Australian Government
Australian Radiation Protection and Nuclear Safety Agency

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Radio Frequency EME exposure levels - prediction methodology

The purpose of this document is to provide a protocol for estimating the radiofrequency electromagnetic energy (RF EME) exposure levels due to mobile telecommunications infrastructure (base stations and small cells).

This method is intended to be used to predict the likely upper bound of exposure levels encountered by the general public when in the vicinity of a base station. Although these exposure levels may be expressed as a percentage of the permitted limit, this method is not intended for use to determine compliance zone boundaries. The infrastructure may be operational or proposed at the time of the evaluation. Information from the network operator about the configuration of transmitting equipment installed at the site is required to perform the calculations. Unobstructed line-of-sight propagation from the transmitting antenna to the evaluation point is assumed. Attenuation due to environmental clutter (buildings, vehicles, vegetation) is not considered. The actual EME levels will generally be significantly less than predicted due to path losses and the base station automatically minimising transmitter power to only serve established phone calls and data requests.

Assumptions:

- The antenna mounting height, position and orientation are all known.
- The antenna mid-point is used as the reference point.
- Both horizontal and vertical gain patterns are used: the off-axis gain appropriate for the angle from the antenna to the evaluation point as determined by trigonometry.
- Unobstructed line-of-sight from transmitting antenna to the evaluation point.
- Calculations are only required for points in the far field, i.e. source region III as defined in [1].
- Ground reflections are the only significant reflections to be considered in calculations, i.e. environment region 1 as defined in [1].
- All available services are transmitting from the site simultaneously.
- All transmitters are operating at 100% capacity.
- A minimum duty cycle of 75% downlink (DL) is used for time division duplex (TDD) services.
- Appropriate power reduction factors may be used for each technology.

Basic Calculation

The basic equation used to calculate RF EME levels in the far-field of a transmitting antenna is:

$$S_i = \frac{P \times G(\theta, \varphi)}{4\,\pi\,d^2} \times (1 + |\Gamma|)^2 \qquad \textbf{(1)}$$

where S is the power flux density (W/m²)
P is the transmitter power (W)
$G(\theta,\varphi)$ is the isotropic antenna gain in the direction given by elevation θ and azimuth φ
d is the distance from the antenna to the evaluation point (m)
$|\Gamma|$ is the magnitude of the reflection coefficient (for the ground plane).

The transmitter power P is the total power into the antenna and is determined by subtracting all known losses (such as cable loss and combiner loss) from the transmitter output power. The total power into the antenna must take into account the number of transmitters in the site configuration.

The gain G is obtained from the manufacturer's antenna pattern for the specific antenna model and frequency being used. Trigonometry is used to determine the elevation and azimuth to the evaluation point. Both horizontal and vertical gain patterns must be used to determine the off-axis gain. In the case of massive MIMO and beamforming antennas, the envelope traffic radiation pattern should be used to determine $G(\theta,\varphi)$ [1].

The distance d used in the equation is the line-of-sight separation between the antenna mid-point and the evaluation point. This distance is calculated by trigonometry using the vertical and horizontal separations.

Where a reflecting ground plane is present and is likely to have an impact on RF exposure, the reflection coefficient, Γ, will be non-zero. For a perfectly conducting ground plane (such as a flat metallic surface) $\Gamma = 1$, while for typical ground conditions $\Gamma = 0.6$.

Site Specific Calculation

Each base station is designed with specific equipment, configured to provide radio coverage over the nearby geographical area, to meet the anticipated demand for services. A base station may host services and equipment from one or more network operators at a single site.

The base station parameters required as inputs for calculation of the RF EME levels are obtained from the network operators. This information is usually also available to registered users from the Radio Frequency National Site Archive (RFNSA). The RFNSA is a searchable online database with information about Australian base stations including their location, the technology, frequency band as well as the antenna model, total transmit power, bearing, height, mechanical down tilt. Antenna patterns are available from the National Antenna Database (NAD) which is also accessible through the RFNSA for registered users.

The basic equation is used for each antenna and service for all network operators present at a base station and the results summed to provide an estimate of the maximum cumulative RF EME due to the base station.

$$S_{max} = \sum_{i=1}^{N} S_i \qquad \textbf{(2)}$$

This evaluation of the cumulative RF EME of a base station is generally a gross over-estimate. Several factors should be considered to arrive at a more realistic value. The two most important factors account for the duty cycle of the transmission technology and the actual maximum transmission power of the base station.

The base station technology duty-cycle factor, F_{TDC}, depends on both the mobile technology being used (GSM, UMTS, LTE-TDD, LTE-FDD or NR, for example) and on the network operator's implementation of the technology. The default value of F_{TDC} = 1 is to be used for GSM, UMTS and FDD implementations of LTE or NR mobile technologies. In the case of TDD implementations of LTE and NR mobile technologies, the duty-cycle factor is equal to the fraction of the frame time used for downlink signals, typically F_{TDC} = 0.75.

Dynamic Spectrum Sharing (DSS) is a technique in which multiple technologies transmit using the same frequency band and the resources scheduled to each technology vary as necessary to satisfy traffic demands at any given moment. Where DSS is implemented, calculations need only be performed for one of the technologies with the assumption that it has been allocated all of the available resources.

The actual transmitted power of a base station during operation is generally less than the product of the configured maximum power and the technology duty cycle factor. Using the actual maximum transmitted power approach for predictions avoids an unrealistic over-estimation of exposure. A power reduction factor, F_{PR}, derived from statistical analysis of actual transmitted power data or from measurement data, may be used in the estimation of RF EME levels to obtain a more accurate result [1]. Realistic values of F_{PR} are in the range 0.1 to 0.5 [2,3]. Analysis undertaken by ARPANSA of measurement results collected by ACMA has found that a power reduction factor of F_{PR} = 0.19 ensures that in 95% of cases the measured value is less than the calculated RF EME.

A more realistic, or typical, estimation of the cumulative RF EME from a base station is found by applying the reduction factors F_{TDC} and F_{PR} appropriate for the technology to the results from the basic equation prior to summing the different services.

$$S_{typical} = \sum_{i=1}^{N} (S_i \times F_{TDC} \times F_{PR}) \qquad \textbf{(3)}$$

The range of values between $S_{typical}$ and S_{max} provide a conservative estimate for the cumulative RF EME due to a base station.

Exposure Limits

The Australian Communications and Media Authority (ACMA) mandates exposure limits for continuous exposure of the general public to RF EME from mobile phone base stations. The limits at the time of writing this report are based on the reference levels for general public whole-body exposure in the ARPANSA RF exposure standard RPS S-1 [4].

The varying exposure limit across the band of frequencies used by mobile phone base stations does not allow the simple addition of power densities. Compliance is determined by first calculating the percentage of the limit for each transmitter frequency and adding the individual percentages together to determine the cumulative exposure. Compliance is achieved if the sum of the individual percentages is less than 100%.

Because each mobile phone carrier operates over a band of frequencies, for simplicity the mid-band frequency may be specified when determining the compliance limit. Where the exposure limit increases with frequency across the band, it is also reasonable to use a more conservative exposure limit from a nearby lower frequency. Suggested evaluation frequencies and their exposure limits are shown in the table below.

Table 1. Frequency bands used for mobile phone base stations in Australia and the associated general public exposure limits.

Band	Actual Frequency Range (DL)	Evaluation Frequency	RPS S-1 Limit
700	758 – 803 MHz	700 MHz	3.5 W/m^2
850	859 – 890 MHz	850 MHz	4.25 W/m^2
900	935 – 960 MHz	900 MHz	4.5 W/m^2
1800	1805 – 1880 MHz	1800 MHz	9.0 W/m^2
2100	2110 – 2170 MHz	2100 MHz	10.0 W/m^2
2300	2302 – 2400 MHz (TDD)	2300 MHz	10.0 W/m^2
2600	2620 – 2690 MHz	2600 MHz	10.0 W/m^2
3500	3425 – 3700 MHz (TDD)	3500 MHz	10.0 W/m^2
26000	25100 – 27500 MHz (TDD)	26000 MHz	10.0 W/m^2

Report

The layout for the report of the estimated RF EME levels should follow the format of the template document “Electromagnetic Energy Report” that can be found on the ARPANSA website. The recommended report provides estimates of the highest RF EME levels 1.5 metres above ground level out to a distance of 500 metres in all directions from the base station, and over other height ranges for locations of particular interest nearby.

The environmental and locations of interest values are calculated over different spatial ranges. The environmental values are calculated over a horizontal plane at 1.5 m above the ground level (measured at the location of the antenna site) for distances within 500 m of the site (see figure 1). The locations of interest calculations are performed over a vertical line at a single location to the full height of the structure or building concerned (see figure 2). The maximum value found over the vertical range is reported for that location of interest.

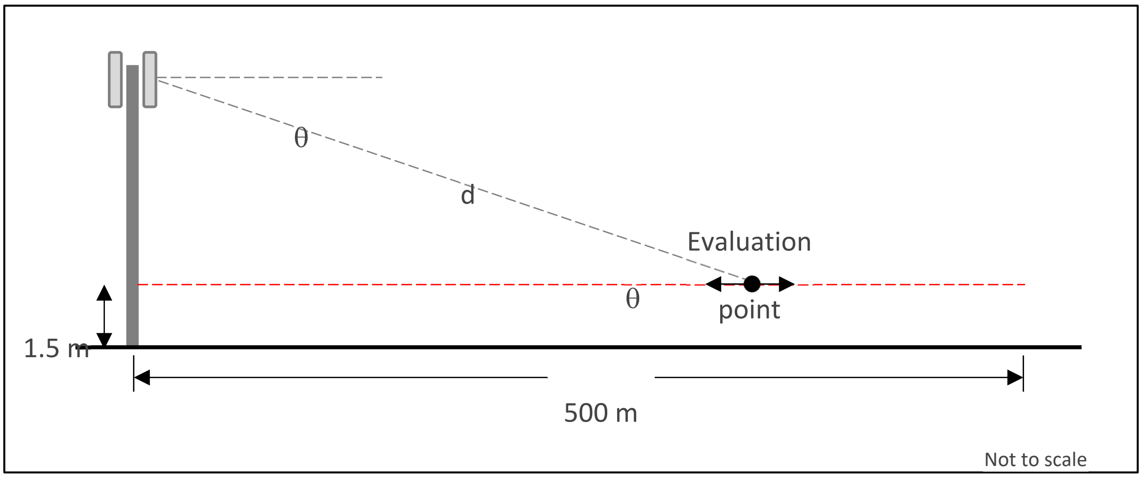

Figure 1. Geometry for calculation of environmental levels of RF EME. The maximum value within 500 m of the base station in any (azimuth) direction is reported.

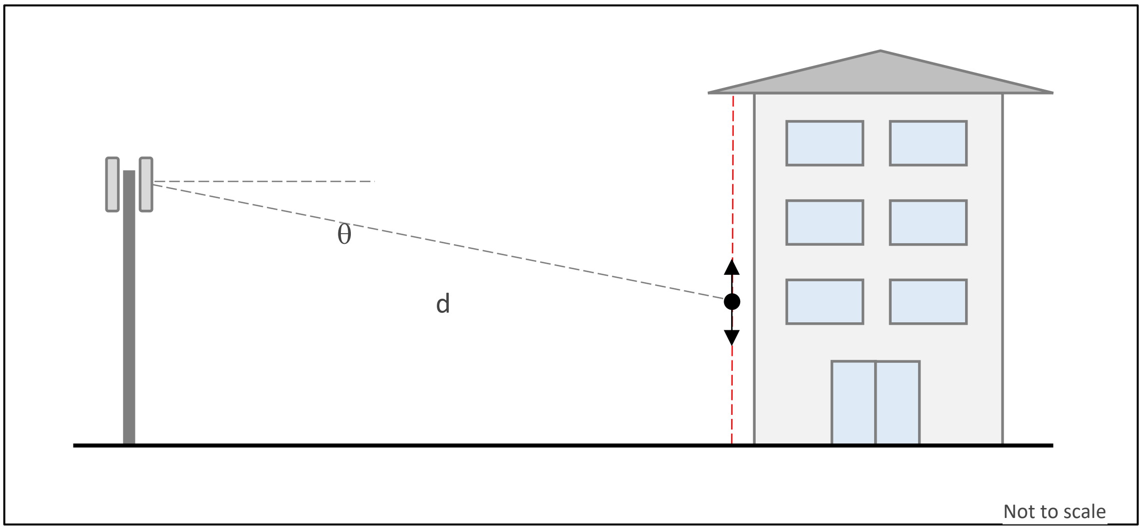

Figure 2. Geometry for calculation of RF EME at location of interest. The maximum value over the entire height range is reported.

Glossary

Array antenna
An antenna composed of multiple elements that can be controlled electronically to direct the signal towards the user or device.

Beamforming
Technique employed by array antennas to direct a wireless signal towards a specific user or device.

Beam steering
Technique employed by array antennas to dynamically adjust the direction of the beam to maintain a stable connection with the user or device.

Envelope traffic radiation pattern
A radiation pattern (or antenna pattern) describes the gain as a function of angle for an antenna. Beamforming array antennas used in 5G networks generally have different radiation patterns for traffic (data and calls) and broadcast signalling beams. The envelope radiation pattern encompasses all possible beam directions.

FDD – Frequency Division Duplex
A communication technique that uses different frequency channels to transmit and receive signals.

GSM – Global System for Mobile communications
A radio transmission standard used for 2nd Generation mobile communications.

LTE – Long Term Evolution
A radio transmission standard used for 4th Generation mobile communications.

MIMO – Multiple Input Multiple Output
A method for increasing the capacity and coverage of a radio link using multiple transmission and receiving antennas (or antenna elements) to exploit multipath propagation. Array antennas exploit MIMO techniques along with beamforming and beam steering to improve network performance.

NR – New Radio
A radio transmission standard used for 5th Generation mobile communications.

TDD – Time Division Duplex
A communication technique that uses different time slots to permit the transmission and reception of signals on the same frequency channel.

UMTS – Universal Mobile Telecommunications System
A radio transmission standard used for 3rd Generation mobile communications.

References

[1] AS/NZS IEC 62232:2023 (2023) *Determination of RF field strength, power density and SAR in the vicinity of base stations for the purpose of evaluating human exposure* (identical adoption of IEC 62232:2022).

[2] Thors, B., Furuskär, A., Colombi, D. and Törnevik, C. *Time-Averaged Realistic Maximum Power Levels for the Assessment of Radio Frequency Exposure for 5G Radio Base Stations Using Massive MIMO.* IEEE Access. 5, 19711-19719 (2017).

[3] Xu, B., Colombi, D., Törnevik, C., Ghasemifard, F. and Chen, J. *On Actual Maximum Exposure From 5G Multicolumn Radio Base Station Antennas for Electromagnetic Field Compliance Assessment.* IEEE Transactions on Electromagnetic Compatibility. 63(5), 1680-1689 (2021).

[4] ARPANSA RPS S-1 (2021) *Radiation Protection Standard for Limiting Exposure to Radiofrequency Fields —100 kHz to 300 GHz (2021)*.