European directive on workers exposed to electromagnetic fields and open problems in application

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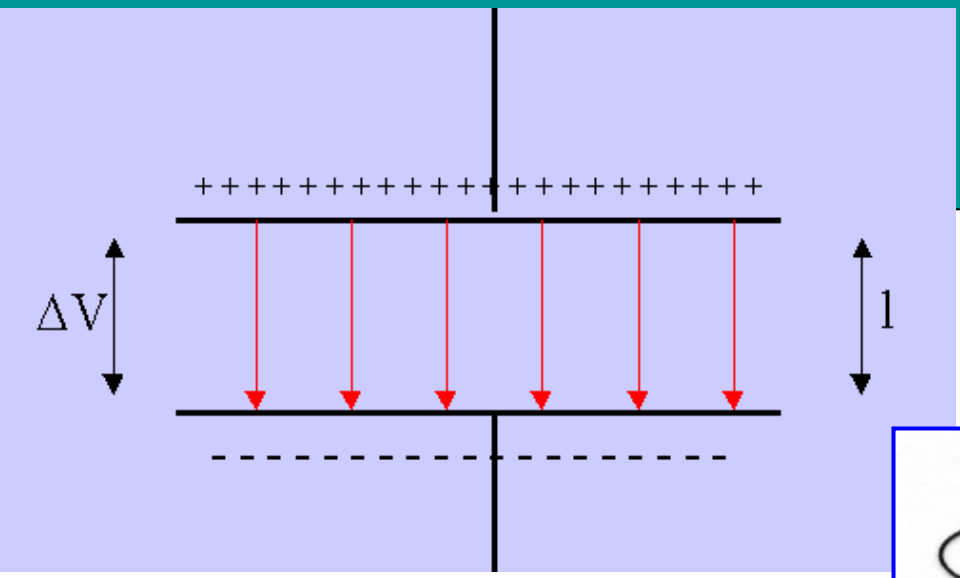
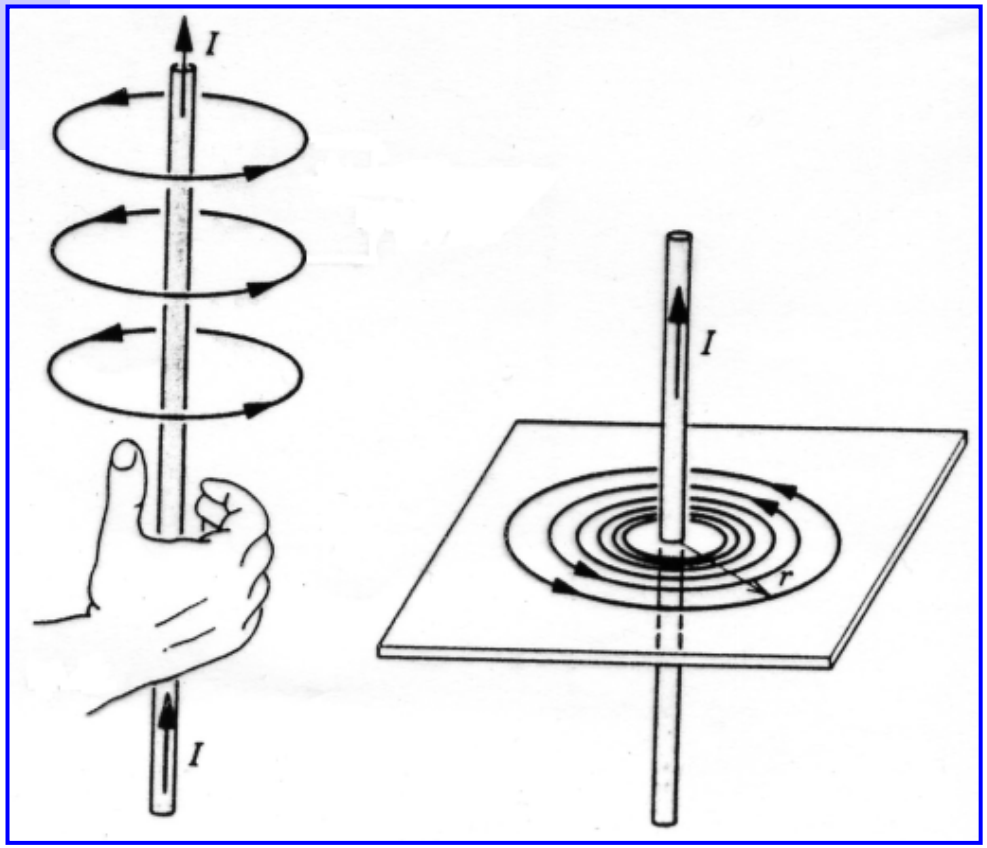
- **Summary on electromagnetic fields**
- Summary on EMF Directive
- Summary on application problems
- Further data

Electric and magnetic fields - Near fields



[Erice, 2004]



Maxwell Equations

$$\nabla \cdot \vec{D} = \rho \qquad \int D_n dS = \int \rho dV \qquad \Phi_{CS}(\vec{D}) = Q$$

$$\nabla \cdot \vec{B} = 0 \qquad \int B_n dS = 0 \qquad \Phi_{CS}(\vec{B}) = 0$$

$$\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t} \qquad \oint E_l dl = -\int \frac{\partial B_n}{\partial t} dS = \qquad C(\vec{E}) = -\frac{d\Phi_s(\vec{B})}{dt}$$

$$\nabla \times \vec{H} = \vec{J} + \frac{\partial \vec{D}}{\partial t} \qquad \oint H_l dl = \int (J_n + \frac{\partial D_n}{\partial t}) dS \qquad C(\vec{H}) = I + \frac{d\Phi_s(\vec{D})}{dt}$$

and

$$\vec{B} = \mu \vec{H} \qquad \vec{D} = \varepsilon \vec{E} \qquad \text{with} \qquad \mu = \mu_r \mu_0 \qquad \varepsilon = \varepsilon_r \varepsilon_0$$

where:

μ = magnetic permeability

ε = dielectric permittivity

ρ = charge density = dq/dV

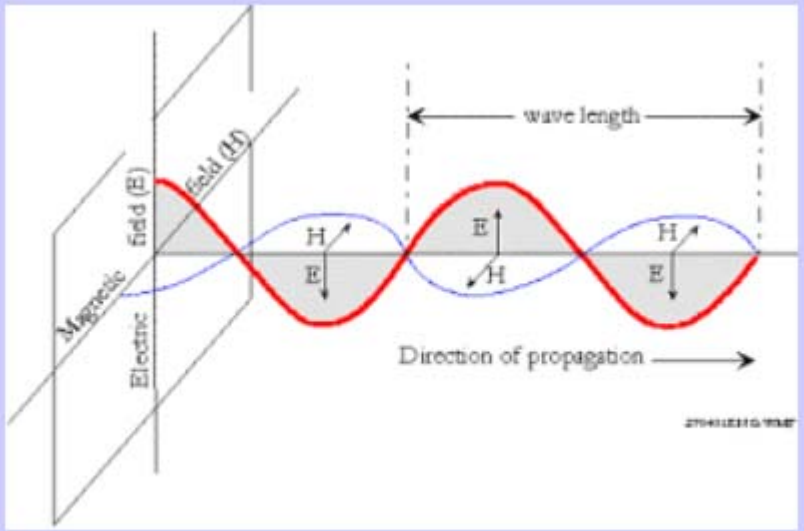
μ_0 = free space magnetic permeability

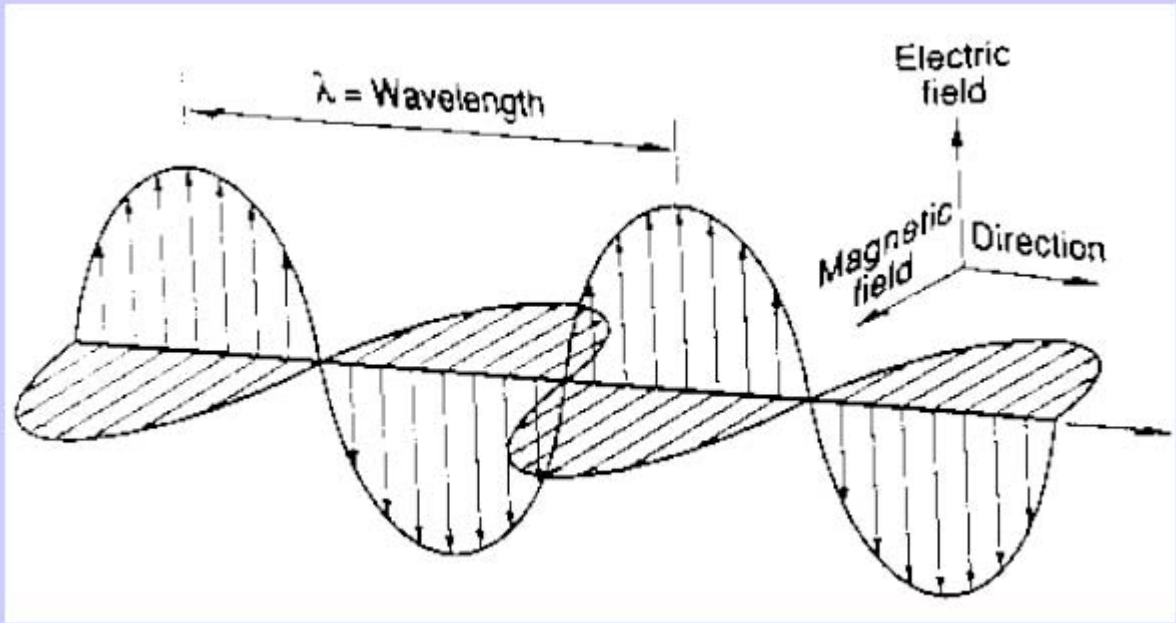
ε_0 = free space permittivity

μ_r = relative magnetic permeability

ε_r = relative dielectric permittivity

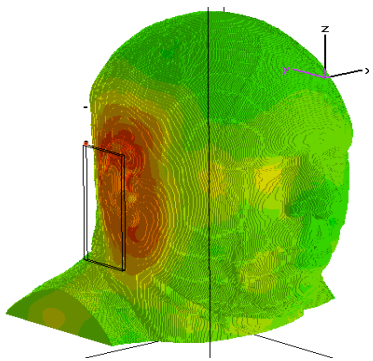
Electromagnetic radiation - Far fields

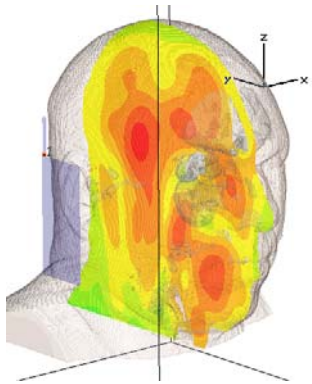


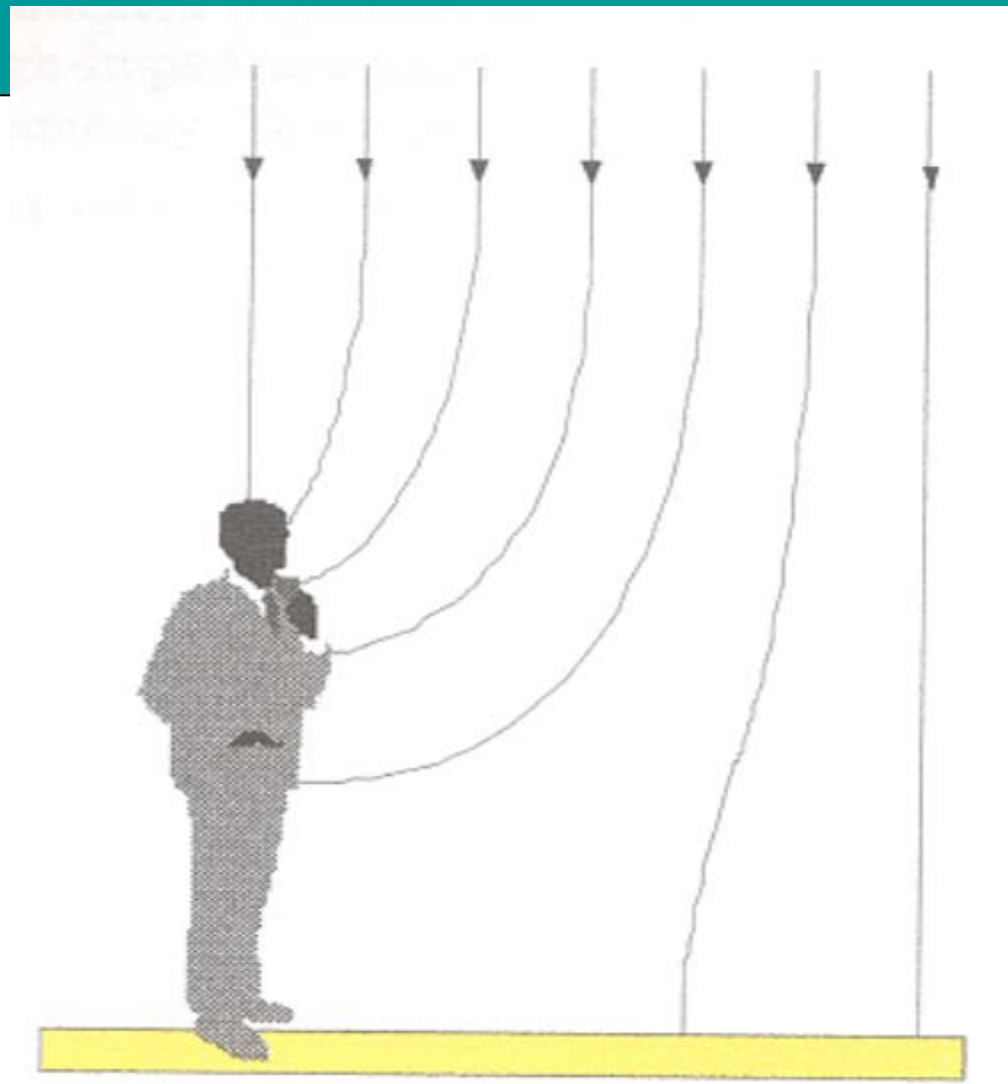


Human in E-field

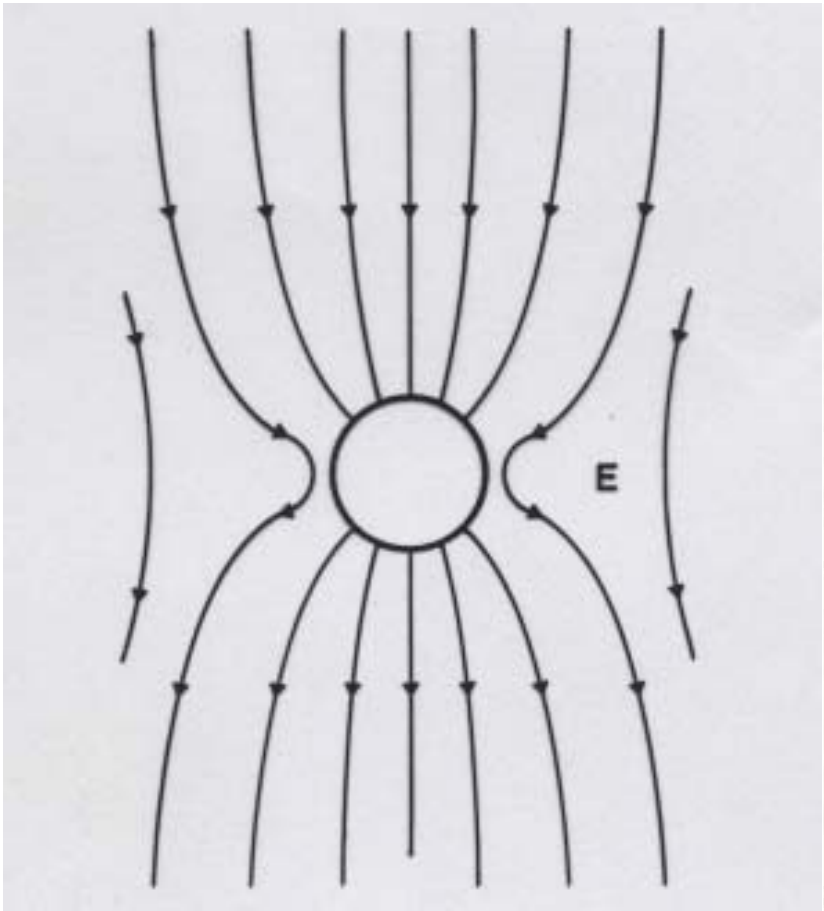
High frequencies

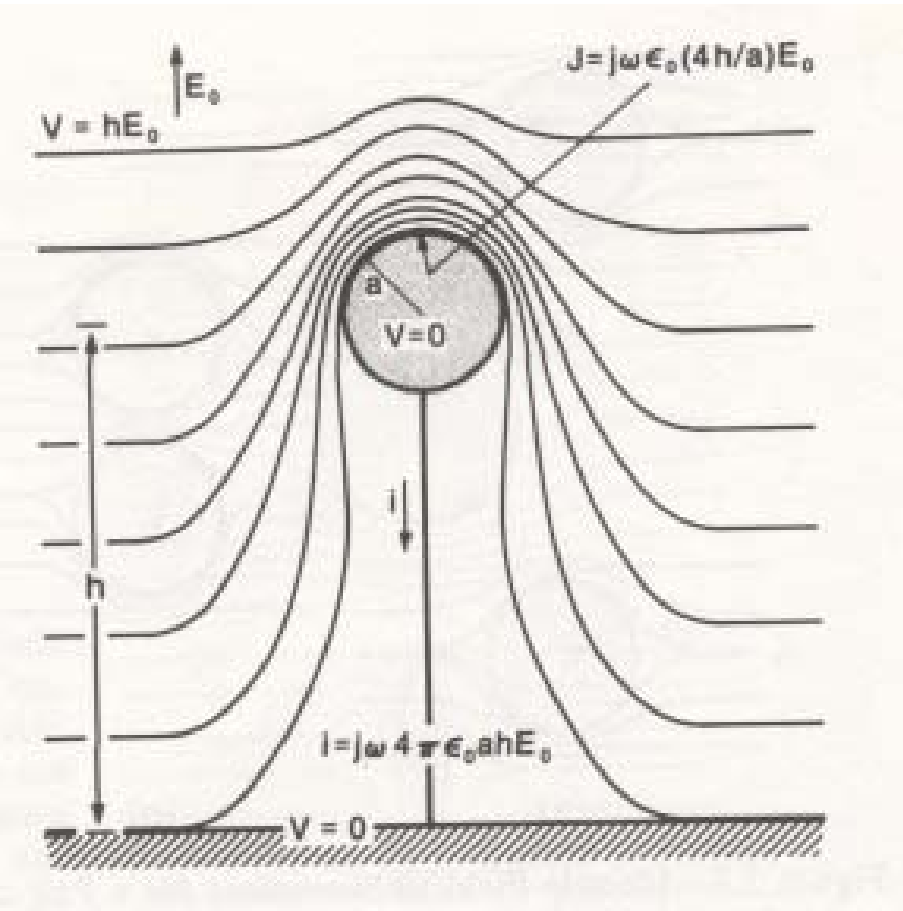






Conductive object in E-field
a) insulated b) grounded





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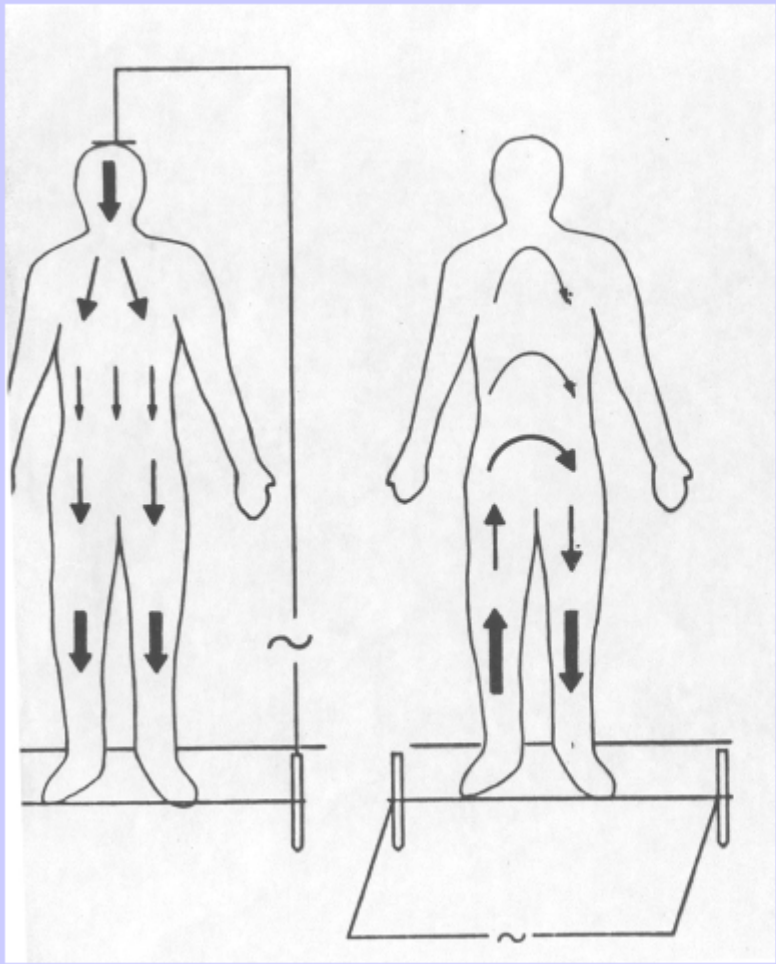
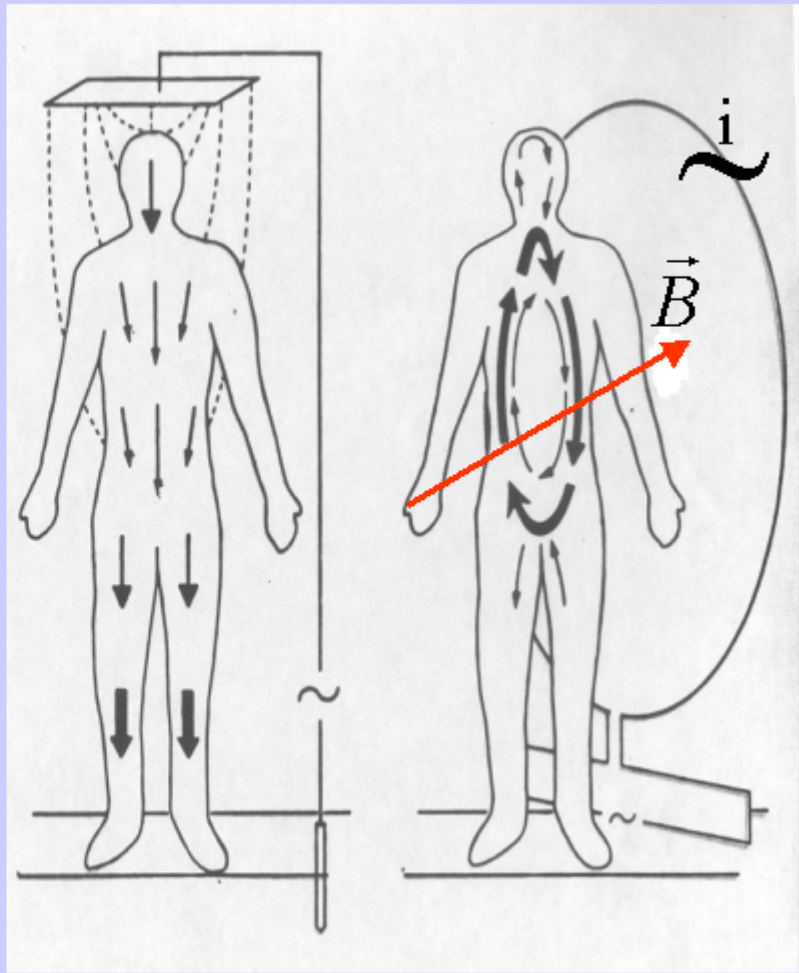
Induced currents





Electromagnetic fields

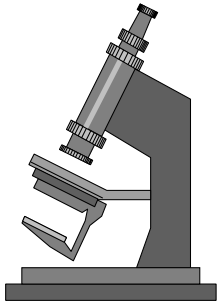
Description of electromagnetic energy in space with the use of **vector quantities** (like: E, B, H) and unisothropic parameters of that space (like: ε, μ)

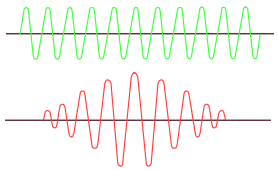
The lack of possibility of measurements of :

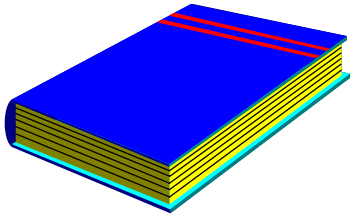
- **E and H fields directly**
- **Induced currents and thermal effects**

Human involved in E-field measurements can dramatically change field spatial distribution

Electromagnetic fields properties

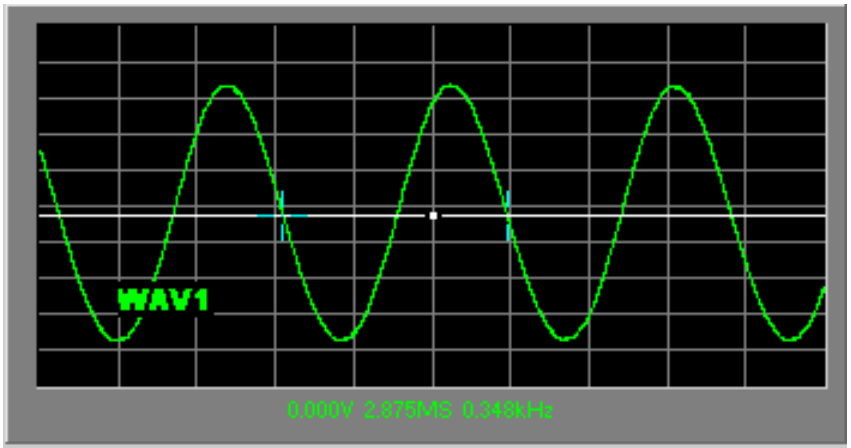


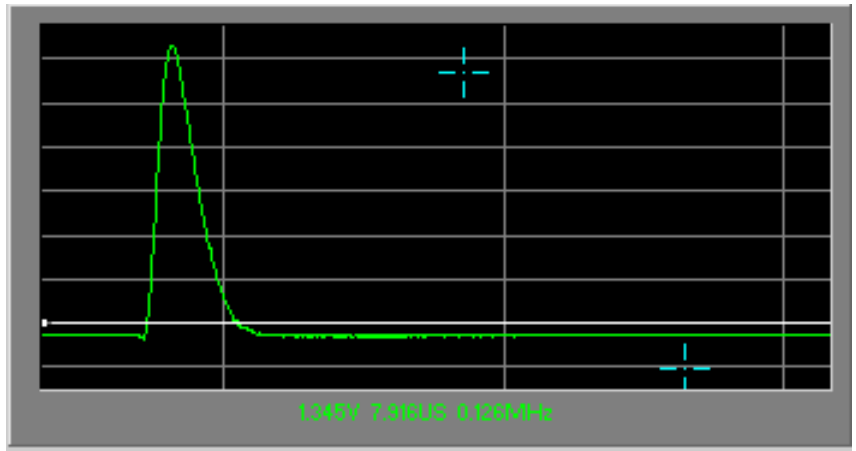


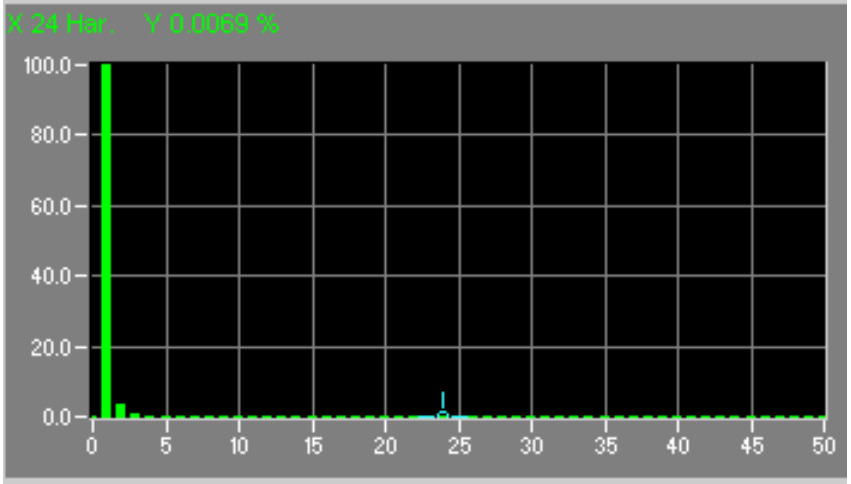


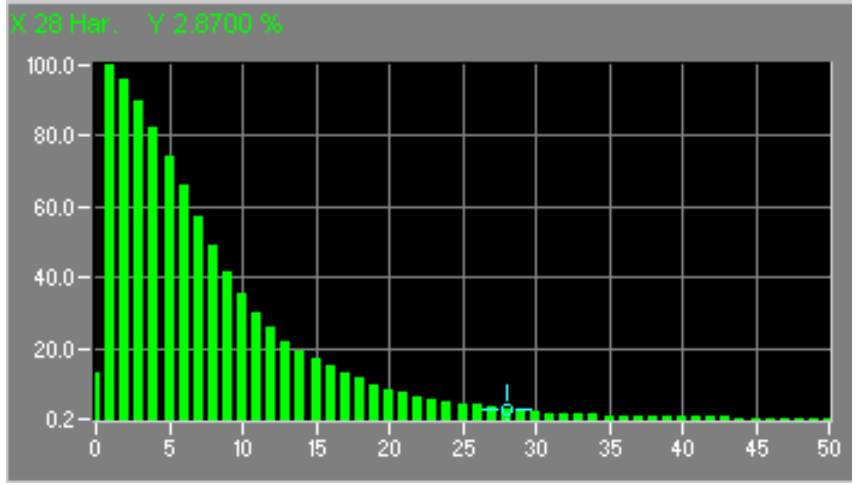
- Frequency
- Wave length (300/f [MHz])
- Wave shape (harmonics)
- Distance from the source of EMF (near/far field area)
- Impedance of EMF (E/H)

Frequency composition









EMF exposure effects (#1)

1) established mechanism of human interaction with EMF (Reilly, 1998)

- synapse activity alteration by membrane polarization (e.g. phosphenes)
- peripheral nerve excitation via membrane depolarization
- muscle cell excitation by membrane depolarization (skeletal)
- electroporation
- **resistive (joule) heating**
- audio effects via thermoelestic expansion
- magneto hydrodynamic effects

EMF exposure effects (#2)

2) proposed mechanism of human interaction with EMF:

- soliton mechanism through cell membrane proteins
- spatial/temporal cellular integration
- stochastic resonance
- temperature mediated alteration of membrane ion transport
- Plasmon resonance
- **radon decay product attractors**
- rectification by cellular membranes
- ion resonance
- Ca++ oscillations
- **nuclear magnetic resonance (MRI)**
- **radical pair mechanism**
- magnetite interactions
- ……

EMF exposure effects (#3)

- The health consequences of various interactions of EMFs with human body are not established **(but it do not mean that risk not exist)** (WHO, 1987, WHO, 1993, WHO, 2006; WHO, 2007, ……..).
- Some acute effects of exposure, which can significantly reduce work-ability are also known, as **vertigo, magneto phosphenes, nausea, metallic taste in mouth, difficulties in eye-hand coordination**, related for example to movements in the static magnetic field of high level (Karpowicz, Hietanen, Gryz, 2007; WHO, 2007).

EMF exposure effects (#4)

- Occupational exposure to EMFs, extended over a period of years, may affect health and ability to work performance.
- So far, results of investigations have not excluded the possibility of adverse health effects of many-years exposure, especially exposures of high level.
- Hypotheses of possible adverse health results linked with EMFs exposure under research covers e.g.: **development of tumours or malfunctions of the cardiovascular, nervous and immunological systems**

EMF exposure effects (#5)

Example: **Cellular/Mobile Phone Use and Intracranial Tumours [by** National Collaborating Centre for Environmental Health at the BC, Centre for Disease Control with funding from the Public Health Agency of Canada, July 2008]

- Meta-analyses based on ≥ 10 years duration of use have detected a slightly increased risk (OR: 1.25, 95%CI: 1.01-1.54) for all intracranial tumours (Kan et al 2008)4. Pooled analyses using shorter duration did not indicate an association (Lahkola et al 2006)2.
- Restricting the analyses to ≥ 10 years and ipsilateral use (cell phone use on the same side as the tumour), the risk increased and was significantly associated for glioma (OR: 2.0, 95%CI: 1.2-3.4) and acoustic neuroma (OR: 2.4, 95%CI: 1.1-5.3, but not for meningioma (OR: 1.7, 95%CI: 0.99-3.1) (Hardell et al 2008)

Conclusion.

- There is insufficient evidence to indicate a causal association between cell phone use and intracranial tumours.
- There is weak evidence supporting an increase in odds of glioma, acoustic neuroma, and meningioma in adults with regular, ipsilateral use for 10 years or longer.
- Existing findings are **suggestive but preliminary** because they **are based on few studies with small numbers and potential biases.**

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- **Summary on EMF Directive**
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DIRECTIVE 2004/40/EC
+ 2008/46/EC (implementation by 2012
⇒ mandatory legislations + voluntary standards)

DIRECTIVE 2004/40/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL ON THE MINIMUM HEALTH AND SAFETY REQUIREMENTS REGARDING THE EXPOSURE OF WORKERS TO THE RISKS ARISING FROM PHYSICAL AGENTS (ELECTROMAGNETIC FIELDS)

(18TH INDIVIDUAL DIRECTIVE WITHIN THE MEANING OF ARTICLE 16(1) OF DIRECTIVE 89/391/EEC)

DIRECTIVE 2004/40/EC (short-term effects only)

- Introduction (4)

It is now considered necessary to introduce measures protecting workers from the risks associated with electromagnetic fields, owing to their effects on the health and safety of workers.

However, the long-term effects, including possible carcinogenic effects due to exposure to time-varying electric, magnetic and electromagnetic fields **for which there is no conclusive scientific evidence establishing a causal relationship, are not addressed in this Directive**.

DIRECTIVE 2004/40/EC (minimum requirements only)

- Introduction (5)

This Directive lays down minimum requirements, thus giving Member States the option of maintaining or adopting more favourable provisions for the protection of workers, **in particular the fixing of lower values for the action values or the exposure limit values for electromagnetic fields**.

The implementation of this Directive should not serve to justify any regression in relation to the situation which already prevails in each Member State.

DIRECTIVE 2004/40/EC (preventive measures)

- Introduction (7)

The level of exposure to electromagnetic fields can be more effectively reduced **by incorporating preventive measures into the design of workstations and by selecting work equipment, procedures and methods so as to give priority to reducing the risks at source**.

Provisions relating to work equipment and methods thus contribute to the protection of the workers involved.

DIRECTIVE 2004/40/EC
(adjustments for technical progress and scientific knowledge on risks)

- Introduction(8)

Employers should make **adjustments in the light of technical progress and scientific knowledge regarding risks related to exposure to electromagnetic fields**, with a view to improving the safety and health protection of workers.

DIRECTIVE 2004/40/EC

- lays down minimum requirements for the protection of workers from risks to their health and safety arising or likely to arise from exposure to electromagnetic fields (0 Hz to 300 GHz) during their work.
- refers to the risk to the health and safety of workers due to known short-term adverse effects in the human body caused by the **circulation of induced currents (CNS only!)** and by **energy absorption (SAR)** as well as by **contact currents**.
- does not address suggested long-term effects.
- **does not address** the risks resulting from contact with **live conductors**.

DIRECTIVE 2004/40/EC (definitions)

- "**electromagnetic fields**": static magnetic and time-varying electric, magnetic and electromagnetic fields up to 300 GHz
- "**exposure limit values**": limits on exposure to EMF which are based directly on established health effects and biological considerations. Compliance with these limits will ensure that workers exposed to EMF are protected against all known adverse health effects; /induced current density, SAR, SA, dB/dt
- "**action values**": the magnitude of directly measurable parameters, provided in terms of electric field strength (E), magnetic field strength (H), magnetic flux density (B) and power density (S), at which one or more of the specified measures in this Directive must be undertaken. **Compliance with these values will ensure compliance with the relevant exposure limit values.** / + contact and limbs induced current

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Significant occupational exposure to EMF

might be caused by **(but not necessary)**:

– industrial appliances
  - induction heaters - operating from 1 kHz to low MHz
  - welding devices - common sources of ELF EMF but can be also a source of tens/hundreds kHz EMF)
  - microwave heaters
  - plastic welding

– medical devices
  - MRI scanners – static fields, low kHz + & RF pulses
  - electrosurgery units - sources of 300 kHz - 1.5 MHz)

– tecommunication - antennas

- anti-theft devices and more others ……..

Occupational exposure to EMF

No	EMF source	EMF frequency related to application				Workers' EMF exposure		
		static	ELF	IF	RF/MW	**probably low level** - detailed exposure assessment not needed	**may be high** - external measures testing - environmental measurements use	**probably high level** - internal measures testing - computational assessment may be needed
1.	induction heating		oo	o			xx	x
2.	surgical and physiotherapeutic use of diathermy			oo	oo		xx	x
3.	dielectric heating (RF: glue drying and plastic welding & MW: heating and vulcanization applications)				oo		xx	x
4.	arc-welding (MIG, MAG, TIG, etc.)	oo	oo	o			xx	xx
5.	spot welding	o	oo	o			xx	x
6.	electrochemical installations or other using microwaves (e.g. chemical activation of processes)				oo	NAD		
7.	electrolytic installations	o	oo			xx	x	
8.	industrial microwave ovens				oo	xx	x	
9.	NMR/MRI medical diagnostic equipment	oo	oo		oo		xx	x
10.	NMR spectrometers	oo			oo	x	x	
11.	electric vehicles (trains, trams, metro)	o	o			xx	x	
12.	plasma discharge equipment					NAD		
13.	plasma polymerisation at RF				o	NAD		
14.	RADAR and other systems				o			xx
15.	broadcasting systems and devices (radio & TV: AM, VHF/UHF)		o	o	o	xx	x	x
16.	mobile telephony base stations				oo	xx	x	x
17.	military and research radiofrequency systems			o	oo	x	xx	x
18.	RFID/EAS and others anti-theft equipment	o	o	o	o	xx	x	x
19.	wireless local area networks (WLANs)				oo	xx		
20.	cordless phones				o	xx		x
21.	bluetooth devices and hands-free kits				oo	xx		x
22.	electricity supplying networks and electricity distribution and transmission equipment	o	oo			xx	x	
23.	electric handheld tools		o			xx	x	x
24.	industrial magnetizers/demagnetizers	o	oo				x	

oo – basic frequency range which is in the most common use for particular applications

o - other frequencies, which can be used for particular applications

xx – the most common situation in the work environment

x – possible situation in the work environment

NAD – no available data

EMF in the working environment

The operation of various types of devices - mainly industrial and medical - is associated with the production of strong electromagnetic fields (EMF).

Occupational exposure:

- relatively high intensity
- hand operated EMF sources
- pulsed modulated exposure
- complex frequency composition, e.g.:
  - static + kHz
  - static + 50 Hz
  - harmonics
  - transients
  - multi sources

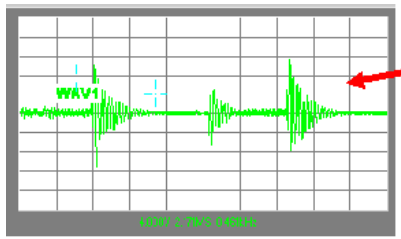
EMF exposure estimators

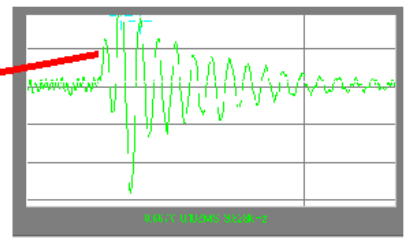
- harmonised with scientific knowledge on:
  - health effects of EMF exposure (thermal effect, nerve excitation, long-term (?))
  - exposure pattern in the real workplace (frequency composition, modulation or spatial distribution, etc.)
- estimators:
  - RMS value
  - peak value
  - time derivative dB/dt
  - exposure factors, of various formulas
  - time-averaged exposure level
  - spatially-averaged field strength
  - spatially-averaged squared field strength
  - .....

EMF in the working environment

Variable parameters:

- locations of the EMF source
- locations of worker's body
- geometry of the source
- frequency and level of EMF
- repetition time of pulses
- duration of pulses
- shape of pulses
- coupling between human body – source





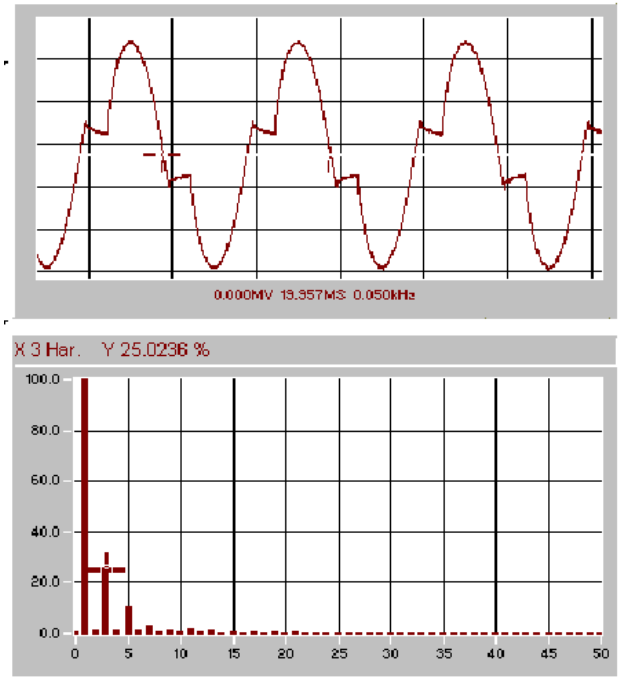
Measurements and exposure assessment needs special attention.

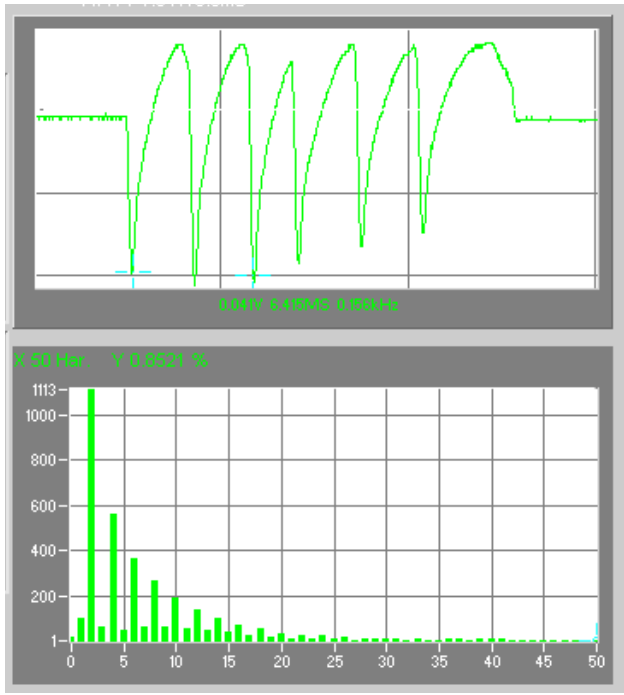
Personal dosimeters or single measurement devices could produce non-informative results.

EMF meters
- RMS measurements

- exchangeable probes for *E* (dipole antennas) and *H* (loop antennas) fields
- the need of the use of a few antennas covering wide range of frequency

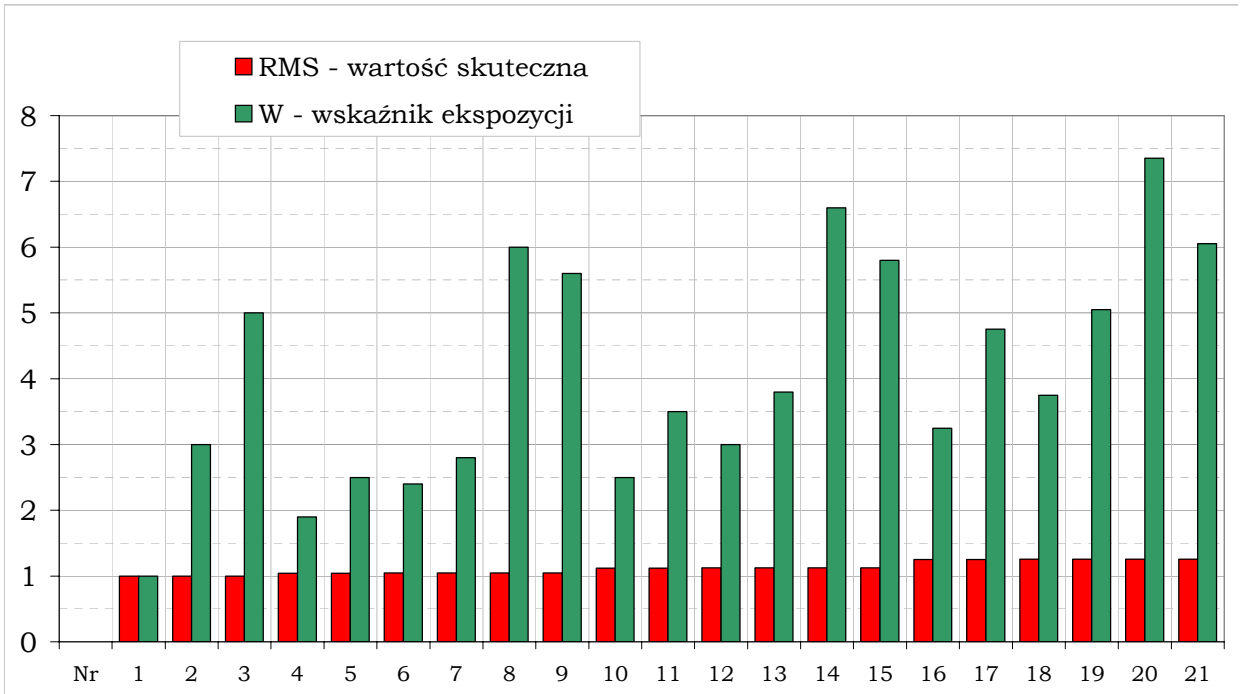
Occupational non-sinusoidal exposure





- tiristors — rectification
- odd harmonics — even harmonics

RMS value / exposure factor *W*
How far we can trust in wide-band RMS measurements?



$$W = \sum_f \frac{B_f}{B_L(f)} \le 1$$

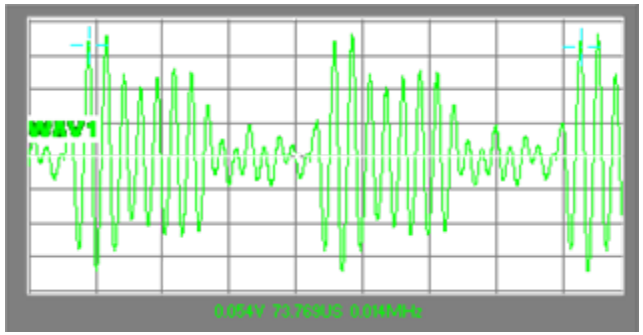
$$RMS = \sqrt{\frac{1}{T}\int_0^T B^2(t)\,dt}$$

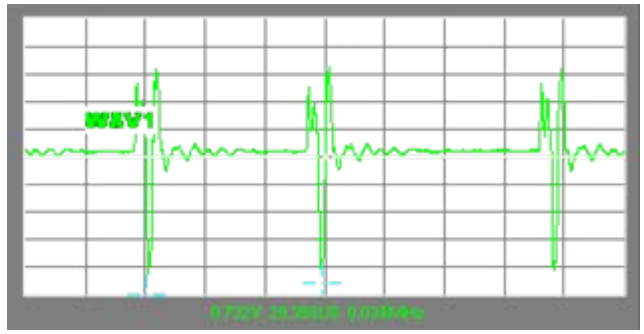
$$RMS = \sqrt{\sum_n \frac{(B_{0n})^2}{2}}$$

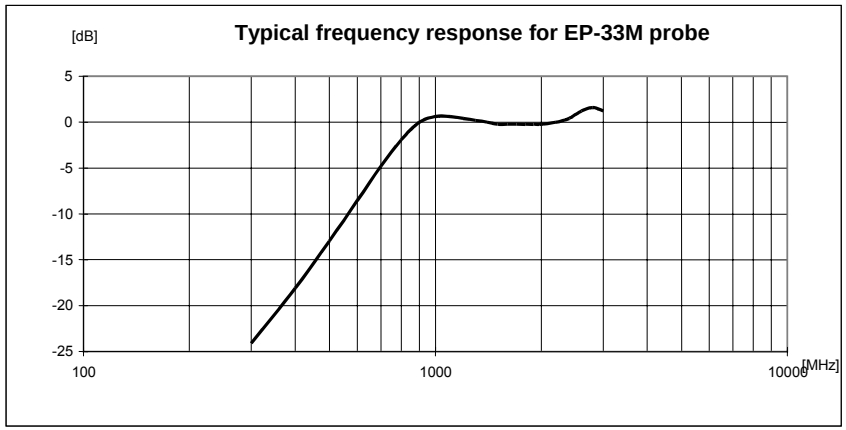
various content of 50 Hz, 150 Hz and 250 Hz components

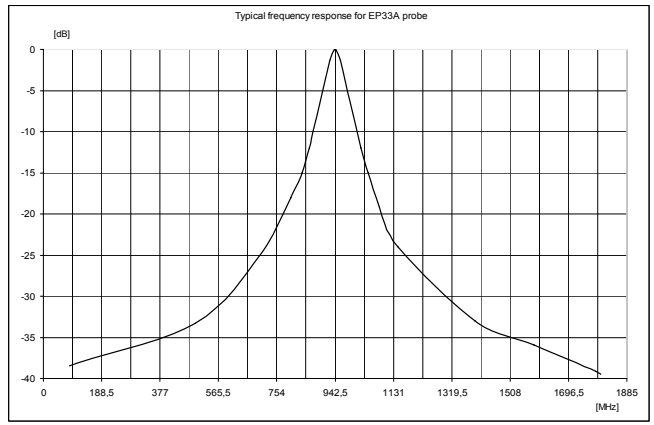
The role of frequency components

- within the exposure assessment procedures
- technical data, concerning the metrological characteristics of measurements devices, provided by manufacturers



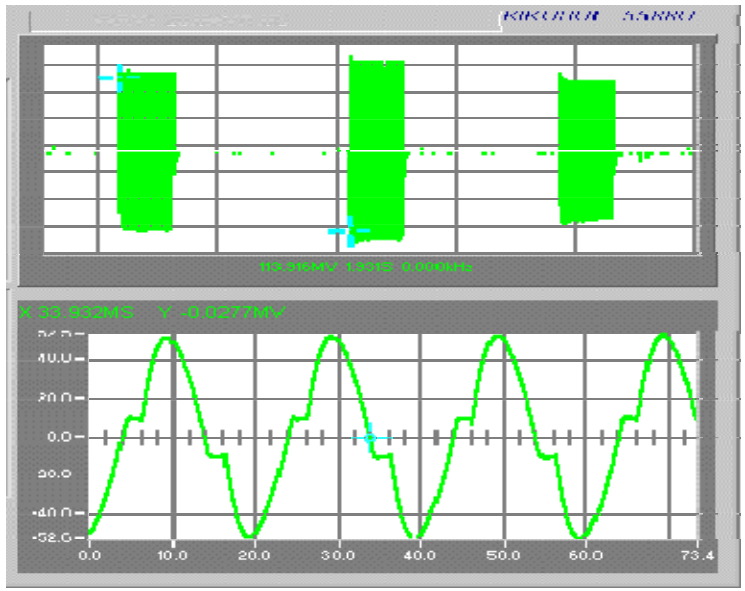






Measurements of pulse-modulated fields

- measurement devices
- assessment protocol
- time-averaging



EMF which exist in the work environment

- usually near fields – even in case of RF
- both electric field strength, *E*, and magnetic field strength, *H*, should be consider for the assessment of EMF
- power density, *S*, is not recommended for the assessment of EMF affecting workers

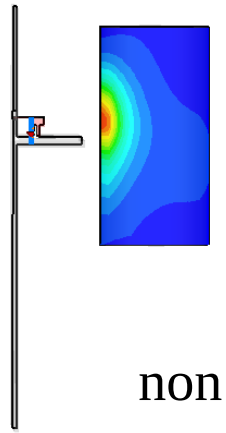
Exposures to EMF

- usually, impedance of EMF in the workplace is high or low, and in consequence, exposure assessment can be executed on the base of testing only one dominating component, e.g. magnetic in the case of induction heaters or electric in the case of electro surgery
- spatial and time distribution of exposure of particular worker can be of complex pattern
- **exposure versus field distribution !!!**

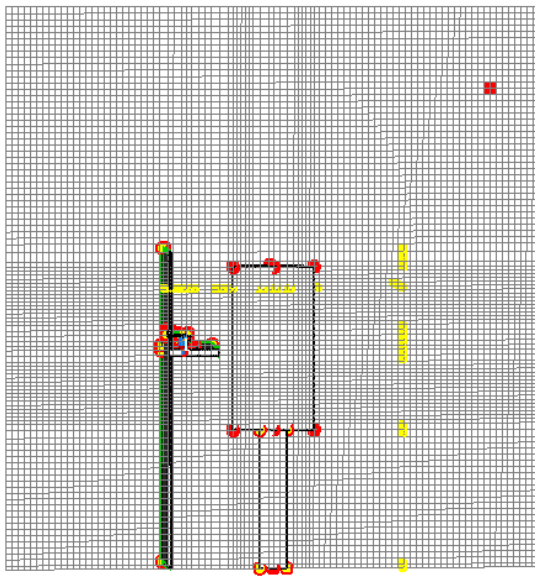
  (movements, capacitive coupling, duration of the operation of EMF sources, etc.)

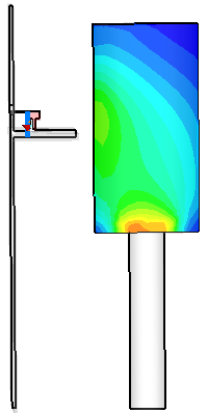
Electrical properties of various elements of workplace:

- Shoes
- floor cover
- furniture's, etc.



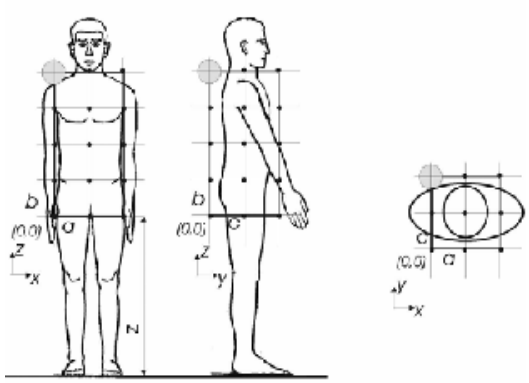
non grounded model



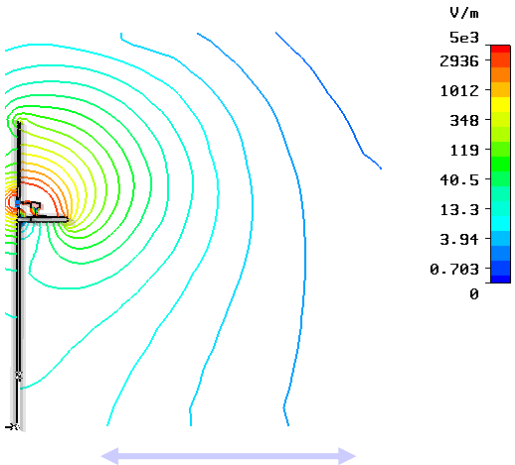


model with grounded metallic „chair”

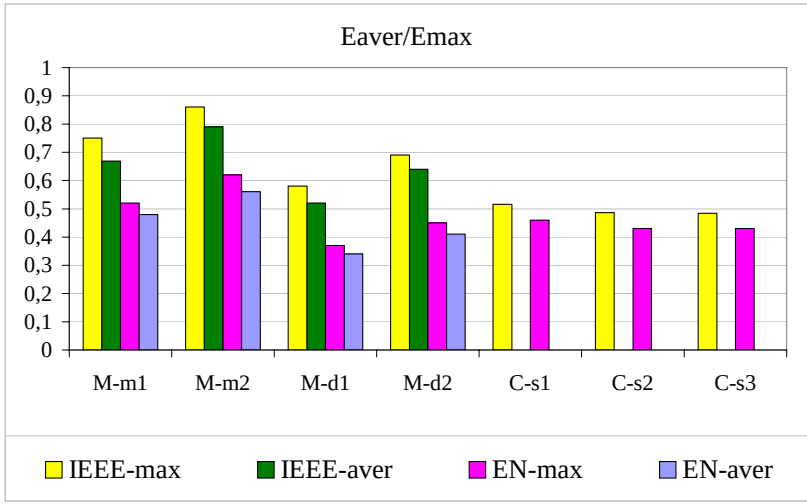
Spot or spatially averaged measurements?
How far we can trust in spot measurements results?



product standard EN 50357 – 0.3x0.3 m



realistic workplace
(1 – 2 m) x (1 -2 m)



spatial averaging of E-field
from dielectric
heaters over the fixed workplace

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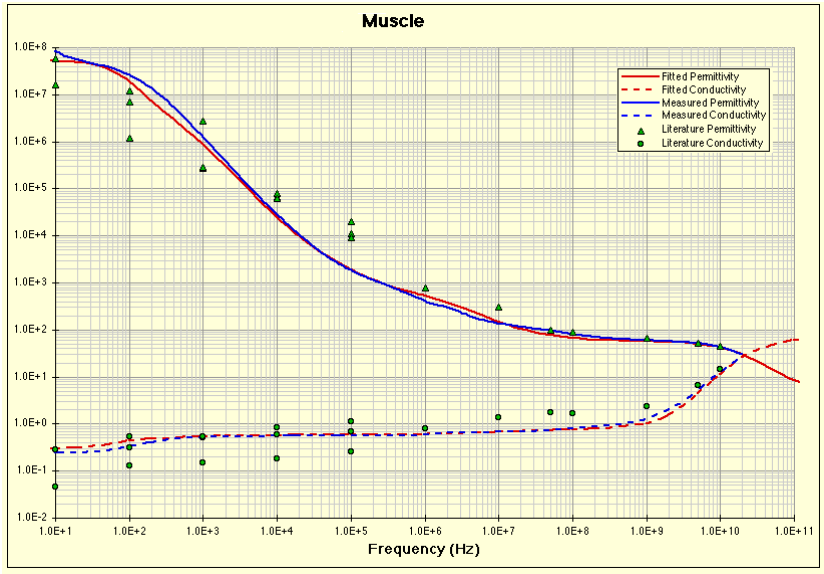
The assessment of intermediate frequency fields

The most of available data and calculations methods were produced for low frequency (50/60 Hz) or high frequency (MHz/GHz range)

for intermediate frequency – kHz range relatively weak scientific data concerning:

- human body models
- electrical properties of tissues
- numerical calculations procedures
- reference data

for models of EMF sources, etc.



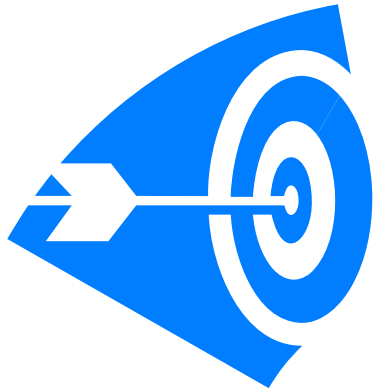
Occupational exposure, eg.:

- welding
- industrial heating
- electrosurgery
- anti-theft systems

Exposures to EMF

- level and pattern of exposure from particular applications might be significantly changes by **new technologies**
- IF exposures significantly growing up because IF is exploring by various new and emerging technologies and applications
- in some cases high level of exposure can be found, even exceeding guidelines on exposure limitation
- in some cases, exposure to EMF of lower or higher frequency simultaneously exist at workplace

Risk Assessment
needs adequate EMF Exposure Assessment



EMF's exposure assessment

adequate to the physical characteristic of exposure and real exposure level is the crucial step towards appropriate:

- risk assessment for occupational safety and health (OSH) engineering
- testing the compliance of exposure conditions against safety guidelines or requirements from legislation
- design or re-design of devices emitting EMF and work environment containing such sources
- epidemiological studies of EMF-exposed groups
- environmental monitoring

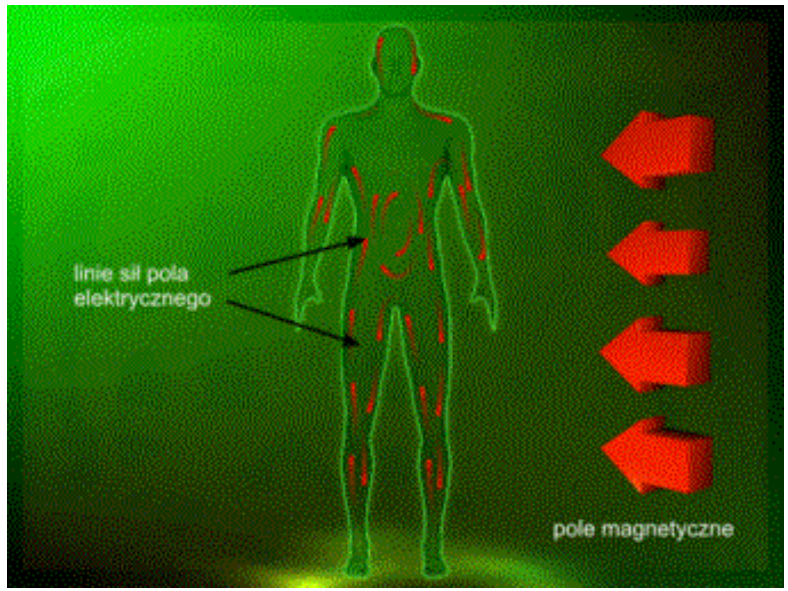
Human body exposure assessment

mandatory risk assessment (Directive 2004/40/EC) – **assessment, measurements or calculations** of EMF exposure

- **exposure level (*E* and *H*)**
- computational quantities (*J* and *SAR*)

for occupational exposures, where the source is directly coupled to the body

- local SAR
- induced currents
- contact currents



Quantities for assessment of exposure to EMF

measurements:

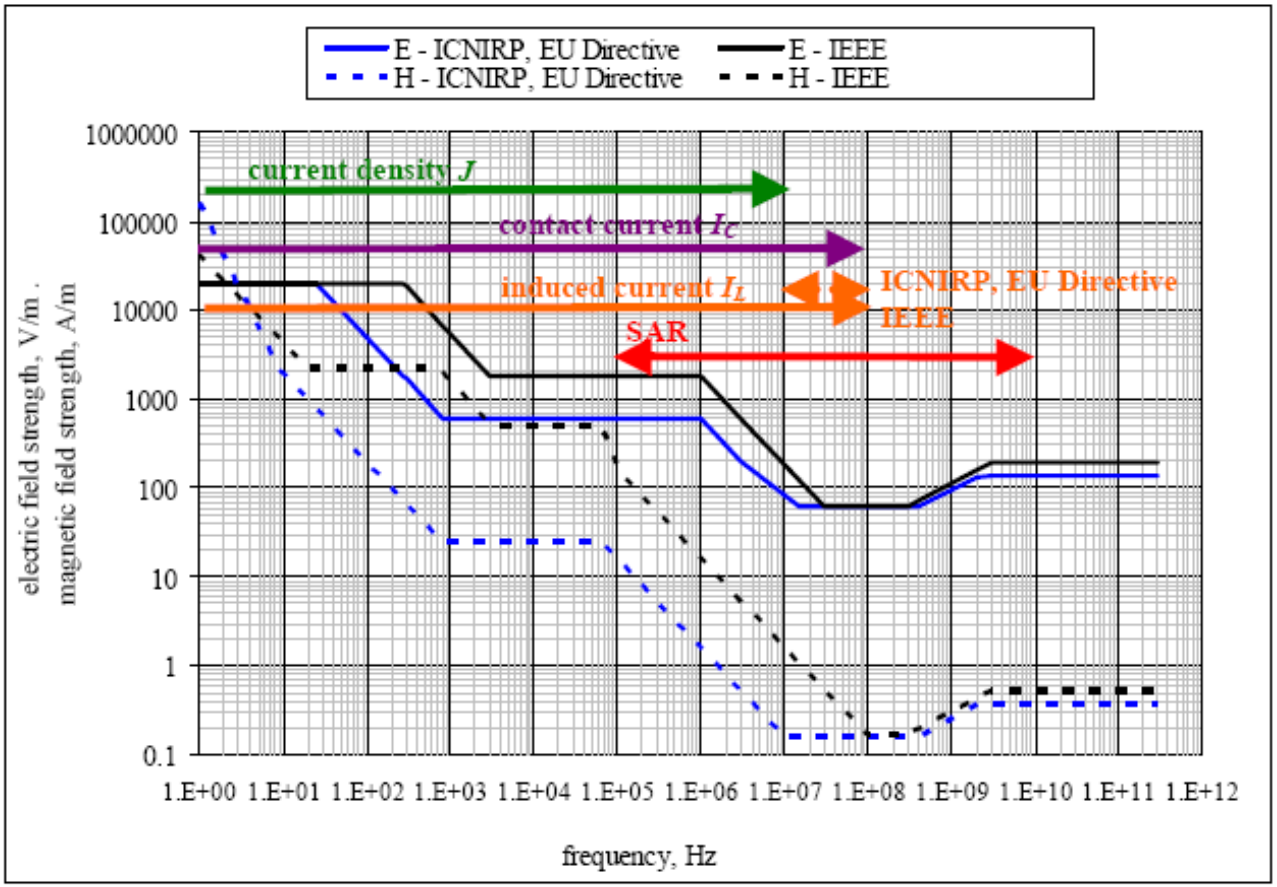
- electric field strength *E*
- magnetic field strength *H* or magnetic flux density *B*
- power density *S* (for far field only)
- contact current I_c
- induced current I_L

calculations only:

- induced current density
- SAR

Human body exposure assessment

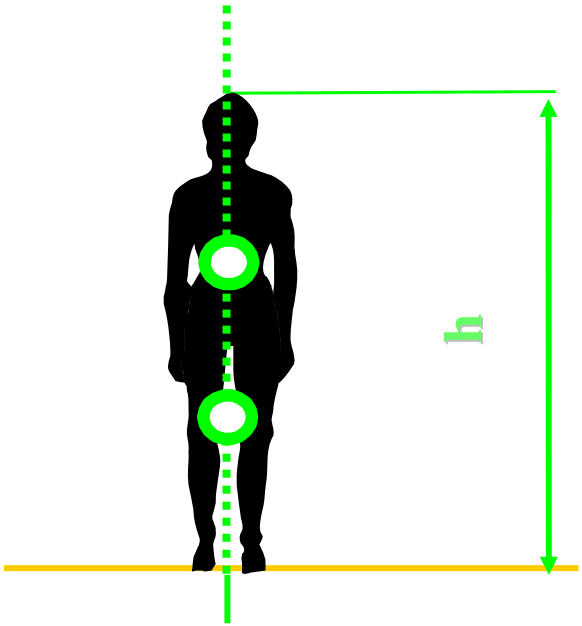
e.g. Directive 2004/40/EC; ICNIRP; IEEE; or mandatory legislation

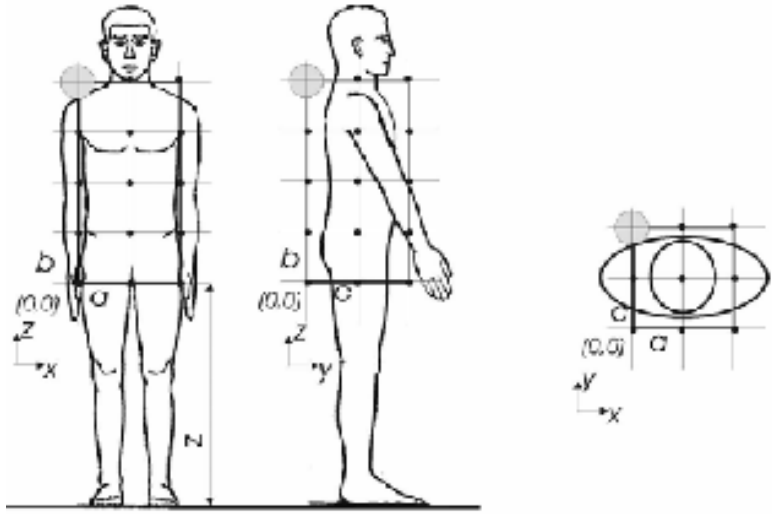


Problems with occupational EMF measurements/assessment (1)

- protocol of spatial averaging of EMF over human body position is non defined (or not enough precise) in some limitation guidelines

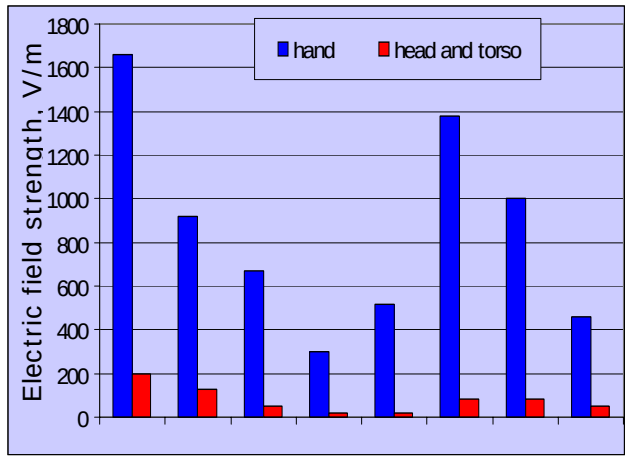
  (e.g. directive 2004/40/EC)





Problems with occupational EMF measurements/assessment (2)

- EMF measurements over the position of trunk not cover the hands' exposure
- usually the most exposed part of worker’s body is hand

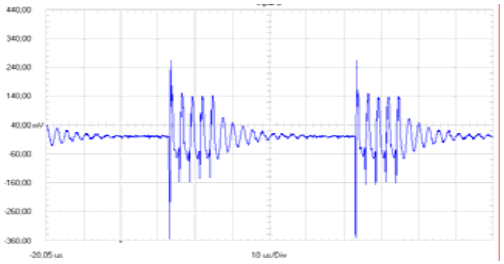


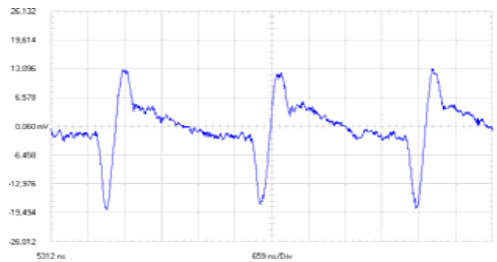
Problems with occupational EMF measurements/assessment (3)

- the assessment of workers exposure should base on unperturbed field
- in case of many EMF-emitting devices, measurement of this field is not possible because of technical limitations
- capacitive coupling influenced field distribution and can significantly changed level of EMF close to the worker's body

Problems with occupational EMF measurements/assessment (4)

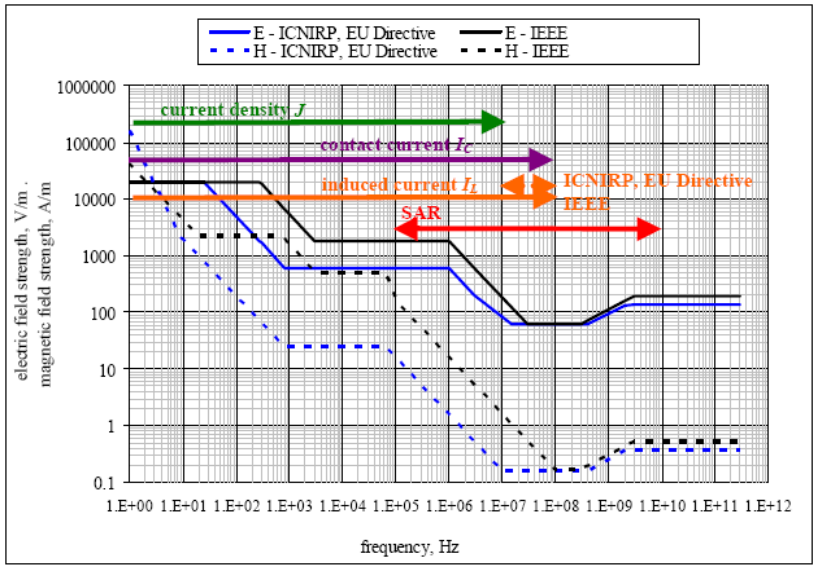
- the need of time-domain measurements for pulse fields - the lack of equipment (only oscilloscopic method with calibrated probes)
- the use of EMF RMS meters calibrated in harmonic reference field for measurements of pulse modulated field may be a source of significant measurement/assessment error



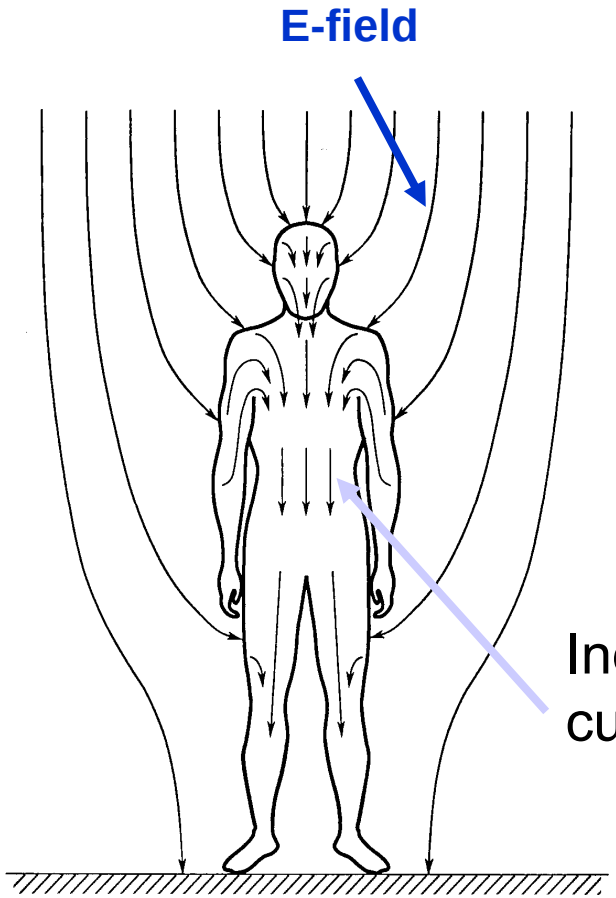


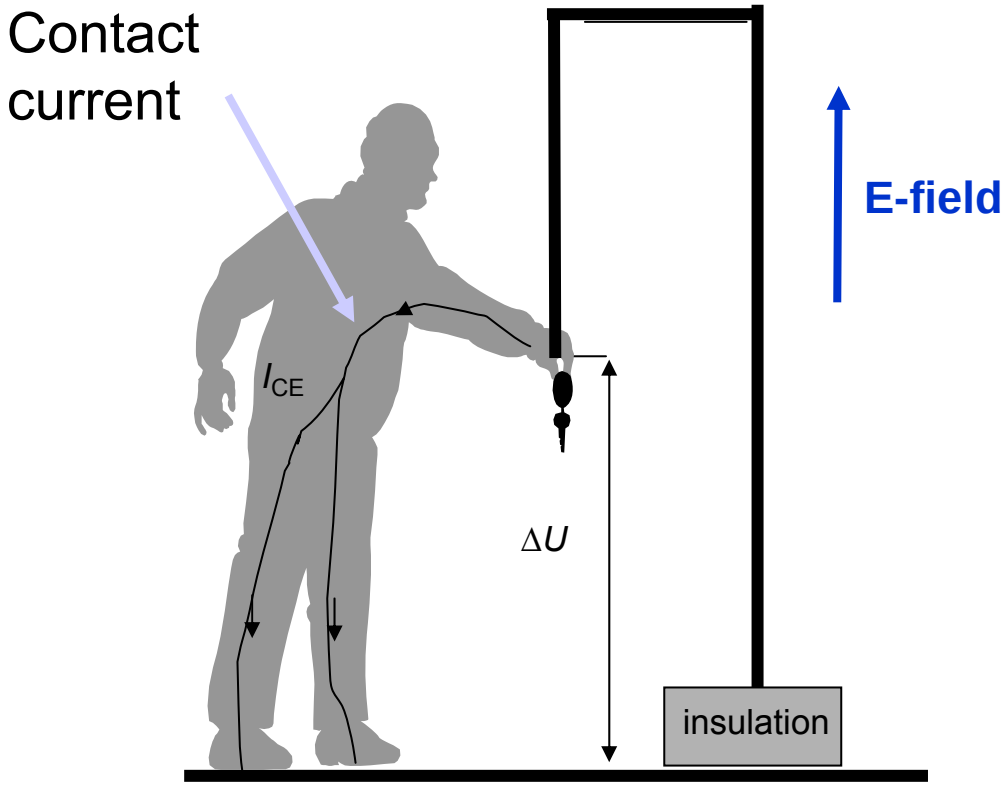
Problems with occupational EMF measurements/assessment (5)

- criteria for induced current in limbs are not given by directive 2004/40/EC for frequency below 10 MHz
- local thermal effect in limbs (local SAR) was limited for frequencies exceeding 100 kHz



Induced versus contact current meters
Time-averaged RMS versus max. value
Hand / leg / grasp / touch?





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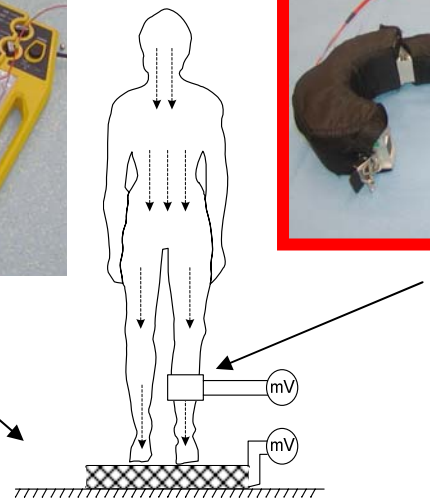
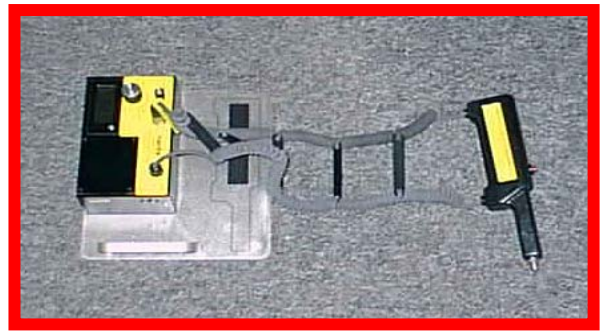
Induced and contact current meters



Capacitive devices (stand-on)

Inductive devices (clamp-on)

Phantoms



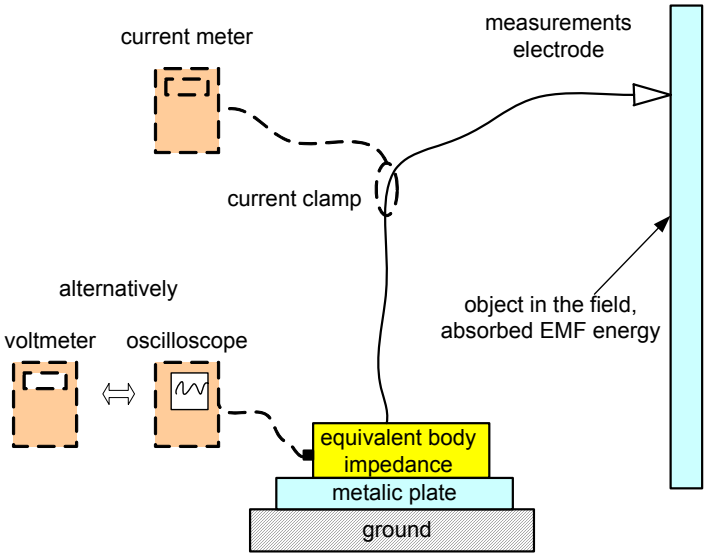
Narda 8850; Holaday HI-3702; Narda 8858; Narda typu 8870

Narda E and H field meters, digital oscilloscopes

Problems with occupational EMF measurements/assessment (6)

Induced and contact current measurements

- from the ethical point of view the use of measurement protocol which needs the workers body in the measurement set-up is very questionable (safety of such procedure is very limited)
- further work on phantom measurement methods is urgently needed



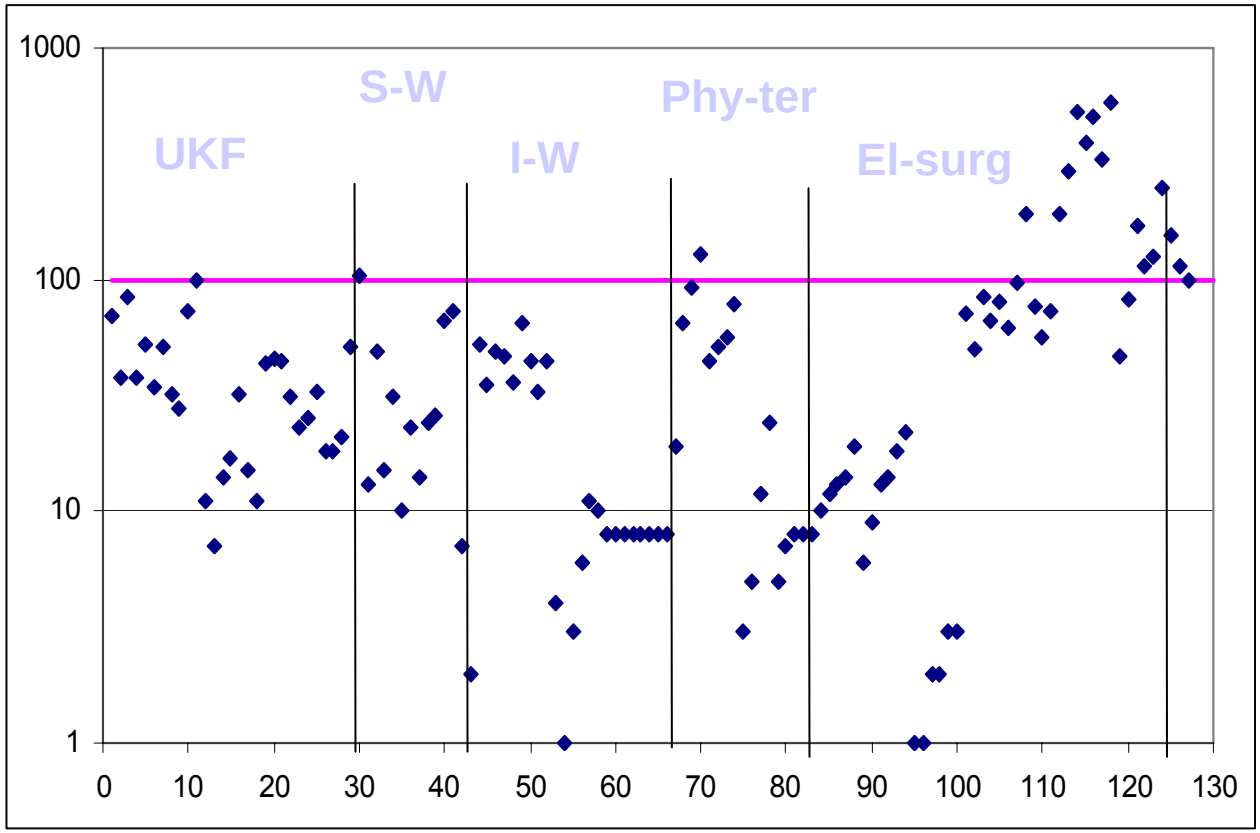
Investigations conducted in variety of workplace:

- in broadcasting centres:
  - UKF radio – 88-110 MHz
  - S-W radio – 10 MHz
  - I-W radio – 2 MHz
  - L-W radio – 0.2 MHz
- health care centres
  - surgery diathermy – 0.3-2 MHz
  - physiotherapeutic diathermy – 27 MHz
- dielectric heaters – 27 MHz

- over 400 workplace investigated
- 50% of results homogeneous and taken for analysis

Induced current, mA

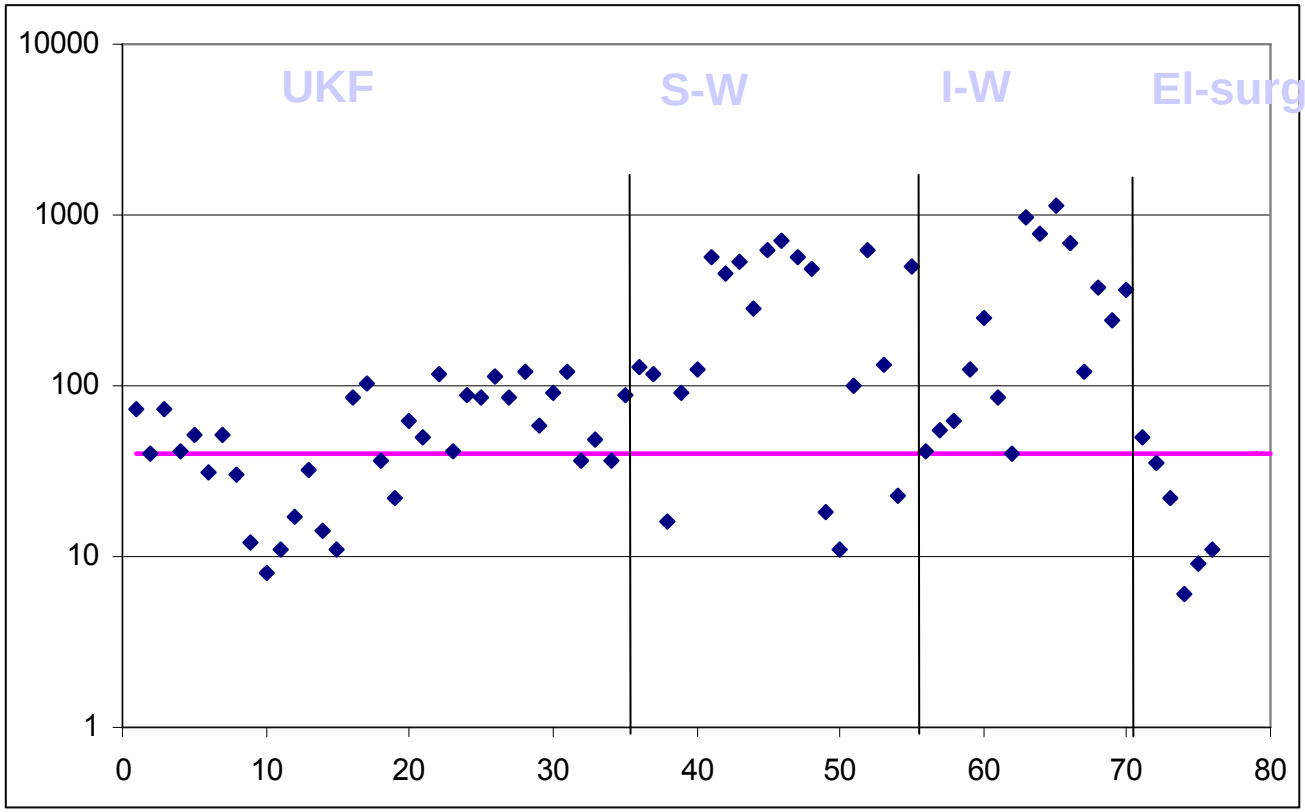
100 mA – limit value



E (max, spot meas.) ≈ 150% of ICNIRP's reference level

Contact currents

40 mA – limit value



E (max, spot meas.) ≈ 150% of ICNIRP's reference level

Phantom - equivalent circuit for contact current measurements
100 kHz - 10 MHz

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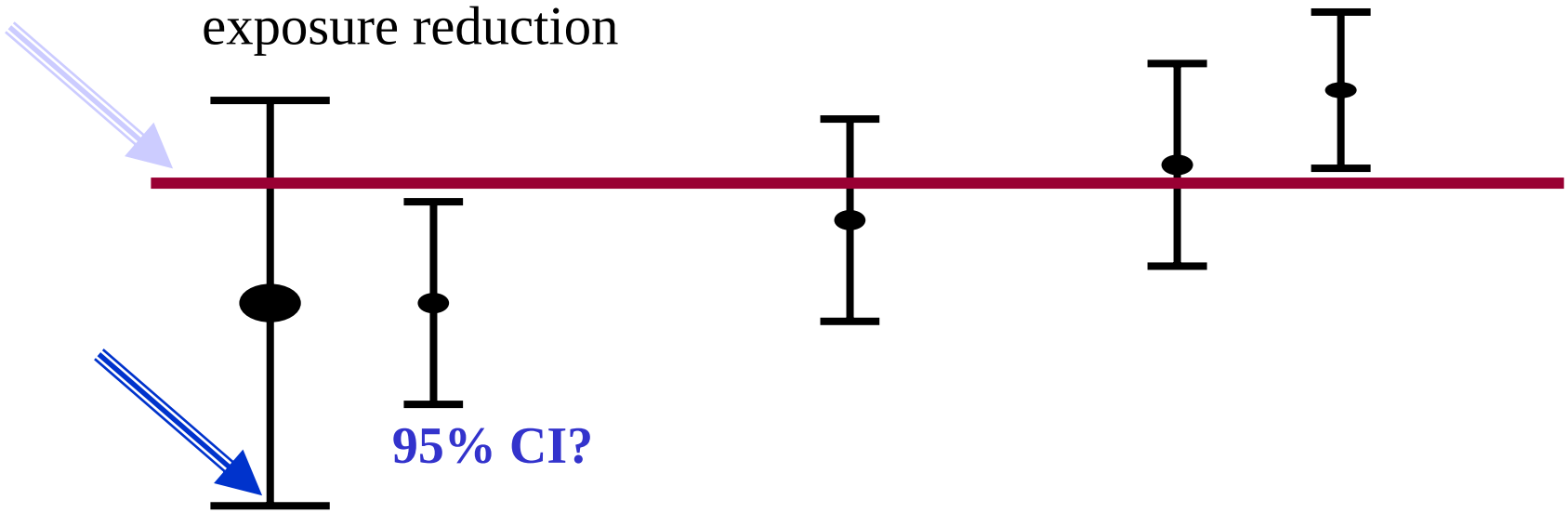
Problems with occupational EMF measurements/assessment (7)

numerical simulations

- limited experience on work environment modelling
- posture of workers body
- EMF sources modelling
- limited experience on IF simulations
- lack of numerical models standardisation
- lack of software standardisation and limited validation
- high level of needed experience (research!!!)
- time consumption and costs
- limited knowledge on uncertainty of simulation results

"legislation's obligations" for EMF assessment – compliance testing

- exposure assessment protocol:
  - uncertainty of the particular assessment results
- the consequences for decision process
  - when worker's exposure could be take as compliant with the directive provisions or not
  - when employer could be treated as obliged for organizing the exposure reduction



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Typical uncertainty range

Calibration – known frequency, polarisation, temperature and humidity **(1-10 %)**

Field measurements in the workplace – unknown frequency composition of the signal and polarisation, environmental conditions might be far from calibration ones **(20-50 %, even more)**

Accreditation ?

ZAKRES AKREDYTACJI
LABORATORIUM POMIAROWEGO
Nr AP 061

wydany przez
POLSKIE CENTRUM AKREDYTACJI
03-469 Warszawa ul. Racławicka 23 A wejście B

Wydanie nr 1 Data wydania: 28 stycznia 2004 r.

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	PION LABORATORIÓW POMIAROWYCH **ul. Czerniakowska 16** **00-701 Warszawa** **tel. (0-22) 623 32 00, fax (0-22) 623 40 54,** **e-mail: daple@ciop.pl**
Stacjonarne	Pole elektromagnetyczne, strumień objętości, wydatek energetyczny, prędkość powietrza, stężenie tlenku węgla
	dr inż. Dariusz Pleban - kierownik laboratorium mgr inż. Grażyna Szlagowska - zastępca kierownika laboratorium
	Wzorcowania: - elektrycznych przyrządów stosowanych do wyznaczania i pomiaru stężeń CO_2, - mierników do pomiaru pól elektromagnetycznych oraz magnetostatycznych stosowanych do oceny ekspozycji ludzi i środowiska, - pompek indywidualnych, - mierników wydatku energetycznego, - anemometrów.

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- Summary on electromagnetic fields
- Summary on EMF Directive
- Summary on application problems
- **Further data**

EMF-NET fact sheets
WHO – EMF project


Practical guidance on occupational EMF exposure assessment

radiofrequency range (100 kHz–300 GHz)

What are Electromagnetic fields, EMFs?

What makes the various forms of electromagnetic fields so different?

An information publication from the EMF NET project SSPE-CT-2004-502173 EMF-NET MT2 working group Effects of the Exposure to Electromagnetic Fields: From Science to Public Health and Safer Workplace. Coordination Action 8. Policy Support and Anticipating Scientific and Technological Needs

Occupational exposure fact sheet

Microwave dryers

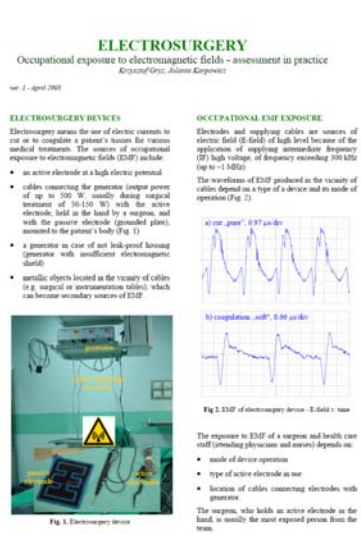

An information publication from the EMF NET project SSPE-CT-2004-502173 EMF-NET MT2 working group Effects of the Exposure to Electromagnetic Fields: From Science to Public Health and Safer Workplace. Coordination Action 8. Policy Support and Anticipating Scientific and Technological Needs

Occupational exposure fact sheet

RF wood glue drying

How does an RF wood glue drying machine work?

More on RF fields


ELECTROSURGERY

Occupational exposure to electromagnetic fields - assessment in practice

ELECTROSURGERY DEVICES

OCCUPATIONAL EMF EXPOSURE

COST BM0704

http://ciop.pl/EMF

journal JOSE vol. 1/2009

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Thank you for your kind attention

GRACJE