Dr.-Ing. Frank Sabath

Lecture script
EMI Risk Management

January 22, 2021

Gottfried Wilhelm Leibniz Universität Hannover
Institut für Grundlagen der Elektrotechnik und Messtechnik

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Chapter 1
Introduction

EMI Risk Management

1. Introduction

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1.1 Motivation

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HPEM Threat

WELT ONLINE

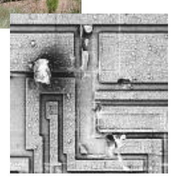
URL: http://www.welt.de/print-welt/article345305/Toedliche_Mikrowellen_aus_dem_Aktenkoffer.html

20. Januar 2003, 00:00 Uhr

VON MANUELA STABAT

Tödliche Mikrowellen aus dem Aktenkoffer

Starke elektromagnetische Pulse könnten die Computerzentren der Industrieländer zerstören – Schutzmaßnahmen sind möglich



TERRORWAFFEN DER ZUKUNFT

TERRORISTISCHE ANWENDUNGEN VON MIKROWELLEN

von Dr. Reinhard Munzert

„The action is silent and invisible" [5] „…the perfect terrorist weapon" [3]

Der Terror bekommt eine unsichtbare Hand. Mikrowellen sind lichtschnell, unsichtbar und waffentauglich. Sie besitzen elektronische, physikalische und biologische Effekte, die für Terroristen interessant sind.

MIKROWELLEN ALS WAFFEN

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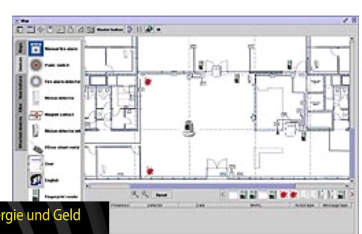
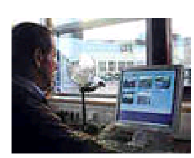
Significance of Electronic Systems

- **Safety Systems**
- Medicine
- Economy
- Transportation
- Communication





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Significance of Electronic Systems

- Safety Systems
- **Medicine**
- Economy
- Transportation
- Communication

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Significance of Electronic Systems

- Safety Systems
- Medicine
- **Economy**
- Transportation
- Communication

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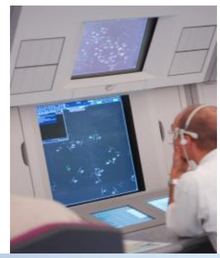
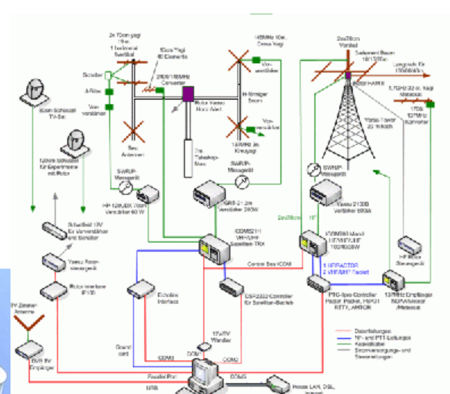
Significance of Electronic Systems

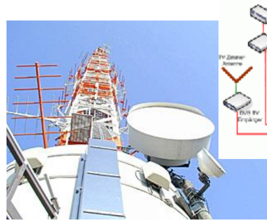
- Safety Systems
- Medicine
- Economy
- **Transportation**
- Communication



Significance of Electronic Systems

- Safety Systems
- Medicine
- Economy
- Transportation
- **Communication**





URSI Resolution (1999)

The URSI "Resolution of Criminal Activities using Electromagnetic Tools" was intended to make people aware of:

1) the existence of criminal activities using electromagnetic tools and associated phenomena;
2) the fact that criminal activities using electromagnetic tools can be undertaken covertly and anonymously and that physical boundaries such as fences and walls can be penetrated by electromagnetic fields;
3) the potential serious nature of the effects of criminal activities using electromagnetic tools on the infrastructure and important functions in society such as transportation, communication, security, and medicine ..);
4) that in consequence, the possible disruption on the life, health and economic activities of nations could have a major consequence

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URSI Resolution (1999)

The URSI "Resolution of Criminal Activities using Electromagnetic Tools" recommended:

1) Perform additional research pertaining to criminal activities using electromagnetic tools in order to establish appropriate levels of vulnerability.
2) Investigate techniques for appropriate protection against criminal activities using electromagnetic tools and to provide methods that can be used to protect the public from the damage that can be done to the infrastructure by terrorists.
3) Develop high-quality testing and assessment methods to evaluate system performance in these special electromagnetic environments.
4) Provide reasonable data regarding the formulation of standards of protection and support the standardization work which is in progress.

Development since 1999

1) Worldwide rise of terrorist (asymmetric) threats;
2) Technological development enabled the design of high-power IEMI sources and components (e.g. antennas)
   - ⇨ Availability of IEMI sources
   - ⇨ Proliferation of IEMI technologies
   - ⇨ Increase of potential threat
3) Increasing dependency of all parts of modern society on IT-technology
4) Worldwide investigation of the susceptibility of electronic systems against IEMI environments
   - ⇨ Decreasing susceptibility levels
   - ⇨ Classical EMC protection measures are ineffective against IEMI disturbances
   - ⇨ Increasing vulnerability

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Key Question

1.) How large is the possibility that an IEMI attack occurs?

$\Rightarrow$ possibility that an electronic system faces an IEMI environment

2.) How dangerous is the IEMI threat?

$\Rightarrow$ ability of the IEMI threat (environment) to cause a serious failure on electronic systems

Documented Criminal Usage of EM

1. In Japan, criminals used an EM disruptor on a gaming machine to trigger a false win
2. In St. Petersburg, a criminal used an EM disruptor to disable a security system an a Jeweler store
3. In Kizlyar, Dagestan, Russia Chechen rebel command disabled police radio communication using RF jammer during a raid.
4. In multiple European cities (e.g. Berlin) criminals used GSM-Jammern to disable the security system of limousines.
5. In Russia, Chechen rebels used an EM disruptor to defeat a security system and gain access to a controlled area.

Documented Criminal Usage of EM

6. In London, UK, a city bank was the target of blackmail attempt whereby the use of EM disruptors was threatened to be used against the banks IT-system.
7. In the Netherlands an individual disrupted a local bank IT network because he was refused loan. He constructed a briefcase-size EM disruptor, which he learned how to build from the internet.
8. In Moscow, the normal work of one automatic telephone station has been stopped as a result of remote injection of a voltage in to a telephone line. As a result 200 thousand people had no phone connection for one day

Example: Car Theft

In several European cities (e.g., Berlin) car thieves used GSM jammer to suppress GSM based security system of sedan cars.

Source: http://de.wikipedia.org/

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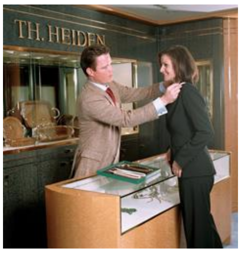
Example: Safety System



In several Russian towns (e.g., St. Petersburg) criminals suppressed the security system of shops (jewellers) with the help of repeating EMI transmitters.

In Kizlyar, Dagestan, Russia Chechen rebel command disabled police radio communication using RF jammer during a raid.

Example: Smart House

Source: http://www.isocket.de/examples/

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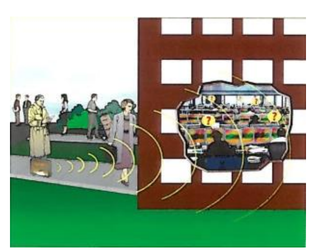
Example: Disturbance of IT-System

In the Netherlands an individual disrupted a local bank IT network because he was refused loan. He constructed a briefcase-size EM disruptor, which he learned how to build from the internet.

More than one month the engineers of the bank had no notion that the component destructions and malfunctions were caused by an external EMI attack.



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Example: Automatic Telephone Exchange

In Moscow, the normal work of one automatic telephone station has been stopped as a result of remote injection of a voltage in to a telephone line.

As a result 200 thousand people had no phone connection for one day

Source: http://de.wikipedia.org/

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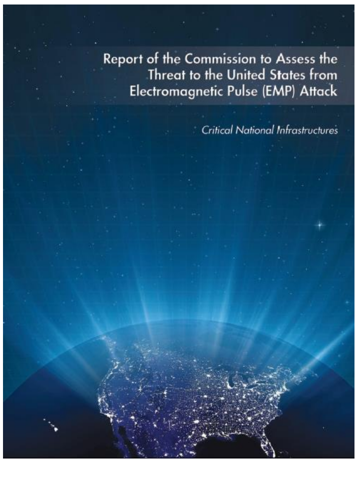
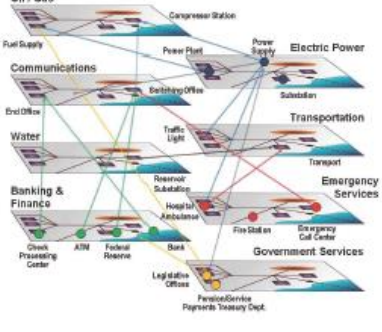
„EMP-Report“ (2008: Critical Infrastructure)





1.2 Content of Lecture

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Aim

The participants shall be capable to

- know the different classes of **EMI sources**,
- name **effects** caused in complex distriubuted systems,
- explain **methods** that are capable to analyze the risk of EMI disturbance of electronic systems, and
- name **areas of their application**, including limits of application.

Content

1. Introduction & Basic Terms
2. Fundamentals of Risk Management
3. Risk Analysis Methods
4. EMI Scenario
5. Modeling of scenarios and systems
6. Effects and Error States
7. Risk Evaluation
8. Risk Treatment and Protection
9. Examples
10. Summary

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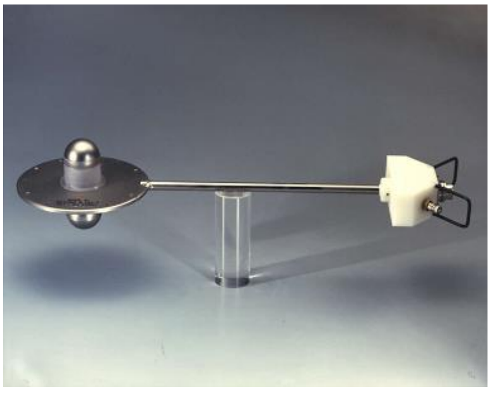
Thank You for Your Attention.

Questions ?



EMI Risk Management

1.3 Basic Terms

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Content

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1.3.1 Critical Infrastructure

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Definition: Infrastructure

The **infrastructure** of a country, society, or organization consists of the **basic facilities** such as transport, communications, power supplies, and buildings, which enable it to function.

Source: COBUILD Advanced English Dictionary. Copyright © HarperCollins Publishers

Definition: Critical Infrastructure

Critical infrastructure means an asset, system or part thereof located in nations which is essential for the maintenance of vital societal functions, health, safety, security, economic or social well-being of people, and the **disruption or destruction** of which would have a significant impact in a nation as a result of the failure to maintain those functions;

Source: Council Directive 2008/114/EC of 8 December 2008

Critical Infrastructures

Basic technical infrastructures

- Energy supply
- Information and communication technology
- Transport and transport
- (drinking) water supply and sanitation

Socioeconomic service infrastructures

- Health service,
- Food,
- Emergency and rescue services, civil protection,
- parliament, government, public administration, judicial institutions,
- finance and insurance,
- Media and cultural assets

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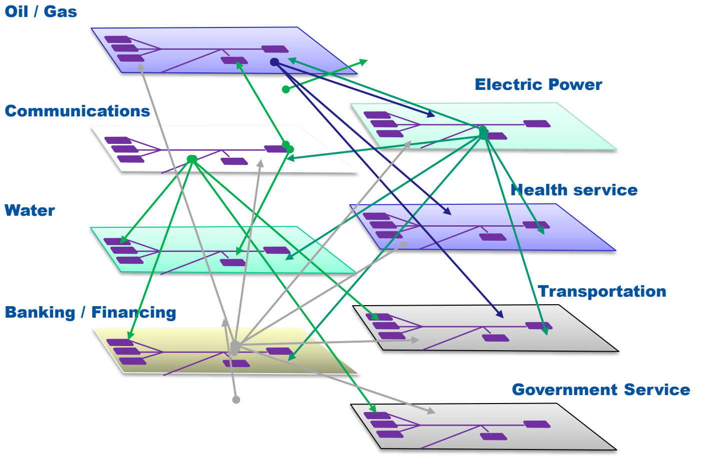
Dependence critical infrastructure



Source: EMP-Report - Critical Infrastructures, 2008

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Properties Basic Technical Infrastructures

Basic Technical Infrastructures

- Distributed systems
- Networked systems
- High proportion of electronic controllers

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Example: Electric Power Network

- Subsystems distributed throughout Germany
- Different operators
- Automatic control
  - of electronic controls
  - data exchange is necessary

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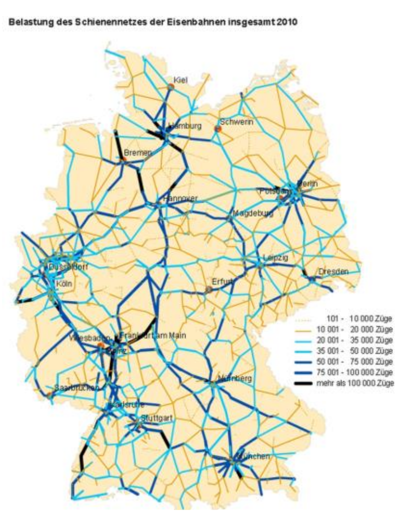
Example: Railroad



Source: Statistisches Bundesamt

1.3.2 Electromagnetic Interference

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Electrical Systems

Electrical systems are systems which are operated or controlled at least in proportion by electrical energy.

Electromagnetic Interference (EMI)

The term **electromagnetic interference** refers to effects caused by the interaction of electrical and electronic systems with their electromagnetic environment and other systems.

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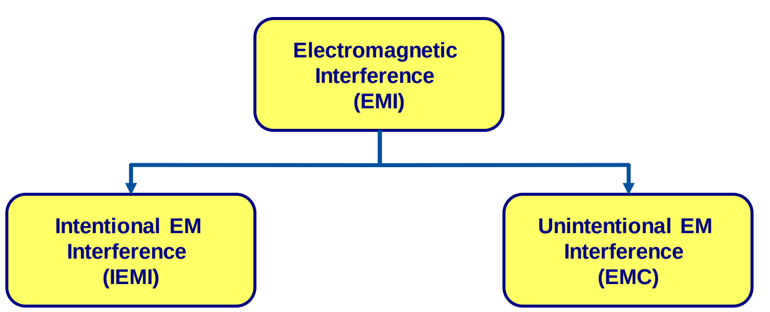
Classification



Definition: EMC

The **electromagnetic compatibility** (EMC) characterizes the desired state that technical devices do not interfere with one another alternately by means of unwanted electrical or electromagnetic effects.

> **Electromagnetic compatibility** addresses technical and legal issues of unwanted reciprocal influence in electrical engineering.

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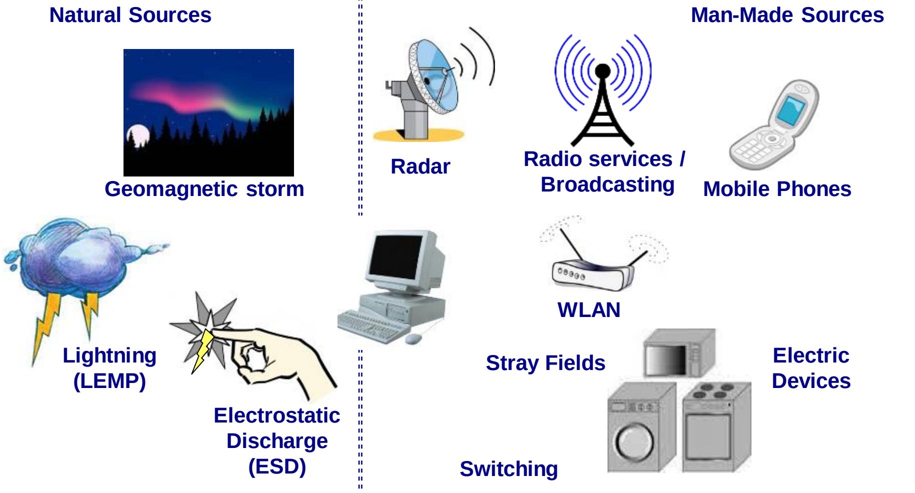
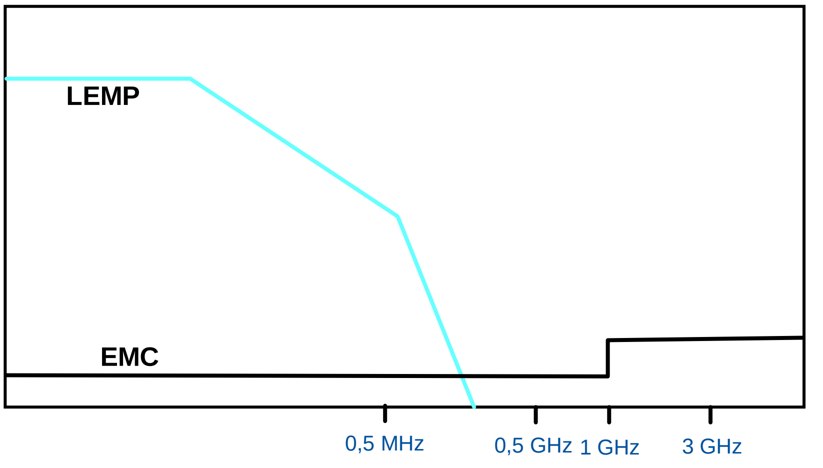
EMC sources of interference



Spectrum EMI Sources



Definition: Intentional Electromagnetic Interference

"Intentional malicious generation of electromagnetic energy introducing noise or signals into electric and electronic systems, thus disrupting, confusing or damaging these systems for terrorist or criminal purposes.

Definition: Jammer

A **jammer** suppresses the correct reception of a radio service (such as radio, television, mobile radio or GPS).

The jammer transmits electromagnetic waves, just like the transmitter to be interfered with, and completely or partially superposes the original waves. The field strength, the modulation of the interference transmitter and the nature of the interfered message are important.

Definition: High-Power Electromagnetics

The term **high-power electromagnetics** generally refers to a technological field which deals with the generation of strong electromagnetic changes. The generated electromagnetic environments of high power can interfere with or destroy electrical and electronic systems.

- power density > 26 W/m^2
- electric field strength > 100 V/m, or
- magnetic field strength > 0.27 A/m

High-Power Sources

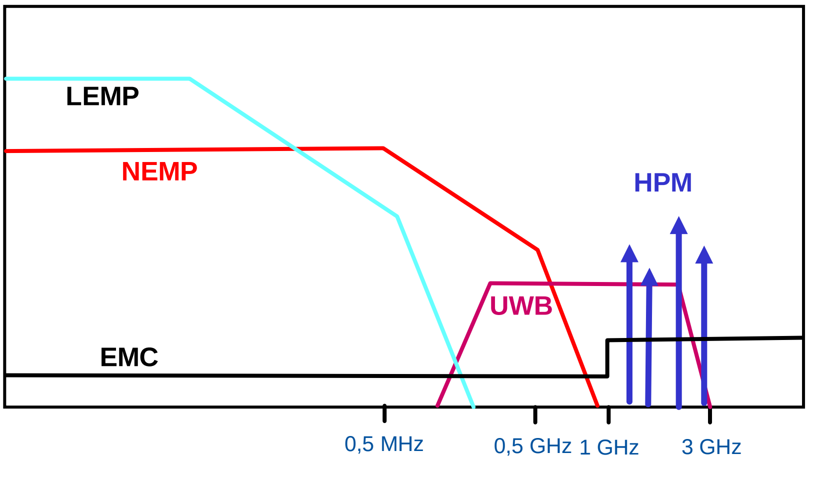
HEMP

High-Power Microwave

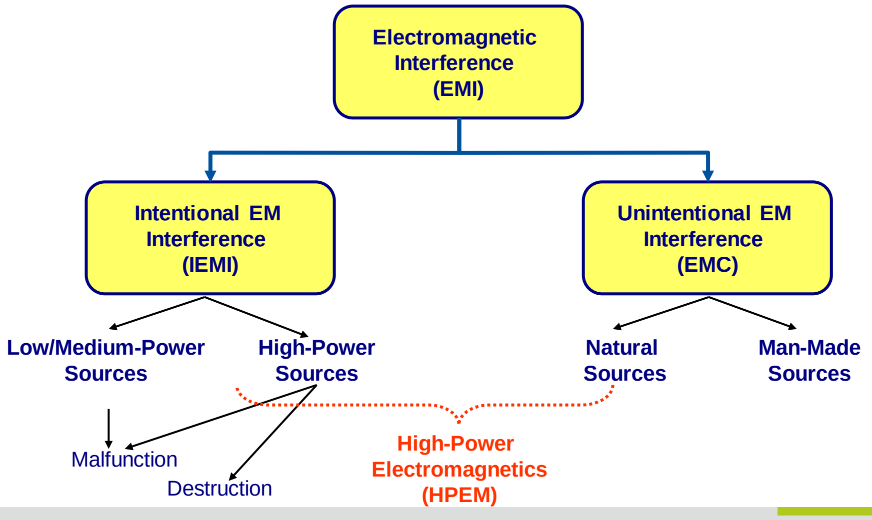
LEMP

UWB

Spectrum EMI Sources



Classification



1.3.3 Risk and Risk Management

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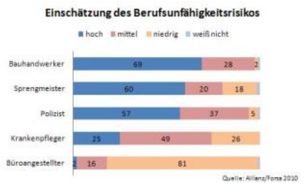
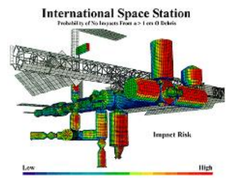
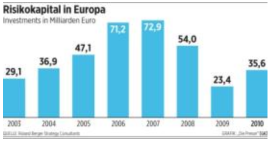
What is Risk?

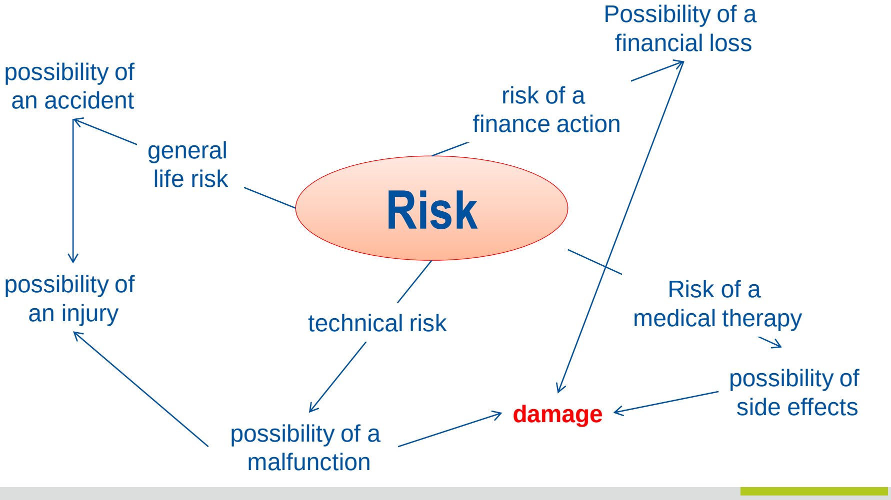




Risk



What is Risk?



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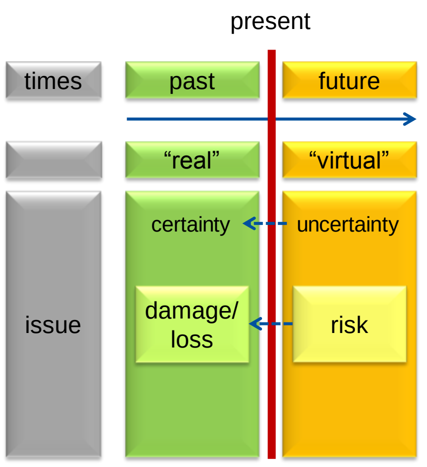
Definition Risk



– **Damage/loss** is a real fact in the past that is certain.

– **Risk** is a virtual fact in the future that is uncertain.

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Definition Risk

The risk

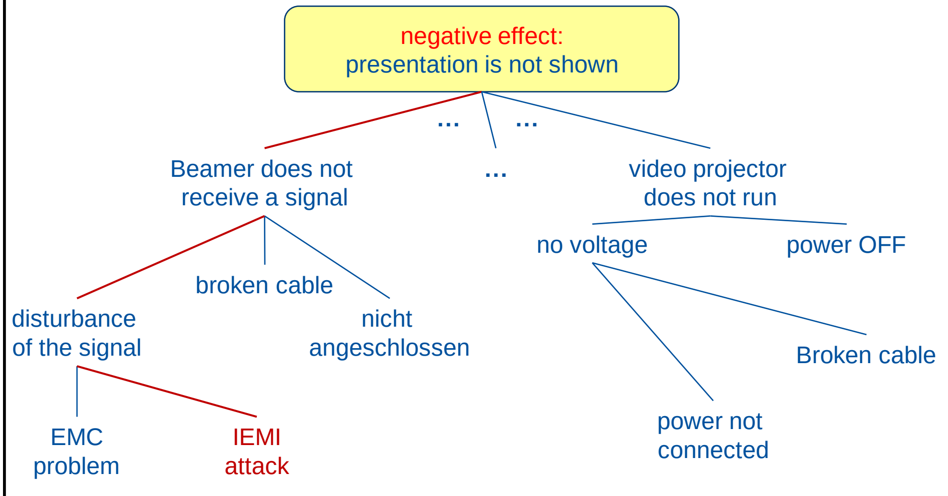
– is the description of a **future event** with the possibility of **negative effects**.

– is the impact of **uncertainty**/uncertainty on goals.

risk = ⟨consequence, likelihood ⟩

$$r_i = \langle c_i, p(c_i) \rangle$$

Risk of Intentional Actions



Risk of Intentional Actions

intentional (criminal) actions

⇒ aspects of risk

- **What** can happen? (**Scenario**)
- What are the **effects**?
- How **likely** can this case occur? (**Uncertainty**)

risk = ⟨scenario, consequence, uncertainty⟩

$$r_i = \langle s_i, c_i, p(s_i \cap c_i) \rangle$$

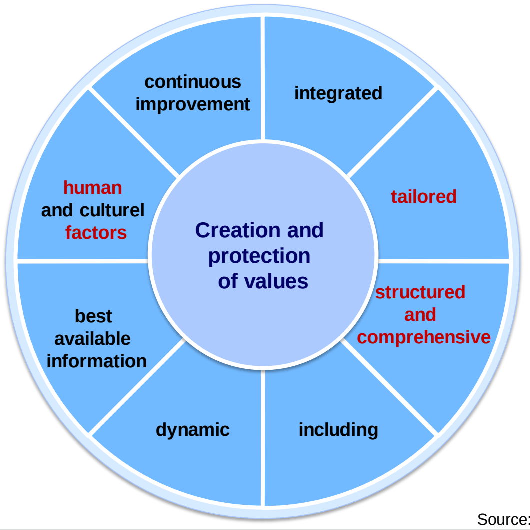
Definition Risk Management

Risk management includes all formal processes and structures for the systematic detection, analysis, evaluation, monitoring and control of risks.

Basic idea of the risk management

- Risk management is based on the idea that the risk can be "managed" by appropriate measures.
- This means "manipulation"
  - the nature of the risk (**qualitative**),
  - the size of the risk (**quantitative**), and
  - the temporal window of the occurrence of the effect of a risk (**time**)

Principles of the risk management



Source: ISO 31000:2018, Kap. 4

"classical" EMI Risk Management

(1) Ignore risk

(2) Consideration of the strongest HPEM environment and assessment if protective measures are necessary

(3) Protection of the system against the strongest HPEM environment

EMI Risk Management

An EMI risk management is required to answer the questions:

(1) Identification of EMI caused effects and their consequences at the system level

(2) Assessment of the identified consequences in regard with the overall function of the system

(3) Determination of the likelihood of the effects, when applying an EMI environment to the system

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1.3.4 Probability

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Definition of Probability

1. Probability axioms
2. Classical definition of probability
3. Subjective definition of probability

Probability Axioms

- First Axiom:
  The probability of an event E is a non-negative real number:
  $$P(E) \in \mathbb{R}, P(E) \geq 0, \forall E \in F$$
  where F is the event space.
- Second Axiom:
  The probability that at least one of the elementary events in the entire sample space Ω will occur is 1
  $$P(\Omega) = 1$$
- Third Axiom
  Any countable sequence of disjoint sets E_1, E_2, … satisfies
  $$P\left(\bigcup_{i=1}^{\infty} E_i\right) = \sum_{i=1}^{\infty} P(E_i)$$

Classical Definition

If a random experiment has only finitely many results and these all have the same probability, then for the probability $P(E)$ of an event E:

$$P(E) = \frac{n(E)}{n(F)}$$

if $n(E)$ denotes the number of elements of event A and $n(F)$ the numbers of elements in the event space F.

– **frequentist interpretation:** The relative frequency of occurrence of an event, observed in a number of repetitions of the experiment, is a measure of the probability of that event.

Subjective Definition

- The subjective concept of probability understands probability as a measure of the safety of the personal assessment of a situation.
- In the case of single or rare random events, their probability of occurrence can only be estimated on the basis of expert **knowledge**, **experience** and **intuition**.

Probability, Scale

P_S	Probability	Criterion	
0 - 1	improbable/ unlikely	< 1%	So unlikely, that it can be assumed that the event does not occurs.
2 - 3	remote	1% - 5%	Low possibility that an event occurs.
4 - 6	occasional	5% - 50%	Event will occur in some, but less than half of the cases.
7 - 8	probable	50% - 90%	Event will occur in more than half of the cases.
9 - 10	frequent	> 90%	Most likely that an event will occur in approximately every case.

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1.3.5 Threat and Hazard

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Threat

A **threat** is generally a **circumstance** or **event** that can cause damage..

⇒ Electromagnetic Interference (EMI)

- the application of electromagnetic energy to a system by means of which:
- the functioning of the system can be impaired or disturbed
- which can cause damage..

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Hazards

In the context of risk management, **potential sources of damage** (risk matters) are referred to as **hazards**.

- Possibility that a protective material can meet a source of damage spatially and/or temporally.
- The deliberate production of a hazard
  ⇒ **Attack**

1.3.6 Reliability and Availability

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Reliability

The **reliability** of a technical system is a property that indicates how reliably a function assigned to the system is fulfilled in a time interval.

Reliability analysis and risk analysis consider the same system property

- Reliability analysis
  - → Probability of trouble-free function
- Risk analysis
  - → Probability of malfunction
  - → Risk mitigation

Availability

The **availability** of a technical system is the **probability** or measure that the system performs its function at a predetermined time or within an agreed time period.

Availability is a performance criterion that can be used to assess the magnitude of the effects of an incident.

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1.4 System Oriented Description

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1.4.1 Phase Modell of the Product Life Cycle

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Phase Modell of the Product Life Cycle

Concept Phase

Information:
- Concepts (documents)
- First predictions
- Draft specifications

Concept of the system
- Definition of the function
- Development of a system concept
- Orienting systems analysis
  - Prediction/estimation of ambient conditions

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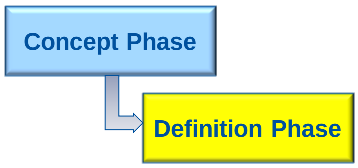
Phase Modell of the Product Life Cycle



Information:
- Concepts (documents)
- First predictions
- Specification of the system
- Specification of modules and components
- Specification of interfaces

System Definition/Design
- Specification of the system concept
- Definition of assemblies/devices
  - Specification of modules and components
  - Classification into sub-systems
  - Definition of interfaces
- Integration analyses

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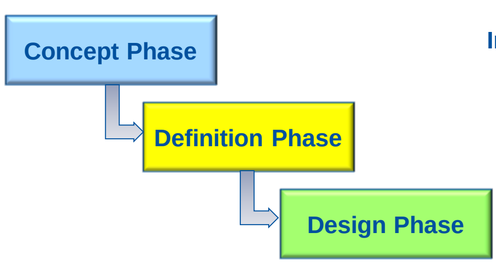
Phase Modell of the Product Life Cycle



Information:
- Modules / Components
- Integration measurements
- Measurement of coupling
- Measurements on prototypes
- Qualification measurements

Design of the system
- Development, construction and integration of the modules and components
- System development (realization of system design)
- System integration
- Construction of prototypes
- Proof (qualification) of the specified functions and properties

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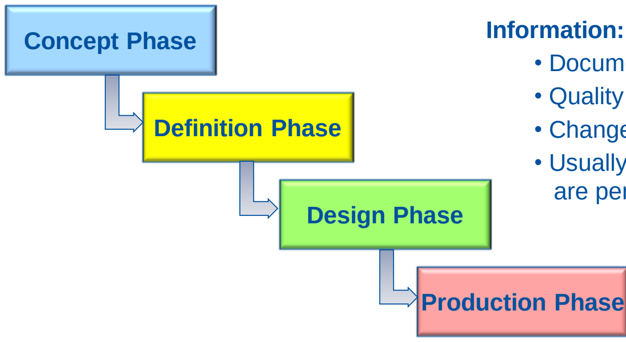
Phase Modell of the Product Life Cycle



Information:
- Documentation / Qualification
- Quality control
- Changes in serial production
- Usually no system measurements are performed in this phase

Construction of the system
- Preparation quantity production
- Quantity production

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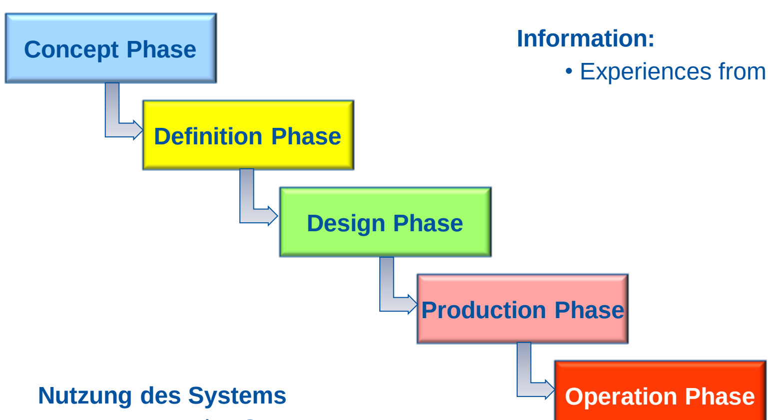
Phase Modell of the Product Life Cycle



Information:
- Experiences from operation/use

Nutzung des Systems
- Nutzung des Systems
- Modernisierung
- ggf. Erweiterung der Funktionalität

Phase Modell of the Product Life Cycle

Concept Phase

Definition Phase

Design Phase

Production Phase

Operation Phase

Recycling Phase

Utilisation of the system

- Decommissioning
- Disposal
- Dismantling
- Recycling

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1.4.2 Electrical Systems

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Electrical Systems

Electrical systems are systems which are operated or controlled at least in proportion by electrical energy.

- Almost all areas of today's life are characterized by the increasing use of electrically operated or controlled systems.
- With regard to electromagnetic interference, the electrical systems provide possible points of entry for electromagnetic couplings and interferences.

1.4.3 EMI Coupling Model

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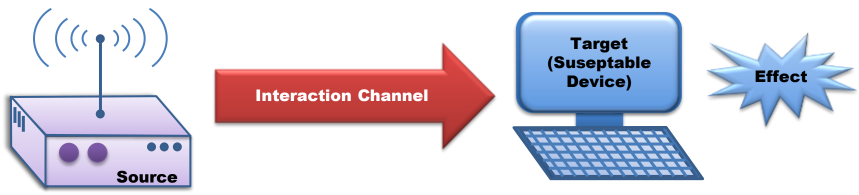
Interaction Channel Model (Source-victim model)



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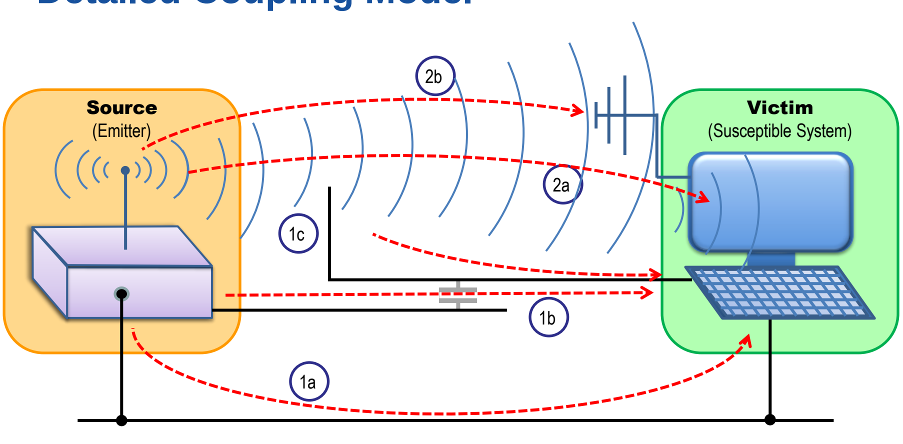
Detailed Coupling Model



Source: D.V. Giri, R. Hoad and F. Sabath; High-Power Electromagnetic Effects on Electronic Systems, Artech House, April 2020, Chapter 3, ISBN 978-1630815882, DOI:

1. Conducted Coupling

a) **purely conducted (galvanic)** coupling, where the emission propagates from the emitter to the victim through interconnecting cable or conductor.

b) Conducted coupling via **two or multiple cables** or conductors which are coupled via electric field (capacitive coupling) or magnetic field (inductive coupled) and connected to either the emitter or the victim.

1. Conducted Coupling

c) Radiation from the emitter to cables, conductors or antennas of the victim. Antennas (e.g. WIFI antennas), improperly shielded wires or metallic pipes are capable of picking up disturbances from surrounding electromagnetic fields.

Cases in which the emission is picked up by non-antenna elements such as apertures, enclosures or cables are often labelled as '***back door***' coupling. This differentiates it from the coupling to actual antennas or electronic sensors, which is known as `***front door***' coupling.

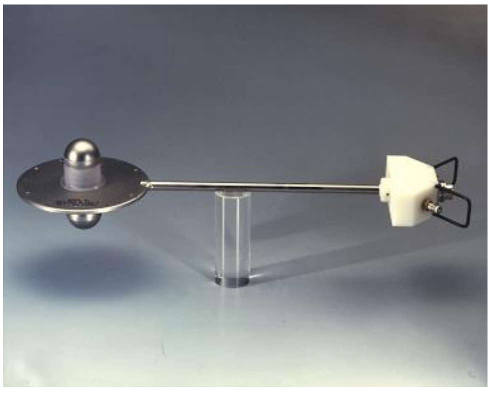
2. Radiated Coupling

a) **Direct radiation** from the emitter to the victim through the air. Usually the emitted field propagates from the source via antenna structures, penetrates the system enclosure and enters the susceptible device via apertures.

b) Radiation form **antennas to antennas**, e.g. the source and receptors are specifically transmitting/receiving devices. This path is representative of normal radio communication (e. g. Wireless Local Area Networks (W-LAN), radio broadcast/reception).

Thank You for Your Attention.

Questions ?



Chapter 2
Fundamentals of Risk Management

EMI Risk Management

2. Fundamentals of Risk Management

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⇒ 2. Fundamentals of Risk Management
3. Risk Analysis Methods
4. EMI Scenario
5. Modeling of scenarios and systems
6. Effects and Error States
7. Risk Evaluation
8. Risk Treatment and Protection
9. Examples
10. Summary

Definition Risk

The risk

- is the description of a **future event** with the possibility of **negative effects**.
- is the impact of **uncertainty**/uncertainty on goals.

risk = ⟨consequence, likelihood ⟩

$$r_i = \langle c_i, p(c_i) \rangle$$

Risk of Intentional Actions

intentional (criminal) actions

⇒ aspects of risk

- **What** can happen? (**Scenario**)
- What are the **effects/consequences**?
- How **likely** can this case occur? (**Uncertainty**)

risk = ⟨scenario, consequence, uncertainty⟩

$$r_i = \langle s_i, c_i, p(s_i \cap c_i) \rangle$$

2.1 Principles of the risk management

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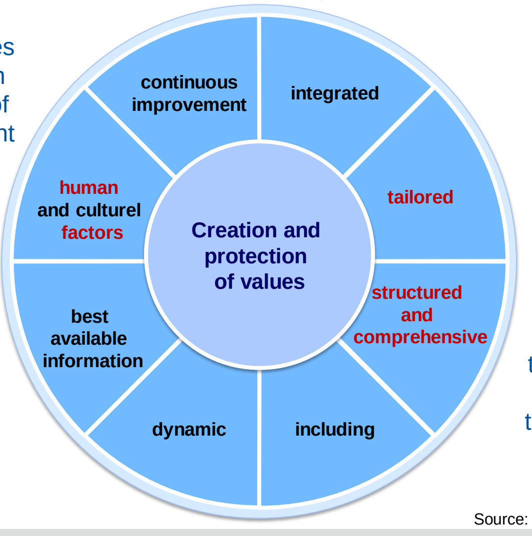
Principles of the risk management

The shown principles provide guidance on the characteristics of effective and efficient risk management, communicate its value and explain its intention and purpose.



These principles form the basis for dealing with risks and should be taken into account when developing the framework and risk management processes.

Source: ISO 31000:2018, Kap. 4

Principles (2)

a) integrated

Risk management is an integral part of all the activities of an organization.

b) structured and comprehensive

A structured and comprehensive risk management approach contributes to consistent and comparable results.

c) tailored

The framework and the processes of risk management are adapted to the external and internal context of an organization and are suitably connected with the objectives of the organization.

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Principles (3)

d) including

The appropriate and timely participation of stakeholders allows for the consideration of their knowledge, views and perceptions.

e) dynamic

Risks can arise, change, or disappear as the external and internal context of an organization changes. These changes and events are **appropriately** and **timely** anticipated, recognized, confirmed and addressed by risk management.

Principles (4)

f) best information available

The input into risk management is based on historical and current information as well as future expectations. Risk management expressly takes into account all restrictions and uncertainties associated with such information and expectations. Information should be timely, understandable and available to relevant stakeholders.

Principles (5)

g) human and cultural factors

Human behavior and culture have a significant impact on all aspects of risk management at all levels and at every stage.

h) continuous improvement

Risk management is continually improved through learning and experience.

2.2 Risk Management Framework

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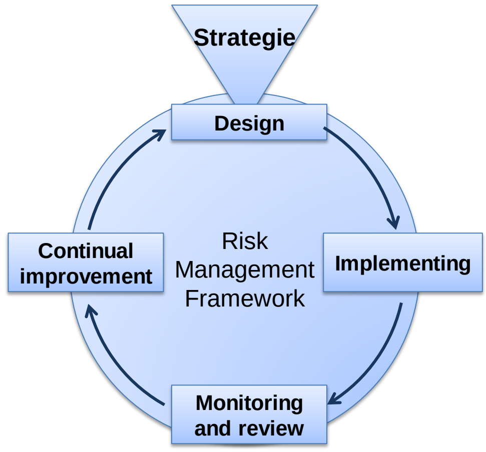
Risk Management Framework



Source: ISO 31000:2009 (Kap. 4)

Strategy

- The risk management strategy should define:
  - Criteria for classifying and evaluating the risks
  - methods of determining risk,
  - responsibilities in risk decisions;
  - provision of risk mitigation resources;
  - internal and external communication on the identified risks (reporting) and
  - Qualification of staff for risk management.

Mandate and commitment

For the successful introduction of the risk management the management has to:

- Define and enforce a strategy for risk management
- Define performance criteria for risk management
- align the objectives of risk management with the strategic objectives of the organisation
- Ensure compliance with legal requirements
- Deploy necessary resources
- Communicate risk management benefits to all stakeholders and stakeholders
- Ensure that the boundary conditions are and remain appropriate.

Mandate and commitment

- What to achieve:
  Objectives, Performance criteria
- What should it be achieved with:
  Resources
- How to achieve it:
  Strategy
- Who should reach it:
  Responsibilities

Context

1. Understanding the organization/system and its constraints
2. Development of a risk management strategy
3. Responsibilites
4. Integration into processes
5. Deploying Resources
6. Development of risk communication mechanisms

Resources

1. Employees, their skills, experiences and competencies
2. Required resources
3. Processes, tools and methods
4. Documentations
5. Tools for information and knowledge management
6. Further training/training

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2.3 Risk Management Process

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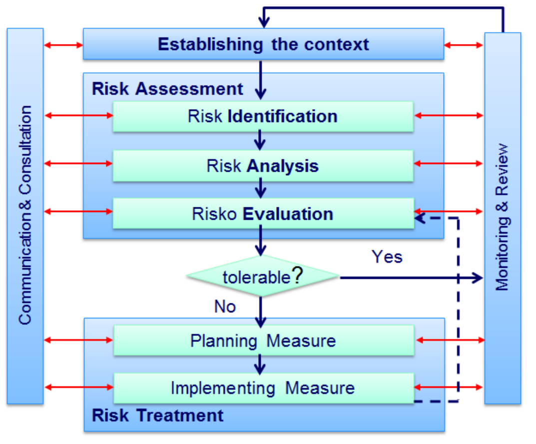
Risk management: ISO 31000 Process



Process cycle risk management — Process cycle risk treatment — Information

Communication and Consultation

Communication and consutlation with external and internal stakeholders should take place at all stages of the risk management process.

Essential information is:

- Risk
- Risk cause
- Consequences and impacts
- Necessary measures

Establishing the Context

The context of the risk management must clearly be articulated before the risk assessment starts.

Important aspects are:

- objective and scope
- external relationships
  (e.g. environmental conditions, interfaces)
- internal relationships of the organization/system
  (e.g. specifications)
- requirements for the risk management process
- risk criteria for the remaining process

Risk Characteristics

1. Name
2. Scope
3. Type
4. Cause
5. Likelihood
6. Strength/Extent of consequences
7. Temporal frame
8. Existing tolerances & redundancies
9. Potential of detection
10. Measures and options

Risk evaluation

The evaluation scheme to be applied depends on the framework conditions such as:

- field of application
- ambient conditions
- extent of damage/loss

Usual evaluation criteria are:

- Likelihood
- Potential damage/loss
- Recovery costs

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Risk evaluation - Likelihood / Probability, Scale

P_S	Probability	Criterion	
0 - 1	improbable/ unlikely	< 1%	So unlikely, that it can be assumed that the event does not occurs.
2 - 3	remote	1% - 5%	Low possibility that an event occurs.
4 - 6	occasional	5% - 50%	Event will occur in some, but less than half of the cases.
7 - 8	probable	50% - 90%	Event will occur in more than half of the cases.
9 - 10	frequent	> 90%	Most likely that an event will occur in approximately every case.

Risk evaluation – Severity of Potential consequences

S	Severity	criterion
1	Negligible	No or minor effects occur; the system can fulfill his mission without disturbances.
2 – 3	Limited/ Marginal	The appearing effects cause functional restrictions or working difficulties. They do not influence the main mission.
4 – 6	Severe	The appearing effects reduce the efficiency and capability of the system.
7 – 8	Very severe	The appearing effects prevent that the system is able to fulfill its main function or mission.
9 - 10	Catastrophic	Effects could result in one or more of the following: death of human being, permanent total damage, irreversible significant environmental impact.

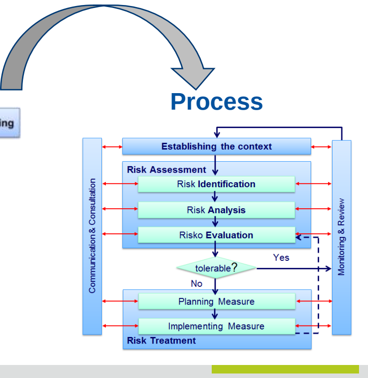
Take Home Messages

Principles

Framework

Establishing the Context
- Objective and scope
- Risk Criteria

Process



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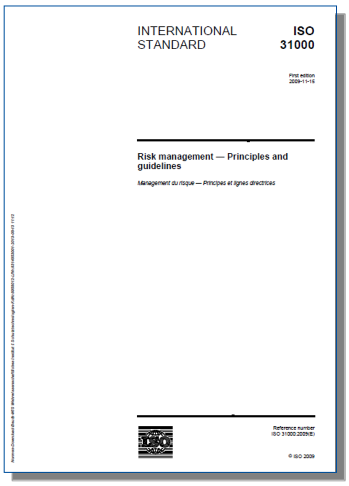
Literature


INTERNATIONAL STANDARD

ISO 31000

First edition 2009-11-15

Risk management — Principles and guidelines

Management du risque — Principes et lignes directrices

Reference number ISO 31000:2009(E)

© ISO 2009

ISO 31000:2018
Risk management
– Principles and guidelines

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Thank You for Your Attention.

Questions ?

Chapter 3
Risk Analysis Methods

EMI Risk Management

3. Risk Analysis Methods

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3.1 Introduction

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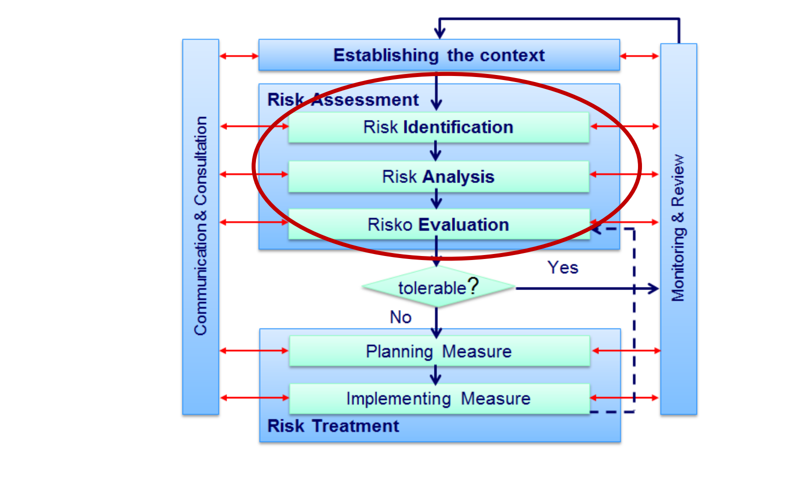
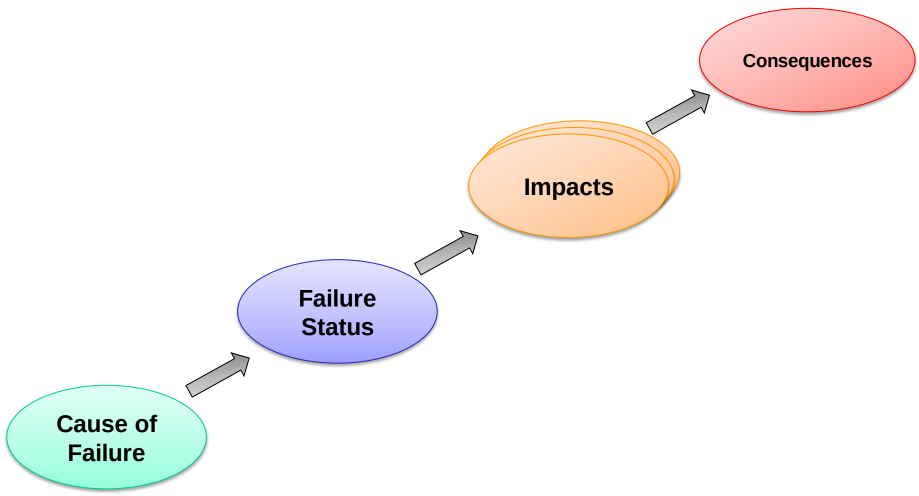
Risk management: ISO 31000 Process



Effect chain



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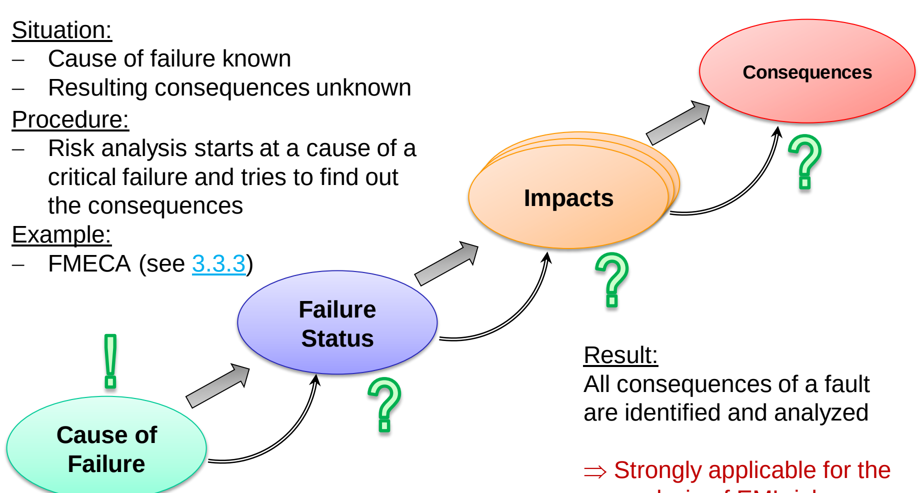
Inductive Methods

Situation:
- Cause of failure known
- Resulting consequences unknown

Procedure:
- Risk analysis starts at a cause of a critical failure and tries to find out the consequences

Example:
- FMECA (see 3.3.3)



Result:
All consequences of a fault are identified and analyzed

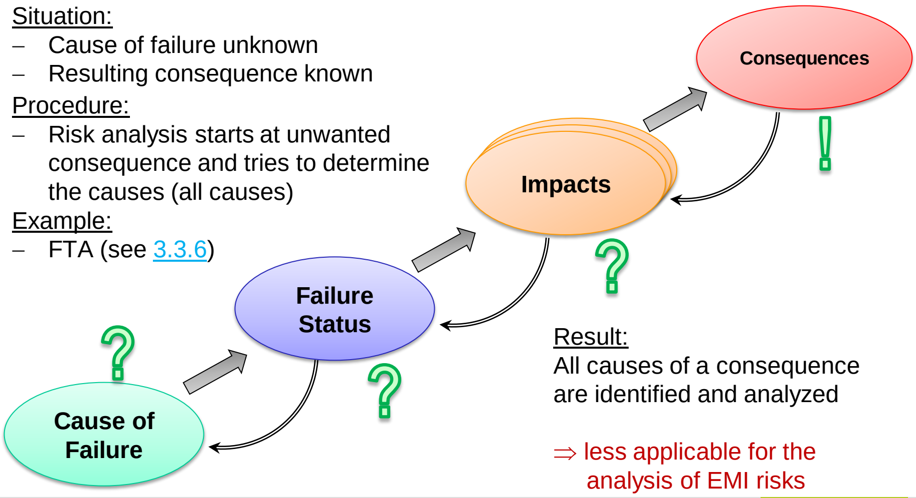
⇒ Strongly applicable for the analysis of EMI risks

Deductive Methods

Situation:
- Cause of failure unknown
- Resulting consequence known

Procedure:
- Risk analysis starts at unwanted consequence and tries to determine the causes (all causes)

Example:
- FTA (see 3.3.6)



Result:
All causes of a consequence are identified and analyzed

⇒ less applicable for the analysis of EMI risks

Categories of Methods

- **inductive Methods:**
  - Cause of failure known
  - Resulting consequences unknown
  - Example: FMECA (see 3.3.3)
- **deductive Methods:**
  - Cause of failure unknown
  - Resulting consequence known
  - Example: FTA (see 3.3.6)
- **explorative Methods**
  - Cause of failure unknown
  - Resulting consequences unknown
  - Example: HAZOP (see 3.3.1)

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Methods – Categories of Application

- used for Risk Identification:
  - Preliminary Hazard List (PHL)
- used for Risk Analysis – Consequences
  - Event Tree Analysis (ETA)
  - HAZOP
- used for Risk Analysis – Probability
  - Failure Modes, Effects and Criticality Analysis (FMECA)
- used for Risk Analysis – Level of Risk
  - FMECA
- used for Risk Analysis Evaluation
  - Consequence/Probability Matrix

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3.2 Methods used for Risk Identification

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3.2.1 Preliminary Hazard List (PHL)

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PHL - Overview

In the Preliminary Hazard List (at minimum), the following textual descriptions are given in tabular form:

- The hazard sources identified
- Causes and/or triggers of hazards determined
- Resulting hazards identified
- Affected operating phase/life cycle phases determined
- The effects of hazards
  (on persons, materials and the environment)

PHL - Process

1) Detection of potential sources of interference
2) Detection of possible coupling paths
3) Estimation of possible effects
4) Documentation

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PHL – Example Documentation Sheet

1	2	3	4	5	6	7
Ref. Nr.	Possible EMI Source		Possible Coupling Path		Affected Subsystem	Possible Effect
	Mobility	Possible Location	Type	Distance		

PHL - Strengths and limitations

Strengths:

- that it is able to be used when there is limited information;
- it allows risks to be considered very early in the system lifecycle.

Limitations:

- PHL provides only provisional information;
- The PHL is neither comprehensive nor provides detailed information on risks and how to best prevent them.

PHL – Exercise / Home Work

Tasks 3.2.1:

Identified and list possible EMI hazards for the system parts of the fictional generic infrastructure installed in the building 2A by employing the PHL.

PHL - Evaluation

Method	**Preliminary Hazard List (PHL)**				
Type of Method	inductive **X**	deductive	explorative		
Application	Identification **++**	Analysis - Consequence	Analysis-Probability	Analysis-Level of Risk	Evaluation
Life Cycle Phase	Concept Phase **X**	Definition Phase **X**	Design Phase **X**	Production Phase **X**	Operation Phase **X**

3.2.2 Preliminary Hazard Analysis (PHA)

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PHA - Overview

The Preliminary Hazard Analysis (PHA) is prepared on the basis of the Preliminary Hazard List (PHL) in order to:

- Evaluate hazard potentials at an early stage
- Identify all contributing security measures
- Examine the extent to which the residual risks are acceptable
- and/or to plan strategies to avoid hazards; or
- used as a basis for further reduction of residual risk
- by planning further safety measures

PHA - Process

1) Detection of potential sources of interference
2) Detection of possible coupling paths
3) Weighting of possible coupling paths
4) Estimation of possible effects
5) Evaluation of effects
6) Identification of risk management measures
7) Documentation

PHA - Documentation

1) Reference Number
2) Possible EMI Source
   - Mobility
   - Type
   - P_{EMI}
   - $E_{max} \cdot r$
3) Possible Location
4) Possible Coupling Path
   - Type
   - Distance
   - Attenuation
5) Affected Subsystem
6) Possible Effect
7) Consequence
8) Criticality / Severity
9) Likelihood
10) Level of Risk (w/o measures)

PHA – Example Documentation Sheet

1	2	2a	2b	2c	3	…	7
Ref. Nr.	Possible EMI Source					…	Possible Effect
	Mobility	Type	P_{EMI}	$E_{max} \cdot r$	Possible Location		

PHA – Example Documentation Sheet (cont.)

1	…	4	5	5a	6	7
Ref. Nr.	…	Possible Coupling Path			Affected Subsystem	Possible Effect
		Type	Distance	Attenuation		

PHA – Example Documentation Sheet (cont.)

1	…	6	7	8	9	10	11
Ref. Nr.	…	Affected Subsystem	Possible Effect	Conse-quence	Criticality / Severity	Likelihood	Level of Risk (w/o meas.)

PHA - Strengths and limitations

Strengths:

- that it is able to be used when there is limited information;
- it allows risks to be considered very early in the system lifecycle.

Limitations:

- PHA provides only provisional information;
- The PHA is neither comprehensive nor provides detailed information on risks and how to best prevent them.

PHA – Exercise / Home Work

Tasks 3.2.2:

Identify, list and evaluate possible EMI hazards for the system parts of the fictional generic infrastructure installed in the building 2A by employing the PHA.

It might be helpful to start from the documentation of task 3.2.1.

PHA - Evaluation

Method	**Preliminary Hazard Analysis (PHA)**				
Type of Method	inductive **X**	deductive	explorative		
Application	Identification **++**	Analysis - Consequence **+**	Analysis-Probability	Analysis-Level of Risk	Evaluation
Life Cycle Phase	Concept Phase	Definition Phase **X**	Design Phase **X**	Production Phase **X**	Operation Phase **X**

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3.3 Methods used for Risk Analysis

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3.3.1 HAZard and OPerability study (HAZOP)

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HAZOP - Overview

- The HAZOP is a method for identifying potential safety and operational problems of technical systems
- The HAZOP study must be carried out by a <u>team of experts</u>.
- An experienced <u>discussion leader</u> systematically guides the analysis team through the analysis process by using appropriate key or guidewords.
- The keywords are linked to certain process parameters during the discussion in order to determine possible deviations from the planned mode of operation.
- The significance of possible deviations for the system, the users and the environment is considered.
- Causes and consequences are investigated.

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HAZOP – Team of Experts

- Moderator or team leader
- System developer
- User / Operator
- EMI or EMC expert
- Experts on other essential aspects

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HAZOP - Process

1) Preparation
2) Selection of a process step
3) Process step attribution
4) Combination of each attribute of a process part with guidewords
5) Risk identification
6) Discussion of possible causes and consequences
7) Development of remedial measures
8) Continue the analysis with a different guide word, attribute, or process part
9) Documentation

HAZOP - Preparation

Prior to the workshop in which the analysis is conducted, the moderator creates a list with

- Guidewords and
- Questions

which are adapted to the system to be considered.

HAZOP – Process step

- **Example: Energy supply**
  - start-up / turning on
  - normal operation
  - full use of the capacity
  - malfunction (e.g. emergency shutdown, insulation violation, ground closure) and
  - shut down / Switch off
  - …

Source: IEC 61882

HAZOP – Guidewords

- Field exposition
- Interference signal
- Malfunction
- Failure / shutdown
- Under voltage / over voltage
- Voltage drop / outrage
- …

Source: IEC 61882

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HAZOP – Guidewords (attributes)

- No, not ⇒ target function does not take place or is negated
- More ⇒ Quantitative growth, too much is happening
- Less ⇒ Quantitative decrease, too little
- Both and ⇒ In addition, something else happens
- Partially ⇒ Target function is incomplete
- Reversal ⇒ The opposite happens

Source: IEC 61882

HAZOP - Risk identification

During a workshop the expert team then discusses whether the deviation described by the selected guide word represents a problem or danger.

Example question:
“What is the immediate consequence of a lower output voltage of the Side Distribution Frame 2?”

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HAZOP - Strengths and limitations

Strengths:

- a HAZOP study may be conducted as soon as a preliminary design of the system has been prepared;
- methodology for systematic and comprehensive analysis of systems and processes;
- provides solutions for risk management.

Limitations:

- A complete system analysis can be very complicated and lengthy;
- The analysis depends heavily on the expertise of the developers, who may be biased over their design.

HAZOP – Exercise / Home Work

Tasks 3.3.1:

Identify, list and evaluate possible EMI hazards for the system parts of the fictional generic infrastructure installed in the building 5 by employing the HAZOP.

- The task should be handled in groups of 3-4 students.
- The result shall be documented in a short report

HAZOP – Evaluation

Method	**HAZard and OPerability study (HAZOP)**				
Type of Method	inductive	deductive	explorative X		
Application	Identification ++	Analysis - Consequence ++	Analysis-Probability +	Analysis-Level of Risk +	Evaluation +
Life Cycle Phase	Concept Phase	Definition Phase	Design Phase X	Production Phase X	Operation Phase X

3.3.2 Structured What-if Technique (SWIFT)

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SWIFT - Overview

- SWIFT was originally developed as a simpler alternative to HAZOP.
- It is a systematic, team based study, utilizing a set of 'prompt' words or phrases that is used by the facilitator within a workshop to stimulate participants to identify risks.
- The facilitator and team use standard 'what-if' type phrases in combination with the prompts to investigate how a system, will be affected by deviations from normal operations and behavior.
- SWIFT is normally applied at more of a systems level with a lower level of detail than HAZOP.

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SWIFT – Team of Experts

- Moderator or team leader
- System developer
- User / Operator
- EMI or EMC expert
- Experts on other essential aspects

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SWIFT - Process

1) Preparation
2) System description and specifications
3) Capture of previously known risks
4) Selection of a process step
5) Discussion of deviations
6) Risk identification
7) Evaluation of remediation measures
8) Documentation

SWIFT - Preparation

Prior to the workshop in which the analysis is conducted, the moderator creates a list with

- ‘Prompt’ words,
- Phrases and
- Questions

which are adapted to the system to be considered.

SWIFT – Process step

- **Example: Energy supply**
  - start-up / turning on
  - normal operation
  - full use of the capacity
  - malfunction (e.g. emergency shutdown, insulation violation, ground closure) and
  - shut down / Switch off
  - …

SWIFT – 'Prompt' Words

- Field exposition
- Interference signal
- Malfunction
- Failure / shutdown
- Under voltage / over voltage
- Voltage drop / outrage
- …

SWIFT – Phrases

- What if,...?
- What would happen if...?
- How could...?
- Could anyone...?
- Could something...?
- Anyone ever...?
- Did anything ever...?
- …

SWIFT – Questions (examples)

- What if, building 1 would be irradiated by an EMI source (M = X/type) on location P?
- Could someone place an EMI source (M = X/type) in building 1?
- What would happen if subsystem S had a malfunction?
- What would happen if subsystem S failed/is shutdown?
- Could someone generate a wrong control signal on the signal line ?
- …?

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SWIFT – Capture of previously known risks

- Known risks
- previous experiences and EMI events
- known control and protection elements and
- Restrictions

SWIFT – Risk identification

At the end of each expert discussion (workshop)

- identified risks (including their consequences) are summarized; and
- existing options to control risks considered.

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SWIFT – Evaluation of remediation measures

The expert's team:

- Checks whether the discussed controls are suitable and effective
- Prepares a statement on the effectiveness of risk controls
- Considers further risk treatment measures (if necessary)

SWIFT - Strengths and limitations

Strengths:

- it is widely applicable to all forms of physical plant or system;
- it needs minimal preparation by the team;
- it is relatively rapid and the major hazards and risks quickly become apparent within the workshop session;
- the study is 'systems orientated' and allows participants to look at the system response to deviations rather than just examining the consequences of component failure;
- it can be used to identify opportunities for improvement of processes and systems;

SWIFT - Strengths and limitations (cont.)

Limitations:

- it needs an experienced and capable facilitator to be efficient;
- careful preparation is needed so that the workshop team's time is not wasted;
- if the workshop team does not have a wide enough experience base or if the prompt system is not comprehensive, some risks or hazards may not be identified;
- the high-level application of the technique may not reveal complex, detailed or correlated causes.

SWIFT – Exercise / Home Work

Tasks 3.3.2:

With the help of SWIFT, the possible EMI hazards for the system parts installed in building 1 of the fictional infrastructure should to be identified and recorded.

- The task should be handled in groups of 3-4 students.
- The result shall be documented in a short report

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SWIFT - Evaluation

Method	**Structured What-if Technique (SWIFT)**				
Type of Method	inductive	deductive	explorative X		
Application	Identification ++	Analysis - Consequence ++	Analysis-Probability ++	Analysis-Level of Risk ++	Evaluation ++
Life Cycle Phase	Concept Phase	Definition Phase	Design Phase X	Production Phase X	Operation Phase X

3.3.3 Failure Mode Effects and Criticality Analysis (FMECA)

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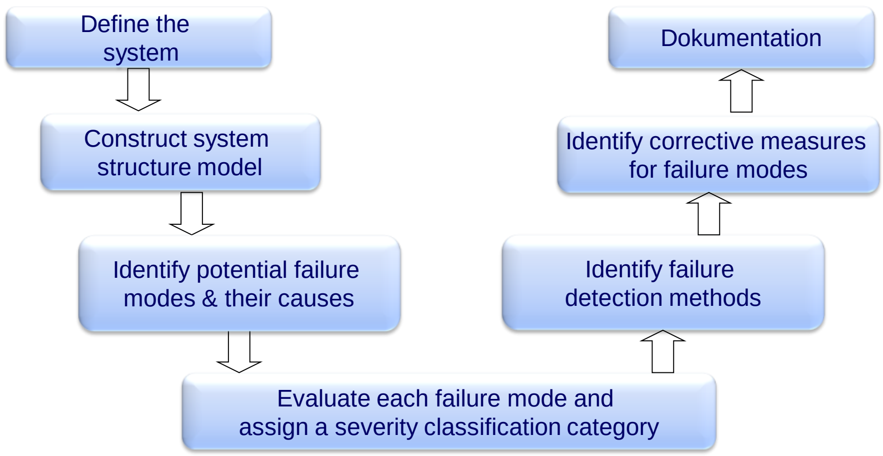
FMECA - Overview

- The FMECA identifies the possible types of failure (individual errors) of a module/system and analyzes their impact.
- The system to be considered is subdivided into "sensible" units.
- The impact of a failure type can be evaluated with regard to:
  - Safety (severity, probability of failure, detectability)
  - Reliability (subsequent failures, vulnerabilities, redundancy)
  - Testability (detectability, test depth of the built-in test)
  - Material durability (detectability, localizability of failures, impact on mission and safety)

FMECA - Process



Source: MIL-STD-1629A
IEC 60812

FMECA - Strengths and limitations

Strengths:

- widely applicable;
- allows the identification of component errors, their causes and effects,
- Clear presentation.

Limitations:

- can only be used to identify single failure modes, not combinations of failure modes;
- unless adequately controlled and focused, the studies can be time consuming and costly;
- they can be difficult and tedious for complex multi-layered systems.

FMECA - Evaluation

Method	Failure Mode Effects and Criticality Analysis (FMECA)				
Type of Method	inductive X	deductive	explorative		
Application	Identification ++	Analysis - Consequence ++	Analysis-Probability ++	Analysis-Level of Risk ++	Evaluation ++
Life Cycle Phase	Concept Phase	Definition Phase	Design Phase X	Production Phase X	Operation Phase X

3.3.4 Threat Scenario, Effect and Criticality Analysis (TSECA)

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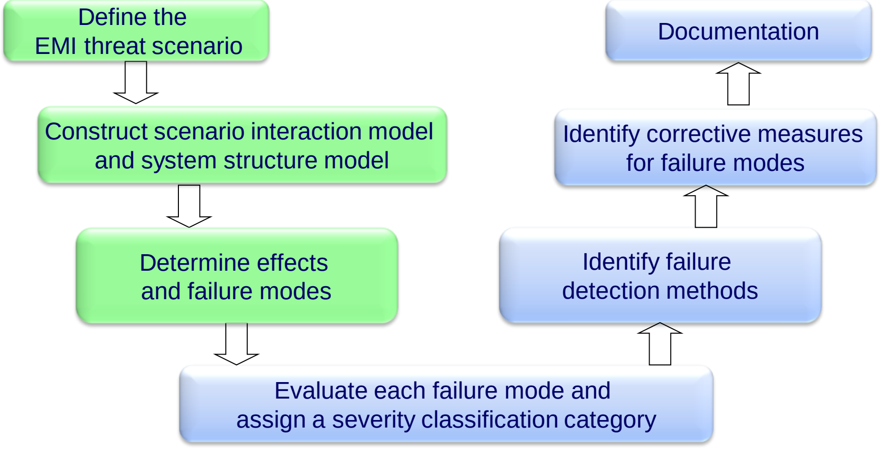
TSECA - Overview

- The Threat Scenario, Effect and Criticality Analysis (TSECA) is an inductive Method for EMI risk analysis based on the methodology of failure mode, effects and Criticality Analysis (FMECA).
- The basic structure of TSECA is similar the structure of the FMECA as described in MIL-STD-1629A
- In contrast to the FMECA the TSECA has been modified to be capable to consider external causes of risks.

TSECA - Process



Source: F. Sabath and H. Garbe, "Concept of stochastic modeling for High-Power Electromagnetics (HPEM) risk analysis at system level," 2013 IEEE International Symposium on Electromagnetic Compatibility, Denver, CO, 2013, pp. 401-406, doi: 10.1109/ISEMC.2013.6670446

TSECA - Strengths and limitations

Strengths:
- widely applicable;
- capable to consider external causes of risks,
- Clear presentation.

Limitations:
- can only be used to identify single failure modes, not combinations of failure modes;
- unless adequately controlled and focused, the studies can be time consuming and costly;
- they can be difficult and tedious for complex multi-layered systems.

TSECA - Evaluation

Method	**Threat Scenario, Effect and Criticality Analysis (TSECA)**				
Type of Method	inductive X	deductive	explorative		
Application	Identification ++	Analysis - Consequence ++	Analysis- Probability ++	Analysis- Level of Risk ++	Evaluation ++
Life Cycle Phase	Concept Phase	Definition Phase	Design Phase X	Production Phase X	Operation Phase X

3.3.5 Event Tree Analysis (ETA)

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ETA - Overview

- ETA is an inductive and graphical technique for representing the mutually exclusive sequences of events following an initiating event according to the functioning/not functioning of the various systems designed to mitigate its consequences.
- It can be applied both qualitatively and quantitatively.
- By fanning out like a tree, ETA is able to represent the aggravating or mitigating events in response to the initiating event, taking into account additional systems, functions or barriers.

ETA - Process

- ETA starts with an initiating event (e.g. component error)
- Starting from the initiating event, possible subsequent states are displayed. Each branch represents the functioning or failure of a component/assembly.
- The paths are weighted with their probability of occurrence.
- The probability of each path passing through the tree represents the probability that all events in this path will be.

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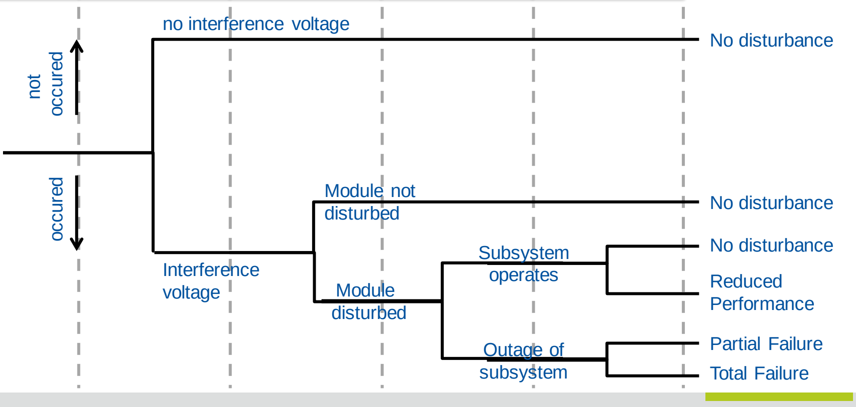
ETA - Process

Initiating event	1. Subsequent event	2. Subsequent event	3. Subsequent event	4. Subsequent event	System level consequence
IEMI Exposition	interference voltage	Disturbance of Module	Outage Subsystem		



ETA - Strengths and limitations

Strengths:

- Represents follow-up events and their impact on the overall function;
- allows you to view temporal dependencies and domino effects.
- Graphic representation of event sequences

Limitations:

- need to identify initiating events;
- ETA can only view function or failure, time-delayed effects or recovery operations cannot be mapped.
- Only functional dependencies are recorded.

ETA - Evaluation

Method	**Event Tree Analysis (ETA)**				
Type of Method	inductive X	deductive	explorative		
Application	Identification +	Analysis - Consequence ++	Analysis-Probability +	Analysis-Level of Risk +	Evaluation
Life Cycle Phase	Concept Phase	Definition Phase	Design Phase X	Production Phase X	Operation Phase X

3.3.6 Fault Tree Analysis (FTA)

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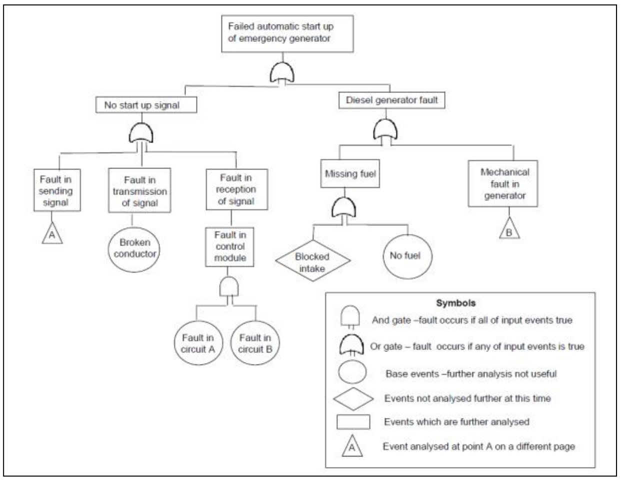
FTA - Overview

- Fault tree analysis (FTA) is a deductive method.
- FTA is a technique for identifying and analyzing factors that can contribute to a specified undesired event (called the “top event”). Causal factors are deductively identified, organized in a logical manner and represented pictorially in a tree diagram which depicts causal factors and their logical relationship to the top event.

FTA - Process

- The top event to be analyzed is defined.
- Starting with the top event, the possible immediate causes or failure modes leading to the top event are identified.
- Each of these causes/fault modes is analyzed to identify how their failure could be caused.
- Stepwise identification of undesirable system operation is followed to successively lower system levels until further analysis becomes unproductive.
- Where probabilities can be assigned to base events the probability of the top event may be calculated.

FTA - Process



Source: IEC 60300-3-9
IEC 2063/09
IEC 61025

FTA - Strengths and limitations

Strengths:

- a systematic approach that facilitates the analysis of complex systems with many interfaces;
- Logic analyses enable the identification of error propagation paths in complex systems

Limitations:

- the FTA is a static analysis; Time dependencies cannot be considered
- FTA can only map binary states
- FTA cannot analyze "domino effects" or dependencies.
- Only one top event can be considered for each fault tree.

FTA - Evaluation

Method	**Fault Tree Analysis (FTA)**				
Type of Method	inductive	deductive X	explorative		
Application	Identification ++	Analysis - Consequence	Analysis- Probability ++	Analysis- Level of Risk +	Evaluation +
Life Cycle Phase	Concept Phase	Definition Phase	Design Phase X	Production Phase X	Operation Phase X

3.3.7 Bow Tie Analysis (BTA)

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BTA - Overview

- Bow tie analysis is a simple diagrammatic way of describing and analyzing the pathways of a risk from causes to consequences.
- It can be considered to be a combination of the thinking of a fault tree analyzing the cause of an event (represented by the knot of a bow tie) and an event tree analyzing the consequences.
- The focus of the bow tie is on the barriers between the causes and the risk, and the risk and consequences.

BTA - Process

a) A particular risk is identified for analysis and represented as the central knot of a bow tie.

b) Causes of the event (Sources of Risk) are listed on the left side.

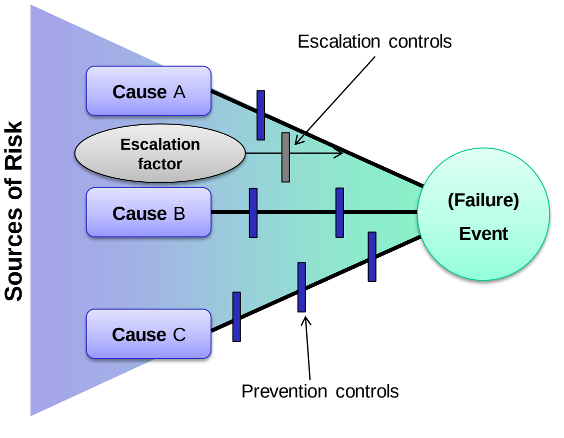
c) The mechanism by which the source of risk leads to the critical event is identified.

d) Lines are drawn between each cause and the event forming the left-hand side of the bow tie. Factors which might lead to escalation can be identified and included in the diagram.

e) Barriers which should prevent each cause leading to the unwanted consequences can be shown as vertical bars across the line.

f) Where there were factors which might cause escalation, barriers to escalation can also be represented.

BTA - Process



Source: IEC 60300-3-9
IEC 2069/09

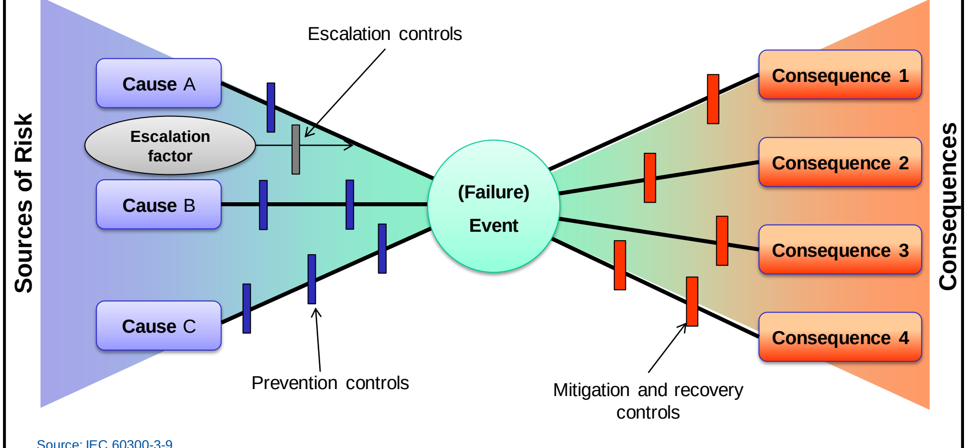
BTA - Process

g) On the right-hand side of the bow tie different potential consequences of the risk are identified and lines drawn to radiate out from the risk event to each potential consequence.

h) Barriers to the consequence are depicted as bars across the radial lines.

i) Management functions which support controls (such as training and inspection) can be shown under the bow tie and linked to the respective control.

BTA - Process



Source: IEC 60300-3-9
IEC 2069/09

BTA - Strengths and limitations

Strengths:

- it is simple to understand and gives a clear pictorial representation of the problem;
- it focuses attention on controls which are supposed to be in place for both prevention and mitigation and their effectiveness;
- it can be used for desirable consequences;
- it does not need a high level of expertise to use.

Disadvantages:

- The necessity of simultaneous occurrence of several causes cannot be illustrated.
- There is a risk of too much simplification of complex contexts.

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BTA – Exercise / Home Work

Tasks 3.3.7:

With the help of BTA, the possible EMI hazards for the system parts installed in building 1 of the fictional infrastructure should to be identified and depicted.

BTA - Evaluation

Method	Bow Tie Analysis (BTA)				
Type of Method	inductive	deductive x	explorative		
Application	Identification	Analysis - Consequence +	Analysis- Probability ++	Analysis- Level of Risk ++	Evaluation
Life Cycle Phase	Concept Phase	Definition Phase **X**	Design Phase **X**	Production Phase **X**	Operation Phase **X**

3.4 Methods used for Risk Evaluation

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Objective of Risk Evaluation

(1) To classify identified risks in

- Risks that can be tolerated
- Risks that require further analysis
- Risks that need to be addressed/mitigated

(2) To priories necessary risk management measures

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Risk Classification

Classification of identified risks by comparison

- defined risk characteristics and **assessment criteria** (see 2.3 Establishing the Context), with:
- the **risk parameters** determined in the risk analysis;

Risk Evaluation

Usual evaluation criteria are:

1) probability of occurrence
2) Severity / extent of damage
3) Potential of detection of hazed / error recognition

Anomaly IEMI Risk

As Probability/Frequently, the damage (effect, impact) **occurs** when the system is exposed to an IEMI environment (IEMI attack)..

- Assumption of IEMI attack/IEMI exposure.
- The likelihood of IEMI attack/IEMI exposure is not considered.
- This is dependent on non-technical aspects and can be determined separately if required.

3.4.1 Risk Index

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Risk Index - Overview

- A risk index is a semi-quantitative measure of risk which is an estimate derived using a scoring approach using ordinal scales.
- Risk indices can be used to rate a series of risks using similar criteria so that they can be compared.
- Risk indices are essentially a qualitative approach to ranking and comparing risks. While numbers are used, this is simply to allow for manipulation.

Example - Risk Priority Index (RPI)

$$RPI = S \cdot P \cdot D$$

S – Severity of damage $\in [0, 10]$
P – Probability of occurrence $\in [0, 10]$
D – Potential of detection $\in [0, 10]$

- By calculating the risk priority number (RPI), an attempt is made to establish a ranking of the risks.
- $1 \leq RPI \leq 1000$
- There is the claim that the RPI, at least in comparison with other RPI of the same risk analysis, allows a statement in the sense of better/worse.

Risk Index - Strengths and limitations

Strengths:

- indices can provide a good tool for ranking different risks;
- they allow multiple factors which affect the level of risk to be incorporated into a single numerical score for the level of risk.

Limitations:

- if the process (model) and its output are not well validated, the results may be meaningless.
- The fact that the output is a numerical value for risk may be misinterpreted and misused, for example in subsequent cost/benefit analysis;

3.4.2 Risk Matrix

(Consequence/ Probability Matrix)

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Risk Matrix - Overview

- Classification of the potential **extent of damage**
- Classification of the **probability of occurrence**
- Representation of the potential **extent of damage** (vertical) and the associated **probability of occurrence** (horizontal) in matrix form.
- Classification of fields into risk classes:
  - Red: high risk/determined risk is not acceptable
  - Yellow: significant risk/risk cannot be taken easily, further analysis is required
  - Green: low risk/risk is acceptable

Risk Matrix - Process

extent of damage	improbable/ unlikely	occasional	probable	frequent
Catastrophic	II	I	I	I
Severe	II	II	I	I
Limited/ Marginal	III	III	II	I
Negligible	III	III	III	II

probability of occurrence

Risk Matrix - Strengths and limitations

Strengths:

- Relatively easy to use;
- Enables rapid classification of risks in significance classes.

Limitations:

- The structure of the matrix should be adapted to the scope. It is therefore difficult to create a general classification for all areas of application.
- it is difficult to define the scales unambiguously.
- The application is always subjectively influenced.
- Risks cannot be summarized.
- It is difficult to compare different risks with different effects

3.5 Comparison of Methods

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Methods used for risk assessment

Method	Risk Assessment				
	Risk Identification	Risk Analysis			Risk Evaluation
		Consequence	Probability	Level of risk	
Brainstorming	SA	NA	NA	NA	NA
Strukturierte Interviews	SA	NA	NA	NA	NA
Delphi Technik (Expertengruppe)	SA	NA	NA	NA	NA
Preliminary Hazard List (PHL)	SA	NA	NA	NA	NA
Preliminary hazard analysis (PHA)	SA	A	NA	NA	NA

SA Strongly applicable. A Applicable. NA Not Applicable.

Source: ISO 31010:2009 (Annex A)

Methods used for risk assessment

Method	Risk Assessment				
	Risk Identification	Risk Analysis			Risk Evaluation
		Consequence	Probability	Level of risk	
HAZard and OPerability study (HAZOP)	SA	SA	A	A	A
Hazard analysis and critical control point (HACCP)	SA	SA	NA	NA	SA
Structured "What-if" Technique (SWIFT)	SA	SA	SA	SA	SA
Scenario analysis	SA	SA	A	A	A

SA Strongly applicable. A Applicable. NA Not Applicable.

Source: ISO 31010:2009 (Annex A)

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Methods used for risk assessment

Method	Risk Assessment				
	Risk Identification	Risk Analysis			Risk Evaluation
		Consequence	Probability	Level of risk	
Root cause analysis (RCA)	NA	SA	SA	SA	SA
Layers of protection analysis (LOPA)	A	SA	A	A	NA
Failure Modes, Effects and Criticality Analysis (FMECA)	**SA**	**SA**	**SA**	**SA**	**SA**

SA Strongly applicable. A Applicable. NA Not Applicable.

Source: ISO 31010:2009 (Annex A)

Methods used for risk assessment

Method	Risk Assessment				
	Risk Identification	Risk Analysis			Risk Evaluation
		Consequence	Probability	Level of risk	
Fault Tree Analysis (FTA)	**A**	**NA**	**SA**	**A**	**A**
Event Tree Analysis (ETA)	**A**	**SA**	**A**	**A**	**NA**
Cause-consequence analysis	A	SA	SA	A	A
Cause-and-effect analysis	SA	SA	NA	NA	NA
Bow tie analysis	**NA**	**A**	**SA**	**SA**	**A**

SA Strongly applicable. A Applicable. NA Not Applicable.

Source: ISO 31010:2009 (Annex A)

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Methods used for risk assessment

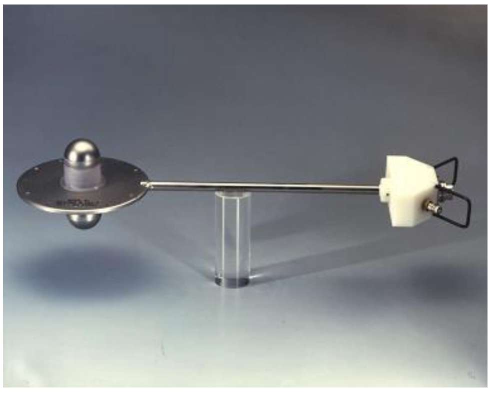
Method	Risk Assessment				
	Risk Identification	Risk Analysis			Risk Evaluation
		Consequence	Probability	Level of risk	
Markov analysis	A	SA	NA	NA	NA
Monte Carlo simulation	**NA**	**NA**	**NA**	**NA**	**SA**
Bayesian statistics and Bayes Nets	NA	SA	NA	NA	SA
Risk indices	A	SA	SA	A	SA
Consequence/ probability matrix	**SA**	**SA**	**SA**	**SA**	**A**

SA Strongly applicable. A Applicable. NA Not Applicable.

Source: ISO 31010:2009 (Annex A)

Thank You for Your Attention.

Questions ?



Chapter 4
EMI Scenario

EMI Risk Management

4. EMI Scenario

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Content

✓ 1. Introduction & Basic Terms
✓ 2. Fundamentals of Risk Management
✓ 3. Risk Analysis Methods
⇒ 4. EMI Scenario
5. Modeling of scenarios and systems
6. Effects and Error States
7. Risk Evaluation
8. Risk Treatment and Protection
9. Examples
10. Summary

4.1 EMI Scenario

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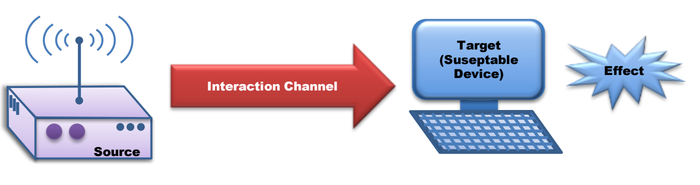
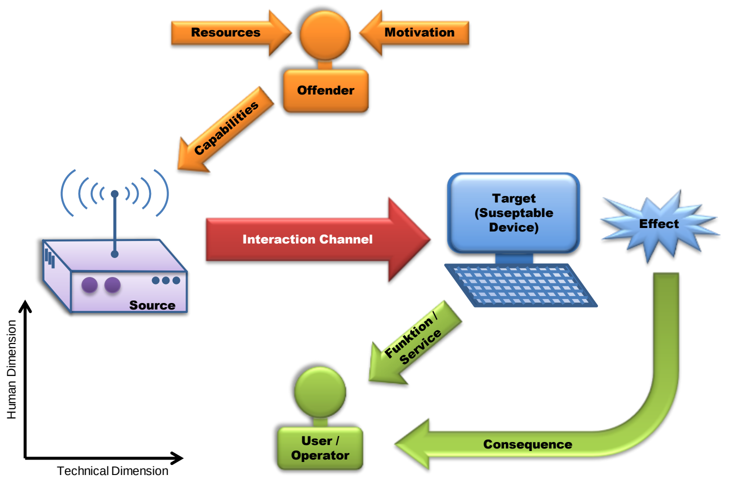
Model of EMI Scenario



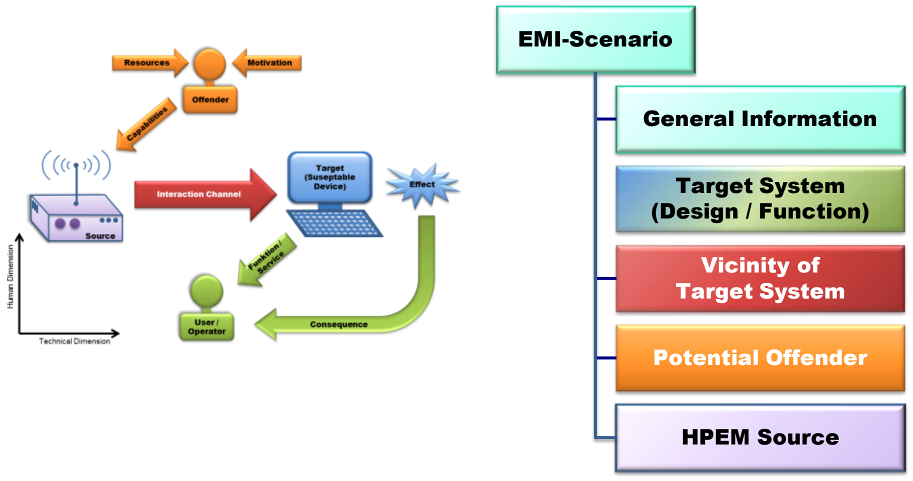
Model of EMI Scenario



Definition EMI Scenario

The **EMI scenario** includes the description and spatial arrangement of possible EMI sources, the target system under consideration, and objects that influence the propagation of the electromagnetic field.

Definition EMI Scenario



EMI Scenario: General Information

Aspect	Remark
Reference Number	EMI scenario identification number
Label / Name	Label / Name of the scenario EMI

EMI Scenario: Target System

Aspect	Remark
Label / Name Target System	Label / Name of the target system to be analyzed
Demanded Function	Description of the main and possibly important secondary functions
Demanded Performance	Specified performancs power as well as tolerated performance limits (collapses) or required minimum performance
Working Conditions	Description of the operating states to be examined (e.g. operation, maintenance, repair)
Operating Conditions	Description of essential operating conditions (e.g. environment, stress factors)
Technology	Characterization of technology level and/or technology
Structure of the System	Description of the structure of the system (e.g. subsystems, assemblies, functional units), as well as their functional relationships and interfaces
Location / Spatial Distribution	spatial arrangement or distribution of the target system

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EMI Scenario: Vicinity of Target System

Aspect	Remark
Accesibility	Description of accessibility to the target system/access zones/drawing or illustration if necessary
Possible coupling paths	Description of possible coupling paths of electromagnetic energy.
Scattering Objects	Scattering objects in the vicinity of the target system.

EMI Scenario: Potential Offender

Aspect	Remark
Type	Internal / external offender
Access	Probability that the potential attacker has access to an area.
Knowledge	Probability that the potential attacker has access to the knowledge required to construction and operation the HPEM source.
Financial Recourses	Probability that the potential offender has access to funds of a given amount.

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EMI Scenario: HPEM Source

Aspect	Remark
Availability of Technology	Availability characterizes the effort involved in obtaining the HPEM source or its components
Bandwidth	Bandwidth of the emitted field signal
Frequency Range	Frequency band that encompasses the center frequency of the HPEM source
Frequency Agility	Tunability of the HPEM source
Volume / Mobility	Overall design size of the HPEM source
operating time	Duration of the exposure / threat
Possible Locations	Locations at which the HPEM source could be operated
Likelihood of Occurrence	Probability that the HPEM source is used by the potential offender and occurs at the potential location.

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Availability of Technology, Scale

AV_C	Availability	Description
1	of-the-shelf	available in the commercial market-place (e.g. department stores); can be bought by anyone
2	commercially available	available in specialty stores; can be bought by anyone
3	specialized trade	available only in specialized trading companies; acquisition is limited to commercial customer
4	limited acquisition	Limited acquisition under conditions or to registered buyer, special designed components
5	restricted acquisition	trade or acquisition prohibited by law

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Bandwidth, Scale

Bandwidth		Fractional Bandwidth $B_F = 2\frac{f_h - f_l}{f_h + f_l}$	Band Ratio $b_r = \frac{f_h}{f_l}$	Examples
HO	Hypoband / Narrowband	$0{,}00 < B_F \leq 0{,}01$	$0{,}00 < b_r \leq 1{,}01$	sinusoidal signal, pulse-modulated sinusoidal.
ME	Mesoband	$0{,}01 < B_F \leq 1{,}00$	$1{,}01 < b_r \leq 3$	damped sinusoidal signal
SH	Sub-Hyperband	$1{,}00 < B_F \leq 1{,}63$	$3 < b_r \leq 10$	Chirp
HE	Hyperband	$1{,}63 < B_F \leq 2{,}00$	$10 < b_r \leq \infty$	gaussian pulse, bipolar pulse, double exponential pulse

Source: IEC 61000-2-13

Frequency Bands

Radar Nomenclature		ITU Nomenclature	
Band (Radar)	Frequency Range	Frequency Range	Band (ITU
HF	$3\ \text{MHz} \le f_c < 30\ \text{MHz}$	$3\ \text{MHz} \le f_c < 30\ \text{MHz}$	HF
VHF	$30\ \text{MHz} \le f_c < 300\ \text{MHz}$	$30\ \text{MHz} \le f_c < 300\ \text{MHz}$	VHF
UHF	$0{,}3\ \text{GHz} \le f_c < 1\ \text{GHz}$	$0{,}3\ \text{GHz} \le f_c < 3\ \text{GHz}$	UHF
L	$1\ \text{GHz} \le f_c < 2\ \text{GHz}$		
S	$2\ \text{GHz} \le f_c < 4\ \text{GHz}$	$3\ \text{GHz} \le f_c < 30\ \text{GHz}$	SHF
C	$4\ \text{GHz} \le f_c < 8\ \text{GHz}$		
X	$8\ \text{GHz} \le f_c < 12\ \text{GHz}$		
Ku	$12\ \text{GHz} \le f_c < 18\ \text{GHz}$		
K	$18\ \text{GHz} \le f_c < 27\ \text{GHz}$		

Source: IEEE Std 521-2002

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Frequency Agility, Scale

F_{AG}	Frequency Agility	Definition	Remarks
1	fixed frequency	$\Delta f = 0$	The source works on a fixed (center) frequency and is not tunable.
2	low	$\lvert \Delta f / f_c \rvert \le 1\%$	The (center) frequency can be tuned up to 1%.
3	moderate	$\lvert \Delta f / f_c \rvert \le 10\%$	The (center) frequency can be tuned up to 10%.
4	high	$\lvert \Delta f / f_c \rvert \le 25\%$	The (center) frequency can be tuned up to 25%.
5	Very high	$\lvert \Delta f / f_c \rvert > 25\%$	The (center) frequency can be tuned by more than 25%.

Usable Volume of possible Platforms



Plattform	Usable Volume
40´ Container	77 m³
20´ Container	38 m³
Light Truck (up to 7,5 t)	9 – 42 m³
Van / Minivan	2 - 6 m³
Suitcase	< 0,2 m³
Briefcase	< 0,02 m³




Volume / Mobility, Scale

Level (M)	Mobility	Volume	Example
1	stationary	> 77m³	Fixed installation
2	transportable	10 - 77m³	light truck – 40‘ Container
3	mobile	0,2 – 10 m³	car / van
4	very mobile	0,02 – 0,2 m³	briefcase
5	highly mobile	< 0,02 m³	beverage can

4.2 Modell „Generic Offender“

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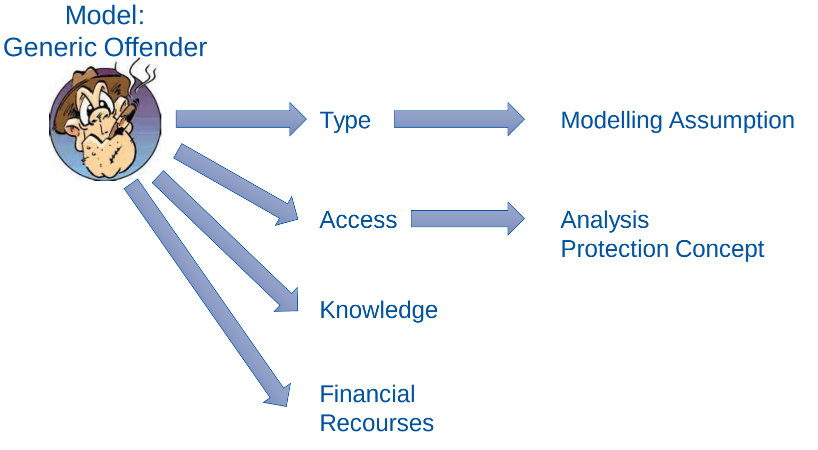
EMI Scenario: Potential Offender

Aspect	Remark
Type	Internal / external offender
Access	Probability that the potential attacker has access to an area.
Knowledge	Probability that the potential attacker has access to the knowledge required to construction and operation the HPEM source.
Financial Recourses	Probability that the potential offender has access to funds of a given amount.

EMI Scenario: Potential Offender



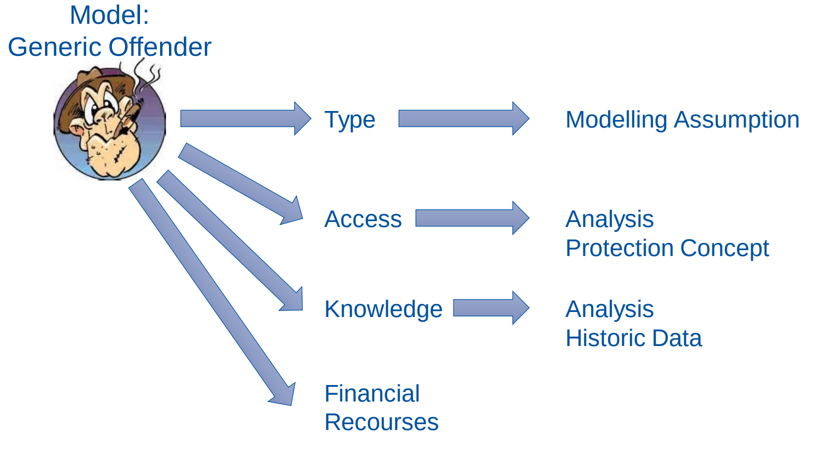
Accessibility, Scale

Level (A_z)	Acces-sibility	outside	inside	Definition
1o	free	X		Area of the **general public (outdoors)** accessible to each person without special effort.
1i	free		X	Area of the **general public (indoors)** accessible to each person without special effort.
2o	monitored	X		Area of the general public whose access is or can be **monitored**.
2i	monitored		X	Area in a building whose access is or can be **monitored**.
3o	controlled	X		Outdoor area that can only be entered after an **identity check**
3i	controlled		X	Area in a building that can only be entered after an **identity check**
4o	restricted	X		Outdoor control / restricted area that can only be accessed by **authorized persons** or after a **pocket check**.
4i	restricted		X	Control / restricted area in the building, which can only be entered by **authorized persons** or after a **pocket check**.

Generic Offender: Access (example)

A_Z	Accessibility	Index of Probability (internal offender)		Index of Probability (external offender)	
1o 1i	free / general public	**10**	frequent (> 97%)	**10**	frequent (> 97%)
2o 2i	monitored	**9**	frequent (90 - 97%)	**8**	probable (75 - 90%)
3o 3i	controlled	**7**	probable (50 – 75%)	**6**	occasional (25 – 50%)
4o 4i	restricted	**5**	occasional (12 – 25%)	**3**	remote (2 – 5%)

EMI Scenario: Potential Offender



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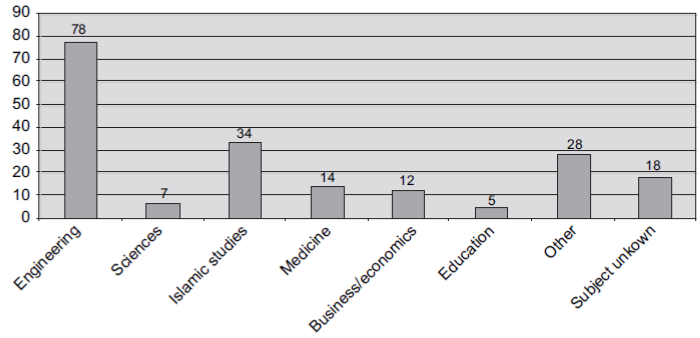
Educational background of radical Islamists (1)

FIG. I

Higher education in our sample (196 cases)



Source: D. Gambetta and S. Hertog, Why are there so many Engineers among Islamic Radicals?, Archives of European Sociology, Volume 50 / Issue 2 / August 2009, pp. 201–230, doi: https://doi.org/10.1017/S0003975609990129

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Educational background of radical Islamists (2)

TABLE IV

Percentages of engineers and oeds in violent and non-violent groups

	% Engineers	% OEDs	Total (N)
Non-violent	40.1	59.9	100 (147)
Violent	77.2	22.8	100 (101)

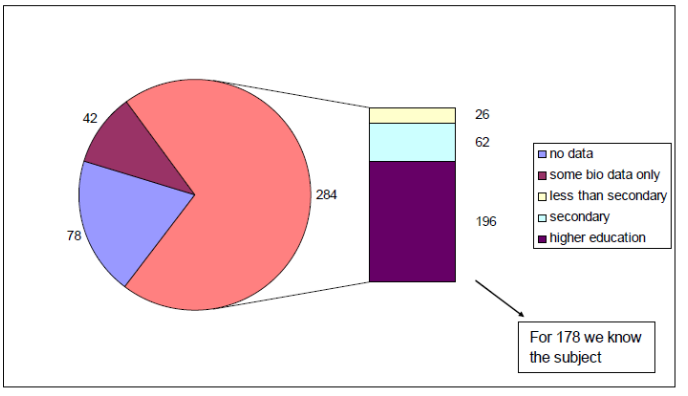
TABLE VI

Overrepresentation of university-educated individuals, engineers and OEDs in radical Islamic groups

Country	Type of group	University educ.	Engineers	OEDs
Middle East	Violent Islamists	Yes	Yes	No
	Non-violent Islamists	Yes	Yes	Yes
S. Arabia	Violent Islamists	Yes	No	None
South East Asia		No	Yes	No
Western		No	Yes	No

Source: D. Gambetta and S. Hertog, Why are there so many Engineers among Islamic Radicals?, Archives of European Sociology, Volume 50 / Issue 2 / August 2009, pp. 201–230, doi: https://doi.org/10.1017/S0003975609990129

Educational background of radical Islamists (3)



Source: D. Gambetta and S. Hertog, Engineers of Jihad, Sociology Working Papers, Paper Number 2007-10, University of Oxford

Educational background delinquent (USA)

Table 2: Census Incarceration Rates for Men by Education (in percentage terms)

	All Years	1960	1970	1980
White Men				
HS Drop Out	0.83	0.76	0.69	0.93
HS Graduate	0.34	0.21	0.22	0.39
Some College	0.24	0.21	0.13	0.27
College +	0.07	0.03	0.02	0.08
Black Men				
Drop Out	3.64	2.94	2.94	4.11
HS Graduate	2.18	1.80	1.52	2.35
Some College	1.97	0.81	0.89	2.15
College +	0.66	0.00	0.26	0.75

Source: L. Lochner and E. Moretti, The E®ect of Education on Crime: Evidence from Prison Inmates, Arrests, and Self-Reports, American Economic Review 94(1), 2004

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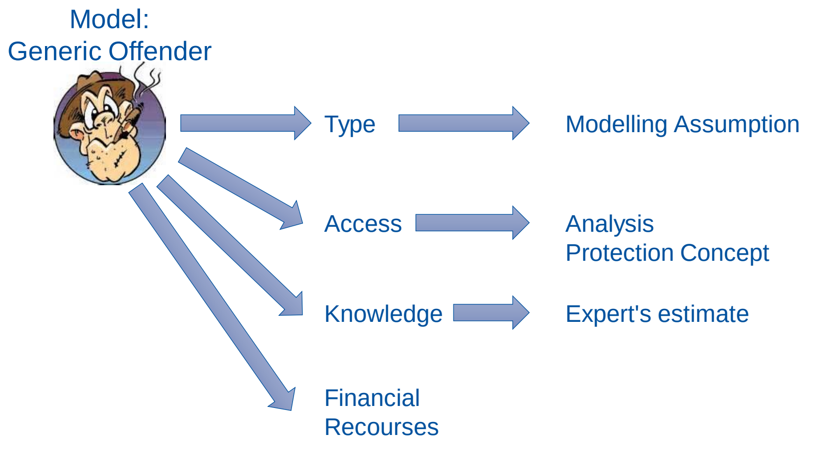
EMI Scenario: Potential Offender



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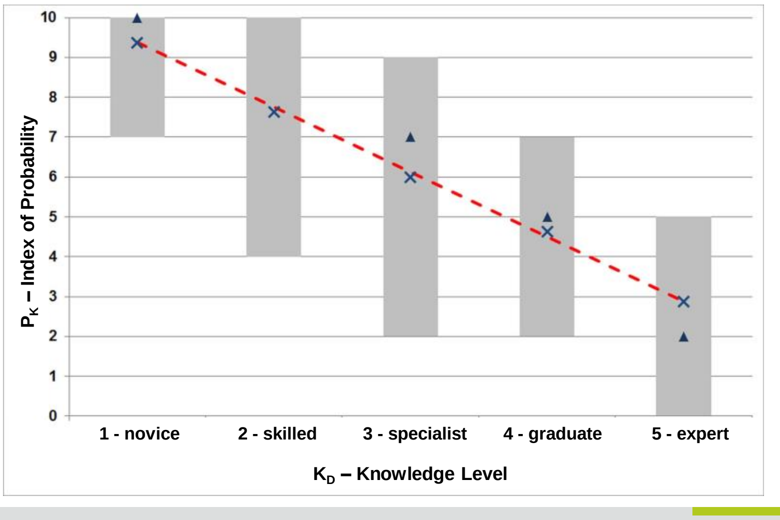
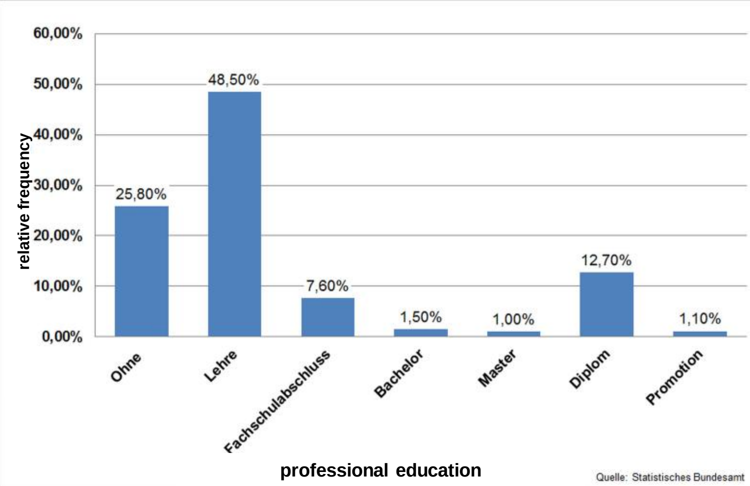
Generic Offender: Knowledge



Professional Education (Germany, 2015)



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Generic Offender: Knowledge

Knowledge Level			Index of Probability	
general knowledge	Novice	**1**	**9**	frequent (90 - 97%)
basic understanding	Skilled	**2**	**7**	probable (50 – 75%)
specialized knowledge and expertise	Specialist	**3**	**6**	occasional (25 – 50%)
academic knowledge and professional expertise	Graduate	**4**	**4**	occasional (5 – 12%)
expert knowledge and profound expertise	Expert	**5**	**3**	remote (2 – 5%)

EMI Scenario: Potential Offender

Model:
Generic Offender

Type	Modelling Assumption
Access	Analysis Protection Concept
Knowledge	Expert's estimate
Financial Recourses	Expert's estimate

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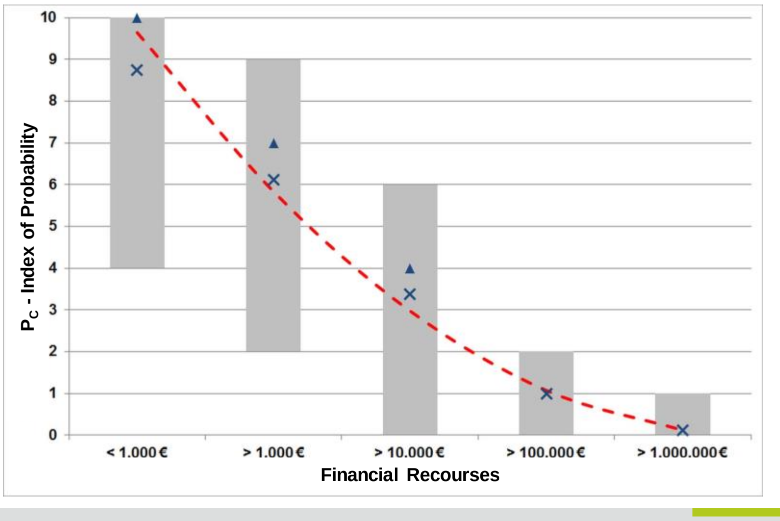
Generic Offender: Financial Recourses



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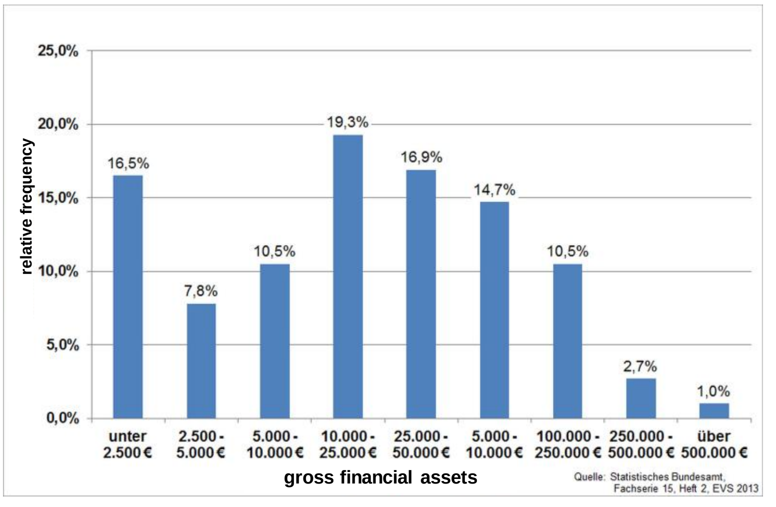
Gross Financial Assets (Germany, 2013)



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Generic Offender: Financial Recourses

Available financial recources			Index of Probability	
< 1.000 €	Low	**1**	**9**	Frequent (90 - 97%)
1.000 – 10.000 €	Moderate	**2**	**6**	occasional (25 – 50%)
10.000 – 100.000 €	Increased	**3**	**4**	occasional (5 – 12%)
100.000 – 1.000.000 €	High	**4**	**2**	remote (1 – 2%)
> 1.000.000 €	Extreme	**5**	**1**	Improbable/ Unlikely <0,5%

4.3 EMI Sources

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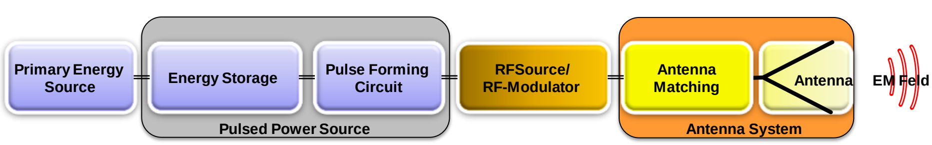
Principal Structure



4.3.1 Primary Energy Source

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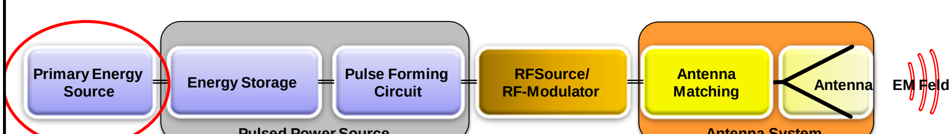
Primary Energy Source



- power supply units
- power transformer
- accumulator / batteries
- HV-Capacitors
- piezoelectric elements

24 V Accumulator-Package

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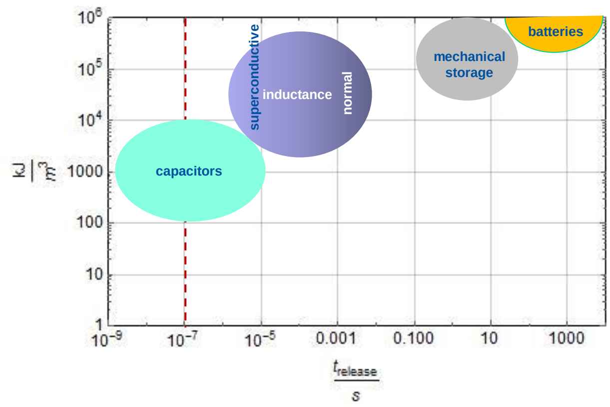
Energy Density vs. Discharge Time



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Evaluation Primary Energy Sources

Criterion	Level	Description
Technology		**Lithium-ion accumulator** systems are increasingly being used as primary energy sources of mobile HPEM sources.
Needed Knowledge		
- Design	$K_D = 2$	The design of a primary energy source consisting of lithium-ion cells requires knowledge at the level of a **hobby electrician**.
- Assembling	$K_A = 2$	The construction and assembling of a primary energy source requires knowledge at the level of a **hobby electrician**.
- Operation	$K_O = 1$	For the operation of primary energy source consisting of lithium-ion cells, only general **basic understanding** is required.
Availability		
- Components	$AV_C = 2$	The required components (lithium-ion cells) are available from specialist retailers.
- Primary Energy Source	$AV_S = 1 - 3$	Lithium ion batteries of various output voltages and capacities are available in **free trade**, **specialized trade** and **commercial specialized trade**.
Costs	$C_{exp} = 1$	Simple lithium-ion accumulators can be realized for less than €100. High-performance lithium-ion accumulators offered for up to €1,000.

4.3.2 Pulsed Power Source

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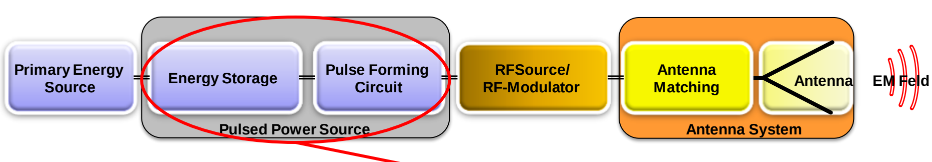
Pulsed Power Source



- DC/DC Converter
- Marx Generator
- Tesla Transformer
- XRAM Generator
- Semiconductor Pulsed Power Sources

DC/DC Converter

Dimensions
High: 43 mm
Width: 120 mm
Length: 185 mm
Cost: ~ €1,000

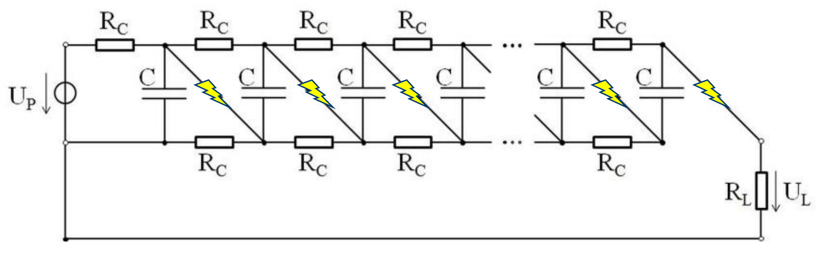
input voltage:	24V DC
input current:	600 mA
output voltage:	0 - 30 kV
output current:	250 µA

Marx Generator: Functional Principle

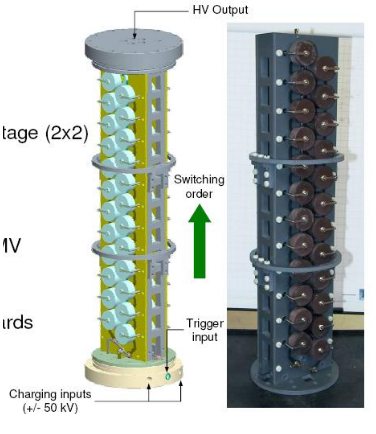
Capacitor bank in which the individual stages

- be loaded in parallel
  - ⇒ low charging voltage U_P
- be unloaded serially
  - ⇒ Summing of charging voltage $U_L = N \cdot U_P$

Marx Generator



Marx Generator (Example)



Evaluation Marx Generator

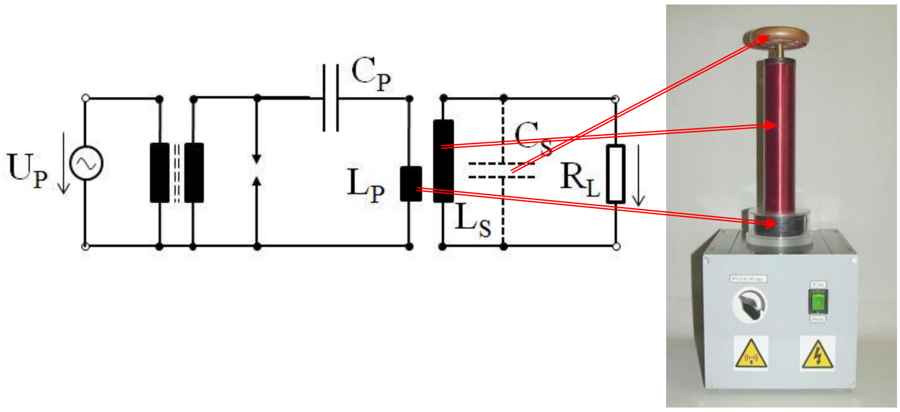
Criterion	Level	Description
Technology		The **Marx Generator** is a high-voltage pulse source consisting of multiple compression stages with **capacitive energy storage** and **closing switches**.
Needed Knowledge		
- Design	$K_D = 2$	The design of a Marx Generator requires knowledge at the level of a **hobby electrician**.
- Assembling	$K_A = 2$	The construction and assembling of a Marx Generator requires knowledge at the level of a **hobby electrician**.
- Operation	$K_O = 1 - 2$	For the operation of a Marx Generator only an instruction in the handling is necessary. (**general knowledge** to **basic understanding**)
Availability		
- Components	$AV_C = 2$	The required components are available from specialist retailers.
- Pulsed Power Source	$AV_S = 3$	Marx generators are available in **commercial retailers** for output voltages up to the MV range.
Costs	$C_{exp} = 1 - 3$	Simple Marx generators can be build for less than €1,000. High-performance Marx generators are offered for up to €100,000 by commercial retailers.

Tesla Transformer: Functional Principle

Transformer which secondary side

- Is operated in resonance:
  - ⇒ overvoltage
- is weakly coupled to the primary side
  - ⇒ voltage decoupling
  - ⇒ short-circuit current capability

Tesla Transformer



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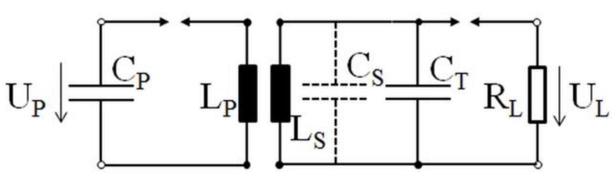
Pulsed Tesla Transformer



Evaluation Tesla Transformer

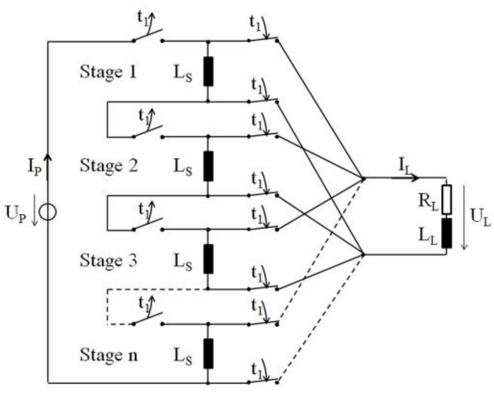
Criterion	Level	Description
Technology		The Tesla Transformer is a high-voltage pulse source, with **inductive energy transmission** and downstream capacitive energy storage.
Needed Knowledge		
- Design	$K_D = 2$	The design of a Tesla Transformer requires knowledge at the level of a **hobby electrician**.
- Assembling	$K_A = 2$	The construction and assembling of a Tesla Transformer requires knowledge at the level of a **hobby electrician**.
- Operation	$K_O = 1 - 2$	For the operation of a Tesla Transformer only an instruction in the handling is necessary. (**general knowledge** to **basic understanding**)
Availability		
- Components	$AV_C = 2$	The required components are available from specialist retailers.
- Pulsed Power Source	$AV_S = 2 - 3$	Simple kits for Tesla Transformers for output voltages up to the kV range are available in **specialist stores**.
Costs	$C_{exp} = 1 - 3$	Simple Tesla Transformers can be build for less than €1,000. High-performance Marx generators are offered for up to €100,000 by commercial retailers.

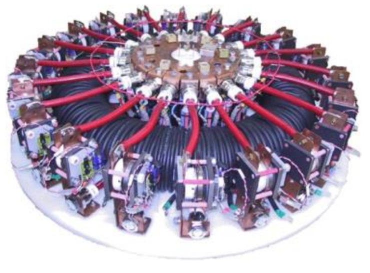
XRAM Generator: Functional Principle

Bank of inductances in which the individual stages

- be loaded serially
  - $\Rightarrow$ low loading current I_P
- be unloaded in parallel
  - $\Rightarrow$ summing of loading current $I_L = N \cdot I_P$
- main challenge:
  - synchronization of opening (loading circuit) and closing (load circuit) switches

XRAM Generator





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Evaluation XRAM Generator

Criterion	Level	Description
Technology		The **XRAM Generator** is a high-**current** pulse source with **inductive energy storage**.
Needed Knowledge		
- Design	$K_D = 4$	The design of an XRAM generator requires **academic skills**.
- Assembling	$K_A = 3$	The construction and assembling of a an XRAM generator, knowledge at the level of a **specialist** (e.g. craftsman or technician) is required.
- Operation	$K_O = 1 - 2$	For the operation of a XRAM Generator only an instruction in the handling is necessary. (**general knowledge** to **basic understanding**)
Availability		
- Components	$AV_C = 2$	The required components (lithium-ion cells) are available from **specialist retailers**.
- Pulsed Power Source	$AV_S = 0$	XRAM generators are currently **not offered** on the market.
Costs	$C_{exp} = 2 - 3$	The cost of building XRAM Generators is in the range 10.000 - 100.000 €

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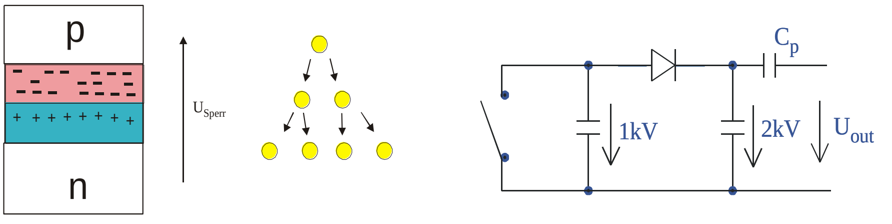
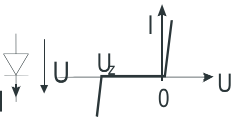
Avalanche Pulsed Generator: Functional Principle



1. Diode is polarized in the blocking direction
2. If a certain blocking voltage is exceeded, a steep current rise occurs (avalanche breakthrough)

⇒ Diode acts as **closing switch**



- Limitation of voltage per element ca. 1kV

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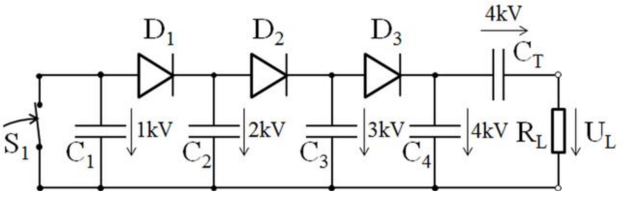
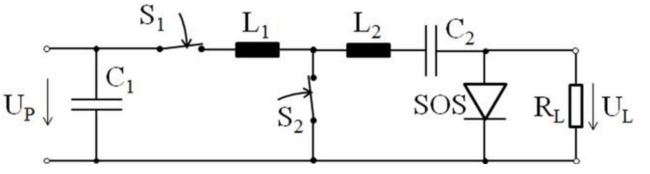
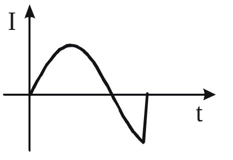
Avalanche Pulsed Generator



SOS-Module: Functional Principle



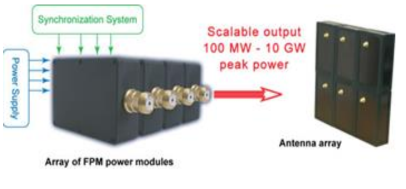


1. During positive half-wave diode is conductive
2. At the beginning of the negative half-wave there is still a charge carrier of the barrier layer
3. After the charge carriers were cleared the diode blocks

⇒ Diode acts as **opening switch**

- Limitation of voltage per element ca. 1kV

Marked Available Semiconductor Pulsed Power Sources (FID)



Series	Output voltage	Rise time	Pulse width	Max pulse repetition frequency	Size (mm)
FPM 1-N	1 kV	1-5 ns	2 - 5 ns	500 kHz	100x100x30
FPM 5-N	5 kV	1-5 ns	2 - 5 ns	300 kHz	200x120x60
FPM 10-N	10 kV	1-5 ns	2 - 5 ns	100 kHz	200x120x60
FPM 30-N	30 kV	1-5 ns	2 - 3 ns	10 kHz	200x120x60
FPM 50-N	50 kV	1-5 ns	2 - 3 ns	1 kHz	240x160x80
FPM 1-P	1 kV	0,1-1 ns	0.2 - 3 ns	500 kHz	100x100x30
FPM 5-P	5 kV	0,1-1 ns	0.2 - 3 ns	300 kHz	200x120x60
FPM 10-P	10 kV	0,1-1 ns	1 - 2 ns	100 kHz	200x120x60
FPM 30-P	30 kV	0,1-1 ns	1 - 2 ns	10 kHz	200x120x60
FPG 50-P	50 kV	0,1-1 ns	1 - 2 ns	1 kHz	240x160x80

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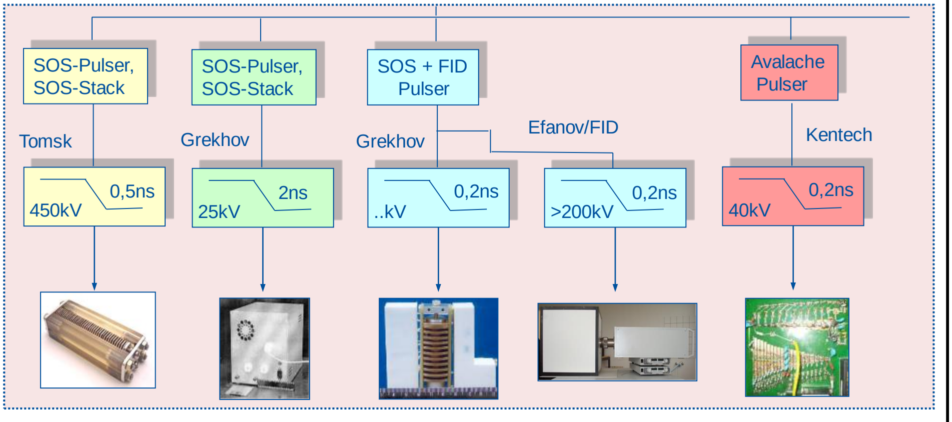
Overview of Semiconductor Pulsed Power Sources



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Evaluation Semiconductor Pulsed Power Sources

Criterion	Level	Description
Technology		**Semiconductor pulse generators** are high-voltage pulse sources based on rapidly opening and/or closing semiconductor switches.
Needed Knowledge		
- Design	$K_D = 4$	The design of a semiconductor pulse generator requires **academic training**.
- Assembling	$K_A = 2 - 3$	The construction of a semiconductor pulse generator requires capabilities at the level of a **specialist** or an **experienced hobby electrician**.
- Operation	$K_O = 1 - 2$	For the operation of a semiconductor pulse generator only an instruction in the handling is necessary. (**general knowledge** to **basic understanding**)
Availability		
- Components	$AV_C = 2$	The required components and modules, in particular the semiconductor switches, are available from specialist retailers.
- Pulsed Power Source	$AV_S = 3$	In **commercial trade**, simple semiconductors pulse generators for output voltages up to 50 kV and pulse repetition rates up to 1 MHz are available.
Costs	$C_{exp} = 1 - 3$	Simple semiconductor pulse generators can be build for less than 1,000 €. High-performance semiconductor pulse generators for up to €100,000 are offered in commercial retailers.

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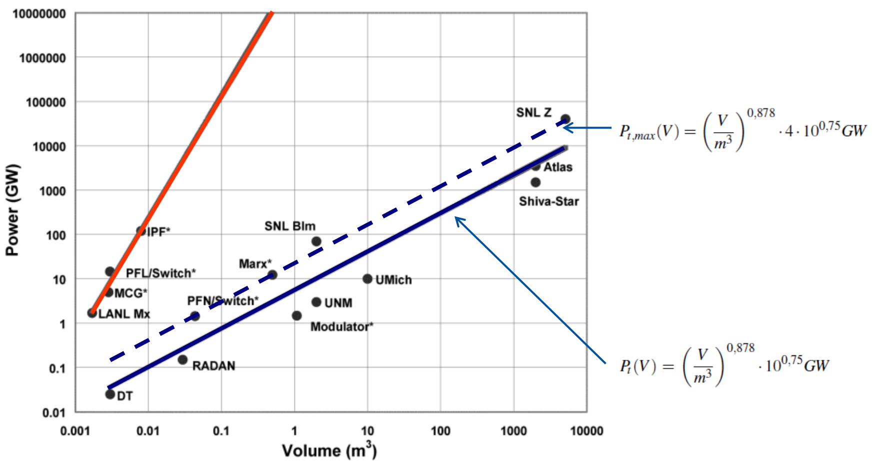
Power Volume Ratio of Pulse Power Sources



Source: E. Schamiloglu, R. J. Barker, M. Gundersen, and A. A. Neuber. Modern pulsed power: Charlie Martin and beyond. In Proceedings of the IEEE, 92(7):1014–1020, July 2004, doi: 10.1109/JPROC.2004.829058

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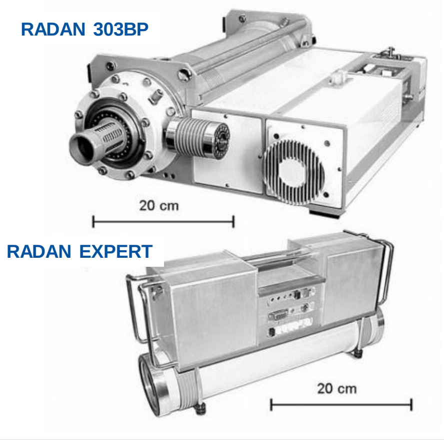
Example: RADAN

relativistic backward wave oscillators (BWO's)

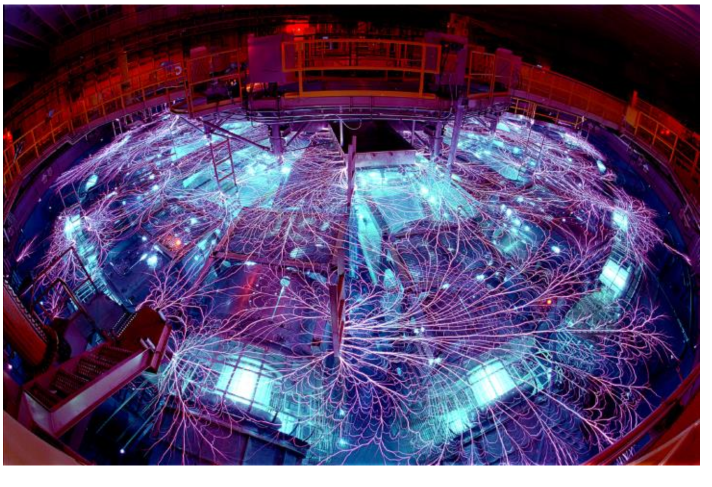


RADAN-303BP

τ_r = 1 ns,
U_{out} = 290 kV
I_{out} = 2 kA
PRF = Single: 1-10 p/min

Example: SNL Z-Machine

Example: SNL Z-Machine



4.3.3 RF-Modulator

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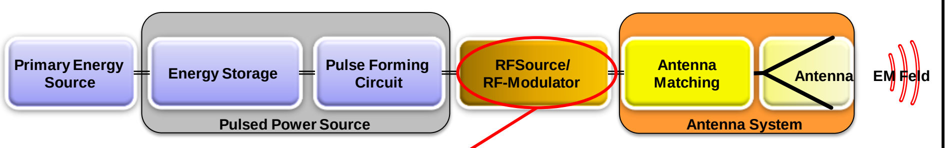
RF-Modulator



- VIRCATOR
- Magnetron
- MILO
- Klystron
- Line Oscillator
- Switched Oscillator
- Antenna Oscillator
- Pulse sources (without RF modulator) / UWB sources

4.3.3.1 Virtual Cathode Oscillator (VIRCATOR)

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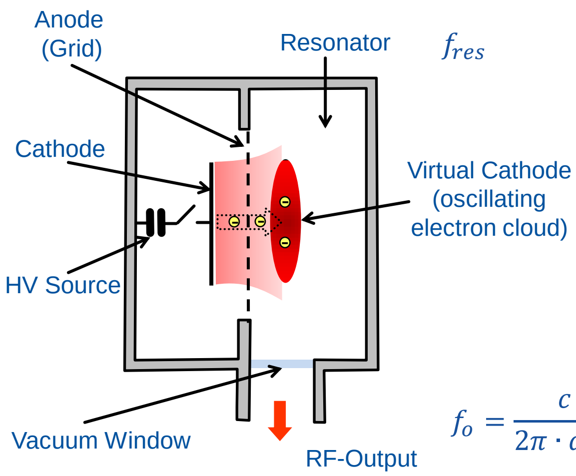
VIRCATOR (axial type)



$$f_o = \frac{c}{2\pi \cdot d_{KA}} \cdot \cosh^{-1}\left(\frac{eU_{HV}}{m_e c} + 1\right)$$

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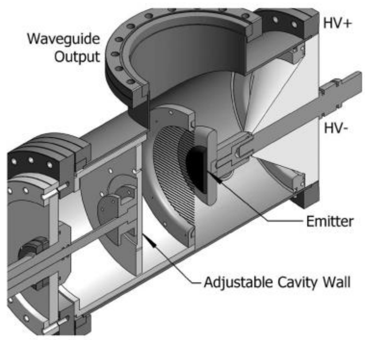
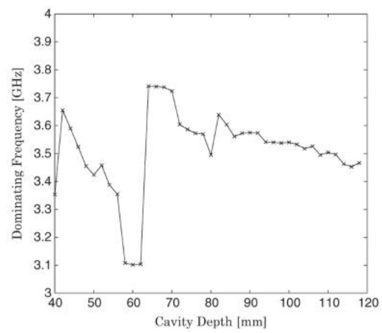
VIRCATOR (axial type)





Source: C. Möller, PhD-Thesis Design and Experiments with High-Power Microwave Sources, Stockholm 2012

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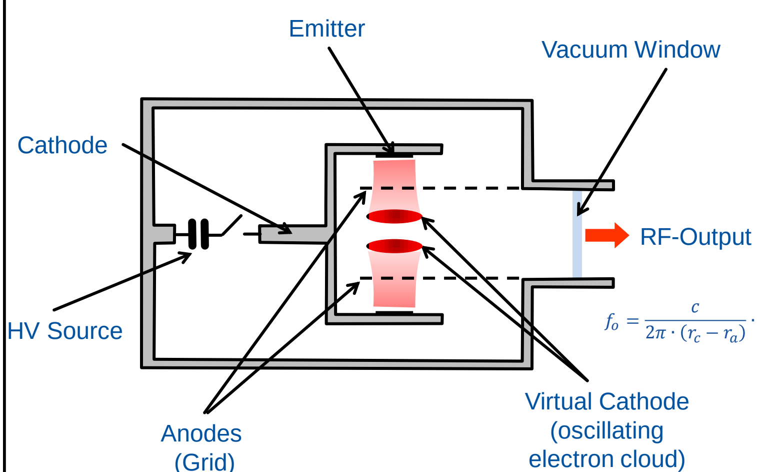
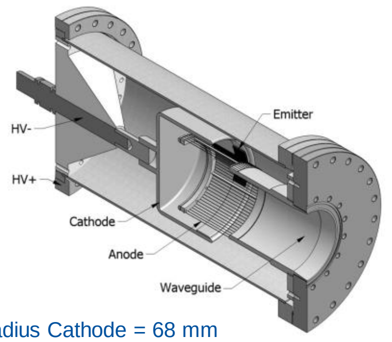
VIRCATOR (radial type)

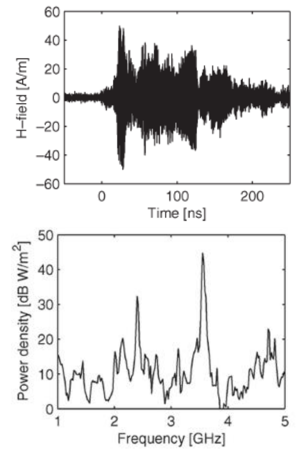


$$f_o = \frac{c}{2\pi \cdot (r_c - r_a)} \cdot \cosh^{-1}\left(\frac{eU_{HV}}{m_e c} + 1\right)\sqrt{\frac{r_a}{r_c}}$$

VIRCATOR (radial type)



Radius Cathode = 68 mm
Radius Annode = 53 mm



Source: Moller, C, et al., "Proof of Principle Experiments on Direct Generation of the Mode in a Coaxial Vircator," *IEEE Transactions on Plasma Science*, vol.38, no.1, pp.26,31, Jan. 2010

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Evaluation VIRCATOR (1)

Criterion	Level	Description
Technology		VIRCATORS are **vacuum electron tubes.**
Needed Knowledge		
- Design	$K_D = 4$	The design of a VIRCATOR requires **academic training**
- Assembling	$K_A = 3$	The construction and assembling of a VIRCATOR, knowledge at the level of a **specialist** (e.g. craftsman or technician) is required.
- Operation	$K_O = 1 - 2$	Depending on the technology readiness level of the built-up VIRCATOR, only an instruction in handling is necessary for its operation. (**general knowledge** to **basic understanding**)
Availability		
- Components	$AV_C = 2 - 3$	The most of the required components are available from **specialist retailers**.
- RF - Modulator	$AV_S = 0$	VIRCATORS are currently not on sale.
Costs	$C_{exp} \leq 2$	The cost of building a VIRCATOR is approx. €5,000.

Evaluation VIRCATOR (2)

Criterion	Level	Description
Volume / Mobility	$M = 3$ $M = 4$ $M = 5$	**UHF-Band** VIRCATOR **L-Band** VIRCATOR **S-Band** and **C-Band** VIRCATOR
		As a rule of thumb, the outer diameter of an axial VIRCATOR is greater than the wavelength ($r_a \geq \lambda/2$). In the coaxial design, the diameter of the VIRCATOR is in the range of twice the wavelength ($r_a \approx \lambda$).
Frequency Range	UHF, L, S, C	f_{RF} = 0,3 - 10 GHz
Max. Power Output	$P_{max} \leq 1$ GW	
Efficiency	$\eta \leq 15$ %	

4.3.3.2 Magnetron

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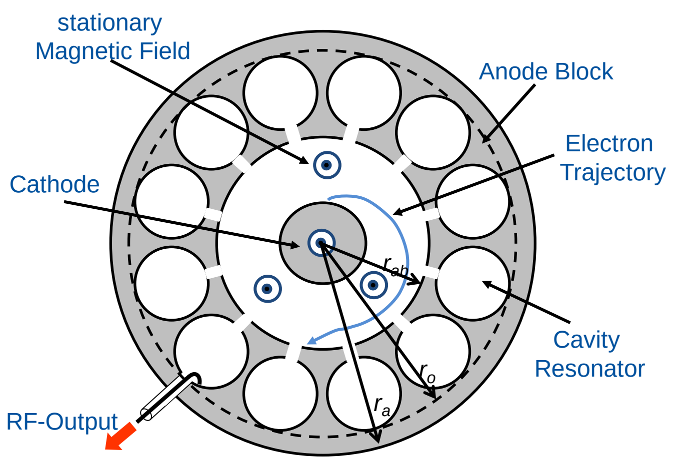
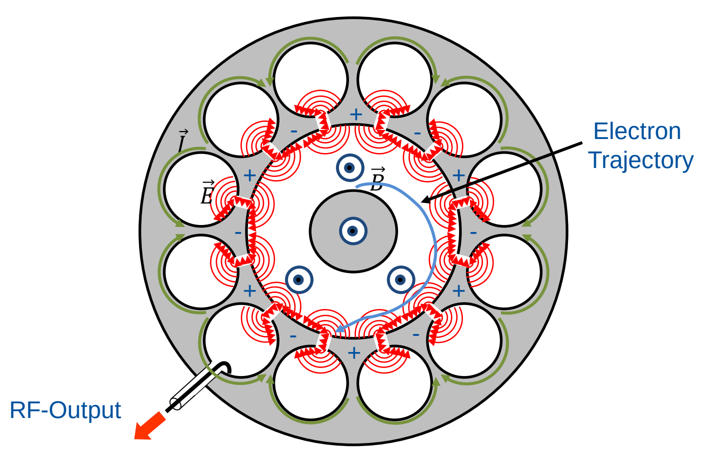
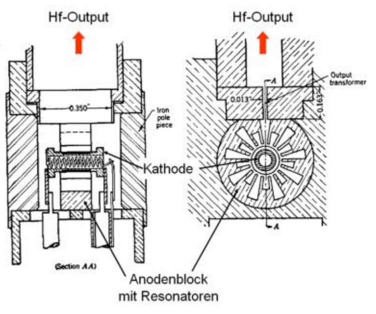
Magnetron



Magnetron



Magnetron: Example 1



Source: George B. Collins, editor. Microwave Magnetrons, Radiation Laboratory Series 6. McGraw Hill, January 1948.

Source: J. Benford. History and future of the relativistic magnetron. In Origins and Evolution of the Cavity Magnetron (CAVMAG), 2010 International Conference on the, pages 40–45, April 2010

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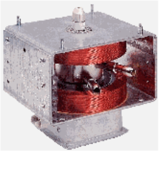
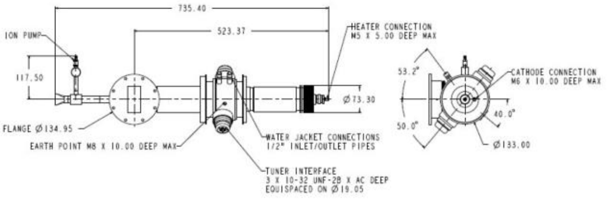
Magnetron: Example 2

Brand:	Goldstar
Modell	MW-MAG1002
Output Power:	1000W
Operating Frequency:	2,455 GHz
Anode Voltage :	4,0 KV
Antenna:	30 mm
Cost:	50 €



Magnetron: Example 3

Brand:	E2V
Modell	MG8076
Output Power:	7,5 MW
Operating Frequency:	2,998 GHz
Anode Voltage :	4,0 KV



Source: e2v; Datenblatt MG8076

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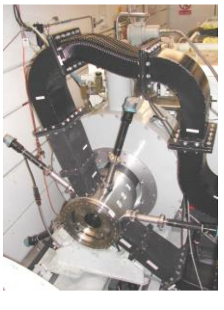
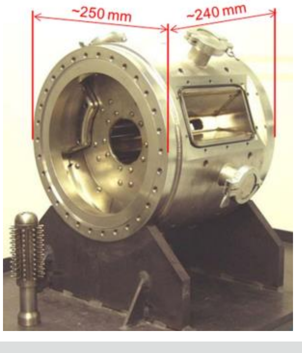
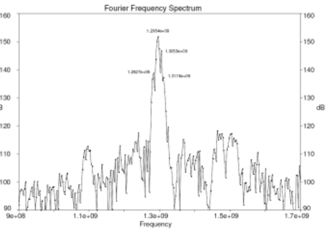
Magnetron: Example 4







Evaluation Magnetron (1)

Criterion	Level	Description
Technology		VIRCATORS are **vacuum electron tubes.**
Needed Knowledge		
- Design	$K_D = 4$	The design of a Magnetron requires **academic training**
- Assembling	$K_A = 3$	The construction and assembling of a Magnetron, knowledge at the level of a **specialist** (e.g. craftsman or technician) is required.
- Operation	$K_O = 1 - 2$	Only an instruction in handling is necessary for the operation of a Magnetron. (**general knowledge** to **basic understanding**)
Availability		
- Components	$AV_C = 2$	The required components are available from **specialist retailers**.
- RF - Modulator	$AV_S = 1 - 2$	Magnetrons up to the MW power range are very good available on the **free market**.
Costs	$C_{exp} = 1 - 3$	Magnetrons of low power level are available as components for household microwaves for approx. €100.

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Evaluation Magnetron (2)

Criterion	Level	Description
Volume / Mobility	$M = 3 - 4$ $M = 5$	**UHF-Band** Magnetron **L-, S-Band** and **C-Band** Magnetron
		As a thumb rule, the outer diameter of a magnetron is 1, 5 times the wavelength. ($r_a \approx 0.75\lambda$) The magnetron height is in the range of 0.6-2 times the wavelength.
Frequency Range	UHF, L, S, C, X, ..	f_{RF} = 0,3 - 300 GHz
Max. Power Output	$P_{max} \leq 10$ MW $P_{max} \leq 1$ GW	Conventional Magnetron Relativistic Magnetron
Efficiency	$\eta \leq 80$ % $\eta \quad \eta \leq 50$ % $\eta \quad \eta \leq 40$ %	Low power conventional Magnetron High power conventional Magnetron Relativistic Magnetron

4.3.3.3 Magnetically Insulated Line Oscillator (MILO)

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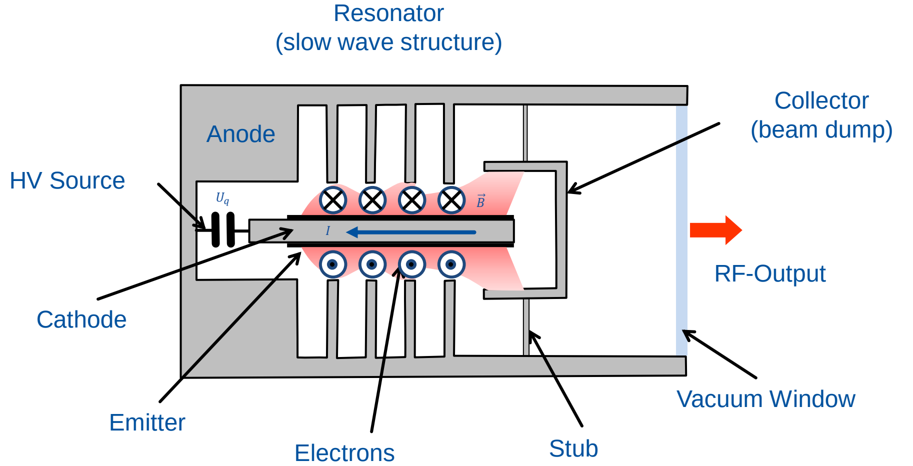
MILO



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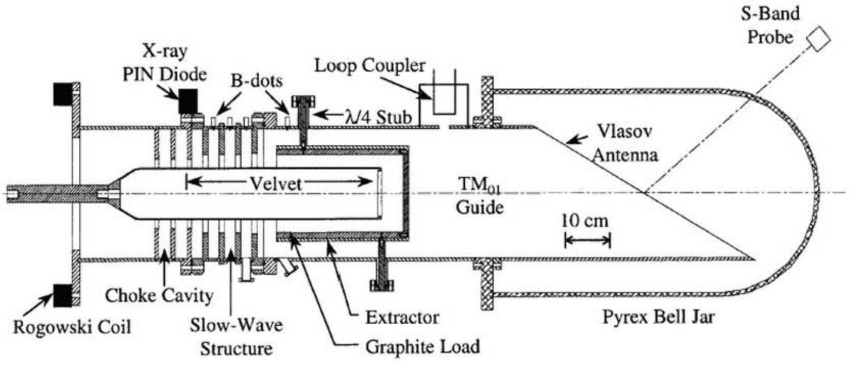
MILO (Example US AFRL)



$$r_a \geq 0{,}38 \cdot \lambda_c$$

Source: M. D. Haworth, et al., Significant pulse-lengthening in a multigigawatt magnetically insulated transmission line oscillator. IEEE Transactions on Plasma Science, 26(3):312–319, Jun 1998.

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Evaluation MILO (1)

Criterion	Level	Description
Technology		The MILO is a cross-field (runtime) **vacuum electron tube**.
Needed Knowledge		
- Design	$K_D = 4$	The design of a MILO requires **academic training**
- Assembling	$K_A = 3$	The construction and assembling of a MILO, knowledge at the level of a **specialist** (e.g. craftsman or technician) is required.
- Operation	$K_O = 1 - 2$	Depending on the technology readiness level of the built-up MILO, only an instruction in handling is necessary for its operation. (**general knowledge** to **basic understanding**)
Availability		
- Components	$AV_C = 2 – 3$	The most of the required components are available from **specialist retailers**.
- RF - Modulator	$AV_S = 0$	MILOs are currently not on sale.
Costs	$C_{exp} \leq 2$	The cost of building a MILO is approx. €5,000.

Evaluation MILO (2)

Criterion	Level	Description
Volume / Mobility	$M = 3 - 4$ $M = 4 - 5$ $M = 5$	**L-Band** MILO **S-Band** MILO **C-Band** and **X-Band** MILO
		As a rule of thumb, the external radius of a MILO can be estimated over the relationship $\mathbf{r_a} \approx \mathbf{0.6\,\lambda}$ and the overall length $\mathbf{L_{ges}} \approx \mathbf{6\,\lambda}$. As an estimate for the construction volume follows $\mathbf{V_{RF}} \approx \mathbf{7\,\lambda^3}$
Frequency Range	L, S, C , X	f_{RF} = 1 - 12 GHz
Max. Power Output	$P_{max} \leq 7$ GW	
Efficiency	$\eta \leq 15$ %	

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4.3.3.4 Klystron

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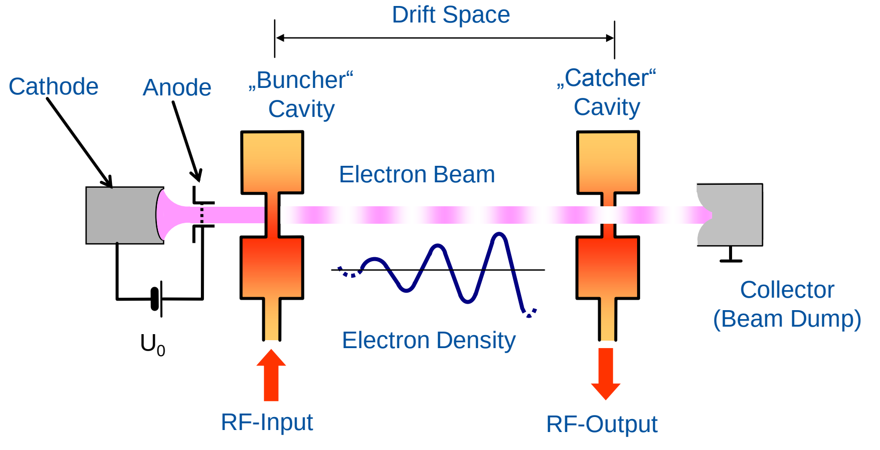
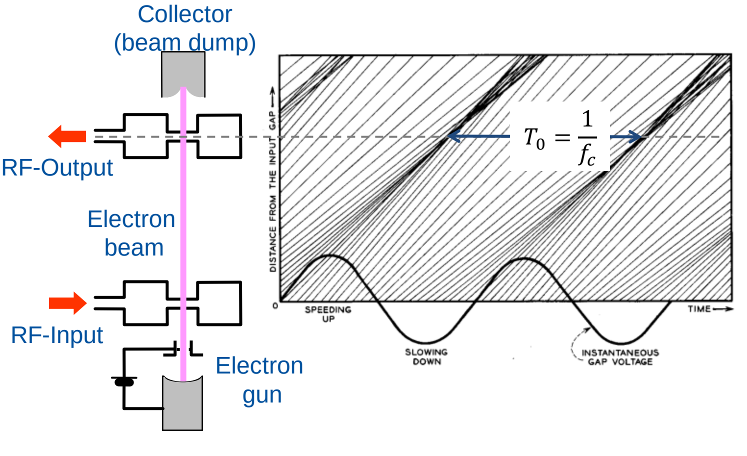
Klystron Amplifier (Operating Principle)

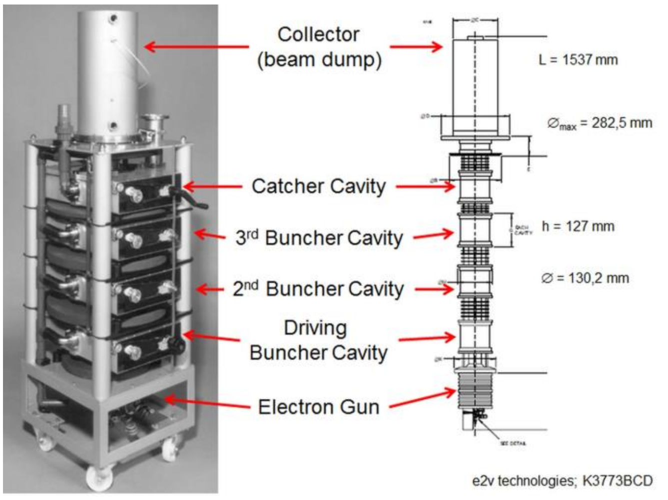


Klystron Amplifier (Applegate Diagram)



Source: J. W. Gewartowski and H. A. Watson, Principles of Electron Tubes: Including Grid-Controlled Tubes, Microwave Tubes and Gas Tubes, p. 295, May 1965, Van Nostrand Company.

Klystron Amplifier (Example)



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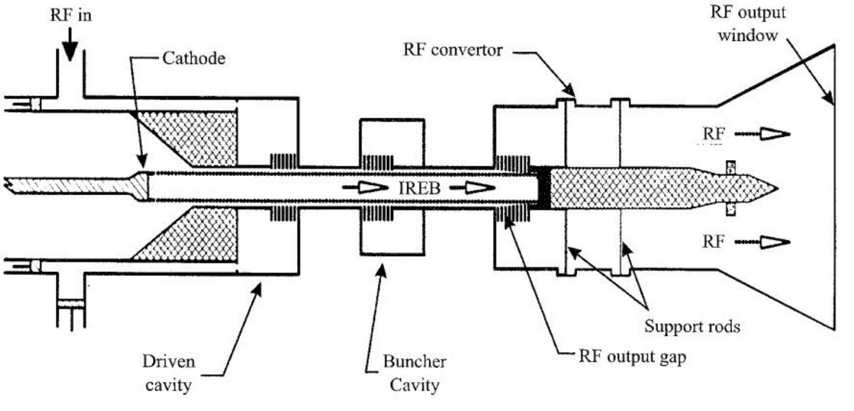
Klystron Amplifier (Example)



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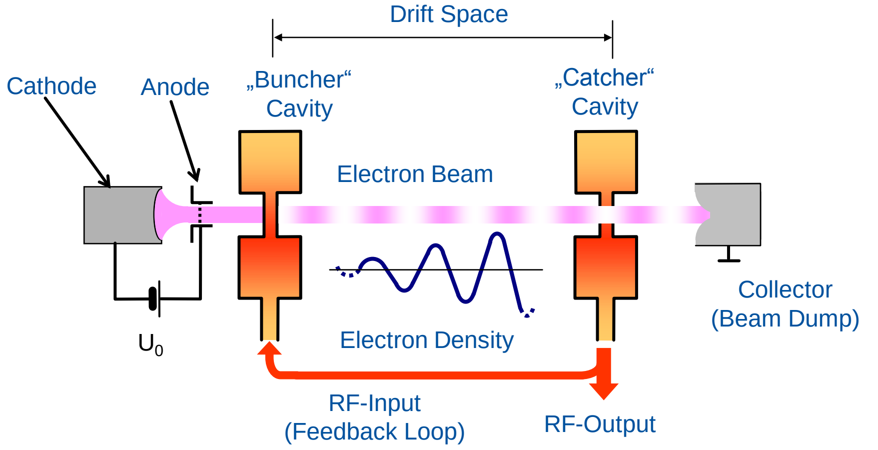
Klystron Oscillator (Operating Principle)



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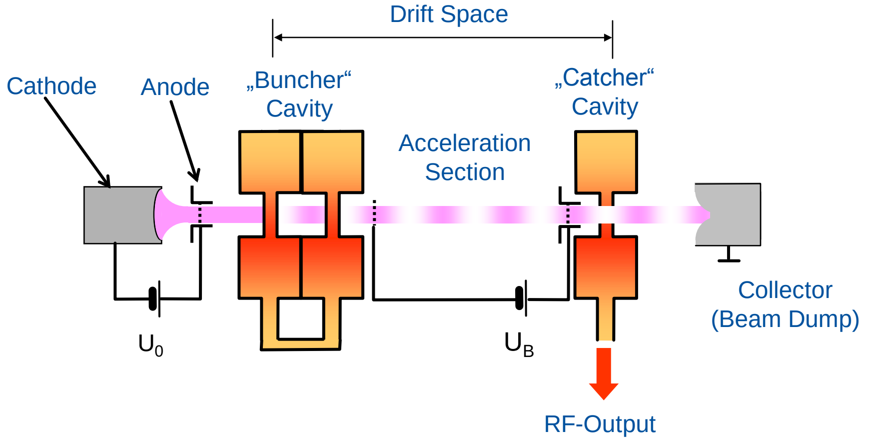
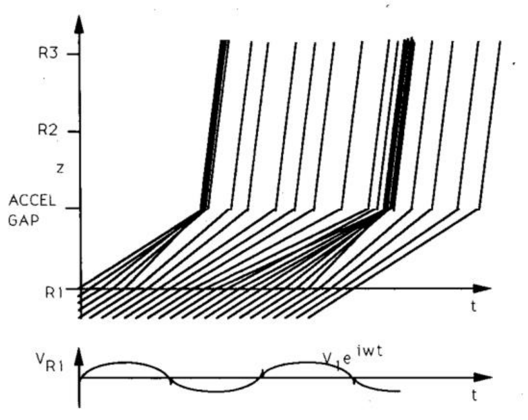
Reltron Oscillator (Operating Principle)

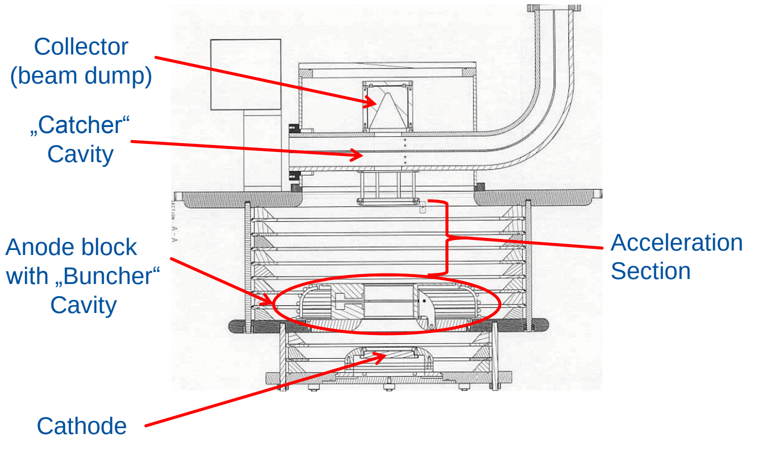


Reltron Oscillator (Applegate Diagram)



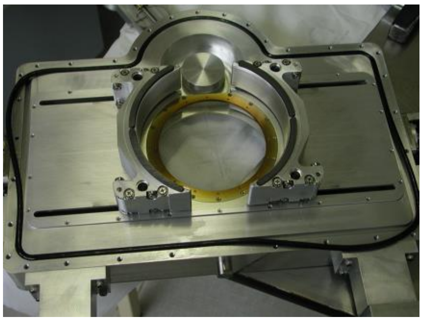
Source: R. B. Miller, et al., Super-reltron theory and experiments,
IEEE Trans. Plasma Sci., 20(3):332, June 1992.

Reltron Oscillator (SUPRA)



Source: Bundeswehr Research Institute for Protective Technologies and CBRN Protection (WIS).

Reltron Oscillator (SUPRA)



Source: Bundeswehr Research Institute for Protective Technologies and CBRN Protection (WIS).

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Evaluation Klystron (1)

Criterion	Level	Description
Technology		The Klystron is a runtime **vacuum electron tube** (drift tube).
Needed Knowledge		
- Design	$K_D = 4$	The design of a Klystron requires **academic training**
- Assembling	$K_A = 3 - 4$	For the construction of a klystron an **academic education** (e.g. bachelor) or knowledge at the level of an **experienced technician** is required
- Operation	$K_O = 1 - 2$	Depending on the technology readiness level of the built-up Klystron, only an instruction in handling is necessary for its operation. (**general knowledge** to **basic understanding**)
Availability		
- Components	$AV_C = 2$	The components and modules are available from **specialist retailers**.
- RF - Modulator	$AV_S = 3$	Klystrons up to the MW power range for broadcasting or industrial applications are offered in **commercial retailers**.
Costs	$C_{exp} = 3$	Klystrons are available for €10,000 - €100,000.

Evaluation Klystron (2)

Criterion	Level	Description
Volume / Mobility	M= 4 M = 5	**UHF-Band and L-Band** Klystron **S-Band**, **C-Band** and **X-Band** Klystron
		As a rule of thumb, the external radius of a Klystron can be estimated over the relationship $r_a \approx 0.5\,\lambda$ and the overall length $L_{ges} \approx 3\,\lambda$.
Frequency Range	UHF, L, S, C, X	f_{RF} = 0,3 - 12 GHz
Max. Power Output	$P_{max} \leq 0{,}5$ GW $P_{max} = 1 - 10$ GW	Conventional Klystron relativistic Klystron (Reltron)
Efficiency	$\eta \leq 70$ % $\eta \leq 60$ % $\eta \leq 75$ %	conventional low power klystron conventional high power klystron relativistic klystron/reltron

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4.3.3.5 (Transmission) Line Resonator

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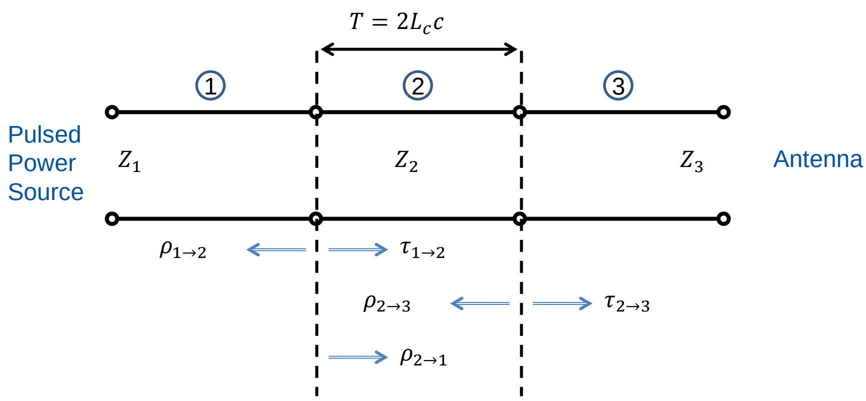
Line Resonator (Operating Principle)



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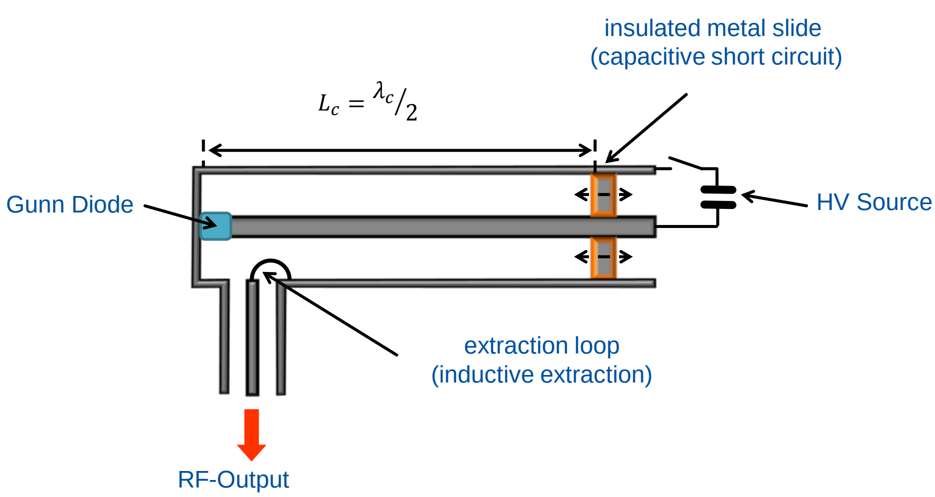
Gunn Diode Oscillator



Evaluation Line Resonator (1)

Criterion	Level	Description
Technology		Line resonators are **transit time oscillators** (delay lines) consisting of mismatched RF lines.
Needed Knowledge		
- Design	$K_D = 2 - 3$	The design of a line resonator requires expertise at the level of a **trained specialist.**
- Assembling	$K_A = 2 - 3$	The construction and assembling of a line resonator requires expertise at the level of a **trained specialist.**
- Operation	$K_O = 1 - 2$	For the operation of line resonators, only an instruction in handling is necessary. (**general knowledge** to **basic understanding**)
Availability		
- Components	$AV_C = 2$	The most of the required components are available from **specialist retailers**.
- RF - Modulator	$AV_S = 1 - 2$	Line resonators (e.g. pot circuits) up to the kW power range for applications in broadcasting or amateur radio are offered in **commercial trade**.
Costs	$C_{exp} \leq 2$	The cost for the acquisition of line resonator is approx. € 10,000.

Evaluation Line Resonator (2)

Criterion	Level	Description
Volume / Mobility	$M = 3 - 4$ $M = 5$	**VHF-Band** Line Resonator **UHF** and **L-Band** Line Resonator
		As a rule of thumb, the external radius of a Line Resonator can be estimated over the relationship $r_a \approx 0.1\lambda$ and the overall length $L_{ges} \approx 0.25\lambda$.
Frequency Range	VHF, UHF, (L)	$f_{RF} = 0{,}03 - 1$ GHz
Max. Power Output	$P_{max} \leq 0.5$ MW	
Efficiency	$\eta \leq 60$ %	

4.3.3.6 Switched Oscillator (SWO)

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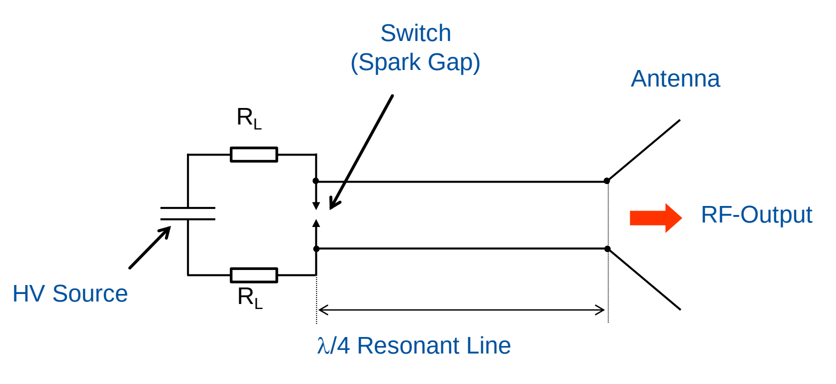
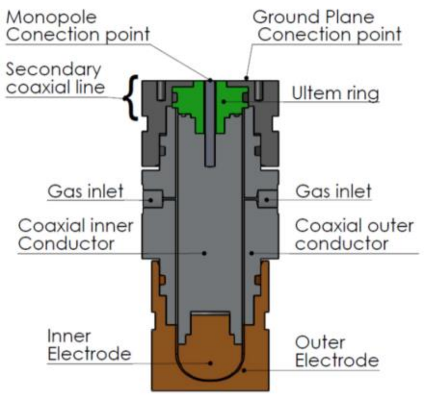
Switched Oscillator (Operating Principle)



Switched Oscillator (Example)



Source: F. Vega and Farhad Rachidi., A Switched Oscillator Geometry Inspired by a Curvilinear Space—Part I: DC Considerations. IEEE Transactions on Plasma Science, 2016

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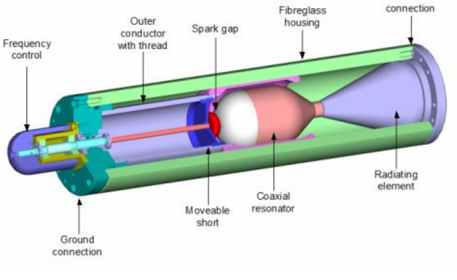
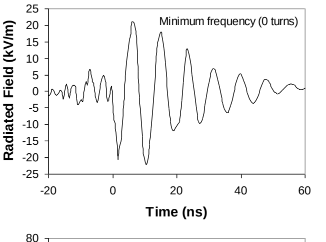
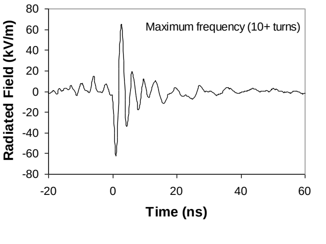
Switched Oscillator (HPMcase™)

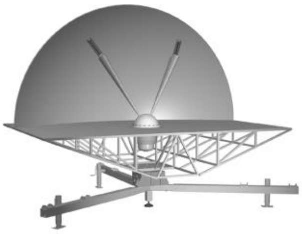


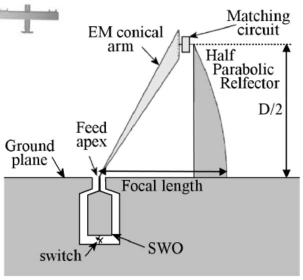


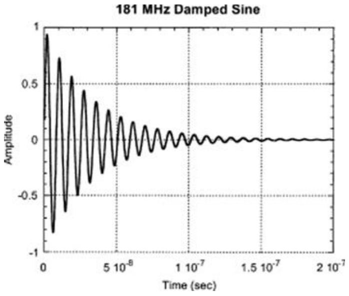


Source: Diehl

Switched Oscillator (MATRIX System)







Source: W. D. Prather, et al., Survey of worldwide high power wideband capabilities, IEEE Trans. EMC, 46(3): 335, Aug 2004

Evaluation Switched Oscillator (1)

Criterion	Level	Description
Technology		Switched Oscillators are **transit time oscillators** (delay lines) consisting of mismatched RF lines..
Needed Knowledge		
- Design	$K_D = 2 - 3$	The design of a switched oscillator requires expertise at the level of a **trained specialist.**
- Assembling	$K_A = 2 - 3$	The construction and assembling of a switched oscillator requires expertise at the level of a **trained specialist.**
- Operation	$K_O = 1 - 2$	For the operation of switched oscillator, only an instruction in handling is necessary. (**general knowledge** to **basic understanding**)
Availability		
- Components	$AV_C = 2$	The most of the required components are available from **specialist retailers**.
- RF - Modulator	$AV_S = 4$	Switched oscillators are currently offered only to a **limited extent** in **commercial retailers**.
Costs	$C_{exp} = 1 - 3$	The cost for the acquisition of switched oscillator is up to. € 100,000.

Evaluation Switched Oscillator (2)

Criterion	Level	Description
Volume / Mobility	M = 3 - 4 M = 5	**VHF-Band** Switched Oscillator **UHF** and **L-Band** Switched Oscillator
		As a rule of thumb, the external radius of a Switched Oscillator can be estimated over the relationship $r_a \approx 0.1\lambda$ and the overall length $L_{ges} \approx 0.25\lambda$.
Frequency Range	VHF, UHF, L	f_{RF} = 0,03 - 2 GHz
Max. Power Output	$P_{max} \leq 1$ GW	
Efficiency	$\eta \leq 60$ %	

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4.3.3.7 Antenna Oscillator (AO)

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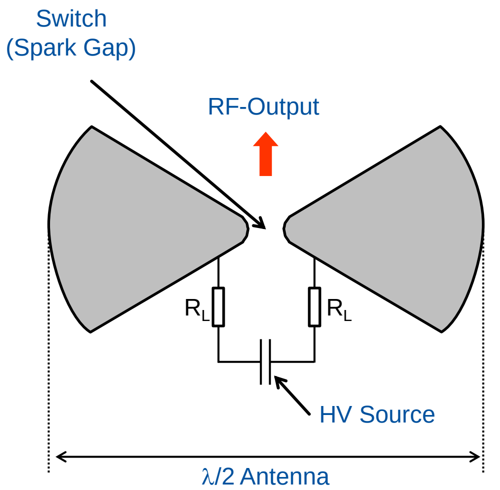
Antenna Oscillator (Operating Principle)



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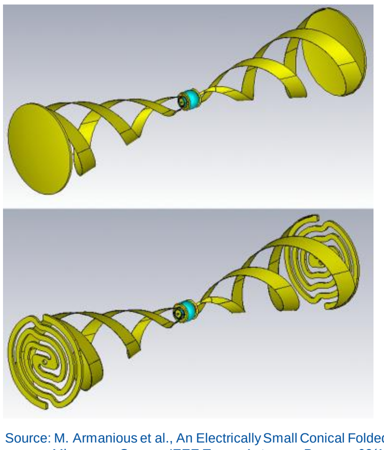
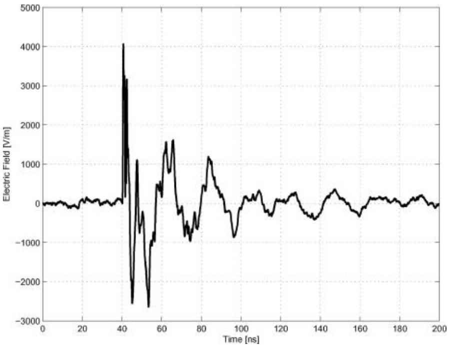
Antenna Oscillator
(Disconnected-Spiral Conically Wound Antenna)





Source: M. Armanious et al., An Electrically Small Conical Folded Dipole Antenna for Use as a Compact, Self-Resonant Mesoband High-Power Microwave Source, IEEE Trans. Antennas Propag., 62(12):5964, Dec 2014

Evaluation Antenna Oscillator (1)

Criterion	Level	Description
Technology		Switched Oscillators are **transit time oscillators** (delay lines) consisting of mismatched RF lines..
Needed Knowledge		
- Design	$K_D = 1 - 3$	The design of a switched oscillator requires expertise at the level of a **trained technician.**
- Assembling	$K_A = 2 - 3$	The construction and assembling of a antenna oscillator requires expertise at the level of a **trained specialist.**
- Operation	$K_O = 1 - 2$	For the operation of antenna oscillator, only an instruction in handling is necessary. (**general knowledge** to **basic understanding**)
Availability		
- Components	$AV_C = 2$	The most of the required components are available from **specialist retailers**.
- RF - Modulator	$AV_S = 0$	Antenna oscillators are currently not on sale.
Costs	$C_{exp} = 1 - 3$	The cost for the acquisition of antenna oscillator is up to. € 100,000.

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Evaluation Antenna Oscillator (2)

Criterion	Level	Description
Volume / Mobility	$M = 2 - 4$ $M = 5$	**VHF-Band** Antenna Oscillator **UHF-Band** Antenna Oscillator
		As a rule of thumb, the external radius of a Antenna Oscillator can be estimated over the relationship $r_a \approx \lambda/8$ and the overall length $L_{ges} \approx \lambda/2$.
Frequency Range	VHF, UHF,	f_{RF} = 0,03 - 1 GHz
Max. Power Output	$P_{max} \leq 10$ MW	
Efficiency	$\eta \leq 50$ %	

4.3.3.8 Comparison RF-Modulator

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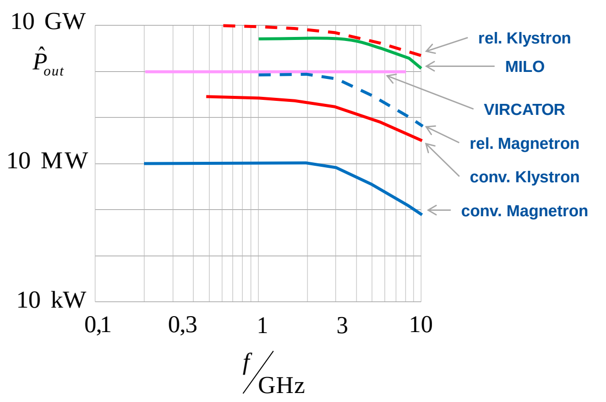
Comparison Hypoband RF- Modulator

Typ	VIRCATOR	Magnetron		MILO	Klystron	
		conv.	rel.		conv.	rel
Frequency Range	UHF, L, S, C	UHF, L, S, C, X		L, S, C, X	UHF, L, S, C, X	
Power Output	≤ 1 GW	≤ 1 MW	≤ 1 GW	≤ 7 GW	≤ 0,5 GW	≤ 10 GW
Efficiency	≤ 15 %	≤ 80 %	≤ 40 %	≤ 15 %	≤ 70 %	≤ 50 %
Needed Knowledge						
- Design	4	4	4	4	4	4
- Assembling	3	3	3	3	3-4	3-4
- Operation	1-2	1-2	1-2	1-2	1-2	1-2
Availability						
- Components	3	3	3	2-3	2	3
- RF-Modulator	0	1-2	3-4	0	3	4
Mobility	3-5	3-5	3-5	3-5	4-5	4-5
Volume	$V_{RF} \approx 2.5\ \lambda^3$	$V_{RF} \approx 1.4\ \lambda^3$	$V_{RF} \approx 4.5\ \lambda^3$	$V_{RF} \approx 8.6\ \lambda^3$	$V_{RF} \approx 4\ \lambda^3$	$V_{RF} \approx 4\ \lambda^3$

Comparison Hypoband RF- Modulator



Generic Hypoband RF- Modulator

Typ	HO-k-1	HO-k-2	HO-b-1	HO-b-2
Example	conv. Magnetron	conv. Klystron	rel. Magnetron VIRCATOR	rel. Klystron MILO
Frequency Range	UHF, L, S, C, X	L, S, C, X	UHF, L, S, C, X	L, S, C, X
Power Output	≤ 10 MW	≤ 0,5 GW	≤ 1 GW	≤ 10 GW
Efficiency	≤ 80 %	≤ 70 %	≤ 30 %	≤ 40 %
Needed Knowledge				
- Design	4			
- Assembling	3			
- Operation	1-2			
Availability				
- Components	nicht anwendbar		2-3	
- RF - Modulator	1-2	3	nicht anwendbar	
Mobility	3-5			
Volume	$V_{RF} \approx 1.4\ \lambda^3$	$V_{RF} \approx 4\ \lambda^3$	$V_{RF} \approx 4.5\ \lambda^3$	$V_{RF} \approx 4\ \lambda^3$

Comparison Meso- und Sub-Hyperband RF- Modulator

Typ	Line Resonator (TLO)	Switched Oscillator (SWO)	Antenna Oscillator (AO)
Frequency Range	VHF, UHF, (L)	VHF, UHF, L	VHF, UHF, L
Power Output	≤ 0.5 MW	≤ 1 GW	≤ 10 MW
Efficiency	≤ 60 %	≤ 60 %	≤ 50 %
Needed Knowledge			
- Design	2 – 3	2 – 3	1 – 3
- Assembling	2 – 3	2 – 3	2 – 3
- Operation	1-2	1-2	1-2
Availability			
- Components	2	2	2
- RF-Modulator	1 - 2	4	0
Mobility	3 - 5	3 - 5	3 - 5
Volume	$V_{RF} \approx 0.01\ \lambda^3$	$V_{RF} \approx 0.01\ \lambda^3$	$V_{RF} \approx 0.03\ \lambda^3$

Generic Meso- and Sub-Hyperband RF- Modulator

Typ	MB-k-1	Mb-b-1	Mb-b-2
Example	TLO	AO	SWO
Frequency Range	VHF, UHF, (L)	VHF, UHF, L	VHF, UHF, L
Power Output	≤ 0.5 MW	≤ 10 MW	≤ 1 GW
Efficiency	≤ 60 %	≤ 50 %	≤ 60 %
Needed Knowledge			
- Design	2 – 3	1 – 3	2 – 3
- Assembling	2 – 3	2 – 3	2 – 3
- Operation	1-2	1-2	1-2
Availability			
- Components	2	2	2
- RF-Modulator	1 - 2	0	4
Mobility	3 - 5	3 - 5	3 - 5
Volume	$V_{RF} \approx 0.01\ \lambda^3$	$V_{RF} \approx 0.03\ \lambda^3$	$V_{RF} \approx 0.01\ \lambda^3$

4.3.4 Pulse Forming Circuits

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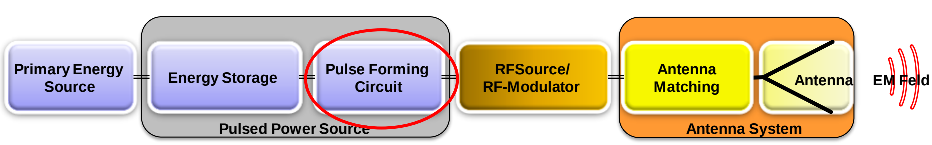
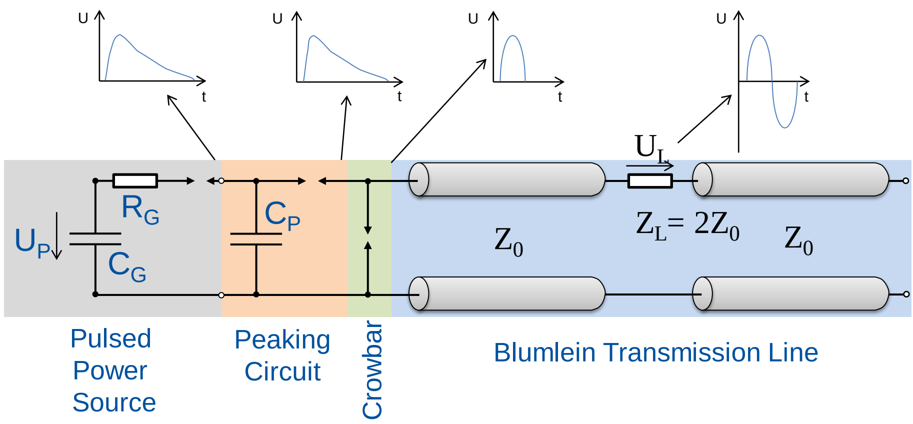
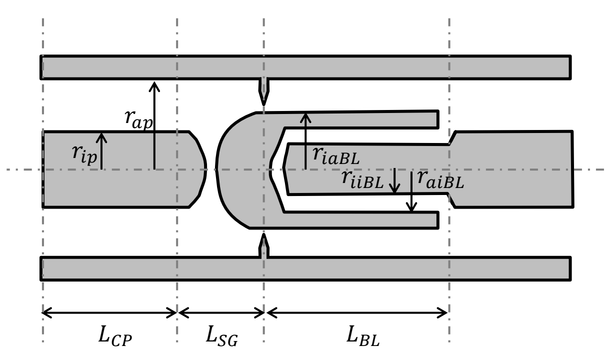
Principal Structure



Principal Design



Design Example



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Evaluation Pulse Forming Circuits

Criterion	Level	Description
Technology		**Pulse Forming Circuits**
Needed Knowledge		
- Design	$K_D = 2$	The design of pulse forming circuits requires expertise at the level of an **experienced hobby electrician**.
- Assembling	$K_A = 2$	The construction and assembling of pulse forming circuits capabilities at the level of an **experienced hobby electrician**.
- Operation	$K_O = 1$ -2	For the operation of an pulse forming circuits only an instruction in the handling is necessary. (**general knowledge** to **basic understanding**)
Availability		
- Components	$AV_C = 2$	The required components are available from specialist retailers.
- Pulsed Power Source	$AV_S = 0$	Pulse forming circuits are currently not offered in the commercial trade.
Costs	$C_{exp} = 1$	The cost of building pulse forming circuits is up to €1,000.

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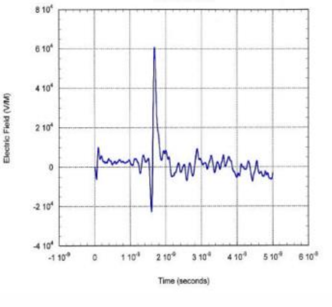
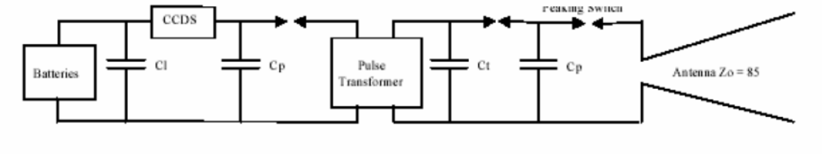
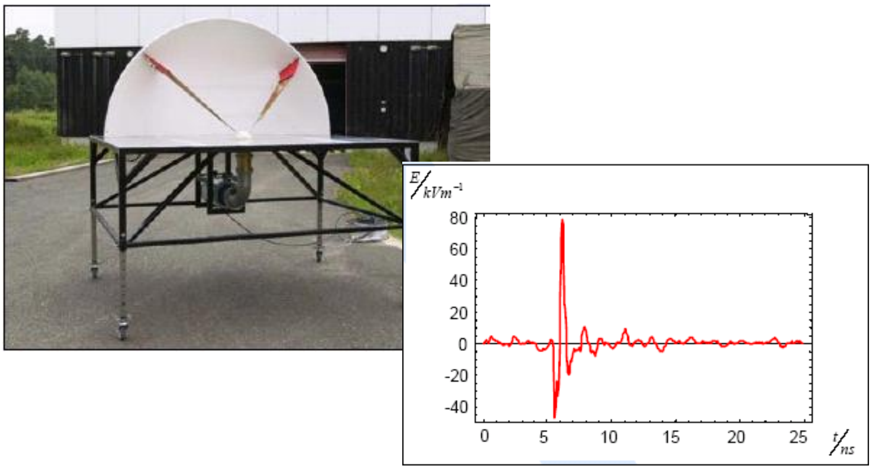
UWB Systems (JOLT)





Source: C. E. Baum et al., "JOLT: a highly directive, very intensive, impulse-like radiator," in Proceedings of the IEEE, vol. 92, no. 7, pp. 1096-1109, July 2004, doi: 10.1109/JPROC.2004.829011..

UWB Systems (HIRA)



Source: F. Sabath, D. Nitsch, M. Jung and T. H. G. G. Weise, "Design and setup of a short pulse simulator for susceptibility investigations," in IEEE Transactions on Plasma Science, vol. 30, no. 5, pp. 1722-1727, Oct. 2002,.doi: 10.1109/TPS.2002.805331.

Evaluation UWB Systems (1)

Criterion	Level	Description
Technology		Switched Oscillators are **transit time oscillators** (delay lines) consisting of mismatched RF lines..
Needed Knowledge		
- Design	$K_D = 3 - 4$	The design of a UWB system requires **academic training** (e.g. engineer) or an **experienced specialist**..
- Assembling	$K_A = 3$	The construction and assembling of an UWB system requires expertise at the level of a **experienced specialist.**
- Operation	$K_O = 1$	For the operation of antenna oscillator, only an instruction in handling is necessary. (**general knowledge**)
Availability		
- Components	$AV_C = 2 - 3$	The most of the required components are available from **specialist retailers**.
- RF - Modulator	$AV_S = 0$	UWB systems are currently not on sale.
Costs	$C_{exp} = 2 - 3$	The cost for the acquisition of UWB systems is in the range € 1,000 - € 100,000.

Evaluation UWB Systems (2)

Criterion	Level	Description
Volume / Mobility	M = 2 - 3	The structural size is determined by the necessary electric strength .
Frequency Range		f_{RF} = 0 - 5 GHz
Max. Power Output	$P_{max} \leq 75$ GW	
Efficiency	$\eta \leq 50$ %	

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4.3.4 Antennas

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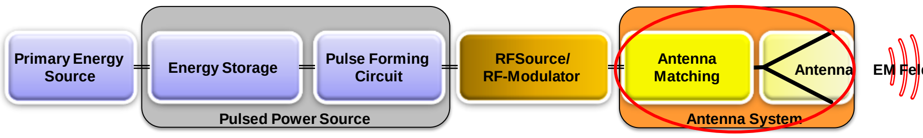
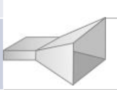
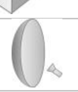
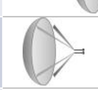
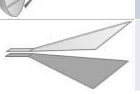
Principal Structure



Antennas: Technology Challenge & Directivity

Type		Required Knowledge	Directivity
Dipole antenna		$K_D = 2$	$D_0 = 1{,}5$
λ/2 cone antenna		$K_D = 2$	$D_0 = 1{,}643$
Horn antenna		$K_D = 4$	$D_0 = 0{,}81 \cdot 4\pi \frac{A_{ap}}{\lambda^2}$
Reflector antenna		$K_D = 4$	$D_0 = e_{ap} \cdot 4\pi \frac{A_{ap}}{\lambda^2}$
IRA		$K_D = 4$	$D_0 = e_{ap} \cdot 4\pi \frac{A_{ap}}{\lambda^2}$
TEM-Horn antenna		$K_D = 3$	$D_0 = 4\pi \frac{A_{ap}}{\lambda^2}$

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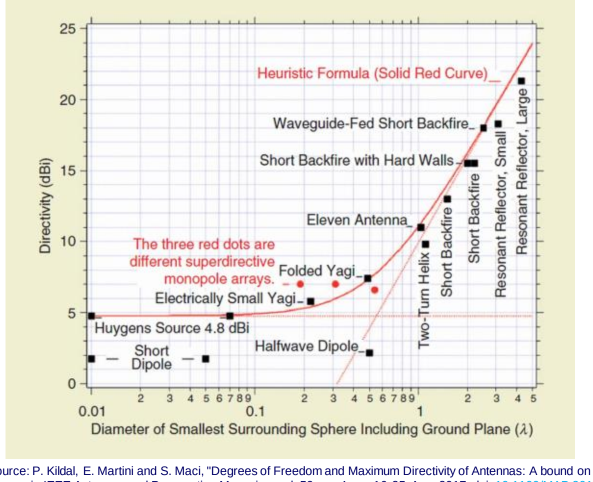
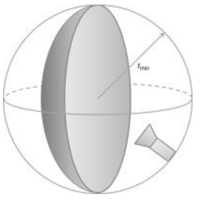
Directivity of Antennas





$$D_{0,max} = \left(\pi \cdot \frac{2 \cdot r_{min}}{\lambda}\right)^2 + 3$$

Source: P. Kildal, E. Martini and S. Maci, "Degrees of Freedom and Maximum Directivity of Antennas: A bound on maximum directivity of nonsuperreactive antennas", in IEEE Antennas and Propagation Magazine, vol. 59, no. 4, pp. 16-25, Aug. 2017, doi: 10.1109/MAP.2017.2706659.

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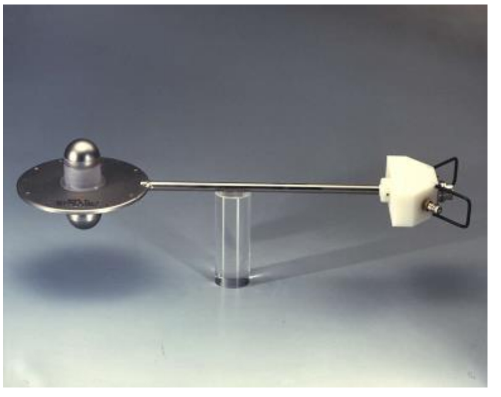
Evaluation Antennas

Criterion	Level	Description
Technology		**Antennas**
Needed Knowledge		
- Design	$K_D = 2 – 4$	
- Assembling	$K_A = 2$	The construction and assembling of an antenna s capabilities at the level of an **experienced hobby electrician**.
- Operation	$K_O = 1 - 2$	For the operation of an antenna only an instruction in the handling is necessary. (**general knowledge** to **basic understanding**)
Availability		
- Components	$AV_C = 2$	The required components are available from specialist retailers.
- Pulsed Power Source	$AV_S = 2$	Various antennas are currently available from specialist retailers.
Costs	$C_{exp} = 1 - 2$	The cost for the construction of an antenna is up to €1,000. Commercial antennas can cost up to €10,000 depending on the size.

Thank You for Your Attention.

Questions ?



Chapter 5
Modeling of Scenarios and Systems

EMI Risk Management

5. Modeling of Scenarios and Systems

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www.geml.uni-hannover.de

Content

✓ 1. Introduction & Basic Terms
✓ 2. Fundamentals of Risk Management
✓ 3. Risk Analysis Methods
✓ 4. EMI Scenario
⇒ 5. Modeling of scenarios and systems
6. Effects and Error States
7. Risk Evaluation
8. Risk Treatment and Protection
9. Examples
10. Summary

5.1 Modeling of Generic IEMI Sources

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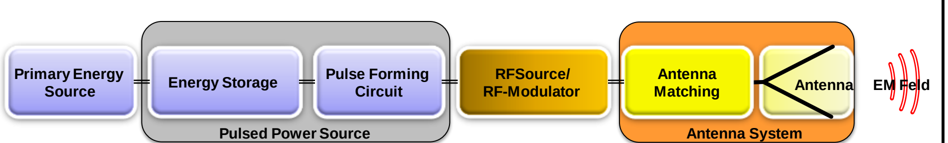
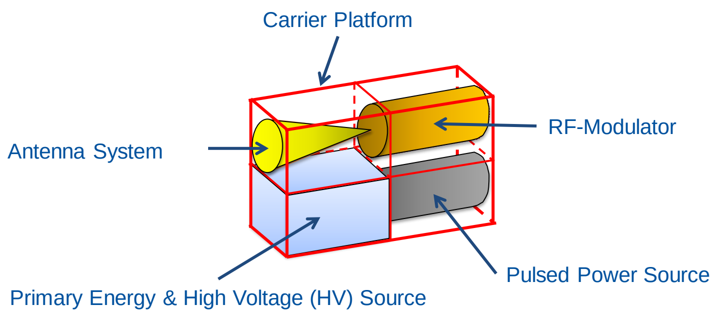
Principal Structure and Integration





Modeling of a Generic IEMI Source

1. **Selection of the carrier platform**
2. Selection of the RF modulator
3. Partition of the useful volume
4. Parameterization of primary energy and high voltage source
5. Parameterization pulse power source
6. Estimation of operating frequency
7. Parameterization antenna
8. Evaluation impulse output RF power
9. Estimation of normed emitted electric field strength

Generic Carrier Platform (M = 5)

Generic carrier platform	Mobility	Volume	Inside dimensions			Outside dimensions			Examples
			L	B	H	L	B	H	
	M	10^{-3} m³	mm	mm	mm	mm	mm	mm	
M5-1	5	2	110	250	75	125	265	80	Index card box, coffee tin, box
M5-2	5	11	400	295	95	455	330	120	Briefcase

M5-1

M5-2

Generic Carrier Platform (M = 4)

Generic carrier platform	Mobility	Volume	Inside dimensions			Outside dimensions			Examples
			L	B	H	L	B	H	
	M	10^{-3} m³	mm	mm	mm	mm	mm	mm	
M4-1	4	25	415	190	315	460	205	350	Pilot's suitcase, small transport box
M4-2	4	45	500	200	450	520	220	470	ATX midi tower, PC case, small case
M4-3	4	90	550	550	300	600	600	330	transport box, Large suitcase
M4-4	4	195	780	480	520	830	530	550	transport box

M4-1

M4-2

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Generic Carrier Platform (M = 3)

Generic carrier platform	Mobility	Volume	Inside dimensions			Outside dimensions			Examples
			L	B	H	L	B	H	
	M	10^{-3} m³	mm	mm	mm	mm	mm	mm	
M3-1	3	320	1,150	750	370	1,200	800	400	Large transport box,
M3-2	3	650	1,150	750	770	1,200	800	800	Large transport box, Car
M3-3	3	1,000	1,150	750	1,170	1,200	800	1,200	Large transport box, Van
M3-4	3	2,000	2,040	1,040	1,000				Single axis trailer
M3-5	3	7,000	7,000	1,400	1,800				Transporter

M3-4

M3-3

1. Selection of the carrier platform

(1) Selection of a carrier platform

(2) Record of the values for

- the knowledge ($K_{D,TP}$) required to integrate the IEMI source into the platform,
- availability ($AV_{S,TP}$) and
- costs ($C_{exp,TP}$)

for the carrier platform

Modeling of a Generic IEMI Source

1. Selection of the carrier platform
2. **Selection of the RF modulator**
3. Partition of the useful volume
4. Parameterization of primary energy and high voltage source
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2. Selection of the RF modulator (Hypoband)

Typ	HO-k-1	HO-k-2	HO-b-1	HO-b-2
Example	conv. Magnetron	conv. Klystron	rel. Magnetron VIRCATOR	rel. Klystron MILO
Frequency Range	UHF, L, S, C, X	L, S, C, X	UHF, L, S, C, X	L, S, C, X
Power Output	≤ 10 MW	≤ 0,5 GW	≤ 1 GW	≤ 10 GW
Efficiency	≤ 80 %	≤ 70 %	≤ 30 %	≤ 40 %
Needed Knowledge				
- Design	4			
- Assembling	3			
- Operation	1-2			
Availability				
- Components	not applicable		2-3	
- RF - Modulator	1-2	3	not applicable	
Mobility	3-5			
Volume	$V_{RF} \approx 1.4\ \lambda^3$	$V_{RF} \approx 4\ \lambda^3$	$V_{RF} \approx 4.5\ \lambda^3$	$V_{RF} \approx 4\ \lambda^3$

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2. Selection of the RF modulator

(Meso- and Sub-Hyperband)

Typ	MB-k-1	MB-b-1	MB-b-2
Example	TLO	AO	SWO
Frequency Range	VHF, UHF, (L)	VHF, UHF, L	VHF, UHF, L
Power Output	≤ 0.5 MW	≤ 10 MW	≤ 1 GW
Efficiency	≤ 60 %	≤ 50 %	≤ 60 %
Needed Knowledge			
- Design	2 – 3	1 – 3	2 – 3
- Assembling	2 – 3	2 – 3	2 – 3
- Operation	1-2	1-2	1-2
Availability			
- Components	2	2	2
- RF-Modulator	1 - 2	0	4
Mobility	3 - 5	3 - 5	3 - 5
Volume	$V_{RF} \approx 0.01\ \lambda^3$	$V_{RF} \approx 0.03\ \lambda^3$	$V_{RF} \approx 0.01\ \lambda^3$

2. Selection of the RF modulator

(1) Selection of the RF modulator

(2) Record of the values for

- the required knowledge ($K_{D,RF}$)
- availability ($AV_{S,RF}$) and
- costs ($C_{exp,RF}$)

for the selected RF modulator

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Modeling of a Generic IEMI Source

1. Selection of the carrier platform
2. Selection of the RF modulator
3. **Partition of the useful volume**
4. Parameterization of primary energy and high voltage source
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8. Evaluation impulse output RF power
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3. Partition of the useful volume

Dividing the useful volume of the carrier system (V_{TP}) into sub-volumes for

- the primary energy and high voltage source (V_{HV}),
- the pulse power source (V_{HV}),
- the RF modulator (V_{RF}) and
- the antenna system (V_{Ant})

according to the associated strategy A to E.

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Problem (1)

When subdividing the useful volume of the carrier platform, we should have in mind:

- The volume of the primary energy & high voltage source specifies the operating time of the system.
- The volume of the pulse power source determines an upper barrier for the pulse output power.
- The maximum pulse output power of the generic RF modulators can only be exceeded with considerable technical effort.

Volume of Pulse Power Sources (at P_{max})

Type RF-Modulator	Output Power	Efficiency	Input Power	Volume Pulse Power Source
	$P_{RF,out}$	η	$P_{RF,in}$	V_{IG}
	GW	%	GW	10^{-3} m^{-3}
HO-k-1	0.01	80	0.013	0.95
HO-k-2	0.5	70	0.714	95.36
HO-b-1	1	30	3.333	551.21
HO-b-2	10	40	25	5,469.82
MB-k-2	0.0005	60	0.0008	0.04
MB-b-1	0.01	50	0.02	1.62
MB-b-2	1	60	1.67	250.30

Problem (2)

When subdividing the useful volume of the carrier platform, we should have in mind:

- The volume for the RF modulator specifies a lower limit for its operating frequency.
- The directional factor of an antenna is proportional to the square of the ratio of the antenna characteristic dimension to the operating wavelength

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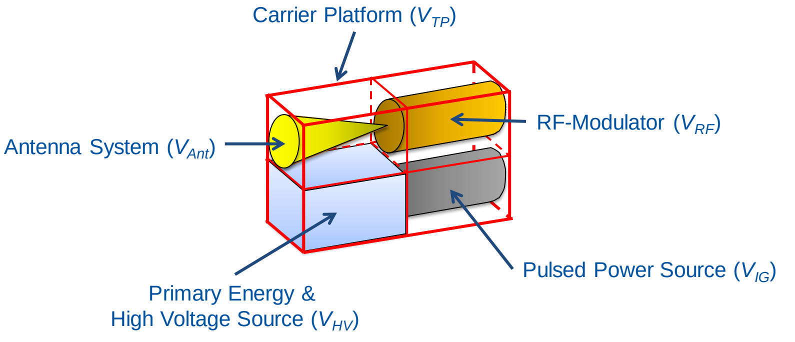
Strategy A) Mobility M > 3 and RF-Modulator HO-k-2, HO-b-1 or HO-b-2



$$V_{RF} = V_{HV} = V_{IG} = V_{Ant} = \frac{V_{TP}}{4}$$

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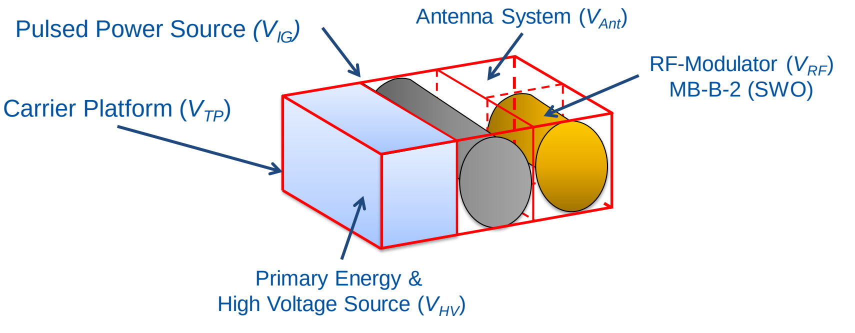
Strategy B) Mobility M > 3 and RF-Modulator MB-b-2



$$V_{HV} = V_{IG} = \frac{V_{TP}}{3} \qquad V_{RF} = V_{Ant} = \frac{V_{TP}}{6}$$

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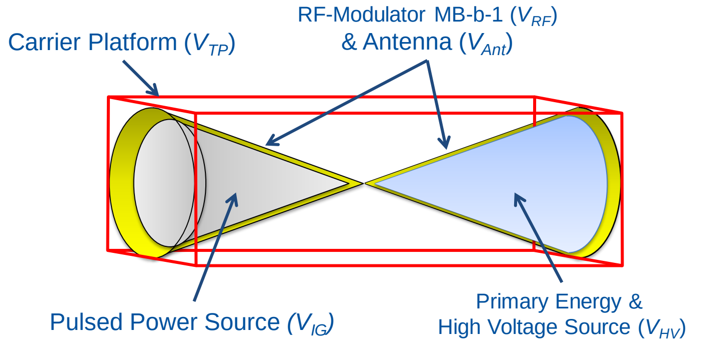
Strategy C.a) RF-Modulator MB-b-1



$$V_{HV} = V_{IG} \leq \frac{V_{TP}}{8} \qquad V_{RF} = V_{Ant} = \frac{V_{TP}}{4}$$

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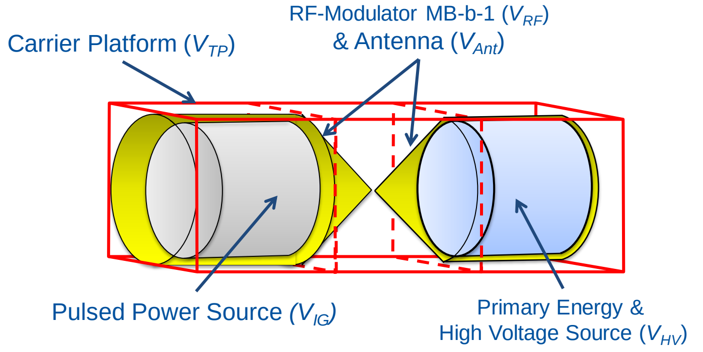
Strategy C.b) RF-Modulator MB-b-1



$$V_{HV} = V_{IG} \leq \frac{V_{TP}}{4} \qquad V_{RF} = V_{Ant} = \frac{7\,V_{TP}}{12}$$

Strategy D) Mobility M > 3 and RF-Modulator HO-k-1 or MB-k-1

HO-k-1:

- $V_{HV} = V_{IG} = 0{,}95 \cdot 10^{-3}\ m^3$
- $P_{RF,out} = 0{,}01$ GW
- $P_{RF,in} = 0{,}013$ GW
- $V_{RF} = V_{Ant} = (V_{TP} - V_{HV} - V_{IG})/2$

MB-k-1:

- $V_{HV} = V_{IG} = 0{,}04 \cdot 10^{-3}\ m^3$
- $P_{RF,out} = 0{,}5$ MW
- $P_{RF,in} = 0{,}8$ MW
- $V_{RF} = V_{Ant} = (V_{TP} - V_{HV} - V_{IG})/2$

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Strategy E) Mobility M ≤ 3

- The carrier system provides more volume as required
  - V_{RF} is deduced from operation frequency
  - V_{HV} and V_{IG} are deduced from maximum output RF power
  - $V_{Ant} \leq V_{TP} - V_{HV} - V_{IG} - V_{RF}$
- Limit:
  - $V_{Ant} = V_{HV} = V_{IG} = V_{RF} = V_{TP} / 4$

Modeling of a Generic IEMI Source

1. Selection of the carrier platform
2. Selection of the RF modulator
3. Partition of the useful volume
4. **Parameterization of primary energy and high voltage source**
5. Parameterization pulse power source
6. Estimation of operating frequency
7. Parameterization antenna
8. Evaluation impulse output RF power
9. Estimation of normed emitted electric field strength

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4. Parameterization of primary energy and high voltage source

Record of the values for

- the required knowledge ($K_{D,HV}$),
- availability ($AV_{S,HV}$) and
- costs ($C_{exp,HV}$)

for the primary energy and high voltage source

Modeling of a Generic IEMI Source

1. Selection of the carrier platform
2. Selection of the RF modulator
3. Partition of the useful volume
4. Parameterization of primary energy and high voltage source
5. **Parameterization pulse power source**
6. Estimation of operating frequency
7. Parameterization antenna
8. Evaluation impulse output RF power
9. Estimation of normed emitted electric field strength

5. Parameterization pulse power source

(1) Record of the values for

- the required knowledge ($K_{D,IG}$),
- availability ($AV_{S,IG}$) and
- costs ($C_{exp,IG}$)

for the primary energy and high voltage source

(2) Estimation of the maximal output power (P_{out})

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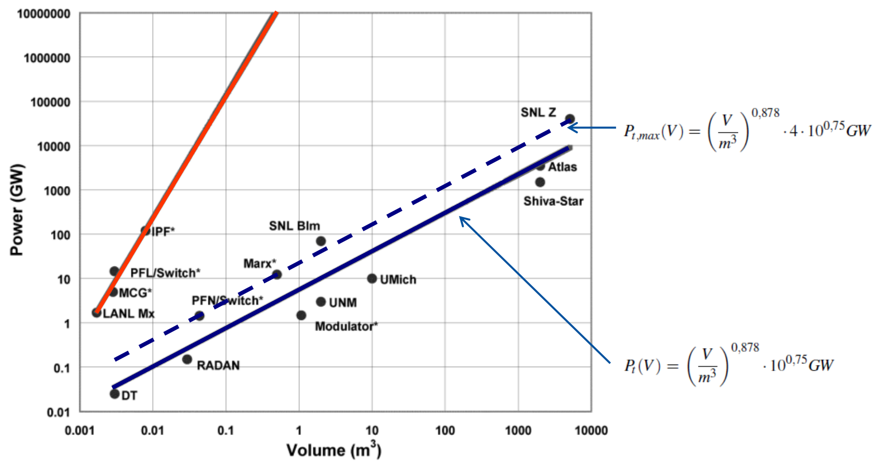
Power Volume Ratio of Pulse Power Sources



Source: E. Schamiloglu, R. J. Barker, M. Gundersen, and A. A. Neuber. Modern pulsed power: Charlie Martin and beyond. In Proceedings of the IEEE, 92(7):1014–1020, July 2004, doi: 10.1109/JPROC.2004.829058

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Modeling of a Generic IEMI Source

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6. Estimation of operating frequency

Estimation of working frequency from the available volume V_{RF} using the estimation formulas for the construction volume of the RF modulator.

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Modeling of a Generic IEMI Source

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6. Estimation of operating frequency
7. **Parameterization antenna**
8. Evaluation impulse output RF power
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7. Parameterization antenna

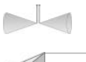
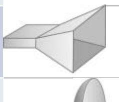
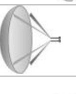
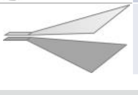
(1) Record of the values for

- the required knowledge ($K_{D,Ant}$),
- availability ($AV_{S,Ant}$) and
- costs ($C_{exp,Ant}$)

for the antenna system

(2) Estimation of the directivity

Antennas: Technology Challenge & Directivity

Type		Required Knowledge	Directivity
Dipole antenna		$K_D = 2$	$D_0 = 1{,}5$
λ/2 cone antenna		$K_D = 2$	$D_0 = 1{,}643$
Horn antenna		$K_D = 4$	$D_0 = 0{,}81 \cdot 4\pi \frac{A_{ap}}{\lambda^2}$
Reflector antenna		$K_D = 4$	$D_0 = e_{ap} \cdot 4\pi \frac{A_{ap}}{\lambda^2}$
IRA		$K_D = 4$	$D_0 = e_{ap} \cdot 4\pi \frac{A_{ap}}{\lambda^2}$
TEM-Horn antenna		$K_D = 3$	$D_0 = 4\pi \frac{A_{ap}}{\lambda^2}$

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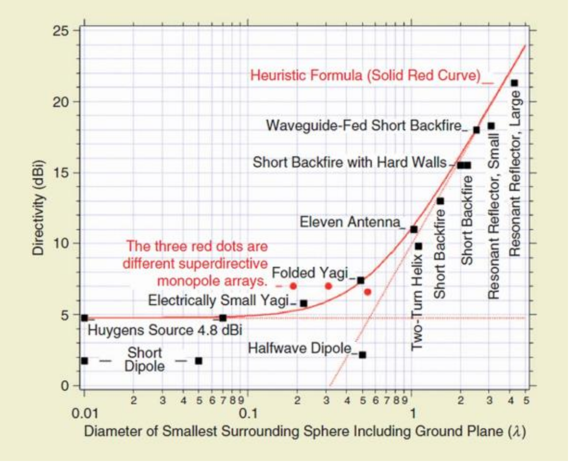
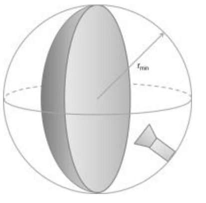
Directivity of Antennas





$$D_{0,max} = \left(\pi \cdot \frac{2 \cdot r_{min}}{\lambda}\right)^2 + 3$$

Source: P. Kildal, E. Martini and S. Maci, "Degrees of Freedom and Maximum Directivity of Antennas: A bound on maximum directivity of nonsuperreactive antennas", in IEEE Antennas and Propagation Magazine, vol. 59, no. 4, pp. 16-25, Aug. 2017, doi: 10.1109/MAP.2017.2706659.

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Modeling of a Generic IEMI Source

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7. Parameterization antenna
8. **Evaluation impulse output RF power**
9. Estimation of normed emitted electric field strength

8. Evaluation impulse output RF power

Estimation of the radiated pulse RF power based on the output power of the pulse power source and the efficiency of the RF modulator via the relationship

$$P_{rad} = P_{out} \cdot \eta$$

Modeling of a Generic IEMI Source

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7. Parameterization antenna
8. Evaluation impulse output RF power
9. **Estimation of normed emitted electric field strength**

9. Estimation of emitted electric field strength

The normalized maximum energy flow density emitted (in the main beam direction) is given by:

$$S_{max} \cdot r^2 = \frac{P_{rad} \cdot D_0}{4\pi}$$

In the far field, the maximum electric field strength emitted by the generic IEMI source can be estimated via:

$$E_{max} \cdot r = \sqrt{S_{max} \cdot r^2 \cdot Z_0} = \sqrt{\frac{P_{rad} \cdot D_0 \cdot Z_0}{4\pi}}$$

Modeling Generic IEMI Sources

Intermediate Result:

During the first 9 modeling steps we

- Assumed
  - the mobility of the IEMI Source (carrier platform)
  - the usage of a selected generic RF modulator
- Recorded
  - required knowledge and cost for the acquisition or assembly of each module
  - availability of technology and/or modules
- Estimated
  - the operating frequency
  - the emitted maximum field strength

Modeling Generic IEMI Sources

Remaining Open Question:

– Probability that the attacker has access to
  – the modules.
  – the considered generic IEMI Source.

Approach:

→ Evaluation of
  → required knowledge
  → availability
  → costs

Modeling of a Generic IEMI Source (2)

10. **Evaluation of required knowledge**
11. Evaluation of required financial resources/costs
12. Evaluation of availability of technology/modules
13. Estimation probability of occurrence of the modules
14. Estimation Probability of occurrence (P_{CU}) of the complete IEMI source

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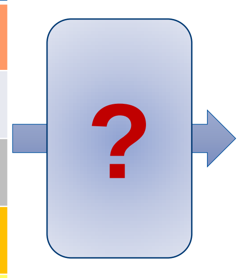
10. Evaluation of Required Knowledge

Module	Knowledge Level
Carrier Platform	$K_{D,TP}$
Primary Energy & High Voltage Source	$K_{D,HV}$
Pulsed Power Source	$K_{D,IP}$
RF-Modulator	$K_{D,RF}$
Antenna System	$K_{D,Ant}$



Index of Probability
$P_{K,TP}$
$P_{K,HV}$
$P_{K,IP}$
$P_{K,RF}$
$P_{K,Ant}$

Probability that the potential attacker has access to the knowledge required to construction and operation the given module.

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Generic Offender: Knowledge

Knowledge Level			Index of Probability	
general knowledge	Novice	**1**	**9**	frequent (90 - 97%)
basic understanding	Skilled	**2**	**7**	probable (50 – 75%)
specialized knowledge and expertise	Specialist	**3**	**6**	occasional (25 – 50%)
academic knowledge and professional expertise	Graduate	**4**	**4**	occasional (5 – 12%)
expert knowledge and profound expertise	Expert	**5**	**3**	remote (2 – 5%)

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10. Evaluation of Required Knowledge

Module	Knowledge Level	Index of Probability
Carrier Platform	$K_{D,TP}$	$P_{K,TP}$
Primary Energy & High Voltage Source	$K_{D,HV}$	$P_{K,HV}$
Pulsed Power Source	$K_{D,IP}$	$P_{K,IP}$
RF-Modulator	$K_{D,RF}$	$P_{K,RF}$
Antenna System	$K_{D,Ant}$	$P_{K,Ant}$

Generic Offender

Probability that the generic offender has access to the knowledge required to construction and operation the given module.

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Modeling of a Generic IEMI Source (2)

10. Evaluation of required knowledge
11. **Evaluation of required financial resources/costs**
12. Evaluation of availability of technology/modules
13. Estimation probability of occurrence of the modules
14. Estimation Probability of occurrence (P_{CU}) of the complete IEMI source

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10. Evaluation of Required Costs

Module	Financial Recources	Index of Probability
Carrier Platform	$C_{exp,TP}$	$P_{C,TP}$
Primary Energy & High Voltage Source	$C_{exp,HV}$	$P_{C,HV}$
Pulsed Power Source	$C_{exp,IP}$	$P_{C,IP}$
RF-Modulator	$C_{exp,RF}$	$P_{C,RF}$
Antenna System	$C_{exp,Ant}$	$P_{C,Ant}$

Generic Offender

Probability that the generic offender has access to the access to funds required to construction and operation the given module.

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Generic Offender: Financial Recourses

Available financial recourses			Index of Probability	
< 1.000 €	Low	**1**	**9**	Frequent (90 - 97%)
1.000 – 10.000 €	Moderate	**2**	**6**	occasional (25 – 50%)
10.000 – 100.000 €	Increased	**3**	**4**	occasional (5 – 12%)
100.000 – 1.000.000 €	High	**4**	**2**	remote (1 – 2%)
> 1.000.000 €	Extreme	**5**	**1**	Improbable/ Unlikely <0,5%

Modeling of a Generic IEMI Source (2)

10. Evaluation of required knowledge
11. Evaluation of required financial resources/costs
12. **Evaluation of availability of technology/modules**
13. Estimation probability of occurrence of the modules
14. Estimation Probability of occurrence (P_{CU}) of the complete IEMI source

12. Evaluation of Availability

Module	Availability Level
Carrier Platform	$AV_{S,TP}$
Primary Energy & High Voltage Source	$AV_{S,HV}$
Pulsed Power Source	$AV_{C,IP}$
RF-Modulator	$AV_{C,RF}$
Antenna System	$AV_{C,Ant}$

Generic Offender

Index of Probability
$P_{A,TP}$
$P_{A,HV}$
$P_{A,IP}$
$P_{A,RF}$
$P_{A,Ant}$

Probability that the generic offender has access to technology and components required to construction and operation the given module.

Generic Offender: Availability

Availability Level		Index of Probability	
of-the-shelf	1	8	probable (75 – 90 %)
commercially available	2	6	occasional (25 – 50 %)
specialized trade	3	4	occasional (5 – 12 %)
limited acquisition	4	2	remote (2 – 5 %)
restricted acquisition	5	1	unlikely (0,5 – 1 %)

Modeling of a Generic IEMI Source (2)

10. Evaluation of required knowledge
11. Evaluation of required financial resources/costs
12. Evaluation of availability of technology/modules
13. **Estimation probability of occurrence of the modules**
14. Estimation Probability of occurrence (P_{CU}) of the complete IEMI source

13. Probability of Occurrence of the Modules

Module	Index of Probability (Knowledge)	Index of Probability (Availability)	Index of Probability (Cost)	Index of Probability (Module)
Carrier Platform	$P_{K,TP}$	$P_{A,TP}$	$P_{C,TP}$	P_{TP} = ?
Primary Energy & High Voltage Source	$P_{K,HV}$	$P_{A,HV}$	$P_{C,HV}$	P_{HV} = ?
Pulsed Power Source	$P_{K,IG}$	$P_{A,IG}$	$P_{C,IG}$	P_{IG} = ?
RF-Modulator	$P_{K,RF}$	$P_{A,RF}$	$P_{C,RF}$	P_{RF} = ?
Antenna System	$P_{K,Ant}$	$P_{A,Ant}$	$P_{C,Ant}$	P_{Ant} = ?

Probability that the generic offender has access to a modules
or is capable to construct, assemble and operation them.

13. Probability of Occurrence of the Modules

Assumption:

Knowledge, Availability, and Cost are independent aspects

- If the probability would satisfies the Kolmogorow Axioms

$$\Rightarrow P_{TP} = P_{K,TP} \cdot P_{A,TP} \cdot P_{C,TP}$$

13. Probability of Occurrence of the Modules

Assumption:

Knowledge, Availability, and Cost are independent aspects

- The Probability Index does not satisfy the Kolmogorow Axioms
- The offender has access to the module if all three aspects are fulfilled.

$\Rightarrow P_{TP} = min\{P_{K,TP} \cdot P_{A,TP} \cdot P_{C,TP}\}$

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13. Probability of Occurrence of the Modules

Module	Index of Probability (Knowledge)	Index of Probability (Availability)	Index of Probability (Cost)	Index of Probability (Module)
Carrier Platform	$P_{K,TP}$	$P_{A,TP}$	$P_{C,TP}$	$P_{C,TP} = \min\{P_{K,TP}, P_{A,TP}, P_{C,TP}\}$
Primary Energy & High Voltage Source	$P_{K,HV}$	$P_{A,HV}$	$P_{C,HV}$	$P_{C,HV} = \min\{P_{K,HV}, P_{A,HV}, P_{C,HV}\}$
Pulsed Power Source	$P_{K,IG}$	$P_{A,IG}$	$P_{C,IG}$	$P_{C,IG} = \min\{P_{K,IG}, P_{A,IG}, P_{C,IG}\}$
RF-Modulator	$P_{K,RF}$	$P_{A,RF}$	$P_{C,RF}$	$P_{C,RF} = \min\{P_{K,RF}, P_{A,RF}, P_{C,RF}\}$
Antenna System	$P_{K,Ant}$	$P_{A,Ant}$	$P_{C,Ant}$	$P_{C,Ant} = \min\{P_{K,Ant}, P_{A,Ant}, P_{C,Ant}\}$

Probability that the generic offender has access to a modules or is capable to construct, assemble and operation them.

Modeling of a Generic IEMI Source (2)

10. Evaluation of required knowledge
11. Evaluation of required financial resources/costs
12. Evaluation of availability of technology/modules
13. Estimation probability of occurrence of the modules
14. **Estimation Probability of occurrence (P_{CU}) of the complete IEMI source**

14. Occurrence of complete IEMI Source

Module	Index of Probability (Knowledge)	Index of Probability (Availability)	Index of Probability (Cost)	Index of Probability (Module)
Carrier Platform	$P_{K,TP}$	$P_{A,TP}$	$P_{C,TP}$	$P_{C,TP}$ $= \min\{P_{K,TP}, P_{A,TP}, P_{C,TP}\}$
Primary Energy & High Voltage Source	$P_{K,HV}$	$P_{A,HV}$	$P_{C,HV}$	$P_{C,HV}$ $= \min\{P_{K,HV}, P_{A,HV}, P_{C,HV}\}$
Pulsed Power Source	$P_{K,IG}$	$P_{A,IG}$	$P_{C,IG}$	$P_{C,IG}$ $= \min\{P_{K,IG}, P_{A,IG}, P_{C,IG}\}$
RF-Modulator	$P_{K,RF}$	$P_{A,RF}$	$P_{C,RF}$	$P_{C,RF}$ $= \min\{P_{K,RF}, P_{A,RF}, P_{C,RF}\}$
Antenna System	$P_{K,Ant}$	$P_{A,Ant}$	$P_{C,Ant}$	$P_{C,Ant}$ $= \min\{P_{K,Ant}, P_{A,Ant}, P_{C,Ant}\}$
Complete IEMI Source	Probability that the generic offender has access to the complete IEMI source			P_{CU}

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14. Occurrence of complete IEMI Source

Module	Index of Probability (Knowledge)	Index of Probability (Availability)	Index of Probability (Cost)	Index of Probability (Module)
Carrier Platform	$P_{K,TP}$	$P_{A,TP}$	$P_{C,TP}$	$P_{C,TP}$ $= \min\{P_{K,TP}, P_{A,TP}, P_{C,TP}\}$
Primary Energy & High Voltage Source	$P_{K,HV}$	$P_{A,HV}$	$P_{C,HV}$	$P_{C,HV}$ $= \min\{P_{K,HV}, P_{A,HV}, P_{C,HV}\}$
Pulsed Power Source	$P_{K,IG}$	$P_{A,IG}$	$P_{C,IG}$	$P_{C,IG}$ $= \min\{P_{K,IG}, P_{A,IG}, P_{C,IG}\}$
RF-Modulator	$P_{K,RF}$	$P_{A,RF}$	$P_{C,RF}$	$P_{C,RF}$ $= \min\{P_{K,RF}, P_{A,RF}, P_{C,RF}\}$
Antenna System	$P_{K,Ant}$	$P_{A,Ant}$	$P_{C,Ant}$	$P_{C,Ant}$ $= \min\{P_{K,Ant}, P_{A,Ant}, P_{C,Ant}\}$
Complete IEMI Source	Probability that the generic offender has access to the complete IEMI source		**P_{CU} $= \min\{P_{C,TP}, P_{C,HV}, P_{C,IG}, P_{C,RF}, P_{C,Ant}\}$**	

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Data Sheet

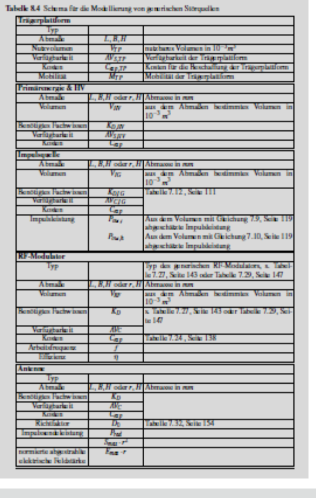
Tabelle 8.4 Schema für die Modellierung von generischen Störquellen

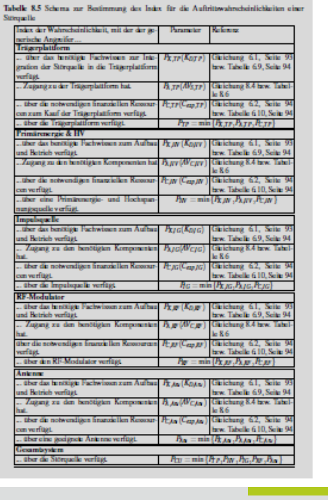
Tabelle 8.5 Schema zur Bestimmung des Index für die Auftrittswahrscheinlichkeiten einer Störquelle

5.2 Example: M4-2:MB-b-2

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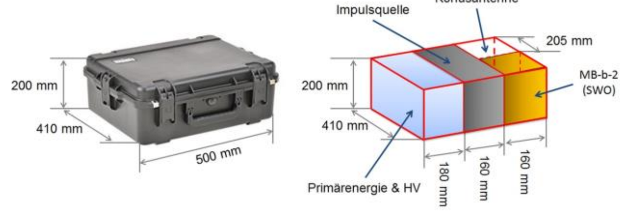
Carrier Platform



1. Carrier Platform: M4-2 $V_{TP} = 41 \cdot 10^{-3}\ m^3$
2. RF-Modulator: MB-b-2 (SWO)
3. Partition of the useful volume: Strategy B
   - $V_{HV} = V_{IG} = V_{TP}/3 = 13{,}67 \cdot 10^{-3}\ m^3$
   - $V_{RF} = V_{Ant} = V_{TP}/6 = 8{,}83 \cdot 10^{-3}\ m^3$

Modules

4. Parameterization of primary energy and high voltage source
5. Parameterization pulse power source

$$P_{out,IG} \leq 4 \cdot (13{,}67 \cdot 10^{-3})^{0{,}878} \cdot 10^{0{,}878} GW = 519\ MW$$

6. Estimation of operating frequency

$$V_{RF} = 0{,}01 \cdot \lambda^3$$
$$\Rightarrow f \geq \frac{c}{\sqrt[3]{V_{RF} \cdot 100}} = 340\ MHz$$

7. Parameterization antenna

$\lambda/4$ Cone Antenna $\Rightarrow D_0 = 1{,}643$

Emitted electric field strength

8. Evaluation impulse output RF power

$$P_{rad} = P_{out,IG} \cdot \eta = 519\ MW \cdot 0{,}6 = 311\ MW$$

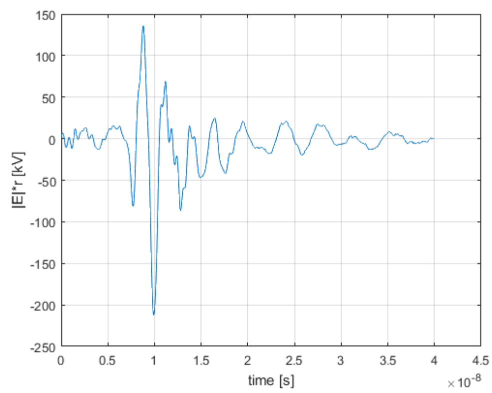
9. Estimation of normed emitted electric field strength

$$S_{max} \cdot r^2 = \frac{P_{rad} \cdot D_0}{4 \cdot \pi} = \frac{311\ MW \cdot 1{,}643}{4 \cdot \pi} = 41\ \text{MW}$$

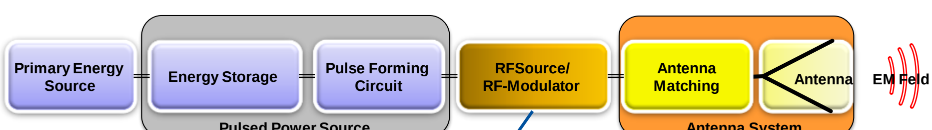
$$E_{max} \cdot r = \sqrt{S_{max} \cdot r^2 \cdot 377\Omega} = 124\ \text{kV}$$

HPMcase Standard F

$D_R = 3{,}37 \Rightarrow E_{max}\, r = 227$ kV

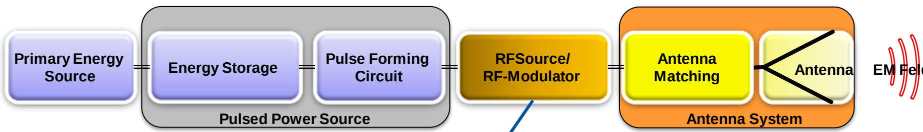


Probability of Occurrence of RF Modulator



RF-Modulator: MB-b-2 (SWO)		
Knowledge	$K_{D,RF}$ = 2 – 3	$P_{K,RF}$ = 6 – occasional
Availability	$AV_{C,RF}$ = 2	$P_{A,RF}$ = 6 – occasional
Financial Recourses	$C_{exp,RF}$ = 2	$P_{C,RF}$ = 6 – occasional

Probability of Occurrence of RF Modulator



RF-Modulator: MB-b-2 (SWO)		
Knowledge	$K_{D,RF}$ = 2 – 3	$P_{K,RF}$ = 6 – occasional
Availability	$AV_{C,RF}$ = 2	$P_{A,RF}$ = 6 – occasional
Financial Recourses	$C_{exp,RF}$ = 2	$P_{C,RF}$ = 6 – occasional
		P_{RF} = min{$P_{K,RF}$, $P_{A,RF}$, $P_{C,RF}$} = 6 - occasional

generic offener

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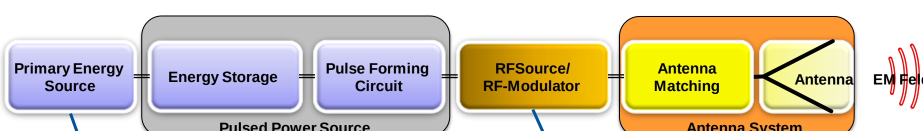
Probability of Occurrence of Modules



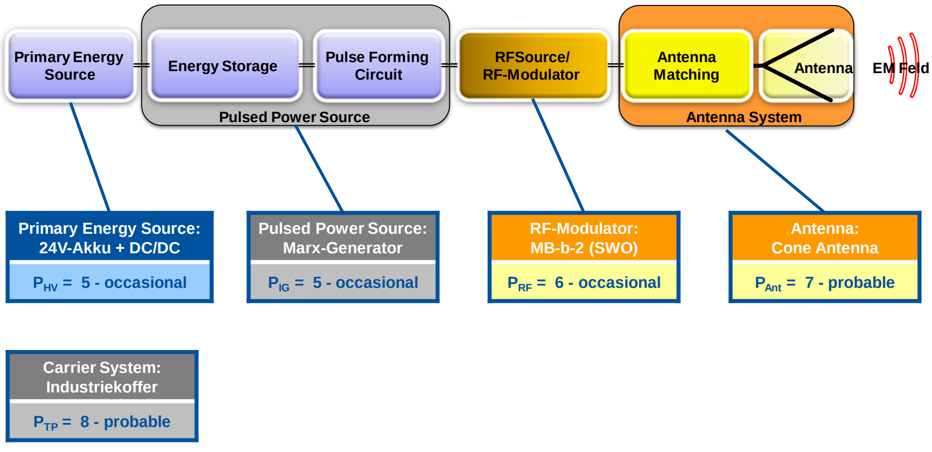
Primary Energy Source: 24V-Akku + DC/DC
P_{HV} = 5 - occasional

Pulsed Power Source: Marx-Generator
P_{IG} = 5 - occasional

RF-Modulator: MB-b-2 (SWO)
P_{RF} = 6 - occasional

Antenna: Cone Antenna
P_{Ant} = 7 - probable

Probability of Occurrence of Modules



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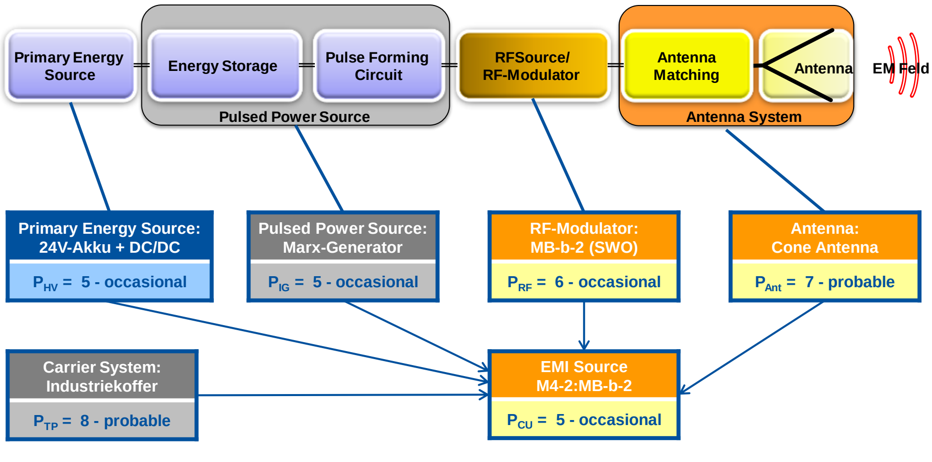
Probability of Occurrence of IEMI Source



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5.3 Modeling of Generic IEMI Scenario

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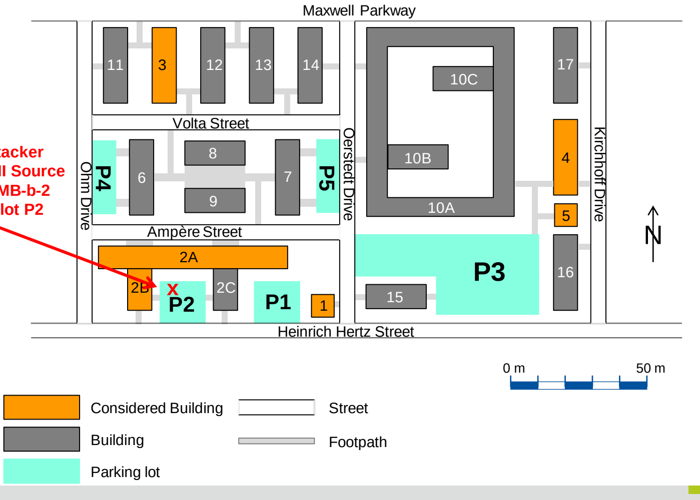
Generic IEMI Scenario

Scenario:
External attacker with an IEMI Source Type M4-2:MB-b-2 on parking lot P2



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Probability of Occurrence of IEMI Scenario

Potential Offender

Access to the **vicinity** of the target system

Protection Concept → P_A

Access to the **IEMI Source**

IEMI Source can be moved to the selected location in vicinity of target system

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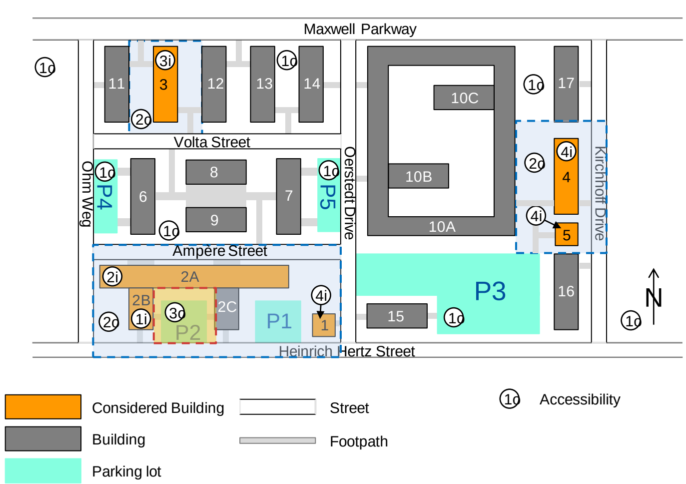
Generic Infrastructure – Accessibility



Generic Infrastructure – Accessibility, Scale

Level (A_z)	Acces-sibility	outside	inside	Definition
1o	free	X		Area of the **general public (outdoors)** accessible to each person without special effort.
1i	free		X	Area of the **general public (indoors)** accessible to each person without special effort.
2o	monitored	X		Area of the general public whose access is or can be **monitored**.
2i	monitored		X	Area in a building whose access is or can be **monitored**.
3o	controlled	X		Outdoor area that can only be entered after an **identity check**
3i	controlled		X	Area in a building that can only be entered after an **identity check**
4o	restricted	X		Outdoor control / restricted area that can only be accessed by **authorized persons** or after a **pocket check**.
4i	restricted		X	Control / restricted area in the building, which can only be entered by **authorized persons** or after a **pocket check**.

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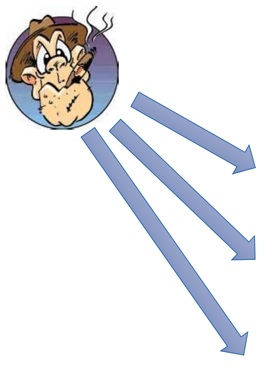
Generic Offender: Access (example)

A_z	Accessibility	Index of Probability (internal offender)		Index of Probability (external offender)	
1o 1i	free / general public	**10**	frequent (> 97%)	**10**	frequent (> 97%)
2o 2i	monitored	**9**	frequent (90 - 97%)	**8**	probable (75 - 90%)
3o 3i	controlled	**7**	probable (50 – 75%)	**6**	occasional (25 – 50%)
4o 4i	restricted	**5**	occasional (12 – 25%)	**3**	remote (2 – 5%)

Probability of Occurrence of IEMI Scenario

Potential Offender



Access to
the **vicinity** of the target system

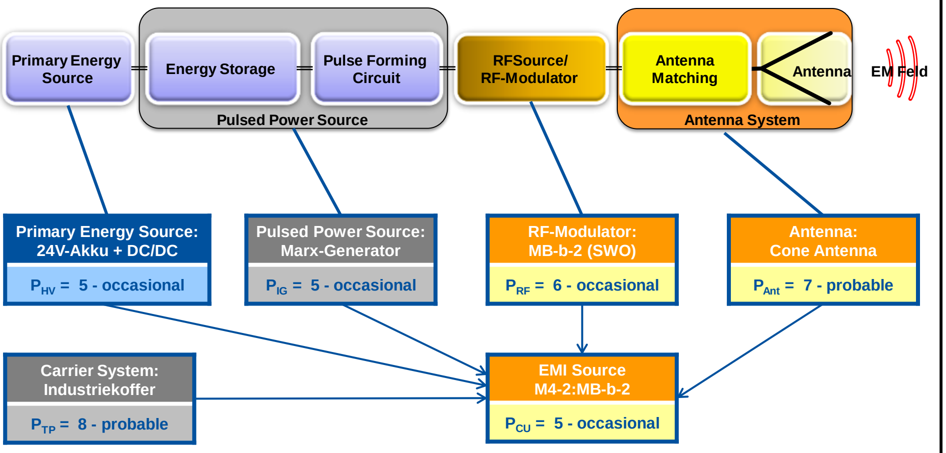
Protection Concept → P_A

Access to
the **IEMI Source**

Technological Challenge → P_{CU}

IEMI Source can be
moved to the selected
location in vincinity of target system

Probability of Occurrence of IEMI Source



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Probability of Occurrence of IEMI Scenario

Potential Offender

Access to the **vicinity** of the target system → Protection Concept → P_A

Access to the **IEMI Source** → Technological Challenge → P_{CU}

IEMI Source can be moved to the selected location in vincinity of target system → Mobility → P_{lo}

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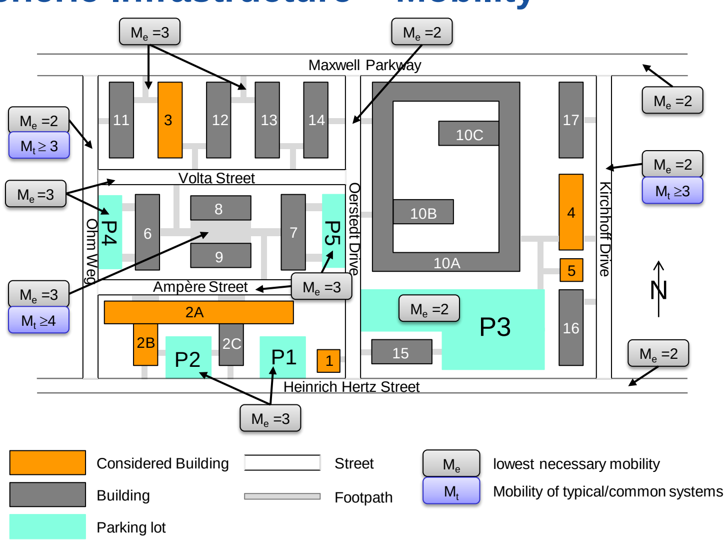
Generic Infrastructure – Mobility



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Generic Infrastructure – Mobility, Scale

Level (M)	Mobility	Volume	Example
1	stationary	> 77m^3	Fixed installation
2	transportable	10 - 77m^3	light truck – 40‘ Container
3	mobil	0,2 – 10 m^3	car / van
4	very mobil	0,02 – 0,2 m^3	briefcase
5	highly mobile	< 0,02 m^3	beverage can

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Likelihood that IEMI Source can be moved to Location

P_{lo}		A_z = 1o (general public)					A_z = 1i (general public)				
		M_{TP}					M_{TP}				
		1	2	3	4	5	1	2	3	4	5
M_e	2	5	8	9	10	10	6	8	9	10	10
	3	3	5	8	9	10	4	6	8	9	10
	4	1	3	5	8	9	2	4	6	8	10
	5	0	1	3	5	8	1	2	4	6	8

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Likelihood that IEMI Source can be moved to Location

P_{lo}		A_z = 2o (monitored) A_z = 3o (controlled)					A_z = 2i (monitored) Az = 3o (controlled)				
		M_{TP}					M_{TP}				
		1	2	3	4	5	1	2	3	4	5
M_t	2	5	8	9	10	10	6	8	9	10	10
	3	3	5	8	9	10	4	6	8	9	10
	4	1	3	5	8	9	2	4	6	8	10
	5	0	1	3	5	8	1	2	4	6	8

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Likelihood that IEMI Source can be moved to Location

P_{lo}		A_z = 4o (restricted)					A_z = 4i (restricted)				
		M_{TP}					M_{TP}				
		1	2	3	4	5	1	2	3	4	5
M_t	2	3	7	7	9	10	4	7	8	9	10
	3	2	4	7	8	9	3	5	7	8	9
	4	0	2	4	7	8	1	3	5	7	8
	5	0	1	2	4	7	0-1	1	3	5	7

Probability of Occurrence of IEMI Scenario

Potential Offender

Access to the **vicinity** of the target system → Protection Concept → P_A

Access to the **IEMI Source** → Technological Challenge → P_{CU}

IEMI Source can be moved to the selected location in vincinity of target system → Mobility → P_{lo}

P_{lo} → P_{CU} → P_A → P_{EMI}

Summary IEMI Szenario

- EMI scenarios include technical and non-technical (e.g. human) aspects
- Assessment of the environment of the target system in terms of accessibility and mobility
- Generic IEMI Source Types
- Estimation of the probability of an EMI scenario occurring
  - Comparison with properties of the generic attacker
  - Comparison mobility

5.4 Scenario Interaction Model

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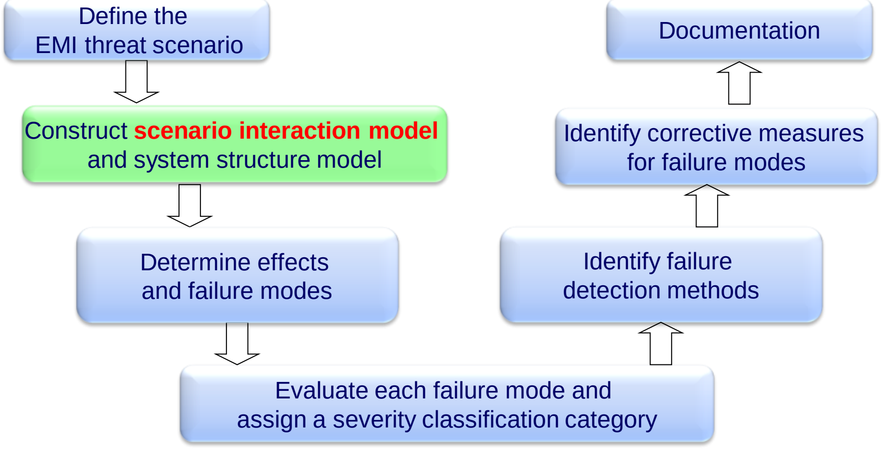
TSECA - Process



Source: F. Sabath and H. Garbe, "Concept of stochastic modeling for High-Power Electromagnetics (HPEM) risk analysis at system level," 2013 IEEE International Symposium on Electromagnetic Compatibility, Denver, CO, 2013, pp. 401-406, doi: 10.1109/ISEMC.2013.6670446

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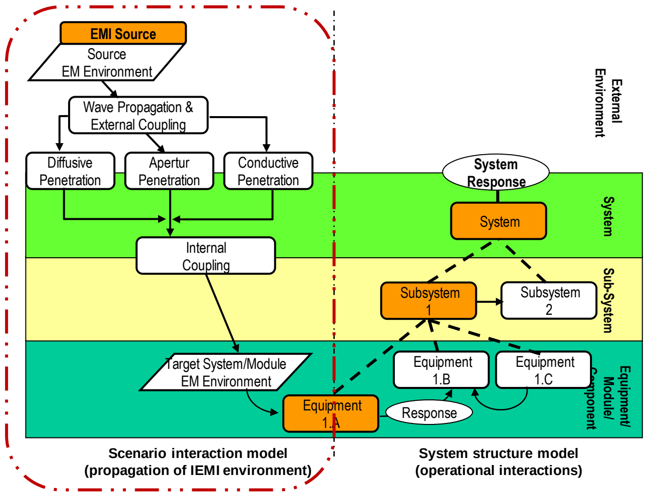
Interaction Model – Interaction Sequence Diagram



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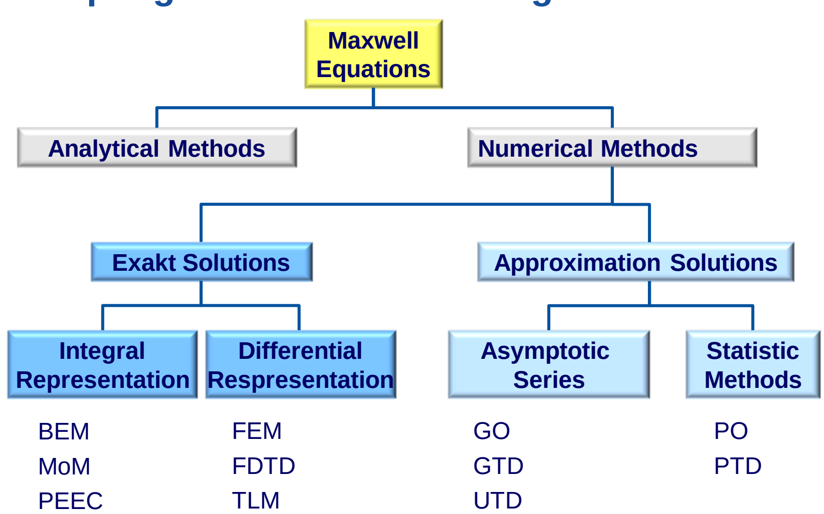
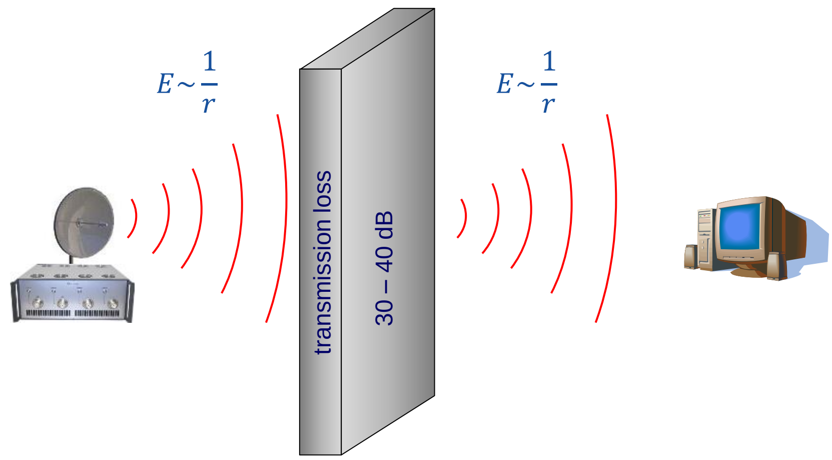
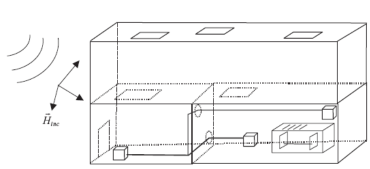
EM Coupling: Numerical Modeling

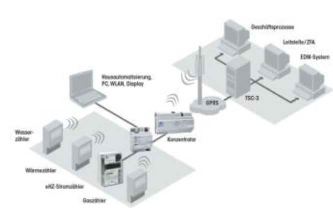


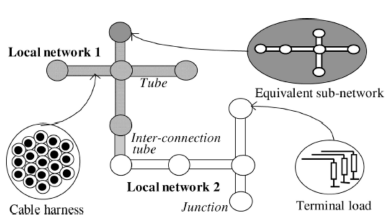
EM Wave Propagation: Approximation



Topologic Concept

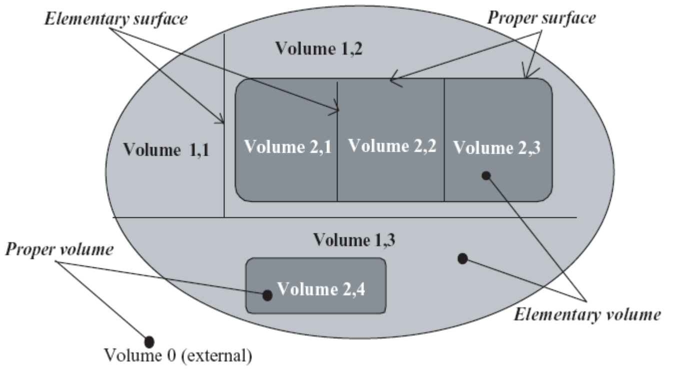






Source: J.-P. Parmantier and I. Junqua I. (2007) EM Topology: From Theory to Application. In: Sabath F., Mokole E.L., Schenk U., Nitsch D. (eds) Ultra-Wideband, Short-Pulse Electromagnetics 7. Springer, New York, NY. https://doi.org/10.1007/978-0-387-37731-5_1.

Topologic Concept - Approach



Source: J.-P. Parmantier and I. Junqua I. (2007) EM Topology: From Theory to Application. In: Sabath F., Mokole E.L., Schenk U., Nitsch D. (eds) Ultra-Wideband, Short-Pulse Electromagnetics 7. Springer, New York, NY. https://doi.org/10.1007/978-0-387-37731-5_1.

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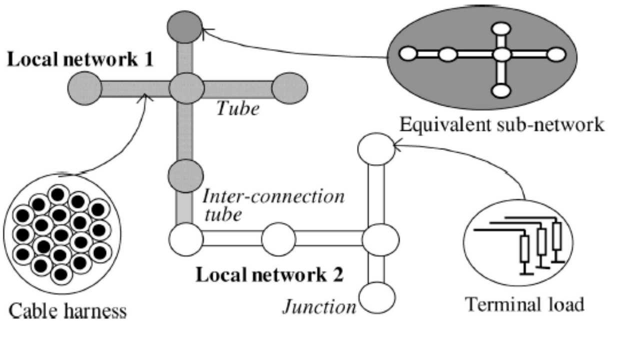
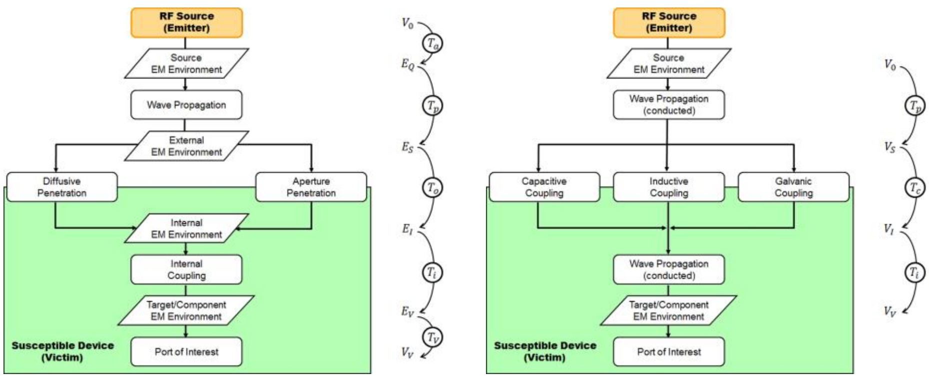
Topologic Concept – Network Representation



Source: J.-P. Parmantier and I. Junqua I. (2007) EM Topology: From Theory to Application. In: Sabath F., Mokole E.L., Schenk U., Nitsch D. (eds) Ultra-Wideband, Short-Pulse Electromagnetics 7. Springer, New York, NY. https://doi.org/10.1007/978-0-387-37731-5_1.

Transfer Functions



Source: D.V. Giri; Richard Hoad; Frank Sabath, High-Power Electromagnetic Effects on Electronic Systems, Chapter 3 HPEM Coupling and Interaction, Artech, 2020.

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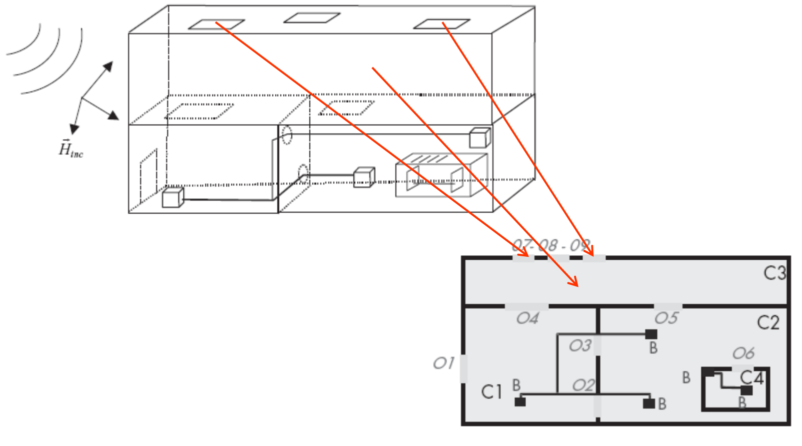
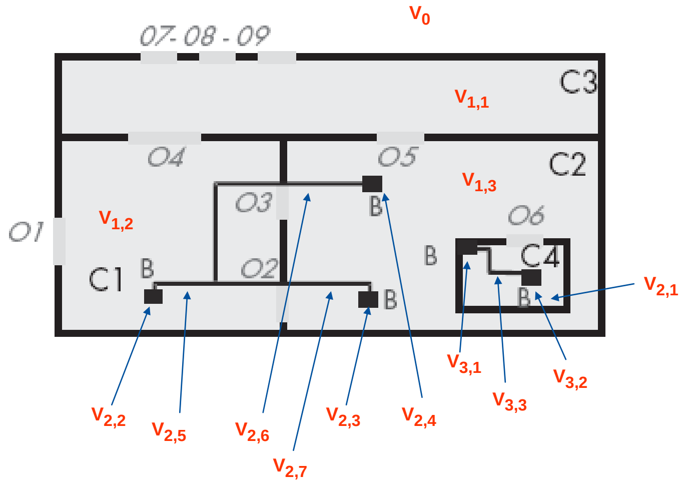
Topologic Concept: Example



Source: J.-P. Parmantier and I. Junqua I. (2007) EM Topology: From Theory to Application. In: Sabath F., Mokole E.L., Schenk U., Nitsch D. (eds) Ultra-Wideband, Short-Pulse Electromagnetics 7. Springer, New York, NY. https://doi.org/10.1007/978-0-387-37731-5_1.

Topologic Concept: Example



Source: J.-P. Parmantier and I. Junqua I. (2007) EM Topology: From Theory to Application. In: Sabath F., Mokole E.L., Schenk U., Nitsch D. (eds) Ultra-Wideband, Short-Pulse Electromagnetics 7. Springer, New York, NY. https://doi.org/10.1007/978-0-387-37731-5_1.

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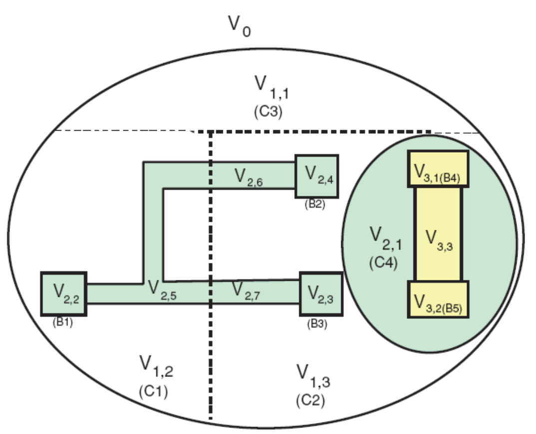

Source: J.-P. Parmantier and I. Junqua I. (2007) EM Topology: From Theory to Application. In: Sabath F., Mokole E.L., Schenk U., Nitsch D. (eds) Ultra-Wideband, Short-Pulse Electromagnetics 7. Springer, New York, NY. https://doi.org/10.1007/978-0-387-37731-5_1.

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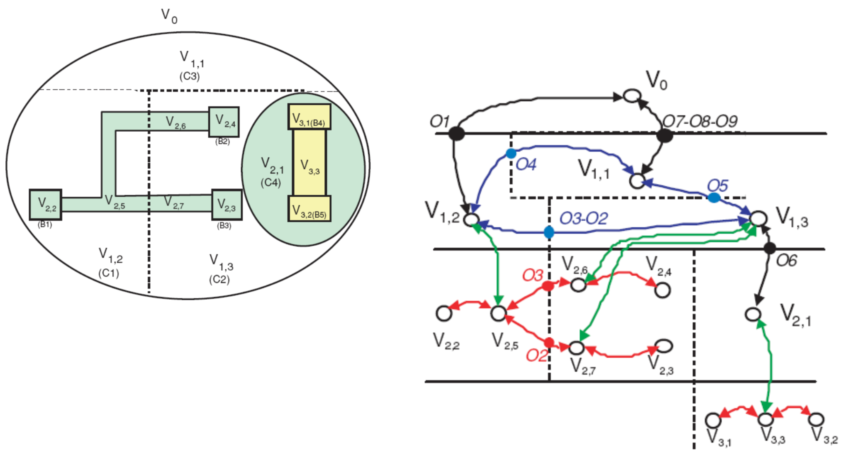

Source: J.-P. Parmantier and I. Junqua I. (2007) EM Topology: From Theory to Application. In: Sabath F., Mokole E.L., Schenk U., Nitsch D. (eds) Ultra-Wideband, Short-Pulse Electromagnetics 7. Springer, New York, NY. https://doi.org/10.1007/978-0-387-37731-5_1.

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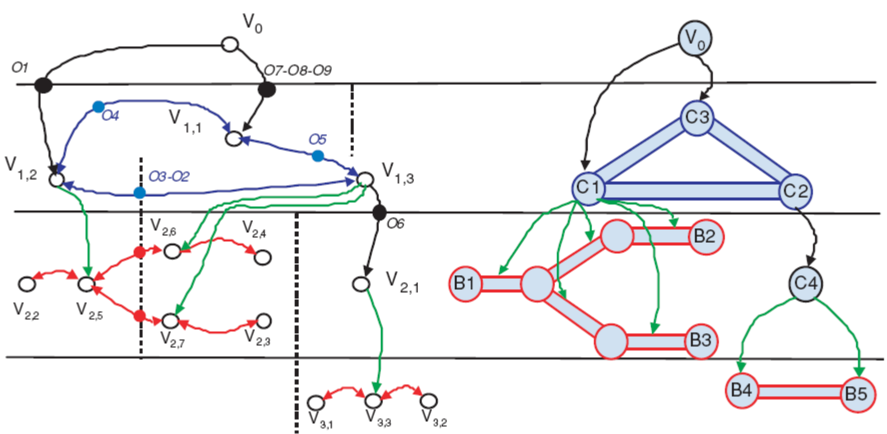
Topologic Concept: Example



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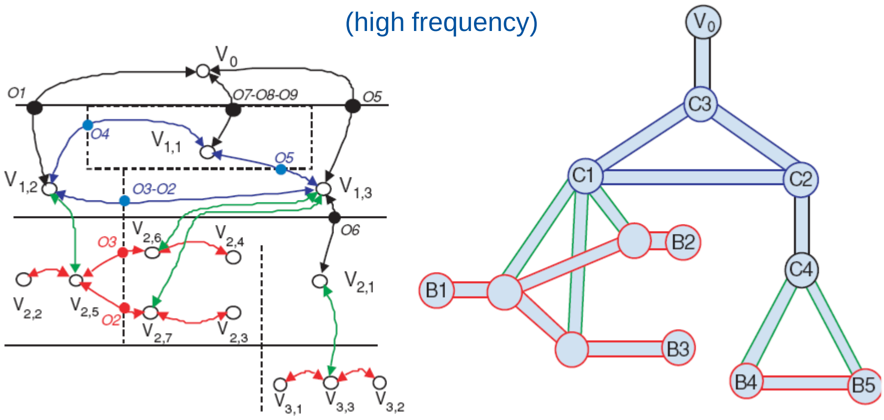
Topologic Concept: Example

(high frequency)



Source: J.-P. Parmantier and I. Junqua I. (2007) EM Topology: From Theory to Application. In: Sabath F., Mokole E.L., Schenk U., Nitsch D. (eds) Ultra-Wideband, Short-Pulse Electromagnetics 7. Springer, New York, NY. https://doi.org/10.1007/978-0-387-37731-5_1.

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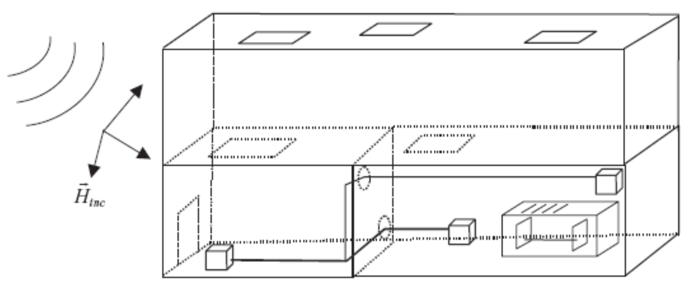
Modeling of Buildings (Difusive Penetration)



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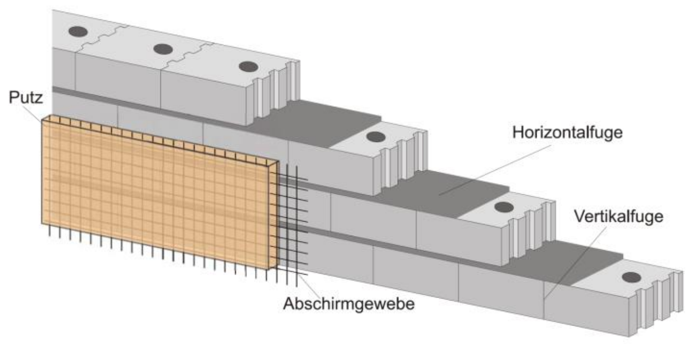
Modeling of Buildings (Difusive Penetration)



Source: Frenzel, T., J. Rohde und J. Opfer: Elektromagnetische Schirmung von Gebäuden – Praktische Messungen, Band BSI-TR-03209-2. Bundesamt für Sicherheit in der Informationstechnik, 2008.

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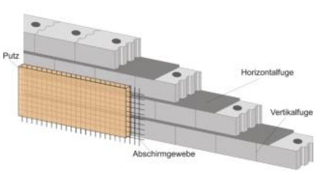
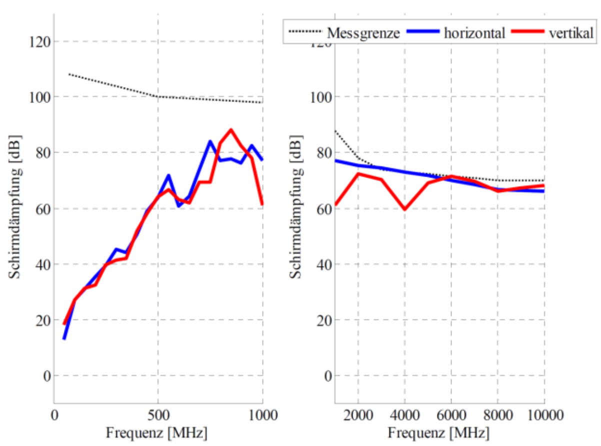
Modeling of Buildings (Difusive Penetration)





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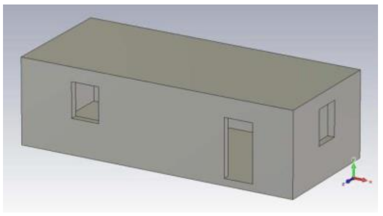
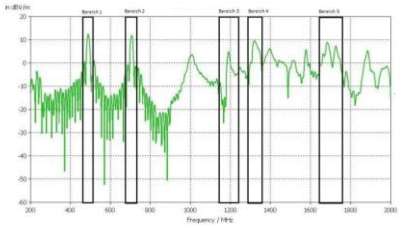
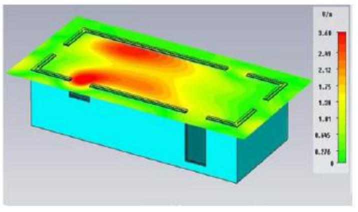
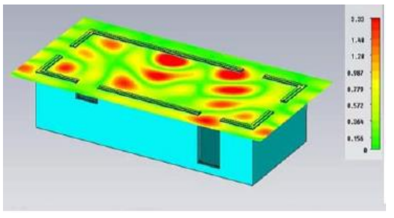
Numeric analysis of external coupling









Source: R. Rambousky, A. Bausen, S. Lange and F. Sabath, "IEMI-testing of electronic systems in critical infrastructure surrounding," 2015 IEEE International Symposium on Electromagnetic Compatibility (EMC), Dresden, 2015, pp. 1057-1062. doi: 10.1109/ISEMC.2015.7256314.

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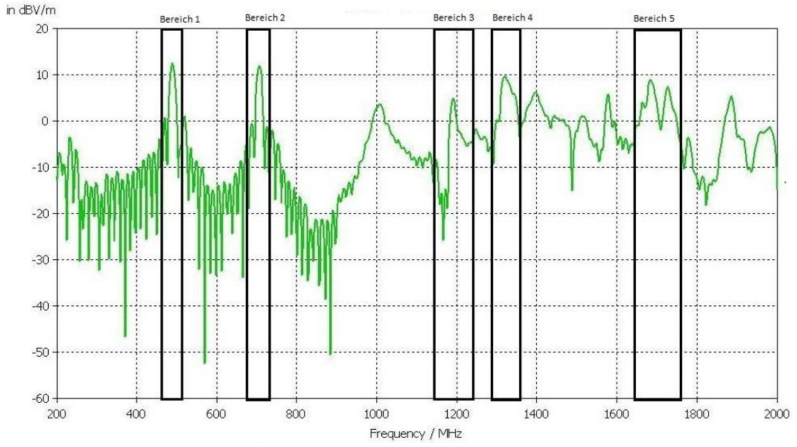
Numeric analysis of external coupling



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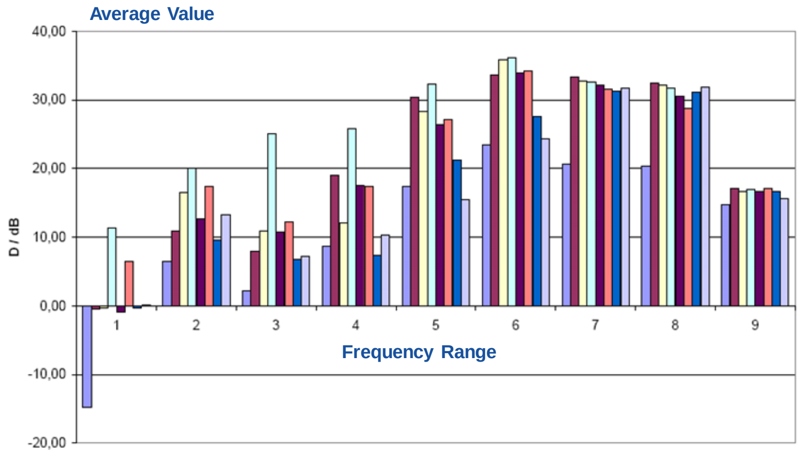
Impact of system casing



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Screening Attenuation (general tendency)

Screening Attenuation	Description
0 - 10 dB	Very low shielding No shielding against disturbances
10 – 30 dB	Low shielding Slight disturbances can be eliminated
30 – 60 dB	Average shielding in the RF range High shield damping against magnetic fields in the LF range
60 – 90 dB	Very good shielding for medium to large EMC problems
90 – 150 dB	Generally the maximum, possible with extremely good shielding designs
150 dB	Detection threshold of current technology

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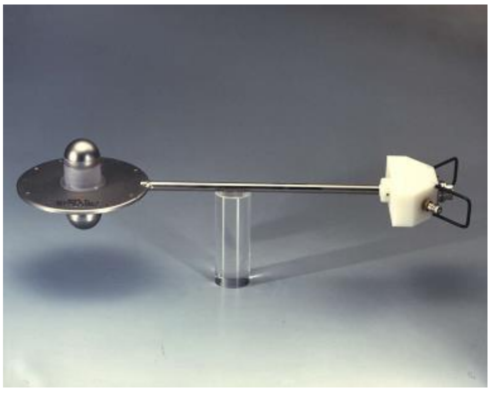
Thank You for Your Attention.

Questions ?



Chapter 6

Effects and Error States

EMI Risk Management

6. Effects and Error States

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Content

✓ 1. Introduction & Basic Terms
✓ 2. Fundamentals of Risk Management
✓ 3. Risk Analysis Methods
✓ 4. EMI Scenario
✓ 5. Modeling of scenarios and systems
⇒ 6. Effects and Error States
7. Risk Evaluation
8. Risk Treatment and Protection
9. Examples
10. Summary

6.1 Introduction

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Effects and Error States

Note the

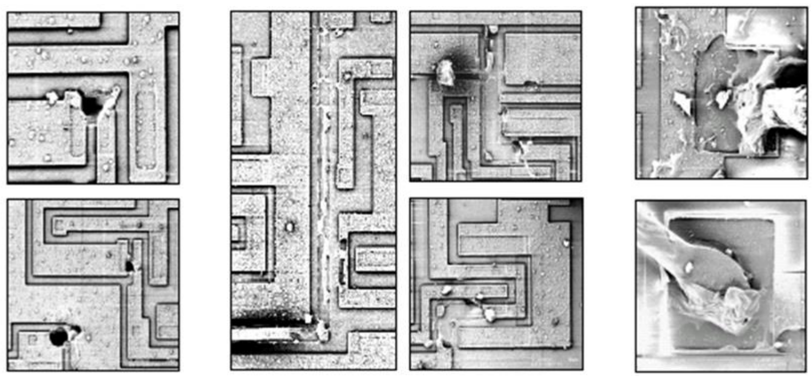
effects and consequences

you observe

on the following slides

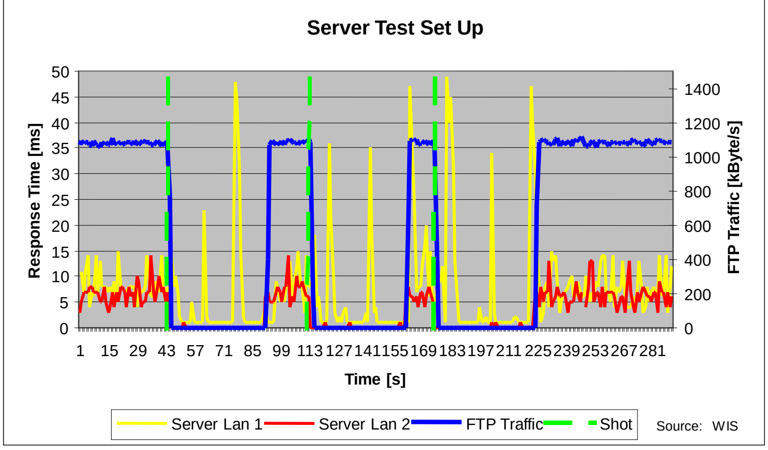
Component and circuit level effects

Component destruction | Trace melting | Debonding



Source: M. Camp. Empfindlichkeit elektronischer Schaltungen gegen transiente elektromagnetische Feldimpuls. Shaker Verlag, Aachen, 2004.

ICT Network Effects



Source: WIS

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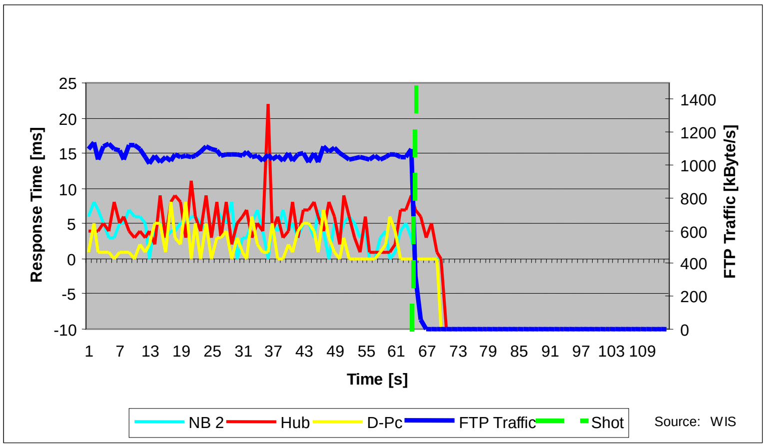
ICT Network Effects



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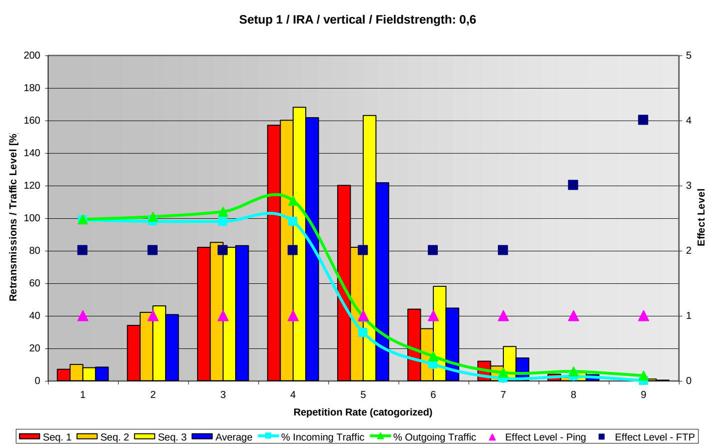
ICT Network Effects



Source: WIS

System level Consequences

Source: BBC

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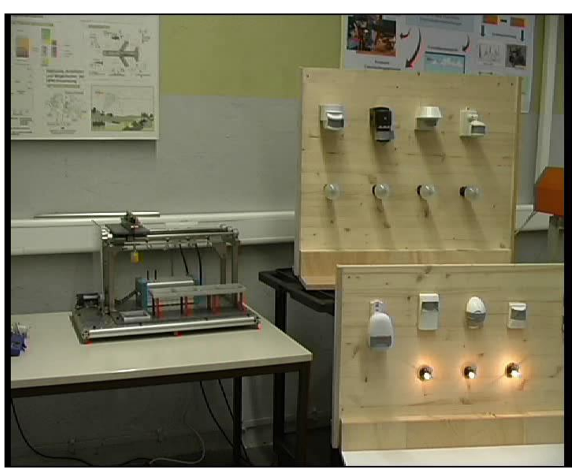
System level Consequences



Source: Diehl

6.2 Effects and Error States

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Effects and Error States

Which

effects and consequences

did you observe?

Effects and Error States

- Flickering screens/distorted display
- Black screen
- Displaying incorrect data
- Responding to sensors
- Decrease in computing power/throughput
- Hang/crash programs
- Falsification of data
- Reboot/Reboot Computers & Controllers
- Failure/destruction

Effects and Error States

How can these effects be compared?

⇒ Categorization

⇒ by Mechanism
- How is the effect caused?
- Where does the effect occur?

⇒ by Duration
- How long (compared to exposure) can the effects be observed?

⇒ by Criticality
- What does the effect mean for the function of the system?

6.3 Effects Mechanisms

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HPEM Effects Mechanisms

Interference

- Noise
- Rectification
- Interference
- Saturation
- Shift of operation point
- False information
- Transient upset
- Chaotic behavior

Destruction

- Latch-Up; Punch-through
- Flashover
- Wire melting and debonding
- Thermal destruction

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Noise

EM environments can add additional noise to a signal line or a receiver.

- the receiver might be able to correctly detect bits so that bit errors can be restored.
- additional noise reduces the signal-to-noise ratio (SNR)
- might therefore decrease the usable data rate.
- Analog circuits are more sensitive to signal noise.
- An induced noise signal on signal or power lines of analog circuits might cause noisy displays or flashing of displays.

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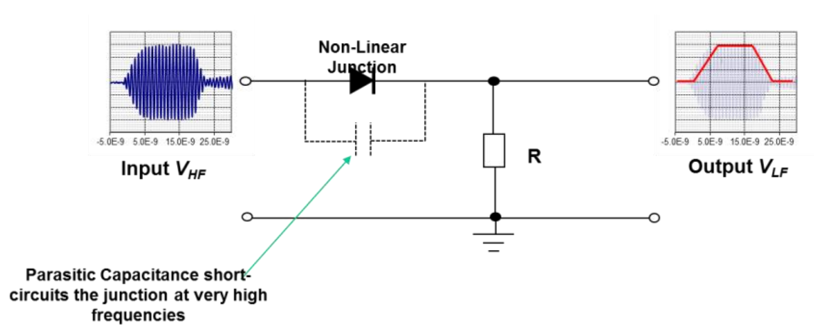
Rectification



Rectification at a non-linear component

- converts an alternating current (AC) into a direct current (DC).
- can also lead to the creation of intermodulation or harmonics.

Source: D. Giri, R. Hoad and F. Sabath; High-Power Electromagnetic Effects on Electronic Systems, Artech House, 2020, ISBN 978-1-63081-588-2, p 149

Interference/Jamming

- Interference or jamming occurs if the interfered signal causes a noise background that **masks the wanted signal** by some, usually small, margin.
- A jamming or interference signal only needs to be a few dB more than the wanted signal and the wanted signal may be very small

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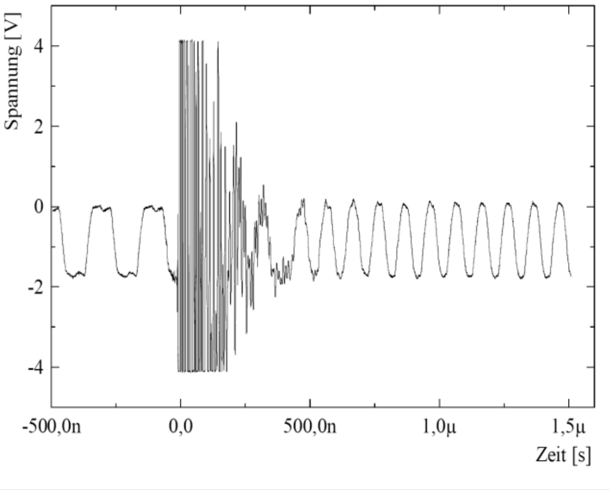
Saturation

- Saturation implies that the receiver components (LNA) goes into compression and results in non-linearity and hence desensitises the receiver and may cause production of spurious modulation and intermodulation products.
- The saturation effect may persist for a short time after the interfering signal is removed.
- This type of effect mechanism can also occur in back-door coupling particularly in analogue circuit components with feedback such as Op-amps.

Shift of operation point

- The behavior of digital and most analogue electronic circuits and components are characterized by non-linear junctions.
- Interference in the power distribution system of electronic components and circuits are capable of causing a change of the potential at the electronic component and respectively into a shift of the operating point of the component.
- A shift of the operating point of a digital-to-analogue converter results in **wrong data**. Other effects are **compression** of analogue data and **DC-offset** of data.

Shift of operation point



Source: WIS

False information

- interference signal may feed **false information** to the data stream or alternate information bits of the data stream.
- The intentional creation of such a situation is known as **spoofing**.
- Consequences can be critical, as the exposed system operates on corrupted or false information.
- During HPEM tests the corruption of data streams resulted in a malfunction of the system or component up to a hang-up or crashing of software and break down of the system under test.

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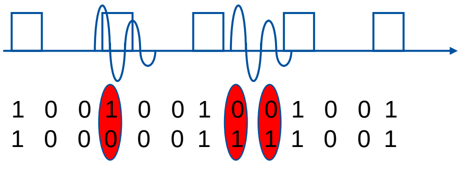
Transient upset

The input interference voltages cause logic input gates

- to detect a supposed signal change or
- not to detect a signal change.



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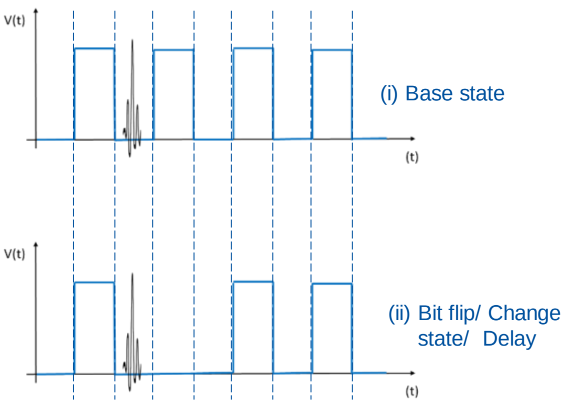
Transient upset



Source: D. Giri, R. Hoad and F. Sabath; High-Power Electromagnetic Effects on Electronic Systems, Artech House, 2020, ISBN 978-1-63081-588-2, p 153

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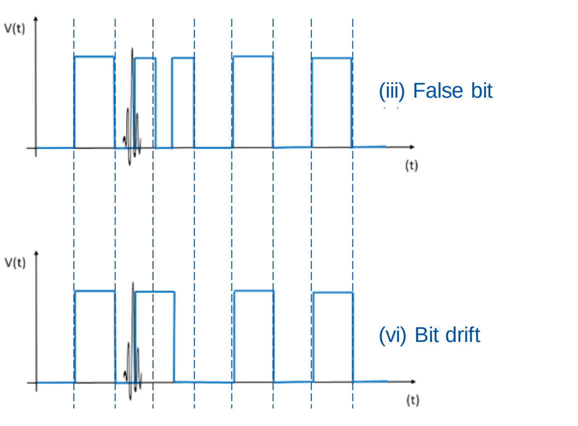
Transient upset



Source: D. Giri, R. Hoad and F. Sabath; High-Power Electromagnetic Effects on Electronic Systems, Artech House, 2020, ISBN 978-1-63081-588-2, p 153

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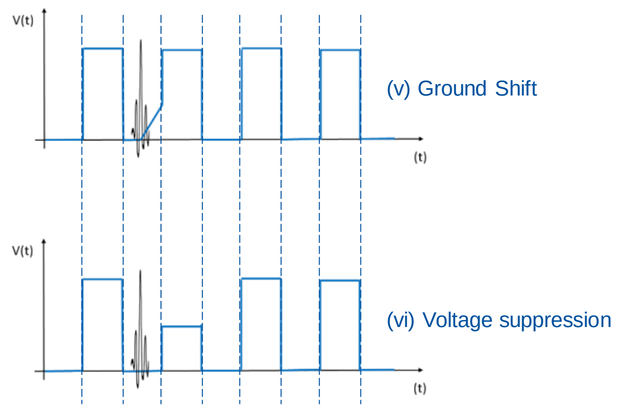
Transient upset



Source: D. Giri, R. Hoad and F. Sabath; High-Power Electromagnetic Effects on Electronic Systems, Artech House, 2020, ISBN 978-1-63081-588-2, p 153

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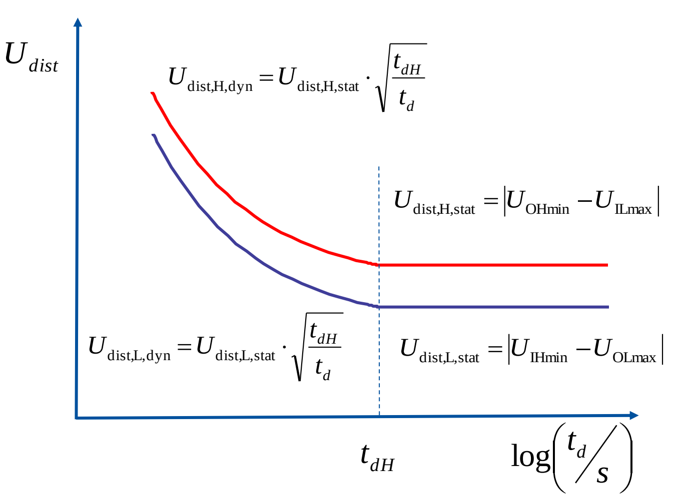
Transient upset



Chaotic behavior

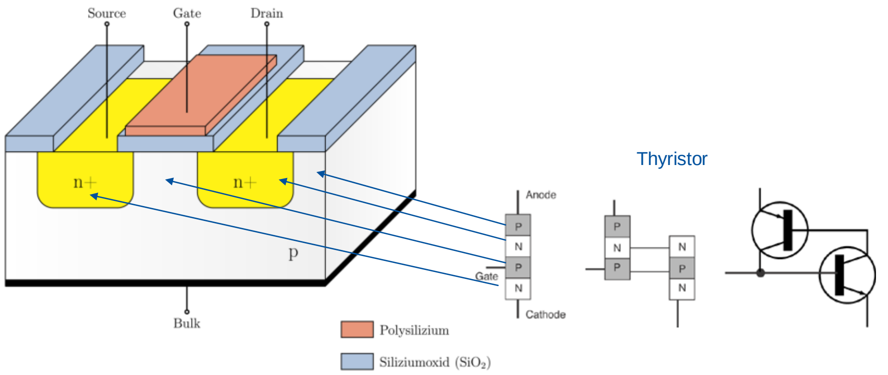
- It has been shown that circuits which incorporate **feedback** to regulate their linear behavior such as **Phase Locked Loops** (PLLs) can be nudged into a chaotic or random state through HPEM exposure.
- Nonlinear systems such as PLLs can exhibit a wide variety of complex behavior including subharmonic, quasiperiodic and chaotic dynamics.

Latch-Up

The term **latch-up** refers to a malfunction at the inputs of a CMOS stage, triggered by a short voltage peak.

The **latch-up** effect is caused by parasitic thyristors which necessarily result from the layer structure of the individual dopings of n-channel and p-channel FETs in a common substrate (bulk) in the semiconductor module. Ignition of these parasitic thyristors results in a direct short circuit of the supply voltage on the CMOS component, which almost always leads to destruction of the component due to thermal overload. Modern CMOS circuits have special geometric arrangements of the doping regions of the n and p FETs for suppressing this interference effect at the inputs.

Latch-Up



Punch-through

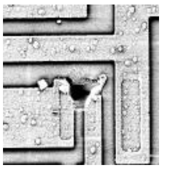
Punch-through in a MOSFET is an extreme case of channel length modulation where the depletion layers around the drain and source regions merge into a single depletion region.

The field underneath the gate then becomes strongly dependent on the drain-source voltage, as is the drain current.

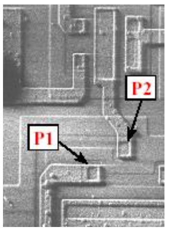
Punch through causes a rapidly increasing current with increasing drain-source voltage. This effect is undesirable as it increases the output conductance and limits the maximum operating voltage of the device.

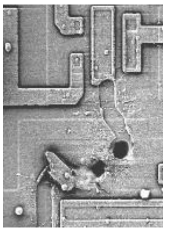
Flashover

- High potential differences lead to flashover between conductive parts such as
  - –GND and VCC layers/elements
  - –Signal roads



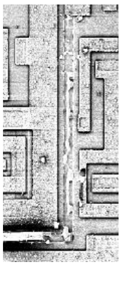
- The high current flowing during the flashover often leads to thermal destruction of components



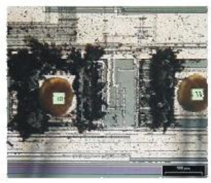


Wire melting and debonding

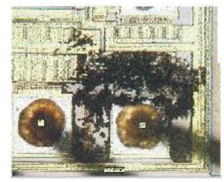
High currents on signal lines (on chip) as well as on bonding lines can lead to thermal melting of signal lines.



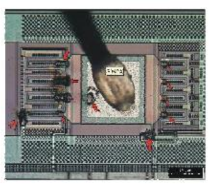
Thermal destruction



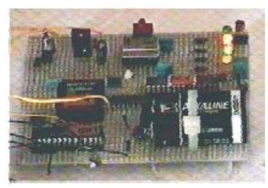
PLD

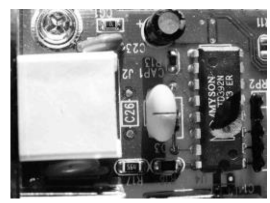


SRAM



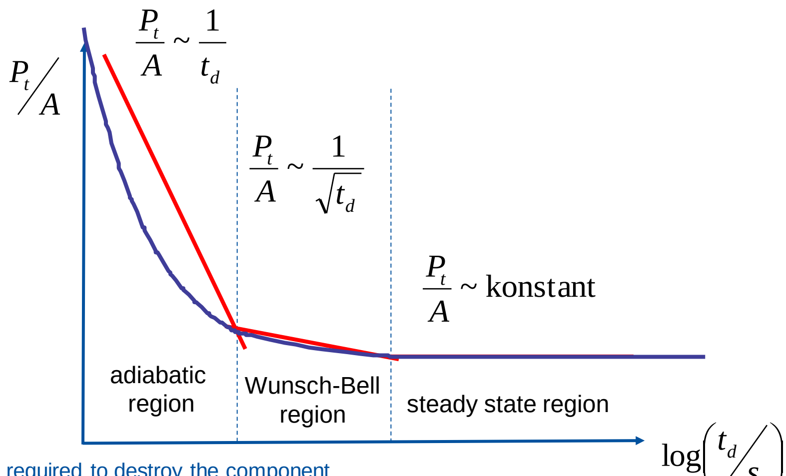
Microcontroller





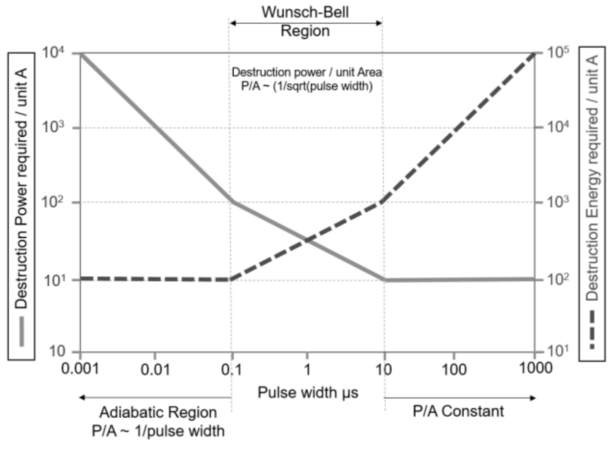
PIC

Thermal destruction



P_t – power required to destroy the component
A - area of the heated region

Thermal destruction



Source: D. Giri, R. Hoad and F. Sabath; High-Power Electromagnetic Effects on Electronic Systems, Artech House, 2020, ISBN 978-1-63081-588-2, p 190

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6.4 Published circuit and component level effects data

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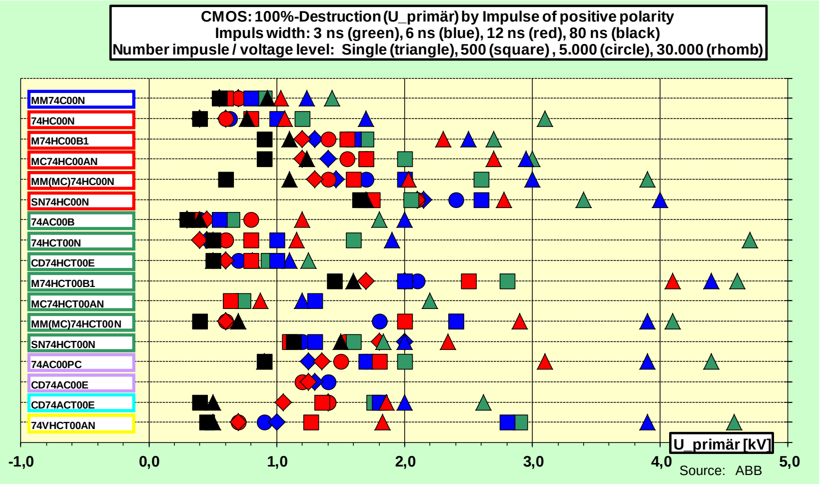

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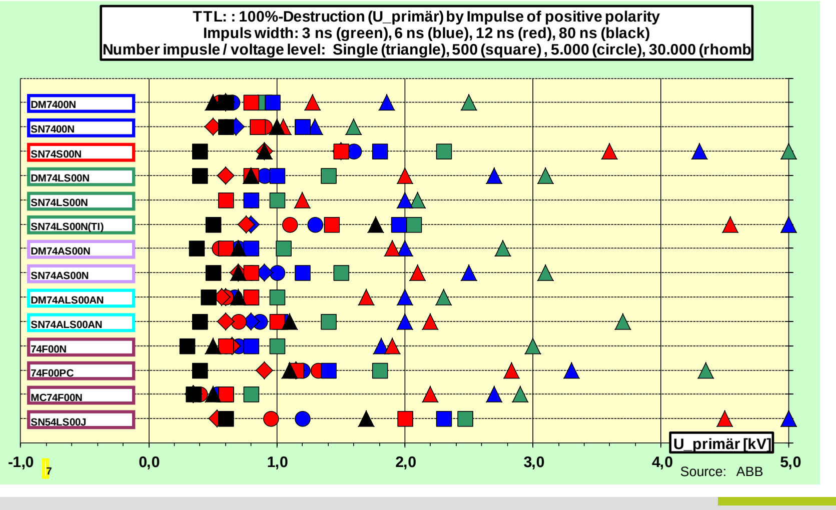

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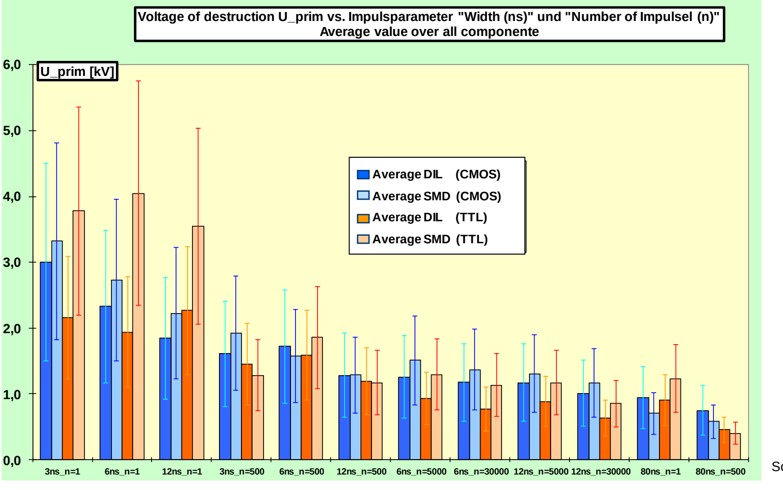

Source: ABB

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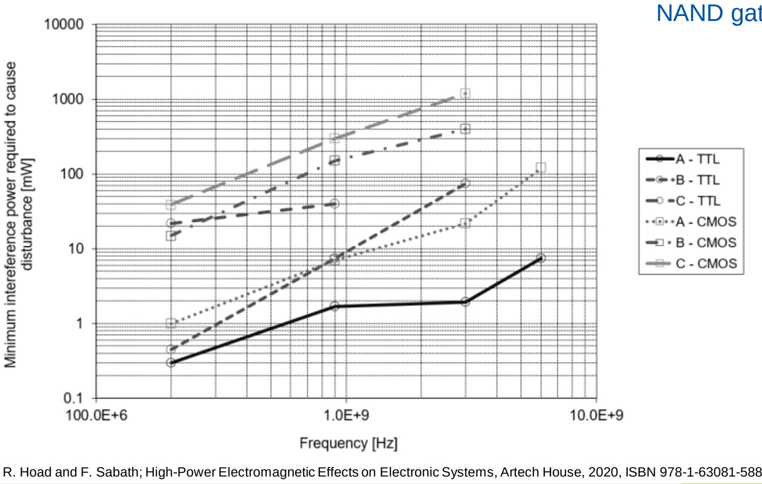
NAND gate



Source: D. Giri, R. Hoad and F. Sabath; High-Power Electromagnetic Effects on Electronic Systems, Artech House, 2020, ISBN 978-1-63081-588-2, p 157

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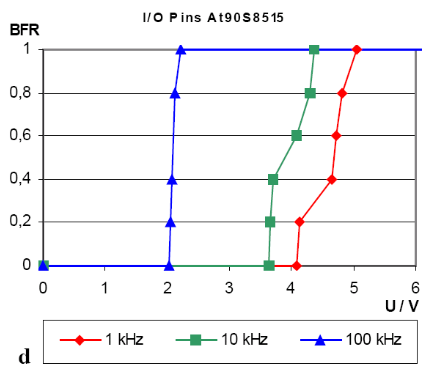
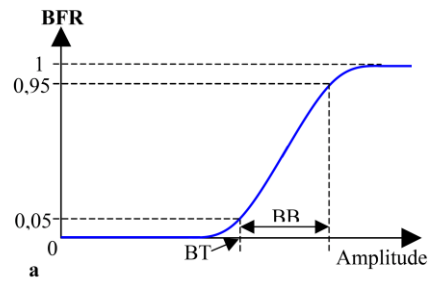
Microprocessor





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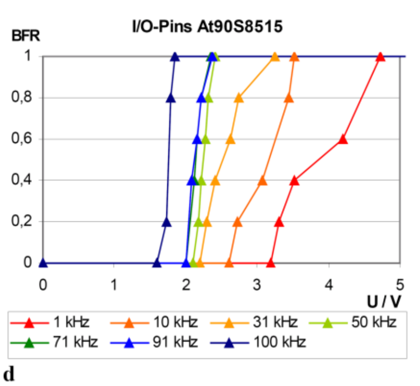
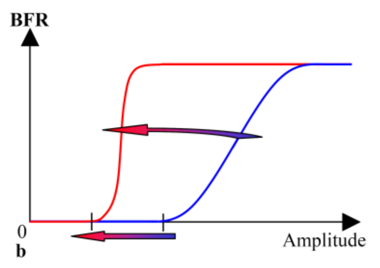
Microprocessor





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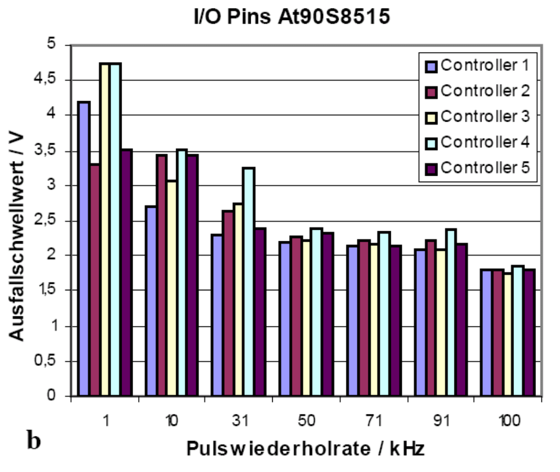
Microprocessor



6.5 System and Network Level Effects

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System and Network Level Effects

Interference

- Loss of data
- Reset (where the computer re-started automatically)
- Network Upset
- Disk Write error (reported by the operating system)
- Loss of hard disk access (reported by the operating system, power down required)
- Power down (computer shuts down)

Destruction

- Damaged components

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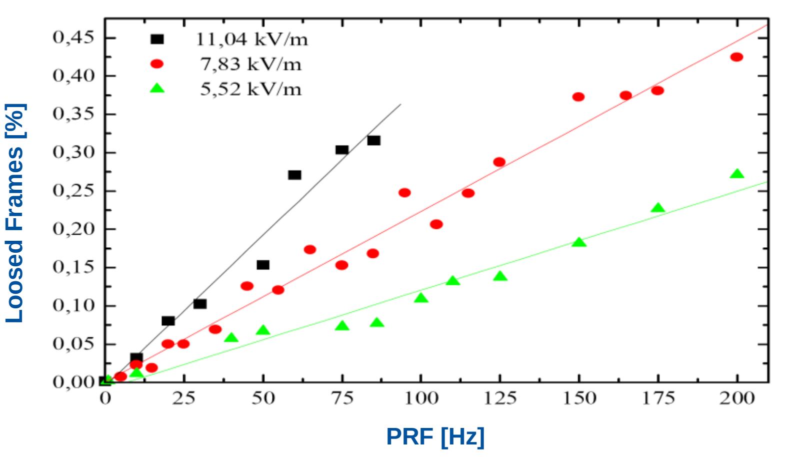
Loss of Data



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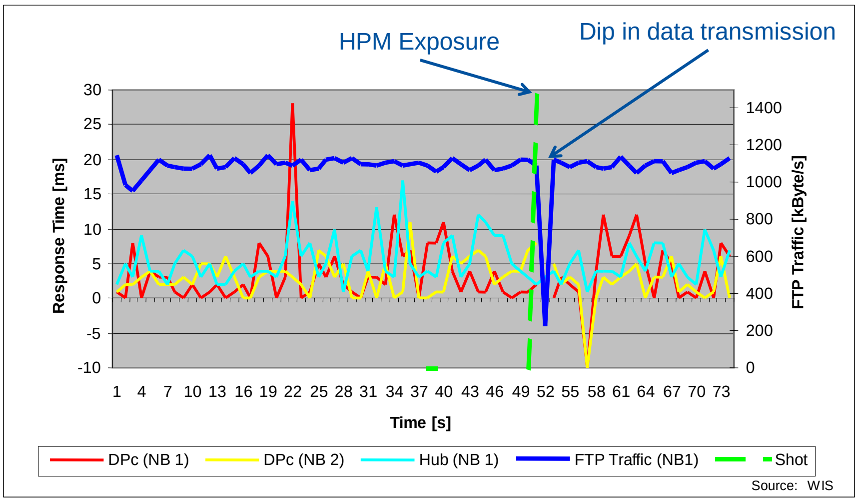
ICT Network, Data Transmission Rate



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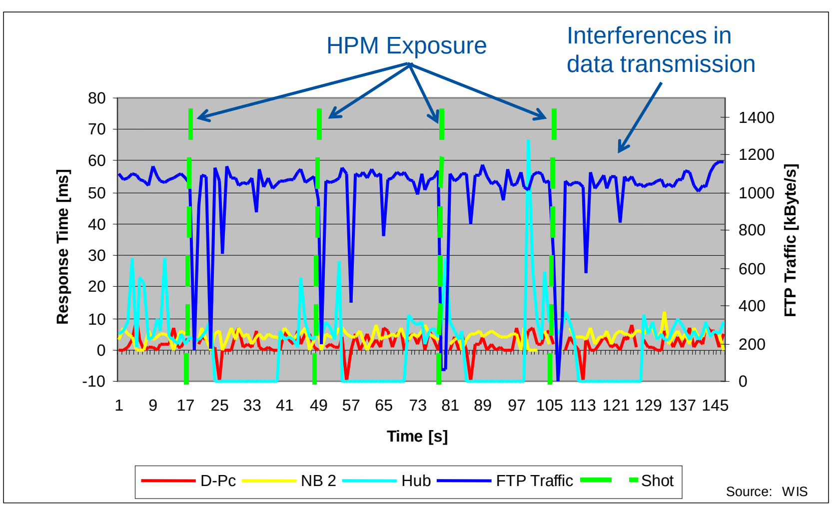
ICT Network, Data Transmission Rate



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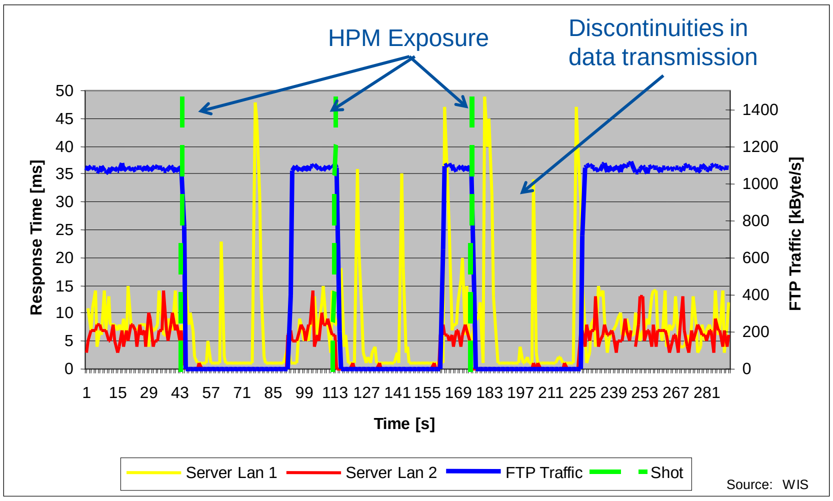
ICT Network, Discontinuities in Data Transmission



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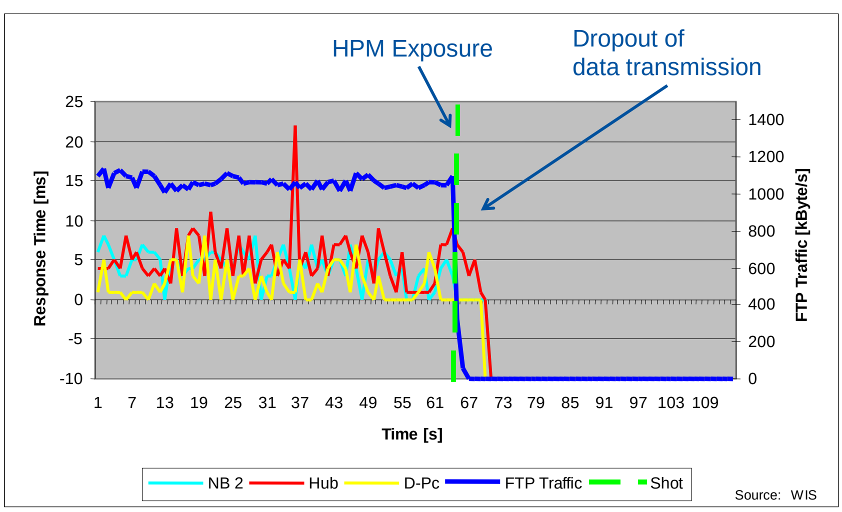
ICT Network, Dropout of Data Transmission



6.6 Classification of Effects

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Classification by Mechanism (I)

Category		Effekt	Description
	U	unknown	Unable to determine due to effects on another component or not observed.
	N	no effect	No effect occurs.
Interference	I.1	noise	Raised noise level on system signal and power lines, which results in flashing of displays or reduced data rates.
	I.2	bit flip	HPEM exposure causes corruption of bits in a data stream.
	I.3	failure	Malfunction of the system / component due HPEM exposure.
	I.4	break down	Hang-up or crashing of software.

Source: F. Sabath; Classification of Electromagnetic Effects at System Level", Ultra-Wideband, Short Pulse Electromagnetics 9, Springer Science + Business Media, pp. 325- 334, 2010, ISBN 978-0-387-77844-0

Classification by Mechanism (II)

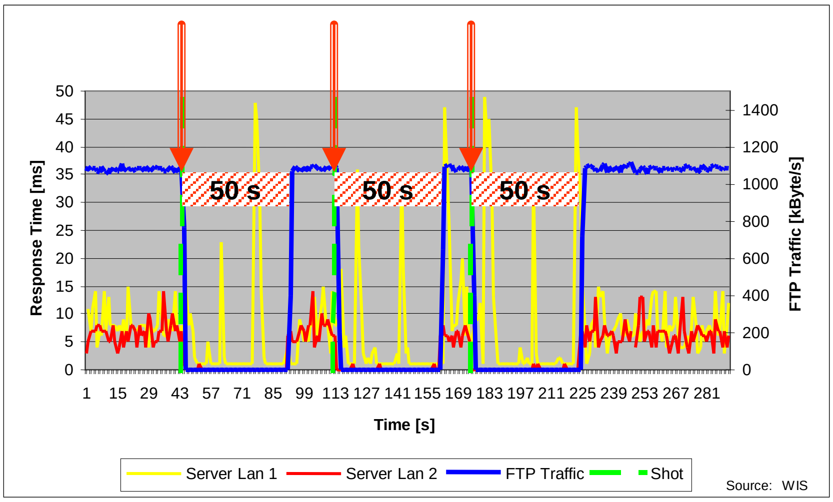
Category		Effekt	Description
Destruction	D.1	latch up	HPEM exposure causes latch up in semiconductor components.
	D.2	flashover	On chip flashover / flashover in components.
	D.3	on chip wire melting	Wires on chip are melted by coupling of HPEM energy.
	D.4	bond wire destruction / wire melting on PCB	Wires on PCB and/or bond wires in semiconductor devices are melted by coupling of HPEM energy.

Source: F. Sabath; Classification of Electromagnetic Effects at System Level", Ultra-Wideband, Short Pulse Electromagnetics 9, Springer Science + Business Media, pp. 325- 334, 2010, ISBN 978-0-387-77844-0

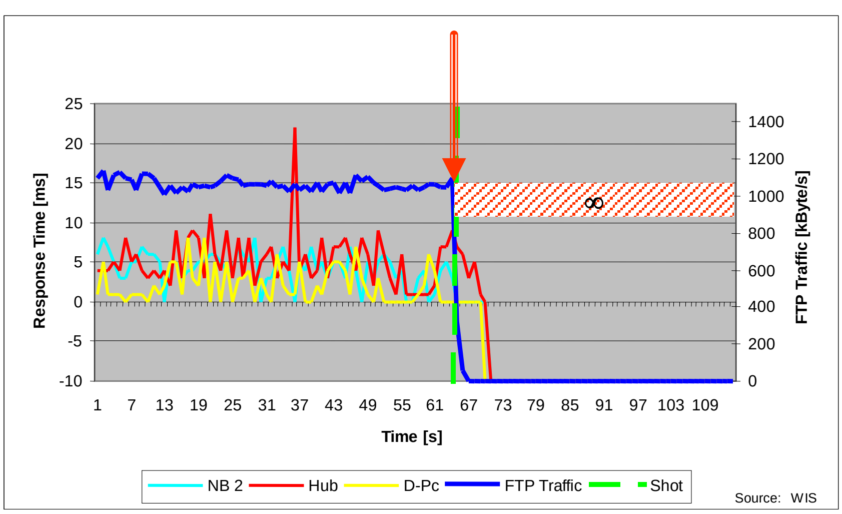
Classification by Duration

Level	Duration	Description
U	<u>u</u>nknown	No effect occurs or the duration of an effect has not been observed. (e.g. observer was unable to determine the duration due to effects on another component).
N	<u>n</u>o effect	No effect occurs.
E	during <u>e</u>xposure only	Observed effect is present only during exposure to HPEM environment; system functionallity is completely available after HPEM exposure is over .
T	some (follow-up) <u>t</u>ime after exposure	Effect is present some time after HPEM exposure is over, but the system recovers without human intervention. Follow-up time is shorter or equal to typical reaction/operation cycle of the system.
H	resistant until <u>h</u>uman intervention	Effect is present untill human intervention (e.g. reset, restart of function). Due to the effect the system is not able to recover to normal operation within an acceptable period (e.g. typical reaction/operation cycle of the system). No replacement of hardware or reload of software is necessary.
P	<u>p</u>ermanent or until replacement of HW / SW	Effect is permanent; usual interactions of an operator or user does not recover normal operation. Effect has damaged hardware to the point that is must be replaced or software to the point that it must be reloaded.

Example: T-Effekt



Example: H/P-Effekt



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Classification by Criticality

Level	Criticality	Severity	Description
U	unknown		Unable to determine due to effects on another component or not observed.
N	no effect	undisturbed	No effect occurs or the system can fulfill his mission without disturbances.
I	interference	limited	The appearing disturbance does not influence the main mission.
II	degradation	severe	The appearing disturbance reduces the efficiency and capability of the system.
III	loss of main function (mission kill)	Very severe	The appearing disturbance prevents that the system is able to fulfill its main function or mission.
IV	Loss of system	catastropically	The occurring effects and error states result in loss or physical destruction of the system component under consideration.

Source: F. Sabath; Classification of Electromagnetic Effects at System Level", Ultra-Wideband, Short Pulse Electromagnetics 9, Springer Science + Business Media, pp. 325- 334, 2010, ISBN 978-0-387-77844-0

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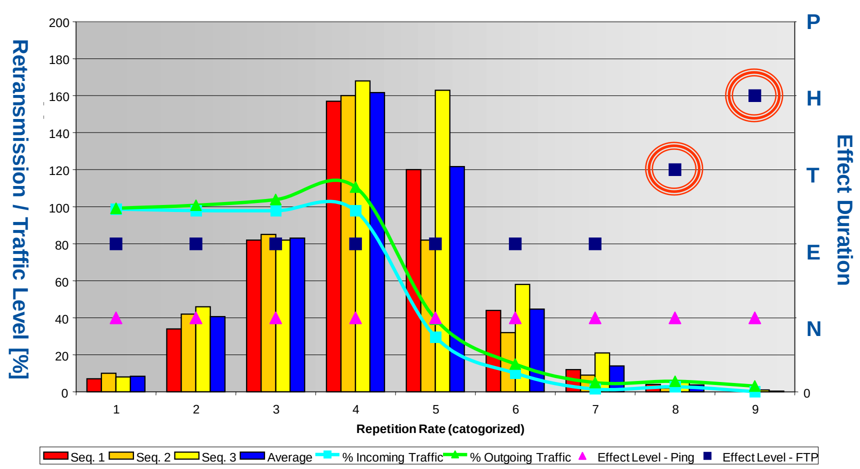
Example PC-Network in UWB Environment



Source: WIS

Evaluation

insensitive		Criticality				
		N	***I***	***II***	***III***	***IV***
Duration	***N***		n/a	n/a	n/a	n/a
	E	n/a	suseptable		vulnerable	
	T	n/a				
	H	n/a				
	P	n/a				

n/a – not applicable

6.7 Survey of Effects

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Classification: Threat Level

Threat Level	Description	Amplitude
XL	Extreme Low	< 0,1 kV/m
L	Low	0,1 – 1 kV/m
M	Intermediate	1 – 10 kV/m
H	High	10 – 100 kV/m
XH	Extreme High	> 100 kV/m

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Summary: Microcontroller

Threat		Effect Level					
	band	U	N	I	II	III	IV
CW	Hypo					L	M
HPM	Hypo					L / M	H
WB	Meso			N / D	N / D	N / D	N / D
UWB	Hyper			L / M	M	M / H	H

N / D: No Data Available

Summary: PC

Threat		Effect Level					
	band	U	N	I	II	III	IV
CW	Hypo			XL / L	L / M	M	N / D
HPM	Hypo		XL	L	L / M	M	N / D
WB	Meso		XL / L	L	M	M	N / D
UWB	Hyper		XL / L	L	M	M	H

N / D: No Data Available

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Summary: PC Network

Threat		Effect Level					
	band	U	N	I	II	III	IV
CW	Hypo			L	L	L / M	M
HPM	Hypo			L	L	L / M	M / H
WB	Meso			N / D	N / D	N / D	N / D
UWB	Hyper		L	M	M	M / H	N / D

N / D: No Data Available

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Summary: Car

Threat		Effect Level					
	band	U	N	I	II	III	IV
CW	Hypo		XL	L	L	N / D	N / D
HPM	Hypo			L / M	M	H	H
WB	Meso			L / M	M	H	H
UWB	Hyper		M	H	H	XH	N / D

N / D: No Data Available

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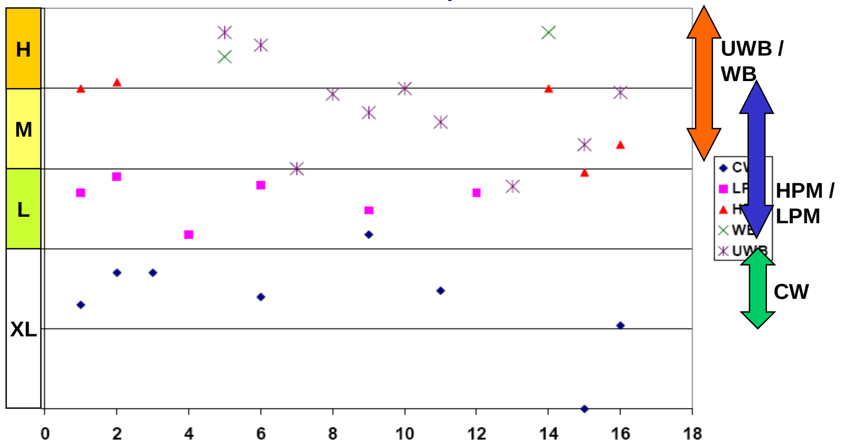
Susceptibility Threshold

Effect Level 4 “Upset”



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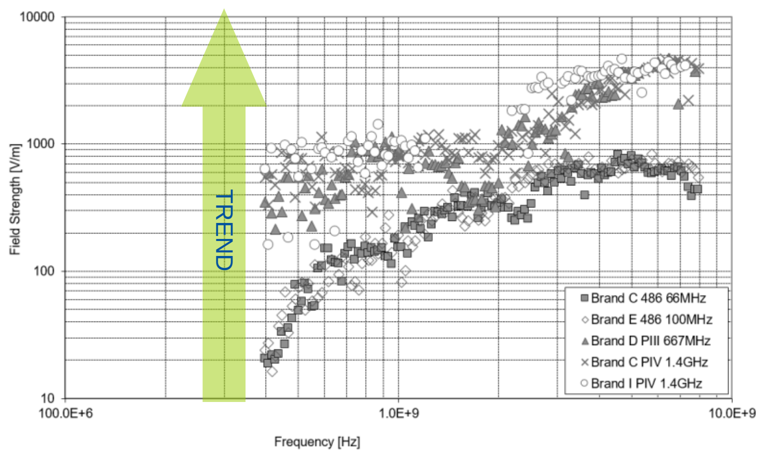
Trend: Computer Susceptibility



Source: D. Giri, R. Hoad and F. Sabath; High-Power Electromagnetic Effects on Electronic Systems, Artech House, 2020, ISBN 978-1-63081-588-2, p 167

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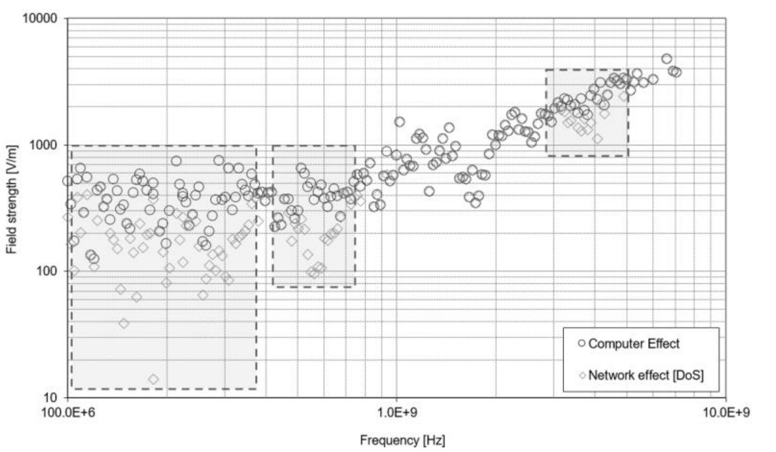
Computer Effect vs. Network Effect



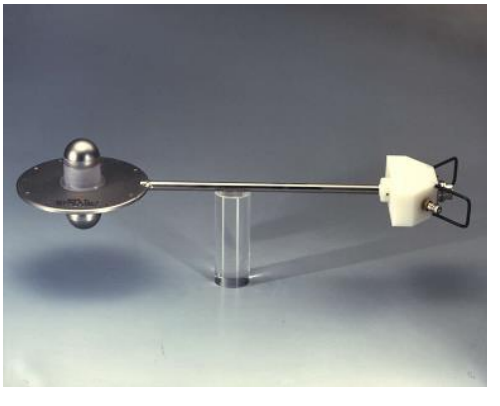
Source: D. Giri, R. Hoad and F. Sabath; High-Power Electromagnetic Effects on Electronic Systems, Artech House, 2020, ISBN 978-1-63081-588-2, p 168

Trend: Susceptibility Threshold (II - degradation)

System	Threat Level			
	CW	HPM	WB	UWB
Civil Electronic (general environment)	XL	L	L	L / M
Civil Electronic (industrial environment)	XL	L / M	L / M	M / H
Cars	L	M	M	H
Avionics	L	M	N / D	N / D
Military Electronics (general)	L	H	M / H	H
Military Electronics (special requirements)	L	H	H	XH

Thank You for Your Attention.

Questions ?



Chapter 7

Risk Evaluation

EMI Risk Management

7. Risk Evaluation

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Content

✓ 1. Introduction & Basic Terms
✓ 2. Fundamentals of Risk Management
✓ 3. Risk Analysis Methods
✓ 4. EMI Scenario
✓ 5. Modeling of scenarios and systems
✓ 6. Effects and Error States
⇒ 7. Risk Evaluation
8. Risk Treatment and Protection
9. Examples
10. Summary

7.1 Introduction

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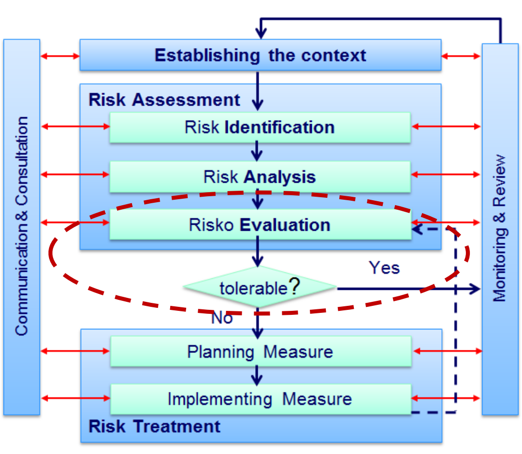
Risk management: ISO 31000 Process



Process cycle risk management — Process cycle risk treatment — Information

Objective

(1) Classification of identified risks in

- Risks that can be tolerated
- Risks that require further analysis
- Risks that need to be addressed/mitigated

(2) Prioritizing necessary risk management measures

Risk Classification

Risk are classified by **comparing**

–risk **characteristics**, evaluation **criteria** and **scales** (as specified during the establishment of the context)

–with the **risk parameters** determined by risk analysis

7.2 Risk Evaluation Criteria

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Risk Assessment Criteria

Usual criteria for the risk assessment are:

– Frequency of Occurrence

– Severity of Consequence

– Chance of Detection

Frequency of Occurrence

How often / likely does the **consequence** (effect, failure) **occur** when the system is exposed to an EMI environment (EMI attack).

- Assumption of EMI attack/EMI exposure.
  - →The likelihood of EMI attack/EMI exposure is not considered.
  - →This is dependent on non-technical aspects and shall be determined separately if required.

Frequency of Occurrence

P	Probability/ Frequency of Occurrence	Criterion	
0 - 1	improbable/ unlikely	< 1%	So unlikely, that it can be assumed that the event does not occurs.
2 - 3	remote	1% - 5%	Low possibility that an event occurs.
4 - 6	occasional	5% - 50%	Event will occur in some, but less than half of the cases.
7 - 8	probable	50% - 90%	Event will occur in more than half of the cases.
9 - 10	frequent	> 90%	Most likely that an event will occur in approximately every case.

Severity of Consequence

How big is the potential damage or loss?

What is the significance of the potential damage to the user of the system?

a) Quantitative evaluation
- Acquisition Costs
- Recovery cost

b) Qualitative evaluation
- Personal damages, environmental damage
- Malfunction/restriction of processes/operation
- Function/System Performance
- Recovery effort

Severity of Consequence

S	Severity	Description
0 - 1	undisturbed /negligible	No effect occurs or the system can fulfill its mission without disturbances.
2 - 3	limited / marginal	The appearing effects cause functional restrictions or working difficulties. They do not influence the main mission.
4 - 6	severe	The appearing disturbance reduces the efficiency and capability of the system.
7 - 8	Very severe	The appearing disturbance prevents that the system is able to fulfill its main function or mission.
9 - 10	catastrophically	Effects could result in one or more of the following: (1) death of human being, (2) permanent total damage or loss of the system, (3) irreversible significant environmental impact.

Chance of Detection

Can the cause of error (EMI exposure) be detected in a timely manner (before secondary sequences occur)

Is it possible to prevent damage by repelling consequential errors?

- Initiation of protective measures
- Change of operating mode
- Warning the user/operator

Chance of Detection

D	Chance of Detection	Description
0 - 1	certain	EMI exposure is certainly detected. Primary error is detected before subsequent errors occurs.
2 - 3	very likely	Discovery of EMI exposure/primary error is very likely.
4 - 6	likely	EMI exposure/primary error is likely to be detected.
7 - 8	unlikely	Detection of EMI exposure/primary error is unlikely.
9 - 10	Not detectable	EMI Exposure/primary error cannot be detected for technical and/or economic reasons

Additional criteria

- Performance parameters of critical functions
- Specified functionalities
  - Functions to be ensured under EMI exposure
- Functional safety

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7.3 Risk Evaluation

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Risk Matrix - Overview

- Classification of the potential **extent of damage**
- Classification of the **probability of occurrence**
- Representation of the potential **extent of damage** (vertical) and the associated **probability of occurrence** (horizontal) in matrix form.
- Classification of fields into risk classes:
  - Red: high risk/determined risk is not acceptable
  - Yellow: significant risk/risk cannot be taken easily, further analysis is required
  - Green: low risk/risk is acceptable

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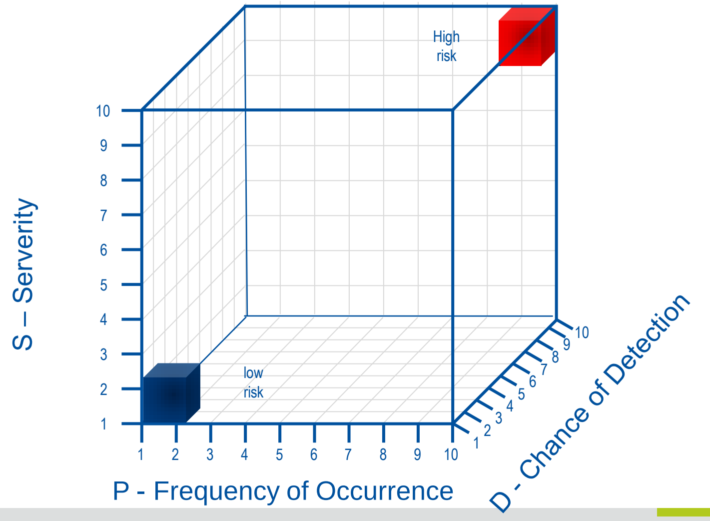
Risk Matrix

Consequence \ Frequency of Occurrence	Improb-able/ unlikely	remote	Occa-sional	probable	frequent
catastrophically	II	III	III	III	III
Very severe	II	II	III	III	III
severe	I	II	II	III	III
limited	I	I	II	II	III
undisturbed	I	I	I	II	III

Risk Cube



Risk Index - Overview

- A risk index is a semi-quantitative measure of risk which is an estimate derived using a scoring approach using ordinal scales.
- Risk indices can be used to rate a series of risks using similar criteria so that they can be compared.
- Risk indices are essentially a qualitative approach to ranking and comparing risks. While numbers are used, this is simply to allow for manipulation.

Risk Priority Index (RPI)

$$\mathbf{RPI} = \alpha_S \cdot S \cdot \alpha_P \cdot P \cdot \alpha_D \cdot D$$

S – Severity of Consequence $\in [0, 10]$
P – Frequency of Occurrence $\in [0, 10]$
D – Chance of Detection $\in [0, 10]$

- By calculating the risk priority number (RPI), an attempt is made to establish a ranking of the risks.
- $1 \leq RPI \leq 1000$
- There is the claim that the RPI, at least in comparison with other RPI of the same risk analysis, allows a statement in the sense of better/worse.

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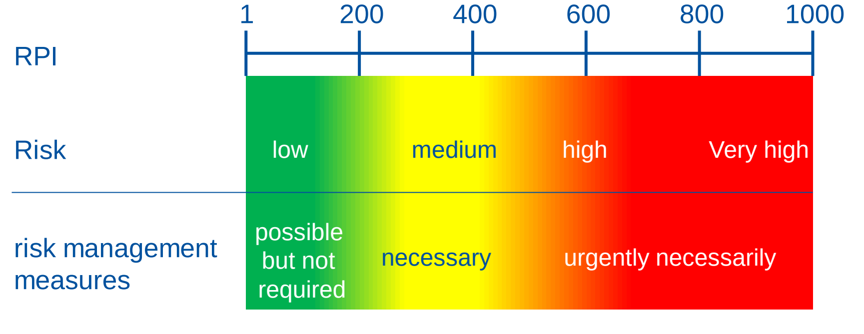
Risk Priority Index (RPI)



Risk Priority Index (Example 1)

• Frequency of Occurrence:	low	P = 2
• Severity of Consequence: limited functionality	high	S = 8
• Chance of Detection:	low	D = 8
• Risk Priority Index	low	RPI = 128

$\Rightarrow$ no measures required

Risk Priority Index (Example 2)

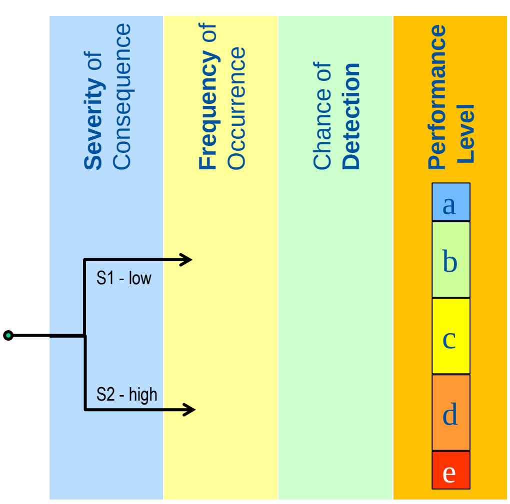
• Frequency of Occurrence:	high	P = 8
• Severity of Consequence: Functional restrictions of operating elements	low	S = 2
• Chance of Detection:	low	D = 8
• Risk Priority Index	low	RPI = 128

$\Rightarrow$ no measures required

Risk Graph - Overview

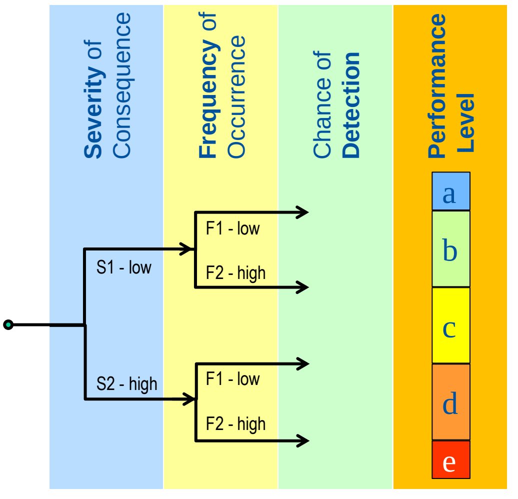
- Risk assessment based on the three criteria
  - Severity of Consequence
  - Frequency of Occurrence
  - Chance of Detection
- Classification of all criteria in ***high*** and ***low*** class
- Representation in the form of a decision tree
- Assignment to five **Performance Levels** that represent
  - the strength of the risk and/or
  - the contribution to risk mitigation.

Risk Graph (ISO 13849)



S	Severity	
0 - 1	undisturbed /negligible	S1 - low
2 - 3	limited / marginal	
4 - 6	severe	S2 - high
7 - 8	Very severe	
9 - 10	catastrophically	

Risk Graph (ISO 13849)



P	Probability/ Frequency of Occurrence	
0 - 1	improbable/ unlikely	F1 – low
2 - 3	remote	
4 - 6	occasional	
7 - 8	probable	F2 - high
9 - 10	frequent	

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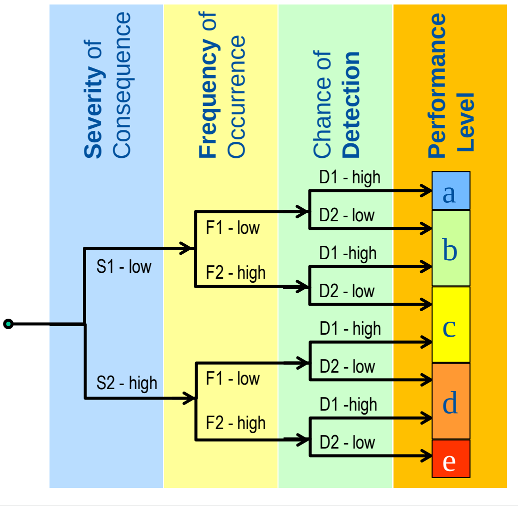
Risk Graph (ISO 13849)



D	Chance of Detection	
0 - 1	certain	D1 - high
2 - 3	very likely	
4 - 6	likely	D2 - low
7 - 8	unlikely	
9 - 10	Not detectable	

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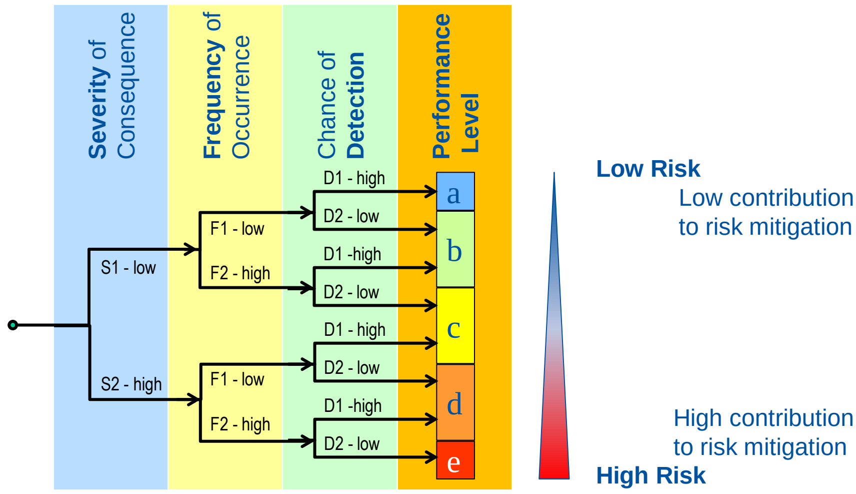
Risk Graph (ISO 13849)



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Thank You for Your Attention.

Questions ?

Chapter 8
Risk Treatment and Protection

EMI Risk Management

8. Risk Treatment and Protection

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Content

✓ 1. Introduction & Basic Terms
✓ 2. Fundamentals of Risk Management
✓ 3. Risk Analysis Methods
✓ 4. EMI Scenario
✓ 5. Modeling of scenarios and systems
✓ 6. Effects and Error States
✓ 7. Risk Evaluation
⇒ 8. Risk Treatment and Protection
9. Examples
10. Summary

7.1 Introduction

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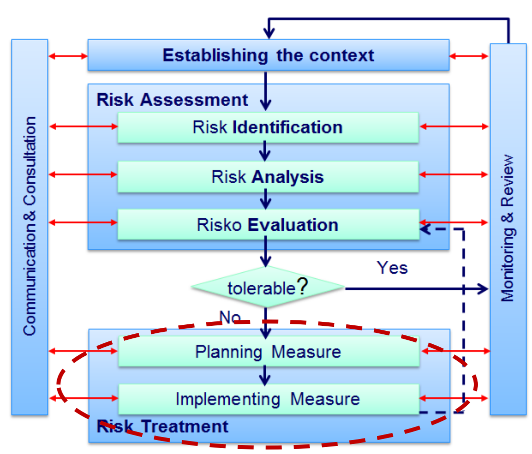

Process cycle risk management
Process cycle risk treatment
Information

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Risk Mitigation / Risk Treatment

Risk Mitigation or **Risk Treatment** includes all measures to

- avoid,
- reduce (strength),
- change (type) and
- transfer

risks.

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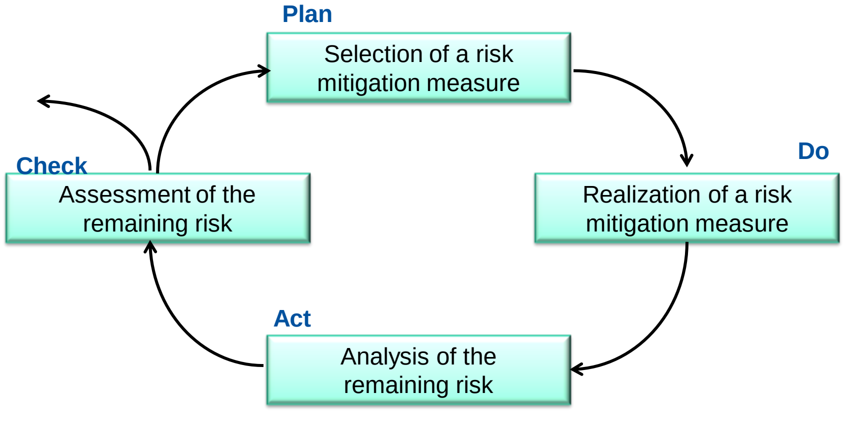
Risk Mitigation Process



Starting Points

- Omission of risk-enhancing processes
- Replacing components/subsystems
- Remove/prevent EMI sources
- Manipulation of the probability of occurrence
- Diversification
- Mitigation / limitation of effects

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7.2 Protective Measures

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Objectives of Protection

(1) **Avoid** destructions
(2) **Prevent** & limit upsets
(3) **Reduce** disturbances and interferences

to
a) maintain **system performance**,
b) ensure **functionality**, and
c) protect **components**

Types of Protective Measures

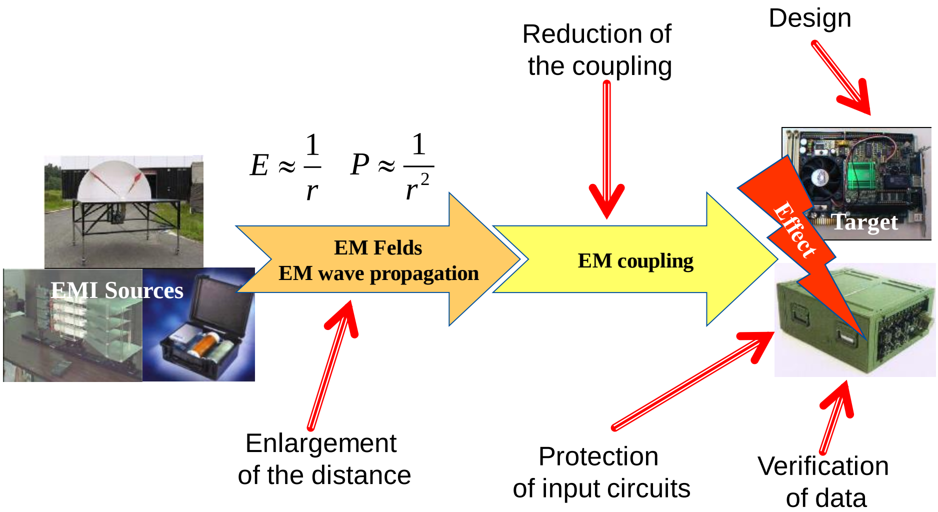
Organizational Measures

- Spatial distribution
- Limited / restricted access
- …

Technical Measures

- Shielding
- Conducted protection
  - surge arrester
  - filter
  - isolating transformer
- Design
- Classification and separation of conductors
- Monitoring
  - of system performance
  - of EM environment

Starting Points in the EMI interaction model



Essential Objectives

- Reduction of energetic effects
- Reduction of the input energy
- Limitation of voltage
  - on signal lines
  - on power lines
- Monitoring
  - of the system state (latch up)
  - of the EM environment
- Checking the consistency of data

Protective Measures

- **Shielding of**
  - **Buildings**
  - **Cases / chassis**
  - **Cable**
- Grounding
- Galvanic Isolation
  - isolating transformer (power lines)
  - optoelectronic coupler / fiber optic lines (FOL) (signal lines)
- Surge arrestor (power lines)
- Filter / band limiter (signal lines)

7.2.1 Shielding

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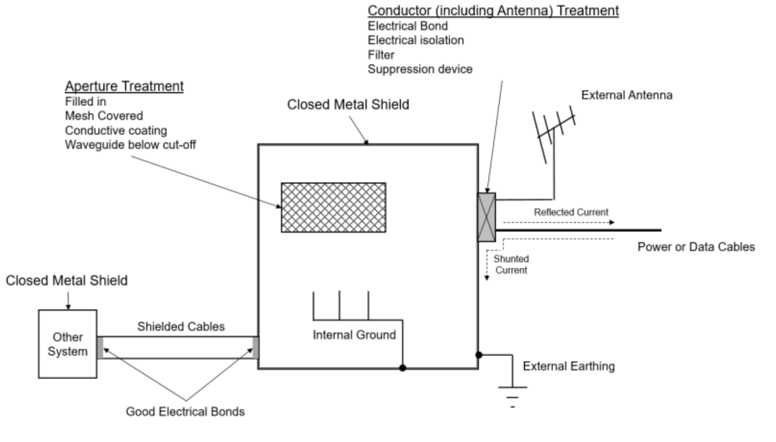
Shielding - Objective

The overall principle is to enclose all of the potentially vulnerable electronics within a **closed metal shield**

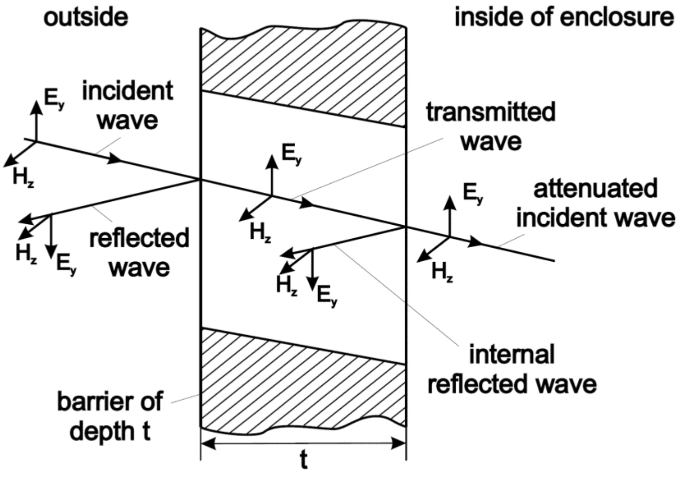
- to **decouple** the **electromagnetic field** via reflection and absorption, and
- to **decouple conducted disturbances** at the shield by
  - making very good quality electrical bonds of the cable shield to the outside of the enclosure shield (shielded cables and conducting penetrations)
  - shunt the coupled current to Earth via the enclosure shield by good bonding and a nonlinear protective device (unshielded conducting penetrations)

Shielding topology protection concept

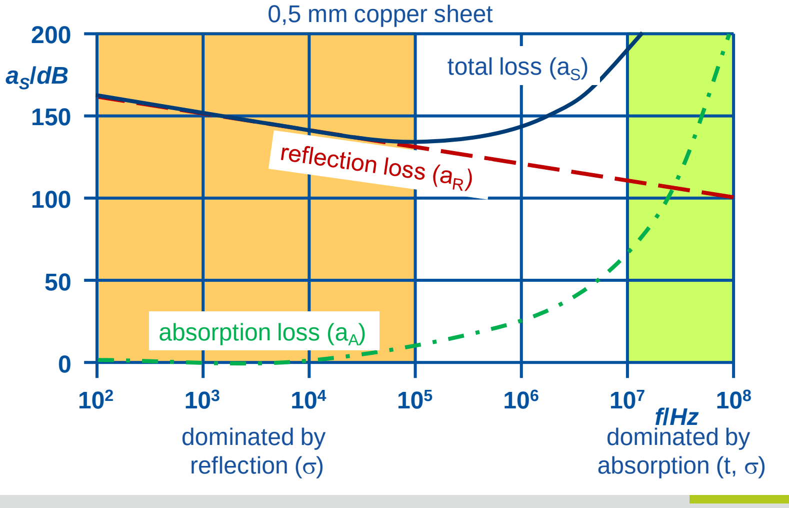


Source: D. Giri, R. Hoad and F. Sabath; High-Power Electromagnetic Effects on Electronic Systems, Artech House, 2020, ISBN 978-1-63081-588-2, p 149

Shielding phenomena of a barrier to a plane wave



Shielding Attenuation

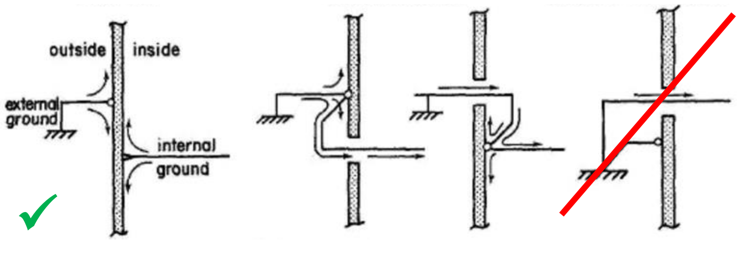


Typical Values of Shielding Attenuation

0 - 10 dB	Very low shielding attenuation No protection against disturbances
10 – 30 dB	low shielding slight disturbances can be eliminated
30 – 60 dB	Average shielding in HF region High shield attenuation against magnetic fields in the LF range
60 – 90 dB	Appropriate shielding for medium to large EMC problems
90 – 150 dB	the maximum which is possible with extremely good shielding
150 dB	Proof border of the today's technology

Shielding integrity; grounding conductors

proper compromising serious validation



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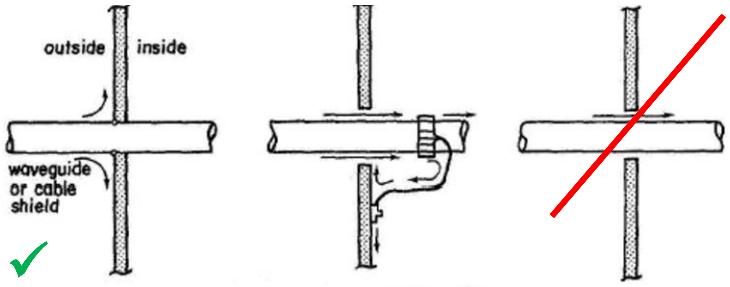
Shielding integrity; groundable conductors

proper | compromising | serious validation



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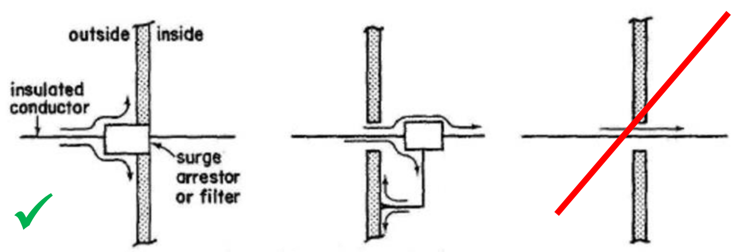
Shielding integrity; insulated conductors

proper | compromising | serious validation



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Protective Measures

- Shielding of
  - Buildings
  - Cases / chassis
  - Cable
- **Grounding**
- Galvanic Isolation
  - isolating transformer (power lines)
  - optoelectronic coupler / fiber optic lines (FOL) (signal lines)
- Surge arrestor (power lines)
- Filter / band limiter (signal lines)

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7.2.2 Grounding

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Grounding - Objective

Ensure that conducting objects and circuits of a (distributed) system operate relatively to the same voltage level by:

- defining a zero-voltage reference (ground structure) and
- bonding conducting (metallic) objects and circuits to that reference structure through a low-impedance, non-current-carrying connection.

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Grounding - important points

Ground structures

- serve as local zero-volt references
- must be a good conductor at the frequencies of interest
- does not have to be electrically small
- does not have to enclose the electronics (A ground structure is not a shielding enclosure)
- cannot carry intentional currents (at least not at the amplitudes and frequencies of interest)
- must be able to carry unintentional currents with a sufficiently low impedance (to control unintentional voltages

Source: American National Standard Dictionary for Technologies of Electromagnetic Compatibility (EMC), Electromagnetic Pulse (EMP), and Electrostatic Discharge (ESD), ANSI C63.14-1992

Protective Measures

- Shielding of
  - Buildings
  - Cases / chassis
  - Cable
- Grounding
- **Galvanic Isolation**
  - **isolating transformer (power lines)**
  - **optoelectronic coupler / fiber optic lines (FOL) (signal lines)**
- Surge arrestor (power lines)
- Filter / band limiter (signal lines)

7.2.3 Galvanic Isolation

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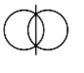
Galvanic isolation - Objective

Galvanic isolation is a principle of isolating functional sections of electrical systems to prevent current flow; no direct conduction path is permitted.

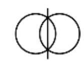
- Energy or information can still be exchanged between the sections by other means, such as capacitance, induction or electromagnetic waves, or by optical, acoustic or mechanical means.
- Galvanic isolation is used where two or more electric circuits must communicate, but their grounds may be at different potentials.
- It is an effective method of breaking ground loops by preventing unwanted current from flowing between two units sharing a ground conductor.

Isolation transformer

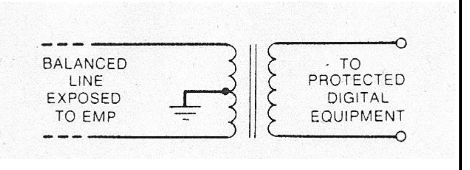


- are designed with attention to capacitive coupling between the two windings
- A grounded Faraday shield between the primary and the secondary greatly reduces the coupling of common-mode noise
- block transmission of the DC component in signals from one circuit to the other
- allow AC components in signals to pass
- are often used to protect secondary circuits and individuals from electrical shocks between energized conductors and earth ground

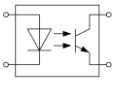
Isolation Transformers



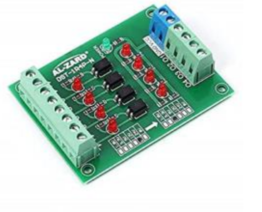
- Large isolation voltages (5 kV),
- good common-mode rejection,
- no attenuation of differential-mode overvoltage
- Block common mode currents



Optoelectronic Coupler



- is an electronic component that transfers electrical signals between two isolated circuits by using light
- Large isolation voltages (5 kV),
- Good common-mode rejection,
- Easy to use to receive data, difficult to use to transmit data,
- Fast devices (<1-ps switching time) are expensive



Protective Measures

- Shielding of
  - Buildings
  - Cases / chassis
  - Cable
- Grounding
- Galvanic Isolation
  - isolating transformer (power lines)
  - optoelectronic coupler / fiber optic lines (FOL) (signal lines)
- **Surge arrestor (power lines)**
- Filter / band limiter (signal lines)

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7.2.4 Surge Arrestor

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Surge Arrestor - Objective

A **surge arrester** is a device to protect electrical equipment from over-voltage transients.

- Also called a surge protection device (SPD) or transient voltage surge suppressor (TVSS)
- To protect a unit of equipment from transients occurring on an attached conductor, a surge arrester is connected to the conductor just before it enters the equipment.
- The surge arrester is also connected to ground and functions by routing energy from an over-voltage transient to ground if one occurs, while isolating the conductor from ground at normal operating voltages.

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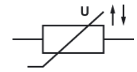
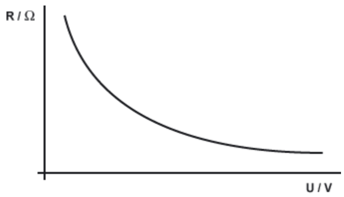
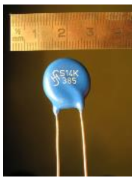
Overview Surge Arrestor

- Voltage Dependent Resistor (VARISTOR)
- Diode (Suppressor Diode, Zener Diode)
- Thyristor (Silicone-controlled rectifier (SCR))
- Spark gap

Voltage Dependent Resistor (VARISTOR)







- VARISTORS are voltage-dependent resistors. They change their resistance value as a function of the applied voltage.
  - The resistance value of a VARISTOR decreases as the voltage increases.
  - When the voltage drops, the resistance value of the VARISTOR rises.
  - From a certain voltage, the VARISTOR becomes low-impedance and thereby prevents a further voltage rise.

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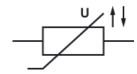
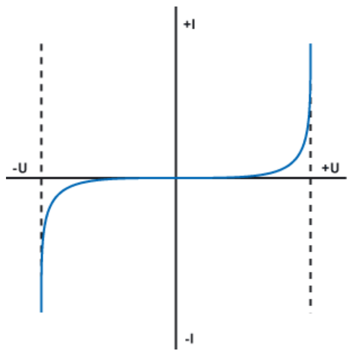
Voltage Dependent Resistor (VARISTOR)

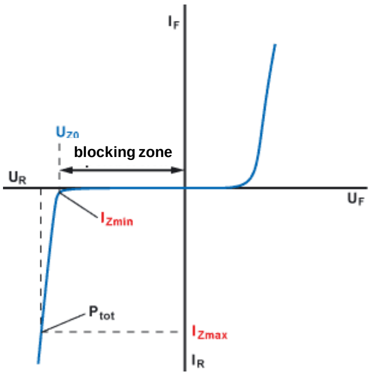


- have a symmetric current/voltage characteristic, i.e. the polarity of the VARISTOR is irrelevant.
- fast response time ($t_{res} < 0,5$ ns);
- capable of large energy absorption;
- can safely conduct large currents (1 kA for 20 ps)
- Characterized by a large parasitic capacitance (1 to 10 nF)
- are inexpensive
- VARISTOR are used both for protecting sensitive electronic circuits and in heavy current technology.



Zener Diode / Suppressor Diode

- A reverse-biased Zener diode exhibits a controlled breakdown and allows the current to keep the voltage across the Zener diode close to the Zener breakdown voltage (U_{Z0}).
- If the blocking voltage falls below U_{Z0}, the blocking layer is immediately restored.
- The range between I_{Zmin} and I_{Zmax} is called the working range or breakthrough range.



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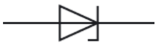
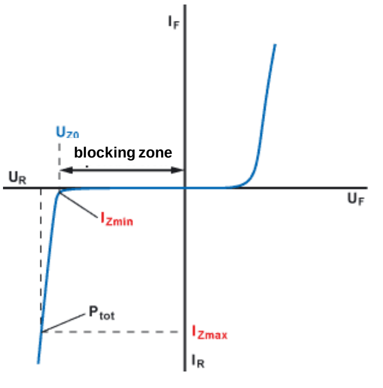
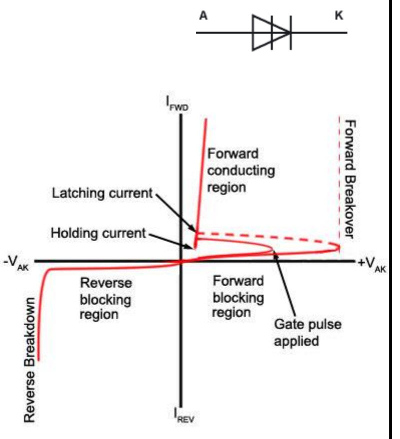
Zener Diode / Suppressor Diode



- have an asymmetric current/voltage characteristic, i.e. the polarity of the Diode is relevant.
- fast response time (t_{res} < 0,1 ns);
- selection of precisely determined clamping voltages (between about 6.8V and 200V)
- small maximum allowable current (<100A for 100 pF)
- large parasitic capacitance (1 to 3 nF).



Thyristor



The characteristic voltage-current curve of a thyristor is subdivided into

- the reverse breakdown
- the reverse blocking region
- the forward blocking region
- the forward transition region
- the forward conducting region

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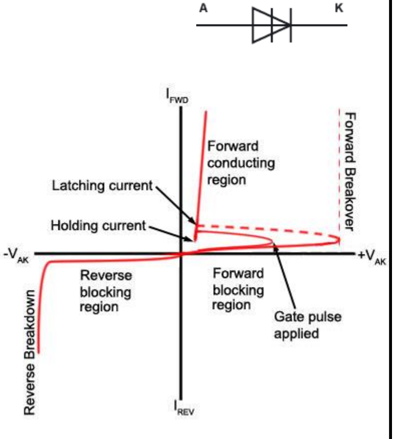
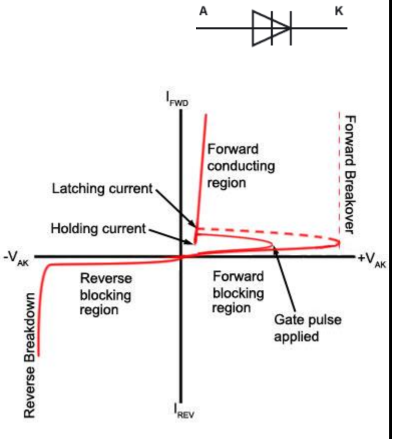
Thyristor



- In the reverse blocking region a thyristor behaves in a similar way to a diode; all current, apart from a small leakage current is blocked.
- If the reverse breakdown region is reached, the insulation breaks down due to the depletion layers at the junctions. In most cases, reverse current flowing in the breakdown region would destroy the thyristor.
- When the thyristor is forward biased no current apart from a small leakage current flows. This is called the forward blocking mode, which extends to a comparatively high voltage called the Forward Break over Voltage.

Thyristor



- If a current is applied to the gate of the thyristor whilst it is operating in the forward blocking region, it is triggered and its forward resistance falls to a very low value.
- due to the low forward resistance of the thyristor in this mode, allows very large (several amperes) currents to flow in the ´forward conducting region´
- if forward current falls below the ´holding current´ value or the anode to cathode voltage is reduced to very near 0V, the thyristor will return to its forward blocking region

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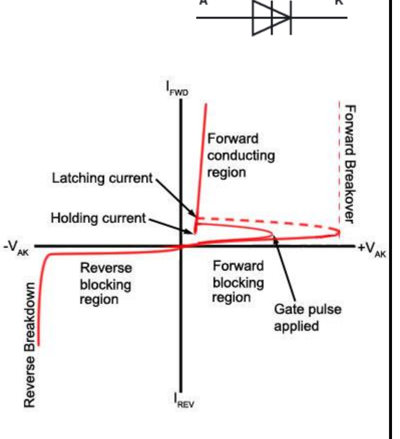
Thyristor



- have an asymmetric current/voltage characteristic, i.e. the polarity of the thyristor is relevant.
- slow to turn on or turn off response (t_{res} < 0,2 µs);
- Small voltage (0,7 V to 2 V) across conducting thyristor
- can tolerate sustained large currents

Spark Gap

- consists of two conducting electrodes separated by a gap usually filled with a gas such as air,
- designed to allow an electric spark to pass between the conductors.
- When the potential difference between the conductors exceeds the breakdown voltage of the gas within the gap, a spark forms, ionizing the gas and drastically reducing its electrical resistance.
- An electric current then flows until the path of ionized gas is broken or the current reduces below a minimum value called the "holding current".

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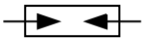
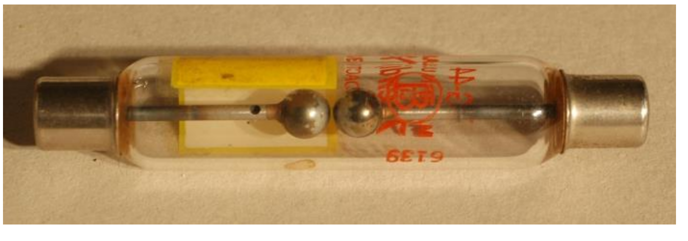
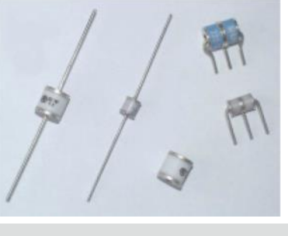
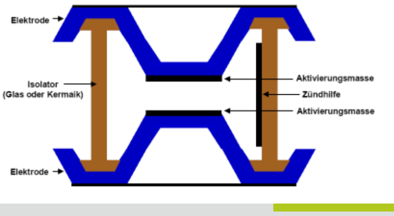
Spark Gap; Examples

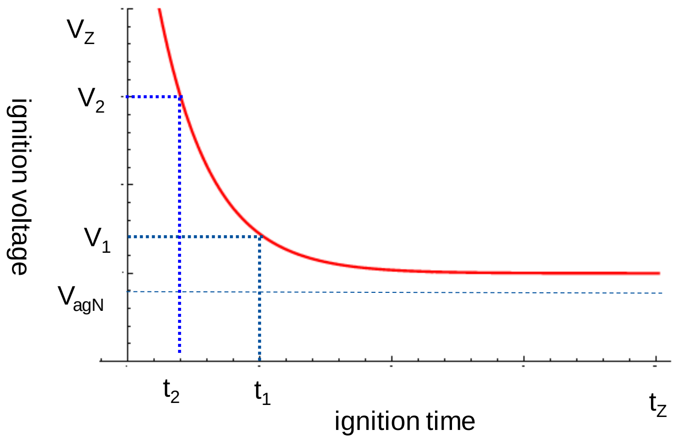








Dynamic Characteristic of a Spark Gap



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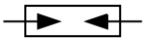
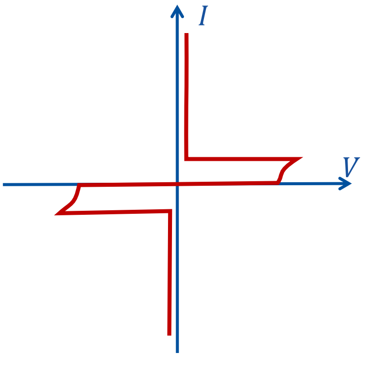
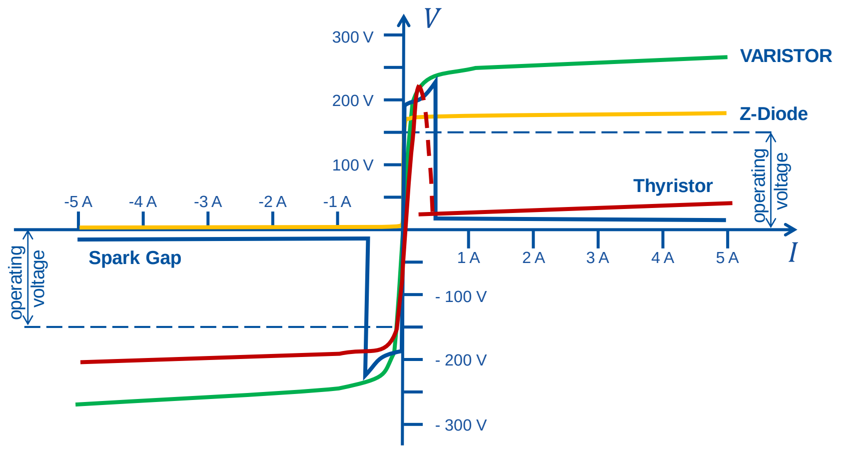
Spark Gap



- have a symmetric current/voltage characteristic, i.e. the polarity of the thyristor is irrelevant.
- requires large voltage (~100V) to conduct;
- can be slow to conduct (large response time)
- low voltage in arc mode
- Can safely conduct large currents (5 kA for 50 pF)
- possible “follow current” (sustained short circuit)
- very small parasitic capacitance (<2 pF)



Comparison characteristic curves



Protective Measures

- Shielding of
  - Buildings
  - Cases / chassis
  - Cable
- Grounding
- Galvanic Isolation
  - isolating transformer (power lines)
  - optoelectronic coupler / fiber optic lines (FOL) (signal lines)
- Surge arrestor (power lines)
- **Filter / band limiter (signal lines)**

7.2.5 Filter and Band Limiter

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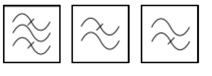
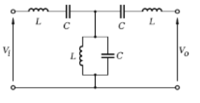
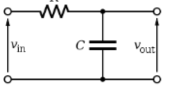
Filter



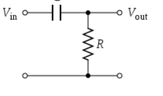
- A **band-pass filter** (BPF) is a device that passes frequencies within a certain range and rejects (attenuates) frequencies outside that range.



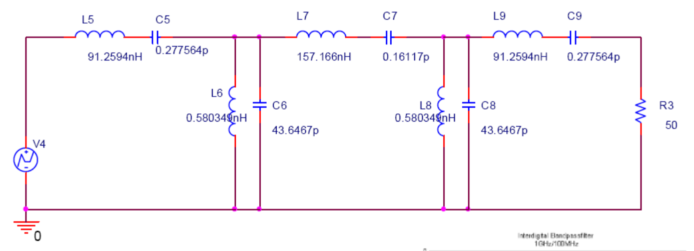
- A **low-pass filter** (LPF) is a filter that passes signals with a frequency lower than a selected cutoff frequency and attenuates signals with frequencies higher than the cutoff frequency.

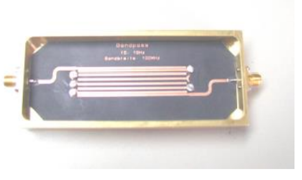


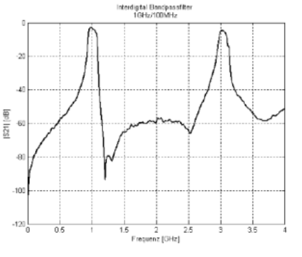
- A **high-pass filter** (HPF) is an electronic filter that passes signals with a frequency higher than a certain cutoff frequency and attenuates signals with frequencies lower than the cutoff frequency.



Band-Pass Filter







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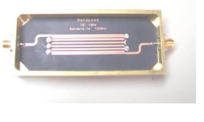
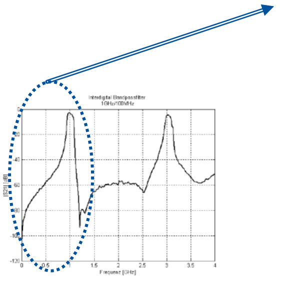
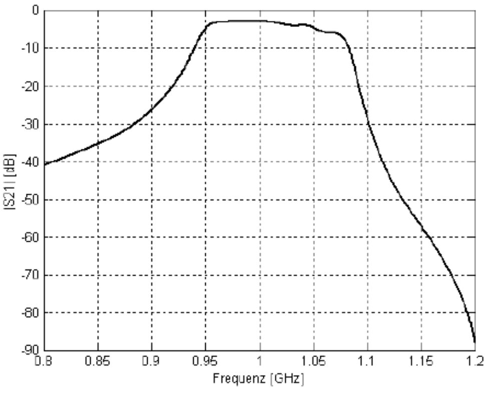
Band-Pass Filter

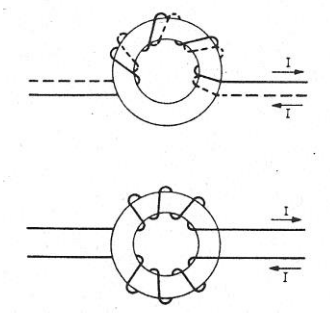




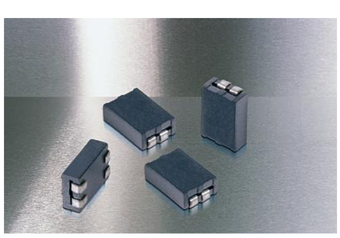


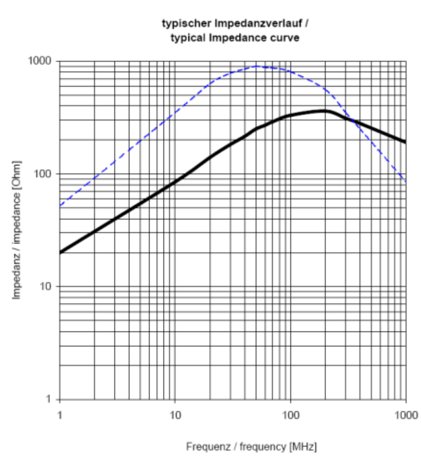
Ferrite Choke / Ferrite Bead

- Ferrite Chokes work by blocking signals traveling via common mode and pass through differential-mode or "balanced" currents unchanged.
- In the common mode all signals running along all the wires travel in the same direction.
- When the unwanted signal is only in the common mode then the desired signal can pass through the filter via the differential-mode.



Ferrite Choke / Ferrite Beads





7.3 Protection Concepts and Methods

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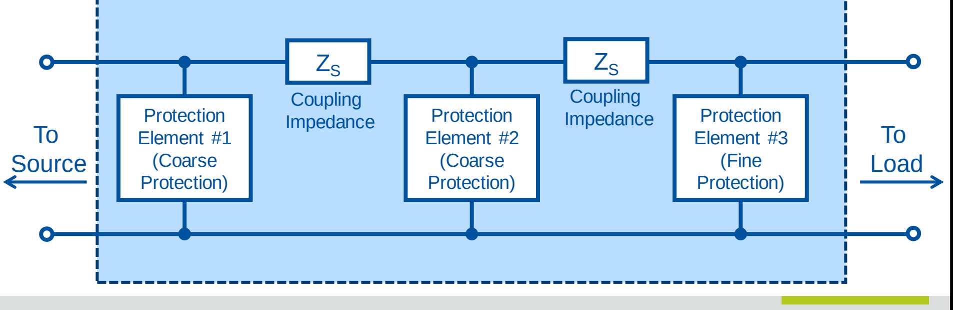
Multistage Protection Concept



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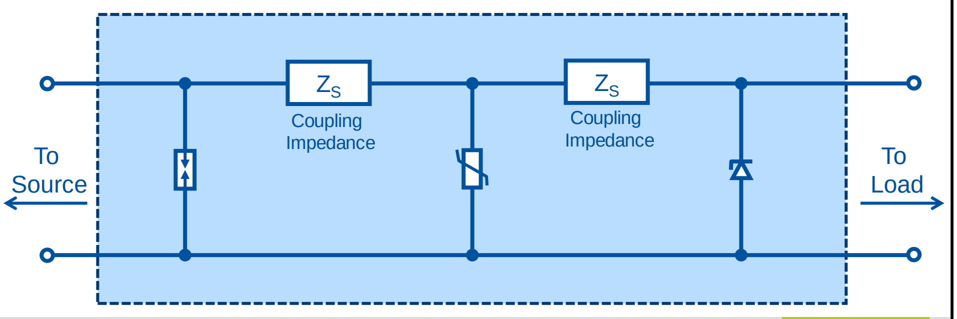
Multistage Protection Concept



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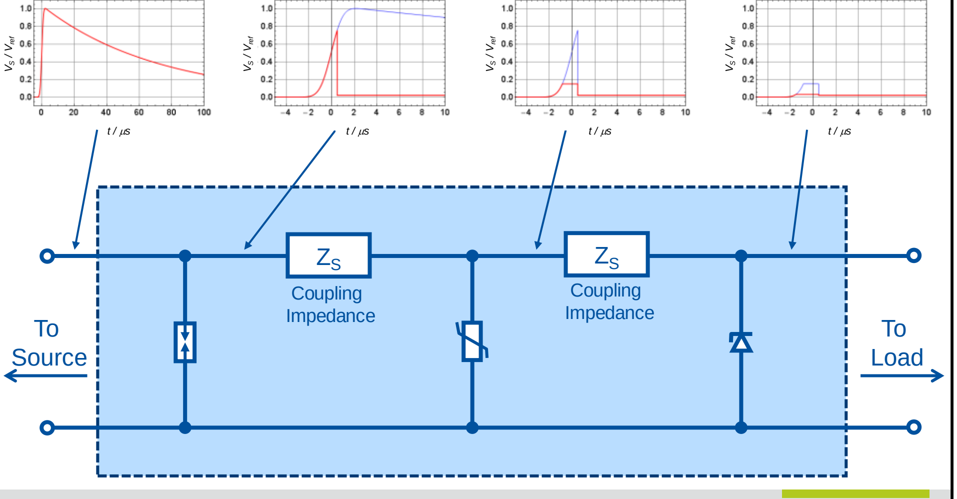
Multistage Protection Concept



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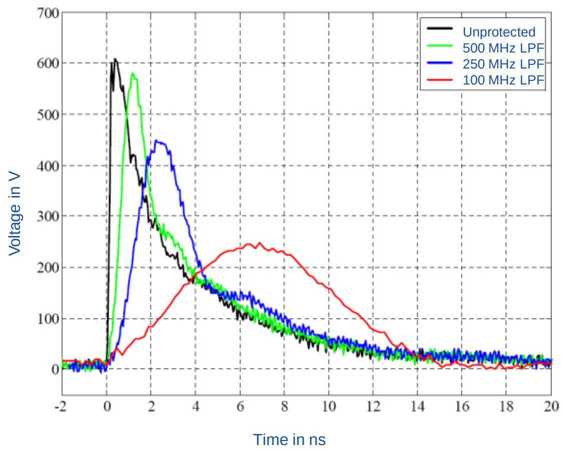
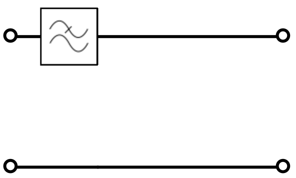
Protection by LPF





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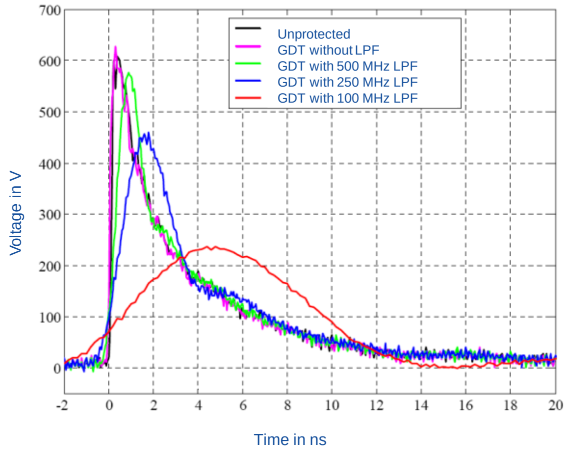
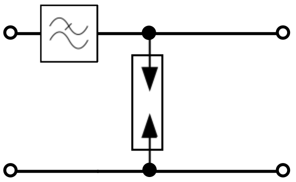
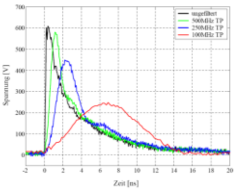
Protection by LPF & GDT







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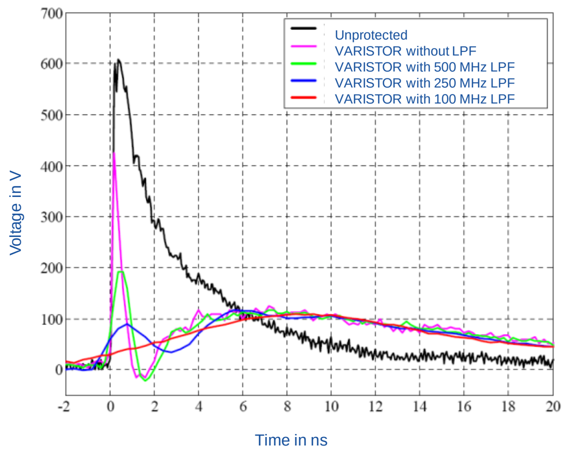
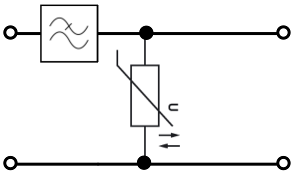
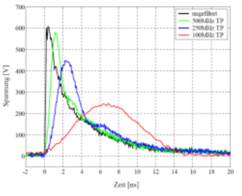
Protection by LPF & VARISTOR







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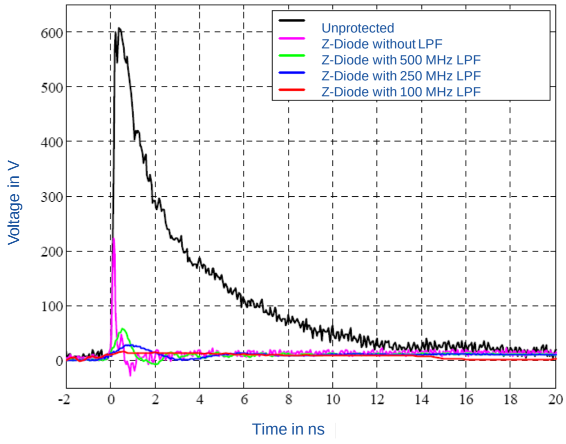
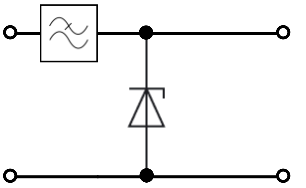
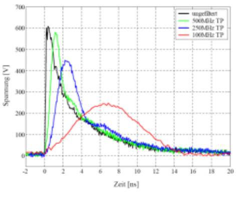
Protection by LPF & Z-Diode







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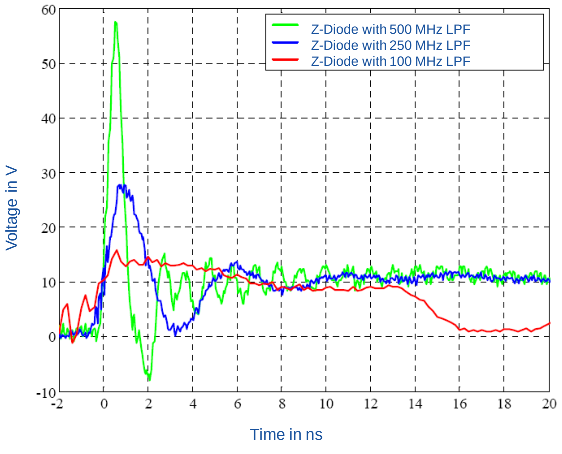
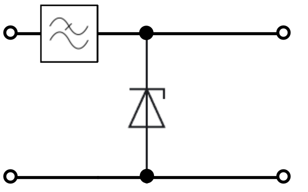
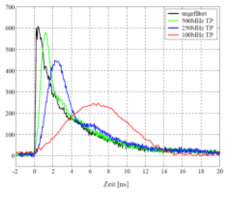
Protection by LPF & Z-Diode (detailed view)







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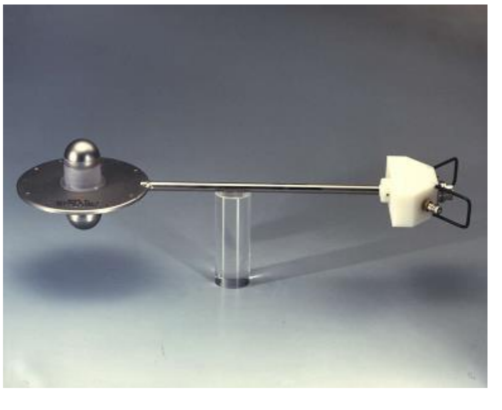
Thank You for Your Attention.

Questions ?



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Appendix A
Fictive Infrastructure

It is in the nature of the EMI threat that the operators of critical infrastructures are treated confidentially in the context of the EMI risk management of documents produced and lessons learned and are therefore not available as examples. As an example for discussing and clarifying the methods of EMI risk management as well as individual work steps in modeling the threat scenario, a fictitious infrastructure was therefore created. This includes all system elements relevant to EMI risk management without being too specific to a single technical infrastructure.

A.1 General Description

The guiding principle in the creation of the fictional infrastructure was the control centre of a technical supply infrastructure, such as:

- Network of an energy utility,
- water supply network,
- Traffic management or
- of a national logistics network.

The fictional infrastructure is located in an industrial area or a technology park (see Fig. A.1). The area where the fictional infrastructure is located is south of the *Maxwell Parkway*, a federal road, and north of the *Heinrich Hertz Street*, a main road. The *Ohm Drive* forms the eastern border of the area, the *Kirchhoff Drive* forms the western border. The roads running north-south between the *Maxwell Parkway* and the *Heinrich Hertz Street* street are regularly driven by trucks. On the other hand, the roads running in the east-west direction between the *Ohm Drive* and the *Oerstedt Drive* are quiet and can only be used by vehicles up to the size of a transporter. As can be seen from the location plan illustrated in Figure A.1, the system elements of the fictional infrastructure are distributed over six buildings.

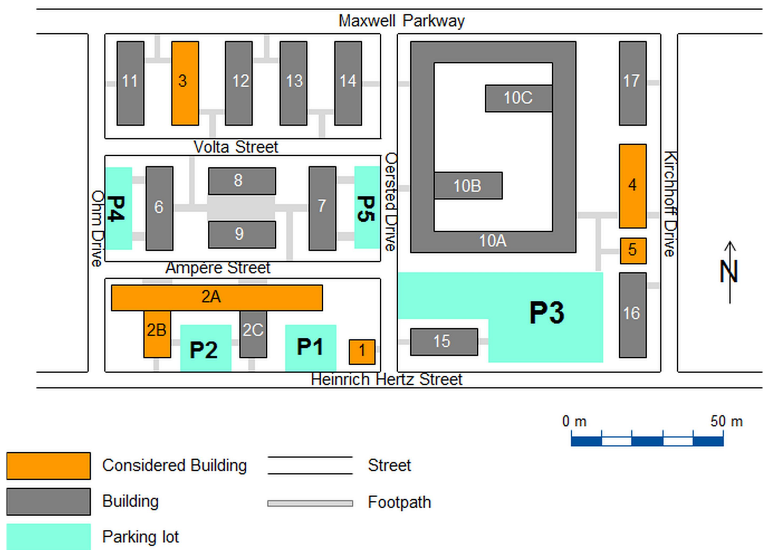

Fig. A.1 Lageplan fiktiven Infrastruktur

Building 1 - Network Station 1:

- **Location:** Building 1 is located on the southern edge of the shown area, at the mouth of *Oersted Drive* into *Heinrich Hertz Street*.
- **Construction:** The net station 1 is a one-story building built with mortar from brick. On the north side there is an access door made of steel and a ventilation opening shielded with a honeycomb grid. The net station 1 is connection to the power supply network via a ground cable.
- **Accessibility:** Access to the building is through a closed steel door. Only the operating staff has a key to open the door. ($A_z = 4i$, limited access)
- **Function:** In the building is the network station 1 (SDF 1) including an uninterruptible power supply (UPS 1) and the associated control technology (SCADA).

Building 2A:

- **Location:** The building 2A is located in the southwestern quadrant of the area under consideration on *Ampére Street*. Two outbuildings (buildings 2B and buildings 2C) are installed in the south. The building 2B is connected to the building 2A and belongs to the considered infrastructure facility. There is no access between building 2A and building 2C . The building 2C does not belong to the considered infrastructure. To the south of the building, on *Heinrich Hertz Street* are two parking areas P2 and P3. The parking area P2 is managed and can only be accessed with an access card.

- **Construction:** Building 2A is a four-story reinforced concrete building. The interior is constructed in dry walling.
- **Accessibility:** The ground floor and 1st floor are freely accessible for general openness (A_z =1i, freely accessible in a building). The 2nd and 3rd floors, on the other hand, are secured by a doorman service. (A_z =2i, supervised access in a building)
- **Function:** There are offices throughout the building. On the ground floor and on the 1st floor there are also laboratory rooms. Local servers are located in selected rooms on the 2nd and 3rd floors.

Building 2B:

- **Location:** The building 2B is an extension to the building 2A. Immediately in front of the building is the restricted parking space P2.
- **Construction:** Building 2B is a three-story reinforced concrete building. The interior was constructed in dry walling.
- **Accessibility:** The entire building is freely accessible for general openness (A_z =1i, freely accessible in a building).
- **Function:** The building 2B is used as an office building.

Building 3:

- **Location:** Building 3 is located on the northern edge of the area under consideration, between *Maxwell Parkway* and *Volta Street*. The building is part of a building row consisting of five similar buildings (buildings 3 and 11 - 14) . Between the buildings there are lawns and footpaths.
- **Construction:** The building is designed in the form of a three-storey solid building made of limestone sandstone.
- **Accessibility:** Access to the building can only be made after identification by means of an access card (A_z =3i, controlled access in a building).
- **Function:** Building 4 contains the ICT network control center, the management of building control technology for the entire infrastructure, office work places and the data center II, consisting of a core switch and a database server farm.

Building 4:

- **Location:** Building 4 is located on the eastern edge of the shown area, north of Building 5, in the middle of the *Kirchhoff Drive*. Southwest of the building lies the parking lot P3, which is freely accessible and regularly used by trucks.
- **Construction:** Building 4 was built as a steel frame building with combined glass/metal facade. The interior was constructed in dry walling.

- **Accessibility:** Access to Building 4 is limited to the employees of ICT maintenance team. After identification by means of an access card, these can enter the building through an access lock (revolving door). All remaining employees and non-service personnel receive access only after an identity check and a pocket control. ($A_z = 4i$, limited access)
- **Function:** In building 4, next to office workstations, is the data center I, with a core switch, a database server farm, and the network node of the ICT network to the Internet.

Building 5 - Network station 2:

- **Location:** Building 5 is located on the eastern edge of the shown area, south of Building 4, in the middle of the *Kirchhoff Drive*. Southwest of the building lies the parking lot P3, which is freely accessible and regularly used by trucks.
- **Construction:** The net station 2 is a one-story building built with mortar from brick. On the north side there is an access door made of steel and a ventilation opening shielded with a honeycomb grid. The net station 2 is connection to the power supply network via a ground cable.
- **Accessibility:** Access to the building is through a closed steel door. Only the operating staff has a key to open the door. ($A_z = 4i$, limited access)
- **Function:** In the building is the network station 2 (SDF 2) including an uninterruptible power supply (UPS 2) and the associated control technology (SCADA).

A.2 Accesibility

The accessibility (A_z) of the respective buildings and their surroundings is shown in Figure A.2. To each building with an accessibility of 2i (monitored) and above there is a range of the general public in which monitoring is possible. By observing these zones, which are characterized in Figure A.2 by a light blue shading, it is possible to detect large interference systems or carrier platforms which are untypical for the environment in a timely manner.

Access to the parking lot P2 requires identification of the driver by means of an access card (controlled area). From the buildings 2A and 3, the terrain lying north of the Ampere Streer between the *Ohm Drive* and the *Oerstedt Weg* is very restricted or not visible due to hedges and shrubs. The parkinglots P4 and P5 on this site are assigned to the general public, e.g. they are accessible to each person. Due to their design they can only be used by vehicles up to the size of a small transporter. The parking lot P3 is regularly used by trucks.

The evaluation for traffic areas and routes in the vicinity of the fictional infrastructure is shown in Figure A.3. In this representation, the minimum required mobility (M_e) is specified in the grey boxes. Mobile systems with less mobility ($M_{TP} < M_e$) cannot be moved into the associated traffic areas and routes as an overall

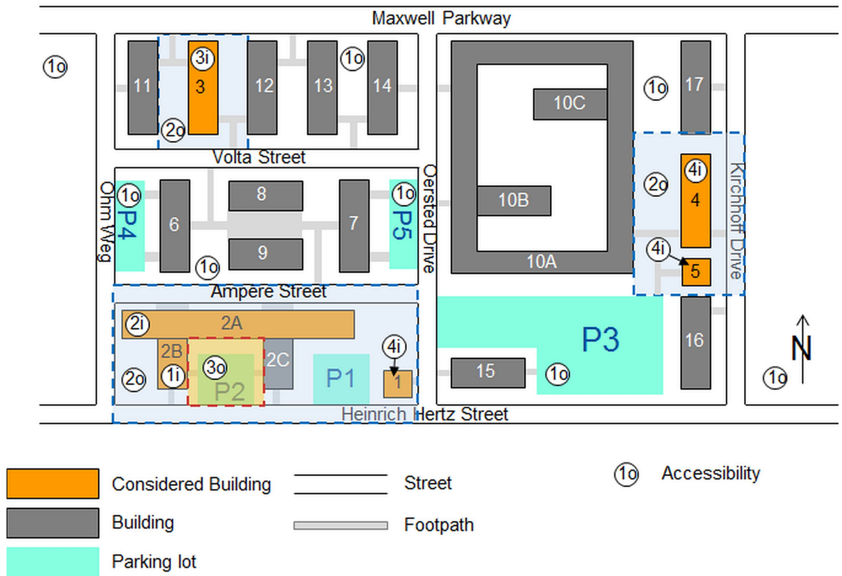

Fig. A.2 Location of the accessibility zones of a fictional infrastructure (Using the scale applied in table **??** (page **??**).)

system due to structural characteristics (e.g. barring, width of the path) or controls. If the mobility (M_t) of the systems typical of the traffic areas and routes deviates from the minimum required mobility (M_e), this is noted in the blue boxes. For example, the Kirchhoff Drive is usually used only by systems with a mobility $M \geq 3$ (car, van, small truck). Due to its design, however, this road could also be used by a truck or a semitrailer.

A.3 Energy Supply Network

The energy supply network of the fictional infrastructure was planned and implemented in compliance with the high availability compendium [1] issued in Volume M of the Federal Office for Security in Information Technology. Following the recommendation of a double feed-in of the energy supply[1], the fictitious infrastructure is supplied with electrical energy via the mains stations located in buildings 1 and 5. The *Main Distribution Frame* (MDF) of building 3 is fed exclusively via network station 1. In contrast, the main distribution frames of buildings 2A/B and 4 are fed both via the network station 1 and via the network station 2. In each building of the fictional infrastructure, a *Distribution Frame* (DF) is connected behind the MDF. The rooms are then supplied with electrical energy from the subdivisions of

[1] measure VM.11.19

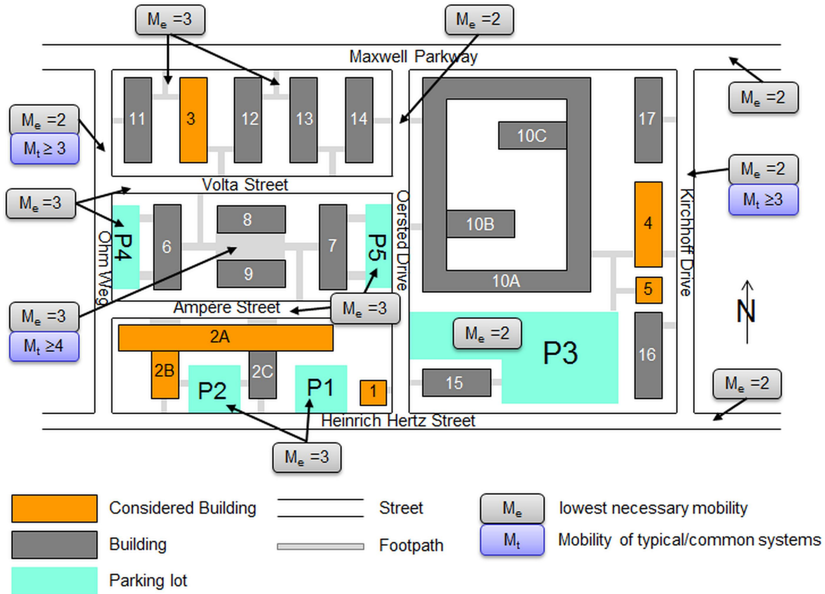

Fig. A.3 Mobility of traffic areas and routes in the vicinity of a fictional infrastructure

the floor. The described power supply network is installed in the form of a TN-S network[2] with differential current monitoring by a *Residial Current Monitor*[3].

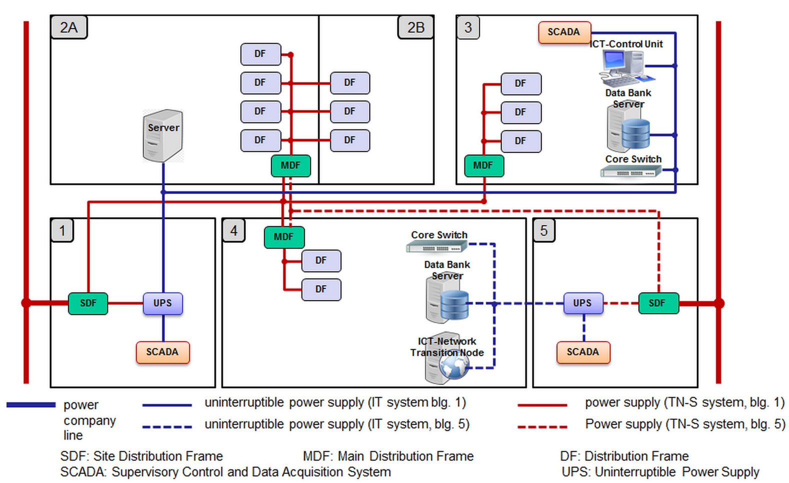

Fig. A.4 Network plan of the electrical power supply of the fictitious infrastructure (solid line: supply by network station 1; dashed line: supply by network station 2; blue: UPS buffered feed

[2] measure VM.11.25

[3] measure VM.11.26

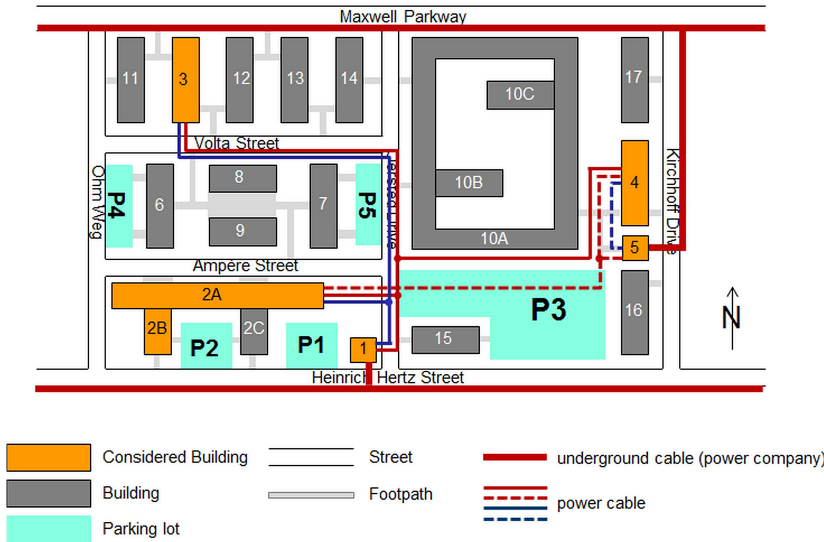

Fig. A.5 Local history of the power supply lines of the fictional infrastructure

In parallel with this power supply network, two uninterrupted power supply networks are deployed in the infrastructure. The uninterruptible power supply (UPS) installed in the building 1 supplies the servers in the building 2A as well as those in the building 3, the ICT network control center and the data center II. The UPS in building 5 feeds the ICT network transition note and the data center I. Both UPS are voltage and frequency independent power supplies (VFI-UPS) which on the one hand support the downstream network at outreach of the power network for a sufficiently long time and simultaneously trigger the targeted shutdown of the supplied computers and servers. Both UPS can be maintained remotely from the ICT control center. The power supply network supported by the UPS was installed in the form of an IT network (without neutral conductor). The local course of the power supply lines on the premises of the fictional infrastructure is shown in Figure A.4.

A.4 Information and Communication Network

The basic structure of the information and communication network (ICT network) of the fictional infrastructure is formed by the data centers installed in the buildings 3 and 4, each consisting of a core switch and a downstream server farm. Both core switches are connected via board-band optical fiber line[4] to the ICT network transition note installed in the building 4 as well as to one another. The core switch in building 3 is also connected to the ICT control centre. The data of the two server farms are available as the main data center (building 3) and backup data center

[4] green marked connections in figure A.6

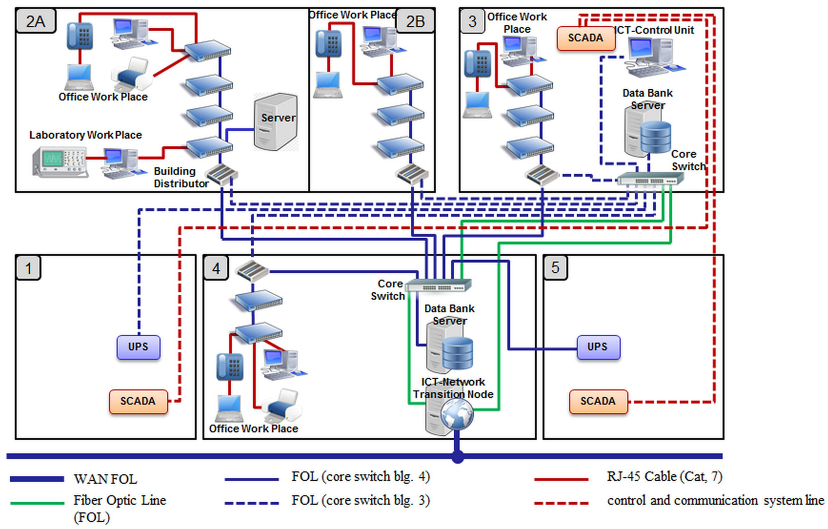

Fig. A.6 Network plan of the ICT network of the fictional infrastructure

(building 4) pursued. In regular operation, the data of the main data center are always mirrored to the backup data center, so that these data remain available in the event of failure of the main data center.

In this sense, all building distributors are connected to both core switches. Within the buildings, a subdivision is installed for each floor, via which the respective office and laboratory workstations are connected to the ICT network. The ICT cabling within the buildings was realised using RJ45 cable (Cat. 7 S/FTP) and between the buildings as optical fiber cables.

The control technology (SCADA) installed in buildings 1 and 5 is connected in a star-shaped manner to the central control unit in building 3, independently of the ICT network.

EMI Risk Management

Generic Infrastructure

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Generic Infrastructure - Objective

- System for explaining individual analysis steps
- Model: Control center of a technical supply infrastructure
  - –Network control center of an power company
  - –Water supply network control unit
  - –Traffic management unit or
  - –A cross-regional logistics network hub

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Generic Infrastructure - Characteristics

- System elements distributed across multiple buildings.
- Stationary
- Computer center
- External bindings
- 95% availability required
- Focus on energy supply & IT system

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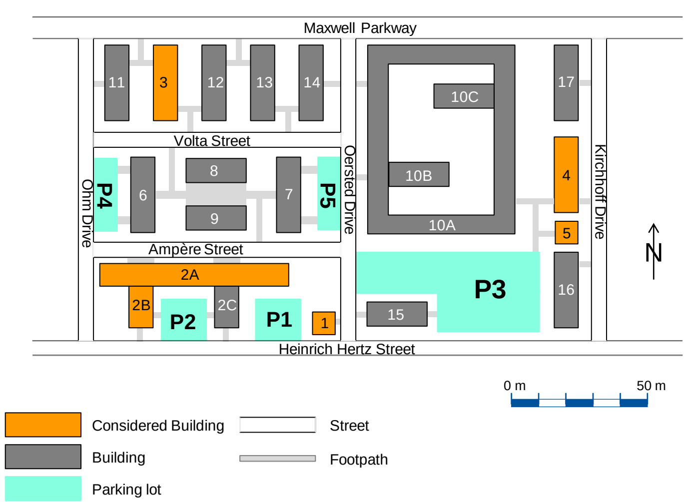
Generic Infrastructure – Ground Plan



Building 1 – Power Network Station 1

- **Location:** The building 1 is located on the northern edge of the shown area, on the Entrance of the *Oersted Drive* to *Heinrich Hertz Street*.
- **Construction:** The net station 1 is a one-story building built with mortar from brick. On the north side there is an access point made of steel and a ventilation opening shielded with a honeycomb grid.
- **Accessibility**: Access to the building is through a closed steel door. Only the operating staff has a key to open the door.
- **Function**: In the building is the network station 1 (SDF 1) including an uninterruptible power supply (UPS 1) and the associated control technology (SCADA).

Building 2A

- **Location:** The building 2A is located in the southwestern quadrant of the shown area on *Ampére Street*. Two outbuildings (buildings 2B and buildings 2C) are installed in the south. The building 2B is connected to the building 2A and belongs to the considered infrastructure facility. There is no access between the building 2A and the building 2C. The building 2C does not belong to the considered infrastructure. To the south of the building, on *Heinrich Hertz Street* are the parking areas P2 and P3. The parking area P2 is managed and can only be accessed with an access card.
- **Construction:** Building 2A is a four-story reinforced concrete building. The interior was constructed in dry walling.
- **Accessibility**: The ground floor and the 1 floor are freely accessible to the general public. The 2 and 3. floor is secured by a doorman service.
- **Function**: There are offices throughout the building. On the ground floor and on the 1 floor there are also laboratory rooms. In selected rooms of the 2nd and 3rd floors local servers are operated.

Building 2B

- **Location:** The building 2B is an extension to the building 2A. Immediately in front of the building is the limited parking space P2.
- **Construction:** Building 2B is a three-story reinforced concrete building. The interior was constructed in dry walling.
- **Accessibility**: The entire building is freely accessible to the general public..
- **Function**: The building 2B is used as an office building.

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Building 3

- **Location:** Building 3 is located on the northern edge of the viewed area, between *Maxwell Parkway* and *Volta Street*. The building is part of a building row consisting of five similar buildings. Between the buildings there are lawns and footpaths.
- **Construction:** The building is designed in the form of a three-story, limestone sandstone-brick massive building.
- **Accessibility**: Access to the building can only be made after identification by means of an access card
- **Function**: Building 4 contains the ICT network control center, the management of building control technology for the entire infrastructure, office work places and the data center II, consisting of a core switch and a database server farm.

Building 4

- **Location:** Building 4 is located on the eastern edge of the viewed area, north of Building 5, in the middle of *Kirchhoff Drive*. Southwest of the building lies the parking lot P3, which is freely accessible and regularly used by trucks.
- **Construction:** Building 4 was built as a steel frame building with combined glass/metal facade. The interior was constructed in dry walling.
- **Accessibility**: Access to Building 4 is limited to the employees of ICT maintenance team. After identification by means of an access card, these can enter the building through an access lock (revolving door). All remaining employees and non-service personnel receive access only after identity and pocket control.
- **Function**: Building 4 contains office work places, the data center I, with a core switch, a database server farm and the network transition node of the ICT network to the Internet.

Building 5 – Power Network Station 2

- **Location:** The building 5 is located on the eastern edge of the shown area, south of building 4, in the middle of the *Kirchhoff Drive*. Southwest of the building lies the parking lot P3, which is freely accessible and regularly used by trucks.
- **Construction:** The net station 1 is a one-story building built with mortar from brick. On the north side there is an access point made of steel and a ventilation opening shielded with a honeycomb grid.
- **Accessibility**: Access to the building is through a closed steel door. Only the operating staff has a key to open the door.
- **Function**: In the building is the network station 2 (SDF 2) including an uninterruptible power supply (UPS 2) and the associated control technology (SCADA).

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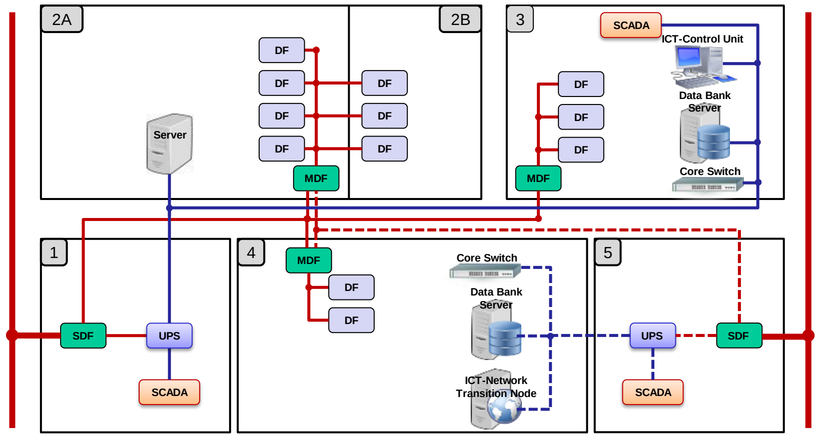
Generic Infrastructure – Power Supply



power company line — uninterruptible power supply (IT system blg. 1) — power supply (TN-S system, blg. 1)
uninterruptible power supply (IT system, blg. 5) — Power supply (TN-S system, blg. 5)

SDF: Site Distribution Frame MDF: Main Distribution Frame DF: Distribution Frame
SCADA: Supervisory Control and Data Acquisition System UPS: Uninterruptible Power Supply

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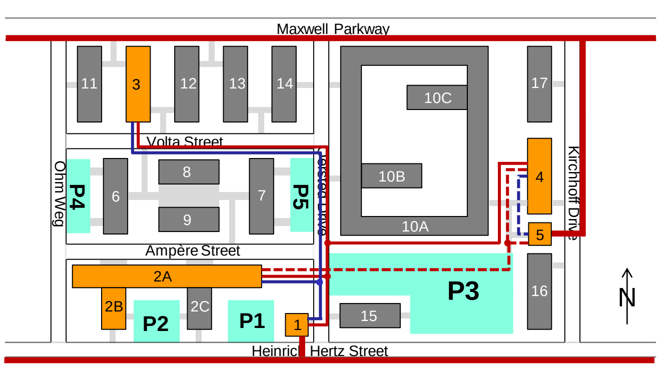
Generic Infrastructure – Power Supply



Considered Building — Street — underground cable (power company)
Building — Footpath — power cable
Parking lot

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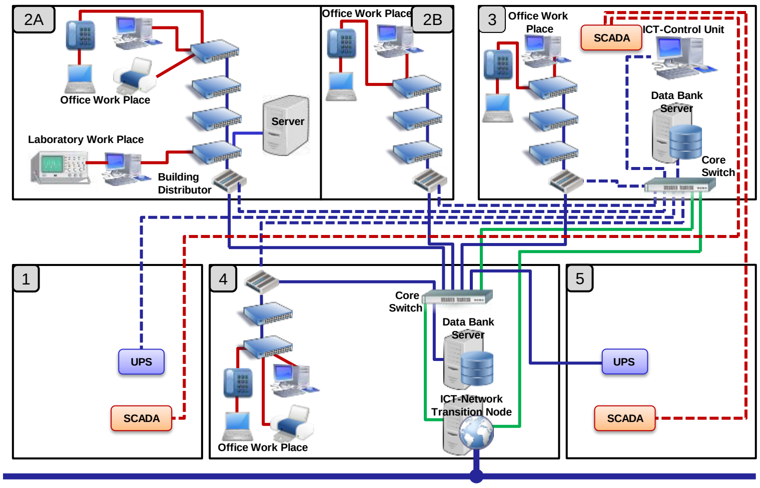
Generic Infrastructure – IT-Network



WAN FOL — FOL (core switch blg. 4) — RJ-45 Cable (Cat, 7)

Fiber Optic Line (FOL) — FOL (core switch blg. 3) — control and communication system line

SCADA: Supervisory Control and Data Acquisition System

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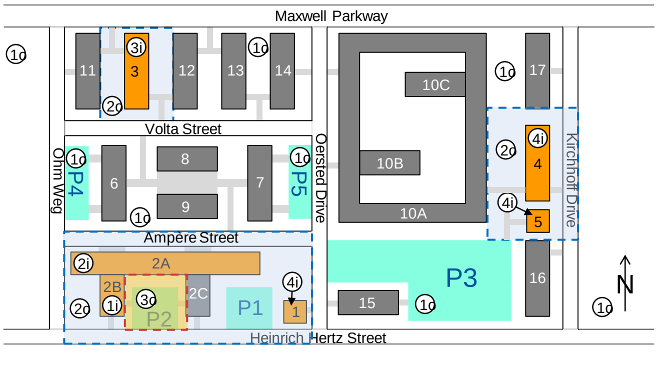
Generic Infrastructure – Accessibility



Considered Building — Street — Accessibility

Building — Footpath

Parking lot

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Generic Infrastructure – Accessibility, Scale

Level (A_z)	Acces-sibility	outside	inside	Definition
1o	free	X		Area of the **general public (outdoors)** accessible to each person without special effort.
1i	free		X	Area of the **general public (indoors)** accessible to each person without special effort.
2o	monitored	X		Area of the general public whose access is or can be **monitored**.
2i	monitored		X	Area in a building whose access is or can be **monitored**.
3o	controlled	X		Outdoor area that can only be entered after an **identity check**
3i	controlled		X	Area in a building that can only be entered after an **identity check**
4o	restricted	X		Outdoor control / restricted area that can only be accessed by **authorized persons** or after a **pocket check**.
4i	restricted		X	Control / restricted area in the building, which can only be entered by **authorized persons** or after a **pocket check**.

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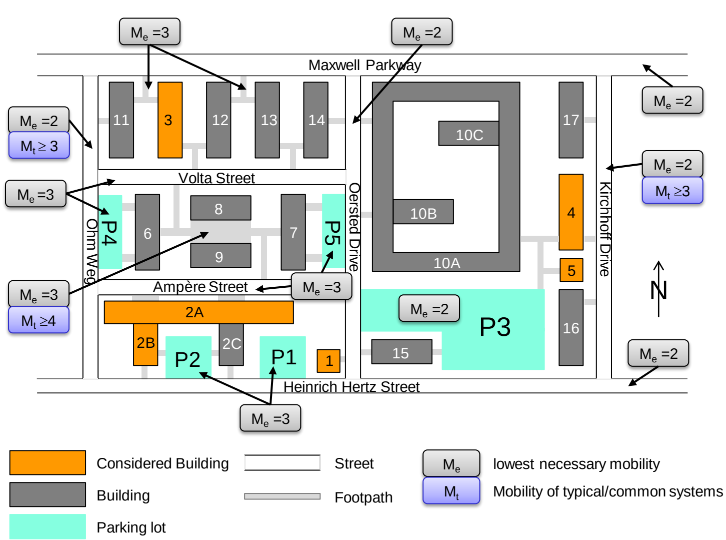
Generic Infrastructure – Mobility



Generic Infrastructure – Mobility, Scale

Level (M)	Mobility	Volume	Example
1	stationary	> 77m^3	Fixed installation
2	transportable	10 - 77m^3	light truck – 40‘ Container
3	mobil	0,2 – 10 m^3	car / van
4	very mobil	0,02 – 0,2 m^3	briefcase
5	highly mobile	< 0,02 m^3	beverage can

Appendix B
Exercises

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EMI Risk Management - Exercise

3.2.1 Preliminary Hazard List (PHL)

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PHL – Exercise / Home Work

Tasks 3.2.1:

Identified and list possible EMI hazards for the system parts of the fictional generic infrastructure installed in the building 2A by employing the PHL.

PHL - Process

1) Detection of potential sources of interference
2) Detection of possible coupling paths
3) Estimation of possible effects
4) Documentation

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PHL – 1.) Detection of potential sources of interference

– Systematic detection of potential sources of interference and their locations
– Objective: Detection of as many sources of interference as possible (comprehensive detection)
– Approach: Capture of source classes
  here: Mobility of sources of interference

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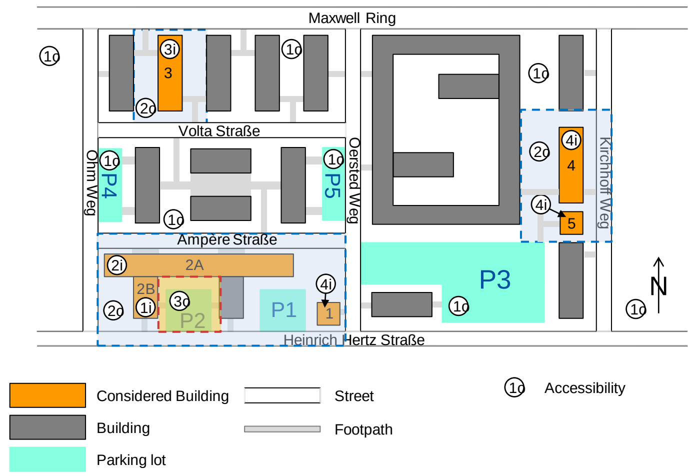
Generic Infrastructure – Accessibility



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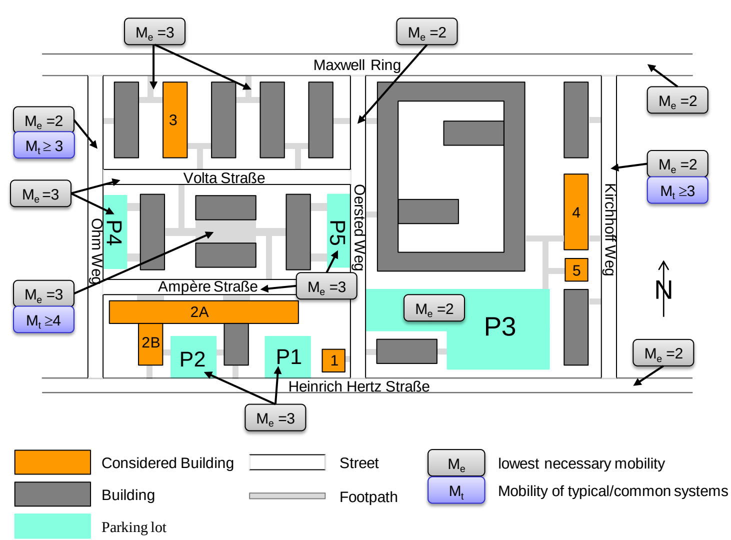
Generic Infrastructure – Mobility



PHL – 1.) Detection of potential sources of interference

M = 2:

- Heinrich Hertz Straße
- Ohm Weg
- Oersted Weg
- Parking Lot P3

M = 3:

- Ampere Straße
- Parking Lot P1
- Parking Lot P2
- Parking Lot P4

M ≥ 4:

- Building 2A
- Building 2B
- Building 2C*
- Area around Building 2
- Building 7*

PHL – 2.) Detection of possible coupling paths

Systematic registration:

1) Affected subsystems
2) Possible coupling paths (e.g. type and length)

Building 2A

- **Location:** The building 2A is located in the southwestern quadrant of the shown area on *Ampére Straße*. Two outbuildings (buildings 2B and buildings 2C) are installed in the south. The building 2B is connected to the building 2A and belongs to the considered infrastructure facility. There is no access between the building 2A and the building 2C. The building 2C does not belong to the considered infrastructure. To the south of the building, on *Heinrich Hertz Straße* are the parking areas P2 and P3. The parking area P2 is managed and can only be accessed with an access card.
- **Construction:** Building 2A is a four-story reinforced concrete building. The interior was constructed in dry walling.
- **Accessibility**: The ground floor and the 1 floor are freely accessible to the general public. The 2 and 3. floor is secured by a doorman service.
- **Function**: There are offices throughout the building. On the ground floor and on the 1 floor there are also laboratory rooms. In selected rooms of the 2nd and 3rd floors local servers are operated.

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Building 2B

- **Location:** The building 2B is an extension to the building 2A. Immediately in front of the building is the limited parking space P2.
- **Construction:** Building 2B is a three-story reinforced concrete building. The interior was constructed in dry walling.
- **Accessibility**: The entire building is freely accessible to the general public..
- **Function**: The building 2B is used as an office building.

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PHL – 2.1) Registration of affected subsystems

Description Function Building 2:

- –Office work places (total building)
- –Laboratory work places (ground floor & 1. floor)
- –Server (2. & 3. floor)
- –Main Distribution Frame (MDF) (ground floor)
- –ICT building distribution (ground floor)

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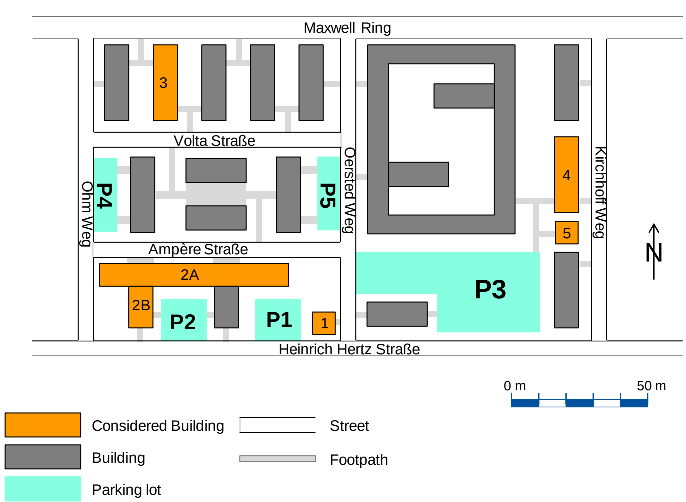
Generic Infrastructure – Ground Plan



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PHL – 2.2) Registration of Possible coupling paths

1	2	3	4	5	6	7
Ref. Nr.	Possible EMI Source		Possible Coupling Path		Affected Subsystem	Possible Effect
	Mobility	Possible Location	Type	Distance		
2.1	M = 2 (transportable)	Heinrich Hertz Straße	radiated	20 m	a) Office work places b) Laboratory work places c) Server d) MDF e) ICT building distribution	
2.2		Ohm Weg		2 – 70 m		
2.3		Oersted Weg		20 – 90 m		
2.4		Parking Lot P3		25 – 95 m		

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PHL – 3.) Estimation of possible effects

1) Malfunctions
2) Destruction of components/modules

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PHL – 3.) Estimation of possible effects

1	2	3	4	5	6	7
Ref. Nr.	Possible EMI Source		Possible Coupling Path		Affected Subsystem	Possible Effect
	Mobility	Possible Location	Type	Distance		
2.1	M = 2 (transportable)	Heinrich Hertz Straße	radiated	20 m	a) Office work places b) Laboratory work places c) Server d) MDF e) ICT Building distribution	i. Malfunctions ii. Destruction of components/ modules
2.2		Ohm Weg		2 – 70 m		
2.3		Oersted Weg		20 – 90 m		
2.4		Parking Lot P3		25 – 95 m		

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PHL – 4.) Documentation

1	2	3	4	5	6	7
Ref. Nr.	Possible EMI Source		Possible Coupling Path		Affected Subsystem	Possible Effect
	Mobility	Possible Location	Type	Distance		
2.1	M = 2 (transportable)	Heinrich Hertz Straße	radiated	20 m	a) Office work places b) Laboratory work places c) Server d) MDF e) ICT Building distribution	i. Malfunctions ii. Destruction of components/ modules
2.2		Ohm Weg		2 – 70 m		
2.3		Oersted Weg		20 – 90 m		
2.4		Parking Lot P3		25 – 95 m		

PHL – 4.) Documentation (2)

1	2	3	4	5	6	7
Ref. Nr.	Possible EMI Source		Possible Coupling Path		Affected Subsystem	Possible Effect
	Mobility	Possible Location	Type	Distance		
3.1	M = 3 (mobile)	Heinrich Hertz Straße	radiated	20 m	a) Office work places b) Laboratory work places c) Server d) MDF e) ICT Building distribution	i. Malfunctions ii. Destruction of components/ modules
3.2		Ohm Weg		2 – 70 m		
3.3		Oersted Weg		20 – 90 m		
3.4		Parking Lot P3		25 – 95 m		
3.5		Ampere Straße		2 m		
3.6		Parking Lot P1		5 m		
3.7		Parking Lot P2		5 m		
3.8		Parking Lot P4		10 – 50 m		

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PHL – 4.) Documentation (3)

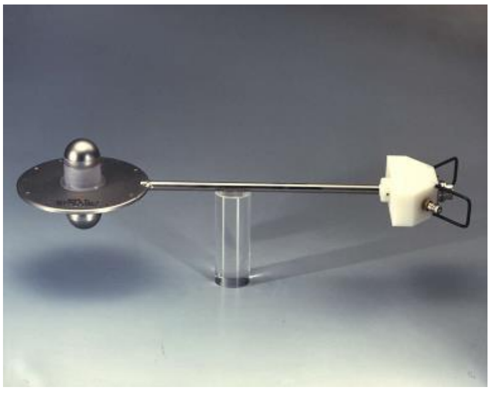
1	2	3	4	5	6	7
Ref. Nr.	Possible EMI Source		Possible Coupling Path		Affected Subsystem	Possible Effect
	Mobility	Possible Location	Type	Distance		
4.1	M = 4 (very mobile)	Heinrich Hertz Straße	radiated	20 m	a) Office work places b) Laboratory work places c) Server d) MDF e) ICT Building distribution	i. Malfunctions
4.2		Ohm Weg		2 – 70 m		
4.3		Oersted Weg		20 – 90 m		
4.4		Parking Lot P3		25 – 95 m		
4.5		Ampere Straße		2 m		
4.6		Parking Lot P1		5 m		
4.7		Parking Lot P2		5 m		
4.8		Parking Lot P4		10 – 50 m		

PHL – 4.) Documentation (4)

1	2	3	4	5	6	7
Ref. Nr.	Possible EMI Source		Possible Coupling Path		Affected Subsystem	Possible Effect
	Mobility	Possible Location	Type	Distance		
4.9	M = 4 (very mobile)	Building 2A	radiated	≤ 10 m	a) Office work places b) Laboratory work places c) Server d) MDF e) ICT Building distribution	i. Malfunctions
4.10		Building 2B		1 – 10 m		
4.11		Building 2C*		1 – 10 m		
4.12		Area around Building 2		1 – 10 m		
4.13		Building 7*		10 - 50 m		

Thank You for Your Attention.

Questions ?



EMI Risk Management - Exercise

3.2.2 Preliminary Hazard Analysis (PHA)

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PHA – Exercise / Home Work

Tasks 3.2.2:

Identify, list and evaluate possible EMI hazards for the system parts of the fictional generic infrastructure installed in the building 2A by employing the PHA.

It might be helpful to start from the documentation of task 3.2.1.

PHA - Process

1) Detection of potential sources of interference
2) Detection of possible coupling paths
3) Weighting of possible coupling paths
4) Estimation of possible effects
5) Evaluation of effects
6) Identification of risk management measures
7) Documentation

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PHA - Process

1) Detection of potential sources of interference
2) Detection of possible coupling paths
3) Weighting of possible coupling paths
4) Estimation of possible effects
5) Evaluation of effects
6) Identification of risk management measures
7) Documentation

(Items 1–4: PHL)

PHA – Starting Point PHL Documentation (M = 4)

1	2	3	4	5	6	7
Ref. Nr.	Possible EMI Source		Possible Coupling Path		Affected Subsystem	Possible Effect
	Mobility	Possible Location	Type	Distance		
4.1	M = 4 (very mobile)	Heinrich Hertz Straße	radiated	20 m	a) Office work places b) Laboratory work places c) Server d) MDF e) ICT Building distribution	i. Malfunctions
4.2		Ohm Weg		2 – 70 m		
4.3		Oersted Weg		20 – 90 m		
4.4		Parking Lot P3		25 – 95 m		
4.5		Ampere Straße		2 m		
4.6		Parking Lot P1		5 m		
4.7		Parking Lot P2		5 m		
4.8		Parking Lot P4		10 – 50 m		

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PHA – Starting Point PHL Documentation (M = 4)

1	2	3	4	5	6	7
Ref. Nr.	Possible EMI Source		Possible Coupling Path		Affected Subsystem	Possible Effect
	Mobility	Possible Location	Type	Distance		
4.9	M = 4 (very mobile)	Building 2A	radiated	≤ 10 m	a) Office work places b) Laboratory work places c) Server d) MDF e) ICT Building distribution	i. Malfunctions
4.10		Building 2B		1 – 10 m		
4.11		Building 2C*		1 – 10 m		
4.12		Area around Building 2		1 – 10 m		
4.13		Building 7*		10 - 50 m		

PHA – 1.) Detection of potential sources of interference

Asumption: HPEM Source Typ M4-2:MB-b-2

$$E_{max} \cdot r = 227 \text{ kV}$$

PHA – 1.) Detection of potential sources of interference

1	2	2a	2b	2c	3	…	7
Ref. Nr.	Possible EMI Source					…	Possible Effect
	Mobility	Type	P_{EMI}	$E_{max} \cdot r$	Possible Location		
4.9.1	M = 4 (very mobile)	M4-2:MB-b-2		227 kV	Building 2A (ground & 1. floor)		
4.9.2					Building 2A (2. & 3. floor)		

PHA – 2.) Detection of possible coupling paths

1	2	2a	2b	2c	3	4	5	5a	6
Ref. Nr.	Possible EMI Source					Possible Coupling Path			Affected Subsystem
	Mobility	Type	P_{EMI}	$E_{max} \cdot r$	Possible Location	Type	Dis-tance	Atten-uation	
4.9.1.a	M = 4 (very mobile)	M4-2: MB-b-2		227 kV	Building 2A (ground & 1. floor)	radiated			Office work places
4.9.1.b									Laboratory work places
4.9.1.c									Server
4.9.1.d									MDF
4.9.1.e									ICT building distribution

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PHA – 2.) Detection of possible coupling paths

1	2	2a	2b	2c	3	4	5	5a	6
Ref. Nr.	Possible EMI Source					Possible Coupling Path			Affected Subsystem
	Mobility	Type	P_{EMI}	$E_{max} \cdot r$	Possible Location	Type	Dis-tance	Atten-uation	
4.9.2.a	M = 4 (very mobile)	M4-2: MB-b-2		227 kV	Building 2A (2. & 3. floor)	radiated			Office work places
4.9.2.b									Laboratory work places
4.9.2.c									Server
4.9.2.d									MDF
4.9.2.e									ICT building distribution

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PHA – 3.) Weighting of possible coupling paths

1	2	2a	2b	2c	3	4	5	5a	6
Ref. Nr.	Possible EMI Source					Possible Coupling Path			Affected Subsystem
	Mobility	Type	P_{EMI}	$E_{max} \cdot r$	Possible Location	Type	Dis-tance	Atten-uation	
4.9.1.a	M = 4 (very mobile)	M4-2: MB-b-2		227 kV	Building 2A (ground & 1. floor)	radiated	≤ 5 m		Office work places
4.9.1.b							≤ 10 m		Laboratory work places
4.9.1.c							6 m / 9 m		Server
4.9.1.d							≤ 5 m		MDF
4.9.1.e							≤ 5 m		ICT building distribution

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PHA – 3.) Weighting of possible coupling paths

1	2	2a	2b	2c	3	4	5	5a	6
Ref. Nr.	Possible EMI Source					Possible Coupling Path			Affected Subsystem
	Mobility	Type	P_{EMI}	$E_{max} \cdot r$	Possible Location	Type	Dis-tance	Atten-uation	
4.9.2.a	M = 4 (very mobile)	M4-2: MB-b-2		227 kV	Building 2A (2. & 3. floor)	radiated	≤ 5 m		Office work places
4.9.2.b							3 - 9 m		Laboratory work places
4.9.2.c							≤ 5 m		Server
4.9.2.d							6 m / 9 m		MDF
4.9.2.e							6 m / 9 m		ICT building distribution

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PHA – 3.) Weighting of possible coupling paths

Geometric damping due to distance and spherical field propagation:

$$D_{dB} = 20 \cdot \lg\left(\frac{1\text{m}}{r}\right)$$

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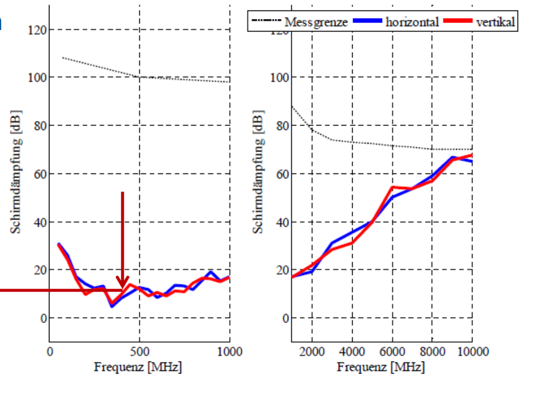
PHA – 3.) Weighting of possible coupling paths

Damping due to propagation through floor and ceiling

f = 340 MHz → 5 dB



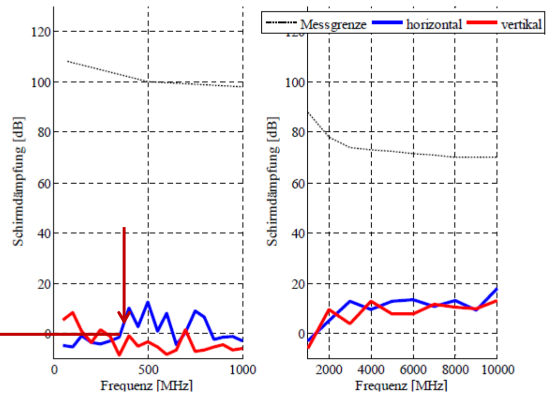
Damping of EM fields by concrete as floor ceiling element

Source: Frenzel, T., J. Rohde und J. Opfer: Elektromagnetische Schirmung von Gebäuden, Band BSITR-03209. BSI, 2007

PHA – 3.) Weighting of possible coupling paths

Damping due to propagation through walls

f = 340 MHz → 0 dB



Damping of EM fields by plasterboard as dry building wall with thermal insulation

Source: Frenzel, T., J. Rohde und J. Opfer: Elektromagnetische Schirmung von Gebäuden, Band BSITR-03209. BSI, 2007

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PHA – 3.) Weighting of possible coupling paths

1	2	2a	2b	2c	3	4	5	5a	6
Ref. Nr.	Possible EMI Source					Possible Coupling Path			Affected Subsystem
	Mobility	Type	P_{EMI}	$E_{max} \cdot r$	Possible Location	Type	Dis-tance	Atten-uation	
4.9.1.a	M = 4 (very mobile)	M4-2: MB-b-2		227 kV	Building 2A (ground & 1. floor)	radiated	≤ 5 m	≤ 14 dB	Office work places
4.9.1.b							≤ 10 m	≤ 20 dB	Laboratory work places
4.9.1.c							6 m / 9 m	25 dB / 34 dB	Server
4.9.1.d							≤ 5 m	≤ 14 dB	MDF
4.9.1.e							≤ 5 m	≤ 14 dB	ICT building distribution

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PHA – 3.) Weighting of possible coupling paths

1	2	2a	2b	2c	3	4	5	5a	6
Ref. Nr.	Possible EMI Source					Possible Coupling Path			Affected Subsystem
	Mobility	Type	P_{EMI}	$E_{max} \cdot r$	Possible Location	Type	Dis-tance	Atten-uation	
4.9.2.a	M = 4 (very mobile)	M4-2: MB-b-2		227 kV	Building 2A (2. & 3. floor)	radiated	≤ 5 m	≤ 14 dB	Office work places
4.9.2.b							3 - 9 m	15 – 34 dB	Laboratory work places
4.9.2.c							≤ 5 m	≤ 14 dB	Server
4.9.2.d							6 m / 9 m	25 dB / 34 dB	MDF
4.9.2.e							6 m / 9 m	25 dB / 34 dB	ICT building distribution

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PHA – 4.) Estimation of possible effects

1) Malfunctions
2) Destruction of components/modules

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PHA – 4.) Estimation of possible effects

1	…	6	7	8	9	10	11
Ref. Nr.	…	Affected Subsystem	Possible Effect	Conse-quence	Criticality / Severity	Likelihood	Level of Risk (w/o meas.)
4.9.1.a.i		Office work places	Malfunctions				
4.9.1.a.ii			Destruction of components				
4.9.1.b.i		Laboratory work places	Malfunctions				
4.9.1.b.ii			Destruction of components				
4.9.1.c		Server	Malfunctions				
4.9.1.d		MDF	Malfunctions				
4.9.1.e.i		ICT building distribution	Malfunctions				
4.9.1.e.ii			Destruction of components				

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PHA – 4.) Estimation of possible effects

1	…	6	7	8	9	10	11
Ref. Nr.	…	Affected Subsystem	Possible Effect	Conse-quence	Criticality / Severity	Likelihood	Level of Risk (w/o meas.)
4.9.2.a.i		Office work places	Malfunctions				
4.9.2.a.ii			Destruction of components				
4.9.2.b		Laboratory work places	Malfunctions				
4.9.2.c.i		Server	Malfunctions				
4.9.2.c.ii			Destruction of components				
4.9.2.d		MDF	Malfunctions				
4.9.2.e		ICT building distribution	Malfunctions				

PHA – 5.) Evaluation of effects

1) Malfunctions

2) Destruction of components/modules

Risk evaluation – Severity of Potential consequences

S	Severity	criterion
1	Negligible	No or minor effects occur; the system can fulfill his mission without disturbances.
2 – 3	Limited/ Marginal	The appearing effects cause functional restrictions or working difficulties. They do not influence the main mission.
4 – 6	Severe	The appearing effects reduce the efficiency and capability of the system.
7 – 8	Very severe	The appearing effects prevent that the system is able to fulfill its main function or mission.
9 - 10	Catastrophic	Effects could result in one or more of the following: death of human being, permanent total damage, irreversible significant environmental impact.

PHA – 5.) Evaluation of effects

1	…	6	7	8	9	10	11
Ref. Nr.	…	Affected Subsystem	Possible Effect	Conse-quence	Criticality / Severity	Likelihood	Level of Risk (w/o meas.)
4.9.1.a.i		Office work places	Malfunctions	Breakdown work place	2 – 3 Marginal		
4.9.1.a.ii			Destruction of components				
4.9.1.b.i		Laboratory work places	Malfunctions				
4.9.1.b.ii			Destruction of components				
4.9.1.c		Server	Malfunctions	reduced efficiency	4 – 6 (Severe)		
4.9.1.d		MDF	Malfunctions	Disturbed energy supply	7 (Very Severe)		
4.9.1.e.i		ICT building distribution	Malfunctions	Disturbed ICT network	4 – 6 (Severe)		
4.9.1.e.ii			Destruction of components	Outage ICT network	7 (Very Severe)		

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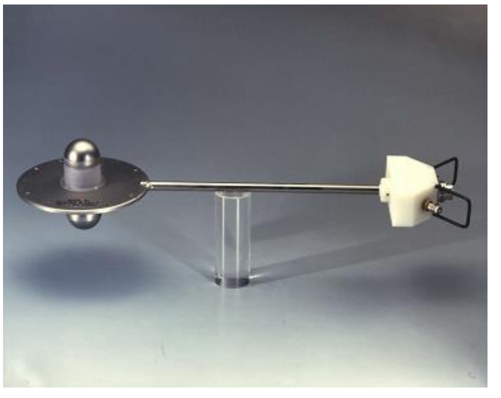
PHA – 5.) Evaluation of effects

1	…	6	7	8	9	10	11
Ref. Nr.	…	Affected Subsystem	Possible Effect	Conse-quence	Criticality / Severity	Likelihood	Level of Risk (w/o meas.)
4.9.2.a.i		Office work places	Malfunctions	Breakdown work place	2 – 3 Marginal		
4.9.2.a.ii			Destruction of components				
4.9.2.b		Laboratory work places	Malfunctions				
4.9.2.c.i		Server	Malfunctions	reduced efficiency	4 – 6 (Severe)		
4.9.2.c.ii			Destruction of components	functional restrictions	7 (Very Severe)		
4.9.2.d		MDF	Malfunctions	Disturbed energy supply	7 (Very Severe)		
4.9.2.e		ICT building distribution	Malfunctions	Disturbed ICT network	4 – 6 (Severe)		

Thank You for Your Attention.

Questions ?



1	2	2a	2b	2c	3	4	5	5a	6	7	8	9	10	11
Ref. Nr.	Possible EMI Source					Possible Coupling Path			Affected Subsystem	Possible Effect	Consequence	Criticality / Severity	Likelihood	Level of Risk (w/o meas.)
	Mobility	Type	P_{EMI}	$E_{max} \cdot r$	Possible Location	Type	Distance	Atten-uation						
4.9.1.a.i	M = 4 (very mobile)	M4-2:MB-b-2		227 kV	Building 2A (ground & 1. floor)	radiated	≤ 5 m	≤ 14 dB	Office work places	Malfunctions	Breakdown work place	2 – 3 Marginal		
4.9.1.a.ii										Destruction of components				
4.9.1.b.i							≤ 10 m	≤ 20 dB	Laboratory work places	Malfunctions				
4.9.1.b.ii										Destruction of components				
4.9.1.c							6 m / 9 m	25 dB / 34 dB	Server	Malfunctions	reduced efficiency	4 – 6 (Severe)		
4.9.1.d							≤ 5 m	≤ 14 dB	MDF	Malfunctions	Disturbed energy supply	7 (Very Severe)		
4.9.1.e.i							≤ 5 m	≤ 14 dB	ICT building distribution	Malfunctions	Disturbed ICT network	4 – 6 (Severe)		
4.9.1.e.ii										Destruction of components	Outage ICT network	7 (Very Severe)		

1	2	2a	2b	2c	3	4	5	5a	6	7	8	9	10	11
Ref. Nr.	Possible EMI Source					Possible Coupling Path			Affected Subsystem	Possible Effect	Consequence	Criticality / Severity	Likelihood	Level of Risk (w/o meas.)
	Mobility	Type	P_{EMI}	$E_{max} \cdot r$	Possible Location	Type	Distance	Atten-uation						
4.9.1.a.i	M = 4 (very mobile)	M4-2:MB-b-2		227 kV	Building 2A (2. & 3. floor)	radiated	≤ 5 m	≤ 14 dB	Office work places	Malfunctions	Breakdown work place	2 – 3 Marginal		
4.9.1.a.ii										Destruction of components				
4.9.1.b							3 - 9 m	15 – 34 dB	Laboratory work places	Malfunctions				
4.9.1.c.i							≤ 5 m	≤ 14 dB	Server	Malfunctions	reduced efficiency	4 – 6 (Severe)		
4.9.1.c.ii										Destruction of components	functional restrictions	7 (Very Severe)		
4.9.1.d							6 m / 9 m	25 dB / 34 dB	MDF	Malfunctions	Disturbed energy supply	7 (Very Severe)		
4.9.1.e							6 m / 9 m	25 dB / 34 dB	ICT building distribution	Malfunctions	Disturbed ICT network	4 – 6 (Severe)		

EMI Risk Management - Exercise

3.3.2 Structured What-if Technique (SWIFT)

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SWIFT – Exercise / Home Work

Tasks 3.3.2:

With the help of SWIFT, the possible EMI hazards for the system parts installed in building 1 of the fictional infrastructure should to be identified and recorded.

- The task should be handled in groups of 3-4 students.
- The result shall be documented in a short report

SWIFT - Process

1) Preparation
2) System description and specifications
3) Capture of previously known risks
4) Selection of a process step
5) Discussion of deviations
6) Risk identification
7) Evaluation of remediation measures
8) Documentation

SWIFT – 1.) Preparation

Prior to the workshop in which the analysis is conducted, the moderator creates a list with

- ‘Prompt’ words,
- Phrases and
- Questions

which are adapted to the system to be considered.

SWIFT – Process step

- **Example: Energy supply**
  - start-up / turning on
  - normal operation
  - full use of the capacity
  - malfunction (e.g. emergency shutdown, insulation violation, ground closure) and
  - shut down / Switch off
  - …

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SWIFT – ‘Prompt’ Words

- Field exposition
- Interference signal
- Malfunction
- Failure / shutdown
- Under voltage / over voltage
- Voltage drop / outrage
- …

SWIFT – Phrases

- What if,...?
- What would happen if...?
- How could...?
- Could anyone...?
- Could something...?
- Anyone ever...?
- Did anything ever...?
- …

SWIFT – Questions (examples)

- What if, building 1 would be irradiated by an EMI source (M = X/type) on location P?
- Could someone place an EMI source (M = X/type) in building 1?
- What would happen if subsystem S had a malfunction?
- What would happen if subsystem S failed/is shutdown?
- Could someone generate a wrong control signal on the signal line ?
- …?

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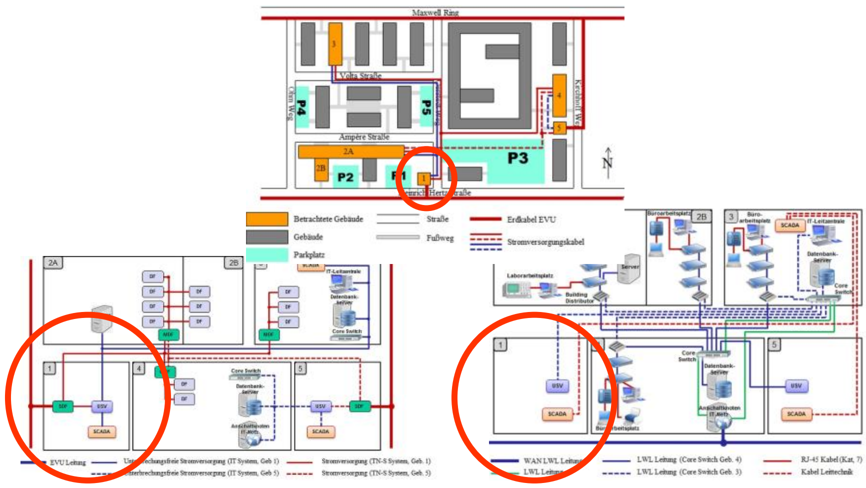
SWIFT – 2.) System description and specifications



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PHL – 2.) System description and specifications

- **Location:** The building 1 is located on the northern edge of the shown area, on the Entrance of the *Oersted Weg* to *Heinrich Hertz Straße*.
- **Construction:** The net station 1 is a one-story building built with **mortar from brick**. On the north side there is an access point made of steel and a ventilation opening shielded with a honeycomb grid.
- **Accessibility**: Access to the building is through a closed steel door. Only the operating staff has a key to open the door.
- **Function**: In the building is the **network station 1** (SDF 1) including an **uninterruptible power supply** (UPS 1) and the associated **control technology** (SCADA).

SWIFT – 3.) Capture of previously known risks

- Known risks
  - → none
- previous experiences and EMI events
  - → none are known
- known control and protection element
  - → redundant feeding of buildings 2A/B and 4
  - → uninterruptible power supply (UPS)
  - → overvoltage protection at the power supply feed-in
- Restrictions
  - → none

SWIFT – 4.) Selection of a process step

- Considered process step
  - – Regular operation at 70% utilization

SWIFT – 5.) Discussion of deviations

Q: What if, building 1 would be irradiated by an EMI source (**M = 3**) on **parking lot P1**?

A: **Field coupling** into the building. 1 (D = 0 dB)

Q: Could this **field coupling** lead to interference in subsystems?

A: Yes, **interference signal** in SCDADA

As a result, the UPS network 1 **shuts down**

As a result, the data center II, ICT control center and server in building 2A **shut down** also.

SWIFT – 5.) Discussion of deviations

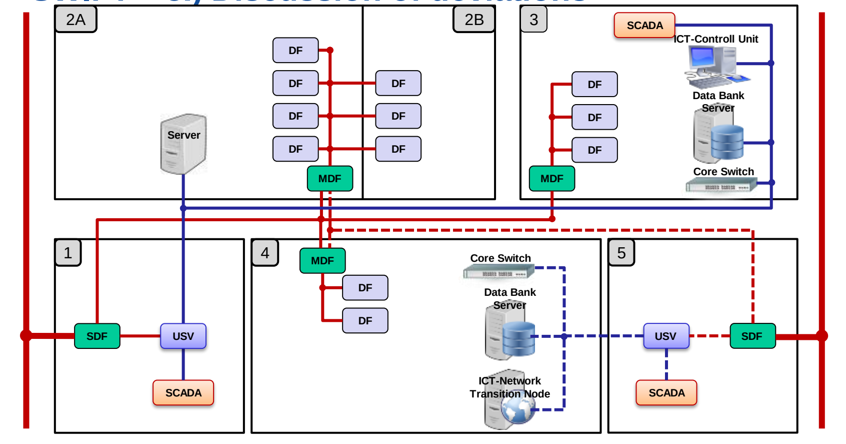
Q: What if, building 1 would be irradiated by an EMI source (**M = 2**) on **parking lot P3**?

A: **Field coupling** into the building. 1 (D = 0 dB)

Q: Could this **field coupling** lead to interference in subsystems?

A: …

SWIFT – 5.) Discussion of deviations



power company line — uninterruptible power supply (IT system blg. 1) — uninterruptible power supply (IT system, blg. 5) — power supply (TN-S system, blg. 1) — Power supply (TN-S system, blg. 5)

SDF: Site Distribution Frame MDF: Main Distribution Frame DF: Distribution Frame
SCADA: Supervisory Control and Data Acquisition System USV: Uninterruptible Power Supply

SWIFT – 6.) Risk identification

At the end of each expert discussion (workshop)

- identified risks (including their consequences) are summarized; and
- existing options to control risks considered.

SWIFT – 6.) Risk identification

Consequences:

–Server in the building. 2A temporarily not usable

–Data Center II Failure

⇒ loss of redundancy

⇒reduced performance

– Failure ICT control unit

Options to control:

⇒ restarting the UPS network

⇒ Filtering the signal lines

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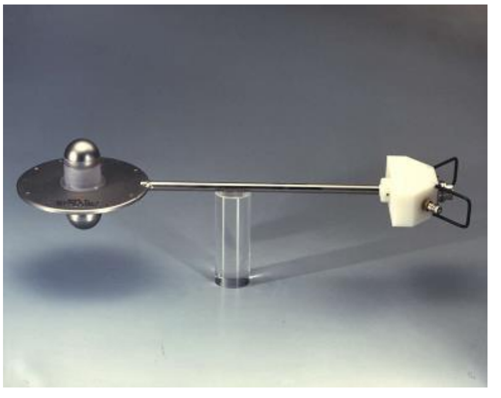
SWIFT – 7.) Evaluation of remediation measures

The expert's team:

- Checks whether the discussed controls are suitable and effective
- Prepares a statement on the effectiveness of risk controls
- Considers further risk treatment measures (if necessary)

Thank You for Your Attention.

Questions ?



EMI Risk Management - Exercise

Bow Tie Analysis (BTA)

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BTA – Exercise / Home Work

Tasks 3.3.7:

With the help of BTA, the possible EMI hazards for the system parts installed in building 1 of the fictional infrastructure should to be identified and depicted.

BTA - Process

1) Definition of Top Event - Hazard
2) Identification causes
3) Possible effects
4) Barriers/measures
5) Documentation

BTA - 1) Definition of Top Event - Hazard

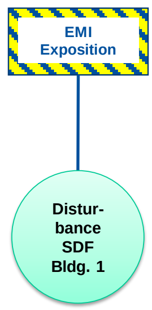
The Top Event

– results from the hazard.

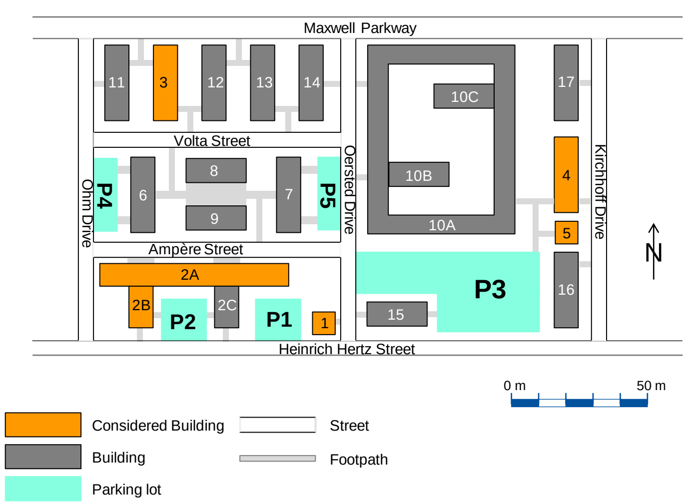
– must be controlled in order to prevent damage

– marks the boundary between effects and damage events.

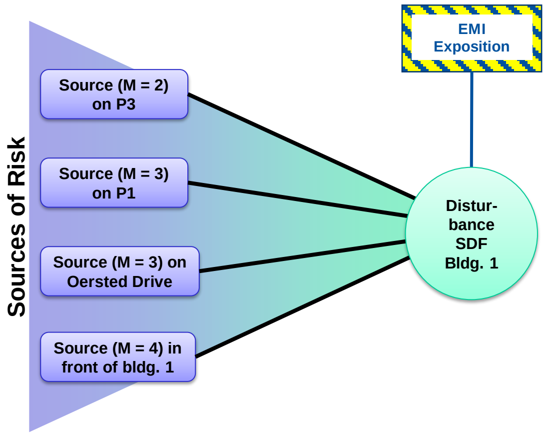
BTA – 1) Definition of Top Event - Hazard



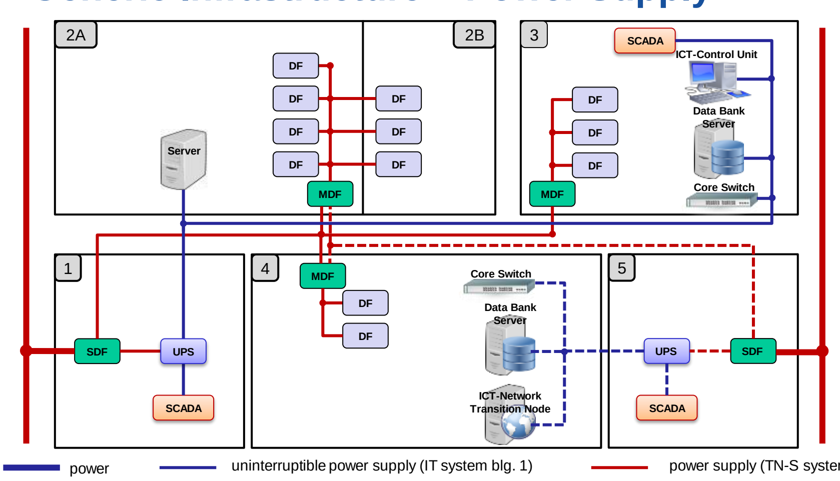
Generic Infrastructure – Ground Plan



BTA – 2) Identification causes



Generic Infrastructure – Power Supply



power company line
uninterruptible power supply (IT system blg. 1)
uninterruptible power supply (IT system, blg. 5)
power supply (TN-S system, blg. 1)
Power supply (TN-S system, blg. 5)

SDF: Site Distribution Frame
MDF: Main Distribution Frame
DF: Distribution Frame
SCADA: Supervisory Control and Data Acquisition System
UPS: Uninterruptible Power Supply

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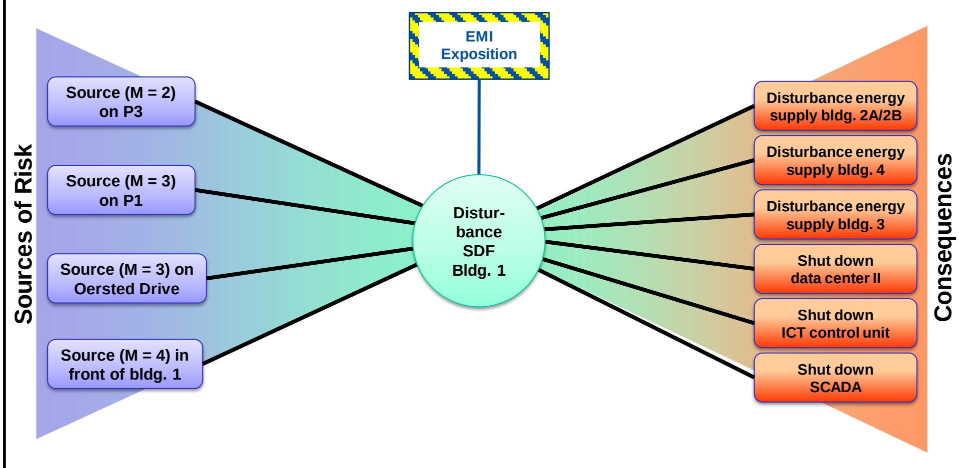
BTA – 3) Possible effects



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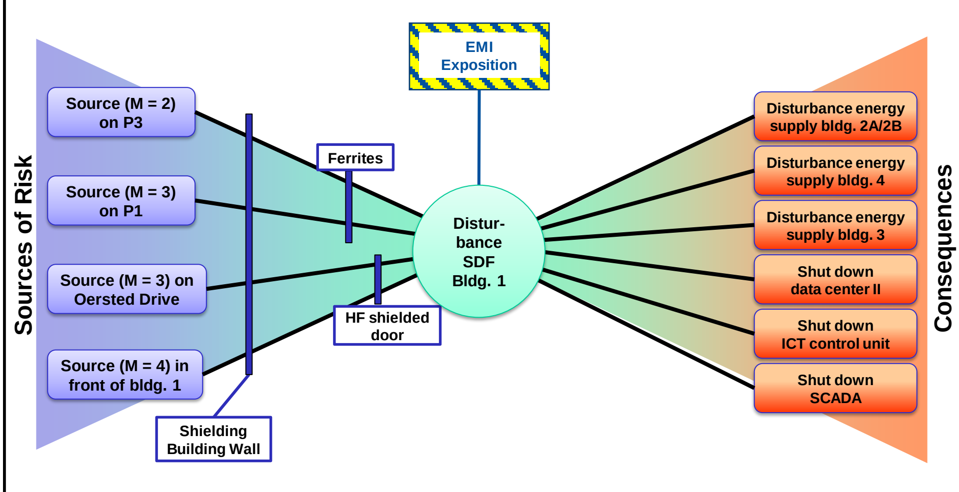
BTA – 4.1) Barriers



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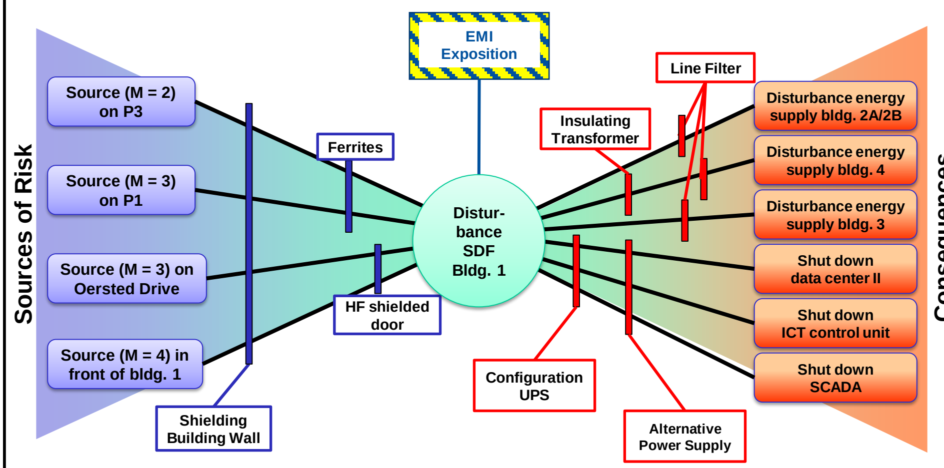
BTA – 4.2) Measures



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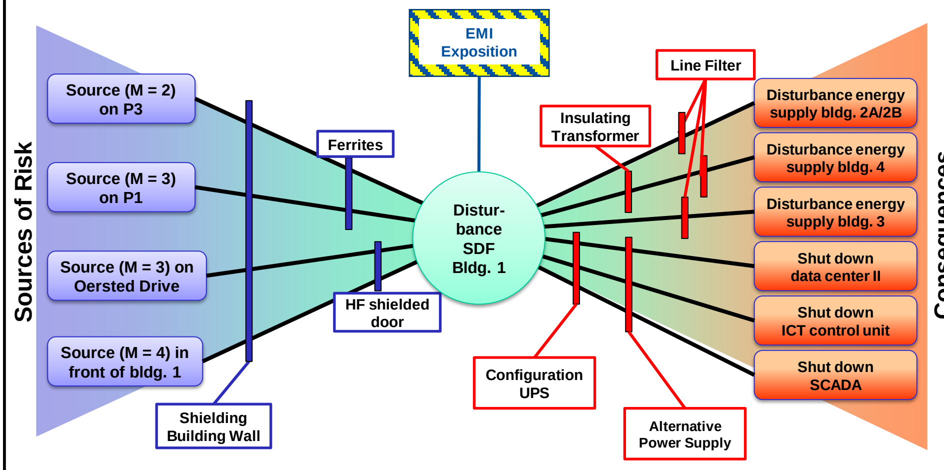
BTA – 5) Documentation



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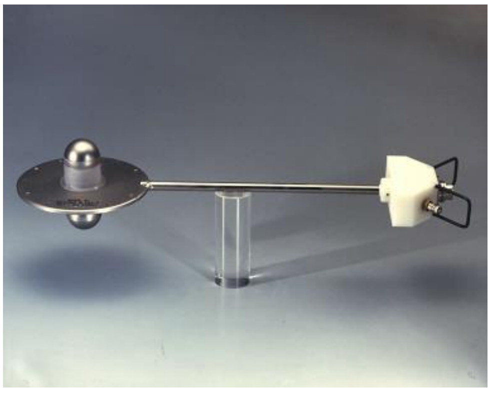
Thank You for Your Attention.

Questions ?



Appendix C
Scales for categorizing characteristic parameters

Scale for Accessability (A_z)

A_z	Acces-sibility	outside	inside	Definition
1o	free	x		Area of the **general public (outdoors)** accessible to each person without special effort.
1i	free		x	Area of the **general public (indoors)** accessible to each person without special effort.
2o	monitored	x		Area of the general public whose access is or can be **monitored**.
2i	monitored		x	Area in a building whose access is or can be **monitored.**
3o	controled	x		Outdoor area that can only be entered after an **identity check**.
3i	controled		x	Area in a building that can only be entered after an **identity check**.
4o	restricted	x		Outdoor control / restricted area that can only be accessed by **authorized persons** or after a **pocket check**.
4i	restricted		x	Control / restricted area in the building, which can only be entered by **authorized persons** or after a **pocket check**.

Scale for Probability

P_O	Probability Level	Description	
0 1	improbable/ unlikely	$< 0,5\%$ $0,5\% - 1\%$	So unlikely, that it can be assumed that the event does not occurs.
2 3	remote	$1\% - 2\%$ $2\% - 5\%$	Low possibility that an event occurs.
4 5 6	occasional	$5\% - 12\%$ $12\% - 25\%$ $25\% - 50\%$	Event will occur in some, but less than half of the cases.
7 8	probable	$50\% - 75\%$ $75\% - 90\%$	Event will occur in more than half of the cases.
9 10	frequent	$90\% - 97\%$ $> 97\%$	Most likely that an event will occur in approximately every case.

Scale for Knowledge

K_D	Knowledge Level	Description	Example
1	Novice	general knowledge	
2	Skilled	basic understanding	amateur electronics
3	Specialist	specialized knowledge and expertise	craftsman, electronics technician
4	Graduate	academic knowledge and professional expertise	engineer
5	Expert	expert knowledge and pro-found expertise	

Scale for Financial Recourses/ Costs

C_{exp}	Financial Recourses	Example	Costs
1	low	< 1.000 €	low costs
2	moderate	1.000 - 10.000 €	moderate costs
3	increased	10.000 - 100.000 €	increased costs
4	high	0,1 - 1 Mio €	high costs
5	extreme high	> 1 Mio €	extreme costs

Scale for Availability of Technology

AV_C	Verfügbarkeit	Definition
0	not available	not offered on the market
1	of-the-shelf	available in the commercial market-place (e.g. department stores); can be bought by anyone
2	commercially available	available in specialty stores; can be bought by anyone
3	specialized trade	available only in specialized trading companies; acquisition is limited to commercial customer
4	lomited acquisition	limited acquisition under conditions or to registered buyer, special designed components
5	restricted acquisition	trade or acquisition prohibited by law

Scale for Volume and Mobility

M	Mobility	Volume	Example
1	stationär	$> 77\ m^3$	fixed installation
2	transportabel	$10 - 77\ m^3$	light truck, conatiner
3	mobil	$0,2 - 10\ m^3$	car, van
4	sehr mobil	$0,02 - 0,2\ m^3$	briefcase, backpack
5	hoch mobil	$< 0,02\ m^3$	beverage can, attache case

Frequency Bands (Table 2 in [2])

Radar Nomenklatur		ITU Nomenklatur		
Band (Radar)	Frequency Range	Frequency Range	Band No.	Band (ITU)
HF	3 MHz $< f \leq$ 30 MHz	3 MHz $< f \leq$ 30 MHz	7	HF
VHF	30 MHz $< f \leq$ 300 MHz	30 MHz $< f \leq$ 300 MHz	8	VHF
UHF	0,3 GHz $< f \leq$ 1 GHz	0,3 GHz $< f \leq$ 3 GHz	9	UHF
L	1 GHz $< f \leq$ 2 GHz			
S	2 GHz $< f \leq$ 4 GHz			
C	4 GHz $< f \leq$ 8 GHz	3 GHz $< f \leq$ 30 GHz	10	SHF
X	8 GHz $< f \leq$ 12 GHz			
Ku	12 GHz $< f \leq$ 18 GHz			
K	18 GHz $< f \leq$ 27 GHz			

Scale for Bandwidth [3]

Bandwidth		Fractional Bandwidth $B_F = 2\frac{f_h - f_l}{f_h + f_l}$	Band Ratio $b_r = \frac{f_h}{f_l}$	Example
Hypoband / Schmalband	HO	$0{,}00 < B_F \leq 0{,}01$	$0{,}00 < b_r \leq 1{,}01$	sinusoidal signal, pulse-modulated sinusoidal
Mesoband	ME	$0{,}01 < B_F \leq 1{,}00$	$1{,}01 < b_r \leq 3{,}0$	damped sinusoidal signal
Sub-Hyperband	SH	$1{,}00 < B_F \leq 1{,}63$	$3{,}00 < b_r \leq 10{,}0$	Chirp
Hyperband	HE	$1{,}63 < B_F \leq 2{,}00$	$10{,}00 < b_r \leq \infty$	gaussian pulse, bipolar pulse, double exponential pulse

Scale for Frequency Agility

F_{AG}	Frequency Agility	Definition	Remarks
1	fixed frequency	$\Delta f = 0$	The source works on a fixed (center) frequency and is not tunable.
2	low	$\lvert\Delta f / f_c\rvert \leq 1\%$	The (center) frequency can be tuned up to 1%.
3	moderate	$1\% < \lvert\Delta f / f_c\rvert \leq 10\%$	The (center) frequency can be tuned up to 10%.
4	high	$10\% < \lvert\Delta f / f_c\rvert \leq 25\%$	The (center) frequency can be tuned up to 25%.
5	very high	$\lvert\Delta f / f_c\rvert \geq 25\%$	The (center) frequency can be tuned by more than 25%.

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2. *Ieee standard letter designations for radar-frequency bands*. IEEE Std 521-2002 (Revision of IEEE Std 521-1984), 2003. doi: 10.1109/IEEESTD.2003.94224.
3. *IEC 61000-2-13, Environment - High-power electromagnetic (HPEM) environments - Radiated and conducted*. IEC, March 2005.