Selection and design of an appropriate functional earth (FE) in fieldbus networks in the use of copper-based networks

Speaker: Dipl.-Ing. (FH) René Heidl
Company: Indu-Sol GmbH
Blumenstrasse 3
04626 Schmoelln
The company

- Control networks.
- Localise weak points.
- Ensure the system availability.

Indu-Sol provides comprehensive products and appropriate solutions to improve the liability and stability of your automated network.

We are your partner for planning, installation, operation & maintenance!
### History / milestones

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>2002</td>
<td>Foundation of Indu-Sol by the two General Managers with its headquarter in Gera</td>
</tr>
<tr>
<td>2004</td>
<td>For the first time, Indu-Sol achieved an annual turnover of one million euros</td>
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<tr>
<td>2006</td>
<td>The PROFIBUS-INspektor® is launched on the market</td>
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<td>2009</td>
<td>Relocation from Gera to Schmoelln because of increasing staff</td>
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<tr>
<td>2011</td>
<td>The intended record turnover of five million euros is achieved</td>
</tr>
<tr>
<td>2013</td>
<td>Take over of the complete company building in Schmoelln, Establishment of a company-specific hardware development department</td>
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</tbody>
</table>
Locations

Headquarters: Schmoelln, Thuringia, Germany
Our employees - our potential!

Total: 89 employees

Back office:
- 31 employees in Sales/Order Processing/Marketing/Logistics
- 20 employees in R&D/ product management

Customer service:
- 20 measuring engineers and service technicians
- 7 sales

Training:
- 11 students/trainees/interns
Company development

**Number of Employee**

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**Turnover in thousands of €**

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System availability through reliable communications

Business unit Products
- Monitoring tools
  - INspektors®
  - PROmanage® software
- Diagnostic tools
- Infrastructure components

Business unit Services
- Status quo analysis/acceptance testing of fieldbus networks
- Inspection
- Troubleshooting/emergency service
- Commissioning
- Training

Business unit Consulting/support
- Network planning
- Documentation
- Commissioning
Our expertise

Indu-Sol is:

- Specialist in all aspects of fieldbus technology and Industrial Ethernet
- Experienced expert in the fieldbus relevant EMC environment
- Pioneer and research partner in the field of wireless technology
Workshop structure

Applicable norms
- DIN EN 50310 (VDE 0800-2-310)
- DIN EN 60204-1 (machine guideline)
  Combined Bonding Network CBN
- DIN VDE 0100-444 (installation of low-voltage systems)
  Chapter 8 – equipotential system
- Summary

Practical experiments
- Shielding effect
- Do I need a shielded cable
- How I contact the shield right
- The influence of high shield currents
- BN in star structure – low resistance / BN in mesh structure – low impedance
- Impacts of short circuit caused by isolation problems
Current situation

Intervention statistic on the reasons for disturbed fieldbusses (PB and PN) by the PI Troubleshooting working group

- Common EMC experiences
  “90% of all the EMC disturbances trace back to a faulty functional earth (FE)”

- Common EMC experiences
  “80 % of the later EMC stability is determined by the quality of the functional equipotential system”

- Indu-Sol EMC experiences
  “most of the EMC “field” problems does (on the end) not base on fields around the housing and/or the cable runs”
Applicable informations

Functional earth by Wikipedia

- Function earth (FE) is used to build an electrical installation, electromagnetically stable.
- Function earth (FE) is significant for an undisturbed function of electronic devices especially in a electromagnetic polluted environment like industrial environment.
- Function earth (FE) is essential for the functional operation of electrical plants.
- There are two earth types: protective earth (PE) and functional earth (FE).
Applicable recommendations from the PI

PROFIBUS
Installation Guideline
for Cabling and Assembly
Applicable recommendations from the PI

Assembling PROFIBUS cables

2.6 Grounding and equipotential bonding

Effective grounding and equipotential bonding are very important for the interference immunity of PROFIBUS networks. Grounding and bonding is thus primarily to ensure correct functioning of PROFIBUS, and not for safety reasons. Proper grounding of the cable shield ensures that electrostatic interference is reduced, so minimizing pickup. Equipotential bonding ensures that the ground or earth potential is the same across the network. This, in turn, prevents ground currents flowing through the PROFIBUS cable shield. The following information provides general guidance for the installation of grounding and equipotential bonding.

Please read the manufacturer’s documentation. The instructions often provide information about grounding and bonding requirements and techniques.
Applicable recommendations from the PI

2.6.2 Functional Earth

The functional earth provides a stable zero-voltage reference point for device screening. The device casing and any additional shielding should be connected to the functional earth. In this way any electrostatic interference is diverted to earth rather than causing pickup in the device electronic circuits.

Read the manufacturer’s instructions. Where available, these instructions may provide important information on how to connect the PROFIBUS-devices to the Equipotential Bonding system and the functional earth.

- Some PROFIBUS devices feature a functional grounding terminal. Connect the grounding terminal of the PROFIBUS station to the system ground. The grounding terminal is identified by the Functional Earth Symbol.

Instruction Manual

Functional Earth Symbol
Applicable norms | DIN EN 50310 (VDE 0800-2-310)

Functional equipotential bonding in process and building automation

- DIN EN 50310 (VDE 0800-2-310)
  "Application of earth and equipotential bonding measures in buildings with information technology equipment"

- **Introduction**
  "It is the purpose of EN 50310 to ensure the best earthing and equipotential bonding measures in buildings, where the operation of information technology systems is provided. EN 50310 should be adapted to new buildings at least, but also to existing buildings whenever possible (e.g. during renovation work)."

- **Scope of the norm**
  a) *Electrical safety for the IT equipment* (protection against currents in case of a short circuit)
  b) *Sufficient electromagnetic compatibility of the IT system* (ensuring the EMC protection about the shields)
  c) *Reliable signal reference potential within the entire plant*
Applicable norm | DIN EN 60204-1

Functional equipotential bonding in factory automation

- DIN EN 60204-1 (machinery guideline)
  „Safety of machinery; electrical equipment of machines“

- 8  Equipotential bonding
- 8.1 General requirements

„This section provides for protective and functional equipotential bonding requirements.

Objective of the functional equipotential bonding is the reduction (see 8.3):

- of effects caused by isolation errors influencing machine operation;
  * Residual current in case of a short circuit

- of the effects on sensitive electrical equipment caused by electrical disturbances influencing machine operation.
  * Reduction of effects on the signal reference potential caused by the equipotential bonding
  * Ensuring the shielding function

Usually, the functional equipotential bonding is provided by connecting it to the protective conductor system (CBN). However, where the level of electrical disturbances on the protective conductor system is not low enough for a proper functioning of the electrical equipment, connecting the functional equipotential bonding to an individual conductor for functional earthing might be required...."
Combined bonding network CBN

Functional earth (FE) + Protective earth (BN) = Combined (BN+FE) bonding network (CBN)
Applicable directives | DIN VDE 0100-444

- DIN VDE 0100-444
  „Construction of low-voltage systems“ | part 4-444 protective provisions - Protection in case of interference voltages and electromagnetic disturbance

- 444.5.3 Different structures for equipotential bonding conductors and und earthing conductors
- 444.5.3.2 Protective conductors in a star structured network

„A star-shaped network like this is used in small installations like apartments or small commercial buildings and as equipment, because they are not connected with another by signal cables.“

Typ A (EN 50310) star structure  Typ A (EN 50310) improved star structure  Typ C (EN 50310) mesh structure
Résumé

Summary of standards regarding tasks and application of functional equipotential bonding

- A good FE guarantees the good shielding function (experiment 1)
- CBN star structures are not usefully for FE, but improved star structures (experiment 2)
- A good CBN for FE purpose needs not only a low resisdens, but also a low impedancy to conduct higher frequenz curents
- Electrical safety against residual currents caused of short circuits inside the low voltage distribution system needs a good (FE) (experiment 3)
- Good signal reference potential (no experiment because it is to device dependent)
- Usually the protective earth system (PE) takes also the task of the function earth system (FE). Called, common bonding network CBN.
Experiment 1: Shielding effects

24 VDC

<table>
<thead>
<tr>
<th>Signal generator</th>
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<tbody>
<tr>
<td>Signal wire</td>
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<tr>
<td>Shield</td>
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<tr>
<td>Protective earth</td>
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</tbody>
</table>

Key:

- Signal generator
- Signal wire
- Shield
- Protective earth
Experiment 1: Shielding effects

Earth conductors between cabinet & field

Switch cabinet

Field cabinet

PLC
BUS
FI

Experiment 1:
Coupling path – H-field motor phase to BUS cable
Earth conductors between cabinet & field

Experiment 1: Shielding effects

**Experiment 1:**
Coupling path – H-field motor phase to BUS cable
Experiment 1: Shielding effects

Key:
- Signal generator
- Signal wire
- Shield
- Protective earth

24 VDC

Signaldern

* Measuring point

Shield

BN

Signal generator

20m PROFINET cable

G

IE FC TP Standard Cable
Experiment 1: Shielding effects

Key:
- **1** = Signal generator
- **2** = Signal wire
- **3** = Shield
- **4** = Protective earth

Experiment 1: Shielding effects

- Shielding effects

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<th>Signal wires</th>
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<tr>
<td>Measuring point shield</td>
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<tr>
<td>BN</td>
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24 VDC

Signal generator

24 VDC

Signal generator

20m PROFINET cable

* Measuring point shield

3120m PROFINET cable
Experiment 1: Shielding effects

Key:
- **= Signal generator**
- **= Signal wire**
- **= Shield**
- **= Protective earth**

* Measuring point shield

24 VDC

- Signal wires

I_{parasitic}

20m PROFINET cable

I_{noise}

H

I_{noise generator}

G

Signal generator

Experiment 1: Shielding effects

- Measuring point shield

24 VDC

- Signal wires

1

3

4

Signal generator
Experiment 1: Shielding effects

24 VDC

Signal wires

* Measuring point shield

BN

I_{parasitic}

20m PROFINET cable

I_{shield}

H_{störgen}

I_{noise generator}

G

Signal generator

I_{shield}

Key:

1 = Signal generator

2 = Signal wire

3 = Shield

4 = Protective earth

24 VDC

20m

MET (Main Earth Terminal)
Résumé experiment 1

End of experiment 1: Shielding

- One-sided shield connection, does not help
- Shield connection about capacitors (5nF), does not help
- Both-sided shield connection, without an additional FE connection, does not help
- Too long lines (resistance / impedance) in BN lead to a worse shielding effect.
- Short connectors, tinned (low-impedance) lead to better results.

Start experiment 2: polluted BN is not suitable for FE

Regarding EN 60204: “The interference potential in BN must be kept sufficiently low”, e.g. by well-structured BN (MESH-BN).
Experiment 2: Star structure in BN | low-resistance/low-impedance

- Signal generator
- Signal wire
- Shield
- Protective earth
Earth conductors between cabinet & field

Experiment 2: Star structure in BN | low-resistance/low-impedance
Earth conductors between cabinet & field

Experiment 2: Star structure in BN | low-resistance/low-impedance

Experiment 2: Coupling path – H-field motor phase to BN line
Experiment 2: Star structure in BN | low-resistance/low-impedance

24 VDC

Signal wires

20m PROFINET cable

Key:

- Signal generator
- Signal wire
- Shield
- Protective earth

20m MET (Main earth terminal)

G

Signal generator
Experiment 2: Star structure in BN | low-resistance/low-impedance

Key:

- Signal generator
- Signal wire
- Shield
- Protective earth

24 VDC

Signal wires

* Measuring point shield

20m PROFINET cable

I_{parasitic}

I_N

24 VDC

Signal wires

20m

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20m

I_N

Signal generator
Experiment 2: Star structure in BN | low-resistance/low-impedance

Key:
= Signal generator
= Signal wire
= Shield
= Protective earth

24 VDC

20m PROFINET cable

I_{parasitic}

M

20m shield discharging conductor

I_BN

I_{parasitic}

24 VDC

I_BN

I_{parasitic}

20m

Signal generator

Experimental setup

Appropriate functional equipotential bonding system | René Heidl, Indu-Sol GmbH | 16.07.2015
Experiment 2: Star structure in BN | low-resistance/ low-impedance

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- **Signal generator**
- **Signal wire**
- **Shield**
- **Protective earth**

24 VDC

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**Signal wires**

* Measuring point shield

- **I_{parasitic}**

20m PROFINET cable

- **I_{noise}**

20m shield discharging conductor

**I_{BN}**

20m

**NET (Main Earth Terminal)**
Experiment 2: Star structure in BN | low-resistance/low-impedance

Key:
1. **Signal generator**
2. **Signal wire**
3. **Shield**
4. **Protective earth**

Key:
- **IBN**: 20m shield discharging conductor
- **24 VDC**: MET (Main Earth Terminal)
- **20m PROFINET cable**
- **Signal wires**
- **G**: Signal generator
- **BN**: 20m PROFINET cable
- **noise generator**: 20m PROFINET cable

- Measuring point shield
- Shielding conductor 20m
Résumé experiment 2

End of experiment 2: Star structure in BN is inapplicable for FE purposes

- The shields close the meshes in a star-shaped BN thus becoming a equipotential bonding conductor.
Résumé experiment 2

End of experiment 2: Star structure in BN is inapplicable for purposes of FE

- A shield discharge conductor made of copper, that is as long as the shielded fieldbus cable (tinned wire), does not help.
- If the point of interference is known, small local edges would help.
- If unknown, use mesh BN:
  - Small-meshed (and max. 20m)
  - Tinned wire (low-impedance, already in kHz range)
  - Blank in order to develop lots of grid points and thus small meshes

Start experiment 3: Short circuit
Experiment 3: Short circuit

Key:
1. Signal generator
2. Signal wire
3. Shield
4. Protective earth

- **24 VDC**
- **Signal wires**
- **BN**
- **Measuring point shield**
- **20m PROFINET cable**
- **MET (Main earth terminal)**

**Experiment**

- **24 VDC**
- **Signal wires**
- **BN**
- **Measuring point shield**
- **20m PROFINET cable**
- **MET (Main earth terminal)**

**Key**

- 1. Signal generator
- 2. Signal wire
- 3. Shield
- 4. Protective earth
Experiment 3: Short circuit

24 VDC
+ -

Signal wires

*B Measuring point
shield

BN

20m

24 VDC
+ -

Signal wires

BN

20m

Key:

= Signal generator

= Signal wire

= Shield

= Protective earth

Iparasitic

short circuit

Iparasitic

20m PROFINET cable

Ishort circuit

Iparasitic

20m PROFINET cable

Ishort circuit

Iparasitic

20m PROFINET cable

Ishort circuit

Key:

1 = Signal generator

2 = Signal wire

3 = Shield

4 = Protective earth

Experiment 3: Short circuit

Key:

1 = Signal generator
2 = Signal wire
3 = Shield
4 = Protective earth

24 VDC

+ -

Signal wires

20m

* Measuring point shield

BN

20m PROFINET-Kabel

Iparasitic

Ishort circuit

Iparasitic

Iparasitic

Iparasitic

Ishort circuit

Ishort circuit

Ishort circuit

24 VDC

+ -

Signal wires

BN

20m

20m

20m

20m
Résumé experiment 3

End of experiment 3: Short circuit (insulation error)

- In the event of a bad protective equipotential bonding the shields serve as short circuit conductor.
- The short circuit current (even 24 VDC) acts physically like a high-frequency current and prefers the path of least impedance (tinned wire, e.g. the shield).
- A low-impedance equipotential bonding (mesh BN) protects the electronics.

Conclusion:

- The functional equipotential bonding has lots of important functions and has to be planned.
- CBN is allowed only where the interference potential is low or rather the interference potential has to be reduced.
Measuring tool EMC-INspektor V2

Fig. 1: EMC-INspektor V2

Fig. 2: Example of web interface EMC-INspektor V2
# Measuring tools MWMZ II and LSMZ I

What does low-impedance mean and how to measure it?

<table>
<thead>
<tr>
<th>Conductor</th>
<th>Resistance / Impedance</th>
<th>Current</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protective conductor (PE)</td>
<td>- max. 0,3 ohm at 2,2 kHz / max. 5% of phase current</td>
<td></td>
</tr>
<tr>
<td>Protective equipotential b. conductor (BN)</td>
<td>- max. 0,3 ohm at 2,2 kHz / max. 300mA (BGV A3)</td>
<td></td>
</tr>
<tr>
<td>Functional equipotential b. conductor (FE)</td>
<td>- max. 0,3 ohm at 2,2 kHz / max. 300mA</td>
<td></td>
</tr>
<tr>
<td>Motor cable shields</td>
<td>- max. 0,3 ohm at 2,2 kHz / max. 300mA (ca. 27mW)</td>
<td></td>
</tr>
<tr>
<td>Signal cable shields</td>
<td>- max. 0,6 ohm at 2,2 kHz / max. 40mA (ca. 1mW)</td>
<td></td>
</tr>
<tr>
<td>(comparative values: max. 60W Bandschutz / max. 1,8 W explosion protection)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

![Fig. 1: Mesh resistance measuring clamp MWMZ II](image1)

![Fig. 2: Leakage current clamp LSMZ I](image2)