Introduction to electromagnetic compatibility and interference mitigation

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Note: These are preliminary notes, intended only for distribution to participants. Beware of misprints!
Main topics for discussion

- What is electromagnetic compatibility?
- Why should we consider it?
- What are basic EMC concepts?
- What are EMC limits?
- Where to find EMC standards, etc.?
- How EMC tests look like?
The purpose of the lecture is to raise the awareness of problems that are peculiar to all electronic technologies, wired and wireless:

- Electromagnetic disturbance
- Electromagnetic immunity
- Electromagnetic interference
- Electromagnetic compatibility
Electrical systems everywhere

• There is an unprecedented proliferation of electrical devices and electronic controls in almost every aspect of human life
• “Intelligence” is being added to even the lowest-cost products due to:
  – General proliferation of electricity
  – Low price of integrated functional blocks
  – Progress in digital signal processing
We depend on electronics…

• Life of individuals and functioning of the society is increasingly dependent on errorless functioning of numerous systems:
  – Emergency telecommunication systems
  – Air, maritime, land transportation systems,…
  – Safety systems, etc., etc, …
• Most of such critical systems are controlled by electronic sub-systems
  – Hardware and software
Side effect

• Whilst electronic controls and "intelligence" bring many benefits, they also suffer from peculiar performance/reliability problems

• EM interference is one of major problems related to performance/reliability, common to all electronic technologies
Electromagnetic Interference (EMI) = any electromagnetic disturbance that interrupts, obstructs, or otherwise degrades the equipment performances.

– It can be induced unintentionally, as a result of spurious emissions, vulnerabilities, etc.
– It can also be induced intentionally, as in some forms of electronic warfare.

» Synonym: RFI, Radio Frequency Interference
» [T1 Telecom Glossary 2000, Radio Regulations 2000]
EMI-provoked avalanche

- EMI is able to cause malfunctioning of any electronic system component, especially *integrated circuits*
- A malfunctioning component can disrupt the operation of the whole system
- Such a disruption in safety-related applications can provoke an accident or catastrophe
The issue is not just academic

- The functioning of numerous industrial plants and large systems (e.g. air, maritime and land navigation, communication, regional/national electricity supply) depends critically on errorless operation of electronic systems that are EMI susceptible

- The EMI/EMC problems have been ‘discovered’ first in military applications (1950’s) and have increased since
Legal consequences

• A user, operator, owner, manufacturer, and provider of an apparatus that caused material losses or other harm to a third party due to EMI may be prosecuted.
Examples

• A lot of publicity was given to electronic pacemakers, aircraft navigational control systems, or ABS car-braking systems, but it is only a ‘tip of iceberg’.

• At a previous lecture, I presented a number of real-life examples taken from open literature (1970-2003) and from personal experience of my colleagues and me.

• It was pointed out that users experiencing equipment performance degradation often do not suspect EMI as a cause, and a number of EMI problems are not registered.
EMI-related threats

• Many EMC-related malfunctions, incidents, and potential incidents are known, especially to EMC consultants, but they are bound by confidentiality agreements and so these do not get reported.

• It is suggested that the actual rate of EMC-related malfunctions exceeds those reported in the press by several thousand-fold or so.

• An increasing number of these will have safety implications as electronic technologies become more widely used in safety-related systems.
EMI threat data

• Neither equipment makers nor plant owners and directors are keen to report on their EMI problems because of competition and because it could be used in possible legal proceedings.

• Thus, equipment/system data on disturbance emissions and on immunity vulnerabilities are often kept confidential.

• Possible use of that data by terrorists give additional reason to keep them secret.
EMI threat assessment

- As no publicly available statistics exists on the number and consequences of EMI incidents, EMI-related threats can be assessed only basing on
  - Indirect evidence
  - Relevant recommendations and standards
  - Case-by-case analyses
EMC recommendations

• Most countries follow the relevant regulations, standards, recommendations, and reports of major international organizations:
  – *The ITU*: regulations, recommendations, handbooks and reports on telecommunication equipment of all kind, including radio ([www.itu.int](http://www.itu.int))
  – *The IEC*: standards and publications on electrical and electronic equipment, including low-voltage power network equipment ([www.iec.ch/zone/emc](http://www.iec.ch/zone/emc))
  – *The WHO*: health issues related to EM energy ([www.who.int/health_topics/electromagnetic_fields/en](http://www.who.int/health_topics/electromagnetic_fields/en))
Warning

- EMC standards **should not** be relied on totally.
  - Actual EMI effects depend on specific situation, current EM environment, and actual degree of coupling. These may differ significantly from those assumed in the standard.
  - Actual EM environment is subject to change (temporary or permanently) due to equipment movement, installation modifications, etc.
  - In safety-related and other critical applications, even temporary degradation of performance or loss of function may not be acceptable.
EMC definition

• Electromagnetic compatibility (EMC): ability of an equipment or system to function satisfactorily without introducing intolerable electromagnetic disturbance to anything in that environment

• Criteria of ‘satisfactory’, and ‘intolerable’ and the definition of ‘anything’ and “environment” are all situation dependent
EMI depends on what?

• Given interference criteria, it depends on
  – System emissions (energy radiated by source)
  – System immunity (ability of a system to perform without degradation in the presence of EM disturbance). [Telecomm Glossary 2000]
  – Coupling between the interference source and victim system

References:
Any electrical/ electronic apparatus emits EM energy

• If that energy (disturbance) exceeds some safe level:
  – it can interfere with the operation of other devices, degrade it, or disrupt it completely.
  – It may be harmful to living organisms.
• The victim may be the user of the apparatus and/or a third party.
Any electrical/electronic apparatus reacts to EM stimuli.

- If the reaction of an apparatus to external EM stimuli (disturbances) exceeds some safe level, it can interfere with the correct operation of the apparatus, degrade it, or disrupt it completely.
- The victim may be the user of the device and/or a third party.
# Principal EM phenomena

**Conducted low-frequency phenomena**
- Voltage dips and interruptions
- Harmonics
- Voltage fluctuations
- Voltage unbalance
- DC in AC networks
- Power-frequency variations
- Signaling voltages
- Induced low-frequency voltages

**Conducted high-frequency phenomena**
- Induced CW voltages or currents
- Unidirectional transients
- Oscillatory transients

**Radiated high-frequency phenomena**
- Magnetic fields
- Electric fields
- Electromagnetic fields
  - Continuous waves
  - Transients

**Radiated low-frequency phenomena**
- Magnetic fields
- Electric fields

**Electrostatic discharge phenomena (ESD)**

**High altitude nuclear electromagnetic pulse (HEMP)**
EM interactions

- Variability
- Probability
Black-Box approach

The apparatus interacts with its electromagnetic environment through a number of physical ‘ports’.
Each port can transport energy in both directions using various EM phenomena and various transport modes.
Ways to EMC

• Decrease emissions from sources
  – Legal means: impose emission limits
  – Technical means: apply EMI filters and shields

• Increase immunity of victim systems
  – Legal means: impose immunity limits
  – Technical means:
    » Apply EMI filters and shields
    » Apply robust signal processing methods

• Reduce coupling between the interference sources and victims systems
  – Legal means: introduce zones
  – Technical means: separate sources and victims in time, geometrical space, and signal space
EMC limits

- **Emission limits**: the maximum disturbance levels which the equipment is allowed to produce
- **Immunity limits**: the minimum disturbance levels which the equipment should withstand without its operation being unacceptably degraded
- Standard ‘average’ conditions and performance criteria are assumed
- Verifying these limits may require special EM energy sources, applicators, etc. (expensive!)
Coupling reduction

• Conductive coupling (various modes)
  – EMI filters & optical couplers
• M-Field (magnetic or inductive) coupling
  – Distance & magnetic shields
• E-Field (Electric or capacitive) coupling
  – Distance & electric shields
• EM-Field Coupling
  – Distance & electromagnetic shields
Mitigating harmful interference

- Harmful interference - when the risk (probability) of interference and extent of its consequences exceed the acceptable levels
- To mitigate interference, the acceptable limits for emissions, immunity, and coupling must be observed during the operation
- These must be observed during the entire life-cycle (design, make, install, upgrade and maintain phases) of the system and verified using appropriate test methods for each port and EM phenomenon
EMC control

• In critical cases the following should be considered:
  – What EM disturbances might my apparatus be exposed to now and in the foreseeable future?
  – What are the foreseeable effects of these disturbances on my apparatus/ system?
  – What EM disturbances my apparatus emits and how these could affect other apparatuses (existing or planned)?
  – What are the foreseeable implications of these disturbances (safety level required, severity of the hazard, scale of the risk)?
  – What level of confidence (tests? verification? proof? specification? documentation? ) is required that the above have been fully considered and necessary actions taken to achieve the desired level of safety?
• When installing new equipment ensure that it will be compatible with the existing and planned equipment.
• Maintenance procedures should also consider EMC.
  – In particular, the use of mobile radiocommunications close to equipment which has had covers removed should be controlled, particularly when equipment is being maintained ‘on-line’.
• Software changes and upgrades in critical electronic equipment can also negatively affect EMC and hence functional safety, so these should be treated as for hardware maintenance.
• Ensure appropriate test/validation after installation, maintenance, modification, upgrade, and refurbishment.
Trends

• Miniaturisation, integration, and increasing complexity, all make electronic systems and components more vulnerable to electrical influences.

• Newer electronic devices (silicon chips) tend to be more susceptible to EM disturbance than the devices they replace.

• The proliferation of electronic/ electrical apparatuses (wired and wireless) brings the sources and victims of disturbance closer together and increases the interference potential
Safety issues

• Safety = the freedom from unacceptable risks that are harmful to an individual, a group, or the public.

• Many safety-related systems use electronic components and sub-systems that are vulnerable to EMI

• Consequences of EMI in safety-related systems may be catastrophic, involving economic, legal, and social factors, in addition to technical ones.
EMC concerns all of us

• The aim of EMC is
  – to ensure the reliability of all types of electronic devices wherever they are used
  – and thus to ensure the reliable and safe operation of the systems in which they are employed.
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- International Telecommunication Union (www.itu.int)
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EMC tests

Courtesy of Rohde & Schwarz
EMC tests
EMC tests
Test antennas

Courtesy of Rohde & Schwarz
Test antennas

Courtesy of Rohde & Schwarz
Tests from the air
Flying laboratory (1)
Flying laboratory (2)
What we have learned

• What is electromagnetic compatibility and why should we consider it
• What are basic EMC concepts and what are EMC limits
• Where to find more information on EMC standards, recommendations, etc.
• How EMC tests looks like
Any questions?

Thank you for your attention
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