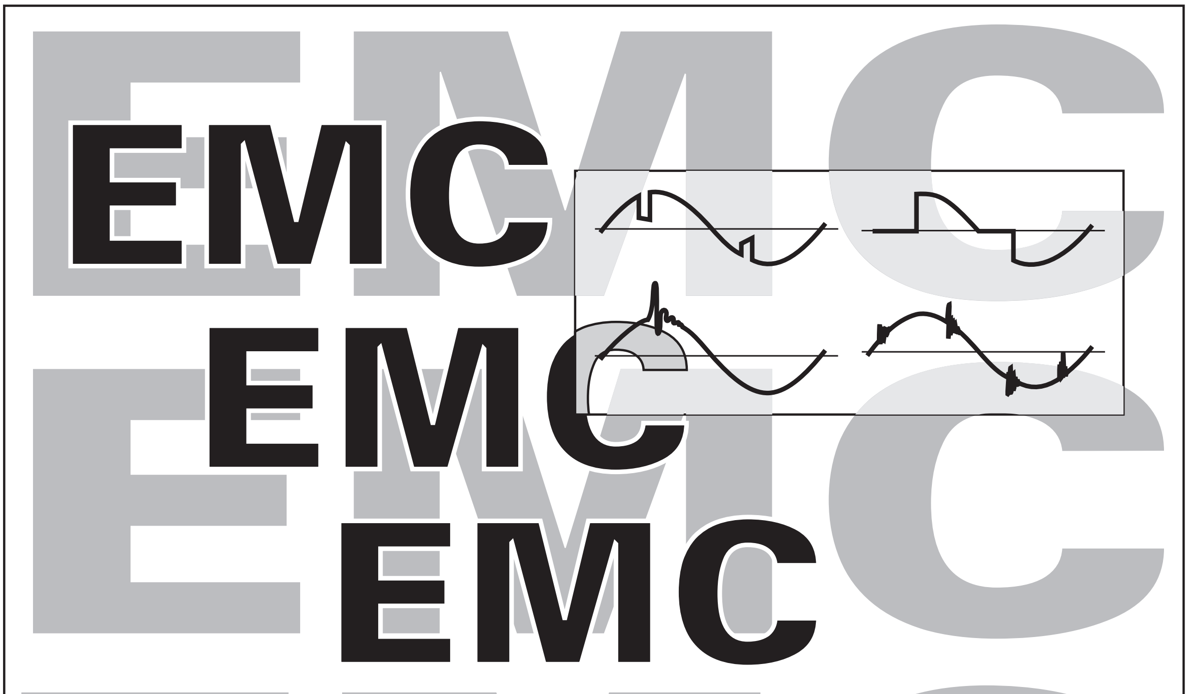
PMA Prozeß- und Maschinen-Automation GmbH

EMC

Electromagnetic compatibility, installation notes



General information

9499-047-09111

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A publication of

PMA Prozeß- und Maschinen-Automation GmbH
P.O.Box 310 229
D-34058 Kassel
Germany

1 EMV terms and signification

Due to the widespread use of electrical and electronic instruments, high packing density of components on the circuit boards and high speeds of digital components, the effects of electromagnetic fields are increasingly important and must not be neglected any more. Unless this fact is taken into account, there can be problems due to electromagnetic interference inside an instrument or as a mutual interference between instruments. In 1989, the European Commission has therefore prepared a guideline which requires that all electrical and electronic instruments must meet conditions (from 1992) which ensure interference-free operation. The requirements for interference-free operation are classified under the term of EMC (electromagnetic compatibility). According to VDE 0100, EMC is defined as follows:

> Electromagnetic compatibility is the capability of an electrical facility to operate ***satisfactorily*** in its ***electromagnetic environment,*** without ***causing itself electromagnetic interference***, which would be unacceptable for other instruments installed in this environment.

Electromagnetic environment: all technical facilities related with electricity or magnetism. *Satisfactory:* the unit is not susceptible to electromagnetic (EM) signals, which are emitted into the environment by other instruments. *Without causing itself inadmissible interference:* the instrument does not affect other units, i.e. the EM signals emitted by the instruments do not cause EM effect problems in other units.

The aim of EMC measures ist to ensure trouble-free operation of all systems involved in a project. Measures for achievement of EMC consist in the reduction of electromagnetic emission at the interference source and in the reduction of propagation by coupling into leads.

2 Which interferences can occur?

Possible interference sources are:

- ❑ stationary interference sources, continuous interference sources
- ❑ transient interference sources, discontinuous interference sources

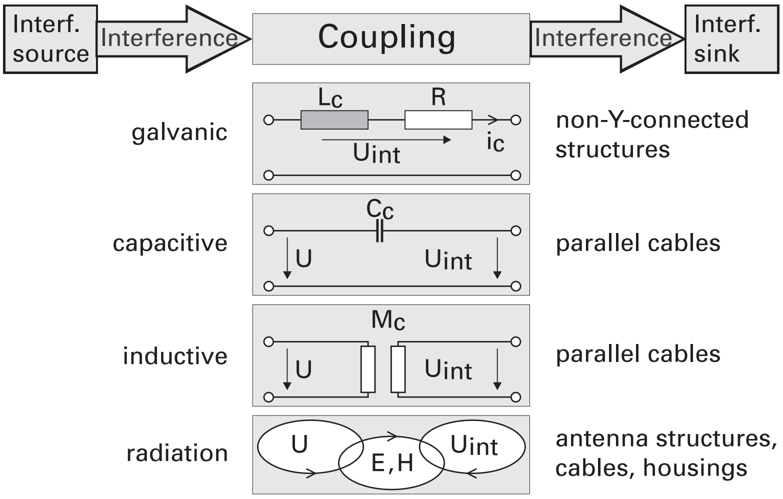
Interference sources which occur in practical operation are e.g. steep signal flanks with thyristor control systems, high or inductive load switch-on or off, switch and sensor settling, resonant circuits, rectifiers, sparking of brushes and commutation sags with drives, switching power supplies, etc.

The potential interferences are simulated by measurable signals and suitable test set-ups during EMC testing according to EN 50 081-1 for residential areas and EN 50 082-2 for industrial areas.

Interference type	**Test standard**		**Test data**
Electro static load of operators, dis-charge via the operating front panel	EN61000-4-2 (IEC801-2)	Electrostatic discharge	8 kV air discharge 4 kV contact discharge
Sparks at contacts when switching inductive loads	EN61000-4-4 (IEC801-4)	Fast transients (burst)	2 kV on power supply and signal leads
High-energy pulses, coupled inductively / capacitively with incorrect cable run	EN61000-4-5 (IEC801-5)	High-energy single pulse (surge)	1 kV symmetrical, 2 kV asymme-trical on power supply leads 0,5 kV symmetrical, 1 kV asym-metrical on signal leads
Magnetic fields (instruments are mounted in stray fields of transformers or contactors)	EN61000-4-8 (IEC1000-4-8)	Low-frequency magnetic field	50 Hz, 30 A/m
High-frequency radiation by high-frequency interference sources, e.g. emitters, HF welding facilities or measuring facilities with HF transmission paths	EN61000-4-6 (IEC801-6)	RF interference on leads ENV 50 141	0,15..80MHz, 10V
	EN61000-4-3 (IEC801-3)	Electromagnetic RF field ENV 50 140	80 ... 1000 MHz, 10V/m

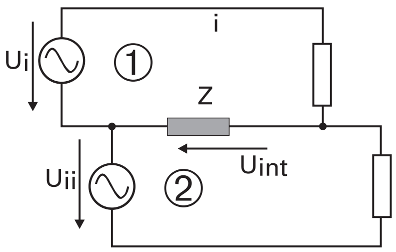
3 Interference propagation and coupling of interference sources

- ❑ galvanic coupling, on leads
- ❑ capacitive coupling
- ❑ inductive coupling
- ❑ irradiation or radiation
- ❑ mutual affect of instruments

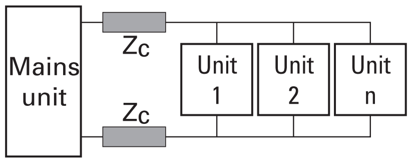


3.1 Galvanic coupling

Galvanic coupling will always occur, when two circuits (① ②) have a common impedance Z.



Coupling of operating circuits.
Galvanic coupling can be due also to coupling of operating circuits.

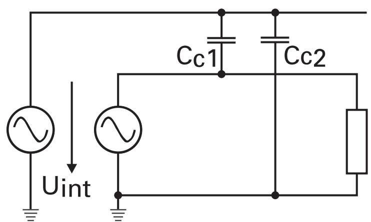


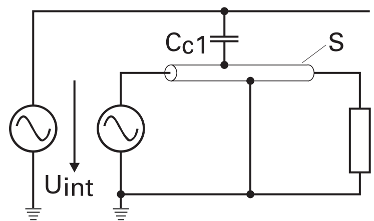
Counter-measures with galvanic coupling are:

- no common return wire for different circuits
- EMC-compliant earthing/grounding concept (Y-connected, flat)
- Use of interference suppression capacitors, chokes, filters

3.2 Capacitive coupling

Capacitive coupling occurs between two circuits, the conductors of which are on different potentials.





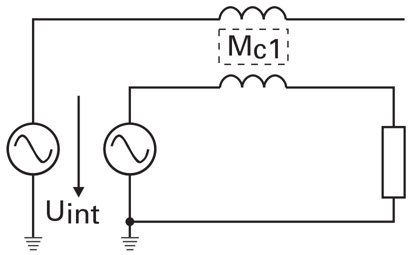
By **screening** (S), direct grounding of capacitively coupled interference is provided.

Counter-measures with capacitive coupling are:

- keeping sections with parallel leads short
- increasing the distance of leads (min. distance of 15 to 20 cm between power cables and measurement input leads)
- reducing coupling capacitances (increased distances)
- installing cables closely upon ground
- terminating disturbed circuits with low impedances
- using screened cables

3.3 Inductive coupling

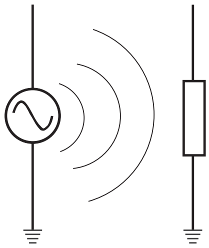
Inductive coupling occurs between two or several current-carrying conductor loops.



Counter-measures with inductive coupling are:

- reducing the loop surface
- increasing the distance between conductor loops
- using screened cables
- using twisted cable pairs (smaller surface, compensation by oppositely-directed coupling of adjacent loops)
- avoiding high rates of current increase

3.4 Radiation coupling



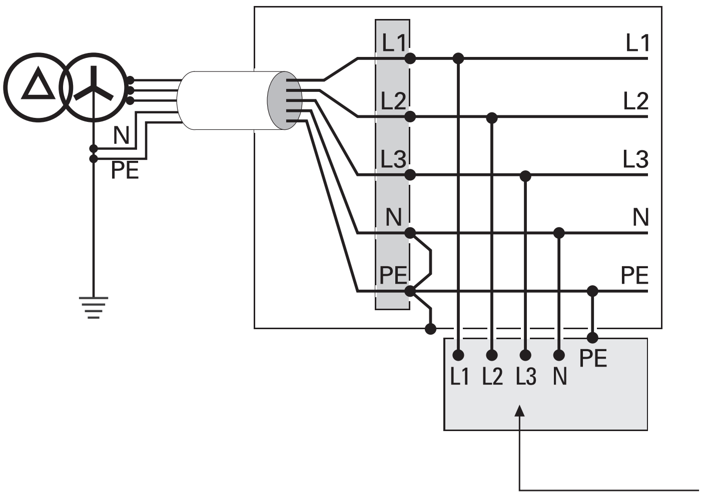
With **radiation coupling**, electric and magnetic field occur simultaneously and are interconnected via the wave resistance of the free space.

Counter-measures with radiation coupling are:

- instrument construction providing inherent protection against RF interference
- screening (note shielding efficiency of various materials)
- reducing the lead lengths (as short as possible and as long as necessary)

4 Earthing, grounding and potential compensation

Cable entry into cabinet



loads

The electrical safety requires low resistance against earth with mains frequency and EMC requires low impedance also in the high frequency range. Basically, these requirements do not contradict each other, i.e. different earthings for safety and EMC are not necessary:
A low-resistance and large-surface earth connection is sufficient. Today, industrial electrical installations are designed preferably according to the principles of a TN-S system (VDE 0100). The advantage is that neutral wire (N) and protective earth (PE) are separate in the overall system. This design prevents current flow due to operation through the protective earth. Consequently, the system provides better electromagnetic compatibility than other systems.

4.1 Control cabinet repartition

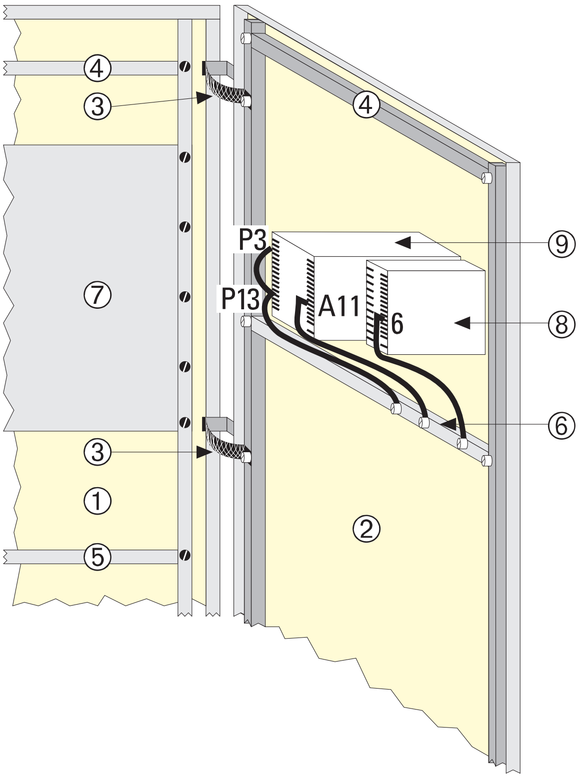
To ensure high interference suppression in the control cabinet, the following rules should always be taken into account:

- Formation of areas with different interference levels
- Mutual screening of areas
- Creation of separate reference potential systems
- Analog section, digital section, power section

Formation of areas with different interference levels

Susceptible area Units susceptible to interference with low signal-to-noise ratio	**Area of interference sources** Units with high interference radiation
PLCs	Control cabinet transformers
Electronic modules	Switching power supplies
Control instrumentation	R.p.m. control systems
Connecting cables of these units, especially inputs and outputs	Contactors, power switches and other correcting elements
Cables for analog signal transmission	Frequency converters
Measuring inputs	Power supply cables
Data cables (bus cables)	Power cables general

Creation of separate reference potential systems



Load current free connections between the ground potentials must be realized so that they are suitable both for the low-frequency range (safety of persons, etc.) and the high-frequency range (good EMC values).

The connections must be made with low impedance. All metal grounds of the components installed in the cabinet ① or in the cabinet door ② must be screwed directly to the sheet-metal grounding plate to ensure good and durable contact. In particular, this applies to earthing rails ④, protective earth rail ⑤, mounting plates for switching units ⑦ and door earthing strips ⑥. Controllers KS40/50/90 ⑧ and KS92/94 ⑨ are shown as an example for earthing. The max. length of connections is 20 cm (see relevant operating instructions).

Generally, the yellow/green protective earth is too long to provide a high-quality ground connection for high-frequency interferences.

Braided copper cables ③ provide a high frequency conducting, low-resistance ground connection, especially for connecting cabinet ① and cabinet door ②.

Because of the skin effect, the surface rather than the cross section is decisive for low impedance. All connections must have large surfaces and good contact. Any lacquer on the connecting surfaces must be removed.

Due to better HF properties, zinc-plated mounting plates and compartment walls are more suitable for large-surface grounding than chromated mounting plates.

4.2 Instrument layout

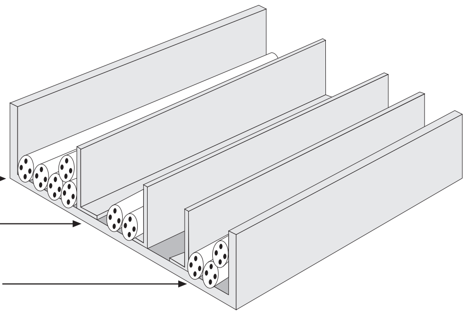
The instruments shall be arranged so that they are not located within the stray fields of high-energy loads (e.g. transformers). In many cases, installation at a sufficient distance from the interference source is helpful. If this is not possible, separation by sheet-metal plates with good contact to reference potential or mounting plate can be necessary.

4.3 Cable run

For selection and application of measures for EMC-compliant cable run, the potential coupling paths must be taken into account. For this purpose, important information is given under "Counter-measures" in sections 3.1 to 3.4. Further important rules for EMC-compliant cabling are:

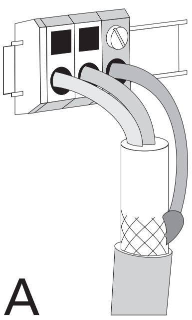
- Cable classification into
  Measuring cables: e.g. thermocouples, Pt100, general measuring inputs
  Control cables: cables for contactors, solid-state relays (SSR), alarm signalling facilities
  Power cables: power supply of the load
  sources of high interference: frequency converter, motor, r.p.m. controller cables
  sources of low interference: analog signal leads,
  transmitter d.c. supply.

  Example for repartition of a cable duct



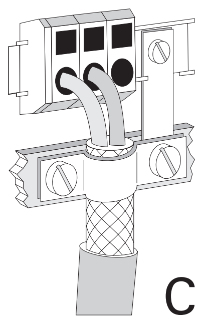
- Power supply cables should always have several conductors and the return wire of a circuit should be in the same cable. Single wire cables should be kept in bundles, with the return wire at the closest possible distance.
- Unscreened flat cables must be mounted at close distance to the metal housing or the metal frame.
- With flat cables, a ground wire should be installed between the signal leads, if possible.
- At least one end of the screenings must be connected. Always ground the screening end at which the connection of the reference potential of the connected electronics to earth/ground is of lower impedance.
- If both screening ends must be connected, installations with far distances between components imply a risk of potential compensating current flow. In such a case, the other ground connections should be provided via coupling capacitors (approx. 100 nF), to permit high-frequency coupling. In this case, the 50 Hz component is not transmitted.
- An improved screening effect can be achieved by grounding both ends of unused cable conductors.

4.4 Screening



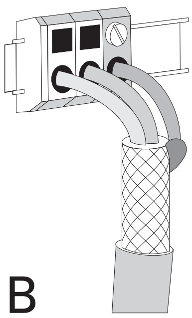
Version A

The lead between screening and potential compensating rail is too long. The impedance is too high, and high-frequency interference is not grounded safely.



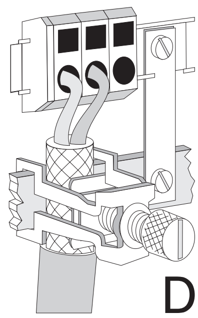
Version C

Largely dimensioned connection to the potential compensating rail. Min. 70% safe contact between screening and ground surface is required to ensure low impedance for high-frequency interference.



Version B

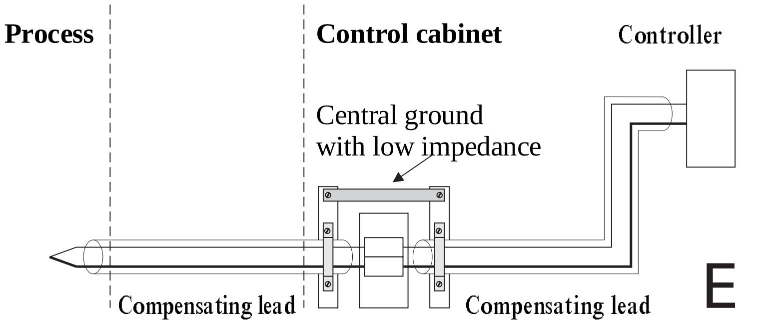
If the lead between screening and potential compensating rail is shorter than 30 mm, the screening effect is mostly sufficient. In practice, however, this version is difficult to handle and should be used only in difficult cases.

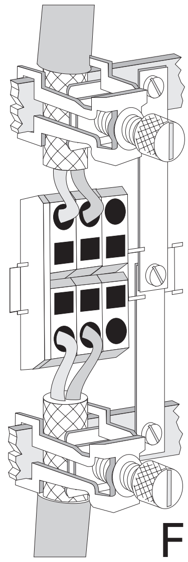


Version D

When using screening clamps with common rail (e.g. 10 x 3 mm), the impedances are very low:
0,001 Ω (30 kHz), 0,01 Ω (100 kHz), 0,03 Ω (1 MHz), 0,3 Ω (10 MHz).

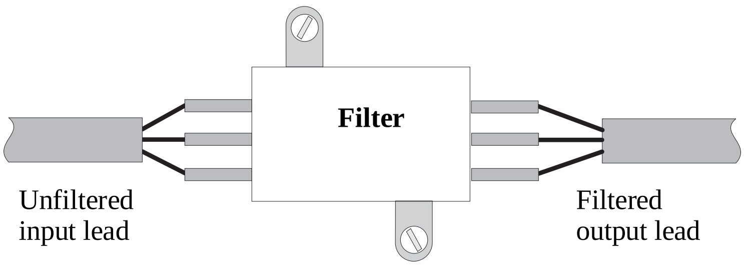
Versions E and F for cable entry with screened thermocouple lead





The thermocouple point may be grounded, if the measuring input is galvanically isolated. If the process end of the thermocouple screening must be earthed for technical reasons, compensating current flow via the screening is not permissible. If required, an additional earth connection between the two points must be provided. Versions E and F show cable collars or screening clamps.

4.5 Interference suppression filters



Interference suppression filters are used for removal of high-frequency common or series mode interference. The easiest solution are ferrite rings slipped over the conductors. Since common mode interference is taken to the filter housing via Y-capacitors, low-impedance grounding is required.

Do not lay input cables next to output cables, in order to prevent coupling between the unfiltered input lead and the filtered output lead. The filter should be fitted as closely as possible to the cable entry gland.

5 Wiring of PMA instruments with measurement earth connection

Load, control and measuring leads must be kept in separate runs. The sensor inputs, such as leads of thermocouples, Pt100, etc. are sensitive leads and must be installed separately. They must not be included in the same cable duct with mains supply and power cables. We recommend twisted and screened measuring leads. If screening is provided, it must be connected to the central ground with low impedance. Only one end of the screening may be grounded.

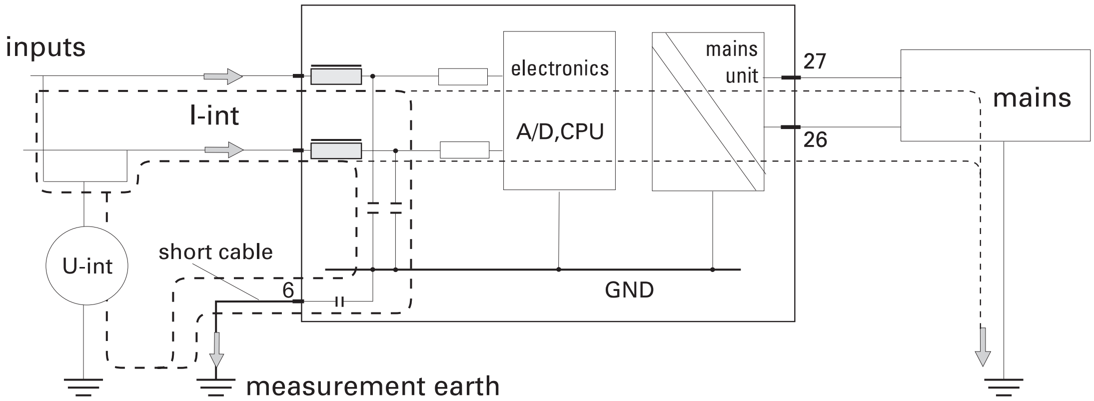
Never connect the screening to the instrument measurement earth.

In principle, the measurement earth of PMA units provides additional input filtering. High-frequency interference on input leads is grounded directly and does not cause interference inside the unit. However, filtering is effective only with low-impedance connection of the measurement earth to the central ground. The lead between the measurement earth connection and central ground must be kept separate from power supply, control and measuring leads and its **max. permissible length is 20 cm** (see also "Creation of separate reference potential systems" in section 4.1). If a unit is installed in a control cabinet door, the measurement earth connection can be connected with an earth rail installed directly at the door.

Connected actuators, e.g. contactors, relays, motors etc. must be provided with protective circuitry according to specification of the actuator manufacturer. This is a prerequisite for avoiding high voltage peaks which can cause trouble to the instrument.

5.1 KS40 / KS50 / KS90 connection

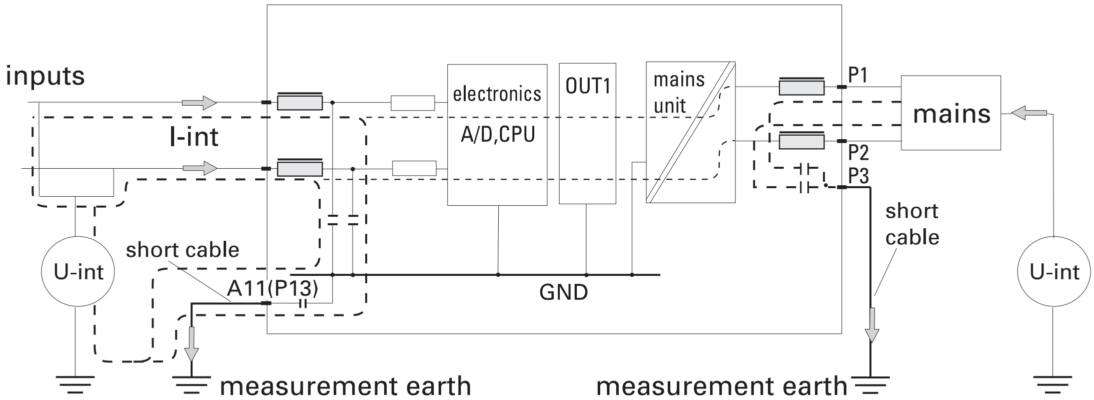
On these instruments, interferences at the input are grounded via the measurement earth connection (6).



5.2 KS92 / KS 94 / KS98 connection

On these instruments, the supply voltage is provided with an additional filter. This connection (P 3) must be handled like the measurement earth (A11, P13). All two (A11, P3) or three (A11, P3, P13) connections must be connected to the earthing point with low impedance.

On versions with 4 output relays, connection P13 must not be grounded.



5.3 Checking in case of trouble

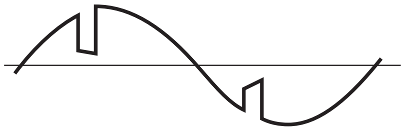
Check	yes / no
How frequently and at which occasion does the fault occur?	
Is the fault reproducible?	
Check the instrument connection	
Are all wires and connectors fitted firmly?	
Are the measuring input leads separate from the control leads?	
Are power supply and data cables installed in the same cable harness?	
Is the distance between measuring input, power and control cables > 15cm?	
Are actuators fitted with protective circuits according to manufacturer specifications? (e.g. with varistor, RC protective circuits)	
Is low-impedance earthing or grounding ensured? (Is braided copper cable used?)	
Are the individual earth potentials connected by means of braided copper cables?	
Are unused leads grounded?	
Was screening used for measuring inputs?	
Is a large-surface ground connection provided for the screening?	
Is the measurement earth connected to the low-impedance ground by means of a short cable (max. 20cm)?	

6 In-depth explanations

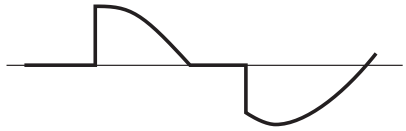
6.1 Pulse-shaped interference signals

In the technical language, pulse-shaped interference signals are frequently classified under the term of ”transients”. The most important sources of pulse-shaped interference signals are switching of inductive loads and discharge of electrostatic charges of persons and objects.

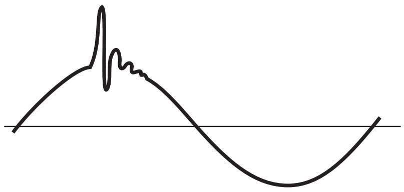
Typical interference pulses on a 230V supply



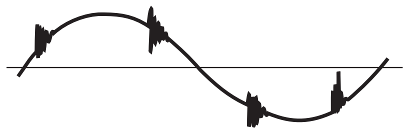
Commutation sags



Phase-clipping control



Transients

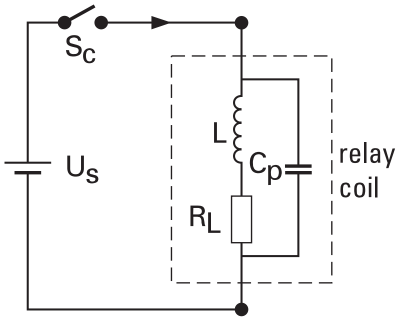


Bursts

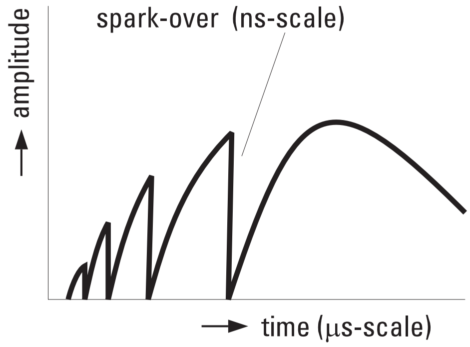
Inductive load switching generates spikes with a duration of 0,1 to 10 µs. The duration of the overall pulse is within 1 and 10 ms. These interference pulses are highly important for units connected to the 230 V supply (e.g. switching of motors, contactors, etc.).

A solid-state relay (SSR) is frequently used as a link between sensitive logic circuits and power loads. With most SSR used today, load circuit and control circuit are galvanically isolated. The load is switched on when the supply voltage passes through zero and switched off when the current passes through zero. Consequently, solid-state relays mostly do not have an interference effect on the logic, if provided in a suitable circuit. Nevertheless, there can be problems due to a low coupling capacitance within 1 and several pF between load circuit and control circuit. Despite this low capacitance, experience shows that there are voltage peaks with gradients up to 1 kV / 100 ns in industrial networks. With these steep pulse flanks, the logic is subjected to stray interference via the above-mentioned coupling capacitance, which cause logic status changes and considerable disturbance of the program sequence.

6.2 Occurrence of induction voltage



a



b

a Current interruption with an inductive load

b Schematic diagram of repeated spark-over

When switching inductive components (e.g. a contactor coil), a pulse is likely to be produced mainly during switch-off. The related current change produces a high voltage by means of self-induction. The max. possible voltage can be determined according to the energy preservation law:

$$\frac{1}{2}(L \cdot I^2) = \frac{1}{2} C_p U^2$$

whereby L is the self-induction and Cp is the parasitic capacitance of the coil.

With L = 0,1 H, I = 1 A and Cp = 100 pF, U can increase up to 32 kV when opening the switch.

In practice, such a value is never reached, because there is a spark-over at the contacts previously (arc or spark), i.e. the current flow continues. As the contact distance increases, spark-over will stop and the voltage continues increasing, until another spark-over occurs, etc. Therefore, switch opening causes a relatively high number of short pulses. During EMC testing, this behaviour is checked as burst. Switching interference is not only bound to leads, but can also occur as radiation. Due to (field) radiation, switching interference is also induced into signal and measuring leads.

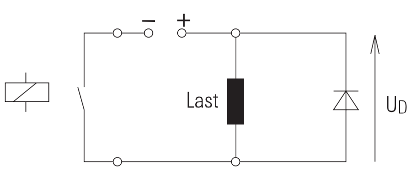
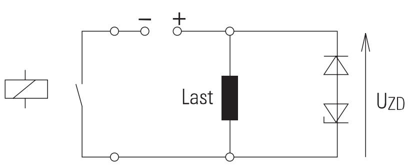
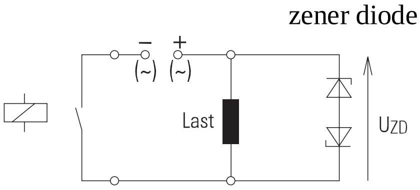
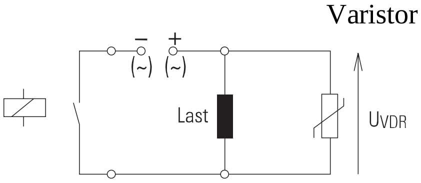
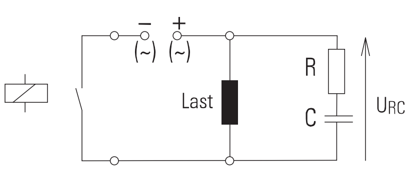
There are two important reasons why switching interference should be avoided:

1. Sparks at the switch must be prevented to protect the contact lifetime (the switch is usually the contact in the instrument), .
2. Since the effects are unpredictable, uncontrolled radiation on measuring or control cables must be prevented.

6.3 How to prevent switching interference?

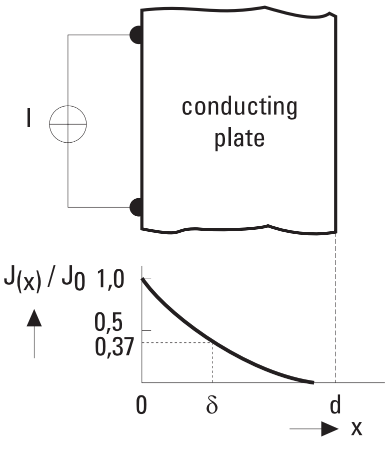
The switching interference must be reduced at the point where the switch-off energy occurs, in order to prevent it from being spread into the overall installation. A practically proven solution consists in providing protective circuits directly at the inductive load. Interference suppression circuitry from the contactor manufacturers or of other specialized companies must be used. However, the protective circuitry should always be matched to the switching element.

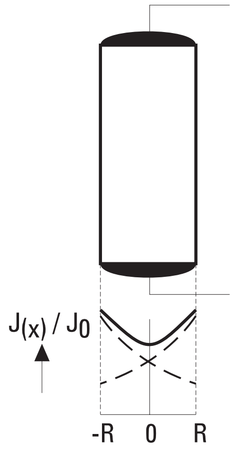
Protective circuit examples for inductive loads

Circuitry	additional switch-off delay	defined limiting of induction voltage	bipolar attenuation	Advantages (+) / disadvantages (-)
Diode 	large	yes (U_D)	no	+ easy realization + low cost + reliable + uncritical dimensioning + low induction voltage - only for d.c. voltage - long switch-off delay
Diode + zener diode 	medium to small	yes (U_{ZD})	no	+ uncritical dimensioning + reliable - attenuation only above U_{ZD}
zener diode 	medium to small	yes (UZD)	yes	+ low cost + uncritical dimensioning + positive peak limiting + suitable for a.c. voltage - attenuation only above U_{ZD}
Varistor 	medium to low	yes (U_{VDR})	yes	+ high energy absorption + uncritical dimensioning + suitable for a.c. voltage - attenuation only above U_{VDR} - limited lifetime
R/C protective circuitry 	medium to low	no	yes	+ HF attenuation due to energy storage + suitable for a.c. voltage + level-independent attenuation - exact dimensioning required - limited lifetime

6.4 The skin effect

When d.c. current flows through a conductor, the current density is equal over the whole cross-section of the conductor at some distance from the connecting points at the source. A.c. current, however, generates induction voltages in the conductor which cause the charge carriers to be pushed towards the conductor surface (skin). Therefore, this effect is called skin effect (Sander and Reed, 1978). The current density, which has now stopped being equal over the whole cross-section, behaves according to an exponential function (see figure a,b).





With a current density Jo at the surface, the following formula is valid for current density J(x) at a depth x:

$$J(x) = J_o\, e^{-x/\delta}$$

whereby δ is the skin depth, which is determined by: $\delta = \sqrt{\dfrac{2}{\omega\sigma\mu}}$

In the equation, $\omega = 2\pi f$, whereby f is the frequency of the a.c. current, σ is the conductivity and μ is the permeability of the conductor.

6.5 Self-induction

For a long conductor with **round cross-section** in the free space (Meinke and Gundlach, 1968), L can be specified by the following expression:

$$L = \frac{\mu\, l}{2\pi}\left[\ln\left(\frac{4\, l}{d}\right) - 1\right] = (H) \qquad \mu = \mu_r \cdot \mu_o \quad \rightarrow \quad \mu_o = 4\pi \cdot 10^{-7}\ \mathrm{H/m}$$

whereby l is the conductor length, d the conductor diameter, and $\delta \ll d$ (δ = skin depth or penetration depth). In this case, a "long conductor" means that the conductor is much longer than its diameter (e.g. 100 times as long), and "free space" means that there is no other circuit with a perceivable interaction in the sourrounding of the circuit.

Under the same conditions, the following formula is applicable to a conductor with **rectangular cross section** (with width b, thickness t) according to Meinke and Gundlach, 1968:

$$L = \frac{\mu\, l}{2\pi}\left[\ln\left(\frac{2\, l}{b+t}\right) + \frac{1}{2} + 0{,}22\ \frac{b+t}{l}\right] = (H)$$

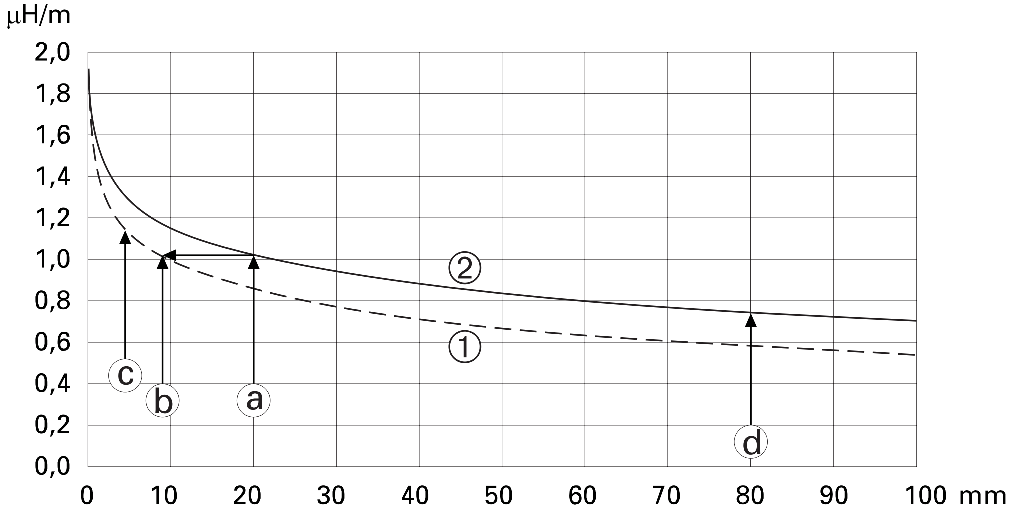
Note that self-induction always belongs to a closed circuit and that the formulas always imply that the circuit configuration is equal, i.e. that L is distributed equally over the circuit.

Consequently, equal L values per length unit are always found. This leads to a useful thumbrule:

The contribution of a conductor to self-induction is 1 μH/m (or 1 nH/mm).

With a conductor length of 1 m and a frequency of 27 MHz, ωL = 170 Ω, a value which is much higher than R_{DC} (ohmic resistance) or R_{AC} (a.c. resistance) is determined by using the thumbrule. Whether the resistance value of the earth conductor is lower than 1 Ω according to the safety standards (VDE 0100) is therefore mostly unimportant for problems with electromagnetic effect. With frequencies above 50 Hz, the problem is almost always determined by the external self-induction.

Consideration of the skin effect shows that a large surface may be more important than a large volume (thick conductor) for a conductor, because the most important part of the current flows in a thin layer of the conductor. A large surface is also an advantage for the external self-induction, because it reduces the value of L. In practice, a large surface is mostly more easy to realize with a strip (tape) than with a wire.



The diagram shows the self-induction per meter (µH/m) of a tape (film, ②) of 0,2 mm thickness and width in mm as well as the self-induction per meter (µH/m) of round wire ① with the diameter in mm.

Example 1:
A 20 mm wide tape has an inductance of 1,02 µH (a). The diameter of a wire with the same inductance is 9 mm (b). The wire cross section is 64 mm^2, however, the cross section of the tape is only 4 mm^2. This shows that a wire will quickly become unhandy, if the impedance shall be low.

Example 2:
A protective wire cross section of 16 mm^2 is required (according to VDE). For a round wire, the diameter is 4,5 mm and the inductance is 1,15 µH/m (c), i.e. 0,23 µH for a 20 cm long ground wire. With a presumable interference frequency of 27 MHz, the resistance R_{AC} of the ground wire is calculated by $\omega L = 39\ \Omega$.

If a tape of 80 x 0,2 mm is used instead (16 mm^2), the inductance is 0,75 µH/m (d) or 0,15 µH with a length of 20 cm, and the resistance R_{AC} of the ground tape is $\omega L = 26\ \Omega$. I.e., the a.c. resistance is lower by 13 Ω. With higher frequencies, the difference is even clearer: with 100 MHz, the resistance is 144 Ω for the ground wire and 85 Ω for the ground tape.

7 Literature

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Elektromagnetische Verträglichkeit	Analyse und Behebung von Störproblemen	Jasper J. Goedbloed

Notes

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P.O.Box 310 229, D-34 058 Kassel, Germany
Printed in Germany 9499-047-09111 (9910)c

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