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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?

Purpose

- 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)
  - ***The IEC***: standards and publications on electrical and electronic equipment, including low-voltage power network equipment (www.iec.ch/zone/emc)
  - ***The WHO***: health issues related to EM energy 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) Fritsch C A: Radiative Heat Transfer; Physical Design of Electronic Systems, Vol. I Design Technology, Prentice-Hall1970, p. 259-286
  - 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 Buus R G: Electrical Interference; Physical Design of Electronic Systems, Vol. I Prentice-Hall1970, p. 381-438

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

Radiated low-frequency phenomena

* Magnetic fields
* Electric fields

Conducted high-frequency phenomena

* Induced CW voltages or currents
* Unidirectional transients
* Oscillatory transients

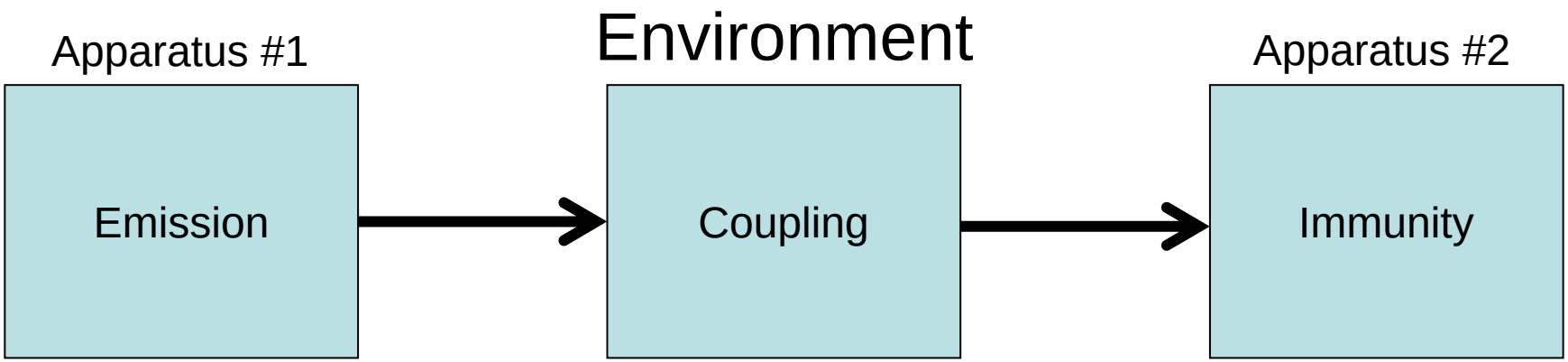
Radiated high-frequency phenomena

* Magnetic fields
* Electric fields
* Electromagnetic fields
  - Continuous waves
  - Transients

Electrostatic discharge phenomena (ESD)

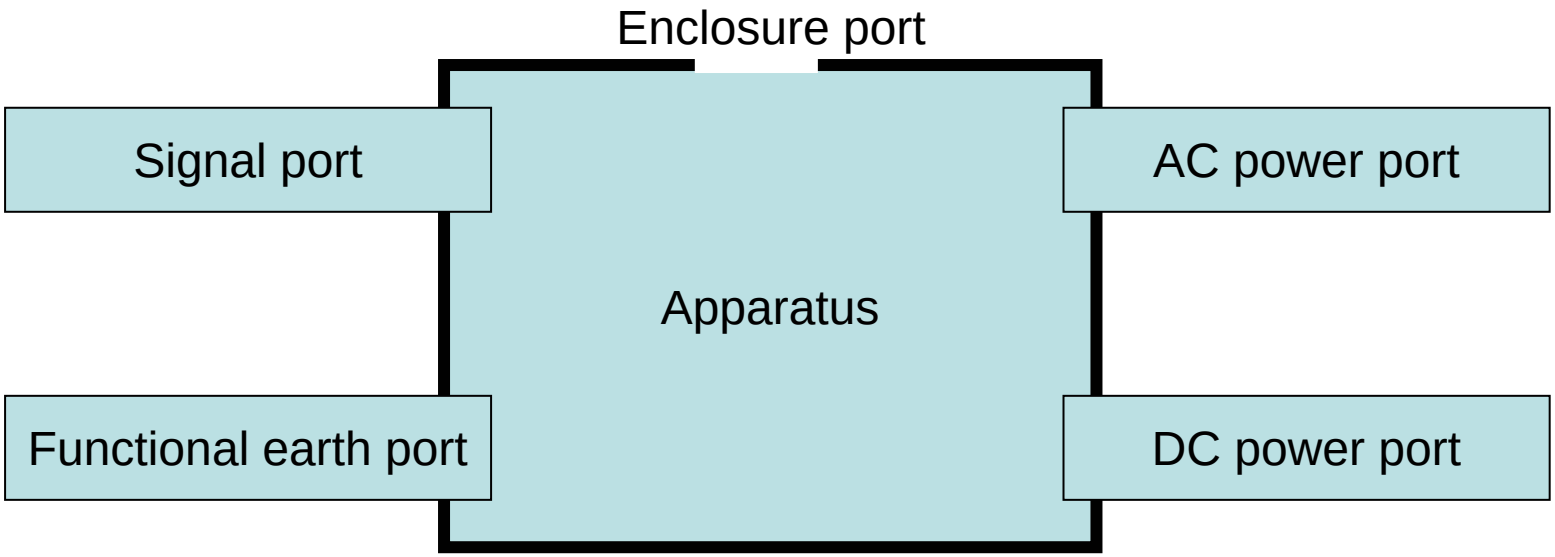
High altitude nuclear electromagnetic pulse (HEMP)

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?

Maintenance

- 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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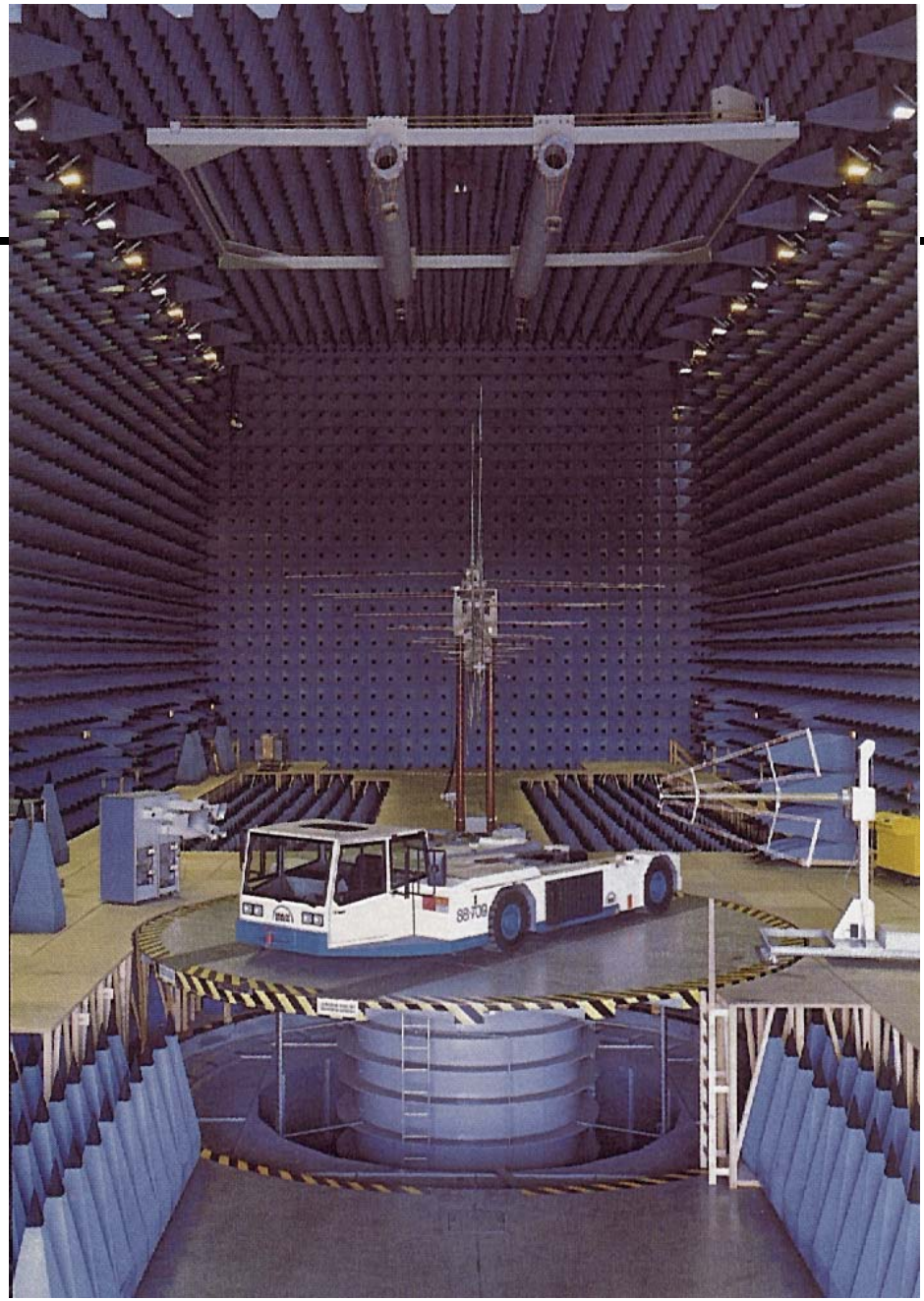
EMC tests

Courtesy of Rohde & Schwarz

EMC tests



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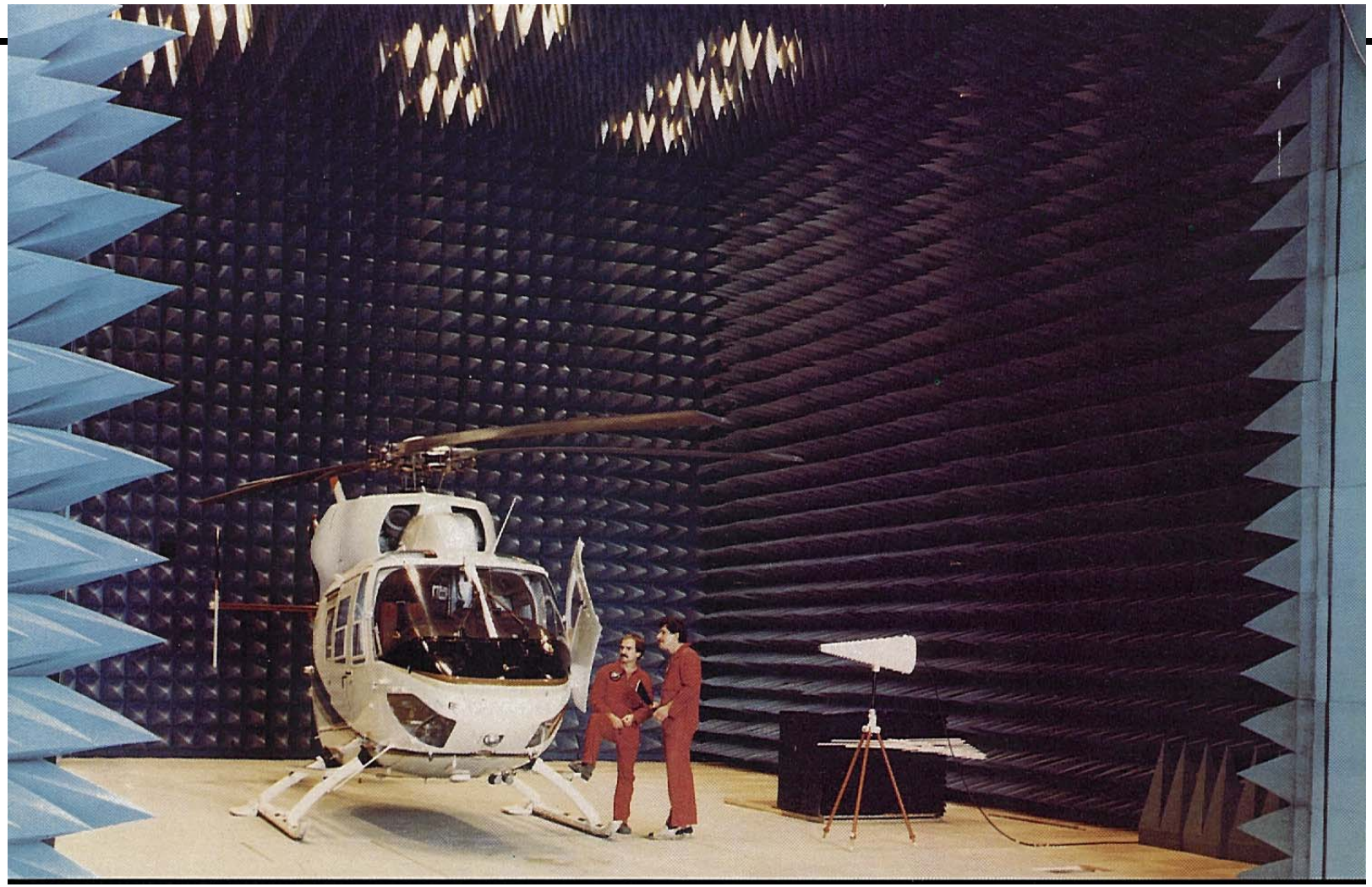

Courtesy of Rohde & Schwarz

Test antennas

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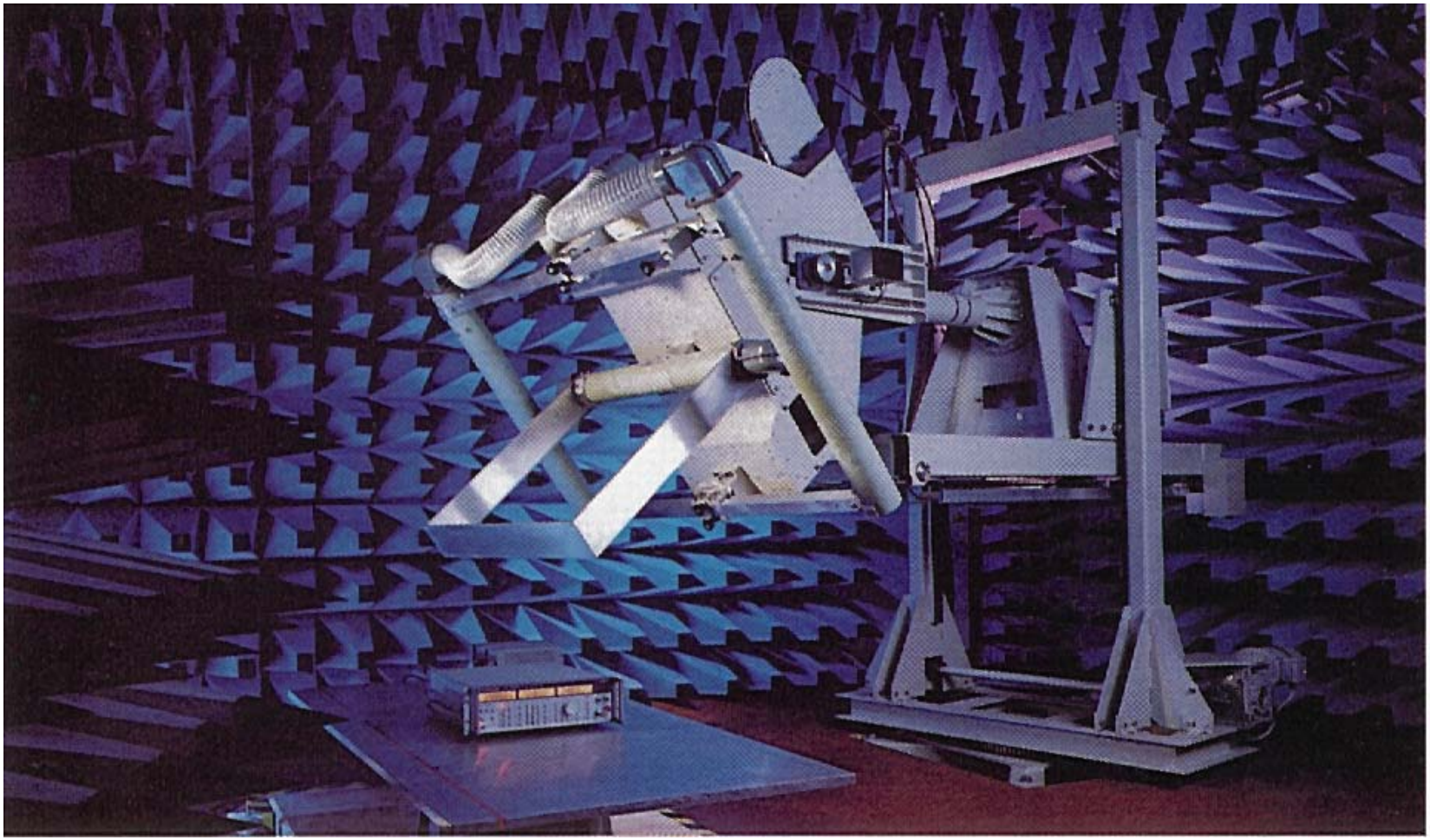
Test antennas



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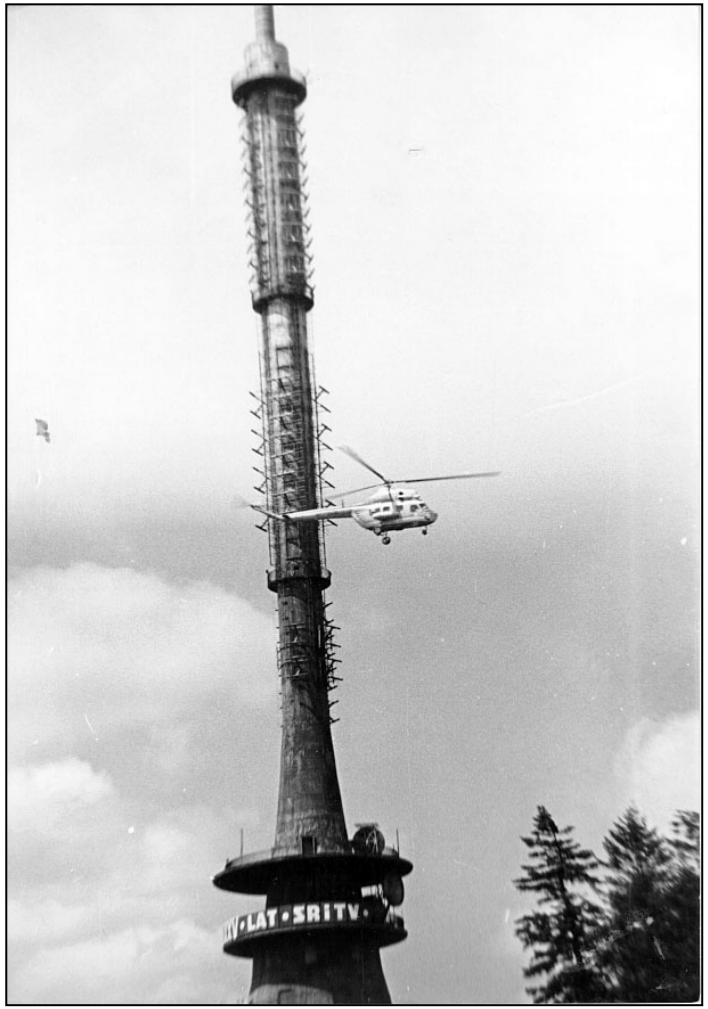
Tests from the air



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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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