Grounding and earthing

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2016-2017

General definition:
- Earth’s ground considered for electrical installations as a reference of 0V
- Variable electrical conductivity – naturally electrical currents are flowing.

Key-roles:
- Lightning current flowing
- Leakage current flowing
- Protection of persons
  (IEC 364 – Electrical Installations of Buildings & IEC 50164 – Lightning protection components)
Earthing/grounding and EMC:
For a lot of EMC phenomena (transient disturbances, HF currents...), earthing conductors are not efficient as they are very long and the used topology means a high impedance versus HF. The only solution is meshing to get equipotentiality. Mesh size: ± λ/10.
All electrical elements, components, should be connected as shielding, screens, CM connections of filters (remember some remarks on good implementation in *Components*).

**Loop between grounding** = surface between 2 grounding cables, resulting of a systematic meshing of ground to insure equipotentiality. Solution? To reduce loop size with a small mesh size.
Grounding loop: surface loop between a power/signal cable and a corresponding grounding cable. Solution? To reduce loop size with a very short distance between power/signal cable and corresponding grounding cable (all along the cables).

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Building:
• ground meshing by level
• connect all metallic structures of building to the ground (pipes, ducts, duckboards…)
• in sensitive zone (computers, data, measurements), consider a small meshed system

Equipment:
• Connect all metallic structures together

Rack:
• a metal plate in the bottom of the rack
• insulating coating and painting!
• good contact between components and metal plate (green-yellow cabling is not sufficient for EMC).
Grounding and earthing

Shielding

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A variable electric field and an infinite conducting wall will induce currents in the wall. These currents will generate a reflected E-field in opposite direction. This is necessary to comply with limit condition \( E=0 \) on the wall. The amplitude of the reflected wave determines the **loss by reflection**. As the wall has a finite conductivity, a part of the current penetrates the wall and a part of this current will be present on the other side of the wall, emitting its own wave. \( E_{\text{incident}} \) over \( E_{\text{transmitted}} \) defines the **shielding efficiency**. The thickness of the wall influences the attenuation of the current. **Loss by absorption** depends on the number of skin depths in the wall thickness.

\[
\frac{E_i}{E_t} > \text{S.E.} = 20 \log \left( \frac{E_i}{E_t} \right) \text{ (dB)}
\]
Skin depth represents the property to limit the current at the internal surface of a conductor. It decreases when: frequency increases, conductivity increases and permeability increases. At each skin depth, E is decreased by 1/e or 8.6 dB. e.g. aluminium, skin depth is 0.015 mm @ 30 MHz.

In the case of high frequencies, very thin conductors are efficient for shielding.

Loss by reflection
These losses are related to the ratio of wave impedance (E/H, in far-field conditions 377 Ω) and impedance of the wall (frequency, conductivity and permeability).
For a good conductor (copper, aluminium), losses by reflection are important.
If frequency increases, losses are decreasing for E and increasing for H.

Plane wave \[ R_{E} = 168 - 10 \log_{10} \left( \frac{\mu_{r}}{\sigma_{r}} \right) f dB \]
E-field \[ R_{E} = 322 - 10 \log_{10} \left( \frac{\mu_{r}}{\sigma_{r}} \right) f^{3} r^{2} dB \]
H-field \[ R_{H} = 14,6 - 10 \log_{10} \left( \frac{\mu_{r}}{\sigma_{r}} \right) f r^{2} dB \]
Loss by absorption

As already mentioned those losses depend of the wall thickness and skin depth, depending of material properties.

If thickness is constant, steel is better than copper regarding those losses.

At high frequency, this is the major part of losses, they are increasing as the square of frequency.

\[ A = 20 \log \left( \frac{E_0}{E_1} \right) = 20 \log e^{t/\delta} = 20.(t/\delta). \log e = 8.69 \cdot (t/\delta) \text{ dB} \]

Where \( t \) is the thickness of the wall and \( \delta \) the skin depth.

Shielding efficiency

The ratio between field without wall and field with wall.

This is the sum of 3 losses:

\[ \text{SE (dB)} = \text{R(dB)} + \text{A(dB)} + \text{B(dB)} \]

R : reflection losses
A : absorption losses
B : contribution of multiple reflections and transmissions inside the wall.
Different kinds of envelops:
- completely conductive (rack, drawer, box);
- metallic structure with insulating panels;
- completely insulating material.

For insulating material, some treatments exist to add a conductive coating. We have already mentioned that it is efficient in high frequency.

Solutions:
- Conductive painting
- Spraying fusion metal
- Metal film deposit
- Vaporisation under vacuum conditions
Solutions:
- Doors and panels separation
- Distance between 2 fixations (screws…)
- Increasing the number of fixations (screws, different sorts of gaskets)
- Contact surfaces to clean: no painting…

**Shielding**
Shielding

Cabling:

- Not shielded cables: filters
- Shielded cables: connections of shielding with structure, walls
- Non electric “cables”: waveguide for non metallic ducts, good connection for metallic ducts
Design rules

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Design rules
Grounding/earthing in racks - connections
Design rules

Power supplies management

- Transformer
  - Equipment perturbateur
  - Equipment sensible
- Non recommandé

Design rules

- Transformer
  - Equipment perturbateur
  - Equipment sensible
- Préférable

Design rules

- Transformer
  - Equipment perturbateur
  - Equipment sensible
- Excellent

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Design rules
Design rules

mauvais :
angles d'intersections
nombreuses boucles
courants faibles et
courants forts mélangés

bon :
angles droits
boucles de surfaces
minimales
courants faibles et
courants forts séparés
(éventuellement par une
séparation métallique)
Design rules

Cabling rules

- Equipotentiality of grounding (LF & HF) is ensured
- Do not use sensitive signals and disturbing signals in the same cable

- Reduce the parallel length of sensitive signals cables and disturbing signals cable
- Shielded cables permits those signals cables in the same duct.
Design rules
Cabling rules

- Keep distance between sensitive cables and distrubing cables (costless and efficient solution) – this distance increases with the length of parallel cables.

Design rules
Cabling rules

- Reduce grounding loop surfaces
- Signal conductor near grounding conductor

* Signaux de classe identique
* : captants bas niveau --- classe 2
- Any unused conductor should be connected to ground at both ends.

- Shielding connections?
  - at both ends?
    - very efficient against external HF disturbances
    - no voltage between cable and ground
- Shielding connections?
  - at 1 end?
    - not efficient against external HF disturbances
    - to delete low frequency signals in shielding called « ronflette »

Design rules
Cabling rules

Protection BF

Design rules
Cabling rules

Protection HF + BF
Design rules

Cabling rules

- Shielding connections?
  - not connected?
  ⚠️ - FORBIDDEN if accessible to touch (voltage between shielding and ground)
  - not efficient against external HF disturbances
Design rules
Cabling rules

[EN 50174-2]
Design rules

Cabling rules

[EN 50174-2]

Design rules
For electronic circuits and PCBs

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Why?

- Frequency is increasing (wireless, Bluetooth)
- Speed in increasing (clock, Mbit/sec)
- $t_r$ and $t_f$ are decreasing
- Components density is increasing (SMD)
- Tracks density /cm$^2$ is increasing

Broadband spectrum interferences

PCB design (PCB design software!)

Circuit design and grounding

Protections classification:

- Primary: circuit design (decoupling, balanced configuration, speed and bandwidth limitations)- PCB design and grounding,
- Secondary: external circuit interfaces, cabling (filtering), connectors,
- Tertiary: full shielding (cost)
1st step: to take care of the division of the circuit

<table>
<thead>
<tr>
<th>Dig. 1</th>
<th>Supply</th>
<th>An. 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>An. 1</td>
<td>I/O</td>
<td>Dig. 2</td>
</tr>
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</table>

Different ports are all over the perimeter – shielding and ports filtering

To spot critical zones:
- sources (µP, video…)
- victims (low level analogue…)

Divided circuit
2nd step: Grounding

- do not confuse ground and earth (PE)
- grounding role: to give a reference for all connections
- low impedance track to send the current to the source
- low transfer impedance solutions
a) To suppress common grounding Z (OK up to some MHz, then $C_p$ et $U_{CM}$ due to length of links)

b) Similar circuits linked together, noisy circuits near grounding point.

c) A lot of short connections ($<0.1\lambda$) for digital circuits.
Track impedance

- Circuit equivalent of a copper plate of 35 microns, length 10 cm, width 0.5 mm

- Inductance approx. 80 nH
- Impedance at 20 MHz 11.3 Ohm
- Impedance at 30 MHz 5.6 Ohm
- Impedance at 60 MHz 3.0 Ohm
- Impedance at 90 MHz 2.4 Ohm
- Impedance at 120 MHz 1.9 Ohm

Grid or meshed grounding

- The number of return path for current to ground should be important to reduce L.
- Tracks with width >>

- The comb configuration is not a good solution.
- Do not interrupt ground plane
- If this interruption is mandatory, add a bridge (as short as possible and near the critical track)
- No slot in the ground plane (multi-layer is ideal).
Design rules
For electronic circuits and PCBs
(part II)

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2016-2017
How to choose the logic family?

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Radiated emission of circuits

**Differential mode**

- R.E.

**Common mode**

- R.E.

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**Table 6.1**

**Table 6.2**

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D.M. ----> R.E. of PCB

Loop = small if dimensions < λ/4, means 1m @ 75MHz
IC loops could considered as small up to some 10² MHz
Maximum E-field of this loop @ 10 m measurement distance:

\[ E \text{ (V/m)} = 263 \times 10^{-12} \times f(\text{MHz})^2 \times A(\text{cm}^2) \times I_s(\text{mA}) \quad \rightarrow \quad +40\text{dB/dec} \]
According to:
$$E (\text{V/m}) = 263 \times 10^{-12} \times f(\text{MHz})^2 \times A(\text{cm}^2) \times I_s (\text{mA}) \quad \text{---}> 40 \text{ dB/dec}$$

**Question:** this PCB needs or not an additional shielding?

**A=10 \text{ cm}^2, \ I_s=20 \text{ mA and } f=50 \text{ MHz}**

\(E=42 \text{ dB}_\mu \text{V/m} \) means 12dB over the limit in class B

So if current \(I\) and frequency \(f\) are fixed, \(A\) could not be reduced, a shielding is necessary.
Cable length resonance @30-100MHz

\[ E \ (V/m) = 1.26 \times 10^{-4} \times f(MHz) \times L(m) \times I_{MC} (mA) \]

if the cable is represented by a short monopole (L<λ/4) @ 10m of the ground
e.g. 1m of cabling, \( E = 42 \)dB\( \mu\)V/m, then \( I_s = 20 \mu\)A (\( I_{ME} \))

---

CM voltage to cable, \( \Delta I \) on ground path
Differential noise voltage \( V_N = \Delta I \omega L \) (between reference ground and cable connection)
\( Z \approx 150\Omega \) (constant with \( f \))
Limit 55022 cl.B

R.E. - Comparaison CM / DM

For the same signal in DM or CM
trapezoidal @12MHz, with τr and τf 3.5ns
CM Ipk 0.1mA in cable, with L 2m
DM 20mA in a loop of 5cm²

\[
E(\text{V/m}) = 263 \times 10^{-12} \times f(\text{MHz})^2 \times A(\text{cm}^2) \times I_s(\text{mA}) \quad \text{loop-IC}
\]

\[
E(\text{V/m}) = 1.26 \times 10^4 \times f(\text{MHz}) \times L(m) \times I_{MC}(\text{mA}) \quad \text{antenna-cable}
\]
R.E. > main source processor clock

Clock @40MHz

Commercial standards: no difference between N.B. and B.B.
- To reduce N.B. with buffer on lines and take care of ground plane.
- To reduce B.B. sources on data lines, video...