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SERIES K: PROTECTION AGAINST INTERFERENCE

Radiofrequency electromagnetic field (RF-EMF) exposure levels from mobile and portable devices during different conditions of use

ITU-T K-series Recommendations – Supplement 13

ITU-T

Supplement 13 to ITU-T K-series Recommendations

Radiofrequency electromagnetic field (RF-EMF) exposure levels from mobile and portable devices during different conditions of use

Summary

Modern mobile devices may be used for many different purposes. There are differences between the ways of using them depending on the service. Also, the exposure to radiofrequency electromagnetic field (RF-EMF) is different depending on the service, environment and the conditions of the use of the mobile devices. Supplement 13 to ITU-T K-series Recommendations describes various factors that determine the level of RF-EMF exposure, as defined by the specific absorption rate (SAR) that is induced in the users of mobile and portable radiocommunication devices. Based on this technical information, practical information and guidance is provided for users of mobile devices.

History

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Introduction

Users of a mobile or portable telecommunications device are exposed to the radiofrequency electromagnetic fields (RF-EMFs) that are transmitted by the device. These RF-EMF transmissions are necessary to convey the communication signals (voice or data) between the device and its corresponding wireless network.

External exposure from a device induces RF-EMF in the person using it, which in turn causes tissue heating due to dissipation of the absorbed RF energy. This internal exposure is commonly characterized as the specific (energy) absorption rate (SAR) in units of W/kg for frequencies below 6 GHz. SAR is distributed in a very non-uniform way inside the body and is typically greatest in those parts of the body closest to the device. At higher frequencies, energy is deposited superficially, and the basic restrictions are given in terms of power density (W/m^2) [b-ICNIRP 2020].

Questions about device SAR generally relate to heating of the skin, brain, and eyes when the device is used in talk mode against the head, or to the skin and organs of the torso when the device may be transmitting data while attached to the hip or chest. Due to low levels of output power from devices the whole-body SAR is in compliance with international standards and guidelines such as [b-ICNIRP 2020] and [IEEE C95.1]. The RF-EMF exposure from the uplink signal (mobile phones and portable devices) is generally larger than the downlink (base stations).

There is a broad international consensus that device SAR should not exceed basic restriction limits that are specified in recognized international standards and guidelines such as [b-ICNIRP 2020] and [IEEE C95.1]. The SAR limits are specified as mass averages (e.g., averaged over any 10 g cube of tissue) and time averages (typically over 6 min) in recognition of the thermal inertia and thermal diffusion characteristics of body tissues. Lower SAR limits are specified for SAR induced in the head and torso of the body compared to its extremities (arms, legs and outer ear) in order to provide a higher level of protection for temperature sensitive and critical organs. In addition, the extremities experience wider ranges of temperature in everyday activities.

Standardized techniques for the assessment of device SAR for exposure to the head and torso are provided in [IEC/IEEE 62209-1528].

The World Health Organization (WHO) states on p. 2 of [b-WHO FS 193] that "While RF energy can interact with body tissues at levels too low to cause any significant heating, no study has shown adverse health effects at exposure levels below international guideline limits." and continues "A large epidemiology study is being co-ordinated in over 10 countries by the International Agency for Research on Cancer (IARC) – a specialised cancer research agency of WHO – to identify if there are links between use of mobile phones and head and neck cancers."

Supplement 13 to ITU-T K-series Recommendations

Radiofrequency electromagnetic field (RF-EMF) exposure levels from mobile and portable devices during different conditions of use

1 Scope

This Supplement considers the types of mobile and portable telecommunication devices that are consumer items in common use by the general public including mobile phones, cordless phones, tablets, phablets and satellite phones.

Taking into account WHO documents and other ITU-T Recommendations on this subject, information is provided that explains the factors affecting personal exposure during the use of mobile and portable devices and how this relates to the provision of communications functionality.

The absorption of RF-EMF energy due to devices used close to the head or body is currently assessed relative to specific absorption rate (SAR) limits for frequencies from 300 MHz to 6 GHz. Further information on the assessment of SAR for mobile devices is provided in clause 6.5 of [ITU-T K.91]. Standardized techniques for the assessment of device SAR for exposure to the head and torso are provided in [IEC/IEEE 62209-1528]. The SAR measurement methodologies are designed to be conservative for mobile device users. The level of SAR induced in the user of a mobile device varies dynamically. The range of considered factors that influences the level of SAR induced from devices includes technical aspects of the devices and their corresponding networks; usage patterns of the device; how the device is held against the body and the physical characteristics of the body. Additional information is provided to minimize misconceptions concerning the use of mobile devices and additional equipment.

2 References

[ITU-T K.52] Recommendation ITU-T K.52 (2021), *Guidance on complying with limits for human exposure to electromagnetic fields*.

[ITU-T K.70] Recommendation ITU-T K.70 (2020), *Mitigation techniques to limit human exposure to EMFs in the vicinity of radiocommunication stations*.

[ITU-T K.91] Recommendation ITU-T K.91 (2022), *Guidance for assessment, evaluation and monitoring of human exposure to radio frequency electromagnetic fields*.

[ITU-T K-Suppl.14] ITU-T K-series Recommendations – Supplement 14 (2019), *The impact of RF-EMF exposure limits stricter than the ICNIRP or IEEE guidelines on 4G and 5G mobile network deployment*.

[IEC/IEEE 62209-1528] IEC/IEEE 62209-1528:2020, *Measurement procedure for the assessment of specific absorption rate of human exposure to radio frequency fields from hand-held and body-worn wireless communication devices – Human models, instrumentation and procedures (frequency range of 4 MHz to 10 GHz)*.

[IEEE C95.1] IEEE C95.1 (2019), *IEEE Standard for safety levels with respect to human exposure to electric, magnetic and electromagnetic fields, 0 Hz to 300 GHz*.

3 Definitions

3.1 Terms defined elsewhere

This Supplement uses the following terms defined elsewhere:

3.1.1 antenna [ITU-T K.70]

3.1.2 antenna gain [ITU-T K.70]

3.1.3 average (temporal) power (P_{avg}**)** [ITU-T K.52]

3.1.4 averaging time (T_{avg}**)** [ITU-T K.52]

3.1.5 basic restrictions [ITU-T K.70]

3.1.6 controlled/occupational exposure [ITU-T K.70]

3.1.7 continuous exposure [ITU-T K.52]

3.1.8 electromagnetic field (EMF) [ITU-T K.91]

3.1.9 exposure [ITU-T K.52]

3.1.10 exposure level [ITU-T K.52]

3.1.11 exposure limits [ITU-T K.70]

3.1.12 exposure, non-uniform/partial body [ITU-T K.52]

3.1.13 general population/uncontrolled exposure [ITU-T K.52]

3.1.14 general public [ITU-T K.52]

3.1.15 near-field region [ITU-T K.52]

3.1.16 power density (S**)** [ITU-T K.52]

3.1.17 radio frequency (RF) [ITU-T K.70]

3.1.18 short-term exposure [ITU-T K.52]

3.1.19 specific absorption rate (SAR) [ITU-T K.52]

3.1.20 transmitter [ITU-T K.70]

3.1.21 whole-body-exposure [IEEE C95.1]

3.1.22 workers [ITU-T K.70]

3.2 Terms defined in this Supplement

This Supplement defines the following terms:

3.2.1 body mounted device – body worn device: A portable device containing a wireless transmitter or transceiver that is located close to a person's torso or limbs (other than the head) by means of a carry accessory during its intended use or operation of its radio functions (e.g., a portable device on a belt-clip, in a holster, in a pouch, or on a lanyard when worn as necklace).

3.2.2 discontinuous transmission (DTX): A method of momentarily powering down, or muting, a mobile or portable radiocommunication device when there is no voice input to the device.

3.2.3 hand-held device (mobile handset): A portable device that is located in a user's hand during its intended use.

3.2.4 specific anthropomorphic mannequin (SAM)

NOTE – See [b-Kainz].

4 Abbreviations and acronyms

This Supplement uses the following abbreviations and acronyms:

3G	third Generation
4G	fourth Generation
5G	fifth Generation
APC	Adaptive Power Control
BS	Base Station
DTX	Discontinuous Transmission
EGPRS	Enhanced General Packet Radio Service
EMF	Electromagnetic Field
GSM	Global System for Mobile
HSPA DC	High Speed Packet Access Dual Carrier
LTE	Long-Term Evolution
MIMO	Multiple Input Multiple Output
MMS	Multimedia Messaging Service
NR	New Radio
R99	Release 1999
RF	Radio Frequency
rms	root mean square
SAM	Specific Anthropomorphic Mannequin
SAR	Specific Absorption Rate
SMS	Short Message Service
WCDMA	Wideband Code Division Multiple Access
Wi-Fi	Wireless Fidelity

5 Conventions

This Supplement uses the following conventions:

device any mobile or portable radiocommunication device as described in the scope of this Supplement;

ρ tissue mass density in units of kg/m³;

σ tissue conductivity in units of S/m;

E_{int} internal electric field induced inside the body from exposure to device RF-EMF in units of V/m (root mean square (rms)).

6 Information for users of mobile devices

This clause provides information for users of mobile devices on factors that affect RF-EMF exposure and related topics. Many of these factors are outside the direct control of users. The technical rationale supporting this content is provided in clause 7 and associated references. Mobile devices are designed to comply with international exposure limits for the public. These exposure limits are intended to ensure protection for all members of the public even in the case of continuous exposure, 24 h a day, 365 days per year. When a mobile device is used to make a voice call, the output power is adjusted depending on the network connection through a process called adaptive power control (APC).

6.1 Voice connection

The process of APC is more sophisticated for newer mobile technologies. For a global system for mobile (GSM) communication phone, the average output level is about 20% to 50% of the maximum. Whereas, for a third, fourth or fifth generation (3G, 4G or 5G) mobile device, the average level of output power is about 1% to 2% of the maximum during a voice call [b-Gati], [b-Persson], [b-Joshi 2017], and [b-Joshi 2020].

6.2 Short message service, multimedia messaging service and Internet

For a short message service (SMS), the duration of transmission is very short and so the exposure is very low. The same is true for a multimedia messaging service (MMS). When browsing the Internet, most of the data is being downloaded and so the mobile device is only transmitting control information. If data is being uploaded, such as sending an email, more energy may be transmitted as more information is being sent. However, the average level is still only a small fraction of the maximum power. In addition, in these uses the mobile device is typically held away from the head or body and this reduces exposure to the head and body [b-Gati], [b-Persson, [b-Joshi 2017] and [b-Joshi 2020].

6.3 Distance – base station to mobile device

Distance from the base station (BS) is an influencing factor for APC but it is not a simple relationship. While a mobile device will often connect to the closest base station, this may not be the case if that BS is busy, or the person needs a high-speed data connection and there is more capacity available from a more distant site. Low-power small cells and in-building coverage solutions can improve the connection to the mobile device and therefore reduce the device output power [b-Aerts]. As small cell BS antennas are closer to people, the levels of exposure are often similar to those from macro cell BS antennas [b-Cooper], [b-Iskra] and [b-Zarikoff].

6.4 Hands-free devices, speaker mode

Use of a hands-free device, whether wired or bluetooth, or using the mobile device in speaker mode reduces exposure by increasing the distance between the mobile device and the head or body (see clause 7.3). Keeping the mobile device away from the body can also produce a better connection to the network, therefore also reducing the output power of the device.

6.5 Connections in car, bus and train

The structure of public transport vehicles may reduce some of the signals, which is also true for other locations. In these cases, mobile device transmissions remain within technical standards. When travelling at speed there can be frequent hand-offs between BSs. In GSM, these hand-offs are linked with an increase in device power and then the mobile device adjusts downwards as the connection is established [b-Wiart]. In 3G and 4G technologies, the handover process is more sophisticated, and the power is not increased during the handover [b-Gati] and [b-Joshi 2017]. On public transport, exposure from the mobile devices used by other people is generally higher than that from the mobile network antennas [b-Plets] and [b-Sagar].

6.6 Body-worn devices

Devices intended for use on the body, such a wearable fitness or health monitors, generally operate at very low power to conserve battery life and often use familiar technologies such as wireless fidelity (Wi-Fi) and Bluetooth. The devices only transmit at intervals and over short distances, e.g., to a nearby smartphone, tablet or laptop. They are designed to comply with international exposure limits for the public. These exposure limits are intended to ensure protection even in the case of continuous exposure, 24 h a day, 365 days per year.

6.7 Shielding devices

The RF-EMF signal transmitted by a mobile phone is below the limit values. Shielding devices may block the proper operation of the APC of the mobile device (see clause 7.2.3). P. 3 of [b-WHO FS 193] states that: "Scientific evidence does not indicate any need for RF-absorbing covers or other 'absorbing devices' on mobile phones. They cannot be justified on health grounds and the effectiveness of many such devices in reducing RF exposure is unproven."

6.8 Use by children

The consensus of expert groups is that scientific evidence does not show any danger to users of mobile devices from RF-EMF exposure, including children and teenagers. The testing methods used for mobile device compliance are designed to be conservative for adults and children (see clause 7.4). Some parents are concerned about whether there are health risks for children using mobile devices. National authorities in some countries have recommended precautionary restrictions on phone use by children. If individuals or parents are concerned, personal hands-free devices have been shown to reduce exposures by a factor of 10 by allowing the phone to be used away from the head and body [b-Bit-Babik].

6.9 Use by pregnant women

The consensus of expert groups is that scientific evidence does not show any danger to users of mobile devices from RF-EMF exposure, including pregnant women (clause 7.4). Most of the RF-EMF energy is absorbed in the skin and exposure of the developing baby to RF-EMF is below international guidelines. If a pregnant woman is concerned about exposure to her baby, then increasing the distance between the mobile phone and the baby will reduce their exposure further.

6.10 Charging of mobile and portable devices

As new devices usually require batteries with higher capacity and require more frequent charging, it might appear to the user that the level of RF-EMF exposure has increased. However, the real explanation is that new mobile and portable devices are increasingly powerful computers that support many applications that consequently increase power consumption. In addition, newer mobile technologies require more computations that increase the device power consumption. As a result, only a fraction of the energy from the device battery is used for wireless connections and for generation of an RF-EMF [b-Perrucci].

6.11 Use by people with electronic medical devices

Persons using on-body or implanted electronic medical devices should ask their physician for guidance on whether electromagnetic interference is possible. The United States Food and Drug Administration, in [b-FDA Med dev], advises that based on current research, mobile devices "do not seem to pose a significant health problem for pacemaker wearers". According to the FDA, the following measures will further reduce the possibility of interference occurring:

- holding the phone to the ear on the opposite side of the body where the pacemaker is implanted to add some extra distance between the pacemaker and the phone;
- avoid placing a turned-on phone next to the pacemaker implant (e.g., do not carry the phone in a shirt or jacket pocket directly over the pacemaker).

Guidance for other types of electronic medical devices may be provided by physicians, national health authorities or equipment manufacturers.

6.12 Use with hearing aids

Some hearing aids, in particular older models, experienced interference from mobile phones used by the hearing aid wearer or other nearby persons. According to [b-FDA Hear aids], the risk of hearing aid interference has been reduced by newer hearing aid designs and newer mobile communications technologies. Hearing aid wearers are advised to try different brands and models of phones to determine the most appropriate mobile device that will work well with their hearing aid. The Global Accessibility Reporting Initiative [b-GARI] provides additional information.

6.13 Exposure limits and compliance assessment

The international limits developed by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) and IEEE are designed to be protective for all persons – adults and children [b-ICNIRP 2020] and [IEEE C95.1]. Compliance testing methods for both BSs and wireless devices have been developed to assess compliance with RF-EMF exposure limits. The assessment is generally conducted with the mobile device or BS antenna configured to operate at maximum power or in a manner typical of the real-world operation.

RF-EMF exposure limits for BSs that are more restrictive than the ICNIRP or IEEE limits affect network planning, requiring operators to install more BSs or to acquire additional RF spectrum if available (section 9.6 of [b-Mazar]) and [ITU-T K-Suppl.14].

7 Factors affecting personal exposure from mobile and portable devices

The factors that influence the level and distribution of SAR induced in the user of a device are many and varied. The system diagram in Figure 1 provides a diagrammatic overview of how the factors discussed in this Supplement interrelate.

The system diagram can be broadly subdivided into five areas that will each be discussed in clauses 7.1 to 7.5:

1) device design (upper left area);
2) transmitter power temporal profile (lower left area);
3) device position and orientation relative to user (upper right area);
4) user's body characteristics (lower right area);
5) SAR assessment technique (middle right area).

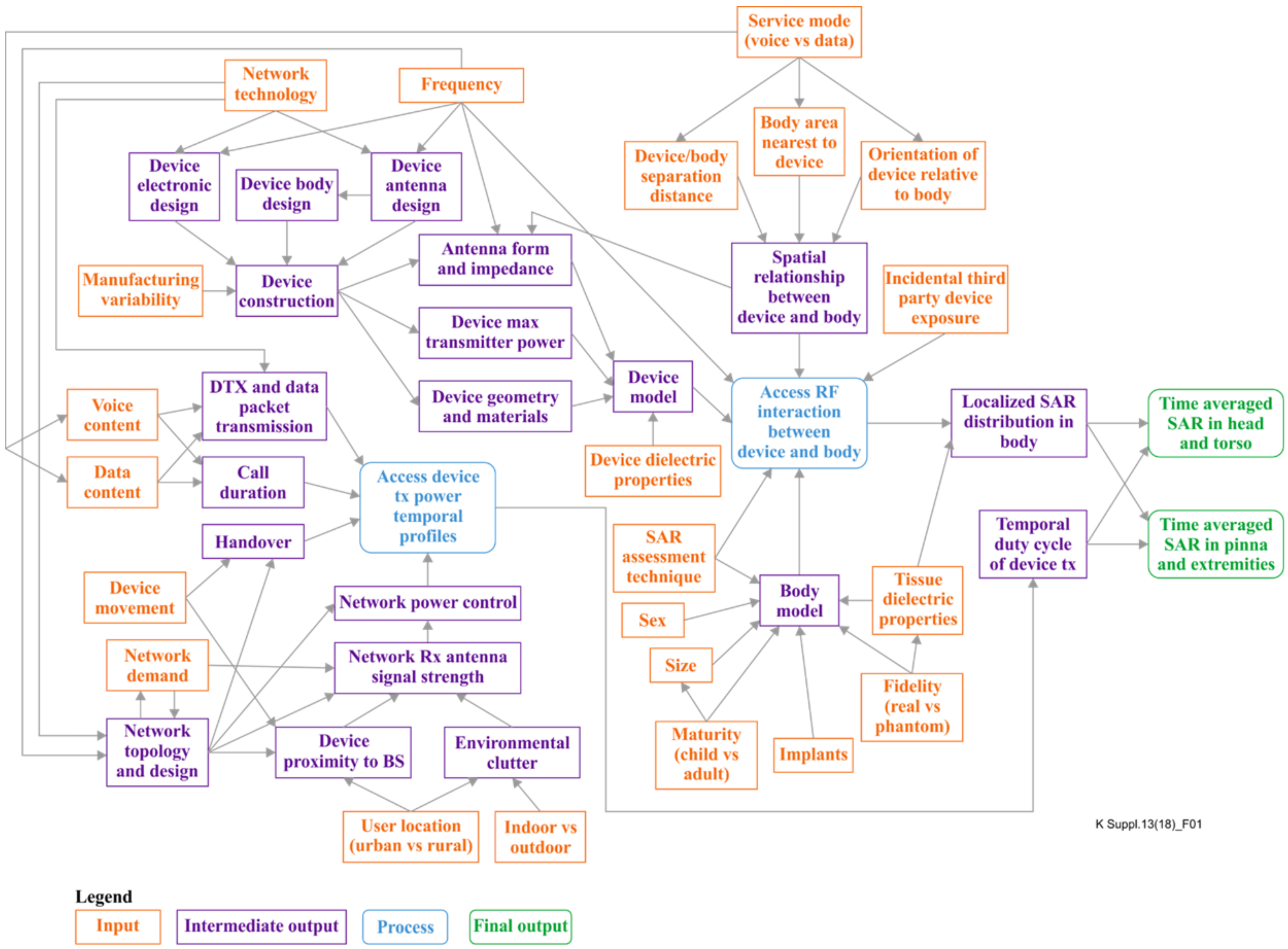


Figure 1 – A system diagram of the interrelationship between the factors which affect device induced SAR

7.1 Device design

SAR factors related to device design are clustered in the top left area of Figure 1.

A modern smartphone is a complex device and may support more than 10 operating bands with multiple antennas [b-Zhao 2013] as well as technical features such as carrier aggregation for increased bandwidth. The chosen network technology of a device and the frequency band in which it operates are fundamental influences on its main design elements, i.e., RF and electronic circuitry, antenna(s) and device form-factor [b-Nielson 2006b]. These intermediate outputs in turn affect aspects of the device that are more closely related to RF coupling between the device and user, namely:

1) the impedance match of the device's transmit antenna to its RF transmitter;
2) the maximum level of RF power that can be generated by the device transmitter;
3) the geometry and materials of the device.

Manufacturing tolerances add a further minor level of variability between the constructed units of the same model.

Apart from being a main determinant in the device design, the RF frequency of the device transmitter also has a more direct effect on induced SAR. As frequency increases, the depth of RF-EMF penetration into the body becomes less, which consequently reduces SAR levels [b-Lee 2017]. Some devices have the ability to operate in multiple frequency bands with broadband or multiple antennas simultaneously. Devices operating at a low power may be excluded from requiring testing [b-Christ 2014]. For some of the frequencies (>6 GHz) under consideration for 5G the exposure limit is specified in power density and new testing methods are in development [b-Colombi]. Greater use of phased array type antennas is also expected [b-Zhao 2016].

There has been a number of studies investigating differences in induced SAR from the design aspects of mobile phones (such as form and technology) [b-Deltour] [b-Cardis] [b-Kuhn 2013][b-Lee 2015][b-Lee 2017][b-Zervos]. These studies reported either insignificant or relatively weak associations in a limited number of phone positions. Nonetheless, [b-Lee 2017] considers that these factors may still be useful indicators for predicting relative brain SAR differences for epidemiological studies. An accurate picture of the mobile device exposure for the purpose of epidemiological studies requires knowledge of the exact mobile communication protocol being used, data rates, network conditions, orientation of the device and input from the user with respect to holding position. Recent research indicates that for teenagers using smartphones Wi-Fi exposure may be more significant than mobile services [b-Mireku].

The spread of measured levels for SAR compliance test purposes between device models and types can be gauged from public records of compliance assessments, such as those published online by the German Federal Office for Radiation Protection [b-BfS SAR search]. A histogram of the 10 g average SAR values in the head for 2 528 mobile phones in this dataset is Figure 2. The histogram has a mean value of 0.75 W/kg and a 95% coverage interval spanning between 0.23 W/kg and 1.41 W/kg.

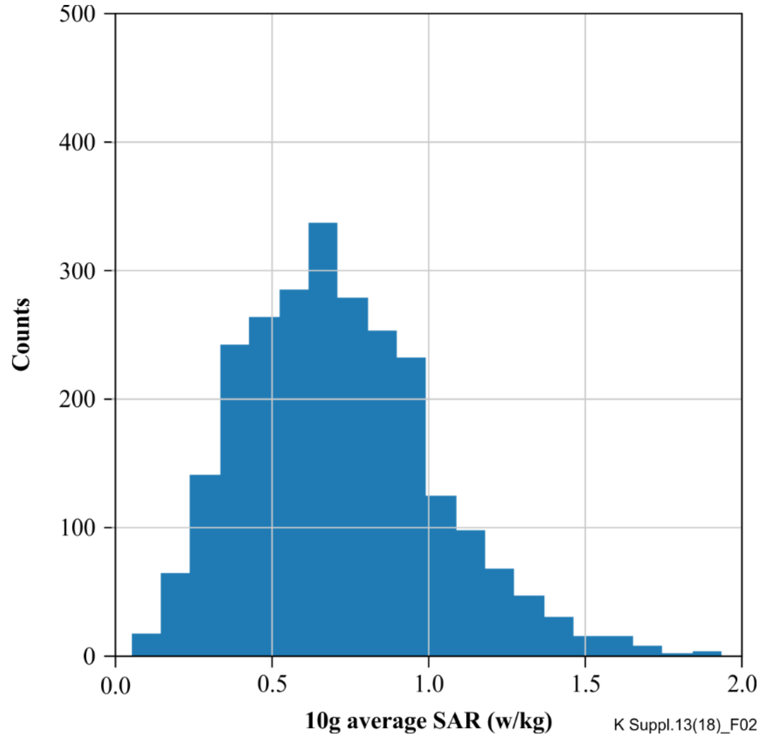


Figure 2 – Histograms of 10 g average SAR compliance values for 2 528 mobile phones obtained from [b-BfS SAR search]

7.2 Transmitter power temporal profile

As a power metric, SAR (W/kg) is linearly related to the radiated power level of the device generating the RF exposure if no other operating, positioning or environmental factor changes [b-Hillert][b-Krayni]. Therefore, an increase or decrease of the device transmit power leads to a commensurate change in the SAR levels induced in its user.

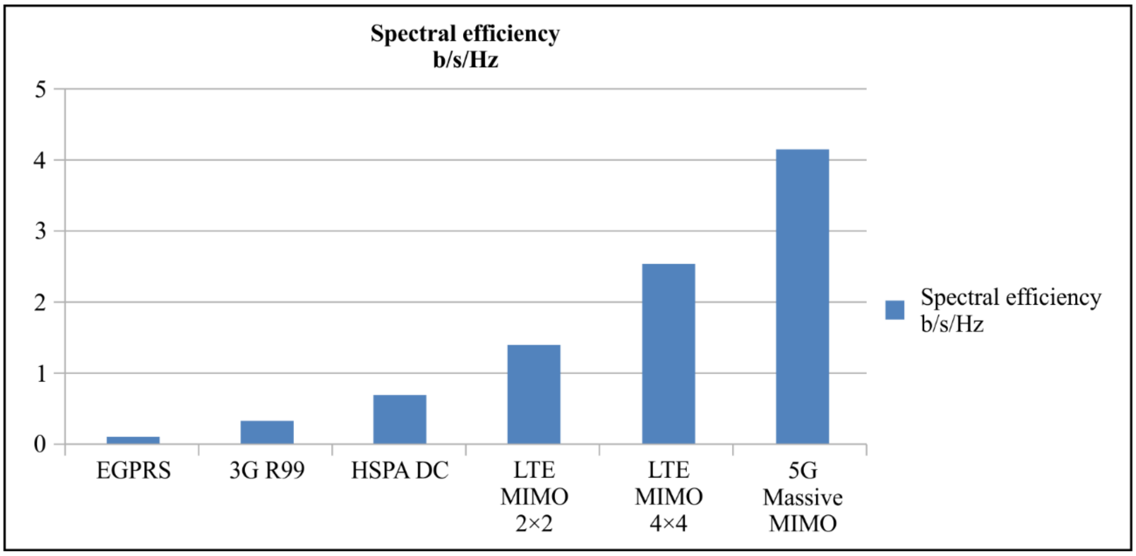
Since SAR is assessed as a time average, typically over 6 min, variations in the temporal power profile of the RF transmitter of a device will affect the assessed SAR level. When a phone is on standby, the RF-EMF exposure is negligible [b-Hansson Mild] and [b-Urbinello].

There are several basic factors that cause a device to vary its RF transmit power over time as shown in the bottom left area of Figure 1:

1) network power control;
2) discontinuous transmission (DTX) and data packet transmission;
3) call duration;
4) handovers;
5) position of the hand holding the phone.

7.2.1 Development of telecommunication systems used for mobile and portable devices

The radio communication technologies used for mobile communications have undergone rapid development. This takes into consideration many factors, including the size of devices, their capabilities and also the spectral efficiency [b-Erdreich][b-Kelsh][b-Picard][b-Shi]. This means that new systems allow delivery of the same amount of information with the use of less energy to the user. A more efficient use of the radio spectrum also means that the RF-EMF exposure of the user is not increased when using the same service via a newer mobile technology [b-Persson], [b-Joshi 2017] and [b-Joshi 2020]. See Figure 3.



Key

EGPRS: enhanced general packet radio service

MIMO: multiple input multiple output

HSPA DC: high speed packet access dual carrier

R99: Release 1999

Figure 3 – Average spectral efficiency of the different mobile technologies

7.2.2 Network influence on mobile device power control

Most wireless networks have the facility to control the transmit power of their connected devices and thereby direct them to reduce their RF transmit power output to the minimal level required to maintain a good quality RF communications link. This strategy helps to minimize battery drain from the transmitter of a device, as well as reducing unnecessary interference of the radio signals of devices with each other. Wireless device RF-EMF output powers can vary between countries [b-Lonn][b-Morrissey][b-Nielson 2006a][b-Vrijheid] for many reasons including the position of antennas; geographic features, the technology in use and network configuration settings.

Table 1 shows how far the transmit power of a device can be reduced below maximum level for various wireless technologies employing network power control. Most enable power reduction across a range spanning several orders of magnitude. Factors that influence the quality the RF links of a device, and hence its transmit output under network power control, include the following.

1) Distance to the network antenna
   a) Signal level of the RF link generally declines with increasing distance from the network antenna
   b) The availability of nearby antennas depends on the network topology
   c) A network configured as smaller cells will generally bring devices closer to their connecting network antenna
   d) High demand in a local mobile network cell may force devices onto more distant antennas in adjacent cells
2) Environmental clutter
   a) Environmental clutter can scatter and absorb RF link signals and thereby degrade their quality
   b) Urban environments tend to be more cluttered than rural ones
   c) Indoor environments are generally more cluttered than outdoor ones
   d) Higher frequencies are more susceptible to degradation from environmental clutter

3) Body effects on device antenna

   a) The presence of the body (hand, head, torso) close to the device affects the performance of the device antenna by altering its impedance, quality factor (Q) and antenna pattern [b-Guo][b-Atanasov][b-Al-Mously][b-Li 2012a][b-Li-2012b]. All these factors impact on the quality of the RF link to the network antennas.

It has been claimed that the use of a mobile phone in a lift or enclosed train carriage could lead to very high RF-EMF exposures; however, this is based on simplistic assumptions and not true for more realistic models or in practice [b-Simba].

Table 1 – Range of transmit power reduction for device under network power control and maximum output power for handheld devices

Device network technology	Maximum output power (rms) of a handheld device (mW)	Minimum device transmit power relative to maximum level	Typical average transmit power relative to maximum level (%)
2G (GSM)	125-250	1/2000 – 1/4000 (−33 to −36 dB)	20-50
3G (wideband code division multiple access (WCDMA))	250	1/25000000 (−74 dB)	1-2
4G (long-term evolution (LTE))	200	1/2000000 (−63 dB)	1-2
5G (new radio (NR))	200	1/400000 (−56 dB)	1-2

7.2.3 Mobile device "shields"

Some products are marketed that claim to "shield" the user from exposure to RF-EMF signals. The position of the FDA [b-FDA RF] is as follows:

> *'Since there are no known risks from exposure to RF emissions from cell phones, there is no reason to believe that accessories that claim to shield the head from those emissions reduce risks. Some products that claim to shield the user from RF absorption use special phone cases, while others involve nothing more than a metallic accessory attached to the phone. Studies have shown that these products generally do not work as advertised. Unlike "hand-free" kits, these so-called "shields" may interfere with proper operation of the phone. The phone may be forced to boost its power to compensate, leading to an increase in RF absorption.'*

In 2015, the [b-DGCCRF] (the French General Directorate for Competition Policy, Consumer Affairs and Fraud Control) investigated the sale of "shielding" devices for mobile phones. They concluded that the selling of these devices is often supported by multiple allegations involving studies that are not officially recognized. In addition, the DGCCRF said that allegations of harm often used a fanciful or entirely invented vocabulary.

7.2.4 Discontinuous transmission and data packet transmission

Both voice and data outputs from wireless devices generally manifest as intermittent streams of information. Accordingly, wireless devices need only transmit to the network as information is presented, rather than as a continuous transmission.

Intermittent voice outputs are managed under DTX protocols. Data outputs are transmitted in discrete packets as needed for file uploads and device responses. Intermittency in both voice and data outputs will generally cause the radiated RF power time averaged over 6 min to vary below maximum levels associated with continuous transmissions.

7.2.5 Call duration

When a mobile device is assessed for compliance with the SAR limits, it is done on the basis that it is transmitting continuously. No allowance is made for factors such as DTX (clause 7.2.3) that may reduce RF transmissions during a real call. If the effects of handovers and call establishment is neglected, then the amount of RF energy absorbed during a short call will be lower than that of a longer one. SAR limits are specified as time averaged levels over 6 min, which is based on the thermal time-constant of the body (p. 53 of [b-ICNIRP 2009]). The period of 6 min in the ICNIRP guidelines is not a specification of how long a person should be exposed to radio signals and it does not relate to duration of calls. The limits for human exposure to RF energy are designed to provide protection for all age groups, including children, on a continuous (24 h a day/7 days a week) basis. This means that it is the view of ICNIRP that if someone, including a child, were to be exposed to RF energy from multiple sources for 24 h a day, 365 days a year, within the ICNIRP limits, that person would experience no adverse health effects.

7.2.6 Handovers

Mobile devices that pass between different network coverage areas are subject to handover protocols. Handovers are common for users in moving vehicles, such as cars and trains. Handovers can generate extra device transmissions that vary according to the network technology [b-Ardoino].

7.3 Device position and orientation relative to user

The influence of device position and orientation relative to the user on induced SAR are shown in the upper right area of Figure 1.

Device location relative to the body has a strong effect on both the level and location of SAR induced in the body of the user [b-Hossain]. When a device is close to the body, exposure drops rapidly with increasing separation distance [b-Kühn 2009]. Exposure to the devices of other nearby users is generally negligible. On public transport, exposure to nearby users is low, but it is greater than that from environmental sources, such as mobile network antennas [b-Sagar].

P.1 of [b-WHO FS 193] explains that:

> "The RF field strength (and hence RF exposure to a user) falls off rapidly with distance from the handset. Therefore, the RF exposure to a user of a mobile phone located 10s of centimetres from the head (using a "hands free" appliance) is far lower than to a user who places the headset against the head."

Since the primary mechanism of induced SAR is via a near field induction effect [b-Kuster], induced SAR levels in the body predominate in areas close to the device. Hence, a device held against the head induces a negligible level of SAR in the torso and vice versa. For devices held against the head, the distribution of SAR throughout the brain can vary quite substantially [b-Ghanmi]. Even the position of the hand holding the mobile devices will influence the SAR [b-Guo] and [b-Al-Mously].

The orientation of the device relative to the body also influences the level of induced SAR, though to a lesser degree than separation distance.

7.4 Human body characteristics

The influences of body characteristics on induced SAR are shown in the lower right areas of Figure 1.

The distribution and dielectric properties (permittivity and conductivity) of body tissues have a primary influence on how RF-EMF transmitted by the device is coupled into the body. Moreover, tissue conductivity (σ) has a direct relationship to SAR, since SAR is given by $\sigma|E_{\text{int}}^2|/\rho$ where $|E_{\text{int}}|$ is the rms magnitude of the induced electric field and ρ is the tissue mass density. Tissue conductivities are somewhat higher in infants (<1 year old) due to higher tissue water content, but settle to adult levels thereafter [b-Anderson 2003].

Sensitivity analyses [b-Anderson 2003] and recent numerical studies of young children and adults[b-Christ 2005b][b-Christ 2010][b-Hadjem][b-Keshvari 2005][b-Keshvari 2011] confirm that age has a negligible impact on device SAR levels in the head, particularly in comparison to the effect of anatomical interpersonal differences of persons within the same age group [b-Adibzadeh]. Tablet type devices also result in exposure levels below the limit values [b-Liorni][b-Oliveira][b-Tateno]. In the case of a pregnant woman using a mobile device, exposure to the developing foetus is always below the international exposure limits [b-Togashi]. Jewellery, such as rings and ear-rings; glasses and dental implants may cause localized enhancements to the fields, but the limits are not exceeded [b-Nikolovski][b-Safari][b-Whittow][b-Yu]. Metallic implants internal to the body can concentrate the field, but temperature rises are generally small. Consideration may be required for workers exposed at occupational levels [b-Anderson 2008] and [b-McIntosh].

Body size is much less influential for local SAR compared to its general effect on whole body SAR absorption (see the introduction). Of more significance are differences in the thickness of the skin and subcutaneous layers, particularly the fat layer that can vary substantially between people and has markedly lower conductivity compared to most other tissues. A thicker fat layer increases the separation distance between the device and underlying organs, thereby reducing their SAR exposure [b-Takei].

7.5 SAR assessment technique

The centre right of Figure 1 relates to SAR assessment.

For regulatory compliance purposes, device SAR is usually assessed through measurement [IEC/IEEE 62209-1528], although it can also be determined numerically.

The main advantage of numerical assessment is that it provides the opportunity to investigate how SAR is distributed in anatomically detailed models of the body.

Measurements on the other hand benefit from better representation of the device itself, which can be difficult to accurately represent in numerical models. For obvious reasons, it is not possible to conduct intrusive SAR measurements inside living bodies that are accordingly represented as standardized anthropomorphic phantoms filled with a homogeneous fluid mixture that approximates the bulk dielectric properties of real tissues [b-Beard 2006]and [b-Christ 2005a]. Different phantoms are specified for head and torso measurements and their shapes are conservative for 90% of the population.

The following measurement methodologies for assessing device compliance with SAR limits are conservative [b-Beard 2004].

1) The device is assessed operating at its maximum transmitter power.
2) Measurements are conducted with the device against the phantom in typical use positions. Moreover, the assessed SAR level is chosen as the maximum level recorded for a range of device orientations relative to the body.
3) Measurements are conducted without the presence of the hand which has been shown to generally reduce SAR levels [b-Keshvari 2016], although in a few cases it may also increase it [b-Li 2012b].
4) The test device is selected from a production line sample.
5) The shapes of the phantom shells and the dielectric properties of the liquid medium are specified, such that they tend to cause overestimation of SAR levels compared to those obtained in a real people [IEC/IEEE 62209-1528]; [b-Keshvari 2016] and [b-Monebhurrun].

This concerted approach to conservatively estimate the SAR level means that actual levels experienced by users are generally far below the SAR measured and the compliance limits.

7.5.1 Typical exposure versus maximum exposure

In many regions manufacturers are required to provide a SAR report when placing a device on the market. The SAR report presents the highest measured value of RF-EMF energy absorption determined under laboratory conditions. For the purposes of the measurements, the device is configured to operate at maximum power. However, due to the influence of power control, the exposure due to mobile phones in actual use is well below the values given at the maximum powers [b-Gati].

8 Conclusion

The SAR level induced in the body of a person using a mobile, portable or radiocommunication device can be affected by a diverse range of factors that include design aspects of the devices and their corresponding networks, personal usage patterns, how the device is held against the body and the physical characteristics of the body. The SAR measurement methodologies are designed to be conservative for mobile device users.

The relative influences of these SAR factors vary significantly between each other. Power control of devices can continuously change SAR levels during actual use over several orders of magnitude. On the other hand, differences between different body types, taking age into consideration, appear to have little effect.

Public records of SAR levels assessed for compliance show a relatively limited degree of variability, as they are drawn from a restricted context of worst-case scenarios.

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