



IEEE Standard for Microwave Structural, Vascular, or Functional Brain Imaging Device Safety

IEEE Engineering in Medicine and Biology Society

Developed by the
Standards Committee

IEEE Std 2725.1™-2024

STANDARDS

IEEE Standard for Microwave Structural, Vascular, or Functional Brain Imaging Device Safety

Developed by the

Standards Committee

of the

IEEE Engineering in Medicine and Biology Society

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Abstract: Requirements and guidelines for the design of radiofrequency (RF) brain imaging systems, to help protect subjects/users/patients from adverse effects from overexposure to RF electromagnetic energy, and from other electrical, mechanical, chemical, and biological hazards are specified by this standard. This standard is limited to brain imaging devices using a brain machine interface (BMI) that intentionally couples low-level RF electromagnetic energy, in the frequency range between 10 MHz and 20 GHz, into the human head using antennas or probes in direct contact with, or close proximity to, the human head.

Keywords: BMI, brain imager, brain machine interface, dosimetric reference limits, DRL, electromagnetic fields, IEEE 2725.1™, microwave, microwave imager safety, RF exposure, SAR, tissue heating

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Introduction

This introduction is not part of IEEE Std 2725.1-2024, IEEE Standard for Microwave Structural, Vascular, or Functional Brain Imaging Device Safety.

The standard has been developed by the P2725.1 Working Group under the Standards Committee of the IEEE Engineering in Medicine and Biology Society.

This standard addresses safety aspects for brain machine interface (BMI) devices using radiofrequency (RF) electromagnetic energy (EME) to probe the human head—as primarily, but not exclusively, used in clinical brain imaging applications. Minimum requirements are specified to limit human exposure to RF EME based on existing international standards and guidelines while acknowledging the requirement to comply with any relevant jurisdictional regulations. Methods are presented for assessing compliance with the RF exposure requirements including some worked examples.

Requirements and guidelines are also included for the design of BMI devices to help protect operators/users/patients from adverse effects from other electrical, mechanical, chemical, and biological hazards.

Contents

1. Overview	10
1.1 Scope	10
1.2 Purpose	10
1.3 Microwave brain imaging technology	11
1.4 How to use this standard	11
1.5 Word usage	12
2. Normative references	12
3. Definitions, acronyms, and abbreviations	13
3.1 Definitions	13
3.2 Acronyms and abbreviations	16
4. Human exposure to RF EME	17
4.1 Requirements for restricting human exposure to RF EME	17
4.2 Relevant RF exposure limits	17
4.3 RF exposure assessment	20
4.4 Design to mitigate risks of RF over exposure under fault conditions	31
5. Electrical, mechanical, chemical, and biohazard safety	32
5.1 Requirements	32
5.2 Design methodologies to minimize electrical shock hazard	33
Annex A (informative) RF exposure compliance assessment	34
A.1 General	34
A.2 Rationale	35
A.3 Estimating epithelial power density	36
A.4 Determining the maximum power per antenna	37
A.5 Determining whole body average SAR	37
A.6 Determining compliance with EME exposure limits	38
Annex B (informative) Estimating power absorbed in the head from a bowtie antenna	40
B.1 Introduction	40
B.2 Time domain method for determining available power from a pulse transmitter	40
B.3 Frequency domain method for determining pulse train powers	43
B.4 Determining power for frequency-swept imaging system	47
Annex C (informative) Multiple transmit antenna cases	49
C.1 Introduction	49
C.2 Power absorbed in SAR cube below transmit antenna	49
C.3 Power from adjacent antenna absorbed in target SAR cube	51
C.4 Determining the range of potential power attenuation coefficient values	53
C.5 Determining the SAR cube power fraction for an adjacent transmit antenna	54
Annex D (informative) Examples of established isolation methodologies	56
D.1 DC blocking capacitor strategy	56
D.2 Back-end isolation strategies	56
Annex E (informative) Worked examples of EMF exposure assessment	58
E.1 General	58
E.2 Clinical application under ICNIRP 2020 exposure limits	58
E.3 Clinical application under FCC exposure limits	61
Annex F (informative) Bibliography	65

IEEE Standard for Microwave Structural, Vascular, or Functional Brain Imaging Device Safety

1. Overview

1.1 Scope

This standard pertains to brain imaging and brain machine interface (BMI) devices that intentionally couple low-level radiofrequency (RF) electromagnetic energy (EME), in the frequency range between 10 MHz and 20 GHz, into the human head using antennas or probes in direct contact with, or in close proximity to, the human head.

This standard specifies requirements and guidelines for the design of such devices to help protect operators, users, and patients from adverse effects from overexposure to RF EME and from other electrical, mechanical, chemical, and biological hazards.

This standard does not cover requirements on Electromagnetic Compatibility (EMC), but it contains safety provisions that assist in preventing the device from producing excessive transmit power as could, for example, occur in the event the device's operation is compromised due to external RF interference. The safety provisions include the requirement for an independent watchdog circuit on every antenna channel to cause it to safely shut down in the case excessive transmit power is detected during operation.

1.2 Purpose

The purpose of this standard is as follows:

- To specify the maximum allowable exposure of RF EME to which the device may expose the human head, and how to evaluate compliance with the relevant exposure limits.
- To specify the required means within the device to continually monitor the device energy emission, to automatically deactivate the device, and alert the operator and the user in the event the exposure limits might be exceeded.
- To specify electrical safety requirements to help ensure that, during normal operation, or in the event of any single-point hardware, firmware, or software failure, the device does not expose the user to RF EME or leakage currents exceeding relevant exposure or safety limits.

- To specify mechanical, chemical, and biohazard safety requirements.

1.3 Microwave brain imaging technology

Microwave brain imaging provides a non-invasive means to observe and monitor the brain structures, potentially over an extended period of time. BMI devices include active sensors that use low levels of RF energy but still require careful design and operational controls to comply with safety regulations.

The potential for use in wearable BMI devices creates the requirement that said apparatus be worn for hours at a time without exposing the user to excessive RF energy, dc and low frequency leakage currents, and mechanically and chemically induced irritation.

Microwave brain imaging is typically implemented using a helmet or cap placed over the scalp. The helmet contains one or more transmitting elements, each feeding an antenna that is placed in direct contact with, or in close proximity to, the scalp. Additionally, the imaging helmet contains an array of receiving elements, each with an antenna placed over an area of the scalp. In many devices, each antenna is connected to both transmitting and receiving circuitry where it serves the purposes of both emitting radiofrequency (RF) signals and receiving RF signals that are either reflections of its own transmitted waveform or, alternatively, transmissions that traveled through multiple paths inside the head after being transmitted by a different antenna.

Microwave imaging systems typically use either electromagnetic pulse trains or frequency-swept continuous wave (CW) sine waves.

- Pulsed imaging systems generally transmit strings of ultra-wideband (UWB) pulses that tend to be Gaussian in shape, have widths ranging from 20 ps to 300 ps, and repetition rates ranging from 10 million pulses per second (MPPS) to 100 MPPS (i.e., pulse-to-pulse intervals of 100 ns to 10 ns).
- CW imaging systems typically transmit sine waves that are swept in frequency, usually in bursts, sometimes referred to as chirps.

In both pulsed and CW brain imaging systems, the signals used tend to have spectral content ranging from approximately 10 MHz to 20 GHz, with the most useful portion of the spectrum for imaging typically residing in the 400 MHz to 10 GHz range. Frequencies below 400 MHz have corresponding wavelengths that are generally too long to provide useful spatial resolution, and frequencies above approximately 10 GHz have limited ability to propagate through head tissues and thereby suffer a high degree of attenuation, generally resulting in insufficient signal amplitude seen at the receiving antennas.

1.4 How to use this standard

Clause 2 provides the normative references that give critical information and/or requirements needed to claim compliance with this standard.

Clause 3 provides the definitions, acronyms and abbreviations used in this standard.

Clause 4 specifies the requirements with respect to human exposure to RF EME by reference to, and interpretation of, the relevant normative references. The relevant exposure limits are clarified with respect to the device application. Methods for assessing compliance with these exposure limits are defined in Clause 4 with additional information on the methodology in Annex A, Annex B, and Annex C. Worked examples are given in Annex E showing how the RF EME exposure assessment methodology in this standard can be applied. Additional design requirements for the management of the RF transmissions are presented in 4.4.

Clause 5 specifies the requirements with respect to electrical, mechanical, chemical, and biohazard safety mainly by reference to specified normative references. Additional design requirements are specified with examples in Annex D.

1.5 Word usage

The word *shall* indicates mandatory requirements strictly to be followed in order to conform to the standard and from which no deviation is permitted (*shall* equals *is required to*).^{6,7}

The word *should* indicates that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others; or that a certain course of action is preferred but not necessarily required (*should* equals *is recommended that*).

The word *may* is used to indicate a course of action permissible within the limits of the standard (*may* equals *is permitted to*).

The word *can* is used for statements of possibility and capability, whether material, physical, or causal (*can* equals *is able to*).

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

ICNIRP, Guidelines for Limiting Exposure to Electromagnetic Fields (100 kHz to 300 GHz), *Health Physics*, vol. 118, no. 5, May 2020.

IEC 60601-1:2005+A1:2012+A2:2020, Medical electrical equipment—Part 1: General requirements for basic safety and essential performance.⁸

IEEE Std C95.1™, IEEE Standard for Safety Levels with Respect to Human Exposure to Electric, Magnetic, and Electromagnetic Fields, 0 Hz to 300 GHz.^{9,10}

IEEE Std C95.7™, IEEE Standard for Electromagnetic Energy Safety Programs, 0 Hz to 300 GHz.

⁶ The use of the word *must* is deprecated and cannot be used when stating mandatory requirements; *must* is used only to describe unavoidable situations.

⁷ The use of *will* is deprecated and cannot be used when stating mandatory requirements; *will* is only used in statements of fact.

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3. Definitions, acronyms, and abbreviations

3.1 Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.¹¹

absorbed power density: *See: epithelial power density.*

absorbed power: The part of the accepted power that is absorbed by the body. *See also: accepted power.*

accepted power: The part of the power incident to the antenna port that is not reflected by mismatch load impedance.

available power (P_{ant}): The power in the pulse or chirp train generated by the pulse or chirp generator terminated in a matched load.

BALUN: A signal transformer that matches balanced to unbalanced transmission lines or devices.

brain machine interface (BMI): Device for delivering radiofrequency (RF) energy to, and receiving reflected RF energy from, the human head.

NOTE 1—Radiofrequency part of a device intended to image the structure of the head and brain.¹²

NOTE 2—Radiofrequency part of a direct brain-to-machine communications device that could potentially bypass the need for, or exceed the capabilities of, conventional methods of communications such as speech and writing.

NOTE 3—A BMI potentially could be used in a neuroprosthetic device, to bypass the spinal cord and enable direct brain control of an exoskeleton or robotic device or to control a device that would externally stimulate muscles.

chirp: A swept frequency pulse of short time duration.

NOTE—Typically, for brain machine interface (BMI) chirps, the amplitude is substantially constant as the frequency is swept between a few hundred megahertz (MHz) and a few gigahertz (GHz) in under 100 ms with a short time between chirps.

clinical application: Application of a brain machine interface (BMI) brain imaging device in the context of supervision of its use for a patient under the direct care of a physician or other medical care professional for diagnostic, therapeutic, and/or research purposes. *See also: brain machine interface (BMI).*

NOTE—Patients using BMI brain imaging devices are required to be made aware of their potential exposure to radiofrequency (RF) fields and how to turn off the device to eliminate exposure if they desire.

consumer application: Application of a brain machine interface (BMI) brain imaging device in the context of use by members of the general population not under the supervision of a physician or other medical professional and who are unaware of their exposure to radiofrequency (RF) fields. *See also: brain machine interface (BMI).*

NOTE—RF exposures associated with consumer applications of BMI brain imaging devices may occur for unlimited periods of time.

¹¹*IEEE Standards Dictionary Online* is available at: <http://dictionary.ieee.org>. An IEEE account is required for access to the dictionary, and one can be created at no charge on the dictionary sign-in page.

¹²Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this standard.

cortical gyri: The distinctive pattern of folds or bumps on the surface of the brain (singular: *gyrus*).

creepage distance: (A) The shortest distance between two conductive paths measured along the surface of a solid insulator/isolation barrier or (B) a spacing requirement between metallic or conductive contacts that are external to the isolation material/device.

NOTE—The creepage distance is a factor related to potential for electrical arcing caused by high operating voltages.

dBm: A measure of power, decibels with respect to a milliwatt.

NOTE—For example, 20 dBm is equal to 100 mW.

epithelial power density (S_{epd}): The power flow through the epithelium per unit area directly under the body surface (i.e., in stratum corneum of the skin or corneal epithelium of eyes). *Syn:* **absorbed power density**.

NOTE 1—The SI unit for epithelial power density is watt per square meter (W/m^2).

NOTE 2—In this standard, the epithelial power density just inside the body surface is employed to define local dosimetric reference limits at frequencies greater than 6 GHz.

exposure: The state of being in the presence of electric, magnetic, or electromagnetic fields, or in contact with a current or voltage source.

exposure limit: A threshold such as a dosimetric reference limit (DRL) or exposure reference limit (ERL) including, when applicable, frequency dependency and spatial and temporal aspects (e.g., averaging).

NOTE— EL_f is the numerical value of the exposure limit at frequency f .

exposure ratio: The ratio of the exposure value to the corresponding dosimetric reference limit (DRL) or exposure reference limit (ERL) at the frequency of interest. *See also:* **total exposure ratio**.

NOTE—When multiple exposure ratios are summed, the frequency dependency of the applicable DRL or ERL is preserved.

FWHM: Full width half maximum, a measurement of pulse duration.

motor prosthesis: A device that supports the function of the autonomous nervous system.

NOTE—In the context of this standard, an example of a motor prosthesis could be a device that monitors brain activity and uses this information to either actuate an external mechanical device or to externally provide direct muscle stimulation.

neuroprosthetics: A scientific discipline related to neuroscience and biomedical engineering concerned with developing neural prostheses. *Contrast:* **brain machine interface (BMI)**.

operator: The person who supervises the use of the brain machine interface (BMI). *See also:* **brain machine interface (BMI)**.

single point of failure: A part of a system that, if it fails, can stop the entire system from working.

specific absorption rate (SAR): The time derivative of the incremental energy (dW) absorbed by (dissipated in) an incremental mass (dm) contained in a volume element (dV) of given mass density (ρ).

$$SAR = \frac{d}{dt} \left(\frac{dW}{dm} \right) = \frac{d}{dt} \left(\frac{dW}{\rho dV} \right)$$

NOTE 1—The SI unit of SAR is watt per kilogram (W/kg).

NOTE 2—SAR can be related to the electric field at a point in the body by:

$$SAR = \frac{\sigma |E|^2}{\rho}$$

where

σ is the conductivity of the tissue (S/m)
 ρ is the density of the tissue (kg/m³)
 E is the root-mean-square (rms) electric field strength in tissue (V/m)

NOTE 3—SAR can be related to the initial rate of rise in temperature at a point by

$$SAR = \frac{c \Delta T}{\Delta t} \Big|_{t=0}$$

where

ΔT is the change in temperature (°C)
 Δt is the duration of exposure (s)
 c is the specific heat capacity [J/(kg·°C)]

This assumes that measurements are made under “ideal” non-thermodynamic circumstances, that is, no heat loss by thermal diffusion, radiation, or thermoregulation (blood flow, sweating, etc.).

specific absorption rate—peak spatial-average (psSAR): The maximum local specific absorption rate (SAR) averaged over a specified volume or mass (e.g., any 10 g of tissue in the shape of a cube).

NOTE—The SI unit of psSAR is watt per kilogram (W/kg).

specific absorption rate—whole-body-average (WBA SAR): The specific absorption rate (SAR) averaged over the entire mass of the body.

NOTE—The SI unit of WBA SAR is watt per kilogram (W/kg).

stack: The vertical configuration of tissues (as in tissue stack comprised of skin, skull, dura, cerebrospinal fluid (CSF), white and gray matter) found in the head that are relevant to determining penetration of radiofrequency (RF) energy during brain imaging.

total exposure ratio: The sum of a set of exposure ratios employed to characterize a total (potential) electromagnetic field (EMF) exposure in relation to a corresponding exposure limit considering that the total exposure ratio incorporates all relevant frequency, temporal, and spatial components necessary to maintain consistency with the corresponding exposure metric.

NOTE—If the total exposure ratio exceeds unity, then the evaluated exposure condition exceeds the corresponding exposure limit.

user: The person who is wearing the brain machine interface (BMI) apparatus on their head. *See also:* **brain machine interface (BMI); operator.**

NOTE—Depending on the function of the BMI, this might be a subject of a study, a patient, a person using the BMI commercially, or a member of the public in a domestic application.

vector network analyzer (VNA): A type of test equipment that measures electrical network parameters, such as, for example, acceptance of radiofrequency (RF) energy, as a function of frequency, by an antenna or other electrical device.

3.2 Acronyms and abbreviations

BMI	brain machine interface
DRL	dosimetric reference limit
EEG	electroencephalography
EMC	electromagnetic compatibility
EME	electromagnetic energy
ERL	exposure reference level
FWHM	full width half maximum
RF	radiofrequency
Rx	receive
SAR	specific absorption rate
TDR	time domain reflectometer
Tx	transmit
UWB	ultra-wideband
VNA	vector network analyzer

4. Human exposure to RF EME

4.1 Requirements for restricting human exposure to RF EME

The BMI apparatus shall be designed and operated as follows:

- a) It complies with exposure limits in IEEE Std C95.1 and ICNIRP 2020 except where local regulations stipulate more restrictive exposure limits, in which case those more restrictive limits shall apply.^{13,14}
- b) It does not transmit appreciable energy below 10 MHz.
- c) The RF exposure cannot exceed the applicable RF exposure limits even in the event of any single-point failure, including the disconnection of any input port to a transmit element.
- d) No transmitting antennas shall be placed in contact with, or in a location where they could directly couple RF energy to, the eyes or eyelids as follows:
 - 1) No transmit antenna shall be placed such that any of its active radiating area encroaches inferior to (below) the supraorbital process nor anywhere within the orbit.
 - 2) Receive-only antennas or probes at locations directly over the eyelid shall not be driven from a transmitter of any type.

Instructions shall be provided to operators with respect to BMI users that have electronic implants in RF-exposed areas of their body. The operator instruction shall be to check if the user has received guidance from their physician on electromagnetic energy (EME) safety actions and to check if there are any special considerations advised by the electronic implant manufacturer or relevant regulator.

4.2 Relevant RF exposure limits

4.2.1 Applicable exposure metrics

Limits for human exposure to electric, magnetic, and electromagnetic fields are defined in IEEE Std C95.1 and ICNIRP 2020. These limits are based on an evaluation of scientific data to determine the lowest exposure levels above which the most vulnerable persons might start to experience adverse health effects—the threshold for harm. Then, for the populations and uses within their scope, IEEE Std C95.1 and ICNIRP 2020 include a risk assessment and apply factors to account for scientific uncertainties thereby determining significantly lower exposure levels that become the exposure limits—the unrestricted/general public limits and the restricted environment/occupational limits.

Over the frequency range of interest, there are several exposure metrics for which limits are defined. This standard identifies the following exposure limit metrics to be applicable:

- a) *Local SAR*: The specific absorption rate—peak spatial-average (psSAR) metric limits the maximum time-averaged power, at frequencies up to 6 GHz, absorbed in a small mass of body tissue.

¹³ For example, non-clinical use devices that are operated in some jurisdictions might be required to comply with more restrictive local SAR levels that apply to 1 g tissue mass (e.g., FCC, 47 CFR 1.1310 [B2], see Table A.1).

¹⁴ Information on references can be found in Clause 2.

- b) *Epithelial power density*: The epithelial power density (also termed *absorbed power density*) (S_{epd}) metric limits the maximum time-averaged power, at frequencies above 6 GHz, absorbed in a small surface area of the body skin.
- c) *Whole body averaged SAR*: The specific absorption rate—whole-body-average (WBA SAR) metric limits the maximum time-averaged power, over the frequency range 100 kHz to 300 GHz, absorbed in the whole body.
- d) In addition, the local SAR and epithelial power density for short-duration exposures under the local exposure limit averaging time are further limited by peak energy density and peak power density constraints.

For these exposure limit metrics, Table 1 shows the applicable limit values for IEEE Std C95.1, ICNIRP 2020.

Table 1—Applicable exposure limits

Extract from IEEE Std C95.1-2019 and ICNIRP 2020		Restricted (occupational)	Unrestricted (general public)
$psSAR_{lim}$	Local SAR limit, frequency ≤ 6 GHz	10 W/kg	2 W/kg
$WBASAR_{lim}$	WBA SAR limit	0.4 W/kg	0.08 W/kg
S_{lim}	Epithelial power density (absorbed power density), frequency > 6 GHz	100 W/m ²	20 W/m ²
ng	Local SAR averaging mass	10 g	
A_{lim}	Area over which S_{lim} is averaged	4 cm ²	
Averaging time WBA	The time window over which power is averaged—WBA limits	30 min	
Averaging time Local	The time window over which power is averaged—Local limits	6 min	

Note that where a broad band RF exposure includes frequencies above and below 6 GHz, the total exposure ratio (TER) shall be less than or equal to 1 considering both the local SAR and epithelial power density exposures and their respective limits according to Equation (1).

$$TER = \frac{psSAR_{ng}}{psSAR_{lim}} + \frac{S_{ab}}{S_{lim}} \leq 1 \quad (1)$$

where

- TER is the total exposure ratio
- $psSAR_{ng}$ is the local SAR in averaging mass ng for the device configuration under test (W/kg)
- $psSAR_{lim}$ is the local SAR limit (W/kg)
- S_{ab} is the epithelial power density (absorbed power density) for the device configuration under test (W/m²)
- S_{lim} is the epithelial power density (absorbed power density) limit (W/m²)

Exposures to bystanders (such as attending medical personnel) shall comply with unrestricted/general public limits except when operating under an RF safety program (IEEE Std C95.7) where higher exposures up to the restricted environment/occupational limit may be specified.

4.2.2 RF exposure requirements applicable to specific BMI applications

4.2.2.1 Clinical applications

These are devices used under clinical supervision for medical treatment or clinical research purposes.

Physicians have a duty of care to their patients and routinely have to assess the potential benefits to their patients against known harm and potential side effects and agree the course of treatment with an informed patient, therefore:

- For medical applications, patient RF exposure should be in compliance with the unrestricted/general public exposure limits (4.2.1) wherever feasible and shall be in compliance with restricted environment/occupational limits under routine medical supervision.
- Subject to case-by-case evaluation by the physician, considering the benefit to the patient and risks for patient RF exposures at or above the threshold for adverse health effects, specific treatments or investigations may involve RF exposure above the restricted environment/occupational limits subject to appropriate ongoing medical supervision under appropriate ethical controls documented in an RF safety program (IEEE Std C95.7).

Researchers, operating within an appropriate ethical framework, have a duty of care to themselves and to the people they expose; therefore, for research applications, user RF exposure should be in compliance with the unrestricted/general public exposure limits wherever feasible. RF exposure may be increased up to the restricted environment/occupational limits under appropriate ethical controls and documented in an RF safety program (IEEE Std C95.7).

4.2.2.2 Consumer applications

Consumer microwave imagers and BMI devices are used by the general public without supervision or special training. Use of microwave imagers as BMIs entails the potential for these systems to be worn for hours at a time, and possibly on a daily basis, comparable to the usage time profiles for cell phone users. Also, the frequency spectrum employed in microwave brain imagers has a considerable overlap with, and is a superset of, the spectrum widely used in 3G, 4G, and 5G cellular communications.

Such imagers and BMI devices are intended to be used by untrained individuals in domestic environments; therefore, for consumer applications, RF exposures shall be in compliance with the unrestricted environment/general public exposure limits.

4.2.2.3 Industrial applications

Industrial microwave imagers and BMI devices are used in non-clinical occupational applications. Use of microwave imagers as BMIs entails the potential for these systems to be worn for hours at a time and possibly on a daily basis.

Such imagers and BMI devices are intended to be used by trained individuals in industrial environments; therefore, for industrial applications, RF exposures shall be in compliance with the restricted environment/occupational exposure limits subject to compliant use constraints documented in an RF safety program (IEEE Std C95.7).

4.3 RF exposure assessment

4.3.1 General

Measurements are made of the available power spectrum from the source and (optionally) the antenna matching parameters (S11). Local SAR exposure limits relate to frequencies below 6 GHz, and epithelial power density exposure limits relate to frequencies above 6 GHz. The power transmitted into the head, the potential maximum absorbed power, is therefore determined for frequencies above and below 6 GHz.

The location immediately under each transmit antenna is where the maximum psSAR and epithelial power density (absorbed power density) occurs. By conservatively assuming that all the power accepted by the antenna (accepted power) below 6 GHz is absorbed in a single psSAR averaging mass, the maximum psSAR will always be less than the accepted power (under 6 GHz) divided by the exposure limit averaging mass. Similarly, for epithelial power density, the maximum exposure from an individual antenna will always be less than the accepted power above 6 GHz divided by the epithelial power density exposure limit averaging area.

The local SAR is proportional (considering array configuration) to the power fed to each individual antenna. The relationship between available power and local SAR is determined for the power components below 6 GHz.

The fraction of the accepted power that is present in the spectrum above 6 GHz and the number of transmit antennas in the assessment area specified by the epithelial power density (also known as *absorbed power density*) exposure limit (e.g., 4 cm²) then enable a relationship to be determined between the available power per antenna and the epithelial power density.

Note that while the BMI device is likely to include an array of several antennas, only those antennas used to transmit energy into the head during any period of 6 min need to be considered in the RF exposure assessment. However, if more than one antenna is actively contributing to the exposure in the SAR assessment cube or epithelial power density assessment surface area, this contribution shall be accounted for in the exposure assessment.

Not all the available power from the pulse or chirp generator is accepted by the antenna and radiated into the head. Some power is reflected and absorbed by the source circuitry. As an enhanced assessment procedure, it is therefore permitted to determine the reflection coefficient at each frequency in the comb or over the frequency range of the chirp, determine the reflected power, and deduct that value from the measured available power from the generator to give just the antenna accepted power.

The maximum available power per antenna (averaged over the local exposure averaging time) is then determined that complies with both the psSAR and epithelial power density exposure limits by determining the available power per antenna for the limit case where the sum of the ratios of the computed psSAR and epithelial power density to their respective exposure limits is 1 [see Equation (1)].

If the maximum duration of the exposure is less than the local exposure averaging time, then the maximum available power per antenna may be increased by a factor. To comply with the peak energy density and peak power density constraints in IEEE Std C95.1™ and ICNIRP 2020, a factor of up to 5 times is permitted depending on the maximum exposure duration in any period of 6 min.

Conservatively, it is assumed that all pulse train or chirp power accepted by the BMI antennas is absorbed by the body. The WBA SAR exposure is determined from the total (accepted) power (for all frequencies) from all active antennas in the array divided by the body mass of the individual. The maximum number of active antennas consistent with the relevant WBA SAR limit can then be established. This is determined considering the actual available power per antenna, the relevant WBA SAR limit including appropriate time averaging, and the mass (i.e., weight) of the user.