A Beginners Guide to EMC

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• EMC Issues In The Real World
  • What Actually is EMC?
• EMC Standards and Legislation
  • The Need For EMC
• How EMC Problems Occur
  • EMC Control Measures
• Some Basics Of EMC
EMC Issues In The Real World –

• Broadcast Interference
• Equipment Malfunction
• EMC: Electromagnetic compatibility:

"The ability of an equipment or system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment."

(IEC defines the electromagnetic (EM) environment as "the totality of electromagnetic EM phenomena existing at a given location.")
The need for EMC

- Limit interference to broadcast reception and mobile radio services, and other users of the mains supply
- Immunity of safety- or user-critical systems from environmental effects (especially transport, medical and process control)
EMC LEGISLATION & STANDARDS
Commercial EMC standards - structure

- **Basic standards**
  - Examples
    - EN 61000-3-XX
    - EN 61000-4-XX

- **Product specific**
  - Examples
    - EN 50199
    - EN 50293
    - EN 50270

- **Product family**
  - Examples
    - EN 55011
    - EN 55022
    - EN 55024

- **Generic**
  - EN 61000-6-XX
The problems of EMC

- **interference with radio reception**
  - household appliances can interfere with broadcast
  - concern over proliferation of broadband

- **interference from radio transmitters**
  - hospitals and aircraft prohibit use of cellphones
  - "audio breakthrough" from nearby transmitters

- **interference from transients**
  - ESD and switching operations disrupt controller operation and cause hard-to-trace unreliability
Typical EMC tests

**Emissions:**
- conducted RF on mains cable
- conducted RF on other ports
- radiated RF
- LF power disturbances

**Immunity:**
- conducted RF on mains cable and other ports
- radiated RF
- supply voltage dips and interruptions
- magnetic fields
- electrostatic discharge
- fast transients
- surges
EMC Directive 2004/108/EC

One route to conformity for Apparatus

ANNEX II - Internal Production Control

Harmonised Standards applied in full?

Yes

ANNEX IV - Technical Documentation

No

EMC Assessment

ANNEX III - Notified Body

ANNEX IV EC Declaration of Conformity

ANNEX V CE Marking
Transposed Harmonised Standards

BS EN [reference number]

Prefix of national body

Fully harmonised standard

Retained throughout Europe

Example:

BS EN 55022 ≅ DIN EN 55022
HOW DO EMC PROBLEMS OCCUR?
EM fields from intentional radiators

- Radio and TV broadcast transmitters, civilian and military radars (fixed and mobile).
- Plastics welders, induction furnaces, microwave ovens and dryers, etc.
- Cellphones, walkie-talkies, wireless LANs, Local Communications
What distance from a ‘hand-held’ is equivalent to the immunity test levels?
<table>
<thead>
<tr>
<th>Typical type of transmitter or radiator</th>
<th>For 3V/m</th>
<th>For 10V/m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domestic, commercial and light industrial generic, and most medical equipment</td>
<td>1.7 metres (5½ feet)</td>
<td>0.5 metres (1½ feet)</td>
</tr>
<tr>
<td>Industrial generic, and medical life support equipment</td>
<td>2.5 metres (8 feet)</td>
<td>0.76 metres (2½ feet)</td>
</tr>
<tr>
<td>Cellphone in strong signal area, ‘intrinsically safe’ walkie-talkie RF power = 0.8 Watts</td>
<td>3.7 metres (12 feet)</td>
<td>1.1 metres (3½ feet)</td>
</tr>
<tr>
<td>Vehicle mobile (e.g. taxicab), Electro-Surgery RF power = 100 Watts, (some ES are 400W or more)</td>
<td>18 metres (59 feet)</td>
<td>5.5 metres (18 feet)</td>
</tr>
<tr>
<td>Multiply distances by ( \sqrt{2} ) for one constructive reflection from a metal surface, by ( \sqrt{3} ) for two reflections, etc.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
EM fields caused by *unintentional* radiators

- **Everything** which uses electricity or electronics always ‘leaks’ and so emits some EM disturbances
  - the higher the rate of change of voltage or current, the worse the emissions tend to be

- Power and signals in devices, printed circuit board (PCB) traces, wires and cables leak EM waves

- Shielded enclosures leak EM waves from apertures, gaps and joints
RF coupling: cables

Disturbance generated by EUT operation creates common mode cable currents which develop emitted fields.

Incoming fields couple with cables to develop common mode disturbance current at interfaces.

Conducted disturbances pass in or out via external connections.
disturbance currents generated by EUT operation create emitted fields which pass through gaps in the shield.

Incoming disturbance fields pass through gaps in shield to induce unwanted currents in the circuit structure.
Electrical Fast Transients: sources

available voltage, peak = $I_L \cdot \sqrt{\frac{L}{C_{\text{stray}}}} + V$

contact breakdown characteristic

unsuppressed $V_C$

suppressed $V_C$

neighbouring conductors

$$V_C$$

$$I_L$$

$$V$$

$L$

$C_{\text{stray}}$

$R_L$
Lightning surge: generation

cloud to cloud

direct strike to primary supply

direct strike to LV supply (esp. rural areas)

ground strike

substation

fault clearance

H-field

fault clearance

load

I_G
Electrostatic discharge: sources

- Movement or separation of surfaces causes a charge differential to build up.
- Charge differential equates to kV between different objects.
- When one object approaches another, air gap breaks down and discharge current flows.
Voltage dips and interrupts

Voltage dips

$U_T = \text{rated voltage}$

Dip as % of $U_T$, 5 cycles

100% dip, 1 cycle

Gradual voltage variations

$0.4 \times U_T$
Radiated magnetic field immunity

Induction coil

Three orthogonal orientations

EUT
Coupling mechanisms

- far-field radiated
- conducted
- near-field induced (capacitive or inductive)
A TYPICAL PROBLEM
A major manufacturer of automotive parts commissioned a series of robotic paint booths

- to save cost, it was agreed that the cabling would be installed by contractors
Robotic paint booth installation  continued...

- The paint booths suffered random (and sometimes dangerous) faults
- 80% of the shielded cables had to be replaced
  - this time using correct shield termination methods
The supplier had not provided any instructions on the correct termination of the screened cables

so, after protracted legal arguments, he picked up the bill for the modifications

and also had to pay the penalty clauses in the contract
EMC CONTROL
MEASURES
EMC control measures

- Primary: circuit design and PCB layout
- Secondary: interface filtering
- Tertiary: screening
Example of ‘layered’ EM mitigation (using shielding and filtering)

Rack cabinet

Chassis (rack) unit

Printed circuit board

Shielding

Example of a cable

Cable filtering
Example: Cutting holes in enclosures

• A single shielded/filtered enclosure could easily achieve suppression of 80dB at 900MHz
  • and is an easy item to purchase from numerous suppliers
  – but cutting a single hole just 15mm in diameter (e.g. to add an indicator lamp) would reduce it to 20dB at 900MHz
SOME BASICS OF EMC
What is current management?

Managing unwanted currents

I_{CM} due to RF, surge, transients etc

Managing wanted currents

ESD

Shielding

Mains

Signal

‘unwanted’ currents

Stray capacitance

Enclosure

Circuit

‘wanted’ currents

Filtering

PS

Ground

Managing wanted currents
Capacitance between plates = \( \varepsilon_r \varepsilon_0 \frac{\text{plate area}}{\text{separation distance}} \)

Impedance \( Z \) ohms = \( \frac{-j}{2 \pi F C} \)

Current and voltage are 90° out of phase
Inductance

• magnetic field around a wire carrying a current

\[ V = -L \cdot \frac{di}{dt} \]
\[ Z = j \cdot 2\pi \cdot F \cdot L \]

• can be concentrated by coiling the wire

Inductance \( L \propto \text{length} \)

• can be concentrated further by including a magnetically permeable material in the path of the field

Inductance \( L \propto N^2 \)

Inductance \( L \propto \mu_r \)
**Bonding conductors**

**Figure 2F** Bonding conductors

Only use bonding conductors where direct metal-to-metal bonding is not practical.

- Long wire is OK for DC-60Hz but poor for higher frequency EMC.
- Minimum wire length is better for control of higher frequencies.
- Short, wide braid strap on its own is good up to approximately 3MHz.
- Short wide metal plates (with multiple bonds) are better for controlling higher frequencies, but direct metal-metal bonds are the best.
Single-point vs. multi-point grounds

- Daisy chain
  - Single-point
  - Multi-point
Differential mode coupling

Differential mode in mains circuits

Differential mode in cables and PCBs

Differential mode in mains circuits
Controlling differential mode coupling

Large loop area – high coupling

Small loop area – low coupling

Twisted pair – coupling is cancelled by alternate half-twists

Uniform magnetic field
Common mode coupling

Common mode in cables and PCBs
- External ground
- Stray capacitance
- Common mode currents ($I_{CM}$)
- Ground impedance

Common mode in mains circuits
- Power supply unit (PSU)
- Line (L), Neutral (N), and Earth (E) connections
- Common mode currents ($I_{CM}$)
RF susceptibility: coupling to cables

A pair of signal wires in a cable ...

… illuminated by a radiated field ...

… creates a common mode current in each wire of the pair, because the illumination is equal for each
When the cable is connected to a circuit ...

... the common mode currents $I_{CM}$ create a differential mode disturbance voltage $V_{DM}$ because of the differing circuit impedances.
When a pair of signal wires are connected to a circuit ...

… intended differential mode currents radiate very little ...

… but the common mode currents radiate a lot
Mode conversion at the interface

How does a circuit create common mode currents?

Unintentional noise voltage due to circuit operation

- Common mode currents driven through a poorly protected interface, may be unrelated to intended signals on cable

- Even a screen can carry common mode currents if it is connected to the wrong place
There must be **no** common mode potential between cable and chassis developed at the interface.

- **Skin depth** $\delta$
- **Interference currents** stay on the outside
- **Signal currents** stay on the inside

**Connector interface must maintain 360° coverage around the inner conductors through the mating shells.**
Filter mode

Differential mode filter

- Differential choke
- Differential capacitor

Common mode filter

- Common-mode choke
- Common-mode capacitors
- GND
Parasitic reactances

Minimum stray capacitance and inductance are required for best performance

Self-resonance

Network attenuation dB

Frequency
Ferrites

Wire through ferrite sleeve

ferrite sleeve over multi-core cable

halved ferrite over ribbon cable

common mode currents create magnetic field and are attenuated

No net magnetic field, so differential mode currents are unaffected
Filtering and Suppression

Power Line Filter

Snap on Ferrite

Bulkhead Filters
Shielding theory: reflection

incident field

reflected field

reflection at change of impedance

\[ E_i \]

\[ E_r \]

\[ Z \]

\[ Z_w \]

\[ Z_B \]

same effect regardless of wall thickness

Transmission line equivalent
Shielding theory: absorption

- **Thick wall barrier**:
  - Impinging field
  - Induced current on surface of barrier
  - Current amplitude decays through barrier
  - Remanent current on far surface
  - Transmitted field
  - Current density through barrier
  - One skin depth $\delta$
  - $8.6\text{dB}$

- **Thin wall barrier**:
  - Reflection from far wall

- **Current density through barrier**
  - $8.6\text{dB}$
Limitations on theory

- Real enclosures are not infinite in extent
- they have imperfections compared to a perfect Faraday cage:
  - they have apertures, seams and joints
  - they are often an irregular shape
  - there are enclosure resonances
  - they include components with complex internal layout
- unknown incident wave impedance
- unknown internal wave impedance
The effect of apertures

\[
SE(dB) = 100 - 20\log[d(mm) \cdot F(MHz)] + 20\log[1 + \ln(d/h)] \quad \text{(for } d < \lambda/2, >> \text{ thickness)}
\]
Fix-Its – RF Enclosures & Shielding

RF Cabinet

Knitted Mesh

Copper Tape
### The EMC margin

<table>
<thead>
<tr>
<th>dB µV/m</th>
<th>Equipment Immunity</th>
<th>V/m</th>
</tr>
</thead>
<tbody>
<tr>
<td>140</td>
<td></td>
<td>10</td>
</tr>
<tr>
<td>130</td>
<td>Equipment</td>
<td>3</td>
</tr>
<tr>
<td>120</td>
<td>Immunity</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
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<tr>
<th>dB µV/m</th>
<th>Equipment Emissions</th>
<th>V/m</th>
</tr>
</thead>
<tbody>
<tr>
<td>74</td>
<td></td>
<td>5mV/m</td>
</tr>
<tr>
<td>66</td>
<td></td>
<td>2mV/m</td>
</tr>
<tr>
<td>47</td>
<td>Equipment</td>
<td>224µV/m</td>
</tr>
<tr>
<td>30</td>
<td>Emissions</td>
<td>32µV/m</td>
</tr>
</tbody>
</table>

**NB**  
\[ \text{dB µV/m} = 20 \log \left( \frac{\text{V/m}}{1 \mu\text{V/m}} \right) \]
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