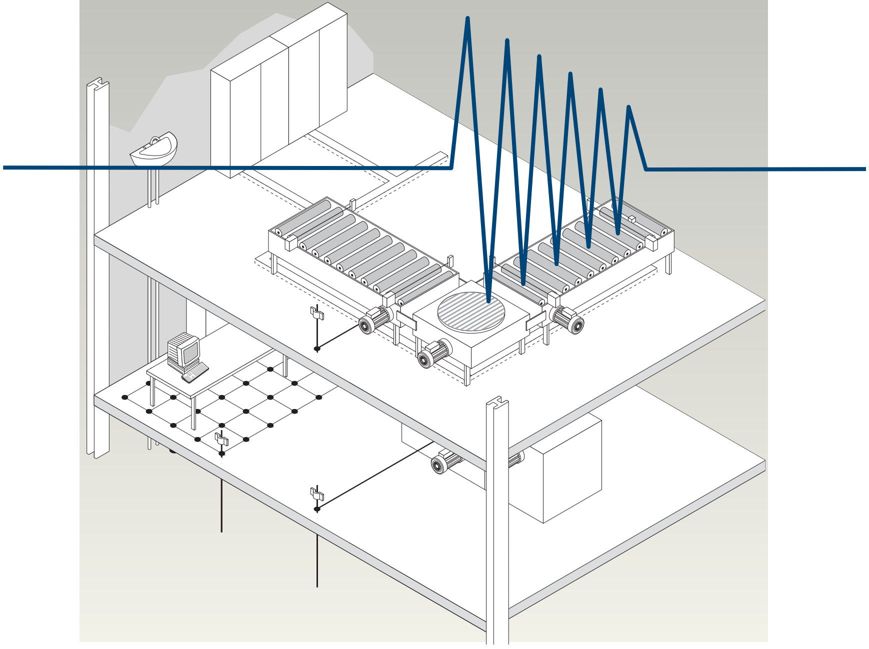

Electromagnetic Compatibility «EMC»

Practical Installation Guidelines

Telemecanique
GROUPE SCHNEIDER

FOR ALL YOUR AUTOMATION NEEDS

This working document is not contractually binding.
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Schneider, expertise in electrical distribution and industrial control

The Schneider group is an integrated multinational organisation with 90,000 employees and comprehensive manufacturing and marketing operations in 130 countries.

■ Telemecanique in a UK market leader and world expert in industrial control and automation. It offers complete industrial control solutions with contactors and delays, pushbuttons, limit switches, photo-electric and proximity devices, switch disconnectors and a range of safety devices. Automation solutions include programmable logic controllers, variable speed drives and communications software; as well as the automation of power distribution systems through prefabricated busbar trunking.

■ Merlin Gerin is one of the foremost experts of electrical distribution products and systems and uninterruptible power supplies. Its comprehensive array of extra-high, medium and low-voltage products and systems is designed to manage and protect electrical installations, ensure safety and provide power supply reliability and continuity.

Schneider's commitment to the UK market

■ Schneider in the UK brings together the expertise of Telemecanique and Merlin Gerin, major players in the UK electrical industry. Telemecanique was established in the UK in 1964, and Merlin Gerin in 1973, have grown to become leaders in their respective fields. This long history of commitment means that we fully understand our customers needs. We are expanding our UK operations, which makes us a reliable partner for the future. We are committed to achieving a close working relationship with our customer to ensure that we provide local support with a fast response time.

■ Our distributors are chosen carefully for their experience, expertise and facilities. They are located throughout the UK, providing local stock holding points and at-the-ready sources of help and advice. Each distributor receives weekly deliveries to ensure continuous high stock availability. It is much more than product availability however. Personnel at all Telemecanique and Merlin Gerin distributors undergo extensive continuing product and applications training, to meet the needs of today's industries.

Création: Gamex, Impression: Sopan

Telemecanique
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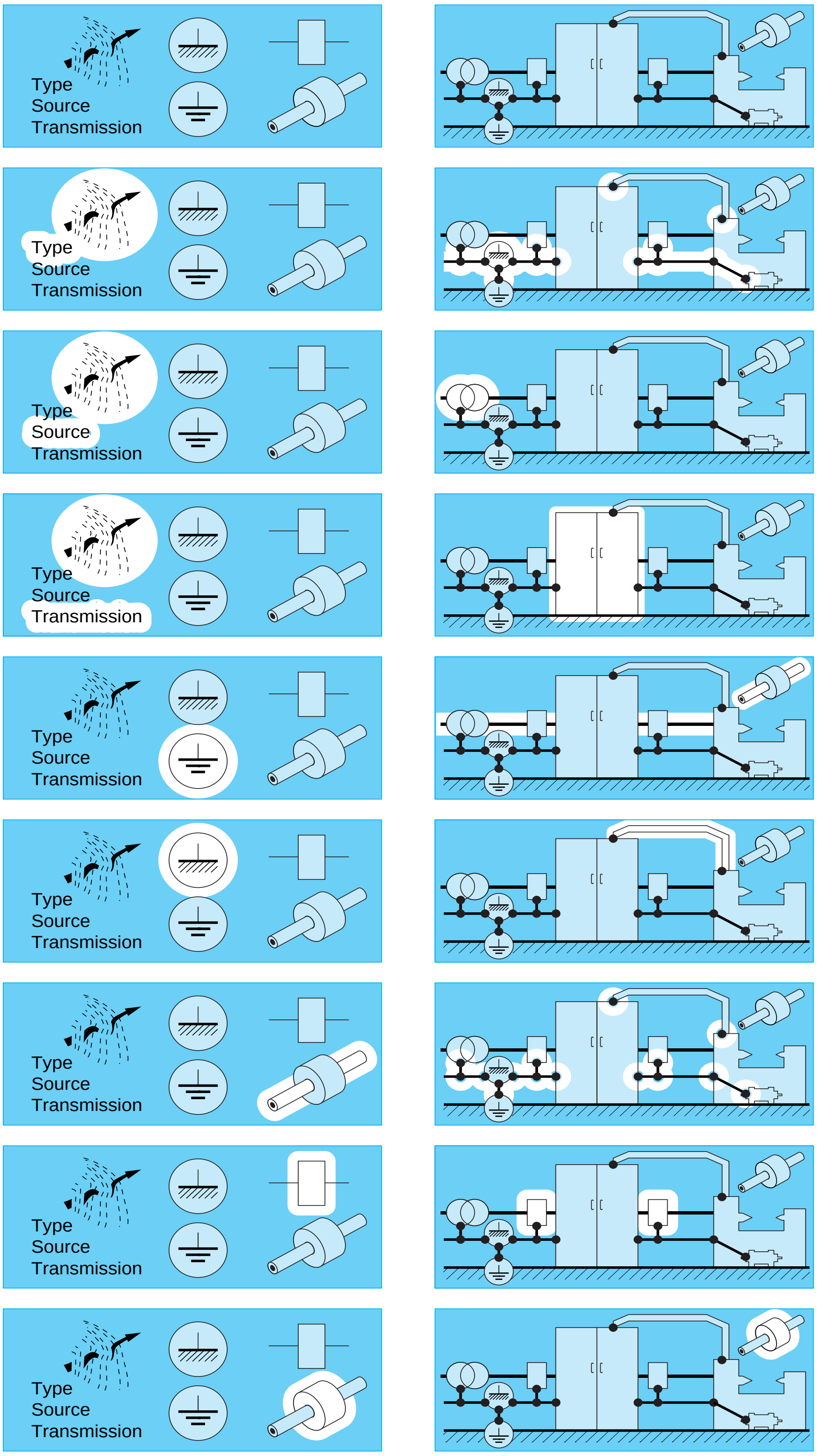
These icons will help you find your way around the various sections in this document



CHAPTER 1

- Type of interference
- Source of interference
- Transmission mode of interference
- Earth
- Chassis or frame connection
- Cables
- Filters
- Ferrite cores

CHAPTER 2

- Earthing system
- Power supply
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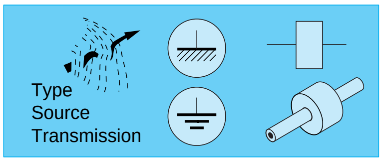
CHAPTER 1



UNDERSTANDING ELECTROMAGNETIC COMPATIBILITY PHENOMENA

Foreword

The attention of readers who are familiar with conventional electrical engineering is drawn to the fact that this chapter deals with concepts relating to phenomena associated with high-frequency (HF) voltages and currents.

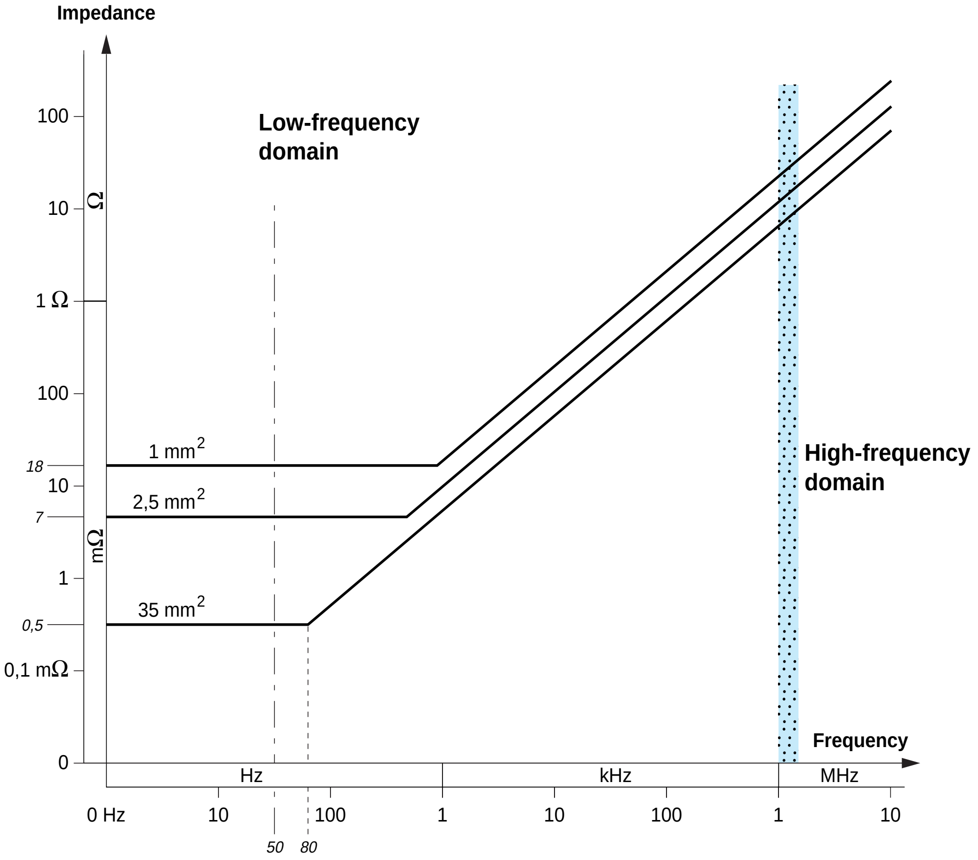
These have the effect of significantly modifying the characteristics and hence the behaviour of our electrical installations.

«Mastering» these phenomena is essential to understanding and, above all, solving the problems that will be encountered on site.

This is illustrated by the following examples.

Foreword

Frequency behaviour of an electric conductor



Characteristic impedance values of an electric conductor of length L = 1 m

- Note that the impedance of the cable increases very sharply with the frequency of the signal that passes along it. (Impedance Ω) Z = **K** (constant) x **f** (frequency Hz)

- For low-frequency (LF) signals (e.g. 50-60 Hz)

==> the impedance of the cable is relatively insignificant
==> the cross-sectional area of the cable is of prime importance

- For high-frequency (HF) signals (f > 5 MHz)

==> the impedance of the cable is decisive
==> the length of the cable is decisive
==> the cross-sectional area of the cable is relatively insignificant

Foreword

Frequency behaviour of an inductance and a capacitance

- $Z = 2\pi Lf$ With high frequency (HF), the **impedance** of a cable becomes very high.

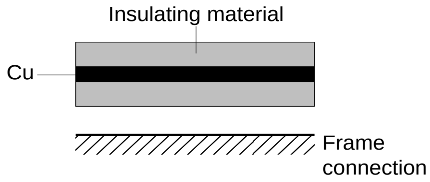
==> The «length» of conductors becomes non negligible,
==> Distortion of the signal (amplitude, frequency, etc.).

- $Z = \frac{1}{2\pi Cf}$ With high frequency (HF), the **impedance** of a stray capacitance becomes very small.

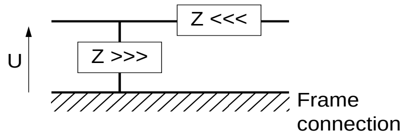
==> Capacitive coupling becomes effective,
==> Leakage currents flow in the installation,
==> The useful signal becomes easily susceptible to interference.

Z = Impedance *L = Inductance* *C = Capacitance* *f = Frequency of signal*

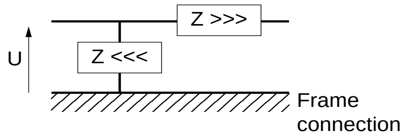
Example : cable



Equivalent low-frequency (LF) circuit diagram



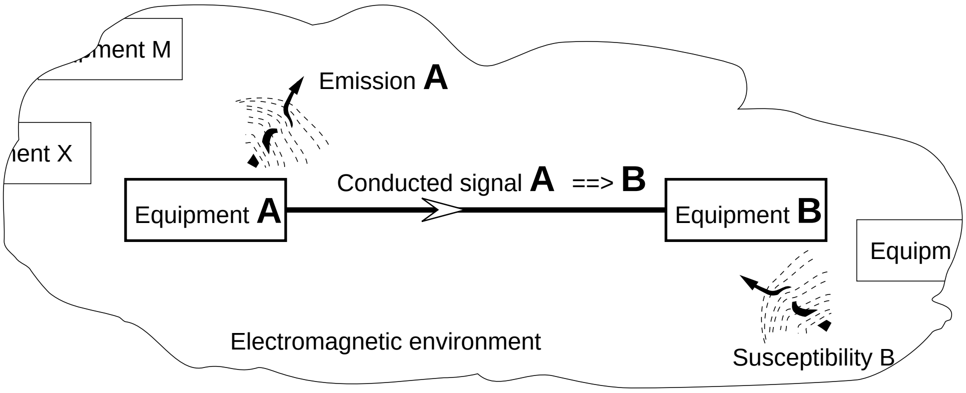
Equivalent high-frequency (HF) circuit diagram



Electromagnetic compatibility of a system

Electromagnetic compatibility : (EMC)

The standards define electromagnetic compatibility (EMC) as «the ability of a device, equipment or a system to function satisfactorily in its electromagnetic environment without introducing intolerable disturbances to that environment or to other equipment».



Electromagnetic compatibility of a system

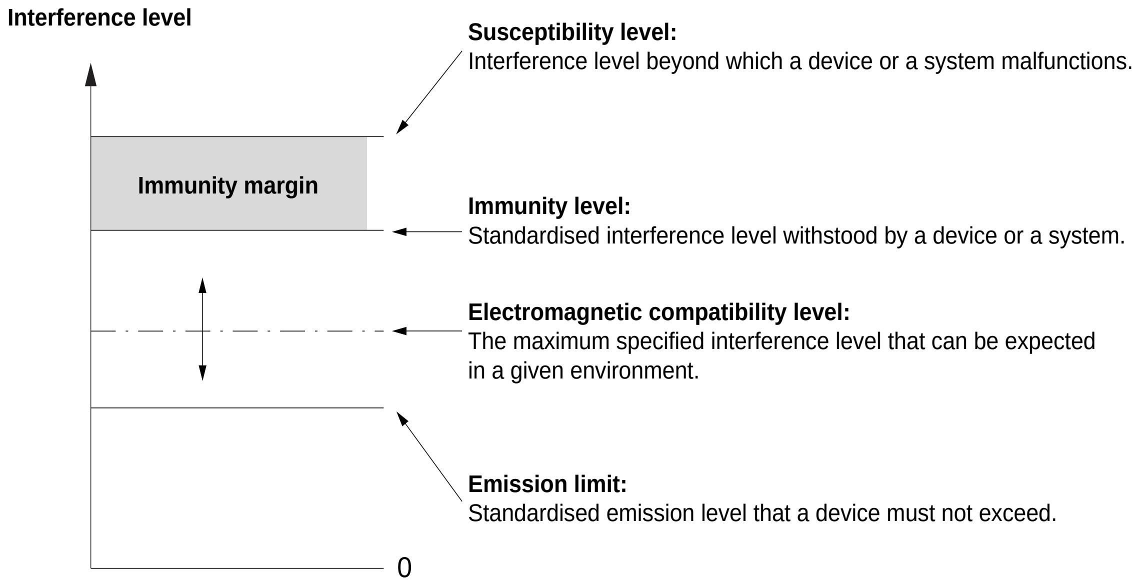
Field of application

1
2
3

A set of equipment (actuators, motors, sensors, etc.) involved in fulfilling a defined function is referred to as a «system».

Note that, in electromagnetic terms, the system comprises all those components that interact with each other, including even mains decoupling devices.

Electric power supplies, connections between various equipment items, associated hardware and their electric power supplies are part of the system.



Susceptibility level:
Interference level beyond which a device or a system malfunctions.

Immunity level:
Standardised interference level withstood by a device or a system.

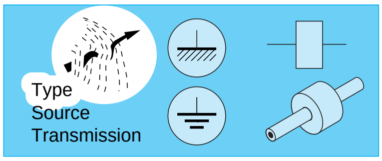
Electromagnetic compatibility level:
The maximum specified interference level that can be expected in a given environment.

Emission limit:
Standardised emission level that a device must not exceed.

This means that :

- The immunity level of each device is such that it is not disturbed by its electromagnetic environment.
- Its interference emission level must be low enough not to interfere with devices located in its electromagnetic environment.

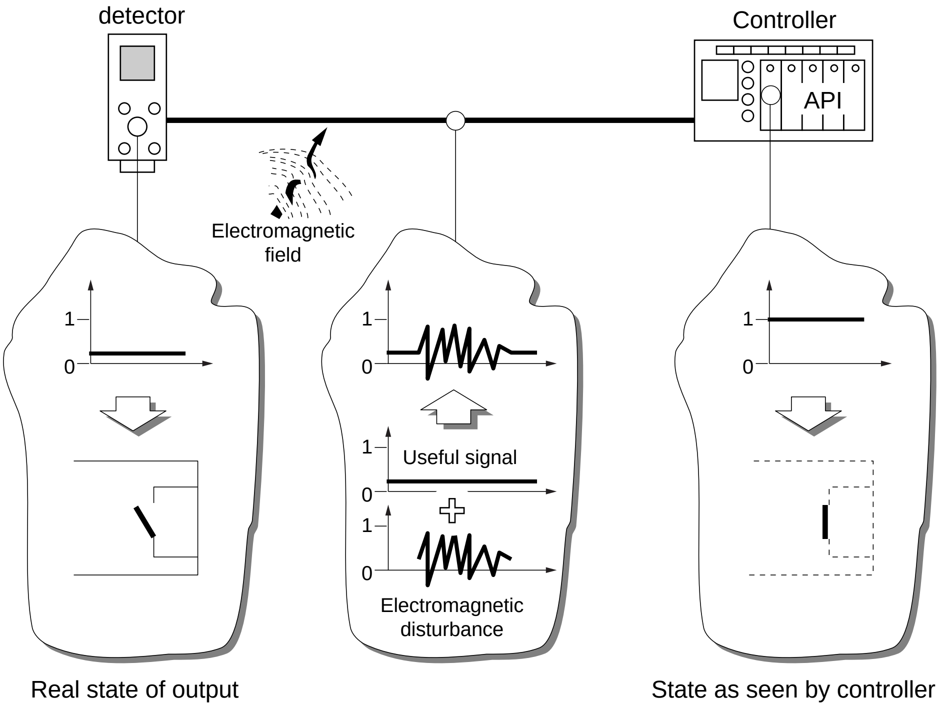
Types of electromagnetic interference



Definition of an electromagnetic disturbance

Any electromagnetic phenomenon capable of impairing the performance of a device, equipment or system, etc.

An electromagnetic disturbance can be electromagnetic noise, an unwanted signal or a change in the propagation medium itself.



In addition, an electromagnetic disturbance, as its name suggests, consists of an electric field $\vec{E}$ generated by a potential difference and a magnetic field $\vec{H}$ difference caused by the flow of a current I along a conductor.

Electro..magnetic

↙ ↘

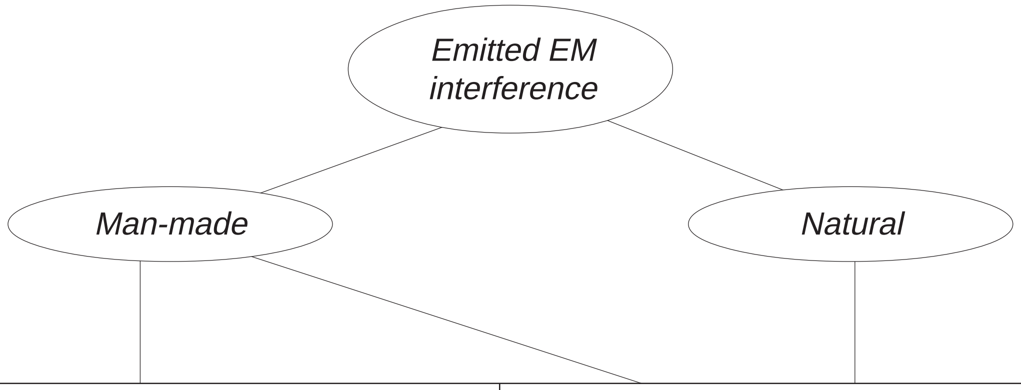
Electric field **Magnetic field**

«Unwanted» electromagnetic interference is simply an unwanted electrical signal that is added to the useful signal.

This unwanted signal is propagated by conduction in conductors and by radiation in air, etc.

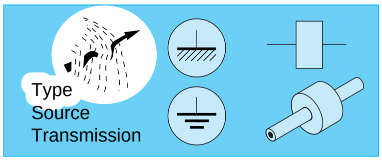
Types of electromagnetic interference

Origin of emitted electromagnetic interference



Deliberate	Unintentional
• Broadcasting stations • TV transmitters • Walkie talkies • Citizen's Band • Portable telephones • Radar systems • etc.	**Accidental** • Short circuits • Sudden earthing **Continuous** This is caused by the normal operation of apparatus. • All systems that switch an electrical signal on and off (hard contact, «power» transistor, etc.) such as : Contacts, relays, inverters, switching power supplies, ignition systems of combustion engines, commutator motors, dimmers, etc. • Gas discharge and fluorescent lamps • Equipment that uses clocks (PC, PLC) • etc.
• Equipment for the processing of materials : -> Melting, welding, soldering, etc. -> Induction ovens (drying timber, etc.) -> Electron torches -> etc.	

Types of electromagnetic interference



Low-frequency (LF) interference

Frequency range :	0 ≲ frequency ≲ 1 to 5 MHz. Low-frequency (LF) interference is encountered in installations chiefly in CONDUCTED form (cables, etc.)
Duration :	Often long duration (several dozen ms) In some cases this phenomenon may be continuous (harmonic).
Energy :	The conducted energy may be high and result in malfunction or even the destruction of connected devices.

(Energy) $\mathbf{W}_{(J)} = \mathbf{U}_{(V)}\ \mathbf{I}_{(A)}\mathbf{t}$ (s)

High-frequency (HF) interference

Frequency range :	Frequency ≳ 30 MHz. High-frequency (HF) interference is encountered in installations chiefly in RADIATED form (air, etc.)
Duration :	HF pulses. Pulse rise time < 10 ns. This phenomenon may occur continuously (rectifiers, clocks, etc.).
Energy :	The radiated energy is generally low and results in malfunction of nearby equipment.

Types of electromagnetic interference

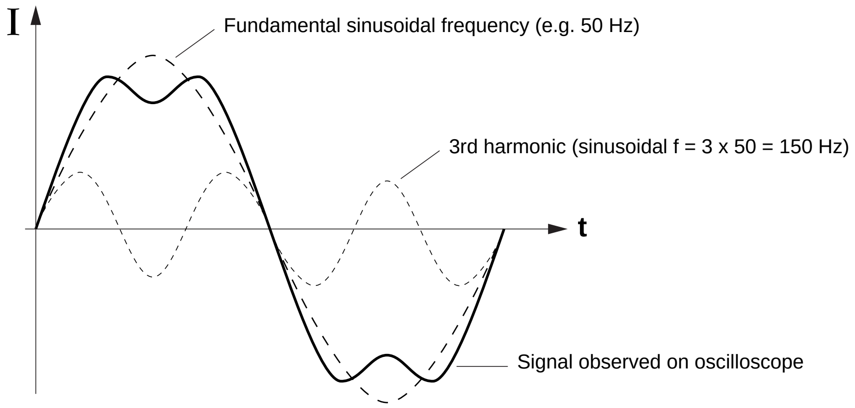
Harmonics

A periodic signal of any shape can be mathematically resolved into a number of sinusoidal signals of various amplitudes and phases of which the frequency is a whole multiple of the fundamental frequency.

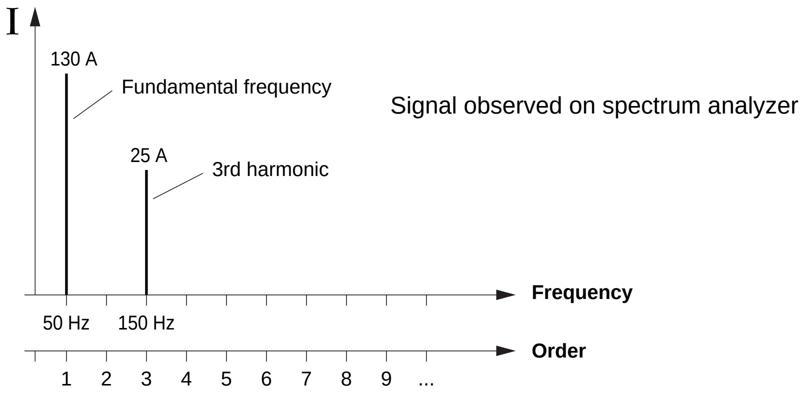
fundamental frequency : lowest useful frequency of the signal.

Breakdown of a signal into a FOURIER series.

Time representation



Spectral representation



Harmonic interference is low-frequency (LF) type interference and is therefore mainly «conducted».

Types of electromagnetic interference

Harmonic distortion

The total harmonic distortion percentage is used to work out the deformation of any signal compared with the fundamental (first-order) sinusoidal signal.

$$\text{TDH \%} = \sqrt{\sum_{2}^{n} \left(\frac{H_i}{H_1}\right)^2}$$

H_i = amplitude of harmonic of order

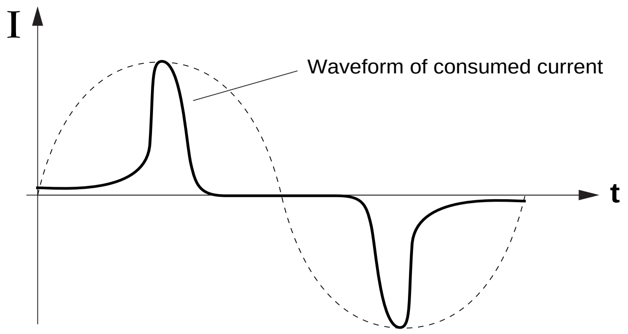
H_1= amplitude of fundamental (first-order) frequency

This can be simplified : $$\text{TDH} \approx \frac{\Sigma \text{ Amplitudes of all harmonics of order} > 2}{\text{Amplitude of fundamental frequency or 1st order harmonic}}$$

Harmonics of order higher than 40 have a negligible effect on harmonic distortion (but not on installations).

Origin

All non-linear (fluorescent lighting, rectifier, etc.) loads (sinks) consume non-sinusoidal current and therefore generate harmonic currents.



Current consumed by a fluorescent tube

The power source converts these harmonic currents into harmonic voltages through its internal impedance (Z).

U = ZI
It is this mains-borne harmonic voltage that can interfere with other loads.

Types of electromagnetic interference

Harmonics (continued)

Main sources of harmonics

- Inverters, choppers,
- bridge rectifiers: electrolysis, welding machines, etc.
- arc furnaces,
- induction ovens,
- electronic starters,
- electronic speed controllers for d.c. motors,
- frequency converters for induction and synchronous motors,
- domestic appliances such as TVs, gas discharge lamps, fluorescent tubes, etc.,
- saturable magnetic circuits (transformers, etc.).

It is evident that these types of sinks are in increasingly widespread use and the «power» that they handle is becoming increasingly higher, hence the growing importance of the associated interference.

Types of electromagnetic interference

Main loads affected by harmonics

Load	*Problems*
Synchronous machines :	Additional temperature rises
Transformers :	Additional losses and temperature rises. Risk of saturation if even-order harmonics are present.
Asynchronous machines :	Additional temperature rises, especially in the case of squirrel-cage motors or motors with a deeply slotted armature Pulsating torques
Cables :	Increased ohmic and dielectric losses
Computers :	Functional problems due to pulsating torque of drive motors for example
«Power» electronics :	Problems associated with waveform: switching, synchronisation, etc.
Capacitors :	Temperature rises, ageing, unwanted circuit resonance, etc.
Regulators, relays, counters :	Falsified measurements, untimely operation, impaired accuracy, etc.

Types of electromagnetic interference

Transients

The term «transient» denotes impulsive spikes picked up by electric circuits and encountered in conducted form on power supply cables and at control and signal inputs of electrical or electronic equipment.

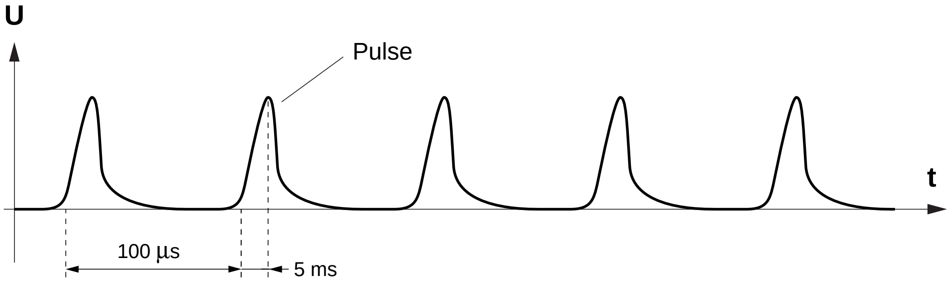
Characteristics of standardised transients (IEC 1000-4-4 type)

The significant features of these disturbances are as follows:

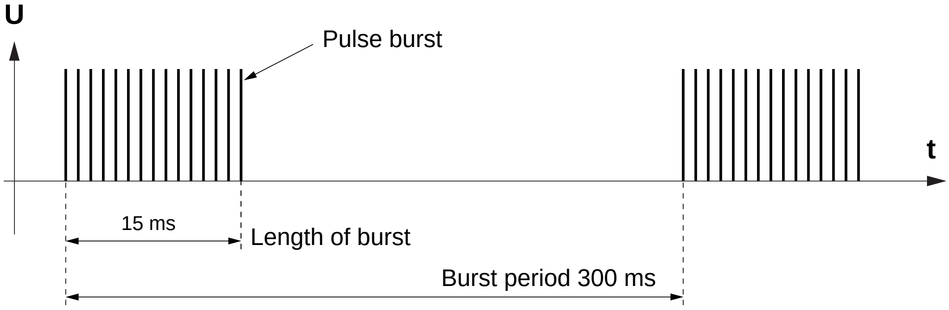
- Very short duration of pulse rise time ≃ 5 ms
- Pulse duration ≃ 50 ms
- Repetitive phenomenon: pulse bursts for roughly ≃ 15 ms
- Repetition frequency : successive bursts roughly every ≃ 300 ms
- Low energy pulses ≃ 1-10^{-3} joule
- High amplitude of overvoltage ≤ 4 kV

Example :

Time representation

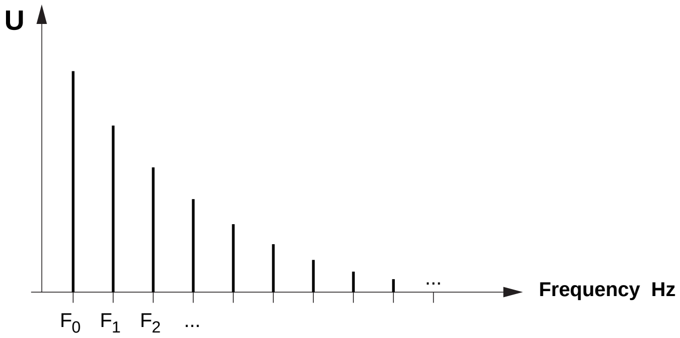


Repetition period depends on the level of the test voltage



Types of electromagnetic interference

Spectral representation



Depending on the nature of the transient in question, the spectrum may be wide-band (0 to 100 MHz or more).

Origin

Transients are caused by the high-speed switching of mechanical and, in particular, electronic «switches».

When a «switch» operates, the voltage across its terminals changes very rapidly from its nominal value to zero and vice versa. This produces sudden high variations in voltage (dv/dt) that are carried along cables.

Main sources

- Lightning, faults to earth, commutation failures in inductive circuits (contactor coils, solenoid valves, etc.)
- Transients are high-frequency (HF) type disturbances.

  They are conducted along conductors but are easily injected into other conductors by radiation.

Types of electromagnetic interference

Electrostatic discharges (ESD)

The term «electrostatic discharge» denotes impulsive currents that flow through any object connected to earth if it comes into (direct or indirect) contact with another object having a potential that is high relative to earth.

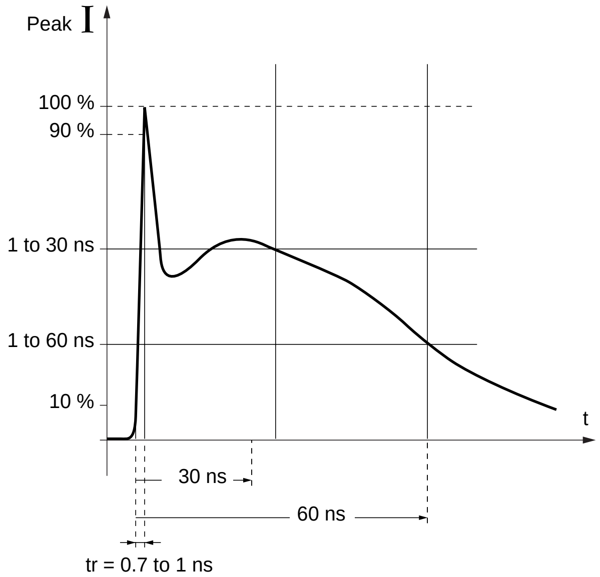
Characteristics of standardised electrostatic discharges (IEC 1000-4-2 type)

The significant features of these disturbances are as follows :

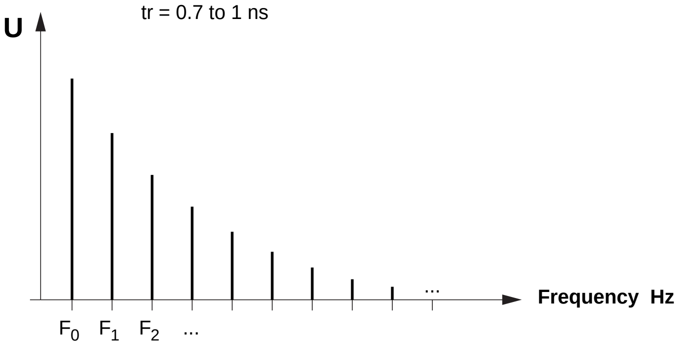
- Very short duration of pulse rise time ≃ 1 ns
- Pulse duration ≃ 60 ns
- The isolated nature of the phenomenon : 1 discharge
- The very high voltage at the start of the discharge (2 to 15 kV or more)

Example :

Time representation



Spectral representation



Wide-band spectrum (0 to 1000 MHz or more)

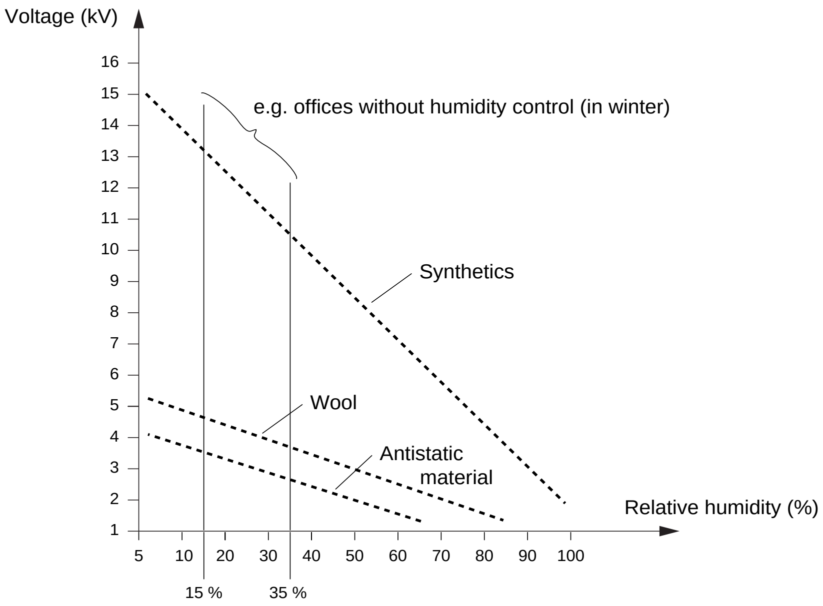
Types of electromagnetic interference

Origin

Electrostatic charges are the result of exchanges of electrons between materials or between the human body and materials. This phenomenon is encouraged by the combination of synthetic materials (plastics, fabric, etc.) and a dry atmosphere.

Main sources

The process may be the result, for instance, of a person accumulating a charge as he/she walks over a carpet (exchange of electrons between the body and the fabric), or of clothes worn by an operator sitting on a chair. Discharges may also occur between a person and an object or between electrostatically charged objects.



Maximum values of electrostatic voltages that may be accumulated by an operator

Effects

The effect of electrostatic discharge from an operator to equipment can range from a simple malfunction through to destruction of the equipment.

☞ Electrostatic discharge type disturbances are high-frequency (HF) type interference that is encountered in conducted form but which is easily injected into other conductors by radiation.

Types of electromagnetic interference

LV mains interference

Voltage : fluctuations, power failures, voltage dip, surge voltages

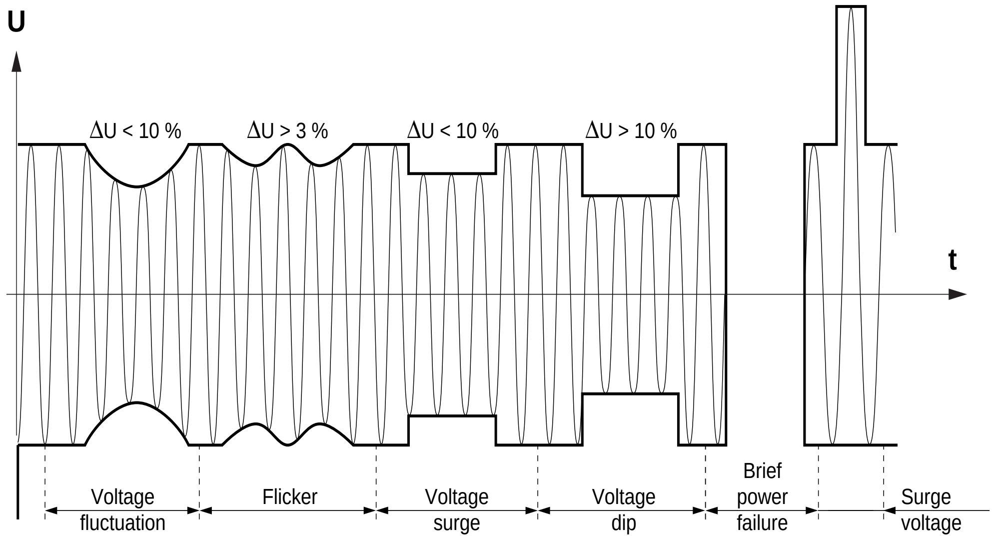
Frequency : variations

Waveform : harmonics, transients, carrier currents

Phases : unbalanced

Power : short circuits, overloads (effects on voltage)

These are chiefly low-frequency (LF) type disturbances.



Examples of low-voltage (LV) mains interference

Types of electromagnetic interference

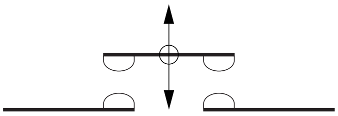
Usual name	Amplitude of variation	Duration of fault	Origin	Consequences
Voltage fluctuation	ΔU < 10% (slow variation) CEI 38 IEC 1000-3-3 IEC 1000-3-5		• Arc furnaces • Welding machines • Large loads involving frequent starting (compressors, lifts, etc.)	• No effect on equipment
Flicker	ΔU > 3%			• Flickering of lighting systems
Voltage surge	ΔU < 10% (fast variation)		• Switching of large loads (starting of big motors, electric boilers, electric furnaces, etc.)	
Voltage dip	10% ≤ ΔU ≤ 100 IEC 1000-2-2	10 ... 500 ms Power failure and voltage dips are Impulsive : < 10 ms Brief : 10 ms to 300 ms	Powering-up (inrush current In 8 to 20 A) : • Large motors and «on-the-fly restarting» • Large transformers • Large capacitors at start of network Short circuit on main LV distribution (wind, storm, fault on neighbouring customer's premises) (power failure due to protective device with reclosing)	• Dropout of high-speed relays; can cause serious problems in process control • Loss of power supply (if DU > 30%) • Loss of braking in motors • Make sure of adequate immunity, especially for controller, sensors, etc. • Slipping of asynchronous motors
Brief power failure	ΔU = 100%	Brief : 10 ms à 1 mn long : 0,3 s à 1 mn permanent : > 1 mn	Powering-up (inrush current In 8 to 20 A) : • Large motors and «on-the-fly restarting» • Large transformers • Large capacitors at start of network if t ≤ 10 ms --> transient phenomenon	• Loss of power supply
Surge voltage	ΔU > 10%	Impulsive	• Accidental (connection mistakes) • MV system	• Destruction of electronic hardware • Absolutely must be taken into account in the design and implementation of electronic apparatus • Generally of no consequence for electrical equipment

Sources of electromagnetic interference

Switching of inductive loads by dry contacts

Switching devices with dry contacts

This term is taken to mean all the devices designed to make or break one or more electrical circuits by means of contacts that can be separated.



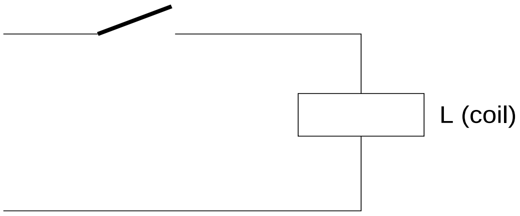
Origin of disturbances

The behaviour of the electric contact and the disturbances generated depend on the nature of the controlled load.

Behaviour when connected to a resistive load

Switching a resistive load by means of a dry contact generates no or little disturbance

Behaviour when connected to an inductive load



Example of inductive loads :
Electromagnet of contactor, solenoid valves, brake, etc

Sources of electromagnetic interference

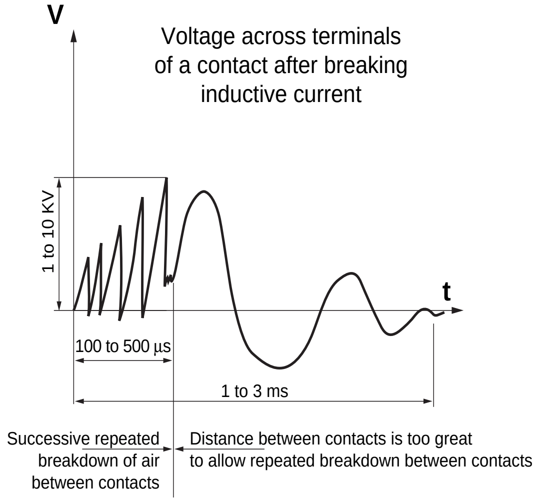
Steady state conditions

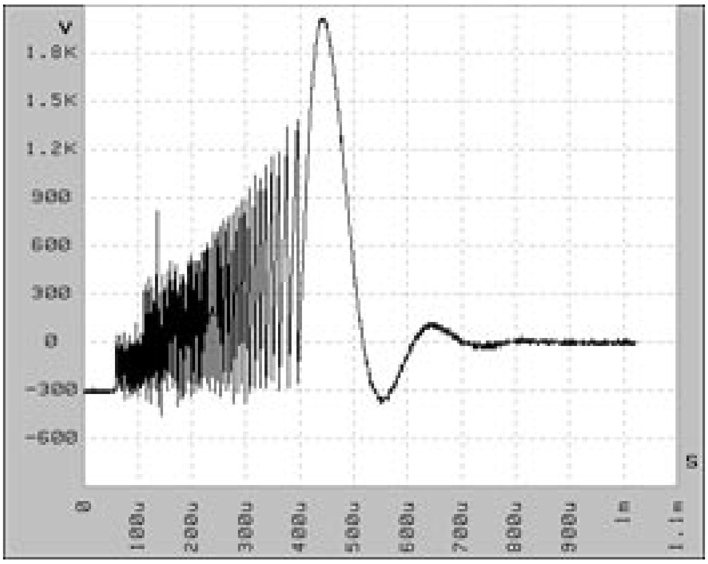
Under steady-state conditions, a contact that «powers» an inductive load does not generate any disturbance.

Switching an inductive circuit

Opening an inductive circuit produces the following across the contact terminals :

- A significant overvoltage resulting in a series of breakdowns of the dielectric, possibly followed by arcing.
- Damped oscillation of the voltage at the natural frequency of the circuit consisting of the inductive load and its control line.





Contactor cutoff, 9A~ without peak limiting

Application to power circuits

The operation of switches, contactors, circuit breakers, etc. in power circuits generates transient disturbances.

Example: closing when connected to capacitors (power-factor compensation battery), tripping of circuit-breaker in the event of short circuit, etc.

Despite the amplitude of the switched currents, the phenomena caused by such operations often cause little interference. The energies involved are high but are characterised by gently-sloping wave fronts (filtering effect of cables, high time constant of loads, etc.)

Sources of electromagnetic interference

Emitted disturbances

Voltage surges vary from 1 to 10 kV and increase the faster the contact is opened. They depend on the energy stored in the controlled circuit.

Example :	50 mJ for a small a.c. contactor
	0.2 J for a small d.c. contactor
	10 J for a large d.c. contactor

The frequency spectrum of the emitted disturbances (breakdown wave-front) ranges from several kilohertz (kHz) to several megahertz (MHz).

Effects on installations

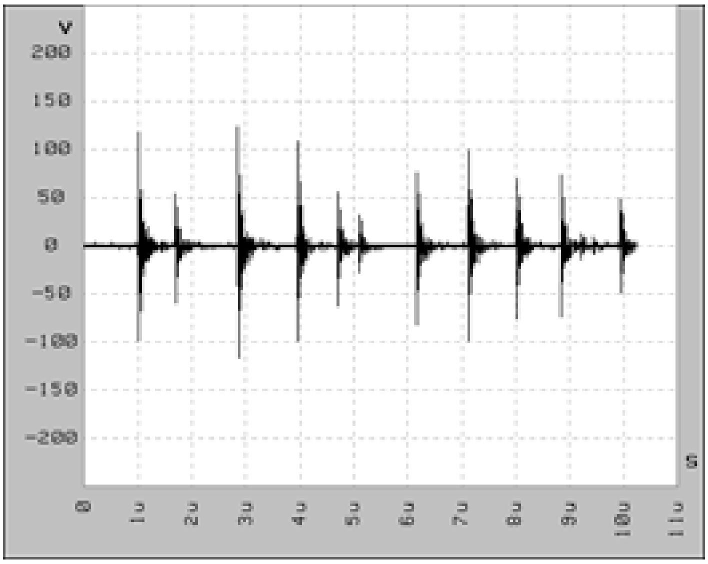
These disturbances have no effect on conventional electrical equipment.

They can cause interference in certain electronic circuits :

In conducted form

Succession of transients superimposed on the power supply current. This can cause inopportune triggering of thyristors, triacs, etc. and switching of or damage to sensitive inputs.

Contactor cutoff 9A~ mains rejection



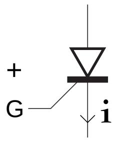
In radiated form

These high-frequency (HF) disturbances can, when radiated, interfere with separate neighbouring circuits (cables in the same trough, printed conductors on PCs, etc.). Finally, they may interfere with nearby telecommunication equipment (television, radio, measuring circuit, etc.).

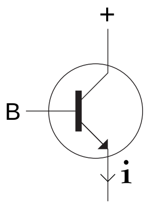
Sources of electromagnetic interference

Switching of inductive loads by semiconductors

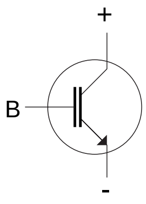
This term is taken to mean all the electronic components designed to make and/or break current flowing through a semiconductor in an electrical circuit.



Thyristor



Transistor



IGBT

IGBT = **I**nsulated **G**ate **B**ipolar **T**ransistor

In some respects, these are extremely high-speed «switches» that will be «open» or «closed» depending on the reference variable applied to the control of the switch, namely the base (B) or the gate (G), depending on the component.

Typical performance of such components

Typical values	Thyristor	Transistor	IGBT
Insulation withstand capability (max)	1,6 kV	1,2 kV	1,2 kV
Max. on state current	1,5 kA	500 A (switched)	400 A (switched)
Switching frequency	3 kHz	5 kHz	10-20 kHz

1
2
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Sources of electromagnetic interference

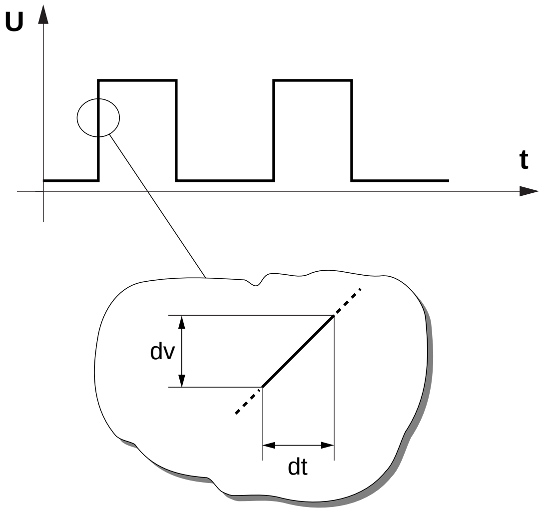
Switching of inductive loads by semiconductors (continued)

Case study

Observed phenomenon

Making and breaking an electrical circuit results in a sudden variation in the current or voltage across the terminals of the control circuit.

This therefore results in steep potential gradients (dv/dt) across the terminals of the circuit which will produce interference.



Emitted signals :

Two types of disturbances are generated :
- *Low-frequency (LF) harmonics: 10 kHz ...*
- *Low- and high-frequency (HF) transients: up to 30 MHz...*

They are encountered in conducted and radiated form.

Effects

Interference in sensitive apparatus such as: measuring systems, radio receivers, telephones, sensors, regulators, etc.

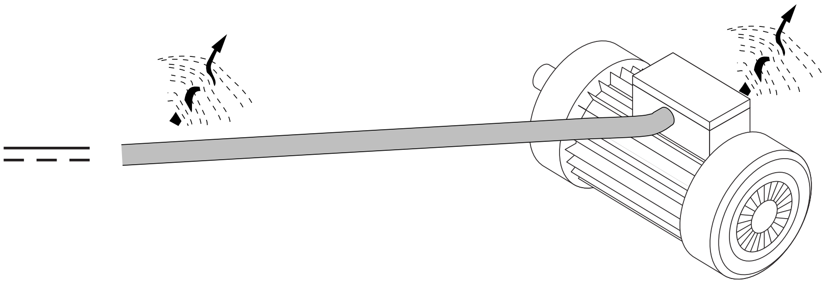
Sources of electromagnetic interference

Electric motors

Rotating machines

Rotating machinery (electric motors) are an important source of conducted and/or radiated interference.

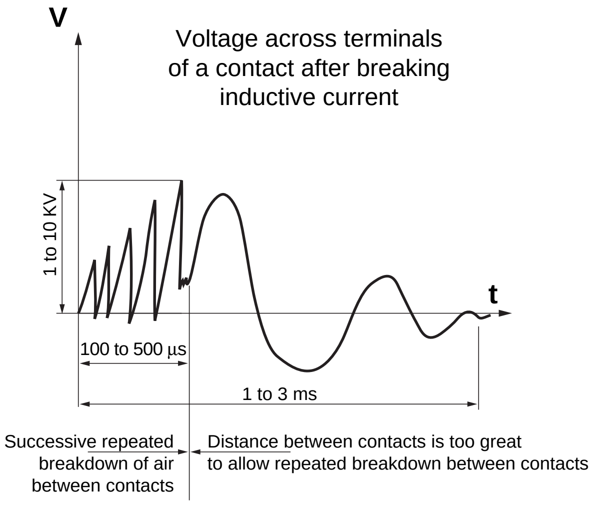
Example: commutator d.c. motor

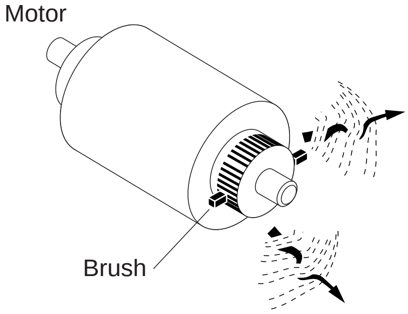


Observed phenomena

During normal operation (continuous running), interference will depend on the type of motor used.

- Induction motors (asynchronous, etc.) cause relatively little interference.
- Motors with brushes and commutators generate «transient» type interference with a steeply-sloping wave front (high dv/dt) produced during the brush commutation phase.





d.c. commutation

Sources of electromagnetic interference

Electric motors (continued)

Nevertheless, asynchronous motors can generate interference :

- Magnetic saturation of motors.

  The load then becomes non linear and this produces harmonics.

- Switch-on or powering-up of motor (starting).

  The resulting high inrush current (6 to 10 I nominal) can produce a power supply voltage dip.

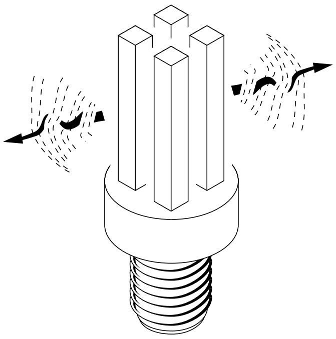
Emitted signals :

- Low-frequency harmonics
- Power supply interference (voltage dips, etc.)
- Low- and high-frequency (HF) transient disturbances, possibly higher than 100 MHz
- Electrostatic discharges caused by the build-up of electrostatic energy resulting from friction between materials of different types.

Sources of electromagnetic interference

Fluorescent lighting

This term is taken to mean all lighting sources that operate on the principle of an electric arc that alternately switches on and off.



Origin

Even when they are compensated and installed in pairs, the current drawn by fluorescent tubes is not sinusoidal.

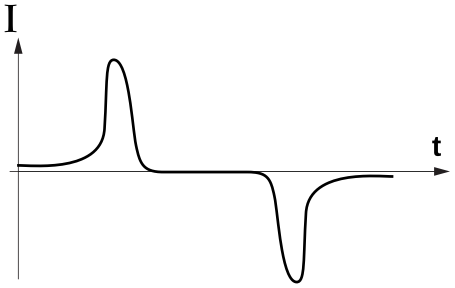
Generated interference

This current is therefore particularly rich in harmonics, especially third harmonics (3 x 50 Hz or 3 x 60 Hz etc.)

Interference will be generated over a wide frequency range (0 to 100 kHz or even 5 MHz).

☞ These disturbances of the low-frequency (LF) type are encountered in the installation in conducted form.

Waveform of absorbed current



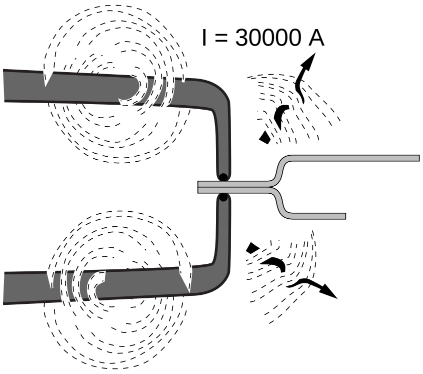
Sources of electromagnetic interference

Spot welding

This includes all electric welding machines or soldering tongs.

Principle

Spot welding is obtained by passing a high current (≃ 30,000 A) through the two parts to be welded. The temperature rise is high enough to achieve welding by fusion.

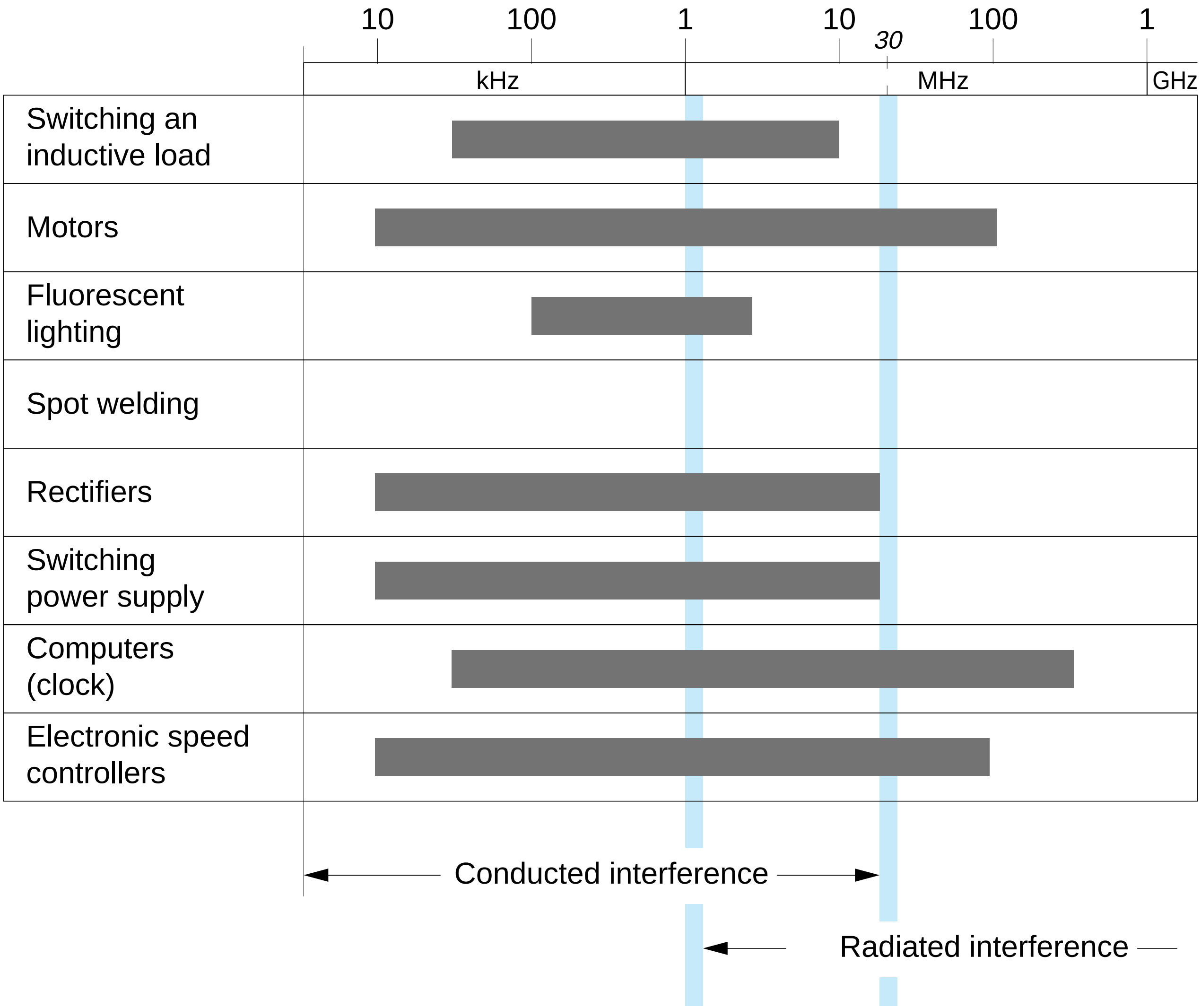


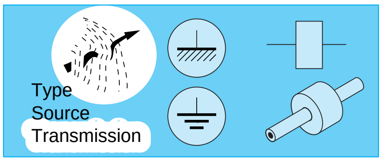
Generated interference

- Harmonic voltages 200 ... 20 kHz
- Strong radiated magnetic field that can cause malfunctioning of inductive proximity switches.

Sources of electromagnetic interference

Spectral distribution of interference



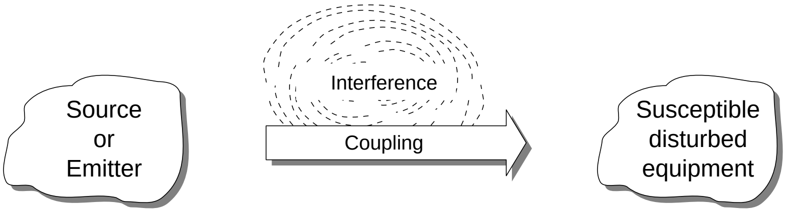


Transmission modes of electromagnetic interference

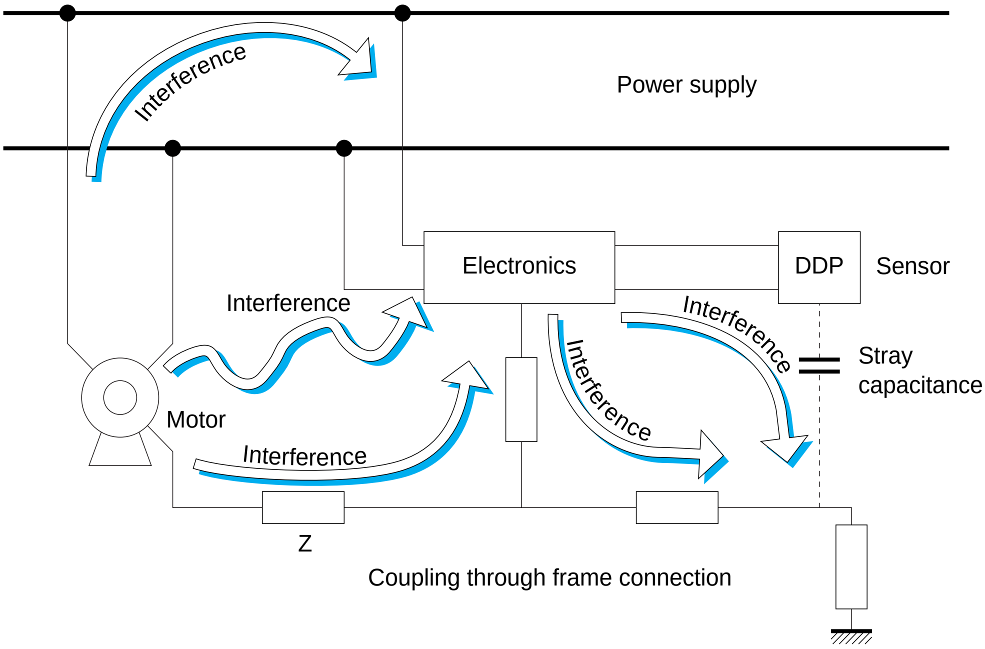
Identifying the transmission mode of interference is an essential aspect of correct analysis of (EMC) phenomena

Coupling : general information

Coupling is the way in which EM disturbances act on susceptible equipment.



Typical installation :



Transmission modes of electromagnetic interference

When «sensitive» (low immunity level) equipment is fed by an electric power source that is shared by several equipment items (distribution system, etc.), the interference generated by «power» equipment (motors, furnaces, etc.) is transmitted to the sensitive equipment over common power supply lines.

There is another type of coupling by conduction that occurs in frame and earth circuits.

Frame earth conductors (PCB, etc.) are all linked to the frame connection of the installation and ultimately to earth by «conductors» having non-zero impedance (Z).

This results in a potential difference between the earth and frame connections as well as between frame connections.

These potential differences cause parasitic currents to flow through the various circuits.

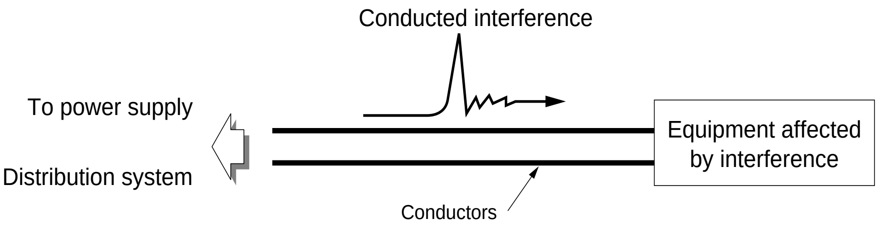
Coupling due to radiated interference in air may also cause malfunctioning of nearby devices.

Transmission modes of electromagnetic interference

Conductive coupling

Conducted interference is carried by an electric «conductor». It can therefore be transmitted via :

- Internal power supply lines or the distribution system,
- Control wires,
- Data transmission lines, buses, etc.
- Earth cables (PE, PEN, etc.),
- Earth,
- Stray capacitance, etc.



Principle

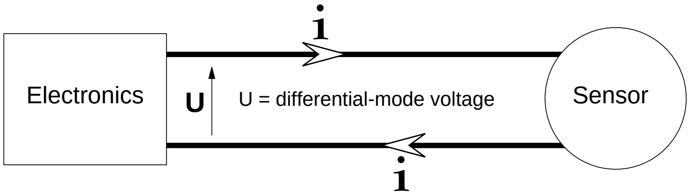
A (wanted or unwanted) signal can travel along a 2-wire connection in two ways :

- Differential mode
- Common mode

Transmission modes of electromagnetic interference

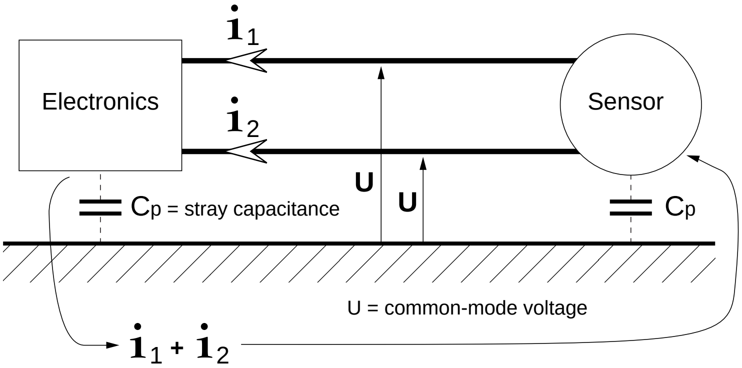
Differential mode

Differential-mode (or series-mode) current travels along one of the conductors, flows through the equipment, may or may not cause malfunctions in it and returns via another conductor.



Common mode

Common-mode current flows along all the conductors in the same direction and returns via the frame connection through stray capacitance.



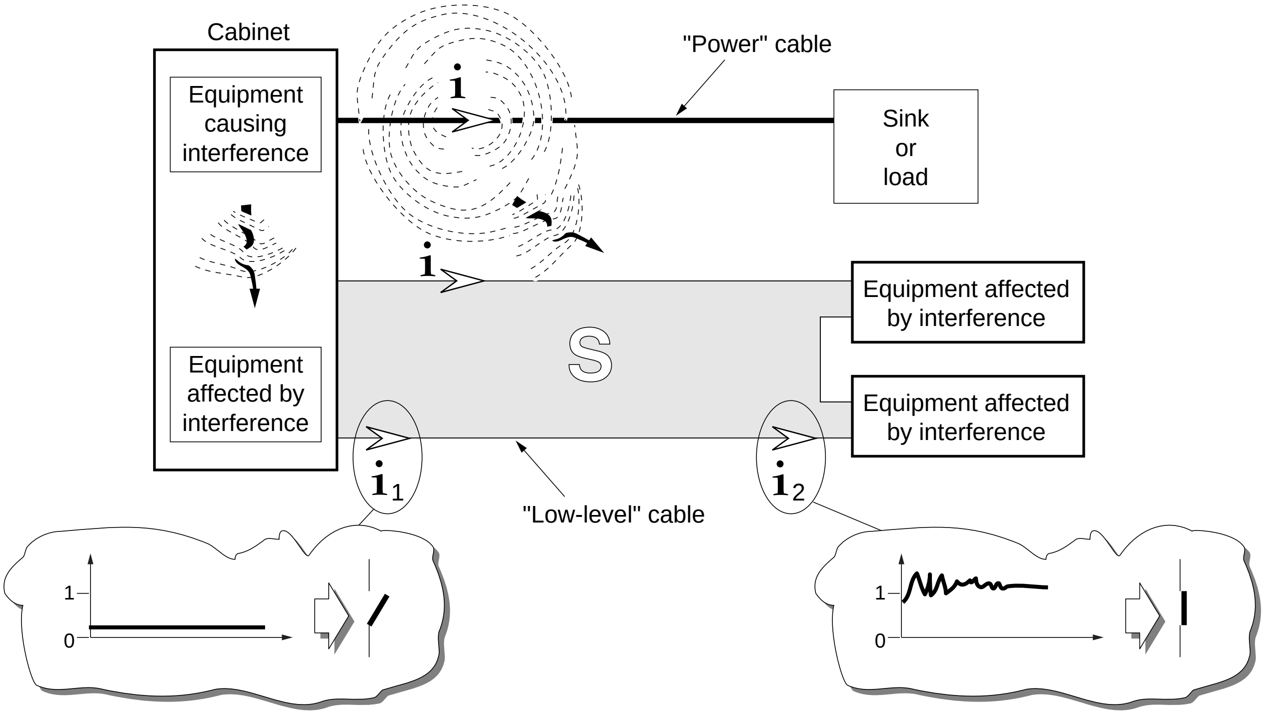
Common-mode interference is the major problem in (EMC)
because its propagation path is difficult to identify.

Transmission modes of electromagnetic interference

Coupling by radiation

Radiated interference travels through the ambient medium (air, etc.).

Typical case :



Principle

Depending on the nature of the emitted interference, there are two types of possible coupling :

- Inductive coupling
- Capacitive coupling

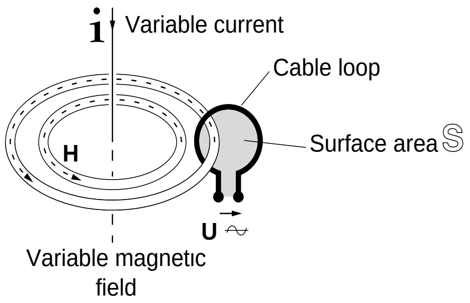
Transmission modes of electromagnetic interference

Inductive coupling

A current **I** flowing through an electric conductor creates a magnetic field that is radiated around the conductor. It is clear that the current which flows must be high; it is usually generated by «power» circuits (which carry high current > 10 A).

Any loop formed by an electric conductor having a surface area S and surrounded by a variable magnetic field will have an alternating voltage U across its terminals.

Schematic diagram



Capacitive coupling

There is always a non-zero capacitance between an electrical circuit (cable, component, etc.) and another nearby circuit (conductor, frame connection, etc.).

The variable potential difference between these two circuits will cause the flow of an electric current from one to the other through the insulating material (air, etc.), thus forming a capacitor or stray capacitance.

This parasitic current increases as the frequency of the voltage across the terminals of the stray capacitance rises.

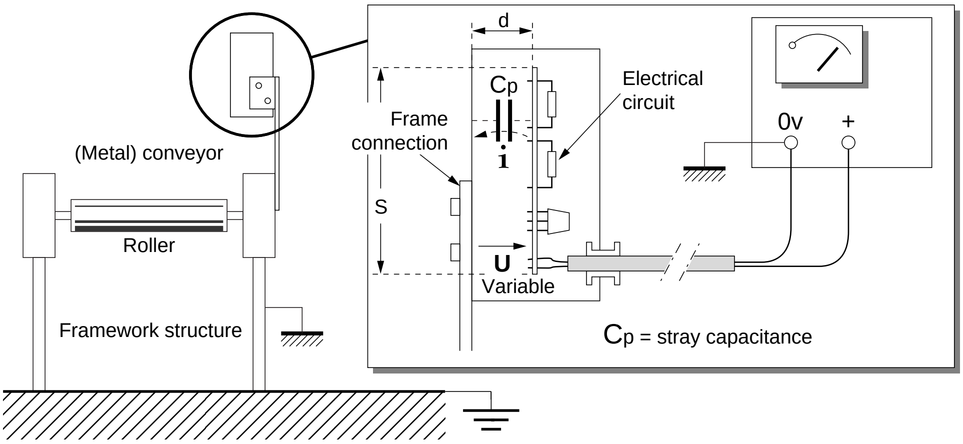
$$\mathbf{I} = \frac{U}{Z} \qquad Z = \frac{1}{C\omega} \qquad \mathbf{I} = \underbrace{UC\,2\Pi}_{k}\,f$$

$$\mathbf{I} = kf$$

Transmission modes of electromagnetic interference

Coupling by radiation (continued)

This phenomenon is also referred to as «hand capacitance».



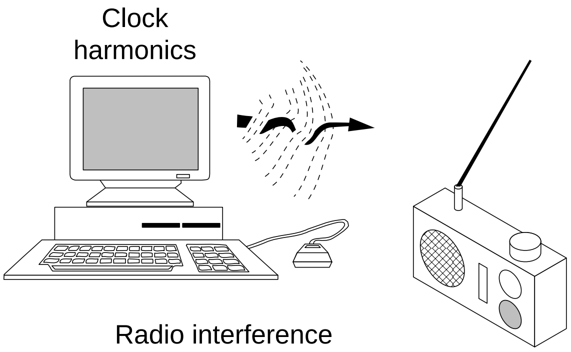
In addition, the value of the stray capacitance formed by both parts of the circuit is :

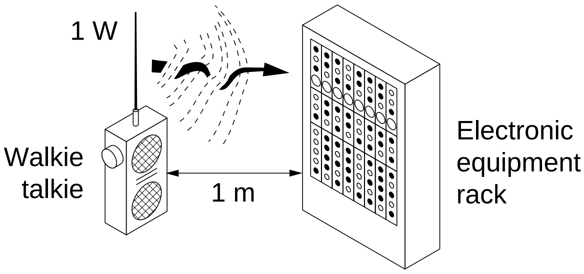
- Proportional to the opposite-facing surface areas of the two circuits (S),
- Inversely proportional to the distance between the two circuits (d).

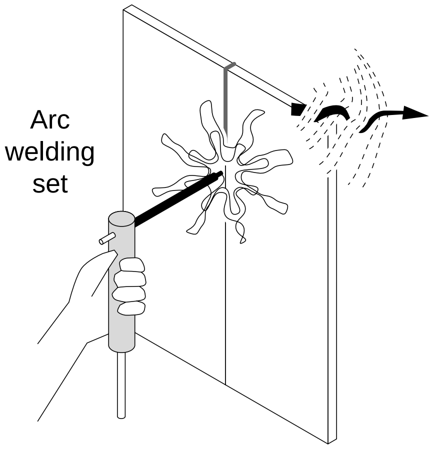
Although the stray capacitance between circuits may be completely negligible at 50 Hz,
it becomes significantly important at high frequency (HF)
and causes the installation to malfunction.

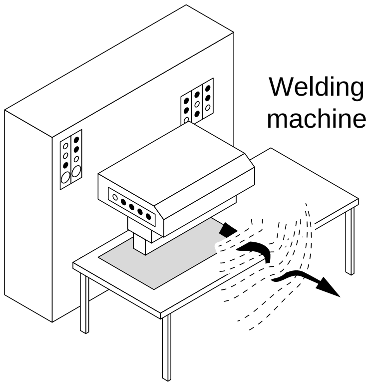
Transmission modes of electromagnetic interference

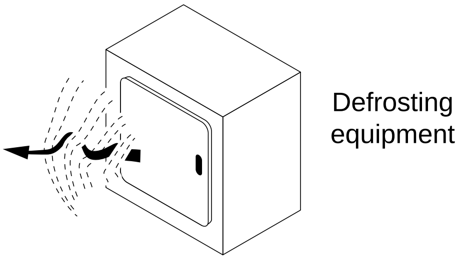
A few sources of electromagnetic interference :

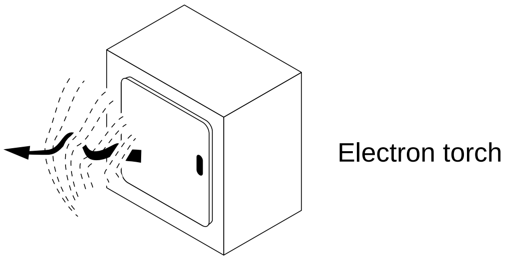


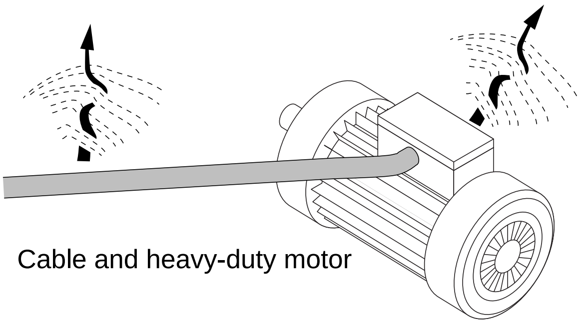


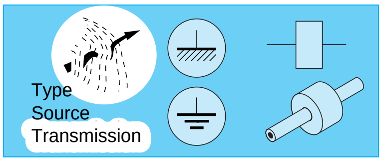












Transmission modes of electromagnetic interference

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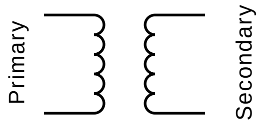
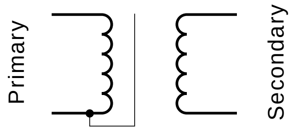
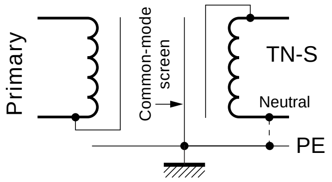
Decoupling of interference

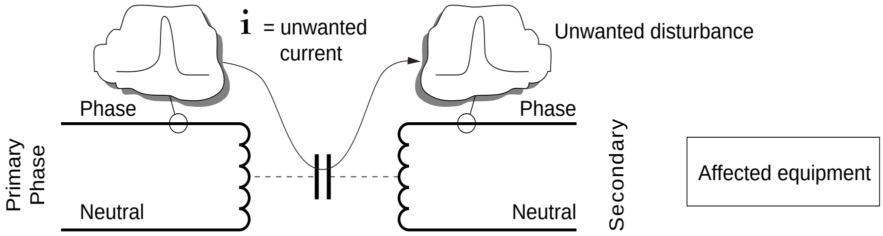
Isolating transformers

Transformer	Symbol	Isolation	
		LF	**HF**
Standard		OK	Ineffective
Single screen		OK	Average
Double screen		OK	Good

Transformers

- Can be used to change the earthing arrangement anywhere in the installation,
- Only ensure satisfactory electrical isolation at low frequency (LF),
- A double-screen transformer is required if appropriate electrical isolation has to be ensured at HF,
- Block and divert common-mode currents to exposed conductive parts
- Can be used to break frame connection loops,

Explanation of phenomena



Transmission modes of electromagnetic interference

Direct current or low frequency (LF) (50 Hz etc.)

Primary/secondary insulation resistance ≥ 10 MΩ
Stray capacitance is negligible.

High frequency (HF)

The primary/secondary insulation resistance is bypassed by the stray capacitance caused by the primary and secondary windings.

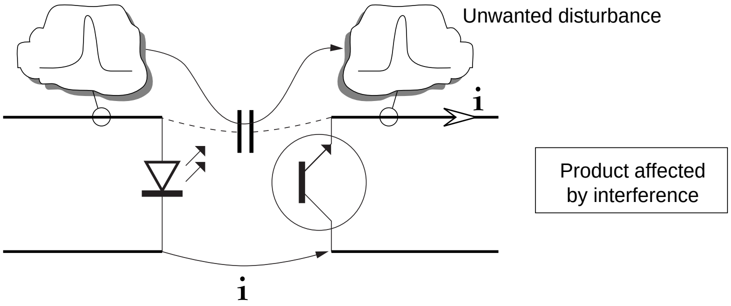
Stray capacitance $\lesssim$ 50 pF for small transformers, > 1 nF for large transformers > 500 VA.

1 nF only represents an impedance of 100 Ω at a frequency of 2 MHz.

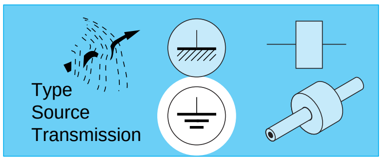
Consequences

As a result, there is risk of any disturbances, e.g. of the transient type with steep wave fronts, in the supply system which originate, for example, from switching surges being transferred to the secondary of the transformer and interfering with equipment that is connected to it.

Optocoupler



The phenomenon is the same with optocouplers although their low-frequency (LF) impedance and high-frequency (HF) performance are generally better than those of signal transformers.



Earth

Symbol : ⏚

For the purposes of this document, the term «earth» denotes all conductive, inaccessible or buried parts or structures.

Although this definition is not official, it will enable us to identify the earth and frame connections in an installation more clearly.

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3

General definition

The earth of our planet is used in certain electrical engineering applications as a conventional «0 V» reference potential and its electrical conductivity (which is highly variable) naturally conducts - or is used by humans to conduct - certain electric currents.

Roles of earth connection in electrical installations

> ***Reminder***
> ***Any current that flows in the earth entered it and will leave it to return to its source***

Applications :

- Distribution of direct lightning-stroke current in the earth «electrode» (disruptive electrostatic discharge from atmosphere to earth).
- Flow of currents induced by lightning in the soil between two points of an overhead power transmission line.
- In the T-T system, the part of the earth between the earth connection of the distribution system and the earth connection of the installation causes the flow of (low) leakage or fault currents produced by the installation.
- Frame connections of installations are also connected to earth (equipotential bonding between earth/soil relative to exposed conductive parts and metal structures) in order to protect persons (and animals) against shock hazards associated with indirect contact.

Electrical earth connections

The provisions concerning these connections in the context of distribution systems of buildings that are relevant to us relate to the following applications (protection of persons and property) and are restated in Standards IEC 364 and IEC 1024.

> ***There must be a single satisfactory earth connection***
> ***for a given electrical insulation***

Satisfactory because the downleads of lightning arresters occasionally have to handle currents of the order of 20 to 30 kA in soil of highly variable resistivity (≃ 5 to 10 000 W.m) without causing excessive damage to the soil/earth connection interface.

Single because the highly variable resistance of the soil may involve extremely high, destructive potential differences under these extreme conditions between the various earth electrodes and that of the installation itself under normal operating conditions (leakage, fault currents, etc.) and this may cause unacceptable interference.

Earth

Typical earthing arrangement for an installation

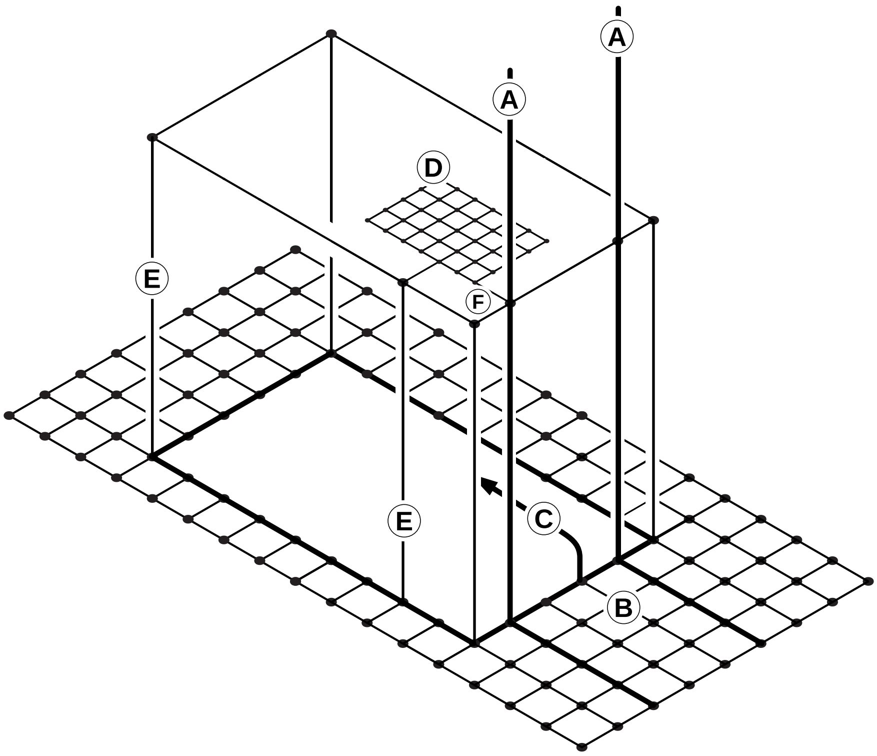
(A) Lightning arrester downleads.

(B) Meshed, buried earthing system with special reinforcement at the bottom of lighting arrester downleads.

(C) Earth electrode conductor of installation connected to earth bus at origin of PE (or PEN) conductors of the installation.

(D) Interconnected exposed conductive parts of part of the installation connected to metal structures or additional meshed elements (E).

(E) Shunt connections between lightning arrester downleads, interconnected exposed conductive parts and nearby metal structure in order to prevent any flashover (fire risk).



Earth and electromagnetic compatibility

As we have seen, the earth plays a quite specific role in relation to lighting discharges but residual currents conducted by power lines to the site still have to be eliminated.

For most other (EMC) phenomena that have to be dealt with *(transients, high-frequency (HF) currents or radiated fields)*, **earthing conductors** of which the length and topology *(star network or in parallel with live conductors)* present extremely high impedances at high frequency (HF) **will be of no use without the help of a system of interconnected exposed conductive parts.**

Frame connections

Symbol : ⏚

General definition

A frame connection is an equipotential connection point or plane that may or may not be connected to earth and which is used as a reference for a circuit or system.

Note: a frame connection having a potential that is deliberately specific or variable must be the subject of special insulation and, if applicable, connection measures.

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Specific definition for electrical installations

A frame connection is any exposed conductive part of apparatus, equipment or an installation that is not live during normal operation but which may become so in the event of a fault.

Examples of frame connections (exposed conductive parts) :

- metal structure of a building (framework, piping, etc.),
- machine bed plates,
- metal cabinets, unpainted cabinet bottoms,
- metal cable troughs,
- transformer casing, Programmable Logic Controller backplate, etc.
- green/yellow wires (PE/PEN) of earthing conductor.

Exposed conductive parts and safety of persons and property

Basic Specification IEC 364 and national texts that are specific to certain installations describe the constructional arrangements that guarantee compliance with adequate safety levels.

Regardless of the installation’s earthing arrangement, green/yellow so-called «PE» or «protective earth» conductors having a defined impedance are provided for connecting exposed conductive parts to earth and to the origin of the installation so that :

- During normal operation or if there is a fault to an exposed conductive part :
  - high fault currents are eliminated (safety of property),
  - no hazardous voltage can occur between two exposed conductive parts, an exposed conductive part and the soil or metal structure (safety of persons),
- Since the safety of installations takes precedence over every other aspect, subsequent work on the connection of exposed conductive parts shall, under any circumstances, involve :
  - disconnecting a «PE» (green/yellow) conductor from an exposed conductive part,
  - increasing the impedance of any «PE» connection.

Frame connections

Exposed conductive parts and electromagnetic compatibility

Making allowance for **HF** phenomena

Systematic, careful and appropriate interconnection of all exposed conductive parts

LF and **HF** equipotential bonding of exposed conductive parts

Satisfactory (EMC)

Correct operation of equipment on site

Low-frequency (LF) performance

Example: at mains frequency (50 or 60 Hz).

Equipotential bonding of exposed conductive parts at low frequency (LF) (50 Hz-60 Hz) is always correctly obtained using green/yellow (PE/PEN) conductors.

Frame connections

High-frequency (HF) performance

As stated in the paragraph dealing with earthing, the earth plays a relatively limited role in terms of (EMC) phenomena.

> *In contrast, exposed conductive parts located in the immediate vicinity of electronic devices act as a reference «plane» or system for high-frequency (HF) phenomena (as well as for certain aspects at a frequency of 50/60 Hz) provided that the problem of their equipotential bonding is first solved.*

The interconnection of exposed conductive parts by protective conductors in a star configuration sometimes creates extremely high HF impedances between two points. In addition, high fault currents cause potential differences between two points and (in the TN-C system) the continuous flow of high currents in the PEN conductor.

It therefore appears necessary (without downgrading the role of PE conductors), to provide as many possible additional interconnections as possible (cables not coloured green/yellow) having a cross-sectional area that is not less than the smallest cross-sectional area of the PE conductors connected to the exposed conductive parts in question. These connections must be made close to the exposed conductive parts of switchgear, cable runs, existing or deliberately added metal structures, etc.

Screens, shielding, common-mode return circuits of filtering devices, etc. will be connected to them.

> *This will create **finely meshed equipotential bonding of exposed conductive parts** that meets (EMC) requirements*

In some exceptional cases (currents induced at mains frequency, potential differences, etc.) connection to the frame earth system will have to be obtained appropriately (e.g. at one end for each «HF»/»LF» capacitor, etc.

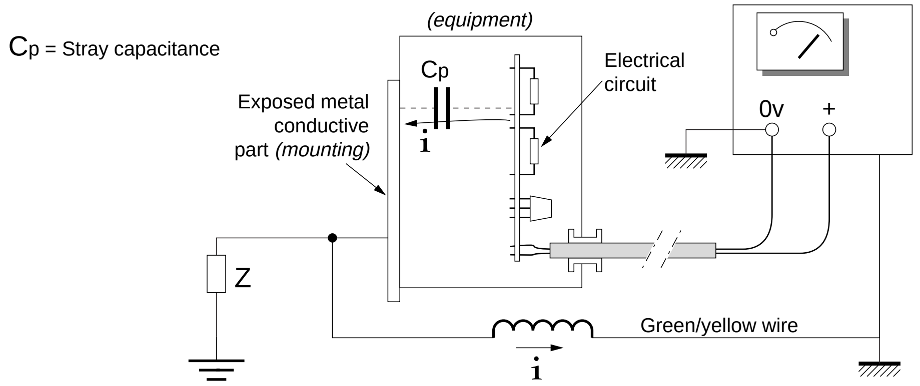
Leakage current in the installation

Because of their proximity to the electrical circuits of the installation, exposed conductive parts will, in conjunction with these circuits, create stray capacitance that will cause the flow of undesired currents through equipment and exposed conductive parts.

In some cases this may result in the malfunctioning of installations (tripping of differential protection devices, etc.).

The reader should refer to the various transmission modes (radiated interference, capacitive coupling).

Frame connections



Exposed conductive parts must therefore be connected by appropriate means at low frequency (LF) (safety of persons, etc.) and at high frequency (HF) (satisfactory EMC).

This will only be effectively feasible in technical and economic terms if :

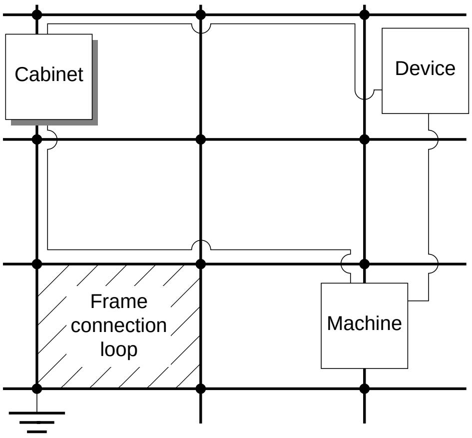
- the problem is taken into account at the DESIGN stage,

- the HF aspects of an installation are mastered

Frame connections

Loops between exposed conductive parts

A loop between exposed conductive parts is the surface area enclosed between two frame-connection wires.



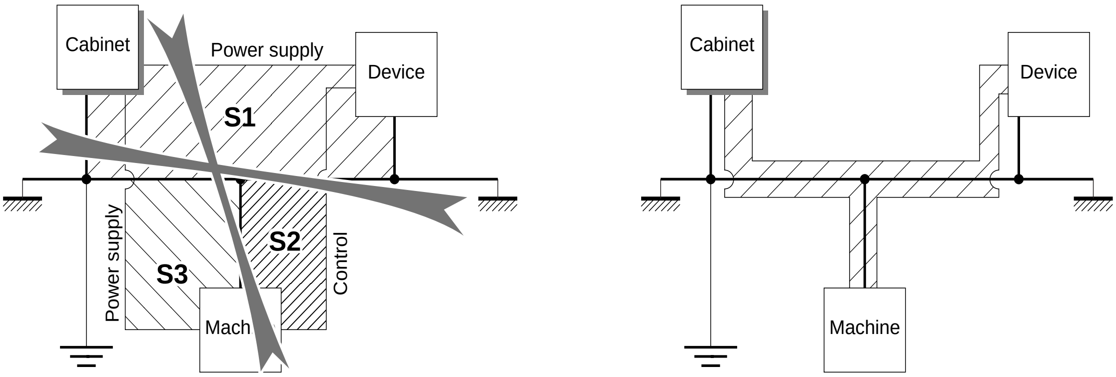
Loops between exposed conductive parts are the result of systematic, careful interconnection to ensure equipotential bonding at a site

It is vitally necessary to have a large number of connections between all exposed conductive parts.

Frame connections

Frame connection loops

A frame connection loop is the surface area enclosed between a functional cable (power supply cables, control lines, communication network, etc.) and the nearest conductor or frame earth.



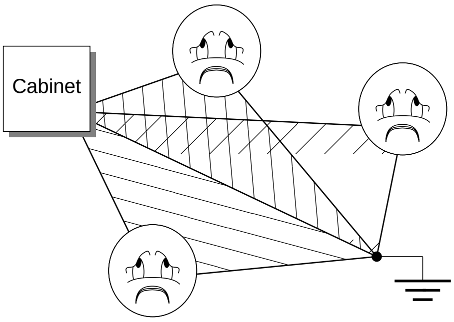
The number of frame connection loops is the same as the number of functional cables.

***It is crucial to minimise the surface area of frame connection loops** by running the entire length of functional cables as close as possible to exposed conductive parts*

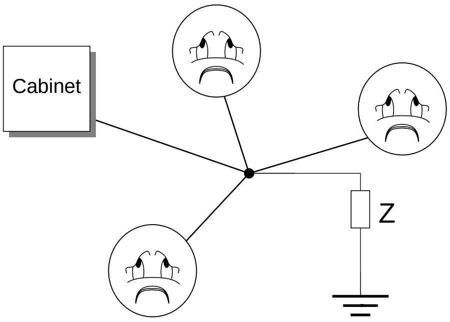
Frame connection loops are the main source of (EMC) problems, coupling of radiated interference is especially effective in them.

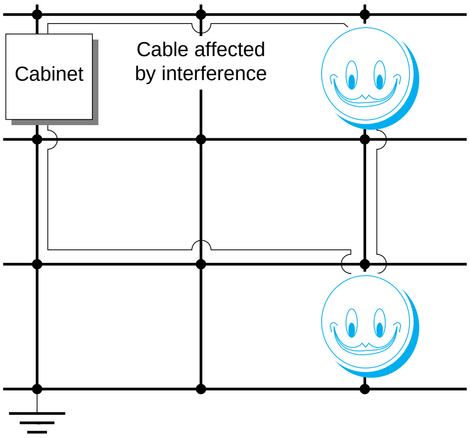
Frame connections

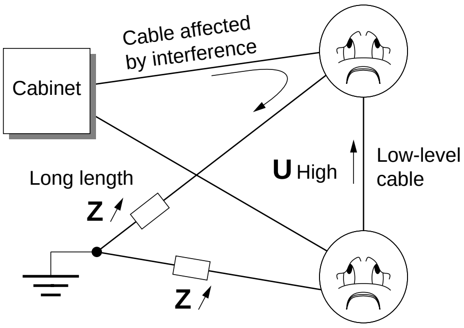
Avoid earthing exposed conductive parts in a star configuration



Large surface-area frame connection loops







High common impedance
==> PD between equipment items

It is crucial not to earth exposed conductive parts in a star configuration.

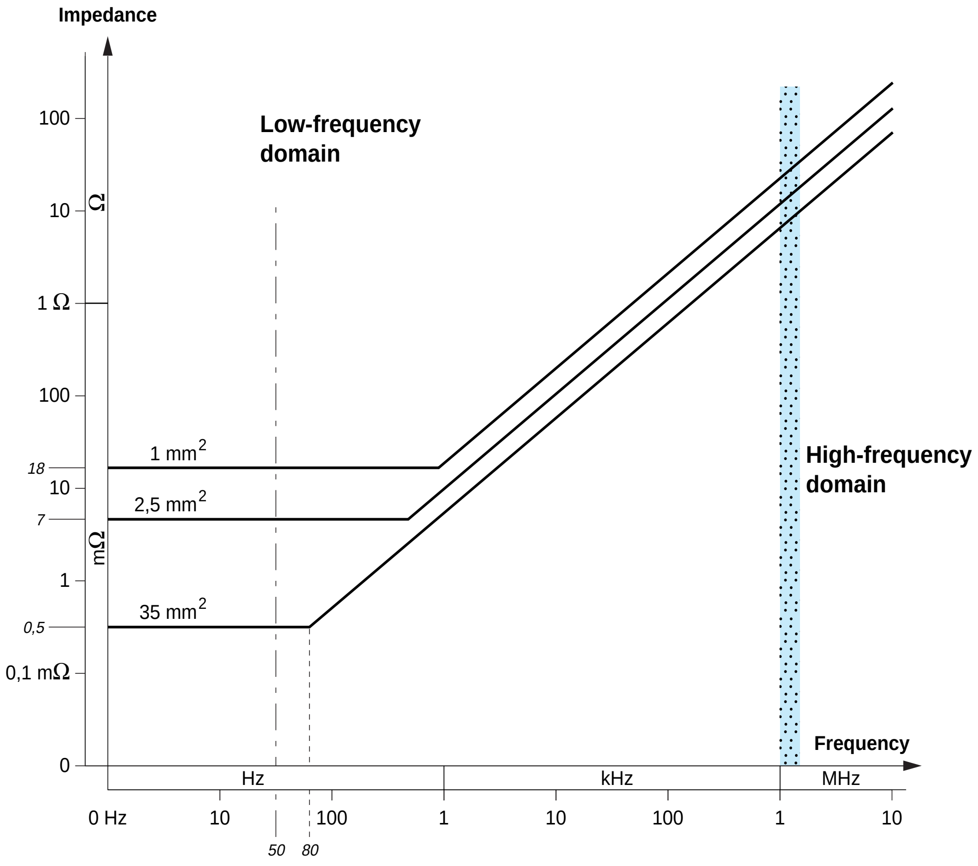
Only systematic, careful interconnection of exposed conductive parts *makes it possib**le to achieve*** *satisfactory high-frequency (HF) equipotential bonding on the site.*

Cables

Frequency behaviour of a conductor

The level of electromagnetic compatibility (EMC) in equipment is linked to the coupling between its circuits and this coupling itself depends directly on the impedances between these circuits.

☞ The conductors used and their mounting arrangement therefore have a decisive influence on the electromagnetic behaviour of the installation.



Typical impedance values of an electrical conductor of length L = 1 m

At 100 kHz, two 1 mm^2 cables laid parallel have less impedance than a 35 mm^2 cable ==> hence the benefit of meshed connection.

Cables

Low-frequency (LF) performance

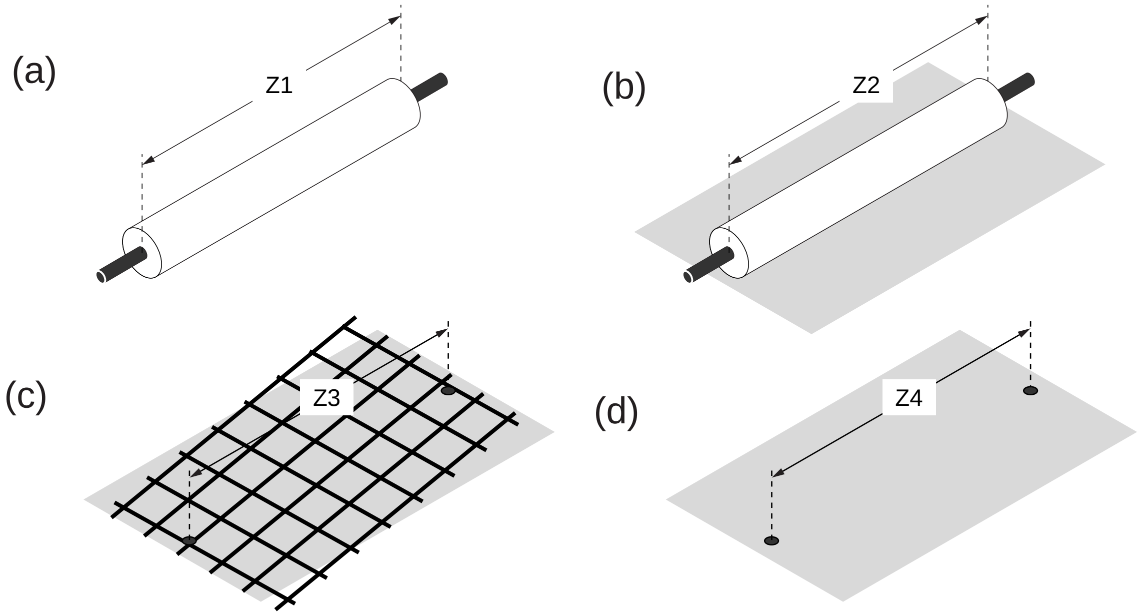
At low frequency (LF), current flows through the conductor whereas the skin effect is dominant at high frequency (HF). Current then flows at the surface of the conductor.

At low frequency (LF) (50 Hz-60 Hz), the cross-sectional area of the wire plays a leading part

High-frequency (HF) performance

At high frequency (HF) (f ≃ > 1 ... 5 MHz ...)

- *The circumference of the cross section of the conductor plays a leading part (skin effect)*
- *The cross-sectional area of the conductor is relatively insignificant*
- *The length of the cable is decisive*



In each case :

a : Z1, cable in air (inductance per unit length : l ≈ 1 µH/m).

b : Z2, cable mounted on a metal surface.

c : Z3, metal grid with contact at each intersection (e.g. welded concrete reinforcing rods).

d : Z4, metal plane.

For a given length of cable, the impedances per unit length are of the order Z1 > Z2 > Z3 > Z4

Cables

Length and cross-sectional area of a conductor

The impedance of a conductor depends primarily on its inductance per unit length which is proportional to the length of the cable.

This inductance begins to play a decisive role above 1 kHz in the case of a standard cable.

This means that, with a conductor that is just a few metres long, the impedance of the cable is as follows :

- several milliohms with direct current or at low frequency (LF)
- several ohms at around 1 MHz
- several hundred ohms at high frequency (HF) (≈100 MHz ...)

1
2
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If the length of a conductor
exceeds 1/30 of the wavelength of the signal it carries
the impedance of the cable becomes «infinite».

==> the installation then behaves as if there was no conductor.

$$L_{(m)} > \frac{\lambda}{30} \qquad \lambda > \frac{300}{f_{(MHz)}} \quad ==> \quad L > \frac{10}{f_{(MHz)}}$$

λ : wavelength of signal on conductor

f : frequency of signal on conductor in MHz

L : length of conductor in metres

☞ *A conductor is useless if* $L > \frac{10}{f_{(MHz)}}$*. Example : pigtail*

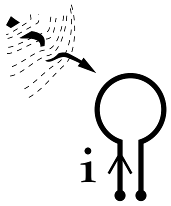
Cables

1
2
3

Antenna effect of a conductor

Conductors act like antennas and the field which they radiate can be picked up. Such conductors can cause emission when a high-frequency (HF) current flows through them.

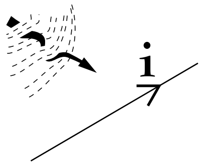
Magnetic field $\vec{H}$



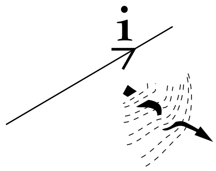
Loop = "receiving" antenna

Loop = "transmitting" antenna

Electric field $\vec{E}$



Conductor = "receiving" antenna



Conductor = "transmitting" antenna

Length of antennas

The antenna effect becomes highly significant for conductors of specific length in relation to the wavelength of the radiated signal.

① $L = \frac{\lambda}{4}$ So-called "quarter-wavelength" antenna

$L_{(m)} > \frac{75}{f_{(MHz)}}$ ==> Tuned antenna

Example : f = 100MHz $L > \frac{75}{100} = 0.75$ m

At this frequency (100 MHz) a conductor of length L > 0.75 m becomes an effective antenna.

② $L = \frac{\lambda}{2}$ So-called "quarter-wavelength" antenna

Cables

Green/yellow PE/PEN conductor

In old installations that were built without making allowance for HF phenomena, the length of the green/yellow (PE/PEN) conductors (L > 1 to 2 m) is such that they :

==> *effectively contribute towards LF (50 Hz-60 Hz) equipotential bonding of the site and therefore to the safety of persons and property (IEC 364, NF C 15 100 etc.).*

==> *play practically no role in HF equipotential bonding and therefore the (EMC) of the site.*

Interconnection of exposed conductive parts

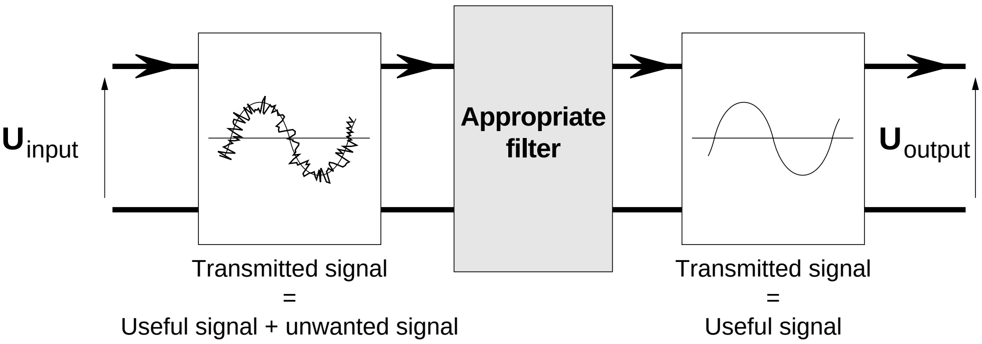
It is crucial to obtain careful, systematic interconnection of all exposed parts in order to achieve HF equipotential bonding.

==> *If the length of the frame earth cable is too long (L > 10/F (MHz)), the installation then becomes «floating», potential differences between equipment items inevitably occur and these cause the flow of undesirable currents.*

Filters

Function of a filter

The function of filters is to allow useful signals through and eliminate the unwanted portion of the transmitted signal.



Field of application :

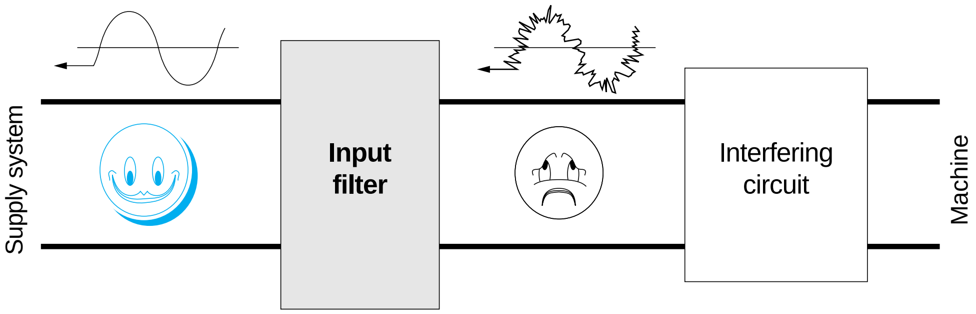
- Harmonic filters, F ≤ 2,5 kHz
- RFI filters (conducted radiofrequency interference) F ≤ 30 MHz

Direction of action :

- Input filters

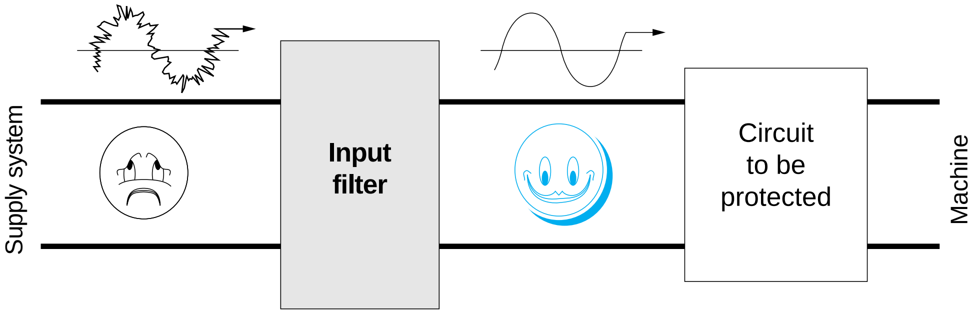
  Example : harmonic filters, RFI filters

  These protect the supply system against disturbances generated by the powered equipment.



Filters

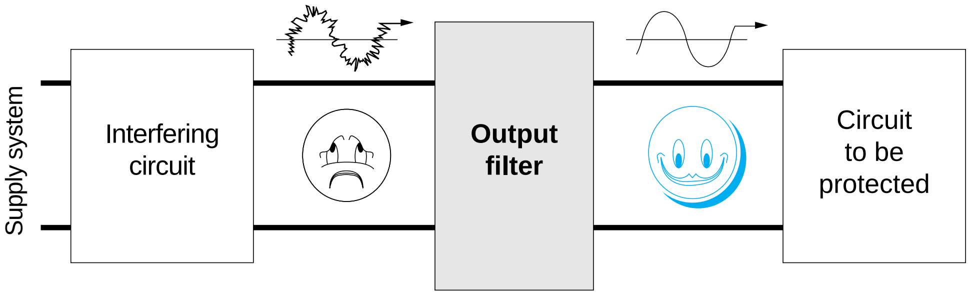
Filters also protect equipment from disturbances originating from the supply system.



- Output filters

  Examples: «sine-wave» filters

  These protect the load against disturbances originating from the equipment.



Various filter types

Types of filtering :

- Differential-mode filters
- Common-mode filters
- Combined filters that provide both common-mode and differential mode filtering.

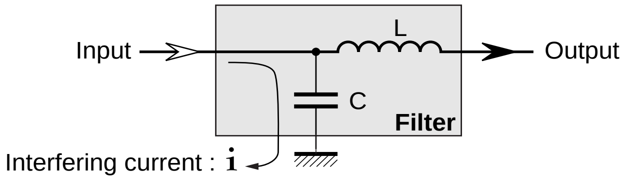
Technology

- Passive filters
- Active equalizers

Filters

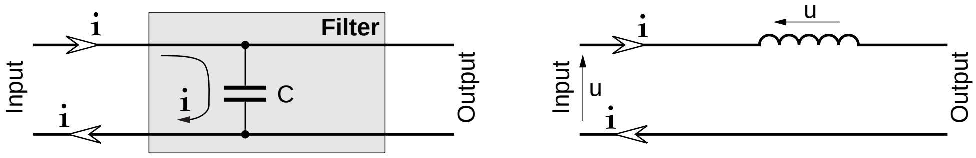
Passive filtering principle = impedance mismatching

- Blocking of disturbances: series inductance $(Z = L\omega)$
- Channelling of disturbances: parallel capacitance $\left(Z = \frac{1}{C\omega}\right)$
- Combining both the above



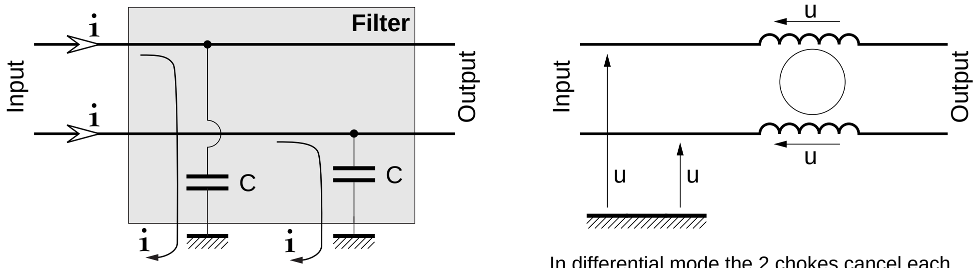
- Dissipating the energy of the disturbances: ferrite cores

Passive filtering in «differential mode»



Differential-mode interfering current

Passive filtering in «common mode»



Common-mode interfering current

In differential mode the 2 chokes cancel each other out because they are wound in the opposite direction on the same core.

Principle of active equalizer

- Only used for filtering out harmonic currents,
- Generates a signal that is the complement of the interfering signal in order to restore a sinusoidal signal.

Ferrite cores

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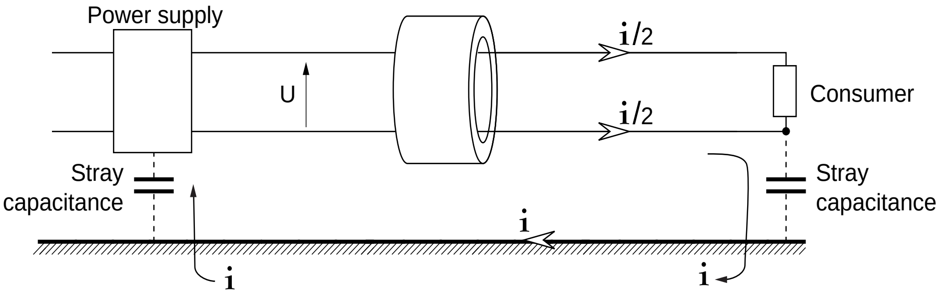
These are common-mode high-frequency (HF) filters.

Ferrite cores consist of a material having a high magnetic permeability (μr).



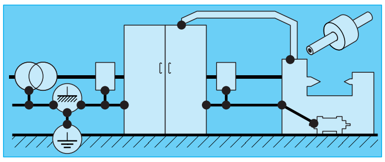
i : common-mode interfering current

Ferrite cores make use of two principles :

- common-mode inductance (see Filters paragraph)
- absorption of resistance losses (temperature rise) induced by common-mode HF interference.

Both these principles result in a common-mode impedance of which the effectiveness depends on its relationship to the impedance of the circuit to be protected.

CHAPTER 2



OBTAINING

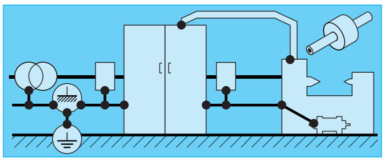
ELECTROMAGNETIC

COMPATIBILITY

IN AN

INSTALLATION

-- *CODE OF PRACTICE* --



Foreword

The design, production, modification or maintenance of equipment always begin with an analysis intended to define the:

- characteristics of materials and components capable of fulfilling the required function,
- mechanical and electrical design rules making it possible to fulfill the desired function.

Such analysis is carried out taking into account both engineering and economic constraints.

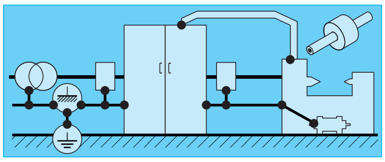
From this point of view, it is advisable to bear in mind **the importance of ensuring the electromagnetic compatibility of an installation right from the start of the design stage**.

This is the best guarantee against malfunctions and cost escalation.

Neglecting (EMC) during analysis of a product may produce an immediate cost saving of several percent of the total cost of the plant ((EMC) specialists agree that the extra cost is 3 to 5%).

However, modifications then often have to be made at the time the installation is commissioned. The overall cost of such modifications, given low operating margins, often exceed several or even twenty percent. This causes additional delivery delays as well as problems in customer relations.

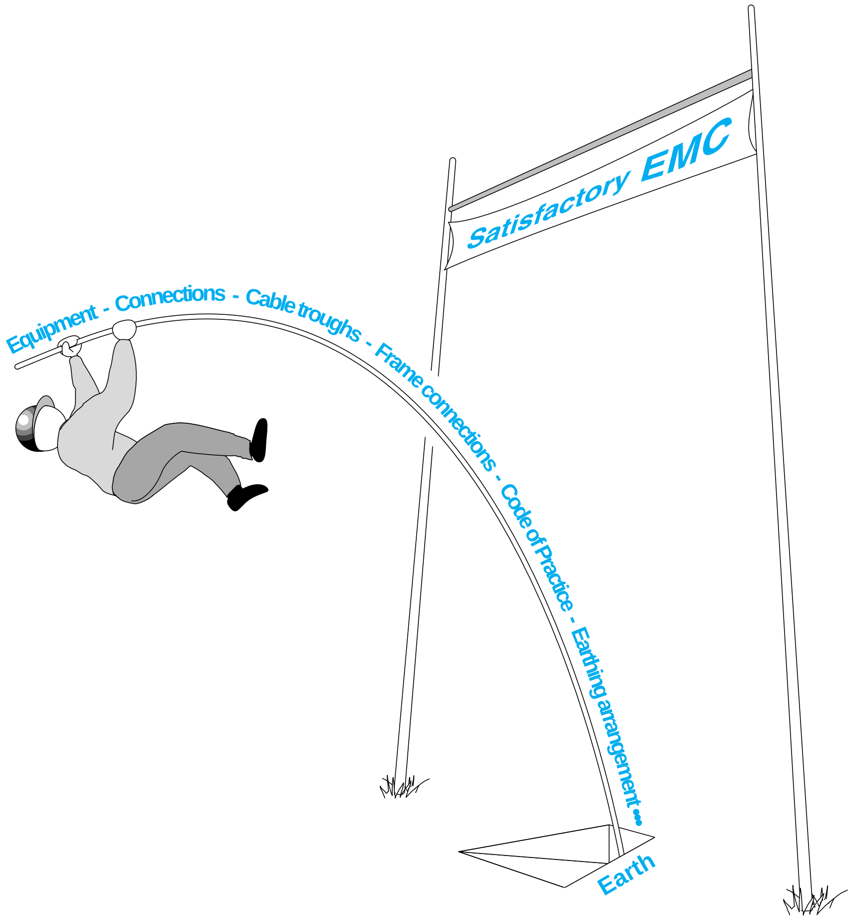
The (EMC) procedure



The (EMC) procedure must be comprehensive

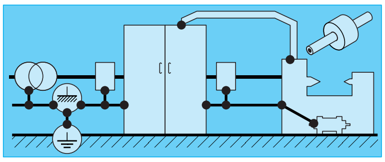
Correct operation relies on the good design, correct selection and proper workmanship of all the links in the chain of the installation.

Regardless of the life cycle of the installation, the CODE OF PRACTICE defined below must be applied seriously and methodically.



The interpretation of (EMC) and HF phenomena in particular is complicated. A cautious attitude is therefore called for and one must not forget that there are no miracle answers or universal truths in (EMC).

Nevertheless, even though the constraints and therefore the action that can be taken are specific to each installation, applying this Code of Practice will create the greatest possible likelihood of achieving correct operation of the installation.



The (EMC) procedure

Designing a new installation or extending an installation

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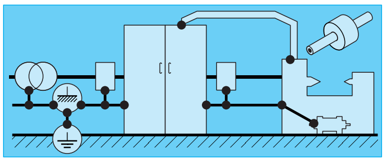
DEFINITION OF (EMC) NORMATIVE SCOPE	• Generic (EMC) standards • Product standards
ANALYSE	The environment • External (public, private network, site, surroundings, etc.) • Internal (building, machine, nearby plant, etc.)
DEFINE	The constraints associated with the site and the application.
DETERMINE	Those (EMC) products and accessories that are compatible with the constraints (installations, specification sheet, etc.).
ESTABLISH	The installation rules needed to obtain satisfactory (EMC) (wiring rules, precautions, etc.).
ERECT	The installation, adhere scrupulously to the defined rules.
CHECK	Correct erection of the installation, correct operation of the equipment.
IF APPLICABLE, MAKE ANY MEASUREMENTS	If the standard requires this.
CORRECT	If applicable.

The (EMC) procedure



Maintaining an installation
or
Upgrading - Updating installed equipment

(EMC) maintenance is a simple activity but it must be well organised, planned and carefully supervised.

TRAIN	Electricians and fitters. They must be made aware of problems associated with interconnection of exposed conductive parts, shielding, effects of connections, etc.
ANALYSE	Consequences of any modification or replacement of a product in terms of the system or the environment.
MONITOR	Set up scheduled preventive inspections in order to replace limiters, varistors, check connections, testing of earthing resistance, etc.
RECORD DETAILS	Record details of all work carried out in a machine maintenance log, etc. fill out defect reports together with remedial action taken

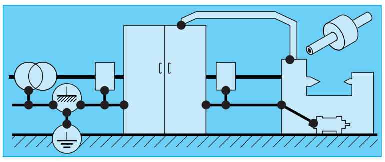
Compliance with these four rules always brings benefits to the company which extend beyond (EMC).

Bear in mind that simple deterioration of an electrical connection (corrosion, forgetting to refit shielding, bolts missing from cable trough) is enough to seriously impair the (EMC) performance of an installation.

Upgrading installed equipment, extending a machine etc.

The approach adopted must be the same as that during the design phase. It is vital to keep comprehensive documentation describing any modifications made in order to facilitate commissioning and future actions.

Regardless of the life cycle of the installation, the CODE OF PRACTICE defined below must be applied thoroughly and methodically.



The (EMC) procedure

Improving an existing installation

The causes of any malfunctions must be found and analysed.

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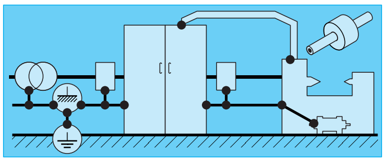
OBTAIN INFORMATION, LISTEN	Obtain information from persons in charge, especially from operators.
IDENTIFY	1- The equipment(s) affected. Obtain a precise idea of the failure. 2- The interference source(s). Assess the orders of magnitude of the interference. 3- Coupling or transmission modes of the interference.
REFER TO	This guide in order to understand the phenomena and identify problems. Read the «Code of Practice» carefully.
DEFINE PRIORITIES	Deal with the most important interference sources on a priority basis. Carry out actions that do not require extensive modification or a prolonged machine shutdown first. Deal with interference inputs one by one until the last input is reached.
DEFINE ACTIONS	Having considered the problem and the «Code of Practice» chapter in depth, inspect the installation, carefully look for any important points and note the action to be taken.
TAKE CORRECTIVE ACTION	Work methodically and deliberately. Deal with actions one at a time. Initially results may not be apparent and things may even get worse but carry on until satisfactory results are obtained without becoming discouraged. Never cancel or undo remedial action. Cancelling a particular remedial action can only be envisaged at the very end after obtaining a result and then only if the remedial action is really having an adverse effect on the installation. It is then that one often realises that remedial action that was initially considered useless actually makes an active contribution towards correct operation.

If a fault cannot be reproduced or if there is a serious problem, the assistance of or action by an (EMC) specialist having in-depth knowledge of the products suspected of causing the problem may be required.

Code of practice



Changes in technology and techniques are making it possible to design and produce increasingly high-performance products, machines, etc.

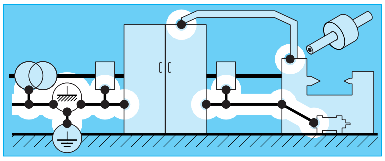
If goes without saying that this also involves changes in constraints and that these entail changes in codes of practice for the design of installations.

The Code of Practice consists of all the concepts that have to be taken into account in order to install equipment and electrical installations satisfactorily.

Adhering to the Code of Practice produces a significant reduction in the constraints and costs associated with most common (EMC) problems.

CHOICE OF COMPONENTS	
Low-frequency (LF) phenomena	High-frequency (HF) phenomena
• Protective systems • Filtering • Length of cables	• EQUIPOTENTIAL bonding of exposed conductive parts (interconnection) • Careful routing of cables • Selection of cables • Proper connections suitable for HF purposes • Shielding of cables • Cable troughs and cable runs • Length of cables
Protective systems more important	**Installation more important**

Related topics :



Earthing system

Introduction

Low and high-frequency EQUIPOTENTIAL BONDING of exposed conductive parts is the golden rule in (EMC)

LF and HF equipotential bonding of the site

==> *by appropriate specific interconnection, etc.*

Local LF and HF equipotential bonding

==> *by interconnecting all exposed conductive parts and, if necessary, providing a specific appropriate earth plane, etc.*

Systematically interconnect all metal structures, racks, chassis, earth conductors.

Connections

(see paragraph entitled «Connections» later on in this chapter.

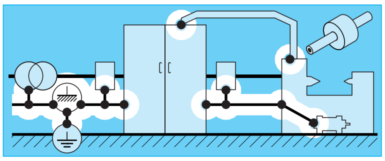
==> *Take special care to ensure that connections are properly made to obtain LF and HF quality and long service life.*

==> *Direct metal-to-metal bonding (no conductor) by bolted fastening.*

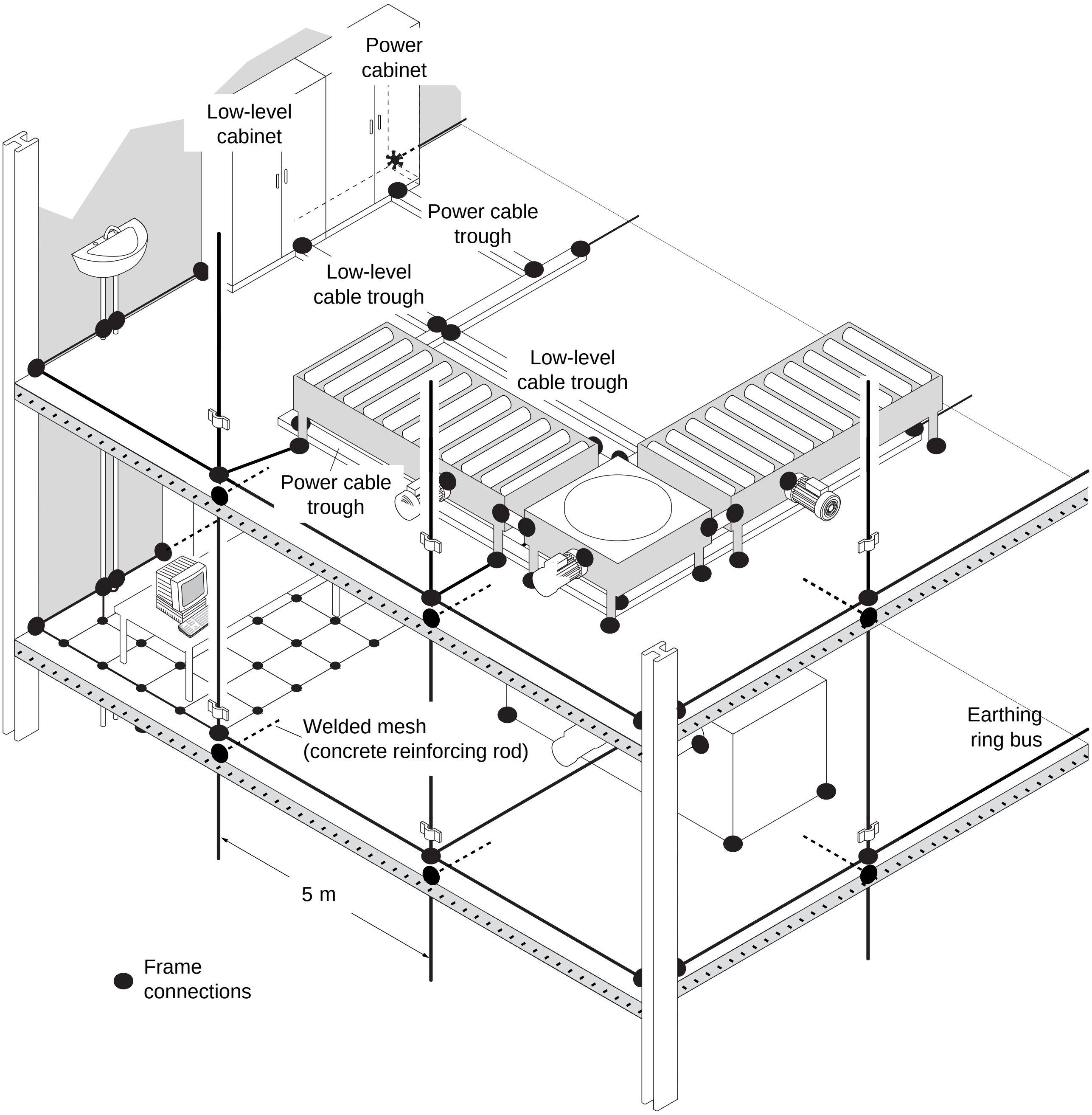
==> *Connection by braided metal strap or any other short, wide connection.*

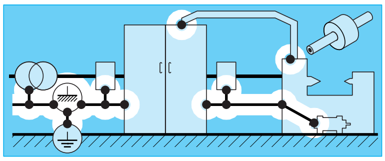
Do not overlook paintwork and coatings made of insulating materials

Earthing system



Building



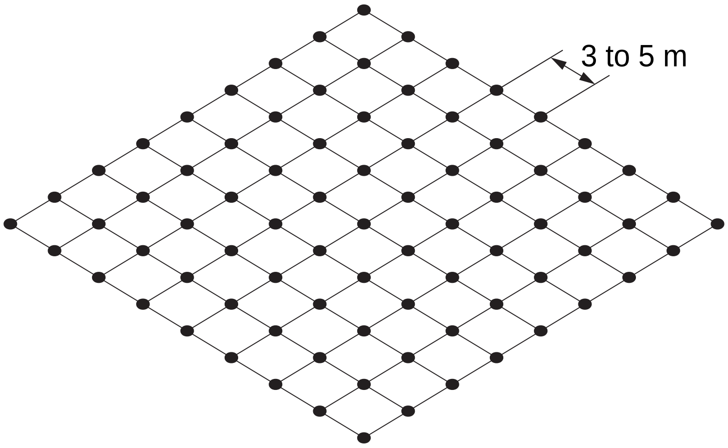


Earthing system

Building (continued)

LF and HF equipotential bonding of the site

==> *Provide an earth plane plus an earthing ring bus for each storey (mesh made of welded concrete reinforcing rods cast into the concrete slab, false floor with grid made of copper conductor, etc.*

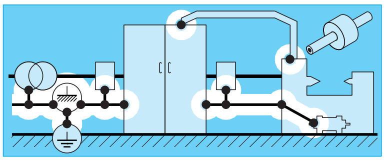


==> *Interconnect all the metal structures of the building to the earthing system (metal steel structural work, welded concrete reinforcement, metal pipes and ducts, cable troughs, conveyors, metal door and window frames, gratings, etc.)*

==> *It is advisable to design and produce a special finely-meshed earth plane in areas intended to accommodate sensitive hardware (data processing, measuring system, etc.).*

==> *etc.*

Earthing system



Equipment / machine

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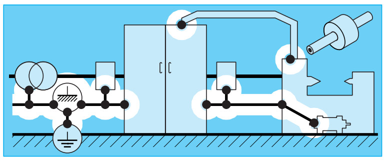
Local LF and HF equipotential bonding of the equipment or machine

==> *fiInterconnect all the metal structures of a single equipment item (cabinet, earth plane plate at bottom of cabinet, cable troughs, pipes and ducts, metal structures and frames of machine, etc.).*

==> *fiIf necessary, add earth conductors intended to enhance the interconnection of exposed conductive parts (both ends of any conductor in a cable that are not used must be connected to frame earth).*

==> *Connect this local frame earthing system to the earthing system of the site by providing the maximum number of distributed connections.*



Earthing system

Cabinet

See paragraph entitled «Component layout» later on in this chapter).

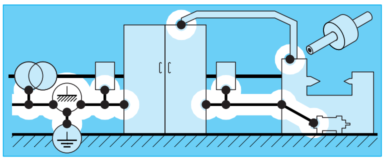
☞ **LF and HF equipotential bonding of cabinet and its components.**

==> *Every cabinet must have an earth plane plate at the bottom of the cabinet.*

⚠ **Watch out for cabinet bottom plates coated in paint or any other insulating covering.**

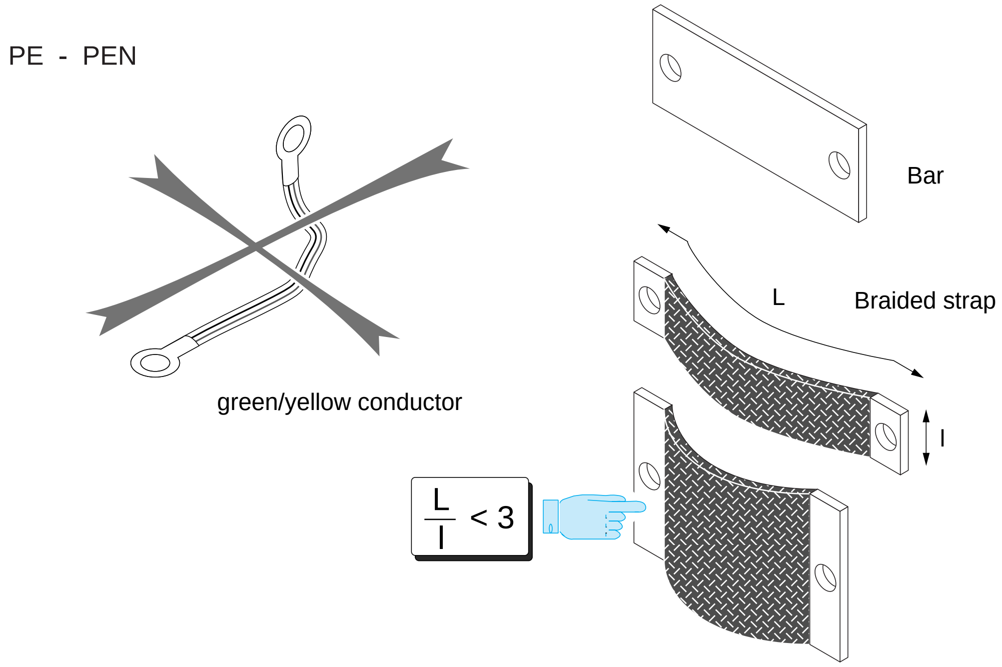
==> *All the exposed metal parts of components and units fitted in the cabinet must be bolted directly onto the earth plane plate in order to ensure high-quality, durable metal-to-metal contact.*

==> *Because of its excessive length, the green/yellow earth conductor cannot generally provide HF quality earthing.*

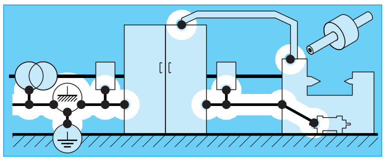


Earthing system

Electrical connections



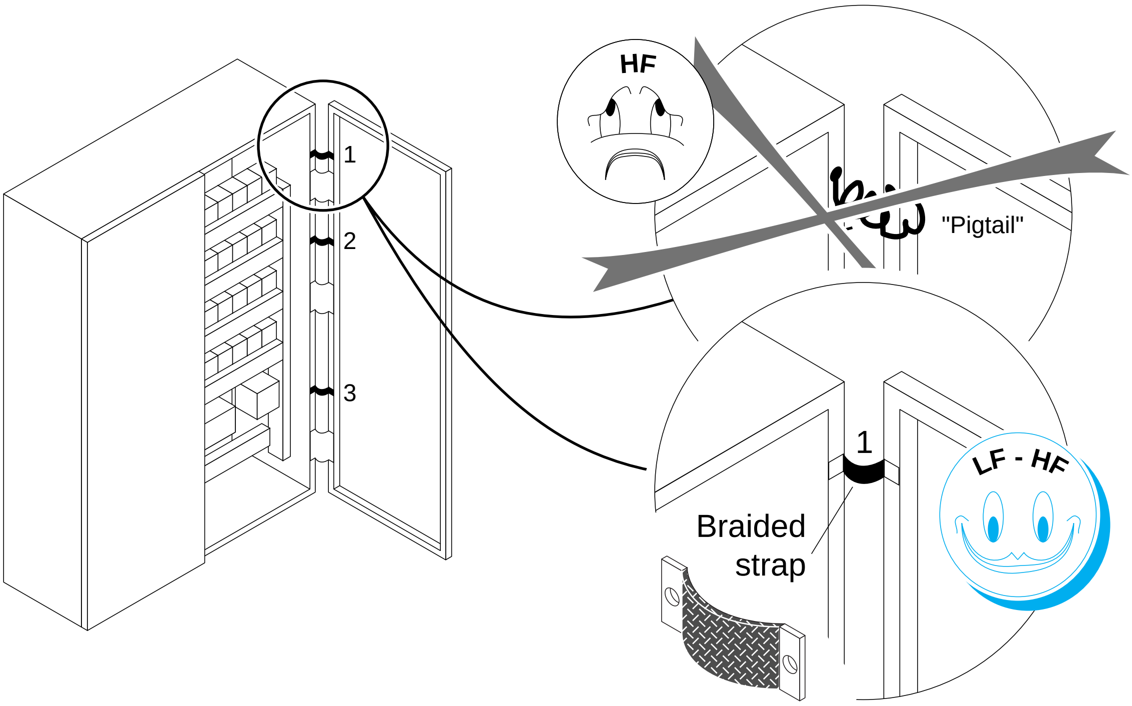
Equipotential bonding - Interconnection - Continuity - IEC 364 safety



Earthing system

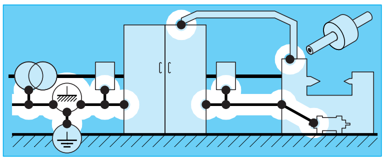
Daisychained interconnection of exposed conductive parts

— CABINET —



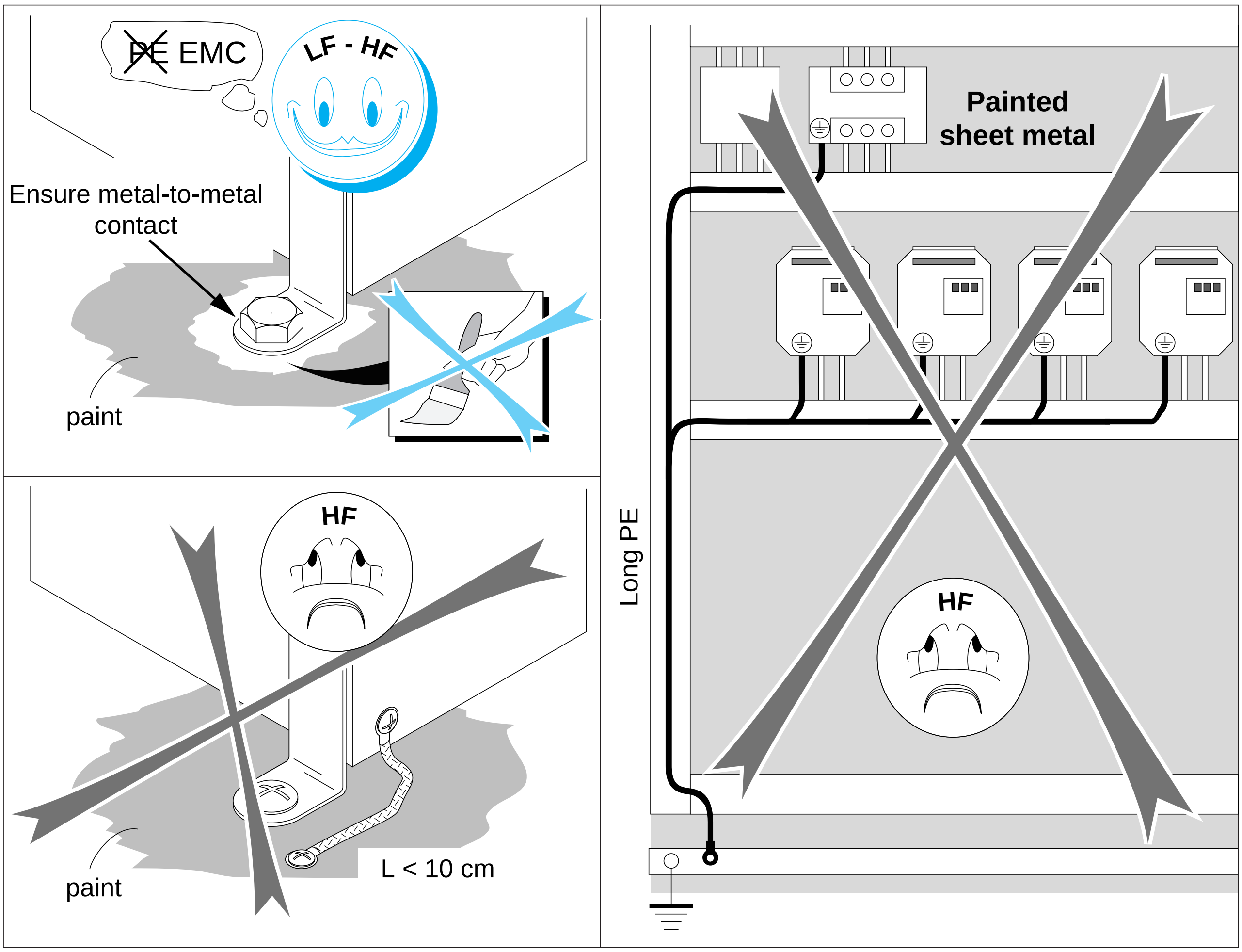
Equipotential bonding - Interconnection - Continuity - IEC 364 safety

Earthing system

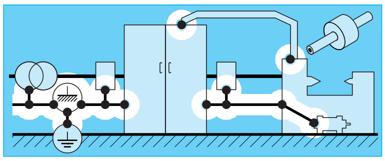


Daisychained interconnection of exposed conductive parts

— CABINET —



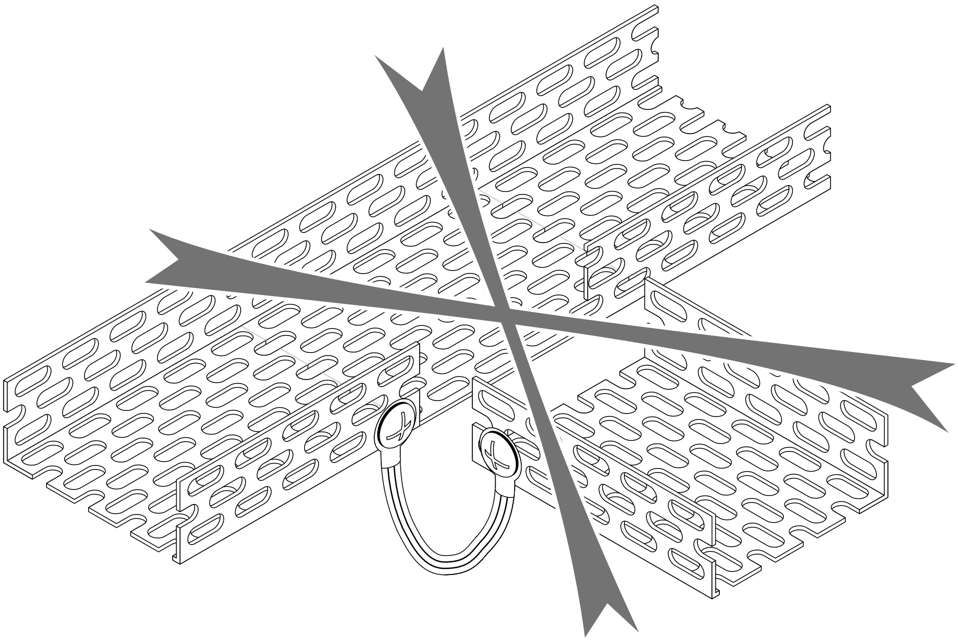
Equipotential bonding - Interconnection - Continuity - IEC 364 safety

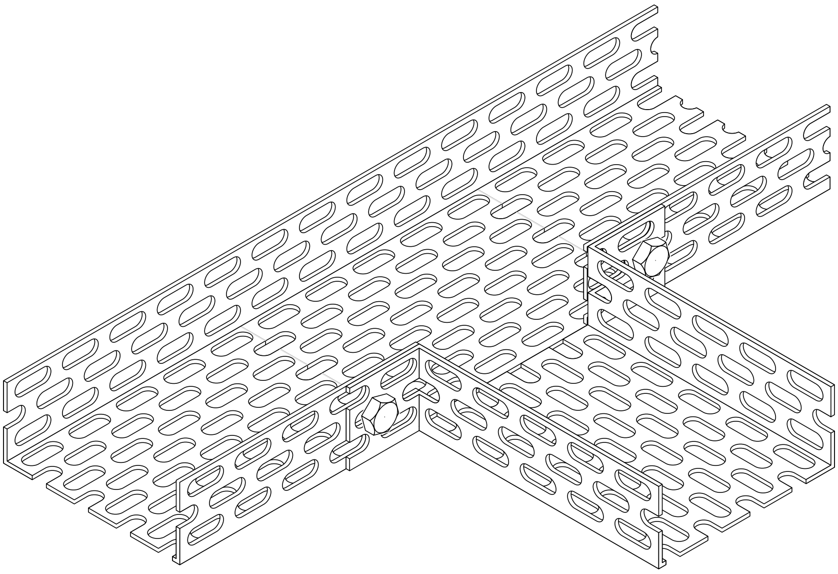


Earthing system

Daisychained interconnection of exposed conductive parts

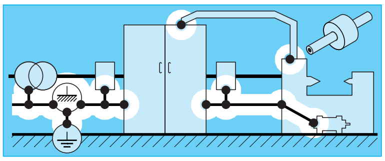
— INSTALLATION —





Equipotential bonding - Interconnection - Continuity - IEC 364 safety

Earthing system



1
2
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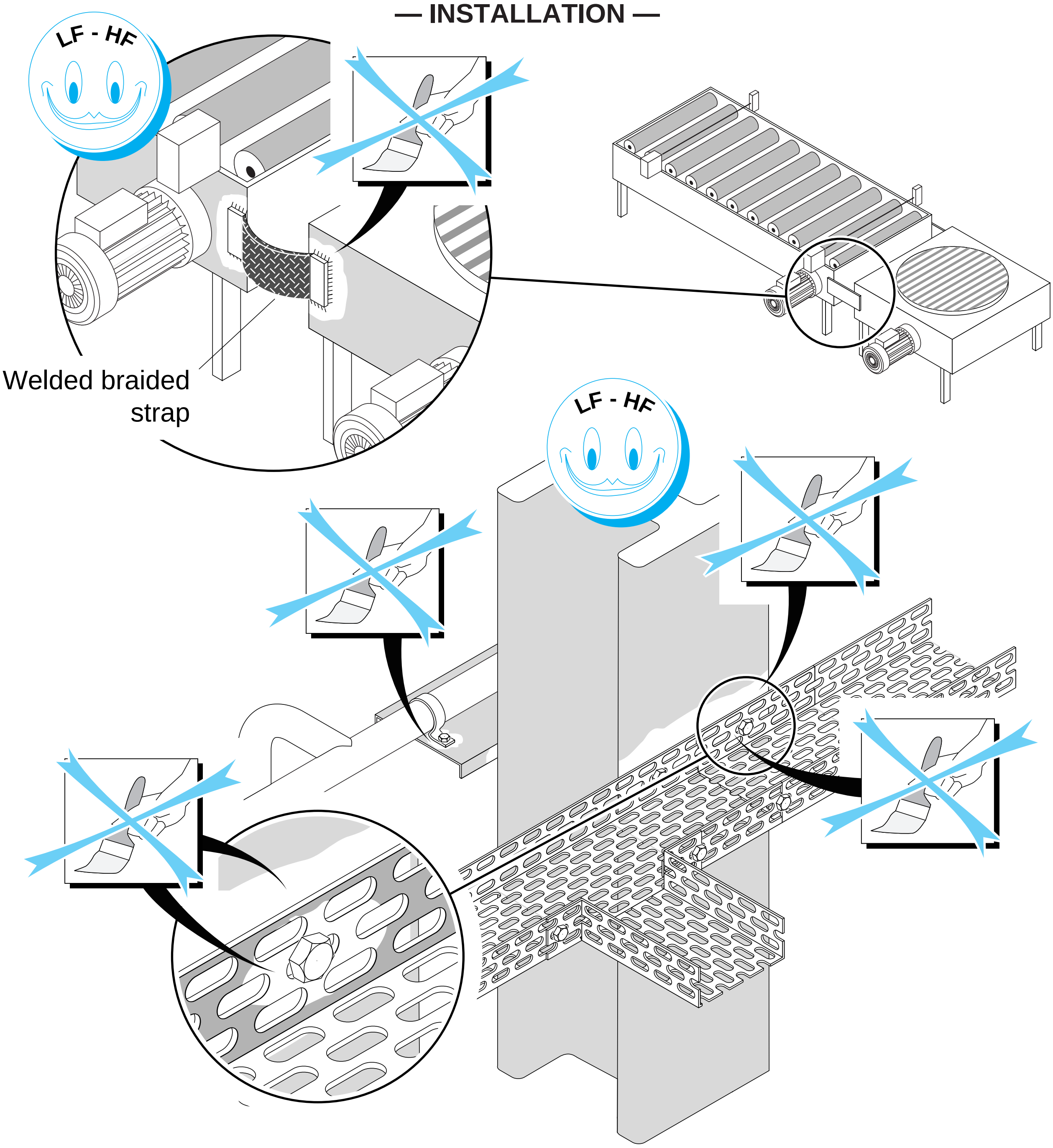
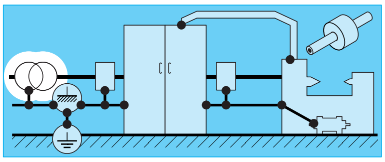
Daisychained interconnection of exposed conductive parts

— INSTALLATION —



Equipotential bonding - Interconnection - Continuity - IEC 364 safety



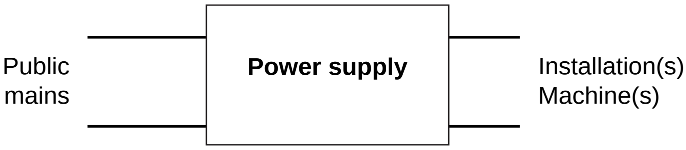
Power supply

Purpose

To provide high-quality power supply and a degree of availability making it possible to achieve correct operation of the installation.

The power supply is an interface between various electrical supplies :

- Public (LV) mains and customers,
- (MV) mains and industrial customers,
- Within a single installation, between general circuits and outgoing feeders.



General rule :

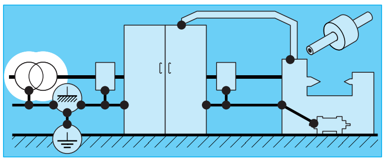
- Filter the power supply

  A properly adjusted industrial mains filter is suitable.

- Fit limiters, spark gaps on the power source.

  Site these components which cause interference during operation away from sensitive equipment.

Power supply



Analysis

Upstream circuit

Identify potential interference sources and the type of disturbance (nature, intensity, frequency, etc.) that might affect the power supply.

Downstream circuit

Identify the various equipment items powered and the type of disturbance they generate which might affect the power supply.

Assess the effects and possible consequences of such disturbances on the installation to be powered.

- Acceptable or unacceptable consequences (continuous, intermittent, etc.)
- Seriousness and cost of impact of interference
- Cost of installation
- Expected availability and reliability, etc.

Technical specifications

Having defined the technical specifications for the power supply :

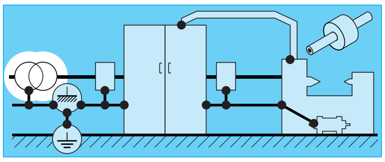
1 - Take into consideration the manufacturer's technical data in the case of «off-the-shelf» power supplies, immunity, emission, common-mode attenuation, filtering characteristics etc.

2 - Confirm, in the case of customised power supplies, the performance of the power supply at the time of delivery (transformer, special power supply, backed-up power supply, uninterruptable, etc.).

3 - Define the technical data of the electric power supply equipment to be constructed and check its characteristics before commissioning.

Isolation by transformer

(See paragraph entitled «Isolating transformers» in Chapter 1 under the heading «Transmission modes of EM interference).



Power supply

Earthing arrangements

The earthing arrangement defines the electrical connection of the neutral point and exposed conductive parts in relation to earth.

For low-voltage (LV) installations, it is identified by :

First letter : state of the neutral point in relation to earth

T = neutral point directly earthed

I = earthed through a high impedance

Second letter : state of the exposed conductive parts in relation to earth

T = exposed conductive parts connected directly to a separate earth

N = exposed conductive parts connected to earth of the neutral point

TN system :

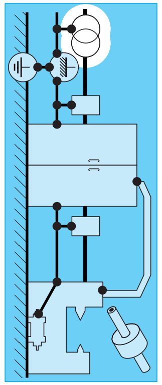
This system is divided into two groups : TN-C, TN-S

TN-C : the earth (PE) and neutral (N) conductors are combined and form a single PEN conductor.

TN-S : the earth (PE) and neutral (N) conductors are separate and each earthed.

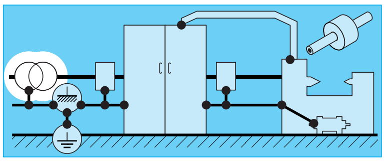
*When choosing an earthing arrangement, **the safety of persons always takes precedence** over functional aspects*

Power supply



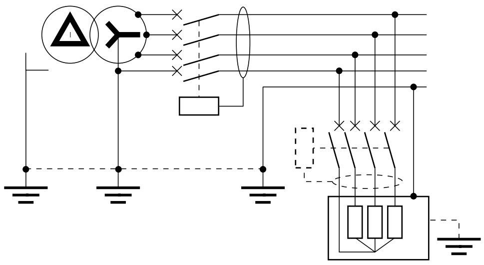
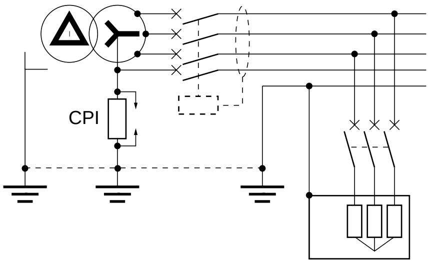
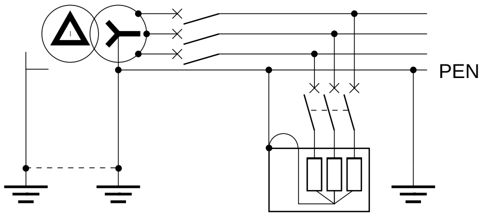
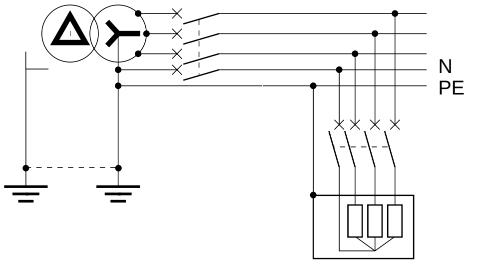
Earthing arrangements : (EMC) performance

	TT	TN-C	TN-S	IT
Safety of persons	**Good** Earth leakage circuit breaker is mandatory	**Good** Exercise caution and check the continuity of the PE conductor when extending the installation		
Safety of property Fire risks Risks to equipment	**Good**	**Bad** Extremely high currents in PEN conductor, may exceed kA Prohibited in hazardous areas	**Bad** Differential protection 500 mA	**Good** Recommended for inherent safety because of absence of arcing
Power availability	**Good**	**Good**	**Good**	**Very good**
(EMC) performance	**Good** PE conductor is no longer a unique potential reference for the installation - Generally provide lightning arresters (overhead transmission lines) - Need to manage equipment with high leakage current located downstream from differential protective devices	**Bad** Flow of interfering current in exposed conductive parts. Radiation of (EMC) interference by PE. Not recommended if installation contains apparatus that generates harmonics.	**Very good** - Need to manage equipment with high leakage current located downstream from differential protective devices. - High fault currents in PE (induced interference) - A single earth	**Bad** Not compatible with use of common-mode filter. - It may be necessary to split the installation in order to reduce the length of cables and limit leakage currents. - the TN system to the 2nd fault.

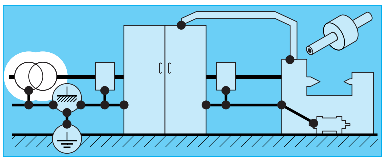


Power supply

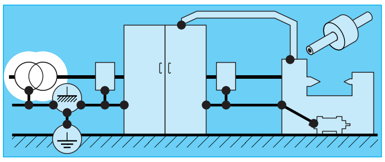
Earthing arrangements : (EMC) performance (continued)

			First letter (defines state of neutral point)		Power supply	
			Neutral point directly earthed	Neutral point earthed through an impedance or no connection	Direct, LV system	Through transformer, private HV/LV
			T	**I**		
State of exposed conductive parts of the installation	Exposed conductive parts interconnected and connected to earth at one point	**T**	**TT** 		YES	YES
				IT 	NO	YES
	Exposed conductive parts connected to neutral point	**N**	**TN-C** 	**Caution** **NOTE 1 :** In the TN-C system, the PEN conductor (combined neutral and PE), must never be cut. In the TN-S system, as in the other systems, the PE conductor must never the cut. **NOTE 2 :** In the TN-C system, the "protective conductor" function takes precedence over the "neutral" function. In particular, a PEN conductor must always be connected to the "earth" terminal of a consumer and a strap must be fitted between this terminal and the neutral terminal. **NOTE 3 :** The TN-C and TN-S systems may be used in the same installation. It is mandatory that the TN-C system is upstream from the TN-S system. The TN-S system is mandatory for cable cross-sectional areas < 10 mm^2 Cu or < 16 mm^2 Al or for flexible cables.	YES With the distributor's consent	YES
			TN-S 		YES With the distributor's consent	YES

Power supply



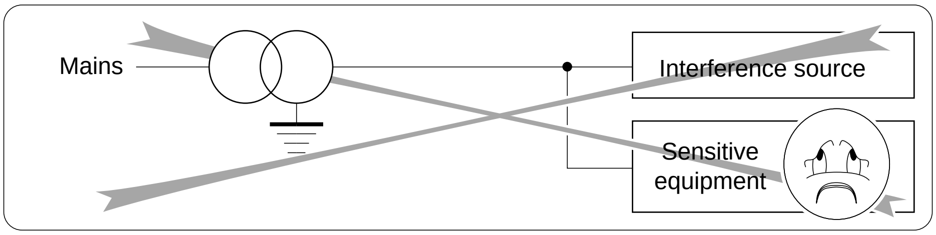
Disconnection	Protective device	Need for maintenance service	Remarks
1st fault	Earth leakage circuit-breaker • At origin And/or • on each outgoing feeder (horizontal selectivity)	NO Periodic inspection	• Intensity of insulation fault current is limited by earthing resistors (a few dozen amperes). • Interconnection of exposed conductive parts and earthing by PE conductor that is separate from the neutral conductor. • No requirement imposed on continuity of the neutral conductor. • Extension without calculation of conductor lengths. • Simplest solution when designing an installation.
2nd fault Continued service ensured	NO Need for tester for continuous insulation monitoring ⚠ Temperature rise n cables in event of 2nd fault	YES Need for intervention to clear 1st fault ⚠ After 1st fault => TN configuration	• Intensity of the 1st insulation fault current cannot create a hazardous situation (tens of mA). • Intensity of double insulation fault current is high. • Operational exposed conductive parts are earthed through PE conductor which is separate from neutral conductor. • First insulation fault does not create any hazard or interference. • Signalling is mandatory on the first insulation fault, followed by fault finding and clearance obtained by a Continuous Insulation Tester (CPI) installed between neutral and earth. • Tripping is mandatory on the second insulation fault by using overcurrent protective devices. • Verification of tripping on 2nd fault must be performed. • This solution ensures optimum continuity of operational service. • Need to install consumers having a phase/earth insulation voltage in excess of the phase-to-phase voltage (1st fault case). • Voltage limiters are indispensable.
1st fault	Prohibited	NO • Verification of tripping must be carried out: - at design stage by calculation - mandatory at the time of commissioning - periodically (every year) by measurements • Verification of tripping must be repeated if the installation is extended or reconditioned.	• Operational exposed conductive parts connected to PEN conductor, latter is earthed. • High intensity of insulation fault currents (increased interference and fire risks) (Ishort circuit kA). • Combined neutral conductor and protective conductor (PEN). • Flow of neutral currents in conductive parts of building and exposed conductive parts is cause of fires and voltage drops that cause interference to sensitive medical, data processing or telecommunication equipment. • Tripping is mandatory on first insulation fault, cleared by overcurrent protective devices.
1st fault	NO But, an earth leakage circuit-breaker is required for long circuits	NO • Verification of tripping must be carried out: - at design stage by calculation - mandatory at the time of commissioning - periodically (every year) by measurements • Verification of tripping must be repeated if the installation is extended or reconditioned.	• Operational exposed conductive parts connected to PEN conductor, latter is earthed. • High intensity of insulation fault currents (increased interference and fire risks) (Ishort circuit kA). • Separate neutral conductor and protective conductor. • Tripping mandatory on first insulation fault, cleared by overcurrent protective devices. Use of ELCBs is always recommended to protect persons against indirect contact, especially in final distribution circuit where loop impedance may not be controllable. • It is tricky to test the correct operation of protective devices. Use of ELCBs helps overcome this problem.

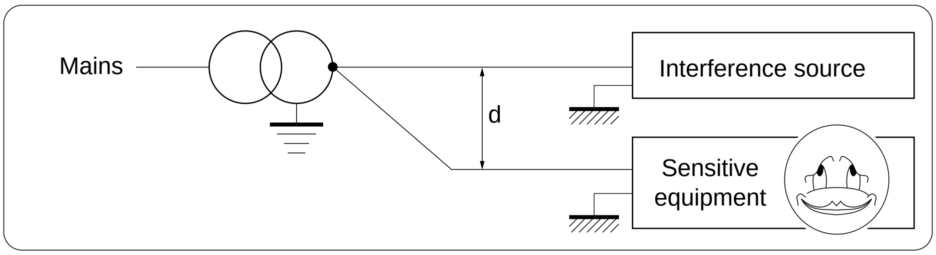


Power supply

Distribution in the installation

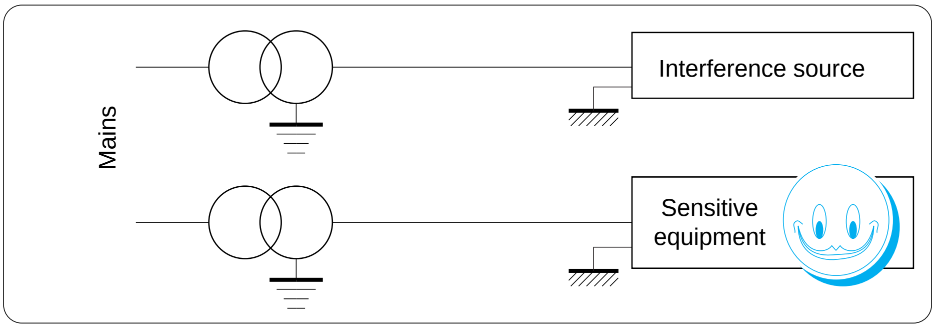
Wire the power supplies of devices in a STAR configuration starting from the power source.



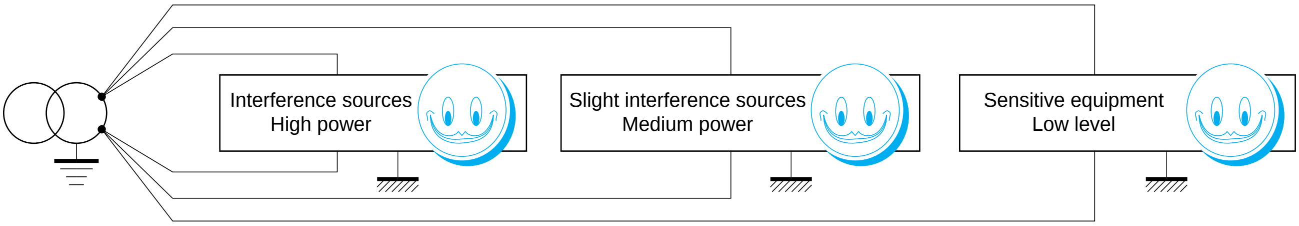


d = distance between cable: see Wiring rules later on in this chapter.

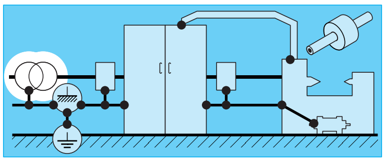
If equipment that is highly sensitive or that generates significant interference is used, power supplies must be separated.



Wire the supply circuits by placing interfering equipment as close as possible to the power source and the most sensitive equipment farthest from the power source.

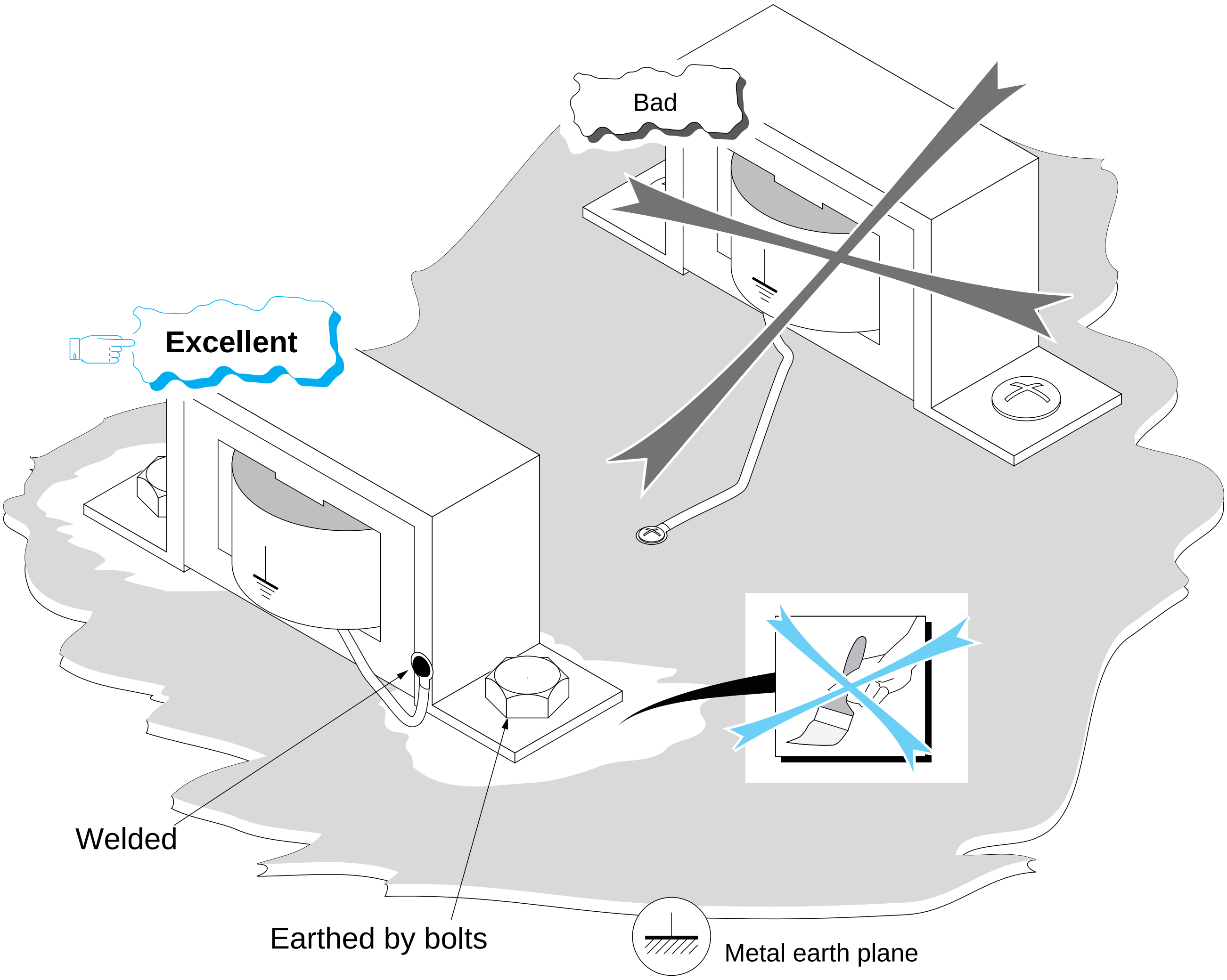


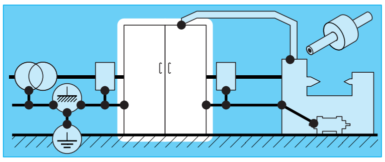
Power supply



Earthing of transformer screens

- Length of frame connections must be as short as possible.
- The case of the transformer must be mounted metal-to-metal on a conductive earth plane.





Cabinet

Analysis

Components

- Identify potential interference sources and determine the type of interference emitted (nature, intensity, frequency, etc.).
- Identify sensitive equipment and determine its immunity level.

  Use manufacturers' documentation, note characteristics such as :

  - power, power supply voltage (380 V, 500 V etc.), type of signals (∿ ; ⎓), frequency of signals (50 Hz, 60 Hz, 10 kHz ...),
  - type of circuit (switching with dry contact, etc.)
  - type of load controlled (inductor or coil, etc.).

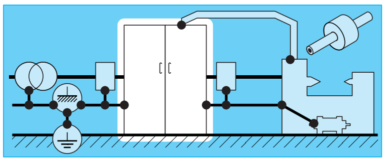
Signals carried by cables

- Identify the «input» cables (signal originating from outside the cabinet) and «output» cables.
- Determine the type of signal on these cables and divide them up into classes*, namely: sensitive, slightly sensitive, slightly interfering, interfering.

  (See paragraph entitled «Cables» later on in this chapter).

— **Non-standardised term adopted for the purposes of this document.* —

Cabinet

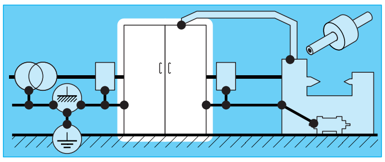


Analysis (continued)

Example of typical classification

Sensitive	Interfering
• Programmable logic controllers (PLC) • PCBs • Regulators • Cables connected to such components, namely inputs and outputs such as (detectors, sensors, probes, etc.) --> class* 1 or 2 • Cables carrying analogue signals --> class* 1	• Transformers in cabinet • Contactors, circuit-breakers, etc. • Fuses • Switching power supplies • Frequency converters • Variable speed drives • d.c. ⎓ power supplies • Microprocessor clocks • Cables connected to such components • Power supply lines • «Power» cables in general --> class* 3 or 4 (See paragraph entitled «Cables» later on in this chapter).

*— *Non-standardised term adopted for the purposes of this document. —*



Cabinet

Earth reference plane

Before doing anything else, define and provide a non-painted earth reference plane in the bottom of the cabinet

- ☞ This metal sheet or grid will be connected at several points to the rack in the metal cabinet which is itself connected to the equipment’s earth system.
- ☞ All components (filters, etc.) are directly bolted onto this earth plane.
- ☞ All cables are laid on the earth plane.
- ☞ 360° shielding is obtained by locknuts directly bolted onto the earth plane.

Special care must be taken when making any connection (see paragraph later on in this chapter).

Cable entrances

Fit filters for cables that cause interference at the point where they enter the cabinet.

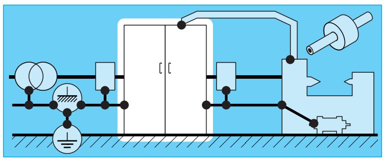
Take special care when selecting cable glands intended to connect shielding to earth (wall).

Routing of cables

(See paragraphs entitled «Cables», «Wiring» and «Cable runs - Cable troughs» later on in this chapter).

Divide the cables up according to class and lay them in separate metal cable troughs separated by an adequate clearance.

Cabinet



Lighting

Do not use fluorescent lamps, gas discharge tubes etc. to illuminate control panel cabinets internally (they generate harmonics, etc.).

☞ Use incandescent bulbs.

Layout of components

Separate and segregate «interfering» and «sensitive» components, cables, etc. in different cabinets.

Small cabinets

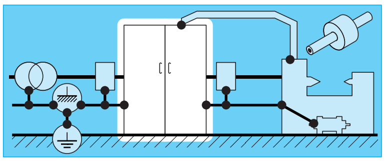
Partitioning by means of sheet metal panels earthed at several points reduces the influence of disturbances.

Large cabinets

Allocate one cabinet for each class of components.

«Interfering» and «sensitive» cabinets must be different and separated from each other.

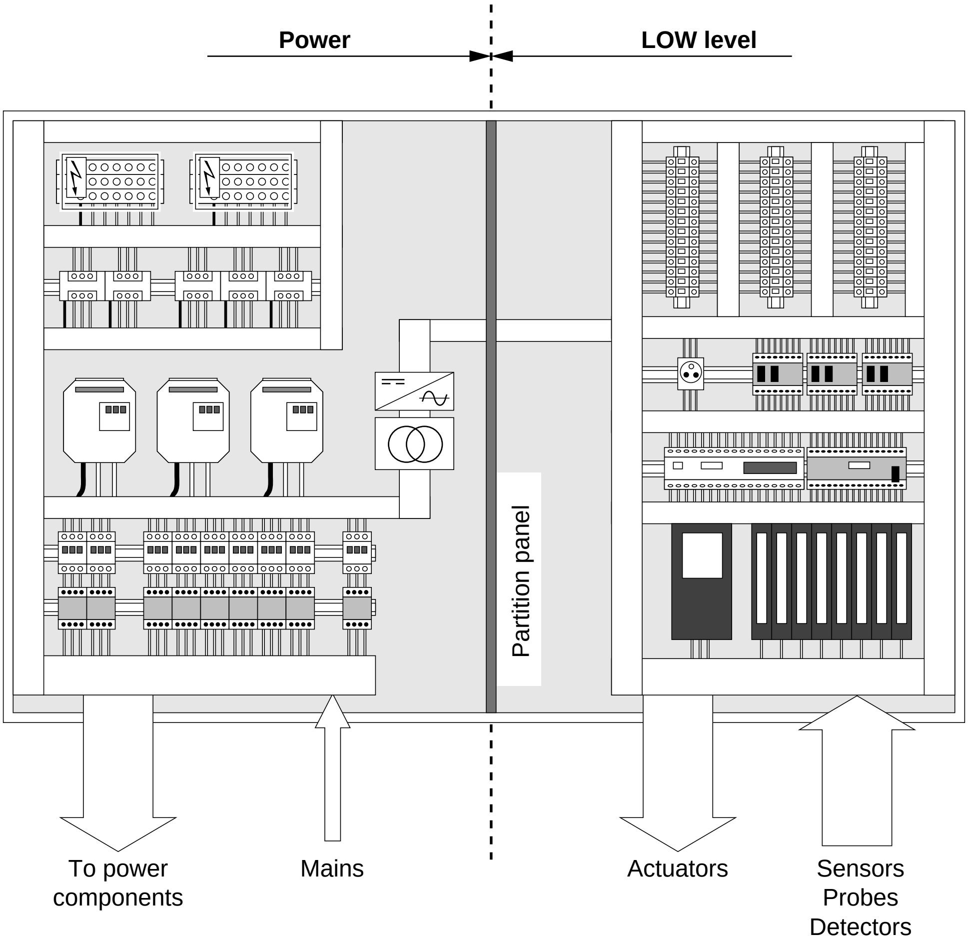
Failure to comply with these instructions may negate all the efforts made at the time of assembly and commissioning.



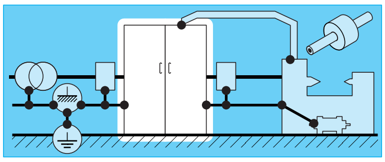
Cabinet

Example of structural layout of a small cabinet

In small cabinets, partitioning by sheet metal panels bolted to the chassis may be sufficient.

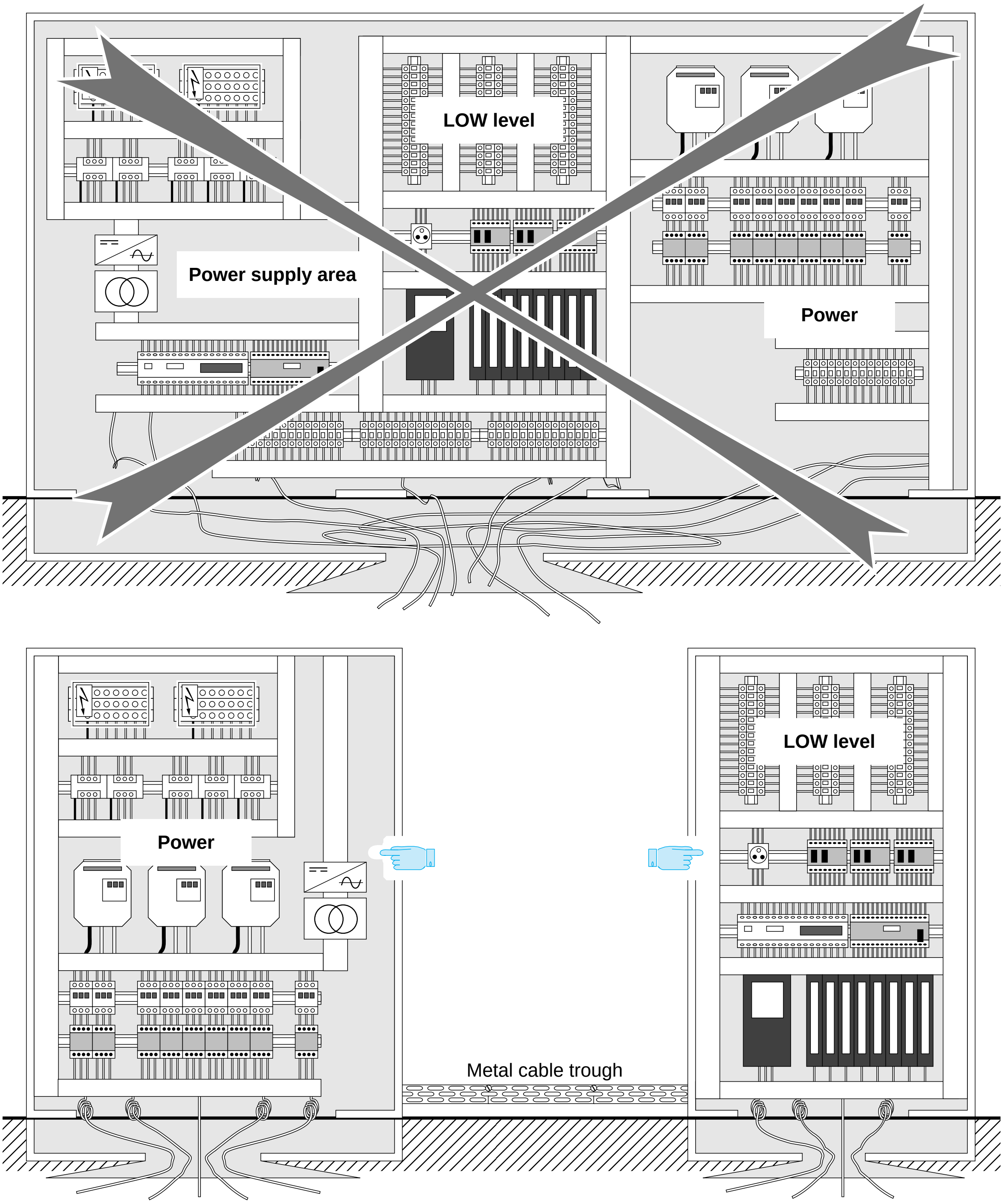


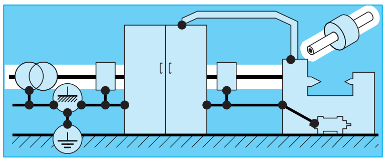
Cabinet



Example of structural layout of a large cabinet

Never mix cables or loop excess cable in coils.





Cables

Classes* of signals

Classification of signals according to level of interference

*Class**	Interfering	Sensitive	Example of carried signals or connected equipment
1 **Sensitive**		**++**	• Low-level circuits with analogue output, Sensors etc. • Measuring circuits (probes, sensors, etc.)
2 **Slightly sensitive**		**+**	• Control circuits connected to resistive load • Low-level digital circuits (bus, etc.) • Low-level circuits with all-or-nothing output (sensors, etc.) • Low-level d.c. power supplies
3 **Slightly interfering**	**+**		• Control circuits with inductive load (relays, contactors, coils, inverters, etc.) with suitable protection • Clean a.c. power supplies • Main power supplies connected to power devices
4 **interfering**	**++**		• Welding machines • Power circuits in general • Electronic speed controllers, switching power supplies, etc.

Choice of cables

Recommended cable types depending on class* of signal

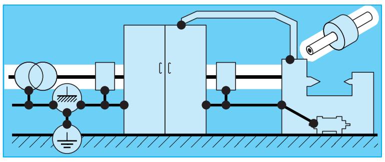
Class*	Type	Single-wire	Twisted pairs	Shielded twisted pairs	Shielded (braids)	Hybrid shielding (screen + braid)
1	Sensitive		▨	▨	▩ Cost ↗	▩
2	Slightly sensitive	▨	▨	▨	▩ Cost ↗	▩
3	Slightly interfering	▨	▨	▨	▩ Cost ↗	▩
4	Interfering				▨	▨

☐ Not recommended

▨ Recommended, reasonable cost

▩ Inadvisable, high cost for this class of signal

— *Non-standardised term adopted for the purposes of this document. —

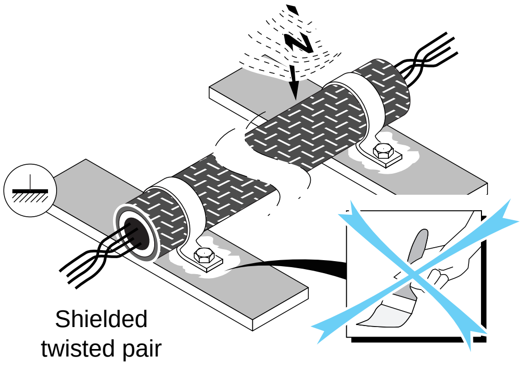


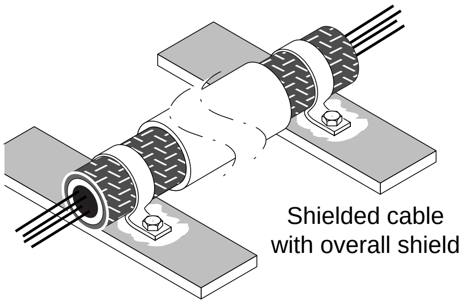
Cables

Example of cables used for various classes* of signals

Class* 1

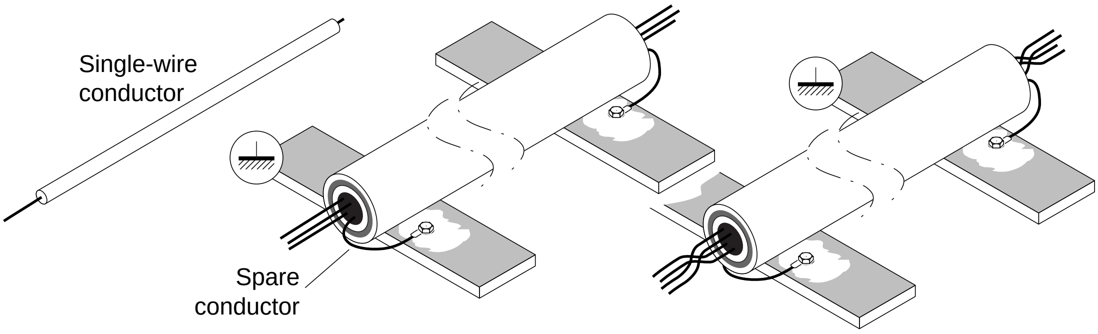
Sensitive signals





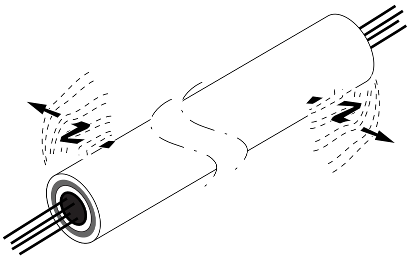
Class* 2

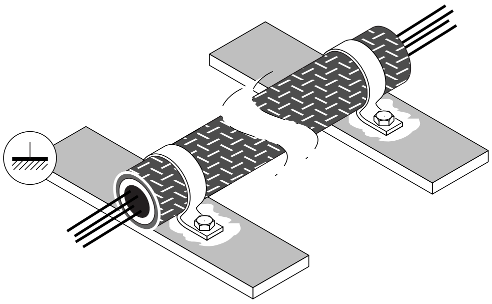
Slightly sensitive signals



Class* 3

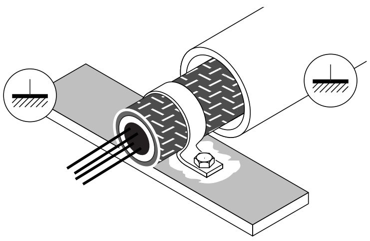
Slightly interfering signals

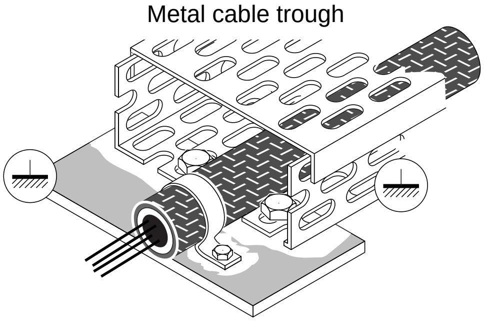


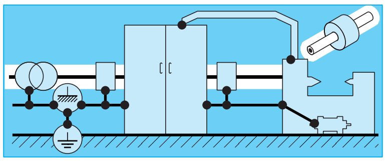


Class* 4

Interfering signals





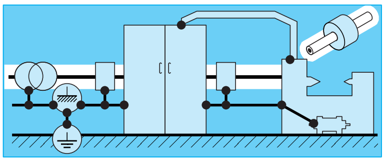


Cables

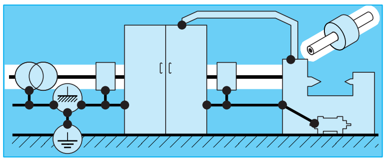
Performance of cables in terms of (EMC)

Cable	**Conducted**	**Radiated**			
		LF : 0 - 50 Hz	LF < 5 MHz	LF > 5-30 MHz	Common mode
Single-wire cable	No effect	Average[1]	Acceptable[1]	Inadequate[1]	Bad
		1 : *If outgoing and incoming cables are very close together*			
2-wire parallel		Average	Acceptable	Inadequate	
2-wire twisted parallel		Good[2]	Good up to 100 kHz	Passable	Bad
		2 : *Depends on the number of twists/m*			
Shielded twisted pair		Good	Good	Average	Good
Aluminium tape shielding		Average	Passable	Inadequate	
Braid		Excellent	Excellent	Good	
Shielding + braid		Excellent	Excellent	Excellent	

Cables



Coupling		Interference level	Application areas
Differential mode	Crosstalk, capacitive, inductive coupling		
Bad	Bad		Non-sensitive equipment only, low-frequency (LF) applications, 50 Hz-60 Hz
Good	Bad	Equipment causing slight interference	Tertiary industry, slightly noisy industrial environments
Excellent	Good	Low man-made interference	Tertiary industry, slightly noisy industrial environments, signals < 10 MHz
	Average	Low man-made interference (radio transmitters, fluorescent lighting)	Slightly noisy industrial premises, local area networks Tertiary data processing hardware
	Good	Typical man-made interference	Typical industrial sector Data processing, measuring, control Local area networks Motor control, etc.
	Good	High man-made interference (heavy industry)	Very sensitive products in a highly noisy environment



Wiring rules

The 10 Commandments

Golden rule in (EMC)

①

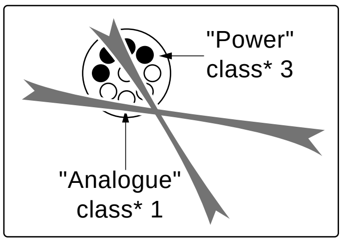
Ensure high-frequency (HF) and low-frequency (LF) EQUIPOTENTIAL BONDING of exposed conductive parts :

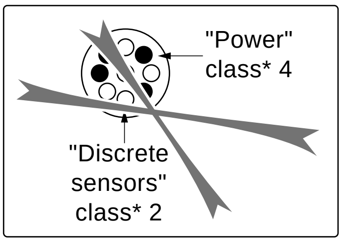
- locally (installation, machine, etc.)

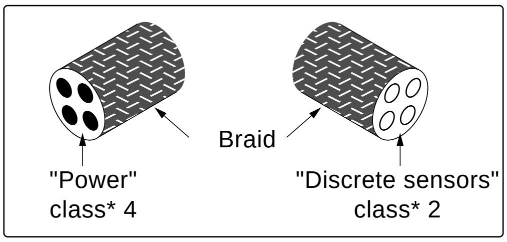
- at site level

②

Never route sensitive class (1-2) signals and interfering class* (3-4) signals in the same cable or bunch of conductors.*







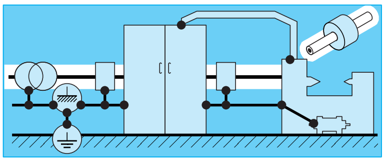
Braid : aluminium tapes, metal armouring, etc. does not constitute a shield

③

Minimise the length of parallel runs of cables carrying signals of different classes: sensitive (class* 1-2) and interfering (class* 3-4).*

Minimise the length of cables.

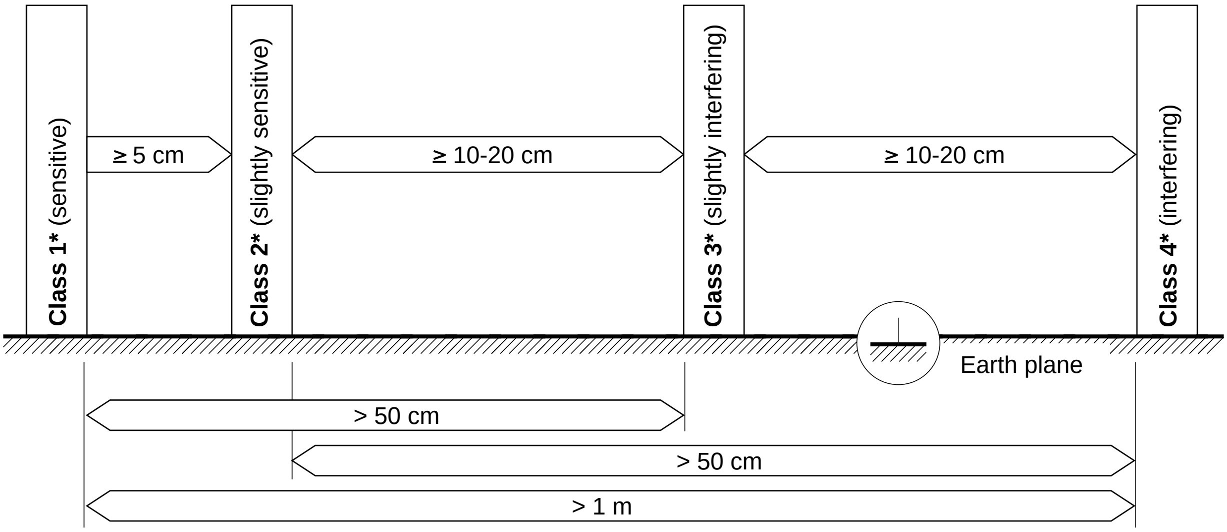
*— *Non-standardised term adopted for the purposes of this document. —*



Wiring rules

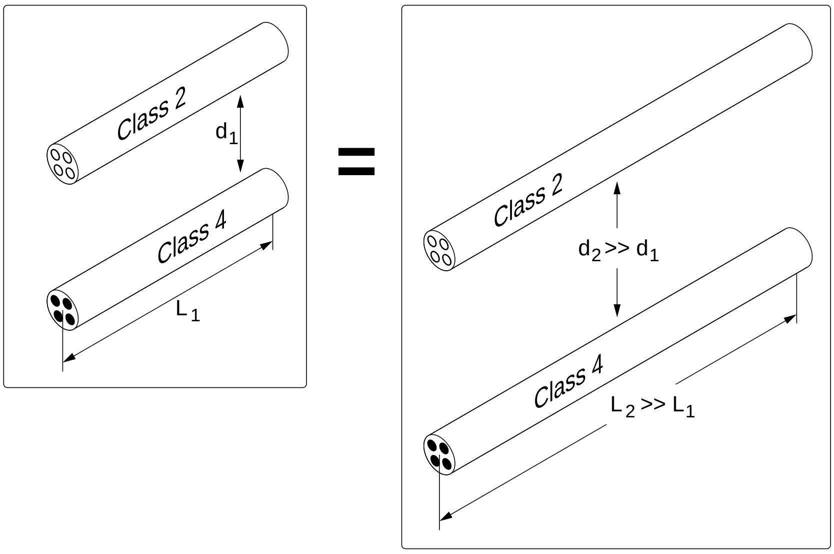
4 *Maximise the distance between cables carrying signals of different classes*, especially sensitive signals (1-2) and interfering signals (3-4) - this is very effective and relatively inexpensive.*

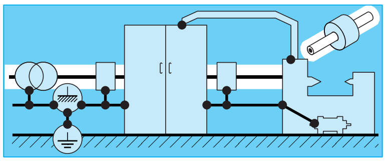
These values are for information only and assume that cables are mounted on an earth plane and are less than 30 m long.



— **Non-standardised term adopted for the purposes of this document.* —

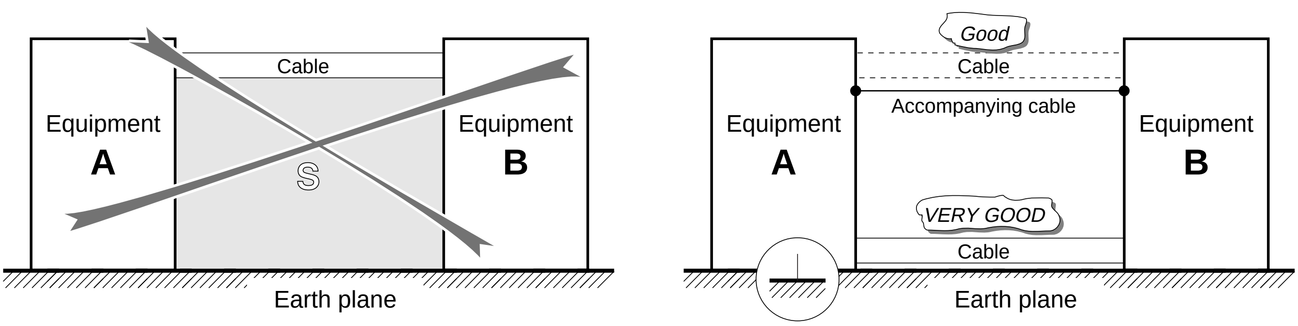
The longer the cable run, the greater the clearance required between cables.



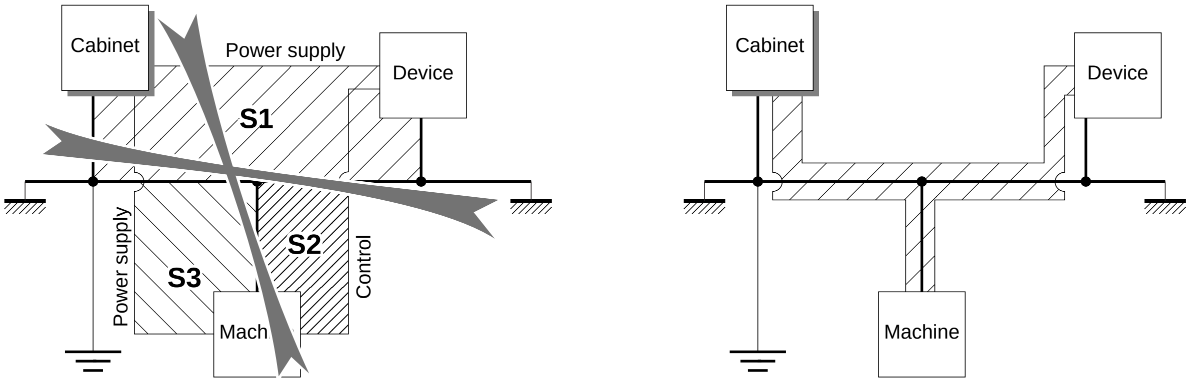


Wiring rules

5 *Minimise the surface area of earth loops*

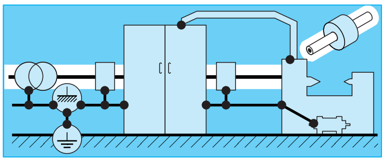


Ensure continuity of earth plane between 2 cabinets, machines, equipment items.

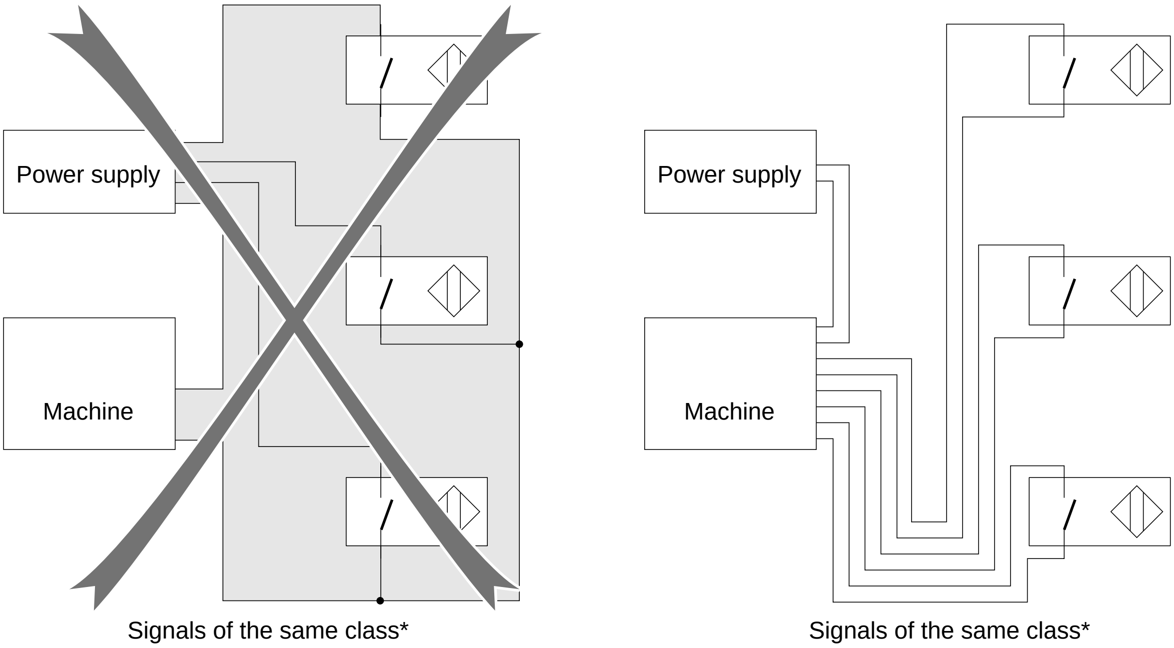


Place all conductors against the earth plane end to end (panel at bottom of cabinet, exposed conductive parts of metal enclosures, equipotential structures of machine or building, accompanying conductors, cable troughs, etc.).

Wiring rules

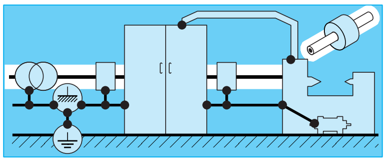


6 *The OUTGOING conductor must always be routed as close as possible to the RETURN conductor.*



** : low-level sensors ==> class 2*

Using 2-wire (2 conductors) cables makes it possible to ensure that the OUTGOING conductor is alongside the RETURN conductor over its entire length.

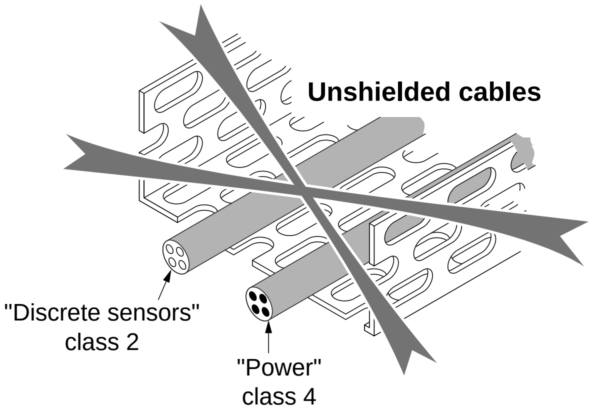


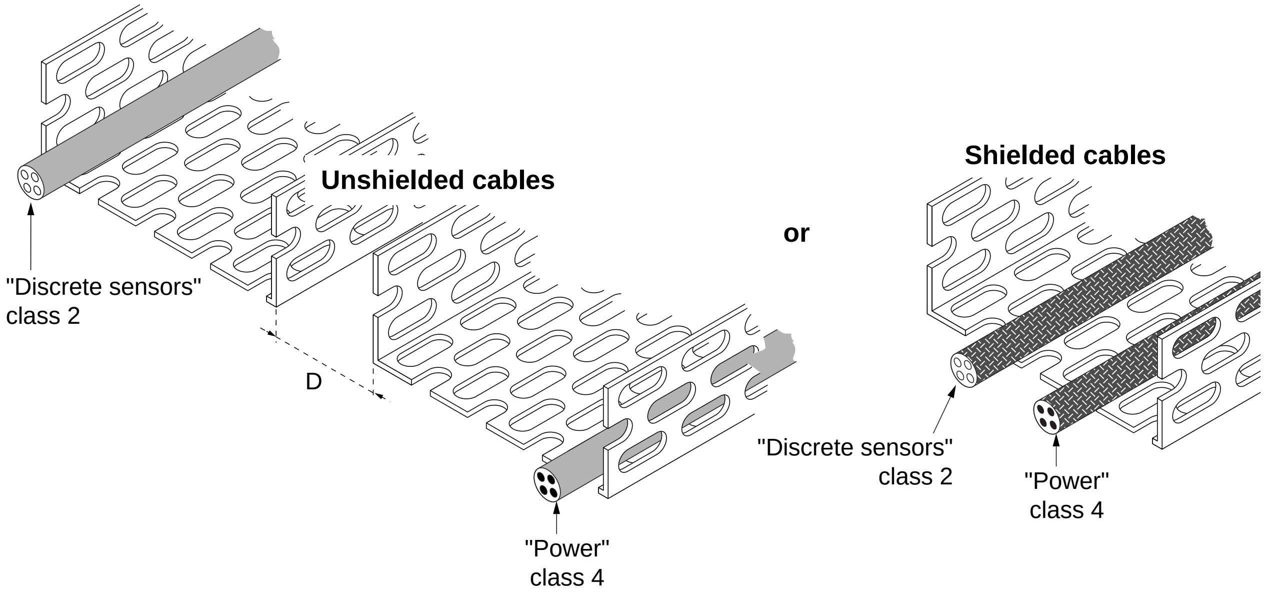
Wiring rules

1
2
3

7

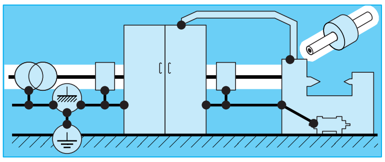
Using shielded cables makes it possible to co-locate cables carrying signals of different classes in a single cable trough.





— *Non-standardised term adopted for the purposes of this document.* —

Wiring rules



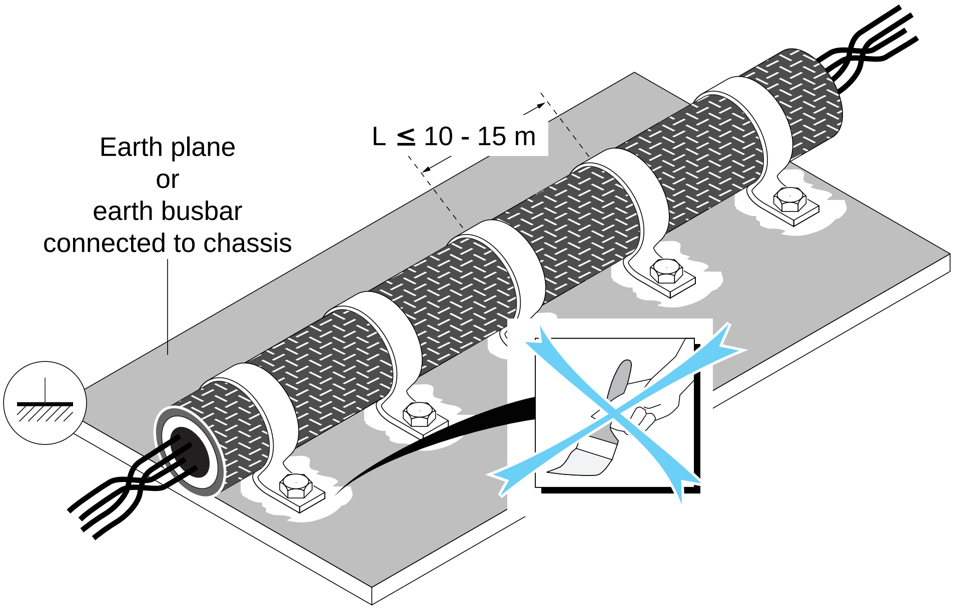
8 Connection of shielding

Shielding connected at both ends

- Very effective against external disturbances (high frequency (HF), etc.),
- Very effective even at resonance frequency of cable,
- No potential difference between cable and frame connection,
- Makes it possible to co-locate cables carrying signals of different classes (assuming satisfactory connection (360°) and equipotential bonding of exposed conductive parts (interconnection, etc.),
- Very high reducing effect (high frequency (HF)) - is $\simeq$ 300,
- In the case of extremely high-frequency (HF) signals, may induce leakage currents to earth for long cables > 50-100 m.

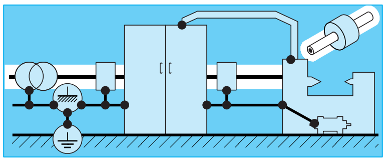
Very effective

Because LF and HF equipotential bonding of the site is a golden rule in (EMC), shielding is best connected to frame earth at both ends.



Shielding loses its effectiveness if the length of the cable is too long.

It is advisable to provide a large number of intermediate connections to frame earth.



Wiring rules

Shielding connected at one end only

- Ineffective against external disturbances in HF electric field,
- Can be used to protect an insulated link (sensor) against LF electric field,
- Shielding may act as antenna and become resonant

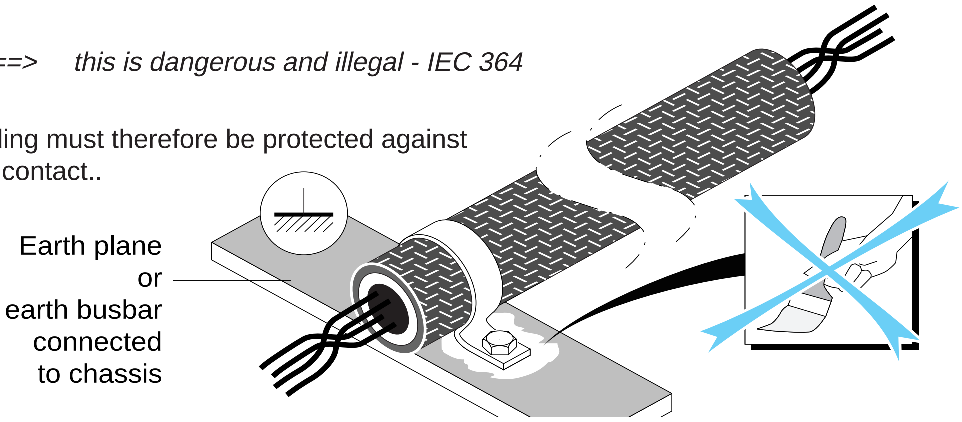
  ==> *in this case interference is greater than without shielding!*
- Makes it possible to prevent (LF) buzz,

  ==> *buzz is caused by flow of LF current in the shielding.*

A large potential difference may exist at the end of the shielding that is not earthed.

==> *this is dangerous and illegal - IEC 364*

Shielding must therefore be protected against direct contact..

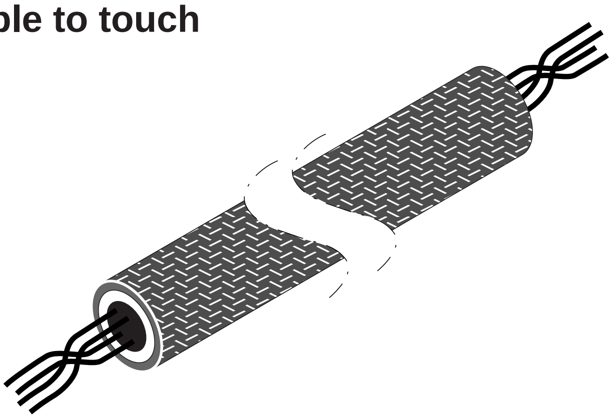


Average effectiveness

In absence of equipotential bonding of site (buzz), connection to one end only is a way of ensuring acceptable operation.

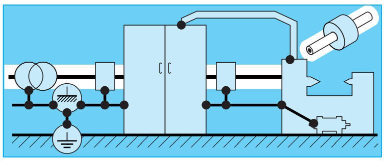
Shielding not connected to frame earth: prohibited if shielding is accessible to touch

- Ineffective against external disturbances (HF) etc.,
- Ineffective against magnetic field,
- Limits capacitive crosstalk between conductors
- A large potential difference may exist between shielding and frame earth ==> this is dangerous and prohibited (IEC 364)

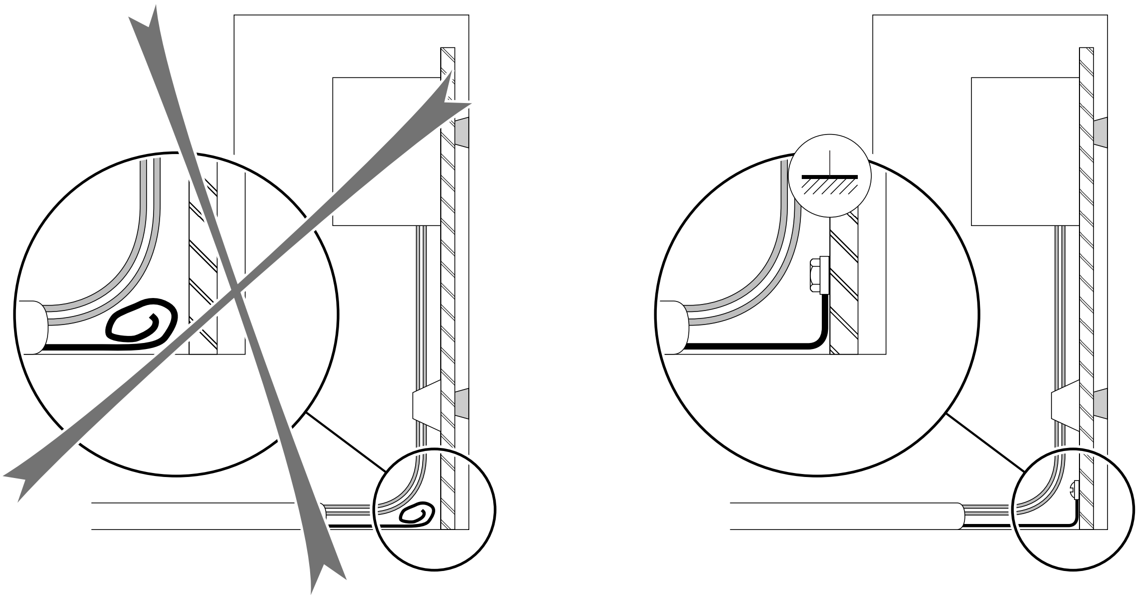


Completely ineffective, especially when compared with capabilities of correctly fitted shielding and its cost.

Wiring rules



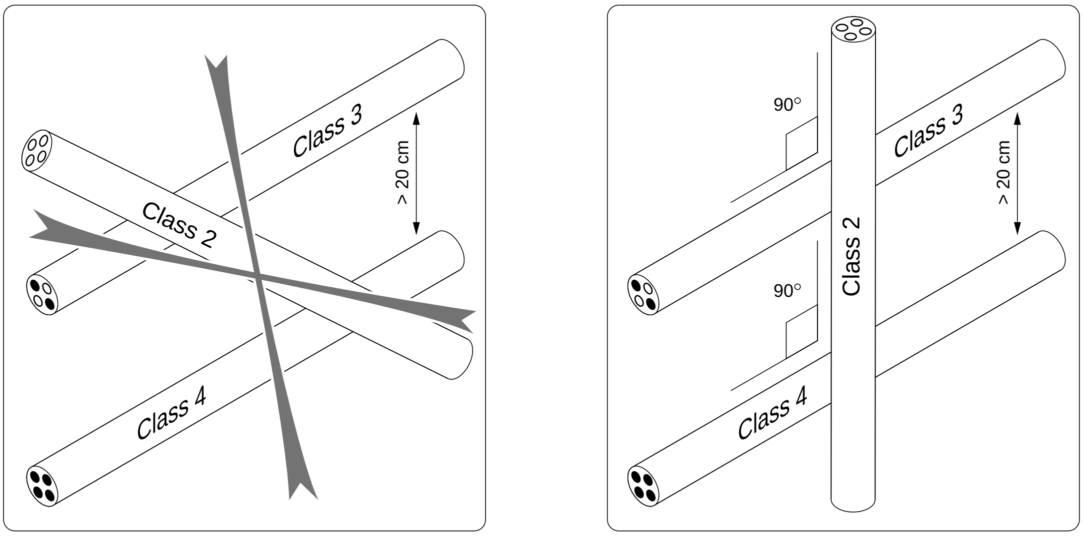
9 *Any conductor in a cable and which is spare or not used must always be earthed (chassis, cable trough, cabinet, etc.) at both ends*

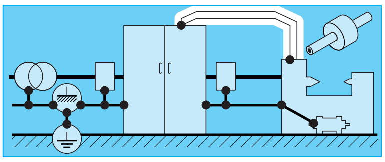


For class* 1 signals, such connection may generate LF buzzing superimposed on the useful signal if the equipotential bonding of the exposed conductive parts of the installation is inadequate.

— **Non-standardised term adopted for the purposes of this document.* —

10 *Make sure conductors or cables carrying signals of different classes, especially sensitive signals (1-2) and interfering signals (3-4) cross each other at right angles*

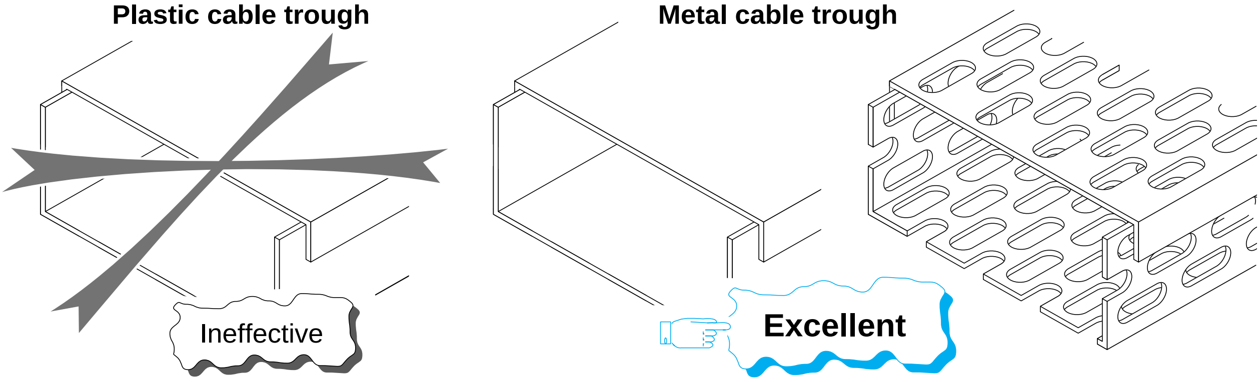




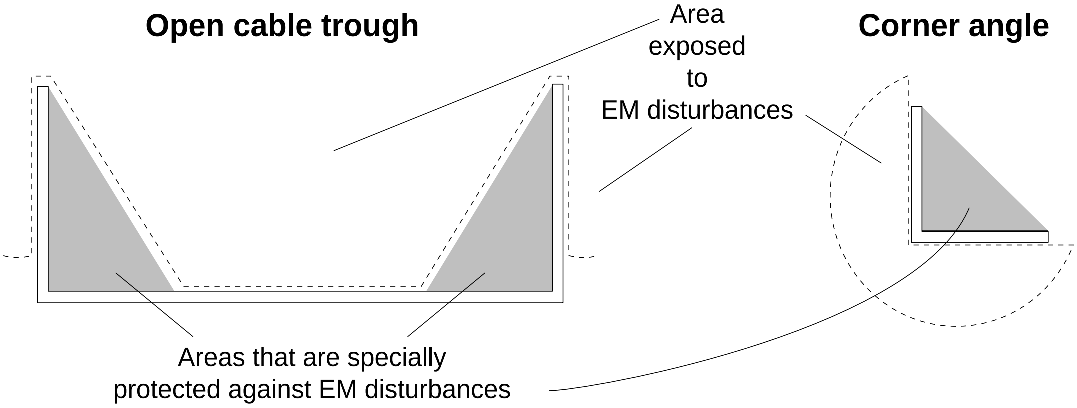
Cable runs

Cable troughs

Correctly connected metal cable troughs, conduits, etc. provide very effective overall shielding of cables.



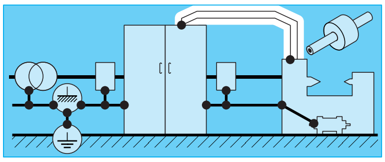
Behaviour in presence of EM disturbances



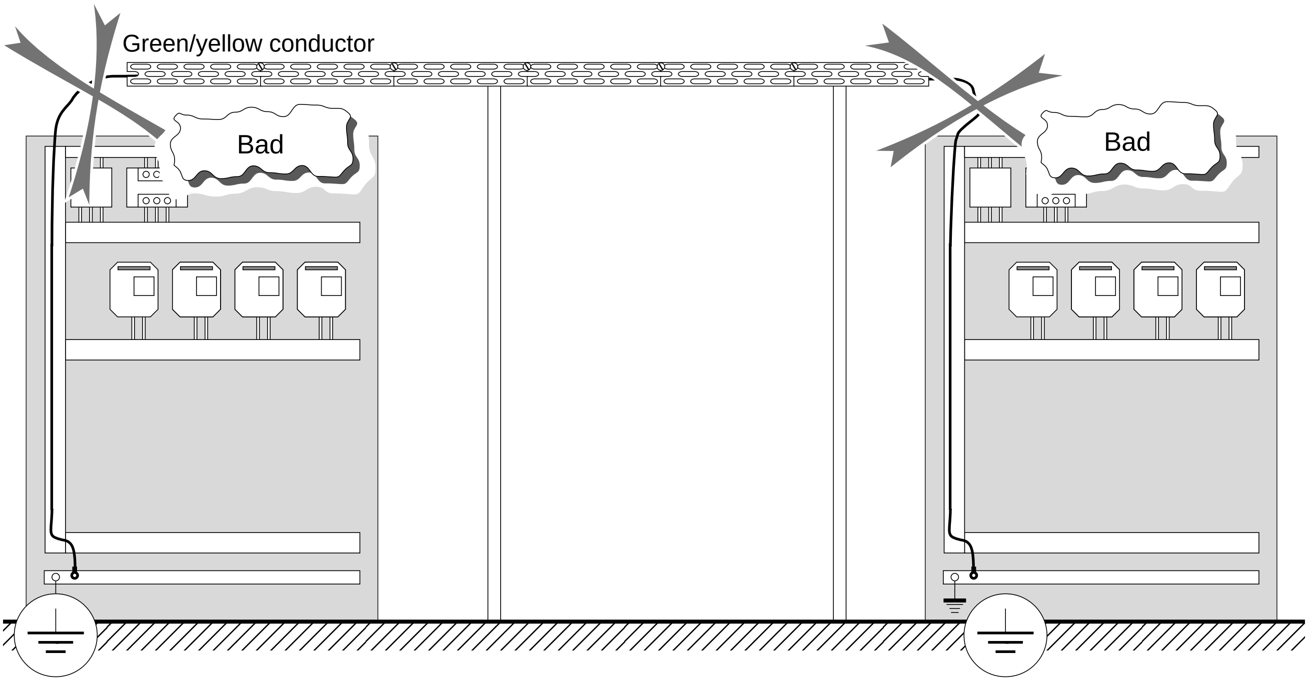
The shielding, protective or screening effect of a metal cable trough depends on the position of the cable.

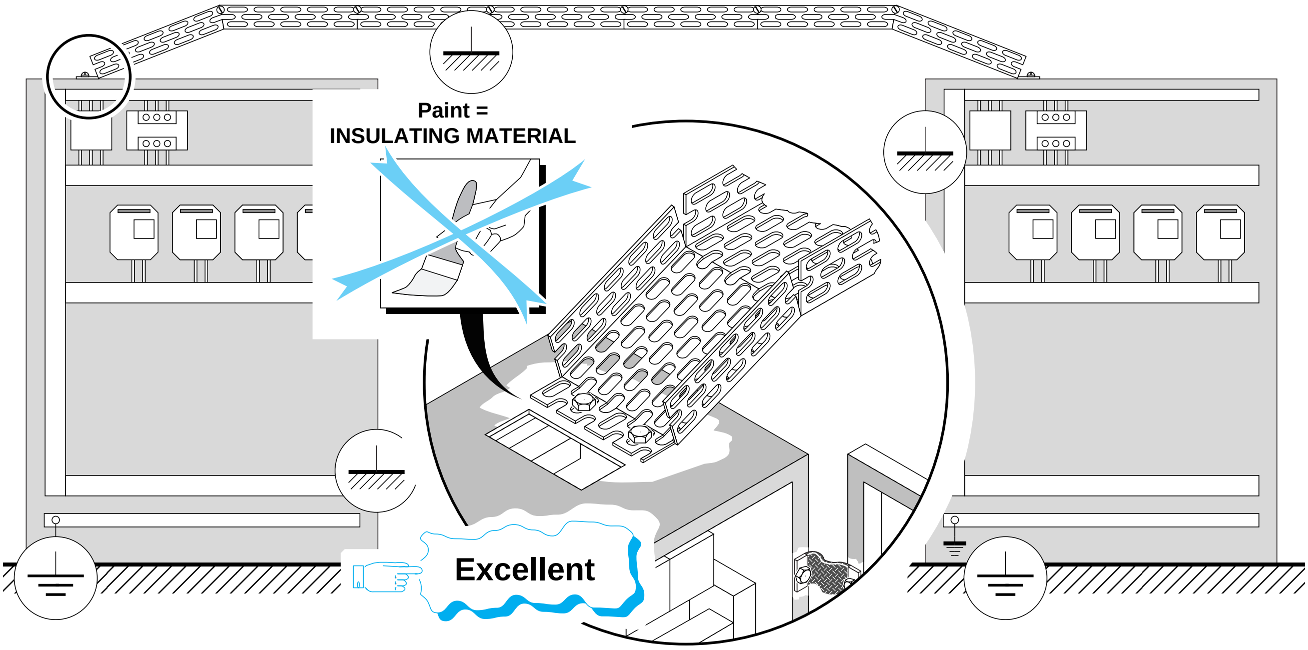
Even the best metal cable trough is ineffective if the end connections are of poor quality.

Cable runs

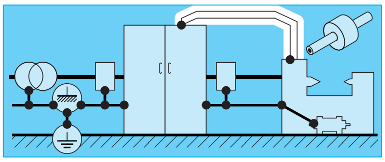


Connection to cabinets





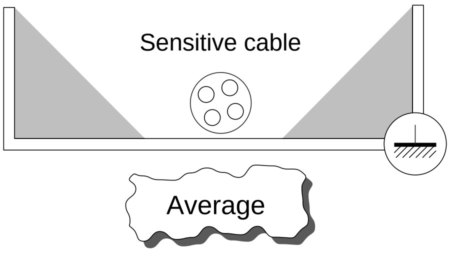
The ends of metal cable troughs, conduits, etc. must be bolted onto metal cabinets to ensure satisfactory connection.

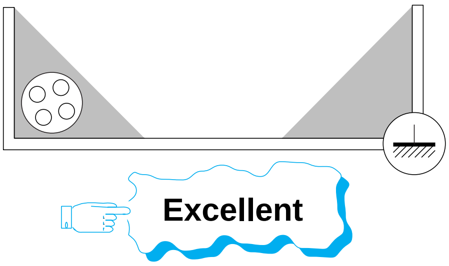


Cable runs

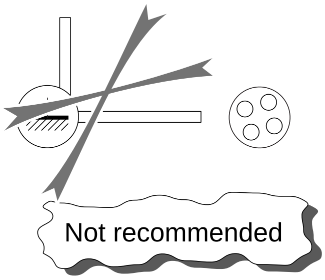
Positioning of cables

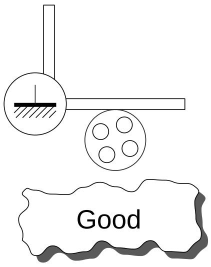
Cable troughs

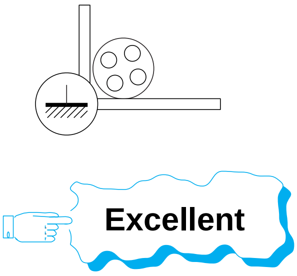




Cable brackets

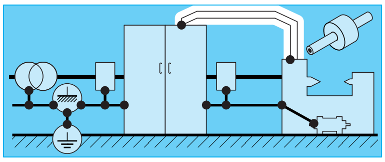






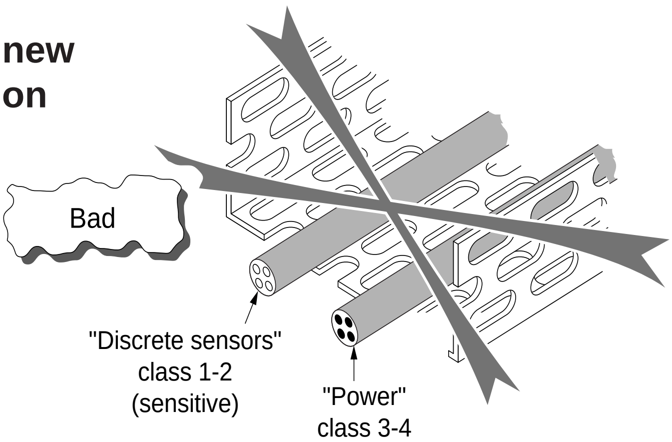
Even the best metal cable trough is ineffective
if the end connections are of poor quality.

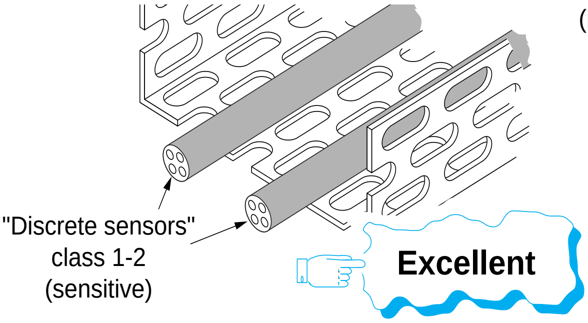
Cable runs

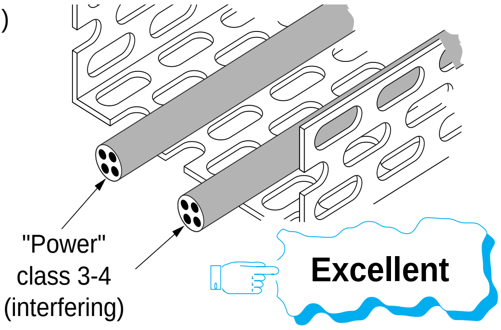


Interfering and sensitive cables must be laid along separate cable routes.

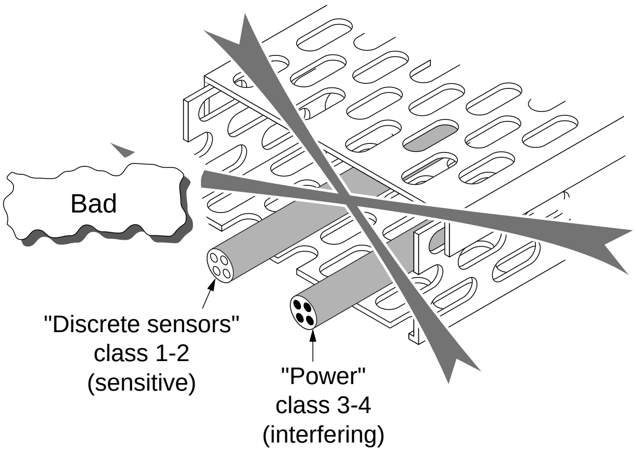
For every new installation

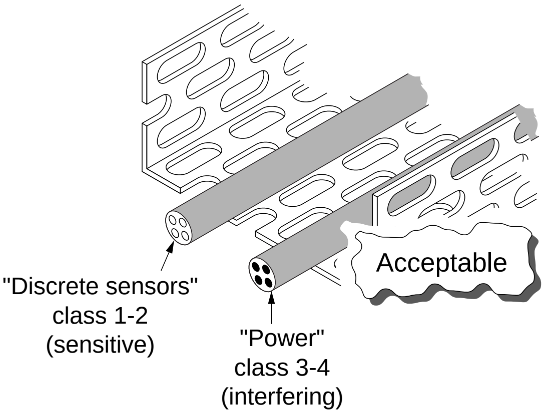




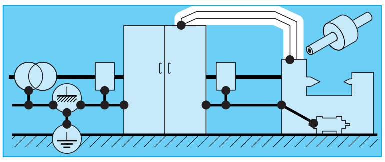


For every existing installation





If «sensitive» (class 1-2) and interfering (class 3-4) cables are laid in the same cable trough despite the fact that this is not at all recommended, it is then preferable to leave the cable trough open.

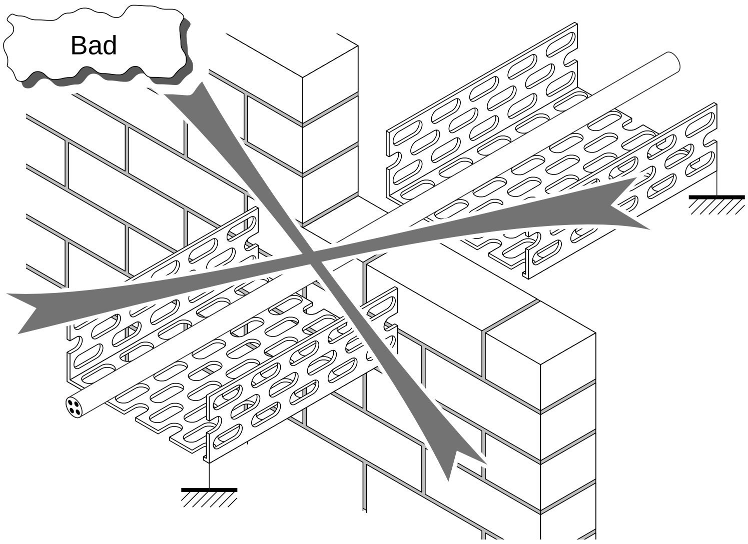


Cable runs

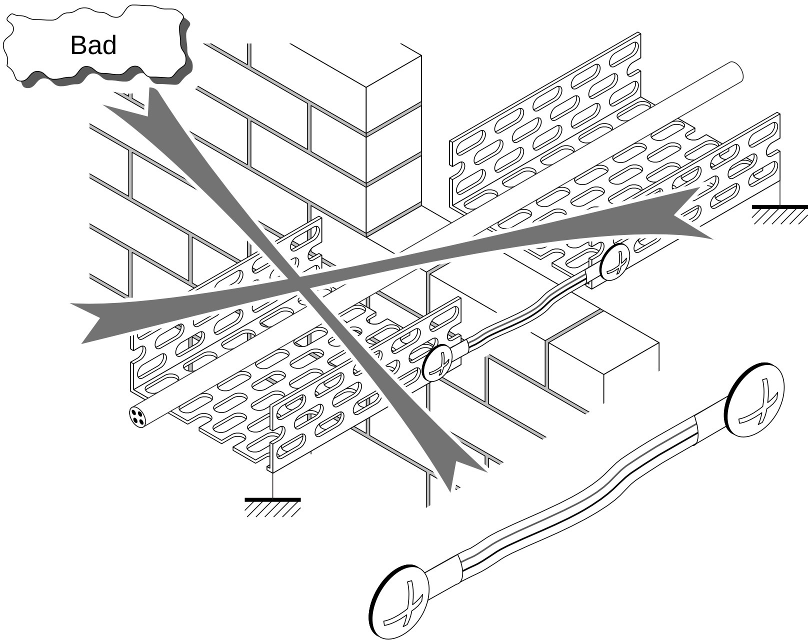
Connection of ends

The ends of metal cable troughs, conduits, etc. must overlap and be bolted together.

(no continuity of earth plane)

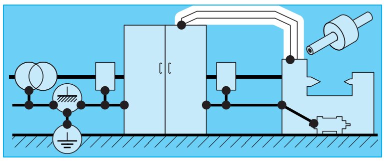


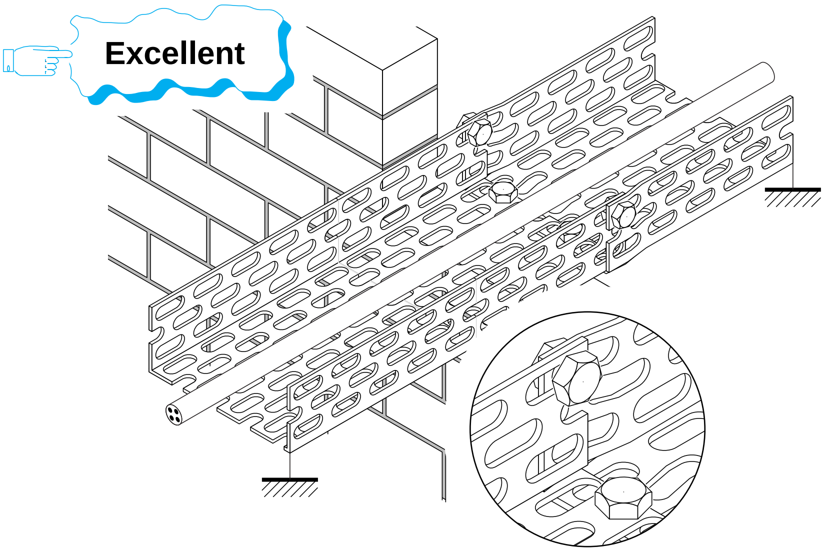
(no continuity of earth plane))



A conductor that is roughly 10 cm long reduces the effectiveness of a cable trough by a factor of 10.

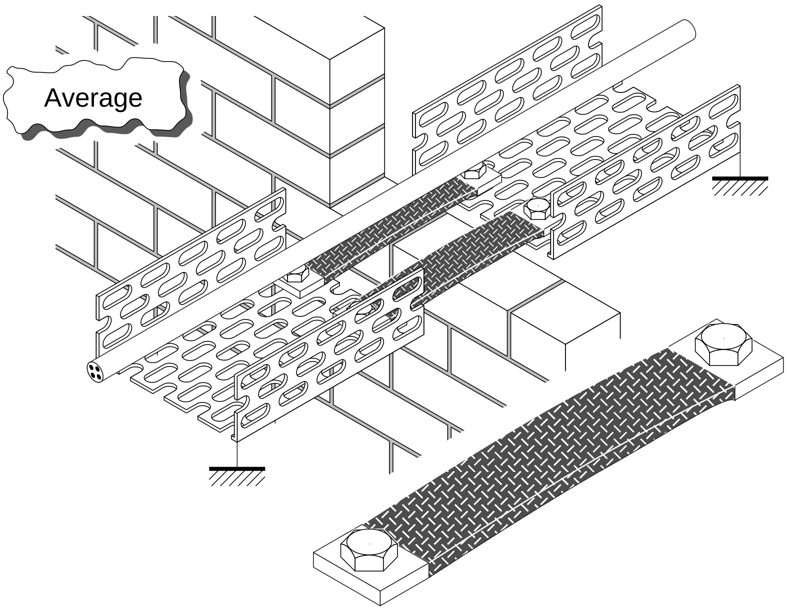
Cable runs



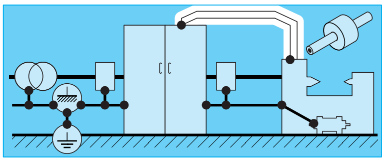


If it is not possible to overlap and bolt the ends of a cable trough:

==> *attach a short, wide braided strap under each conductor or cable.*



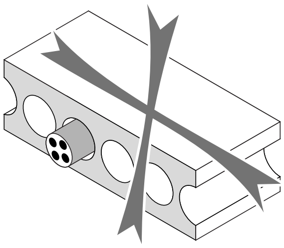
Even the best metal cable trough is ineffective
if the end connections are of poor quality.

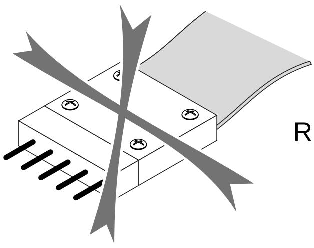


Cable runs

Methods of cable laying not recommended

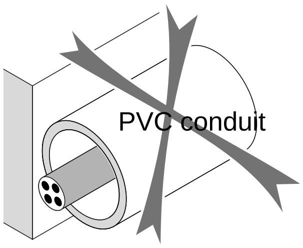
Structural void
in partition wall

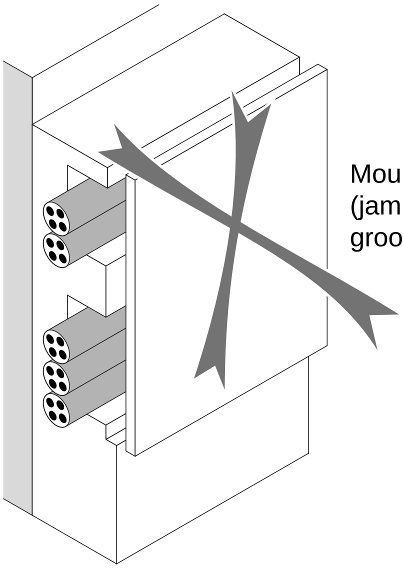




Ribbon cable, bus ...

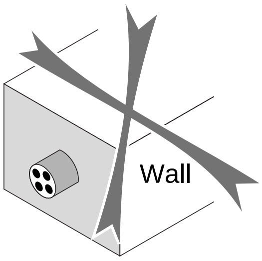
Surface-mounted
conduit

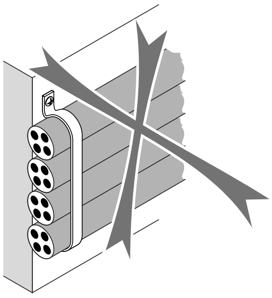




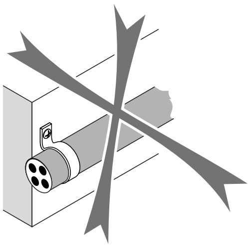
Moulding, skirting
(jamb lining) with
grooves

Buried conduit



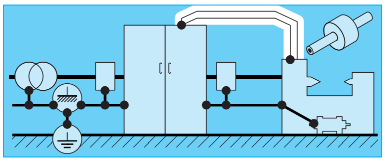


Direct attachment
to walls and ceilings
using clips, ties, etc.

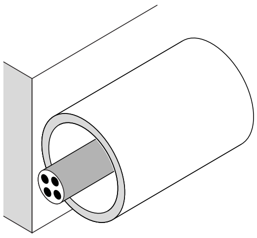


Even the best metal cable trough is ineffective
if the end connections are of poor quality.

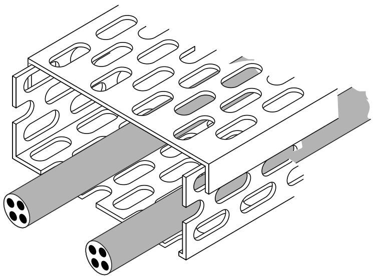
Cable runs



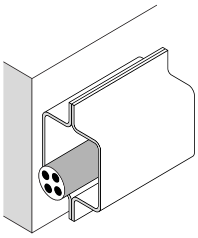
Recommended methods of cable laying



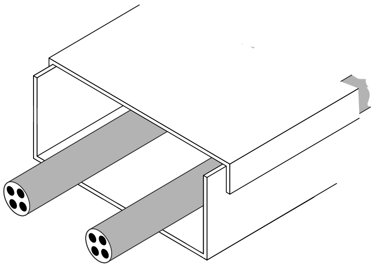
Steel conduit



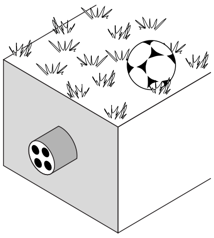
Steel cable trough



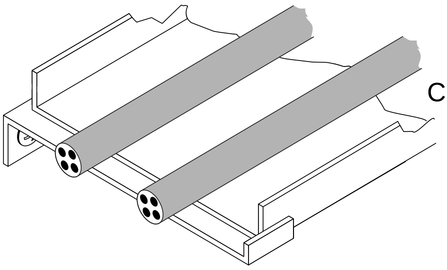
Trunking



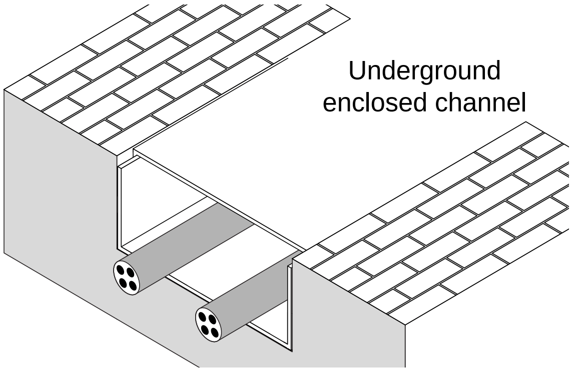
Steel cable duct



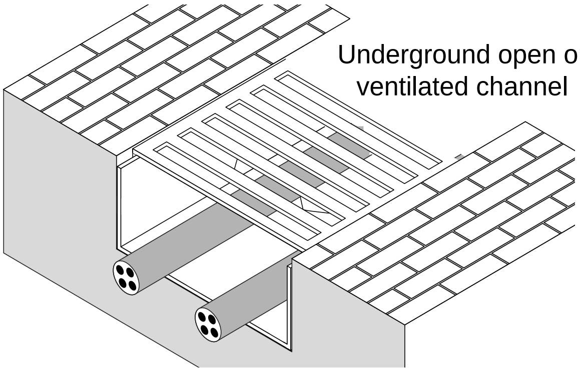
Buried cable



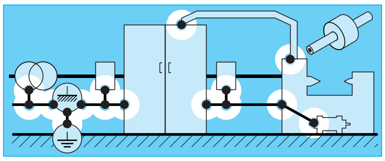
Cable shelves or
steel trays



Underground
enclosed channel



Underground open or
ventilated channel



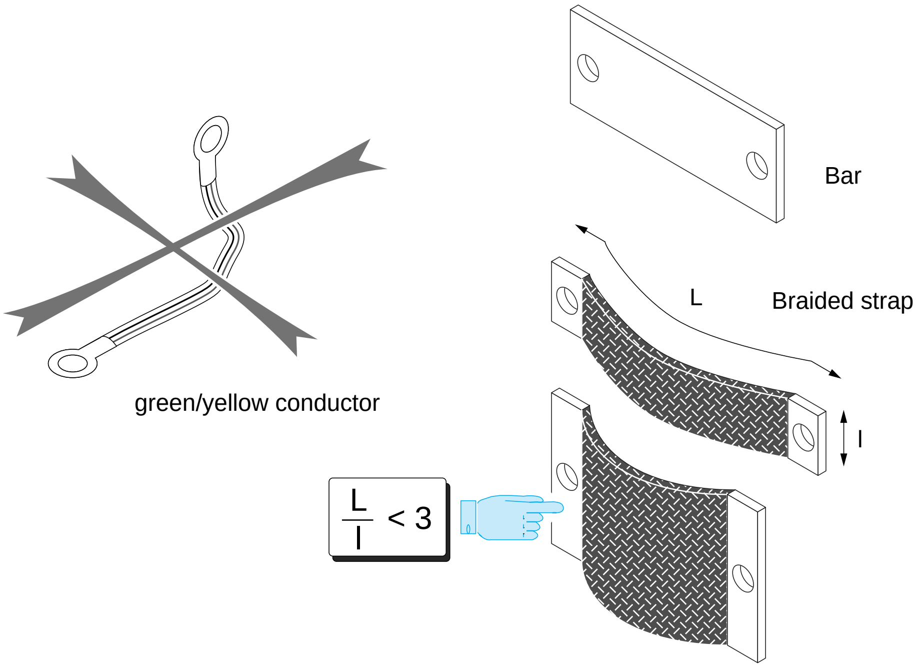
Connections

__The quality of CONNECTIONS__ is just as important as the best cable, shielding, earthing system

It is assumed that the reader is completely familiar with high-frequency (HF) phenomena, otherwise the reader should refer to Chapter I (especially the section entitled «Cables»).

Type and length of connections

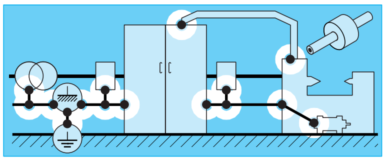
Frame earth connections, etc. must be as short and wide as possible in every case.



Reminder : at high frequency (HF), the length of the cable is the decisive factor (see Chapter I)

The quality of connections is a decisive factor in (EMC).

Connections



Making a connection

It is crucially necessary to ensure «metal-to-metal» contact and a high contact pressure between conductive parts.

Procedure :

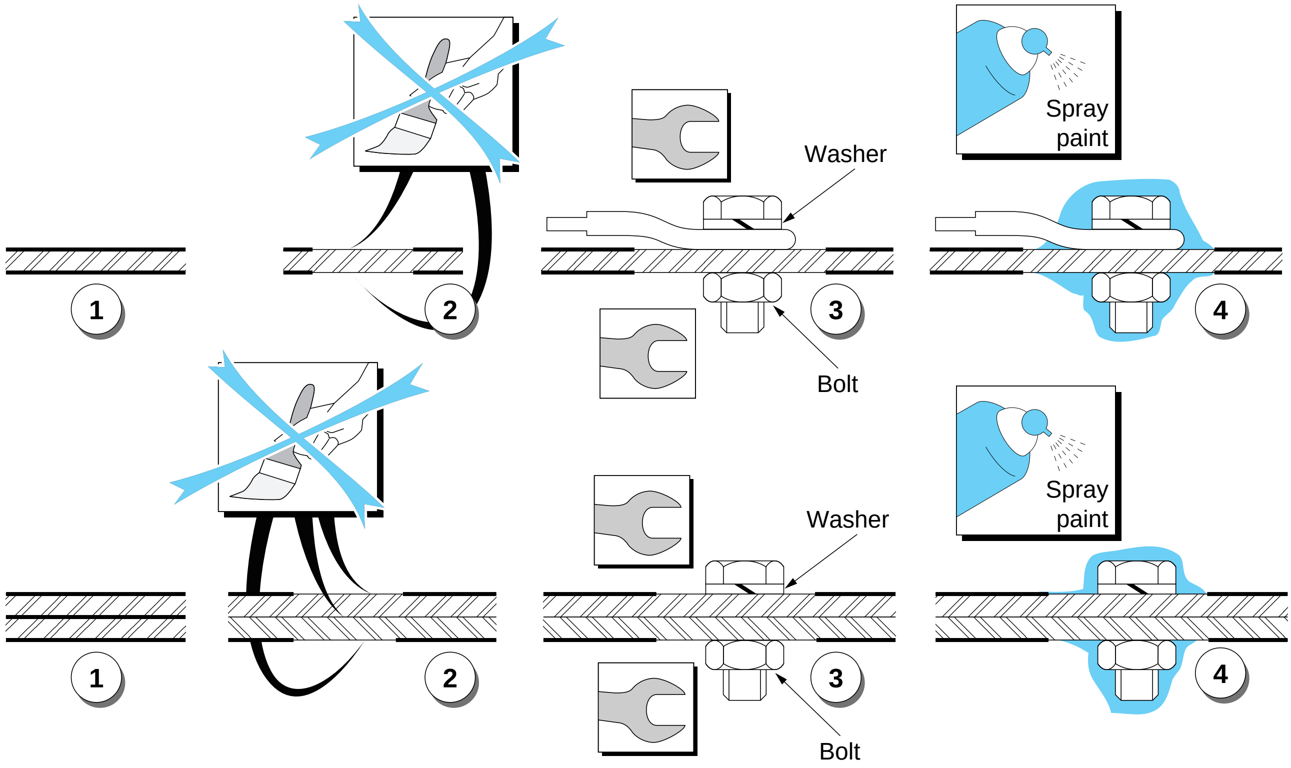
1 - Painted sheet metal,

2 - Masking - removal of paint,

3 - Ensure adequate tightening by means of a nut and bolt system with washers for example,

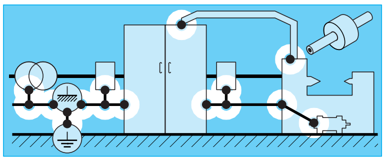
4 - Ensure high-quality contact is maintained over time.

==> apply paint or grease to protect against corrosion after tightening.



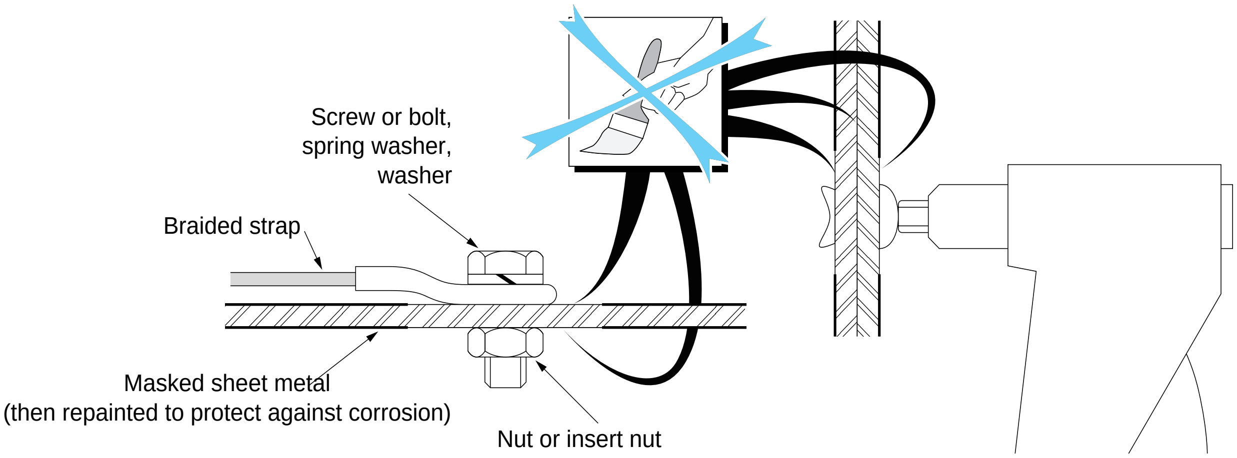
Remove insulating coatings, paintwork, etc. between the surfaces in contact

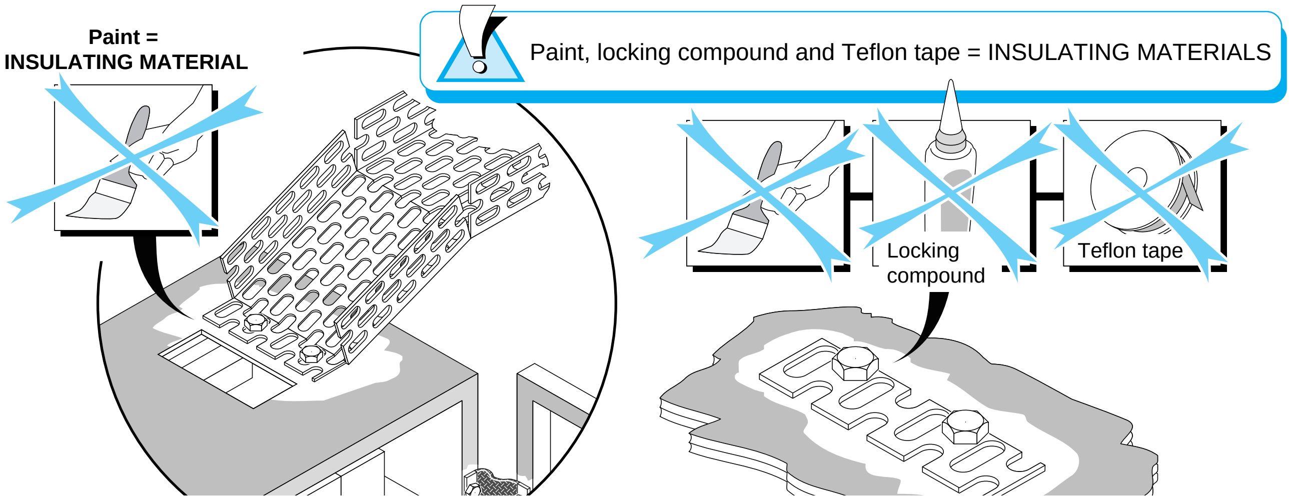
The quality of connections is a decisive factor in (EMC).



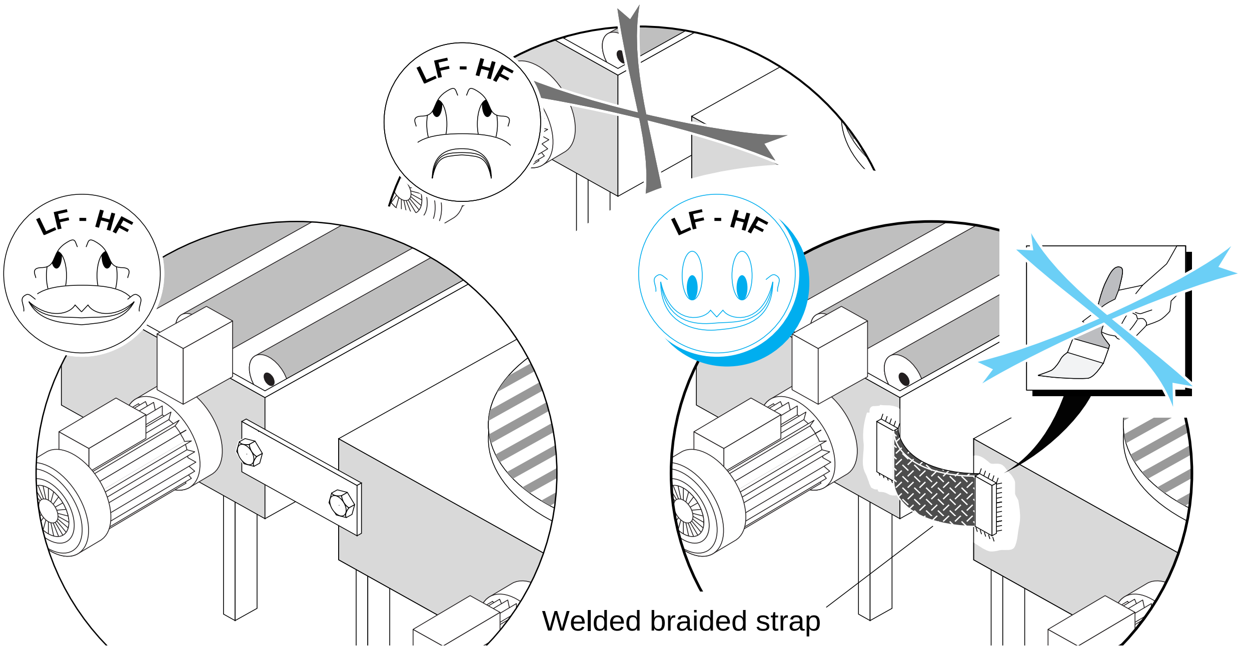
Connections

Pitfalls to avoid

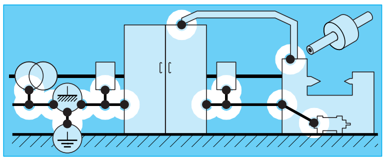




Paint, locking compound and Teflon tape = INSULATING MATERIALS



Connections



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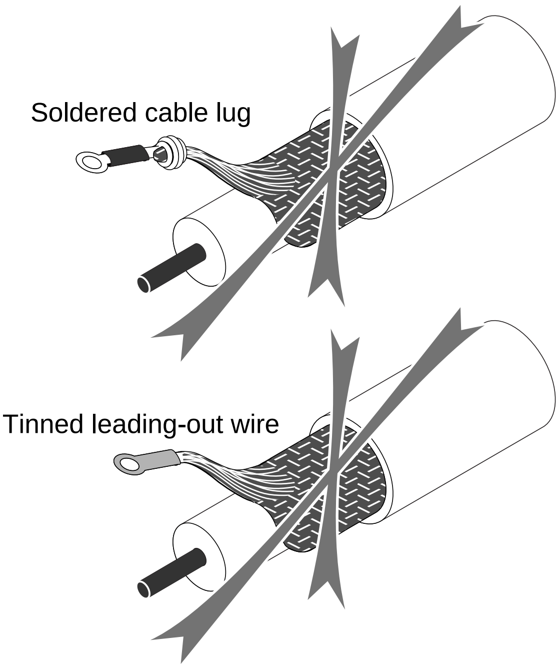
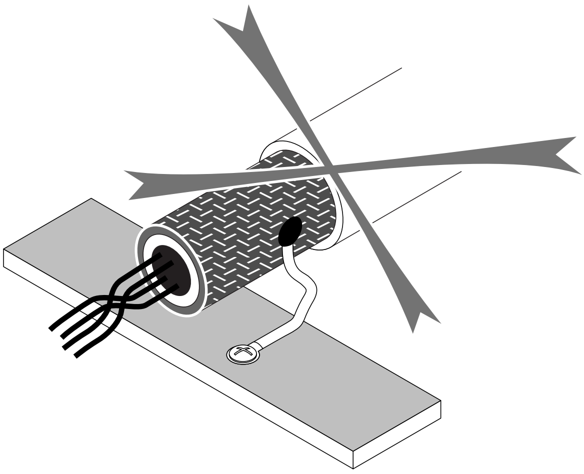
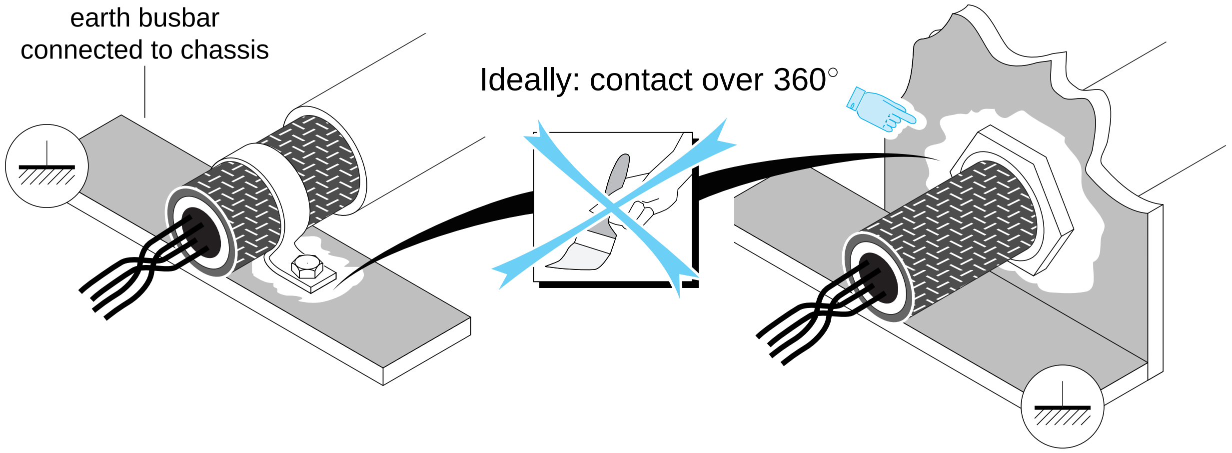
Connection of shielding





Ensure metal-to-metal contact

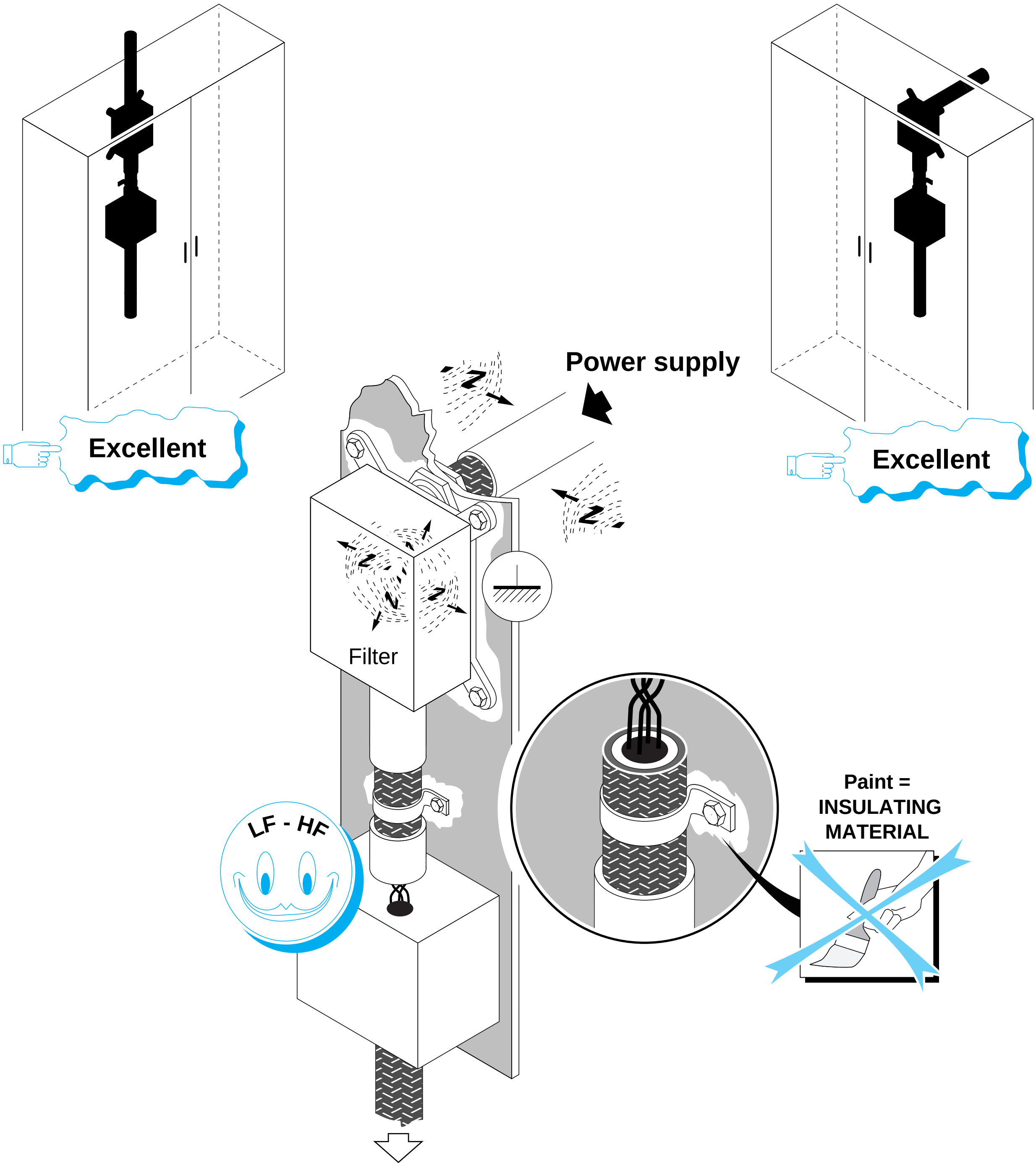


Watch out for insulating plastic tape between shielding and sheath

Connections at the end of shielding must provide metal-to-metal bond over 360°.

Filters

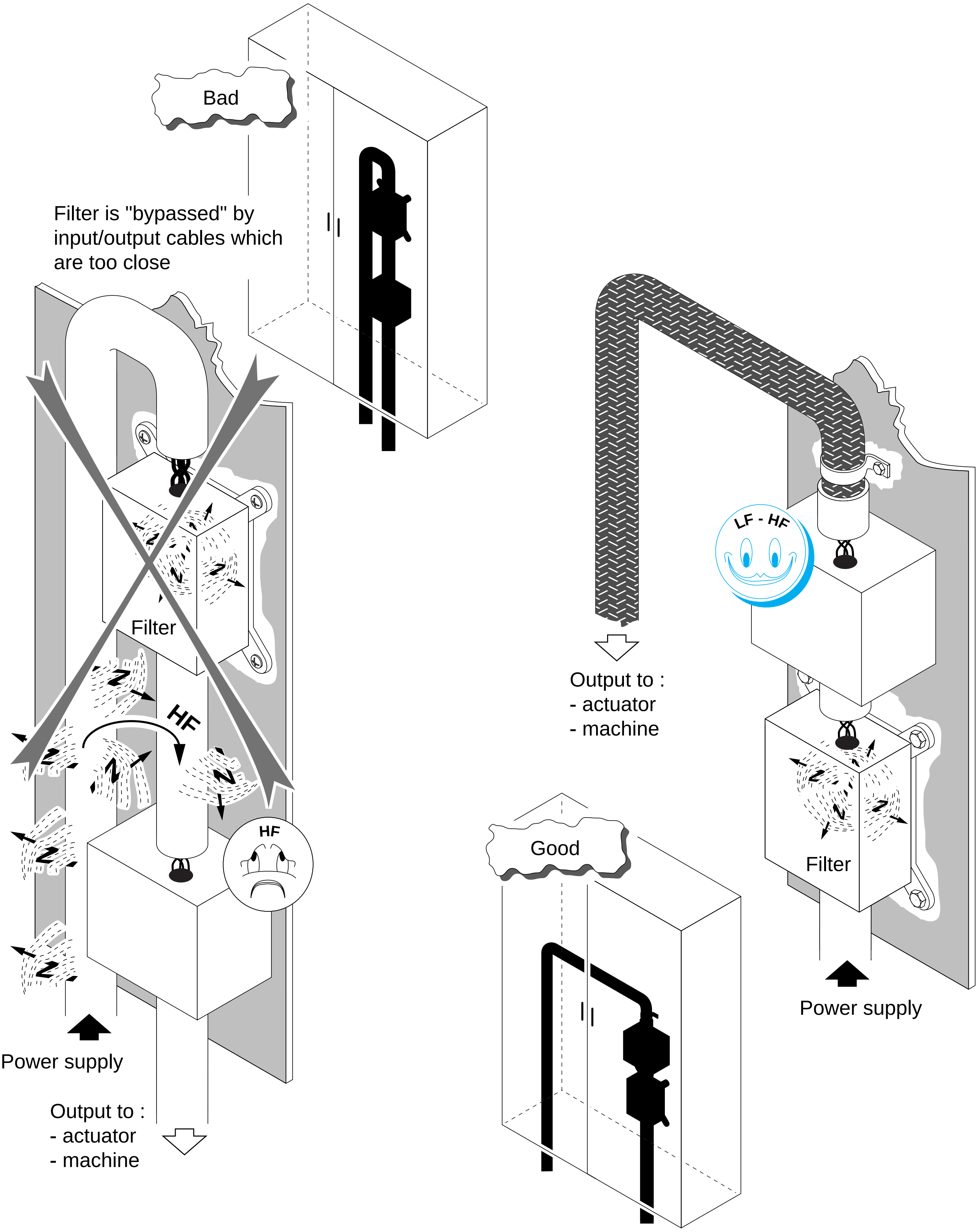
Layout in cabinet

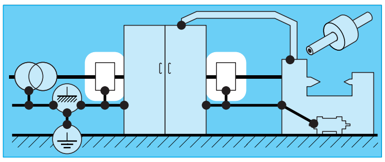


Output to :
- actuator
- machine

Filters

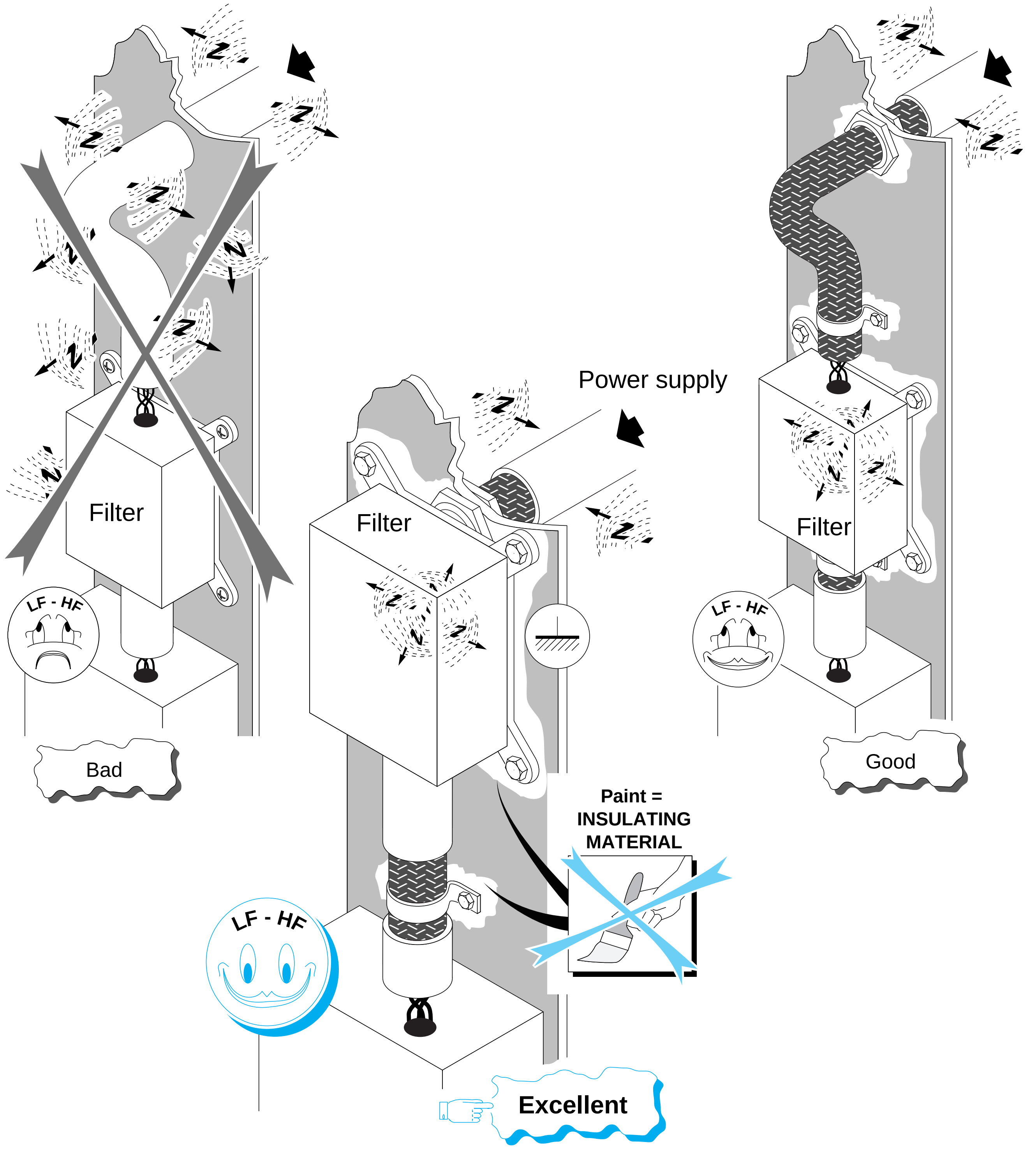
The input cable must not run alongside the output cable





Filters

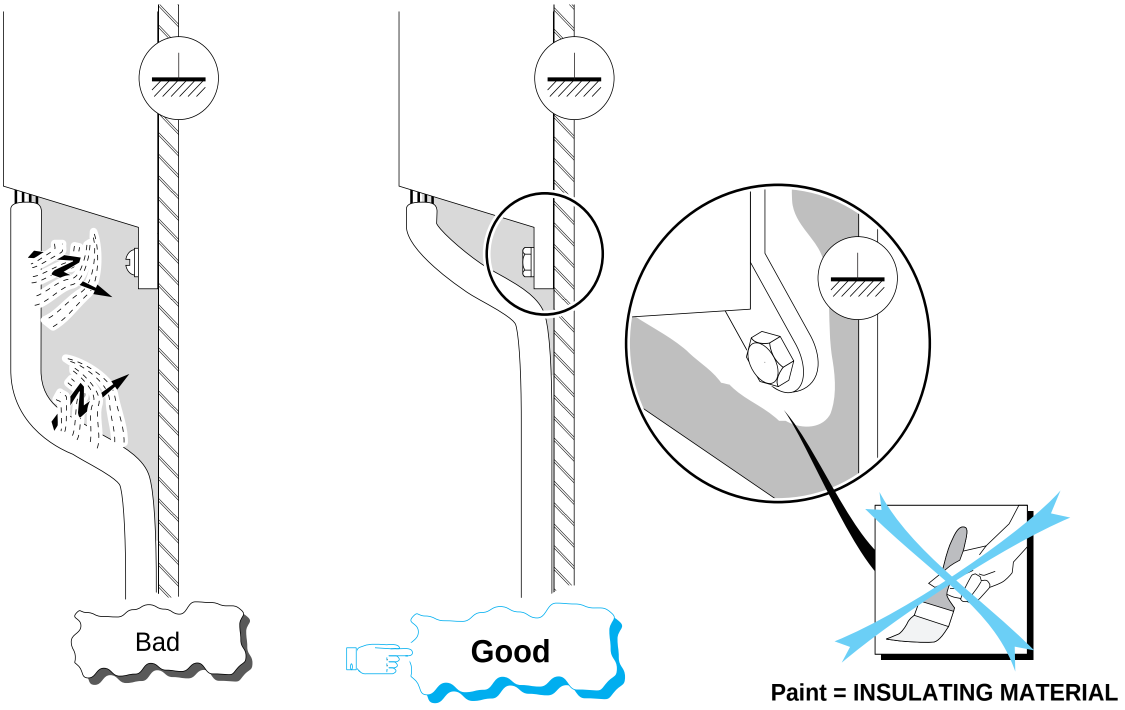
Mounting of filters



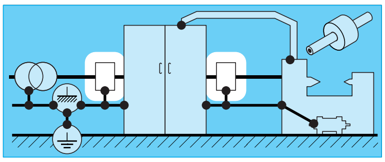
Filters must be fitted at the point where cable enters the cabinet cable and be bolted to the chassis or earth plane at the bottom of the cabinet

Filters

Connections of filters



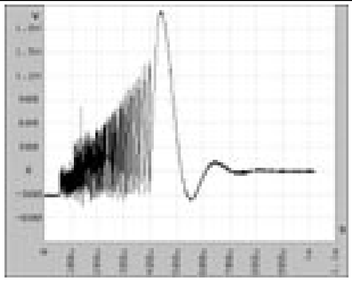
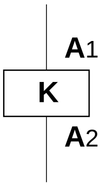
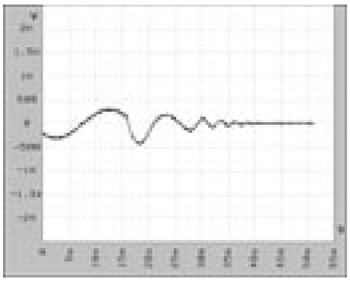
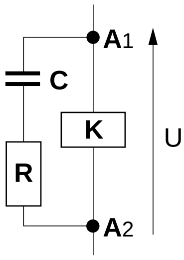
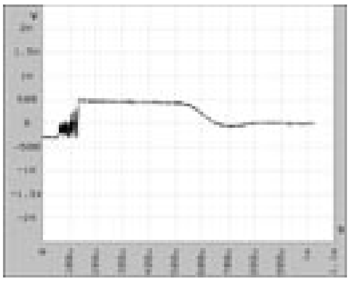
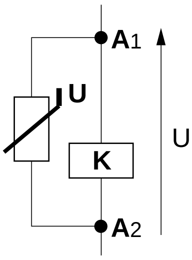
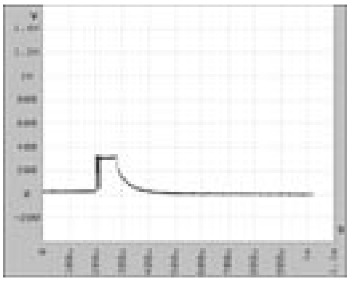
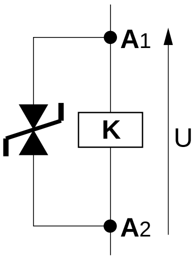
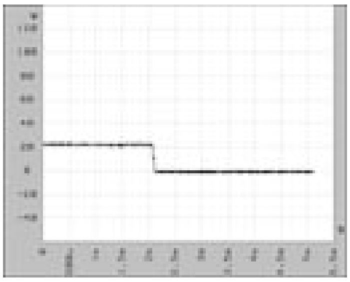
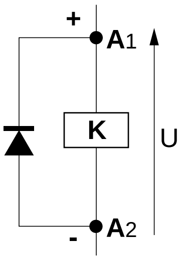
Lay cables against earth reference plane at the bottom of the cabinet

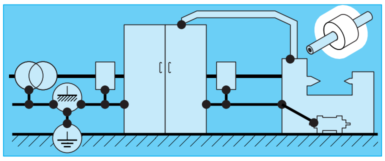


Surge arresters

Surge arresters or coil interference suppression modules : choice

The various devices listed below are intended to reduce:
- disconnection surges
- residual high frequency (HF) (level, quantity and slope of disruptive-breakdown wave fronts)

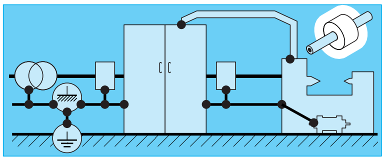
Oscillogram	Type of interference suppression	Circuit diagram	Overvoltage limiting	
	- - -		> 1 kv	No limiting. High overvoltage of up to several kV preceded by a train of breakdown impulses with steep wave fronts.
	R - C circuit The RC damps the wave front		≃ 2Uc	Good limiting: of the order of twice the control voltage UC. (Variable depending on instant of disconnection, coil type and values of R and C).
	Varistor		≃ 2Uc Predetermined	Limiting of overvoltage to a predetermined peak clipping value of the order of twice the maximum control voltage UC.
	Bidirectional clipper diode		≃ 2Uc Predetermined	Limiting of overvoltage to a predetermined peak clipping value of the order of twice the maximum control voltage UC.
	"Frewheeling" diode		Uc No overvoltage	Total elimination of overvoltage.



Surge arresters

A combination of clipper diodes + RC combines the advantages of both circuits

Application	Fall time	Effect on function
Typical overvoltage across the terminals of a coil disconnected by a dry contact. Example: contactor, 9 A rating. For details, see Chapter 1.	Tr_1	
● In conjunction with a.c. powered devices. Not widely used with d.c. (volume and cost of equalizer). ● Assists disconnection (reduced wear of control contact). ● Effect on high frequencies (HF) : - Eliminates steep wave fronts or disruptive breakdown (no flow of high-frequency (HF) currents in the control circuit. - Only a damped low-frequency (LF) oscillating voltage waveform can be observed (order of magnitude ≃100 Hz).	Tr = 1 to 2 Tr_1	● Increase in fall time by a factor of the order of 1 to 2. (Generally acceptable given the large dispersion of fall times with a.c.)
● In conjunction with a.c. or d.c. powered devices. ● Assists disconnection (reduced wear of control contact). ● Effect on high frequencies (HF): - Before clipping threshold is reached, a train of short-duration breakdown pulses may occur depending on the type of contact and order of magnitude of UC. - Possible flow of low-amplitude, short-duration high-frequency (HF) current in control circuit. courte durée possible dans le circuit de commande. ● Capable of handling significant energy (more than RC).	Tr = 1,2 to 2 Tr_1	● Increase in fall time by a factor of the order of 1.2 to 2.
● In conjunction with a.c. or d.c. powered devices (excluding unidirectional clipper diodes that have interference suppression). ● Assists disconnection (reduced wear of control contact). ● Effect on high frequencies (HF) : - Little residual HF (limited risk of breakdown) for low-level control voltages (UC). - Possible flow of low-amplitude, very short-duration HF currents in control circuit for high control voltages > 200 V (HF performance similar to that of varistor).	Tr = 1,2 to 2 Tr_1	● Increase in fall time by a factor of the order of 1.2 to 2.
● In conjunction with d.c. powered devices (biassed component). ● Assists disconnection (reduced wear of control contact). ● Effect on high frequencies (HF) : On disconnection, the diode handles the energy restored by the inductor in the form of a current, the voltage across its terminals is almost zero and the voltage across the terminals of the control contact equals UC ● No risk of breakdown and corresponding HF interference.	Tr = 4 to 8 Tr_1	● Increase in fall time by a factor of the order of 4 to 8. (Variable depending on type and size of electromagnet).



Ferrite cores

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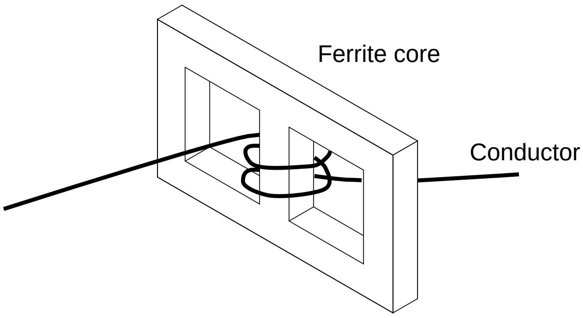
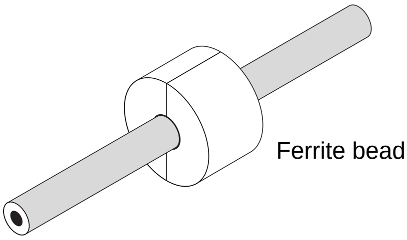
The «outgoing» and «return» conductors for the signal to be cleaned up must both pass through the ferrite core.

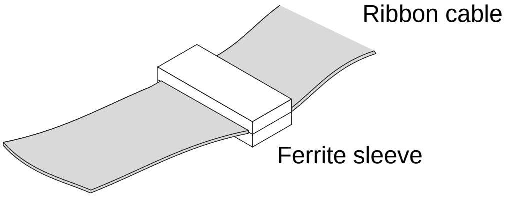


The number of turns increases the effectiveness but also creates stray capacitance between turns. The max. number of turns not to be exceeded depends on the :

- frequency of interference
- cable
- ferrite core

==> Experiment to find the optimum.





Half-shell ferrite sleeves are easier to install but less effective than solid (enclosed) ferrite sleeves.

☞	Emission problem :	ferrite sleeve must be located as close as possible to the interfering device.
☞	Immunity problem :	ferrite sleeve must be located as close as possible to the sensitive device only if the interfering equipment cannot be interference suppressed or it cannot be identified.

CHAPTER 3

(EMC) STANDARDS, FACILITIES AND TESTS

Standards

Introduction

A standard is a collection of rules, descriptions and methods that manufacturers can use as a reference when defining and testing one of their products.

There are 3 types of (EMC) standards

Basic publications or standards

These are standards or guides that define, in general terms, requirements relating to (EMC) (phenomena, tests, etc.).

They are applicable to all products and are used as a reference, especially by committees who have to prepare specific standards.

Basic standards will not be harmonized at a European level.

Generic (European) standards

These standards define essential requirements in terms of levels that must be withstood by each product, type tests, etc. borrowed from basic standards.

If there is no product or product family standard, they apply to any product installed in a defined environment.

Product or product family standards

These standards define the applicable constructional provisions, characteristics, test methods and severity levels etc. applicable to given products or product families.

Where they exist, these standards take precedence over generic standards.

Note: the type of standard is stated in the header of each publication.

Standards

Standardising bodies

CISPR : International Special Committee on Radio Interference,

IEC : International Electrotechnical Commission (Geneva),

CENELEC : European Committee for Electrotechnical Standardisation (Brussels),

Document references start with the letters EN, ENV, HD ...

UTE : Union Technique de l’Electricité en France
(French Electrical Engineering Association),
The UTE is the French member of CENELEC

UTE document references start with the letters NF ...

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CISPR Publications

The first CISPR Publications were printed in 1934. They aim to protect the transmission and reception of radio waves.

They define, in particular, the test conditions and emission limits for electrical and electronic products.

Standards

Examples of CISPR Publications applicable to our products

CISPR 11-1990	Limits and methods of measuring the characteristics of electromagnetic interference produced by radiofrequency industrial, scientific and medical (ISM) devices.
CISPR 14-1993	Limits and methods of measuring the radiofrequency interference produced by domestic or similar electrical appliances having motors or thermal devices, electric tools and similar electrical appliances.
CISPR 16-1-1993	Specifications for methods and instruments for measuring radiofrequency interference and immunity to radiofrequency interference. First part : Measuring instruments for radiofrequency interference and immunity to radiofrequency interference.
CISPR 17-1981	Méthodes de mesure des caractéristiques d'antiparasitage des éléments de réduction des perturbations radioélectriques et des filtres passifs.
CISPR 18-1-1982	Methods of measuring the interference suppression characteristics of components to reduce radiofrequency interference and of passive filters. First part : Description of phenomena.
CISPR 22-1993	Limits and methods of measuring the characteristics of data processing equipment relating to radiofrequency interference.

Standards

IEC Publications

Standards in the IEC 801-X series

Standards in the IEC 801-X series first appeared in the 1970's. They deal with the Electromagnetic Compatibility of industrial-process measurement and control equipment.

They are aimed at manufacturers and users of these types of equipment.

These standards are currently being superseded by standards in the IEC 1000-4-X series.

Standards in the IEC 1000-X-X series

IEC 1000-X-X Publications are devoted entirely to Electromagnetic Compatibility and have incorporated all IEC standards relating to this area since 1991.

Standards

Part	IEC	Current IEC Reference	Topic	EN/ENV equivalent	NF C Equivalent
General		IEC 1000-1-1 (1992)	Application and interpretation of fundamental definitions and terms.		
Environment		IEC 1000-2-1 (1990)	Electromagnetic environment for conducted low-frequency (LF) interference and the transmission of signals over public supply networks.		
		IEC 1000-2-2 (1990)	Compatibility levels for conducted low-frequency (LF) interference and the transmission of signals over low-voltage public supply networks.		
		IEC 1000-2-3 (1992)	Radiated phenomena and conducted phenomena at frequencies other than mains frequencies.		
		IEC 1000-2-4 (1994)	Compatibility levels in industrial installations for conducted low-frequency interference.		NF C 91-002-4 (1995-08)
		IEC 1000-2-5 (1995)	Classification of electromagnetic environments.		
Limits	555-2	IEC 1000-3-2(1995)	Limits for rated harmonic current < 16 A per phase emitted by appliances.	EN 61000-3-2 (1995)	NF C 91-003-2 (1995-08)
	555-3	IEC 1000-3-3 (1994)	Limitation of voltage fluctuations and flicker in low-voltage systems for equipment having a rated current ≤ 16 A.	EN 61000-3-3 (1995)	NF C 91-003-3 (1995-08)
		IEC 1000-3-5 (1994)	Limitation of voltage fluctuations and flicker in low-voltage systems for equipment having a rated current > 16 A.		
Test and measurement techniques	801-1	IEC 1000-4-1 (1992-12)	Overview of immunity tests. Basic (EMC) publication.	EN 61000-4 (1994-08)	NF EN 61000-4-1 NF C 91-004-1 (1995-01)
	801-2	IEC 1000-4-2 (1995-01)	Testing of immunity to electrostatic discharges. Basic (EMC) publication.	EN 61000-4-2 (not yet published)	NF C 91-004-2 (1995-06)

Standards

Part	IEC	Current IEC Reference	Topic	EN/ENV Equivalent	NF C Equivalent
Test and measurement techniques (continued)	801-3	IEC 1000-4-3 (1995-02)	Testing of immunity to radiated radiofrequency electromagnetic fields.	ENV 50140 (1993)	
	801-4	IEC 1000-4-4 (1995-01)	Testing of immunity to high-speed burst transients. Basic (EMC) publication.	EN 61000-4-4 (not yet published)	NF C 91-004-4(1995-06)
	801-5	IEC 1000-4-5 (1995-02)	Testing of immunity to impulse waves.	EN 61000-4-5 (not yet published)	NF C 91-004-5 (1995-06)
		pr IEC 1000-4-6	Immunity to conducted interference induced by radiofrequency fields.	ENV 50141 (1993)	
		IEC 1000-4-7 (1991-07)	Guidance on measurement of harmonics and interharmonics and measuring apparatus applicable to power supply systems and devices connected to them.	EN 61000-4-7 (1993-03)	NF EN 61000-4-7 NF C 91-004-7 (1993-06)
		IEC 1000-4-8 (1993-06)	Testing of immunity to mains-frequency magnetic fields. Basic (EMC) publication.	EN 61000-4-8 (1993-09)	NF EN 61000-4-8 NF C 91-004-8 (1994-02)
		IEC 1000-4-9 (1993-06)	Testing of immunity to impulsive magnetic fields. Basic (EMC) publication.	EN 61000-4-9 (1993-09)	NF EN 61000-4-9 NF C 91-004-9 (1994-02)
		IEC 1000-4-10 (1993-06)	Testing of immunity to damped oscillating magnetic fields. Basic (EMC) publication.	EN 61000-4-10 (1993-09)	NF EN 61000-4-10 NF C 91-004-10 (1994-02)
		IEC 1000-4-11 (1994-06)	Testing of immunity to voltage dips, brief power failures and voltage variations.	EN 61000-4-11 (1994-09)	NF EN 61000-4-11 NF C 91-004-11 (1995-01)
		pr IEC 1000-4-12	Testing of immunity to damped oscillating waves. Basic (EMC) publication.		
Installation recommendations		IEC 1000-5-1	General considerations		
		IEC 1000-5-2	Earthing and wiring		
		IEC 1000-5-3	External influences		

Standards

CENELEC Publications

EN or ENV ... Publications lay down the standards that are applicable throughout the European Free Trade Area (EFTA).

They are currently being harmonised with the (EMC) Directive.

They generally reproduce existing international standards.

Examples: EN 55011 restates CISPR 11

EN 61000-4-1 restates IEC 1000-4-1

Generic (European) standards

In the absence of specific standards for products or product families, these generic standards are applicable within the European Free Trade Area (EFTA).

They are harmonised at a European level.

Product or product family standards

These standards are applicable to the products or product families concerned.

They lay down the applicable requirements and test severity levels.

Within Europe, if they exist and are harmonised, they take precedence over generic or basic standards.

Example : EN 60947-1 A11

Low-voltage switchgear and controlgear (general), Amendment A11: Specific (EMC) details.

(EMC) facilities and tests

National standards

These are issued in France by the UTE.

The standards currently circulated in France generally restate European standards.

Example: NF EN 60947-1 A11 (France)
DIN EN 60947-1 A11 (Germany)

These standards supersede existing national standards that deal with the same topics.

Example : VDE 871, 875 ...

(EMC) facilities and tests

A distinction must be made between two types of tests that can be performed on a product by using appropriate means.

Type tests

These are tests that the manufacturer performs to obtain qualification approval of products before they are put on sale.

On-site tests

These are tests that are performed on the equipment that the product incorporates. They are performed under the customer’s responsibility and are intended to validate an installation, equipment or machine.

Test facilities

The facilities and arrangements for applying these tests are precisely described in the standards.

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