

**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.

03
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

- **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.)

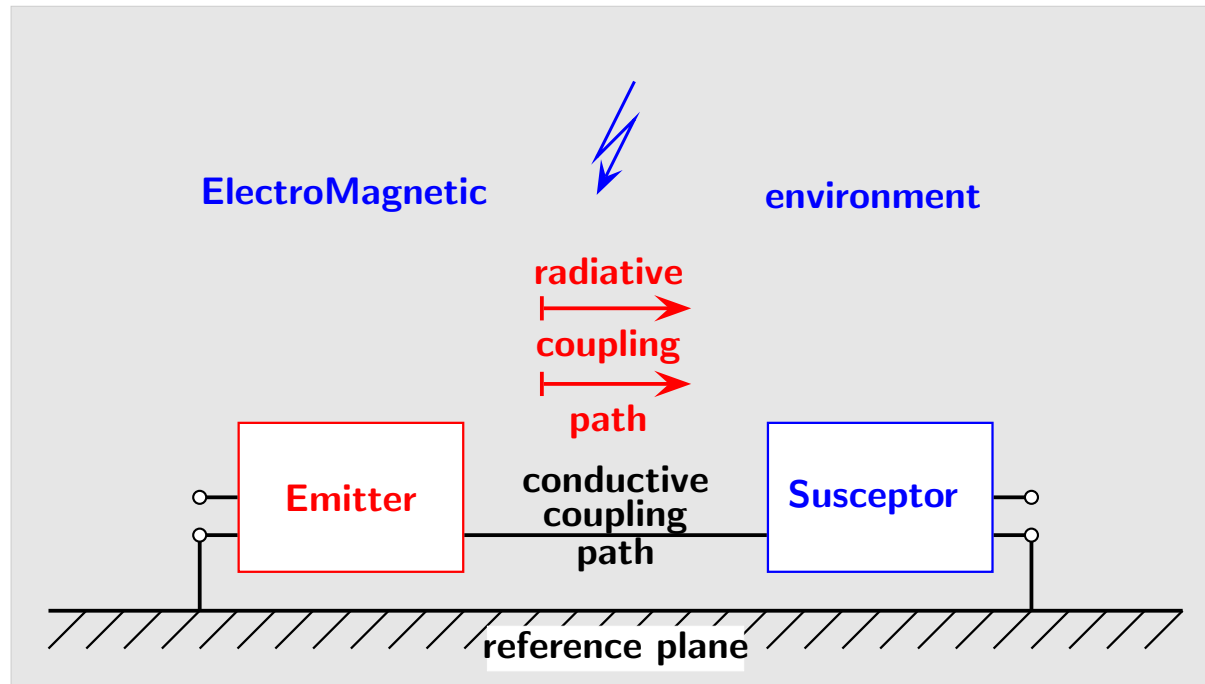
- **Emitter (of electromagnetic disturbance)**

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) ⁰⁵



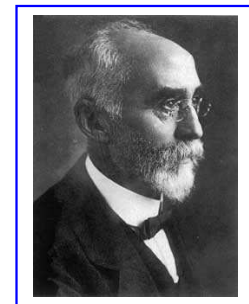
- EMC triptych: **Emitter** / Coupling path / **Susceptor**

Universal EMC properties of ElectroMagnetic Fields:

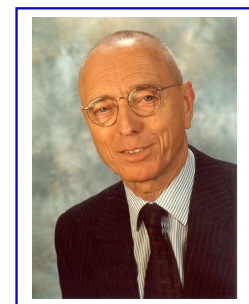
- EM Fields are **omnipervious**: they penetrate into all **matter** as well as into **vacuum** (space devoid of matter).
- EM Fields satisfy the **Principle of Reciprocity**: each device emitting EM Fields is also susceptible to EM Fields & each device susceptible to EM Fields is also emitting EM Fields. 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

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

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

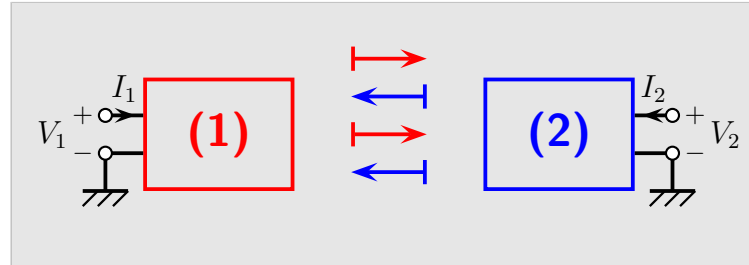
Lorentz's reciprocity relation

(interaction between two EM 'States' A and B

in linear, time-invariant, causal configuration) ($*$ = time convolution)

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

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



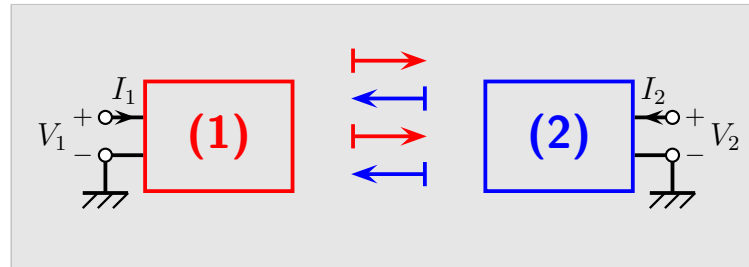
Impedance matrix description ($[Z]$, time domain)

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

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



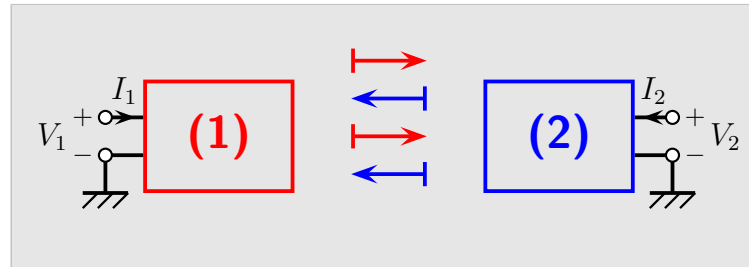
Admittance matrix description ($[Y]$, time domain)

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

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

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

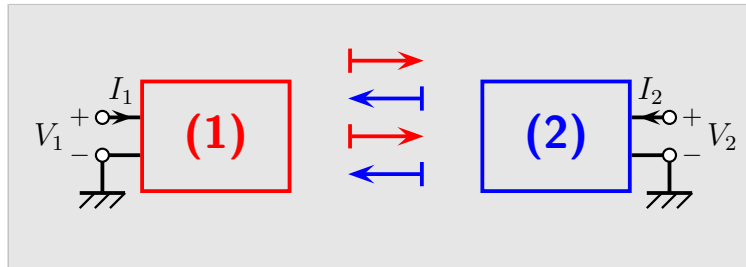
Two interfering linear, time-invariant, causal 1-port systems



Susceptibility figure (electric current excitation):

- From $\left. \frac{\hat{V}_2}{\hat{V}_1} \right|_{\hat{I}_1 \neq 0}$ **(1) → (2)** $\implies \frac{\int_{t=0}^{\infty} |\mathbf{Z}_{2,1}(t)|^2 dt}{\int_{t=0}^{\infty} |\mathbf{Z}_{1,1}(t)|^2 dt} \stackrel{\text{(Parseval)}}{=} \frac{\frac{1}{2\pi} \int_{\omega=-\infty}^{\infty} |\hat{\mathbf{Z}}_{2,1}(j\omega)|^2 d\omega}{\frac{1}{2\pi} \int_{\omega=-\infty}^{\infty} |\hat{\mathbf{Z}}_{1,1}(j\omega)|^2 d\omega}$
- From $\left. \frac{\hat{V}_1}{\hat{V}_2} \right|_{\hat{I}_2 \neq 0}$ **(2) → (1)** $\implies \frac{\int_{t=0}^{\infty} |\mathbf{Z}_{1,2}(t)|^2 dt}{\int_{t=0}^{\infty} |\mathbf{Z}_{2,2}(t)|^2 dt} \stackrel{\text{(Parseval)}}{=} \frac{\frac{1}{2\pi} \int_{\omega=-\infty}^{\infty} |\hat{\mathbf{Z}}_{1,2}(j\omega)|^2 d\omega}{\frac{1}{2\pi} \int_{\omega=-\infty}^{\infty} |\hat{\mathbf{Z}}_{2,2}(j\omega)|^2 d\omega}$

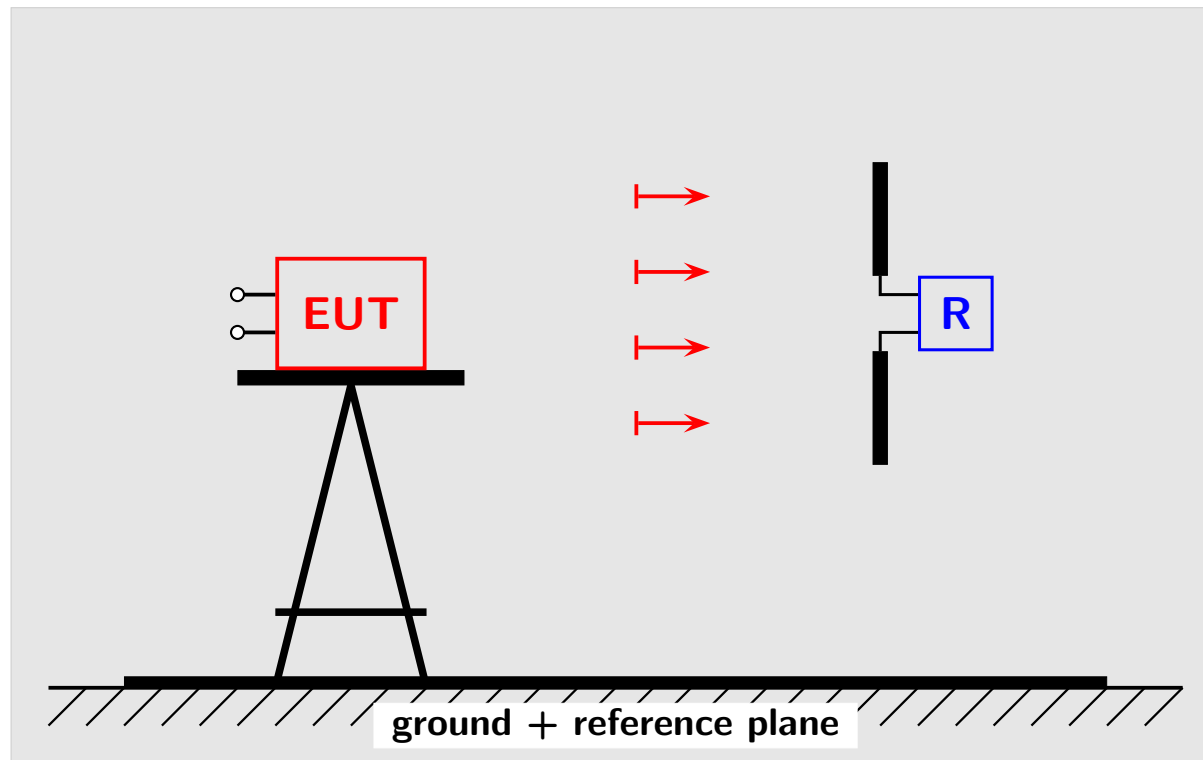
Two interfering linear, time-invariant, causal 1-port systems



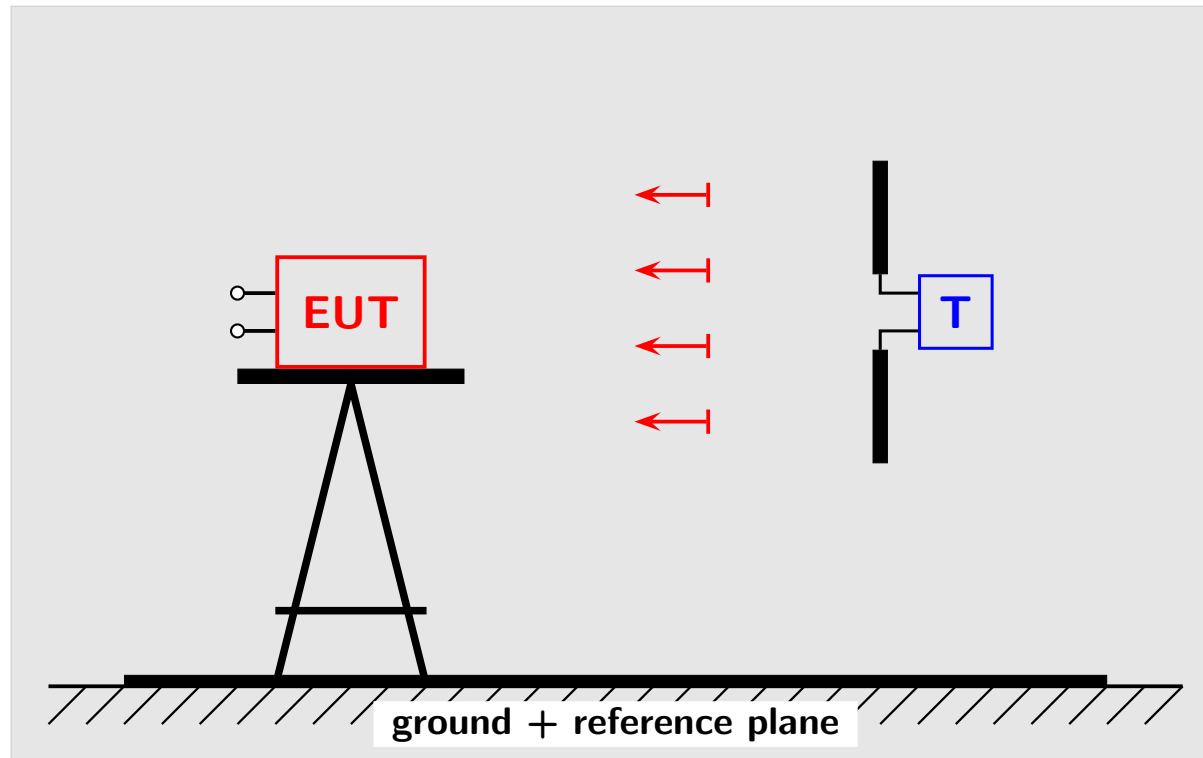
Susceptibility figure (voltage excitation):

- From $\left. \frac{\hat{I}_2}{\hat{I}_1} \right|_{\hat{V}_1 \neq 0}$ **(1) → (2)** $\implies \frac{\int_{t=0}^{\infty} |\mathbf{Y}_{2,1}(t)|^2 dt}{\int_{t=0}^{\infty} |\mathbf{Y}_{1,1}(t)|^2 dt}$ $\stackrel{\text{(Parseval)}}{=} \frac{\frac{1}{2\pi} \int_{\omega=-\infty}^{\infty} |\hat{\mathbf{Y}}_{2,1}(j\omega)|^2 d\omega}{\frac{1}{2\pi} \int_{\omega=-\infty}^{\infty} |\hat{\mathbf{Y}}_{1,1}(j\omega)|^2 d\omega}$
- From $\left. \frac{\hat{I}_1}{\hat{I}_2} \right|_{\hat{V}_2 \neq 0}$ **(2) → (1)** $\implies \frac{\int_{t=0}^{\infty} |\mathbf{Y}_{1,2}(t)|^2 dt}{\int_{t=0}^{\infty} |\mathbf{Y}_{2,2}(t)|^2 dt}$ $\stackrel{\text{(Parseval)}}{=} \frac{\frac{1}{2\pi} \int_{\omega=-\infty}^{\infty} |\hat{\mathbf{Y}}_{1,2}(j\omega)|^2 d\omega}{\frac{1}{2\pi} \int_{\omega=-\infty}^{\infty} |\hat{\mathbf{Y}}_{2,2}(j\omega)|^2 d\omega}$

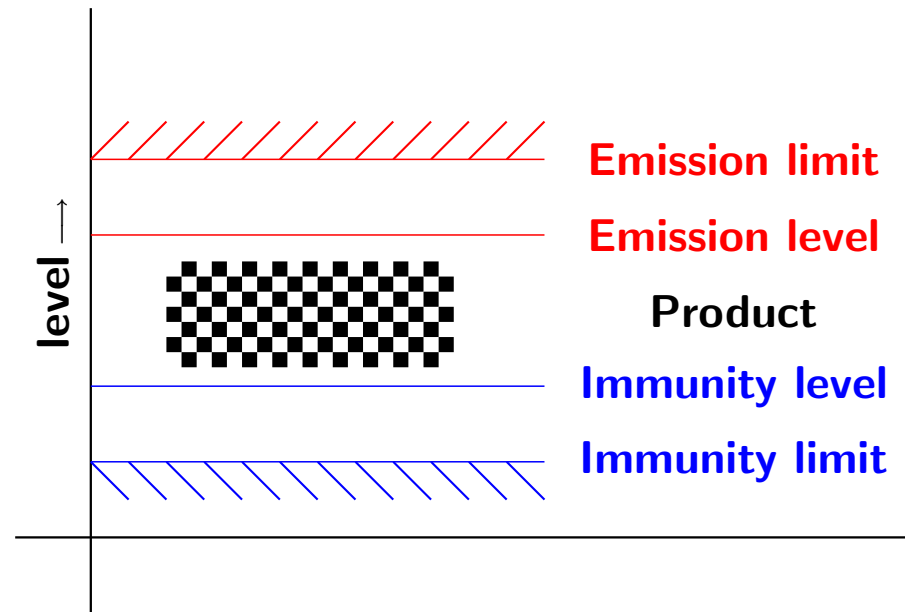
System's figure of susceptibility (voltage excitation)



- **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

Examples of industrial EMC concern

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)