UNIVERSITAT DE BARCELONA

Wireless Biodevices and Systems

FUNDAMENTALS

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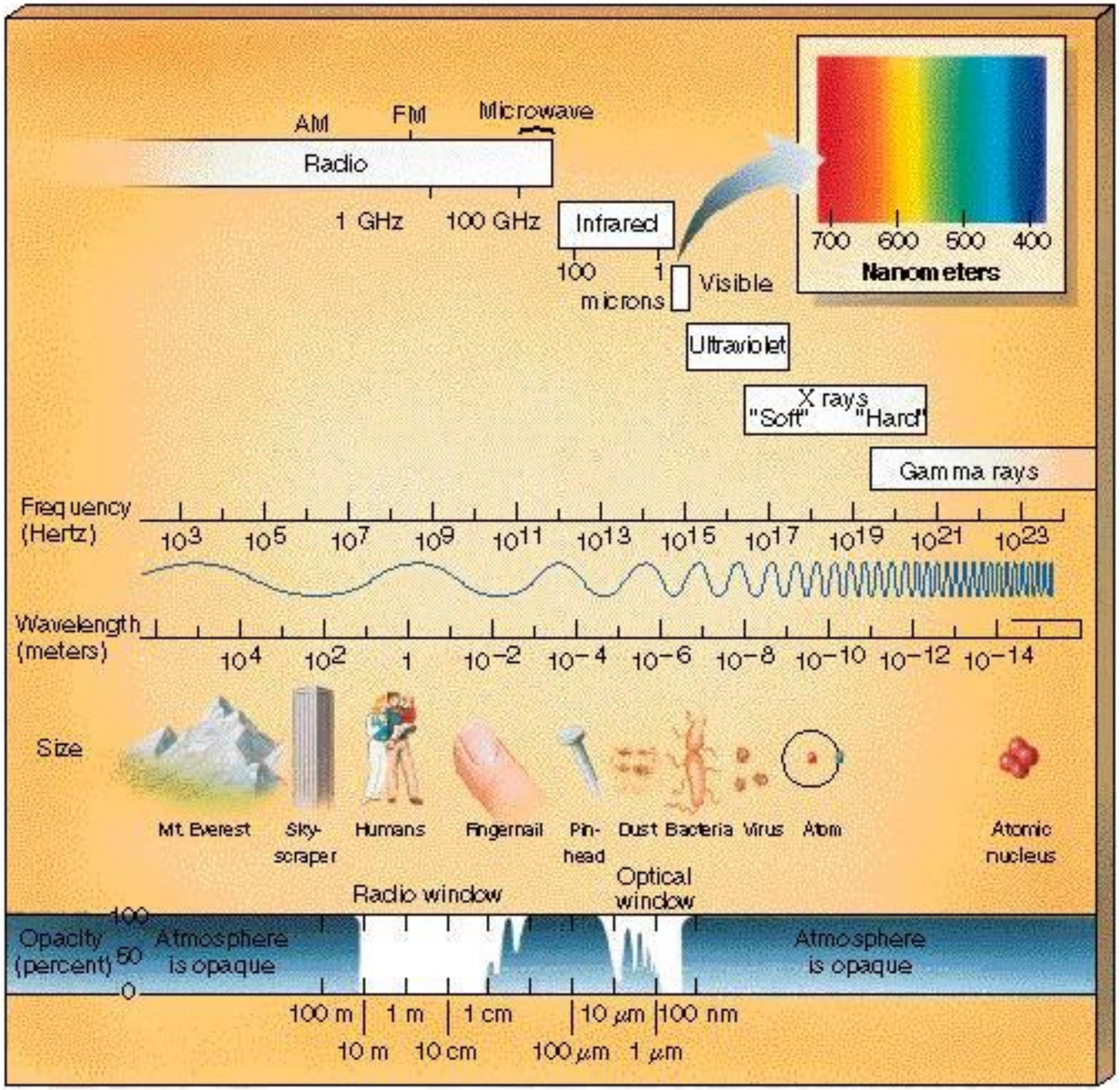
OUTLINE

- RF spectrum
- Networks
- Communication types
- Propagation in Biological Media
- Body Tissues
- Dosimetry
- Examples

Spectrum



http://www.astro.princeton.edu/~gk/A402/pix.html

Most wireless communication is via radiofrequency (RF) electromagnetic signals.

Communication within the infrared (IR) band has found popularity in computer peripherals.
However infrared transmission is limited by line-of-sight requirements for communication. The communication is blocked when objects pass between transmitter and receiver and hence is not suitable for many applications.

Spectrum

The RF spectrum (3 kHz to 3000 GHz) is managed on an international level by an agency of the United Nations, the International Telecommunication Union (ITU), by means of the Radio Regulations. These regulations contain a table of frequency allocations, in which ranges of frequencies (called spectral bands) are allocated to particular services.

Use of radio frequency bands of the electromagnetic spectrum is regulated by governments in most countries.

International Telecommunication Union (ITU)

Federal Communication Commission (FCC)

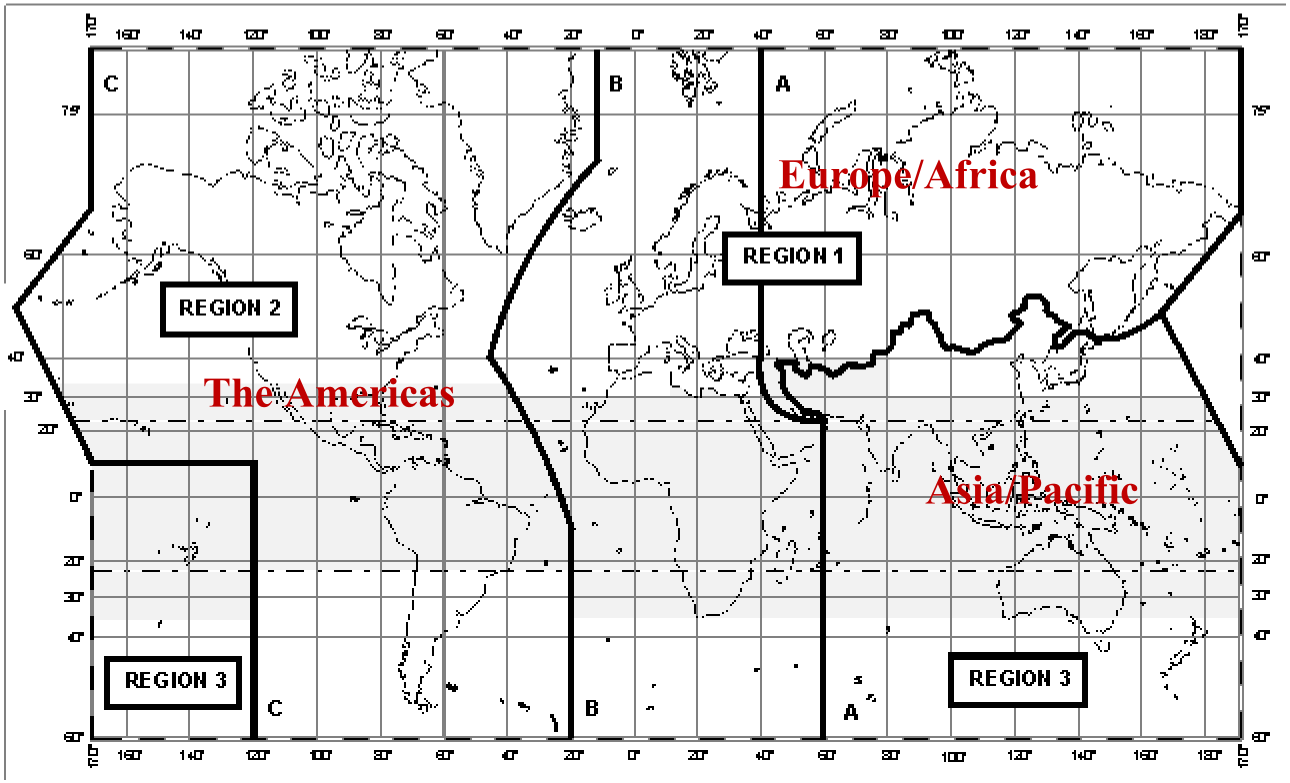
European Conference of Postal and Telecommunications Administrations (CEPT)

European Telecommunications Standards Institute (ETSI)

International Special Committee on Radio Interference (Comité international spécial des perturbations radioélectriques - CISPR)

These standards bodies have assigned frequency bands in three types of allocation: no one may transmit, anyone may transmit and license is required to transmit.

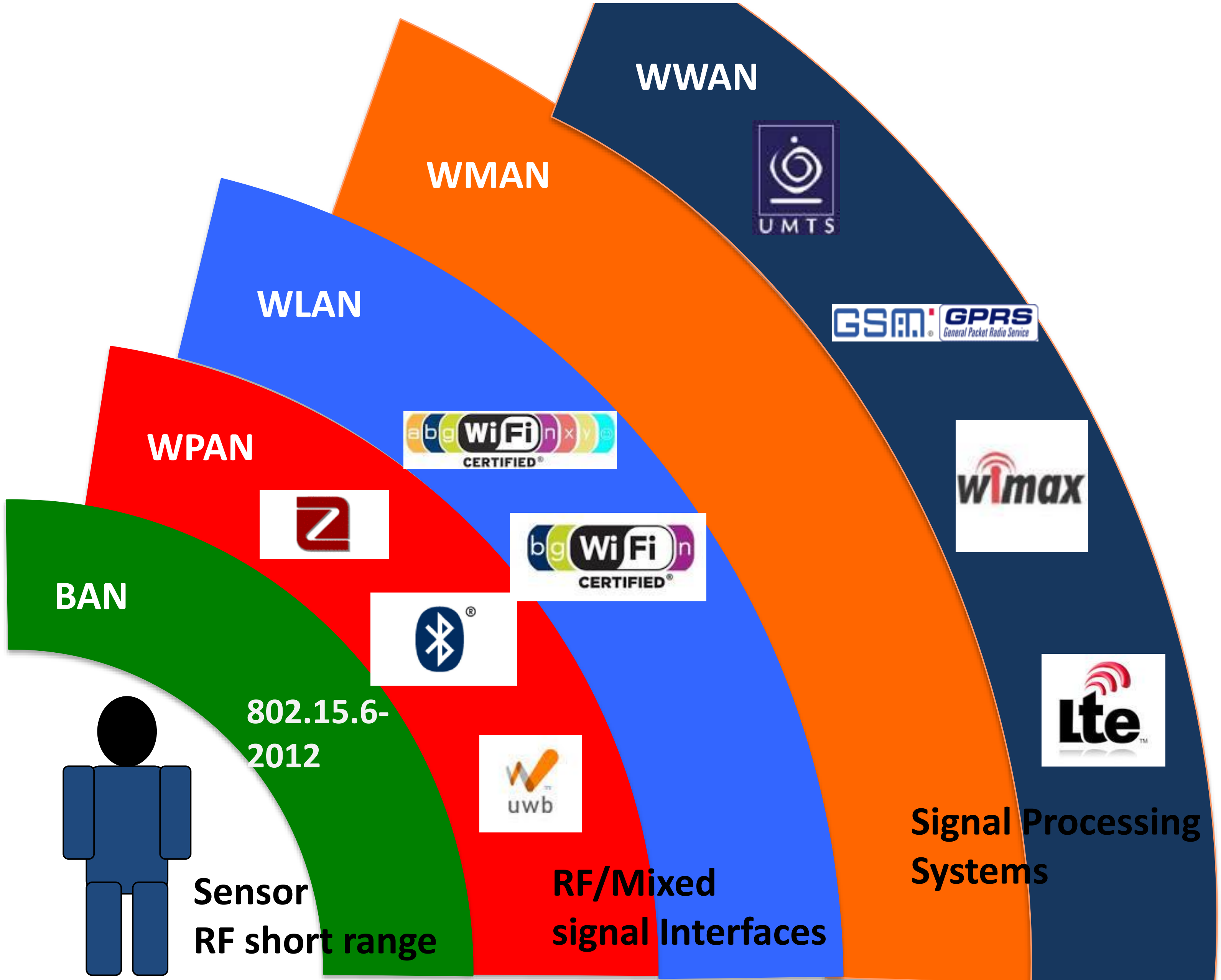
Spectrum



The International Telecommunication Union (ITU, agency of the United Nations) publishes a table of frequency allocations that represents agreement among the member-states. Allocations may differ among the different regions.

http://www.itu.int/pub/R-REG-RR-2008/en

Networks

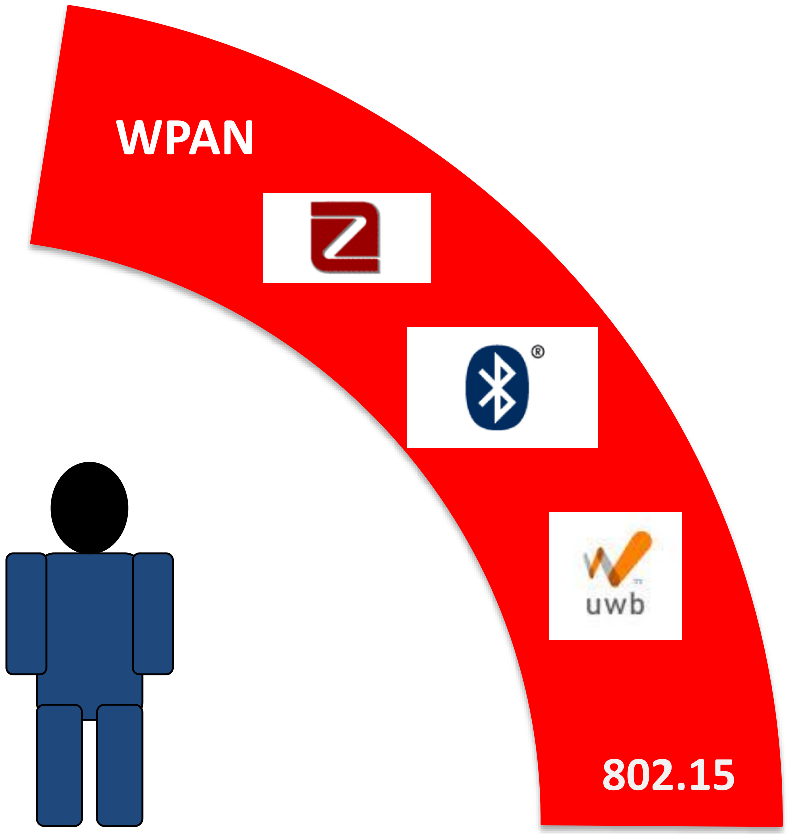


WWAN
UMTS
GSM
GPRS
General Packet Radio Service
wimax
lte
WMAN
WLAN
WiFi CERTIFIED
WPAN
BAN
802.15.6-2012
uwb
Sensor
RF short range
RF/Mixed signal Interfaces
Signal Processing Systems

Networks

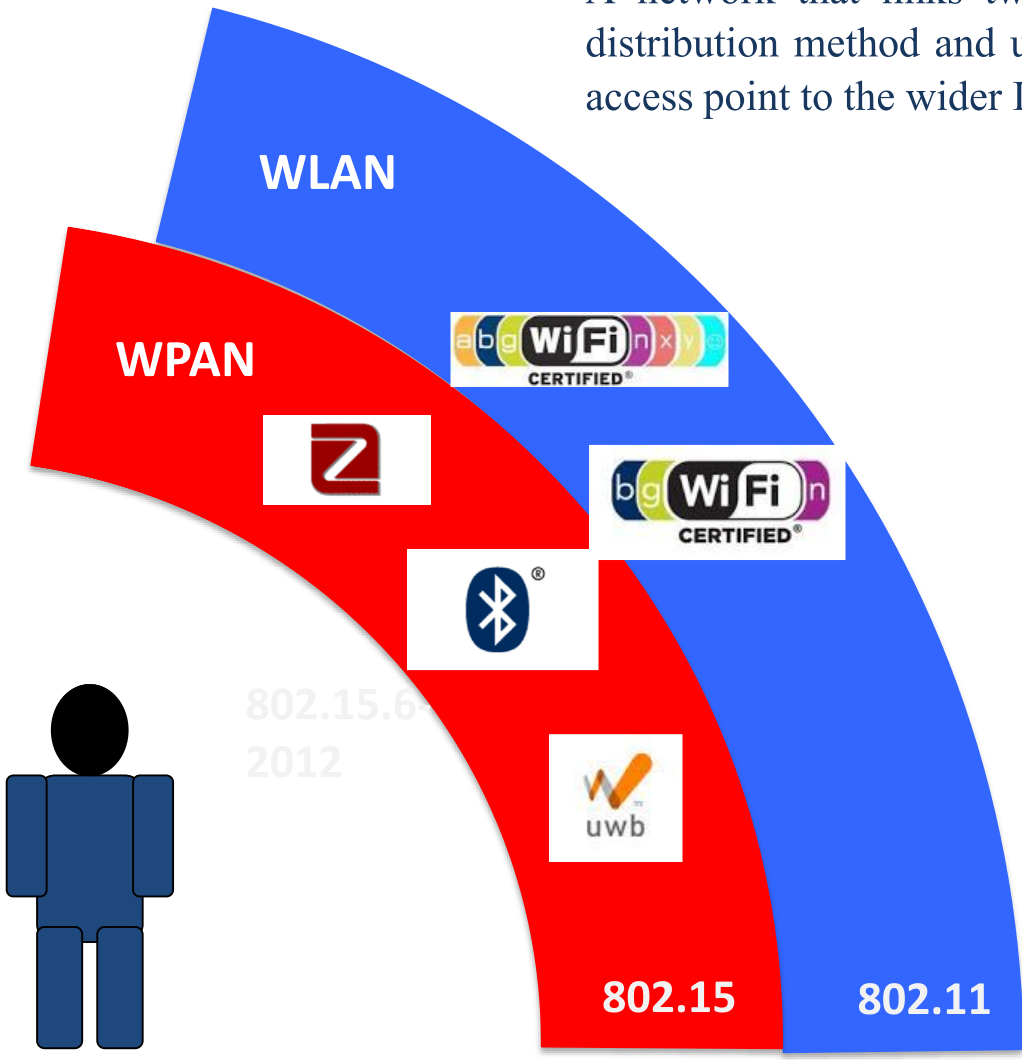
WPAN - Wireless Personal Area Network

A network for interconnecting devices centered on an individual person's workspace

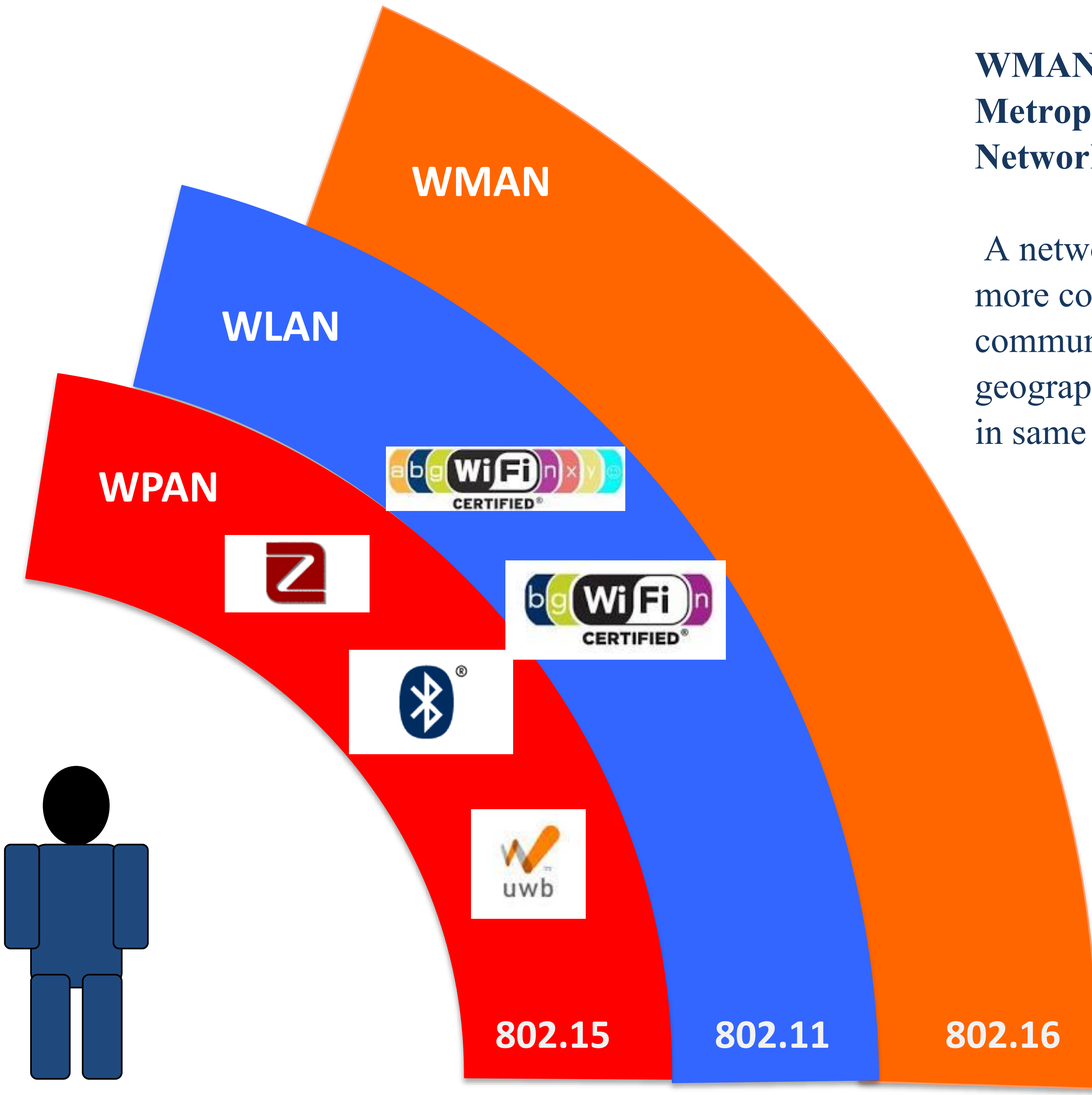


WLAN - Wireless Local Area Network

A network that links two or more devices using some wireless distribution method and usually providing a connection through an access point to the wider Internet.



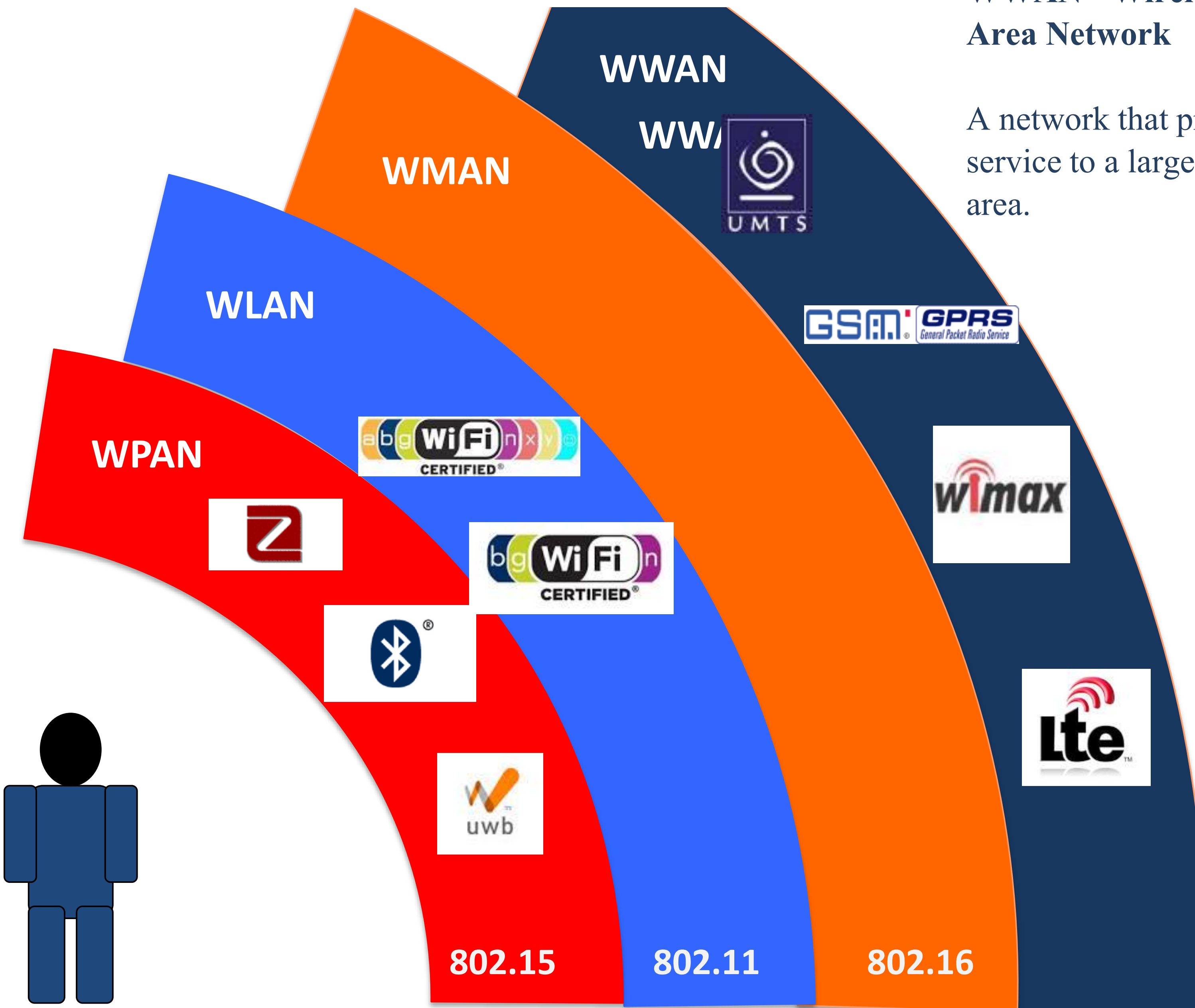
Networks



WMAN - Wireless Metropolitan Area Network

A network in which two or more computers or communicating devices are geographically separated but in same metropolitan city.

Networks



WWAN - Wireless Wide Area Network

A network that provides service to a large geographic area.

Standards

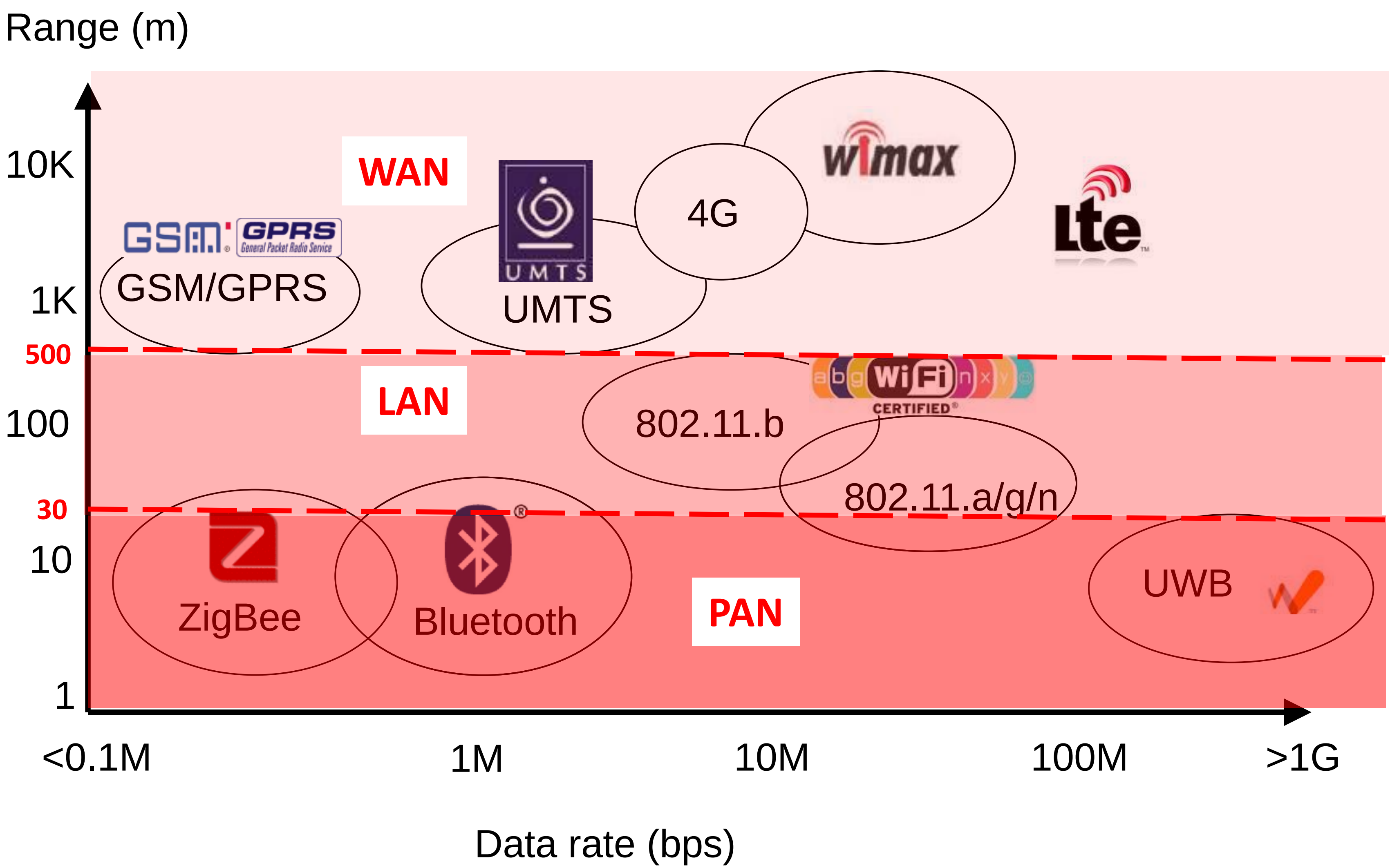
The information exchanged between devices is governed by rules and conventions that can be set out in technical specifications called communication protocol standards.

V·T·E **802.11 network PHY standards** [hide]

802.11 protocol	Release date[6]	Frequency (GHz)	Bandwidth (MHz)	Stream data rate[7] (Mbit/s)	Allowable MIMO streams	Modulation	Approximate range[citation needed] Indoor	Approximate range[citation needed] Outdoor
802.11-1997	Jun 1997	2.4	22	1, 2	N/A	DSSS, FHSS	20 m (66 ft)	100 m (330 ft)
a	Sep 1999	5	20	6, 9, 12, 18, 24, 36, 48, 54	N/A	OFDM	35 m (115 ft)	120 m (390 ft)
		3.7[A]						5,000 m (16,000 ft)[A]
b	Sep 1999	2.4	22	1, 2, 5.5, 11	N/A	DSSS	35 m (115 ft)	140 m (460 ft)
g	Jun 2003	2.4	20	6, 9, 12, 18, 24, 36, 48, 54	N/A	OFDM	38 m (125 ft)	140 m (460 ft)
n	Oct 2009	2.4/5	20	Up to 288.8[B]	4	MIMO-OFDM	70 m (230 ft)	250 m (820 ft)[8]
			40	Up to 600[B]				
ac	Dec 2013	5	20	Up to 346.8[B]	8		35 m (115 ft)[9]	
			40	Up to 800[B]				
			80	Up to 1733.2[B]				
			160	Up to 3466.8[B]				
		0.054-0.79[C]	6-8	Up to 568.9[10]	4			
ad	Dec 2012	60	2,160	Up to 6,757[11] (6.7 Gbit/s)	N/A	OFDM, single carrier, low-power single carrier	3.3 m (11 ft)[12]	
ah	Dec 2016	0.9	1-16	Up to 347 [13]	4	MIMO-OFDM		
aj	Est. Jul 2017	45/60						
ax	Est. Dec 2018	2.4/5		Up to 10.53 Gbit/s		MIMO-OFDM		
ay	Est. Nov 2019	60	8000	Up to 20,000 (20 Gbit/s) [14]	4	OFDM, single carrier,	10 m (33 ft)	100 m (328 ft)
az	Est. Mar 2021	60						
802.11 Standard rollups								
802.11-2007	Mar 2007	2.4, 5		Up to 54		DSSS, OFDM		
802.11-2012	Mar 2012	2.4, 5		Up to 150[B]		DSSS, OFDM		
802.11-2016	Dec 2016	2.4, 5, 60		Up to 866.7 or 6,757[B]		DSSS, OFDM		

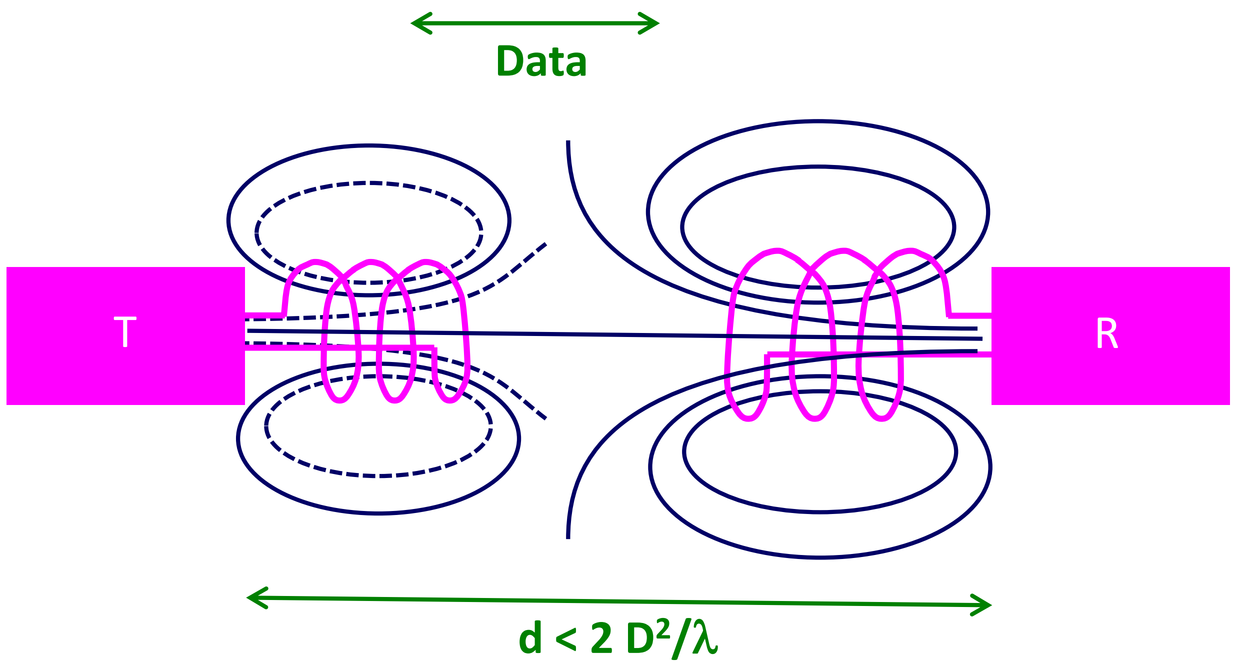
- A1 A2 IEEE 802.11y-2008 extended operation of 802.11a to the licensed 3.7 GHz band. Increased power limits allow a range up to 5,000 m. As of 2009, it is only being licensed in the United States by the FCC.
- B1 B2 B3 B4 B5 B6 Based on short guard interval; standard guard interval is ~10% slower. Rates vary widely based on distance, obstructions, and interference.
- C1 IEEE 802.11af about using white space spectrum for WiFi based on the PHY layer of 802.11ac

https://en.wikipedia.org/wiki/IEEE_802.11


Range (m)
10K
1K
500
100
30
10
1
WAN
LAN
PAN
GSM/GPRS
UMTS
4G
802.11.b
802.11.a/g/n
ZigBee
Bluetooth
UWB
<0.1M
1M
10M
100M
>1G
Data rate (bps)

Communication Types

Magnetic coupling

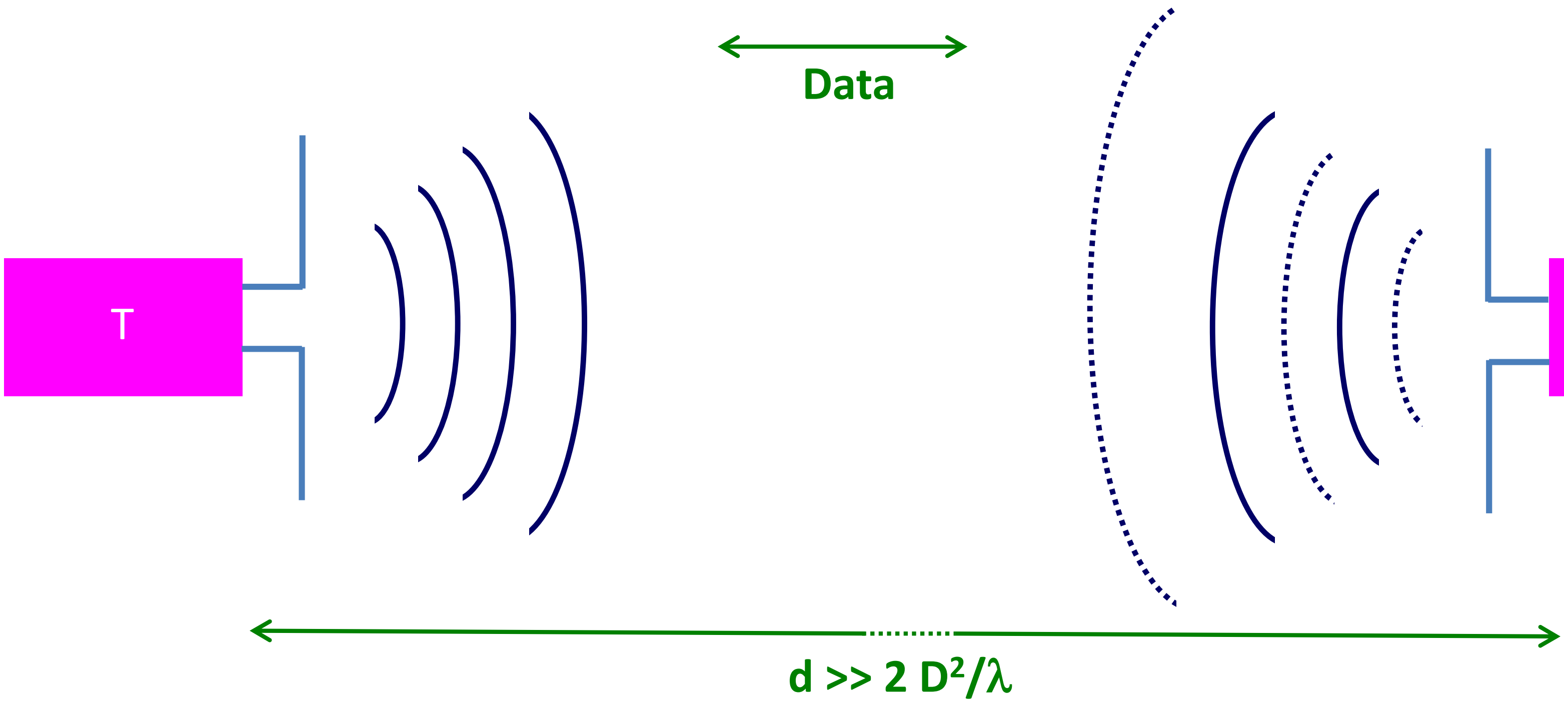


Uses magnetic coupling
Very short rang of distances, typically few tens of cm
Low bit rates
Easy to implement

Communication Types

RF radiation - ANTENNAS

Far Field



Uses RF coupling
Medium range of distances, typically up to tens of m
More complex implementation, mainly due to the antenna (design, environment, matching, etc.)

* Maxwell Equations

Maxwell's equations are a fundamental set of equations that form the framework of all of classical electromagnetic field theory.

$$\vec{\nabla}\cdot\vec{D} = \rho$$

$$\vec{\nabla}\cdot\vec{B} = 0$$

$$\vec{\nabla}\times\vec{E} = -\frac{\partial \vec{B}}{\partial t} - \vec{j}_M$$

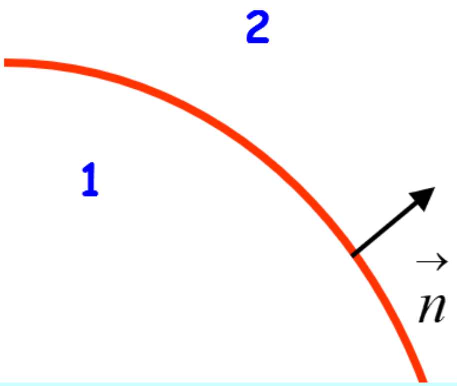
$$\vec{\nabla}\times\vec{H} = \vec{j} + \frac{\partial \vec{D}}{\partial t}$$

$$\vec{B} = \mu_o\left(\vec{H} + \vec{M}\right)$$

$$\vec{D} = \varepsilon_o \vec{E} + \vec{P}$$

$$\varepsilon_o = 8.85\times10^{-12} \quad F/m$$

$$\mu_o = 4\pi\times10^{-7} \quad H/m$$



$$\vec{n}\cdot\left(\vec{D}_2 - \vec{D}_1\right) = \sigma_f$$

$$\vec{n}\cdot\left(\vec{B}_2 - \vec{B}_1\right) = 0$$

$$\vec{n}\times\left(\vec{E}_2 - \vec{E}_1\right) = 0$$

$$\vec{n}\times\left(\vec{H}_2 - \vec{H}_1\right) = \vec{\kappa}_f$$

Electric and Magnetic Field Interactions with Materials.

One of the more important aspects of bioelectromagnetics is how electromagnetic fields interact with materials, for example, how **E** and **B** fields affect the human body and how the body affects the fields. Because **E** and **B** were defined to account for forces among charges, the fundamental interaction of **E** and **B** with materials is that **E** and **B** exert forces on the charges in the materials.

The interaction is described macroscopically in terms of three effects of fields on the charges in the material:

1) Induced dipole polarization.

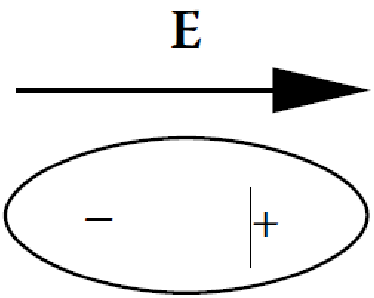
2) Alignment of already existing electric dipoles.

3) Movement of free charges.

1) Induced dipole polarization.

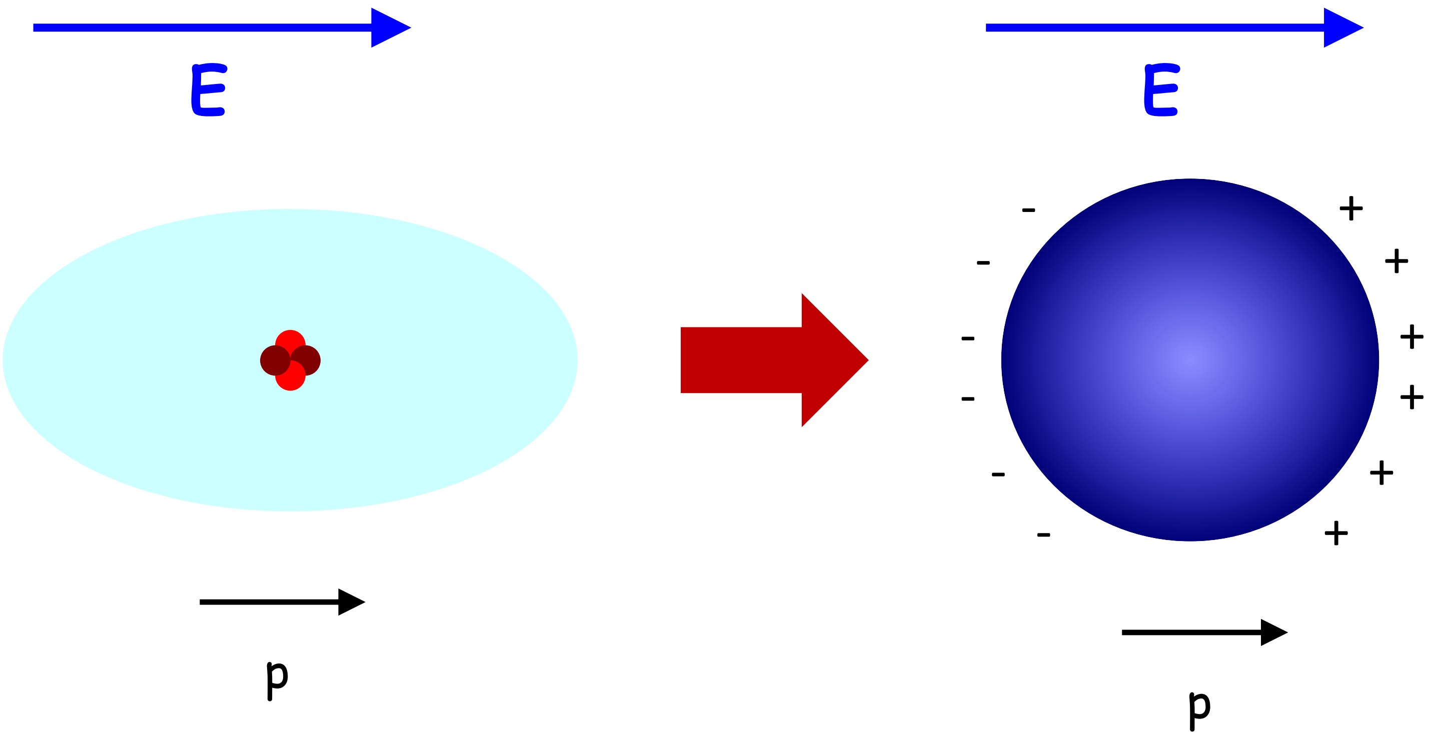
The figure illustrates the concept of induced dipoles. Before the **E** is applied, the positive and negative charge centers are so close together that the macroscopic fields they produce cancel each other.

When an **E** field is applied, the positive charge center moves in one direction and the negative charge center in the opposite direction, resulting in a slight separation of charge. The combination of a positive and a negative charge separated by a very small distance is called an electric dipole.



These are bound charges, because they are held in place by molecular bonds and are not free to move to another molecule. The creation of electric dipoles by this separation of charge centers is called induced polarization.

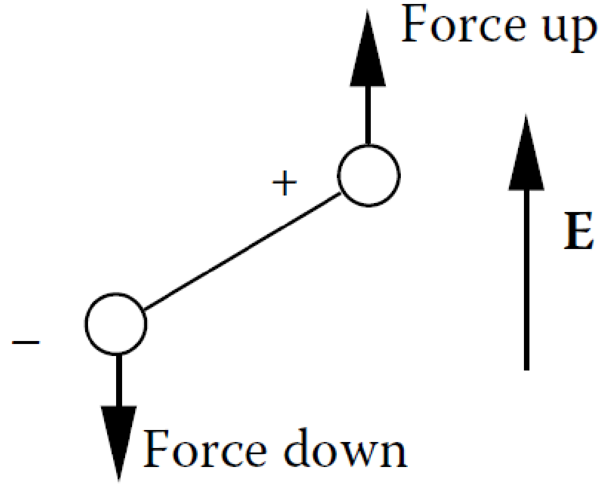
1) Induced dipole polarization.



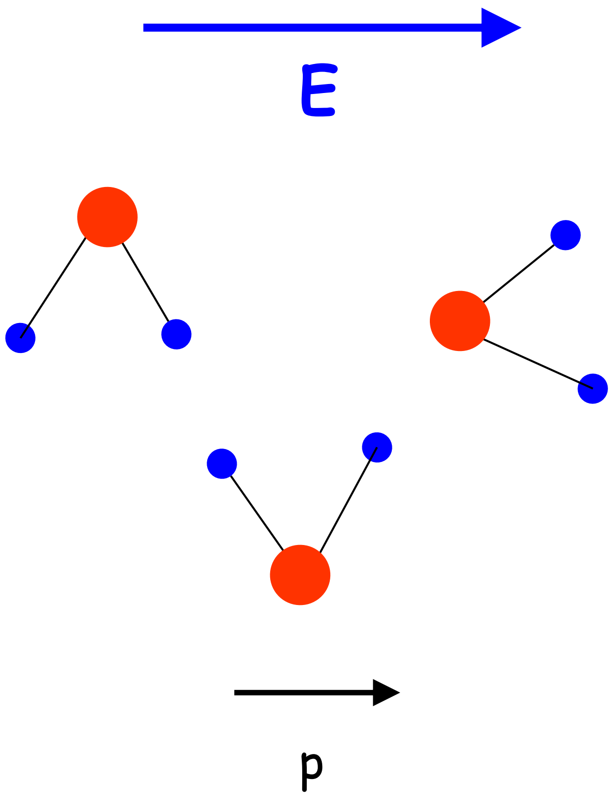
2) Alignment of already existing electric dipoles.

In some materials, such as hydrogen-based biological materials, electric dipoles already exist, even in the absence of an applied **E** field.

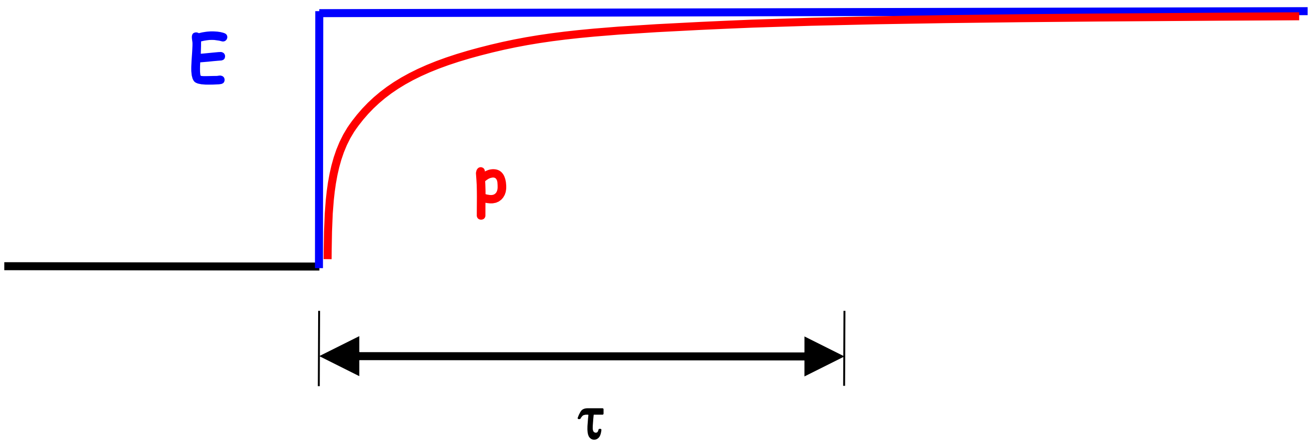
These permanent dipoles are randomly oriented, so that the net fields they produce are zero. When an **E** field is applied, the permanent dipoles partially align with the applied **E**, as illustrated in the figure. The applied **E** exerts a force on the positive charge of the dipole in one direction and on the negative charge in the opposite direction, causing the dipole to rotate slightly, and thus partially align with the applied **E**.

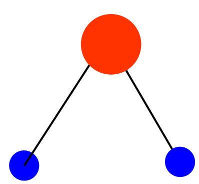


2) Alignment of already existing electric dipoles.



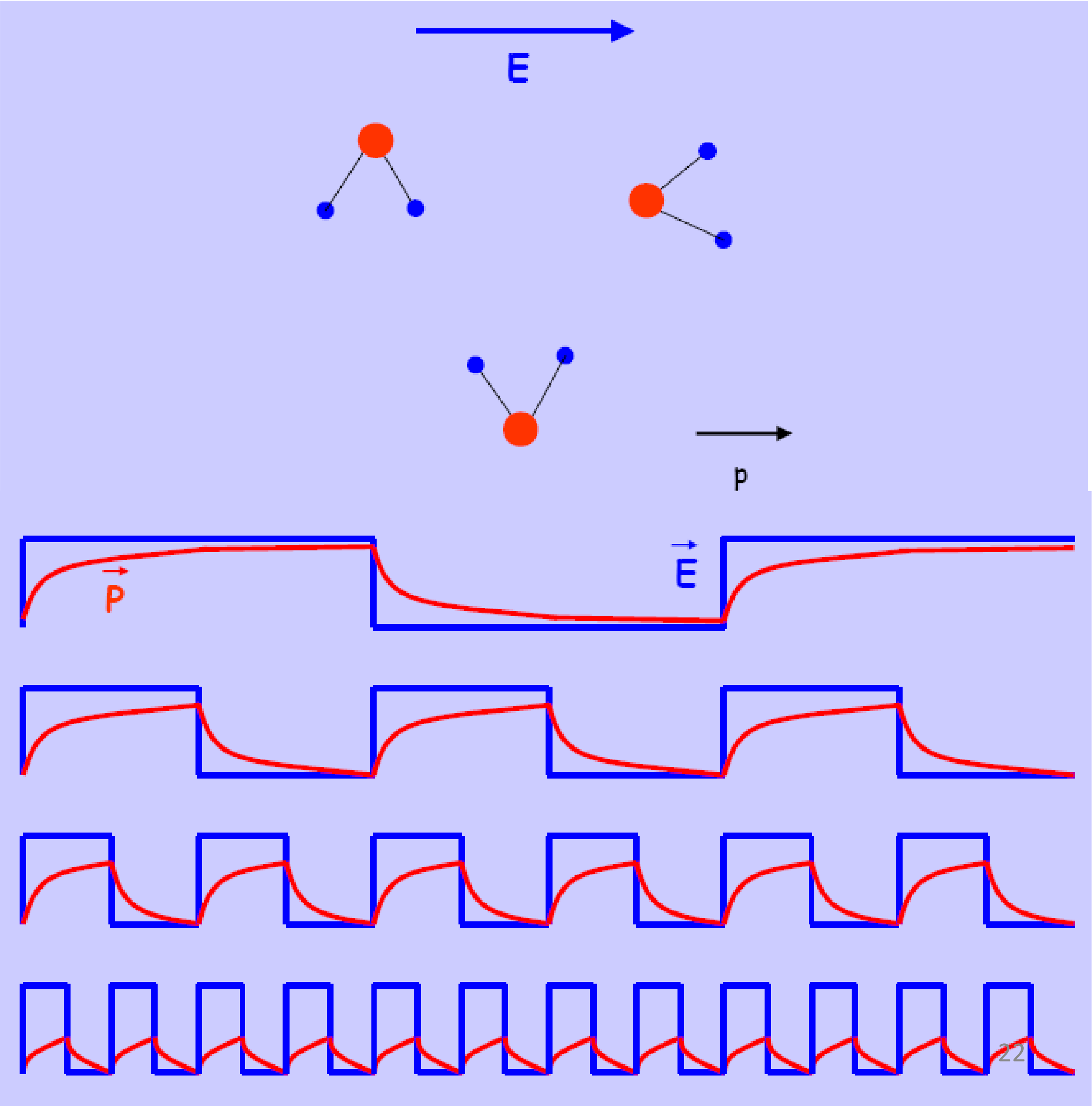
2) Alignment of already existing electric dipoles.





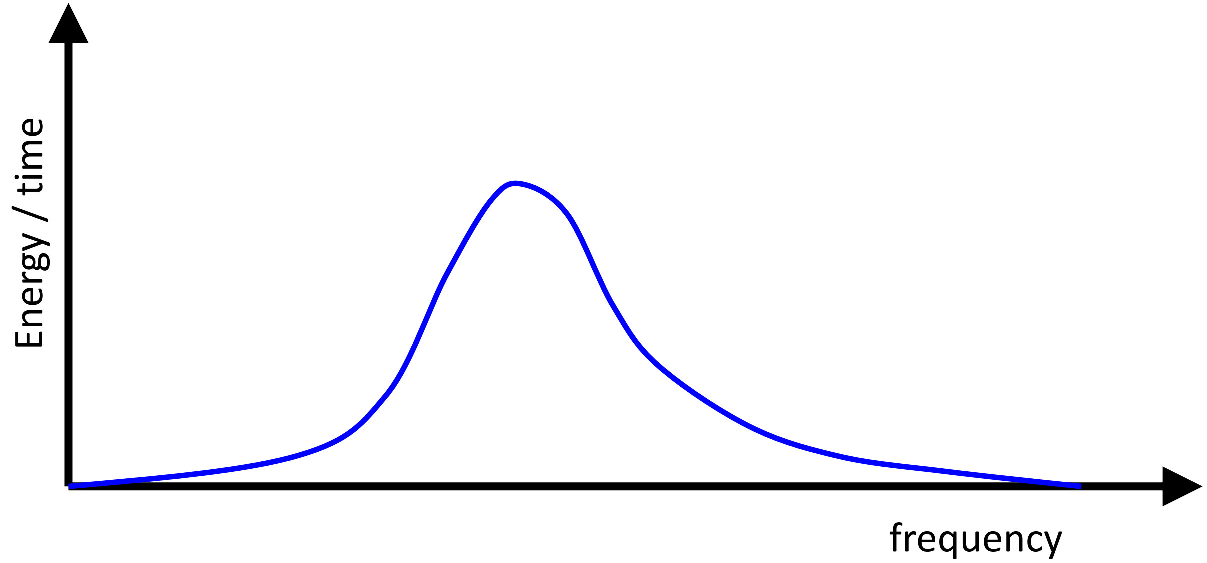
$$\vec{P} = \vec{P}_o + \Delta \vec{P}\left(1 - e^{-t/\tau}\right)$$

2) Alignment of already existing electric dipoles.



2) Alignment of already existing electric dipoles.

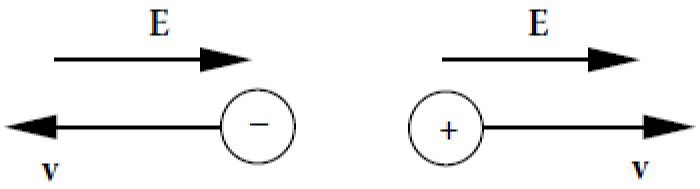
$$\vec{P} = \vec{P}_o + \Delta\vec{P}\left(1 - e^{-t/\tau}\right)$$



https://www.youtube.com/watch?v=FGdwEPEU61U

3) Movement of free charges.

The third effect of applied **E** fields on material charges is illustrated in the figure. Some charges (electrons and ions) in materials are free in the sense that they are loosely bound, and can move between molecules in response to an applied **E** field.



These charges move a short distance, collide with other particles, and then move in a different direction, resulting in some macroscopic average velocity in the direction of the applied **E** field. The movement of these free charges constitutes a current, which is called conduction current.

$$\vec{j} = qn\,\vec{v}_p = qn\,\mu\,\vec{E}$$

$$\sigma = qn\,\mu$$

Propagation in Biological Media

Because the interactions of **E** and **B** with materials are too complex to keep track of in terms of individual charges, three parameters are defined to account for these interactions on a macroscopic scale.

a) Induced polarization and alignment of permanent electric dipoles is accounted for by **permitivity** (ε), also called dielectric constant, which describes how much induced polarization and partial alignment of permanent electric dipoles occurs for a given applied **E**.

b) Conduction current is accounted for by **conductivity** (σ), which describes how much conduction current density a given applied **E** will produce.

c) Alignment of permanent magnetic dipoles is accounted for by **permeability** (μ), which describes how much partial alignment of permanent magnetic dipoles occurs for a given applied **B**.

Permittivity is often represented by the Greek letter epsilon (ε).
Its units are farads per meter (F/m).
The permittivity of free space (no charges present) is called ε_0 and in the International System of Units (SI), ε_0 = 8.854 × 10–12 F/m.
Relative permittivity is defined as $\varepsilon_r = \varepsilon/\varepsilon_0$; it is the permittivity relative to that of free space, and is unit less.

Conductivity is often represented by the Greek letter sigma (σ); its units are siemens per meter (S/m) which is the same as 1/ohm-m.

Permeability is usually represented by the Greek letter mu (μ); its units are henrys per meter (H/m). The permeability of free space is $\mu_0 = 4\pi \times 10^{-7}$ H/m.
Relative permeability is defined as $\mu_r = \mu/\mu_0$; it is unit less.
For most applications, the human body is so weakly magnetic that we can assume $\mu = \mu_0$, so $\mu_r = 1$.

Biological media:

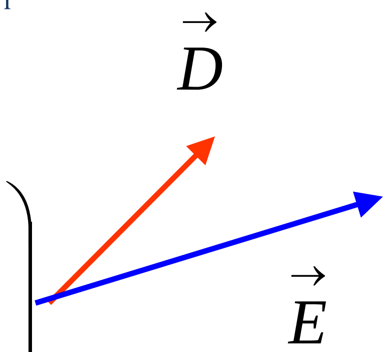
- The human body is so weakly magnetic that we can assume $\mu = \mu_0$, so $\mu_r = 1$.

$$\vec{M} \approx 0 \longrightarrow \vec{B} = \mu_o \vec{H}$$

- We can assume that they are linear media.

$$\vec{P} = \varepsilon_o \vec{\vec{\chi}} \vec{E} \longrightarrow \vec{D} = \vec{\vec{\varepsilon}} \vec{E}$$

$$\vec{\vec{\varepsilon}} = \begin{pmatrix} \varepsilon_{11} & \varepsilon_{12} & \varepsilon_{13} \\ \varepsilon_{21} & \varepsilon_{22} & \varepsilon_{23} \\ \varepsilon_{31} & \varepsilon_{32} & \varepsilon_{33} \end{pmatrix}$$



- We can assume that they are ohmic media.

$$\vec{j} = \vec{\vec{\sigma}} \vec{E}$$

$$\vec{\vec{\sigma}} = \begin{pmatrix} \sigma_{11} & \sigma_{12} & \sigma_{13} \\ \sigma_{21} & \sigma_{22} & \sigma_{23} \\ \sigma_{31} & \sigma_{32} & \sigma_{33} \end{pmatrix}$$

- We can assume that they are isotropic media.

$$\left.\begin{array}{ll} \varepsilon_{ij} = 0 & \forall\, i \neq j \\ \varepsilon_{ii} = \varepsilon & \forall\, i \end{array}\right] \longrightarrow \vec{D} = \varepsilon \vec{E}$$

$$\left.\begin{array}{ll} \sigma_{ij} = 0 & \forall\, i \neq j \\ \sigma_{ii} = \sigma & \forall\, i \end{array}\right] \longrightarrow \vec{j} = \sigma \vec{E}$$

- We can assume they are media invariant over time.

$$\varepsilon \neq \varepsilon(t) \qquad \sigma \neq \sigma(t)$$

Wave equation propagation in biological media:

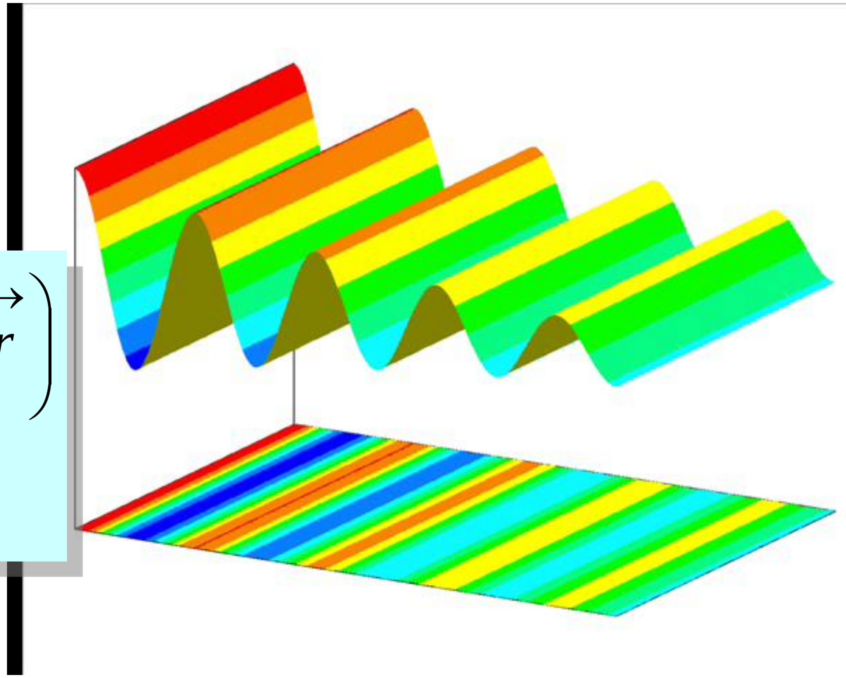
$$\vec{\nabla} \times \vec{E} = -\mu_o \frac{\partial \vec{H}}{\partial t}$$

$$\vec{\nabla} \times \vec{H} = \sigma \vec{E} + \varepsilon \frac{\partial \vec{E}}{\partial t}$$

$$\Delta \vec{E} - \mu_o \sigma \frac{\partial \vec{E}}{\partial t} - \mu_o \varepsilon \frac{\partial^2 \vec{E}}{\partial t^2} = 0$$

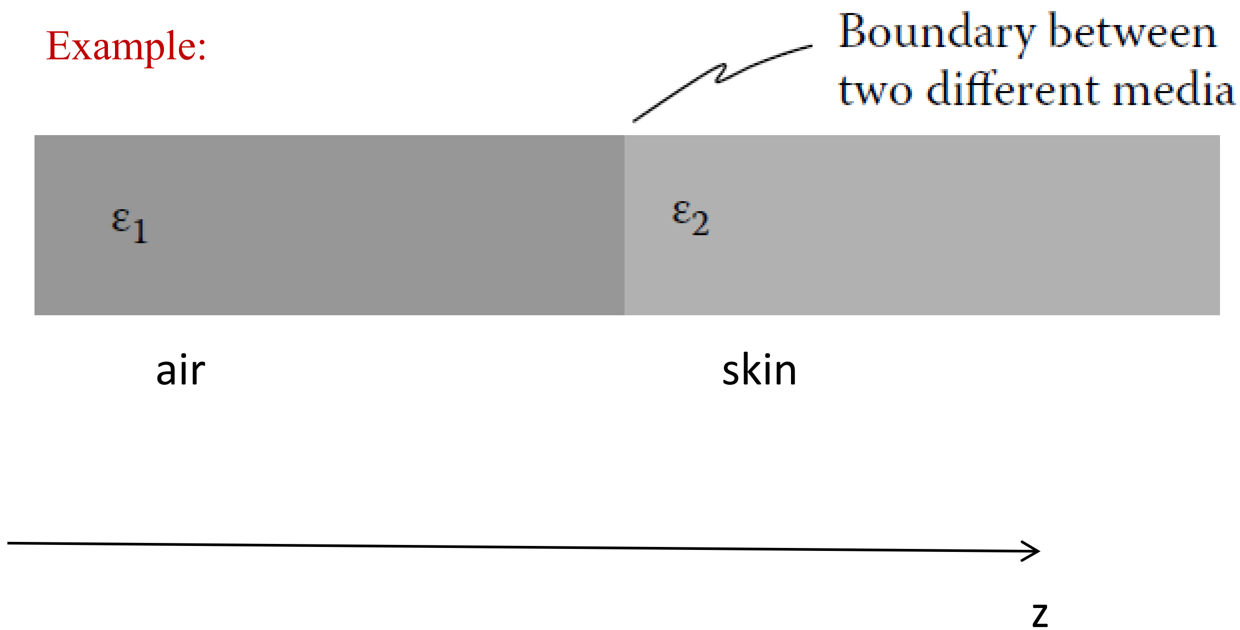
Solution:

$$\vec{E}\left(\vec{r}\right) = \vec{E}_o \, e^{-\vec{\alpha} \cdot \vec{r}} \, e^{j\left(wt - \vec{\beta} \cdot \vec{r}\right)}$$



Propagation in Biological Media

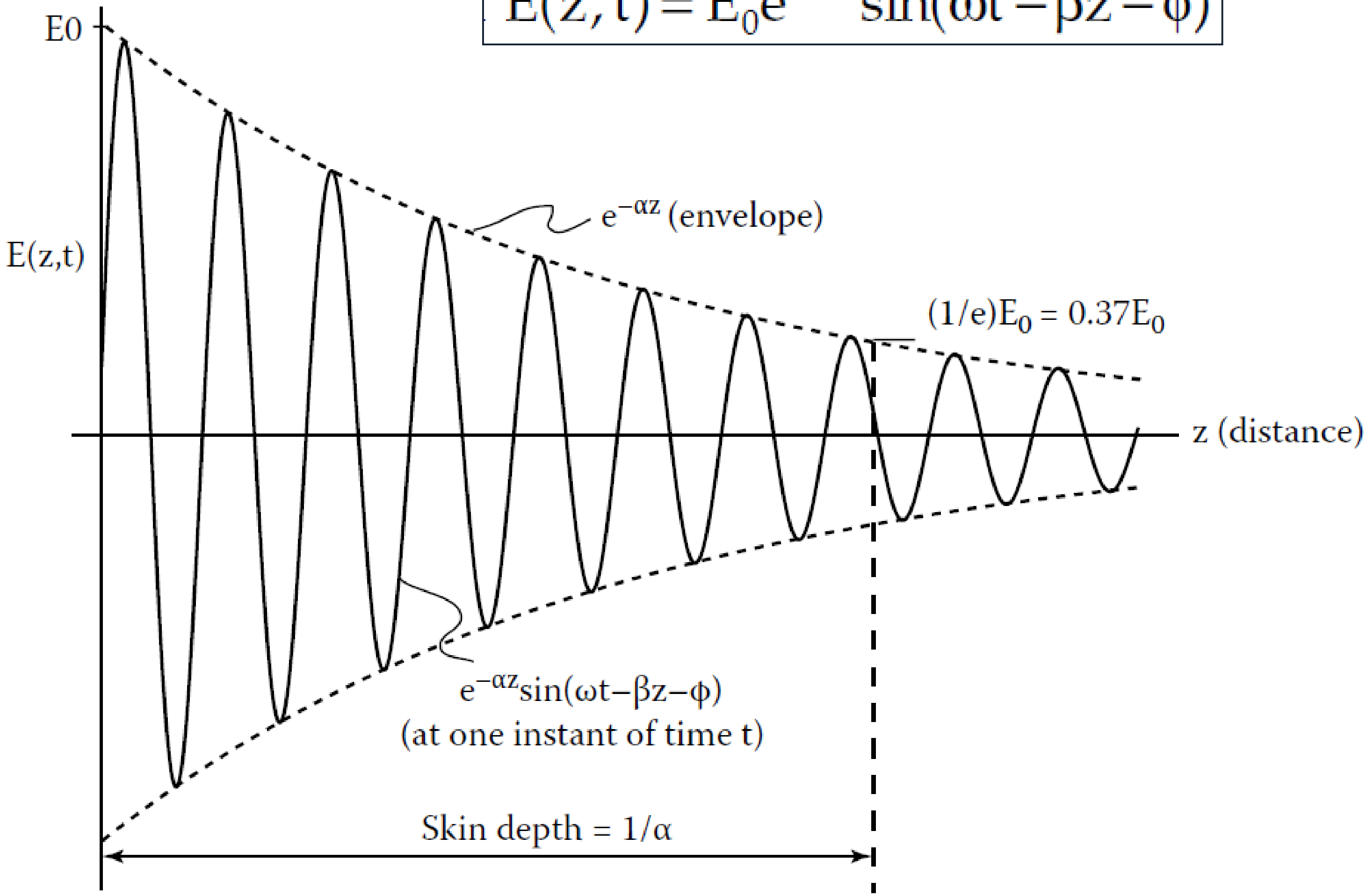
Example:



$$E(z,t) = E_0 e^{-\alpha z} \sin(\omega t - \beta z - \phi)$$

Propagation in Biological Media

$$E(z,t) = E_0 e^{-\alpha z}\sin(\omega t - \beta z - \phi)$$

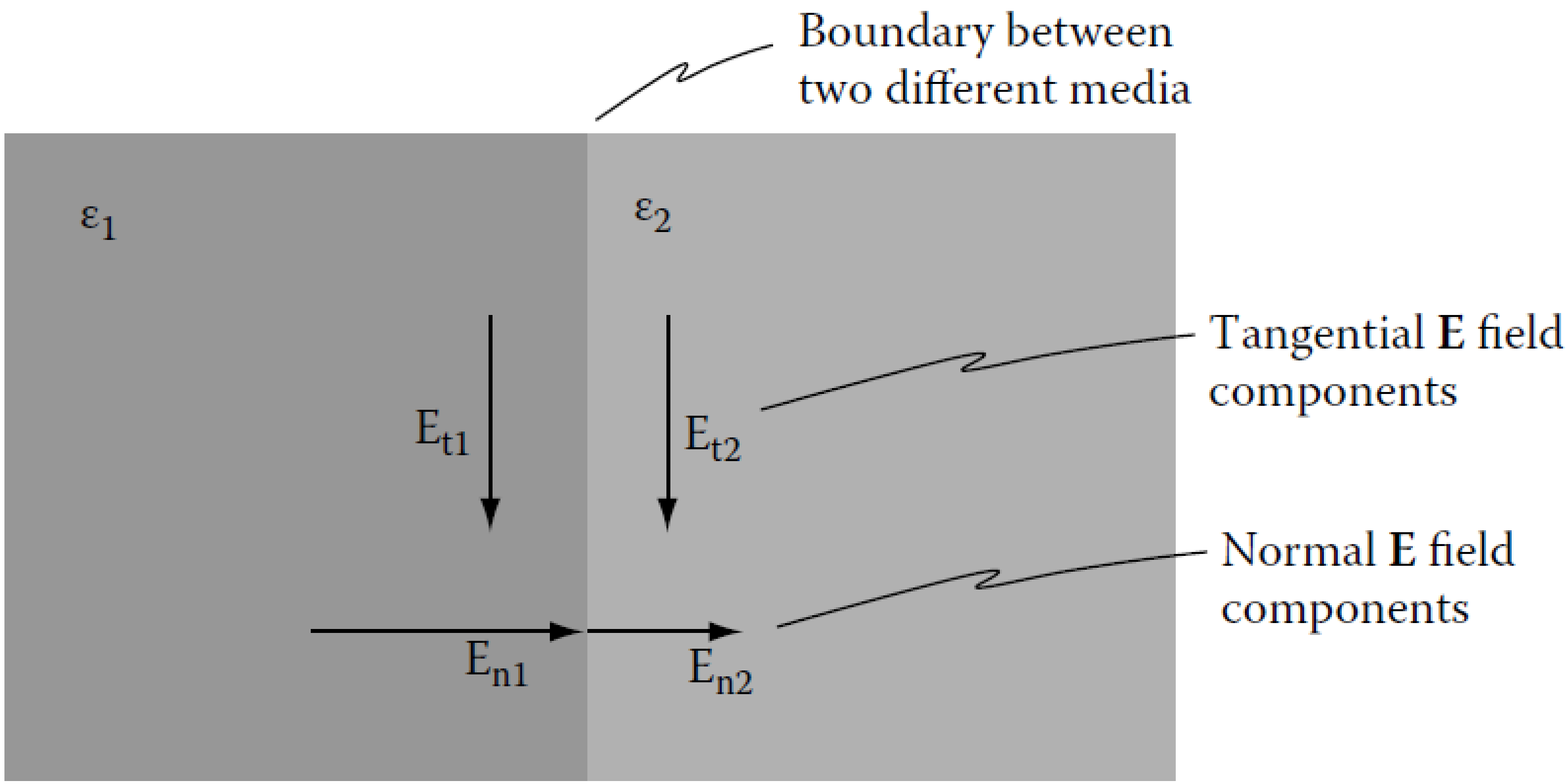


$$\alpha = \omega\sqrt{\frac{\mu'\varepsilon'}{2}\left(\sqrt{1+\left(\frac{\sigma_{eff}}{\omega\varepsilon'}\right)^2} - 1\right)} \cdot \ (\mathrm{Np/m})$$

$$\beta = \omega\sqrt{\frac{\mu'\varepsilon'}{2}\left(\sqrt{1+\left(\frac{\sigma_{eff}}{\omega\varepsilon'}\right)^2} + 1\right)} \cdot \ (\mathrm{rad/m})$$

$$\sigma_{eff} = \sigma_c + \omega\varepsilon_{b,imag}$$

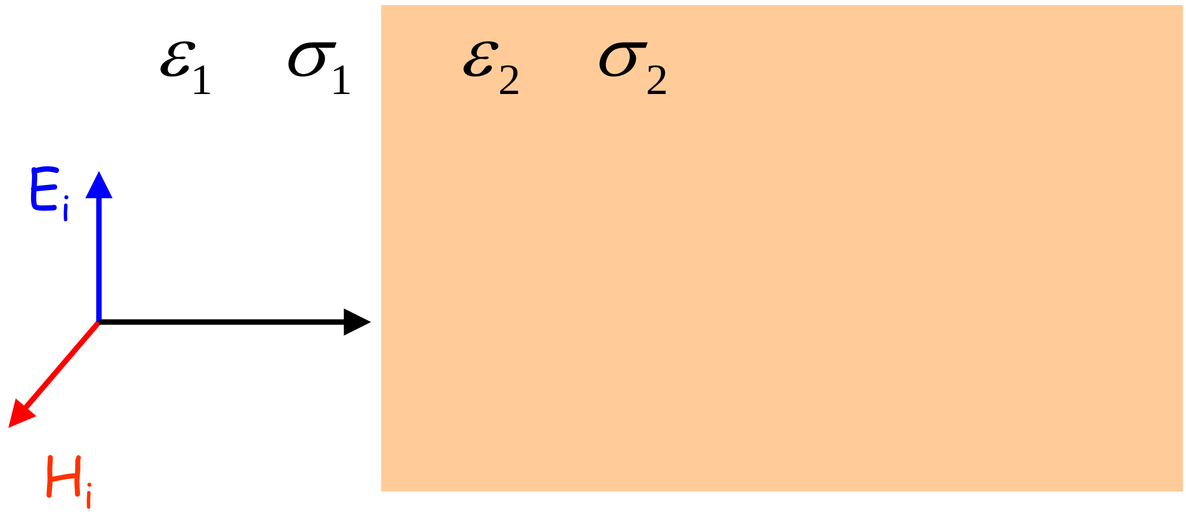
Propagation in Biological Media

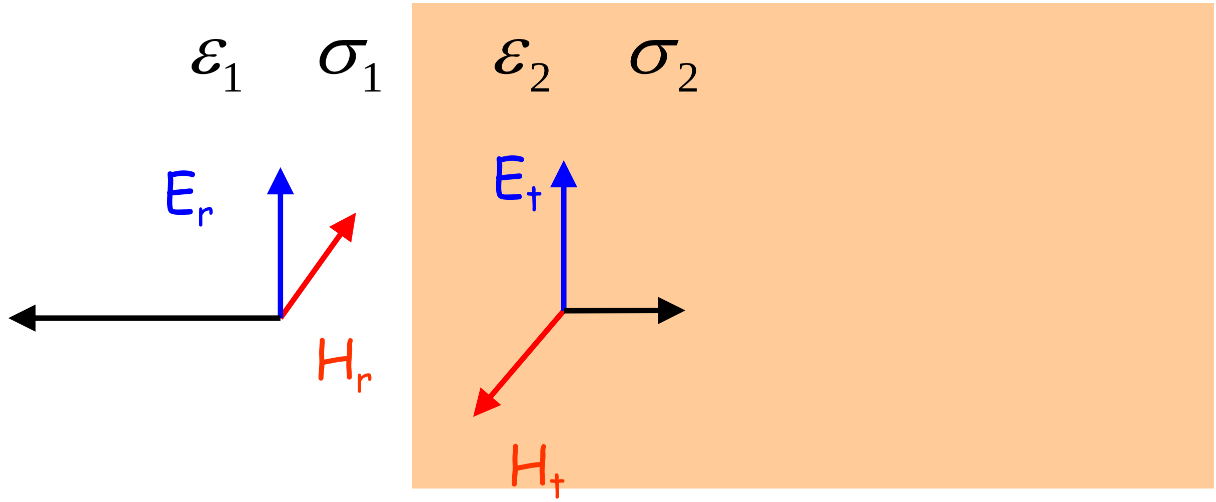


$$E_{t1} = E_{t2}$$
$$\varepsilon_1 E_{n1} = \varepsilon_2 E_{n2}$$

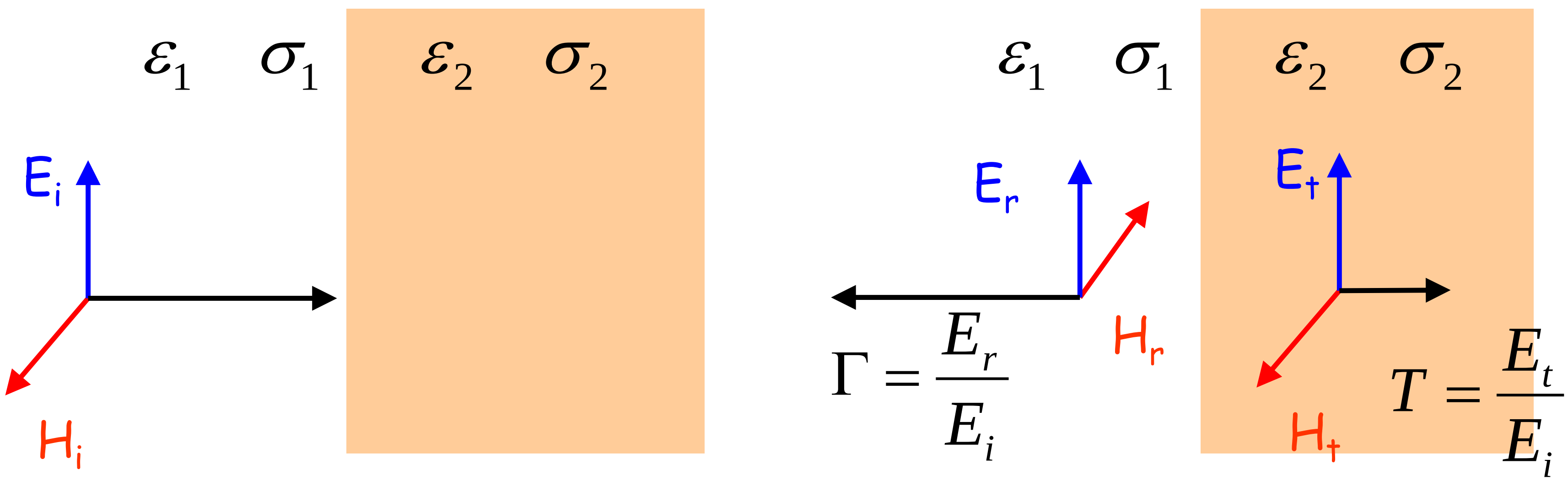
Required boundary conditions

Propagation in Biological Media





Propagation in Biological Media



$$\Gamma = \frac{E_r}{E_i}$$

$$T = \frac{E_t}{E_i}$$

Transmission and reflection coefficients

$$\Gamma = \frac{\eta_2 - \eta_1}{\eta_2 + \eta_1}$$

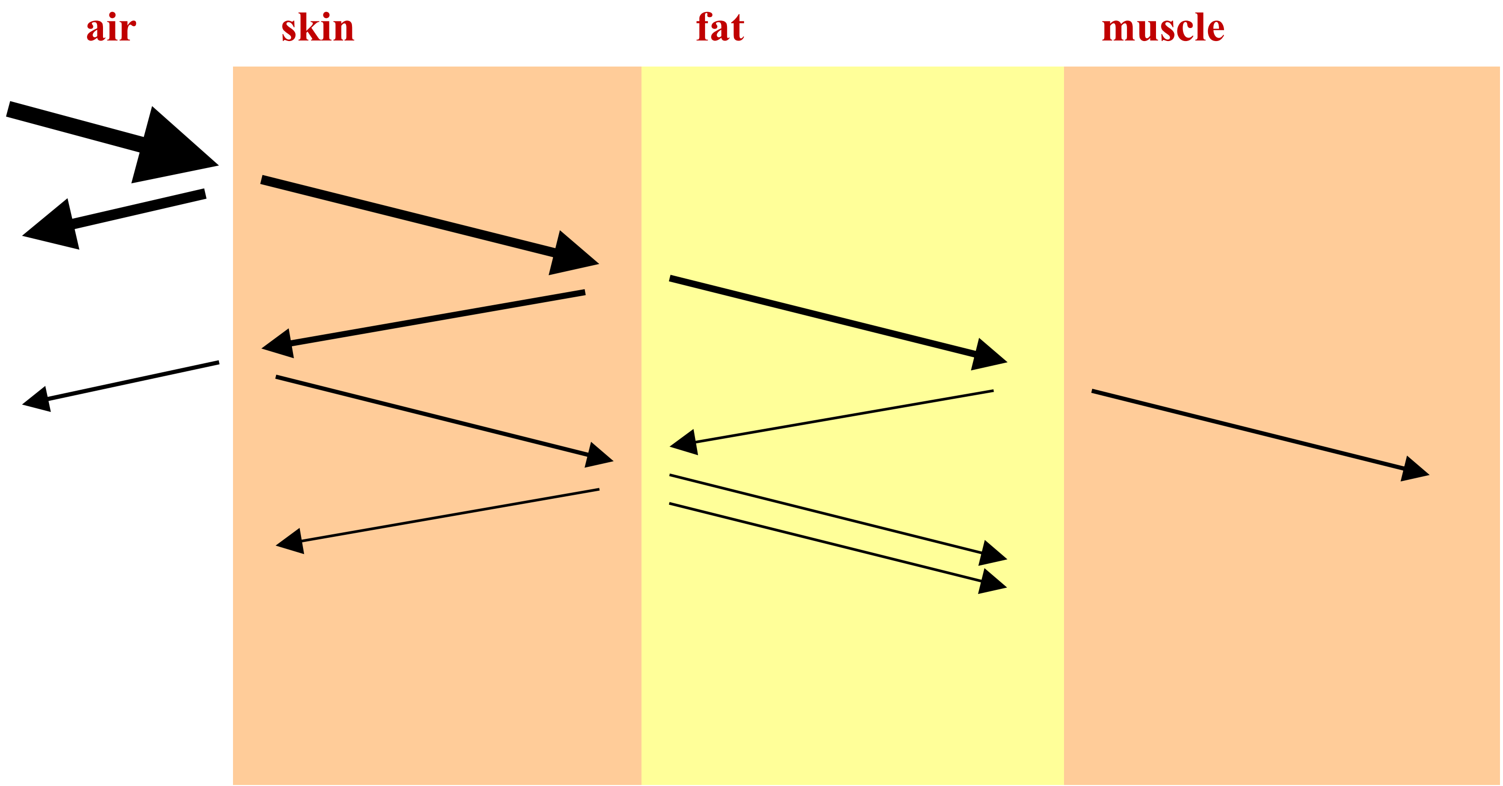
$$\begin{cases} T_E = \dfrac{2\eta_2}{\eta_2 + \eta_1} = 1 + \Gamma \\ T_M = 1 - \Gamma \end{cases}$$

$$\eta = \left(\frac{jw\mu}{\sigma + jw\varepsilon} \right)^{1/2}$$

$$T_E \times T_M = 1 - |\Gamma|^2 = |\tau|^2$$

$$|\Gamma|^2 + |\tau|^2 = 1$$

Propagation in Biological Media



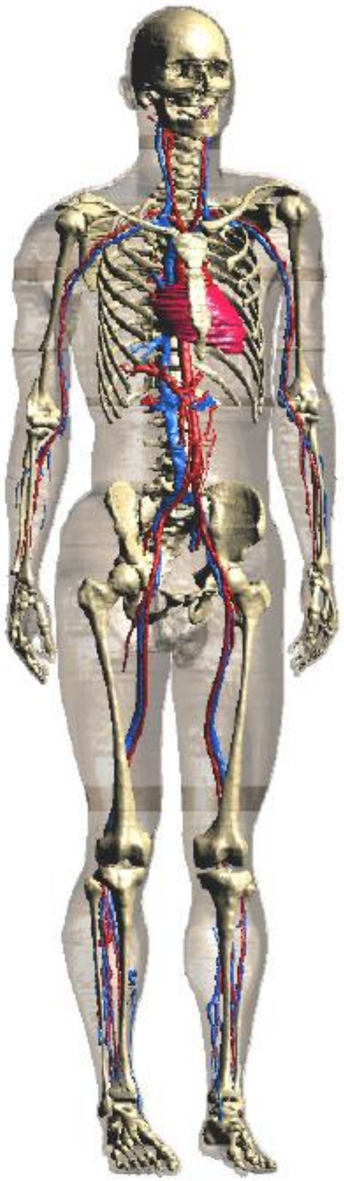
Body Tissues

O The electrical properties of human tissues control the propagation, reflection, attenuation, and other behavior of electromagnetic fields in the body.

O These properties depend strongly on the tissue type and the frequency of interest.

O Temperature, blood or fluid perfusion, and individual differences are second-order effects that are normally not considered.

O The body is so weakly magnetic that generally μ_r is assumed to be 1, except for magnetic resonance imaging and spectroscopy applications where a very large magnetic field is used.

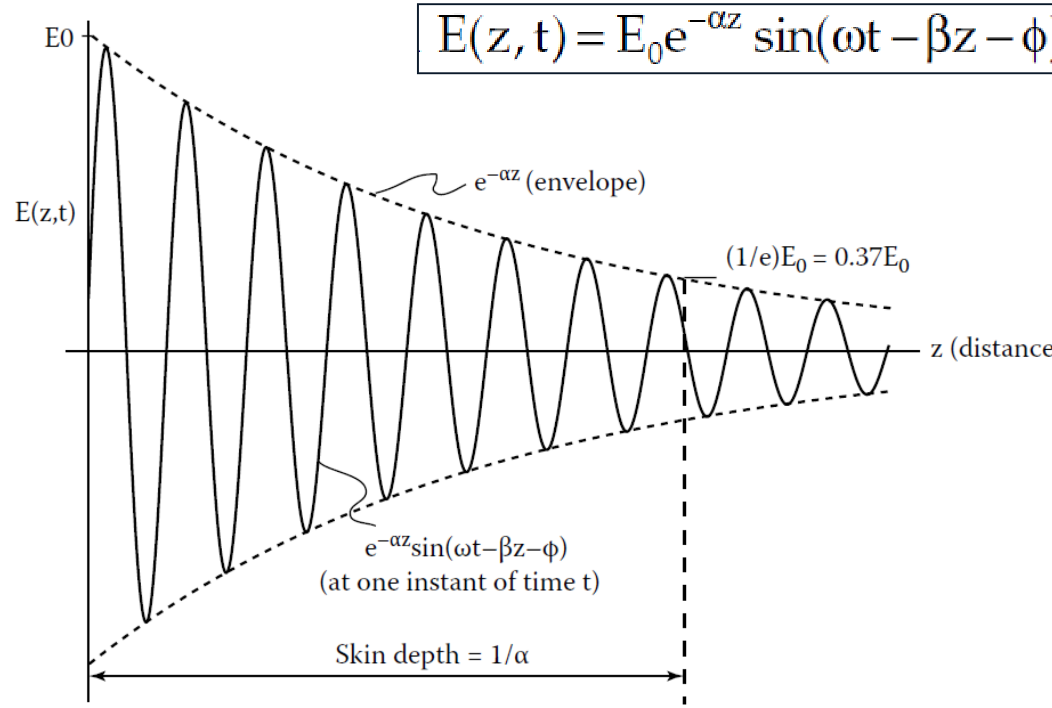


Body Tissues

- The electrical properties of the body (εr and σeff) control the wavelength and attenuation. The attenuation of the field is calculated as $e^{-\alpha z}$, where z is the distance the wave must propagate through that tissue.

- The higher-water-content (higher-conductivity) tissues have more attenuation.

$$E(z,t) = E_0 e^{-\alpha z} \sin(\omega t - \beta z - \phi)$$



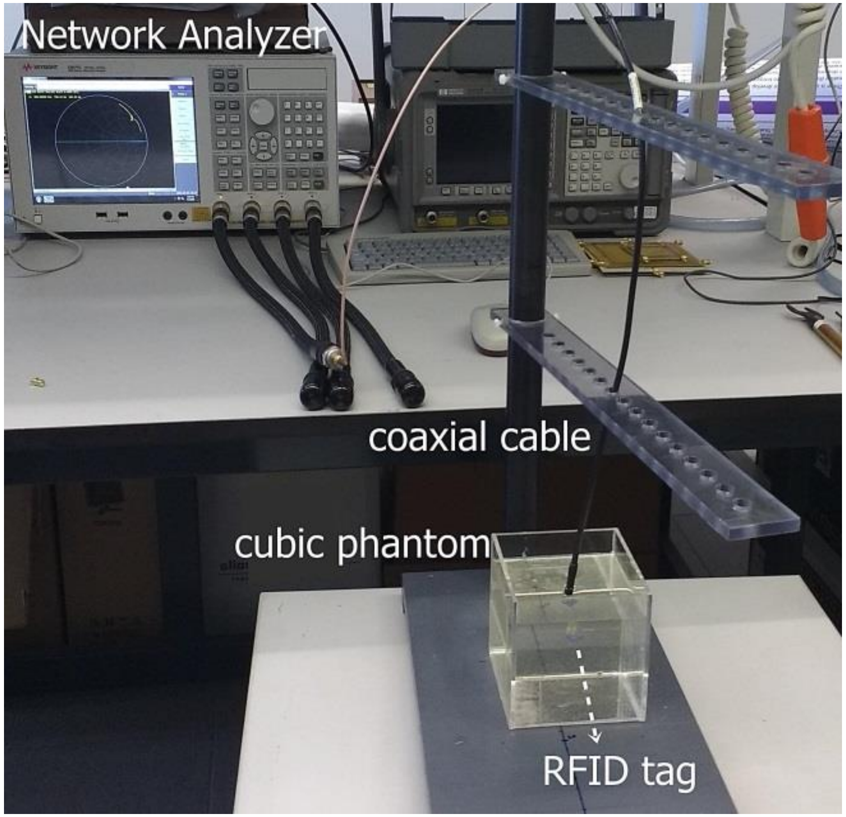
$$\alpha = \omega \sqrt{\frac{\mu'\varepsilon'}{2}\left(\sqrt{1+\left(\frac{\sigma_{eff}}{\omega\varepsilon'}\right)^2}-1\right)} \quad (\mathrm{Np/m})$$

$$\beta = \omega \sqrt{\frac{\mu'\varepsilon'}{2}\left(\sqrt{1+\left(\frac{\sigma_{eff}}{\omega\varepsilon'}\right)^2}+1\right)} \quad (\mathrm{rad/m}) \qquad \sigma_{eff} = \sigma_c + \omega\varepsilon_{b,imag}$$

In the Lab?

O Electromagnetic measurements such as assessment of cellular telephones, evaluation of the performance of telemetry (communication) devices implanted in the body, or other measurement applications often require body-simulating materials.

O These can be solid, semisolid, or (most commonly) liquid materials that have electrical properties that mimic those of human tissues.



Body Tissues

Federal Communications Commission
Office of Engineering & Technology

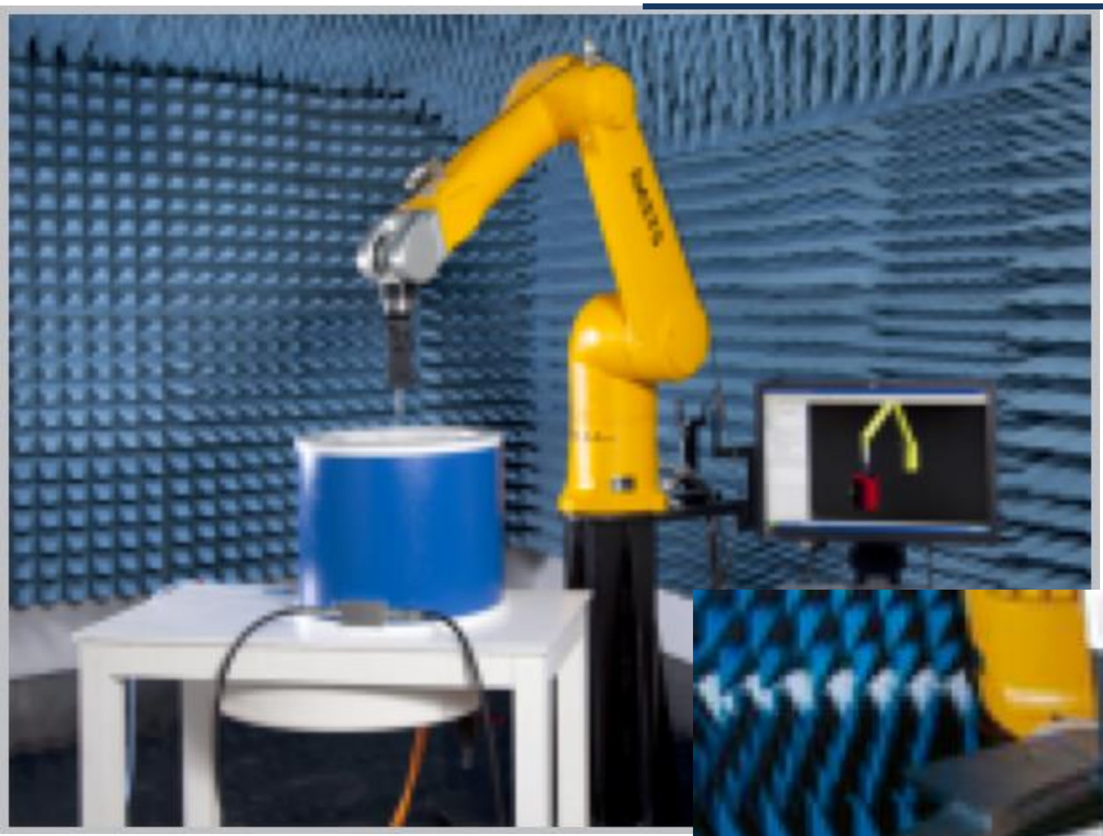
Evaluating Compliance with FCC Guidelines for Human Exposure to Radiofrequency Electromagnetic Fields

INGREDIENTS FOR LIQUID TISSUE PHANTOMS

Ingredients (% by weight)	Frequency (MHz)									
	450		835		915		1900		2450	
Tissue Type	Head	Body	Head	Body	Head	Body	Head	Body	Head	Body
Water	38.56	51.16	41.45	52.4	41.05	56.0	54.9	40.4	62.7	73.2
Salt (NaCl)	3.95	1.49	1.45	1.4	1.35	0.76	0.18	0.5	0.5	0.04
Sugar	56.32	46.78	56.0	45.0	56.5	41.76	0.0	58.0	0.0	0.0
HEC	0.98	0.52	1.0	1.0	1.0	1.21	0.0	1.0	0.0	0.0
Bactericide	0.19	0.05	0.1	0.1	0.1	0.27	0.0	0.1	0.0	0.0
Triton X-100	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	36.8	0.0
DGBE	0.0	0.0	0.0	0.0	0.0	0.0	44.92	0.0	0.0	26.7
Dielectric Constant	43.42	58.0	42.54	56.1	42.0	56.8	39.9	54.0	39.8	52.5
Conductivity (S/m)	0.85	0.83	0.91	0.95	1.0	1.07	1.42	1.45	1.88	1.78

Salt: 99^{+}% Pure Sodium Chloride
Sugar: 98^{+}% Pure Sucrose
Water: De-ionized, 16 $M\Omega^{+}$ resistivity
HEC: Hydroxyethyl Cellulose
DGBE: 99^{+}% Di(ethylene glycol) butyl ether, [2-(2-butoxyethoxy)ethanol]
Triton X-100 (ultra pure): Polyethylene glycol mono [4-(1,1, 3, 3-tetramethylbutyl)phenyl]ether

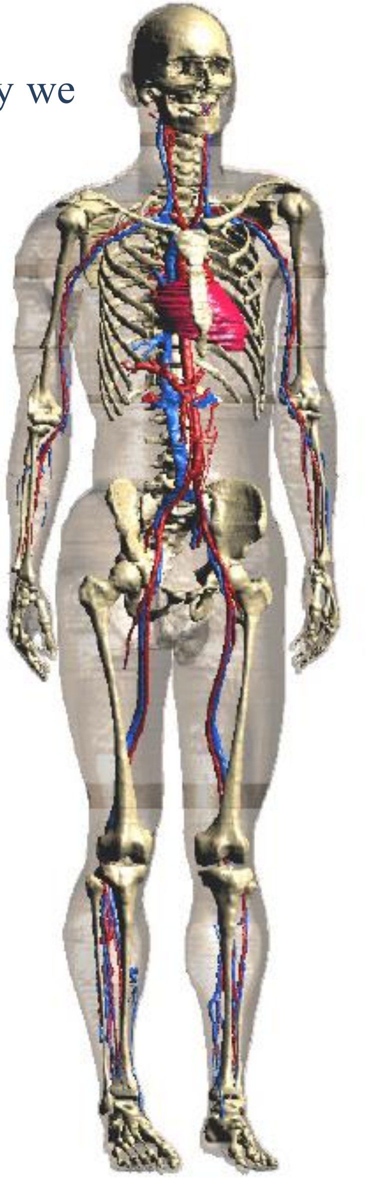
Body Tissues



Schmid & Partner Engineering AG

Dosimetry

To analyze the interaction between electromagnetic radiation and the human body we define a new physical magnitude: **the specific absorption rate**.



The specific absorption rate (SAR) is defined as transferred power divided by the mass of the object. Specific refers to the normalization to mass, and absorption rate to the rate of energy absorbed by the object.

For sinusoidal steady-state EM fields the time-average SAR is given by:

$$SAR = \sigma_{eff} E_{rms}^2/\rho \quad (W/kg)$$

where ρ is the mass density of the object in kg/m^3, which is close to 1.0 kg/m^3 for most biological tissues (except for lung, which is about 0.347 kg/m^3). E_{rms} is the root mean square (rms) value of the electric field E at that point. This equation is a point relation, because it applies only at the given point where E has that particular value.

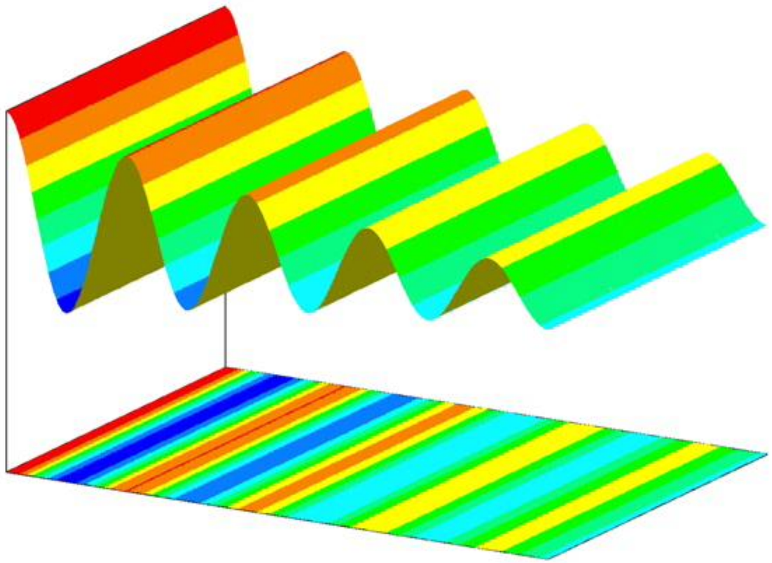
Dosimetry

$$SAR = \sigma_{eff}\, E_{rms}^{2}/\rho \quad (W/kg)$$

The SAR varies directly with σ_{eff}.

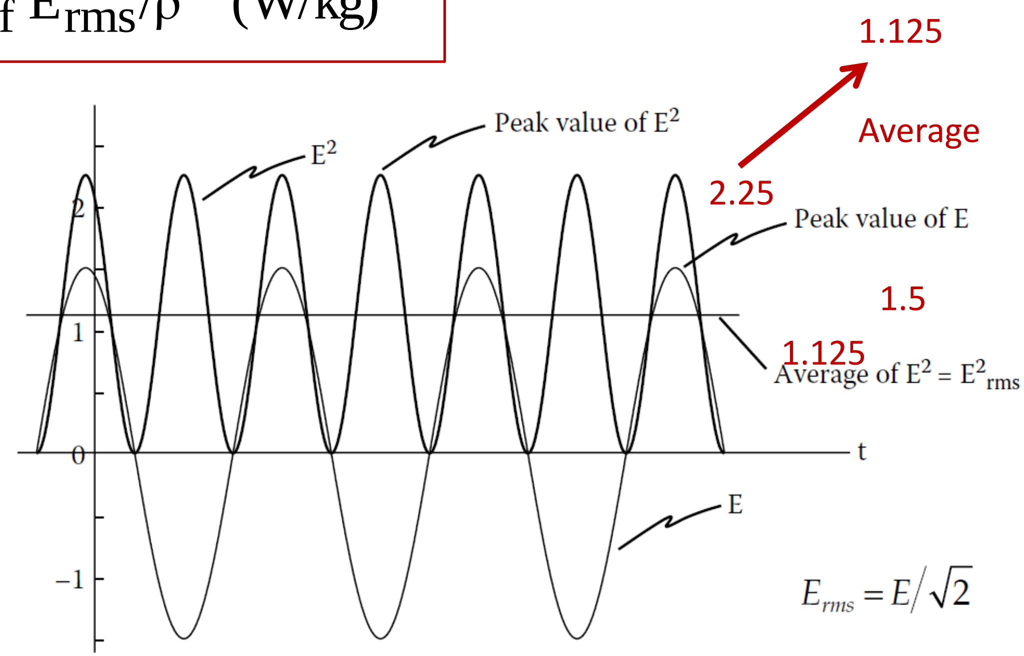
A tissue with higher water content, such as muscle, is more lossy for a given E field magnitude than drier tissue, such as bone and fat.

The higher the frequency, the higher σ_{eff}, due to the part of the loss caused by the motion of the bound charges. If the same field were present at both high and low frequencies, the power absorbed would be higher at the higher frequencies. The high frequencies attenuate more as they propagate through tissues than the low frequencies, however, so in general much less field is present at high frequencies.



$$SAR = \sigma_{eff}\, E^2_{rms}/\rho \quad (W/kg)$$

In many instances, it is convenient to describe time-varying fields in terms of their root mean square (rms) values. Of particular importance is the use of rms values in describing average power, which most EM equipment measures. The relationship between average power and rms values is illustrated in the figure.



The instantaneous (not average) power transferred to tissue by a time-varying E field is proportional to E^2 at any instant of time. For example, if E is a sinusoidal function of time, the instantaneous power transferred will be proportional to the square of a sine wave, as shown in figure.

The rms value is also called the effective value. In general, as given by its name, the rms value of a function is defined as the square root of the mean of the square of the function. Thus, to find the rms value of a given function, first square it, then find the mean (average) of the squared function, then take the square root of that. For sinusoidal functions, this procedure always gives an rms value that is equal to the peak value divided by 2.

Dosimetry

O The temperature rise in tissue is determined by the rate of electromagnetic power deposition in the tissue.

The temperature rise is predicted by the **bioheat equation**:

$$\rho\, c \frac{dT}{dt} = \nabla \cdot (k \nabla T) + \left[-\rho_b\, w\, c_b \left(T - T_b\right)\right] + Q_m + SAR\, \rho$$

where the different values for r (material density), c (heat capacity), k (thermal conductivity), w (perfusion by blood), and Q_m (heat generated by metabolism).

Heat capacity or thermal capacity, is the measurable physical quantity that characterizes the amount of heat required to change a substance's temperature by a given amount.

Thermal conductivity is the property of a material's ability to conduct heat.

In physiology, perfusion is the process of delivery of blood to a capillary bed in the biological tissue.

STANDARS FOR SAFETY

Radio Signals

↓

The absorption may produce heating

↓

NO increases of more than 1^0 C (person at rest)

↓

This is obtained for a SAR value of 4 W/Kg during 6 minutes

Principal Organizations

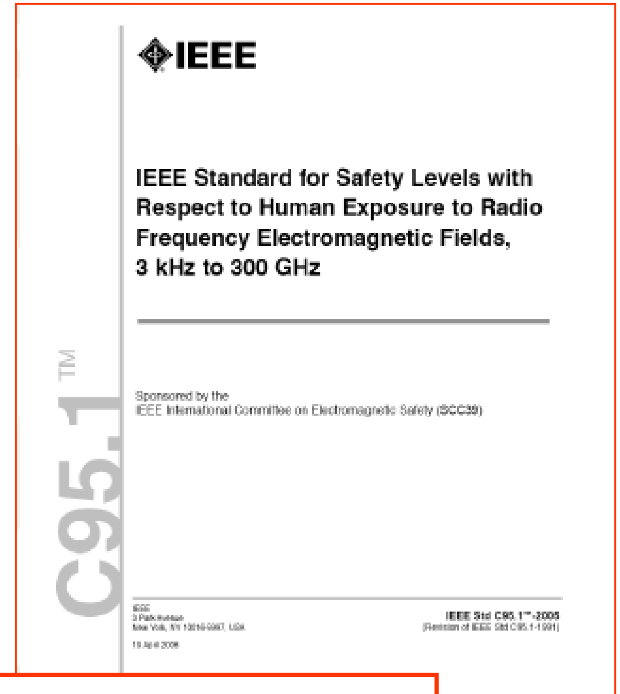
- **Institute of Electrical and Electronics Engineers (IEEE)**
- **International Commission on Non-Ionizing Radiation Protection (ICNIRP)**
- **Federal Communications Commission (FCC)**

Dosimetry

Standard for safety levels with respect with human exposure to EM Fields.

- 1998, ICNIRP.
- 1999, FCC based on ANSI/IEEE C95.1-1999.

- 2005, European Standard EN 62209-1
- 2005, IEEE C95.1-2005


IEEE

IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz

Sponsored by the
IEEE International Committee on Electromagnetic Safety (SCC39)

C95.1™

Dosimetry

Types of exposure:

Occupational ⇨ **Controlled exposure**

*The person is aware of the exposure.

*The person is trained and knows the procedures.

*There are security measures.

*Short-time exposure, periodic exposure.

Dosimetry

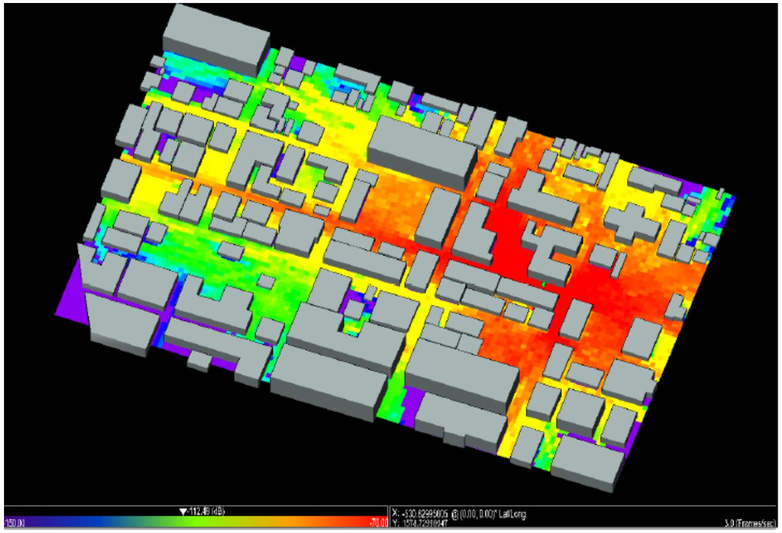
Types of exposure:

General → **Not controlled exposure**

*The person is not aware of the exposure.

*There are no security measures.

*Continuous exposure.



Dosimetry

Due to the difficulty of measuring the SAR, there were restrictions of other pre-existing electromagnetic variables which can be measured:

- **Electric field strength**
- **Magnetic field strength**
- **Power density**

The established limits are referred to as "reference levels"

Electromagnetic regulations

Exposure category	Frequency range	E-field strength (V/m rms)	H-field strength (A/m rms)
Occupational	100 kHz – 1 MHz	614	1.63 / *f*
	1 MHz – 10 MHz	614 / *f*	1.63 / *f*
	10 MHz – 400 MHz	61.4	0.163
	400 MHz – 2 GHz	$3.07 \times f^{0.5}$	$0.00814 \times f^{0.5}$
	2 GHz – 300 GHz	137	0.364
General public	100 kHz – 150 kHz	86.8	4.86
	150 kHz - 1 MHz	86.8	0.729 / f
	1 MHz - 10 MHz	$86.8 / f^{0.5}$	0.729 / f
	10 MHz – 400 MHz	27.4	0.0729
	400 MHz – 2 GHz	$1.37 \times f^{0.5}$	$0.00364 \times f^{0.5}$
	2 GHz – 300 GHz	61.4	0.163

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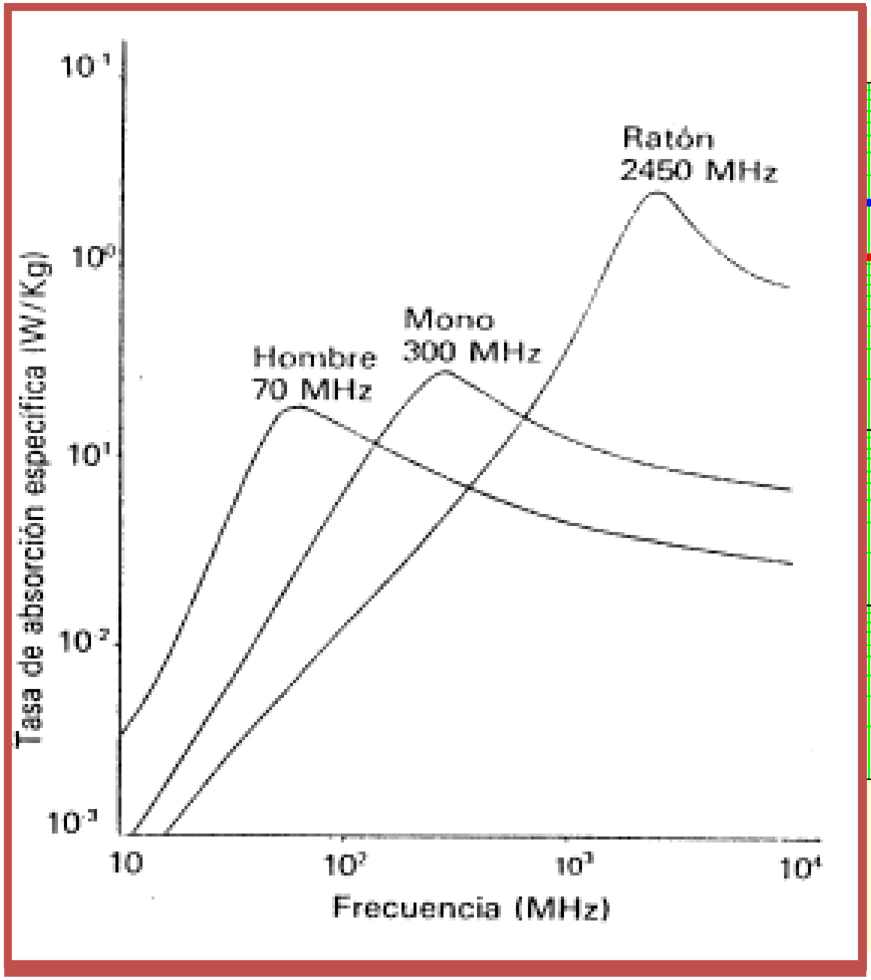
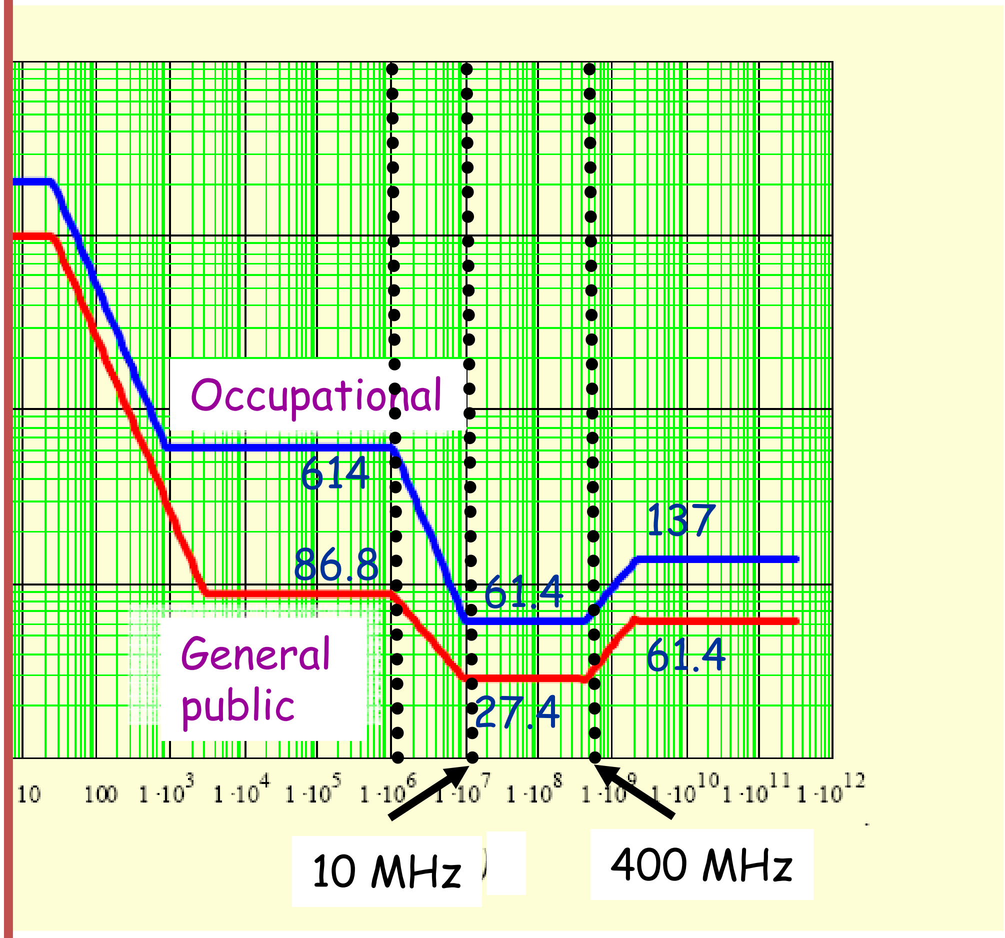
Electromagnetic regulations





Dosimetry

Local SAR

Thermoregulation effect

Average SAR

Dosimetry

Up to 10 GHz

	Controlled / Occupational	Uncontrolled / General Public
Whole Body Averaged SAR	0.4 W/kg	0.08 W/kg
Spatial peak *1 -Head & Torso	10 W/kg	2 W/kg
Spatial peak *1 -Limbs	20 W/kg	4 W/kg

*1. SAR measured in a 10 gram cube of tissue

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Dosimetry

From 10 GHz to 300 GHz

	Controlled / Occupational	Uncontrolled / General Public
Equivalent plane wave power flux density S	**50 W/m²**	**10 W/m²**

Multiple Sources

$$\sum_{i=100\,kHz}^{10\,GHz} \frac{SAR_i}{SAR_L} + \sum_{i>10\,GHz}^{300\,GHz} \frac{S_i}{S_L} \leq 1$$

Dosimetry

Comparison of SAR Limits Non-occupational/General Public

EMC Technologies

	Australia ARPANSA	USA	Europe (ICNIRP)	Japan	New Zealand
	ACMA	ANSI C95.1	EN50360	ARIB-T56	NZS2772.1
Whole Body	0.08 W/kg	0.08 W/kg	0.08 W/kg	0.04 W/kg	0.08 W/kg
Spatial Peak	1.6 W/kg	1.6 W/kg	2 W/kg	2 W/kg	2 W/kg
Averaging Time	6 min	30 min	6 min	6 min	6 min
Averaging Time	1 g	1g	10g	10g	10g
Shape	Cube	Cube	Cube	Cube	Cube

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8

iPhone FAQ
News, reviews, tips, guides, and more.

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What is the SAR (Specific Absorption Rate) of my Apple iPhone?

Your iPhone is a radio device, and therefore regularly emits energy at wavelengths of 850MHz or 1900MHz to keep contact with cellular towers.

The US FCC (Federal Communications Commission) and the US FDA (Food and Drug Administration) have established limits for safe exposure to radio frequency (RF) energy. These limits are given in terms of a unit known as the Specific Absorption Rate (SAR), a measure of how much radio energy is absorbed by your body when using a mobile phone.

The FCC limit for public exposure from mobile phones is an SAR level of 1.6 watts per kilogram. Any cellular phones legally sold in the US must have SAR levels of 1.6 W/kg or less to be considered safe for consumers. These standards also apply to Bluetooth and Wi-Fi connections.

Apple iPhone SAR levels are listed below for all models in W/kg:

Original iPhone: 0.974 (FCC ID: BCGA1203)
iPhone 3G: 1.38 (FCC ID: BCGA1241)
iPhone 3GS: 0.79 (FCC ID: BCGA1303A)
iPhone 4 GSM: 1.17 (FCC ID: BCG-E2380A)
iPhone 4 CDMA: 1.18 (FCC ID: BCG-E2422A)
iPhone 4S: 1.11 (FCC ID: BCG-E2430A)

Dosimetry

iPhone
News, reviews, tips, guides, and more.

SAR (FCC e IC)

Banda de frecuencia (MHz)	Límite SAR 1 g FCC e IC (W/kg)	Valor máximo (W/kg)
Modelo A1395		
2400–2483,5	1,6	0,99
5150–5250	1,6	0,81
5250–5350	1,6	0,78
5500–5700	1,6	0,80
5725–5850	1,6	0,51
Modelo A1396		
824–849	1,6	1,18
1850–1910	1,6	1,19
2400–2483,5	1,6	1,07
5150–5250	1,6	0,79
5250–5350	1,6	0,82
5500–5700	1,6	0,68
5725–5850	1,6	0,62

SAR (UE)

Banda	Banda de frecuencia (MHz)	Límite SAR UE 10 g (W/kg)	Valor máximo (W/kg)
Modelo A1395			
Wi-Fi 2,4 GHz	2400–2483,5	2	0,69
Wi-Fi 5 GHz	5150–5350	2	0,68
	5470–5725	2	0,76
Modelo A1396			
EGSM 900	880,2–914,8	2	0,84
GSM 1800	1710–1784,8	2	0,93
UMTS Band VIII	880–915	2	0,98
UMTS Band I	1922,4–1977,6	2	0,95
Wi-Fi 2,4 GHz	2400–2483,5	2	0,70
Wi-Fi 5 GHz	5150–5350	2	0,69
	5470–5725	2	0,72