



Effetti biologici delle Radio Frequenze impiegate in Telecomunicazioni

Massimiliano Pieraccini



Salute

500 milioni di utenti di telefoni cellulari

Previsione: 1 miliardo di utenti nel 2005

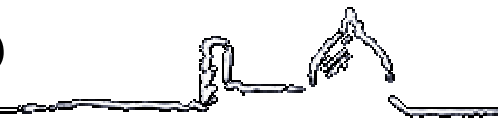
Utilità

Interessi economici



15000 articoli scientifici (2002)

Lo standard GSM (Global System for Mobile Communication)



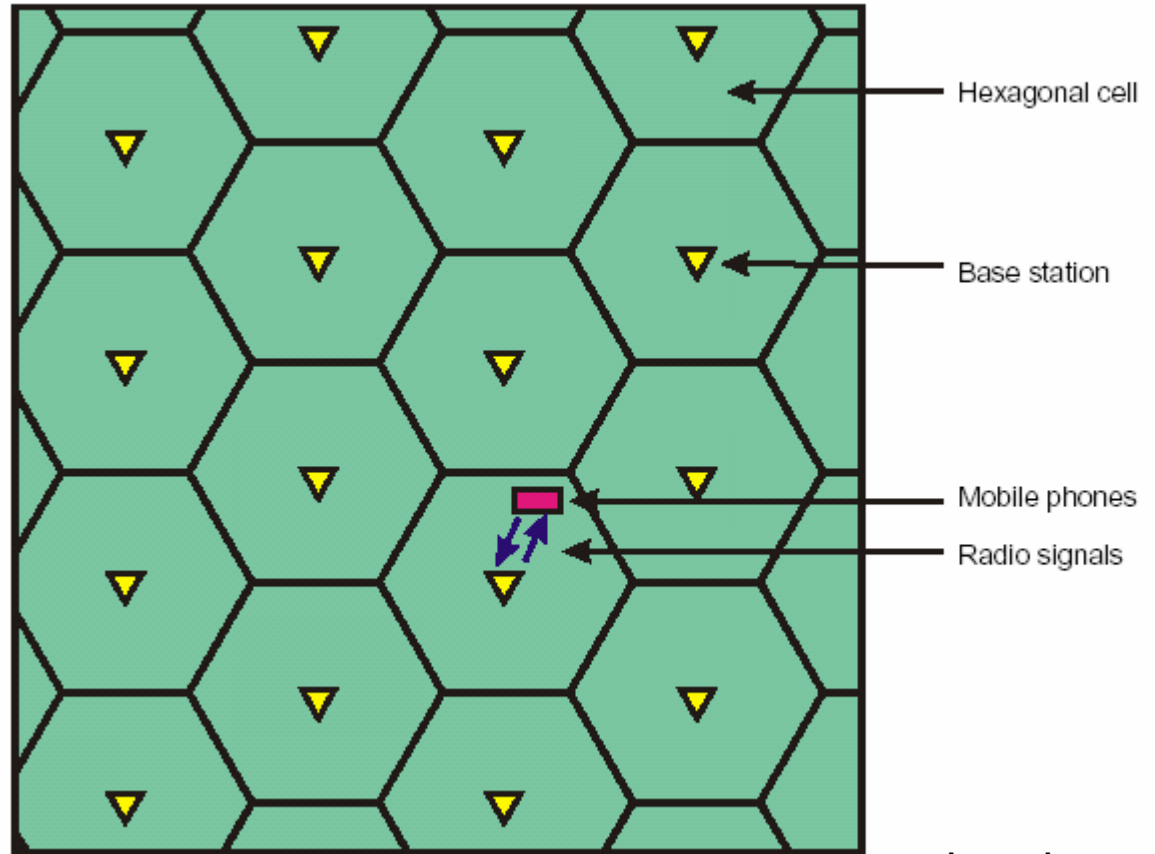
GSM900 900 MHz 2W

GSM1800 1800 MHz 1W

- Macrocelle
 >10 W – 35Km

- Microcelle
 100 m

- Picocelle
 edifici



handover



1) GSM900

70 MHz di banda allocata a 900MHz

Banda per ciascun canale 200 KHz 

uplink

880-915 MHz

downlink

925-960 MHz

350 canali (di cui uno di servizio)

2) GSM1800

150 MHz di banda allocata a 1800MHz

Banda per ciascun canale 200 KHz 

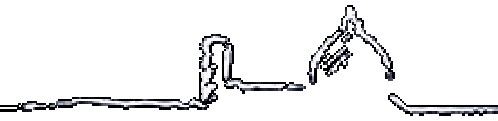
uplink

1710-1785 MHz

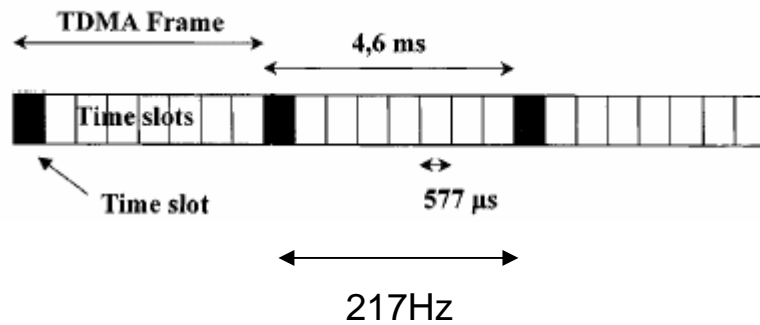
downlink

1805-1880 MHz

750 canali (di cui uno di servizio)

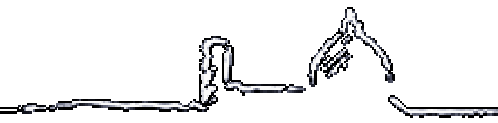


1) TDMA (Time Domain Multiple Acces)



8 slot di cui uno di servizio

(il cell. trasmette con un duty cycle di $1/8$)



2) APC (Adaptive Power control)

30 dB a step di 2dB

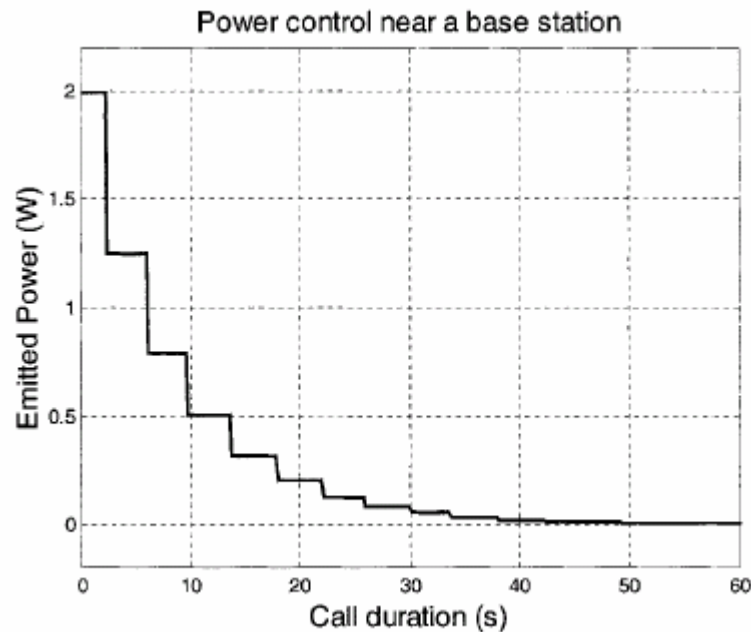
33 dBm

3 dBm

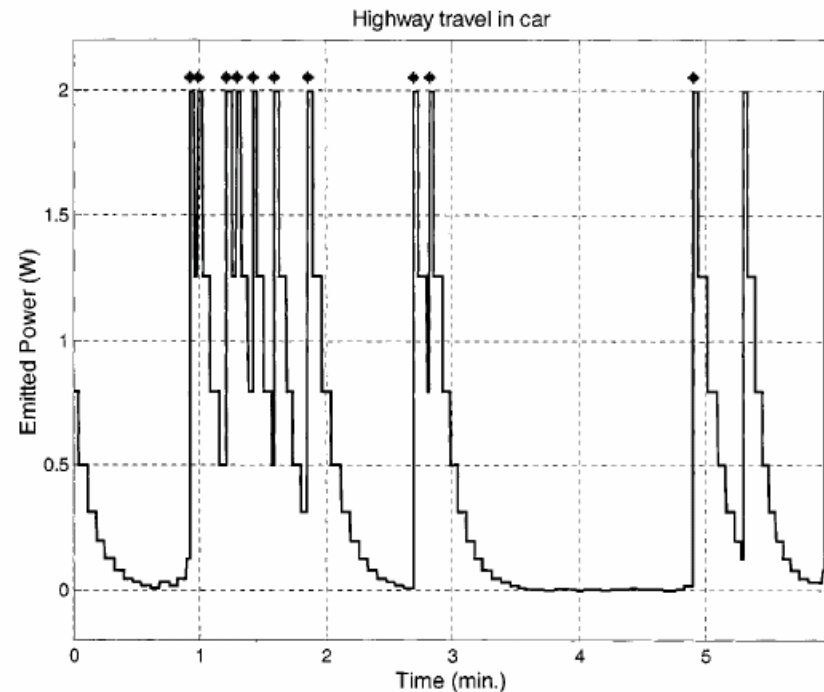
Ogni 13 TDMA frames (60 ms),

in teoria può raggiungere il minimo in meno di un secondo,

In pratica gli algoritmi delle stazioni base impiegano circa 1 minuto



handover





3) DTX (Discountinuos Transmission)

Quando l'interlocutore non parla viene trasmesso un singolo SID (Silence Descriptor) con i parametri del rumore di conforto (comfort noise)

Il SID è trasmesso alla frequenza di circa 2Hz, mentre un segnale SACCH (Slow Associated Control Channel) viene trasmesso a circa 8 Hz

Considerando che una normale conversazione ha il 50% di pause, il protocollo DTX riduce la potenza di circa il 30% (-1dB)



GSM900

P=2W

/8

X 0.7

$$\overline{P}_{900} = 175mW$$

22 dBm

GSM1800

P=1W

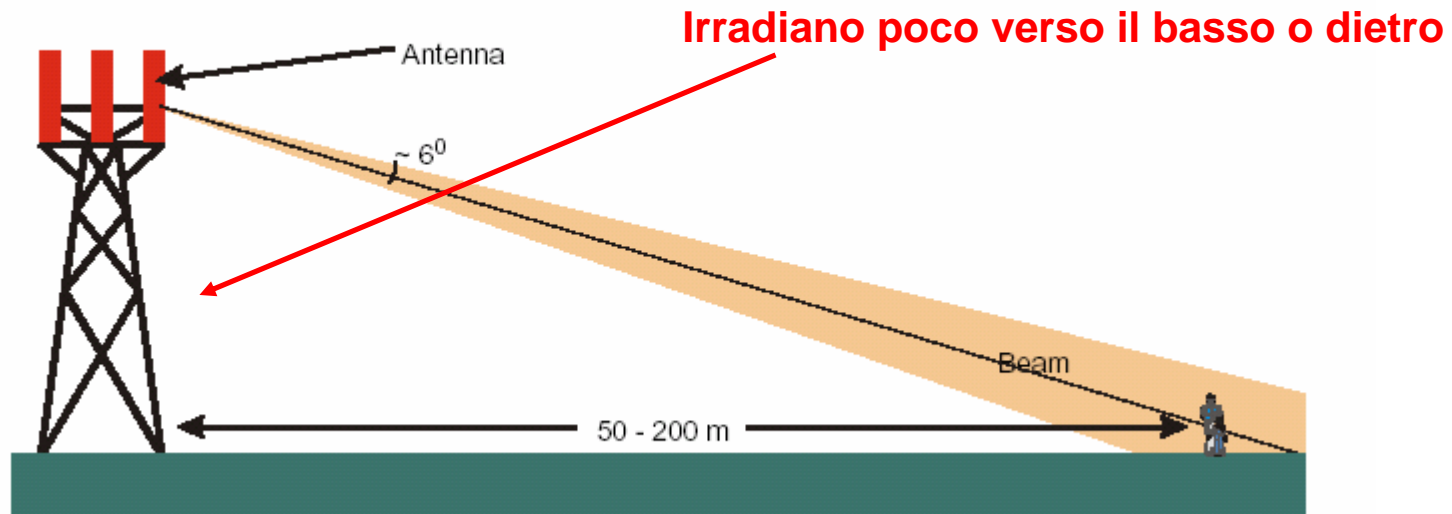
/8

X 0.7

$$\overline{P}_{1800} = 88mW$$

19 dBm

Stazioni base

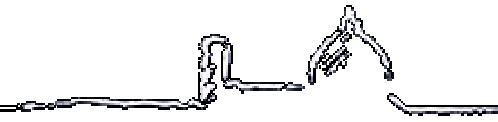


EIRP=Equivalent Isotropically radiated power

EIRP=Guadagno di antenna x Potenza

G=40-60

$$I = \frac{EIRP}{4\pi R^2} \quad \left(\frac{W}{m^2} \right)$$



EIRP < 1500W per canale \longrightarrow 30-40 W per canale

Max 16 canali per GSM1800

Max 10 canali per GSM900

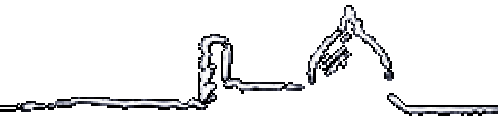
In pratica < 4 canali per antenna

Esempio:

Calcolare la distanza alla quale l'intensità è inferiore a 6 W/m² per una stazione base che trasmette EIRP=1500W su 16 canali

$$\frac{1500 \times 16}{4\pi R^2} = 6 \longrightarrow R = 18 \text{ m}$$

Tipicamente una stazione base urbana EIRP < 100W per canale



$$R_{far\ field} = \frac{2D^2}{\lambda}$$

D= 1m

$\lambda=0.33$ m



R=6m



Radiazioni ionizzanti

(ultravioletto-raggi X-raggi gamma)

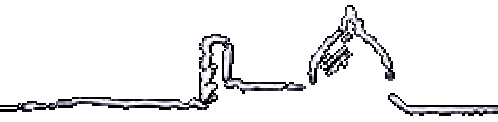
$$E_{\text{fotone}} \approx 1eV$$

Radiazioni non-ionizzanti

(infrarosso-onde millimetriche-microonde-RF)

Effetti termici

Effetti non-termici



- Perdite ohmiche degli ioni liberi nel fluido cellulare
- Moti rotazionali delle molecole biologiche polari

Specific Absorption Rate W/Kg

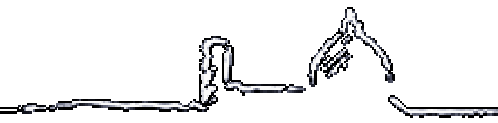
$$SAR = \frac{1}{VT} \int \frac{\sigma |E|^2}{\rho} dV dt$$

T=tempo di integrazione

V= volume di integrazione

σ =conducibilità (S/m)

ρ =densità (Kg/m³)



$$SAR = \frac{\sigma E_{eff}^2}{\rho} \quad \longrightarrow \quad E_{eff} = \sqrt{\frac{\rho SAR}{\sigma}} \quad (\text{all'interno del corpo})$$

$$E_1 = \left| \frac{\sqrt{\epsilon_r} - 1}{\sqrt{\epsilon_r} + 1} \right| E_0$$

$$E_2 = \left(1 - \left| \frac{\sqrt{\epsilon_r} - 1}{\sqrt{\epsilon_r} + 1} \right| \right) E_0$$

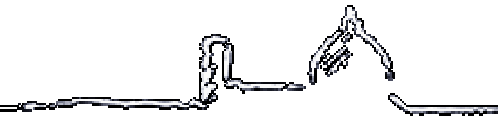
ϵ_r

$$\epsilon_r = 40$$

$$E_0 = 3.7 E_2$$

$$E_{eff} = \frac{\sqrt{\frac{\rho SAR}{\sigma}}}{1 - \left| \frac{\sqrt{\epsilon_r} - 1}{\sqrt{\epsilon_r} + 1} \right|}$$

$$E = \frac{\sqrt{2} \sqrt{\frac{\rho SAR}{\sigma}}}{1 - \left| \frac{\sqrt{\epsilon_r} - 1}{\sqrt{\epsilon_r} + 1} \right|}$$

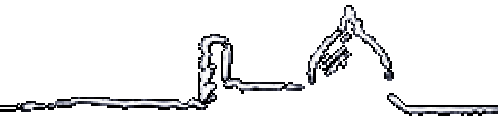


$$I = \frac{E^2}{377\Omega}$$

Campo lontano

$$E = \frac{\sqrt{2} \sqrt{\frac{\rho SAR}{\sigma}}}{1 - \left| \frac{\sqrt{\epsilon_r} - 1}{\sqrt{\epsilon_r} + 1} \right|}$$

$$I = \frac{2}{(377\Omega) \times \left(1 - \left| \frac{\sqrt{\epsilon_r} - 1}{\sqrt{\epsilon_r} + 1} \right| \right)^2} \frac{\rho}{\sigma} (SAR)$$



Esempio:

$$\text{SAR} = 0.08 \text{ W/Kg}$$

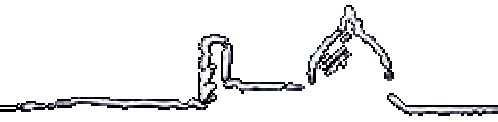
$$\begin{aligned} 900 \text{ MHz} \quad \varepsilon_r &= 40 \\ \rho &= 1000 \\ \sigma &= 1 \end{aligned}$$



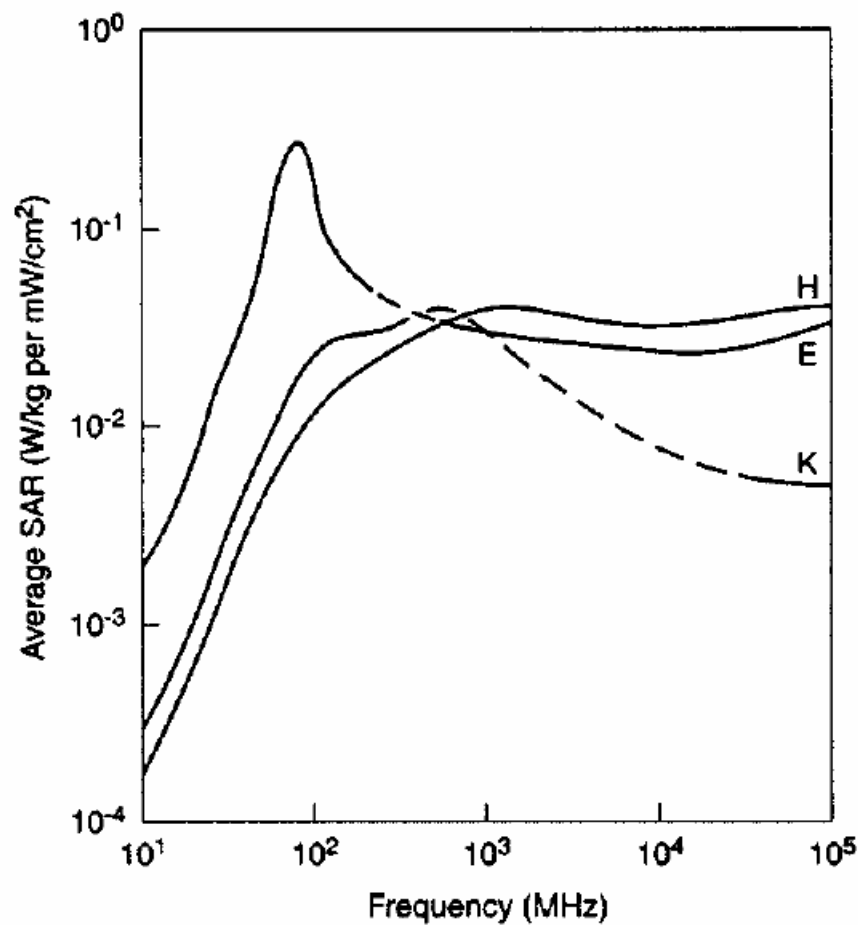
$$\mathbf{E = 46 \text{ V/m}}$$

$$\mathbf{I = 5.7 \text{ W/m}^2}$$

$$\text{Intensità insolazione} \quad I \approx 1000 \text{ W/m}^2$$



Effetto della forma del corpo umano sull'assorbimento



Freq di risonanza di un uomo standard ≈ 70 MHz



La temperatura del corpo umano è $37^{\circ} \pm 1^{\circ}$

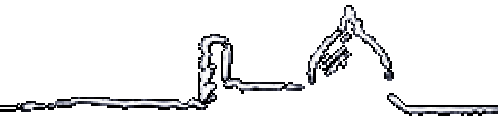
Danno ai neuroni	+4.5 °C per trenta minuti
Cataratta	+3-5 °C $\approx 100 \text{ W/Kg}$
Pelle	+10 °C
Vari effetti fisiologici	+0.4 °C intero corpo

**4 W/Kg produce un incremento $< 1^{\circ}\text{C}$ in 30 minuti,
tenendo conto dei meccanismi di termoregolazione**

1 W/Kg produce un incremento di circa 0.1°C ,
tenendo conto dei meccanismi di termoregolazione

1W/Kg è circa il metabolismo umano,
ed è 1/8 del metabolismo del cervello

Il cristallino NON ha metabolismo o circolazione sanguigna
(il calore si disperde per diffusione o convezione)



Limite SAR di ragionevole sicurezza

$$\approx 1 \text{ W/Kg}$$

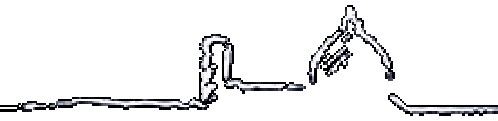


Effetti termici indotti da segnali AM o impulsati

Click, buzz, chirp..



Effetto termoelastico



Esistono effetti non termici?

$$900 \text{ MHz} \longrightarrow 4\mu\text{eV}$$

$$1800 \text{ MHz} \longrightarrow 7\mu\text{eV}$$

$$E_{\text{fotone}} = h\nu$$

ν = frequenza

h = costante di Plank

L'energia di un legame chimico è dell'ordine di 1 eV


$kT = 26\text{meV}$ a temperatura ambiente



Esistono effetti non termici?

I batteri muoiono a temperatura più bassa se scaldati con microonde

Effetti sulla crescita dei batteri

Effetto biologico  Rischio per la salute

Un rischio per la salute è un effetto biologico
al di fuori del range normale di compensazione
che è di danno alla salute o al benessere

- 1) Studi epidemiologici
- 2) Studi su volontari
- 3) Studi su cavie (topi)
- 4) Studi in vitro



1978 Lilienfeld

Impiegati dell'ambasciata USA a Mosca 1953-1976

1800 impiegati, 2500 casi di controllo in altre ambasciate dell'Europa dell'Est ($< 0.15 \text{ W/m}^2$)

Nessuna associazione tra esposizione e tumore

A.M. Lilienfeld, J. Tonascia, S. Tonascia, C.H. Libauer, G. M. Canthen, J.A. Morkowitz, and S. Weida, "Foreign service health status study: Evaluation of health status of foreign service and other employees from selected Eastern European posts" Dept. of Epidemiology, Johns Hopkins Univ., Final Rep., NTIS PB 288, 1978

1980 Robinette

20000 persone dell' U.S. Navy in servizio durante la guerra di Corea
studiati nel periodo 1950-1974 ($< 100 \text{ W/m}^2$)

Si dichiara che non è evidenziata nessuna associazione tra esposizione e tumore,
Tuttavia si nota una correlazione tra le più alte esposizioni e vari tipi di cancro

C.D. Robinette, C. Silverman, and S. Jablon "Effects upon health of occupational exposure to microwave radiation (radar) 1950-1974" Amer. J. Epidemiology, vol. 112, pp. 39-53, 1980

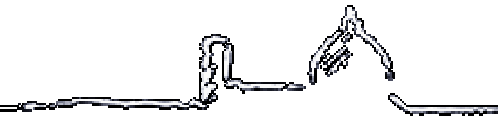
1988 Milham

Radiomatori negli USA occidentali

Tumori al cervello (1.4), leucemia (1.8), cancro nei tessuti linfatici (1.6)

Effetti dei fumi del saldatore?

S. Milham, "Increased mortality in amateur radio operators due to lymphatic and hematopoietic malignancies" Amer. J. Epidemiology, vol. 127, pp. 50-54, 1988



1992 Selvin

Popolazione infantile entro 3.5 Km da una torre RF a San Francisco

Nessuna correlazione

S. Selvin, J. Schulman, and D.W. Merrill, “Distance and risk measures for the analysis of spatial data: A study of childhood cancers” *Social Science in Medicine*, vol. 34, pp. 769-777, 1992

1992 Tynes

Lavoratori nel settore elettrico

Leucemia (+2.8)

T.Tynes, A. Andersen and F. Langmark, Incidence of cancer in Norwegian workers potentially exposed to electromagnetic fields” *Am. J. Epidemiol.*, vol. 136, pp. 81-88, 1992

1993 Maskarinec

Popolazione infantile entro 4.2 Km da una torre RF alle Hawaii

Leucemia (2.1)

G. Maskarinec and J. Cooper, “Investigation of a childhood leukemia cluster near low frequency radio towers in Hawaii” *Amer. J. Epidemiology*, vol. 138, p. 666, 1993

1996 Rothman

250000 utenti di telefoni cellulari

Nessuna differenza di mortalità tra utenti con cellulare a mano e cellulare veicolare

K.J. Rothman, J.E. Loughlin, D.P. Funch and N.A. Dreyer, “Overall mortality of cellular telephone customers, “*Epidemiology*”, vol. 7, pp. 303-305, 1996

Effetti non termici: studi epidemiologici

1996 Grayson

Personale dell' U.S. Air Force 1970-1989

Tumori al cervello (1.39)

K. Grayson, "Radiation exposure, socioeconomic status, and brain tumor risk in the US Air Force: A nested case-control study" Amer. J. Epidemiology, vol. 143, pp. 480-486, 1996

1996 Hocking

Popolazione infantile entro 12 Km da una torre TV a Sidney

Leucemia (1.58)

B. Hocking, I. R. Gordon, H.L. Grain, and G.E. Hatfield "Cancer incidence and mortality and proximity to TV towers" Med. J. Australia, vol. 165, pp. 601-605, 1996

1997 Dolk

Popolazione entro 10 Km da 20 torri radio-TV in Inghilterra

Leucemia (1.15)

H. Dolk, P. Elliott, G. Shaddick, P. Walls, and B. Thakrar, "Cancer incidence near radio e television transmitters in Great Britain. 2. All high power transmitters" Amer. J. Epidemiology, vol. 145, pp. 10-17, 1997

1997 Dolk

Popolazione entro 2 Km da una torre TV in Inghilterra

Leucemia (1.83)

H. Dolk, G. Shaddick, P. Walls, C. Grundy, B. Thakrar, I. Kleinschmidt, and P. Elliott, "Cancer incidence near radio and television transmitters in Great Britain. 1. Sutton Coldfield transmitters" Amer. J. Epidemiology, vol. 145, pp. 1-9, 1997



1999 Dreyer

300000 utenti di telefoni cellulari

Nessuna correlazione tra mortalità e minuti al giorno di uso del cellulare (eccetto che per incidenti stradali. N.B. :Il rischio è statisticamente lo stesso per telefoni a mano o viva voce!)

N.A. Dreyer, J.E. Loughlin, and K.J. Rothman, “Cause-specific mortality in cellular telephone users” J. Am. Med. Assoc., vol. 282, pp. 1814-1816, 1999

1999 Hardell

209 casi di tumore al cervello, 425 casi di controllo

Nessuna correlazione tra esposizione e tumore al cervello, tuttavia una tendenza (statisticamente poco significativa) a sviluppare il tumore dal lato dove si tiene il cellulare

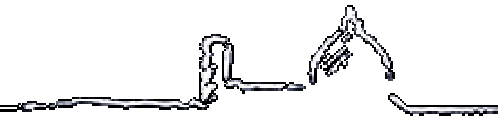
L. Hardell, A. Nasman, A. Pahlson, A. Hallquist, and K. H. Mild, “Use of cellular telephones and the risk for brain tumors: a case-control study” J. Oncol., vol. 15, pp. 113-116, 1999

2000 Morgan

200000 impiegati della Motorola 1976-1996

Nessuna associazione tra esposizione e tumore al cervello o leucemia

R.W. Morgan, M.A. Keish, K. Zhao, K.A. Exuzides, S. Heringer, and W. Negrete, “Radiofrequency exposure and mortality from cancer of the brain and lymphatic/hematopoietic systems, “Epidemiology”, vol. 11, pp. 118-127, 2000



2000 Muscat

Pazienti di ospedali USA 1994-1998

Nessuna evidenza

J. E. Muscat, M.G. Malkin, S. Thompson, R.E. Shore, S.D. Stellman, D. McRee, A.I. Neugut, and E.L. Wynder, “Handheld cellular telephone use and risk of brain cancer” J. AMA, vol. 284, pp. 3001-3007, 2000

2001 Inskip

782 pazienti, 799 casi di controllo

Non significativa tendenza a sviluppare il tumore dal lato dove è usato il cellulare.

Tuttavia: neuroma acustico (1.4)

P.D. Inskip, R.E. Tarone, E.E. Hatch, T.C. Wilcosky, W.R. Shapiro, R.G. Selker, H.A. Fine, P.M. Black, J.S. Loeffler, and M.S. Linet “Cellular-telephone use and brain tumors”, New Eng. J. Med, vol. 344, pp. 79-86, 2001

2001 Johansen

400000 utenti di cellulari in Danimarca 1982-1995

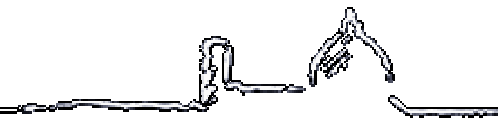
No associazione tra uso del telefono e tumori al cervello

C. Johansen, J.D. Jr Boice, JK McLaughlin, JH Olsen, “Cellular telephones and cancer – a nationwide cohort study in Denmark” J. Natl Cancer Inst, vol. 93, pp. 203-207, 2001



Limiti degli studi epidemiologici

- 1) Difficoltà nella stima della dose
- 2) Correlazioni (ad esempio alcool-tumore al polmone)
- 3) Lunga latenza dei tumori al cervello
- 4) Alta sensibilità di piccoli gruppi



1998 Braune

Cambiamenti nella pressione del sangue di volontari irradiati

S. Braune, C. Wrocklage, J. Raczek, T. Gailus, and C.H. Lucking, “Resting blood pressure during exposure to a radio-frequency electromagnetic field” **Lancet**, Vol. 351, pp. 1857-1858, 1998

1998 Freude

Test cognitivi e della memoria

Durante il periodo di esposizione i risultati erano peggiori

G. Freude, P. Ullsperger, S. Eggert, I. Ruppe, “Effect of microwaves emitted by cellular phones on human slow brain potentials” Bioelectromagnetics, Vol. 19, pp. 384-7, 1998

1999 Preece

Test cognitivi e della memoria

Durante il periodo di esposizione i risultati erano peggiori

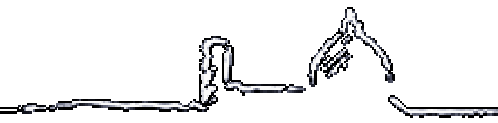
A. W. Preece, G. Iwi, A. Davies-Smith, K. Wesnes, S. Butler, E. Lim, and A. Vary, “Effect of a 915 MHz simulated mobile phone signal on cognitive function in man” Int. J. Radiat. Biol., Vol. 75, pp. 447-456, 1999

2000 Krause

Test cognitivi e della memoria

Durante il periodo di esposizione i risultati erano peggiori

CM Krause, L Sillanmaki, M Koivisto, A Haggqvist, C Saarela, A. Revonsuo, “Effect of electromagnetic field emitted by cellular phones on the EEG during a memory task” Neuroreport, Vol. 11, pp. 761-4, 2000



1971 Spalding

Test su cavie 13W/Kg

Nessuna evidenza

JF Spalding, RW Freyman, and LM Holland, “Effects of 800 MHz electrognetic radiation on body weight, activity, hematopoiesis and life span in mice” Health Phys., Vol. 20, pp. 421-424, 1971

1992 Chou

Test su cavie 2450 MHz 0.4W/Kg

Aumento di tumori maligni primari

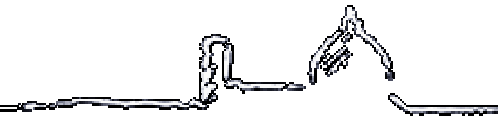
CK Chou, AW Guy, LL Kunz, RB Johnson, JJ Crowley, and JH Krupp, “Long-term, low-level microwave irradiation of rats” Bioelectromagnetics, Vol. 13, pp. 469-496, 1992

1997 Toler

Test su cavie 0.32 W/Kg

Nessuna evidenza

JC Toler, WW Shelton, MR Frei, JH Merritt, and MA Stedharm, “Long-term, low-level exposure of mice prone to mammary tumors to 435 MHz radiofrequency radiation” Radiat. Res. Vol. 148, pp. 227-234, 1997



1998 Frei

Test su cavie 2450 MHz 0.3-1.0 W/Kg

Nessuna evidenza

MR Frei, RE Berger, SJ Dutch, V Guel, JR Jauchem, JH Merritt, and MA Stedharm, “Chronic exposure of cancer-prone mice to low level 2450 MHz radiofrequency radiation”

Bioelectromagnetics, vol. 19, pp. 20-31, 1998

MR Frei, JR Jauchem, SJ Dutch, V Guel, JH Merritt, RE Berger, and MA Stedharm, “Chronic low-level (1.0 W/Kg) exposure of mammary cancer-prone mice to 2450 MHz microwaves” Radiat. Res., vol. 150, pp. 568-576, 1998

1999-2000 Adey

Test su cavie

Nessun aumento di tumori al cervello

WR Adey, CV Byus, CD Cain, “Spontaneous and nitrosourea-induced primary tumors of the central nervous system in Fischer 344 rats chronically exposed to 836 MHz modulated microwaves” Radiat Res, vol. 152, pp. 293-302, 1999

WR Adey, CV Byus, CD Cain, “Spontaneous and nitrosourea-induced primary tumors of the central nervous system in Fischer 344 rats exposed to frequency modulated microwave fields” Cancer Res, vol. 60, pp. 1857-1863, 2000



Aumento dell'incidenza di tumori in cavie geneticamente modificate per sviluppare linfomi

1997 Repacholi

Cavie geneticamente modificate per sviluppare linfomi, 0.13-1.4 W/Kg 900 MHz

Aumento dell'incidenza dei linfomi (2.4)

I risultati sponsorizzati da Telstra (Australia telecom) furono pubblicati con 2 anni di ritardo, Attualmente Repacholi lavora per la WHO a Ginevra

M.H.Repacholi et al., "Lymphomas in Eμ-Pim1 trasgenic mice exposed to pulsed 900 MHz electromagnetic field" Radiat. Res., vol. 147, pp. 631-640, 1997

2000 Utteridge

Cavie geneticamente modificate per sviluppare linfomi

Nessuna evidenza

T.D. Utteridge, V. Gebiski, J. W. Finnie, B. Vernon-Roberts, T. R. Kuchel, "Long-Term Exposure of Eμ-Pim1 trasgenic mice to 898.4 MHz Microwave Does Not Increase Lymphoma Incidence" Radiat. Res., vol. 158, pp. 357-364, 2002



Rottura di catene di DNA

1994 Sarkar

Singole rotture del DNA nelle cellule di cervello di cavie irradiate 1.18 W/Kg 2.45 GHz

S. Sarkar, S. Ali, and J. Behari, "Effect of low power microwave on the mouse genome: A direct DNA analysis" *Mutation Research*, Vol. 320, pp. 141-147, 1994

1995-1996 Lai

Singole e doppie rotture del DNA nelle cellule di cervello di cavie irradiate 0.6 W/Kg

H.Lai and N.P. Singh, "Acute low-intensity microwave exposure increases DNA single-strand breaks in rat brain cells" *Bioelectromagnetics*, vol. 16, pp. 207-210, 1995

H.Lai and N.P. Singh, "Single- and double-strand DNA breaks in rat brain cells after exposure to radiofrequency electromagnetic radiation" *Int. J. Radiation Biol.*, vol. 69, pp. 513-521, 1996

1997 Malyapa

Non osserva rotture del DNA

R. S. Malyapa, E.W. Ahern, W.L. Straube, E.G. Mors, W.F. Picard, J.L. Roti Roti, "Measurement of DNA damage after exposure to 2450 MHz electromagnetic radiation" *Radiat. Res.*, Vol. 148, pp. 608-617, 1997

R. S. Malyapa, E.W. Ahern, W.L. Straube, E.G. Mors, W.F. Picard, J.L. Roti Roti, "Measurement of DNA damage after exposure to electromagnetic radiation in the cellular phone communication frequency band (835.62 and 847.74 MHz)" *Radiat. Res.*, Vol. 148, pp. 618-627, 1997



BBB: Blood Brain Barrier

1973 Polyaschak

Blood-Brain Barrier

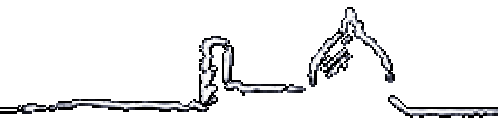
L.Polyaschak, “Changes in Permeability of Histo-Hematic Barriers Under the Effects of Microwaves” Dokl. Akade. Nauk. Ukraine, Vol. 8, pp. 754-758, 1973

1993 Salford

Blood-Brain Barrier 1.6 W/Kg

L.G. Salford, A. Brun, K., Eberhardl, B.R.R. Person, “Permeability of the Blood-Brain Barrier Induced by 915 MHz Electromagnetic Radiation, Continuous Wave and Modulated at 8, 16, 50, and 200 Hz” Bioelectrochemistry & Bioenergetics, Vol. 30, pp. 293-301, 1993

B.R.R. Person, L.G. Salford, A. Brun, “Blood-Brain Barrier Permeability in Rats Exposed to Electromagnetic Fields Used in Wireless Communication” Wireless Networks, Vol. 3, pp. 455-461, 1997



International Commission on Non-Ionizing Radiation Protection

<http://www.icnirp.de/documents/emfgdl.pdf>

1) Effetti termici $<1^{\circ}\text{C}$ $<4\text{W/Kg}$

2) Effetti termici indotti da segnali AM o impulsati

Effetto termoelastico ← **Click, buzz, chirp..**

$$I_{\text{peak}} < 1000 I_{\text{average}}$$

**3) Effetti di minore entità sul sistema nervoso a bassa frequenza (<10 MHz)
causati dalle correnti indotte**

Stimolazione di nervi (cl clinicamente impiegato)

Effetti visivi

Nessuna evidenza di effetti non reversibili a lungo termine

$$I < 10 \text{ mA/m}^2 \quad 1\text{kHz}$$

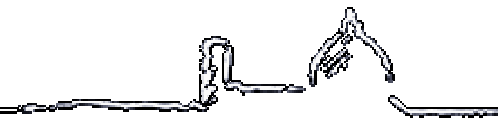


4) *Effetti non termici*

“Epidemiological studies on exposed workers and the general public have provided limited information and **failed to demonstrate any health effects**. [..]

In general, the effects of exposure of biological systems to athermal levels of amplitude-modulated EMF are small and very difficult to relate to potential health effects”

“Data on cancer risk associated with exposure to ELF (Electromagnetic Low Frequency) fields among individuals living close to power lines are apparently consistent in indicating a slightly higher risk of leukemia among children. [..] In absence of support from laboratory studies, the epidemiological data are insufficient to allow an exposure guideline to be established.”



International Commission on Non-Ionizing Radiation Protection

<http://www.icnirp.de/documents/emfgdl.pdf>

Basic restrictions

- Densità di corrente (Ampere/m²) per $f < 10\text{MHz}$
- SAR (W/Kg) 100kHz-10GHz
- Intensità (W/m²) per $f > 10\text{GHz}$



Reference levels

J → E, B, I

SAR → E, B, I

Assorbimento superficiale

Sistema nervoso

$$J = \sigma E$$

$$J = \pi R f \sigma B$$

Occupational exposure

General public exposure

ICNIRP Guidelines (up to 300 GHz)



Table 4. Basic restrictions for time varying electric and magnetic fields for frequencies up to 10 GHz.^a

Exposure characteristics	Frequency range	Current density for head and trunk (mA m ⁻²) (rms)	Whole-body average SAR (W kg ⁻¹)	Localized SAR (head and trunk) (W kg ⁻¹)	Localized SAR (limbs) (W kg ⁻¹)
Occupational exposure	up to 1 Hz	40	—	—	—
	1–4 Hz	40/ <i>f</i>	—	—	—
	4 Hz–1 kHz	10	—	—	—
	1–100 kHz	<i>f</i> /100	—	—	—
	100 kHz–10 MHz	<i>f</i> /100	0.4	10	20
	10 MHz–10 GHz	—	0.4	10	20
General public exposure	up to 1 Hz	8	—	—	—
	1–4 Hz	8/ <i>f</i>	—	—	—
	4 Hz–1 kHz	2	—	—	—
	1–100 kHz	<i>f</i> /500	—	—	—
	100 kHz–10 MHz	<i>f</i> /500	0.08	2	4
	10 MHz–10 GHz	—	0.08	2	4

^a Note:

1. *f* is the frequency in hertz.
2. Because of electrical inhomogeneity of the body, current densities should be averaged over a cross-section of 1 cm² perpendicular to the current direction.
3. For frequencies up to 100 kHz, peak current density values can be obtained by multiplying the rms value by $\sqrt{2}$ (~ 1.414). For pulses of duration t_p the equivalent frequency to apply in the basic restrictions should be calculated as $f = 1/(2t_p)$.
4. For frequencies up to 100 kHz and for pulsed magnetic fields, the maximum current density associated with the pulses can be calculated from the rise/fall times and the maximum rate of change of magnetic flux density. The induced current density can then be compared with the appropriate basic restriction.
5. All SAR values are to be averaged over any 6-min period.
6. Localized SAR averaging mass is any 10 g of contiguous tissue; the maximum SAR so obtained should be the value used for the estimation of exposure.
7. For pulses of duration t_p the equivalent frequency to apply in the basic restrictions should be calculated as $f = 1/(2t_p)$. Additionally, for pulsed exposures in the frequency range 0.3 to 10 GHz and for localized exposure of the head, in order to limit or avoid auditory effects caused by thermoelastic expansion, an additional basic restriction is recommended. This is that the SA should not exceed 10 mJ kg⁻¹ for workers and 2mJ kg⁻¹ for the general public, averaged over 10 g tissue.

Table 5. Basic restrictions for power density for frequencies between 10 and 300 GHz.^a

Exposure characteristics	Power density (W m^{-2})
Occupational exposure	50
General public	10

^a Note:

1. Power densities are to be averaged over any 20 cm^2 of exposed area and any $68/f^{1.05}$ -min period (where f is in GHz) to compensate for progressively shorter penetration depth as the frequency increases.
2. Spatial maximum power densities, averaged over 1 cm^2 , should not exceed 20 times the values above.



Table 6. Reference levels for occupational exposure to time-varying electric and magnetic fields (unperturbed rms values).^a

Frequency range	E-field strength (V m ⁻¹)	H-field strength (A m ⁻¹)	B-field (μT)	Equivalent plane wave power density S_{eq} (W m ⁻²)
up to 1 Hz	—	1.63×10^5	2×10^5	—
1–8 Hz	20,000	$1.63 \times 10^5/f^2$	$2 \times 10^5/f^2$	—
8–25 Hz	20,000	$2 \times 10^4/f$	$2.5 \times 10^4/f$	—
0.025–0.82 kHz	$500/f$	$20/f$	$25/f$	—
0.82–65 kHz	610	24.4	30.7	—
0.065–1 MHz	610	$1.6/f$	$2.0/f$	—
1–10 MHz	$610/f$	$1.6/f$	$2.0/f$	—
10–400 MHz	61	0.16	0.2	10
400–2,000 MHz	$3f^{1/2}$	$0.008f^{1/2}$	$0.01f^{1/2}$	$f/40$
2–300 GHz	137	0.36	0.45	50

^a Note:

1. f as indicated in the frequency range column.
2. Provided that basic restrictions are met and adverse indirect effects can be excluded, field strength values can be exceeded.
3. For frequencies between 100 kHz and 10 GHz, S_{eq} , E^2 , H^2 , and B^2 are to be averaged over any 6-min period.
4. For peak values at frequencies up to 100 kHz see Table 4, note 3.
5. For peak values at frequencies exceeding 100 kHz see Figs. 1 and 2. Between 100 kHz and 10 MHz, peak values for the field strengths are obtained by interpolation from the 1.5-fold peak at 100 kHz to the 32-fold peak at 10 MHz. For frequencies exceeding 10 MHz it is suggested that the peak equivalent plane wave power density, as averaged over the pulse width, does not exceed 1,000 times the S_{eq} restrictions, or that the field strength does not exceed 32 times the field strength exposure levels given in the table.
6. For frequencies exceeding 10 GHz, S_{eq} , E^2 , H^2 , and B^2 are to be averaged over any $68/f^{1.05}$ -min period (f in GHz).
7. No E-field value is provided for frequencies <1 Hz, which are effectively static electric fields. Electric shock from low impedance sources is prevented by established electrical safety procedures for such equipment.



Table 7. Reference levels for general public exposure to time-varying electric and magnetic fields (unperturbed rms values).^a

Frequency range	E-field strength (V m ⁻¹)	H-field strength (A m ⁻¹)	B-field (μT)	Equivalent plane wave power density S_{eq} (W m ⁻²)
up to 1 Hz	—	3.2×10^4	4×10^4	—
1–8 Hz	10,000	$3.2 \times 10^4/f^2$	$4 \times 10^4/f^2$	—
8–25 Hz	10,000	$4,000/f$	$5,000/f$	—
0.025–0.8 kHz	$250/f$	$4/f$	$5/f$	—
0.8–3 kHz	$250/f$	5	6.25	—
3–150 kHz	87	5	6.25	—
0.15–1 MHz	87	$0.73/f$	$0.92/f$	—
1–10 MHz	$87/f^{1/2}$	$0.73/f$	$0.92/f$	—
10–400 MHz	28	0.073	0.092	2
400–2,000 MHz	$1.375f^{1/2}$	$0.0037f^{1/2}$	$0.0046f^{1/2}$	$f/200$
2–300 GHz	61	0.16	0.20	10

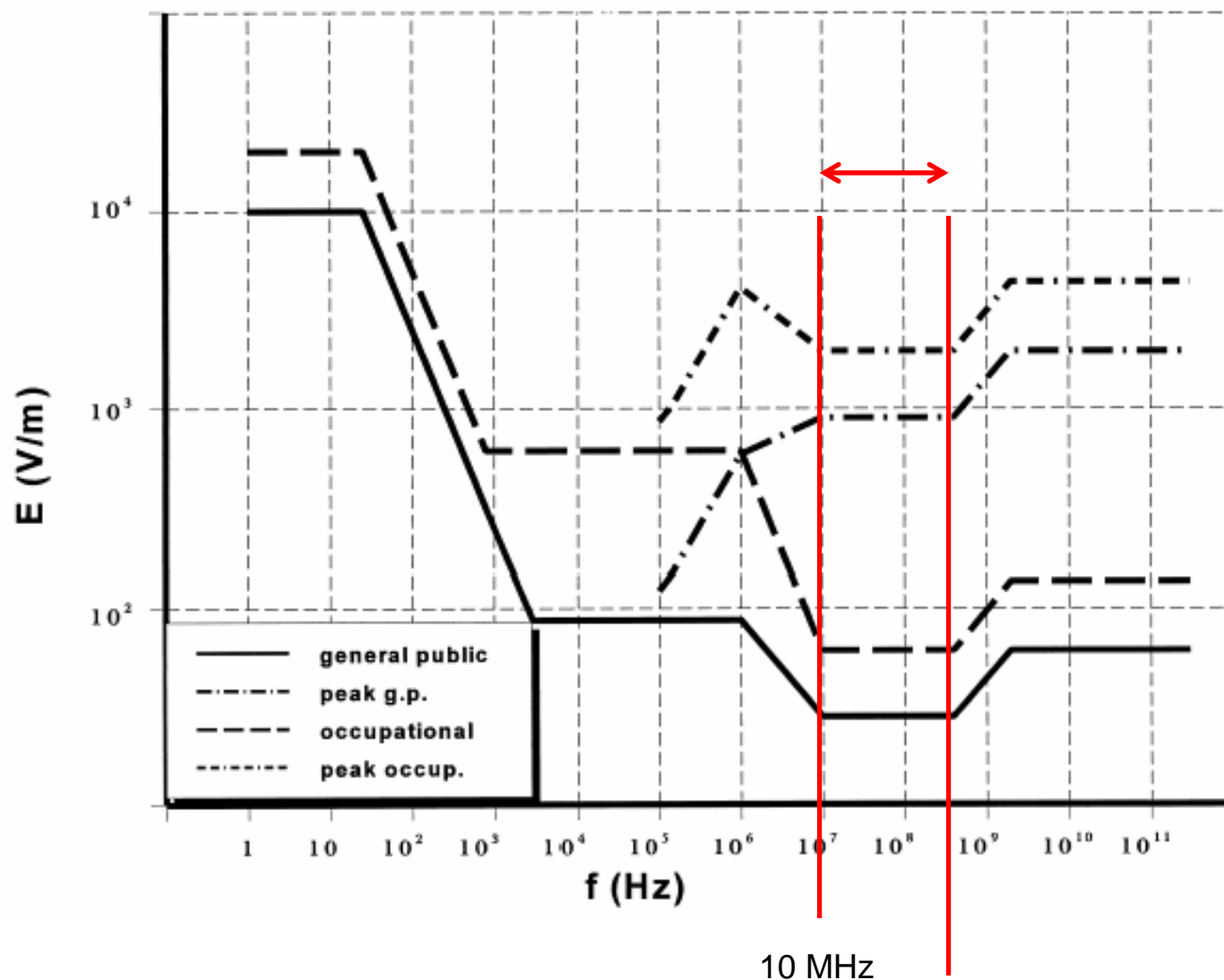
^a Note:

1. f as indicated in the frequency range column.
2. Provided that basic restrictions are met and adverse indirect effects can be excluded, field strength values can be exceeded.
3. For frequencies between 100 kHz and 10 GHz, S_{eq} , E^2 , H^2 , and B^2 are to be averaged over any 6-min period.
4. For peak values at frequencies up to 100 kHz see Table 4, note 3.
5. For peak values at frequencies exceeding 100 kHz see Figs. 1 and 2. Between 100 kHz and 10 MHz, peak values for the field strengths are obtained by interpolation from the 1.5-fold peak at 100 kHz to the 32-fold peak at 10 MHz. For frequencies exceeding 10 MHz it is suggested that the peak equivalent plane wave power density, as averaged over the pulse width does not exceed 1,000 times the S_{eq} restrictions, or that the field strength does not exceed 32 times the field strength exposure levels given in the table.
6. For frequencies exceeding 10 GHz, S_{eq} , E^2 , H^2 , and B^2 are to be averaged over any $68/f^{1.05}$ -min period (f in GHz).
7. No E-field value is provided for frequencies <1 Hz, which are effectively static electric fields. perception of surface electric charges will not occur at field strengths less than 25 kVm⁻¹. Spark discharges causing stress or annoyance should be avoided.

900 MHz E = 41V I = 4.5 W/m²

1800 MHz E = 58V I = 9 W/m²

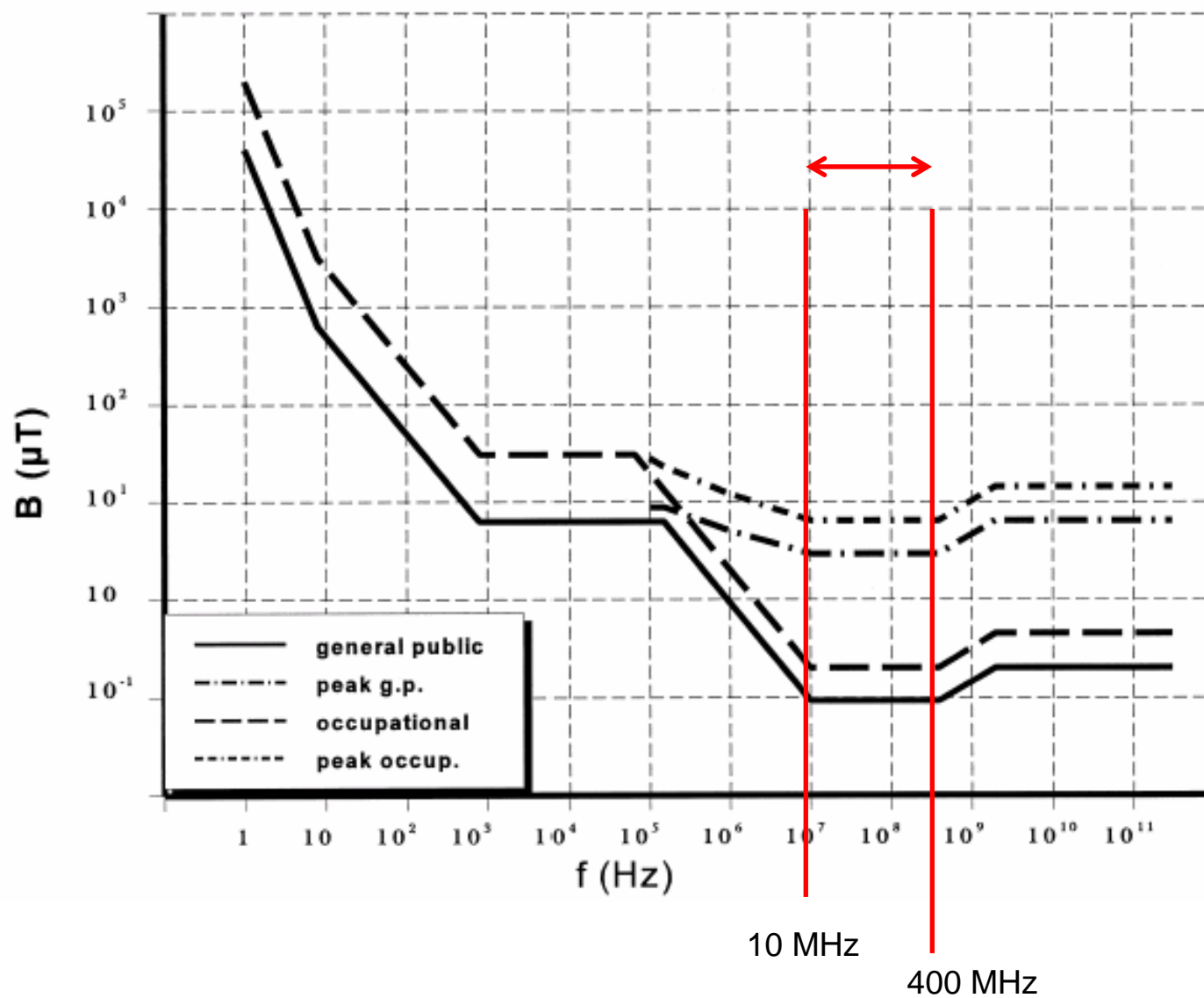
ICNIRP Guidelines (up to 300 GHz)



Freq di risonanza di un uomo standard ≈ 70 MHz

400 MHz

ICNIRP Guidelines (up to 300 GHz)





ICNIRP/CENELEC (Comité Européen de Normalisation Electrotechnique)

2 W/Kg mediato su 10 g di tessuto per 6 minuti

Public

10 W/Kg mediato su 10 g di tessuto per 6 minuti

Occupational

ANSI/IEEE

1.6 W/Kg mediato su 1g di tessuto per 30 minuti

8 W/Kg mediato su 1 g di tessuto per 6 minuti

Ambiente controllato

Standard Canadese

$$SAR_{eye} = 0.2 \text{ W / Kg}$$

Standard “Sovietico”

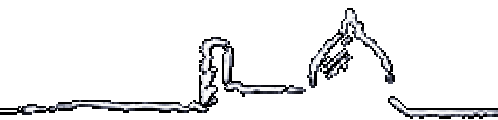
$$I = 0.1 \text{ W / m}^2 \quad (\text{fin dal 1959})$$

$$E = 6 \text{ V / m}$$

Standard Svizzera

$$I = 0.04 \text{ W / m}^2$$

$$E_{eff} = 3.3 \text{ V / m}$$

DECRETO 10 settembre 1998, n. 381.

Art. 3.

Limiti di esposizione

1. Nel caso di esposizione al campo elettromagnetico i livelli dei campi elettrici, magnetici e della densità di potenza, mediati su un'area equivalente alla sezione verticale del corpo umano e su qualsiasi intervallo di sei minuti, non devono superare i valori di tabella 1.

Tabella 1
LIMITI DI ESPOSIZIONE PER LA POPOLAZIONE AI CAMPI
ELETTROMAGNETICI

Frequenza f (MHz)	Valore efficace di intensità di campo elettrico E (V/m)	Valore efficace di intensità di campo magnetico H (A/m)	Densità di potenza dell'onda piana equivalente (W/m ²)
0,1 - 3	60	0,2	--
> 3 - 3000	20	0,05	1
>3000 - 300.000	40	0,1	4

Art. 4.

Misure di cautela ed obiettivi di qualità

1. Fermi restando i limiti di cui all'articolo 3, la progettazione e la realizzazione dei sistemi fissi delle telecomunicazioni e radiotelevisivi operanti nell'intervallo di frequenza compresa fra 100 kHz e 300 GHz e l'adeguamento di quelle preesistenti, deve avvenire in modo da produrre i valori di campo elettromagnetico più bassi possibile, compatibilmente con la qualità del servizio svolto dal sistema stesso al fine di minimizzare l'esposizione della popolazione.

2. Per i fini di cui al precedente comma 1, in corrispondenza di edifici adibiti a **permanenze non inferiori a quattro ore** non devono essere superati i seguenti valori, indipendentemente dalla frequenza, mediati su un'area equivalente alla sezione verticale del corpo umano e su qualsiasi intervallo di sei minuti: **6 V/m** per il campo elettrico, 0,016 A/m per il campo magnetico intesi come valori efficaci e, per frequenze comprese tra 3 Mhz e 300 GHz, **0,10 W/m(elevato a)2** per la densità di potenza dell'onda piana equivalente.



Disciplina in materia di impianti di radiocomunicazione. 16 gennaio 2002.

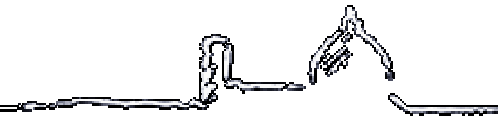
CRITERI INERENTI L'IDENTIFICAZIONE DELLE AREE SENSIBILI

Le aree sensibili sono di due tipi:

- a) aree di interesse storico-architettonico, e paesaggistico-ambientale, nelle quali devono essere evitati impatti di tipo visivo degli impianti;
- b) aree comprese nel perimetro di cinquanta metri di distanza da asili, scuole, ospedali, case di cura, aree verdi attrezzate, aree destinate all'infanzia, aree di particolare densità abitativa.

OBIETTIVI DI QUALITA' INERENTI LE AREE SENSIBILI

1. Nelle aree sensibili identificate ai sensi dell'articolo 4, comma 1, della legge regionale 6 aprile 2000, n.54 (Disciplina in materia di impianti di radiocomunicazione), deve essere perseguito il raggiungimento degli obiettivi di qualità di **0,5 V/m** per i campi elettrici generati da impianti fissi per telefonia cellulare e di **3 V/m per i campi elettrici generati da tutte le altre sorgenti inquinanti** rientranti nel campo di applicazione della legge regionale 54/2000,
2. Il raggiungimento degli obiettivi di qualità sopra indicati deve avvenire secondo le seguenti modalità:
 - i campi elettrici generati da impianti fissi per telefonia cellulare devono raggiungere il valore di 3 V/m entro un anno dalla pubblicazione della presente deliberazione e l'obiettivo di qualità di 0,5 V/m entro tre anni;
 - i campi elettrici generati da tutte le altre sorgenti inquinanti rientranti nel campo di applicazione della legge regionale 54/2000 devono raggiungere l'obiettivo di qualità di 3 V/m entro tre anni dalla pubblicazione della presente deliberazione.



1) Phantom con sonde impiantate

- 3 piccoli dipoli ortogonali
(15-50 mm)

- Sonde di temperatura $SAR = c \frac{\Delta T}{\Delta t}$
 - c = calore specifico
 - ΔT = incremento di temperatura
 - Δt = intervallo di tempo

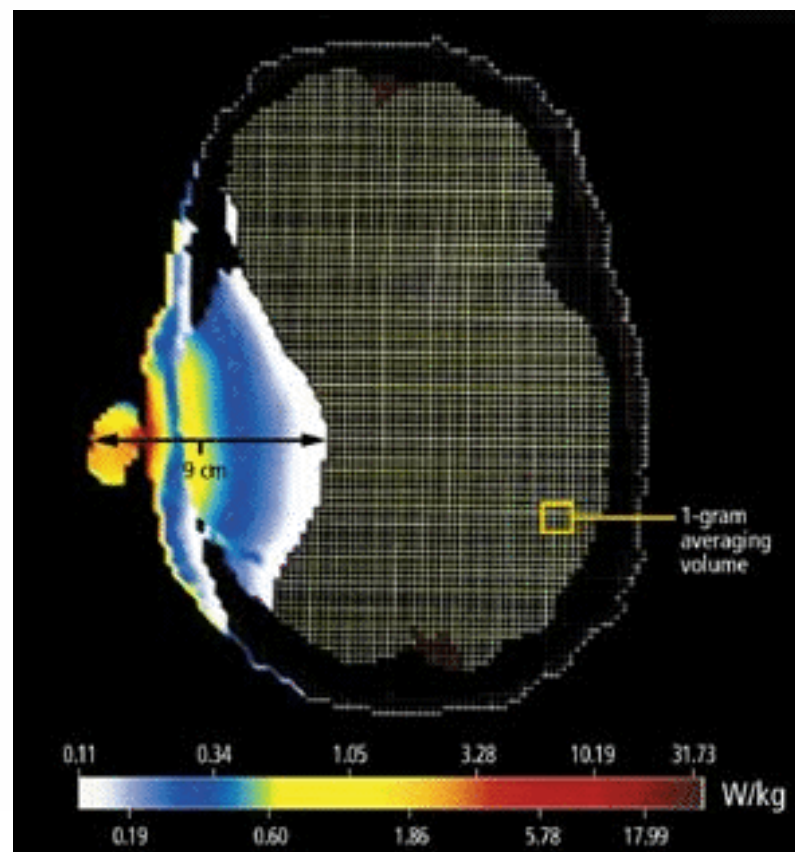
Fenomeni di trasporto (diffusione, convezione..) possono produrre sottostime

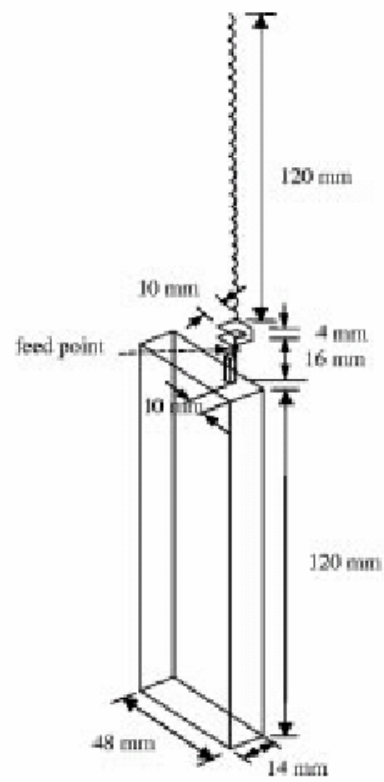
2) Simulazioni

FDTD: Finite-difference Time domain

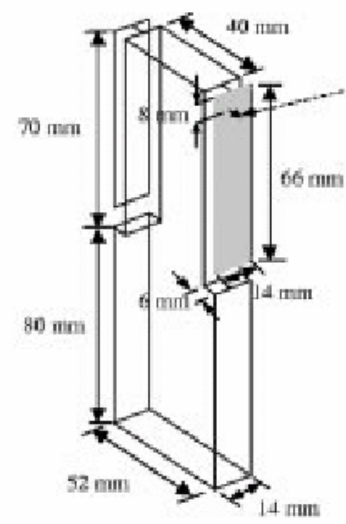
TABLE 1
MASS DENSITY AND DIELECTRIC PARAMETERS OF THE HEAD TISSUES
AT 900 MHz

	ρ [kg/m ³]	ϵ_r	σ [S/m]
Skin	1010	41.4	0.87
Muscle	1040	55.0	0.94
Bone	1810	21.0	0.32
Blood	1060	61.4	1.54
Fat	920	11.3	0.11
Cartilage	1100	40.8	0.81
Grey matter	1040	54.7	1.19
White matter	1040	35.7	0.61
Humor	1010	74.1	1.97
Lens	1100	51.3	0.89
Sclera/Cornea	1170	52.1	1.22
Cerebellum	1040	49.6	1.03
Hypophysis	1040	49.6	1.03
CSF	1010	74.0	2.12
Parotid	1040	49.6	1.03
Tongue	1040	57.0	0.80





WHIP



PIFA

TABLE III
TOTAL POWER ABSORBED IN THE HEAD (P_{abs}), MAXIMUM SAR AS AVERAGED OVER 1g (SAR_{1MAX}) AND 10g (SAR_{10MAX}) OF TISSUE IN THE HEAD, AND MAXIMUM SAR AS AVERAGED OVER 1g OF BRAIN ($SAR_{1MAXbrain}$) OR EYE ($SAR_{1MAXeye}$). PHONE POSITIONS: VERTICAL (V) AND TILTED (T). POWER RADIATED IN FREE SPACE: 600 mW
FREQUENCY: 900 MHz

Phone model		P_{abs} [mW]	SAR_{1MAX} [W/kg]	SAR_{10MAX} [W/kg]	$SAR_{1MAXbrain}$ [W/kg]	$SAR_{1MAXeye}$ [W/kg]
WHIP	V	313	2.30	1.14	0.93	0.033
	T	272	2.31	1.25	0.66	0.059
MONOPOLE	V	365	2.17	1.29	1.21	0.022
	T	323	2.40	1.29	0.73	0.077
DIPOLE	V	388	2.74	1.93	1.85	0.022
	T	323	2.83	1.08	0.81	0.015
PIFA (Side mounted- frontal patch fed)	V	428	3.72	1.88	1.22	0.071
	T	402	3.40	1.99	1.28	0.165

<0.2 W/Kg



Calcolo degli incrementi di temperatura dopo 50 min
(90% della temperatura finale è raggiunta dopo 15 minuti)

TABLE II
THERMAL PARAMETERS OF THE HEAD TISSUES

	C [J/(kg·°C)]	K [J/(s·m·°C)]	A ₀ [J/(s·m ³)]	B [J/(s·m ³ ·°C)]
Skin	3500	0.42	1000	9100
Muscle	3600	0.50	690	2700
Bone	1300	0.40	0	1000
Blood	3900	0.00	0	0
Fat	2500	0.25	180	520
Cartilage	3400	0.45	1000	9100
Grey matter	3700	0.57	10000	35000
White matter	3600	0.50	10000	35000
Humor	4000	0.60	0	0
Lens	3000	0.40	0	0
Sclera/Cornea	4200	0.58	0	0
Cerebellum	3700	0.57	10000	35000
Hypophysis	3700	0.57	10000	36000
CSF	4000	0.60	0	0
Parotid	3700	0.57	7000	25000
Tongue	3300	0.42	3700	13000

A₀ = metabolismo

B = flusso sanguigno

TABLE IV
STEADY-STATE TEMPERATURE RISE, MAXIMUM IN THE WHOLE HEAD (ΔT_{MAX}), IN THE BRAIN ($\Delta T_{MAXbrain}$), AND IN THE LENS ($\Delta T_{MAXlens}$).
PHONE POSITIONS: VERTICAL (V) AND TILTED (T). POWER RADIATED IN FREE SPACE: 600 mW. FREQUENCY: 900 MHz

Phone model		ΔT_{MAX} [°C]	$\Delta T_{MAXbrain}$ [°C]	$\Delta T_{MAXlens}$ [°C]
WHIP	V	0.23	0.12	0.005
	T	0.25	0.08	0.008
MONOPOLE	V	0.22	0.13	0.003
	T	0.23	0.09	0.010
DIPOLE	V	0.33	0.19	0.003
	T	0.29	0.13	0.002
PIFA (Side mounted- frontal patch fed)	V	0.43	0.14	0.011
	T	0.39	0.16	0.022

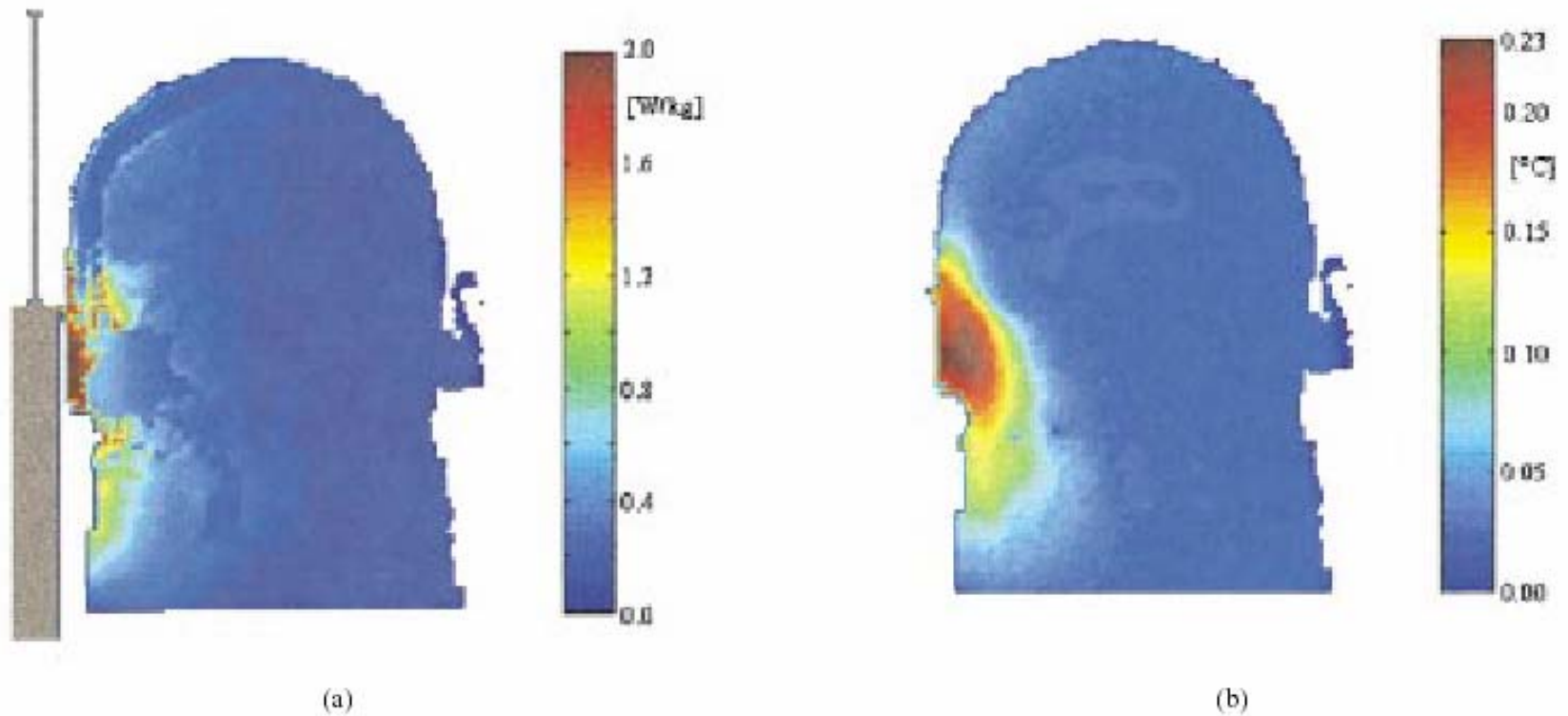
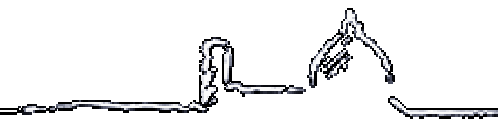


Fig. 3. Frontal section of the head in which the maximum local SAR occurs for a whip phone in the vertical position. (a) SAR distribution. (b) Temperature increase distribution. Power radiated in free space: 600 mW. Frequency: 900 MHz.

TABLE I
SAR IN THE HEAD OF A USER OF A PHONE EQUIPPED WITH A DUAL-BAND
MONOPOLE-HELIX ANTENNA. AVERAGE RADIATED POWER 250 mW
AT 900 MHz AND 125 mW AT 1800 MHz

Frequency [MHz]	Position	SAR _{1g} [W/kg]	SAR _{10g} [W/kg]	SAR _{1gBRAIN} [W/kg]
900	Vertical	2.06	1.19	0.32
	"Cheek"	1.65	0.91	0.13
1800	Vertical	1.81	0.87	0.12
	"Cheek"	1.08	0.56	0.06

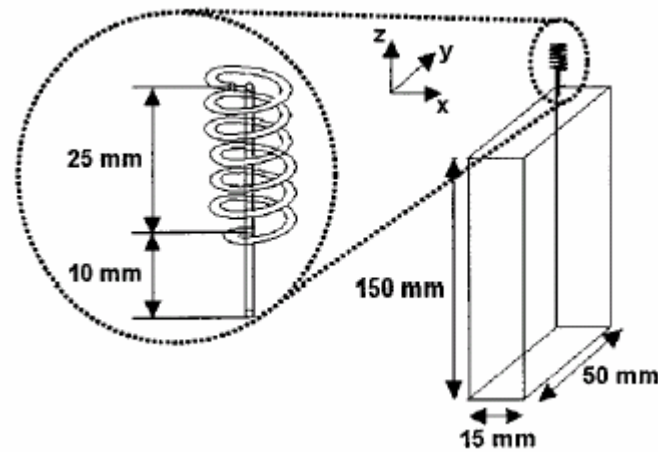


TABLE II
TEMPERATURE ELEVATIONS INDUCED IN THE USER'S HEAD, AFTER
15 min, BY A PHONE EQUIPPED WITH A DUAL-BAND MONOPOLE-HELIX
ANTENNA. AVERAGE RADIATED POWER: 250 mW AT 900 MHz AND
125 mW AT 1800 MHz

Freq. [MHz]	Position	Heating cause	ΔT _{max} [°C]	ΔT _{maxBRAIN} [°C]
900	Vertical	SAR	0.221	0.061
	"Cheek"	SAR	0.136	0.023*
		Contact	1.543	0.012**
		Contact + power dissipation	1.544	0.012**
		Contact + power dissip. + SAR	1.581	0.023*
1800	Vertical	SAR	0.155	0.036
	"Cheek"	SAR	0.085	0.011*
		Contact	1.543	0.012**
		Contact + power dissipation	1.543	0.012**
		Contact + power dissip. + SAR	1.549	0.012**

* ΔT_{maxBRAIN} located in the upper external brain region
** ΔT_{maxBRAIN} located in the lower external brain region

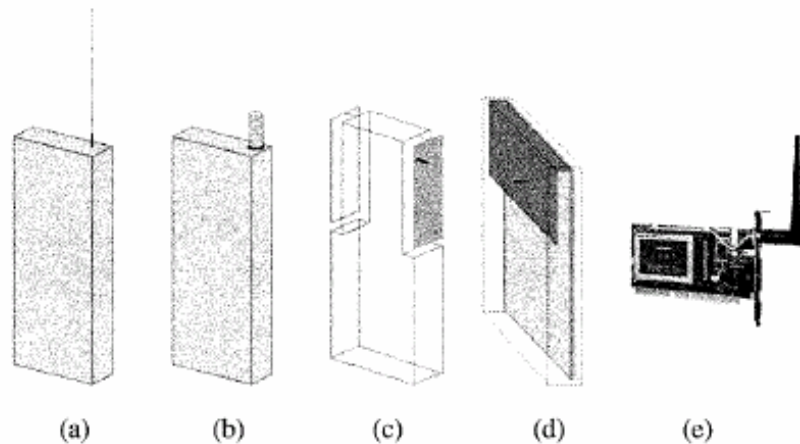


Fig. 2. Mobile phone and WLAN antennas under consideration. (a) Quarter wavelength monopole. (b) Helix. (c) Side-mounted PIFA. (d) Patch. (e) WLAN antenna. Feeds are shown with a thick line.

A large number of numerical simulations has been conducted for the GSM 900 and 1800 case, with an input power of 600 and 250 mW, respectively. Both the vertical (*V*) and tilted (*T*) positions of the phones have been examined. The WLAN antenna has an input power of +20 dBm at the frequency of 2.45 GHz.

TABLE I
 MAXIMUM SAR QUANTITIES (W/kg) AND EFFICIENCY FOR VARIOUS
 ANTENNA TYPES (GSM 900) **/2.4**

		Max SAR	Max 1g Avg SAR	Max 10 g Avg SAR	Antenna Efficiency
Monopole	V	7.993	3.181	2.061	25.29 %
	T	4.596	2.925	2.072	30.40 %
Helix	V	7.255	4.011	2.531	54.36 %
	T	5.771	3.477	2.385	62.21 %
Side PIFA	V	13.852	5.305	3.299	20.41 %
	T	6.078	3.902	2.430	29.57 %
Patch antenna	V	7.819	4.76412	3.178	28.50 %
	T	8.622	5.02242	3.105	31.37 %

TABLE II
 MAXIMUM SAR QUANTITIES (W/kg) AND EFFICIENCY FOR VARIOUS
 ANTENNA TYPES (GSM 1800, WLAN) **/2**

		Max SAR	Max 1g Avg SAR	Max 10 g Avg SAR	Antenna Efficiency
Monopole	V	2.171	1.473	0.946	64.98 %
	T	2.013	1.141	0.689	64.80 %
Helix	V	3.838	8.550	5.402	46.07 %
	T	3.347	6.621	4.097	53.21 %
Side PIFA	V	16.032	8.769	4.565	23.78 %
	T	8.372	5.397	3.302	33.43 %
Patch antenna	V	1.152	0.855	0.591	66.33 %
	T	0.808	0.626	0.447	71.82 %
WLAN	-	0.231	0.089	0.064	-

US Food and Drug Administration

Ottobre 1999

“The available science does not allow us to conclude that mobile phone are absolutely safe, or that they are unsafe.

However, the available scientific evidence does not demonstrate any adverse health effects associated with the use of mobile phones”

NRPB: National Radiologic Protection Board

Maggio 1999

“There was no human evidence of a risk of cancer resulting from exposure to radiations that arise from mobile phones”

IEGMP: Independent Expert Group on Mobile Phones (“Stewart committee”)

2000

“The balance of evidence to date suggests that exposures to RF radiation below [recommended limits] **do not cause adverse health effects to the general population**”

“[...] We conclude therefore that it is not possible at present to say that exposure to RF radiation, even at levels below national guidelines, is totally without potential adverse health effects, and that gaps in knowledge are sufficient to justify a **precautionary approach**”

“[...] Overall we conclude that the detrimental effects of hand-free operation are sufficiently large that **drivers should be dissuaded from using either hand-held or hand-free phones whilst on the move**”