

Co-existence: introduction to electromagnetic compatibility

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Note: These are preliminary notes, intended only for
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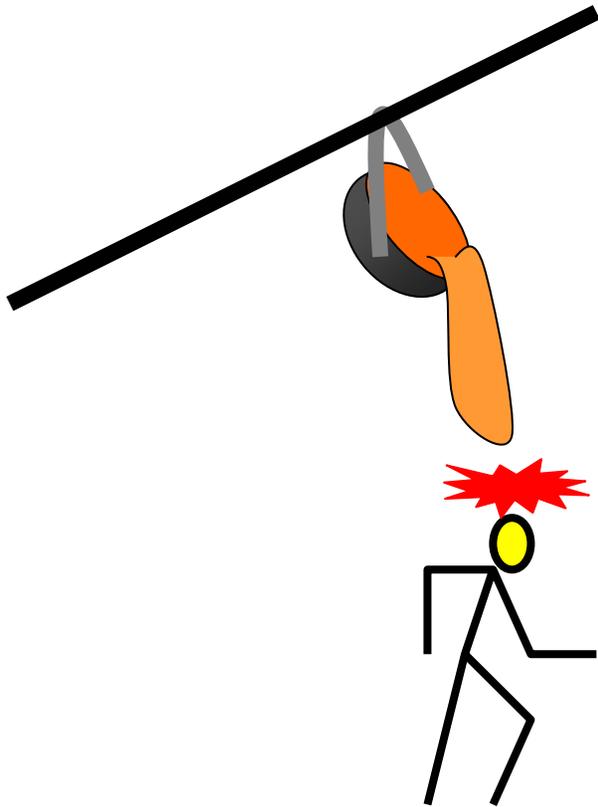
Purpose

- The purpose of the lecture is to raise the awareness of electromagnetic compatibility (EMC) or 'co-existence' problems of electronic devices

What will we discuss?

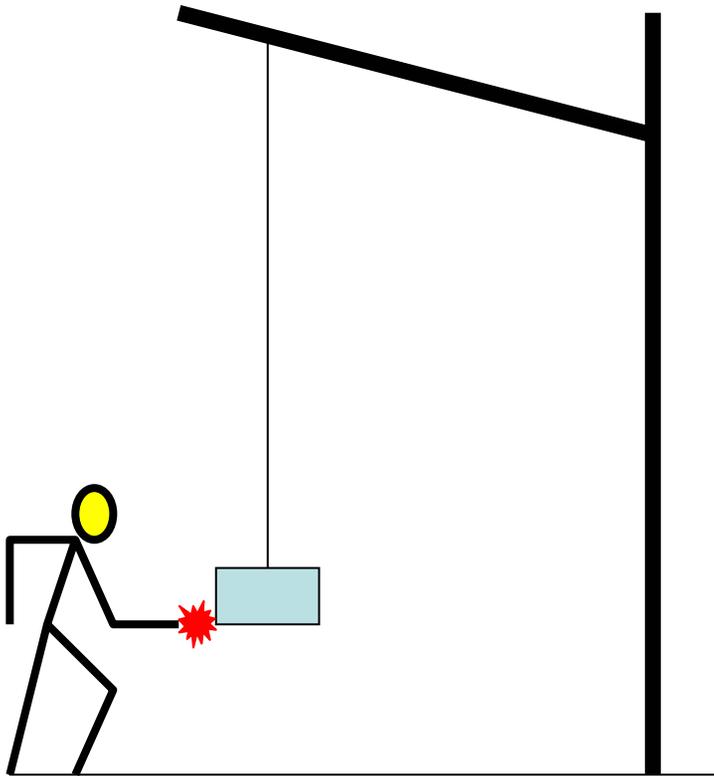
- Some real-life examples
- What are the basic EMC concepts?
- Where to find EMC standards?
- How EMC tests look like?

Accident at Foundry Plant



- A foundry worker died when the radio-controlled overhead transporter thought out a few tons of liquid metal on him.
- Cause: an accidental signal from a radio transmitter was interpreted by the automatic system as the legitimate order to get rid of the load.

Burning Crane



- A building worker was burned when touching the load of a crane installed for building operations.
- Cause: an electric arc due to the RF current induced in the metallic structure by a nearby broadcasting transmitter

ABS Failure

- Early Antilock Braking Systems (ABS) systems on both aircraft and automobiles were susceptible to electromagnetic interference.
- Accidents occurred when the brakes functioned improperly because EMI disrupted the ABS control system.





- During the early years of ABS's, some automobiles equipped with ABS had severe braking problems along a certain stretch of the German autobahn. The brakes were affected by near-by radio transmitters. The near term solution was to erect a mesh screen along the roadway to attenuate the EM field strength. (Source: NASA Reference Publication 1374 July 1995)

"Black hole" in railway system



- An automatic registration system of rail wagons passing checkpoints indicated that wagons enter into some region, but never go out of it; it was as a black hole were there.
- Cause: radiation from a high-power radar station newly-constructed near the checkpoint burned out electronic components installed on the wagons
 - » (Source: private communication from a NTIA source)

Aircraft Passenger Carry-On Devices

- Passenger carry-on devices provide a separate group of case histories. They show the susceptibility of modern electronic systems aboard aircraft to EMI from seemingly innocuous electronic devices, such as portable computers, AM-FM "walkman" cassette players, dictaphones, radios, heart monitors, and cellular phones.
- NASA maintains a database (ASRS - Aviation Safety Reporting System) - a compilation of voluntary reports detailing safety problems submitted by pilots. These reports are, for the most part, anonymous with non-specific aircraft models and unidentified operating companies.
- During the period 1986 - 1995, the database registered in average 5200 reports a year. (Source: NASA Reference Publication 1374 July 1995)

Runaway Wheelchairs



- Some powered-wheelchairs experienced erratic, unintentional movements when police, fire, or CB transmitters were activated nearby.
- These movements included sudden starts that caused wheelchairs to drive off curbs or piers . Although no fatal injuries have been reported, FDA has ordered manufacturers of motorized wheelchairs to shield them from EMI and to educate users on the potential EMI hazards. (Source: NASA Reference Publication 1374 July 1995)

Ambulance Heart Monitor



- Susceptibility of medical equipment to conducted or radiated emission is a concern.

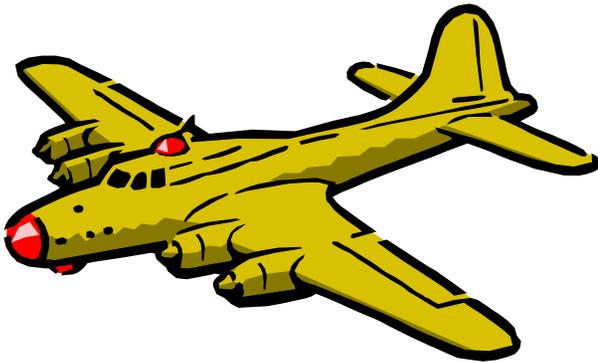
Case: a heart attack victim was being taken to the hospital with a monitor/ defibrillator attached to the patient. But, every time the personnel turned on the radio to request medical advice, the machine shut down and the patient died.

Cause: the combination of insufficient immunity of monitor/ defibrillator and excessive RF field strength from the radio (the ambulance roof had been changed from metal to fibreglass). (Source: NASA Reference Publication 1374 July 1995)

Crosstalk mobile - fixed phones

- Antennas of a base station of mobile system were installed at the top of high building in the city centre. After putting the mobile system into operation, all conversations of the mobile users could be heard at every telephone connected to the old fixed telephone installation. Investigations showed that the reason was the coupling between the antennas and the wired telephone installation and nonlinearities in electronic devices.

B-52 Stability Case



- When electronic flight-control systems were first added to the B-52 bomber autopilot system, uncommanded activation of rear flight control surfaces was experienced when the HF radio was activated on the board
- Cause: spurious HF radio signals induced in the wiring system.
 - » (Source: NASA Reference Publication 1374, July 1995)

Blackhawk Crashes



- Between 1981 and 1987, five *Blackhawk* army helicopters crashed and killed or injured all on board when flew too near radio broadcast transmitters.
- Cause: insufficient immunity of flight (on-board) control electronic sub-system against high intensity radiated fields (HIRF) that produced uncommanded movements while flying past radio broadcast towers. (Source: NASA Reference Publication 1374 July 1995)

Unintended Missile Launch

- During a B-52 missile interface unit test, an uncommanded missile launch signal took place. One of the contributing factors was crosstalk in the systems wiring. The outcome was a yearlong redesign and test effort.

» (Source: NASA Reference Publication 1374, July 1995)

Pioneer Crash

- Pioneer is the name of a remotely piloted vehicle (RPV) using a portable remote control box. During its flight tests performed by the US Navy in January 1987 aboard the U.S.S. Iowa, the pilot experienced a series of uncommanded manoeuvres that caused loss of control and a crash landing. Subsequent investigation found that the remote control boxes received false signals from HF communication transmitting antennas located aboard the Iowa due to inadequate shielding and cable termination.

» (Source: NASA Reference Publication 1374, July 1995)

Sheffield Catastrophe

- The British Ship *Sheffield* had the most sophisticated antimissile defence system available. Despite that fact, during the Falklands War (1982), it was hit by an Exocet missile and sank with heavy casualties. It was possible because the antimissile system created electromagnetic interference to radio communication system of Sheffield's *Harrier* jet contingent assigned to the ship. While the *Harriers* took off and landed, the missile defence was disengaged to allow communications with the jets. This provided a 'window of opportunity' for the Exocet missile.

» (Source: NASA Reference Publication 1374 July 1995)

Severmorsk Disaster

- In mid-May 1984, a Soviet ammunition depot exploded. The cause of the accident, according to the Soviets, was an over-the-horizon radar that had illuminated the depot.
 - » (Source: NASA Reference Publication 1374 July 1995)

F-16 Flight Controls

- An F-16 fighter jet crashed in the vicinity of a Voice of America (VOA) radio transmitter because its fly-by-wire flight control system was susceptible to the radio waves transmitted. Since the F-16 is inherently unstable, the pilot must rely on the flight computer to fly the aircraft. Subsequently, many of the F-16's were modified to prevent this type EMI, caused by inadequate military specifications on that particular electronics system. This F-16 case history was one of the drivers for institution by the Federal Aviation Administration (FAA) of the certification programs.

» (Source: NASA Reference Publication 1374 July 1995)

Tornado Fighter Case

- Another case occurred in 1984 near Munich, Germany. A West German *Tornado* fighter crashed after flying too close to a powerful Voice of America transmitter.

» (Source: NASA Reference Publication 1374 July 1995)

Medical Equipment Cases

- Modern medical equipment has experienced EMI problems. From 1979 to 1993, the FDA received over 90 reports concerning EMI problems in the field. It was pointed out that users experiencing medical equipment performance degradation might not suspect EMI as a possible cause. Thus, EMI problems are more likely to be under-reported to the FDA.

» (Source: NASA Reference Publication 1374 July 1995)

Electronic Implant Activation

- An English-language journal read by over 1 million readers reported the following story. A pastor in San Francisco wanting to cure his impotence was trying an experimental electronic penis implant, which produced erection at the touch of a button. However, in addition to the intended erections, the man experienced also random ones. Investigations revealed that the cause was insufficient immunity to signals from a radio-steered garage-door opener. Every time his next-door neighbour used the opener, the pastor had an erection. He commented: "It's bad enough when I'm pottering around the back yard, but it gets really mortifying when I'm delivering my Sunday sermon."
– (Source: Europa Times No.22, March 1995)

Hearing Aids

- Millions of pensioners using a hearing-aid device were forced to endure 24-hour rap and rock music from the 41 powerful radio transmitters of 'Ailing Radio 1' network in the UK. It was caused by a flaw in the device that acted as unintended radio receiver, in addition to its intended function.

» (Source: Europa Times No.22, March 1995)

- Publicity was given to electronic pacemakers, or aircraft and air traffic navigational control systems, but it is only a 'tip of iceberg'.
 - It was pointed out by many researchers that users experiencing equipment performance degradation often do not suspect EMI as a cause, and thus a number of EMI problems are never registered.

Outline

- Some real-life examples
- **What are the basic EMC concepts?**
- Where to find EMC standards?
- How EMC tests look like?

EMC: what is it?

- Electromagnetic compatibility (EMC): ability of an equipment or system to
 - (1) function satisfactorily in its EM environment
 - (2) without introducing intolerable disturbance to anything in that environment
 - Criteria of '*satisfactory*', and '*intolerable*' and the definition of '*anything*' and "*environment*" are all situation-dependent
 - Harmful (intolerable) interference - when the risk (probability) of interference and extent of its consequences exceed the acceptable levels

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-system hardware and/ or software

- Whilst electronic controls ("intelligence") bring many benefits, they also suffer from peculiar performance/ reliability problems
- EM interference is one of major problems related to performance and 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 or terror

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

Trends

- Integration, and increasing complexity make electronic systems and components more vulnerable to electrical influences.
 - New silicon chips tend to be more susceptible to EM disturbance than the devices they replace.
- Miniaturisation and proliferation of electronic/ electrical apparatuses (wired and wireless) brings the sources and victims of disturbance closer together, which increases the interference potential

EMI-provoked 'avalanche'

- EMI is able to cause malfunctioning of any electronic system component, especially of integrated circuits
- A malfunctioning component can disrupt the operation of a subsystem or system
- Such a disruption in safety-related applications can provoke an accident or catastrophe

Safety-related systems

- Many safety-related systems use electronic components and sub-systems that are vulnerable to EMI
 - Safety = the freedom from unacceptable risks that are harmful to an individual, a group, or the public.
- Consequences of EMI in safety-related systems may be catastrophic

The issue is not just academic

- The functioning of numerous industrial plants, communication and transportation systems, and the electricity supply of whole regions depends critically on errorless operation of electronic systems that are EMI susceptible
 - The EMI/EMC problems have been ‘discovered’ first in military applications in 1950’s and now are more and more being suffered in civilian applications too

Legal consequences

- A manufacturer, provider, owner, user, or operator of an apparatus that caused death, injury, material losses, or other harm to a third party may be prosecuted
 - Example: To prevent EMI-provoked losses, it is illegal to introduce on the European market any device that could produce unacceptable EMI – see the EMC Directive and the RTTE Directive:
http://europa.eu.int/comm/enterprise/electr_equipment/emc/guides/english.pdf;
http://europa.eu.int/eur-lex/pri/en/oj/dat/1999/l_091/l_09119990407en00100028.pdf

EMI-related threats

- Many EMC-related malfunctions, incidents, and potential incidents are known, especially to EMC consultants, but consultants are usually 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 malfunctions 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
 - As a consequence, equipment/ system data on disturbance emissions and on immunity vulnerabilities are most often kept confidential
 - Possible use of that data by terrorists give additional (false) justification of keep the EMC-related data secret

EMI threat assessment

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

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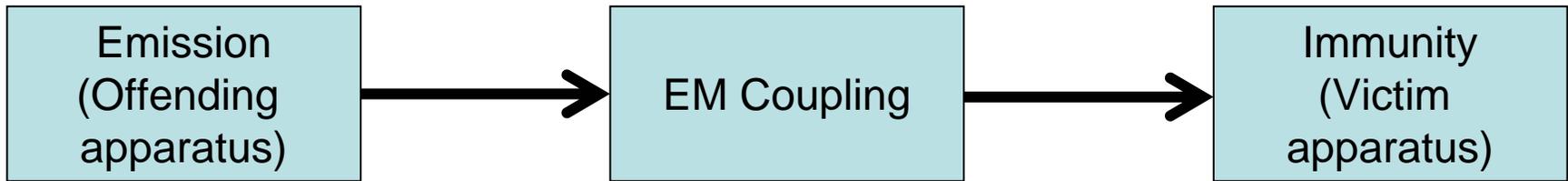
EMC-related recommendations

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

Warning

- EMC recommendations and standards should not be followed without full understanding
 - Actual EMI effects depend on specific situation, current EM environment, and actual coupling. These may differ significantly from those assumed in a recommendation or 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.

EMI depends on what?



Given interference criteria, EMI effects depend on

1. System emissions
2. System immunity
3. Degree of coupling

Fritsch C A: Radiative Heat Transfer; Physical Design of Electronic Systems, Vol. I Design Technology, Prentice-Hall1970, p. 259-286; ;
Buus R G: Electrical Interference; Physical Design of Electronic Systems, Vol. I Prentice-Hall1970, p. 381-438; Telecomm Glossary 2000

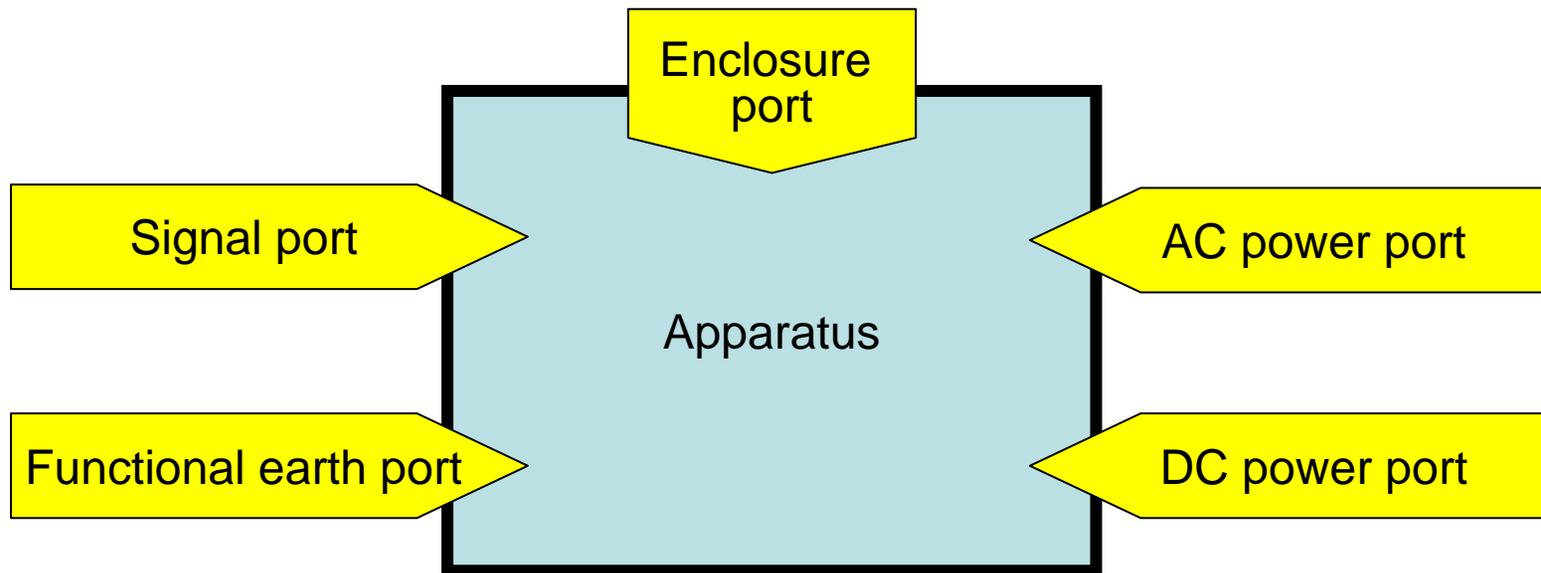
Emission

- 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.

Immunity

- Any electrical/ electronic apparatus reacts to external EM stimuli (disturbances)
 - If the reaction exceeds some safe level, it can disturb 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.

Coupling (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

Principal EM phenomena

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

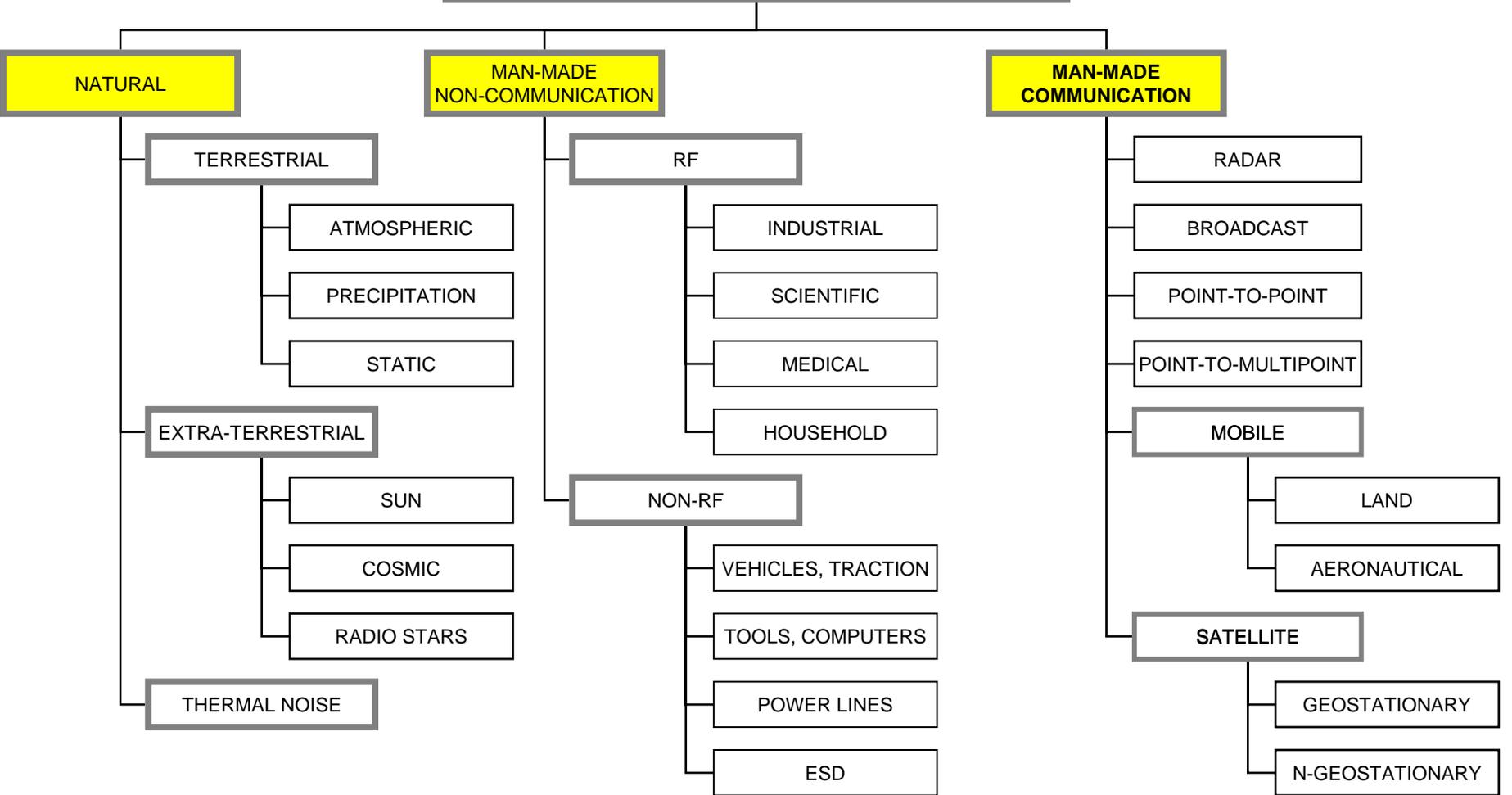
How to assure EMC?

- To mitigate interference, the acceptable limits for emissions, immunity, and coupling must be observed when systems/ devices operate
- 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
 - Note: Beware of parameter variability and influence of the environment

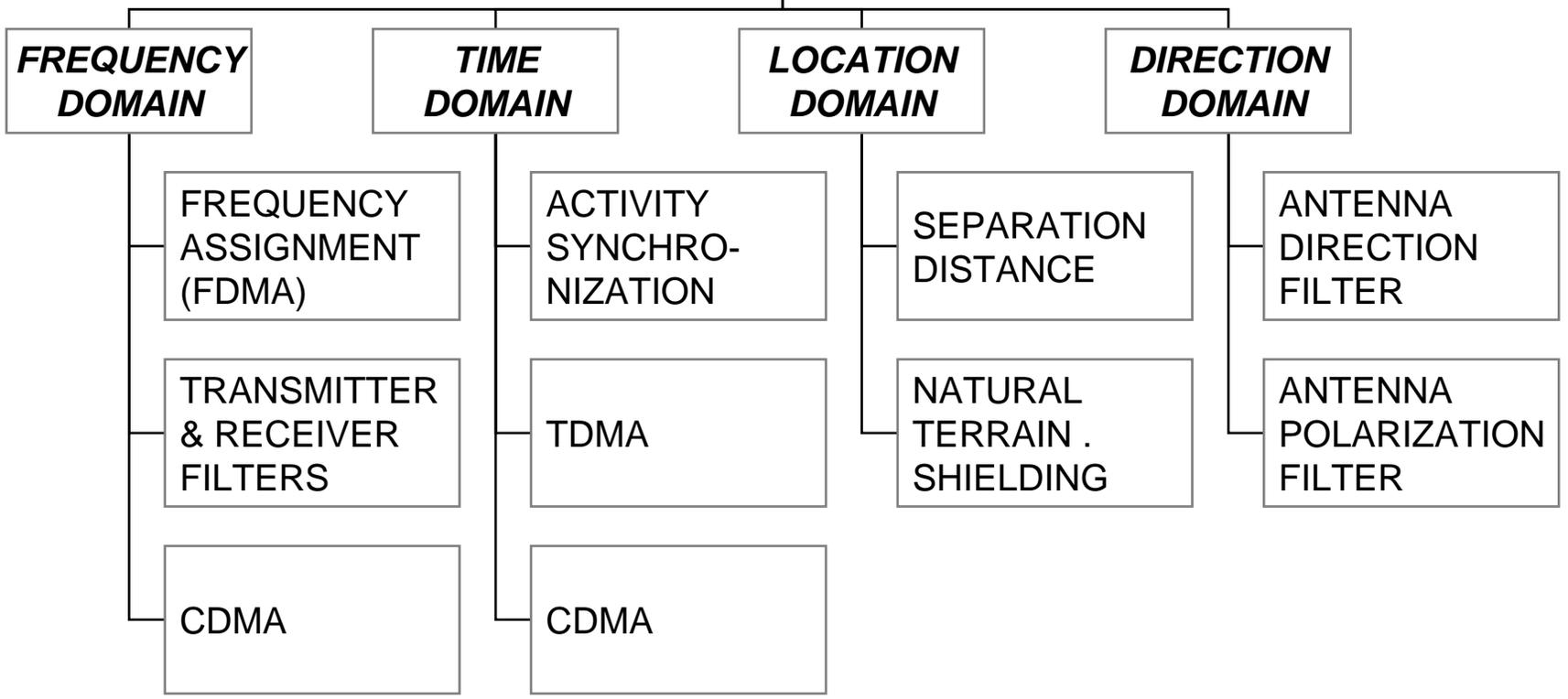
EMC limits

- *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
 - Different classes of EM environmental stress
 - Standard ‘average’ conditions and performance criteria, or ‘worst-case’ are to be distinguished
 - Verifying these limits may require special (expensive!) EMC test equipment

EM ENVIRONMENT COMPONENTS



EMC CONTROL



EM coupling reduction

- Conductive coupling (various modes)
 - EMI filters & optical couplers to mitigate
- M-Field (magnetic or inductive) coupling
 - Distance & magnetic shields to mitigate
- E-Field (Electric or capacitive) coupling
 - Distance & electric shields to mitigate
- EM-Field Coupling
 - Distance & electromagnetic shields to mitigate

- 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 system?
 - What EM disturbances my apparatus emits and how these could affect other systems (existing or planned)?
 - What are the foreseeable implications of these disturbances (scale of the risk, severity of the hazard)?
 - 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?

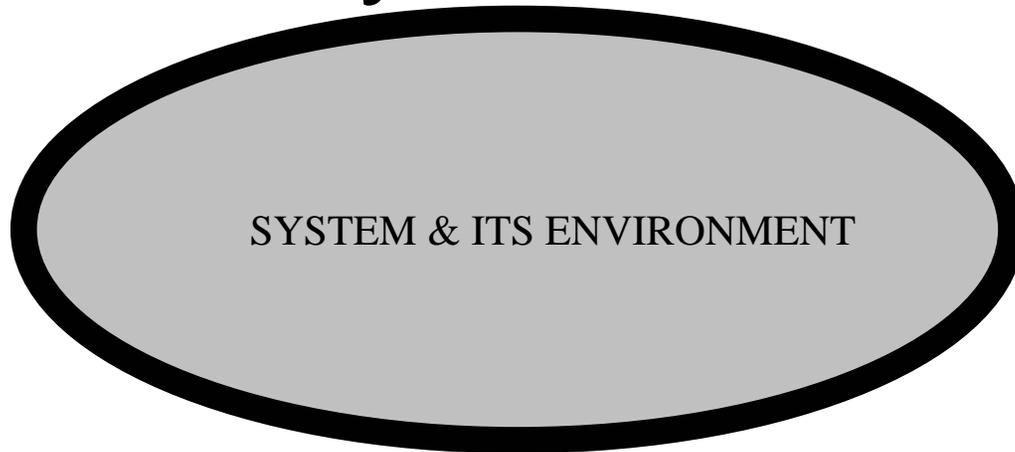
Maintenance

- 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.

What will we discuss?

- Some real-life examples
- What are the basic EMC concepts?
- Where to find EMC standards?
- **How EMC tests look like?**

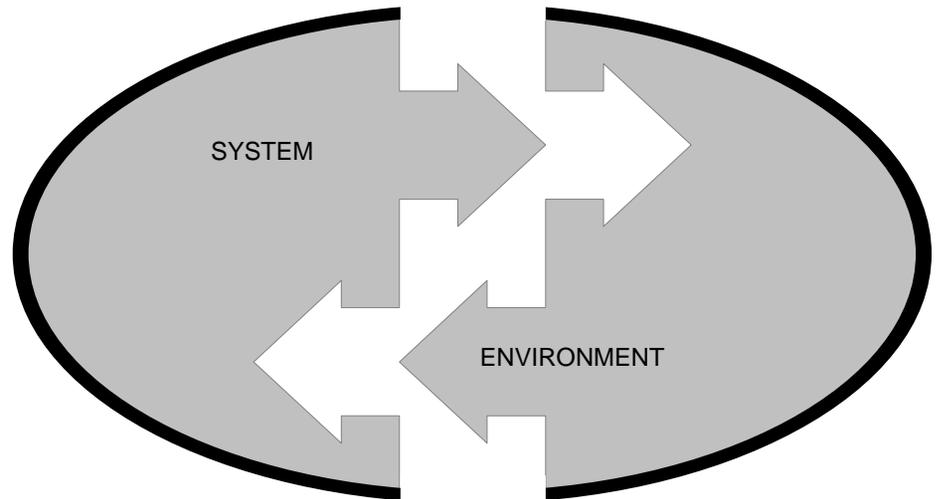
System & Environment

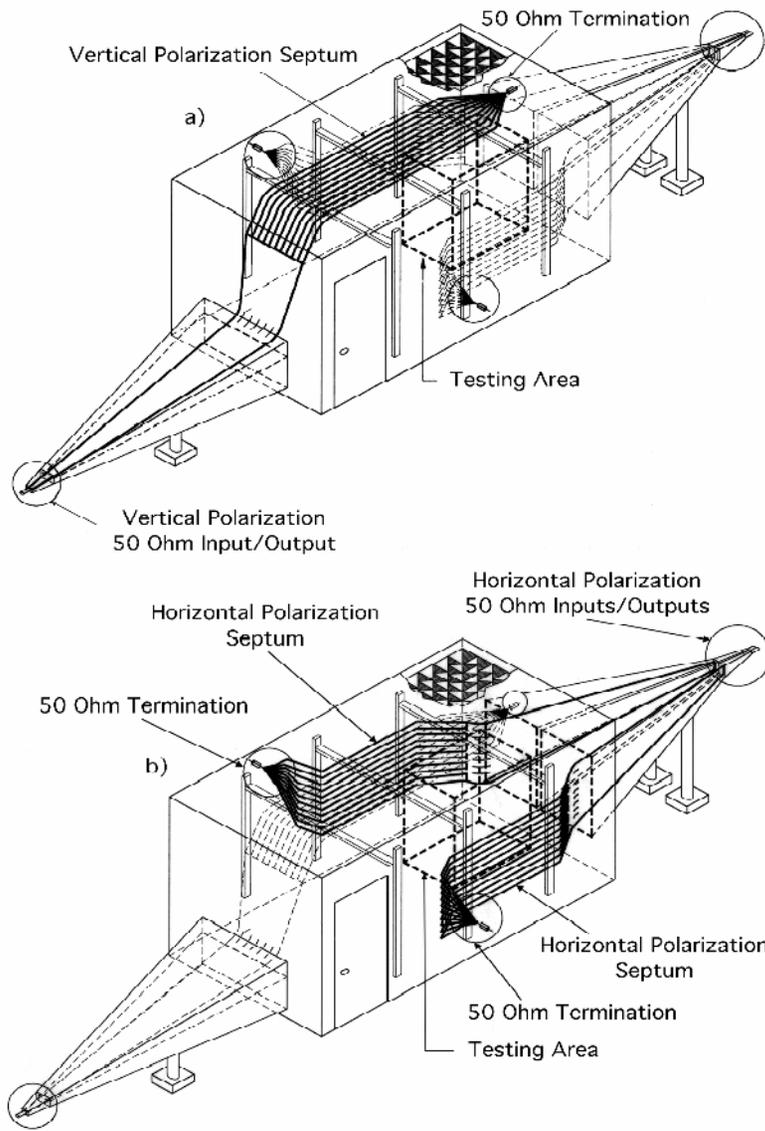


For tests we separate the system from its environment.

In emission testing we replace the environment by test equipment that evaluate the level of emissions.

In immunity tests we create a known EM stress and observe reactions.

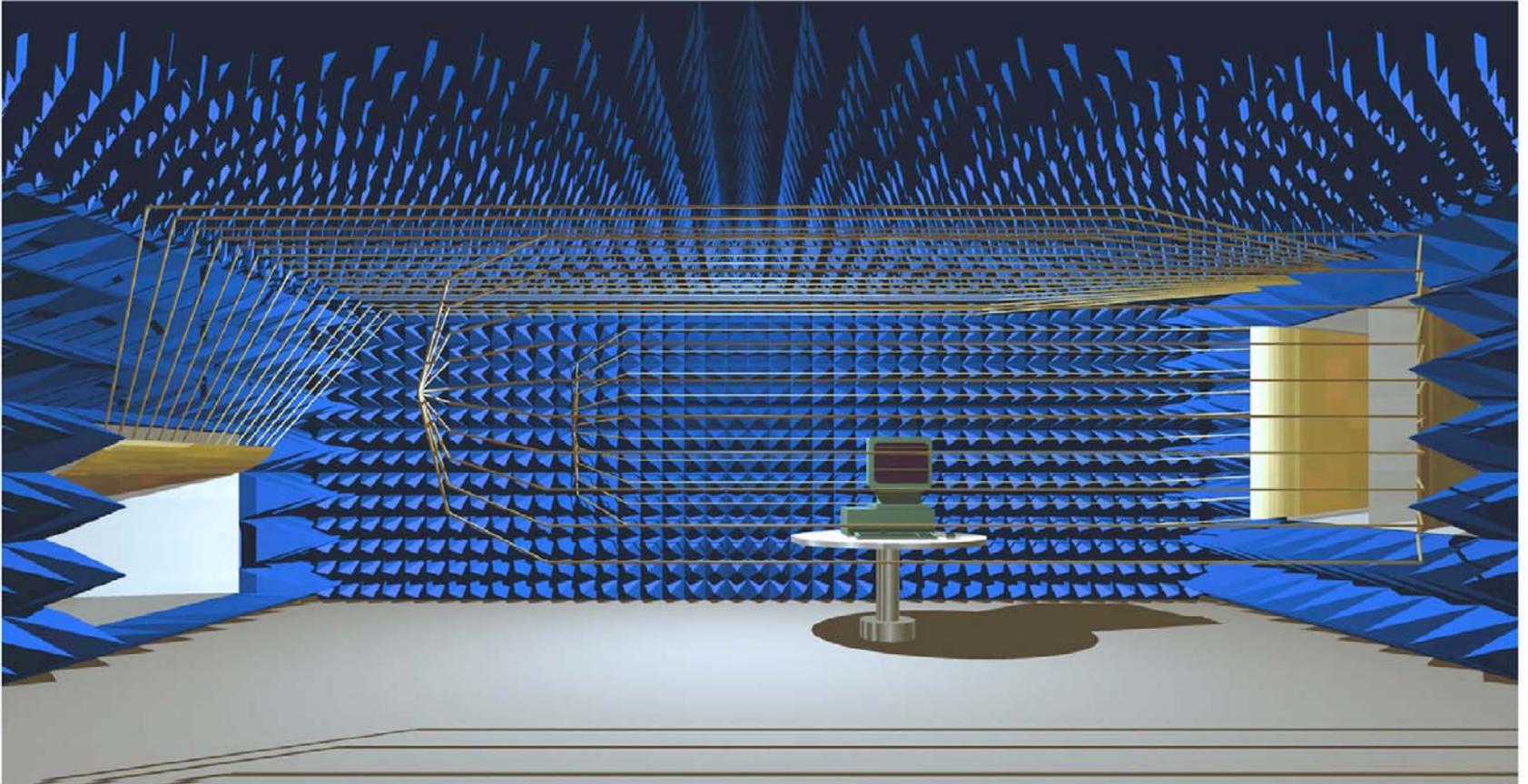




Source: A Podgorski

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TEM cell



Source: A Podgorski

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Test room



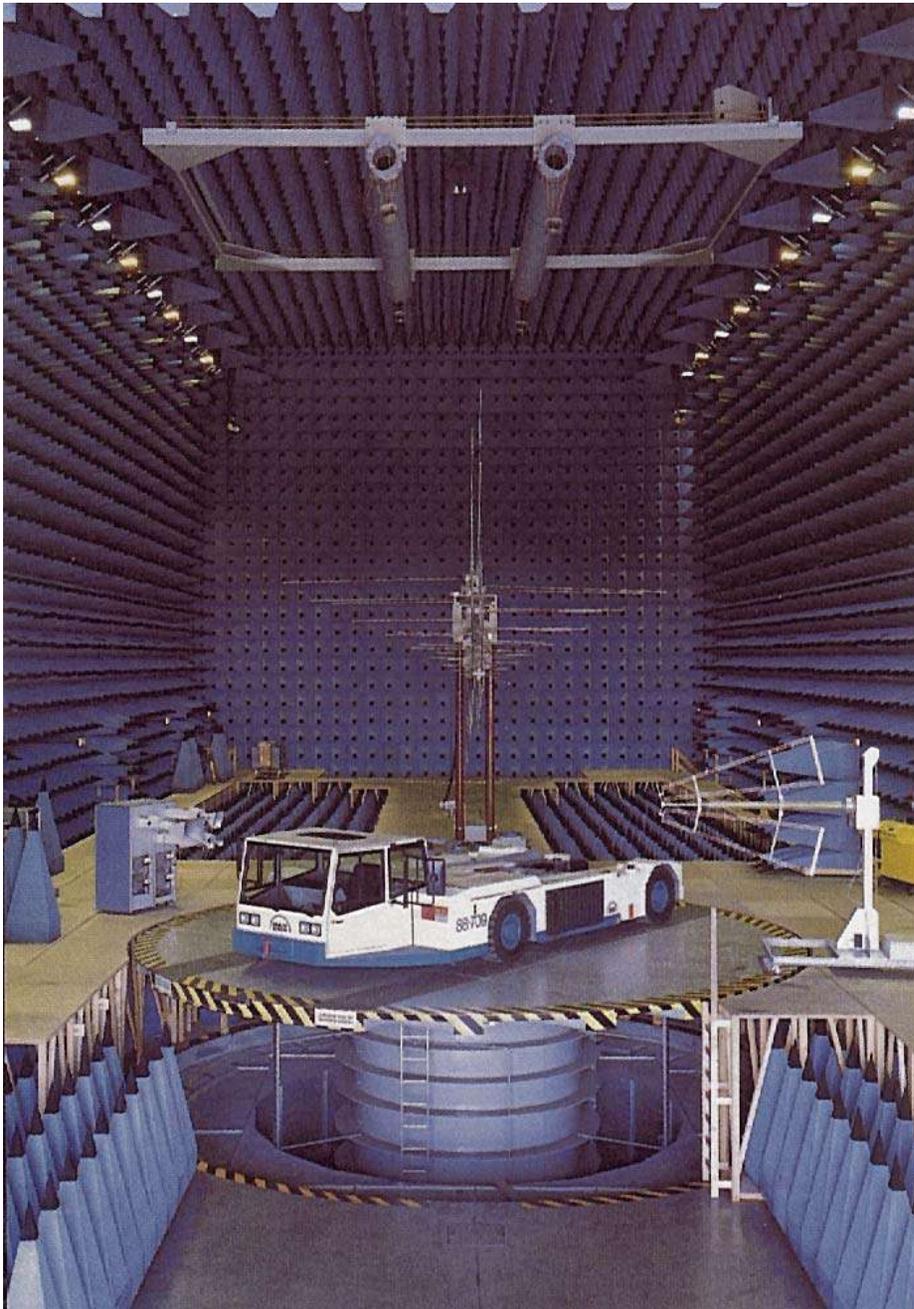
Courtesy of Rohde & Schwarz

EMC tests



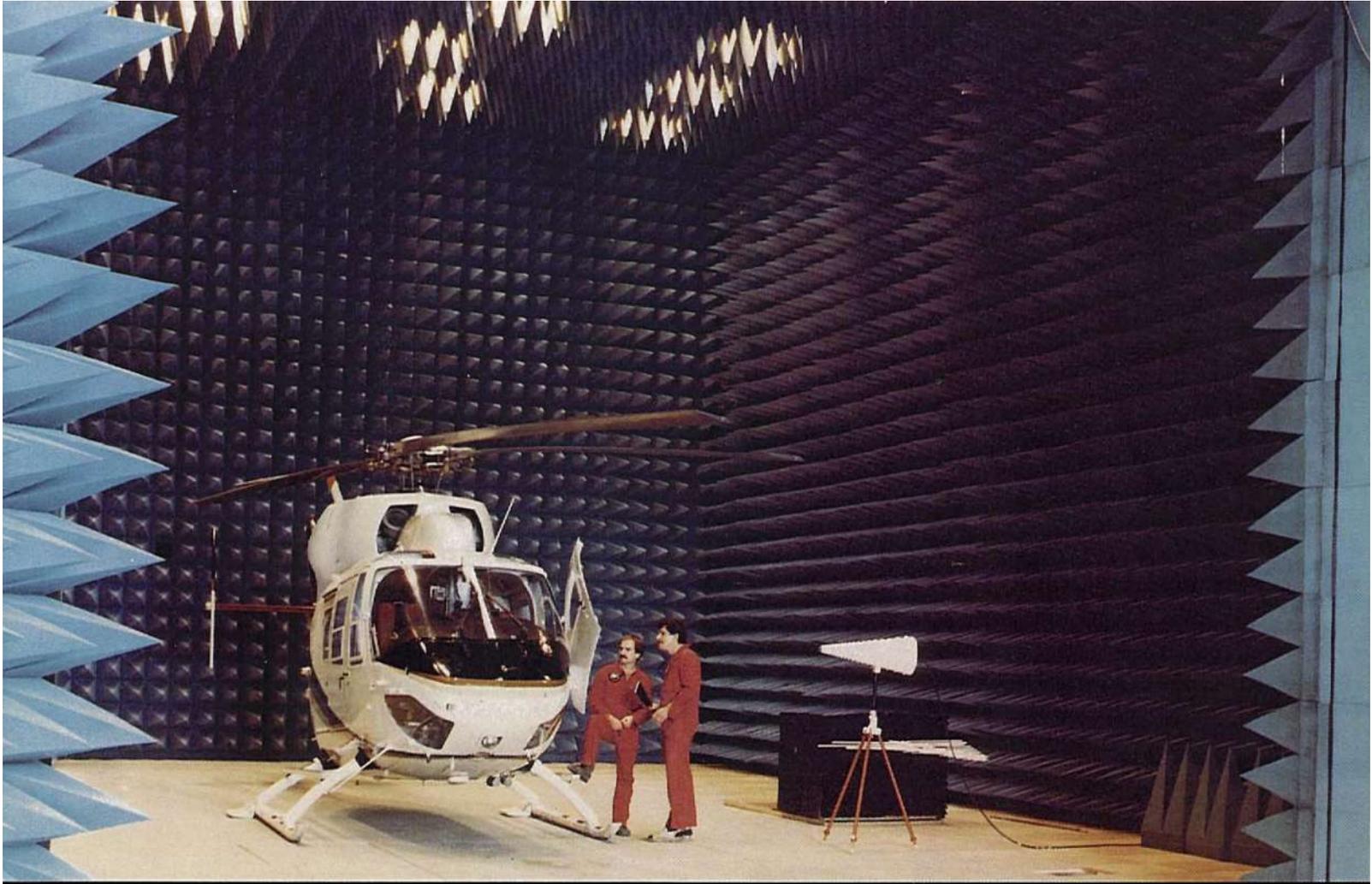
Courtesy of Rohde & Schwarz

EMC tests



Courtesy of Rohde & Schwarz

EMC tests



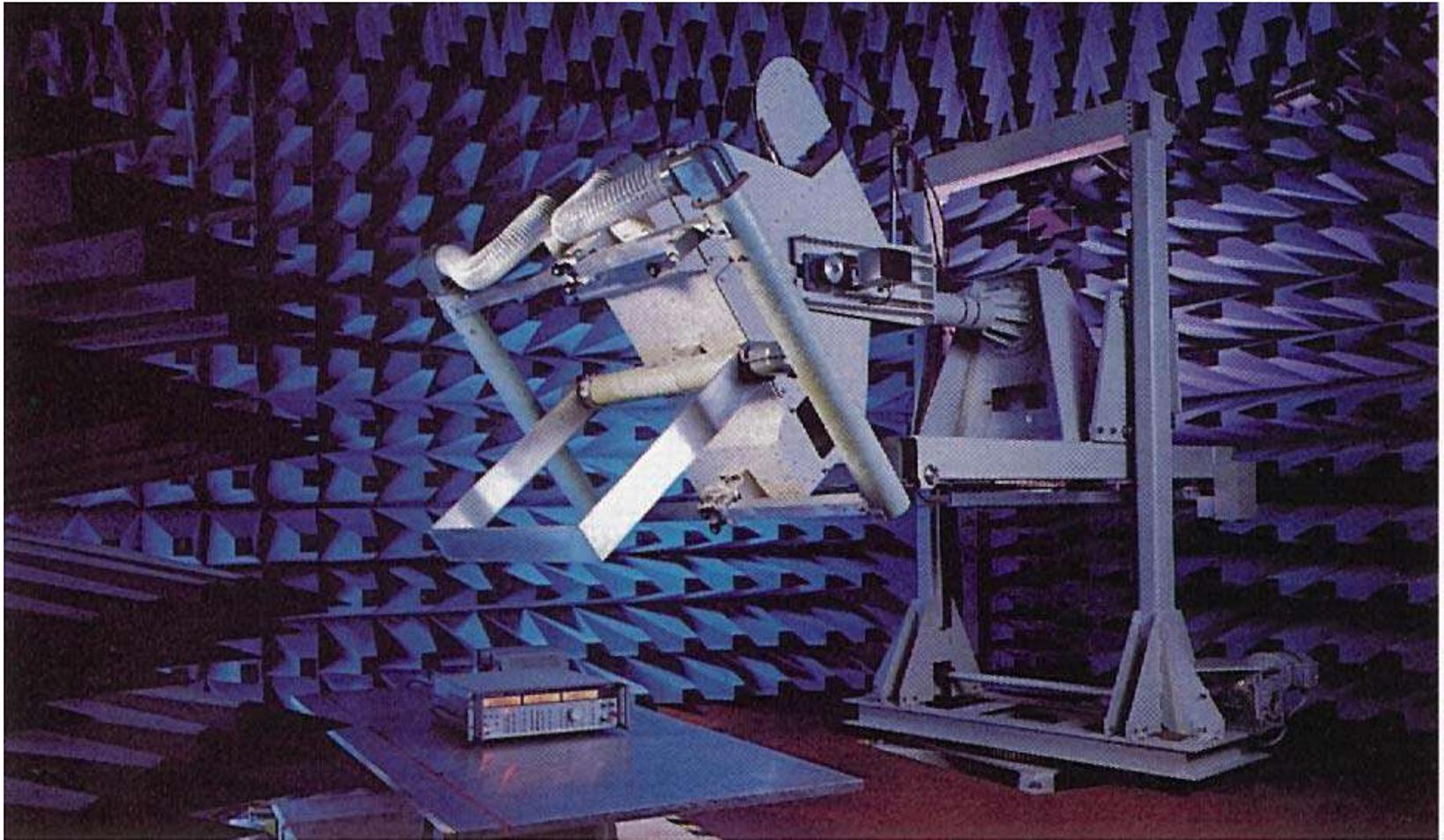
Courtesy of Rohde & Schwarz

Test antennas



Courtesy of Rohde & Schwarz

Test antennas



Courtesy of Rohde & Schwarz

Tests from the air



This photo shows a flying laboratory on manned helicopter I designed and supervised many years ago.

Modern technology allows such measurements to be made at distance, using miniature unmanned radio-controlled airplanes and helicopters

Flying laboratory (1)



Flying laboratory (2)



References

- *Armstrong K*: EMC-related functional safety; ITEM update 2001, p. 52-59
- *EUROPEAN EMC Directive*
(http://europa.eu.int/comm/enterprise/electr_equipment/emc/guides/english.pdf)
- *EUROPEAN RTTE Directive* (http://europa.eu.int/eur-lex/pri/en/oj/dat/1999/l_091/l_09119990407en00100028.pdf)
- *IEEE Electromagnetic Compatibility Society*: <http://www.emcs.org/>
- *IEE Guide to EMC and Functional Safety*, IEE September 2000 (free)
<http://www.iee.org/Policy/Areas/Emc/index.cfm>
- *International Electrotechnical Commission* (www.iec.ch)
- *International Telecommunication Union* (www.itu.int)
- *Mannon J, Johnson E*: Radio Waves Spell Trouble for Industry; *New Scientist*, 5 May 1983
- *Moroñ W*: *Nature and Technology: improving relations*; in *Struzak R (Ed.) Global Communications Asia 1997*, ISBN 0946393869, p. 259-263

- NASA Reference Publication 1374, Jul. 1995
- *Online guide to EMC* (<http://www.interferencetechnology.com/>)
- Rohde & Schwarz: Measuring EMI and wanted signals; News from Rohde & Schwarz Special
- *Struzak R: Terrestrial Electromagnetic Environment; in Rotkiewicz W (ed.) Electromagnetic Compatibility in Radio Engineering, p.3-57, ISBN 0-444-99722-9, Elsevier 1982*
- *Szentkuti B: EMC standards today: starting point into the future; in Struzak R (Ed.) Global Communications Interactive 1999, ISBN 1902221230, p.86-92*
- *Teichmann H: Electromagnetic compatibility concerns all of us; in Struzak R (Ed.) Global Communications Asia 1998, ISBN 190222101-X, p. 80-85*
- www.emc.wroc.pl

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

Summary

- 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.
- EMC concerns all of us

Any questions?

Thank you for your attention

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