since the 20 cm^2 averaged power density from the antenna is always decreasing with distance. At 2 cm, P_{\max} is equal to 7.8 dBm for FCC and 14 dBm for ICNIRP. The corresponding value for IEEE is about 19 dBm.

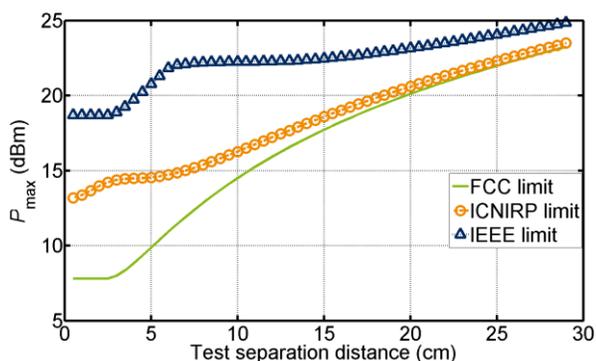


Fig. 2. Maximum output power for a 4 x 4 antenna array to meet compliance with the FCC and ICNIRP EMF exposure limits at 15 GHz as a function of the distance.

IV. CONCLUSION

Above 6 GHz for FCC and 10 GHz for ICNIRP, EMF exposure limits are defined in terms of free-space power density rather than SAR. It was shown that at the transition frequency where the exposure metric changes, the maximum

radiated power to meet compliance with ICNIRP and FCC EMF limits, for a device used in close proximity of the body, presents a strong discontinuity (in the order of 6 dB for the investigated case). This discrepancy has no scientific basis and is due to inconsistencies in the exposure limits. As a consequence, the estimated maximum output power in uplink for devices operating at frequencies above 6 -10 GHz, is about 18 dBm and 15 dBm for ICNIRP and FCC, respectively. These figures were obtained by numerical simulations of a canonical dipole at frequencies up to 70 GHz. It was shown that for more directive antennas, the maximum available power can be substantially lower. For the IEEE limits, the incongruity at the transition frequency is less evident. This is because the IEEE PD limits make use of a larger averaging area than the ICNIRP and FCC limits. The IEEE limits, however, have not yet been adopted in any national regulations.

With a growing interest for utilizing frequency bands above 6 GHz for mobile communications, it is important that the inconsistencies at the transition frequency from SAR to PD based basic restrictions are timely solved. If not, the observed discrepancy might have a large impact on the development of future mobile communication networks. We therefore encourage the relevant standardization organizations and regulatory authorities responsible for defining EMF exposure limits to address this issue.

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