

**ElectroMagnetische Interferentie -
Storen en gestoord worden**

by

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**ElectroMagnetic Interference -
Disturbing disturbances**

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Synopsis

- Concepts
- Terminology
- EMC triptych
- Emission test / Immunity test / Product liability
- Universal EM Field EMC properties
- Examples of industrial EMC concern
- Computational EMC challenges
- Challenges in EMC indoctrination

ElectroMagnetic Interference (EMI) is a phenomenon manifesting itself via **Electromagnetic (EM) fields**

Electromagnetic (EM) fields are **omnipervious**:

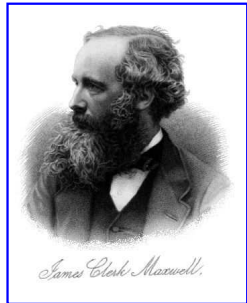
- permeate into all matter
- permeate into empty space (vacuum)

EM fields behave as **waves** traveling at a **finite wavespeed**

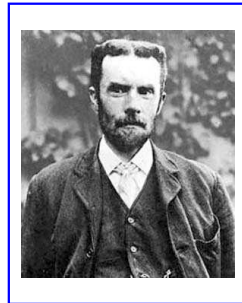
- **Electromagnetic wavespeed in vacuum:**
 - $c_0 = 299792458 \text{ m/s (exactly, SI)}$

EM fields carry

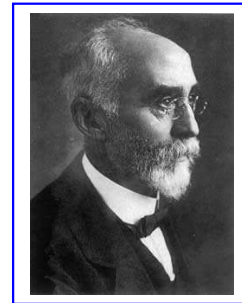
- **energy & information**

Principal actors in EM theory:

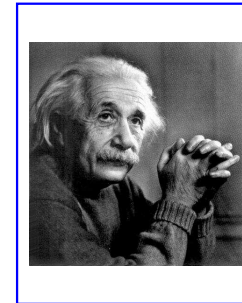
J. C. Maxwell
(1831 – 1879)



O. Heaviside
(1850 – 1925)



H. A. Lorentz
(1853 – 1928)



A. Einstein
(1879 – 1955)

- **Maxwell, James Clerk (1831–1879)**
- **Heaviside, Oliver (1850–1925)**
- **Lorentz, Hendrik Antoon (1853–1928)**
- **Einstein, Albert (1879–1955)**



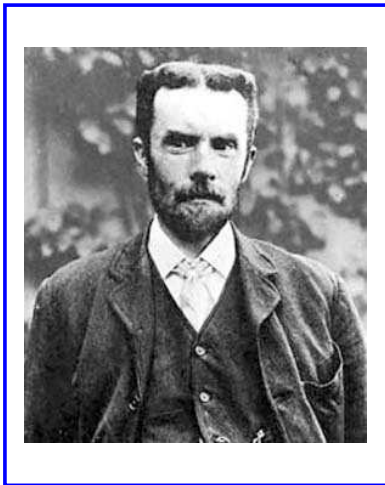
J. C. Maxwell
(1831 – 1879)

Maxwell, J. C., *A Treatise on Electricity and Magnetism*, Oxford, Clarendon Press, Vols. I & II, 1873.



- Unifies the description of electric and magnetic phenomena (on a laboratory scale) into a single, ElectroMagnetic Theory
- Concludes, on theoretical grounds, that 'Light' must be an electromagnetic (wave) phenomenon

James Clerk Maxwell (1831–1879)



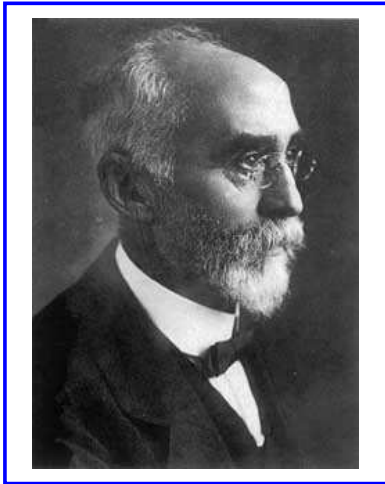
O. Heaviside
(1850 – 1925)

Heaviside, O., *Electromagnetic Theory*, New York, Van Nostrand & Co, Vols. I, II & III, 1893.



- Brings to attention the parallel structure of Maxwell's equations and the 'telegraphist's equations' of electric transmission line theory
- Casts Maxwell's equations into their 'Engineering form'
- Invents his 'Operational Calculus'

Oliver Heaviside (1850–1925)



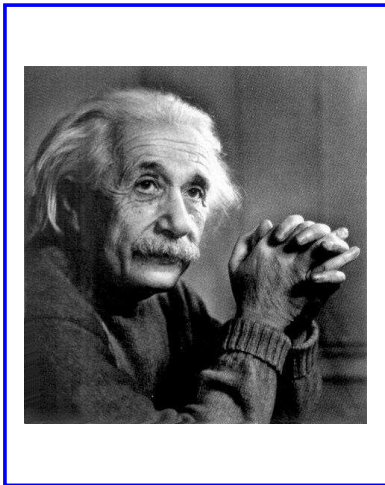
H. A. Lorentz
(1853 – 1928)

Lorentz, H. A. , *The Theory of Electrons and its Applications to the Phenomena of Light and Radiant Heat*, Leipzig, Teubner, 1909.



- Extrapolates Maxwell's equations to moving matter ('Lorentz transformation')
- Extrapolates the concept of EM field action to the atomic scale
- **BUT:** The procedure fails to explain quantum phenomena

Hendrik Antoon Lorentz (1853–1928)



A. Einstein
(1879 – 1955)

Einstein, A., *The Meaning of Relativity*, Princeton University Press, 5th. ed., 2004.



- 'Any physical field quantity = (Geometrical) tensor quantity'
- Extrapolates the concept of EM field action to the cosmological scale
- **BUT:** The procedure fails to explain gravity phenomena

Albert Einstein (1879–1955)

The following well-known **LIMERICK** contains statements that are not substantiated by the (special) theory of relativity (Lorentz transformations interrelating space-time observations of observers in relative motion with uniform velocity):

**There once was a lady named Bright
who traveled much faster than light.
She left home one day
in a relative way
and returned on the previous night.**

A limerick on relativity

08lim

From the **International Electrotechnical Vocabulary (IEV)** of the
International Electrotechnical Commission (IEC)
(<http://std.iec.ch/iec60050>,
click on **161: Electromagnetic Compatibility**) :

- **ElectroMagnetic Compatibility (EMC)**

The ability of an equipment or system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment. (*Note: "Anything" includes both living and inert matter.*)

- **ElectroMagnetic environment**

The totality of electromagnetic phenomena existing at a given location.

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ElectroMagnetic Compatibility (EMC), ElectroMagnetic Interference (EMI)

- **ElectroMagnetic Interference (EMI)**

Degradation of the performance of an equipment, transmission channel or system caused by an electromagnetic disturbance.

- **ElectroMagnetic disturbance**

Any electromagnetic phenomenon which may degrade the performance of a device, equipment or system, or adversely affect living or inert matter

(*Note: An electromagnetic disturbance may be an electromagnetic noise, an unwanted signal or a change in the propagation medium itself.*)

- **ElectroMagnetic emission**

The phenomenon by which electromagnetic energy emanates from a source

*ElectroMagnetic Compatibility (EMC), ElectroMagnetic Interference (EMI)*¹⁰

- **Immunity (to a disturbance)**

The ability of a device, equipment or system to perform without degradation in the presence of an electromagnetic disturbance

- **(ElectroMagnetic) susceptibility**

The inability of a device, equipment or system to perform without degradation in the presence of an electromagnetic disturbance

(Note: Susceptibility is a lack of immunity.)

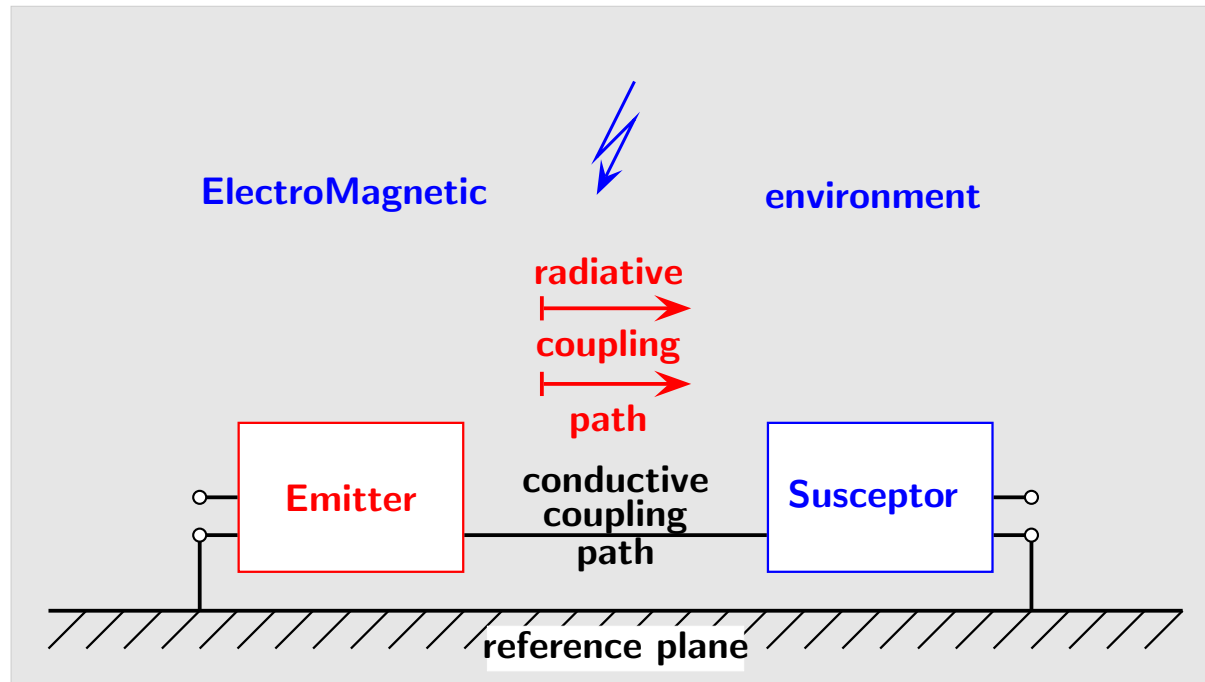
- **Emitter (of electromagnetic disturbance)**

Device, equipment or system which gives rise to voltages, currents or electromagnetic fields that can act as electromagnetic disturbances

- **Susceptible device**

Device, equipment or system whose performance can be degraded by an electromagnetic disturbance

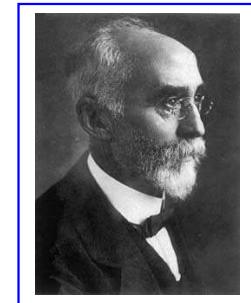
ElectroMagnetic Compatibility (EMC), ElectroMagnetic Interference (EMI)



- EMC triptych: **Emitter** / Coupling path / **Susceptor**

Universal EMC properties of ElectroMagnetic Fields:

- EM Fields are **omnipervious**: they penetrate into all **matter** as well as into **vacuum** (space devoid of matter).
- EM Fields satisfy the **Principle of Reciprocity**: each device emitting EM Fields is also susceptible to EM Fields & each device susceptible to EM Fields is also emitting EM Fields. The **H. A. Lorentz Reciprocity Theorem (1896)** quantifies this property.



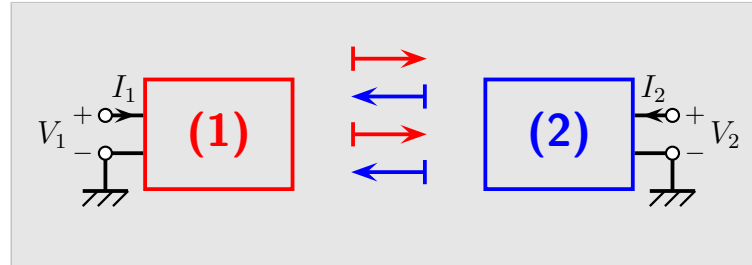
H. A. Lorentz
(1853 – 1928)

For extensive applications of Reciprocity, see:

- De Hoop, A. T., *Handbook of Radiation and Scattering of Waves*, London, Academic Press, 1995, xxx + 1085 pp.

EM Fields (universal EMC properties)

Two interfering linear, time-invariant, causal 1-port systems



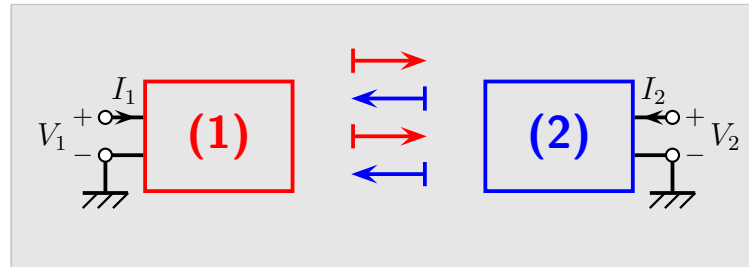
Impedance matrix description ($[Z]$, time domain)

- $$\begin{bmatrix} V_1 \\ V_2 \end{bmatrix} = \begin{bmatrix} Z_{1,1} & Z_{1,2} \\ Z_{2,1} & Z_{1,2} \end{bmatrix} \begin{matrix} (t) \\ * \end{matrix} \begin{bmatrix} I_1 \\ I_2 \end{bmatrix} \quad \text{reciprocity} \implies Z_{1,2} = Z_{2,1}$$

Impedance matrix description ($[\hat{Z}]$, complex frequency domain)

- $$\begin{bmatrix} \hat{V}_1 \\ \hat{V}_2 \end{bmatrix} = \begin{bmatrix} \hat{Z}_{1,1} & \hat{Z}_{1,2} \\ \hat{Z}_{2,1} & \hat{Z}_{1,2} \end{bmatrix} \cdot \begin{bmatrix} \hat{I}_1 \\ \hat{I}_2 \end{bmatrix} \quad \text{reciprocity} \implies \hat{Z}_{1,2} = \hat{Z}_{2,1}$$
- $$[\widehat{\dots}](s) = \int_{t=0}^{\infty} \exp(-st) [\dots](t) dt \quad \text{(Laplace transformation)}$$

Two interfering linear, time-invariant, causal 1-port systems

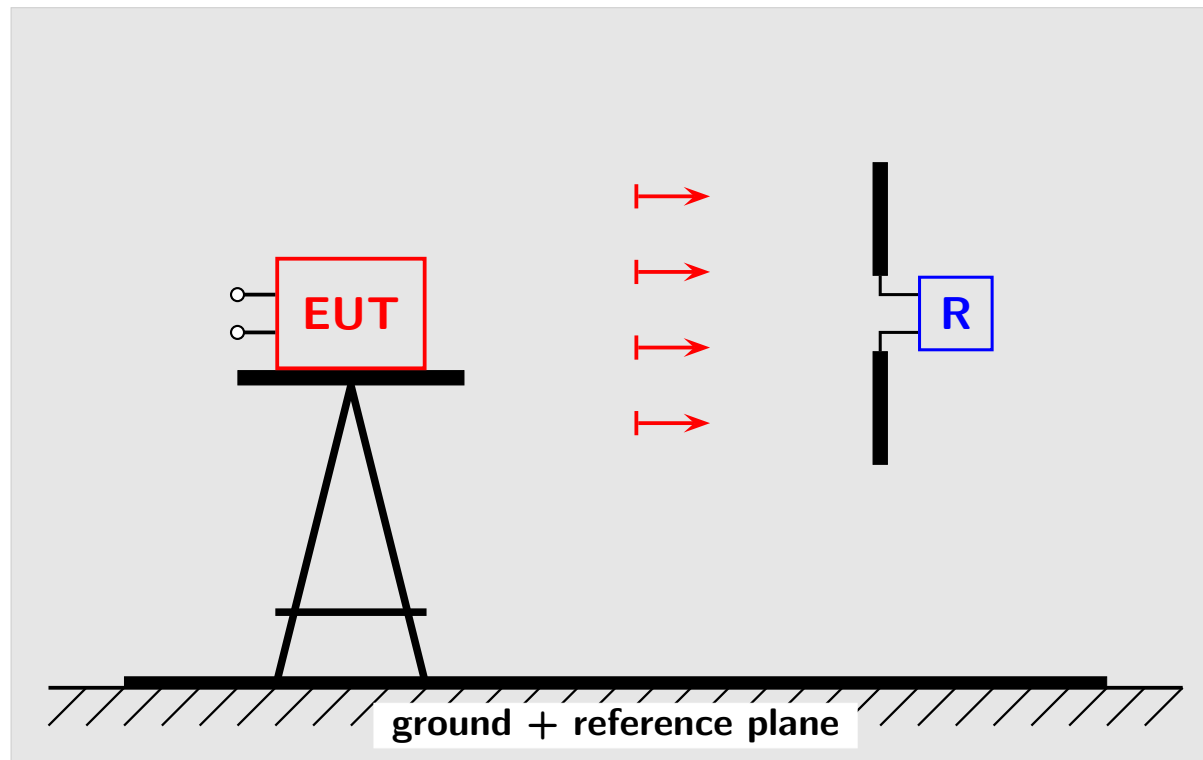


Admittance matrix description ($[Y]$, time domain)

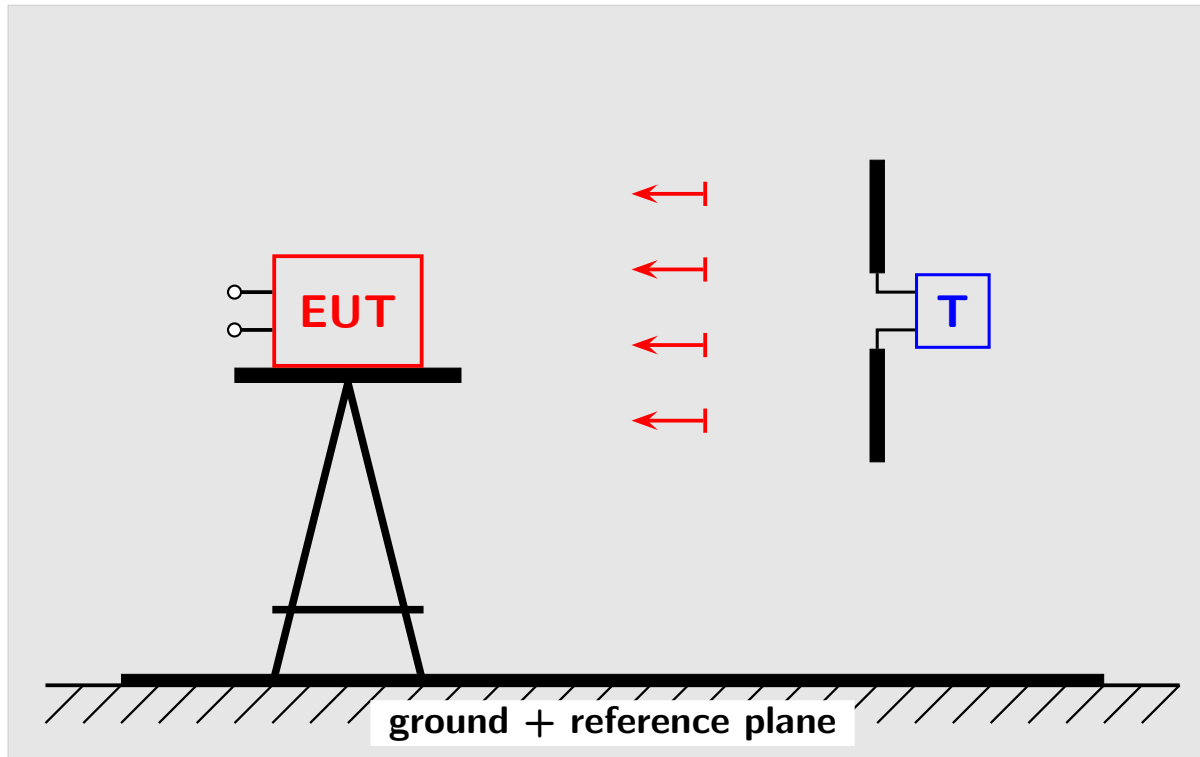
- $$\begin{bmatrix} I_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} Y_{1,1} & \mathbf{Y}_{1,2} \\ \mathbf{Y}_{2,1} & Y_{1,2} \end{bmatrix} \begin{matrix} (t) \\ * \end{matrix} \begin{bmatrix} V_1 \\ V_2 \end{bmatrix} \quad \text{reciprocity} \implies \mathbf{Y}_{1,2} = \mathbf{Y}_{2,1}$$

Admittance matrix description ($[\hat{Y}]$, complex frequency domain)

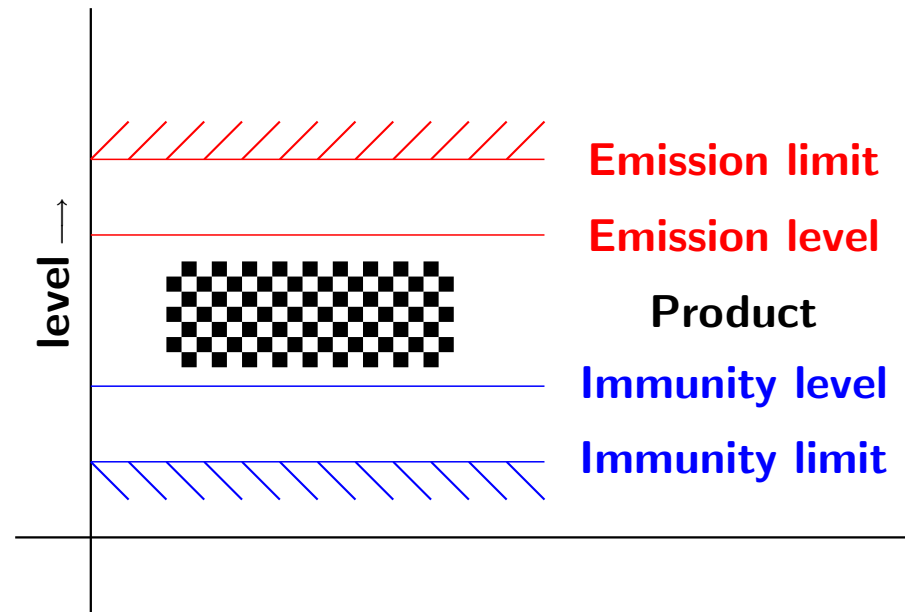
- $$\begin{bmatrix} \hat{I}_1 \\ \hat{I}_2 \end{bmatrix} = \begin{bmatrix} \hat{Y}_{1,1} & \mathbf{\hat{Y}}_{1,2} \\ \mathbf{\hat{Y}}_{2,1} & \hat{Y}_{1,2} \end{bmatrix} \cdot \begin{bmatrix} \hat{V}_1 \\ \hat{V}_2 \end{bmatrix} \quad \text{reciprocity} \implies \mathbf{\hat{Y}}_{1,2} = \mathbf{\hat{Y}}_{2,1}$$
- $$[\widehat{\dots}](s) = \int_{t=0}^{\infty} \exp(-st) [\dots](t) dt \quad \text{(Laplace transformation)}$$



- **EM Emission test:** **EUT** = **E**quipment **U**nder **T**est, **R** = **R**eceiving antenna
- **Emission level** (under specified conditions) < **Emission limit** (specified by, e.g., EU)



- **EM Immunity test:** **EUT** = **E**quipment **U**nder **T**est, **T** = **T**ransmitting antenna
- **Immunity level** (under specified conditions) > **Immunity limit** (specified by, e.g., EU)



- Emission test: Emission level < Emission limit
 - Immunity test: Immunity level > Immunity limit
- BUT \implies Product liability remains!**

- **Computer & Automation Industry**

- susceptibility of multiwire flexible cable interconnects
- emission by ElectroStatic Discharge

- **Aircraft Industry** (less metal in fuselage and wing structures)

- fly-by-wire system susceptibility
- susceptibility to lightning stroke impact on engine

- **Public Radio Broadcast**

- susceptibility to FM Digital Audio Broadcast (with guaranteed reception electric field strength)

- **Automobile Industry** (electronic car control)
 - susceptibility of fuel injection and gear shift control systems to external disturbances
- **Consumer Electronics & Telecommunication Industries**
 - safety in household appliances (e.g., water tap control in electronically controlled washing machines)
 - susceptibility of electronic hearing aid to EM emission from cellular telephones
 - susceptibility to induction damage from lightning strokes
- **Bioelectromagnetics**
 - BioEM safety standards in Mobile Communication Systems

Develop analytical and/or computational techniques that yield EM field values in complex configurations

- fast
- in time domain
- with accuracy up to a factor of 2 (in view of 3 dB safety margins in emission and susceptibility)
- with simple expressions for upper bounds (for worst-case analysis)

Make electronics engineers aware that

- digital electronic systems and devices require **time-domain EMC specifications** (rather than – the customary – frequency-domain specifications)
- EM field behavior description inherently surpasses an 'explanation' in terms of Kirchhoff electric circuit quantities (voltage, electric current, impedance, admittance)