Interference distance

Source (culprit)  Coupling  Receptor (victim)

- Conductive coupling
- Capacitive coupling
- Inductive coupling
- Electromagnetic coupling

Countermeasures:
- electrical isolation or electromagnetic attenuation

Figures of Chapter 6: Electromagnetic Compatibility (EMC)
Nodes S as near as possible to the power supply
Interfering magnetic field $H$

\[ V_{i1} \]

\[ V_{i2} \]

\[ H \]

\[ V \]
Single-point reference, single point ground

Reference plane, ground plane

Low-resistance and low-inductance reference plane
Cable shielding

Signal reference

System ground

Power

Chassis ground

Increasing wire cross-section

IC, MCM, PCB grounding scheme

Module grounding scheme

System grounding scheme
Any conductor, housing element, etc

Reference/ground plane
Power supply
0 V
Reference point

IF filter

$V_B$
Earth current $\rightarrow$ Ground resistance

Equivalent circuit

$V_{\text{earth}}$ $\rightarrow$ $R_L$
Disturbance field
\[ E_{out}, H_{out}, (E_{out}, H_{out}) \]

Source (culprit, interference source)

Shield

Residual field
\[ E_{in}, H_{in}, (E_{in}, H_{in}) \]

Receptor (victim, interference sink)

Interference distance
\[ \mu = \mu_0 \]

\[ \mu = \mu_0 \cdot \mu_r \]

\[ \mu = \mu_0 \]

\[ H_i \ll H_a \]
<table>
<thead>
<tr>
<th>Material</th>
<th>Superalloy</th>
<th>Mu metal</th>
<th>Permalloy</th>
<th>Nickel-iron</th>
<th>Carbon steel</th>
<th>Nickel</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\mu_r$</td>
<td>100,000</td>
<td>25,000</td>
<td>4,500</td>
<td>1,000</td>
<td>200</td>
<td>100</td>
</tr>
</tbody>
</table>
Shielding effectiveness $SE_H$ (in dB)

**Sphere**

$$SE_H = 20 \cdot \log_{10} \left(1 + \frac{2}{3} \mu_r \cdot \frac{d}{r_i}\right)$$

**Cylinder**

$$SE_H = 20 \cdot \log_{10} \left(1 + \frac{1}{2} \mu_r \cdot \frac{d}{r_i}\right)$$

**Cube (approximation)**

$$SE_H \approx 20 \cdot \log_{10} \left(1 + \frac{4}{5} \mu_r \cdot \frac{d}{w}\right)$$
Good

Bad

Spot welding with low weld pitch

Adapt weld (do not solder)
Time-varying magnetic field

$B_i$
<table>
<thead>
<tr>
<th>Material</th>
<th>Frequency</th>
<th>50 Hz</th>
<th>800 Hz</th>
<th>1 MHz</th>
<th>100 MHz</th>
<th>10 GHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper</td>
<td>9.6</td>
<td>2.4</td>
<td>0.067</td>
<td>6.7 \cdot 10^{-3}</td>
<td>6.7 \cdot 10^{-4}</td>
<td></td>
</tr>
<tr>
<td>Aluminum</td>
<td>13.3</td>
<td>3.3</td>
<td>0.94</td>
<td>9.4 \cdot 10^{-3}</td>
<td>9.4 \cdot 10^{-4}</td>
<td></td>
</tr>
<tr>
<td>Iron (μ = 300)</td>
<td>1.5</td>
<td>0.38</td>
<td>0.011</td>
<td>1.1 \cdot 10^{-3}</td>
<td>1.1 \cdot 10^{-4}</td>
<td></td>
</tr>
<tr>
<td>Mu-metal (μ = 25 000)</td>
<td>0.333</td>
<td>0.084</td>
<td>2.36 \cdot 10^{-3}</td>
<td>2.36 \cdot 10^{-3}</td>
<td>2.36 \cdot 10^{-5}</td>
<td></td>
</tr>
</tbody>
</table>
$E_i = 0$

Diagram showing a circular region with electric fields indicated by arrows, and terminals labeled with charges and symbols.
Connections for electrical potential equalization
$$I_s \approx \frac{V_2}{L}$$
$H_{\text{out}}, E_{\text{out}}$

Reflection

Absorption

$H_{\text{in}}, E_{\text{in}}$

$Z_{\text{out}} Z_{\text{screen}} Z_{\text{screen}} Z_{\text{in}}$

Outside

Inside
A Steel  
Copper  
Aluminum

Shield thickness  
\(d = 0.8\text{ mm}\)

\(f\)  
\(10^1\)  
\(10^2\)  
\(10^3\)  
\(10^4\)  
\(10^5\)  
\(10^6\)  
\(10^7\)  
\(10^8\)

\(E_{\text{out}} : E_{\text{in}}\)  
\(H_{\text{out}} : H_{\text{in}}\)  
\(1000000:1\)  
\(100000:1\)  
\(10000:1\)  
\(1000:1\)  
\(100:1\)  
\(10:1\)  
\(1:1\)

\(A\)  
Steel  
Copper  
Aluminum

Shield thickness  
\(d = 0.8\text{ mm}\)

\(f\)  
\(10^1\)  
\(10^2\)  
\(10^3\)  
\(10^4\)  
\(10^5\)  
\(10^6\)  
\(10^7\)  
\(10^8\)

\(E_{\text{out}} : E_{\text{in}}\)  
\(H_{\text{out}} : H_{\text{in}}\)  
\(1000000:1\)  
\(100000:1\)  
\(10000:1\)  
\(1000:1\)  
\(100:1\)  
\(10:1\)  
\(1:1\)
Shielding

EMC-compliant wiring

EMC-compliant PCB layout

Selecting technology and components

EMC-compliant electrical and mechanical design, defining the grounding concept
Analog signal conditioning
Analog power electronics
DC-voltage generation
Digital electronics
Power electronics

Power line filter with integrated power switch
Reference conductor for signal voltages (insulated)

Shielding reference conductor (insulated)

Busbar

0V +5V
0V +24V

Module 2
Shield Shield ASG DSG

Module 1
DSG ASG Shield ASG Shield

Power supply
5V –
24V +

Line filter

Ground plane (insulated conductor)

PE N L1 L2 L3
Output driver → Transmission line → Input driver

Interference voltage to ground