EMI&EMC at TTF2
-motivation to for careful treatment-

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- ***definition***
- ***coupling***
- ***examples at TTF2: LLRF, Toroids, …***
- ***pulsed cables***
- ***summary***

Definitions

- EMI = Electromagnetic Interference

Unwanted electromagnetic emissions, generated by electronic or electrical devices, that degrade the performance of another electronic device.

The interference is produced by a source emitter and is detected by a susceptible victim via coupling path. The coupling path may involve one or more of the following coupling mechanisms:

- Conduction (electric current)
- Radiation (electromagnetic field)
- Capacitive coupling (electric field)
- Inductive coupling (magnetic field)

Maximum acceptable levels of EMI from electronic devices are detailed i.e. by the FCC = Federal communications commission (US)

Definitions

- EMC = Electromagnetic compatibility

The ability of a device, unit of equipment or system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment.

Common methods of noise reduction:
proper equipment circuit design, shielding, grounding, filtering, isolation, separation and orientation, circuit impedance level control, cable design, cable distribution, and noise cancellation techniques.

EMC is regulated in EU: legal character,
but DESY as self-user of developments needs not to certify!
Requirements on devices might be even more stringent as legal!

Motivation for EMC

• System-Integrity: Function of large system only successful if the perturbation of the sub-systems to each other is small.

→ Interdisciplinary topic

• Pulsed operation: The combination of

-high pulsed currents and voltage sources (source emitter) and

-the need of high precision measurements (susceptible victim)

is especially critical (transient effects).

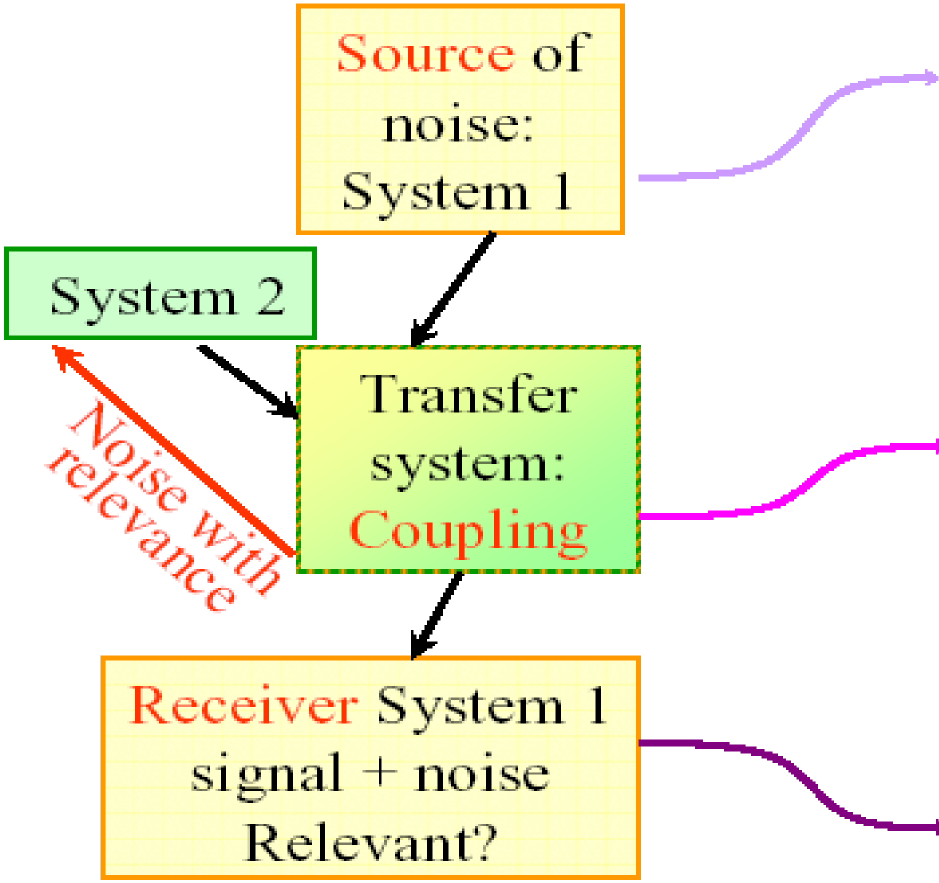
→ Special care depending on the specific system required

• Cost and success: Studies in industry (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

→ Increase of costs, machine commission time and performance!

Motivation for EMC



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

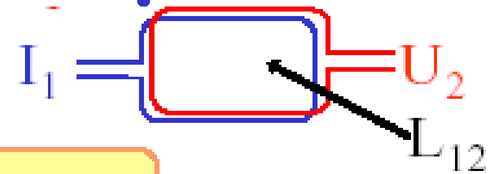
Normally: Technique for
low emission ⇆ low sensitivity

Courtesies: P. Göttlicher

Coupling: magnetic principle

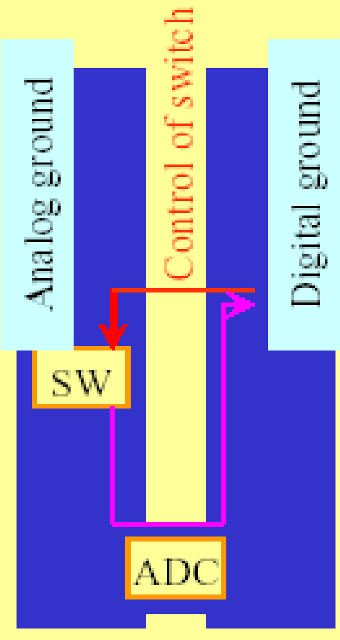
Each loops of current couples to other loop

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



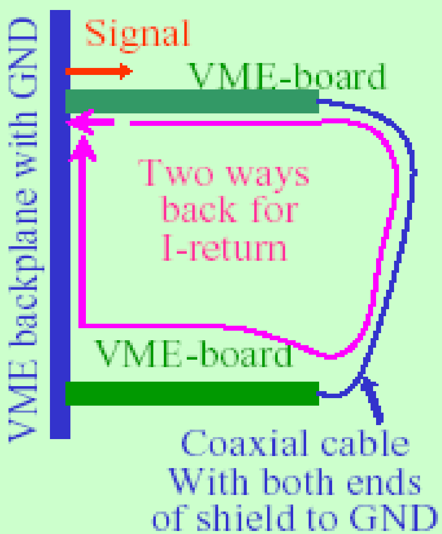
⇨ Keep return current close to signal
⇨ Keep currents away from uncontrollable PE-ground

Electronic board



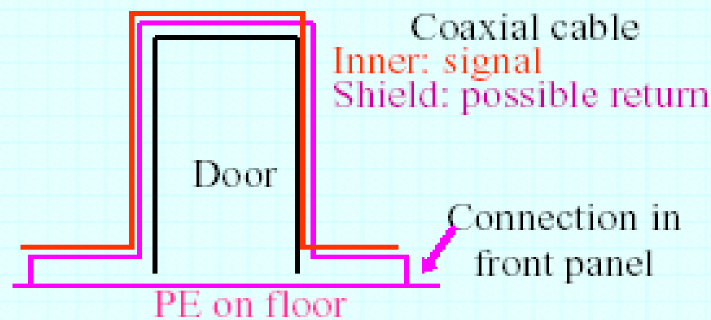
No signals across gaps in plane !

Crate



Careful, if both ends of coax connected !

System installation



If complete return to floor:

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

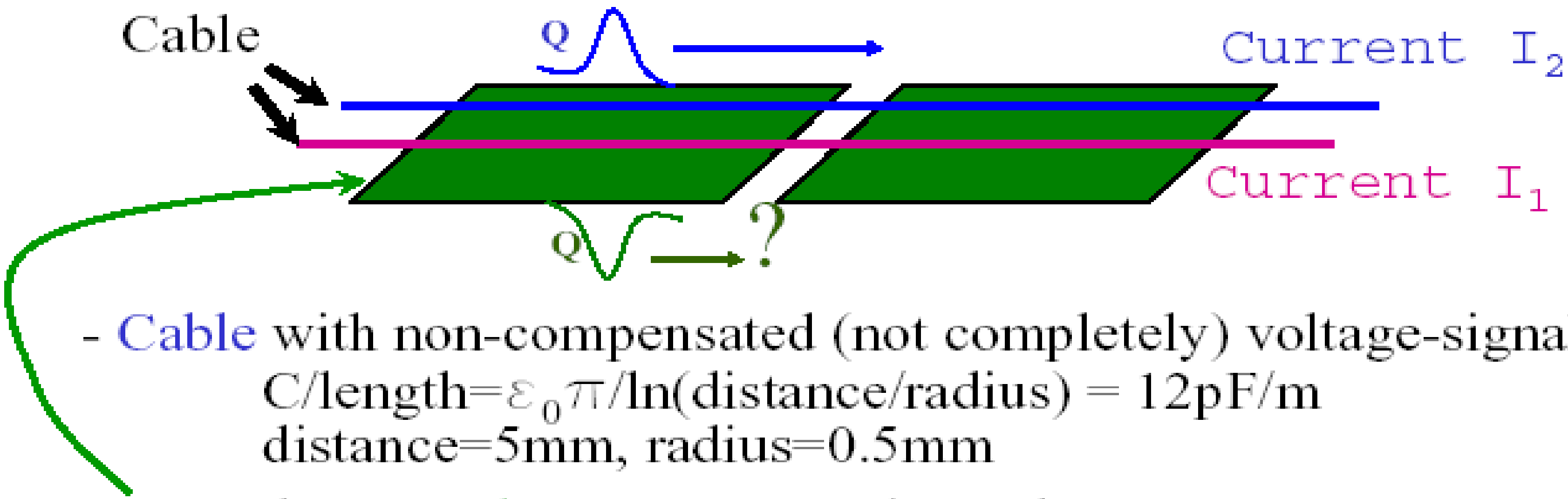
$I_1 = 3V/50\Omega \cdot \sin(2\pi \cdot 1MHz \cdot t)$ -TTL

⇨ parallel cable with no current:

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

Courtesies: P. Göttlicher

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?

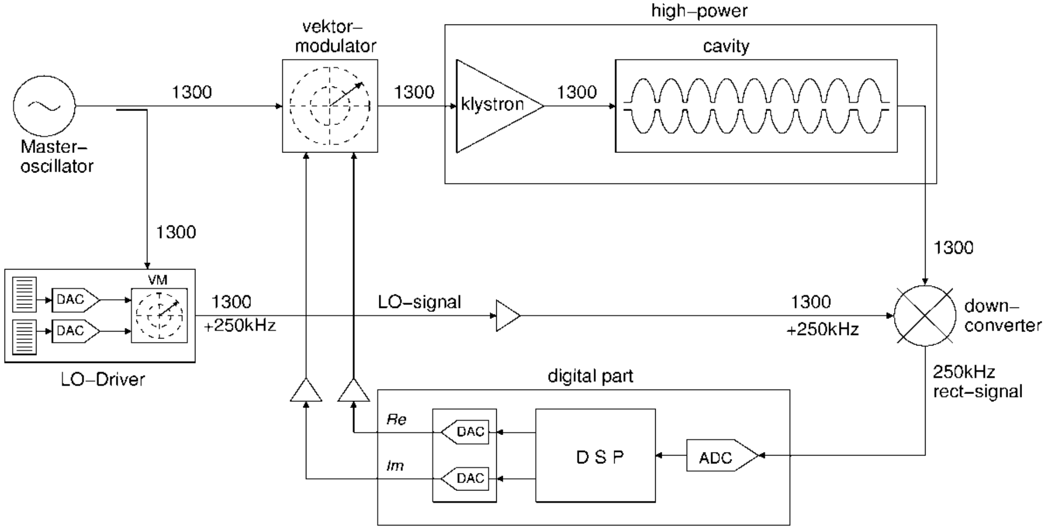
  Large way around; Use other cable (=noise, crosstalk)

⇨ 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

Courtesies: P. Göttlicher

Example: Sensitive detection in LLRF

- LLRF system

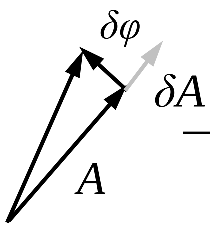


$$\delta U_{TTF2} \approx 10 \times \delta U_{XFEL} \approx 0.1^{\circ}$$

- **Stability requirements on phase and amplitude of the vector sum of the cavity field vector :**

Amplitude stability : $\frac{\delta A}{A} < 10^{-4}$
and linearity

Phase stability : $\delta\varphi < 0.01°$

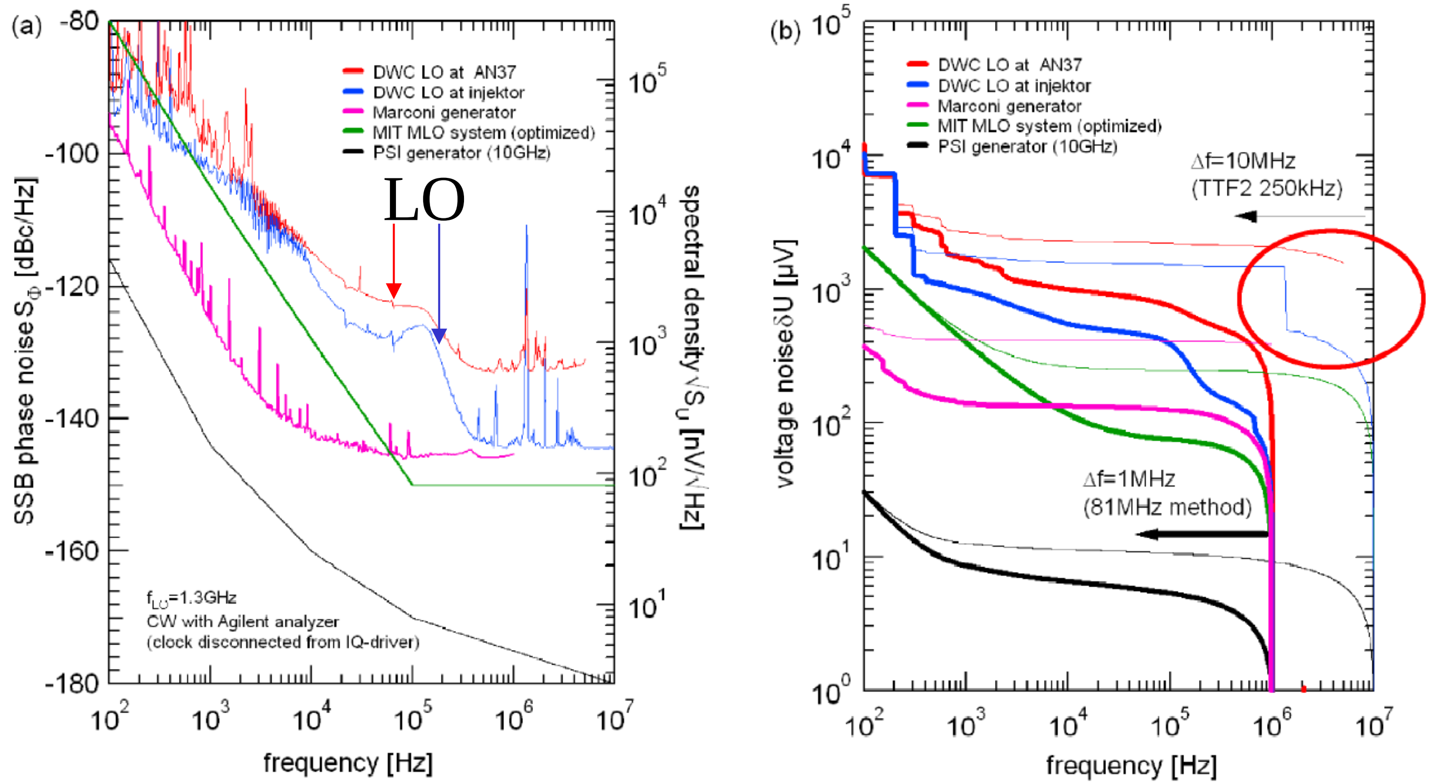


$\delta U_{XFEL} < 100 \mu V$
(normalized to A=1V)

Courtesies: F. Ludwig

Example: Noise in LLRF system

- Noise conversion of the LO-signal at down-converter from master-oszillator : $\delta U(f) = \sqrt{\int_f^{\Delta f} S_U(f')df'}$



$\delta U_{MO} \approx 10 \times \delta U_{XFEL}$

Large noise signal from LO (large difference at injector or Anbau)

Courtesies: F. Ludwig

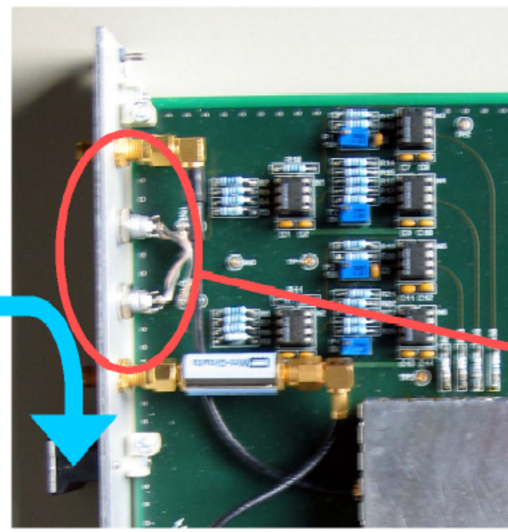
Example: Noise in LLRF system

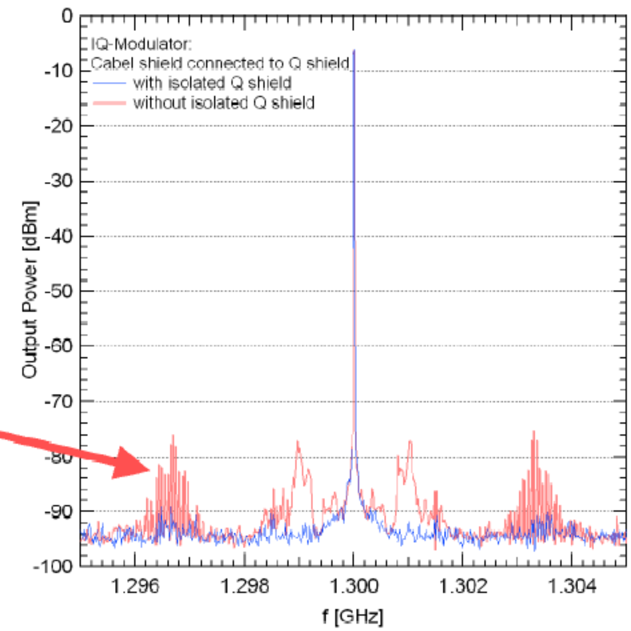
Due to improper design additional sidebands are generated (internal problem, be solved)

- **Shielding, cable effects and rf-packaging :**

Currents to undefined ground

Metallic RF-packaging :

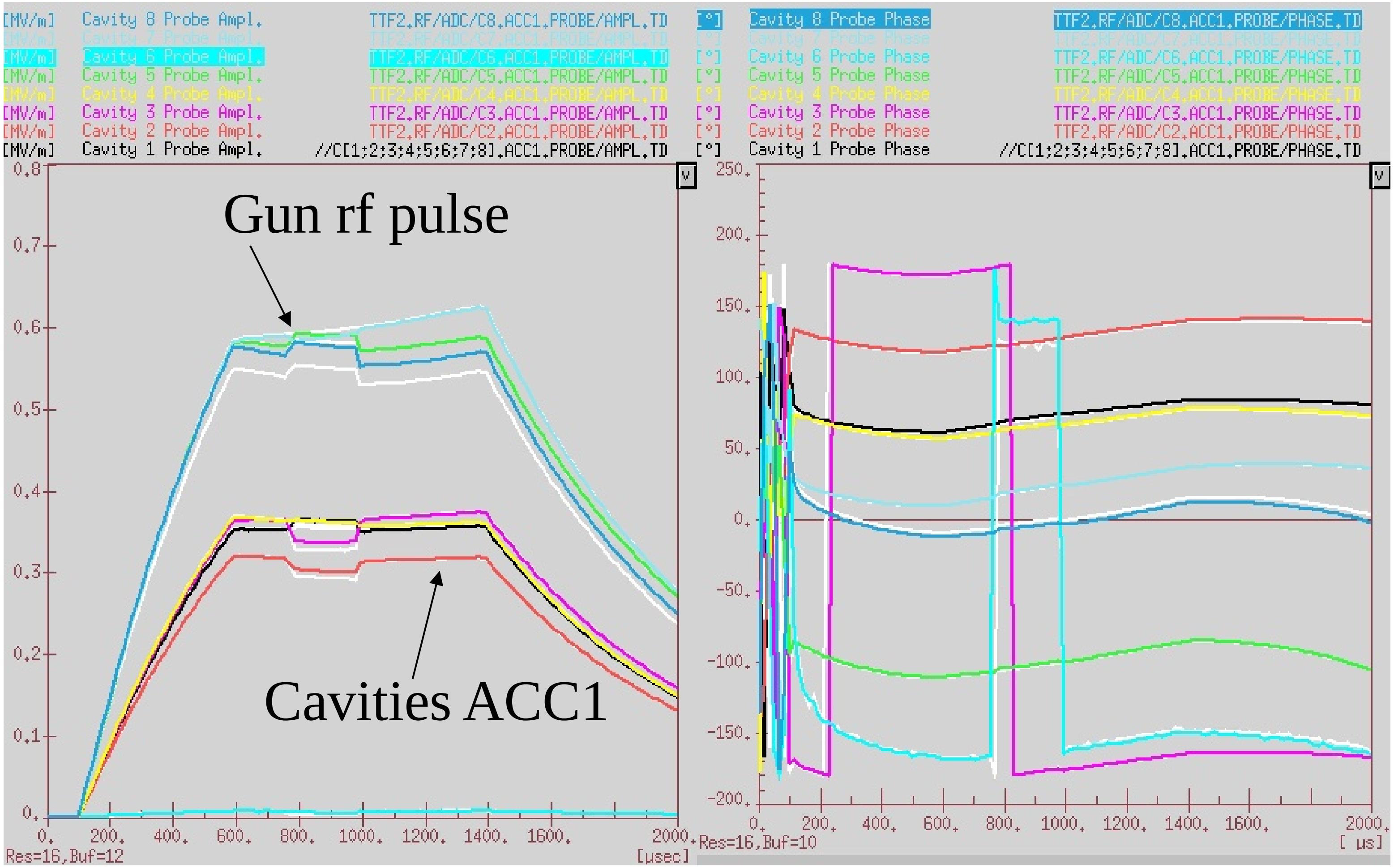




Courtesies: F. Ludwig

Example: Noise in LLRF system

- Cross talk observed to gun RF (03.Nov.2004)



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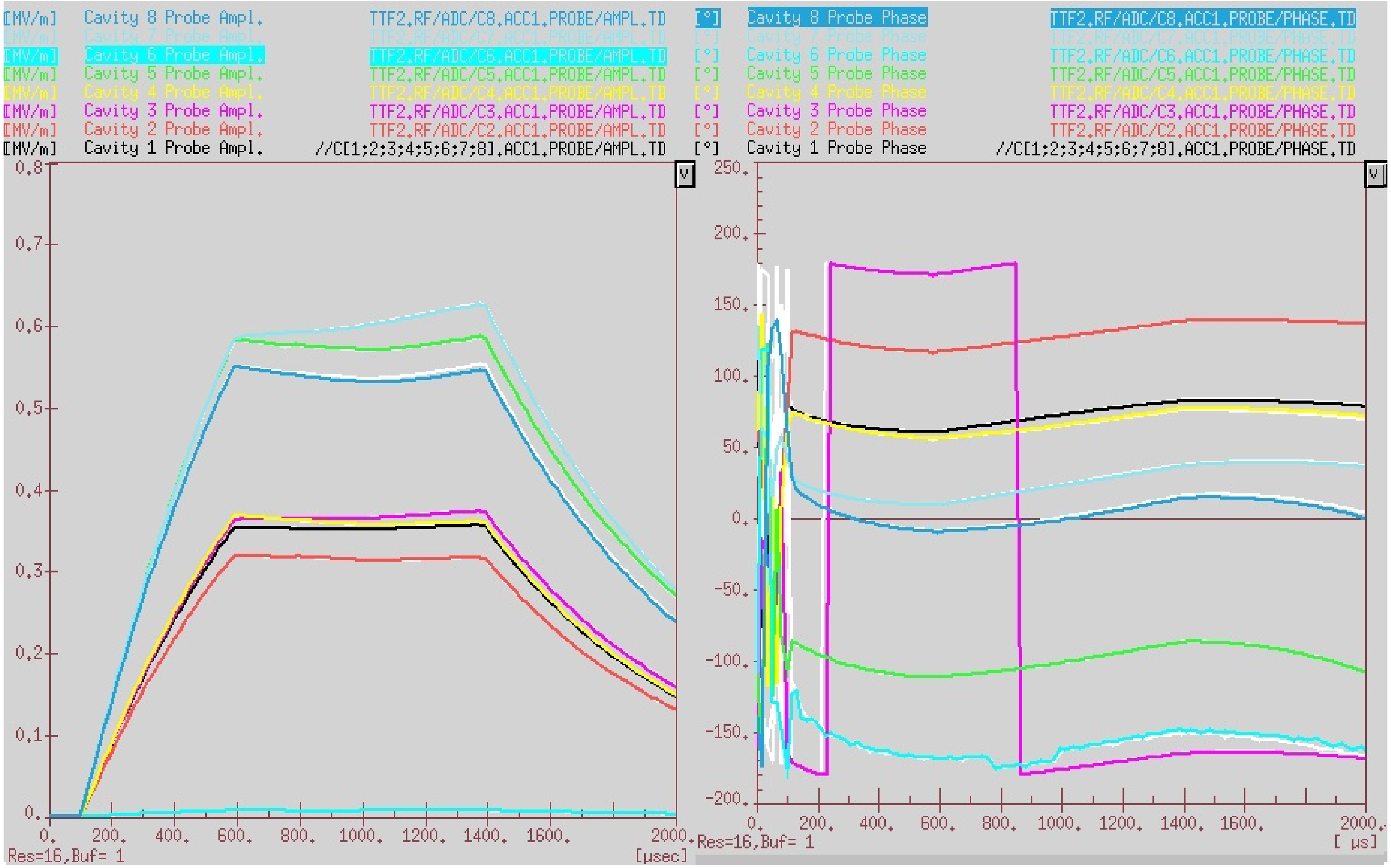
Example: Noise in LLRF system

- in this case the Reflected power cable from gun was damaged

Example: Noise in LLRF system

- after replacing the cable …



Example: Noise in LLRF system

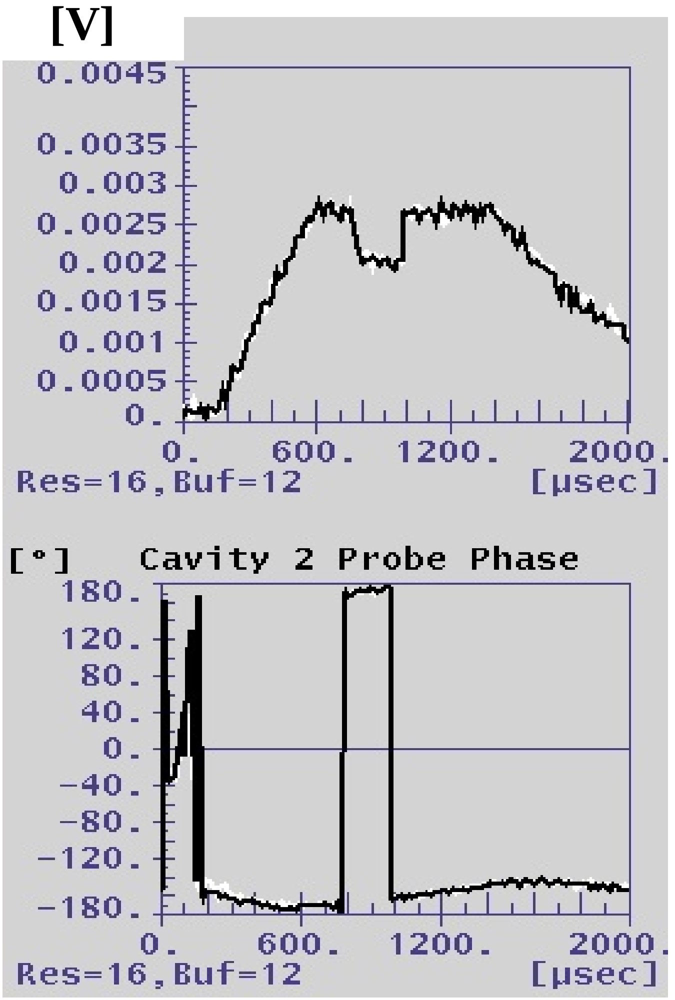
- but there is still are large cross talk:

a) 2.7 mV noise from the other cavities

b) -0.7 mV noise from the gun RF

Several option for the source of the cross talk:

- other leaking cable connection
- via the power supply
- within the down converter (in lab -65dB measured)
- Improper earth/mass connections
- from the downconverter to the ADCs
- …?

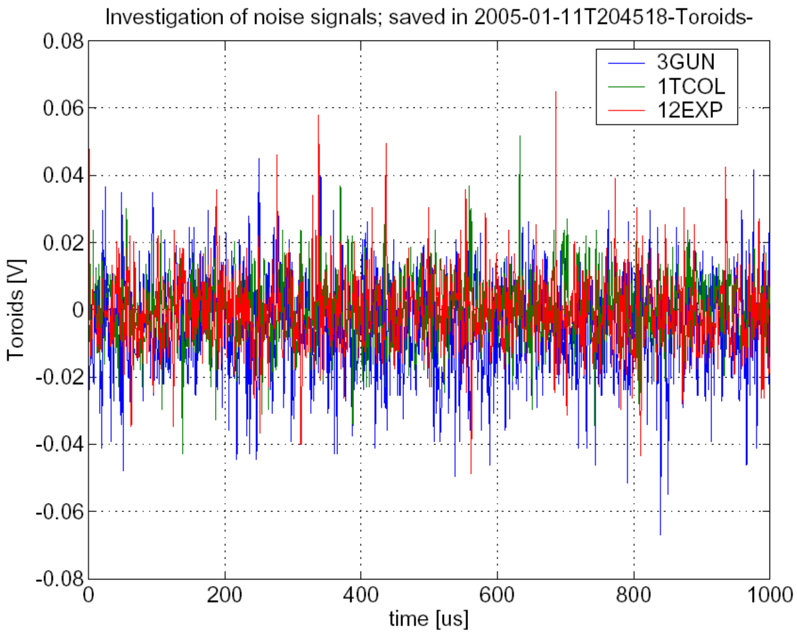


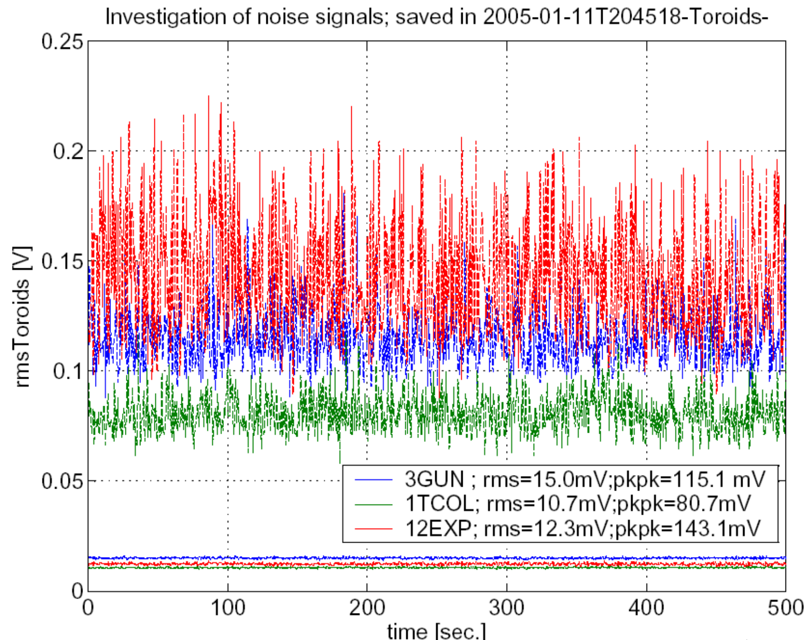
Example: Noise on toroid signals

- Noise on signals for diagnostics (here charge measurements)

Rms ~ 10mV => 4% @0.5nC
Pkpk ~ 100mV => 40% @0.5nC

Signal [V]



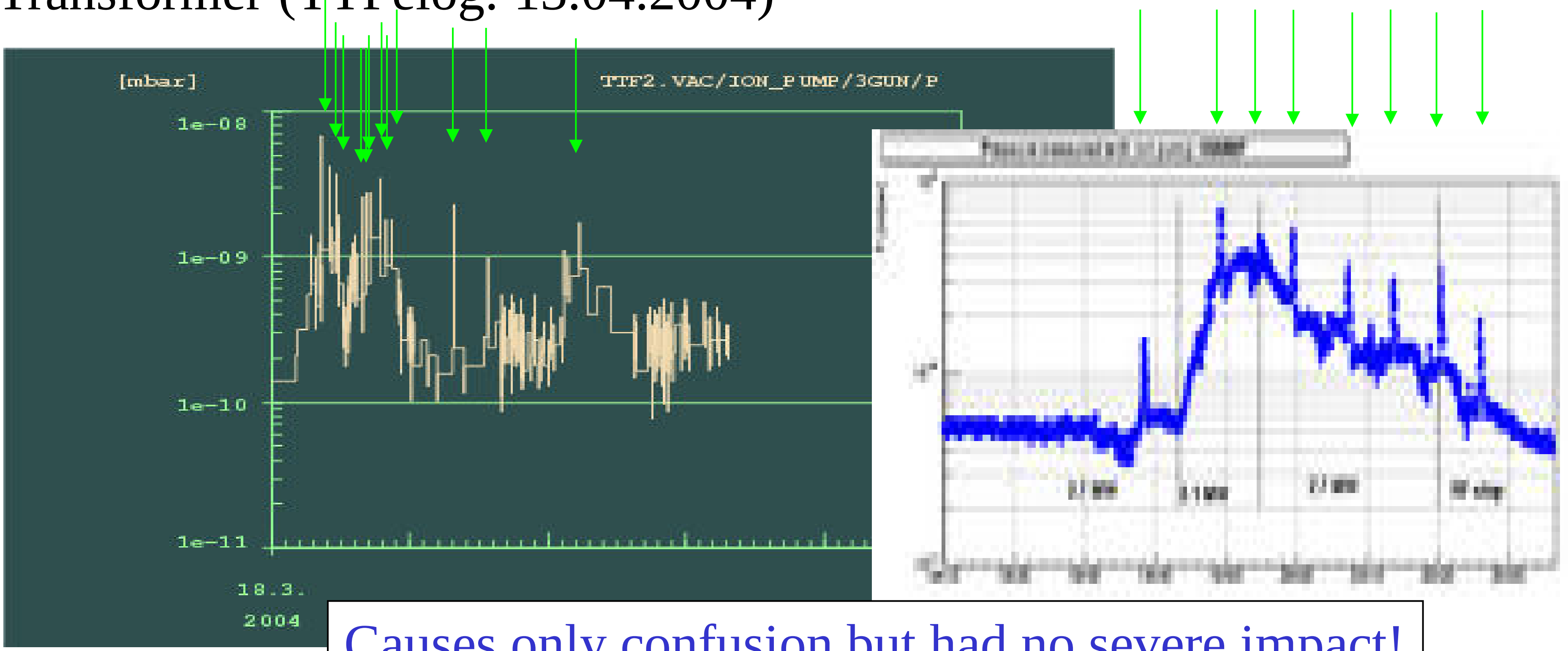


Time in macro-pulse

Time from pulse to pulse

Example: HV jumps during PETRA Proton proton ramp

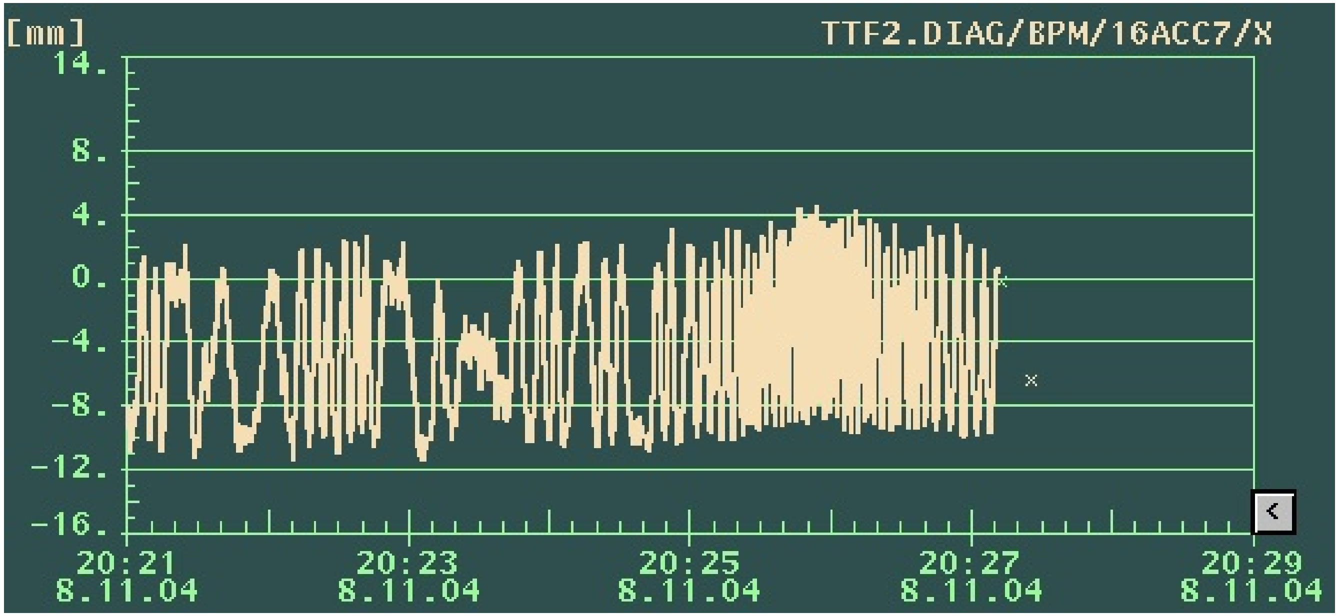
- The interference probably comes via voltage drops and rises in the 10 kV mains (the changing load of 'ramping PETRA' cannot be Completely compensated by the voltage regulation of the main power Transformer (TTFelog: 13.04.2004)



Causes only confusion but had no severe impact!

Example: Orbit jitter due to magnet regulation loop failure

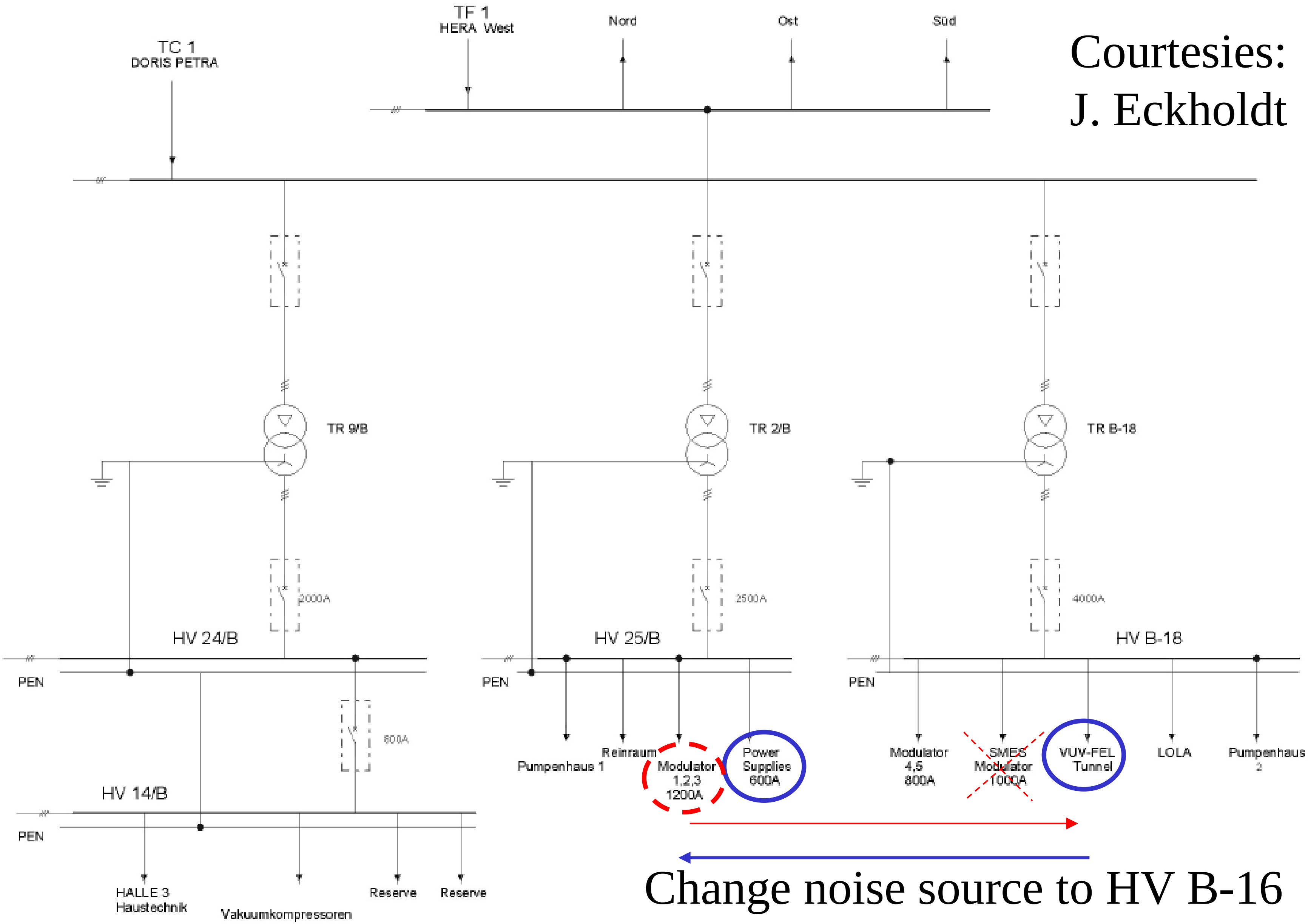
- extreme case: orbit jitter at exit of the linac



Identified as oscillating PS for Quad Q1BC2.
Problem: regulation loop was adjusted during switched of kly3
disturbance of power line due to kly3 caused instability together with high noise floor in this environment (grounding and shielding problems).

Changes of HV distribution of TTF2

Courtesies:
J. Eckholdt

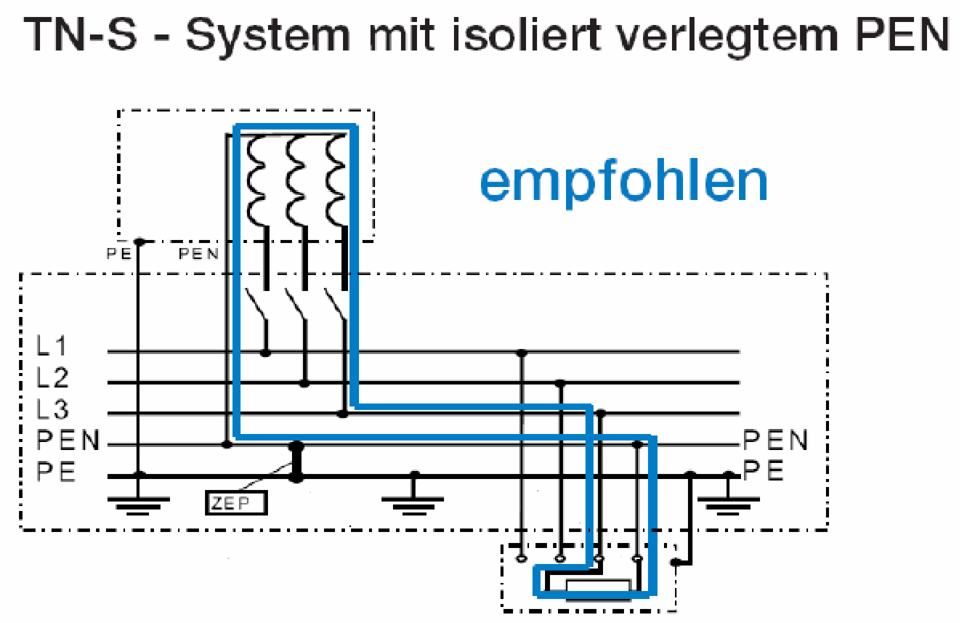


Change noise source to HV B-16

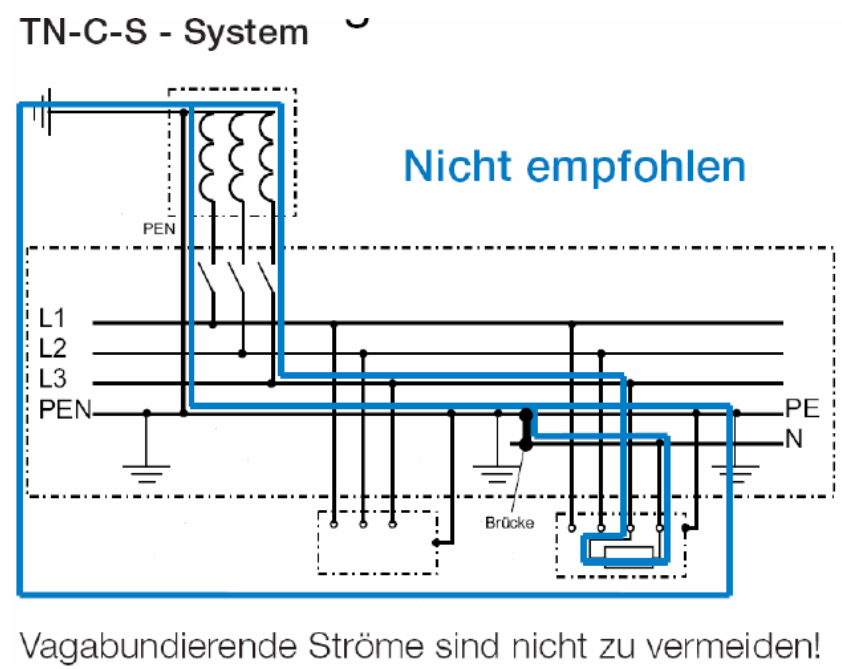
Grounding and HV distribution

due to historical reasons: old system not preferable for HV distr.

Modern distribution



Present distribution at TTF



→For XFEL dedicated investigation on HV distribution required

→Ground scheme especially in building and tunnel needs careful design

→Separation between power net for measurements and 'noisy net'

Example: Filter for noise reduction

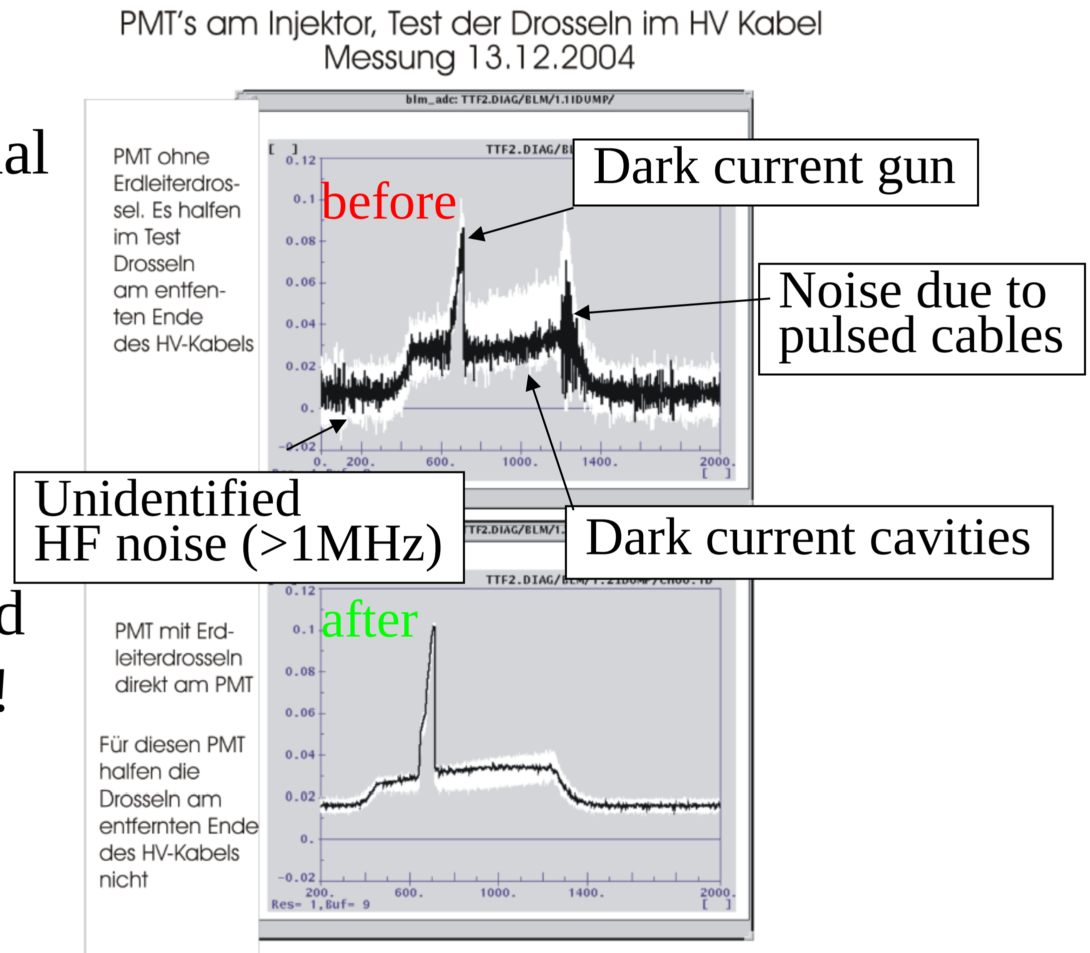
- large noise detected by photomultipier of beam protection system

- uses already differential signal transport
- but HV powersupply and HV cables picked up EMI noise

→Inductive coil for normal mode rejection implemented

→Removed all relevant noise!

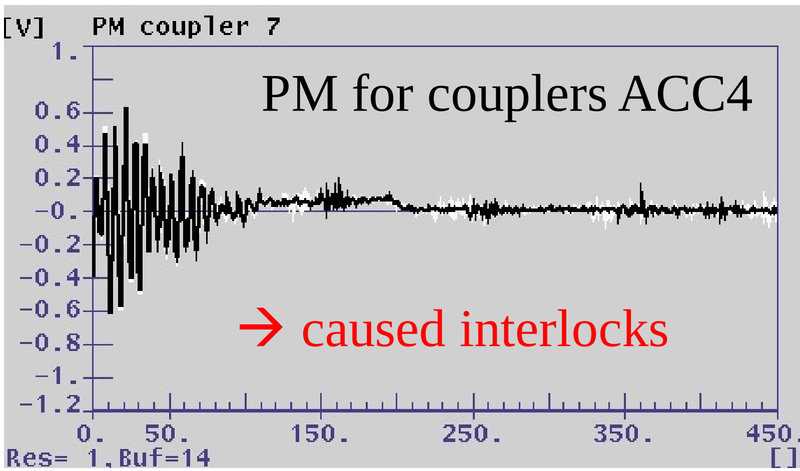
Now system fulfills EMC standards. (low cost, small mending, high success)



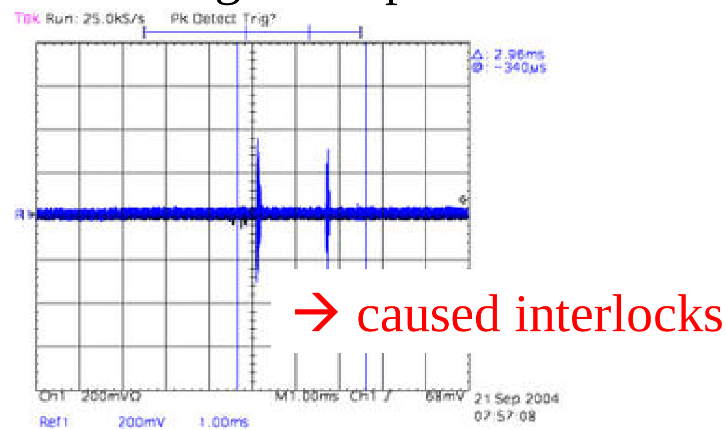
Courtesies: P. Göttlicher

Example: EMI in PMs due to pulsed power cables (modulator to klystron)

- when first time connected to klystron 5 (operating ACC2&ACC3)



PM for gun coupler



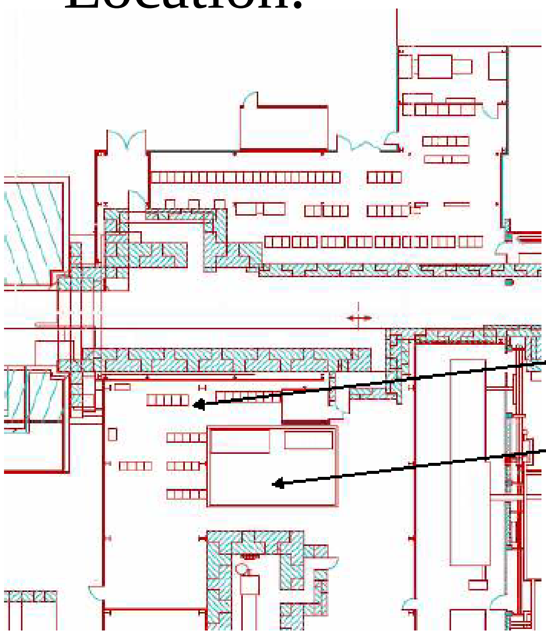
Logbook entry: /TTFelog/data/2004/38/17.09_M 17.09.2004 13:41 O.Hensler
Subject: Pulsed cables of modulator 5:
During the puls cable tests some weeks ago, we had problems to connect our VME to the CANbus readout. The VME crates went to overtemperature and switched off. Was ok the last two days, after we connected the VME chassis to rack ground

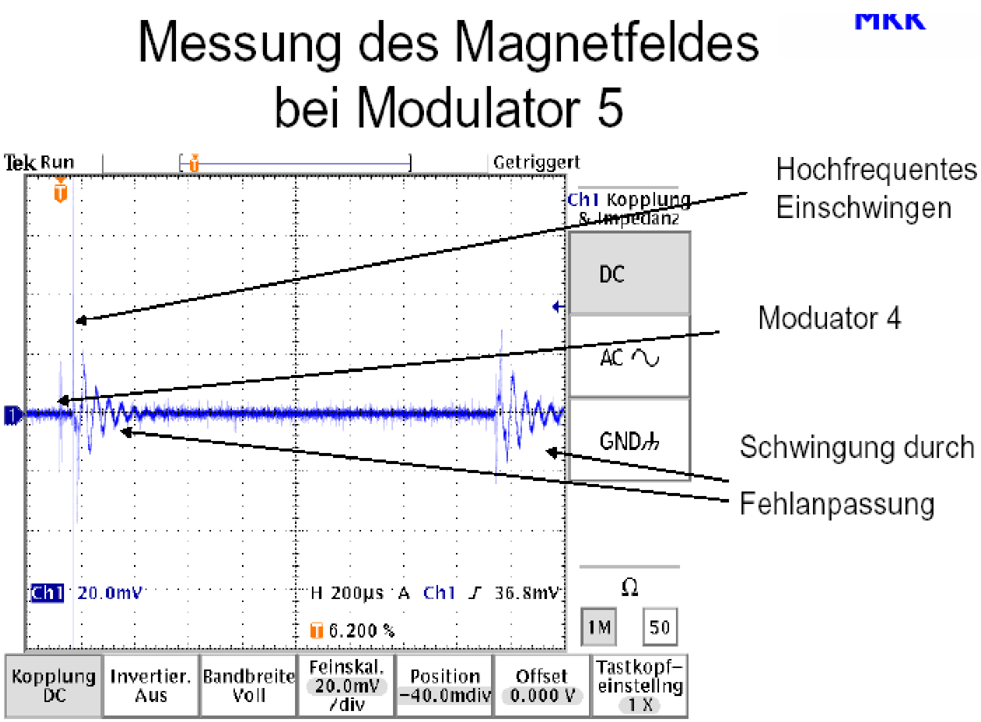
When the Modulator 5 is running, the use of walkie-talkie is impossible ! (C.Mueller)

Example: Investigations pulsed power cables

- lower noise signal due to improved grounding
- some investigations on radiation from cables done
- improved adaptation network required
- still too high current flow on outer cable shield

Location:





Summary & Conclusion

- EMI can critical influence the performance and the cost of the machine
- has big impact on the machine commissioning time!
- Complex subject since:

→ spans large range in power i.e. from 10kV …. 100 uV
→ spans large range in frequencies DC …. ~100 MHz
→ many different groups involved (MKK,MHV-p, LLRF, …)

- Requires:
  - Systematic study of EMI occurrence at TTF2
  - Needs assessment of the various subsystem (TTF2/XFEL/ILC)
  - Development of cost efficient solutions (TTF2/XFEL/ILC)
  - Development of standard EMC protocol and tests for accelerator equipment
  - Development of grounding scheme