Electromagnetic Interference (EMI)
Electromagnetic Interference (EMI)

Electronic equipment must be switched off during take-off and landing...

The Heusweiler Motorway Faraday Cage

Clothing, shoes, and optical stores...
EMC Directive

- The ability of the system to operate without interfering with other systems
- The ability of the system to operate despite interference from other systems
- Under *typical* conditions (domestic, commercial, industrial)
Sources of Interference

• Supply voltage interruptions: dips, surges, and fluctuations
• Transient over-voltages on supply, signal, and control lines.
• Radio-frequency fields, both pulsed (radar) and continuous, coupled directly onto equipment or onto its connected cables.
• Electrostatic discharge (ESD) from a charged object or person.
• Low frequency magnetic or electric fields.
Radio Spectrum
UNITED STATES FREQUENCY ALLOCATIONS

THE RADIO SPECTRUM

RADIO SERVICES COLOR LEGEND

ISM - 2450.0 ± 50 MHz

3 GHz
Disturbances on the Mains Supply

- An perfect power supply is not cost-effective!
- Voltage variations
  - UK: ±10%
  - US: National Electric Code (NEC) recommends ±3% in households
- Voltage fluctuations
- Voltage interruptions
- Waveform distortion
- Reactive impedances and harmonic currents
- Transients and surges
Disturbances on the Mains Supply

• Mains Signaling
  • Superimposed signals (3kHz-150kHz)
  • No extra wiring/aerial emission required
  • Installation can be as simple as plugging in the system components
  • No frequency variation from country to country or licensing issues

• ....Same frequency band as motors, power supplies, fluorescent
Electromagnetic Interference

Case to mains cable

Common earth impedance

Common mains impedance

External mains interference

Source equipment

Peripheral

Case to case

Cable to cable

ESD to interface

Input

External mains interference

Source equipment

Victim equipment
Common Impedance Coupling

PROBLEM:

System A

Input

Load

\( I_{LOAD} \)

System B

\( V_N \)

\( V_{IN} \)

Inductance, \( L \), of the wire

System B: input = \( V_{IN} + V_N \)

SOLUTION:

System A

Input

Load

\( I_{LOAD} \)

System B

\( V_{IN} \)
Mains Coupling

Mains equivalent circuit model

![Diagram of mains coupling circuit with source and victim, connected by a 50Ω resistor and 50μH inductor.](image)
Magnetic Inductance

\[ V_N = -M \frac{dI_L}{dt} \]

\( M \) = mutual inductance \([H]\)

\( M \) depends on...

- Loop area
- Loop orientation
- Distance between loops
- Screening material

**EQUIVALENT CIRCUIT**

(magnetic coupling)
Electric Inductance

\[ V_N = C_C \cdot \frac{dV_L}{dt} \cdot \frac{Z_{in}}{R_S} \]

\( C_C \) is the coupling capacitance
\( Z_{in} // R_S \) is victim impedance to ground

\( C_C \) depends on...
- Distance between conductors
- Their effective areas
- Screening material

May be stray capacitances to ground...

System A

\[ V_L \]

LOAD

\[ I_L \]

System B

\[ C_C \]

\[ R_S \]

\[ V \]

EQUIVALENT CIRCUIT (electric coupling)
Mutual Capacitance and Inductance

- **Mutual Capacitance**
- **Mutual Inductance**
Mutual Capacitance and Inductance

• Electric field coupling increases with increasing $Z_{IN}$
• Electric coupling is more of a problem for high impedance circuits
• Magnetic field coupling decreases with increasing $Z_{IN}$
• Magnetic coupling is more of a problem for low-impedance circuits
Radiated Coupling

Complex field geometry, Ratio E/H varies with position
Radiated Coupling

- **Near Field**: Complex field geometry, ratio E/H varies with position.
- **Far Field**: Plane of E-field, plane of H-field, ratio of E/H is constant.

Direction of propagation.
Radiated Coupling

Near field; wave impedance determined by Maxwell’s equations

Wave impedance, $\Omega$

Distance from source, normalized to $\lambda/2\pi$

Electric field predominates

Magnetic field predominates

Near-field impedance may be anywhere in this region
Radiated Coupling

Distance from source, normalized to $\lambda/2\pi$

Wave impedance, $\Omega$

- Electric field predominates
- Magnetic field predominates

transition region
Radiated Coupling

Far field; plane wave. E and H decay with distance at the same rate, therefore the impedance is constant.

Wave impedance, $\Omega$

Distance from source, normalized to $\lambda/2\pi$

Far-field

Plane wave, $Z_0 = 377 \, \Omega$

Electric field predominates

Magnetic field predominates

transition region
Radiated Coupling modes
Radiated Coupling modes

- Differential mode
- Common mode

(Shaded areas indicate part of circuit that couples with external fields)
Radiated Coupling modes

intended circuit

\[ +I_{DM}, +I_{CM} \]

\[ -I_{DM}, +I_{CM} \]

\[ -2I_{CM} \]

stray circuit

\[ Z_A, Z_B, R_L \]
Radiated Coupling modes

Figure 5.10 Radiated coupling modes
Emissions

Figure 5.12 PCB radiated emissions
Emissions

Figure 5.13 Cable radiated emissions
Electrostatic Discharge

c) equivalent circuit and waveform

Figure 5.23 The electrostatic discharge
## Electrostatic Discharge

<table>
<thead>
<tr>
<th>Static Voltage Generation at different Relative Humidity (RH) levels</th>
<th>10-25% RH</th>
<th>60-90% RH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generation Method</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Walking across a carpet</td>
<td>35,000Volts</td>
<td>1,500Volts</td>
</tr>
<tr>
<td>Walking across vinyl tiles</td>
<td>12,000Volts</td>
<td>250Volts</td>
</tr>
<tr>
<td>Worker at a workbench</td>
<td>6,000Volts</td>
<td></td>
</tr>
<tr>
<td>Poly bag picked up from workbench</td>
<td>20,000Volts</td>
<td></td>
</tr>
<tr>
<td>Sitting on chair with urethane foam</td>
<td>18,000Volts</td>
<td></td>
</tr>
</tbody>
</table>

Diagram showing materials with increasing static charge from positive to negative:
- Air
- Human Skin
- Glass
- Human Hair
- Wool
- Fur
- Paper
- Cotton
- Wood
- Hard Rubber
- Acetate Rayon
- Polyester
- Polyurethane
- PVC (Vinyl)
- Teflon
Electrostatic Discharge

Figure 5.24  The cause of secondary discharge
PCB Layout and Grounding

“Ground is a low-impedance path by which current can return to its source”

Figure 6.2 The haphazard system
PCB Layout and Grounding

“Ground is a low-impedance path by which current can return to its source”
PCB Layout and Grounding

a) initial circuit

b) externally induced noise currents

c) revised to prevent ground noise in circuit
PCB Layout and Grounding
Good Practices for EMI Immunity

• Control the flow of interference into and out of the equipment
  • Keep interference paths away from critical logic circuitry
• Add I/O filters / isolation
• Use high-noise threshold logic (e.g. 74HC)
• Avoid edge triggered inputs if possible
• Use a watchdog
System Partitioning

- Critical circuitry (digital or sensitive analogue)
- Non-critical power supply
- Non-critical circuitry
- Screened sub-enclosure
- Filtered interfaces
- Overall enclosure
Twisted Wires!

If \( A = -A_{\text{ret}} \) then \( L_{\text{ret}} = L_{\text{wire}} \cdot (1 - K) \)

Mutual coupling \( K = 0.95 \) for closely twisted pair

Signal return currents \( A_{\text{ret}} \) and \( B_{\text{ret}} \) flow through their local twisted pair return path rather than through ground because this offers the lowest overall path inductance \( L_{\text{ret}} \)
Shielded wires

Preferred: screen grounded only at input end if input is grounded

Stray capacitance between screen and inner compromises separation at high frequencies

Preferred: screen grounded only at source end if source is grounded

Reduced performance: screen grounded at both ends if both source and input are grounded
Go Wire Robots!