Electromagnetic Noise and Grounding for TTF2
General Electrical Engineering

- Motivation for EMC
- Electronic Design: Avoid sources
- Coupling of the Noise
- Signal Receivers: Reduce Sensitivity
- Guidelines for the Practice
- Case Study
- Available Components
- Concluding Remarks

Used Literature:
EMV-Messe 2001, Augsburg, Anton Kohling (Siemens)
Seminar EMV-Praxis 2000, Prof. Chr. Dirks
Motivation for EMC:
Why follow EMC regulations?

- Electro Magnetic Compatibility is regulated by EU:
  Legal character
  But DESY as self-user of developments needs not to certify

- System-Integrity Important for successful operation!
  Function of large systems only, if: Do not disturb each another
  Insensitive to external noise
  might be even more stringent as legal!

- Same technique: Therefore today in one short: EMC/SI

For SI: Norm = Standard for all developments, tests,…
  Important for use of commercial products.
  Fulfilling the regulation is important, certifying not required
Motivation for EMC: Costs and Success

Siemens:

<table>
<thead>
<tr>
<th>System</th>
<th>Estimated costs afterwards in %</th>
<th>mended instruments afterwards in %</th>
<th>Remaining malfunctions afterwards in %</th>
<th>mended instruments planned in %</th>
<th>Remaining malfunctions planned in %</th>
</tr>
</thead>
<tbody>
<tr>
<td>EMC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Technical simple</td>
<td>2…5</td>
<td>1…2</td>
<td>&lt;50</td>
<td>&lt;3</td>
<td>2…10</td>
</tr>
<tr>
<td>Technical very complex</td>
<td>5…&gt;10</td>
<td>1…4</td>
<td>10…&gt;50</td>
<td>&lt;5</td>
<td>5…&gt;10</td>
</tr>
</tbody>
</table>

Problems observed at DESY:

- Typical: Voltages GND-GND
  - Repetition frequencies: 3kHz, 20kHz, 100kHz
- Power: 50Hz, 100Hz, 150Hz, 300Hz

DESY: Small Signals ⇔ High Currents
Not everywhere the EMC-optimum possible
  e.g. current return for beam charge

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## Motivation for EMC: Issues to watch

<table>
<thead>
<tr>
<th>Source of noise: System 1</th>
<th>Digital electronics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transferring system: Coupling</td>
<td>Switching power supplies</td>
</tr>
<tr>
<td>Receiver System 1 signal + noise Relevant?</td>
<td>DC/DC converters</td>
</tr>
<tr>
<td>No system is perfect: Neither: Source, Coupling, Receivers ⇒ Do your best/adequate at each</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Protection ground (PE)</th>
<th>Normally: Technique for low emission ⇔ low sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parallel cables</td>
<td>Electronic design,</td>
</tr>
<tr>
<td>Current loops</td>
<td>Choose of commercial products</td>
</tr>
<tr>
<td>Radio waves, not seen since long</td>
<td>Infrastructure</td>
</tr>
<tr>
<td>Electronic design</td>
<td></td>
</tr>
</tbody>
</table>

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Electronic design: Avoid Sources by Limiting Frequency

Fast transients: Pickup by others = noise for others
Faster not better: Use only, what is needed

Sources are:
- Logic family, programmable rise/fall time,
- Switching power, DC/DC-converters

Limit the rise time + amplitude:

Frequency to look at: \( \Theta \) (100MHz)

Transients times [ns]

Document from Fairchild

Document from Prof. Chr. Dirks

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Electronic design: Avoid Sources
by Stabilizing Supply Voltage

Important because:  
- Power couples a lot of components,  
- Large area antennas

⇒ keep fluctuation local and small

High frequencies:
Capacitor inside multilayer board:
\[ \gamma = \frac{C}{A} = \varepsilon_0 \varepsilon_r / d = 70 \text{pF/cm}^2 \]
\[ C / \text{time}^2 = \gamma \cdot \pi \left( \frac{r}{\text{time}} \right)^2 \]
\[ = \gamma \cdot \pi \cdot c^2 / \varepsilon_r = 0.5 \text{nF/(0.1ns)}^2 \]
**Coupling: Principles**

**Radio waves:**
Propagation over long distance without material
Personal experience: No negative since long time.
never worked close to RF-Instrumentation
Mostly because of technical understanding since long time

**Ground-System:**
Problem: together
Protection Earth (PE)
Reference potential $V$
Current compensator $I$

Example: Common ground pass for two users
**Coupling**: Principles, Current on ground

*Old solution:*
Follow with ground from stage to stage

- **Sensor**: Microphone
- **Signal**
- **Preamplifier**
- **Main amplifier**
- **Loud speaker**

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*Today: higher power, lots of Grounds*

- **Sensor**
- **Preamplifier**
- **Main amplifier**
- **Consumer**
- **Computer with own ground**

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**Concept: Unavoidable GND-network**
- Minimal current on ground
- Control of return outside ground

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Coupling: Magnetic Principle

Each loops of current couples to other loop
\[ U_2 = -L_{12}I_1 \text{ ideal} \rightarrow -\mu_0 \cdot A_{\text{Area}} \cdot \frac{\text{Circumference}}{l} \cdot I_1 \]

⇒ Keep return current close to signal
⇒ Keep currents away from uncontrollable PE-ground

Electronic board

No signals across gaps in plane!

Crate

Careful, if both ends of coax connected!

System installation

If complete return to floor:
\[ A = 1m \cdot 2m \quad I = 2(1m+2m) \]
\[ I_1 = 3V/50\Omega \cdot \sin(2\pi \cdot 1MHz \cdot t) - \text{TTL} \]
⇒ parallel cable with no current:
\[ U_2 = 0.48V \cdot \cos \ldots \]

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Coupling: Capacitive Principle, Interruption of Currents

- **Cable** with non-compensated (not completely) voltage-signal
  \[ C/\text{length} = \varepsilon_0 \pi / \ln(\text{distance/radius}) = 12\text{pF/m} \]
  \[ \text{distance}=5\text{mm}, \text{radius}=0.5\text{mm} \]
- Routed on **metal support** ➔ Mirrored current on support
- At interruption of support: What can happen?
  
  Large way around; Use other cable (=noise, crosstalk)

⇒ **Voltage-compensation on small distance**: \( U_2 = -U_1(\text{AC}), I_2 = -I_1 \)
⇒ **Interconnections at small distances (grid) in the ground**
⇒ **Small distances of signal cables to metal support**
Coupling: Bothering Frequencies

- Possible for all

- DC $\nu = 0$ Hz
  large distances, inside conductors (only) offsets
can be kept small with cross sections of conductors

- middle range frequencies $\mathcal{O}(1\text{MHz})$
  propagate into system; conductors and free room
typical effects in circuits and in large electrical environment

- high frequencies $\mathcal{O}(1\text{GHz})$
  return current wants to be close to signal $\Rightarrow$ low emission
  small wave length $\Rightarrow$ Small pickup by large systems
  $\Rightarrow$ reduction of the problem
Don’t forget: Transmission by civilization (Handy, Radio)
  large power at TTF and effects at input diode of circuit

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Signal Receivers: Reduce Sensitivity

What are the problems:
- Current balancing
- Breaking ground loops
- Ground level shifts

Example for coax-cable:
Twisted pair, DuplexCoax similar
- For RF without DC also transformer
- Common Mode coils, ferrits

Gained by differential input:
- Receivers has high input impedance: Very limited pickup
- Large reduction of sensitivity to common mode voltage (<2V)

Price:
- Opening in housing : Reduced ESD, RF has small entrance ring
- Instrumentation amplifier instead of standard Op-amplifier
Guidelines for the Practice: Basics

Signal transmission:
- Use differential drivers
- Use symmetric cables: Twisted, Duplex coaxial
  - Voltage compensation with low capacitive coupling
  - Current compensation with low magnetic coupling
  - low coupling to support and other cables
  - low sensitivity to ground level shifting

Power supply:
- Separation of Current return (N) and protection earth (PE) = Ground
- Current return close to phase
  - Low current on PE and stable PE

Following hints or not a statement, that DESY does it wrong
Guidelines are mainly from A.Kohling
Guidelines for Practice: Infrastructure

- **Group** the cable in categories and route separated:
  
  EMC-noisy/EMC-sensible

- Compensation is not perfect: **Plan the cable support** carefully

- Cables should be **routed close to a ground plane**:
  
  - Reduces the noisy volume
  - **Use metal** as cable support
  - **Interconnect** consecutive cable supports with low impedance

- **Parallel cable channels** interconnect every 20-30m

- **Connect** cable supports every 20-30m to PE

- **Cable channels and racks** should be connected with low impedance
Guidelines for Practice: Signal cables

- Don’t use asymmetric or potential referenced transmission over large distances: *In discussion “large” > 5m*
- Signal shield connected at both ends,
  if not specified other (e.g. analog).

  Discussion:  
  - Contra experience from the practice, 
  - only good, if ground = ground  
    ground free of current  
  - advantage: less E/B-field into the instruments  

  But at DESY: condition for ground is most cases violated  
  *I got better behavior with only one side + diff. receiver*

- Outer shields should regularly be connected at both ends,  
  Discussion see above  

- Current for signal and return close to each another and parallel.  
  also for the branch line to switches.
Guidelines for Practice: Power supply

- Low voltage net (240V) should always be TN-S –type.
  This is: 3-wire or 5-wire connections,
  isolated neutral (N) and protection ground (PE)
  ➡️ low current on explicit PE, metal of building, shields…

  See next pictures:
  Exact one connection from PE to N per transformer
  Attention to extension leads (DESY-stock is OK.)
  interconnections in power distributors (HV/UV)

- Power supply cables should regularly be multi conductor
  (conductor twisted, close to each another)
  The exception should be single wire:
    But rooted parallel and low distance
- Current for signal and return close to each another and parallel.
  also for the branch line to switches.
Concept from Siemens:
A. Kohling

Construction of the building
Cable channels

Main grounding point

Local PE
Transformer

Only connection from PE to N

… distributor (UnterVerteiler)
No connection N-PE

Main distributor (HauptVerteiler)
No connection N-PE

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Minimal configuration: But Current on PE

Price for “no” current is a fifth wire,
but don't forget VDE100 (low voltage regulation)

4. Contact:

N Neutral
and
PE Ground

Bridge from
PE to N

Via the earth, water, lamination

4 visible inputs

No statement, whether both are the same circuit,
But picture might make it easier to understand
Guidelines for Practice: Documentation

- Documents for cables should contain:
  - cable type
  - cable category (EMC, signal, power, analog/digital, etc.)
  - type of internal cable geometry: coax, twisted, etc.
  - type of shielding
  - position of connections of shield (and other) to ground
  - description of signal used / possible on that cable

- Document for installed instruments:
  - possible pattern of noise
  - non fulfilling EMC-regulation

Experience at DESY:

Difficult to fight against noise pickup
Normally noise transmitter not identifiable
   - no understand of the coupling
   - low information for improvement
Case Study for an isolated hut (EOS)

Outside hut: No information about I, U on Ground

Inside the hut
1. Keep current away from PE
   - Main grounding crate, connect all external GND, transform to differential?, decouple external GND.
   - Internal all differential
   - RF might not be a transmitter
2. Metal cable supports and network of GND – keep options
3. Input, if possible optical
4. Left problem:
   3 external GND, likely I ≠ 0
   modulation of external signal?

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**Available Components**

**Electronic development:**

**Analog transmission:** Video-lines, diff. ADC-drivers, (diff. ADC’s)

**Digital transmission:**

Well established: diff. ECL (ECL dying, PECL alive)

diff. NIM (no production of NIM-driver)

RS422 (10Mbps)

optical

last years and new LVDS (100Mbps)

transformer decoupling

**Cables:**

LAN-cables: 4 twisted pairs, individual shield, common GND

15.4dB/100m @ 100MHz, compatible to RG58

Duplex coax: used since long time at DESY
Available components: Comparison of Cables

![Graph showing attenuation vs frequency for different cable types.]

- **Twisted pair Kerpen, megaline 8**
- **Koax: C-50-6-1 (11mm), DESY-Lager**
- **Koax: GX03272 (5.4mm) DESY Lager**

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Available Components: Comparison of Cables

Study for VUV-FEL
Beam loss monitor

Twisted pair

Input pulse

MEGALINE 8, 100m, 10ns input

20ns/div

40% remaining peak height

Cable 11mm, 100m, Typ C-50-6-1

Input (5V, 10ns, 10MHz)

Output

5ns/div

GX 03272, 100m

Input

Output

5ns/div
Concluding Remarks

- Regulation is one thing: No replacement for individual case study

- Small signal together with high currents … is a challenge, needs effort

- Not every thing can be improved later
  Better plan in advance, but also prepare for later repairs

- System installations only function, if all in their duty keeps disturbance and couplings small

- Beside EMC/SI keep priority of personal safety in mind (VDE100)

EMC as legal regulation is an other item.
At DESY only in the starting phases.