ELECTROMAGNETIC COMPATIBILITY (EMC)

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2. Electromagnetic Interference (EMI)
3. Historical EMI Related Incidents
4. EMI Control Techniques
5. EMC Standards
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Introduction – EMI

- An electromagnetic disturbance which may degrade the performance of an equipment or causes malfunction of the equipment, is called electromagnetic interference (EMI).
- EMI is electromagnetic energy that adversely affects the performance of electrical/electronic equipment by creating undesirable responses or complete operational failure.
- EMI is the degradation in the performance of a device due to the fields making up the electromagnetic environment

Introduction - EMC

- Electromagnetic compatibility (EMC) is a near perfect state in which a receptor functions satisfactorily in the common electromagnetic environment, without introducing intolerable electromagnetic disturbance to any other devices / equipment / system in that environment.
- EMC is the ability of electrical / electronic equipment or system to function in the intended operating environment without causing or experiencing performance degradation due to intentional EMI
- EMC is achieved when a device functions satisfactorily without introducing intolerable disturbances to the electromagnetic environment

Introduction - Coupling

origin of disturbance

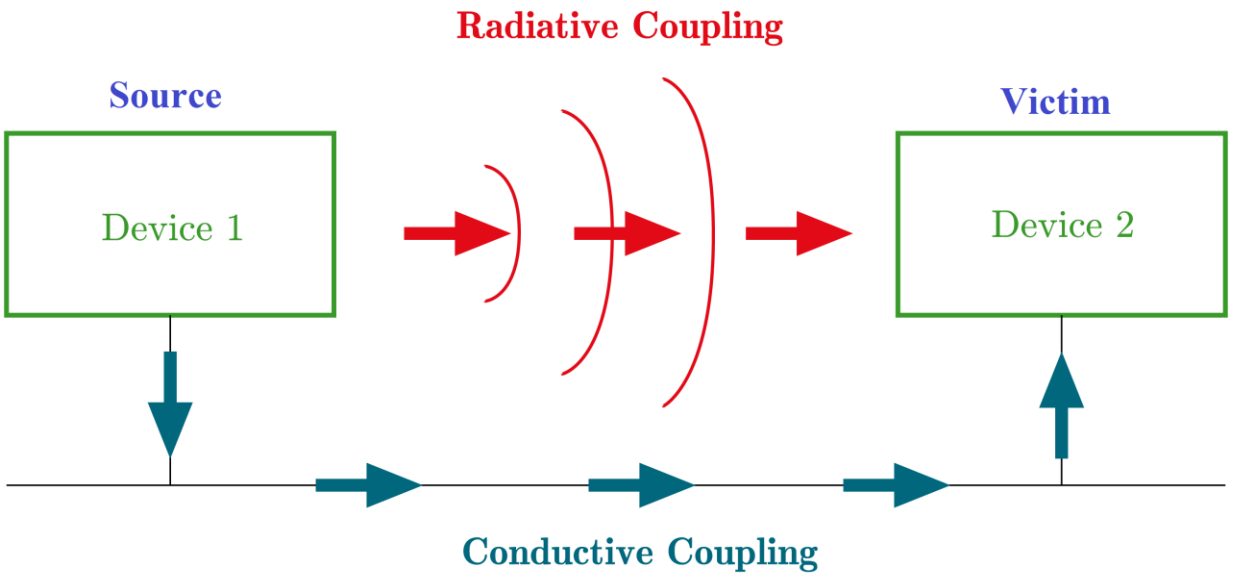
means by which disturbances are transmitted

equipment likely to be disturbed

- Interference occurs if the received energy causes the victim / receptor to function in unwanted manner

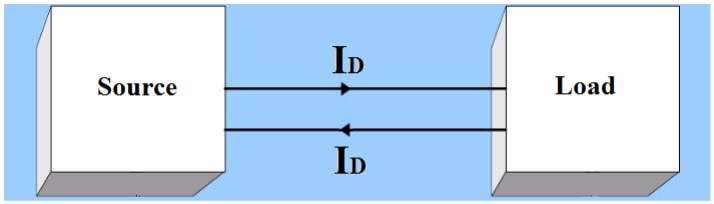
Introduction - Coupling

- Conductive coupling (through cables)
- Radiative coupling



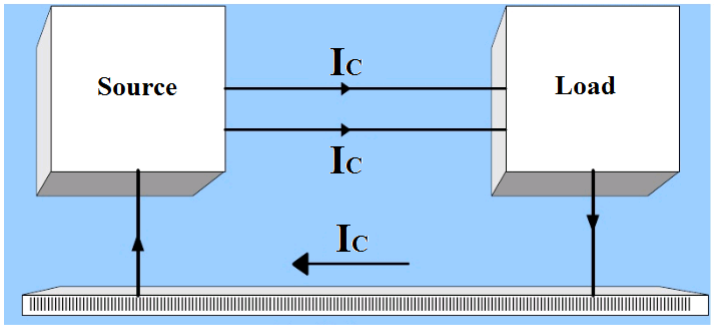
Conductive coupling (through cables)

- Interference signals in two lines are oppositely directed
- No ground current path required



differential mode

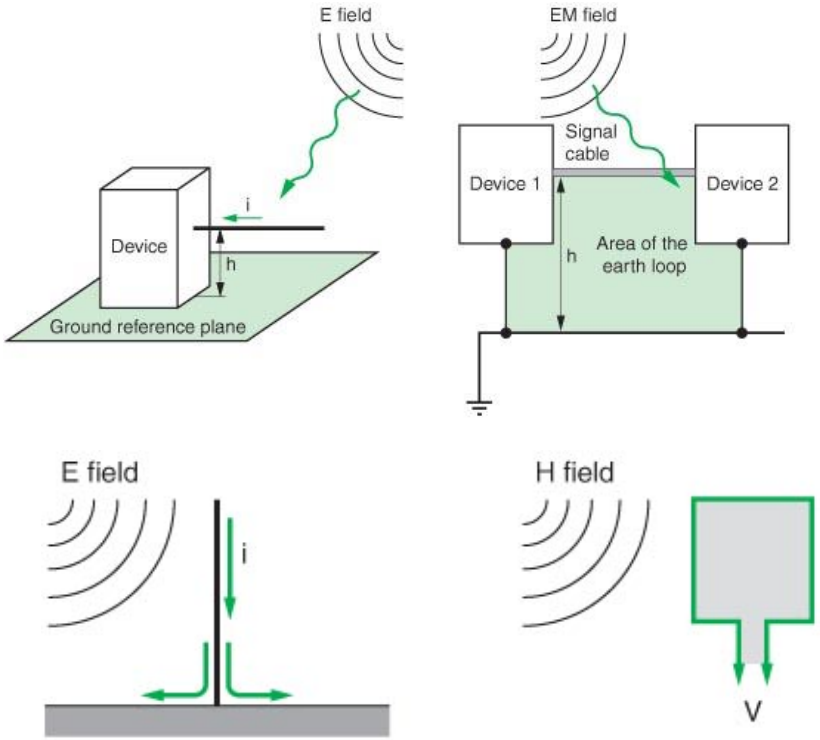
- Interference signal in two lines are unidirectional
- Signal returns through ground



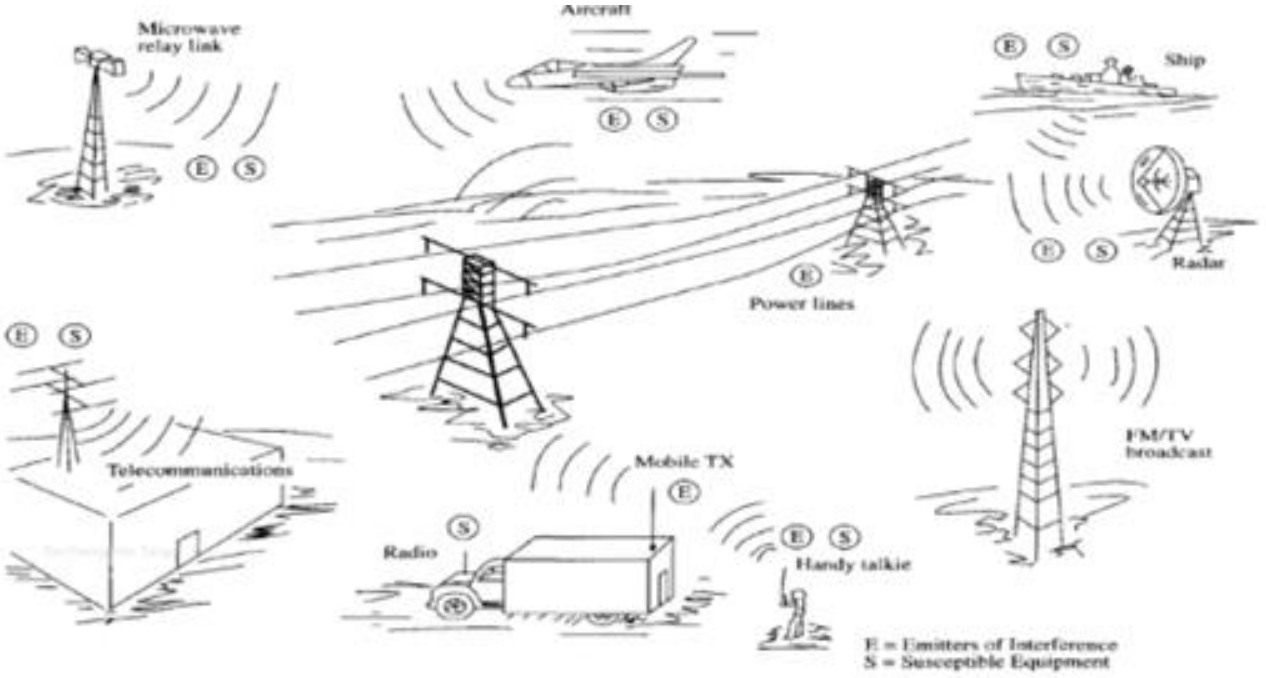
common mode

Radiative coupling

- Antenna to antenna
- Case radiation
- Case penetration
- Field to wire
- Wire to field
- Wire to wire



Electromagnetic Interference

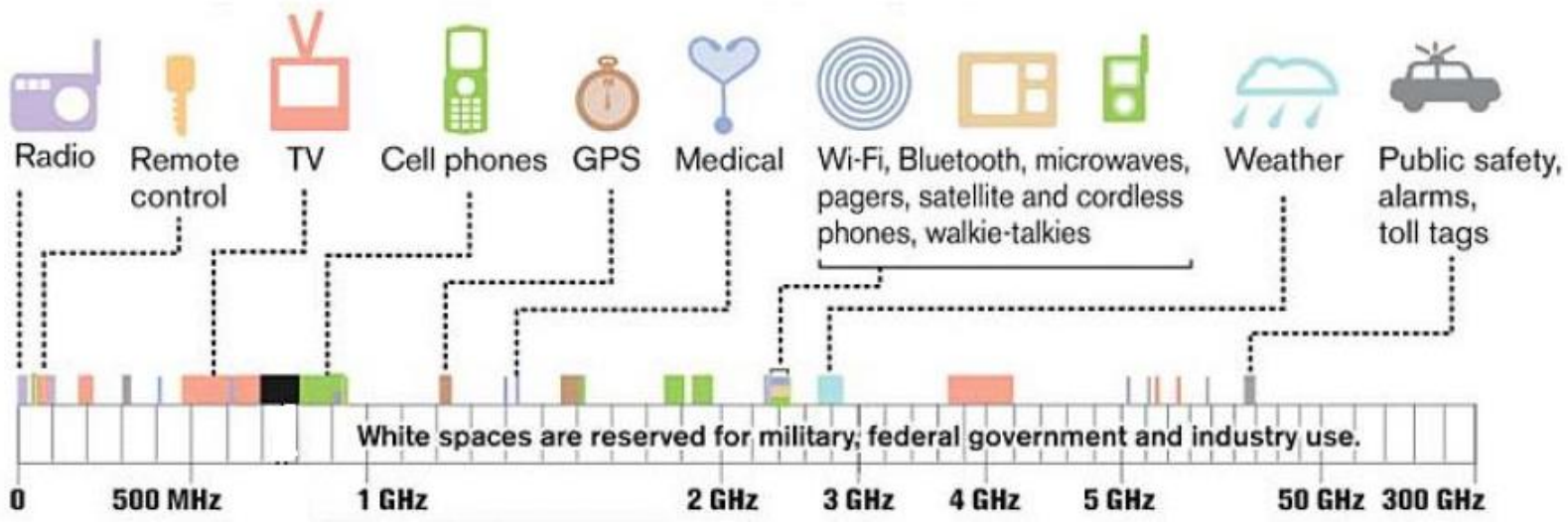


Electromagnetic Interference

- **Before 1930's:** Only radio transmitters and receivers
  - → Few and simple EMI problems
- **1930 – 1950:** Electric motors, electrical railroads, navigation devices, radars, radios
  - → Slight increase in EMI, uncrowded spectrum
- **1950 – 1970:** Inventions of high-density electronic components (bipolar transistors, integrated circuits, microprocessor chips)
  - → Huge increase in EMI, considerable increase in frequency spectrum density
- **After 1970:** Computers, digital processing, increased switching speed of ICs, very crowded spectrum (electromagnetic pollution)
  - → Evolution of EMI control technology; standards, regulations, limits and laws getting more and more strict to control EMI sources;

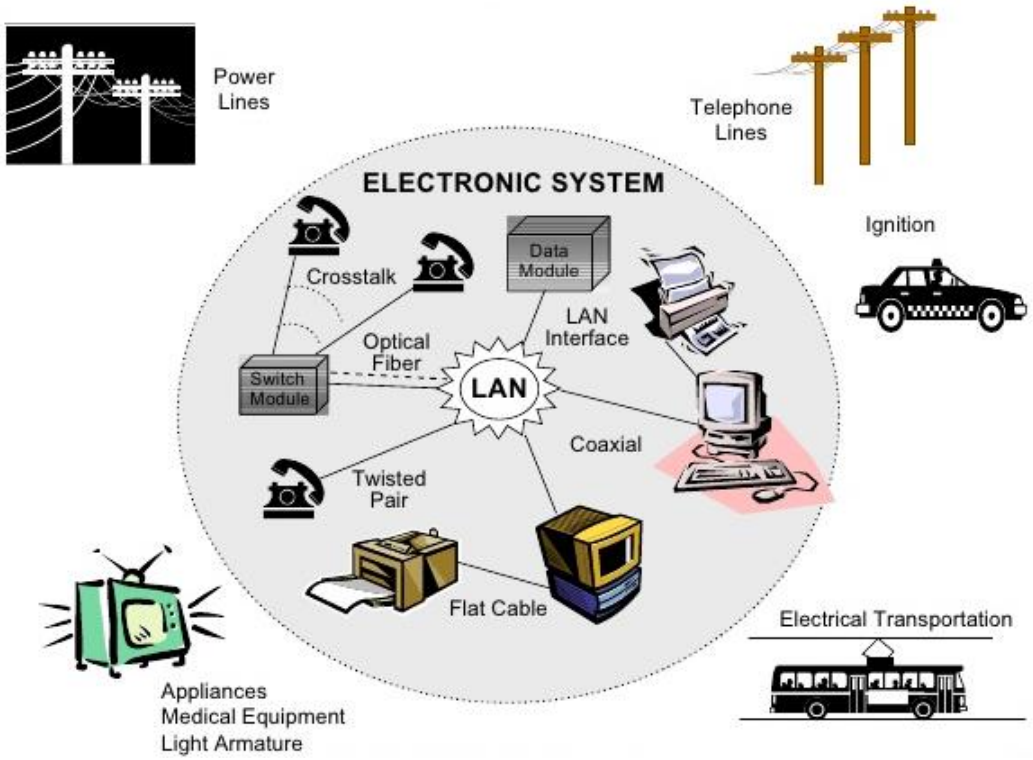
Sources of EMI

- **Functional:** EMI can originate from any source designed to generate EM energy and which create interference as a result of its normal operation.



Sources of EMI

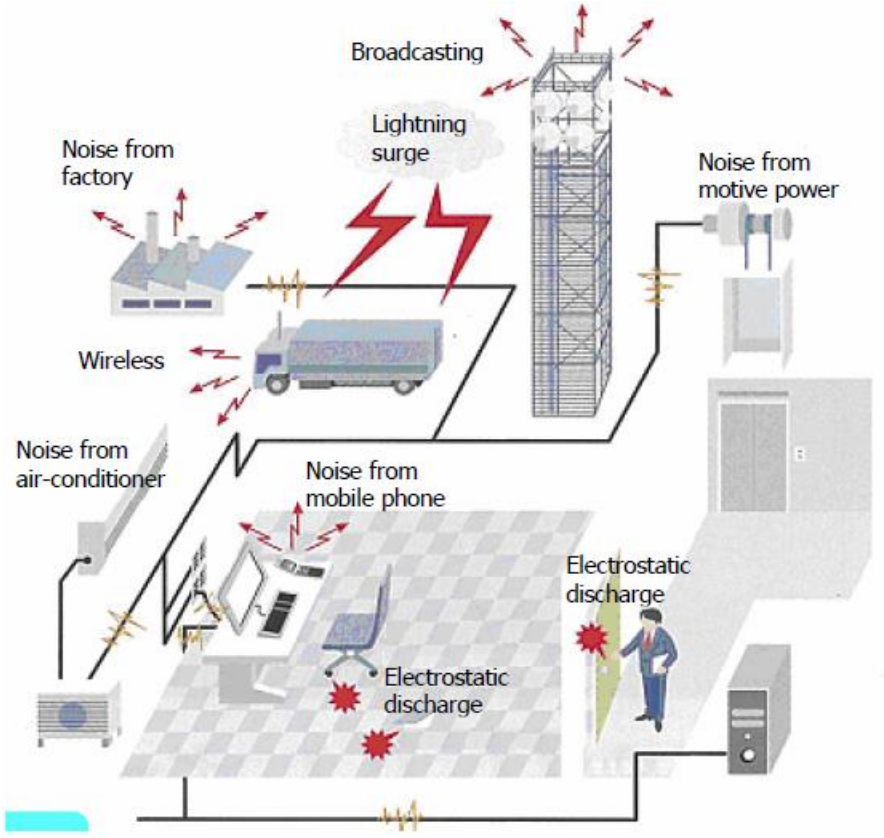
- **Incidental:** EMI can originate from man-made sources not specifically designed to generate EM energy.



Sources of EMI

- **Natural:** Electromagnetic interference can be caused by natural phenomena
  ⟹ ligthning, solar and interstellar radiation.

EMI Interactions



EMI SOURCE (EMITTER)	PRIMARY COUPLING MECHANISM	EMI VICTIM (RECEPTOR)
TRANSMITTERS	RADIATED ANT-ANT	RECEIVERS
	RADIATED ANT-CABLE ANT-CASE	ELECTRONIC EQUIPMENT
ELECTRICAL & ELECTRONIC EQUIPMENT	RADIATED CABLE-ANT CASE-ANT	RECEIVERS
	RADIATED CABLE-CABLE CABLE-CASE CASE-CABLE CASE-CASE CONDUCTED POWER LINES SIGNAL LINES GROUND	ELECTRONIC EQUIPMENT

Intra-system EMI

Intrasystem interference comes about as a result of self jamming or undesirable emission coupling within a system.

Sources / Emitters		Victims / Susceptors
Power supplies	→	Relays
Radar transmitters	→	Radar receivers
Mobile radio transmitters	→	Mobile radio receivers
Fluorescent lights	→	Ordnance
Car ignition systems	→	Car radio receivers

Inter-system EMI

Intersystem EMI is the interference between two or more discrete systems or platforms which are frequently under seperate user control.

Sources / Emitters		Victims / Susceptors
Lightning strikes	→	Radio receivers
Computers	→	TV sets
Power lines	→	Heart pacers
Radar transmitters	→	Aircraft navigation systems
Police radio transmitters	→	Taxicab radio receivers
Aircraft transmitters	→	Ship receivers

Primary EMI Effects

- Momentary disturbance in TV reception
- Power supply ‘hum’ in radio sets
- Crosstalk on telephones
- Reset of computers and loss of data
- Burnout of sensitive components, antennas
- Performance degradation of receiver signal processing unit
- Biological hazards
- Failure of pacemaker (due to a walkie-talkie)
- Malfunction of flight control system (due to a laptop)
- False initiation of electro-explosive detonator
- Malfunction of missile guidance system

Historical EMI Related Incidents

USS FORRESTAL

- Vietnam – 1967
- ZUNI rocket inadvertently launched by a ship radar
- 134 dead – 27 Aircrafts destroyed
- $ 335M damage to ship
- Largest Naval loss of life since WW-II

Historical EMI Related Incidents

HMS SHEFFIELD

- Falkland Islands – 1982
- Hit by undetected EXOCET Missile
- Anti-missile radar (965) caused degradation of communication system and so was turned off.
- 21 dead
- Ship sank 4 days later

Historical EMI Related Incidents

Operation Restore Democracy

- Haiti – 1995
- Air wings of USS America (warship) & USS Eisenhower (nuclear powered aircraft carier) replaced with men and helicopters
- Army aircraft not designed or tested for carrier operation
- Carriers required to turn off almost all communications and radar surveillance systems

Historical EMI Related Incidents

PERSHING II NUCLEAR MISSILE

- Germany – 1985
- Missile motor exploded during routine maintenance
- Electrostatic discharge identified as the cause
- 3 dead

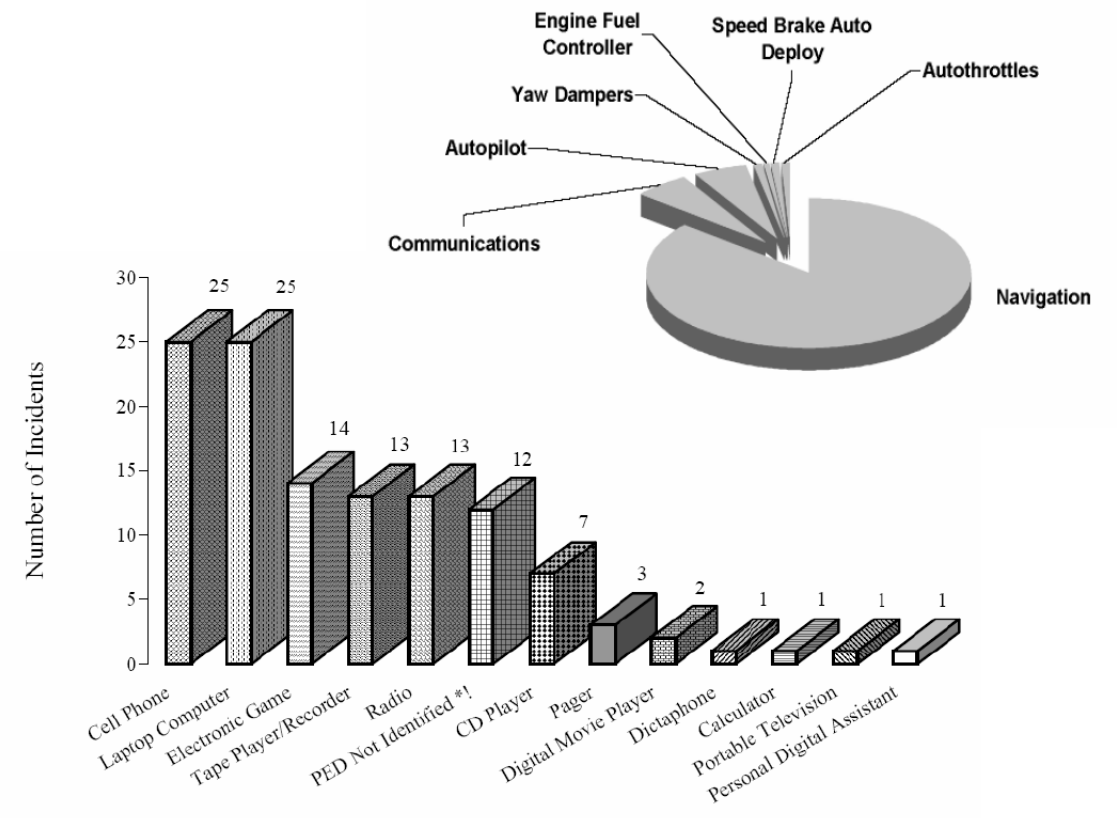
Historical EMI Related Incidents

BLACKHAWK HELICOPTER

- Germany & USA – 1987
- Several potentially fatal incidents and a fatal crash
- Interference from high power radio transmitters
- Entire fleet grounded for 3 months during investigation
- Extensive test and retrofit program solved the problem

Historical EMI Related Incidents

PLANE INCIDENTS



- NASA study from 1986 – 1999 on PEDs affecting aircraft systems

Methodologies to prevent EMI

- Suppress the emissions at source point
- Make the coupling path as inefficient as possible
- Make the receiver less susceptible to emission

FILTERING

GROUNDING

SHIELDING

PROPER PCB DESIGN

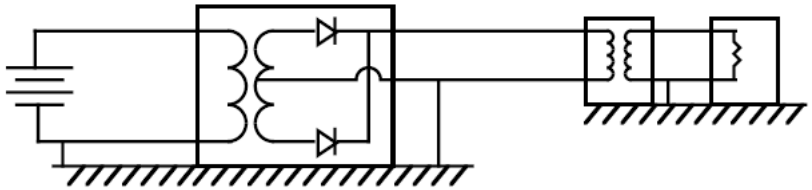
GROUNDING & BONDING

- Grounding is the establishment of an electrically conductive path between two points to connect electrical and electronic elements of a system to one another or to some reference point.
- An ideal ground plane is a zero-potential, zero-impedance body that can be used as a reference for all signals in associated circuitry and to which any undesired current can be transferred for the elimination of its effects.
- Bonding is the establishment of a low-impedance path between two metal surfaces. Grounding is a circuit concept, while bonding denotes physical implementation of that concept.
- Bonds provide protection from electrical shock, current return paths, antenna ground plane connections, also minimize the potential difference between the devices.

GROUNDING & BONDING

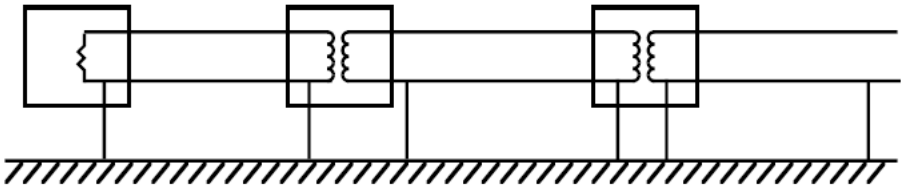
- PCB & Equipment Internal Grounding
  - Make the impedance of system reference as low as possible; can be achieved by using a ground plane, grid or strip
  - Divide and seperate ground systems as: analog/video ground, digital ground, RF ground, control ground
  - Use seperate returns for each circuit
  - Place quiet circuits farthest from single point ground and noisy circuits closest to ground connection
- System & Platform Grounding
  - Bond connector frames to chassis
  - Maintain isolation to prevent ground loop radiation
  - Ground all systems and sub-systems using single point, multi-point or star ground scheme which is appropriate

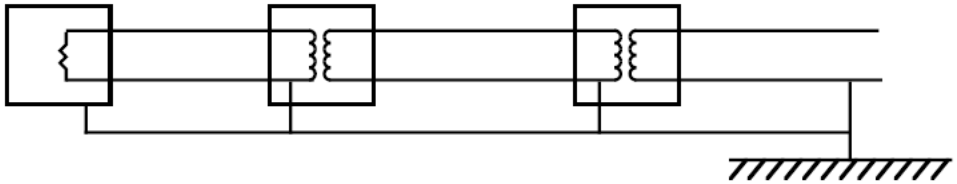
GROUNDING & BONDING



- Single Point Ground

- Multi Point Ground





- Star Ground

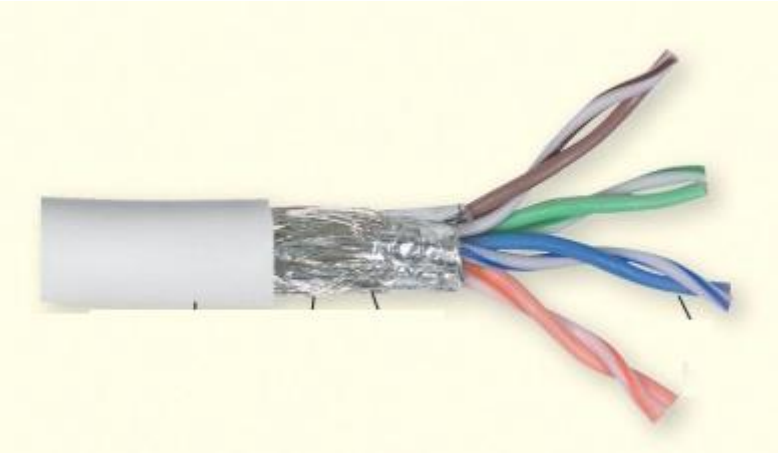
SHIELDING

- Shield is a metal barrier used to prevent radiated EM energy from entering a specific region (equipment, shelter, vehicle) and confine radiated energy to a specific region.
- Shields may be in the form of partitions and boxes as well as in the form of cable and connector shields.
- Shield types include solid, nonsolid and braid as is used on cables.
- A shield can be characterized by its shielding effectiveness:

SE = 10* log (incident power density / transmitted power density)

  - *incident power density:* power density before shield is installed
  - *transmitted power density:* power density after shield is in place

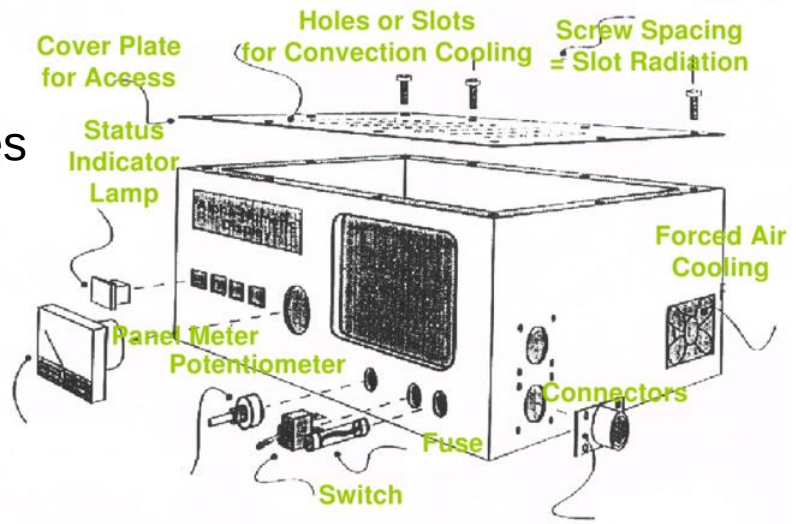
SHIELDING



- Cable Shielding
  - Use braid-covered foil shield
  - Use 360° shield termination and ground the shield at both sides
  - Terminate shield grounds to metallized connector shells and terminate shells to chassis.

SHIELDING

- The mechanical parts and accessories of the shielded box compromise the desired shielding.



- Equipment enclosure
  - To prevent electric field radiation use good conductor: copper, aluminum
  - To prevent magnetic field radiation use a material with high permeability: μ-metal
  - If not possible, use plastic with conductive coating

SHIELDING

- Equipment enclosure cont.
  - Minimize size and number of apertures and seams
  - Maintain a continuous metal-to-metal contact along the seam or joint
  - Use conductive gaskets or fingers to seal metal-to-metal interface and be sure that interfaces are free from paint
  - Use conductive control/display components
  - Use adequate number of contact points
  - For ventilation holes, use honey-comb panels, perforated metal sheet or metal mesh
  - Try to integrate all switches, displays and LEDs on the same surface of the equipment

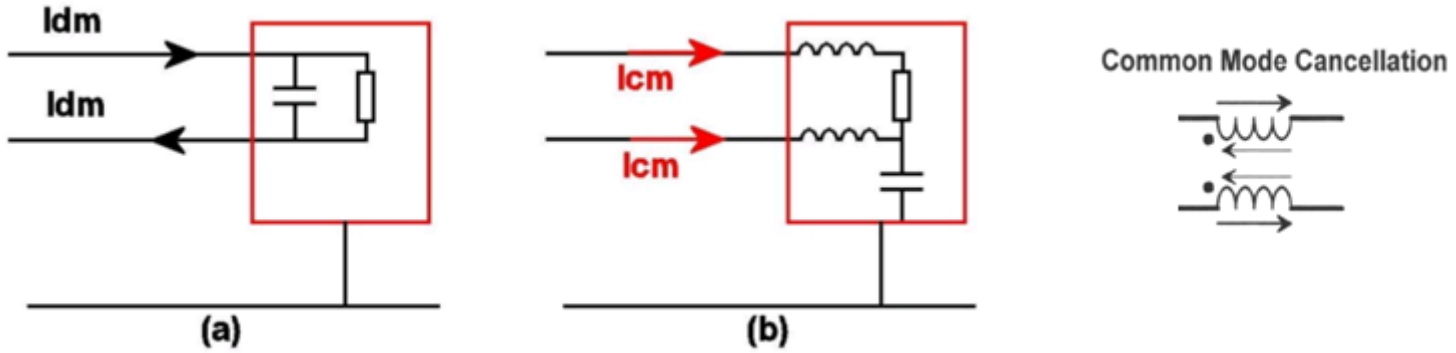
FILTERING

- An electrical filter is a network of lumped or distributed constant resistors, inductors, and capacitors that offers comparitively little opposition to certain frequencies, while blocking the passage of other frequencies.
- Filter provides the means whereby levels of conducted interference are substantially reduced.
- The most significant characteristic of a filter is the insertion loss it provides as a function of frequency.

$$IL = 20 * \log (V_2 / V_1)$$

- ***V1*** *:* output voltage of a signal source with the filter in the circuit
- ***V2*** *:* output voltage of the signal source without the use of filter

FILTERING



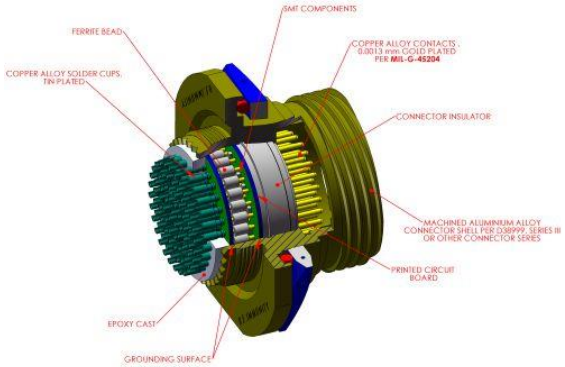
- Parallel capacitor at (a) reduces differential mode voltage developed at the input.
- Series inductances (or common mode choke) shown at (b) reduce common mode current flow to ground. The capacitor between each line and ground also reduces common mode voltage developed.

FILTERING

- Try to reduce radiation by placing a ferrite bead, choke or clamp (easy to implement) in the path of the current.
- When a mains filter is used, do not add primary and secondary wires in the same assembly
- Keep the connection as short as possible to get a good connection between reference of the filter and the ground
- When mounting the metal filter cover to the application, be sure there is a good contact
- Keep cables from secondary filter side to the circuit as short as possible
- Try to install filters at enclosure wall
- Provide LC filtering on unshilded cables

FILTERING

- If there is no space enough for adding any filter, the last and the most expensive solution is filter connector



PROPER PCB DESIGN

- Dedicate one layer of the PCB to achieve a low impedance reference path
- Keep the current between the circuits low with isolation amplifier or optocoupler
- Decrease capacitive cross-talk by increasing the distance between the two conductors or twisting the wires of two circuits
- Place a small resistor in the signal and supply lines
- Use only the bandwidth that is needed
- Position analog devices on the same ground plane and the high frequency components seperately from low speed components
- Place high frequency circuits close to the connectors in order to shorten the length of the interconnects

PROPER PCB DESIGN

- Seperate ground planes of the digital and analog sections
- Use buried and narrow traces when possible
- Keep input and output leads away from electromagnetic noise generators
- Minimize capacitive coupling to chassis grounds
- Route power and return traces as closely as possible
- Reduce trace impedance and loop areas of high speed signals
- If possible, devote one side of the board for a ground plane
- Isolate critical control circuits from external noise such as ESD
- Locate filters at the connector

EMC Standards

- The EMC standards are required for trouble free co-existence and to ensure satisfactory operation
- Standards are required to provide compatibility between electrical, electronic, computer, control and other systems.
- Standards are required as manufacturer – user interaction and user's knowledge on EMI are limited.
- Standards are required for establishing harmonized documents to reduce international trade barriers and to improve product reliability and life of the product.

Advantages

- ✓ Compatibility, reliability and maintainability are increased.
- ✓ Design safety margin is provided.
- ✓ The equipment operates in EMI scenario satisfactorily.
- ✓ Product life and profits are increased.
- ✓ EM spectrum is protected.

Types of EMC Standards

- **Military Standards:** Military EMC standards are made in order to ensure system-to-system compatibility in real time military environment. Military standards are more stringent than civilian standards, mostly. Military standards are broadly based on MIL-STD-461 and MIL-STD-464.

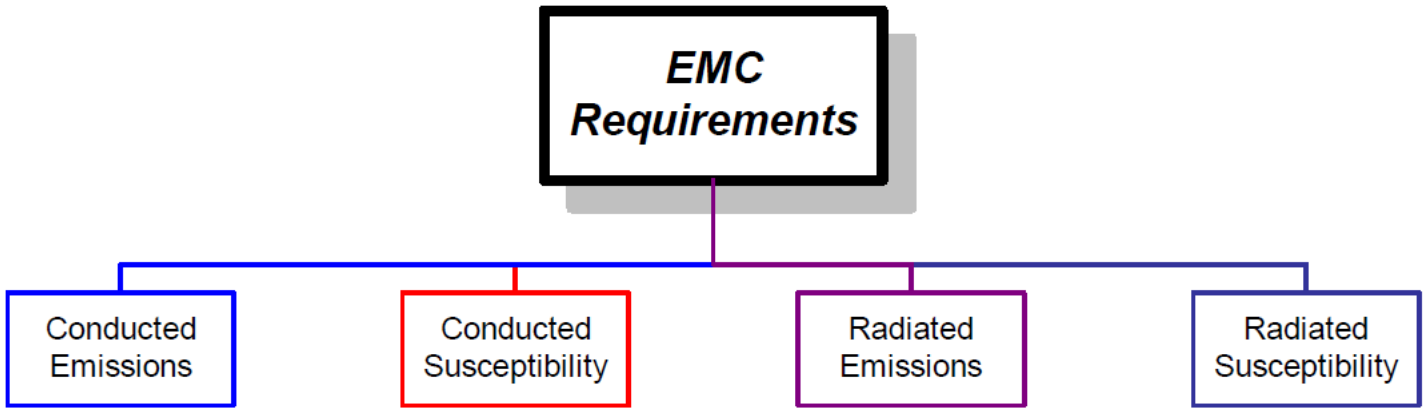
- **Civilian Standards:** The civilian EMC standards are applicable for equipments used for commercial, industrial and domestic applications. The emission standards are specified to protect the broadcast services from interference.

Organizations & Institutions

- DOD: *Department of Defence (USA)*
- IEC: International Electrotechnical Commission (EU)
- CISPR: International Special Committee on Radio Interference (operating under IEC)
- FCC: Federal Communication Commission (USA)
- BSI: British Standard Institution (UK)
- VDE: Verband Deutscher Electrotechniker (Germany)
- IEEE: Institute of Electrical and Electronics Engineers (Int.)
- SAE: The Engineering Society for Advancing Mobility Land, Sea, Air and Space (International)
- RTCA: Radio Technical Commission for Aeronautics (USA)

MIL-STD-461

- Department of Defence – USA; 1968
- This standard establishes interface and associated verification requirements for the control of EMI characteristics of electronic, electrical and electromechanical equipment and subsystems.
- An equipment-level standard
- Army, Navy & Air Force



MIL-STD-461 Standard

- **A= Applicable**
- **L= Limited Applicability**
- **S= Must be explicitly specified by the Procuring Activity**

Equipment and Subsystems Installed In, On, or Launched From the Following Platforms or Installations	Requirement Applicability																
	CE101	CE102	CE106	CS101	CS103	CS104	CS105	CS109	CS114	CS115	CS116	RE101	RE102	RE103	RS101	RS103	RS105
Surface Ships		A	L	A	S	S	S		A	L	A	A	A	L	A	A	L
Submarines	A	A	L	A	S	S	S	L	A	L	A	A	A	L	A	A	L
Aircraft, Army, Including Flight Line	A	A	L	A	S	S	S		A	A	A	A	A	L	A	A	L
Aircraft, Navy	L	A	L	A	S	S	S		A	A	A	L	A	L	L	A	L
Aircraft, Air Force		A	L	A	S	S	S		A	A	A		A	L		A	
Space Systems, Including Launch Vehicles		A	L	A	S	S	S		A	A	A		A	L		A	
Ground, Army		A	L	A	S	S	S		A	A	A		A	L	L	A	
Ground, Navy		A	L	A	S	S	S		A	A	A		A	L	A	A	L
Ground, Air Force		A	L	A	S	S	S		A	A	A		A	L		A	

- Applicability of individual EMC requirements for a particular equipment or subsystem is dependent upon the platforms where the item will be used.

MIL-STD-461 Conducted Emissions

- In the lower frequency portion, the primary concern is power quality on the power busses.
- In the higher frequency portion, the primary concern is radiated emissions associated with the conducted emissions of EMI.
- The related tests:
  - CE101
  - CE102
  - CE106

MIL-STD-461 Conducted Susceptibility

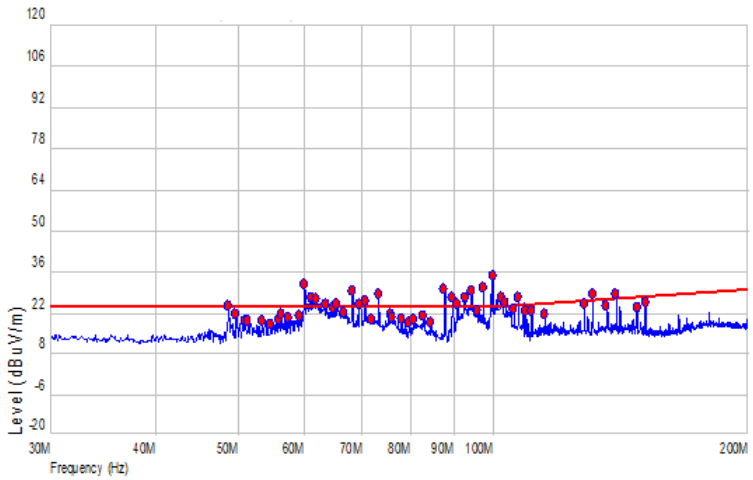
- The conducted susceptibility testing is about power quality and disturbances on the power busses.
- The conducted susceptibility testing is also about EMI induced on cables due to high-level radiated fiels generated by intended transmitters and natural phenomenas.
- The related tests:
  - CS101
  - CS106
  - CS114
  - CS115
  - CS116

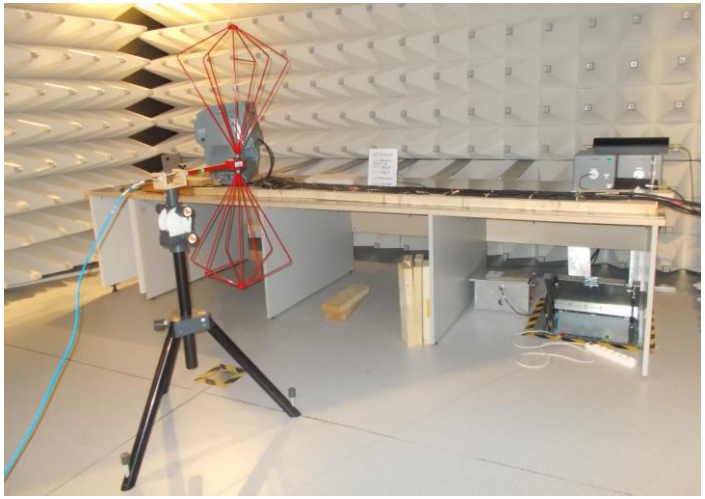
MIL-STD-461 Radiated Emissions

- In the lower frequency portion, the primary concern is to control magnetic fields at lower frequencies to protect the antenna connected receivers in the related frequency band.
- In the higher frequency portion, the primary concern is to control electric fields at higher frequencies to protect the antenna connected receivers in the related frequency band.
- The related tests:
  - RE101
  - RE102
  - RE103

MIL-STD-461 RE102

- Radiated emissions (electric field) from equipment and subsystem enclosures including electrical cable interfaces are measured.
- The emissions shall not exceed the applicable limits
- The frequency range: 10 kHz – 18 GHz





MIL-STD-461 Radiated Susceptibility

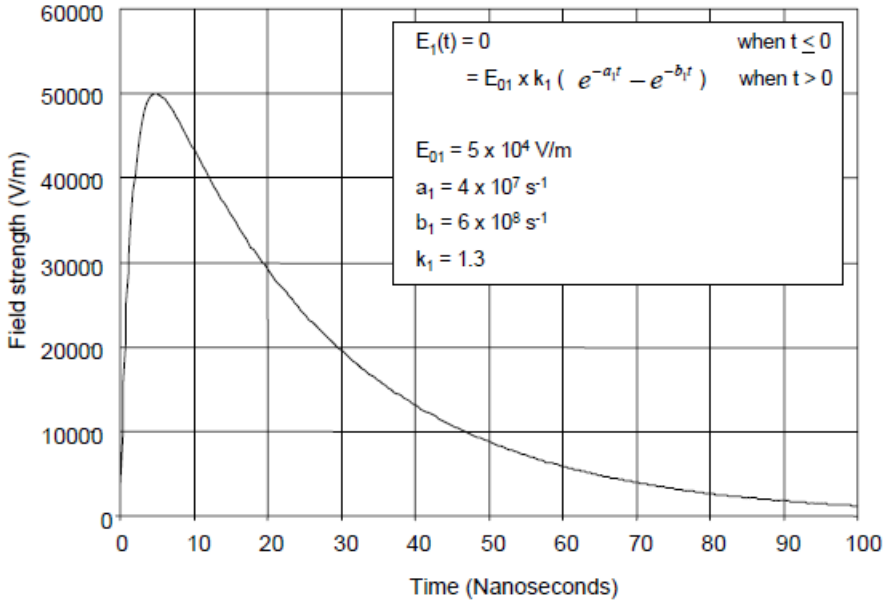
- In the lower frequency portion, the primary concern is to ensure that performance of equipment potentially sensitive to low frequency magnetic fields is not degraded.
- In the higher frequency portion, the primary concern is to to ensure that performance of equipment is not degraded when subjected to electric field levels to be encountered during the service life of the equipment.
- The related tests:
  - RS101
  - RS103
  - RS105

MIL-STD-461 RS103

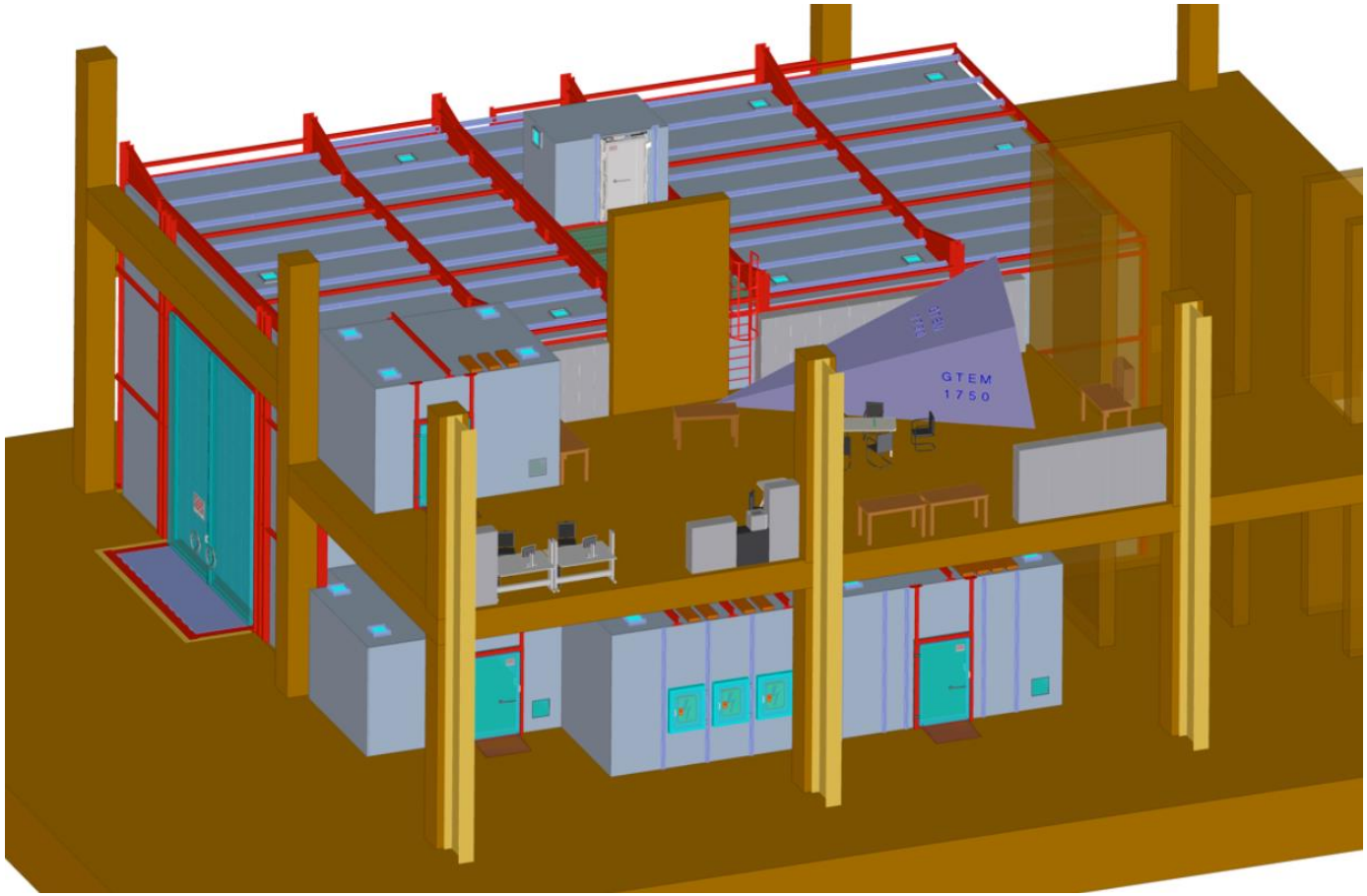
- Radiated electric fields via antennas are coupled to the equipment and subsystem enclosures including electrical cable interfaces to see the effect of electric fields in the operating environment.
- The EUT shall not exhibit any malfunction, degradation of performance, or deviation from specified indications.
- The frequency range: 2 MHz – 40 GHz

MIL-STD-461 RS105

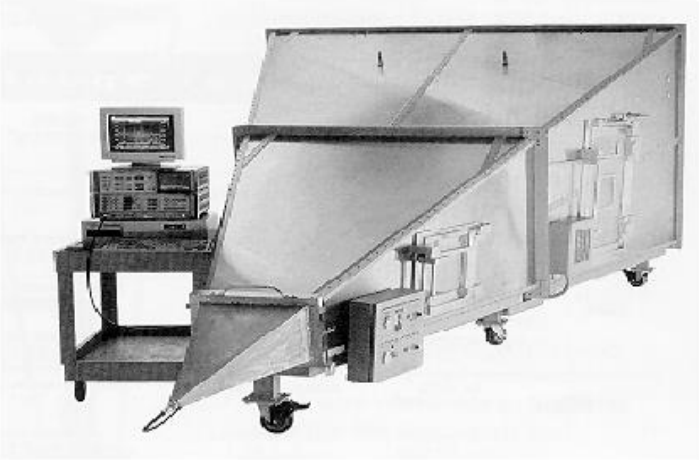
- The pulse defined is coupled to the equipment and subsystem enclosures to see the effect of electromagnetic pulse (EMP).
- The EUT shall not exhibit any malfunction, degradation of performance, or deviation from specified indications.



Overall View



GTEM CELL



- RS103(>1 GHz)
- Commercial RE-RS Testing
- RE102 (Pre-compliance)
- E-Field Probe Calibration

Shielded Room

Shielded Room

(Shielded room)

5030 x 3980 x 3450mm

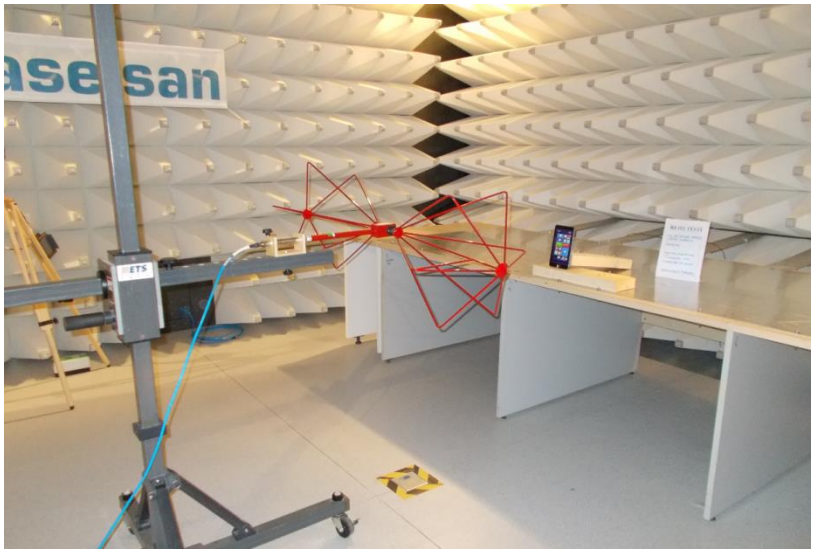
(L x W x H)

- All MIL-STD-461 tests except RE102 and RS103

Control Room

- A shielded room to control testing activities in semi anechoic chambers.

Small Semi Anechoic Chamber



Chamber SSAC

(MIL Std.)

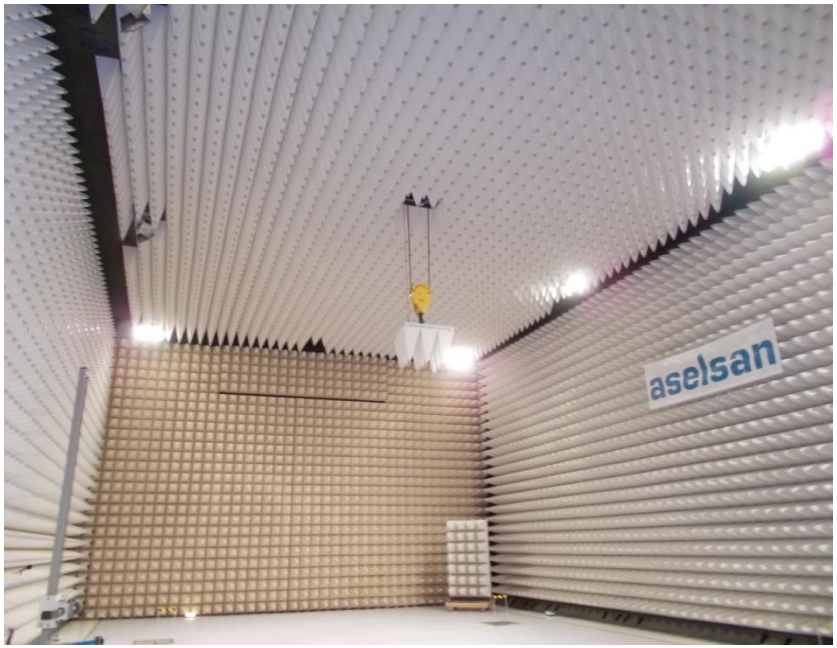
7430 x 6305 x 3900mm

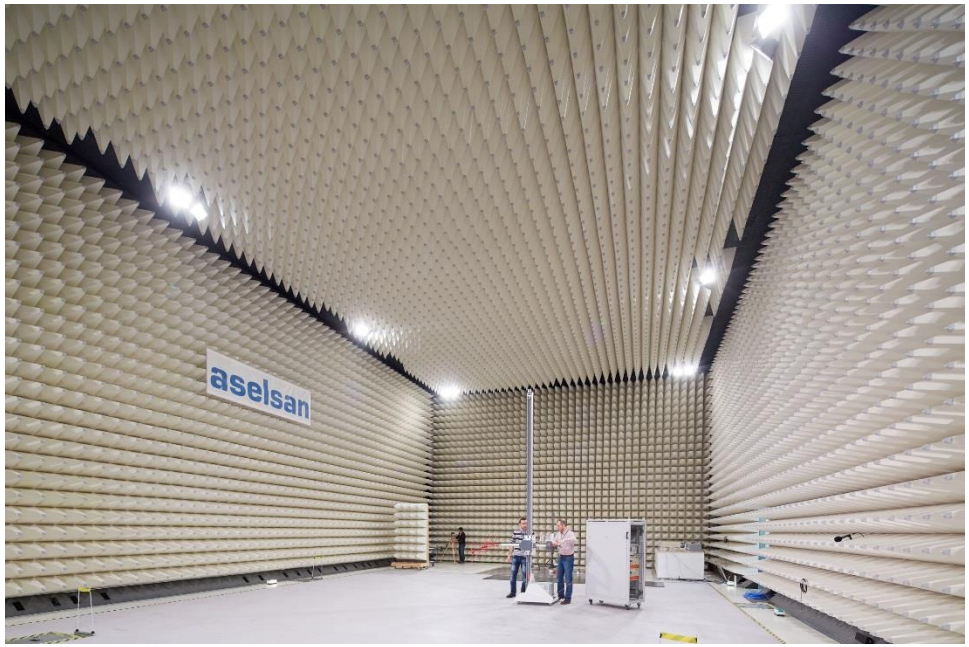
(L x W x H)

- All MIL-STD-461 Tests

Big Semi Anechoic Chamber

Big Semi Anechoic Chamber





Chamber BSAC
(MIL Std & Civil Std)

22505 x 12830 x 8550mm
(L x W x H)

Summary

- EMC studies the unintentional generation, propagation and reception of electromagnetic energy with reference to the unwanted effects (EMI) that such energy may induce
- The goal of EMC is the correct operation, in the same electromagnetic environment, of different equipment which use electromagnetic phenomena, and the avoidance of any interference effects
- A system is said to be electromagnetically compatible if:
  - it does not cause interference with other system
  - it is not susceptible to emissions from other systems
  - it does not cause interference with itself
- EMI is a phenomenon while EMC is an equipment characteristic
- EMC ⇒ LIVE AND LET LIVE

References

- www.emcs.org: IEEE EMC Society
- www.yorkemc.co.uk: University of York EMC Services
- «EMC for Product Designers», Tim Williams
- «EMC for Systems and Installations», Keith Armstrong & Tim Williams
- «Tasarımdan Üretime Elektromanyetik Uyumluluk», Levent Sevgi

THANKS...

A Simple Question

- Write down the primary techniques / methods to control EMI