Preconference Workshop: EMF exposure from 5G equipment: the state of art of research and standardization

EMF EXPOSURE LIMITS ABOVE 6 GHZ

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(As individual)
✓ Power absorption in biological tissues from 100 kHz to 300 GHz

- In frequency band between 30 MHz and 130 MHz, the resonance occurs over the body, corresponding to 0.4-0.45 wavelength in free space.
- From a few hundreds megahertz to GHz region, (weak) partial-body resonance may occur.
- Above a few gigahertz (3 or 6 GHz) power absorption is superficial (skin).

Whole-body averaged SAR for exposure at the field strength of the ICNIRP Reference level.

With the increase of frequency, the penetration depth becomes shallower.

Above 6 GHz, skin surface heating is dominant.
On human protection above 6 GHz

Physical Quantities in Standards

- **SAR**  Specific Absorption Rate [W/kg]
  - Averaged over 10 g of tissue
- **Incident Power Density** [W/m²]
  - Averaged over a specific area

1. SAR applicable frequencies
   - ICNIRP guidelines†
   - IEEE standard††

2. Incident Power Density  (Basic Restriction: 10 [W/m²])
   - ICNIRP guidelines†
   - IEEE standard††
     - \(100\lambda^2 [cm^2] (3 - 30 \text{ GHz})\)
     - \(100 [cm^2] (\text{above 30 GHz})\)

Definition are different in guidelines/standard

Only a limited numbers of papers were available for frequencies higher than 6 GHz. mmW use was not expected = Scientific rationale is needed.

Necessity of reassessment of physical quantities and limit

✓ Gap at 3-10 GHz (Local SAR versus incident power density)

• SAR is internal physical quantities, while incident power density is external ones.
• As compared with local SAR, the number of papers investigating the relationship between temperature elevation and incident power density are limited.

![Graph showing SAR and Incident power density vs Frequency]

Relation between incident power density and its averaging area should be discussed simultaneously.


* Note in the ICNIRP guidelines (for small area) was not considered.


✓ Gap at 300 GHz (Radio-wave versus optical radiation)

1. ICNIRP has optical radiation guidelines (> 300 GHz) in addition to EMF guidelines (< 300 GHz). ANSI has also has a laser standard (under revision).
2. There are two guidelines in the optical regime of the ICNIRP: Incoherent visible and infrared radiation and laser radiation.

ICNIRP guidelines

Radio spectrum | Optical/Laser spectrum
---|---
300 | Frequency [GHz]

**Radio-wave**

1. General public versus Occupational environment
2. Definition of Averaging time

**Optical Radiation**

- No definition of environment
- No definition of averaging time
- Intense short-time exposure (< 10 sec)
- Averaging area (approximately 1 cm$^2$), depending on the frequency (wavelength)

It would be preferable if the RF guidelines match up with the optical guidelines.

Averaging area of Incident Power Density (1)

**ICNIRP Guidelines**
- Frequency independent
- Side length of averaging area [cm]: 4.5
- Averaging area [cm²]: 20

**IEEE Standard C95.1**
- Dependent on frequency from 3 to 30 GHz
- Side length of averaging area [cm]: 100, 50, 30, 10, 10
- Averaging area [cm²]: 1000, 250, 90, 36, 100

Distributions of power density for patch antenna array with 4 elements

- **10 GHz**: 10 cm × 10 cm
- **30 GHz**: 2 cm × 2 cm

**Averaging area of incident power density**
- May not depend on the frequency (except for small beam)
- Can be correlated with temperature rise

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✓ Averaging area of Incident Power Density (2)

ICNIRP Guidelines
20cm² (Reference level 10 W/m²). 20 times higher RL can be allowed for the area of 1 cm² (200 W/m²).

IEEE Standard
3-30 GHz: 100λ² [cm²] (λ : wave length in free space[cm])
> 30 GHz: 100 cm²

Recent research papers
6 (10)-30 GHz: 4 cm², at higher frequencies: 1cm²†
Circle with a diameter of 1.5 cm (approximately heat conduction distance in biological tissues) ††

Averaging area of incident power density:
Scientific results suggest the averaging area of 1-4 cm²

Computational Examples (exposure from dipole antenna and its array)

✓ Incident Power Density, SAR, and Temperature Distributions

Incident Power Density

SAR

Temperature Elevation

10 GHz 150 GHz 10 GHz 150 GHz

Dipole Antenna Antenna Array
Effect of Averaging Area on Heating Factor (Ratio of ΔT to Avg. Inc. Power Density)

(a) 100 mm²

(b) 400 mm²

(c) 900 mm²

(d) 2000 mm²
What is appropriate “dose” above 3-10 GHz.

Heating Factor of dipole antenna for SAR (10 g) and Transmitted Power Density (4 cm²)

The boarder frequency is \(\sim 6\) GHz. Above that transition, the power transmitted to the human (mainly in the skin) is good surrogate to estimate the temperature rise.

Frequency independent BR/DRL can be derived from the heating factor.
Incident Power Density vs Skin Temperature Rise
The transmitted energy density required to certain temperature rise may follow the function of $t^{0.5}$ as suggested in Foster et al (2017).

**Transmitted Energy Density (TED) required for $\Delta T$ of 1 °C**

![Graph showing the relationship between exposure duration and transmitted energy density for different frequencies and types of waves.](image-url)
Can TED match up for CW exposure?

Regression curve for the allowable TED matches up that of 36 kJ/m² at 6 min.
Temperature Rise for Multi-pulse Exposure

a) 300 GHz Plane Wave (1-sec pulse)

b) 300 GHz Plane Wave (200-sec pulse)

Amplitude of multiple pulses was set so as to satisfy the TED regression curve.
Summary

- Transmitted power density (TPD) is a good metric to estimate the temperature elevation in the skin at frequencies above 3-10 GHz.
- 2cm*2cm is appropriate averaging area for of IPD/TPD; at higher frequencies, smaller averaging area may be needed.
- Transmitted power density (TED) is a good metric to estimate brief exposure; if matching up with CW exposure at 6 min, computation suggests it applicability for different pulse patterns.
- In international standard/ guidelines, the ambient condition etc is included in reduction/safety factor.
Our publication above 6 GHz

- Manuscripts on TPD and brief exposure are in preparation.