ElectroMagnetic Compatibility - A brief introduction

by

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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

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.

- **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

- **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**

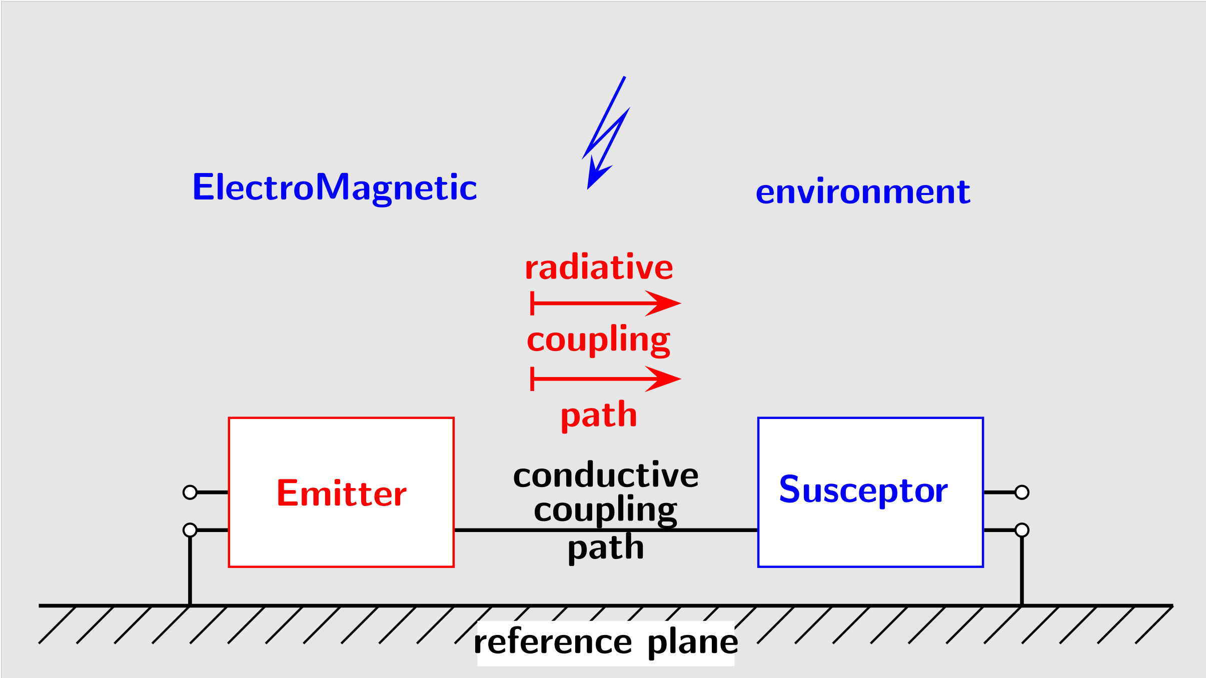
  The inability of a device, equipment or system to perform without degradation in the presence of an electromagnetic disturbance
  (*Note*: Susceptibility is a lack of immunity.)

- **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



- **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.

  For extensive applications of Reciprocity, see:

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

H. A. Lorentz
(1853 – 1928)

A. T. de Hoop
(1927)

EM field behavior of Electrical & Electronic circuits

At (circuital) **Kirchhoff N-port**

[$E_r(x_m,t) = -\partial_m \Phi(x_m,t)$, $\Phi(x_m,t)$ = electric scalar potential]:

- $V_n(t) =$ electric voltage across port n (V)
- $I_n(t) =$ electric current flowing into port n (A)

Lorentz's reciprocity relation

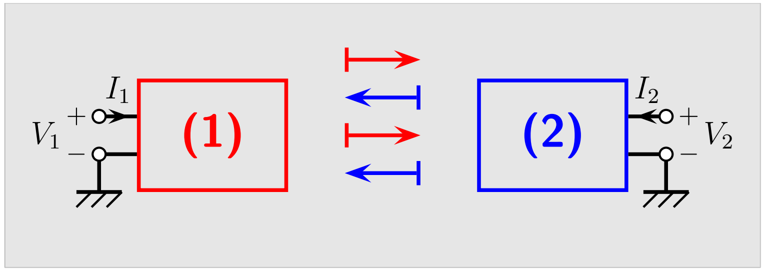
(interaction between two EM 'States' A and B

in linear, time-invariant, causal configuration) ($\overset{(t)}{*}$ = time convolution)

- $$\oint_{\{\text{port apertures}\}\subset\mathcal{S}} \epsilon_{m,r,p}\nu_m (E_r^A \overset{(t)}{*} H_p^B - E_r^B \overset{(t)}{*} H_p^A)\mathrm{d}A =$$
$$\sum_{n=1}^{N} (V_n^A \overset{(t)}{*} I_n^B - V_n^B \overset{(t)}{*} I_n^A)\Big|_{\text{port}_n \subset\, \mathcal{S}}$$

EM field description at Kirchhoff ports

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



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

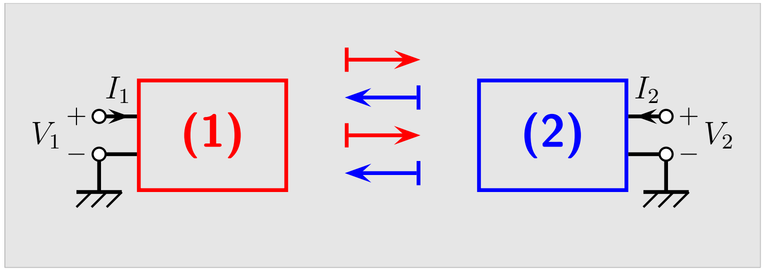
- $\begin{bmatrix} V_1 \\ V_2 \end{bmatrix} = \begin{bmatrix} Z_{1,1} & \boldsymbol{Z_{1,2}} \\ \boldsymbol{Z_{2,1}} & Z_{1,2} \end{bmatrix} \overset{(t)}{*} \begin{bmatrix} I_1 \\ I_2 \end{bmatrix}$ **reciprocity** $\Longrightarrow \boldsymbol{Z_{1,2}} = \boldsymbol{Z_{2,1}}$

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

- $\begin{bmatrix} \hat{V}_1 \\ \hat{V}_2 \end{bmatrix} = \begin{bmatrix} \hat{Z}_{1,1} & \boldsymbol{\hat{Z}_{1,2}} \\ \boldsymbol{\hat{Z}_{2,1}} & \hat{Z}_{1,2} \end{bmatrix} \cdot \begin{bmatrix} \hat{I}_1 \\ \hat{I}_2 \end{bmatrix}$ **reciprocity** $\Longrightarrow \boldsymbol{\hat{Z}_{1,2}} = \boldsymbol{\hat{Z}_{2,1}}$
- $[\widehat{\ldots}](\boldsymbol{s}) = \int_{t=0}^{\infty} \exp(-\boldsymbol{s}t)[\ldots](t)\mathrm{d}t$ **(Laplace transformation)**

System's description of EMI (impedance matrix formulation)

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



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

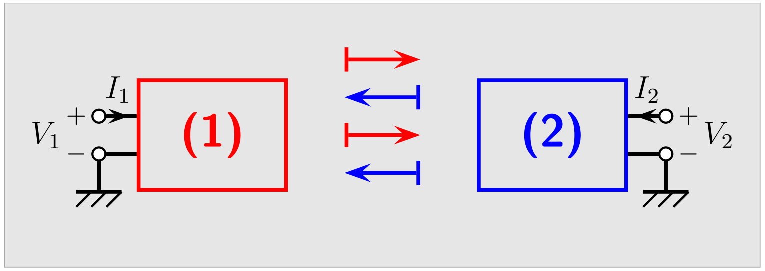
- $$\begin{bmatrix} I_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} Y_{1,1} & \boldsymbol{Y_{1,2}} \\ \boldsymbol{Y_{2,1}} & Y_{1,2} \end{bmatrix} \overset{(t)}{*} \begin{bmatrix} V_1 \\ V_2 \end{bmatrix}$$ **reciprocity** $\Longrightarrow \boldsymbol{Y_{1,2}} = \boldsymbol{Y_{2,1}}$

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

- $$\begin{bmatrix} \hat{I}_1 \\ \hat{I}_2 \end{bmatrix} = \begin{bmatrix} \hat{Y}_{1,1} & \boldsymbol{\hat{Y}_{1,2}} \\ \boldsymbol{\hat{Y}_{2,1}} & \hat{Y}_{1,2} \end{bmatrix} \cdot \begin{bmatrix} \hat{V}_1 \\ \hat{V}_2 \end{bmatrix}$$ **reciprocity** $\Longrightarrow \boldsymbol{\hat{Y}_{1,2}} = \boldsymbol{\hat{Y}_{2,1}}$
- $[\widehat{\ldots}](\boldsymbol{s}) = \int_{t=0}^{\infty} \exp(-\boldsymbol{s}t)[\ldots](t)\mathrm{d}t$ **(Laplace transformation)**

System's description of EMI (admittance matrix formulation)

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

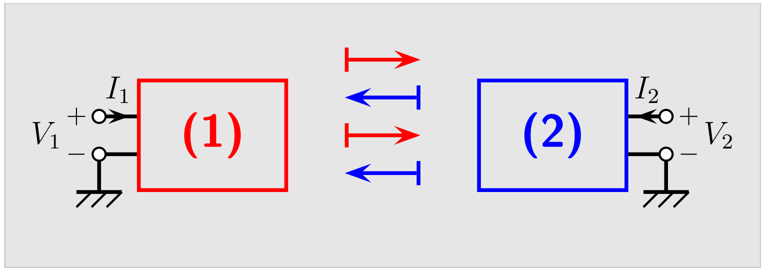


Susceptibility figure (electric current excitation):

- From $\left.\dfrac{\hat{V}_2}{\hat{V}_1}\right|_{\hat{I}_1\neq 0}$ (1) → (2) $\Longrightarrow \dfrac{\displaystyle\int_{t=0}^{\infty}|\boldsymbol{Z}_{2,1}(t)|^2\mathrm{d}t}{\displaystyle\int_{t=0}^{\infty}|\boldsymbol{Z}_{1,1}(t)|^2\mathrm{d}t} \overset{\text{(Parseval)}}{=} \dfrac{\displaystyle\frac{1}{2\pi}\int_{\omega=-\infty}^{\infty}|\hat{\boldsymbol{Z}}_{2,1}(\mathrm{j}\omega)|^2\mathrm{d}\omega}{\displaystyle\frac{1}{2\pi}\int_{\omega=-\infty}^{\infty}|\hat{\boldsymbol{Z}}_{1,1}(\mathrm{j}\omega)|^2\mathrm{d}\omega}$
- From $\left.\dfrac{\hat{V}_1}{\hat{V}_2}\right|_{\hat{I}_2\neq 0}$ (2) → (1) $\Longrightarrow \dfrac{\displaystyle\int_{t=0}^{\infty}|\boldsymbol{Z}_{1,2}(t)|^2\mathrm{d}t}{\displaystyle\int_{t=0}^{\infty}|\boldsymbol{Z}_{2,2}(t)|^2\mathrm{d}t} \overset{\text{(Parseval)}}{=} \dfrac{\displaystyle\frac{1}{2\pi}\int_{\omega=-\infty}^{\infty}|\hat{\boldsymbol{Z}}_{1,2}(\mathrm{j}\omega)|^2\mathrm{d}\omega}{\displaystyle\frac{1}{2\pi}\int_{\omega=-\infty}^{\infty}|\hat{\boldsymbol{Z}}_{2,2}(\mathrm{j}\omega)|^2\mathrm{d}\omega}$

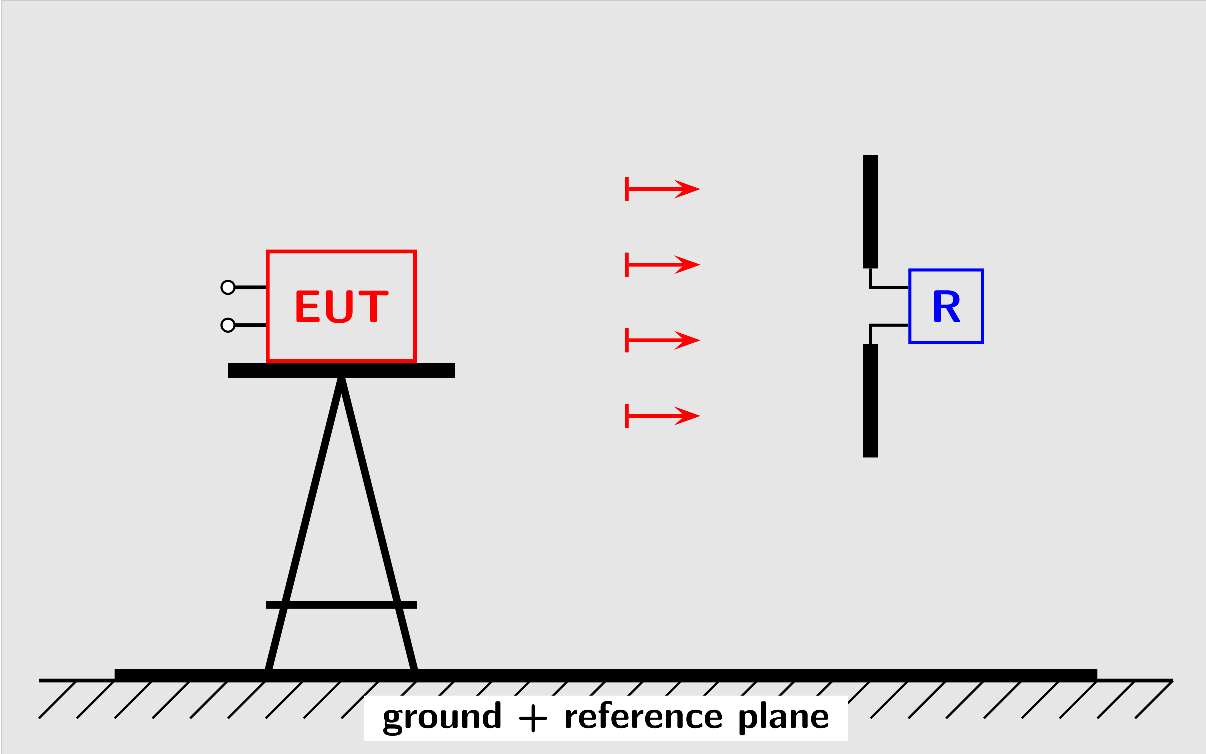
System's figure of susceptibility (electric-current excitation)

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

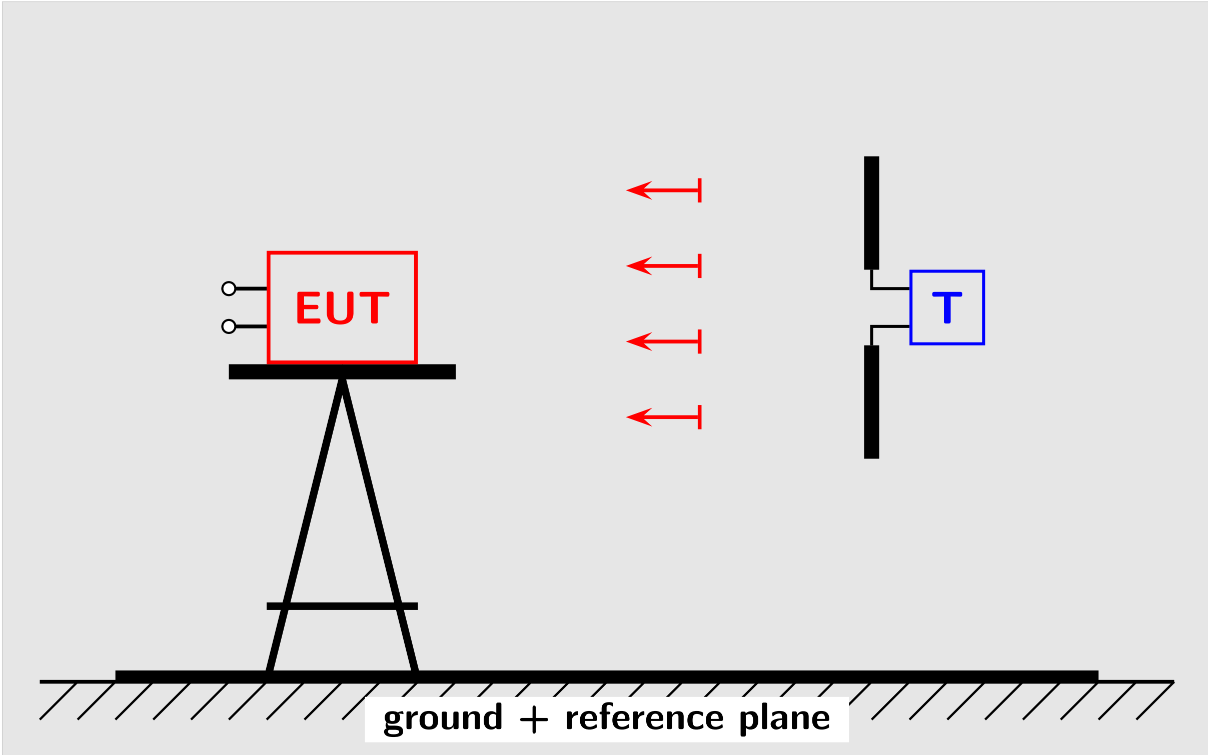


Susceptibility figure (voltage excitation):

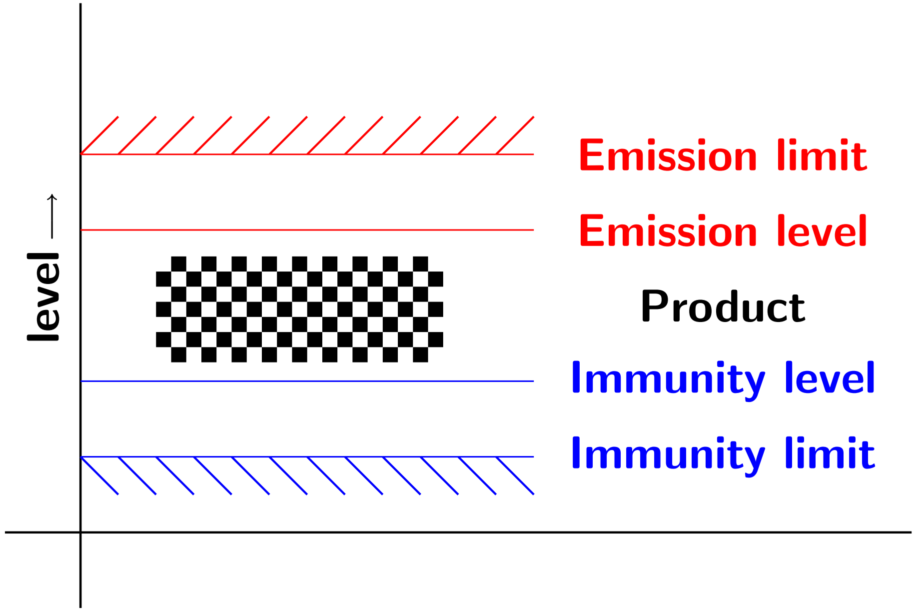
- From $\left.\dfrac{\hat{I}_2}{\hat{I}_1}\right|_{\hat{V}_1 \neq 0}$ **(1) → (2)** $\Longrightarrow \dfrac{\displaystyle\int_{t=0}^{\infty} |\boldsymbol{Y}_{2,1}(t)|^2 \mathrm{d}t}{\displaystyle\int_{t=0}^{\infty} |\boldsymbol{Y}_{1,1}(t)|^2 \mathrm{d}t} \overset{\text{(Parseval)}}{=} \dfrac{\dfrac{1}{2\pi}\displaystyle\int_{\omega=-\infty}^{\infty} |\hat{\boldsymbol{Y}}_{2,1}(\mathrm{j}\omega)|^2 \mathrm{d}\omega}{\dfrac{1}{2\pi}\displaystyle\int_{\omega=-\infty}^{\infty} |\hat{\boldsymbol{Y}}_{1,1}(\mathrm{j}\omega)|^2 \mathrm{d}\omega}$
- From $\left.\dfrac{\hat{I}_1}{\hat{I}_2}\right|_{\hat{V}_2 \neq 0}$ **(2) → (1)** $\Longrightarrow \dfrac{\displaystyle\int_{t=0}^{\infty} |\boldsymbol{Y}_{1,2}(t)|^2 \mathrm{d}t}{\displaystyle\int_{t=0}^{\infty} |\boldsymbol{Y}_{2,2}(t)|^2 \mathrm{d}t} \overset{\text{(Parseval)}}{=} \dfrac{\dfrac{1}{2\pi}\displaystyle\int_{\omega=-\infty}^{\infty} |\hat{\boldsymbol{Y}}_{1,2}(\mathrm{j}\omega)|^2 \mathrm{d}\omega}{\dfrac{1}{2\pi}\displaystyle\int_{\omega=-\infty}^{\infty} |\hat{\boldsymbol{Y}}_{2,2}(\mathrm{j}\omega)|^2 \mathrm{d}\omega}$



- **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 ⟹ 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)

Examples of industrial EMC concern

- **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

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)