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FEB
June, 3rd 2004

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?

- Eelectro 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

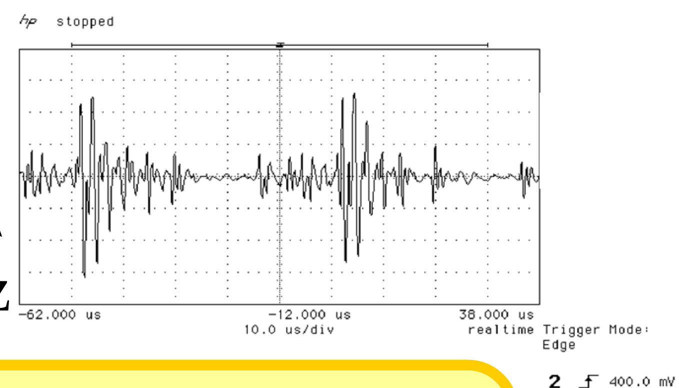
Motivation for EMC: Costs and Success

Siemens:

System	Estimated costs in %		mended instruments in %		Remaining malfunctions in %	
EMC	afterwards	planned	afterwards	planned	afterwards	planned
Technical simple	2…5	1…2	<50	<3	2…10	<1
Technical very complex	5…>10	1…4	10…>50	<5	5…>10	<2

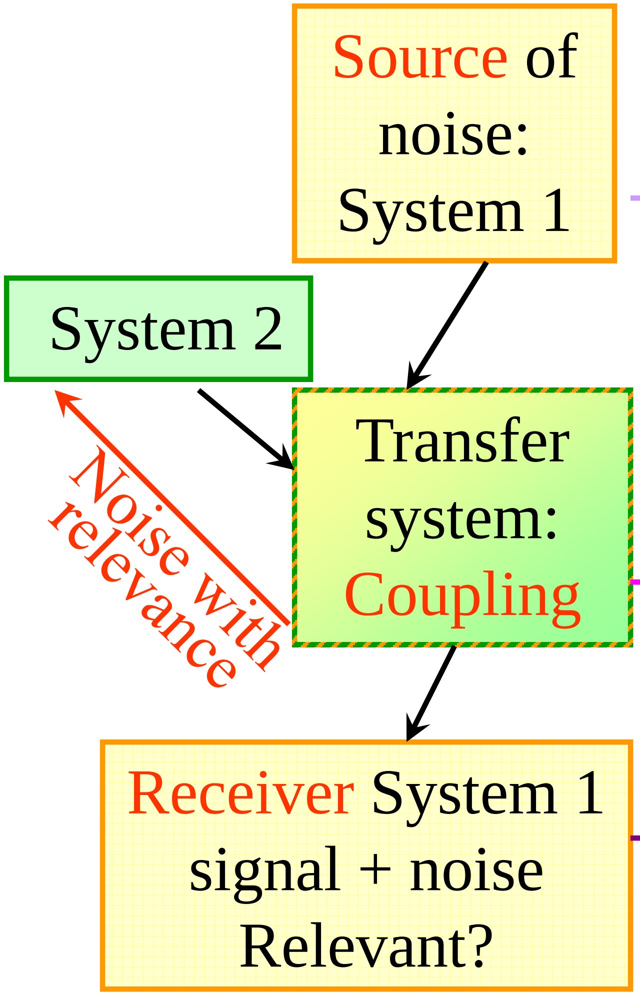
Problems observed at DESY:

- 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

Motivation for EMC: Issues to watch



Digital electronics
Switching power supplies
DC/DC converters
Malfunction of analog electronic
⇨ Electronic design,
⇨ Choose of commercial products

Protection ground (PE)
Parallel cables
Current loops
Radio waves, not seen since long
⇨ Infrastructure
⇨ Electronic design

Current through receiver
Voltage level shifts
⇨ Electronic design

No system is perfect: Neither:
Source, Coupling, Receivers
⇨ Do your best/adequate at each

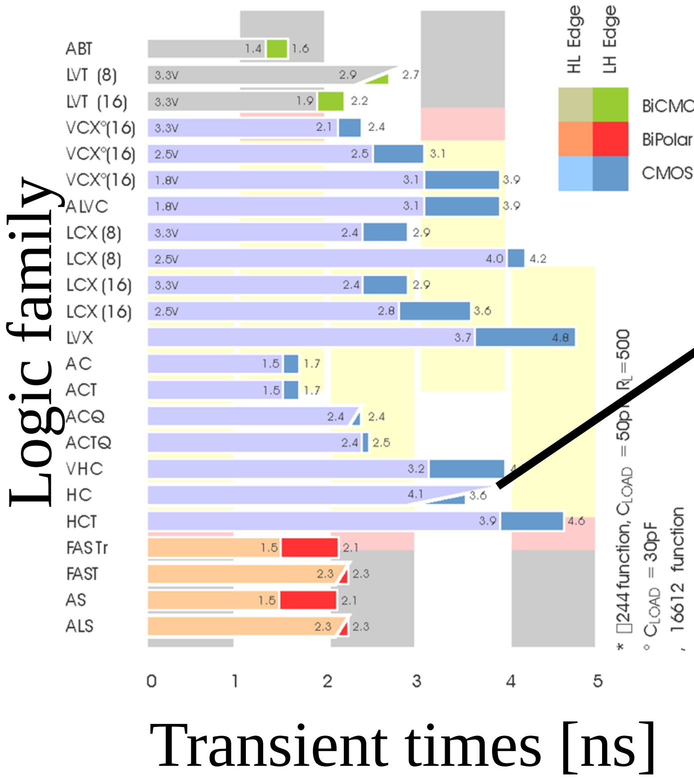
Normally: Technique for
low emission ⇋ low sensitivity

Electronic design: Avoid Sources

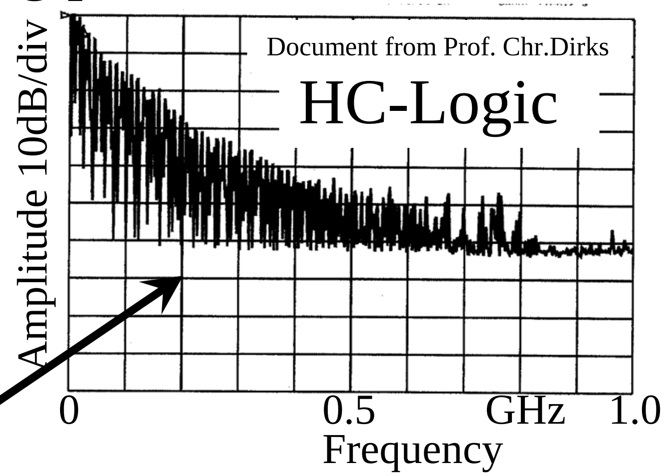
by Limiting Frequency

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

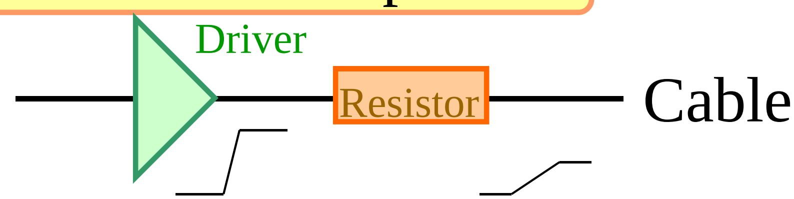


Document from Fairchild



Frequency to look at: $\mathcal{O}$ (100MHz)

Limit the rise time + amplitude:

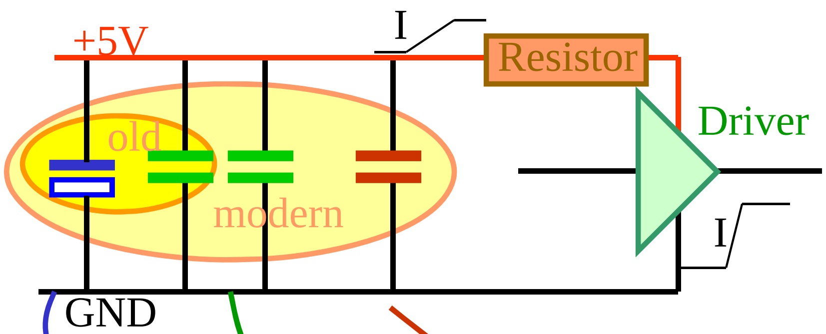


Electronic design: Avoid Sources

by Stabilizing Supply Voltage

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

⇨keep fluctuation local and small



High frequencies:

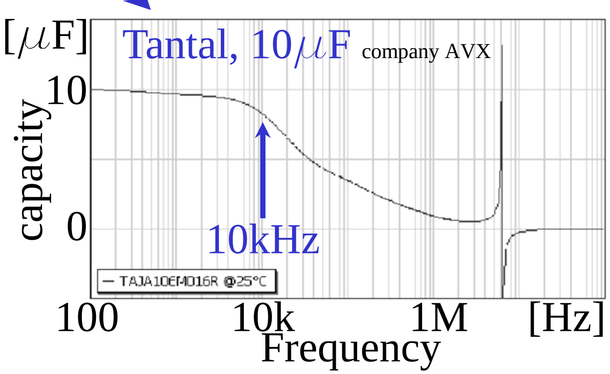
Capacitor inside multilayer board:

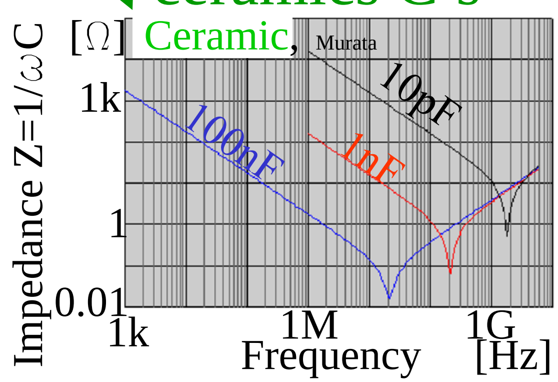
$\gamma = C/A = \varepsilon_0 \varepsilon_r / d = 70 pF/cm^2$

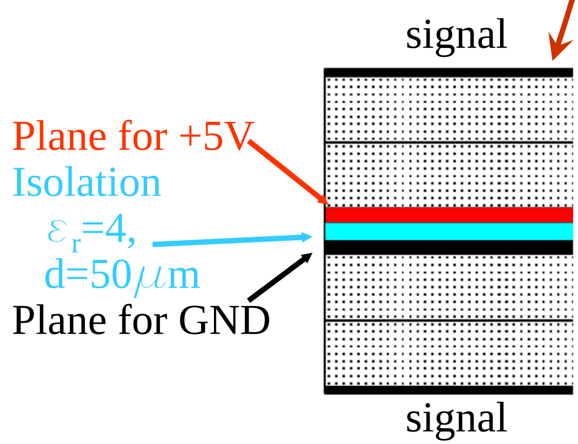
$C/time^2 = \gamma \bullet \pi \left(r/time \right)^2$

$= \gamma \bullet \pi \bullet c^2/\varepsilon_r = 0.5 nF/(0.1 ns)^2$

Combination of ceramics C's







Coupling: Principles

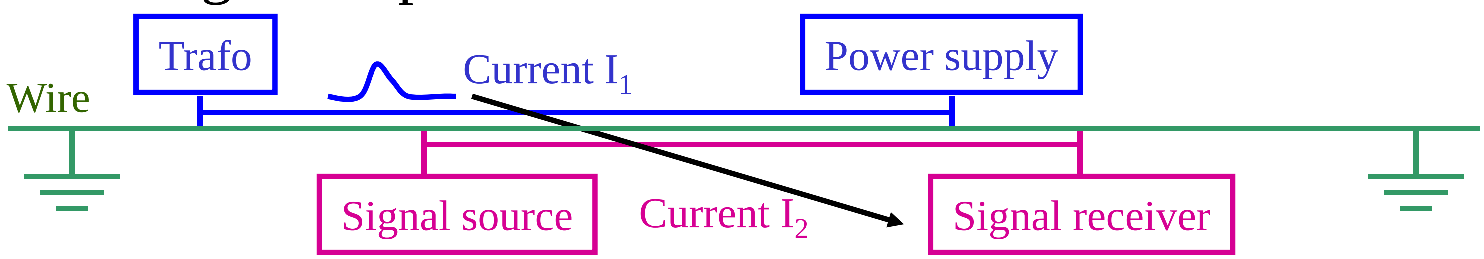
Radio waves:

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:

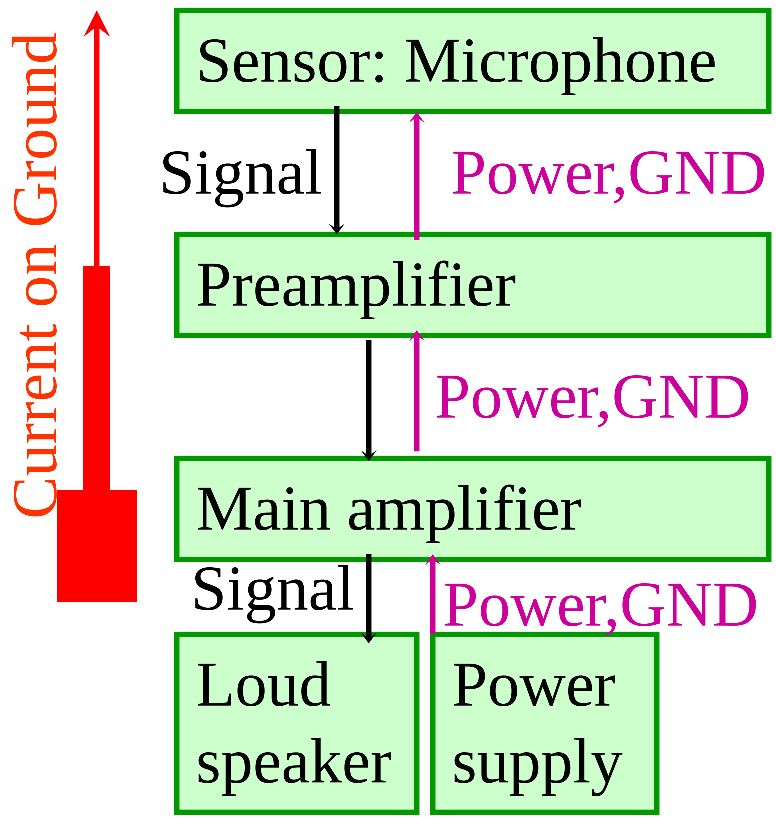
Problem: together
- Protection Earth (PE)
- Reference potential V
- Current compensator I

Example: Common ground pass for two users

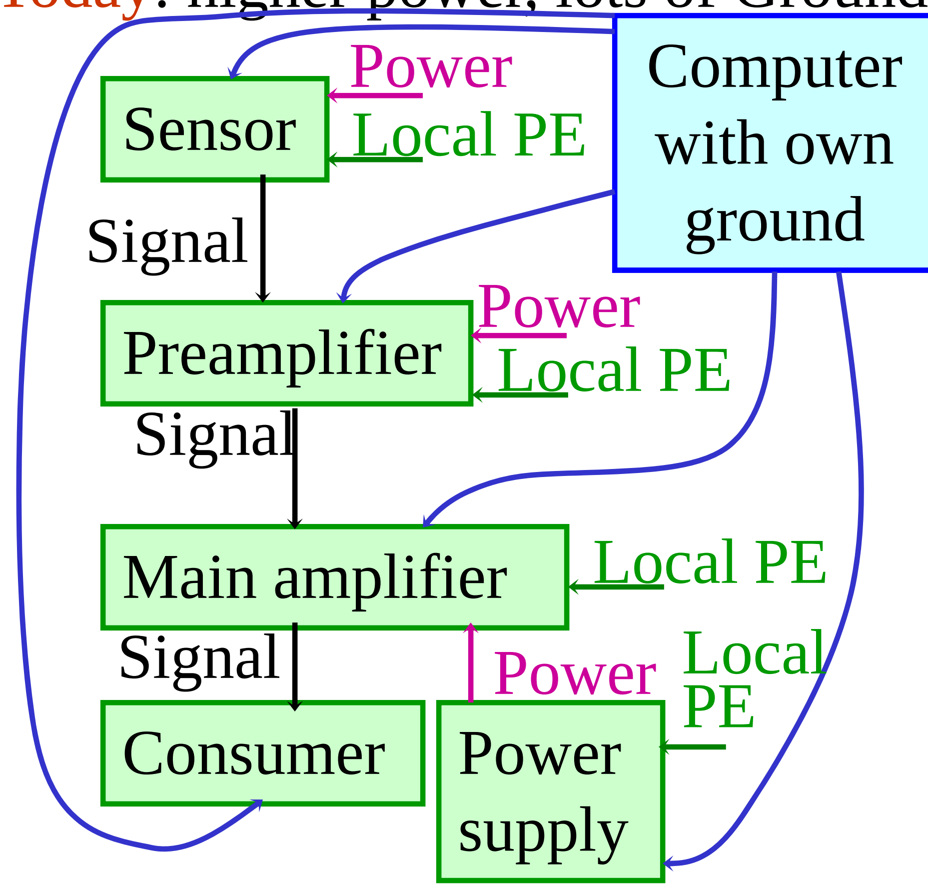


Coupling: Principles, Current on ground

Old solution:
Follow with ground from stage to stage



Today: higher power, lots of Grounds

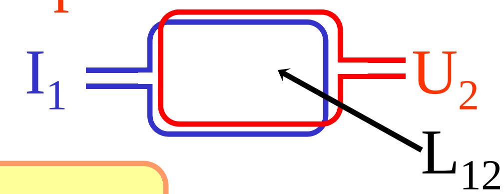


Concept: Unavoidable GND-network
- Minimal current on ground
- Control of return outside ground

Coupling: Magnetic Principle

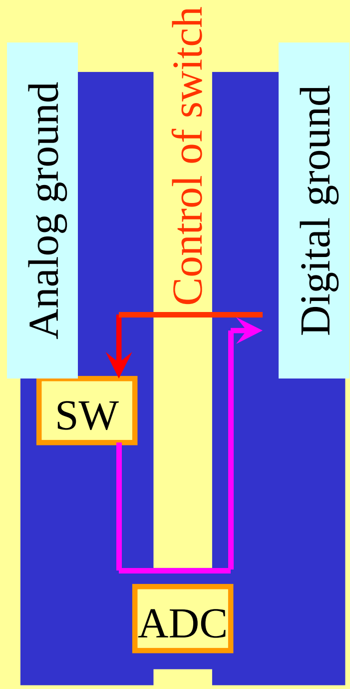
Each loops of current couples to other loop

$$U_2 = -L_{12}\dot{I}_1 \overset{\text{ideal}}{\rightarrowtail} -\mu_0 \bullet A_{Area}/\ell_{Circumference} \bullet \dot{I}_1$$



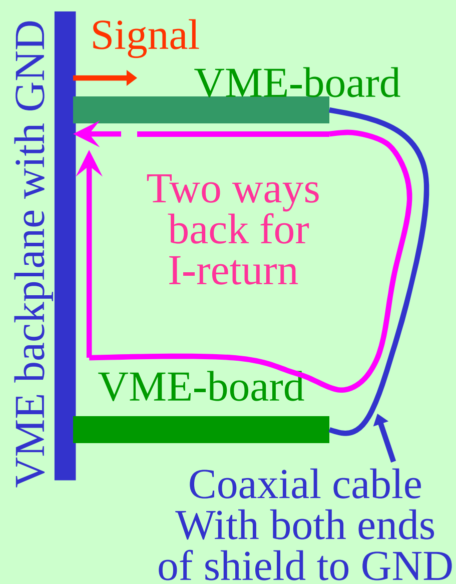
- ⇨ Keep return current close to signal
- ⇨ Keep currents away from uncontrollable PE-ground

Electronic board



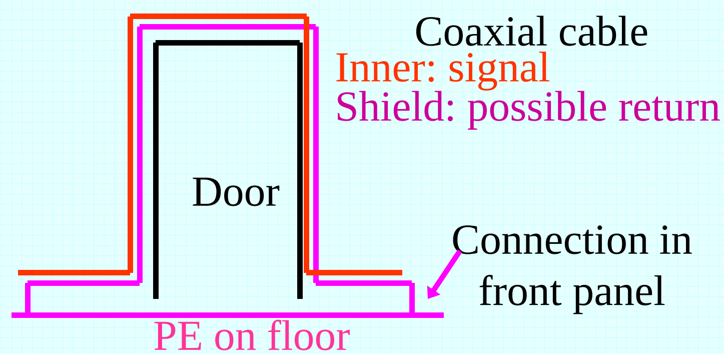
No signals across gaps in plane !

Crate



Careful, if both ends of coax connected !

System installation



If complete return to floor:

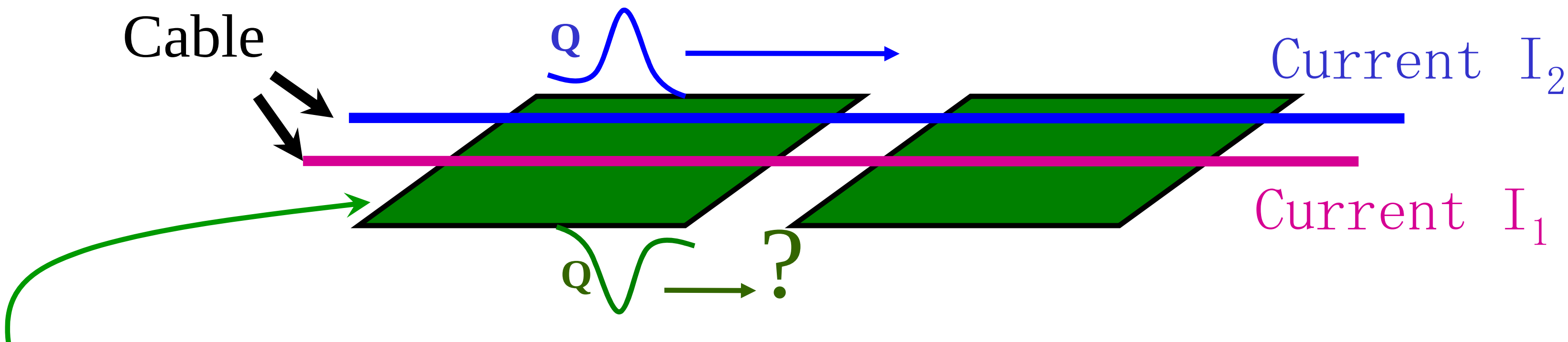
$A = 1m \bullet 2m \quad \ell = 2(1m + 2m)$

$I_1 = 3V/50\Omega \bullet \sin(2\pi \bullet 1MHz \bullet t)$ -TTL

⇨ parallel cable with no current:

$U_2 = 0.48V \bullet \cos\ldots$

Coupling: Capacitive Principle, Interruption of Currents



- Cable with non-compensated (not completely) voltage-signal
  C/length=$\varepsilon_0\pi$/ln(distance/radius) = 12pF/m
  distance=5mm, radius=0.5mm
- Routed on metal support ➡ Mirrored current on support
- At interruption of support: What can happen?

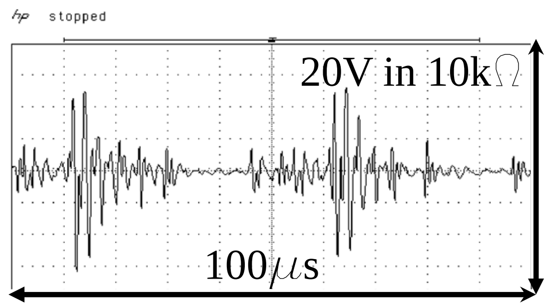
  Large way around; Use other cable (=noise, crosstalk)

⇨ Voltage-compensation on small distance: U_2=-$U_{1(AC)}$, 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

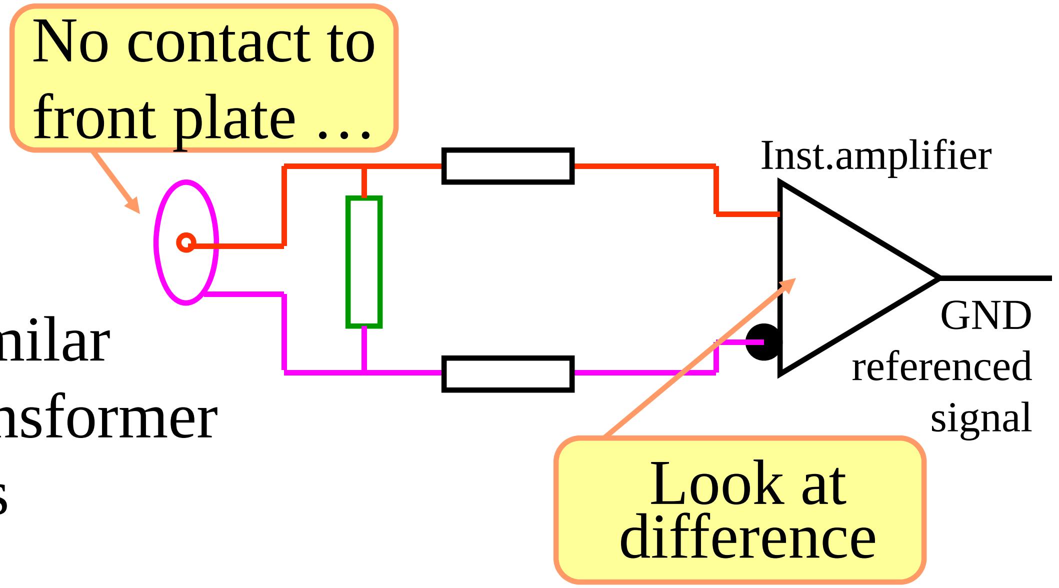
- middle range frequencies $\mathcal{O}$(1MHz)
  propagate into system; conductors and free room
  typical effects in circuits and in large electrical environment

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

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

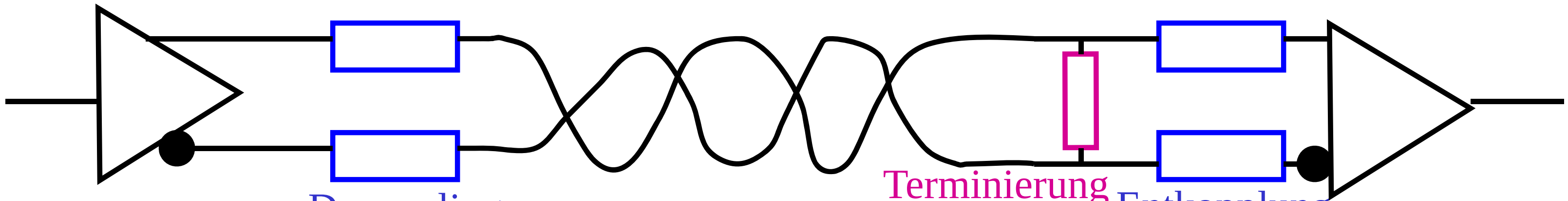
Gained by differential input:

- 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

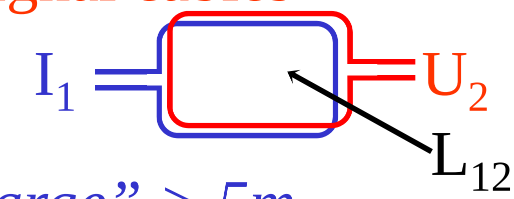
- Cables should be routed close to a ground plane:
  ➩Reduces the noisy volume
    - Use metal as cable support
    - Interconnect consecutive cable supports with low impedance

- 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

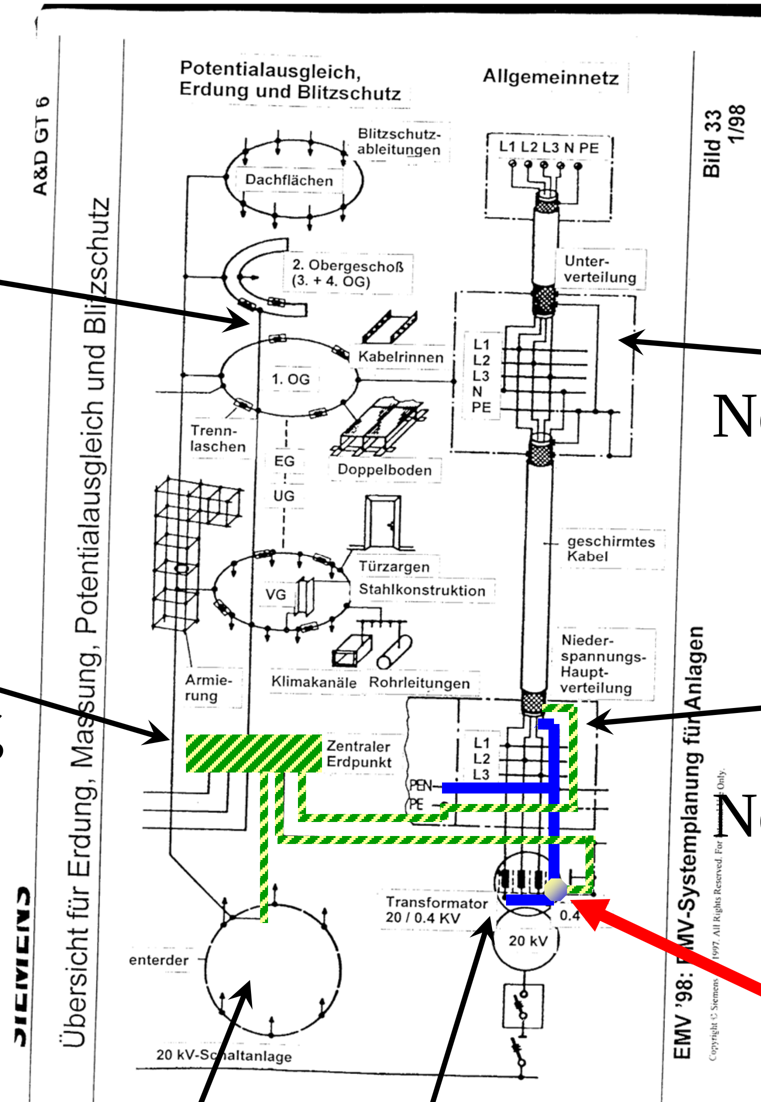
- Current for signal and return close to each another and parallel.

  also for the branch line to switches.

Concept from Siemens:

A.Kohling

Construction of the building
Cable channels



… distributor
$(U_{nter}V_{erteiler})$
No connection N-PE

Main grounding point

Main distributor
$(H_{aupt}V_{erteiler})$
No connection N-PE

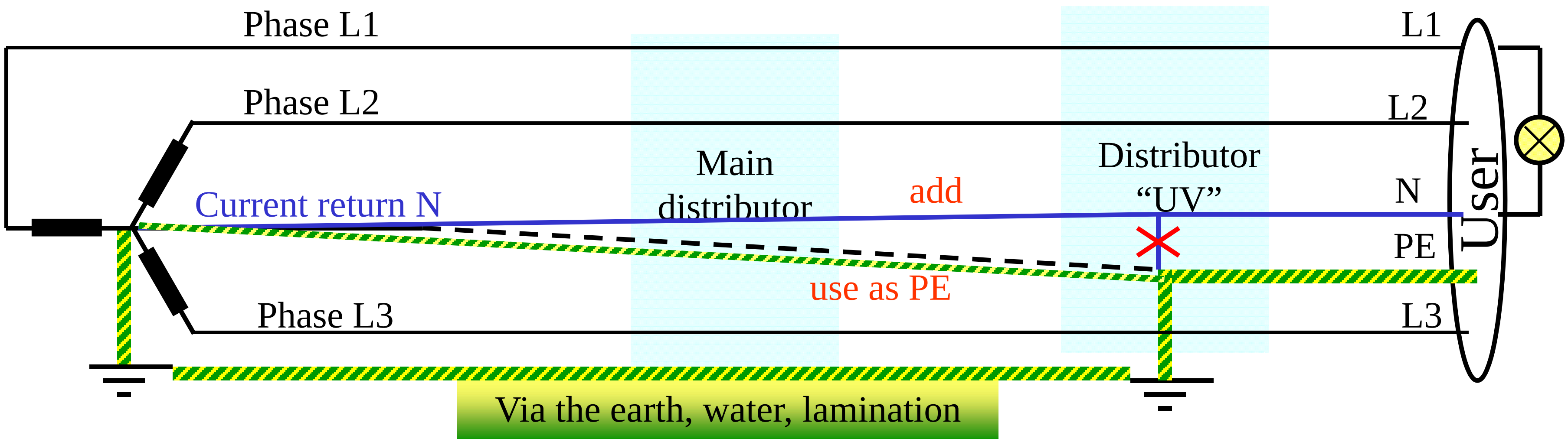
Only connection from PE to N

Local PE

Transformer

Minimal configuration: But Current on PE

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

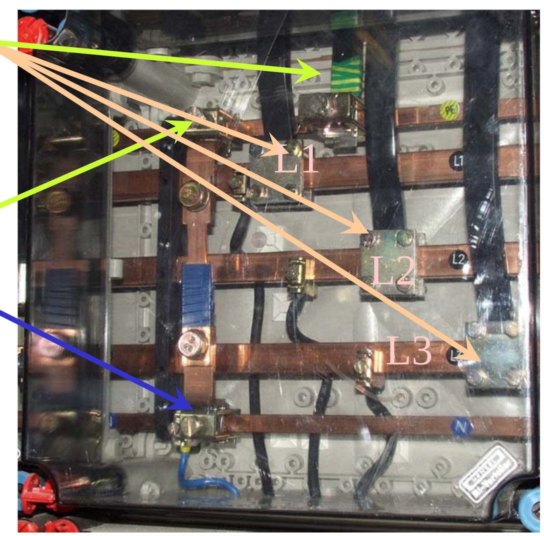


Transformer at DESY

4. Contact:
N Neutral
and
PE Ground

4 visible inputs

Bridge from PE to N



Distributor (UV) at DESY

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….)
- type of internal cable geometry: coax, twisted,….
- type of shielding
- position of connections of shield (and other) to ground
- description of signal used / possible on that cable

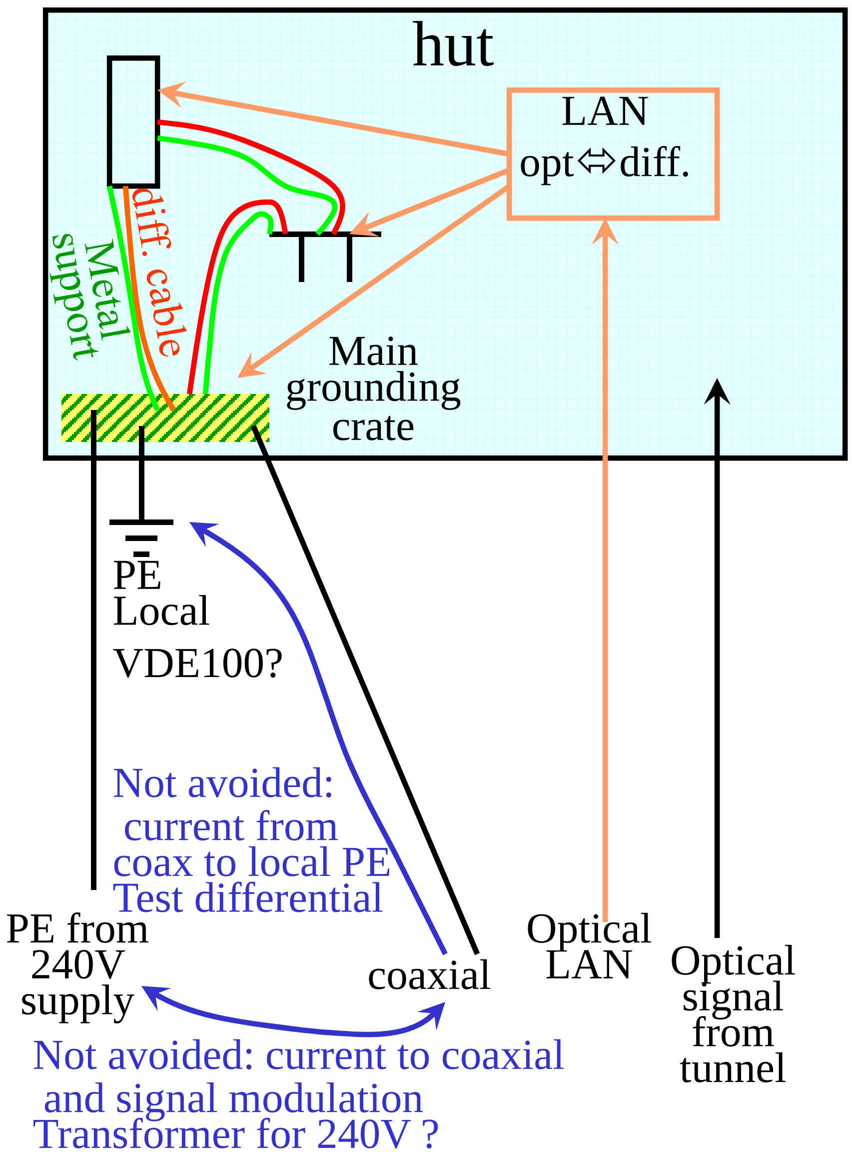
-Document for installed instruments:

- 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 a 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?

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

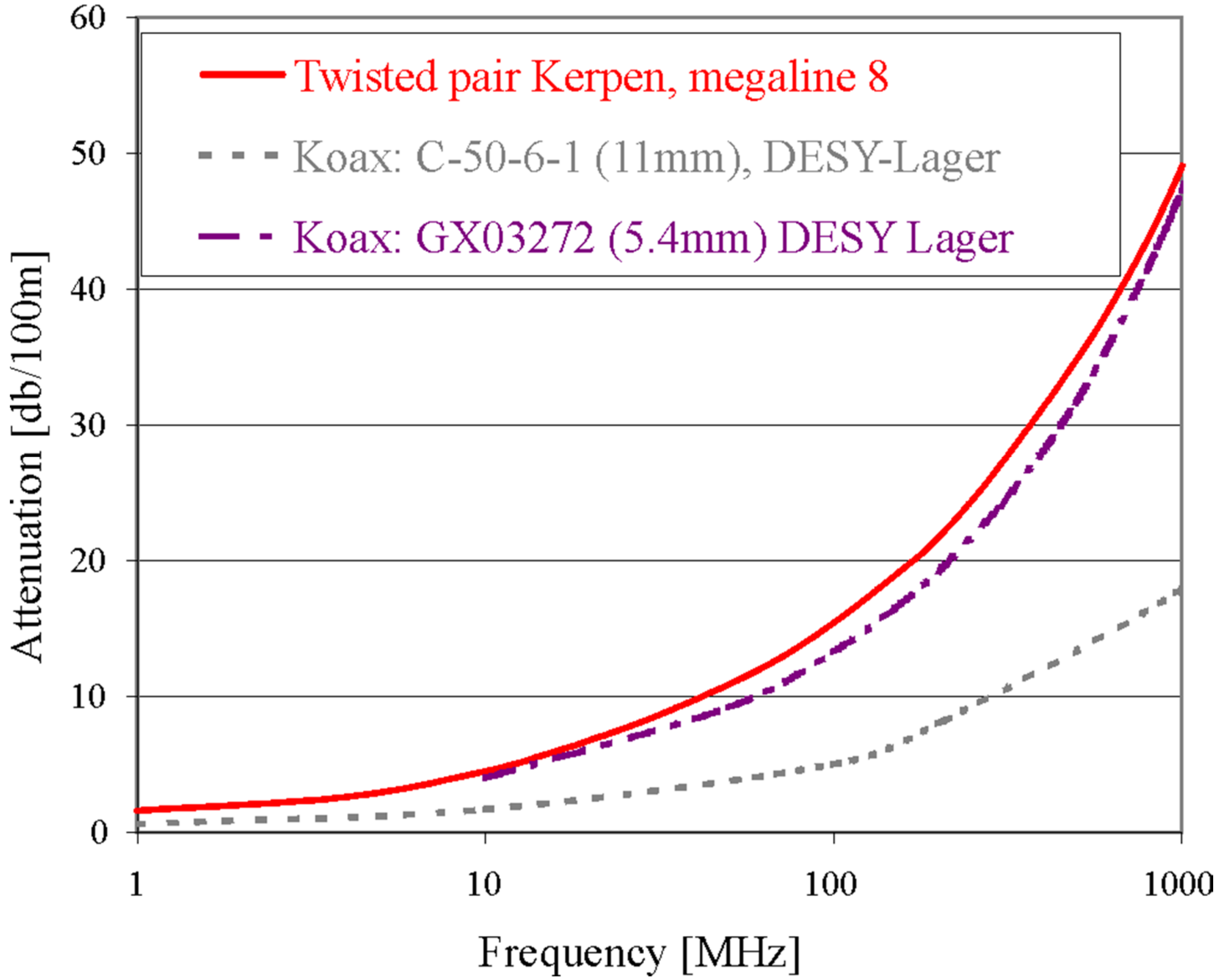
last years and new LVDS (100Mbps)
transformer decoupling

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

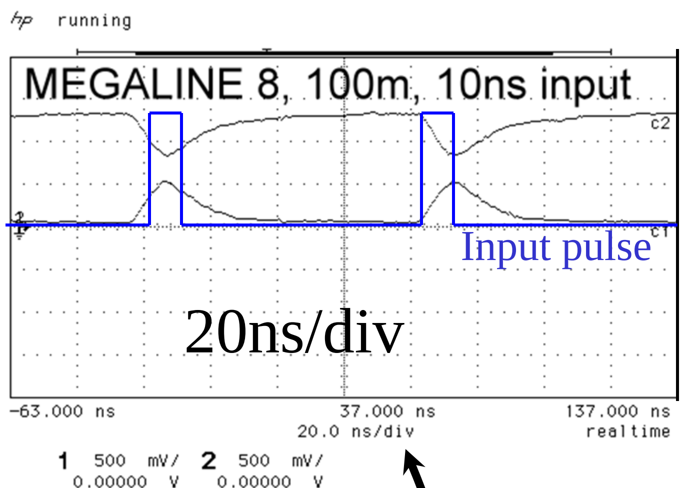
Available components: Comparison of Cables

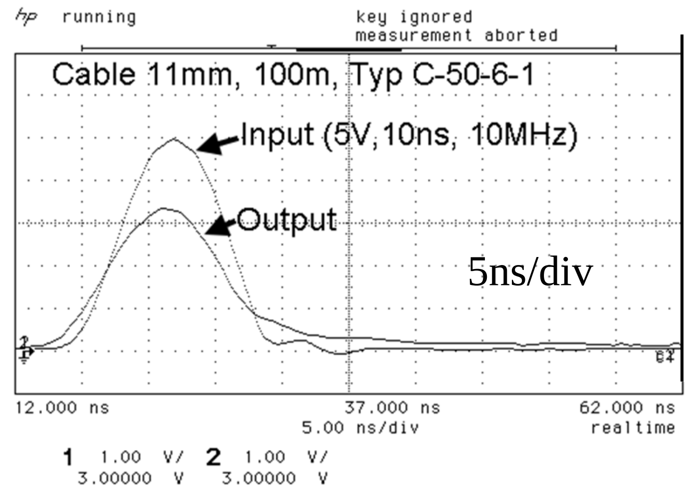


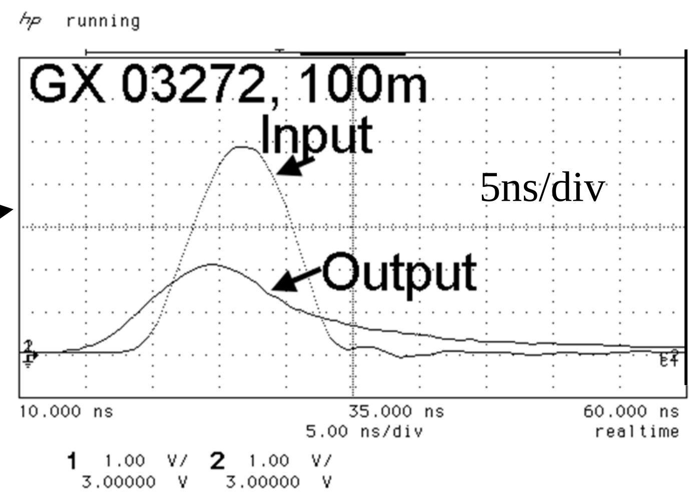
Available Components: Comparison of Cables

Study for VUV-FEL
Beam loss monitor

Twisted pair







40% remaining
peak height

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.