Master Degree in Information Technology Engineering for Health and Communication: Health Curriculum

Electromagnetic interactions and diagnostics

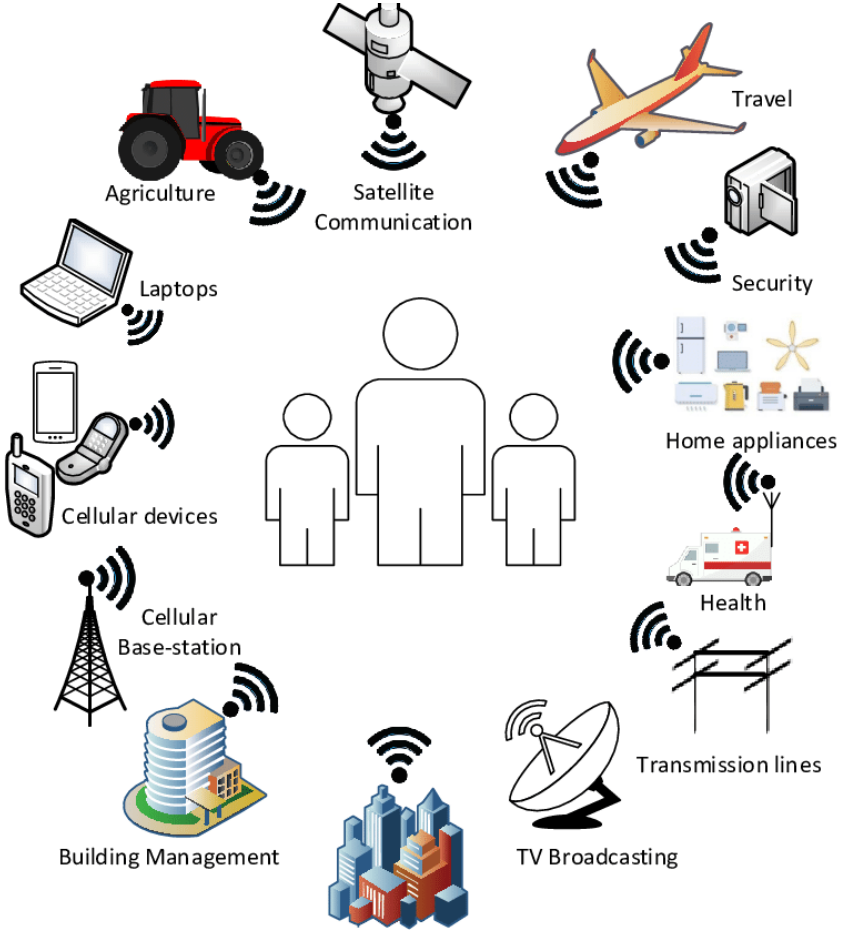
Human exposure to EM fields

Human exposure to EM fields

Table of contents:

Human exposure to EM fields

Biological effects:



EMF sources:

- Intentional sources (their characteristics are completely known), e. g., TLC devices, heating devices, lasers, UV sterilization lamps, TAC, MRI, etc.;

- Unintentional sources (mostly unpredictable features), e. g., power lines, sun, lightning, motors, LCD displays, reflectors, etc.

Human exposure to EM fields

Biological effects:

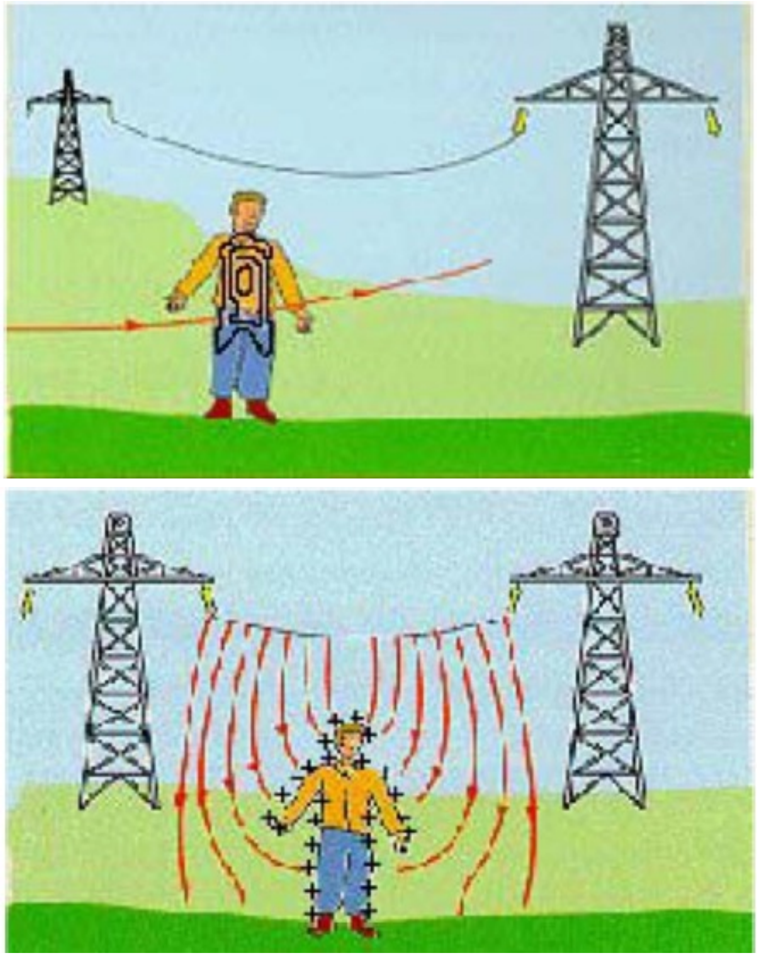
ELETTRODOMESTICI (50 HZ)	CAMPO MAGNETICO (μT) ALLA DISTANZA DI		
	3 cm	30 cm	100 cm
Apriscatole	1000-2000	3,5-30	0,07-1
Asciugabiancheria	0,3-8	0,08-0,3	0,02-0,06
Lavatrice	0,8-50	0,15-3	0,01-0,15
Lavastoviglie	3,5-20	0,6-3	0,07-0,3
Trapano	400-800	2-3,5	0,08-0,2
Lampada da tavolo	40-400	0,5-2	0,05-0,25
Robot da cucina	60-700	0,6-10	0,02-0,25
Asciugacapelli	6-2000	<0,01-1	<0,01-0,3
Ferro da stiro	8-30	0,12-0,3	0,01-0,025
Forno a microonde	75-200	4,8	0,25-0,6
Forno elettrico	1-50	0,15-0,5	0,04-0,091
Termosifone	10-180	0,15-5	0,01-0,25
Frigorifero	O,5-1,7	0.01-0,25	<0,01
Rasoio elettrico	15-1500	0,08-7	<0,01-0,3
Televisore	25-50	0,04-2	<0,01-0,15
Aspirapolvere	200-800	2,20	0,13-2
Coperta elettrica	2-3	0,1-0,2	<0,05

Altough EMFs decrease fast with distance, they can reach relatively high intensity values when the source device is very close to the user.

Human exposure to EM fields

Biological effects:

At the international level, guidelines for the safe exposure of human beings have been issued by the International Commission on Non Ionizing Radiation Protection (ICNIRP). They cover the large part of the non-ionizing radiations spectrum, i. e., 0 Hz – 300 GHz, that do not have enough energy to break chemical bonds (and, therefore, to ionize the matter) and whose effects on human tissues depend on frequency.



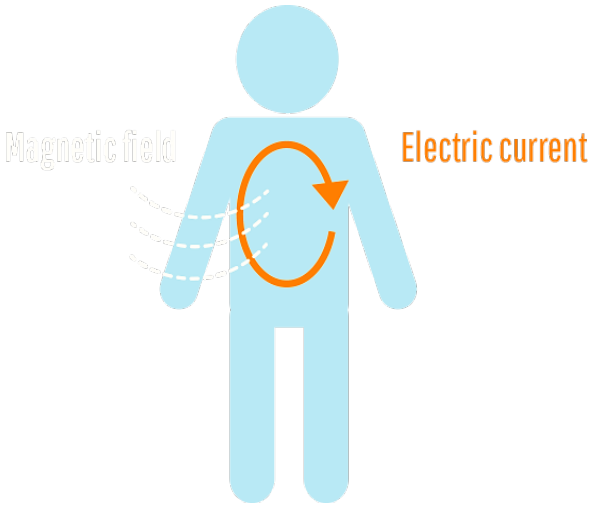
- ELF (0 – 300 Hz): electric and magnetic fields induce currents that may stimulate sensitive tissues as nervous and muscular systems.

Human exposure to EM fields

Biological effects::

The biological/health effects at ELF depend on the amount of induced current density

Current density (mA/m²)	Biological effects
> 1000	Extrasystole and ventricular fibrillation
100 – 1000	Tissue stimulation: potentially dangerous
10 – 100	Potential impact on central nervous system
1 – 10	Minor (headache, insomnia, etc.)

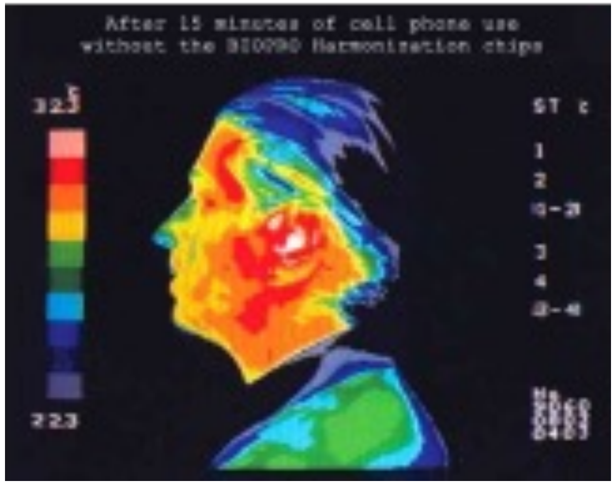


It is worth mentioning that the presence of chemical/physical substances could be considered a concurrent factors that may combine with the EMFs to reduce/emphasize biological effects.

Human exposure to EM fields

Biological effects:

- The energy associated to MW and RF (30 kHz – 300 GHz) fields is absorbed by tissues and transformed in heat, resulting in an increase of temperature whose rate depends on the kind of exposure. Since those thermal effects are an indirect consequence of EM field exposure, they can be observed only if the increase of temperature is larger than temperature variations normally induced by physiological processes (acute effects).



- When increasing frequency (i. e., > 10 GHz), the penetration depth decreases such that energy absorption occurs at the body surface. In general, at a given frequency, the lower the water content of the tissue, the deeper an EM wave can penetrate.

Human exposure to EM fields

Biological effects:

The health effects of HF EMFs mainly depend on:

- Frequency
- Intensity/power density
- Exposure time

Exposure to HF EMFs can lead to:

- Lens opacification
- Neuronal and neuro-muscular functions alterazion
- Cornea anomalies

Human exposure to EM fields

Biological effects:

The health effects of EMFs can be grouped as:

- Acute or short-term effects: they are triggered by direct exposure to EMFs above a threshold value (e. g., in particular working places).

- Chronic or long-term effects. They have stochastic nature and are typically related to daily environments, i. e., prolonged exposure to low EMF values.

Human exposure to EM fields

Biological effects:

Based on epidemiological evidence, electric and magnetic fields associated to commercial energy distribution and MW and RF fields are classified by International Agency for Research on Cancer (IARC) as «**2B, potentially carcinogenic**» for human beings. At this time, there is no agreement about their potential risk for human health.

Hence, to quantify human exposure to EM fields is needed.

Human exposure to EM fields

Dosimetry:

The established effects shall be quantitatively related to the exposure. However, the entity of a given effect not only depends on the external field level, but also on the coupling of the field with the exposed body, or selected body organs. The quantitative relationship by which the external exposure affects a biologically effective parameter of the target tissue is unique to a single exposure condition.

Therefore, effects are better described by quantities that reflect the efficacy by which the external exposure causes a certain biological effect. These are termed biologically effective quantities, or dosimetric quantities.

Human exposure to EM fields

Dosimetry:

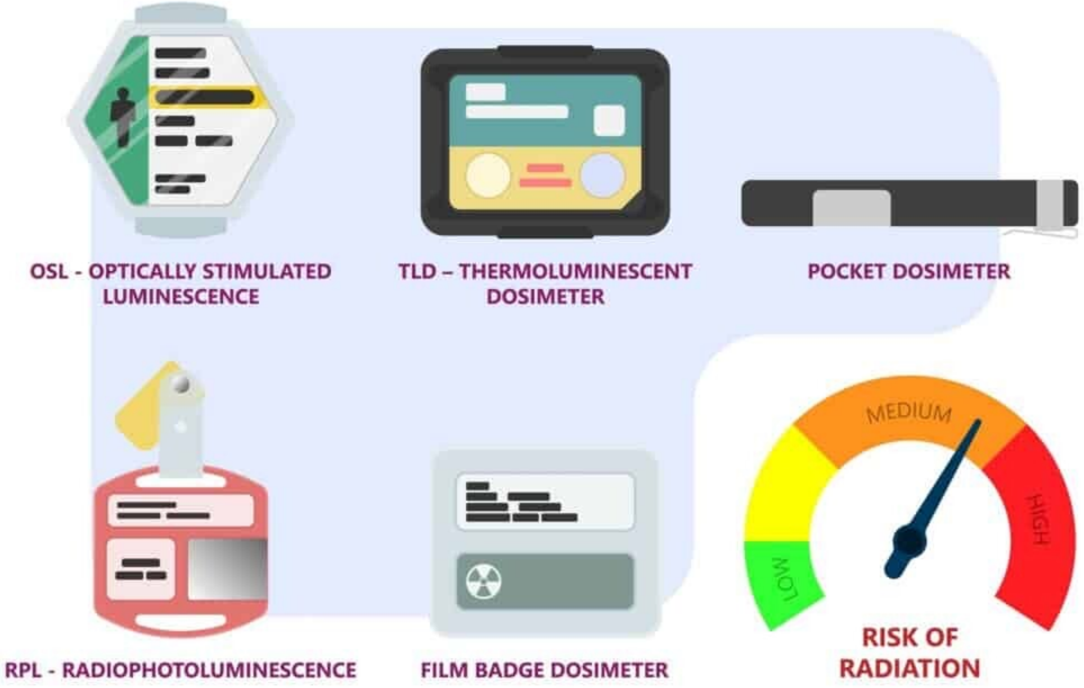
Different dosimetric quantities have been identified as suitable for different interaction mechanisms and biological effects

EMF spectral region	Relevant mechanism of interaction	Adverse effect	Biologically effective physical quantity	External exposure, reference level
Time-varying electric fields (up to 10 MHz)	Surface electric charges	Annoyance from surface effects, electric shock and burn	External electric field strength	Electric field strength
	Induction of internal electric fields and currents	Stimulation of nerve and muscle cells; effects on nervous system functions	Tissue electric field strength or current density	Electric field strength
Time-varying magnetic fields (up to 10 MHz)	Induction of internal electric fields and currents	Stimulation of nerve and muscle cells; effects on nervous systems functions	Tissue electric field strength or current density	Magnetic flux density
Electromagnetic fields (100 kHz to 300 GHz)	Induction of internal electric fields and currents; absorption of energy within the body	Excessive heating, electric shock and burn	Specific energy absorption rate	Electric field strength; magnetic field strength; power density
	> 10 GHz: Surface absorption of energy	Excessive surface heating	Power density	Power density
	Pulses < 30 μs, 300 MHz to 3GHz, thermoacoustic wave propagation	Annoyance from microwave hearing effect	Specific energy absorption	Peak power density

Human exposure to EM fields

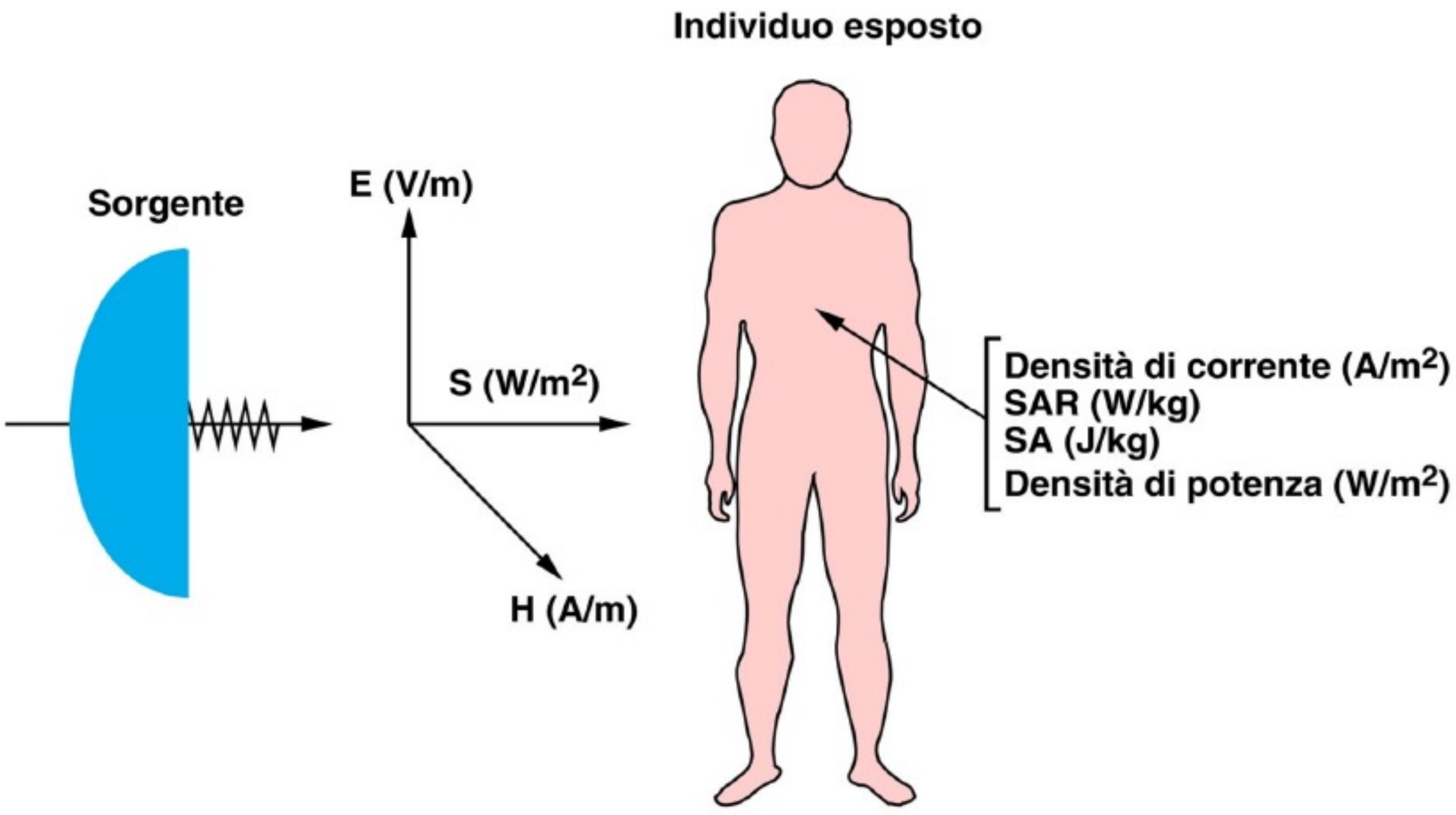
Dosimetry:

These quantities are generally internal to the body and therefore cannot be directly measured.
A correspondence shall therefore be established between biologically effective quantities and external EMFs, taking exposure conditions in due account. This is accomplished through theoretical and experimental modelling techniques that constitute what is called dosimetry.



Human exposure to EM fields

Dosimetry:



Frequency range	Dosimetric parameter
Static/quasi-static	B [T], I [A]
0 – 10 MHz	J [A/m^2]
100 kHz – 10 GHz	SAR [W/kg]
10 GHz – 300 GHz	S [W/m^2]

Human exposure to EM fields

Dosimetry:

The SAR concept has proven to be a simple and useful tool in quantifying the interactions of RF/MW radiation with living systems, enabling comparison of experimentally observed biological effects for various species under various exposure conditions, providing the only means, however imperfect, of extrapolating the animal data into potential hazards to humans exposed to RF radiation, and facilitating, planning, and effectively executing the therapeutic hyperthermic treatment.

$$\mathrm{SAR} = \left(\frac{d}{dt}\right)\left(\frac{dW}{dm}\right) = \left(\frac{d}{dt}\right)\left[\frac{dW}{\rho(dV)}\right] = \left(\frac{\sigma}{2\rho}\right)\left|\overline{E}_i\right|^2 = \left(\frac{\omega\varepsilon_0\varepsilon''}{2\rho}\right)\left|\overline{E}_i\right|^2$$

Human exposure to EM fields

Dosimetry:

The average SAR is defined as the ratio of the total power absorbed in the exposed body to the mass in which it is absorbed, which is not necessarily that of the total body. The SAR is the ratio of absorbed power by absorbing mass. The local SAR refers to the value within a defined unit volume or unit mass, which can be arbitrarily small.

$$\mathrm{SAR} = \frac{1}{V}\int \frac{\sigma(r)|\boldsymbol{E}(r)|^2}{\rho(r)}\,dr$$

SAR measurements are usually obtained after 6 minutes time window averaging over:

- Whole body
- Local (head, trunk, extremities)

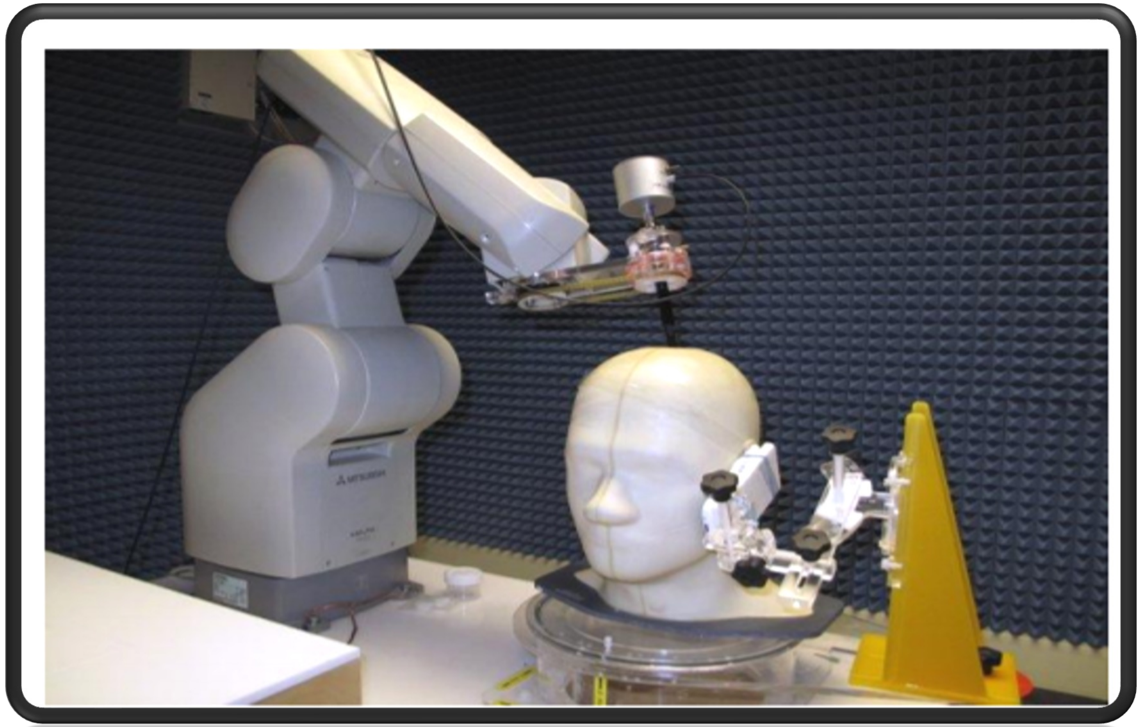
Human exposure to EM fields

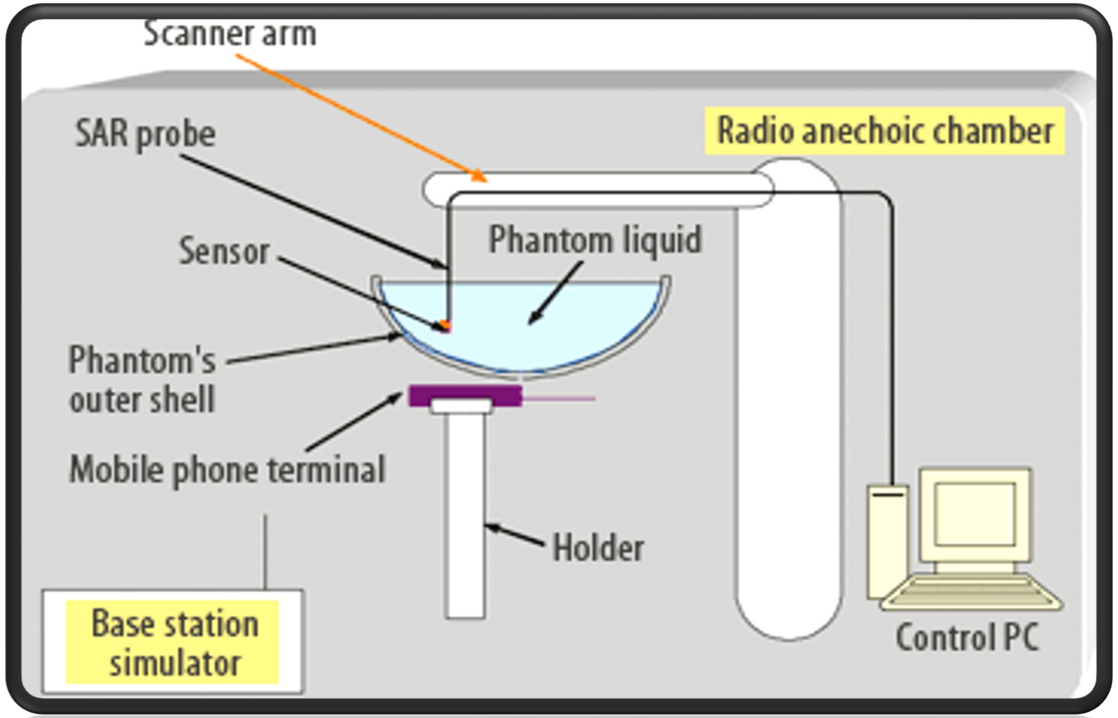
Dosimetry:

In some respect, since SAR is based on absorption only, it cannot takes into account biological effects of different nature (i. e., non-thermal ones). In fact, it may be a valid dosimetric parameter to quantify non-absorptive interaction mechanisms when the latter depend on the intensity of the EMFs and not when the field polarization is of importance for the biological structure.

Human exposure to EM fields

Showcase: SAR measurements from mobile phones





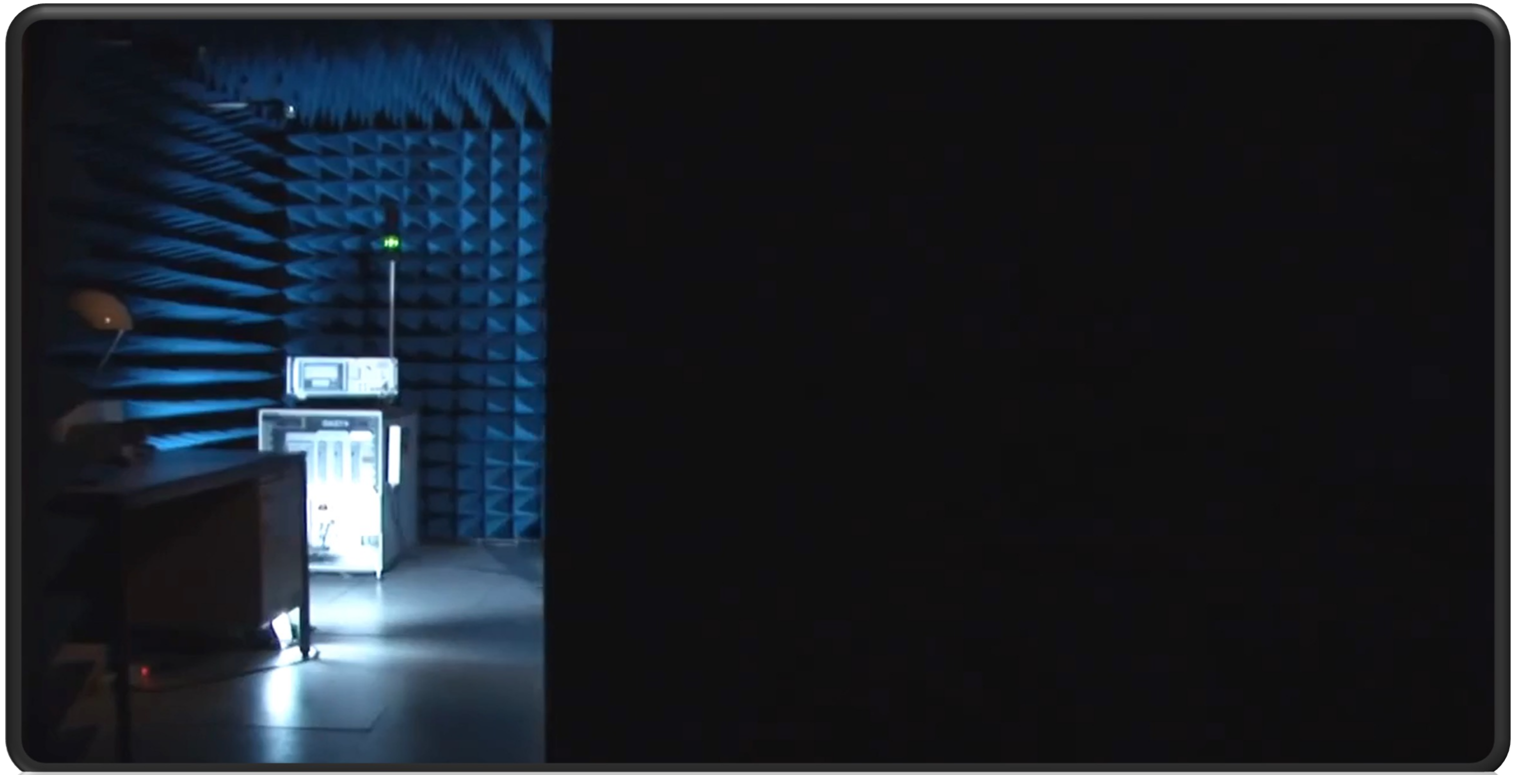
Human exposure to EM fields

Showcase: SAR measurements from mobile phones

- Anechoic chamber
- SAM phantom (specific anthropomorphic mannequin) or liquid phantom
- Electric field probes
- Radio-base station emulator
- Max TX power for each frequency
- Peak SAR measurements averaged over 6 minutes

Human exposure to EM fields

Showcase: SAR measurements from mobile phones



Human exposure to EM fields

Showcase: SAR estimation from mobile phones

HUAWEI

TESTING No. L0310

ACCREDITED TESTING CERT #2174.01

FCC SAR Compliance Test Report

Product Name: UMTS Mobile Phone

Model: HUAWEI U5760, U5760, ORINO QUIA JASPE

Report No.: SYBH(Z-SAR)023082014-2

FCC ID: QISU5760

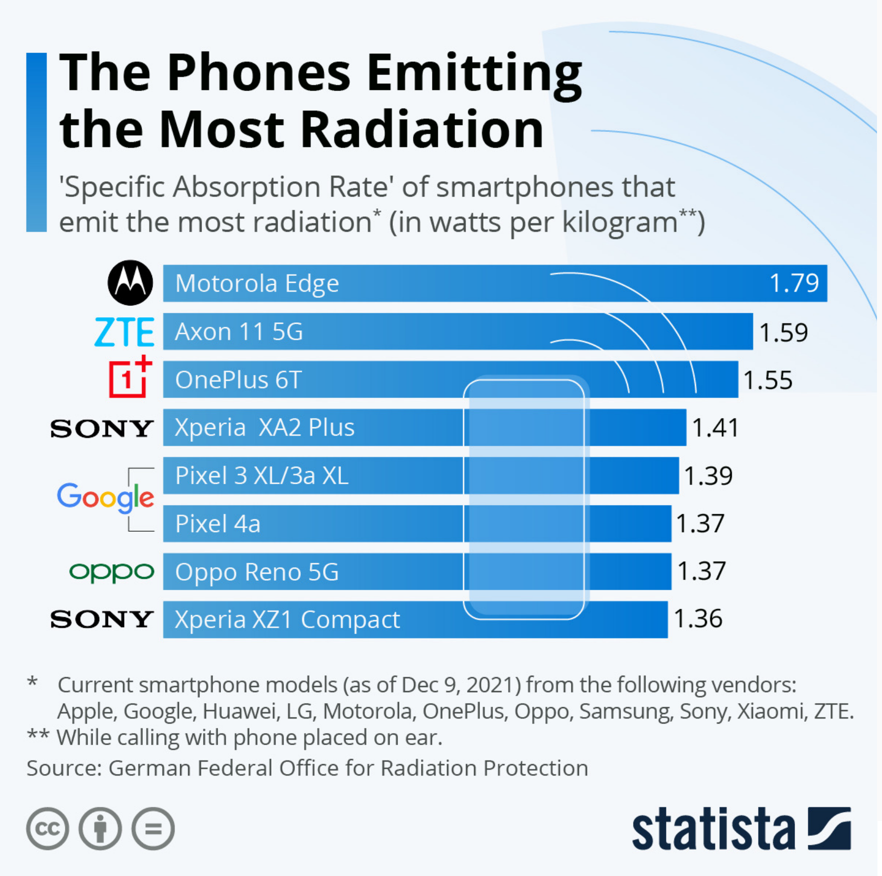
	APPROVED (Lab Manager)	PREPARED (Test Engineer)
BY	Wei Huanhn	Gong Zhong
DATE	2014-09-15	2014-09-15

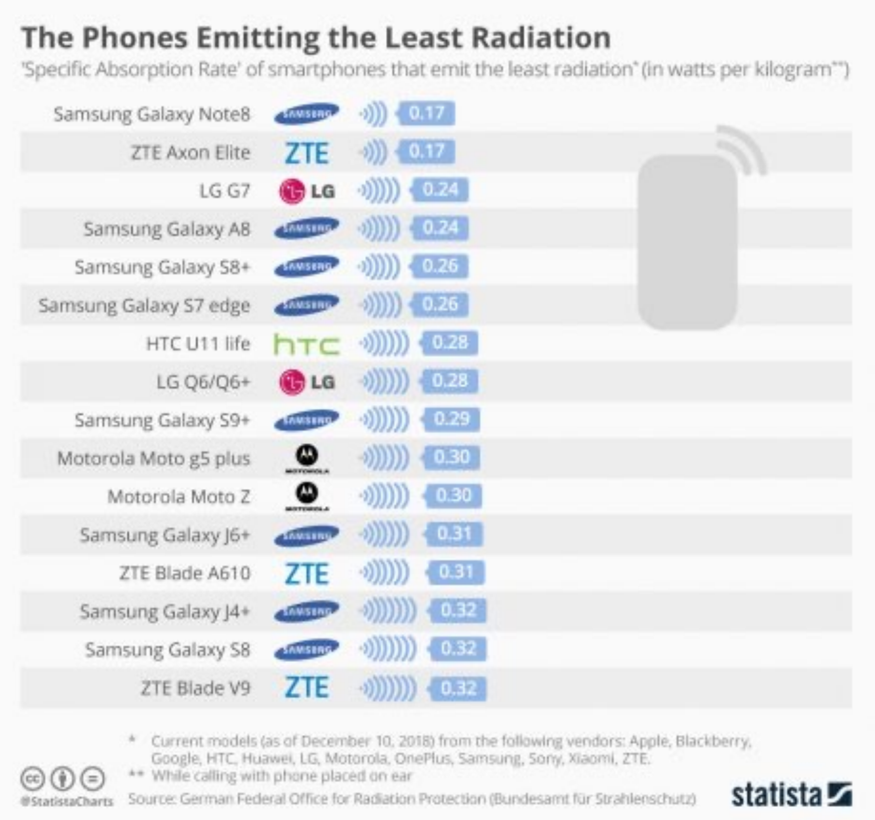
Band	Max Reported SAR(W/kg)	
	1-g Head	1-g Body-worn (15mm) *
GSM850	1.195	**1.325**
GSM1900	0.559	0.255
UMTS Band V	1.040	1.066
UMTS Band II	**1.489**	0.617

Human Exposure	Uncontrolled Environment General Population	Controlled Environment Occupational
Spatial Peak SAR* (Brain/Body/Arms/Legs)	**1.60 mW/g**	8.00 mW/g
Spatial Average SAR** (Whole Body)	0.08 mW/g	0.40 mW/g
Spatial Peak SAR*** (Hands/Feet/Ankle/Wrist)	4.00 mW/g	20.00 mW/g

Human exposure to EM fields

Showcase: SAR estimation from mobile phones

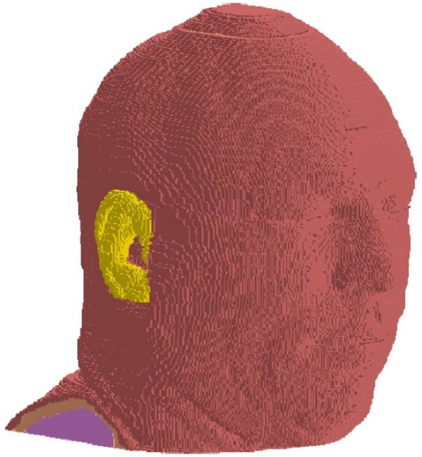


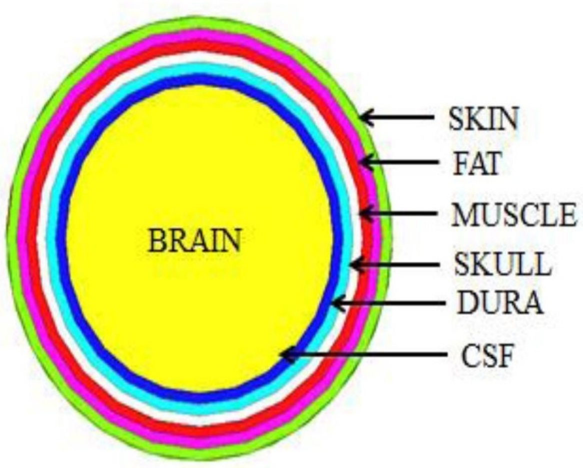


Product name	Honor 70 5G Green (8GB / 256GB)
Head SAR	0.79 W/kg
Trunk SAR	1.19 W/kg
Extremities SAR	2.99 W/kg

Showcase: SAR estimation from mobile phones

Numerical simulations are also useful to understand underlyingh physical/biological mechanisms and to obtain reasonable estimate of SAR values. To this aim, accurate modeling tools are needed.

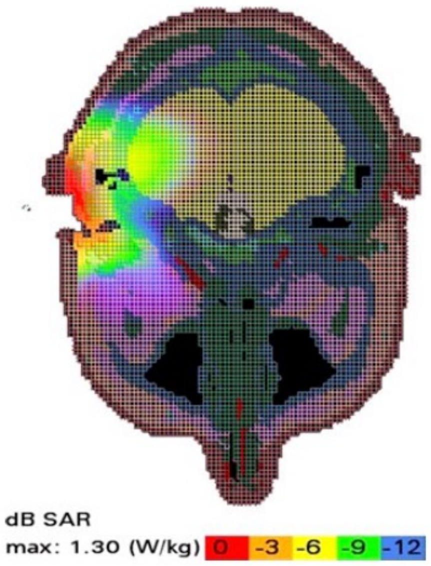




Frequency (MHz)	900		2100		2300		2400		2500		Mass density
Tissue type	ε_r	σ(S/m)	ε_r	σ(S/m)	ε_r	σ(S/m)	ε_r	σ(S/m)	ε_r	σ(S/m)	ρ (kg/m^3)
SKIN	43.8	0.86	38.43	1.30	38.18	1.40	38.06	1.44	37.95	1.49	1100
FAT	11.3	0.11	5.32	0.09	5.30	0.10	5.28	0.10	5.27	0.11	1100
MUSCLE	55.9	0.97	54.04	1.57	53.77	1.70	53.64	1.77	53.51	1.85	1040
SKULL	20.8	0.34	15.28	0.50	15.10	0.56	15.01	0.59	14.92	0.61	1850
DURA	44.4	0.96	42.49	1.47	42.23	1.58	42.10	1.64	41.97	1.70	1030
CSF	68.6	2.41	66.76	3.15	66.47	3.32	66.32	3.41	66.17	3.50	1030
BRAIN	45.8	0.77	43.05	1.31	42.75	1.42	42.61	1.48	42.47	1.54	1030

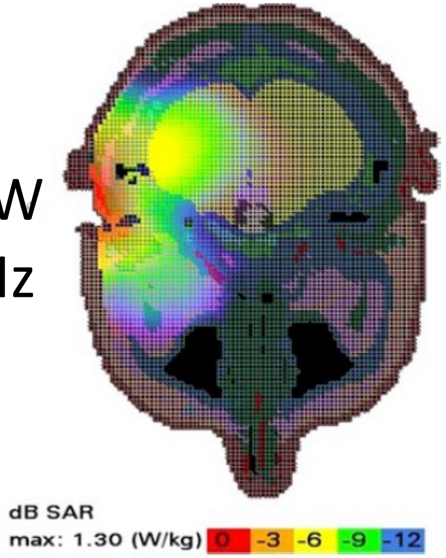
Human exposure to EM fields

Showcase: SAR estimation from mobile phones

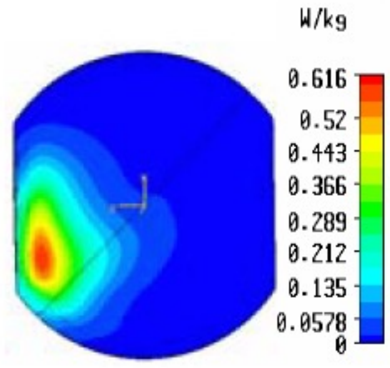


Man

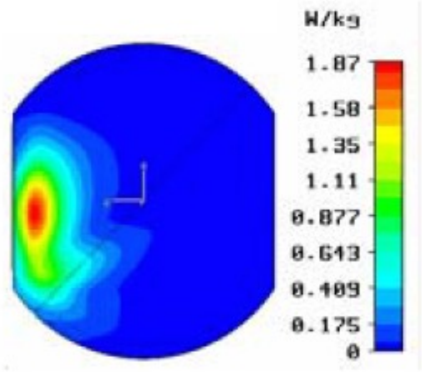
- SAR_{10g}
- P_{TX} = 0.25 W
- *f* = 900 MHz
- *d* = 2.2 cm



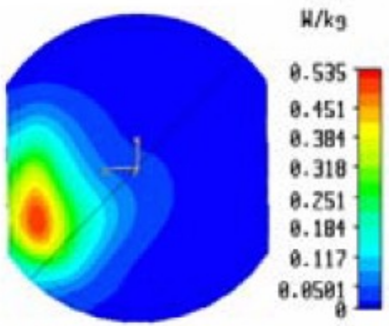
Child



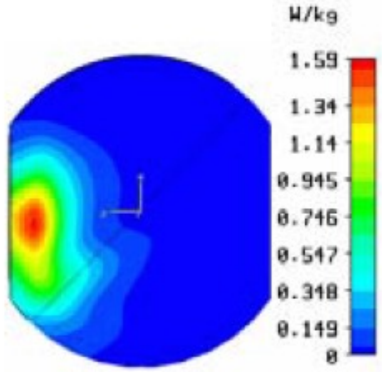
SAR_{1g} (900 MHz)



SAR_{1g} (1.8 GHz)



SAR_{10g} (900 MHz)



SAR_{10g} (1.8 GHz)

Human exposure to EM fields

Standards and regulations:

- Short-term effects: EMF exposure limits to protect from acute effects;
- Potential long-term effects: attention values;

At this time, EU regulations in the frequency range 0 Hz – 300 GHz rely on thermal effects only without accounting for non-thermal ones that may be induced by middle-/long-term exposure, whose knowledge still needs to be assessed.

There is no scientific evidence about potentially harmful long-term effects potentially due EMF exposure below limits.

Human exposure to EM fields

Standards and regulations:

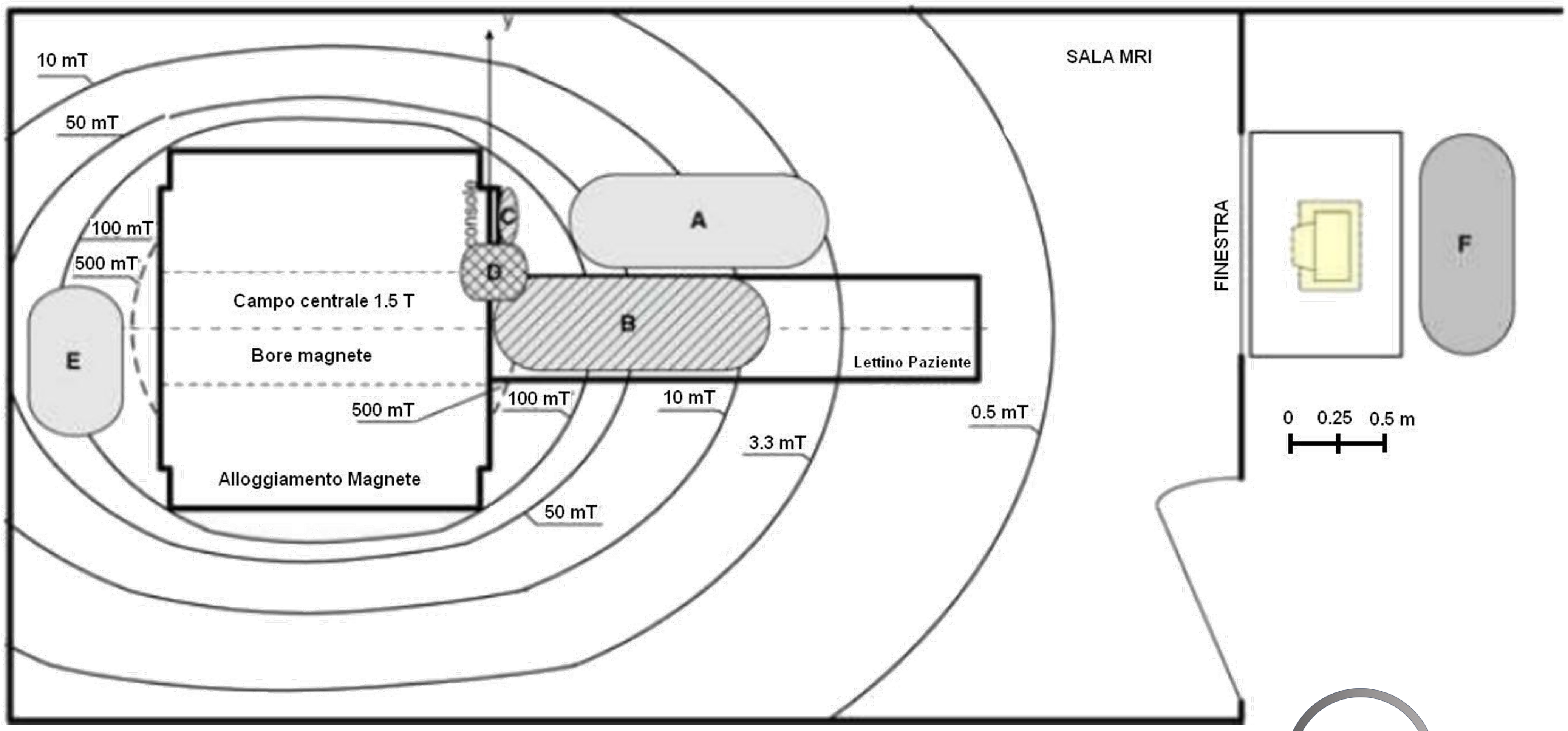
Critical areas as schools and hospitals, characterized by the prolonged stay of sensible subjects (children, elderly people), and working places where non-ionizing radiations are widely used, must be carefully monitored and preserved.

As an example, exposure risks associated to the motion of operators in the magnetic field area in MRI sites could be considered by evaluating fields and currents induced in the human body.

Limit exposure values are determined in terms of dosimetric quantities to ensure that no health effect induced by acute exposure occurs. To this aim, suitable (large) safety factors are introduced.

Human exposure to EM fields

Standards and regulations:



Human exposure to EM fields

Standards and regulations:

- Exposure limits: EMFs values that must not be exceeded, in any exposure condition, to protect people and workers from acute health effects;

- Attention value: EMFs value that must not be exceeded in environments characterized by prolonged exposure as houses, schools, etc.

- Quality targets: EMFs values to be targeted within short-, middle- and long-term to minimize human exposure.

Human exposure to EM fields

Standards and regulations: ELF

Electric field (V/m)	Magnetic induction (μT) Instant value	Magnetic induction (μT) 24-h averaged
5000	100	10

Magnetic induction (μT) 24-h averaged	
Attention value	Quality target
100	3

D.P.C.M. 8 july 2003

Human exposure to EM fields

Standards and regulations: HF

Frequency range	Electric field (V/m)	Magnetic field (A/m)	Power density (W/m²)
100 kHz – 3 MHz	60	0.20	--
3 MHz – 3 GHz	20	0.05	1
3 GHz – 300 GHz	40	0.10	4

Frequency range	Electric field (V/m)		Magnetic field (A/m)		Power density (W/m²)	
	Attention values	Quality targets	Attention values	Quality targets	Attention values	Quality targets
100 kHz – 300 GHz	6	6	0.016	0.016	0.10	0.10

Note that power density values refer to the frequency range 3 MHz – 300 GHz

D.P.C.M. 8 july 2003

Human exposure to EM fields

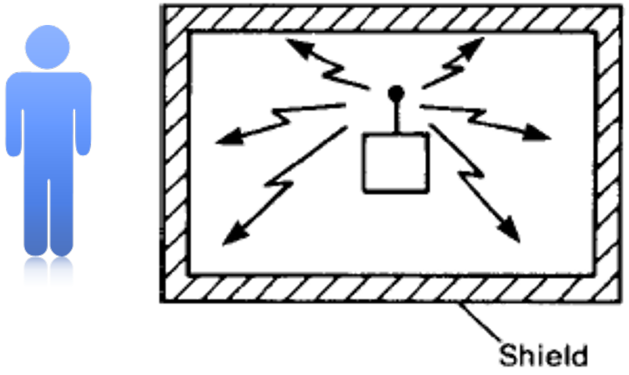
Standards and regulations:

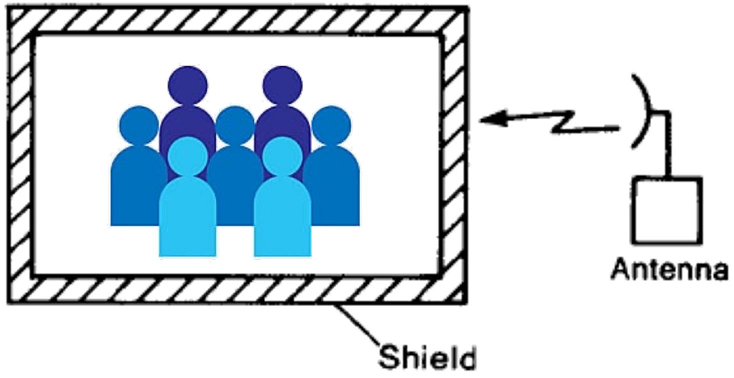
- SAR (10 g tissue) = 2.0 W/kg
- SAR (1 g tissue) = 1.6 W/kg
- SAR (whole body) = 0.08 W/kg
- SAR (extremities) = 4 W/kg

Human exposure to EM fields

Electromagnetic shielding:

Shielding refers to the use of metallic enclosures or slab to completely separate two critical environments.
Shielding can be used to protect people from undesired and potentially harmful EM radiations, especially in clinical environments.





Human exposure to EM fields

Electromagnetic shielding:

The **shielding effectiveness** can be defined as:

$$\begin{cases} \mathrm{SE} = 20\log_{10}\left|\dfrac{\hat{E}_i}{\hat{E}_t}\right| \geq 0 \\ \mathrm{SE} = 20\log_{10}\left|\dfrac{\hat{H}_i}{\hat{H}_t}\right| \geq 0 \end{cases}$$

- The ratio of the amplitude of an incident electric/magnetic field on a slab to the amplitude of the one transmitted through the slab;
- The ratio of an incident electric/magnetic field on an electronic device without the shield to that with the shield in place.

Reference to the electric or magnetic field is made depending on the type of radiating source (e. g., SE with respect to magnetic field is considered in MRI applications).

Human exposure to EM fields

Electromagnetic shielding:

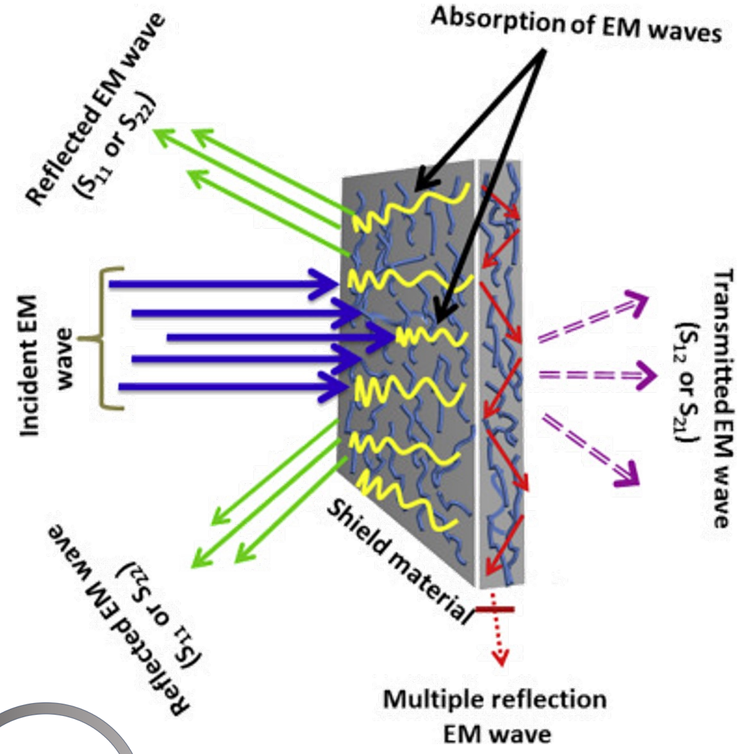
Several processes contribute to reduce the amplitude of the incident EM wave crossing the slab:

1) **REFLECTION LOSS** at the interfaces (due to the reflection coefficient of the shield);

2) **ABSORPTION LOSS** (due to the attenuation along the conductive shield, $e^{-\alpha z} = e^{\frac{-z}{\delta}} = e^{-z\sqrt{\pi f \mu \sigma}}$);

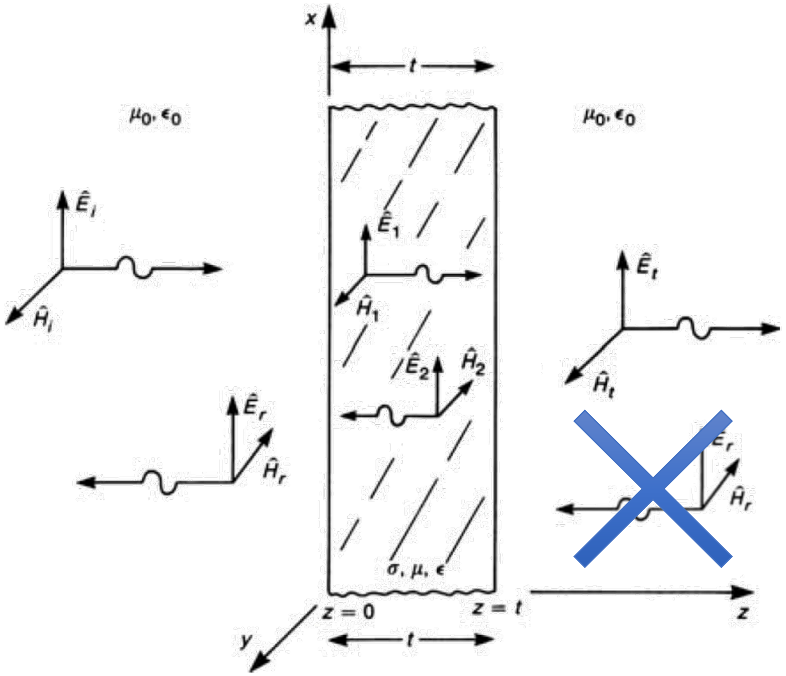
3) **MULTIPLE REFLECTIONS** within the shield;

They result in a SE given by: $\boxed{\mathrm{SE_{dB}} = R_{\mathrm{dB}} + A_{\mathrm{dB}} + M_{\mathrm{dB}}\,, M < 0}$



Electromagnetic shielding:

In the far-field source case, i. e., when an incident uniform plane wave is considered (which is assumed to be known), the shielding effectiveness of a metallic slab can be obtained by solving a system of four independent equations imposing boundary conditions at the interfaces (z = 0 and z = t).



Free space propagation outside the slab:

$$\beta_0 = \omega\sqrt{\mu_0\varepsilon_0} \qquad \eta_0 = \sqrt{\frac{\mu_0}{\varepsilon_0}}$$

Propagation in a conductive medium inside the metallic slab:

$$\hat{\gamma} = \sqrt{j\omega\mu(\sigma + j\omega\varepsilon)} = \alpha + j\beta \qquad \hat{\eta} = \sqrt{\frac{j\omega\mu}{\sigma + j\omega\varepsilon}} = \eta Arg(\theta_\eta)$$

Electromagnetic shielding:

By assuming a metallic (e. g., good conductor) thick shield, the following relationships hold:

$$\hat{\eta} \ll \eta_0 \rightarrow \frac{\eta_0 - \hat{\eta}}{\eta_0 + \hat{\eta}} \cong 1 \qquad t \gg \delta \rightarrow \left|e^{-\hat{\gamma}t}\right| = \left|e^{-\alpha t} e^{-j\beta t}\right| = \left|e^{-\frac{t}{\delta}}\right| \left|e^{-j\beta t}\right| \ll 1$$

We have:

$$\frac{\hat{E}_i}{\hat{E}_t} = \frac{(\eta_0 + \hat{\eta})^2}{4\eta_0\hat{\eta}} \left[1 - \left(\frac{\eta_0 - \hat{\eta}}{\eta_0 + \hat{\eta}}\right)^2 e^{-2\frac{t}{\delta}} e^{-j2\beta t}\right] e^{\frac{t}{\delta}} e^{j\beta t} e^{-j\beta_0 t} \Longrightarrow \left|\frac{\hat{E}_i}{\hat{E}_t}\right| = \left|\frac{(\eta_0 + \hat{\eta})^2}{4\eta_0\hat{\eta}}\right| e^{\frac{t}{\delta}} \cong \left|\frac{\eta_0}{4\hat{\eta}}\right| e^{\frac{t}{\delta}}$$

Human exposure to EM fields

Electromagnetic shielding:

Hence, the assumptions led to neglect the SE term associated to multiple reflections within the shield:

$$\mathrm{SE_{dB}} \cong \underbrace{20\log_{10}\left|\frac{\eta_0}{4\hat{\eta}}\right|}_{R_{\mathrm{dB}}} + \underbrace{20\log_{10} e^{\frac{t}{\delta}}}_{A_{\mathrm{dB}}} + M_{\mathrm{dB}}$$

where:

$$M_{\mathrm{dB}} = 20\log_{10}\left|1-\left(\frac{\eta_0-\hat{\eta}}{\eta_0+\hat{\eta}}\right)^2 e^{-2\frac{t}{\delta}} e^{-j2\beta t}\right| \cong 20\log_{10}\left|1-e^{-2\frac{t}{\delta}} e^{-j2\frac{t}{\delta}}\right|$$

- $t \gg \delta$ ⟶ $M = 1$ ($M_{\mathrm{dB}} = 0$), multiple reflections do not affect the SE
- $t \ll \delta$ ⟶ $M_{\mathrm{dB}} < 0$, multiple reflections reduce the SE ($t = \delta/10$ results in $M_{\mathrm{dB}} \approx -12$ dB)

Human exposure to EM fields

Electromagnetic shielding:

An approximate solution for the SE of a metallic slab can be found that leads to the following key findings:

1. The main transmission of the electric field occurs at the right interface (z = t)
2. The main transmission of the magnetic field occurs at the left interface (z = 0)

From which:

- The slab thickness, being related to absorption, significantly affects the magnetic field;
- When shielding the electric field, a left-side thin slab is enough to “short out” the field;
- Multiple reflections within the shield have larger effect on the magnetic field.

Human exposure to EM fields

Electromagnetic shielding:

An approximate solution for the SE of a metallic slab can be found that leads to the following key findings:

$$R_{\mathrm{dB}} = 168 + 10\log_{10}\left(\frac{\sigma_r}{\mu_r f}\right)$$

$$A_{\mathrm{dB}} = 131.4t\sqrt{f\mu_r\sigma_r}$$

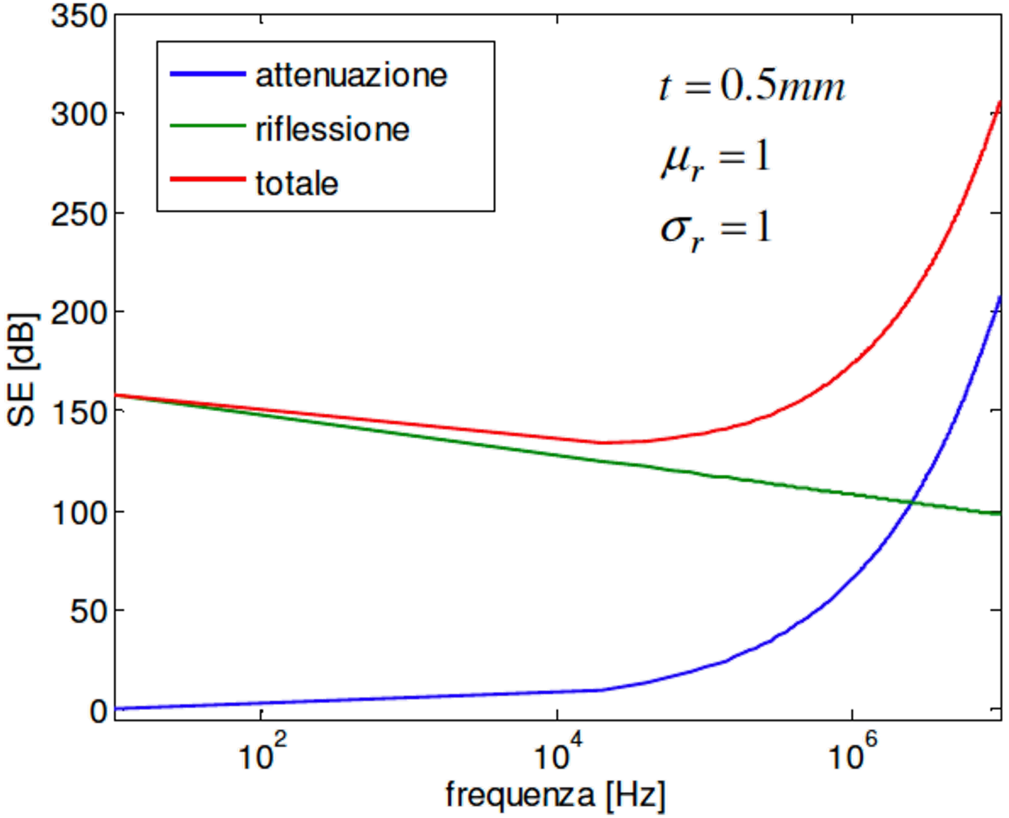
**Reference is made to the copper conductivity, σ = 5.8 × 10⁷ S/m.*

Material	σ_r *	μ_r	$A \sim \mu_r\sigma_r$	$R \sim \sigma_r/\mu_r$
Silver	1.05	1	1.05	1.05
Copper	1	1	1	1
Gold	0.7	1	0.7	0.7
Aluminum	0.61	1	0.61	0.61
Brass	0.26	1	0.26	0.26
Bronze	0.18	1	0.18	0.18
Tin	0.15	1	0.15	0.15
Lead	0.08	1	0.08	0.08
Nickel	0.2	600	120	3.3×10^{-4}
Stainless steel (430)	0.02	500	10	4×10^{-5}
Steel (SAE 1045)	0.1	1000	100	1×10^{-4}
Mumetal (at 1 kHz)	0.03	30,000	900	1×10^{-6}
Superpermalloy (at 1 kHz)	0.03	100,000	3000	3×10^{-7}

- Reflection losses rule low-frequency (-10 dB/decade) high-conductivity non ferromagnetic material shielding;
- Absorption losses rule high-frequency (+10 dB/decade) high-conductivity ferromagnetic material shielding.

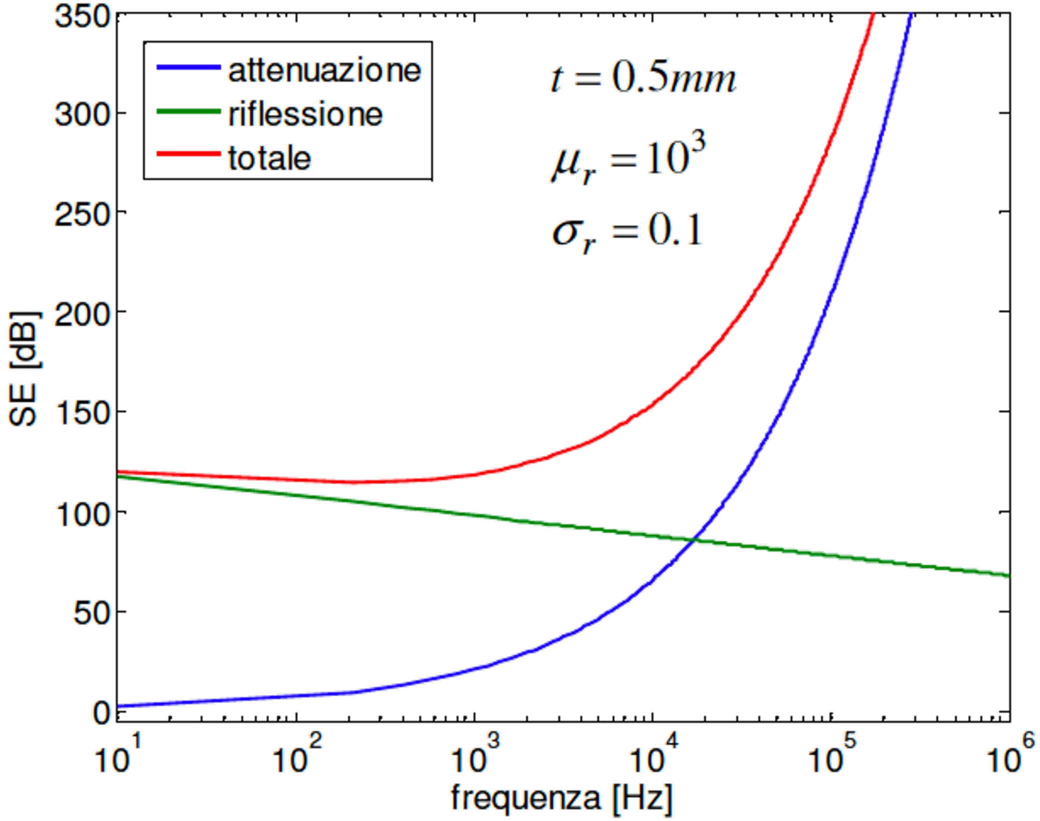
Human exposure to EM fields

Electromagnetic shielding:



Copper

Steel (SAE 1045)



Human exposure to EM fields

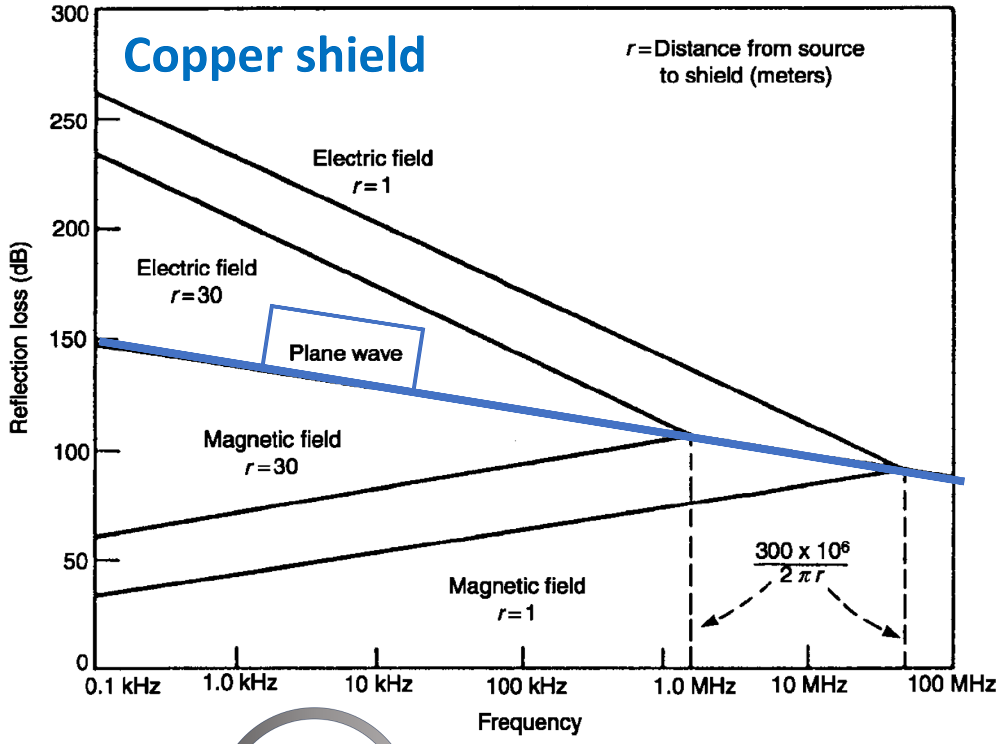
Electromagnetic shielding:

When near-field sources have to be considered, the SE associated to each loss mechanism can be obtained by replacing the free-space intrinsic impedance η_0 with the source wave impedance $\hat{Z}_w$ in the SE formula obtained for the far-field case, considering that absorption is not affected by the source type:

$$R_{\mathrm{dB}} = 20\log_{10}\left|\frac{\left(\hat{Z}_w+\hat{\eta}\right)^2}{4\hat{Z}_w\hat{\eta}}\right| \cong 20\log_{10}\left|\frac{\hat{Z}_w}{4\hat{\eta}}\right|$$

$$R_{e,\mathrm{dB}} = 322 + 10\log_{10}\left(\frac{\sigma_r}{\mu_r f^3 r^2}\right)$$

$$R_{\mathrm{m,dB}} = 14.57 + 10\log_{10}\left(\frac{f r^2 \sigma_r}{\mu_r}\right)$$



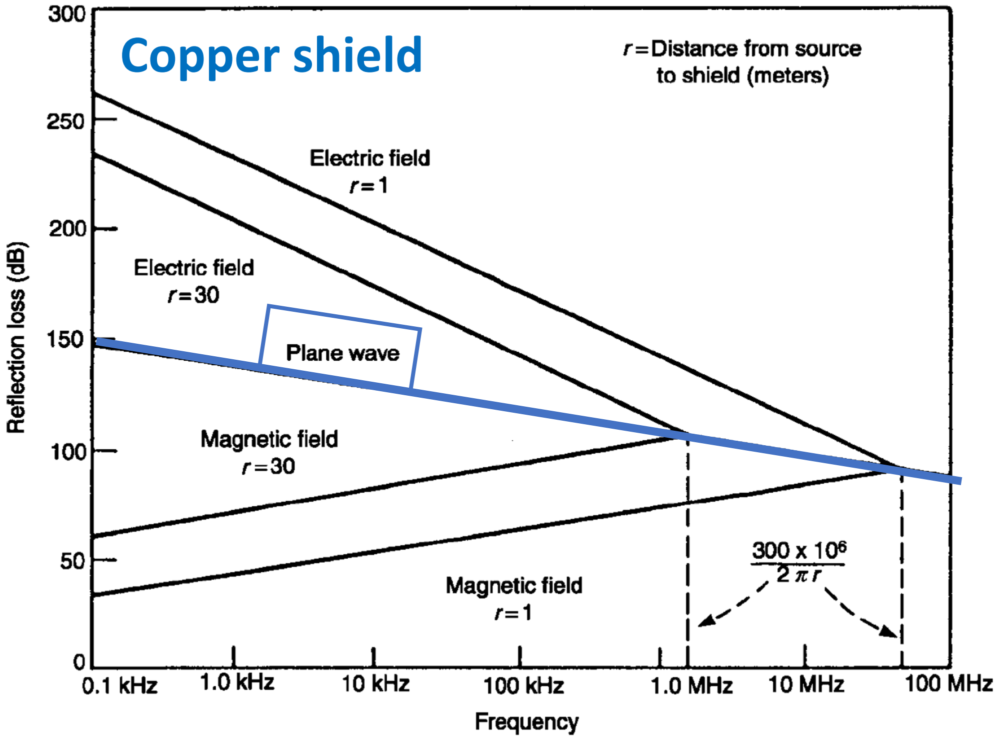
Human exposure to EM fields

Electromagnetic shielding:

- **Far-field sources:**
  - ➢ Reflection losses dominate at lower frequencies;
  - ➢ Absorption losses dominate at higher frequencies;

- **Near-field electric sources:**
  - ➢ Reflection losses dominate at lower frequencies;
  - ➢ Absorption losses dominate at higher frequencies;

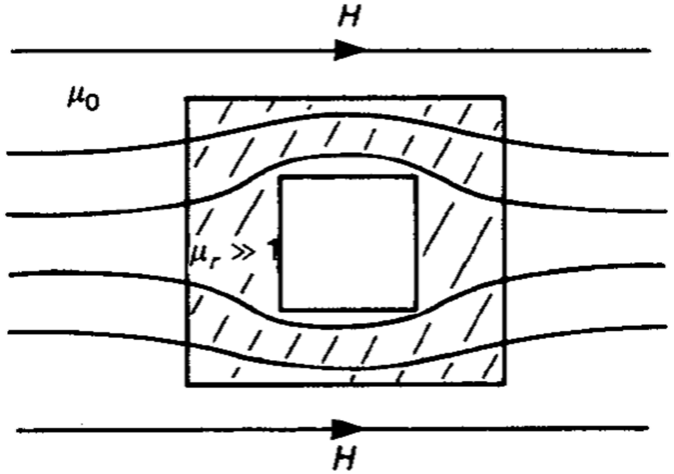
- **Near-field magnetic sources:**
  - ➢ Absorption losses tend to be the dominant shielding mechanism for any frequency;
  - ➢ Absorption and reflection losses are quite small at lower frequencies.

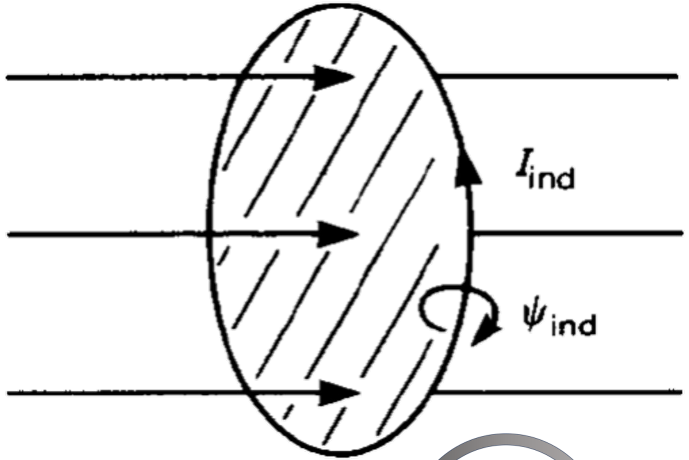


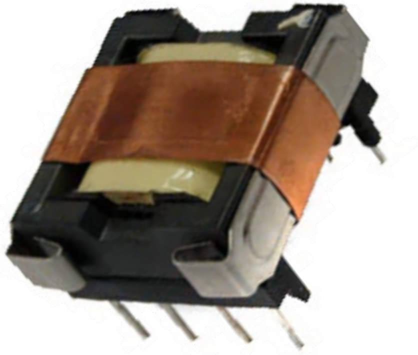
Electromagnetic shielding:

Hence, being both reflection and absorption losses quite small in the case of low-frequency near-field magnetic sources, tailored methods must be adopted to achieve effective shielding:

- ✓ Use of high-permeability materials to divert the magnetic flux
- ✓ Shorted-turn method to generate an opposing magnetic flux







Human exposure to EM fields

Electromagnetic shielding:

Non-ideality factors that reduce shielding effectiveness:

- Apertures
- Slots
- Holes
- …

This is due to their radiating capabilities (Booker-Babinet principle). Tailored methods must be used to minimize their impact on SE.