Turn-Up the Volume

Electrical Noise Susceptibility Standards

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Life Is On Schneider Electric

Agenda

- EMC Intro
- EM Disturbance Examples
- EM Coupling Mechanisms
- IEC Standard Intro
- Disturbance Phenomena & Classification
- Product Standard Example
- Disturbance Test Standards
- Lab Test Bench Examples

Electro-Magnetic Compatibility - EMC

Overview

- Electro-Magnetic Compatibility (EMC) is the design and coordination of a component, subassembly or system for:
  - Withstanding external noise disturbances (susceptibility/immunity)
  - Limiting self-generated noise emissions (typically in the RF spectrum)
  - Aligning to the intended environment for equipment type (Residential, Commercial, Industrial)
- EMC Requirements can be enforced from:
  - Government jurisdictions (for example, FCC for USA, CE for Europe, CCC for China, etc.)
  - Standardization bodies and Industry associations (UL, ANSI, SAE, IEC, IEEE, NEMA, etc.)
  - Company internal practices (for customer satisfaction, completive edge and safety)
- EMC standards cover a wide spectrum of frequencies
  - DC, Line frequency (50/60Hz) and into GHz

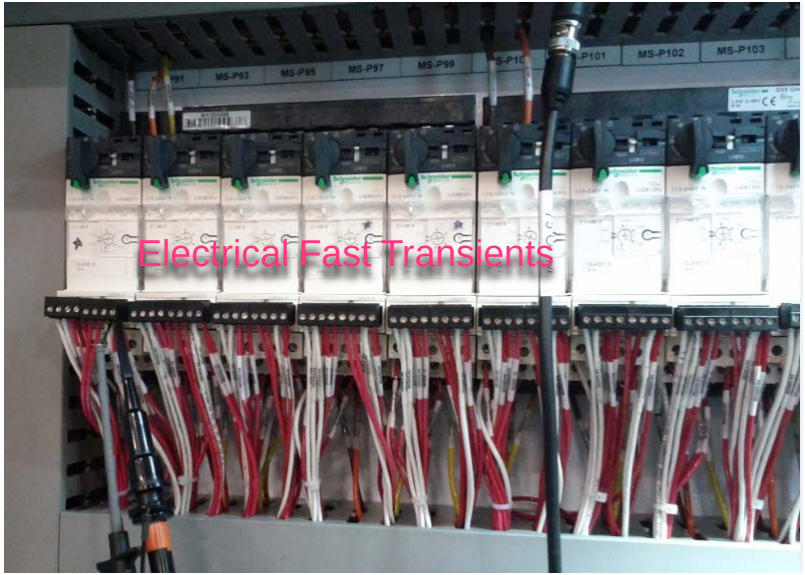
Electrical Disturbance Sources

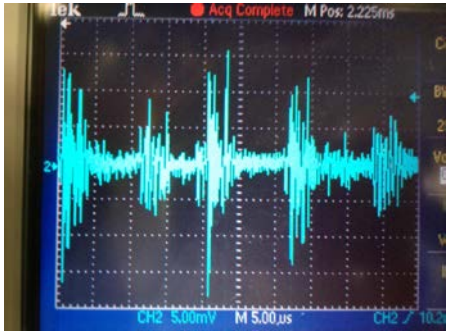
An Industrial environment is plagued with different electrical disturbances.

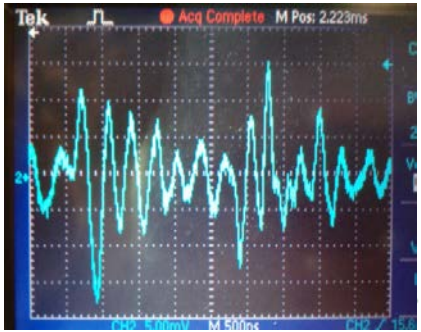
Some disturbances are generated from equipment or systems within the environment, like an Welders, VFD's, across the line motor controls, etc.

Other disturbances are received from sources external to the environment, like the power grid or radio towers.

Electrical Disturbance Example: Motor Starters & VFD's

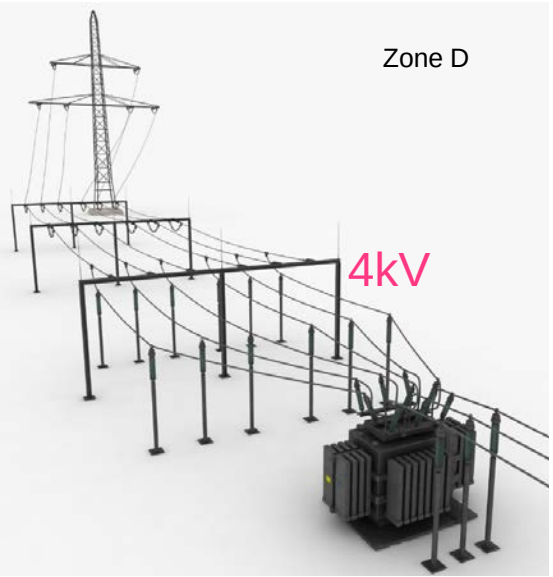






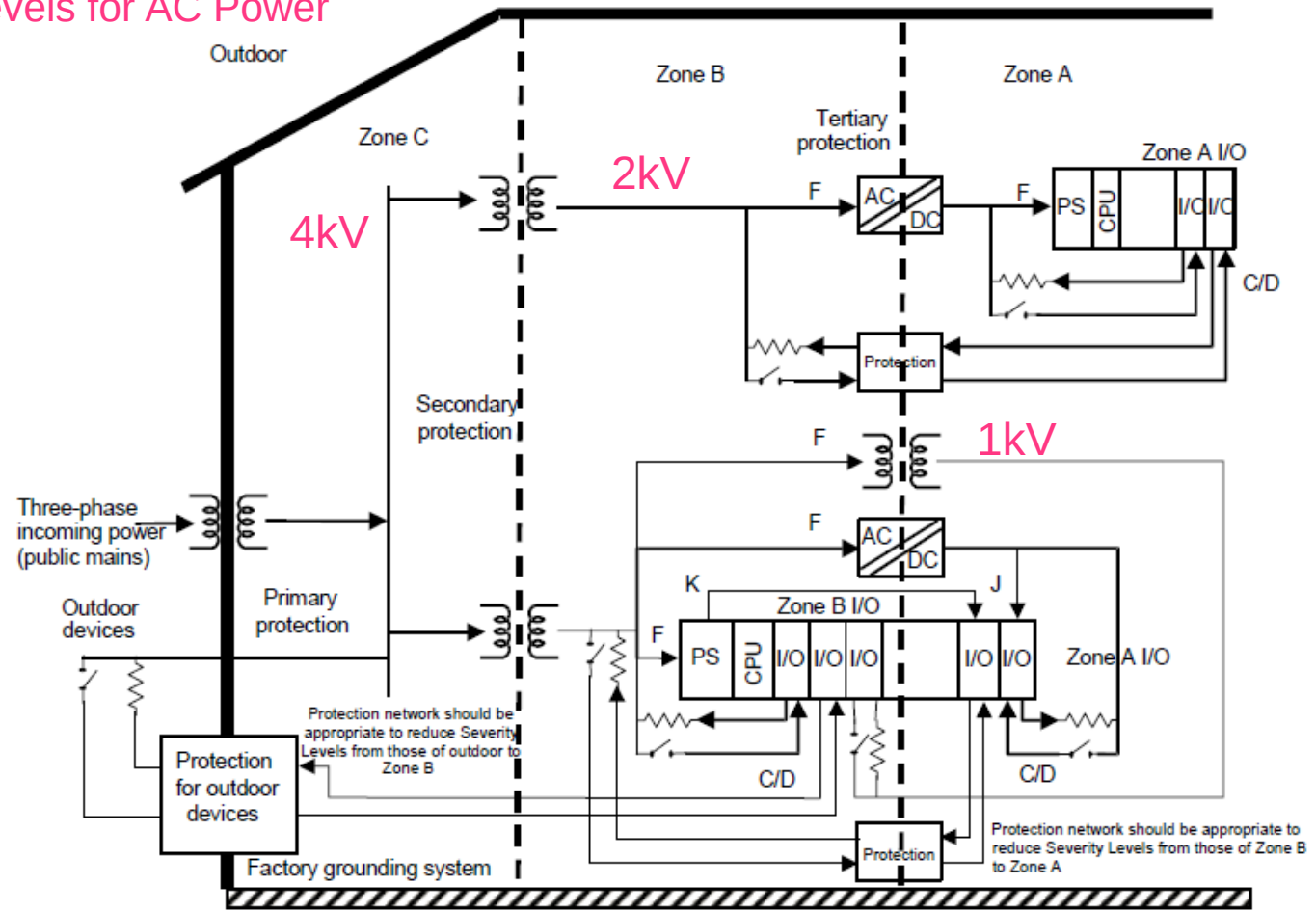
Industrial Site “Zone” Concept

Electrical Fast Transient Levels for AC Power



From IEC 60255-26 Measuring Relays & Protective Equipment

From IEC 61131-2 Programmable Logic Controlers



Disturbance Phenomena

Disturbances are the result of one or more phenomena related to current flow, electric field radiation, magnetic field coupling and EM wave propagation.

The extent or level of disturbances “tend” to scale with factors like system voltage/current, switching occurrence rate, load inductance and component & cable density/proximity.

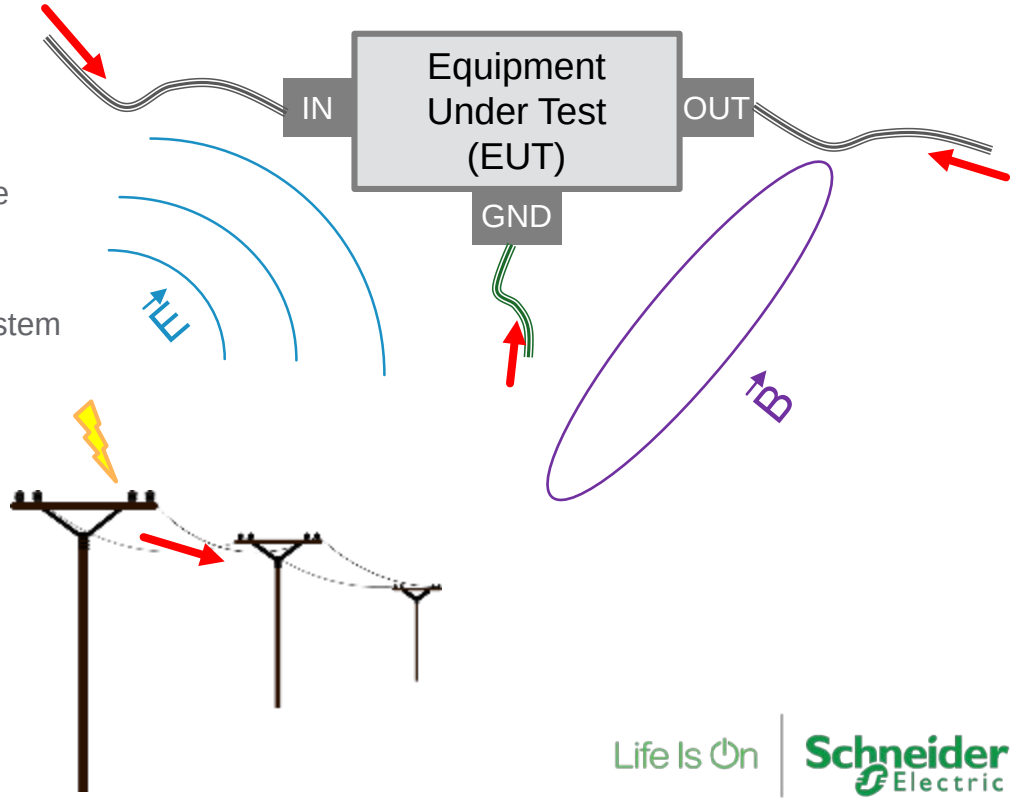
Conversely, the disturbances are generally reduced by introducing separation between elements and establishing a “solid” ground/reference structure/system.

Electro-Magnetic Coupling Mechanisms

How does noise get in to a component, subassembly or system?

Typically received through attached cables:

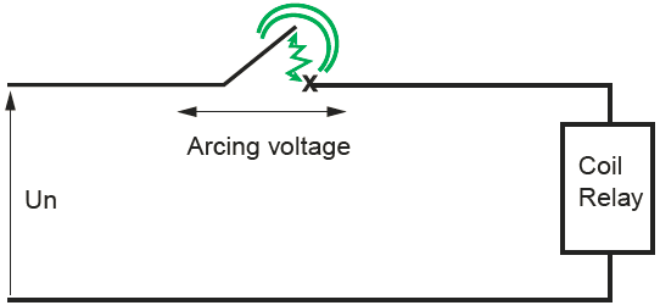
1) Conducted from connected equipment disturbances
2) Capacitively coupled from other cables with disturbance
3) Inductively coupling from other cables with disturbance
4) Common Mode Impedance coupled through ground system
5) Antenna coupled from Electric Fields
6) Loop coupled from Magnetic Fields
7) Lightning coupling into power grid
8) ESD directly on or in proximity to cables /devices
9) Artifacts in power system / grid (i.e. Harmonics, etc.)

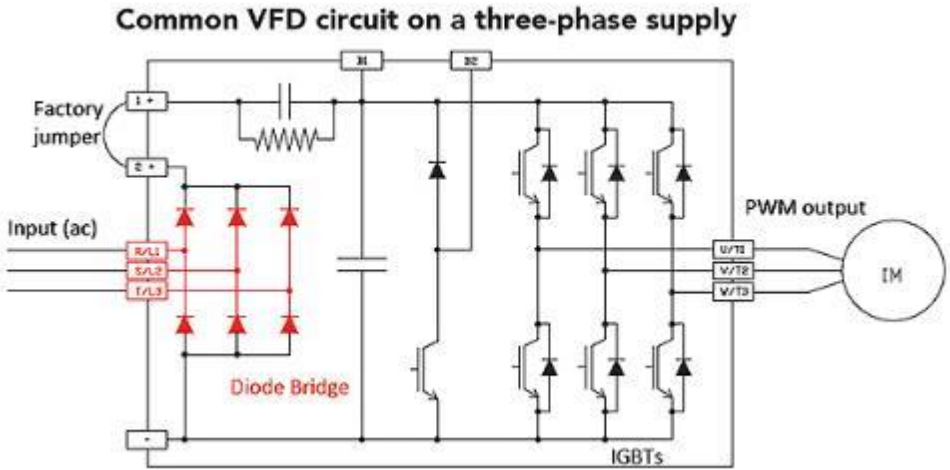


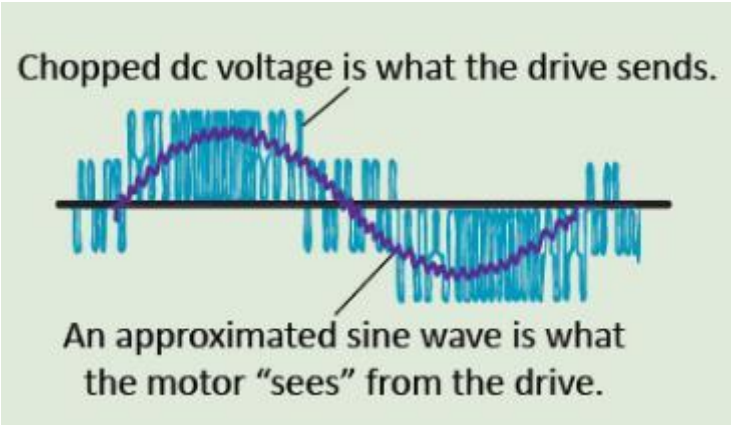
Conducted from connected disturbances or loads

Examples include:

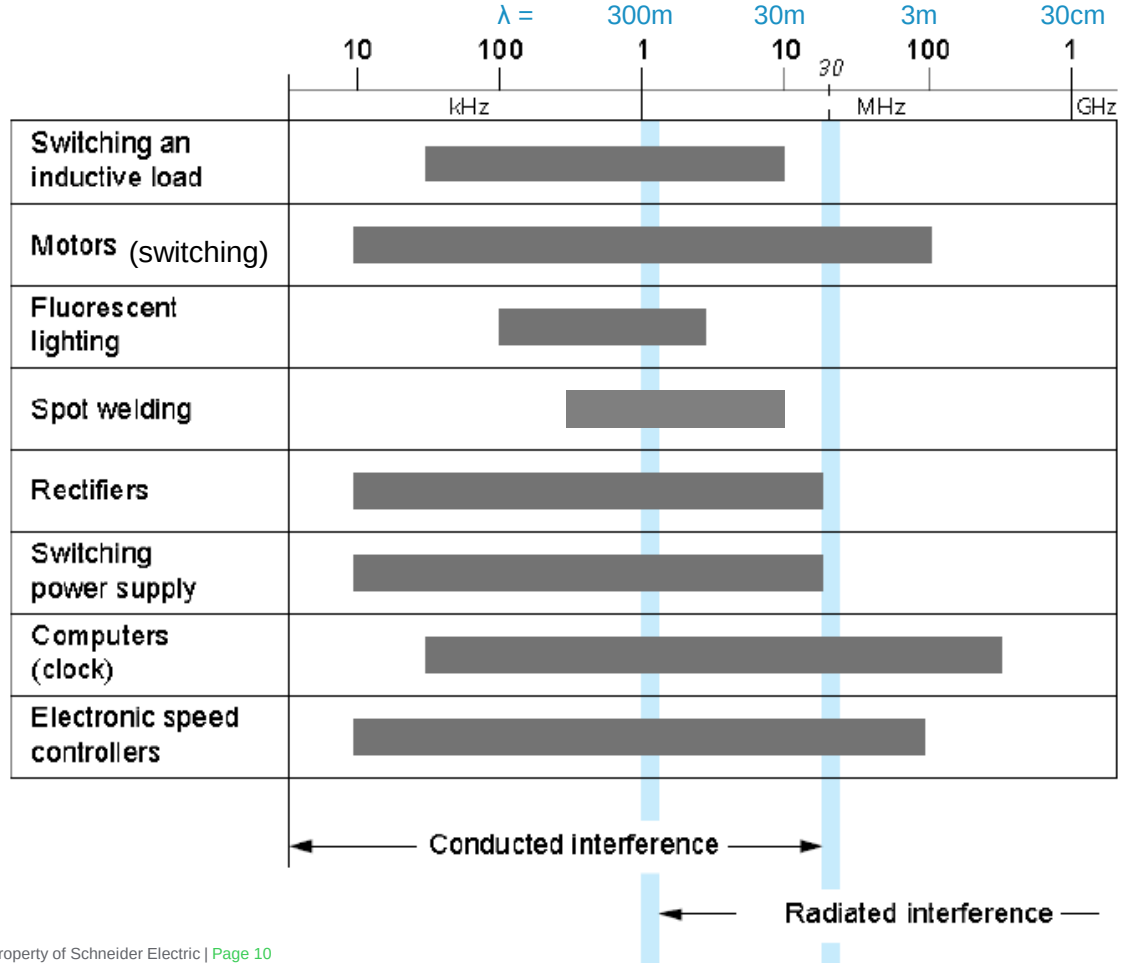
- Switching inductive loads like motors, relays, solenoids
- Large active converters like VFD's, Solar & welding equipment
- Distributed active loads for LED and Fluorescent lighting
- Small active loads like DC switch mode power supplies







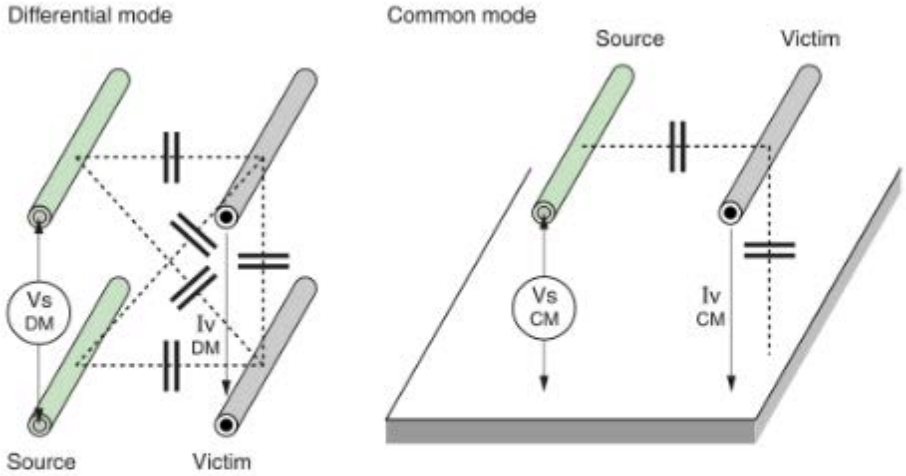
Spectral Distribution of Typical Conductive Disturbances



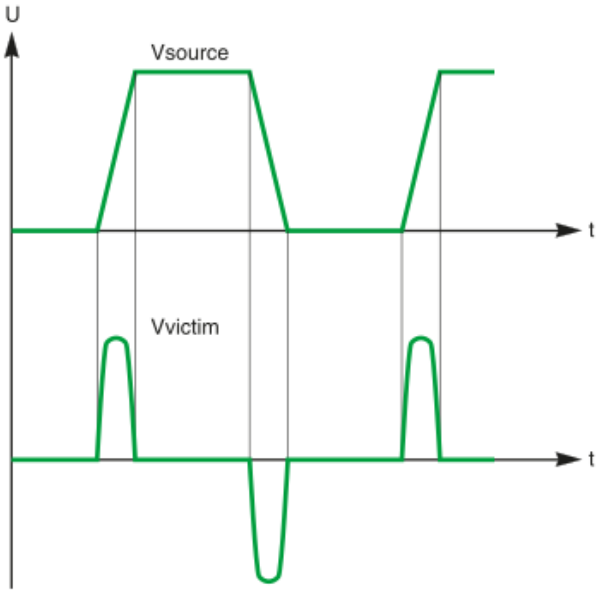
Capacitive Coupling from other cables with disturbances

Cables that run in parallel will couple capacitively based on:

- dV/dt of disturbing cable (source)
- Proximity of the disturber to the victim (closer is worse)
- Length of the parallel cables (longer is worse)
- Height of the cables with respect to a ground referencing plane (further away is worse)
- Input impedance of the victim circuit (circuits with a high input impedance are typ. more vulnerable)
- Insulation of the victim cable (εr of the cable insulation), particularly for tightly coupled pairs



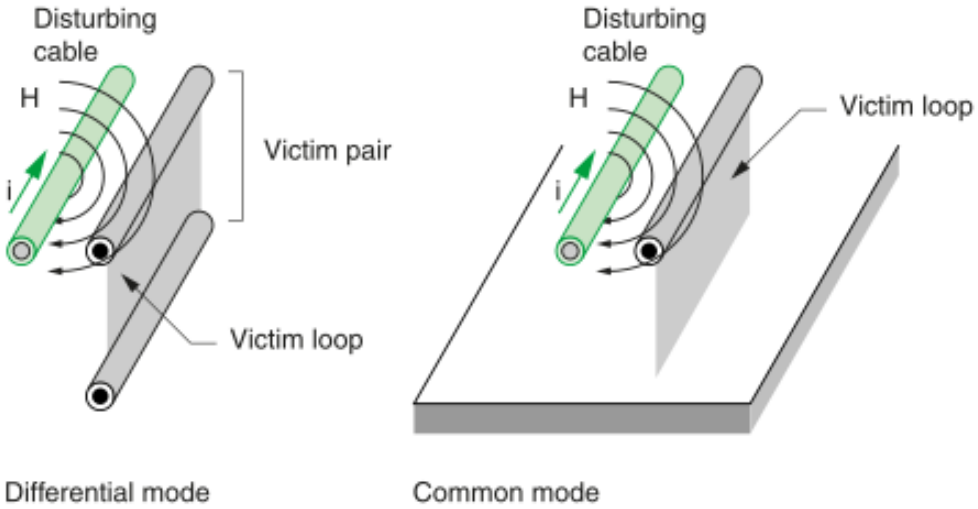
Vs DM: Source of the disturbing voltage (differential mode)
Iv DM: Disturbing current on victim side (differential mode)
Vs CM: Source of the disturbing voltage (common mode)
Iv CM: Disturbing current on victim side (common mode)



Inductive coupled from other cables with disturbance

Cables that run in parallel will couple inductively based on:

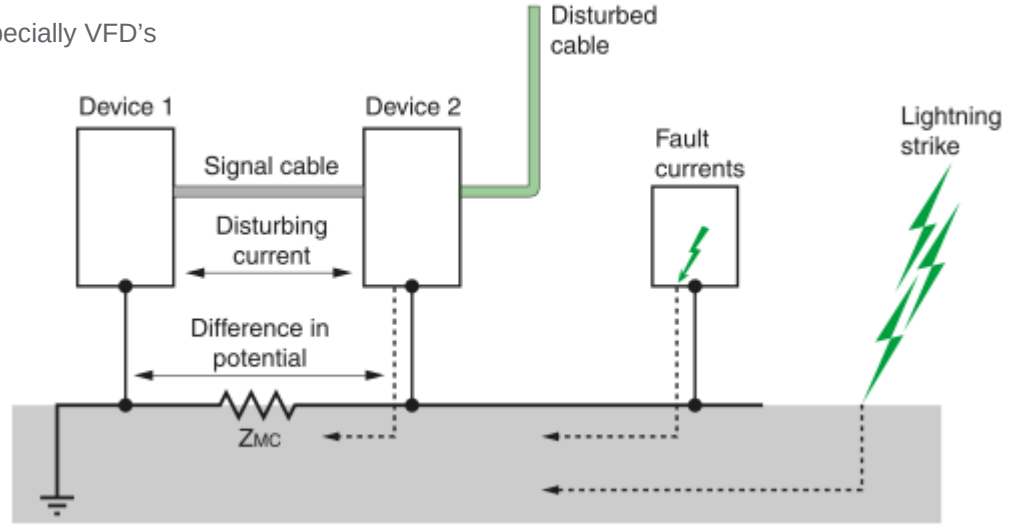
- dI/dt of disturbing cable (source)
- Proximity of the disturber to the victim (closer is worse)
- Length the parallel cables (longer is worse)
- Height of the cables with respect to a ground referencing plane (further away is worse) – more so for HF region
- Input impedance of the victim circuit (circuits with a high input impedance are typ. more vulnerable)



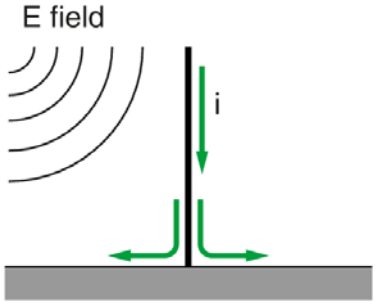
Common Mode Impedance Coupling into Ground System

Disturbance CURRENTs flow through ground system:

- Ground impedance produces voltage difference between devices
  - Typically appear as Common Mode voltage on signal lines
- Increases with current and dI/dt of disturbance
  - Ground impedance has resistive and inductive elements
- Can originate from
  - Lightning strikes
  - Fault currents
  - High 50/60 Hz ground currents
  - Improperly grounded/shielded active switching devices, especially VFD's



Field to Cable Coupling from EM Fields



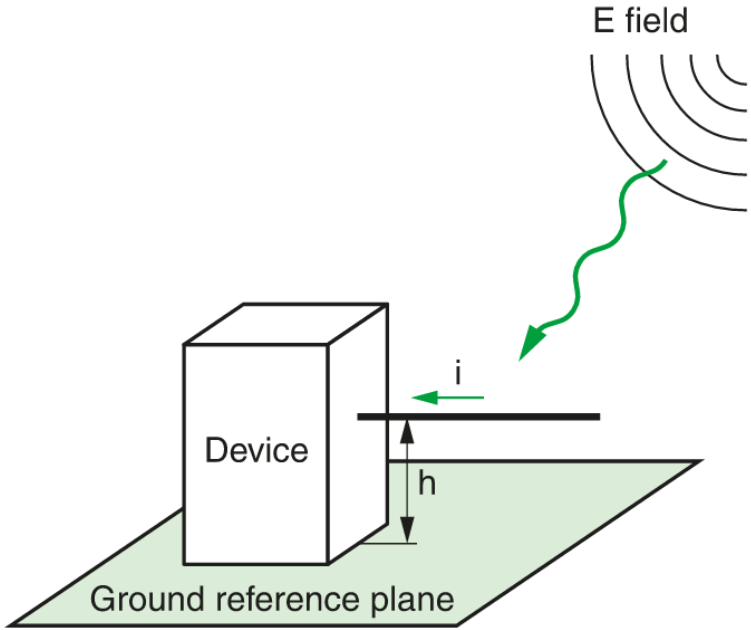
Cables behave as antenna based on:

- Field Strength (V/m) based on Power and Proximity of RF source
- Height of the cables with respect to a ground referencing plane (further away is worse)
- Input impedance of the victim circuit (circuits with a high input impedance are typ. more vulnerable)
- Alignment of cable length to RF wavelength

In order for a cable to act as a reasonable antenna to transmit or receive RF energy, the length must correspond to at least ¼ wavelength.

Frequency	λ	λ/4
1MHz	300m	75m
30MHz	10m	2.5m
80MHz	3.75m	93cm
100MHz	3m	75cm
1GHz	30cm	7.5cm

As seen above lower frequency requires much longer "exposed" cables in order to provide reasonable antenna action. Therefore short routings between devices only are affected by higher frequency RF.



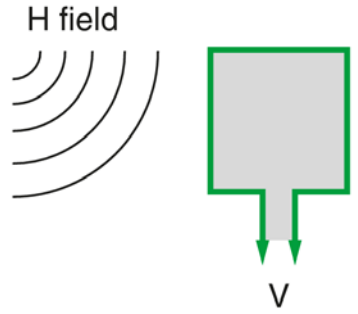
Field to Loop Coupling from EM Fields

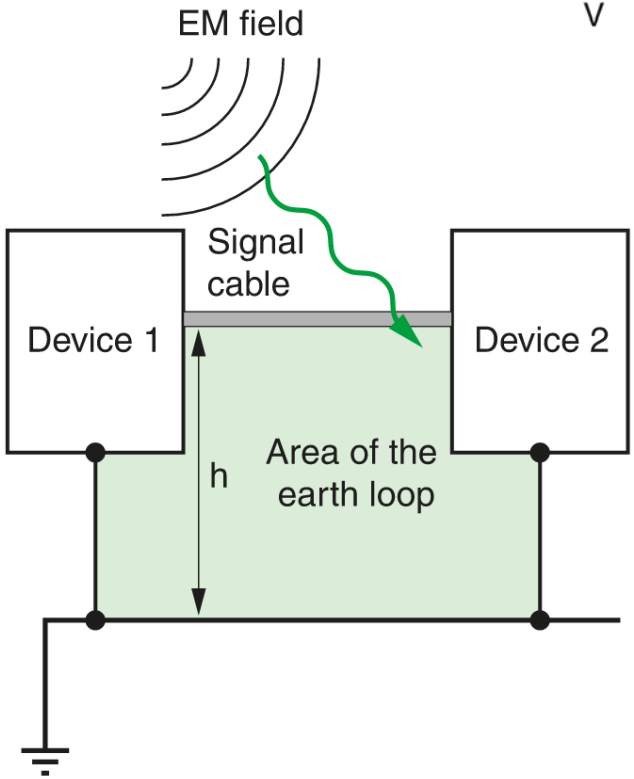
Cables behave as Loop antenna based on:

- Field Strength (A/m) based on Power and Proximity of RF source
- Area of Loop (based on cable routing)
- Input impedance of the victim circuit (circuits with a high input impedance are typ. more vulnerable)

Note1: Field to loop coupling occurs in RF, but also line frequency (50/60 Hz) when in close proximity to high current carrying conductors, like bus bars.

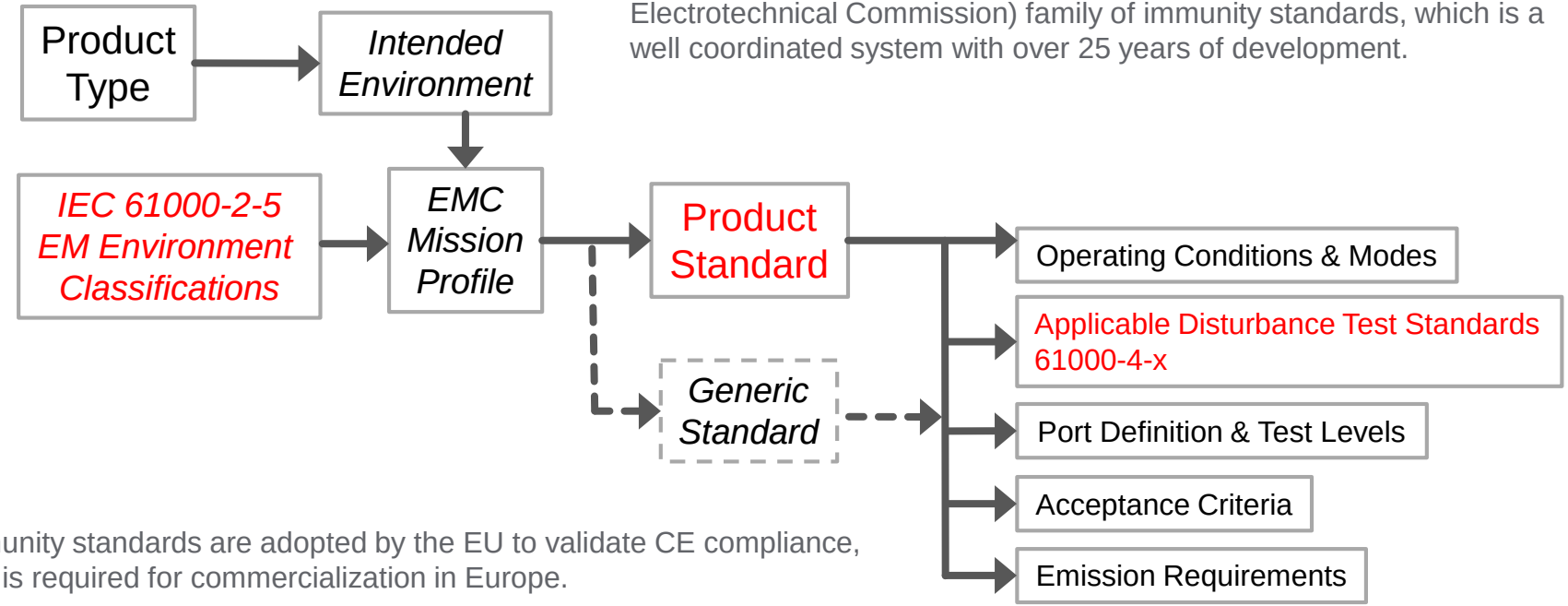
Note2: Devising magnetic "shielding" is generally much more involved than applying common electric field shielding techniques.





IEC Standards

Going forward in this presentation we will focus on the IEC (International Electrotechnical Commission) family of immunity standards, which is a well coordinated system with over 25 years of development.



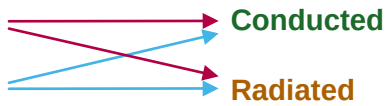
IEC immunity standards are adopted by the EU to validate CE compliance, which is required for commercialization in Europe.

IEC immunity standards (or versions very similar) are being introduced in North America, Canada and Mexico as agencies like UL, ANSI, CSA, NOM want to address the ever worsening noise landscape and product/system inter-compatibility.

Disturbance Phenomena & EM Classifications

IEC 61000-2-5 Ed. 3 was released this year which covers:

- List of disturbance Phenomena
  - Low Frequency (LF) < 9kHz
  - High Frequency (HF) > 9kHz
  - **ESD**
- Classification of Environments
  - Residential
  - Commercial / Public
  - Industrial
- Assigning Phenomena and Disturbance Degree (Level) to Environments
  - Port by Port
- Mapping of Phenomena to Standard Test Methods
  - 61000-4-x series



LF Disturbance Phenomena

Frequency	Form	Coupling	Phenomena	Basic Test Standard	*61000-2-5 Industrial Level*	*Notes*
LF	Conducted	Power Supply Network	Harmonics	61000-4-13	*L3*	
			Voltage Variations	61000-4-14	*L3: +10/-15%*	
			Voltage Dips / Interruptions	61000-4-11	*Class 3: 300cycles*	
			Voltage Unbalance	61000-4-27	*L3: 3%*	
			Voltage Frequency Variations	61000-4-28	*L3: +/-1Hz*	
		Power Supply Coupled	Common Mode Voltages	61000-4-16	*L3: 10V*	*15Hz-150kHz*
			Utility Signalling / Ripple Control	61000-4-13	*L1 < 9%Un*	*0.1kHz - 3kHz*
			Induced LF	61000-4-16	*L3 < 10V*	*CM*
			DC in AC network	-	-	
		Signal and Control Cabling	Induced LF (normal)	61000-4-16	*L3 < 10V*	
			Induced LF (Fault)	61000-4-16	*L3: 1kV*	
	Radiated	LF Magnetic Field	Power System Line Frequency	61000-4-8	*L3: 30A/m*	*Much higher if near bussway, etc.*
			Power System Harmonics	61000-4-8	*L3: (30A/m)/nth*	
			Misc. other	61000-4-8	*L3: 0.15A/m*	
		LF Electric Field	Power System Line Frequency	see 61000-2-3	*L2: 1kV/m*	

HF Disturbance Phenomena

Frequency	Form	Coupling	Phenomena	Basic Test Standard	*61000-2-5 Industrial Level*	*Notes*
HF	Conducted	Direct to AC	2kHz - 150kHz	61000-4-19	*L4: 10V DM*	*PLT/Signalling, DM*
			150kHz - 80MHz	61000-4-31	*L3: -40dBm/Hz DM+CM*	*Broadband OFDM*
		EM Field Coupled / Induced	10kHz - 150kHz	61000-4-16	*L4: 10V CM*	
			0.15MHz - 150MHz	61000-4-6	*L4: 10V CM*	*30V for Switchyards*
	Conducted Uni-Directional Transient	On AC, DC, Signal	Electrical Fast Transients	61000-4-4	*AC 4kV CM, Other 1kV CM*	*5ns rise x 50ns half-decay*
			Surges / Lightning	61000-4-5	*4kV CM, 2kV DM*	*1.2us rise x 50us half-decay Different levels for other ports*
	Conducted Oscillatory Transient	On AC, DC, Signal	Ring Wave - 100kHz	61000-4-12	*2kV CM, 1kV DM*	*Inductive switching or lightning impulses*
			Slow Damped Osc: 0.10 - 1MHz	61000-4-18	*L2: 1kV CM, 500V DM*	*Located in MV substation switching*
			Fast Damped Osc: 3 - 30MHz	61000-4-18	*L4: 4kV CM*	*Electrical Plants and HV substations*
	Magnetic Field	Entire System	8us x 20us current pulse	61000-4-9	*L4: 300A/m pk*	*Power plants, MV/HV substations*
	ESD (E&M Fields)	Entire System	Direct & Indirect	61000-4-2	*L3: 6kV contact, 8kV air*	

Radiated RF Disturbance Phenomena

Frequency	Form	Coupling	Phenomena	Basic Test Standard	*61000-2-5 Industrial Level*	*Notes*
HF	Radiated Modulated	Entire System	Group 2 ISM bands	61000-4-3	*L4: 10V/m*	
			f < 30MHz:			
			Amateur		*L3: 3V/m*	
			CB		*L2: 1V/m*	
			AM		*L2: 1V/m*	
			30MHz < f < 1GHz:	61000-4-3		
			Analogue services		*3V/m*	
			Mobile units of phones		*3V/m*	
			Base stations of phones Outside		*3V/m*	
			Base stations of phones Inside		*L5: 30V/m*	
			Medical/bio. telemetry		*L1: 0.3V/m*	
			Unlicensed radio services 1		*1V/m*	
			Unlicensed radio services 2		*10V/m*	
			Amateur radio > 30 MHz		*3V/m*	
			Paging services/base		*1V/m*	
			TETRA		*1V/m*	
			Walkie-Talkie		*10V/m @ 1m*	
			TV, FM		*10V/m @ 500m*	
			1GHz < f < 6GHz:	61000-4-3		
			Mobile units of phones		*10V/m*	
			Base stations Outside		*3V/m*	
			Base stations Inside		*30V/m*	
			Amateur radio		*3V/m*	
			Other RF services (1)		*10V/m*	
			Other RF services (2)		*3V/m*	
			UWB		*0.3V/m*	
			f > 6GHz:	61000-4-3		
			Amateur radio		*3V/m*	
			Other RF items (3)		*10V/m*	
			Other RF items (4)		*0.3V/m*	
			UWB		*0.3V/m*	
			Other RF items (6)		-	

Example Product Standard

From IEC 61131-2: Programmable Logic Controllers

- Product Standards define environmental, electrical, constructional, functional, safety and verification test (including EMC) requirements for a particular product type / family.
- The goal is to deliver consistent product function and performance in alignment with the customer expectations and intended environment.

Overall Product/System

Table 32 – Enclosure port tests, Zones A and B

Environmental phenomenon	Reference standard	Test		Test level	Test set-up	Normative items	Performance criteria
Electrostatic discharge	IEC 61000-6-2	Contact		±4kV	Table 38	1	B
		Air		±8kV			
Radio-frequency Electro-magnetic field Amplitude modulated	IEC 61000-6-2	80% AM, 1kHz Sinusoidal	2,0-2,7 GHz	1 V/m	Table 39	4	A
			1,4-2,0 GHz	3 V/m			
			80-1000 MHz	10 V/m			
Power frequency magnetic fields	IEC 61000-6-2	60 Hz		30 A/m	Table 40	2, 3	A
		50 Hz		30 A/m			

From IEC 61131-2: Programmable Logic Controllers

Example Acceptance Criteria

Table 31 – Criteria to prove the performance of a PLC-system against EMC disturbances

Performance criterion		
Criterion	Operation	
	During test	After test
A	The PLC-system shall continue to operate as intended. No loss of function or performance, according to PFVPs (2.5)	The PLC-system shall continue to operate as intended
B	Degradation of performance accepted Examples: analogue values vary within manufacturer-specified limits, communication delay times vary within manufacturer-specified limits, flickering on HMI display, etc. No change of operating mode Examples: loss of data or uncorrected errors in communication, unintentional state changes of digital I/O which are seen by the system or test set-up, etc. No irreversible loss of stored data, according to PFVPs (2.5)	The PLC-system shall continue to operate as intended. Temporary degradation of performance must be self-recoverable
C	Loss of functions accepted, but no destruction of hardware or software (programme or data)	The PLC-system shall continue to operate as intended automatically, after manual restart or power off/power on

- *Acceptance Criteria can be shaped by the anticipated service continuity for the product, as in a substation or hospital.*
- *The level of disturbance and/or rate of occurrence might be low in certain applications, but since service continuity has to be very high, the acceptance criteria will be stringent.*
- *For industrial control applications, maintaining proper logic state is critical as it is tied to process control.*
- *For electrical safety products, earth leakage detection, overload and fault protection should be maintained.*

IEC Disturbance Test Standards

The intent of an disturbance test standard is to provide a description of the disturbance source and how to apply / couple it to the product/system in a uniform fashion.

The test standard does include general definitions of Acceptance Criteria, however they are not related to any particular product/system function.

Detailed Acceptance Criteria are placed in the "Product Standard" along with Test Levels, Durations, Port Definitions and unique Set-up requirements (if applicable).

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NORME INTERNATIONALE

INTERNATIONAL STANDARD

CEI
IEC
61000-4-1

Deuxième édition
Second edition
2000-04

PUBLICATION FONDAMENTALE EN CEM
BASIC EMC PUBLICATION

Compatibilité électromagnétique (CEM) –

Partie 4-1:
Techniques d'essai et de mesure –
Vue d'ensemble de la série CEI 61000-4

Electromagnetic compatibility (EMC) –

Part 4-1:
Testing and measurement techniques –
Overview of IEC 61000-4 series

Disturbance Test Standard List

61000-4-2 ESD

61000-4-3 Radiated electromagnetic field

61000-4-4 EFT/Burst.

61000-4-5 Surge

61000-4-6 Conducted disturbances by RF fields

61000-4-7 Harmonics and Inter-harmonics Guide

61000-4-8 50/60 Hz magnetic field

61000-4-9 Pulse magnetic field

61000-4-10 Oscillatory magnetic field

61000-4-11 Voltage dips and interruption

61000-4-12 Oscillatory waves "ring wave".

61000-4-13 Harmonics & mains signaling

61000-4-14 Voltage fluctuations

61000-4-15 Flicker meter

61000-4-16 Conducted disturbances 0 - 150 kHz

61000-4-17 Ripple on DC power supply.

61000-4-20 TEM cells

61000-4-21 Reverberation chambers

61000-4-23 HEMP radiated disturbance

61000-4-24 HEMP conducted disturbance

61000-4-25 HEMP tests for equipment and systems

61000-4-27 Unbalance in three-phase mains

61000-4-28 Variation of power frequency

61000-4-29 Voltage dips, interruptions on DC power ports

61000-4-30 Measurement of power quality parameters

61000-4-31 AC Mains Broadband Disturbances (New)

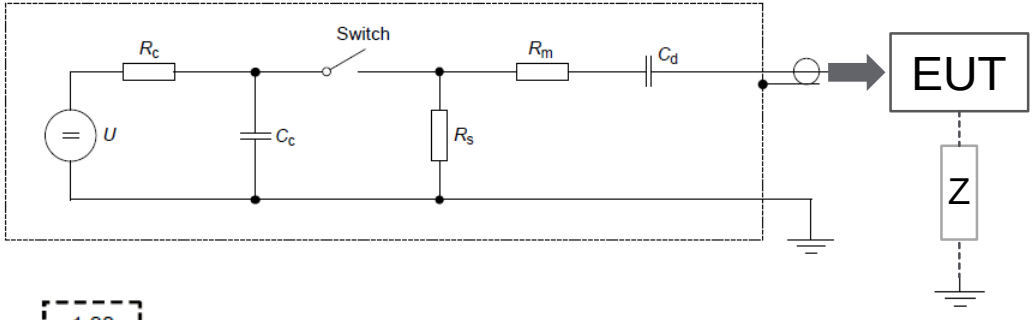
61000-4-39 Radiating Close Proximity Devices (New)

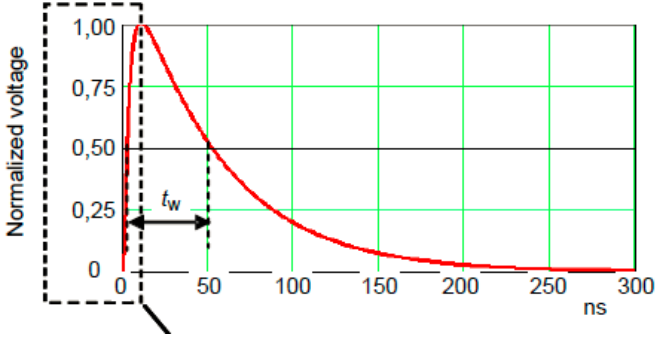
Source Definition and Coupling to EUT

Each standard test tries to represent a particular phenomena, typically by defining a disturbance source (characterized by source impedance and wave shape), an occurrence rate and coupling means.

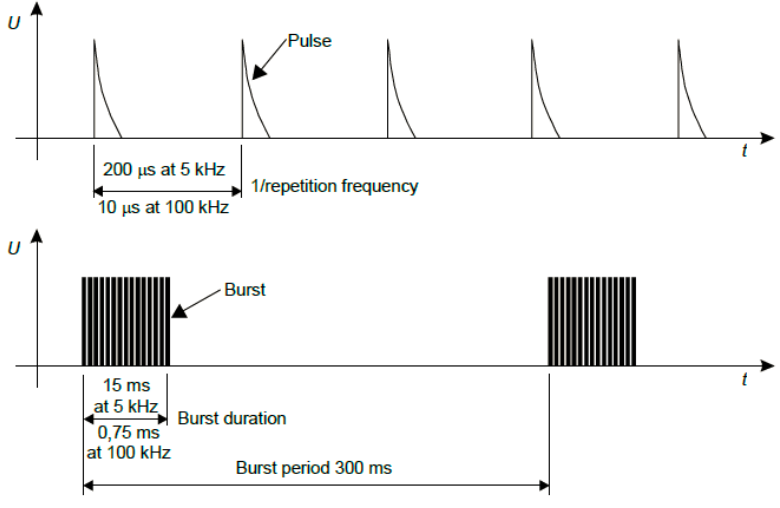
Although some test “levels” are defined in simple “voltage” and “current” quantities in the standard, the **interaction** of the “source” with the Equipment Under Test (EUT) will create a unique energy transformation profile (absorbed / reflected / passed-on) dependent on the unique characteristics of the product/system.

A system with a low impedance will interact quite differently with the test standard source than one with a high impedance. The interaction will hopefully be “engineered” by the product design team, and not left for chance.





61000-4-4 Electrical Fast Transient Burst (EFTB)

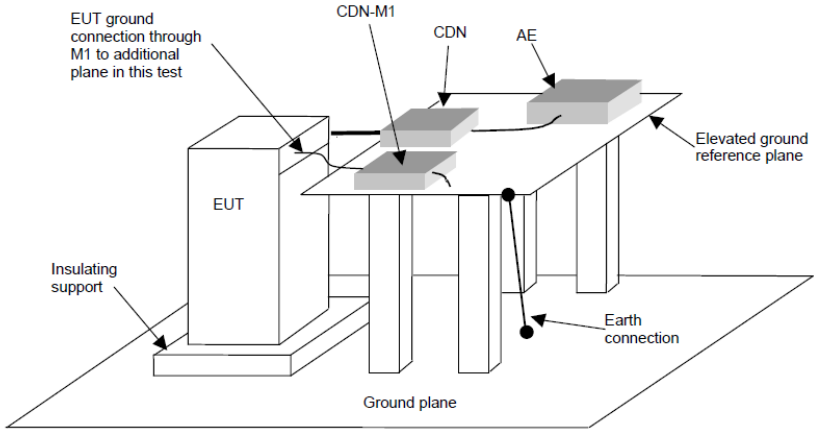


Recreating Disturbances in the Lab

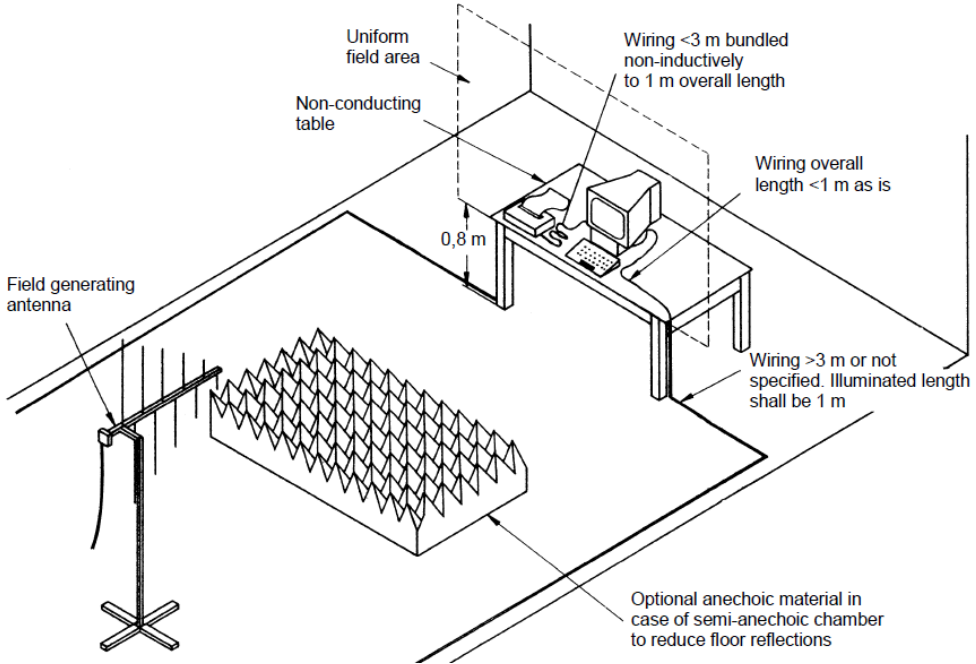
A significant portion of the standard defines the test set-up, including items like cable lengths, distance to ground planes, coupling/decoupling devices, etc.

Without set-up restrictions, the RF and current paths would vary significantly from site to site.

61000-4-6 Conducted Immunity



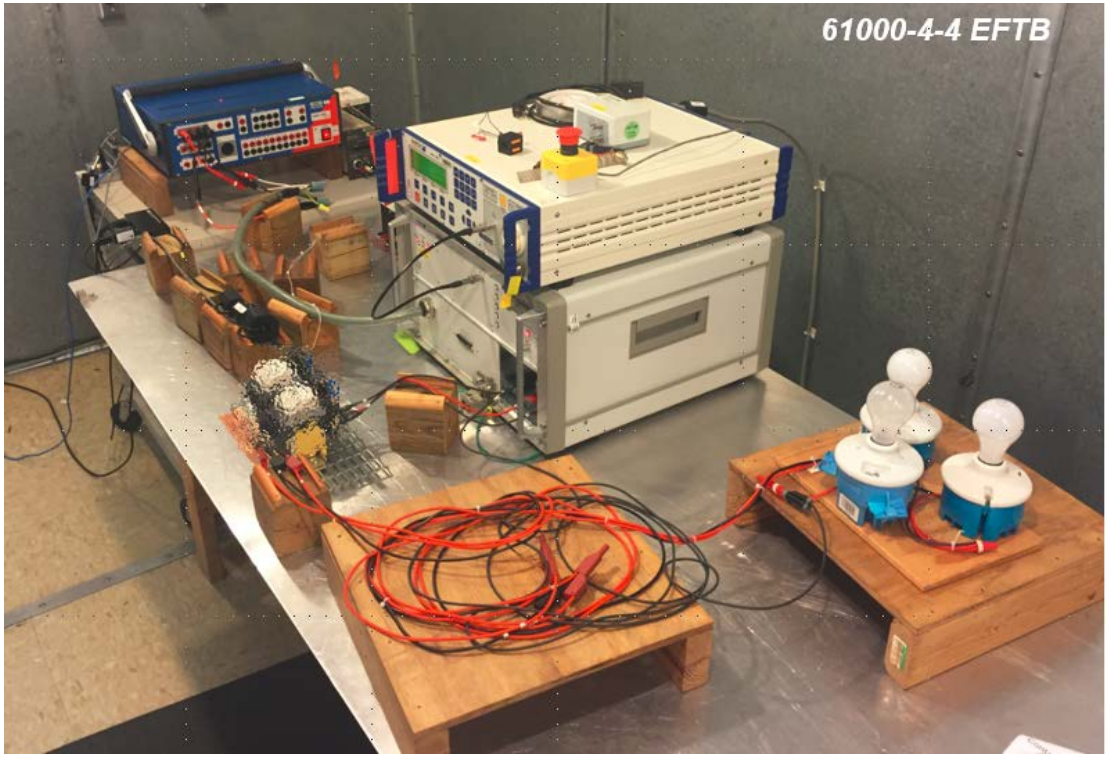
61000-4-3 Radiated Immunity



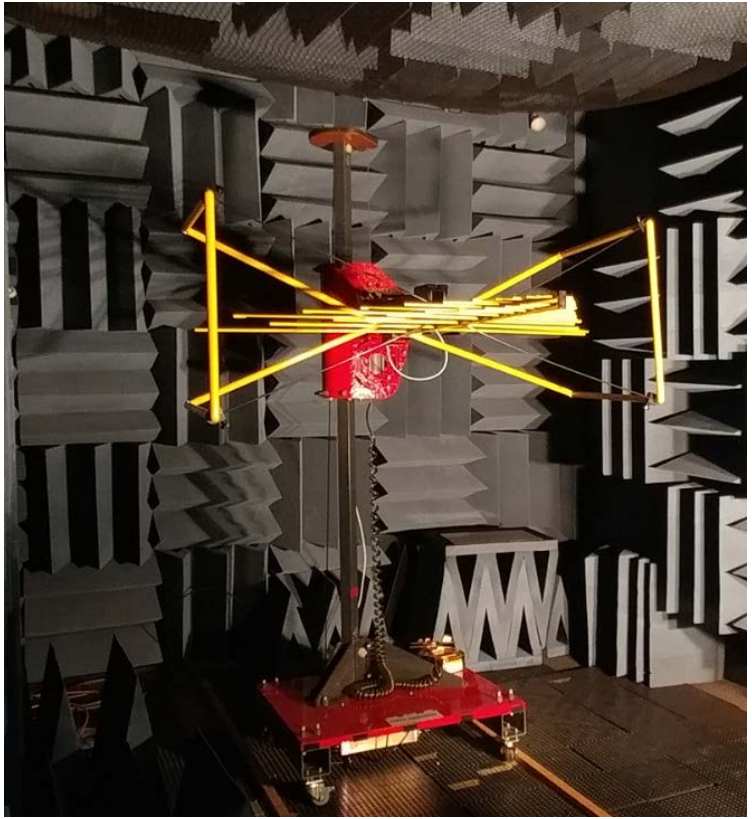
Example EMC Test Benches

@ Schneider Raleigh 17025 EMC Lab

1. Sources/Generators
2. Coupling & Decoupling Means
3. EUT
4. Local Environment: Chamber, Reference Ground Plane (RGP) or open air



61000-4-3 RF Immunity Chamber



Other Test Benches

61000-4-20 RF Immunity in GTEM Chamber

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