

Frequently Asked Questions About Cabling, Grounding, and Power Distribution at the European XFEL

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This note about cabling, grounding, and power distribution at the European XFEL had a very slow start. The main problem was to find a format which (1) will be accepted by the readers and (2) presents a low threshold to the writer. I finally came to the conclusion that a catalogue of Frequently Asked Questions (FAQ) offers several advantages:

- It is just a structured list of small articles. The threshold to write one of those is low. Even if I answer only one question per day, useful information will accumulate quite fast.
- The document is useful from the very beginning.

In many cases there will be a short answer for quick reference and a long answer which tells the whole story. Sometimes there will be more than one answer. For pedagogical reasons sometimes good and bad (or even wrong) answers will be contrasted.

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1 Electromagnetic Compatibility

1.1 General Concepts

1.1.1 What is electromagnetic interference?

ANSWER: *Electromagnetic interference (EMI)* means any electromagnetic phenomenon which may degrade the performance of equipment.

1.1.2 What is electromagnetic compatibility?

SHORT ANSWER: *Electromagnetic compatibility (EMC)* is *not* the absence of EMI but the state of having it under control.

LONG ANSWER: *Electromagnetic compatibility (EMC)* means the ability of equipment to (1) function satisfactorily in its intended electromagnetic environment, and (2) not to introduce intolerable electromagnetic interference to other equipment in that environment. EMC therefore has two aspects, *susceptibility* and *emission*.

1.1.3 What are the characteristics of an EMI problem?

ANSWER: A typical EMI problem involves a *source* which generates noise, a *receptor* which is disturbed by the noise, and a *coupling path* which transmits the noise between the two. All of these must be investigated for solving the problem.

1.1.4 Is there a general recipe for fighting EMI problems?

ANSWER: Yes, but it is indeed quite general. With decreasing priority do the following:

1. *Characterize the problem.* One cannot solve an EMI problem without understanding it. Measurements are most important here. A broadband spectrum analysis gives a first impression of what is going on. Usually one learns much more from measuring currents than from measuring voltages.
2. *Eliminate the noise source.* This is the best method of solving EMI problems. However, it will not help if you don't have control of the source, e.g. for thunderstorm lightning.
3. *Break the noise path.* One can either block the path by high impedance means or shunt the noise current away from the receptor by low impedance means. It is generally better to build low impedance highways rather than high impedance road blocks because then you stay in active control about where the noise currents flow.
4. *Protect the receptor.* A great variety of measures is available here: Shielding, grounding, filters and so on.

Required efforts and available resources (money, time, manpower) may dictate a certain balance of these methods.

1.1.5 Are there any readable books about EMC?

ANSWER: Meanwhile yes, twenty years ago it was different. My favourite books are the following:

1. *Noise reduction techniques in electronic systems* by Henry W. Ott [1]: This is an excellent introduction to EMC and it contains lots of practical hints.
2. *Introduction to electromagnetic compatibility* by Clayton R. Paul [2]: This book goes a bit deeper into electrodynamics and contains a lot more calculations than [1], but it is well readable.
3. *Inductance – loop and partial* by Clayton R. Paul [3]: This book turns out to be quite useful when one must calculate the inductances of arbitrarily shaped metallic structures.

1.2 Classical Electrodynamics

1.2.1 What kind of magic is needed to fight EMI problems?

ANSWER: None. Electromagnetic interference is mediated by electromagnetic fields. Hence some knowledge of classical electrodynamics is sufficient. This knowledge may also reside in books on your shelf, as long as you know where to find what. The more difficult part in solving EMI problems is to see the electrical quantities in the equipment and in the environment. However, you may need magic if you ignore item 1 in answer 1.1.4.

1.2.2 Which EMI is most difficult to handle?

1.2.3 What is the impedance of an electromagnetic field?

1.3 Legal Aspects

1.3.1 Which laws regulate EMC at the XFEL?

ANSWER: In December 2004 the Council of the European Union (EU) issued the Directive 2004/108/EC “on the approximation of the laws of the Member States relating to electromagnetic compatibility” (EMC Directive). In its Article 16 the Member States are ordered to publish national laws that comply with the EMC Directive until January 2007. In Germany this resulted in the “Gesetz über die elektromagnetische Verträglichkeit von Betriebsmitteln” (Law about the electromagnetic compatibility of equipment) or briefly “EMV-Gesetz” (EMC Law) or even more briefly EMVG of February 2008. Equipment in a German accelerator laboratory must comply with this law.

1.3.2 What do these EMC laws say?

1.3.3 What does the CE mark mean?

1.3.4 Which technical norms are relevant for EMC?

2 The European XFEL

2.1 General Concepts

2.1.1 What is the European XFEL?

ANSWER: The *European X-Ray Free Electron Laser (XFEL)* is an international research facility to be built at Deutsches Elektronensynchrotron (DESY) in Hamburg. A detailed description can be found in the Technical Design Report [4].

2.1.2 What buildings are there in the European XFEL?

ANSWER: This is best answered by Figure 1 which shows the general layout of the facility.

2.1.3 What are the EMC challenges in the European XFEL?

ANSWER: The main EMC challenge in the European XFEL is the close proximity of very high power components and ultra-precise diagnostic equipment. - describe the facility - describe the EM environment - describe the typical susceptibility

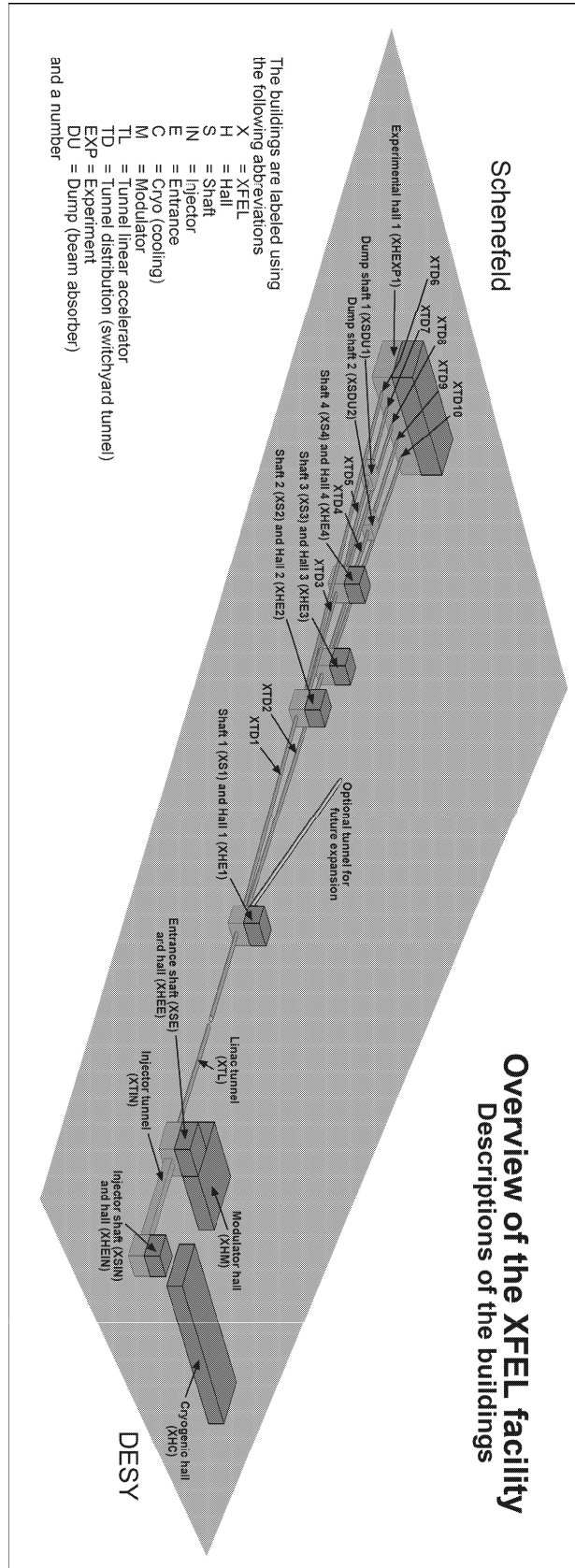


Figure 1: General layout of the European XFEL, from the Injector building on the DESY campus to the Experimental Hall located in Schenefeld.

3 Grounding

3.1 Grounding Systems

3.1.1 What is ground?

The circuit diagram of a simple amplifier (Figure 2) is well suited to illustrate two common definitions of ground.

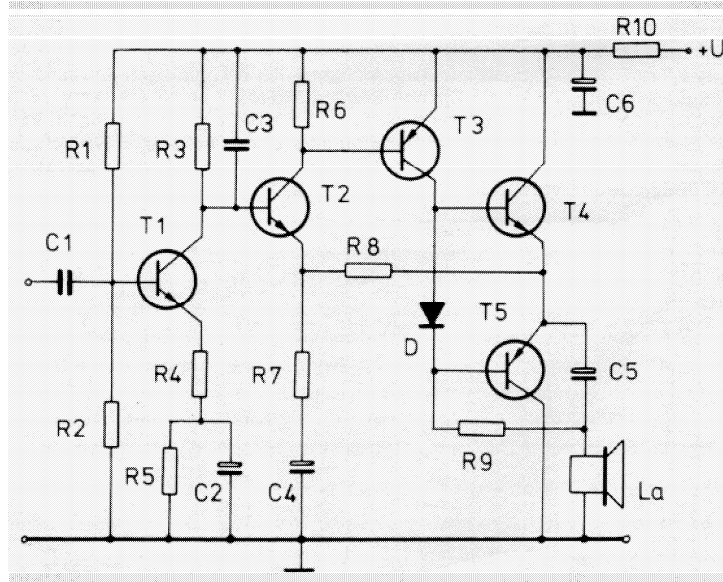


Figure 2: Example of an amplifier circuit diagram with ground denoted by the bold bottom line.

FIRST ANSWER: The first definition of ground comes from a *voltage* point of view. In this view *ground represents an equipotential electrode to which voltages in a circuit refer*. This definition applies to the ideal world of circuit diagrams where all connection lines have zero resistance or to the world of electrostatics where no currents flow. But circuits without currents are utterly boring because nothing happens in them. A ground electrode with current flowing in it is no equipotential electrode. There are applications, however, where approximate equipotentiality is fully sufficient. *Potential equalisation* (a.k.a. equipotential bonding) for *electrical safety* is an important example.

SECOND ANSWER: The second definition of ground comes from a *current* point of view. In this view *ground represents a low impedance path through which currents in a circuit return to their sources*. This definition much more suits the real world of circuits since it completely avoids the idealistic concept of equipotentiality. Following this definition *it is important to know where the currents flow* in a given or planned installation.

3.1.2 What is the purpose of grounding?

ANSWER: Corresponding to the voltage and the current view of ground, grounding can serve two purposes:

1. *Prevention of hazardous potential differences* by measures of *potential equalisation*. This means to interconnect all accessible metallic parts of an installation. This addresses the safety aspect of grounding.

2. *Conduction of noise and stray currents back to their sources in a designed low impedance path.*

3.1.3 Where do the currents flow?

Grounding system design is governed by a few fundamental principles:

Current always flows in closed circuits.

The practical problem will be to find (all of) those in your installation.

Current always takes the path of least impedance.

In most cases the major contribution to impedance is inductance, not resistance. Therefore: Think high frequency.

3.1.4 What is a grounding system?

A good grounding system must be *designed*, it does not come by itself. Inductance L is a property of the whole circuit, because its definition involves the magnetic flux Φ through any surface S bounded by the current I :

$$L = \frac{\Phi}{I} = \frac{1}{I} \int_S \vec{B} \cdot d\vec{S} \quad (1)$$

Nevertheless the concept of *partial inductance* is useful.

While DC resistance only depends on cross section, inductance depends on shape. For the same cross section, flat conductors have less inductance than round ones. Planes are even better.

Introduce the concept of *cable cutoff frequency*.

3.1.5 Signal vs. Safety Ground

3.1.6 Single-Point vs. Multi-Point Ground

3.2 XFEL Grounding Concept

3.2.1 XFEL Hybrid Ground System

3.2.2 XFEL Facility Ground

3.2.3 Local Ground Systems

3.3 XFEL Lightning Protection

4 Power Distribution

4.1 General Topics

4.1.1 What is meant by power distribution?

ANSWER:

4.1.2 What voltage levels do we have at DESY?

ANSWER: DESY has three connections to the public 110 kV high-voltage network (*Hochspannungsnetz*), see Figure 3). The locations of the transformers TA1, TC1 and TF1 are

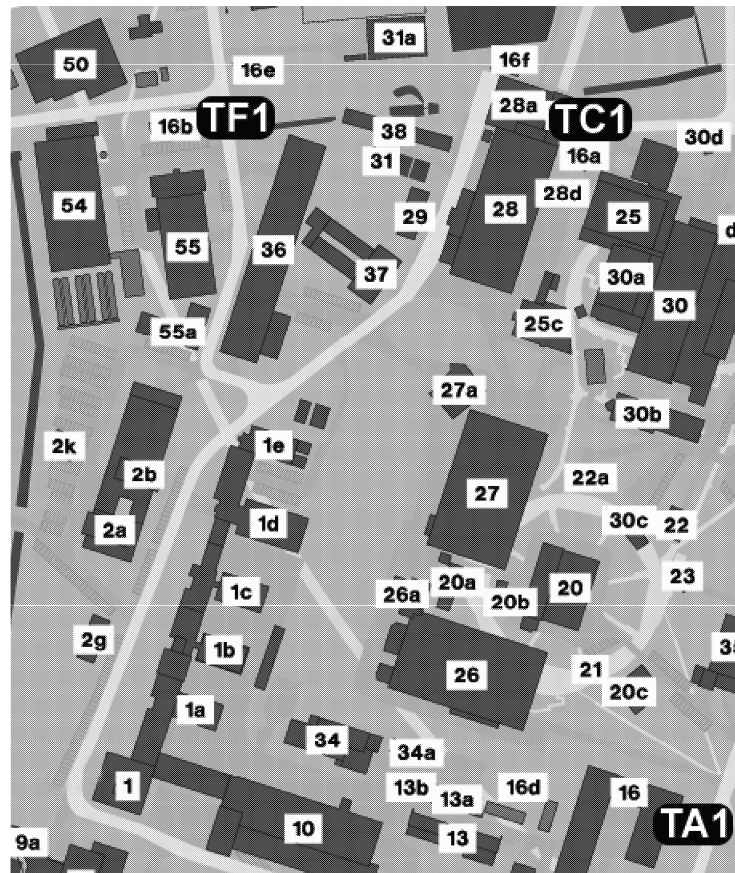


Figure 3: DESY connections to the 110 kV high-voltage network.

marked in the map in delta-connection (Dreieckschaltung) star-connection (Sternschaltung)

4.1.3 Are there 4 or 5 conductors in the low-voltage network?

ANSWER: In a modern 400 V low-voltage three-phase network there are five conductors:

- 3 line conductors (Außenleiter, Phasen) L1, L2, L3
1 neutral conductor (Nullleiter) N
1 protective earth (Schutzerde) PE

Ancient installations often combine N and PE to a PEN conductor, in order to save 20 % of the cable costs. From the EMC and personal safety point of view this is a nightmare

because operating currents will distribute into all grounded metal parts like cable shields, cabinets, metal pipes etc. If N and PE are separate, all operating currents return in the neutral conductor N, and PE only carries fault and noise currents.

5 Cabling Rules

1. Mutually ground all operator accessible equipment to a designated local ground point.
2. Use single-point grounding practices with respect to each local area ground point. Connect each subsystem ground to the local ground point with a low-impedance conductor.
3. No conductive cables should be allowed to interconnect subsystems connected to separate single-point grounds.
4. Shields in any local subsystem, including cable shields, should be shorter than $\approx \lambda/10$.
5. Keep currents through shields and ground connections to a minimum. Provide current return paths in the same cable or tray for every source or supply. Do not use thin shields for current return; use balanced sources and cable if possible. Signal cable shields from ungrounded signal sources should be grounded only on one end.
6. Eliminate or minimize conductive cables entering receptor enclosures. Position grounded cable entrances near the ground point/power entrance. Use fiber optics or isolators where possible. If not possible, cables should meet restrictions of Rules 3, 4 and 5.
7. Minimize magnetic flux coupling to/from cables: route cables on the ground plane, use enclosed raceways or conduit for cabling and keep raceways close to the ground plane unless they are constructed of material > 6 skin depths thick.
8. Noise radiating cables should be shielded and grounded at both ends.
9. Power entrances to subsystems often define the ground point. Respect them; group all required ground connections together to minimize currents in shields.
10. Use shielded transformers, properly connected, for power supplies. Avoid the use of capacitor input line filters with low impedance EMI; use filters only with respect to the ground point they define.
11. Establish and mark local subsystem ground points that do not violate ground rules or impair system integrity for casual use by technicians and experimenters. Show grounds on the system prints.

6 XFEL Subsystem Requirements

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