GSMA

# 5G millimetre wave safety

## Electromagnetic field (EMF) health related science and research

October 2022

## GSMA

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# Contents

# Executive Summary

Millimetre wave (mmWave) spectrum is essential for maximising 5G's potential. The range provides fibre-like connectivity to suburban and rural areas. It is also crucial for providing ubiquitous connectivity in manufacturing plants, stadia and travel hubs. National and international safety guidelines already include mmWaves. So, importantly, the guidelines protect all people against all established health hazards.

5G mmWave frequencies, specified as above 24 GHz, are not new and have been used for decades in satellite and other communication networks. National and international safety guidelines for radio waves apply to all the frequencies used for 5G, including 5G mmWave. The international guidelines protect all people against all established health hazards.

> *'The ICNIRP RF EMF guidelines have taken the above considerations into account and protect against all potential adverse health effects relating to exposure to RF EMFs from 5G technologies.*
> **- International Commission on Non-Ionizing Radiation Protection (ICNIRP)**

Measurements show that the total level of radio waves in publicly accessible areas from all mobile technologies, including 5G mmWave, is typically less than 1% of international guidelines.

*'Provided that the overall exposure remains below international guidelines, no consequences for public health are anticipated.'*
**- World Health Organization (WHO)**

## Recommendations for policymakers

The following recommendations will support efficient deployment of 5G mmWave based services.

**Adopt international RF-EMF limits and compliance methods:** Countries should adopt the ICNIRP (2020) limits and use international technical standards for RF-EMF compliance assessment.

**Update RF-EMF deployment rules:** Streamline deployment rules to support greater densification of antennas, especially in urban centres.

**Practice effective EMF communication:** National authorities should take the lead role in efforts to inform the public and address misinformation about RF-EMF.

**Prepare for interest during mmWave licensing:** There may be submissions questioning safety and it is important to prepare responses based on the consensus of health agencies.

# 5G mmWaves overview

5G in mid-band spectrum allows for higher capacity than previous generations of mobile networks. To achieve even higher capacity, 5G can also use frequencies above 24 GHz known as millimetre waves (mmWaves), where much more spectrum is available. mmWaves are not new and have been used for decades in satellite and other communication networks, see Figure 1.

The rapidly growing number of 5G use cases demands a fully coordinated, multi-layer network where 5G mmWave spectrum provides the massive capacity and low latency needed for a full 5G experience.

Find out more at www.GSMA.com/5GmmWave and https://www.gsma.com/spectrum/resources/mmwave-5g-benefits/

## 5G mmWave is covered by existing international safety guidelines

*'The ICNIRP RF EMF guidelines have taken the above considerations into account and protect against all potential adverse health effects relating to exposure to RF EMFs from 5G technologies. This includes potential differences in the effect of RF EMFs as a function of age, health status, and depth of penetration, the effect of both acute and chronic exposures, and it includes all substantiated effects regardless of mechanism.'*

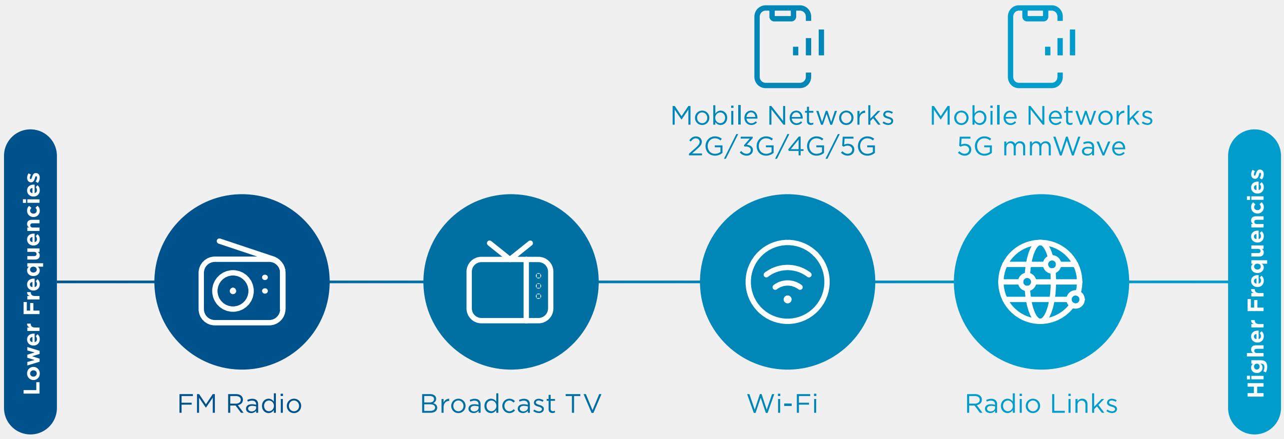
**- International Commission on Non-Ionizing Radiation Protection (ICNIRP)**

National and international safety guidelines for radio waves apply to all the frequencies used for 5G, including 5G mmWave.

Measurements show that the total level of radio waves in publicly accessible areas from all mobile technologies, including 5G mmWave, is typically less than 1% of the international safety guidelines[1].

1 https://www.gsma.com/publicpolicy/emf-and-health/safety-of-5g-networks/5g-emf-surveys

Figure 1
**mmWaves have been used for decades in satellite and other communication networks**



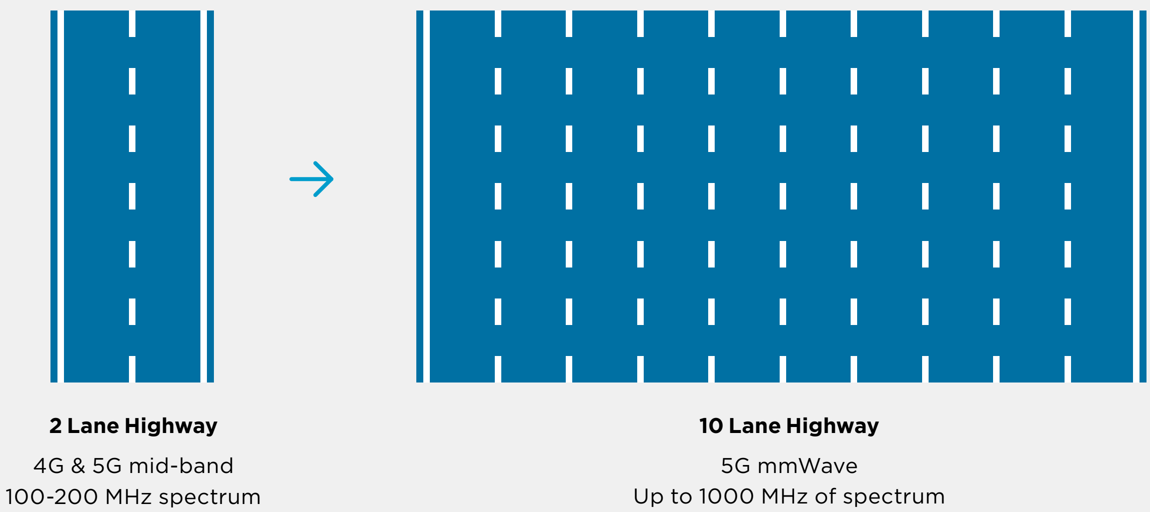

## What is 5G mmWave?

Many initial 5G deployments are at frequencies similar to 3G/4G mobile networks and Wi-Fi. This also means that networks can reuse many existing antenna sites for 5G. While low- (below 1 GHz) and mid-band (1-7 GHz) spectrum provide wide area coverage, they can't compete with 5G mmWave on capacity. The mmWave frequency range offers more bandwidth (see Figure 2). It can support gigabit speeds in localised areas for each user and enables more users.

5G mmWave refers to the higher range of radio frequencies (above about 24 GHz) supported by 5G.

Commercial 5G mmWave deployments are underway at 26 GHz (USA), 26 GHz (Asia, Europe), 38 GHz (China, USA) and 47 GHz (USA).

Figure 2
**5G mmWave provides significant capacity increase with additional spectrum**



# What does 5G mmWave enable?

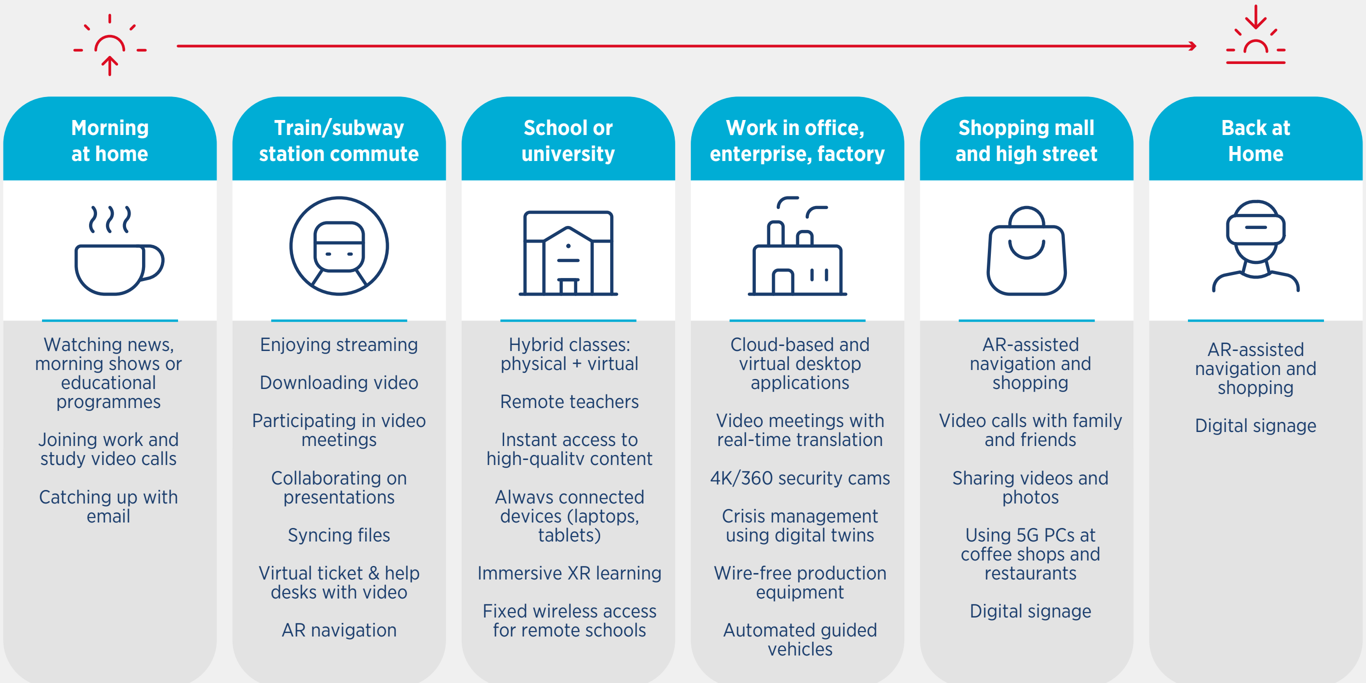
5G mmWave technology enables many more users and devices to connect to the internet with faster responses. 5G mmWave caters for the significant increase in people using and depending on wireless technology, the increasing number of internet-connected devices, the growth of smart cities and societies, the increase in connected vehicles, and increasing industrial automation.

# What are some 5G mmWave applications?

5G mmWave applications rely on high data rates with very low latency, such as interactive gaming, industrial automation, virtual and augmented reality, and connected cars, which have not been feasible with previous generations of mobile connectivity.

5G mmWave can be used in virtually any location, for example at home, transport hubs, universities, offices, and entertainment venues. This is summarised in Figure 3.

Figure 3
**5G mmWave applications rely on high data rates with very low latency**



# How does 5G mmWave technology work?

5G mmWave transmission works in a similar way to any other radio transmission, except that the range is shorter, typically requiring a line of sight to the antenna. The power into the antenna is also low, typically about 1 watt. The range of 5G mmWave small cells placed on street furniture, such as bus shelters and light poles, will be shorter than for 5G mmWave antennas positioned on a taller structure.

In general, the length of an antenna is directly proportional to the wavelength of the signal to be transmitted/received (and therefore, inversely proportional to the frequency of the signal). At mmWave frequencies, in which signals have short wavelengths, multiple antenna elements can be used in a small space. These multiple antenna elements can support increased data rates compared to a single antenna as well as better directionality through a technique called beamforming (see below and page 18).

Figure 4
**Examples of 5G mmWave small cells**

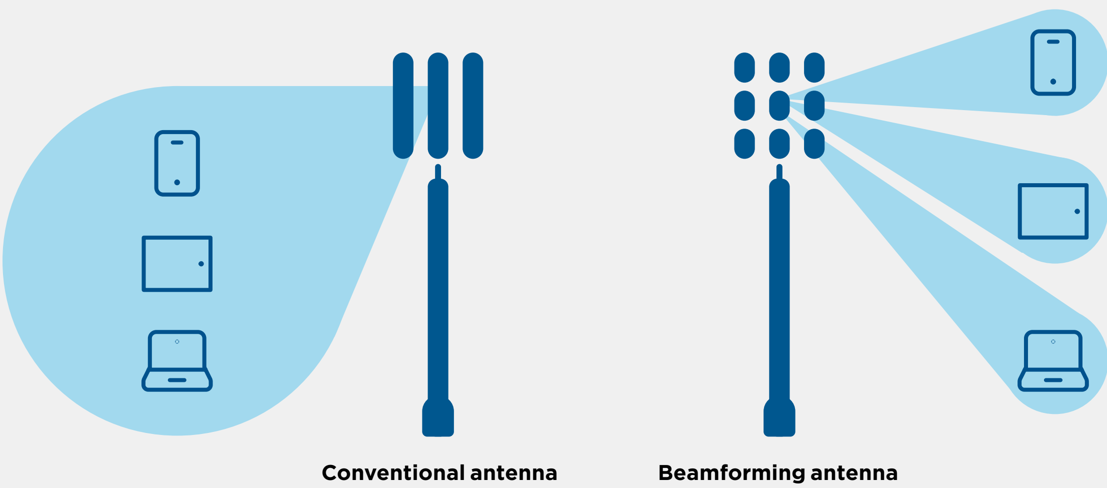
**Example: Residential**

**Example: City information booth (with other antennas)**

The equipment used for 5G mmWave transmission and reception is smaller than the equipment used for lower frequencies (for example those used for 2G, 3G or 4G). 5G mmWave antennas support beamforming to direct the radio signal to a desired area. Conventional antennas provide coverage that is similar to how a floodlight illuminates a wide area. Beamforming antennas are like a flashlight providing coverage where it is needed and reducing unwanted signals. A few meters away from the core of the beam, the 5G signal is negligible.

Figure 5

**Conventional antenna coverage compared to antenna with beamforming**



# The basics of mmWaves

Simply speaking, mmWaves are radio signals with a wavelength of a few millimetres, this corresponds to frequencies of about 30 GHz and higher. They are not new and have been used for decades in satellite and other communication networks.

Table 1
**Frequency and wavelength for some applications of radio signals**

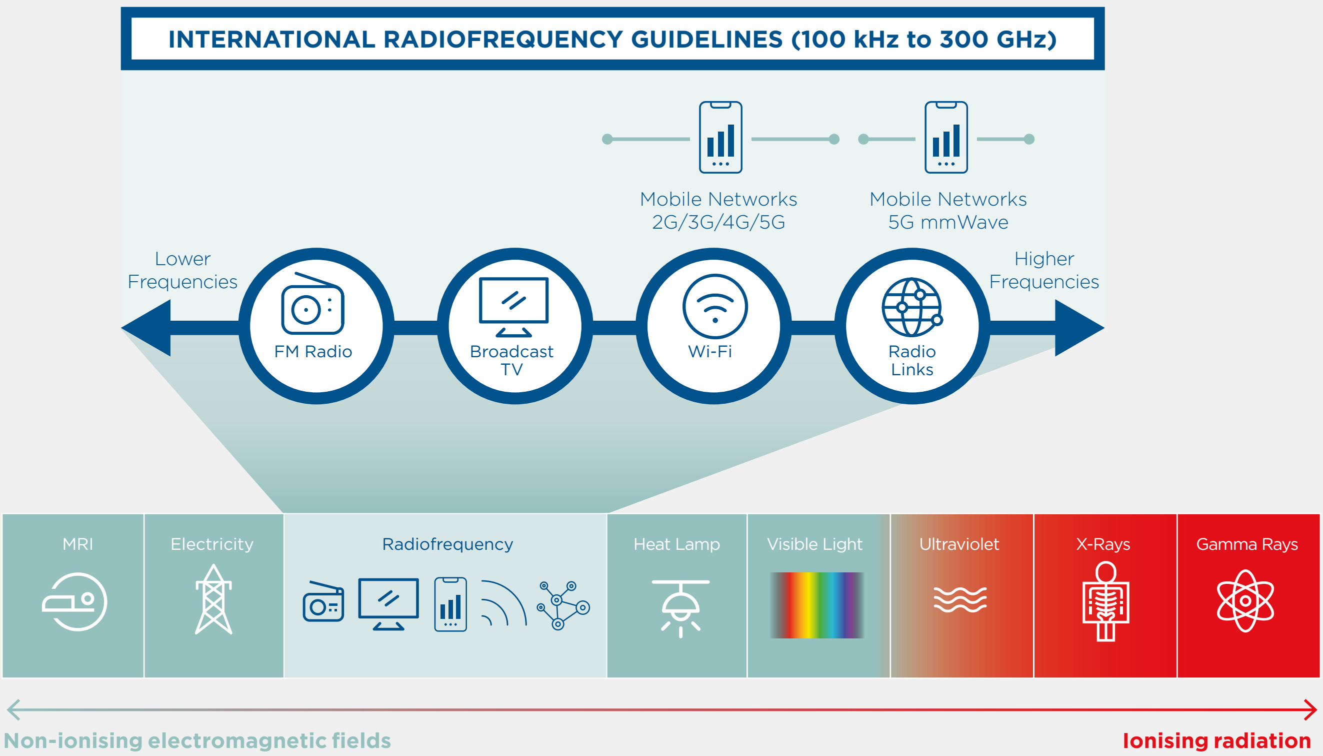
| Frequency (GHz) | Wavelength (mm) | Example existing radio applications |
|---|---|---|
| 0.1 | 3000 | FM broadcast radio |
| 0.9 | 333 | Mobile communications |
| 2.45 | 122 | Wi-Fi |
| 3.5 | 86 | 5G (formerly wireless broadband – WiMAX – in some countries) |
| 5.0 | 60 | Wi-Fi |
| 24/26 | 12 | 5G mmWave in Australia, Europe and North America |
| 35 | 9 | Traffic police speed-detecting radar |
| 60 | 5 | Wi-Fi (also known as WiGig) |
| 80 | 4 | Base station radio data links (in some countries) |

## How do mmWaves relate to other radio signals?

5G mmWave refers to the higher range of radio frequencies supported by 5G (beyond 4G frequencies). This is termed 5G FR2 (Frequency Range 2) and extends above 24 GHz. The lower 5G FR1 bands are from 410 MHz to 7125 MHz.

The mmWave frequencies are in the RF-EMF portion of the overall electromagnetic spectrum. Radio signals are non-ionising, which means that they cannot directly impart enough energy to a molecule to break or change chemical bonds. A wide range of applications, such as FM radio, broadcast TV, Wi-Fi and radio links, use radio waves as depicted in Figure 6.

Figure 6
**The electromagnetic spectrum showing 5G mmWave and other radio signals**



## Some non-5G applications of mmWaves

At mmWave frequencies radio signals propagate (travel) mainly in line-of-sight paths. This is used in applications such as point-to-point radio links, radar, airport security screening, medical therapies (in some countries), and crowd control systems.

### Point-to-point data links

Fixed radio links using directional dish-shaped antennas are used to provide data connections, such as wireless backhaul for base stations. These typically operate at a range of frequencies between 6 and 80 GHz.

### Radar

Radar applications include speed detection by police (24 GHz); short-range airport surveillance (24-40 GHz); autonomous vehicle sensors (24, 74, 77, and 79 GHz).

### Airport security screening

Some whole-body airport security scanners use mmWaves to detect items concealed under clothing. These systems typically operate in frequencies from 24 to 30 GHz.

### Medical applications

mmWave medical therapies are widely used in Eastern Europe and China but they are not generally recognised by Western medicine. These therapies typically use various frequencies between 37 and 70 GHz.

### Active denial technology for crowd control

The US military has developed Active Denial Technology (ADT) using very high-power mmWaves to produce intolerable heating of the skin so that the targeted individual will instinctively move away.

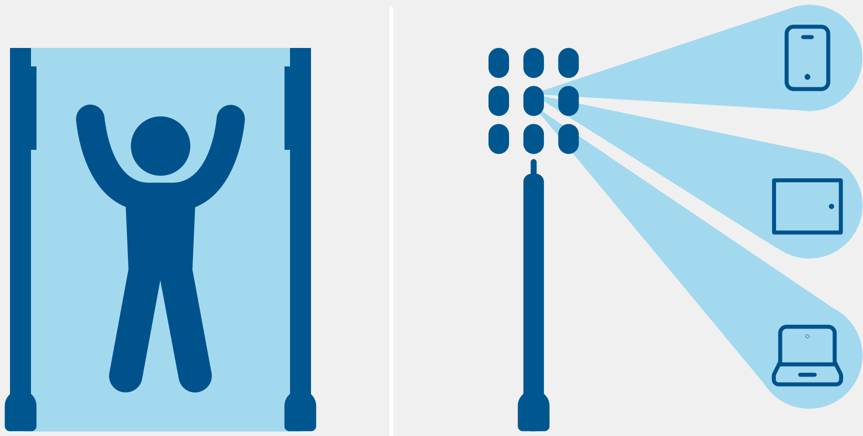
## Some airport security scanners use mmWave frequencies

Health risk assessments were conducted in France (2010)[2] and the USA (2017)[3] when airport security systems using mmWave frequencies were introduced. The evaluated systems used frequencies between 24 and 30 GHz. The scanners result in very low RF-EMF exposures to passengers, and peak exposures during a scan are of the order of 1,000 times below public safety limits[4]. These levels are comparable to or higher than the environmental exposures from 5G mmWave base stations.

The French and US assessments reported no known health effect related to exposure to mmWave for the considered frequency range at the exposure levels of these systems.

Figure 7
**Similar peak environmental levels from mmWave security scanners and 5G mmWave networks**

Peak levels at about **1,000 times** below safety limits for the public




## Medical therapies using mmWaves

Millimetre wave therapies are widely used in the countries of Eastern Europe, Russia, and China for treatment of more than 30 diseases. These therapies use various frequencies, typically between 37 and 70 GHz. However, most of the supporting studies have not been independently replicated by Western scientists and the therapies are generally not available or accepted by Western medicine [1-4].

The average power density incident on the skin is less than 200 W/m² [1]. This is much higher than the ICNIRP (2020) [5] limit for the public for this frequency range[5].

Figure 8
**Medical therapies using millimetre waves (Eastern Europe)**

**Typically 37-70 GHz** Levels about 10-times above the public exposure limits

2 Assessment of Health Risks Related to Use of the ProVision 100 "Millimetre-Wave" Body Scanner.8 Published by the French Agency for Environmental and Occupational Health Safety (AFSSET), Collective Expert Assessment Report, Maisons-Alfort, France, February.

3 National Academies of Sciences, Engineering, and Medicine 2017. Airport Passenger Screening Using Millimeter Wave Machines: Compliance with Guidelines. Washington, DC: The National Academies Press. https://doi.org/10.17226/24936.

4 The National Academies of Science report adds that when pulse duration and scan times are considered the average pulsed power density during a scan is 270,000 times below the applicable public limit.

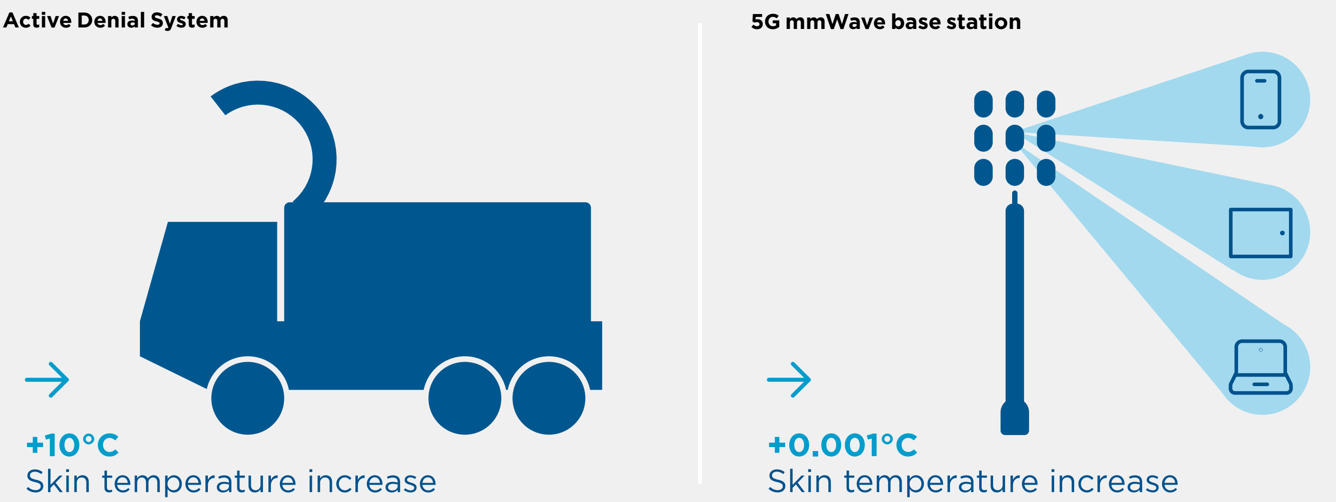
5 ICNIRP considers medical procedures to be outside the scope of the ICNIRP (2020) guideline *'as medical procedures rely on medical expertise to weigh potential harm against intended benefits.'*

## Active denial systems for crowd control

The US military developed truck-mounted Active Denial Technology (ADT) using very high-power mmWaves at 95 GHz, where the RF-EMF energy penetrates the skin to a depth of 0.4 mm (equivalent to about three sheets of paper). Exposure to 3-s pulses at very high power (more than 1,000 times than the international public limit for continuous RF-EMF exposure) produces an '*intolerable heating sensation*' by increasing skin temperature to approximately 45 °C so that the targeted individual will instinctively move. The sensation stops when the person moves away.

Testing during development involved about 10,000 volunteer subjects. In addition, an animal study found no effect of mmWaves on skin cancer [6]. A health risk assessment concluded that there was a *'low probability of injury'* from the system and a '*wide safety margin*' [7].

Figure 9
**Active denial systems use very high power mmWaves**



# Biological effects of mmWaves relevant to mobile communications

There is a significant and ever-growing body of research publications related to RF-EMFs and health. Research on the possible human health effects of exposure to RF-EMF, including frequencies similar to the 5G mmWave, goes back many decades and is continuing.

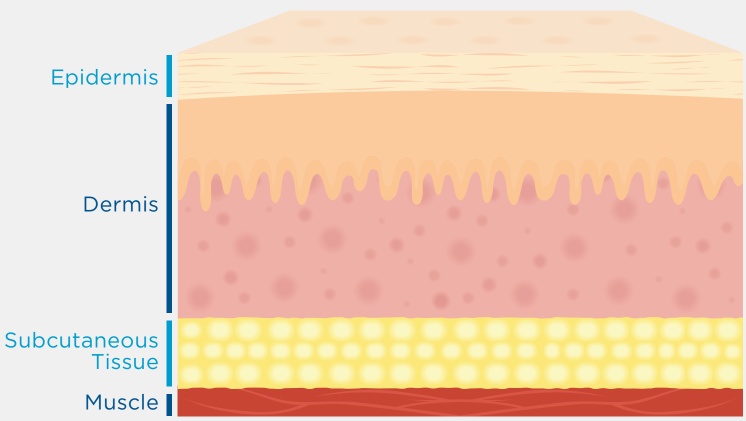
The radio signal characteristics of 5G FR1 are like those of previously existing mobile technologies. In particular, 5G uses similar transmission powers and operates in similar frequency ranges as 2G, 3G and 4G. 5G FR2 (mmWave) uses similar powers and frequencies to the radio data links used to connect antenna sites.

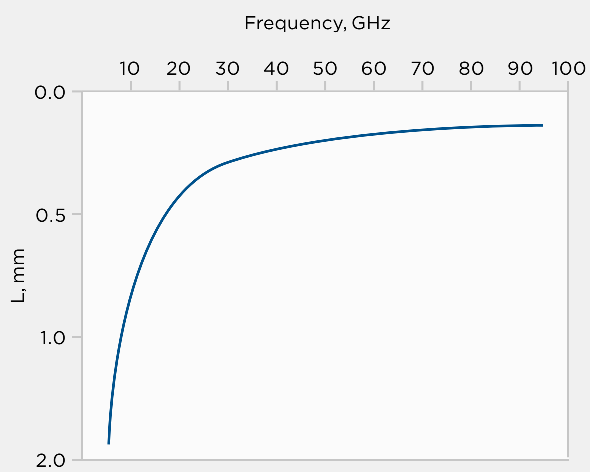
National and international safety guidelines for radio waves apply to all the frequencies used for 5G, including 5G mmWave. Knowledge about how RF-EMF interacts with the human body is used to set exposure limits up to 300 GHz. The guidelines are not technology specific and are periodically reviewed. Therefore, existing health risk assessments are valid independently of the wireless technology for the whole RF-EMF frequency range.

## mmWave absorption in skin tissue

At mmWave frequencies, RF-EMF energy is absorbed superficially by the body, mostly by the skin (to a depth of about 1 mm or less) – see Figure 10 (adapted from [2]). The biological effects of these frequencies have been studied previously and new studies are underway.

Figure 10
**Layers of the skin (left) and power penetration depth of radio wave versus frequency (right)**

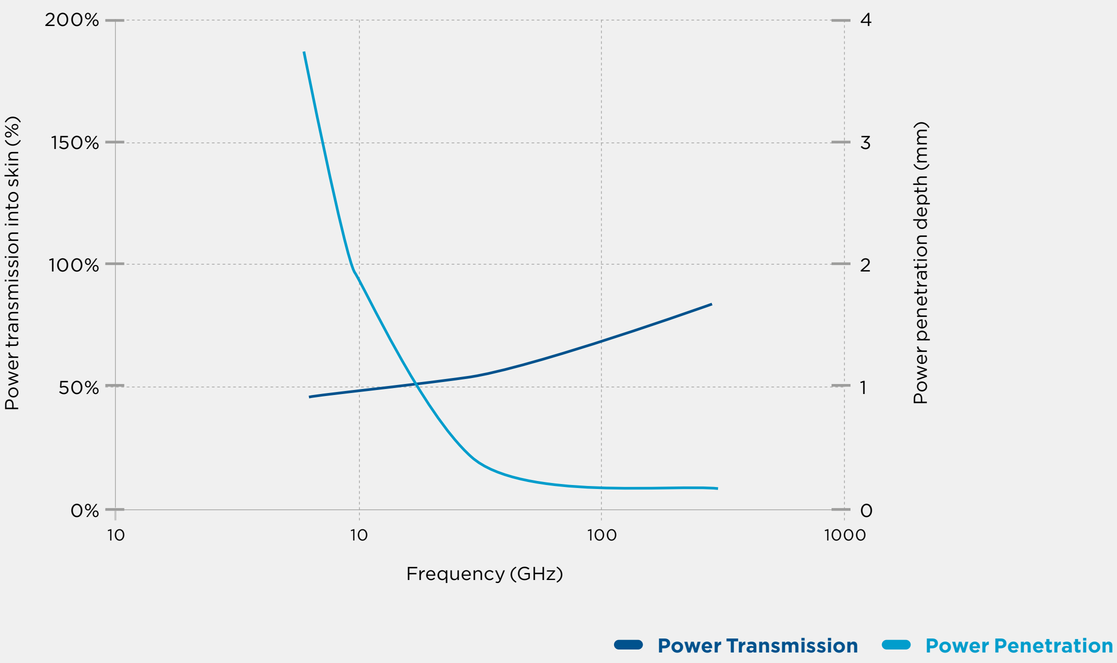


Less than half the incident power is transmitted into the skin at the lower mmWave frequencies currently used for some 5G services, see Figure 11 (adapted from [8]. This proportion increases as the frequency increases, but the depth of penetration is smaller.

Figure 11

**Power penetration, and power transmission into the skin versus frequency.**



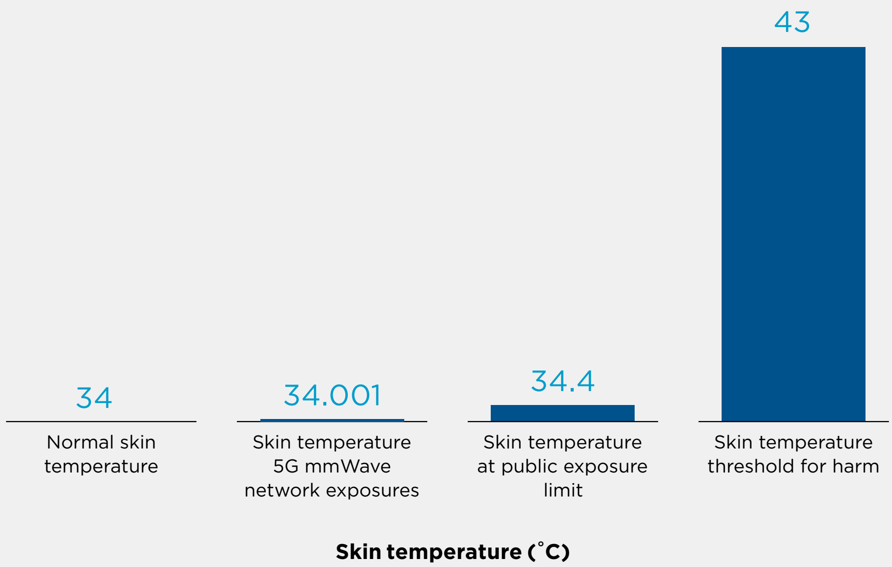

At lower frequencies, absorbed RF-EMF energy can cause heating of body tissues and this is the basis of protection standards. At mmWave frequencies the energy is absorbed superficially and can cause heating in skin tissue, however, blood flow and sweating limit the temperature increase.

The international public limit for exposure to base station radio signals above 6 GHz is 10 W/m$^{2.}$ As a comparison, the sun may impose a heat load of as much as 800 W/m$^2$ to exposed skin [9].

For mmWave exposure at the allowable public limit value, the steady-state temperature rise at the surface of the skin was calculated to be 0.4 °C [10]. For exposures from sources, such as 5G mmWave antennas, the temperature rise would be around 0.001 °C [11].

Normal skin temperature is about 34 °C and the threshold for adverse effects is 9 °C higher at about 43 °C [12].

Figure 12
**Skin heating by 5G mmWave signals**




Infrared is that part of the electromagnetic spectrum just above the RF-EMF portion (see page 6). Infrared also causes skin heating and *'people are frequently exposed to infrared energy, from heat lamps, cooking appliances, infrared space heaters, as well as from simply sitting near a fireplace,'* at levels that far exceed the limits applied to mmWaves, *'even though the defined hazards for both parts of the spectrum involve excessive heating of tissue'* [13].

# RF-EMF exposure guidelines for mmWave frequencies

The mmWave frequencies used for 5G are covered by national standards and/or international guidelines on RF-EMF exposure that protect all people against all established health hazards.

The consensus among national health agencies and international bodies, such as the World Health Organization (WHO), the International Commission on Non-Ionizing Radiation Protection (ICNIRP) and the European Commission, is that RF-EMF exposures below international guidelines have no known health consequences.

## World Health Organization (WHO)[6]

*'As the frequency increases, there is less penetration into the body tissues and absorption of the energy becomes more confined to the surface of the body (skin and eye). Provided that the overall exposure remains below international guidelines, no consequences for public health are anticipated.'*

A similar conclusion was reached by the IEEE Committee on Man and Radiation (COMAR).

## IEEE Committee on Man and Radiation (COMAR)

*'COMAR concludes that while we acknowledge gaps in the scientific literature, particularly for exposures at millimeter wave frequencies, the likelihood of yet unknown health hazards at exposure levels within current exposure limits is considered to be very low, if they exist at all.' [3]*

6 https://www.who.int/news-room/questions-and-answers/item/radiation-5g-mobile-networks-and-health

## ICNIRP guidelines above 6 GHz

The ICNIRP (1998) guidelines cover frequencies up to 300 GHz and are the basis of policy in most countries. In 2020, ICNIRP published updated RF-EMF exposure guidelines covering the frequency range 100 kHz to 300 GHz and these have been adopted by some countries with more expected to follow.[7]

ICNIRP[8] makes clear that both the 1998 and the 2020 guidelines apply to 5G, with the latter guidelines providing more detailed limits above 6 GHz.

> *'It is important to note that, in terms of the 5G exposure levels measured so far, the ICNIRP (1998) guidelines would also provide protection for 5G technologies. However, as it is difficult to predict how new technologies will develop, ICNIRP (2020) has made a number of changes to ensure that new technologies such as 5G will not be able to cause harm, regardless of our current expectations. These changes include the addition of whole body average restrictions for frequencies >6 GHz, restrictions for brief (<6 minutes) exposures for frequencies >6 GHz, and the reduction of the averaging area for frequencies >6 GHz.'*

Further explanation of the ICNIRP (2020) guidelines is provided in the GSMA publication *International EMF Exposure Guidelines*[9].

## Implications of ICNIRP (2020) for base station compliance

Analysis of the influence of ICNIRP (1998) versus ICNIRP (2020) RF-EMF limits on the compliance boundaries of base station equipment found that the impact is marginal [14]. The authors says that base stations that currently comply with ICNIRP (1998) will remain compliant under ICNIRP (2020). The analysis covered low-power small cells and macro cell equipment, operating in frequency bands above and below 6 GHz, and is of relevance for 2G to 5G mobile technologies.

## Implications of ICNIRP (2020) for mobile device compliance

The ICNIRP (2020) guidelines introduce a new basic restriction termed absorbed power density (APD, symbol $S_{ab}$) that applies from 6 to 300 GHz. It takes account of the more superficial absorption of RF-EMF as the frequency increases.

The pair of standards IEC/IEEE 63195-1:2022 and IEC/IEEE 63195-2:2022 provide test methods [15] and computational procedures [16] to determine compliance with power density limits for devices used within 200 mm of the head or body.

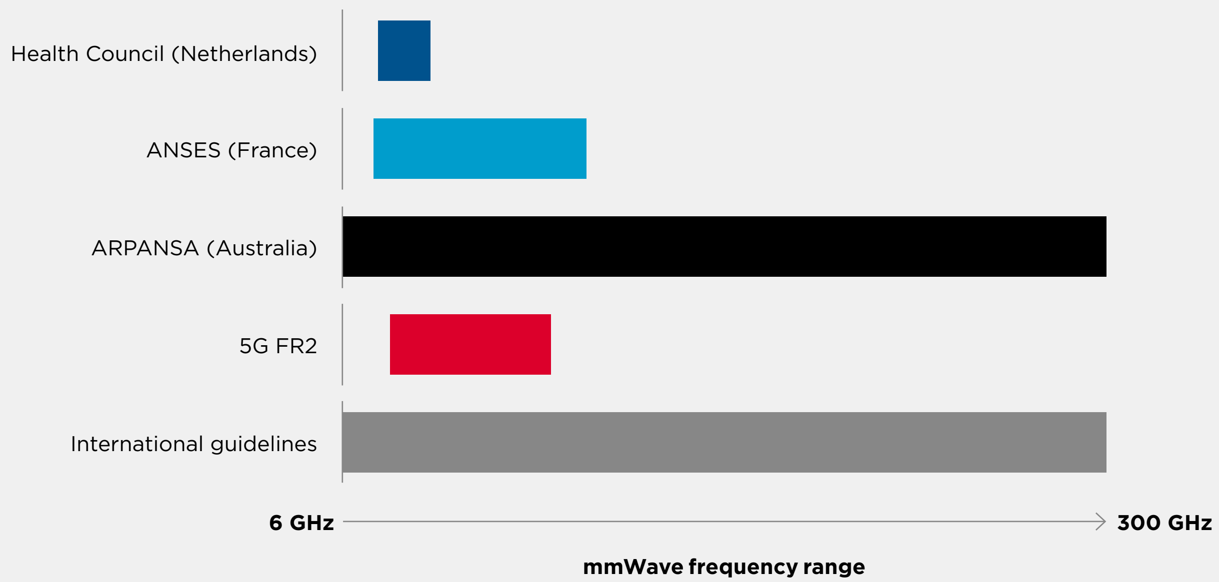
7 For current status see: https://www.gsma.com/publicpolicy/emf-and-health/emf-policy
8 https://www.icnirp.org/en/applications/5g/index.html
9 https://www.gsma.com/publicpolicy/resources/emf-exposure-guidelines

# Reviews of EMF research relevant to 5G mmWave

Health agencies from Australia, France, the Netherlands and the USA have reviewed existing RF-EMF research relevant to 5G mmWave. As can be seen in Figure 13, the agencies took different approaches to definition of the frequency ranges used when selecting relevant research.

None of the agencies found indications that mmWave frequencies are more dangerous than other bands but they differ in their assessment of the strength of the available evidence as a basis for using mmWave frequencies for 5G.

Figure 13
**mmWave frequency ranges used by some health agency reviews**



## Netherlands, September 2020

The Health Council of the Netherlands (HCN) committee on EMF restricted the frequencies for relevant mmWave studies to the range 20 to 40 GHz for its advisory report [17], and identified three epidemiological studies (related to occupational exposure to radar).

The HCN EMF committee concludes[10]:

> *'Such associations are deemed neither proven nor probable for any of the diseases and conditions studied, but cannot be excluded for a number of them … The committee recommends monitoring the exposure levels, carrying out further research and postponing the start of using the highest frequency band for 5G (26 GHz) until more is known about any health effects.'*

On 20 November 2020, the government of the Netherlands responded to the HCN committee. Regarding use of the 26 GHz band, the government responded[11]:

> *['According to the WHO, the European Commission and ICNIRP, there is currently no reason to assume that the use of the 26 GHz band negative health effects. The Health Council has also confirmed this. Partly for this reason, the government sees no reason to wait for more research results before using this band. The 26 GHz band is in use in the Netherlands, but not (yet) for mobile communication…']*

The frequency assignment process has not commenced so the 26 GHz band is not yet available for commercial 5G deployment in the Netherlands.

## Australia, March 2021

The Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) state-of-the-science review [18] and meta-analysis [19] identified 107 experimental and 31 epidemiological studies in the frequency range 6 to 300 GHz.

ARPANSA concluded:

> *'This review showed no confirmed evidence that low-level RF fields above 6 GHz such as those used by the 5 G network are hazardous to human health.'*

Commercial 5G mmWave services were launched in Australia in 2021.

## France, February 2022

The French Agency for Food, Environmental and Occupational Health & Safety (ANSES[12]) produced a preliminary report [20], which used the frequency range 24-60 GHz and identified 174 studies. This was followed by a final report [11] that considered studies between 18 and 100 GHz.

ANSES concluded:

> *'… no positive or negative conclusions can be drawn as to the existence of possible health effects associated with exposure to radiofrequencies in the 26 GHz band at a level below the regulatory limit values…'*

5G mmWave trials are underway in France. The dates for the spectrum assignment and commercial launches have not yet been set.

10 Note that the HCN report makes clear that it *'does not make any statement about the actual occurrence of health damage after exposure to 5G'*. The committee *'only makes statements about the potential for radiofrequency electromagnetic fields to cause adverse health effects.'*

11 [Cabinet response Health Council of 5G and health], M.CG Keijzer, State Secretary for Economic Affairs and Climate; T. van Ark, Minister for Medical Care; and S. van Veldhoven-van der Meer, State Secretary for Infrastructure and Water Management. 20 November 2020. Available at https://www.tweedekamer.nl/kamerstukken/brieven_regering/detail?id=2020Z22274&did=2020D47317

12 l'agence nationale de sécurité sanitaire de l'alimentation, de l'environnement et du travail

# 5G mmWave EMF exposure levels

All 5G radio signals must comply with relevant national or international RF-EMF limits. Studies to date show that 5G networks and devices result in similar exposure levels to 4G and other radio technologies. This is true for mmWaves and other 5G frequency bands.

Importantly, the use of a higher frequency does not mean higher exposure. Higher frequencies generally mean shorter ranges (also more superficial penetration to human tissues) and higher data rates (due to the increase of the available bandwidth).

Higher data rates mean the information is transmitted far more quickly and efficiently and will cater for the increased data demand from end-users, whilst maintaining low RF-EMF levels. Assessments of 5G networks, operating across all bands, show exposure levels that are similar to existing mobile services.

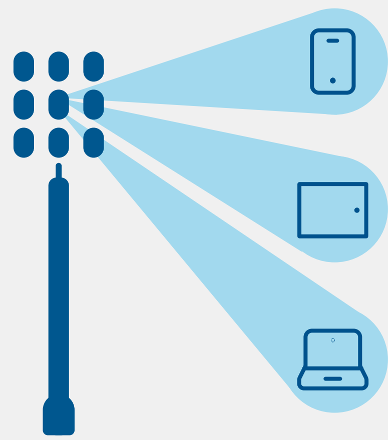
Beamforming antennas have been used in 4G but their expanded use for 5G means more efficient use of radio signals and the energy is directed where it is needed for communications. There will also be more use of small cells with 5G, especially for mmWave deployments.

## Effect of beamforming on RF-EMF levels

Just as a light source can illuminate a wide area (for example a floodlight) or a narrow area (for example a stage light), a transmitted radio signal can also be used to cover a wide area or a narrow area.

With a light source, a reflector is used to focus the light. With 5G mmWave transmission, multiple small antenna elements are used to direct the radio energy as a beam pointing towards a specific area (as shown in Figure 14). This narrow beam can be steered to follow the user. This makes the communication efficient in several ways: it focuses the energy of the radio signal towards a desired area, increases spatial reusability, minimises energy wastage, allows for higher data rates and provides a better user experience.

Figure 14
**5G mmWave antenna directs signal to users**



5G antenna using massive MIMO

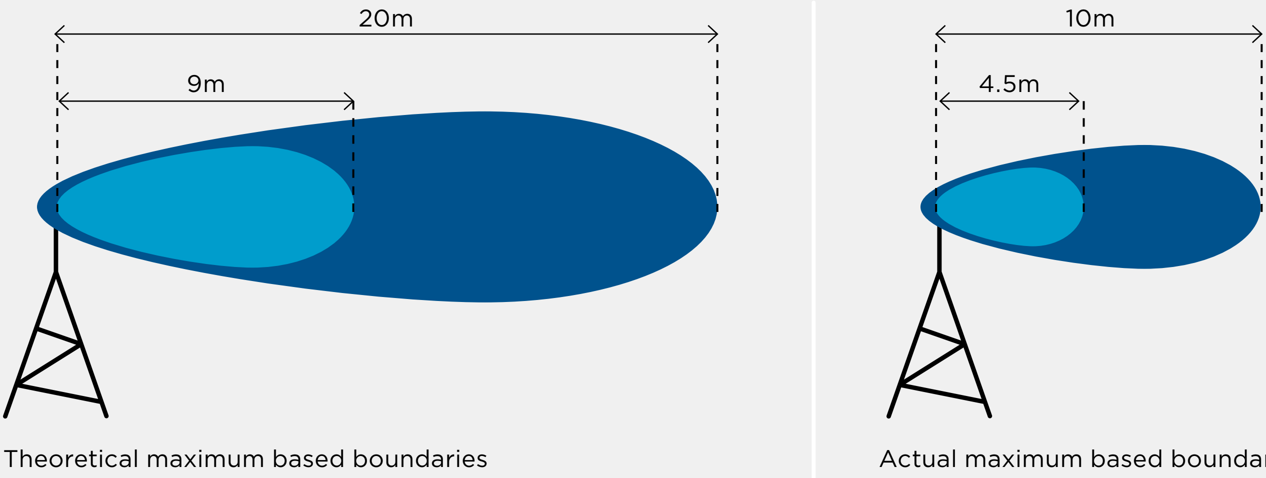
Beamforming is delivered by the antenna technology massive multiple-input multiple-output (MaMIMO) – where massive refers to the many small elements making up the antenna and not the overall size.

Measurements by French authorities showed that the beams of the 5G antenna in the 26 GHz band are very narrow and outside the beam the strength of the 5G signal is negligible [21].

Real-world measurements and computational models demonstrate that the actual time-averaged exposure from 5G antennas is much lower than theoretical maximum assumptions. This is important because the human safety limits are based on time-averaged exposure.

The RF-EMF compliance boundaries for antennas define the areas where the public or worker limits are exceeded. As can be seen in Figure 15, the compliance boundary size is greatly overestimated when theoretical maximum values are used (left) compared to more accurate boundaries when actual maximum conditions are used (right).

Figure 15
**Comparison of theoretical and actual maximum compliance boundaries**




*Note: individual site boundary sizes will differ depending on specific site parameters*

The detailed description of the implementation of the actual maximum approach is described in the international standard IEC 62232 [22].

## Effect of small cell densification on RF-EMF levels

Small cells are low power transmitters and are used by current mobile networks to provide localised coverage or capacity. They may be mounted on streetlights or inside buildings, where over 80% of mobile usage occurs in developed markets. Small cells need power and data backhaul to operate.

The use of small cells will expand with 5G, especially in the mmWave band.  It is expected that 5G mmWave small cells will be deployed in specific locations (i.e., airport, stadiums, shopping malls) and not in whole urban areas [23].

Measurements on 4G small cells by authorities in Australia and France found that levels in nearby areas remained well below the international safety guidelines and about the same as the level due to the macro network [24, 25]. Similar results were found in study of almost 100 small cell sites in South Africa, the Netherlands and Italy [26]. Mobile phones connected to small cells operate at lower transmit powers [27].

Studies of 5G mmWave small cells show similar exposure levels to 4G small cells (and macro sites) [28, 29]. A report for the European Commission concluded that for 5G mmWave small cells *'even in the worst case, the EMF values lie below the ICNIRP limit by a factor of more than 100'* [30].

A comparison of 5G RF-EMF levels to other sources is shown in Figure 16. Levels from [29, 31] with 5G data for Australia and France from the 5G EMF Surveys map[13]. Baby monitor and walkie-talkie measured at 20 cm.

Figure 16
**Comparison of 5G network levels and some other RF EMF sources**

**International public limit**
100%

**Walkie-talkie (push to talk)**
53%

**Baby monitor**
1.3%

**5G mid-band**
0.0005 to 1.1%

**5G mmWave**
0.0005 to 0.3%

**Wi-Fi (indoors)**
0.0002 to 0.2%

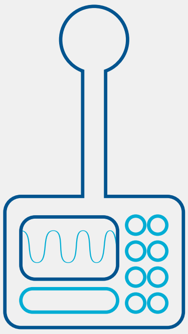
**Natural RF-EMF from the human body**
0.005%

**Natural RF EMF from the earth**
0.003%

**Broadcast towers**
0.001%

13 https://www.gsma.com/publicpolicy/emf-and-health/safety-of-5g-networks/5g-emf-surveys

Figure 17
**Results from global 5G RF-EMF surveys covering all bands**



→

**Survey Types**

Measurements conducted on commercial and trial networks using normal and high data rate traffic.

→

5G maximum EMF levels **typically less than 1%** of international public limit

## 5G mmWave network EMF levels

Across the world, national health agencies, government regulators, academia, test laboratories, mobile operators and manufacturers have conducted extensive testing on commercial and test networks in publicly accessible areas in the community to determine 5G RF-EMF exposure levels. These surveys show that:

- International safety and testing standards are in place for all 5G frequencies including 5G mmWave.
- Measured levels from 5G networks operating in all continents are low, and well below the international safety limits.
- 5G RF-EMF levels are similar to other wireless technologies with little difference between frequency bands.

Surveys[14] of 5G mmWave sites in commercial and trial 5G networks show low levels ranging from 0.0002% to 1.5% of the international public limits. The typical maximum measured 5G RF-EMF level across the surveys in publicly accessible areas is less than 1% of the international public limits.

## 5G mmWave device EMF levels

The evolution of mobile technologies has been associated with more efficient use of power control by mobile devices, which affects the mean (average) output power. Measurements of actual output power levels of 5G mmWave mobile devices in commercial networks show levels that are far below maximum output powers, with average exposures less than 3% of maximum, whether operating at mmWave or mid-band frequencies, and comparable to device output power levels in 3G and 4G networks [32].

14 For more details see the GSMA 5G EMF Surveys interactive map - https://www.gsma.com/publicpolicy/emf-and-health/safety-of-5g-networks/5g-emf-surveys

# Recommendations for policymakers

mmWave spectrum is essential for the deployment of high-capacity, low-latency 5G networks. It complements low and mid-band spectrum implementations in dense urban areas and provides fibre-like connectivity to suburban areas, and households in rural towns through 5G fixed wireless access (FWA) technologies. It also helps ensure secure, reliable and low-latency networks in contexts such as manufacturing plants or high-density locations e.g., stadia and travel hubs.

The following RF-EMF policy recommendations support efficient deployment of 5G mmWave based services.

## Adopt international RF-EMF limits and compliance methods

Countries should adopt RF-EMF limits based on the ICNIRP (2020), which are based on up-to-date and acknowledged scientific evidence. The ICNIRP RF-EMF guidelines form the basis of policy in the majority of countries around the world.

GSMA recommends that national RF-EMF compliance regulations reference international technical standards. Specifically, IEC 62232 [22] provides methods for assessment of 5G compliance for mobile network sites. IEC/IEEE 63195-1 [15] covers measurement of 5G mmWave devices and IEC/IEEE 63195-2 [16] covers computational procedures for these devices.

## Update RF-EMF deployment rules

5G networks in generally and 5G mmWave deployments in particular make greater use of antenna technologies such as beamforming and small cells. Providing high capacity 5G services using mmWave frequencies requires greater densification of sites in urban centres. Authorities should streamline deployment rules to support greater densification of antennas, especially in urban centres. Small cell sites at mmWave frequencies are small and use low transmit powers. This should be reflected in simplified deployment rules.

For more details see the GSMA recommendations for *EMF Exposure Compliance Policies for Mobile Network Sites* [33].

## Practice effective EMF communication

It is important that national regulatory authorities take a leading role efforts to inform the public and address misinformation about RF-EMF. It has been found that the wrong communication messages can increase public concern. Information should be based on credible sources, for example, the WHO and ICNIRP.

## Prepare for interest during mmWave licensing

Experience shows that in some countries the mmWave spectrum licensing process may result in submissions questioning safety. It is important to prepare for such questions and develop responses based on the consensus of health agencies and the scientific community.

# Abbreviations

| | |
|---|---|
| **2G/3G/4G/5G** | 2nd to 5th generation mobile technology |
| **ADT** | Active Denial Technology |
| **ANSES** | L'agence nationale de sécurité sanitaire de l'alimentation, de l'environnement et du travail (French Agency for Food, Environmental and Occupational Health & Safety) |
| **APD** | Absorbed power density (symbol $S_{ab}$, units $W/m^2$) |
| **ARPANSA** | Australian Radiation Protection and Nuclear Safety Agency |
| **COMAR** | IEEE Committee on Man and Radiation |
| **FR1/FR2** | Frequency Range 1 (410 MHz to 7125 MHz)/Frequency Range 2 (above 24 GHz) |
| **FWA** | Fixed wireless access |
| **GHz** | Gigahertz |
| **HCN** | Health Council of the Netherlands |
| **ICNIRP** | International Commission on Non-Ionizing Radiation Protection |
| **IEC** | International Electrotechnical Commission |
| **IEEE** | Institute of Electrical and Electronics Engineer |
| **kHz** | Kilohertz |
| **MHz** | Megahertz |
| **MaMIMO** | Massive multiple-input multiple-output |
| **mmWave** | Millimetre wave |
| **RF-EMF** | Radiofrequency electromagnetic field |
| **WHO** | World Health Organization |

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