Maximum electromagnetic field levels and the development of wireless networks

Francesco Pugliese

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STUDIO TECNICO DI INGEGNERIA

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Our Firm deals with:

- Design and analysis of radio communication systems
- Electromagnetic Impact Analysis and environmental measurements
- Plans for telecommunications facilities deployments
- Safety for electromagnetic fields exposure in workplaces
- Development of professional software for EMF analysis
- National and international conferences on the topic of EMF

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WIRELESS TECHNOLOGIES FOR **TELECOMMUNICATIONS** AND **SMART CITIES**

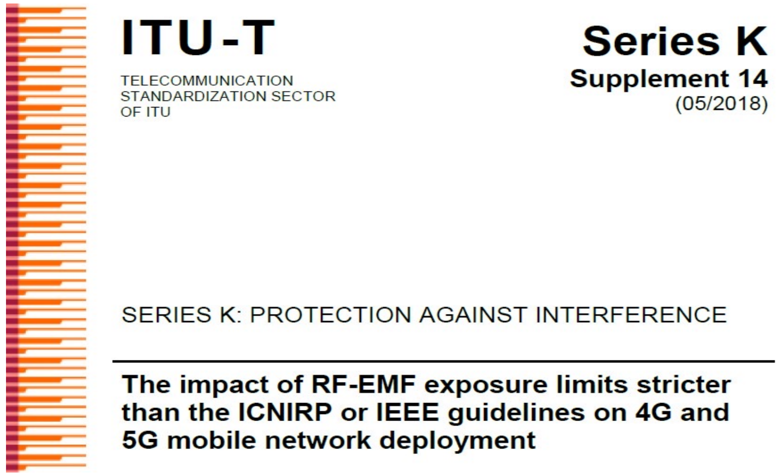
Wireless communication technologies are a key component in the realization of telecommunication and thus interconnection networks.
The main emerging wireless technologies include (source: Gartner)

- ✓ Wi-Fi
- ✓ Mobile telephony (5G)
- ✓ V2X (Vehicle to X)
- ✓ LPWA (Low Power Wide Area: NB IoT, LTE-M, LoRa, etc.)
- ✓ Wireless Sensing

We will therefore see a plurality of technologies, protocols and systems that will add to and go beyond the current scenario of classical telecommunications infrastructures.
The physical layer used for the realization of these systems is radio transmission, i.e. using **electromagnetic fields or waves** propagating in common space.

A further source of electromagnetic fields is the power lines.

EMF REFERENCE LEVELS FOR THE **DEPLOYMENT** OF **WIRELESS DEVICES**


ITU-T
TELECOMMUNICATION STANDARDIZATION SECTOR OF ITU

Series K
Supplement 14
(05/2018)

SERIES K: PROTECTION AGAINST INTERFERENCE

The impact of RF-EMF exposure limits stricter than the ICNIRP or IEEE guidelines on 4G and 5G mobile network deployment

The **Supplement 14 to ITU-T K-series Recommendations** asserts that:

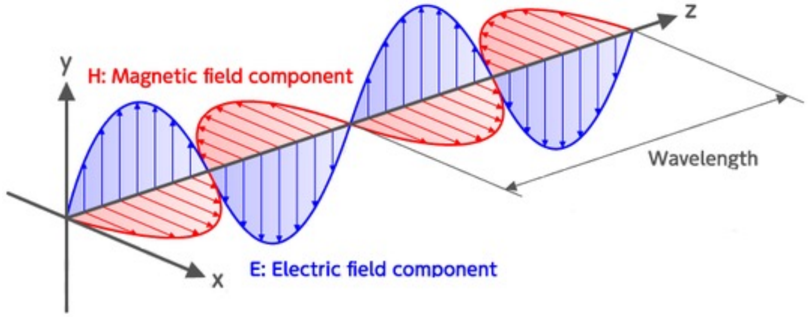
« Radio frequency electromagnetic field (RF-EMF) exposure limits have become a critical concern for further deployment of wireless networks, especially in countries, regions and even specific cities where RF-EMF limits are significantly stricter than the ICNIRP or Institute of Electrical and Electronics Engineers (IEEE) guidelines » .

This issue currently regards also several extra EU Countries such as **China, India, Russia** and **Switzerland**.

The results of the simulations [carried out] indicate that where RF-EMF limits are stricter than ICNIRP or IEEE guidelines, *the network capacity buildout (both 4G and 5G) might be severely constrained and might prevent addressing of the growing data traffic demand and the launching of new services on existing mobile networks*.»

WHAT IS AND HOW WE MEASURE AN

ELECTROMAGNETIC FIELD



The **electromagnetic (e.m.) field** is formed by the interaction of two variables that vary over time: the **electric field** and the **magnetic field.**

The electric field **(E)** is defined as a perturbation of the space caused by the presence of electric charges (positive or negative) and is measured in **Volt / meter [V/m].**

The magnetic field **(B)** can be defined as a perturbation of the space produced by the movement of electric charges (electric currents or permanent magnets) and is measured in **Ampere / meter [A/m] .** Magnetic induction **(H)** is a quantity associated with it, determining a force that acts on moving charges, and is measured in **Tesla [T]** (or more often in **[μT]**).

An EM field variable during time constitutes an **electromagnetic wave**, characterized by a **frequency [Hz]** and therefore by a wavelength, and a power density **(S)** convoyed by the wave, measured in **Watt/m^2.**

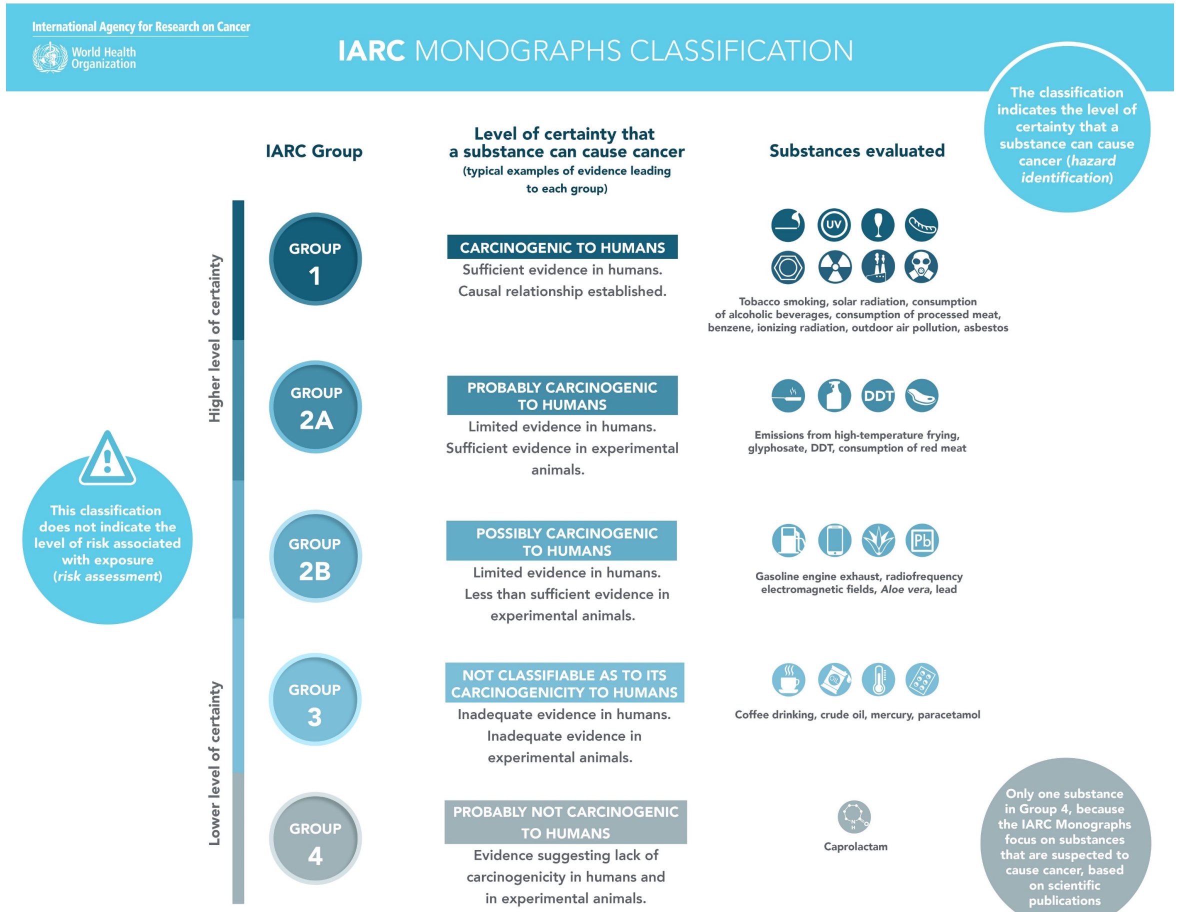
For High Frequency EMF and in points not very close to antenna, E and B are strictly proportional, so usually we evaluate only the electrical field [V/m].

CRITICAL ASPECTS ABOUT (RADIO FREQUENCY)

ELECTROMAGNETIC FIELD

IARC: International Agency for Research on Cancer

The **IARC** Working Group has classified radiofrequency electromagnetic fields as *"possibly human carcinogens"*, thus allocating them in Group **2B** of the IARC classification system.



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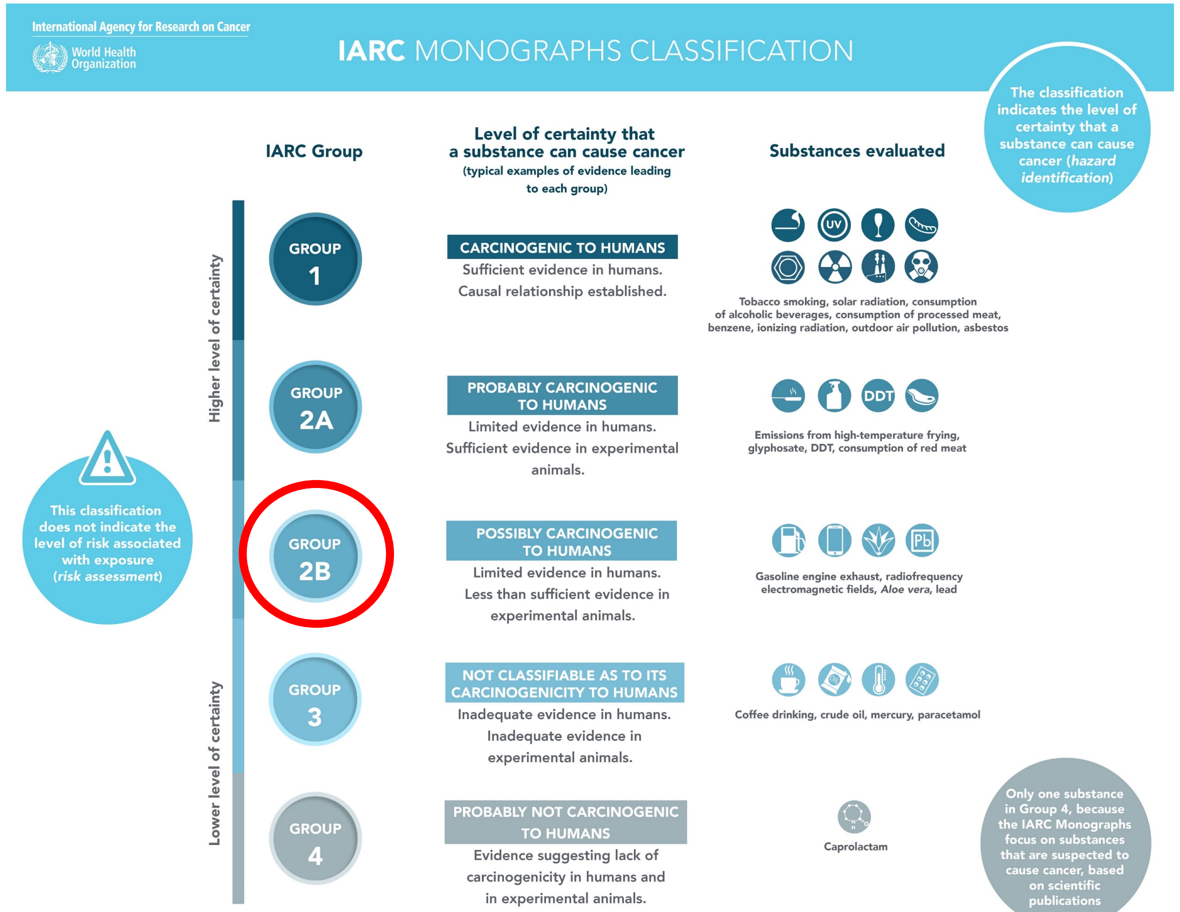
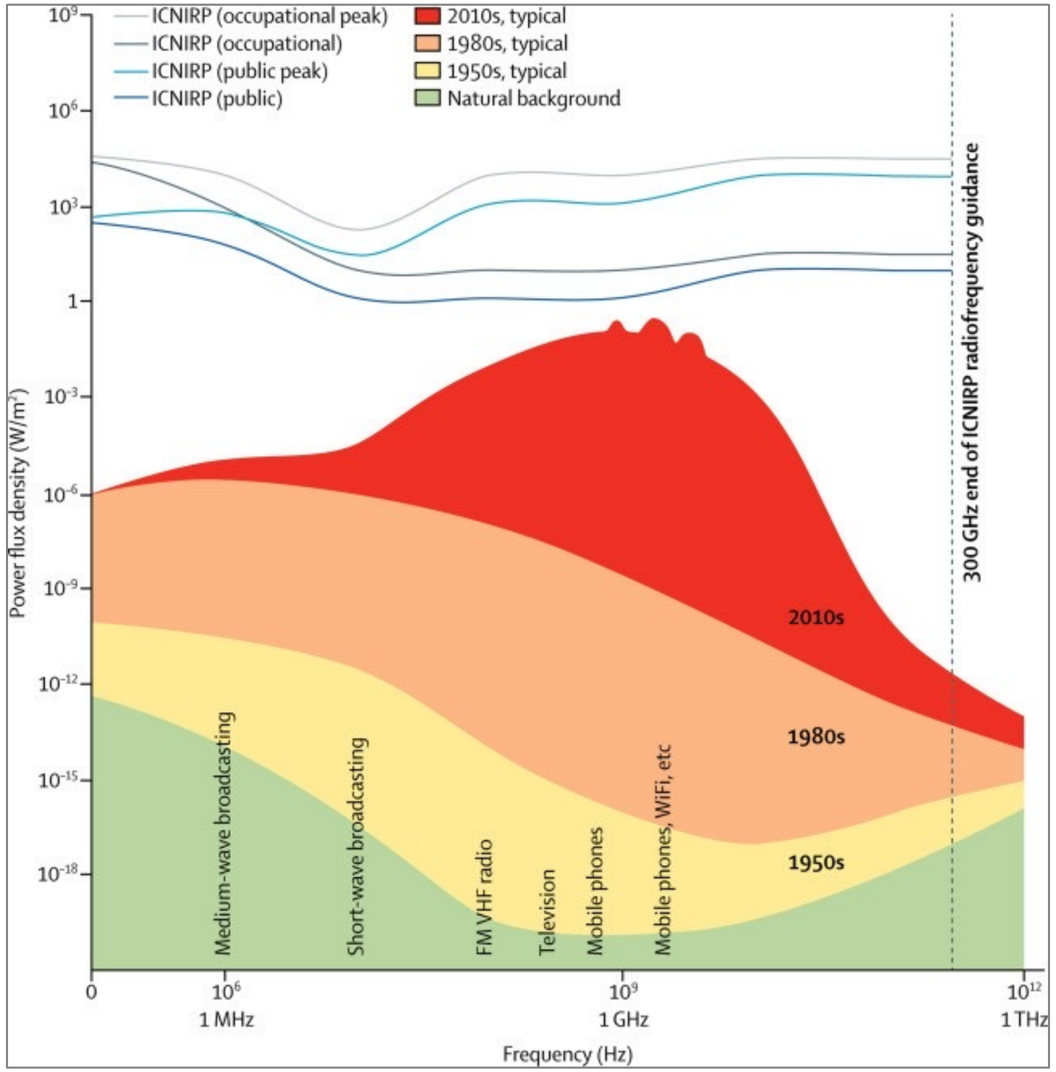


THE INCREASING OF EMF LEVELS



Source:

Philips A, Lamburn G. "Natural and human-activity-generated electromagnetic fields on Earth." Childhood Cancer. 2012; (London; April 24–26, 2012.) modificato da Bandara P., Carpenter D.O., 2018.

Natural levels of radio frequency electromagnetic radiation are based on the *NASA report CR-166661.*

CRITICAL ASPECTS ABOUT (RADIO FREQUENCY)
ELECTROMAGNETIC FIELD

Antenne, i comitati contro il Comune

Da Tobbiana parte la proposta di una manifestazione cittadina

L'assessore all'ambiente: «Siamo al lavoro per il nuovo piano che tuteli i cittadini»

Sabato prossimo esperti a Lucca

ICNIRP REFERENCE LEVELS FOR RF ELECTROMAGNETIC FIELD

INTERNATIONAL COMMISSION ON NON-IONIZING RADIATION PROTECTION

ICNIRP
INTERNATIONAL COMMISSION ON NON-IONIZING RADIATION PROTECTION

ICNIRP GUIDELINES

FOR LIMITING EXPOSURE TO ELECTROMAGNETIC FIELDS (100 kHz TO 300 GHz)

PUBLISHED IN: HEALTH PHYS 118(5): 483–524; 2020

Important: *here we will consider exposure for* ***general population!***

ICNIRP REFERENCE LEVELS FOR RF ELECTROMAGNETIC FIELD

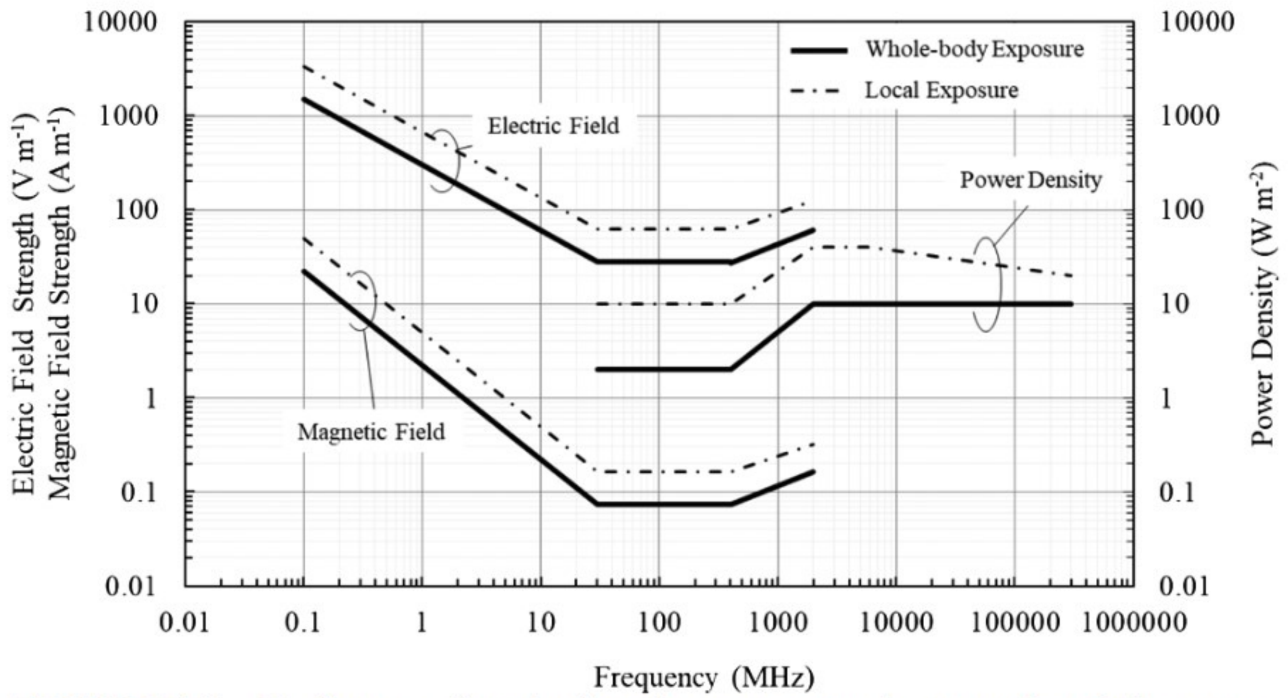


FIGURE 2. Reference levels for time averaged general public exposures of ≥6 min, to electromagnetic fields from 100 kHz to 300 GHz (unperturbed rms values; see Tables 5 and 6 for full specifications).

Important: *In telecommunications systems we consider only HIGH FREQUENCY EMF (100 KHz – 300 Ghz) !!*

ICNIRP REFERENCE LEVELS FOR RF ELECTROMAGNETIC FIELD

ICNIRP Guidelines ● ICNIRP

Table 5. Reference levels for exposure, averaged over 30 min and the whole body, to electromagnetic fields from 100 kHz to 300 GHz (unperturbed rms values).[a]

Exposure scenario	Frequency range	Incident E-field strength; E_{inc} (V m^{-1})	Incident H-field strength; H_{inc} (A m^{-1})	Incident power density; S_{inc} (W m^{-2})
Occupational	0.1 – 30 MHz	$660/f_M^{0.7}$	$4.9/f_M$	NA
	>30 – 400 MHz	61	0.16	10
	>400 – 2000 MHz	$3f_M^{0.5}$	$0.008f_M^{0.5}$	$f_M/40$
	>2 – 300 GHz	NA	NA	50
General public	0.1 – 30 MHz	$300/f_M^{0.7}$	$2.2/f_M$	NA
	>30 – 400 MHz	27.7	0.073	2
	>400 – 2000 MHz	$1.375f_M^{0.5}$	$0.0037f_M^{0.5}$	$f_M/200$
	>2 – 300 GHz	NA	NA	10

[a]Note:

1. "NA" signifies "not applicable" and does not need to be taken into account when determining compliance.

2. f_M is frequency in MHz.

3. S_{inc}, E_{inc}, and H_{inc} are to be averaged over 30 min, over the whole-body space. Temporal and spatial averaging of each of E_{inc} and H_{inc} must be conducted by averaging over the relevant square values (see eqn 8 in Appendix A for details).

4. For frequencies of 100 kHz to 30 MHz, regardless of the far-field/near-field zone distinctions, compliance is demonstrated if neither E_{inc} or H_{inc} exceeds the above reference level values.

5. For frequencies of >30 MHz to 2 GHz: (a) within the far-field zone: compliance is demonstrated if either S_{inc}, E_{inc} or H_{inc}, does not exceed the above reference level values (only one is required); S_{eq} may be substituted for S_{inc}; (b) within the radiative near-field zone, compliance is demonstrated if either S_{inc}, or both E_{inc} and H_{inc}, does not exceed the above reference level values; and (c) within the reactive near-field zone: compliance is demonstrated if both E_{inc} and H_{inc} do not exceed the above reference level values; S_{inc} cannot be used to demonstrate compliance, and so basic restrictions must be assessed.

6. For frequencies of >2 GHz to 300 GHz: (a) within the far-field zone: compliance is demonstrated if S_{inc} does not exceed the above reference level values; S_{eq} may be substituted for S_{inc}; (b) within the radiative near-field zone, compliance is demonstrated if S_{inc} does not exceed the above reference level values; and (c) within the reactive near-field zone, reference levels cannot be used to determine compliance, and so basic restrictions must be assessed.

ICNIRP REFERENCE LEVELS FOR RF ELECTROMAGNETIC FIELD

…RP Guidelines ● ICNIRP

…ed over 30 min and the whole body, to ele…

Table 5. Reference levels for ex… fields from 100 kHz to 300 GHz (unperturbed rms v…

Exposure scenario	…e	Incident E-field strength; E_{inc} ($V\ m^{-1}$)	Incident H-field strength; H_{inc} ($A\ m^{-1}$)	Incident power …sity; S_{inc} ($W\ m^{-2}$)
Occupational	…Hz	$660/f_M^{0.7}$	$4.9/f_M$	NA
	…MHz	61	0.16	10
	…MHz	$3f_M^{0.5}$	$0.008f_M^{0.5}$	…/40
	…GHz	NA	NA	50
General public	…Hz	$300/f_M^{0.7}$	$2.2/f_M$	…A
	…Hz	27.7	0.073	2
	…Hz	$1.375f_M^{0.5}$	$0.0037f_M^{0.5}$	…/200
		NA	NA	10

[a]Note:

1. "NA" signifies "not ap…
2. f_M is frequency in MHz.
3. S_{inc}, E_{inc}, and H_{inc} are to b… …f E_{inc} and H_{inc} must be conducted by averaging ov…
4. For frequencies of 100 kHz to … …strated if neither E_{inc} or H_{inc} exceeds the above reference l…
5. For frequencies of >30 MHz to 2 G… …E_{inc} or H_{inc}, does not exceed the above reference level values (only one… …e near-field zone, compliance is demonstrated if either S_{inc}, or both E_{inc} and H_{inc}… …) within the reactive near-field zone: compliance is demonstrated if both E_{inc} and H_{inc} do… …annot be used to demonstrate compliance, and so basic restrictions must be assessed.
6. For frequencies of >2 GHz to 300 GHz: (a) within the far-field zone: compliance is demonstrated if S_{inc} does not exceed the above reference level values; S_{eq} may be substituted for S_{inc}; (b) within the radiative near-field zone, compliance is demonstrated if S_{inc} does not exceed the above reference level values; and (c) within the reactive near-field zone, reference levels cannot be used to determine compliance, and so basic restrictions must be assessed.

…to be taken into account when determining co…

…e-body space. Temp…

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ICNIRP REFERENCE LEVELS FOR RF ELECTROMAGNETIC FIELD

Health Physics May 2020, Volume 118, Number 5

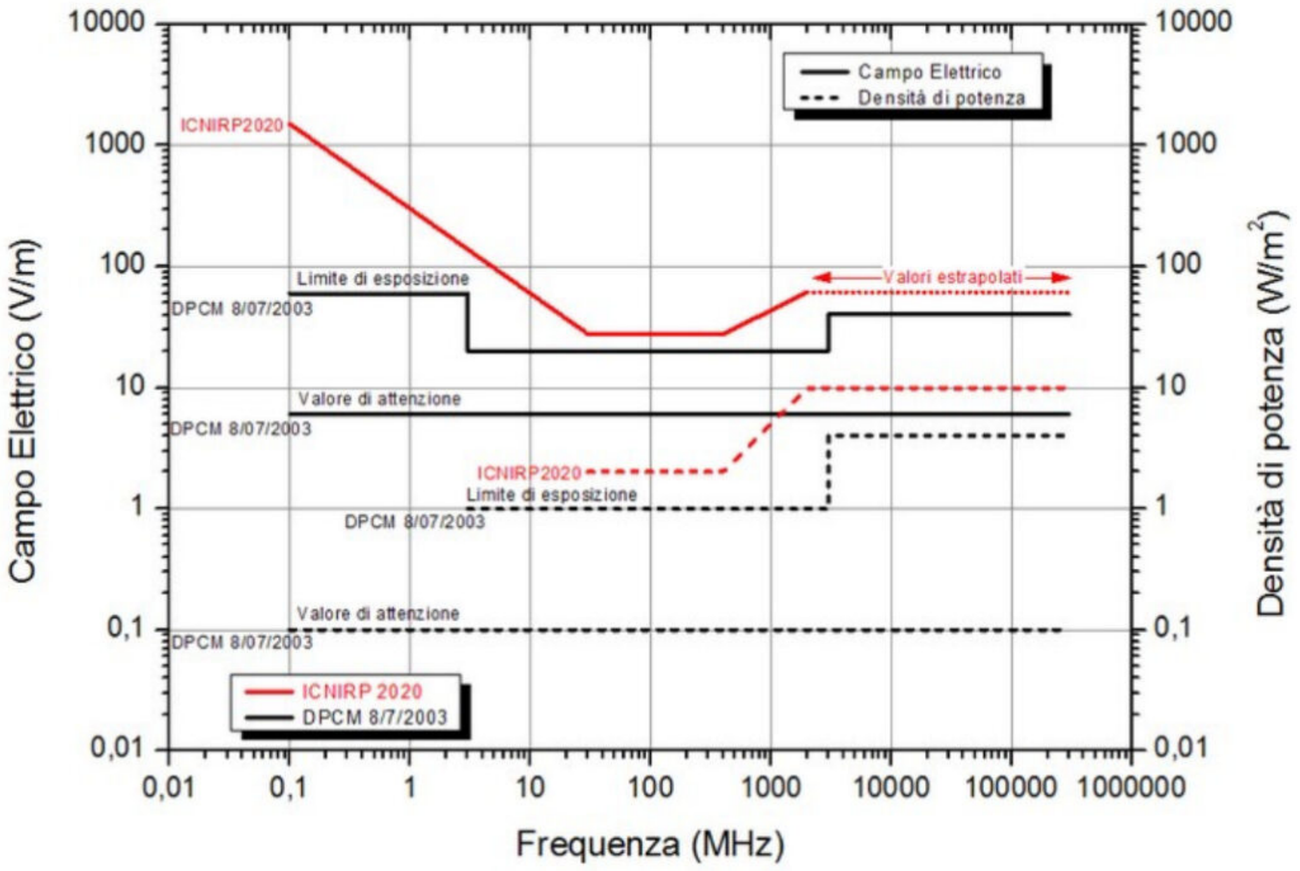
Table 6. Reference levels for local exposure, averaged over 6 min, to electromagnetic fields from 100 kHz to 300 GHz (unperturbed rms values).[a]

Exposure scenario	Frequency range	Incident E-field strength; E_{inc} (V m^{-1})	Incident H-field strength; H_{inc} (A m^{-1})	Incident power density; S_{inc} (W m^{-2})
Occupational	0.1 – 30 MHz	$1504/f_M^{0.7}$	$10.8/f_M$	NA
	>30 – 400 MHz	139	0.36	50
	>400 – 2000 MHz	$10.58f_M^{0.43}$	$0.0274f_M^{0.43}$	$0.29f_M^{0.86}$
	>2 – 6 GHz	NA	NA	200
	>6 – <300 GHz	NA	NA	$275/f_G^{0.177}$
	300 GHz	NA	NA	100
General public	0.1 – 30 MHz	$671/f_M^{0.7}$	$4.9/f_M$	NA
	>30 – 400 MHz	62	0.163	10
	>400 – 2000 MHz	$4.72f_M^{0.43}$	$0.0123f_M^{0.43}$	$0.058f_M^{0.86}$
	>2 – 6 GHz	NA	NA	40
	>6 – 300 GHz	NA	NA	$55/f_G^{0.177}$
	300 GHz	NA	NA	20

[a] Note:

1. "NA" signifies "not applicable" and does not need to be taken into account when determining compliance.
2. f_M is frequency in MHz; f_G is frequency in GHz.
3. S_{inc}, E_{inc}, and H_{inc} are to be averaged over 6 min, and where spatial averaging is specified in Notes 6–7, over the relevant projected body space. Temporal and spatial averaging of each of E_{inc} and H_{inc} must be conducted by averaging over the relevant square values (see eqn 8 in Appendix A for details).
4. For frequencies of 100 kHz to 30 MHz, regardless of the far-field/near-field zone distinctions, compliance is demonstrated if neither peak spatial E_{inc} or peak spatial H_{inc}, over the projected whole-body space, exceeds the above reference level values.
5. For frequencies of >30 MHz to 6 GHz: (a) within the far-field zone, compliance is demonstrated if one of peak spatial S_{inc}, E_{inc} or H_{inc}, over the projected whole-body space, does not exceed the above reference level values (only one is required); S_{eq} may be substituted for S_{inc}; (b) within the radiative near-field zone, compliance is demonstrated if either peak spatial S_{inc}, or both peak spatial E_{inc} and H_{inc}, over the projected whole-body space, does not exceed the above reference level values; and (c) within the reactive near-field zone: compliance is demonstrated if both E_{inc} and H_{inc} do not exceed the above reference level values; S_{inc} cannot be used to demonstrate compliance; for frequencies >2 GHz, reference levels cannot be used to determine compliance, and so basic restrictions must be assessed.
6. For frequencies of >6 GHz to 300 GHz: (a) within the far-field zone, compliance is demonstrated if S_{inc}, averaged over a square 4-cm^2 projected body surface space, does not exceed the above reference level values; S_{eq} may be substituted for S_{inc}; (b) within the radiative near-field zone, compliance is demonstrated if S_{inc}, averaged over a square 4-cm^2 projected body surface space, does not exceed the above reference level values; and (c) within the reactive near-field zone reference levels cannot be used to determine compliance, and so basic restrictions must be assessed.
7. For frequencies of >30 GHz to 300 GHz, exposure averaged over a square 1-cm^2 projected body surface space must not exceed twice that of the square 4-cm^2 restrictions.

ICNIRP VS ITALIAN NATIONALS REFERENCE LEVELS FOR RF ELECTROMAGNETIC FIELD



LIMITI DI ESPOSIZIONE
Valori di immissione che non devono essere superati in alcuna condizione di esposizione

Frequenze	Intensità di campo elettrico E (V/m)	Intensità di campo magnetico H (A/m)	Densità di potenza D (W/m²)
0,1 < f ≤ 3 MHz	60	0,2	-
3 < f ≤ 3000 MHz	20	0,05	1
3 < f ≤ 300 GHz	40	0,01	4

VALORI DI ATTENZIONE*
Valore di immissione che non deve essere superato negli ambienti abitativi a permanenze prolungate

Frequenze	Intensità di campo elettrico E (V/m)	Intensità di campo magnetico H (A/m)	Densità di potenza D (W/m²)
0,1 MHz < f ≤ 300 GHz	6	0,016	0,10 (3 MHz < f ≤ 300 GHz)

* all'interno di edifici utilizzati come ambienti abitativi con permanenze continuative non inferiori a quattro ore giornaliere e nelle loro pertinenze esterne, quali balconi, terrazzi e cortili (esclusi i tetti anche in presenza di lucernai ed i lastrici solari con funzione prevalente di copertura, indipendentemente dalla presenza o meno di balaustre o protezioni anti-caduta e di pavimentazione rifinita, di proprietà comune dei condomini) – testo come modificato dalla L.221/2012 (art. 14 c. 8)

OBIETTIVO DI QUALITÀ**
Valori di immissione da conseguire nel breve, medio e lungo periodo, anche attraverso l'uso di tecnologie e metodi di risanamento disponibili

Frequenze	Intensità di campo elettrico E (V/m)	Intensità di campo magnetico H (A/m)	Densità di potenza D (W/m²)
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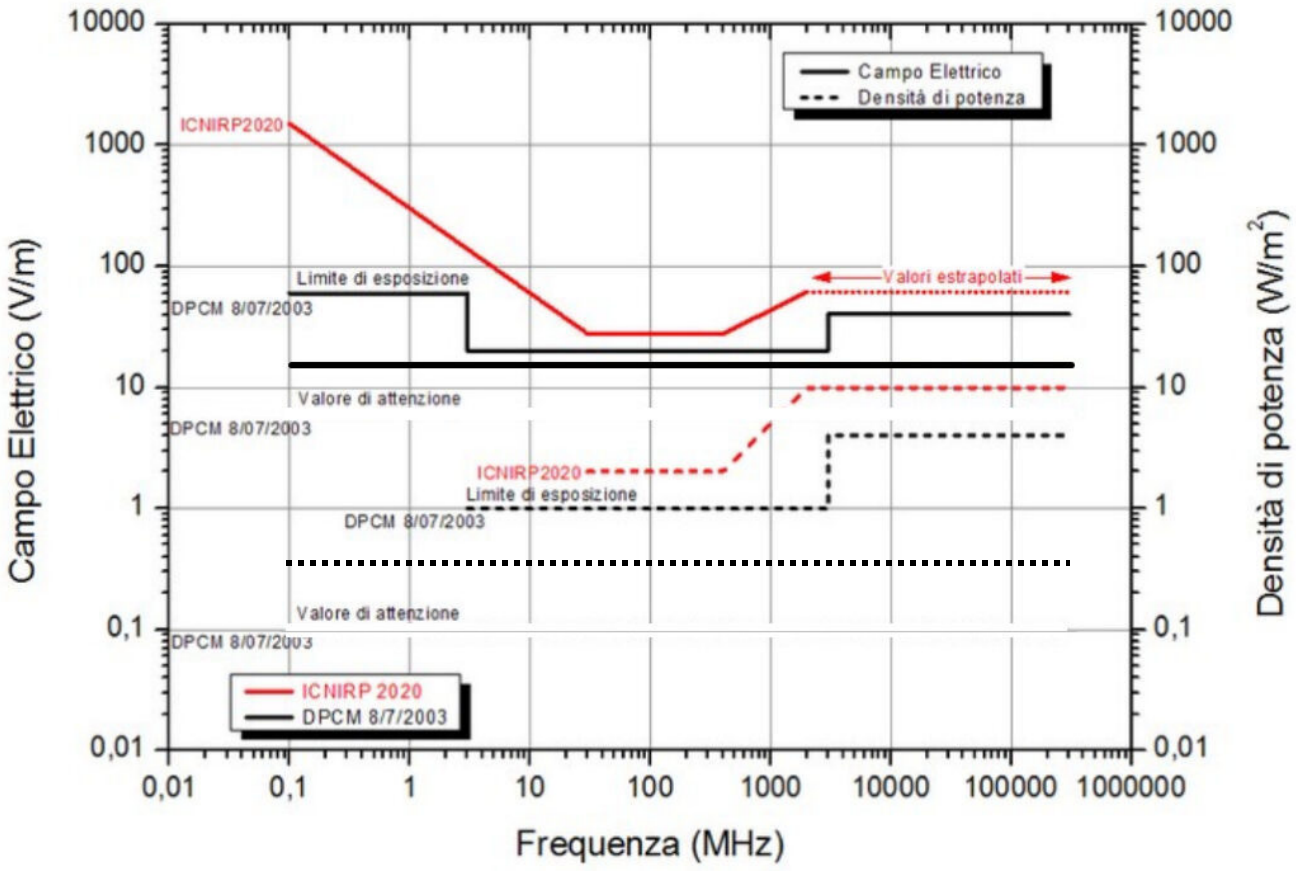
**all'aperto nelle aree intensamente frequentate, per le quali si intendono anche superfici edificate ovvero attrezzate permanentemente per il soddisfacimento di bisogni sociali, sanitari e ricreativi

The warning values («*valori di attenzione*») were conceived as prudential limits for possible **long-term effects on health**, they are defined as a **mean over 24 hours**; they are not covered by the ICNIRP thresholds, so they should not be considered in a comparative analysis.

ICNIRP VS **ITALIAN NATIONALS** REFERENCE LEVELS
FOR **RF ELECTROMAGNETIC FIELD**



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15 V/m
0,6 W/m²

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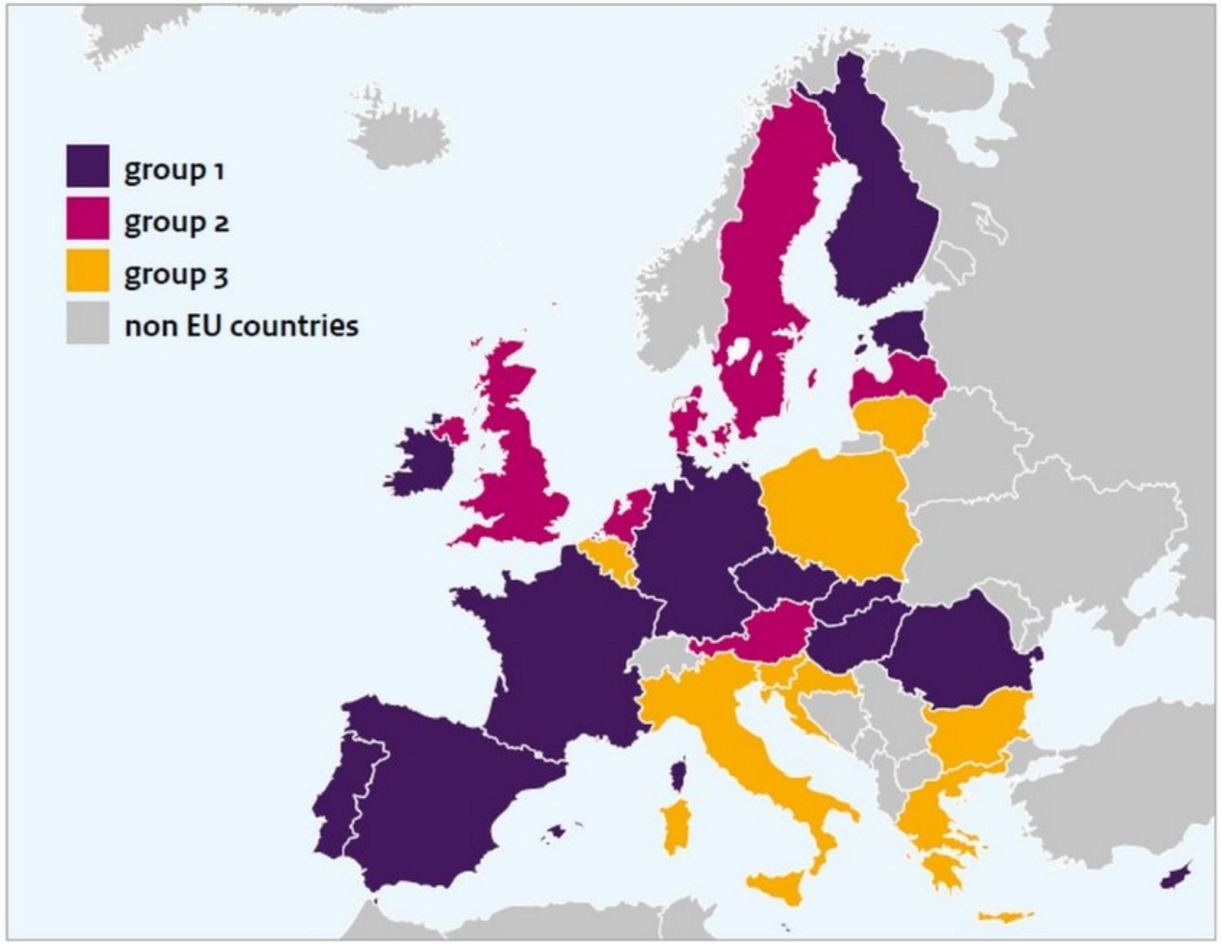
ICNIRP VS ITALIAN NATIONALS REFERENCE LEVELS FOR RF ELECTROMAGNETIC FIELD

Figure 2 Overview of limits for exposure of the general population to radiofrequency EMF in the EU. Group 1 (purple): legal limits derived from EU recommendation; Group 2 (pink): no legal limits or limits less strict than in EU recommendation; Group 3 (yellow): stricter limits than in EU recommendation.



Source:
Comparison of international policies on electromagnetic fields (power frequency and radiofrequency fields)*, National Institute for Public Health, Netherlands, Dr. R. Stam, 2018.*

Table 1 Reference levels or exposure limits for the general public for electromagnetic fields in inhabited areas in member states of the European Union and selected industrial nations outside the European Union (situation July 2017)

	50 Hz		900 MHz			1800 MHz			2100 MHz		
Country:	electric field strength (V/m)	magnetic flux density (µT)	electric field strength (V/m)	magnetic flux density (µT)	equivalent plain wave power density (W/m²)	electric field strength (V/m)	magnetic flux density (µT)	equivalent plain wave power density (W/m²)	electric field strength (V/m)	magnetic flux density (µT)	equivalent plain wave power density (W/m²)
1999/519/EC	**5000**	**100**	**41**	**0.14**	**4.5**	**58**	**0.20**	**9**	**61**	**0.20**	**10**
Austria	[5000]	[100] 1)	[41]	[0.14]	[4.5]	[58]	[0.20]	[9]	[61]	[0.20]	[10]
Belgium	—	10 2)	21 3)	—	—	29 3)	—	—	31 3)	—	—
Bulgaria	— (4	— (4	—	—	0.1	—	—	0.1	—	—	0.1
Croatia	2000 5)	40 5)	17 5)	0.055 5)	0.72 5)	23 5)	0.078 5)	1.4 5)	25 5)	0.084 5)	1.7 5)
Cyprus	[5000]	[100]	41	0.14	4.5	58	0.20	9	61	0.20	10
Czech Republic	2000	200	41	0.14	4.5	58	0.20	9	61	0.20	10
Denmark	—	— 6)	—	—	—	—	—	—	—	—	—
Estonia	5000	100	41	0.14	4.5	58	0.20	9	61	0.20	10
Finland	[5000]	[100] 7)	41	0.14	4.5	58	0.20	9	61	0.20	10
France	5000 8)	100 8)	41	0.14	4.5	58	0.20	9	61	0.20	10
Germany	5000 9)	100 9)	41	0.14	4.5	58	0.20	9	61	0.20	10
Greece	5000	100	32 10)	0.11 10)	2.7 10)	45 10)	0.15 10)	5.4 10)	47 10)	0.16 10)	6 10)
Hungary	5000	100	41	0.14	4.5	58	0.20	9	61	0.20	10
Ireland	5000 11)	100 11)	41	0.14	4.5	58	0.20	9	61	0.20	10
Italy	—	3 12)	6 13)	0.02 13)	0.1 13)	6 13)	0.02 13)	0.1 13)	6 13)	0.02 13)	0.1 13)
Latvia	—	—	—	—	—	—	—	—	—	—	—
Lithuania	500 14)	20 14)	—	—	0.45	—	—	0.9	—	—	1
Luxemburg	5000 15)	100 15)	41 16)	0.14	4.5	58 16)	0.20	9	61 16)	0.20	10
Malta	[5000]	[100]	41	0.14	4.5	58	0.20	9	61	0.20	10
Netherlands	[5000] 17)	[100] 17)	—	—	—	—	—	—	—	—	—
Poland	1000	75	7	—	0.1	7	—	0.1	7	—	0.1
Portugal	5000	100	41	0.14	4.5	58	0.20	9	61	0.20	10
Romania	5000	100	41	0.14	4.5	58	0.20	9	61	0.20	10
Slovakia	5000	100	41	0.14	4.5	58	0.20	9	61	0.20	10
Slovenia	500 18)	10 18)	13 18)	0.04 18)	0.45 18)	18 18)	0.06 18)	0.9 18)	19 18)	0.06 18)	1 18)
Spain	[5000] 19)	[100] 19)	41	0.14	4.5	58	0.20	9	61	0.20	10
Sweden	[5000]	[100]	[41]	[0.14]	[4.5]	[58]	[0.20]	[9]	[61]	[0.20]	[10]
United Kingdom	[9000]	[360]	[41]	[0.14]	[4.5]	[58]	[0.20]	[9]	[61]	[0.20]	[10]

	50 Hz		900 MHz			1800 MHz			2100 MHz		
Country:	electric field strength (V/m)	magnetic flux density (µT)	electric field strength (V/m)	magnetic flux density (µT)	equivalent plain wave power density (W/m²)	electric field strength (V/m)	magnetic flux density (µT)	equivalent plain wave power density (W/m²)	electric field strength (V/m)	magnetic flux density (µT)	equivalent plain wave power density (W/m²)
1999/519/EC	**5000**	**100**	**41**	**0.14**	**4.5**	**58**	**0.20**	**9**	**61**	**0.20**	**10**
Australia	—	—	41	0.14	4.5	58	0.20	9	61	0.20	10
China	4000	100	12	0.04	0.4	12	0.04	0.4	12	0.04	0.4
India	—	—	13	0.041	0.45	18	0.058	0.9	20	0.063	1.1
Japan	3000 20)	200 20)	48	0.16	6	61	0.20	10	61	0.20	10
Russia	500	5 21)	—	—	0.1	—	—	0.1	—	—	0.1
Switzerland	—	1 22)	4 23)	—	—	6 23)	—	—	6 23)	—	—
U.S.A.	— 24)	— 24)	—	—	6	—	—	10	—	—	10

Source:
Comparison of international policies on electromagnetic fields (power frequency and radiofrequency fields), *National Institute for Public Health, Netherlands, Dr. R. Stam, 2018.*

Table 1 Reference levels or exposure limits for the general public for electromagnetic fields in inhabited areas in member states of the European Union and selected industrial nations outside the European Union (situation July 2017)

Country:	50 Hz electric field strength (V/m)	50 Hz magnetic flux density (µT)	900 MHz electric field strength (V/m)	900 MHz magnetic flux density (µT)	900 MHz equivalent plain wave power density (W/m^2)	1800 MHz electric field strength (V/m)	1800 MHz magnetic flux density (µT)	1800 MHz equivalent plain wave power density (W/m^2)	2100 MHz electric field strength (V/m)	2100 MHz magnetic flux density (µT)	2100 MHz equivalent plain wave power density (W/m^2)
1999/519/EC	**5000**	**100**	**41**	**0.14**	**4.5**	**58**	**0.20**	**9**	**61**	**0.20**	**10**
Austria	[5000]	[100] [1)]	[41]	[0.14]	[4.5]	[58]	[0.20]	[9]	[61]	[0.20]	[10]
Belgium	—	10 [2)]	21 [3)]	—	—	29 [3)]	—	—	31 [3)]	—	—
Bulgaria	— [(4]	— [(4]	—	—	0.1	—	—	0.1	—	—	0.1
Croatia	2000 [5)]	40 [5)]	17 [5)]	0.055 [5)]	0.72 [5)]	23 [5)]	0.078 [5)]	1.4 [5)]	25 [5)]	0.084 [5)]	1.7 [5)]
Cyprus	[5000]	[100]	41	0.14	4.5	58	0.20	9	61	0.20	10
Czech Republic	2000	200	41	0.14	4.5	58	0.20	9	61	0.20	10
Denmark	—	— [6)]	—	—	—	—	—	—	—	—	—
Estonia	5000	100	41	0.14	4.5	58	0.20	9	61	0.20	10
Finland	[5000]	[100] [7)]	41	0.14	4.5	58	0.20	9	61	0.20	10
France	5000 [8)]	100 [8)]	41	0.14	4.5	58	0.20	9	61	0.20	10
Germany	5000 [9)]	100 [9)]	41	0.14	4.5	58	0.20	9	61	0.20	10
Greece	5000	100	32 [10)]	0.11 [10)]	2.7 [10)]	45 [10)]	0.15 [10)]	5.4 [10)]	47 [10)]	0.16 [10)]	6 [10)]
Hungary	5000	100	41	0.14	4.5	58	0.20	9	61	0.20	10
Ireland	5000 [11)]	100 [11)]	41	0.14	4.5	58	0.20	9	61	0.20	10
Italy	—	3 [12)]	6 [13)]	0.02 [13)]	0.1 [13)]	6 [13)]	0.02 [13)]	0.1 [13)]	6 [13)]	0.02 [13)]	0.1 [13)]
Latvia	—	—	—	—	—	—	—	—	—	—	—
Lithuania	500 [14)]	20 [14)]	—	—	0.45	—	—	0.9	—	—	1
Luxemburg	5000 [15)]	100 [15)]	41 [16)]	0.14	4.5	58 [16)]	0.20	9	61 [16)]	0.20	10
Malta	[5000]	[100]	41	0.14	4.5	58	0.20	9	61	0.20	10
Netherlands	[5000] [17)]	[100] [17)]	—	—	—	—	—	—	—	—	—
Poland	1000	75	7	—	0.1	7	—	0.1	7	—	0.1
Portugal	5000	100	41	0.14	4.5	58	0.20	9	61	0.20	10
Romania	5000	100	41	0.14	4.5	58	0.20	9	61	0.20	10
Slovakia	5000	100	41	0.14	4.5	58	0.20	9	61	0.20	10
Slovenia	500 [18)]	10 [18)]	13 [18)]	0.04 [18)]	0.45 [18)]	18 [18)]	0.06 [18)]	0.9 [18)]	19 [18)]	0.06 [18)]	1 [18)]
Spain	[5000] [19)]	[100] [19)]	41	0.14	4.5	58	0.20	9	61	0.20	10
Sweden	[5000]	[100]	[41]	[0.14]	[4.5]	[58]	[0.20]	[9]	[61]	[0.20]	[10]
United Kingdom	[9000]	[360]	[41]	[0.14]	[4.5]	[58]	[0.20]	[9]	[61]	[0.20]	[10]

Country:	50 Hz electric field strength (V/m)	50 Hz magnetic flux density (µT)	900 MHz electric field strength (V/m)	900 MHz magnetic flux density (µT)	900 MHz equivalent plain wave power density (W/m^2)	1800 MHz electric field strength (V/m)	1800 MHz magnetic flux density (µT)	1800 MHz equivalent plain wave power density (W/m^2)	2100 MHz electric field strength (V/m)	2100 MHz magnetic flux density (µT)	2100 MHz equivalent plain wave power density (W/m^2)
1999/519/EC	**5000**	**100**	**41**	**0.14**	**4.5**	**58**	**0.20**	**9**	**61**	**0.20**	**10**
Australia	—	—	41	0.14	4.5	58	0.20	9	61	0.20	10
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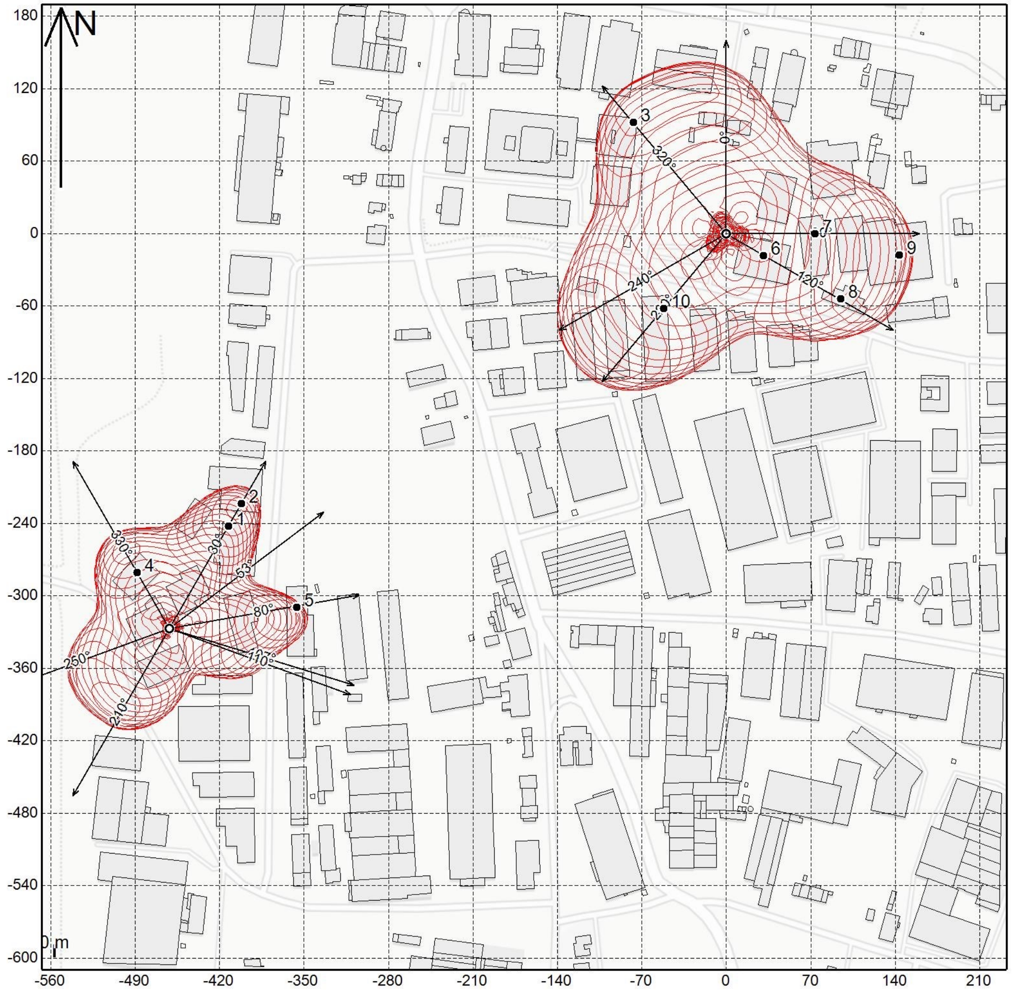
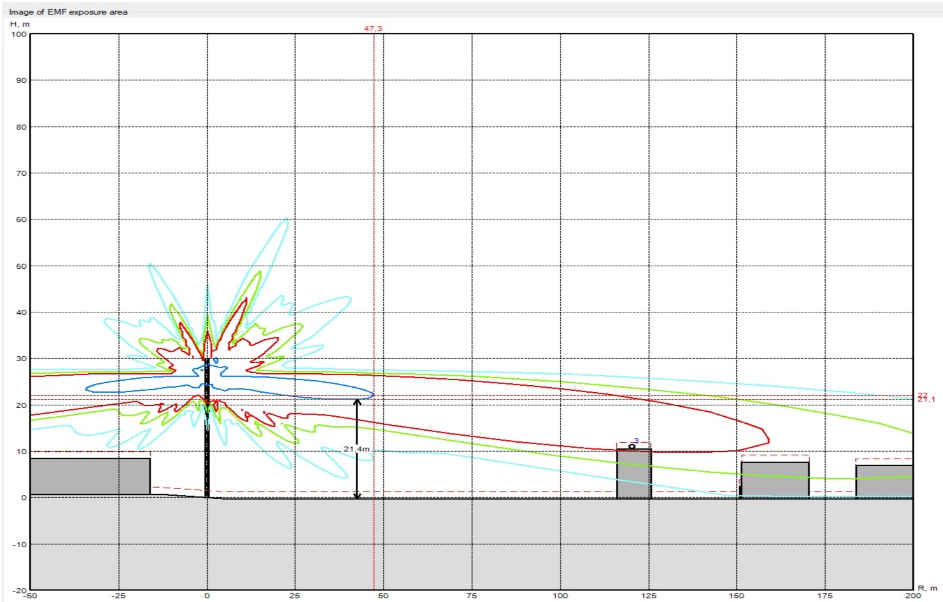
India	—	—	13	0.041	0.45	18	0.058	0.9	20	0.063	1.1
Japan	3000 [20)]	200 [20)]	48	0.16	6	61	0.20	10	61	0.20	10
Russia	500	5 [21)]	—	—	0.1	—	—	0.1	—	—	0.1
Switzerland	—	1 [22)]	4 [23)]	—	—	6 [23)]	—	—	6 [23)]	—	—
U.S.A.	— [24)]	— [24)]	—	—	6	—	—	10	—	—	10

Source:
Comparison of international policies on electromagnetic fields (power frequency and radiofrequency fields)*, National Institute for Public Health, Netherlands, Dr. R. Stam, 2018.*

DETERMINING THE ELECTROMAGNETIC FIELD LEVELS : CALCULATIONS

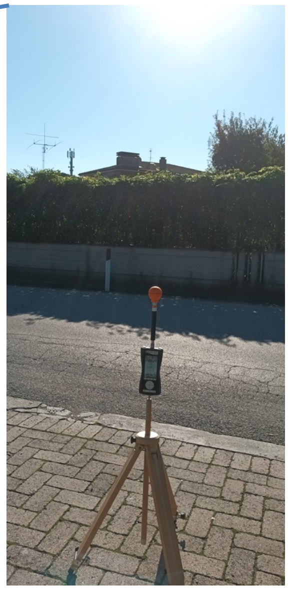




Control point calculation results

Radiating Source / Control Point	1	2	3	4	5	6	7	8	9	10
Location	Building	Building	Building	Building	Building	Building	Building	Building	Building	Building
Height (m)	7,9 m	7,2 m	11,4 m	7,1 m	7,4 m	7,7 m	7,3 m	8,3 m	8,4 m	7,9 m
Elevation (m)	12,0 m	12,0 m	13,0 m	12,4 m	12,7 m	14,0 m	13,9 m	14,0 m	14,0 m	14,0 m
Measured E-field strength (V/m)	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
Calculated E-field strength (V/m)	5,7481	5,8659	6,5616	1,6961	5,2305	2,8123	2,3848	4,0041	5,3710	2,9256
Simultaneous exposure (%)	91,780	95,581	119,59	7,9916	75,995	21,969	15,798	44,536	80,135	23,776
Total E-field strength (V/m)	5,7481	5,8659	6,5616	1,6961	5,2305	2,8123	2,3848	4,0041	5,3710	2,9256
Total eq. plane-wave power density (W/m²)	0,0876	0,0912	0,1142	0,0076	0,0725	0,0209	0,0150	0,0425	0,0765	0,0227

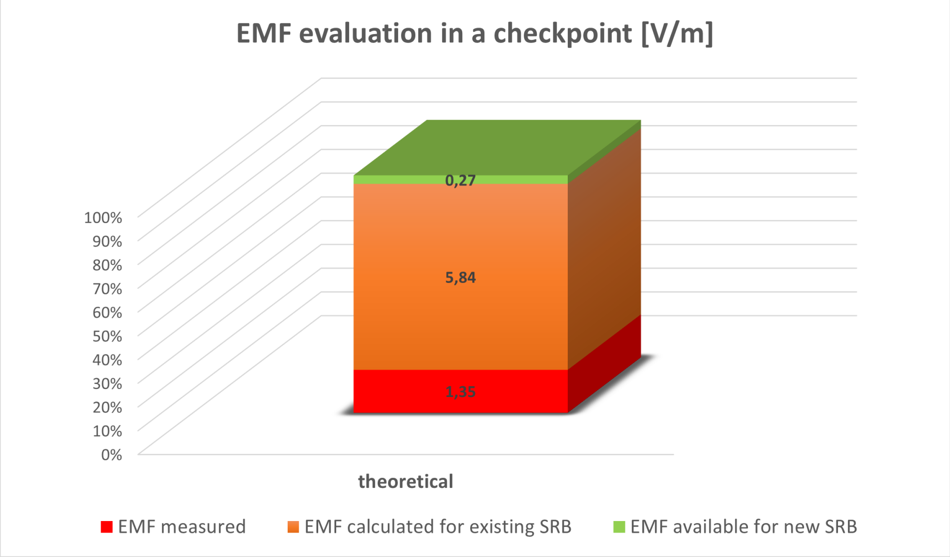
DETERMINING THE ELECTROMAGNETIC FIELD LEVELS: MEASUREMENTS



DETERMINING THE ELECTROMAGNETIC FIELD LEVELS

Steps for e.m. field assessment for a new of upgraded RBS: we need

1. **to measure** the e.m. field before new or upgraded RBS is on air (E_{meas}) ;
2. **to calculate** the e.m. field generated from new and near existing RBS (E_{RBS}) ;
3. **to add** them quadratically $\sqrt{E_{meas}^2 + E_{RBS}^2}$;
4. **To quantify** the amount of EMF value to reach the threshold, verifying that it's not exceeded. ***This condition is strictly required no matter if RBS have or not mandatory EMF risk assessment!***



SATURATION: OVERSTIMATING THE ELECTROMAGNETIC FIELD MEASUREMENTS

Steps for e.m. field assessment for a new of upgraded RBS: we need

1. **to measure** the e.m. field before new or upgraded RBS is on air (E_{meas}) ;
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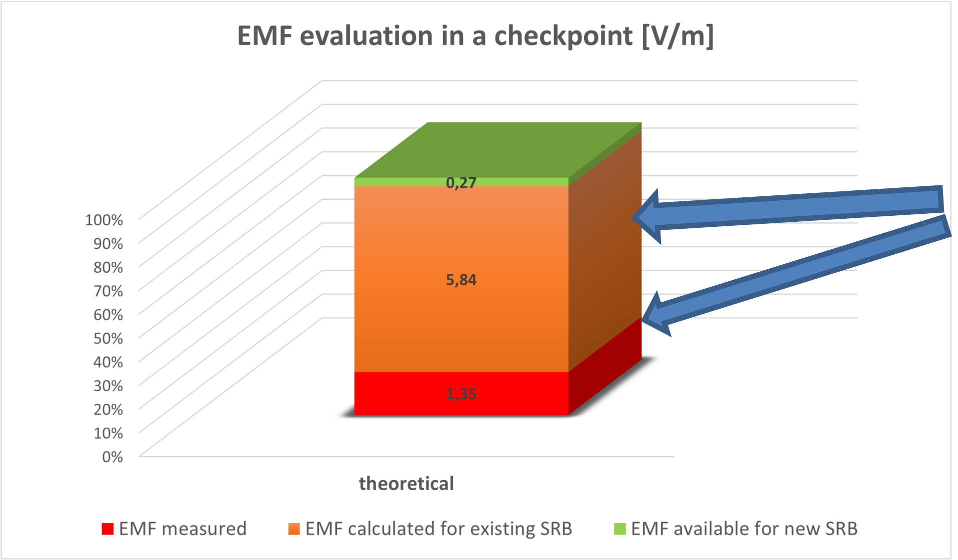


RBS in the vicinity usually are NOT switched off during the measurements.
So they will be counted **twice**!

SATURATION: OVERSTIMATING THE ELECTROMAGNETIC FIELD CALCULATIONS

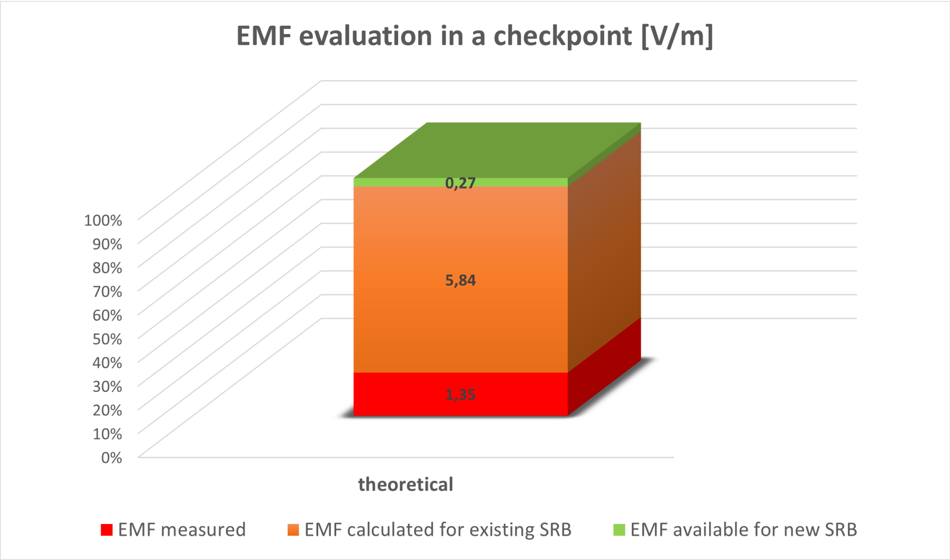
Steps for e.m. field assessment for a new of upgraded RBS: we need

1. to measure the e.m. field before new or upgraded RBS is on air (E_{meas}) ;

2. to calculate the e.m. field generated from new and near existing RBS (E_{RBS}) ;

3. to add them quadratically $\sqrt{E_{meas}^2 + E_{RBS}^2}$;

4. To quantify the amount of EMF value to reach the threshold, verifying that it's not exceeded. ***This condition is strictly required no matter if RBS have or not mandatory EMF risk assessment!***



SATURATION: OVERSTIMATING THE ELECTROMAGNETIC FIELD CALCULATIONS

The EMF level **calculation** method used is based on the formulas for the determination of the electric field in the hypothesis of propagation by plane wave - far field and point source, as the Recommendation ITU-T K.70 (2020) (former ITU-T K.52):

(in Italy: CEI 211-10)

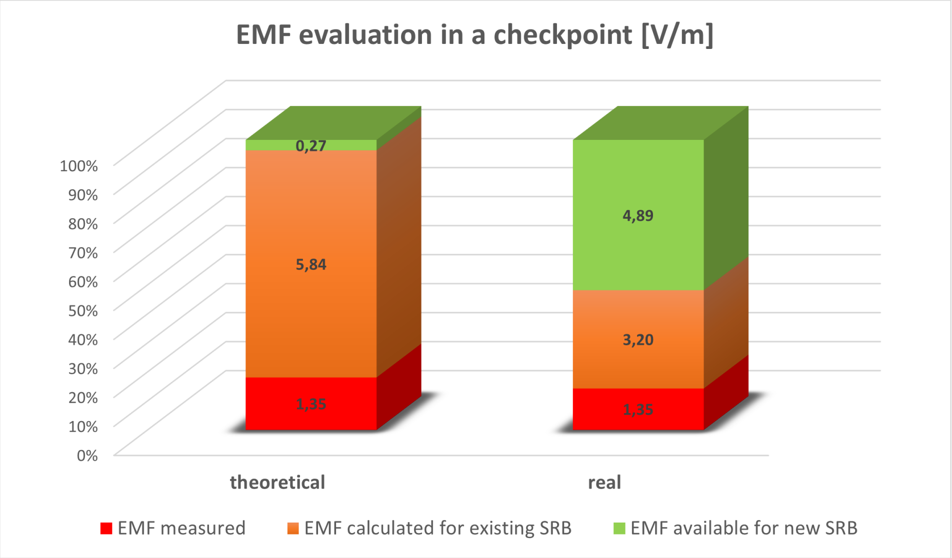
$$E(d,\vartheta,\emptyset) = \frac{\sqrt{30*P_{TX}*G(\vartheta,\phi)}}{d} \qquad [V/m]$$

It only considers free space attenuations and does not take into account reflections, refractions, other attenuations, etc. This could lead to overstimate EMF values.

SATURATION: OVERSTIMATING THE ELECTROMAGNETIC FIELD CALCULATIONS

Because that, we can have considerable **overestimates** in calculated EMF because:

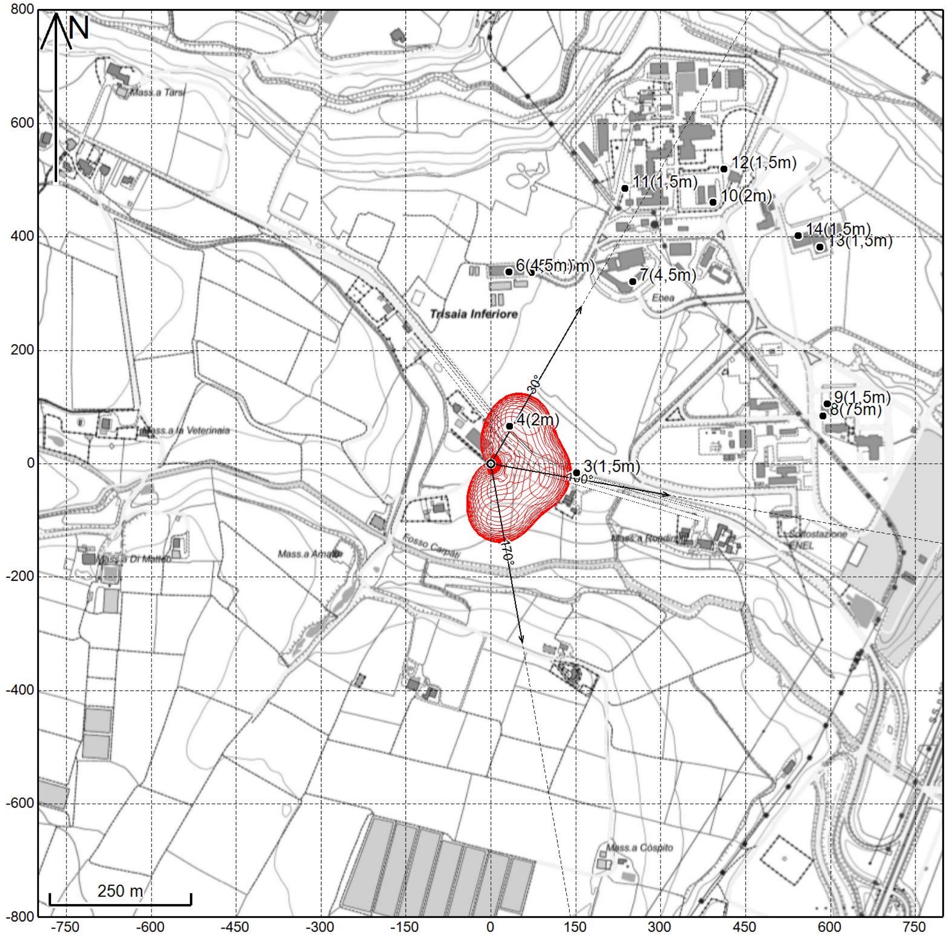
a) the measured EM field and the theoretical EM field calculated as produced by existing SRBs in the vicinity might be, at least in part, a double-counted contribution;
b) it is common practice to compile RBS data sheets with higher transmission powers than those actually onair, so that by performing EMF calculations from the data sheets, the latter turns out to be much higher than it actually is. **This theoretically results in a much smaller availability margin than it actually is**. It is estimated that RBS with a power consistent with the design target power are about 52% of 3G systems and only 25% of 4G systems (*).

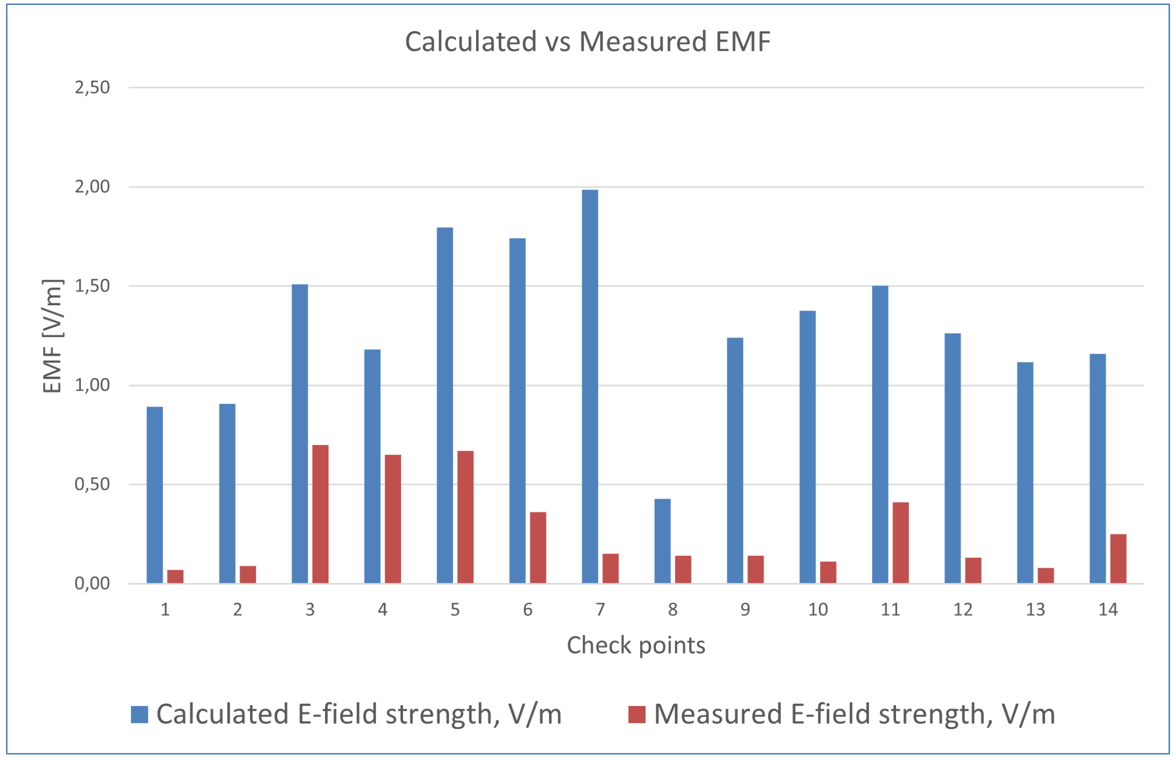


(*) Gianola P., Bastonero S., Scotti R., Cimò R., Macrì M., *"Normativa CEM e sviluppo delle reti di telefonia mobile"*, Telecom Italia S.p.A.

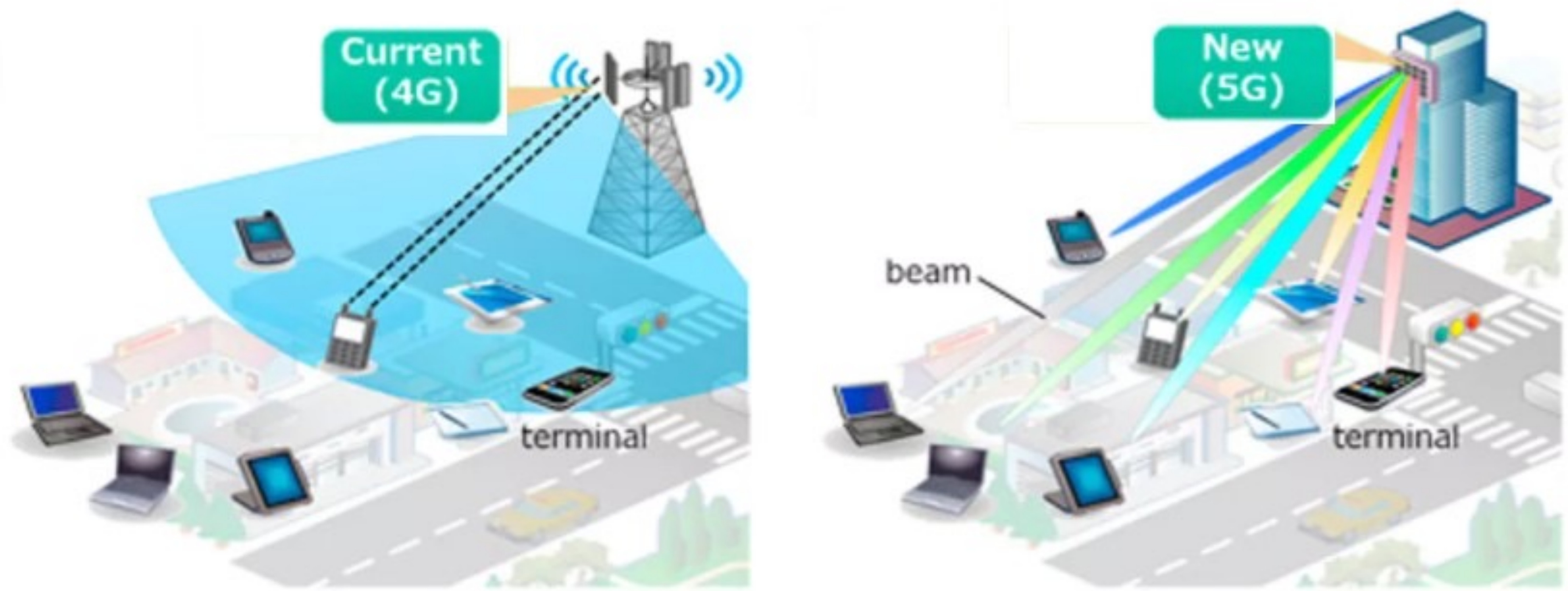
SATURATION: OVERSTIMATING THE ELECTROMAGNETIC FIELD CALCULATIONS

A case-study by PuglieseProgettazioni (Vodafone RBS – GSM / UMTS / LTE):





SATURATION: OVERSTIMATING THE ELECTROMAGNETIC FIELD CALCULATIONS



In order to mitigate overestimates due to temporal and spatial variability (dynamic beamforming) of EMF emissions, a number of correction coefficients are already currently adopted.

SATURATION: OVERSTIMATING THE ELECTROMAGNETIC FIELD CALCULATIONS

To take into account the spatial and temporal variability of transmission power, the international reference standards for evaluation of the exposure levels of the new 5G systems at the moment are:

- Technical Report IEC EN 62232 ed 2 – "*Determination of RF field strength, power density and SAR in the vicinity of radiocommunication base stations for the purpose of evaluating human exposure*", 2017
- Technical Report IEC 62669 ED2 - "*Case studies supporting IEC62232 - Determination of RF field strength and SAR in the vicinity of radio communication base stations for the purpose of evaluating human exposure*", 2019.

where the IEC 62669 defines the maximum real transmitted power (P_{TXAM}) as follows:

$$P_{TXAM} = P_{TXM} * F_{TDC} * F_{PR}$$

where F_{PR} is the reduction factor deriving from statistical analysis of the values of normalized value of the transmitted power and of the normalized value of the time-varying component of the antenna gain, and they are provided by operators.

The value of F_{TDC}, on the other hand, is purely deterministic and depends on the duty cycle of the TDD technology used.

SATURATION: OVERSTIMATING THE ELECTROMAGNETIC FIELD CALCULATIONS

In order to take into account the **temporal** variability of transmission power, some power attenuation coefficients have been introduced into the algorithms for **calculating** EMF levels:

	SYSTEM(S)	K	description
1	All (GSM, UMTS, LTE, 5G)	α_{24H}	Mean of emitted power in 24 hours, considering 1 year. This number goes from 0 to 1, and it is provided by mobile operators. If it is not provided, must be assumed as 1.
2	GSM	$\frac{[1 + (n-1) * \alpha_{PC} * \alpha_{DTX}]}{n}$	where • n is the number of GSM carriers • α_{PC} is 0.7 (power control) • α_{DTX} is 0.7 (discontinuous transmission)
3	TDD systems (*)	F_{TDC}	used in TDD (Time Division Duplexing) mMIMO; this value is usually 0.75 (0.31 for 6 V/m threshold)

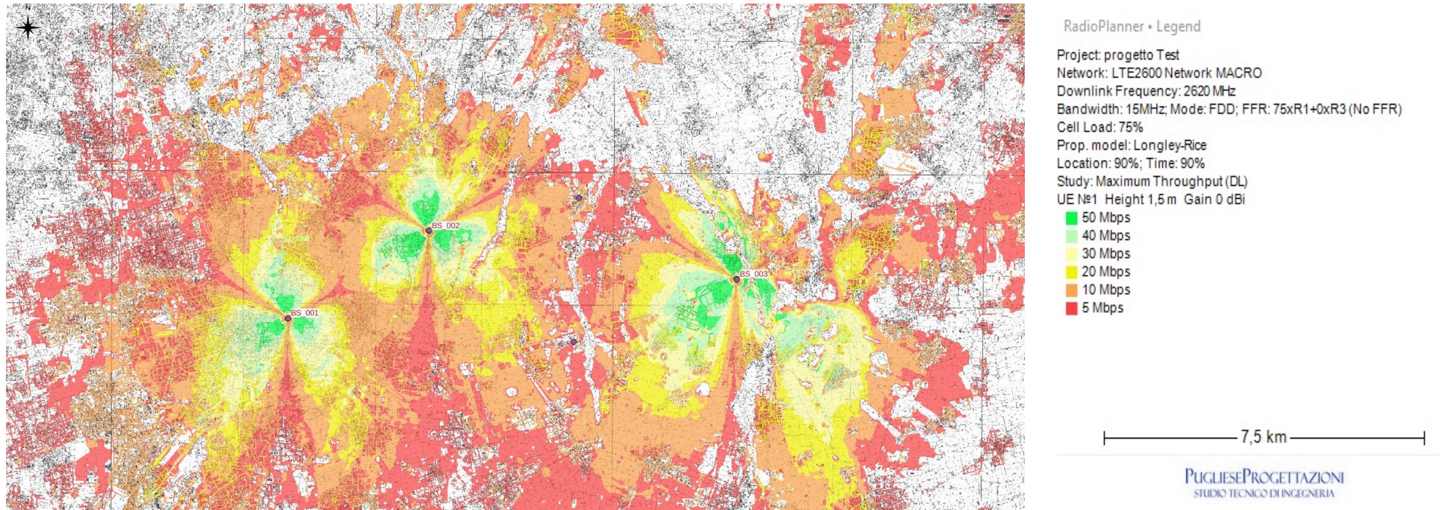
(*) currently under technical review

ELECTROMAGNETIC FIELD AND NETWORK DEVELOPEMENT AND PERFORMANCE

Higher EMF limits would mean that a certain territory could be covered with fewer Base Radio Stations radiating a stronger signal. This would produce three effects:

- more concentration of transmitters (more systems/operators) on the same location;
- much higher electromagnetic fields in the vicinity of a SRB;
- larger areas with weaker signal at the boundaries of the territory served by the facility.

Weaker signal means lower connection speed. Thus we would have the wider area the larger is the serving cell and therefore the transmitting power; a certain portion limited to the vicinity of the Radio Base Station with maximum throughput, and then gradually zones with decreasing throughput until the loss of the signal or the 'handover (i.e., communication is established with another Radio Base Station, always at the minimum speed since we are at the borders of the area served by the latter).



Network:	LTE2600 Network Ch15MHz
Ptx (all transmitters)	40 W
Propagation Model	
Type	Longley-Rice
Situation	90%
Time	90%
Margin	6 dB
Refractivity	301 N-units
Conductivity	0,02 S/m
Dielectric Constant	15
Climate Zone	Continental Temperate
Antenna Polarization	Vertical
Add Clutter Loss	Yes

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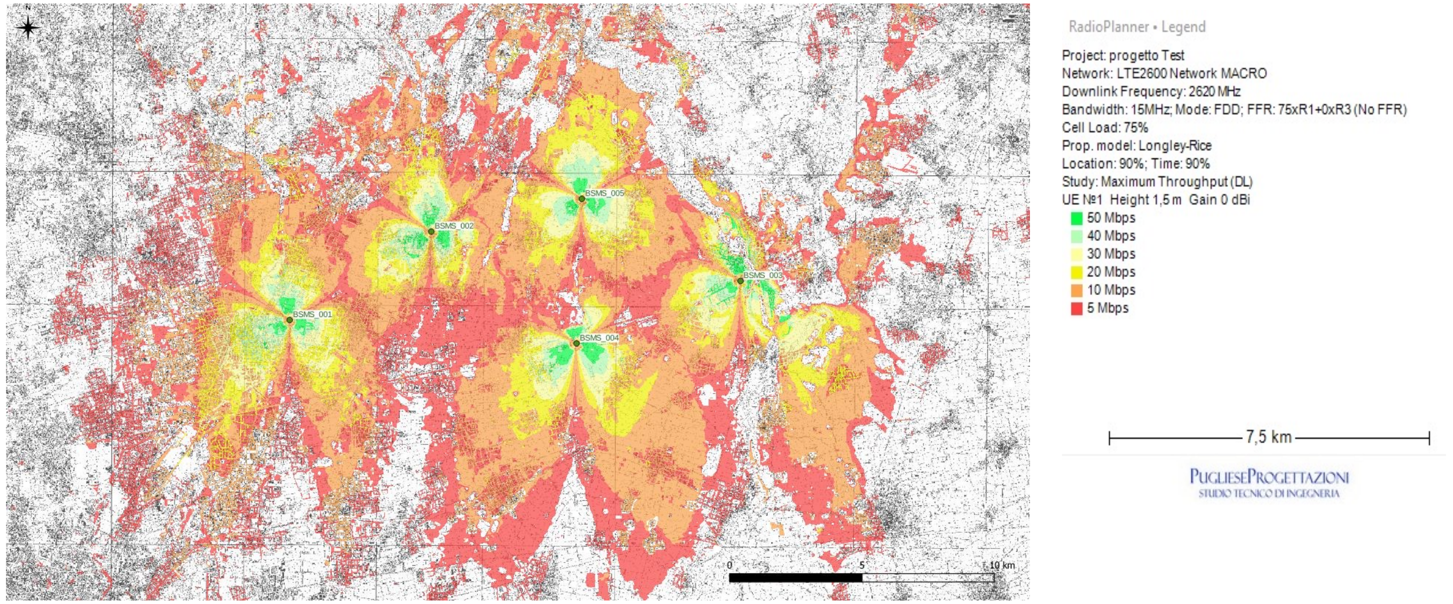
ELECTROMAGNETIC FIELD AND NETWORK DEVELOPEMENT AND PERFORMANCE

Lower EMF limits mean that more SRBs are needed to cover a certain territory. This produces three effects:

- greater total amount of RBS and less concentrated (fewer systems/operators) on the same location;
- lower electromagnetic field values in the vicinity of a facility;
- similar or even better performance (throughput), but higher roll-out costs.

Since in assessing the electromagnetic field for limit compliance purposes we use far–field and plane wave approximation for the propagation, in the given example we have that, given a certain point in the vicinity of an SRB, for example using a quarter of the power the electric field is reduced by half.

With a more accurate positioning of reduced power RBS it is also possible to more carefully cover areas with higher throughput, provided of course the relevant backhauling network is adequately sized.



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Dielectric Constant	15
Climate Zone	Continental Temperate
Antenna Polarization	Vertical
Add Clutter Loss	Yes

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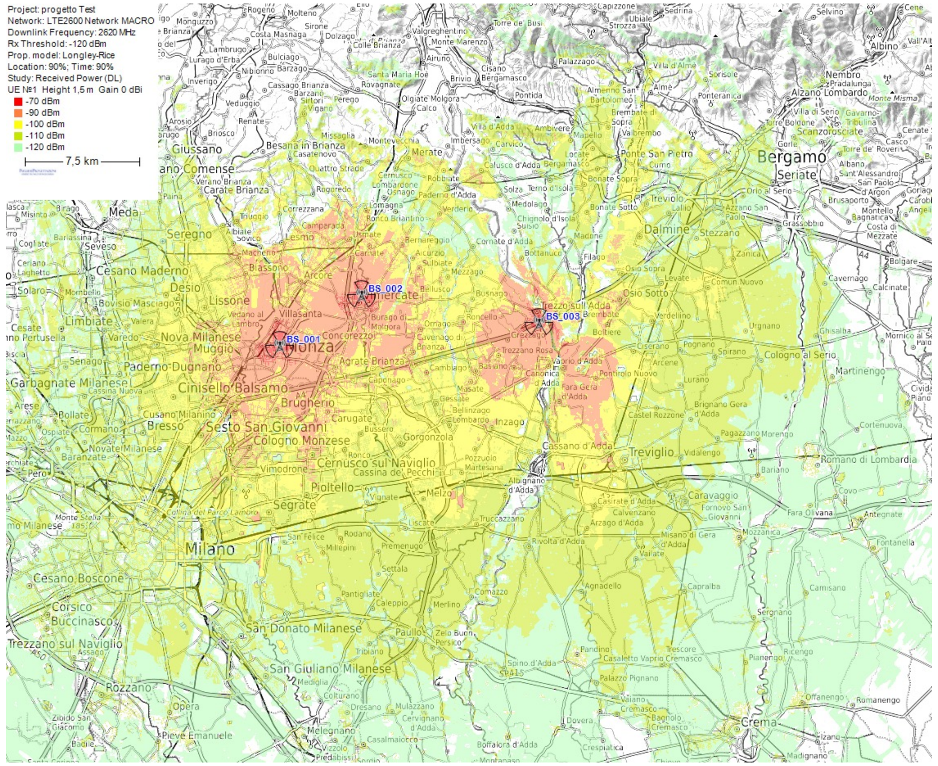
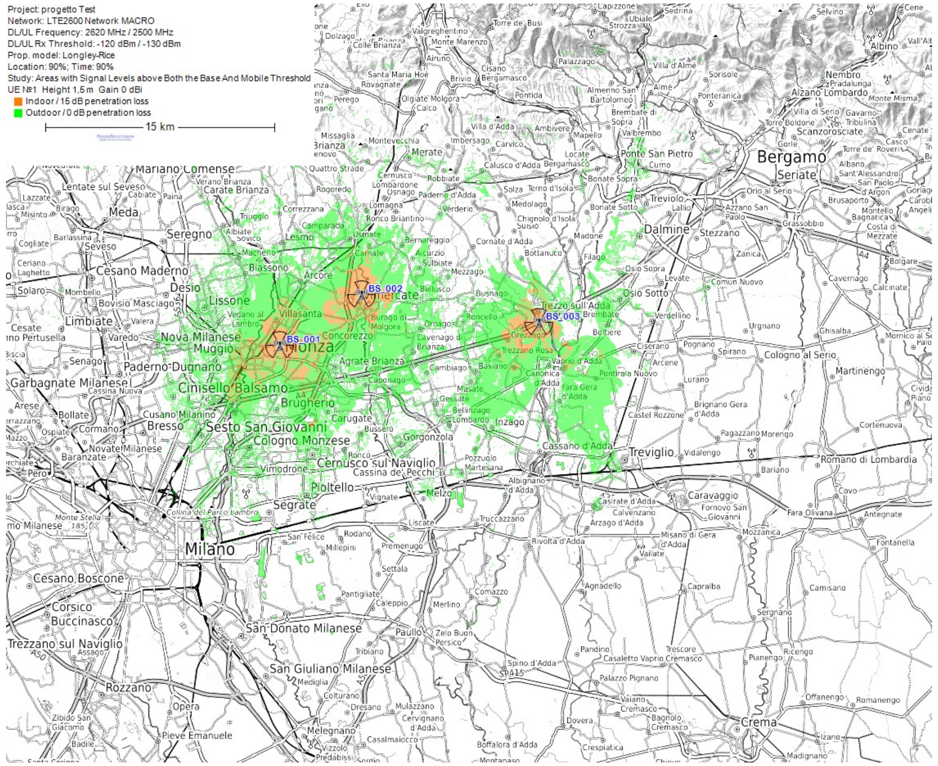
ELECTROMAGNETIC FIELD AND NETWORK DEVELOPEMENT AND PERFORMANCE

Greater power transmitted by the Radio Base Station does not necessarily mean greater coverage, both due to possible interference and because there is another fundamental parameter to keep in mind, namely the uplink transmission power of the mobile device, which is much more limited.



Downlink received signal



Area with signal above the mobile and RBS threshold

KEY POINTS AND CONCLUSIONS

The new wireless technologies (5G, Iot, etc.) will most likely cause a significant overspreading and increasing of the total amount of the e.m. high frequency field, as more and more will be the number of RBS/access points and of user devices (smartphones, IoT, Car2Car, etc.)

A EMF evaluation and risk assessment is and will be more and more crucial for the deployment of this new technologies, because in general if (or whereas) there is no more margin to allocate an e.m. field increase, new technologies will not be allowed or possible without prior important corrective actions .

Since a high-performance wireless network can also be deployed with lower electromagnetic field levels, prior to consider the review of EMF limits, which should depend exclusively on scientific evidences and studies, and **should be guided exclusively by issues related to health protection**, some important technical and procedural corrections should be made to improve the RBS compliance and EMF risk assessment process:

1. **to allow to be declared only the transmission power actually used onair.** Not only does this make the risk assessment process more truthful, it is also a **requirement to make it fairer for all operators to be able to install their RBS;**
2. standardize the details of the evaluation procedure at least nationally, **avoiding excessive overestimates that create a saturation of the purely virtual electromagnetic field;**
3. **facilitating (not complicating) the procedures for carrying out instrumental measurements of EMF levels,** so as to get as real a picture as possible of the situation in a given study area.

Therefore, a fundamental requirement for new RBS deployment will be the side by side placing of an ***accurate radioplanning*** and a ***smart EMF assessment,*** where “smart” means that **the 5G/IoT/small cells/etc. deployment will require a shift from the concept “EMF assessment of a single radio station” towards “EMF assessment of a network or area”.**

Thank you for your attention!

For any question or issue:

write to ing.pugliese@puglieseprogettazioni.it
or visit www.puglieseprogettazioni.it