Drive Technology \ Drive Automation \ System Integration \ Services

Drive Engineering – Practical Implementation

EMC in Drive Engineering
- Theoretical Principles
- EMC-Compliant Installation in Practice

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Contents

1 Basic Theoretical Principles

Electromagnetic compatibility (EMC) denotes the capability to operate several electrical and electronic components together and next to each other within a certain environment without any interference.

In this volume of the series "Drive Engineering - Practical Implementation", SEW-EURODRIVE offers special information on the subject of "EMC in Drive Engineering".

The main topics are:

- Basic theoretical principles
  - Causes of EMC problems
  - Implementation and effectiveness of EMC measures
- EMC-compliant installation in practice
  - Planning EMC-compliant systems
  - Useful information for optimizing EMC

This volume is based on practical situations and experience. The information gives general guidelines. Because of the wide variations between different installations, absolute guidelines for individual cases cannot be given.

For exact project planning details of SEW-EURODRIVE products, please refer to the respective catalogs.

1.1 Coupling factors

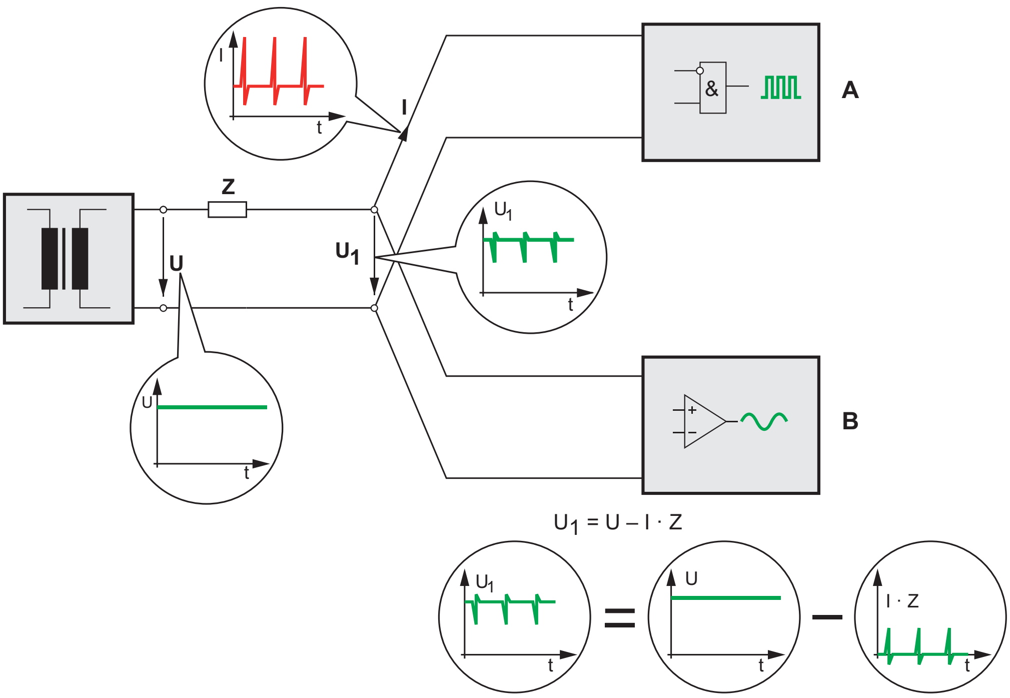
This chapter describes how interference is transmitted from the source to susceptible equipment. Coupling is divided into 4 coupling mechanisms:

- Galvanic coupling
- Inductive coupling
- Capacitive coupling
- Radiative coupling

1.1.1 Galvanic coupling

Galvanic coupling occurs when several circuits share voltage sources, PCB tracks, conductors, or similar.

The following figure shows the basic principle:



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The current in circuit A (digital circuit) causes a voltage drop in the common impedance Z. This voltage drop causes a dip in the supply voltage in circuit B (analog circuit). The voltage drop increases with increased current and increased common coupling impedance Z.

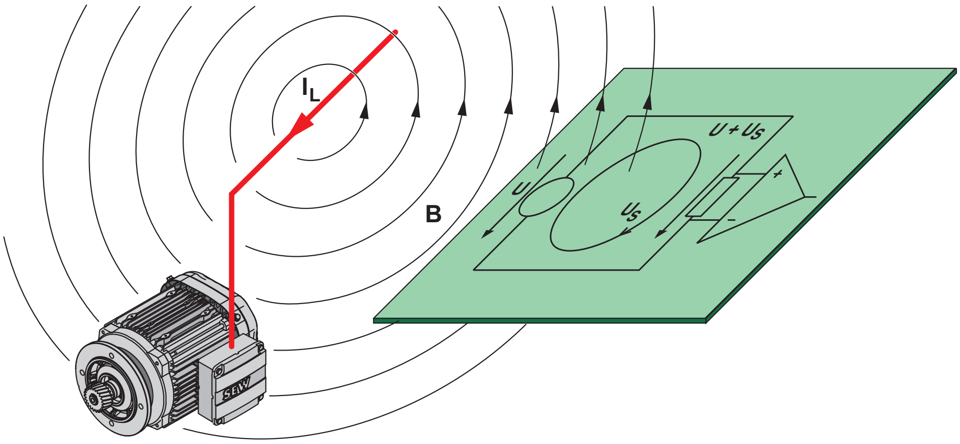
The galvanic coupling between two circuits can be reduced by the following measures:

- Separate supplies for power circuits and low-level signal circuits
- Star connection to reduce the coupling impedance Z

  For higher frequencies, the impedance of the supply cable mainly depends on its length. This is why the star point should be as close to the voltage source as possible.

1.1.2 Inductive coupling

The following figure shows inductive coupling between a motor cable and the control circuit on a PCB:



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I_L Current in the motor cable
B Magnetic field
U_S Interference voltage

A magnetic field B builds up around every conductor carrying a current, this field being proportional to the current I_L in the conductor.

If this magnetic field passes through a conductor loop perpendicular to it, it induces a voltage in this loop (transformer principle). The voltage is proportional to the area of the loop and the change in the magnetic field. This means that an interference voltage will only be induced if the current intensity in the load circuit changes (alternating current or switched direct current). A constant direct current does not cause an interference voltage.

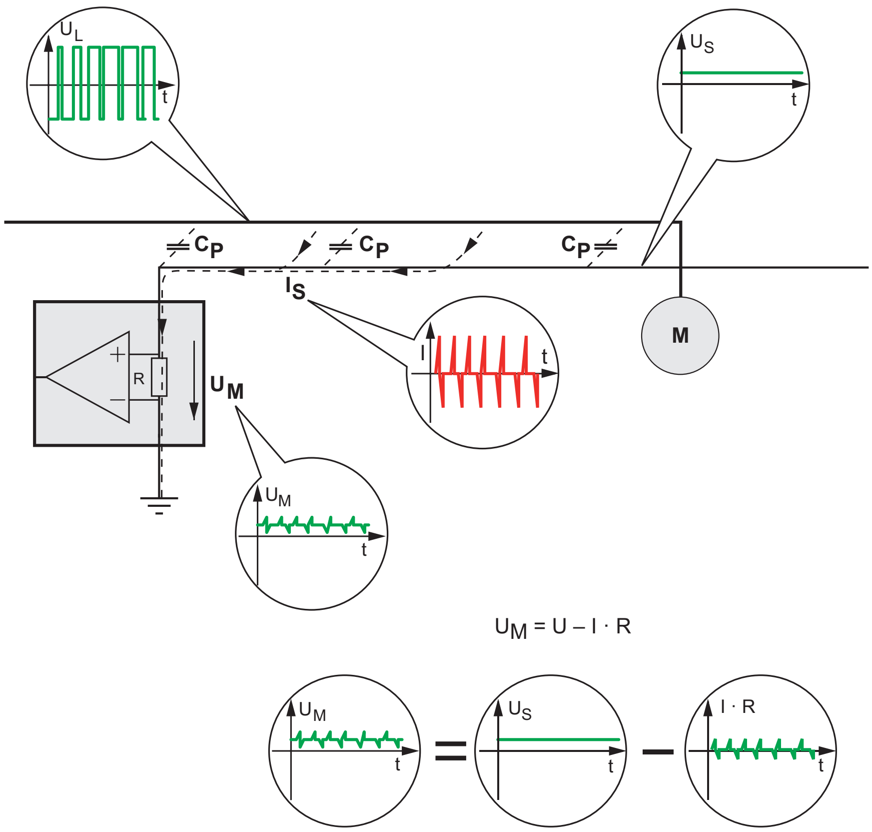
The interference voltage is affected by the following factors:

- **Distance:** The interference voltage is reduced with increased spacing between load circuit and the circuit affected by the interference.
- **Orientation:** If the conductor loop is parallel to the magnetic field lines, no interference voltage will be induced. The maximum interference voltage occurs when the loop and magnetic field lines are at right angles.
- **Frequency:** The interference voltage increases with increasing frequency in the load circuit.
- **Area of the conductor loop:** The interference voltage is proportional to the area of the conductor loop.

Interference voltages may occur if the conductor loop moves within the magnetic field (dynamo principle), e.g. because of vibration.

1.1.3 Capacitive coupling

The following figure shows an example of capacitive coupling between a pulsed power conductor and a signal conductor:



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Two neighboring conductors have a parasitic capacitance. If the voltage in one conductor changes, an interference current I_S flows via the parasitic capacitance C_P to the neighboring conductor and causes an interference voltage in the measuring resistance.

The interference current is proportional to the parasitic capacitance C_P and to the change rate of the voltage U.

The following factors influence the interference current:

- **Input resistance R:** The greater the input resistance, the greater the interference voltage that is caused by the interference current.
- **Spacing of the conductors:** The greater the spacing, the smaller the parasitic capacitance and the smaller the interference current. The parasitic capacitance increases with smaller conductor spacing and with the length over which the conductors lie in parallel to each other.
- **Amplitude of the interference voltage:** The interference current increases with increasing voltage amplitude in the interference-source cable.
- **Steepness of the edge of the interference voltage** (rate of change): The interference current increases with increasing steepness of the interference voltage edge.

1.1.4 Radiative coupling

Interference in a conductor can also be transmitted to a circuit by electromagnetic radiation. The conductors and circuits act as transmitting and receiving antennas for the electrical or magnetic component of the field.

Signals are radiated in an increasing amount at higher frequencies and propagate through space in the form of a wave. The higher the frequency of the produced signal, the smaller the volume expansion of this wave (wavelength λ). There is the following relationship between the wavelength λ and the signal frequency f:

$\lambda = c / f$

λ	Wavelength
f	Signal frequency
c	Speed of light in a vacuum (c = 299 792 458 m/s)

It is known from radio technology that optimum radiation is achieved with an antenna (dipole) with a length of 1/4 λ. However, from a length of 1/10 λ, a conductor can already emit a measurable amount of radiation and signal components.

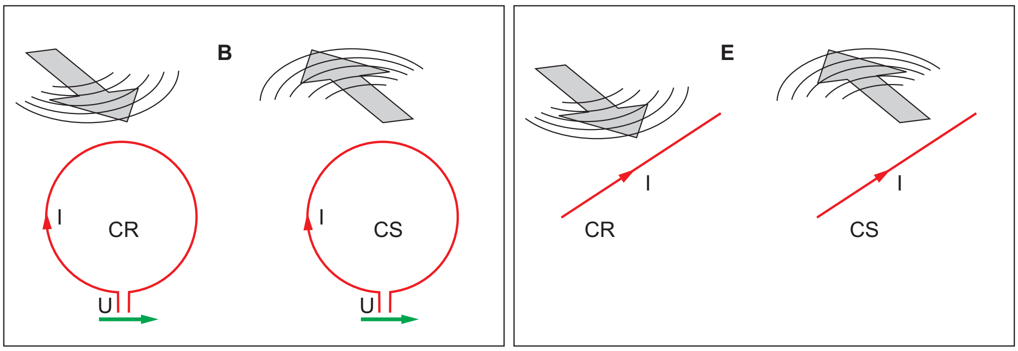
The table on the right shows that in the high-frequency range, which is used more and more often, even small spatial structures respond to the electromagnetic field and can become transmitting or receiving antennas.

Frequency:	**Wavelength:**[1)]
50 Hz	6000 km
100 Hz	3000 km
1 kHz	300 km
10 kHz	30 km
1 MHz	300 m
100 MHz	3 m
1 GHz	30 cm

1) Values are rounded.

There are basically two types of antenna:

Magnetic dipole (Ring-shaped configuration) — Electric dipole (Linear configuration)



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B	Magnetic field	CR	Conductor / receiving antenna
E	Electric field	CS	Conductor / transmitting antenna

Ring-shaped configurations, such as cable loops, respond to and generate magnetic field components.

Linear configurations, e.g. cables connected to a frequency inverter, respond to and generate electric field components.

1.2 HF behavior of a conductor

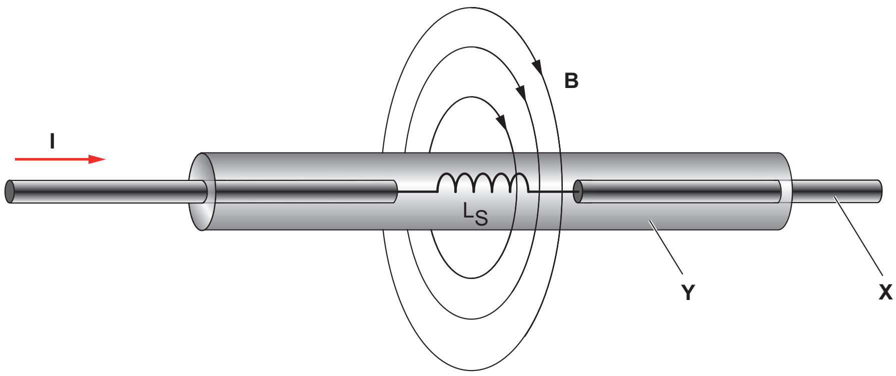
To understand the interference that occurs, it is important to investigate the behavior of certain components. These components can respond differently in low frequency (LF) and high frequency (HF) ranges.

This chapter shows the main differences between the low frequency and high frequency range in the frequency behavior of a conductor. The frequency-dependent resistance, referred to as the impedance of the conductor, is examined.

1.2.1 Conductor inductance

When a current flows through a conductor, a magnetic field forms around it that stores energy. When the current changes, energy must be supplied to this magnetic field or drawn off from it. This manifests itself as a resistance against the change in current. This resistance is called conductor inductance.

The following figure shows a current-carrying conductor with its magnetic field.



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I	Current
B	Magnetic field
L_S	Conductor inductance
X	Conductor
Y	Insulation

Conclusion

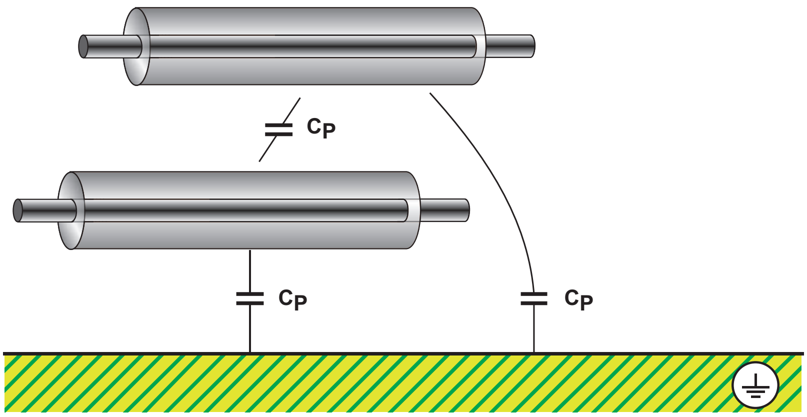
The conductor inductance increases with the conductor length and depends on the type and wiring of the conductor.

1.2.2 Conductor capacitance

When a voltage is applied between the conductors or between each conductor and earth, an electric field forms that stores energy. When this voltage changes, energy is supplied to this electric field or drawn off from it. This manifests itself as a resistance against the change in voltage. This resistance is called conductor capacitance.

When operating a conductor with changing voltage, current flows via the insulation to other conductors in the vicinity due to conductor capacitance. When these recharge currents flow towards earth, they are called leakage currents.

The following figure shows 2 parallel conductors:



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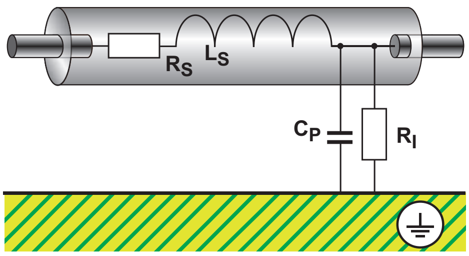
Conclusion

The conductor capacitance increases with increasing conductor length and with decreasing spacing between the conductors. It depends on the conductor type, conductor insulation, and installation.

1.2.3 Equivalent circuit diagram of a conductor

Technical literature usually represents complete equivalent circuit diagrams of a conductor as a combination of conductor inductance, capacitance and ohmic components.



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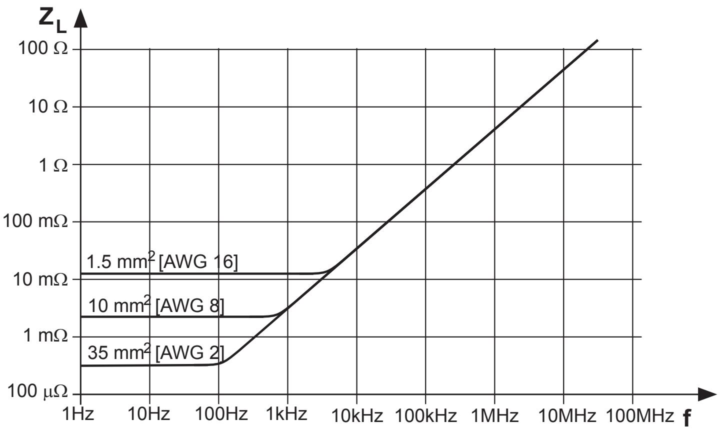
R_S	Series resistance
R_I	Insulation resistance
L_S	Series inductance
C_P	Parasitic capacitance

The following diagrams show the longitudinal and radial impedances of a conductor when considering the frequency dependency of the impedance of inductors and capacitors.



Longitudinal impedance

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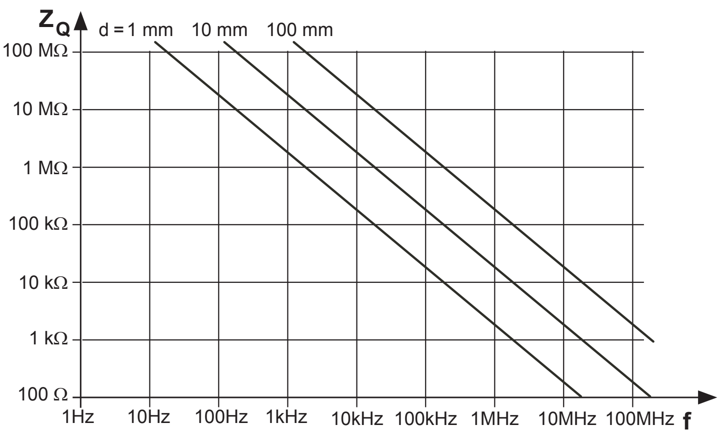

Radial impedance

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Z_L	Longitudinal impedance of the conductor (length 1 m)
Z_Q	Radial impedance (impedance of the insulation)
d	Distance between the conductors

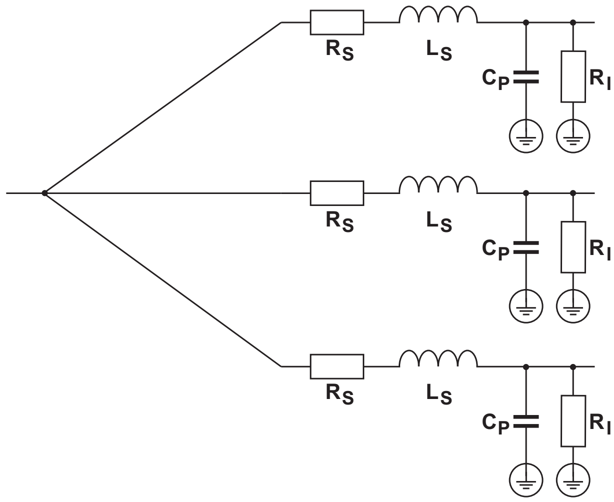
In the low frequency range, the longitudinal impedance of a long conductor is low. The radial impedance (insulation resistance), however, is very high. Low frequency signals can propagate well along the longitudinal impedance.

- The longitudinal impedance of the conductor increases with increasing frequency due to the conductor inductance.
- However, the radial impedance of the conductor decreases with increasing frequency due to the conductor capacitance.

The higher the frequency of a signal, the easier the signal can propagate along the radial impedance.

1.2.4 Parallel connection of conductors

The following figure shows the equivalent circuit diagram of conductors connected in parallel:



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R_S Series resistance
R_I Insulation resistance
L_S Series inductance
C_P Parasitic capacitance

Connecting conductors in parallel not only reduces the longitudinal but also the radial impedances because parallel connection of inductors and capacitors leads to lower impedances. The load on an AC voltage source caused by conductors connected in parallel is much higher than that from a single conductor that is as long as all parallel-connected conductors together. This means that conductors connected in parallel cause higher recharge currents. This must be taken into account for project planning.

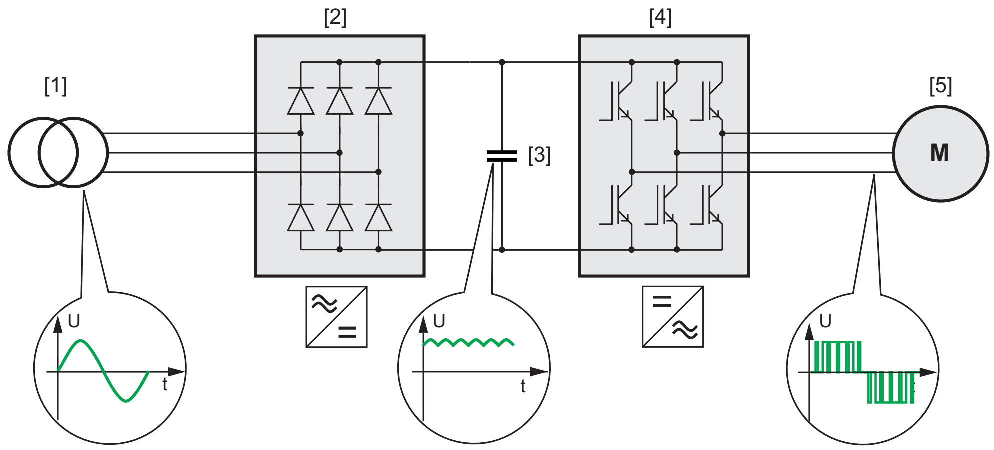
1.3 *EMC aspects of the frequency inverter*

Today, frequency inverters are commonly used in the industrial environment. They convert the energy supplied by the power grid (voltage and current) into a form that matches the required drive function. Like with any other energy converter, the efficiency should be as high as possible.

These basic requirements lead to special EMC aspects that are discussed below.

1.3.1 Basic principle

The following figure shows a block diagram of a frequency inverter with DC link.



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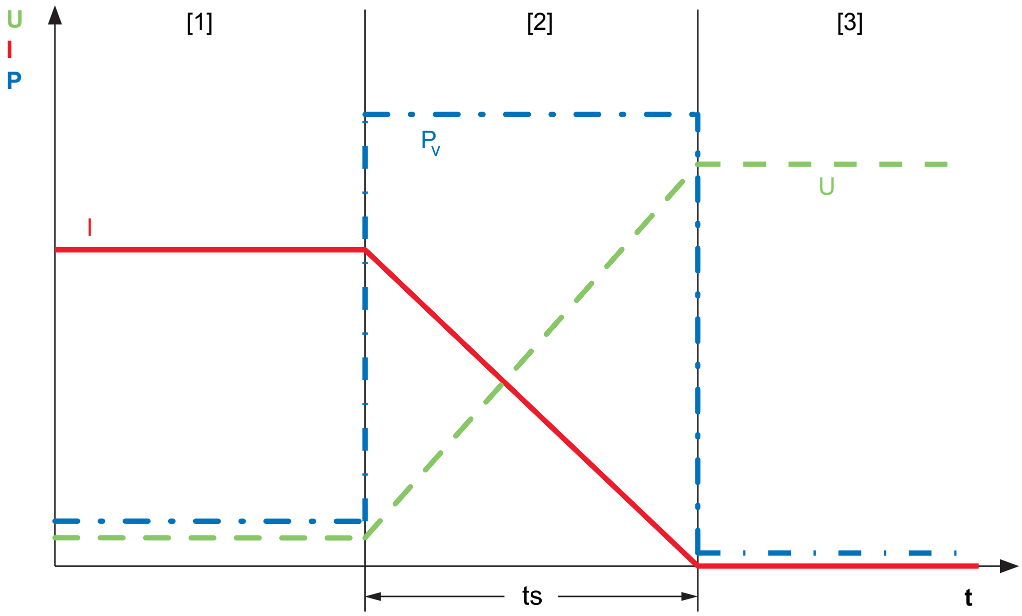
[1] AC voltage source
[2] Rectifier
[3] DC link capacitor
[4] Inverter module
[5] Motor

From the sinusoidal AC supply voltage, a frequency inverter produces an output voltage the amplitude and frequency of which can be varied over a wide range. For this purpose, the supply voltage is rectified to the so-called DC link voltage. The inverter module generates a pulsed output voltage from this DC link voltage. A controller varies the pulse width of the output voltage in such a way that an approximately sinusoidal current is produced at the motor inductance (pulse width modulation = PWM).

The different components of the frequency inverter cause different EMC phenomena. In addition to the effects of the line rectifier and DC link capacitor, which are also used in most commercial electronic devices, it is especially the inverter module that causes the inverter-typical effects. Its output voltage is made up of a series of pulses of varying width that are repeated at a fixed carrier frequency. The individual pulses are characterized by their amplitude, their pulse width, and their edge steepness. The steepness and frequency of the switching edges is of special significance, not only for the losses and, as such, for the efficiency, but also for electromagnetic compatibility.

The following figure shows the 3 switching states of the inverter and the switching edges for voltage and current:



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U Voltage at the switch of the inverter
I Current flowing through the switch of the inverter
P_V Power loss at switch
t_s Switching time

Switching states

[1] The switch is closed.
Despite the high operating current, the small voltage drop generates little power loss.

[2] During switching, significant voltages and currents occur at the switch. In this switching state, the power losses are high.

[3] When the switch is open, a high voltage is present. As the current is negligible, the losses can also be neglected.

To keep the losses in the inverter small, the switching must be fast, i.e. the switching time must be as short and the edges as steep as possible. You should also aim at a low switching frequency, which can be achieved with a small pulse frequency. However, motor current control is more accurate with increasing pulse frequencies. Modern inverters are characterized by short switching times and high pulse frequencies. This allows them to realize dynamic drive tasks and to meet demands for compact design, which requires minimized inverter losses.

With respect to the EMC behavior of a frequency inverter, steep edges and high pulse frequencies cause increased electromagnetic interference (EMI, see chapter "Electromagnetic interference caused by inverter pulses"). EMI must be controlled by EMC measures in the inverter and its immediate vicinity.

Manufacturers must make a compromise for their frequency inverters on the basis of these requirements. They must take into account that modern power semiconductors cannot operate below a certain switching frequency.

In practice, the frequency inverter switches several 100 V periodically at intervals of much less than 1 µs at its output (inverter module).

Conclusion

Overview of requirements for the switching behavior of the inverter:

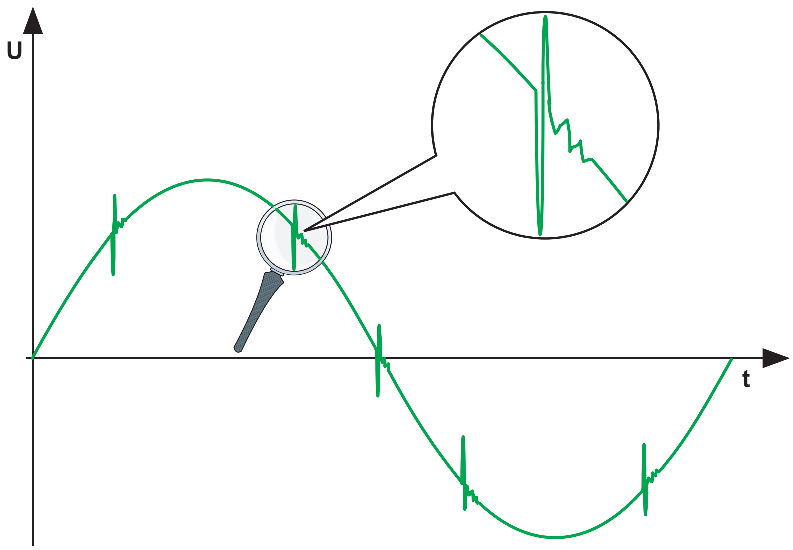
- Short switching times and low pulse frequencies are aimed at minimizing the power losses in the transistors.
- Long switching times and low pulse frequencies are aimed at minimizing EMI from the transistors.
- For a low current ripple, higher pulse frequencies are preferred for control-related reasons.

1.3.2 Commutation

Frequency inverters have a rectifier connected to the power input. Current flows to the frequency inverter via alternating diodes of the rectifier. During the reversal (commutation), the line phases can be short-circuited briefly when one diode is not in blocking state yet, while the other diode is already in conducting state.

In frequency inverters with non-controlled diode bridge, this effect is negligible due to the very short reverse recovery time of the used line diodes.

Units with block-shaped regeneration are a special case. When operated on high line impedances, they can cause cyclical voltage dips that distort the line voltage.



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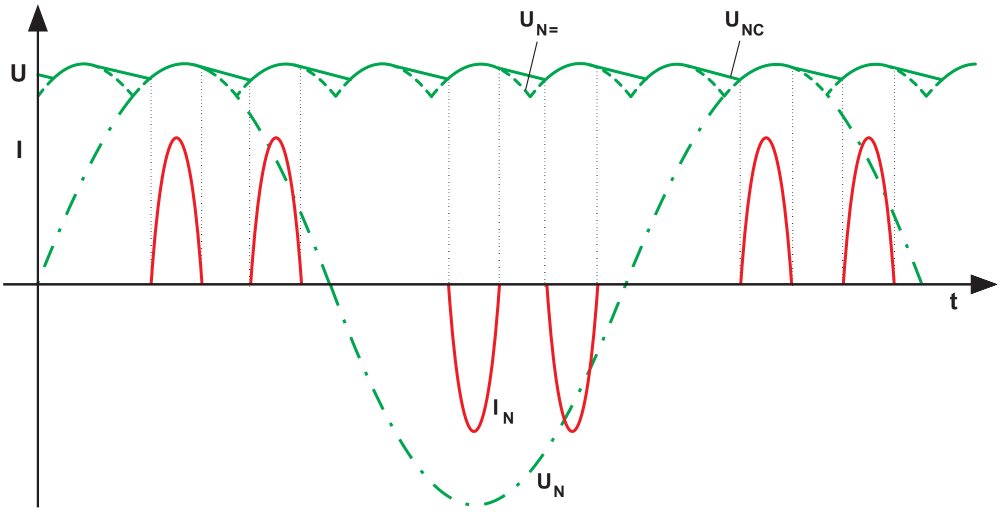
1.3.3 Power line harmonics

Using a rectifier at the inverter input leads to non-sinusoidal current consumption.

The DC link capacitor (energy buffer) can only be recharged via the power line if the instantaneous value of the line voltage is above the instantaneous value of the DC link voltage. This causes gaps in the current flow. According to the Fourier analysis, the non-sinusoidal current comprises sinusoidal current components, the frequency of which is a multiple of the line frequency. These so-called harmonic currents cause a distortion in the line voltage due to the voltage drop at the line impedance.

The following figure shows the resulting line current for large DC link capacitances.



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I_N	Supply current	$U_{N=}$	Rectified line voltage
U_N	Line voltage phase-phase	U_{NC}	Voltage at DC link capacitor

In practice, different DC link technologies are employed that create harmonics to different extents. The following table shows an example comparison of low-frequency harmonic contents of inverters with large (electrolytic capacitors) and small DC link capacitances ("lean DC link"):

Harmonic	Inverter with electrolytic capacitors	Inverter with electrolytic capacitors and line choke	SEW inverter with "lean" DC link
5.	86 %	42 %	25 %
7.	72 %	17 %	13 %
11.	42 %	8 %	9 %

The table illustrates the advantages of modern frequency inverters with a lean DC link, these have up to 20% lower line currents with significantly lower harmonic load for the same power output.

Conclusion

Modern frequency inverters witha lean DC link from SEW-EURODRIVE have line current harmonics that are usually low enough so that a line choke is not necessary.

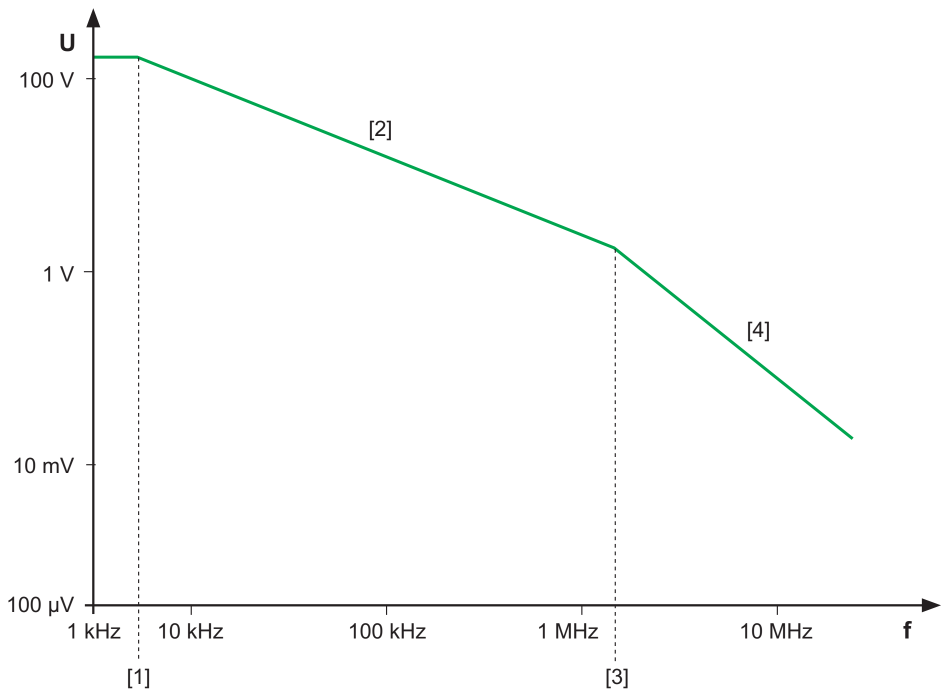
1.3.4 Electromagnetic interference caused by inverter pulsing

This chapter describes the effects of the inverter-typical pulsing of the inverter module. This pulsing has the following characteristics:

- Voltage value (typically several hundred volts)
- Pulse frequency (typically several kilohertz)
- Short switching times (typically several hundred nanoseconds)

When you look at a single clock pulse in the time domain as a trapezoidal pulse, you can deviate its amplitude density spectrum by means of Fourier transformation. This lets you estimate which interference amplitudes will occur in the high frequency range.

The following figure shows the envelope of the frequency spectrum of the output voltage of a frequency inverter:



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[1] Pulse frequency of the frequency inverter
[2] Amplitude decreases proportionally to 1/f
[3] Inverse switching time
[4] Amplitude decreases proportionally to $1/f^2$

Depending on the switching time of the power semiconductor in the inverter, the output voltage has HF interference content with amplitudes of several millivolts up to the frequency range around 100 MHz.

The effects of this HF interference content of the output voltage can affect sensitive systems in the form of interference current, interference voltage, or electromagnetic radiation. To prevent this , the relevant EMC standards stipulate limits for electromagnetic interference. For example, the conducted EMI in the frequency range from 150 kHz to 30 MHz is measured in the form of interference voltage in the power supply line. As of 30 MHz, the electromagnetic radiation of the system consisting of a frequency inverter, motor, and connected cables, is measured by means of antennas. For example, in the frequency range far above 1 MHz, interference voltages of only a few millivolts are permitted, depending on the applied limit value. When comparing these limit values with the interfering frequency range in the figure above, it becomes apparent that measures for reducing EMI are necessary. Without shielding and filtering measures, the EMI limit values for a certain area of application can be exceeded and interference can affect the environment and adjacent conductors.

The magnitude and frequency content of this EMI depends on many factors, especially:

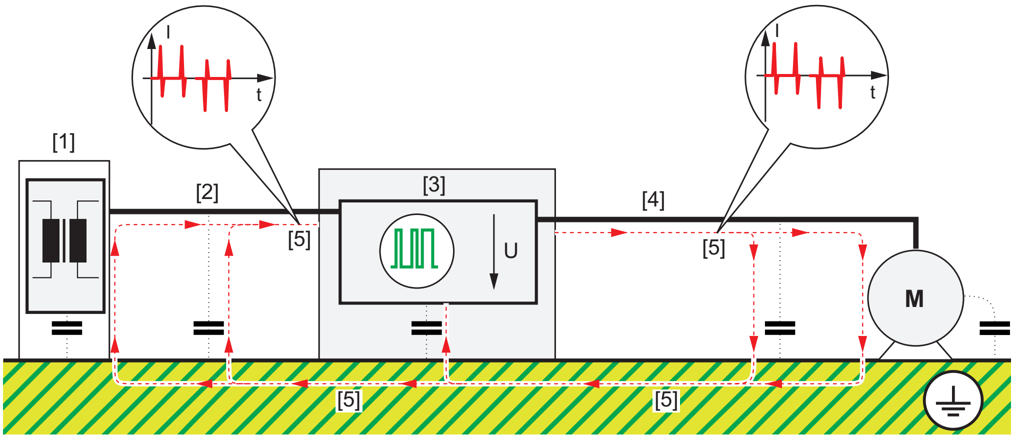
- The type of conductors used and how they are installed
- The grounding situation and impedances
- The geometry of the installed system

Manufacturers of frequency inverters usually offer matching filters for their inverters that have been proven to maintain the specified limit values in typical applications.

1.3.5 Leakage currents caused by inverter pulsing

A special aspect of inverter-generated EMI are the leakage currents. They occur when capacitive structures at the inverter output are recharged due to pulsing. These aren't residual currents that must be detected by a residual current device (RCD), but operational recharge currents that are mainly generated in the motor cable and motor insulation.

The following block diagram shows the leakage currents to ground that are generated by the frequency inverter:



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[1] Power transformer
[2] Line cable
[3] Frequency inverter
[4] Motor cable
[5] Leakage current

As it is not possible in most cases to predict how the leakage currents flow back to the source in the frequency inverter via the PE and grounding system, they are often called stray currents. There is a risk that they couple into sensitive circuits and affect them.

Recharge current peaks and leakage currents depend on:

- The cable length
- The cable type (e.g. shielded, low-capacitance cable)
- The number of conductors routed in parallel
- The size of the motors
- The number of motors connected in parallel

Conclusion

For EMC-compliant operation of a frequency inverter, it is important that the PE conductors are complemented by a HF-capable equipotential bonding system that ensures controlled and thus safe dissipation of these interference currents.

The output cables should be as short as possible and have as low a capacitance as possible. This is implemented in an ideal way in decentralized inverter installations, where the output cables are omitted completely by mounting the frequency inverter directly to the motor.

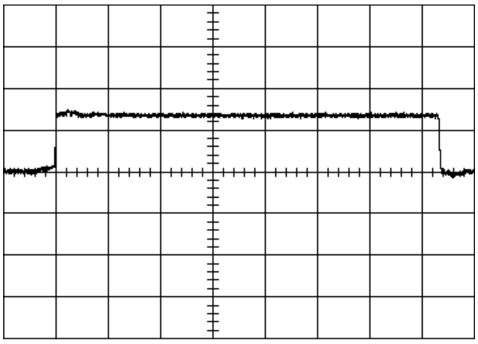
1.3.6 Voltage load of the motor caused by inverter pulsing

In practice, the almost square-wave voltage at the inverter output is transmitted to the motor via motor cables of different lengths. The reflection and signal runtime effects known from HF technology can lead to overvoltages in the connected motor.

In general, the motor with its inductive character acts as a non-adjusted terminating impedance for the motor cable. This means that reflections with twice the amplitude of the inverter output voltage can occur at the motor terminals.

The signal runtime of an inverter pulse edge is mainly determined by the structure and length of the motor cables. If more inverter pulse edges are fed into the motor cables during this signal runtime, this can cause interference between outgoing and returning signals. If this interference occurs at the motor terminals in the worst case, more than twice the amplitude of the inverter output voltage can be measured there.

The following oscilloscope images show an example of the voltage characteristics at the ends of the motor cables:



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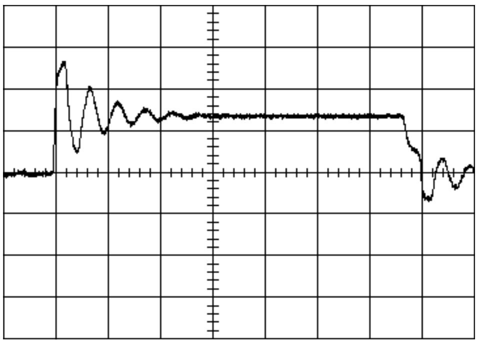
Voltage characteristics
at the output of the frequency inverter



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Voltage characteristics
at the motor terminals

Due to a variety of factors, it is often not possible in practice to determine exactly in advance whether a certain configuration leads to overvoltage at the motor. This is why we recommend motors that are designated for inverter operation. For motors that are not suitable for inverter operation, filtering measures might be necessary, see chapter "Filtering" (page 22).

1.4 Filtering

1.4.1 Line choke

A line choke is a passive, inductive component. It consists of one or several copper or aluminum coils through which the entire load current of the connected consumer flows. These coils are usually wound on a core made from soft-magnetic material. The type of core material and the design of the coil determine the properties of the line choke (e.g. inductance, leakage inductance, course of the inductance over the frequency, current-carrying capacity, losses).

Line chokes are usually connected in series in front of the consumer. They are an effective device for countering a number of EMC phenomena.

Harmonics

Line chokes prevent grid disturbances caused by harmonic currents (see chapter "Power line harmonics" (page 17)) or other LF interference. However, in frequency inverters with lean DC link, the harmonic content is usually so low that a line choke is not necessary. For single-phase units or units with a large DC link, a line choke is used as standard. Its size depends on the line impedance and the power rating of the frequency inverter. Usually, chokes with u_k values of about 2 – 4% are used.

Commutation notches

Commutation notches occur when both diodes are in conducting state during the current transition from one diode to the other, see chapter "Commutation" (page 16). This brief "short circuit" of two phases leads to high currents that are only limited by the line impedance and cause an accordingly high voltage dip. Installing a line choke upstream increases the line impedance, which limits the current flow / voltage dip. In case of frequency inverters with passive diode bridge, the commutation notches are negligibly low. Only in case of units that have a controlled line rectifier or regenerative function (active front end inverter), these commutation chokes are still required.

Inrush load

Charging a DC link capacitor can cause a high inrush current, depending on the capacitance. This inrush load can lead to increased wear in the components upstream of the branch circuit (e.g. welding of line contactors). A line choke, due to its inductive behavior, smoothens these current peaks and reduces their amplitudes.

Overvoltage

Switching operations, short circuits in the grid, or indirect lightning strokes can generate high-energy overvoltage pulses. These overvoltages can exceed the maximally permitted voltage of the power semiconductors, overloading them. An upstream line choke reduces the current caused by the overvoltage pulse. Due to the resulting voltage drop, the line choke reduces the voltage at the unit terminals.

1.4.2 Line filter

A line filter reduces EMI via the line cable, which is generated by the inverter due to its operating principle. It mainly serves to meet interference voltage limit requirements in the frequency range from 150 kHz to 30 MHz at the power supply. In addition, a line filter dampens the interference from the grid affecting the inverter.

Installation

In the line filter, inductors and capacitors are connected in such a way that they lead back the currents generated by the inverter to the interference source without loading the power supply system. The high-frequency design of the filter circuit is extremely important. This also applies to the connection of the circuit to the filter housing, which acts as reference ground. Noise suppression capacitors in the inverter make sure that the interference source can be connected to this reference ground. The filter housing and the inverter housing must form a common reference ground for this purpose. In the control cabinet, this is best done via the mounting plate.

This design makes it possible that HF interference can be safely routed back to the source through the filter. The effectiveness of the filter depends to a decisive extent on the HF-capable design of the reference ground in the installation.

Dimensioning

The line filter is selected according to the recommendation of the component manufacturer, who has proven compliance with the limit values in typical configurations. Proof for the variety of possible combinations of grid conditions, line filters, inverters, motor cables, and motors is not stipulated in the standards.

It is not recommended to select line filters according to damping curves, because they only apply for idealized measurement conditions and can deviate considerably from that in specific applications.

A common line filter for the complete control cabinet can also be used instead of a line filter for each inverter. This common line filter must then be dimensioned for the total current. It is usually calibrated for the application, as it is not possible according to the state of the art to make a general statement about compliance with limit values.

Use

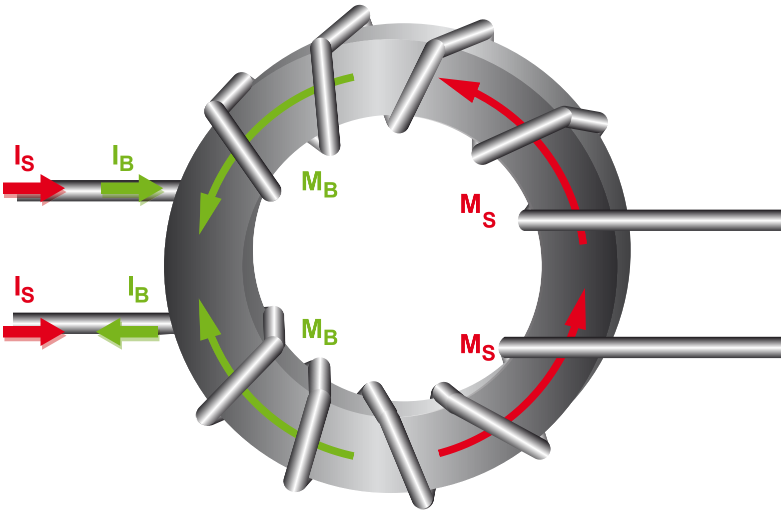
The use of line filters is recommended for the following requirements:

- Reduced EMI via the line cable
- Compliance with limit values
- Reduced equipotential bonding currents
- Reduced leakage currents in case of long motor cables

1.4.3 Output choke

An output choke is a cost-effective measure to reduce the EMI potential of the motor lead of the inverter. It dampens HF leakage currents caused by inverter pulsing. As an alternative to the motor cable shield, it can effectively reduce radiation from the motor cable, so that compliance with limit values is ensured.

A so-called current-compensated choke is formed when the 3 cores of the motor cable are wound in the same direction on a suitable magnet ring core. The figure below shows a simplified version of the functional principle of current-compensated chokes:



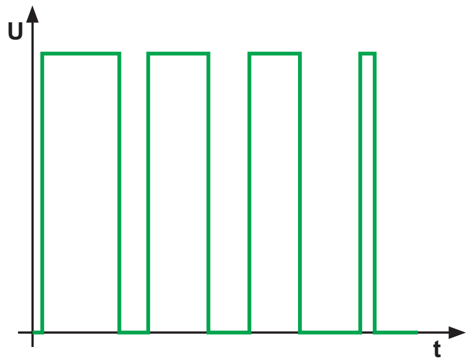
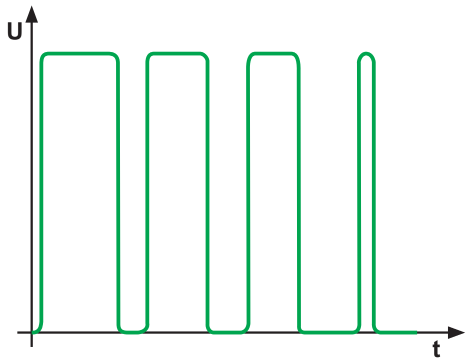
237098123

I_S	Interference current	M_S	Magnetic field induced by interference current
I_B	Operating current	M_B	Magnetic field induced by operating current

The magnetic fields that the operating current generates in the core cancel each other out, so that no inductance is effective for the operating current. Only interference currents that flow via the grounding system, for example, generate an effective magnetic field in the core that dampens the interference currents. This simplified principle also applies to a 3-phase system with symmetrical operating currents, as is the case with the output choke. The magnetic circuit of the current-compensated choke is only loaded by the magnetic field of the interference or leakage currents; the operating or output current does not affect the magnetic circuit. This allows for more compact designs than would be possible with 3 individual line chokes that have to be dimensioned for the output current.

With a suitable material, the output choke is a very high HF impedance that dampens leakage currents and overshoots of the output voltages.

The effect of the output choke on the inverter output voltage can be represented schematically as follows:

Effect of the output choke	
Inverter output without output choke	**Inverter output with output choke**
 238074763	 238079627

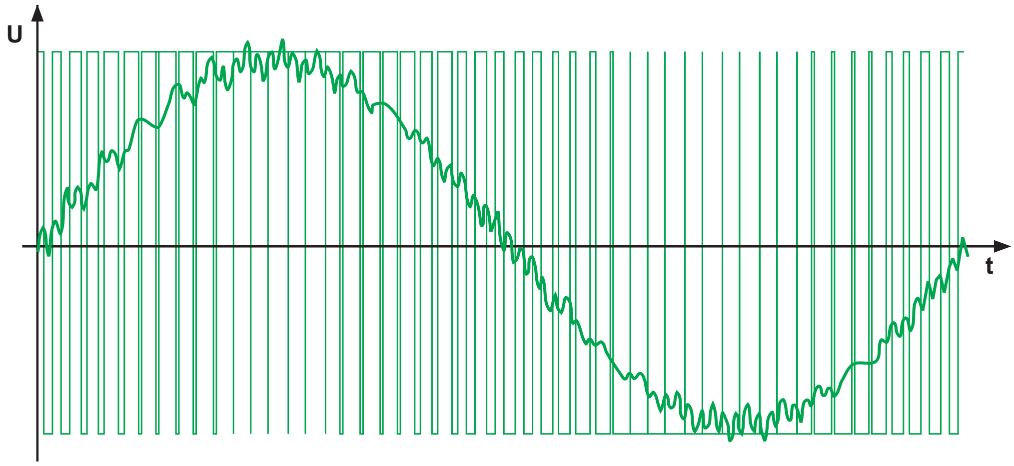
As the output choke is a negligible impedance for the operating currents, the voltage drop at the choke can be disregarded. The choke is also suitable for use in current-controlled drives.

In contrast to the output filter, the output choke only dampens the HF components and not the pulse frequency. This means it cannot be used to filter sound and to extend the permitted cable lengths, e.g. for group drives.

1.4.4 Output filter

An output filter converts the square-wave output voltage of the inverter to an almost sinusoidal output voltage.

The following figure shows the voltage at the motor input with and without output filter:



237376395

The output filter is a 3-phase symmetrical LC filter that acts as a low pass. The low motor frequency passes through undampened, while the high pulse frequencies are filtered. The series inductances in the filter must be dimensioned according to the motor current, which leads to large sizes.

U_Z connection

In the control cabinet variant, the filter capacitor stage can be connected to the DC link of the inverter. This integrates the interference suppression capacitors of the inverter into the output filter circuit, which improves the filter effect against the ground potential. Feeding the inverter output signals back to the DC link increases the current flow through the filter, which must be taken into account for project planning.

The basic function of the output filter affects the following:

Recharge current peaks and leakage currents

The square-wave output voltage induces recharge current peaks and leakage currents in the motor cables and motor windings. These put a load on the transistors in the inverter (especially in case of long or shielded cables and group drives). This is why recharge current peaks and leakage currents must be considered in project planning. In addition, stray leakage currents often cause EMI.

When using an output filter, these currents are significantly reduced, as the output voltage is sinusoidal.

Overvoltage peaks

When overvoltage peaks occur at the motor terminals through the motor cable, the inverter pulsing can put excessive voltage load on the motor. An output filter prevents the feeding of clock pulses into the motor cable, and thus the reason for overvoltage peaks. This reduces the load on the motor insulation, and it is possible to operate motors with insufficient electric strength on the inverter.

Use is recommended for:

- Third-party motors that are not designed for inverter operation
- Long motor cables

Reducing the motor noise

The square-wave inverter output voltage generates a pulse frequency component in the motor current that produces noise in the motor by means of magnetostriction. If this noise is found to be annoying, an output filter can remedy this. The output filter smoothens the pulse frequency component of the motor current, reducing the noise in the motor. As the current in the output filter contains pulse frequency components in any case, strong magnetostriction occurs at the filter chokes, which can produce distinct noise.

The noise can be reduced by increasing the inverter pulsing. Observe the installation notes from the manufacturer.

Radio interference suppression

The radiation tendency of the unshielded motor cable is also dampened by filtering the pulse frequency output signals of the inverter. When the output filter is dimensioned correctly by the manufacturer, the radio interference limit requirements are also met with long, unshielded motor cables. The reduction of leakage currents relieves the line filter and reduces EMI on the supply system end. Observe the installation notes from the manufacturer.

Limitations for using an output filter

An output filter cannot be used in every case. Due to the additional filter current component, the inverter might have to be dimensioned larger and cannot be used in current-controlled applications. Part of the output voltage drops proportionally to the output frequency at the filter choke. This leads to an unpermitted reduction of the motor breakdown torque especially in the field-weakening range.

- Do not use output filters in hoist applications.
- Flying start function is not possible with output filters.

Capacitive loads at the filter output to ground can cause resonance behavior when they exceed a certain level. This is the case, for example, with motor cables of more than 20 m or with group drives. HF oscillations are generated between these capacitances and the filter chokes. The resulting iron losses in the chokes can cause thermal overload in the output filter. This effect is prevented by using unshielded motor cables or by using the switching variant with U_Z connection.

1.5 Equipotential bonding

As described in chapter "Conductor capacitance" (page 11), each conductor has parasitic capacitance to adjacent conductors and to ground. Each voltage change, e.g. through switching operations, causes a recharging of these parasitic capacitances. The recharge currents make themselves felt as potential equalization currents that can flow via the grounding system and the conductive parts of the entire plant (so-called "stray leakage currents"). These currents flow back to the voltage source, e.g. to the frequency inverter, and cause a voltage drop along the electric conductors. This voltage drop represents noise voltage that can interfere with the useful voltages and cause problems in sensitive systems.

The magnitude of the interference voltage is proportional to

- the parasitic capacitance
- the edge steepness of the switching operation
- the impedance of the equipotential bonding

The parasitic capacitance can be influenced by the selection and installation of the connection cables. The edge steepness of the switching operation can be reduced by filtering the interference source.

Due to the variety of the usually existing interference sources and coupling paths, the most effective and cheapest measure for improving EMC in practice is to minimize the equipotential bonding impedance. Equipotential bonding carries the major part of the interference current, taking load off the electric conductors of sensitive systems. For this, the HF impedance of equipotential bonding must be much smaller than the HF impedance of the electric conductors.

For safety reasons, all electrically conductive parts of a plant must be linked with the PE conductor via a low-resistance connection. It makes sense to use the mechanical structure and especially the metallic cable duct as large-surface equipotential bonding (low resistance for high frequencies) in parallel with the electric conductors. The most common measures are described in chapter "EMC-compliant installation in practice".

1.6 Cable installation

1.6.1 Cable characteristics with respect to EMC

There are a variety of different cable types, all with very different EMC properties. The cable types can be characterized as follows:

Cable type	Property
Single conductors	Single conductors offer no EMC protection. The EMC behavior can be optimized by jointly routing supply and return cables while keeping a large distance to neighboring conductors.
Shielded single conductors	Shielded single conductors are not common in industrial environments. They are mainly used to transmit HF broadband signals (coaxial cables). By using the shield as return conductor, useful signals are fed back into the shield system, which causes asymmetrical interference currents, especially in multi-conductor systems. In addition, such conductors have high conductor capacitances, which result in high recharging currents.
Twisted pair wire	Twisted pair cables offer good protection against magnetic interference fields. However, they do not offer protection against electric fields.
Multi-core cables	These cables, e.g. plastic sheath cables, offer good protection against magnetic interference fields. However, they do not offer protection against electric fields. The minimal distance between the cores in the cable leads to maximum coupling effects between the cores. Signal transmission can be critical if signals of several electric circuits are routed through one cable. Especially critical is signal transmission when the signals belong to different conductor groups.
Shielded cables	Shielded cables, when installed correctly, offer good protection against magnetic and electric fields. The properties of different shield types are discussed in chapter "Shield types" (page 65).
Hybrid cables	As hybrid cables bundle signals of varying sensitivity in one cable, their structure is usually complex, and component manufacturers specify them for individual applications. When using hybrid cables, you must always observe the approvals of the respective component manufacturer.
Optical waveguide	From an EMC perspective, signal transmission via optical waveguides is ideal. Neither EMI fields nor equipotential bonding affect the signal quality. This is why optical waveguides are perfectly suited for extreme EMI environments and for transmitting sensitive signals between areas with poor equipotential bonding.

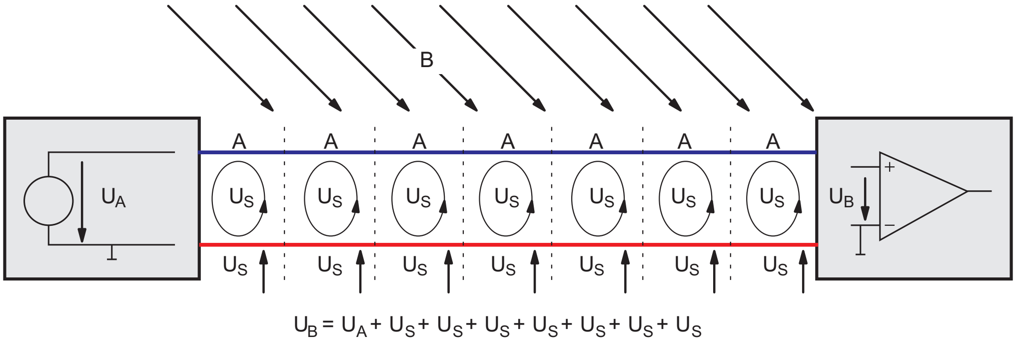
For many components, the manufacturer recommends the types of conductors that are suitable for EMC-compliant use.

For practical information about cable routing, refer to chapter "Cables" (page 60).

1.6.2 Twisting

A very effective method for reducing magnetic coupling is to twist supply and return cables together.

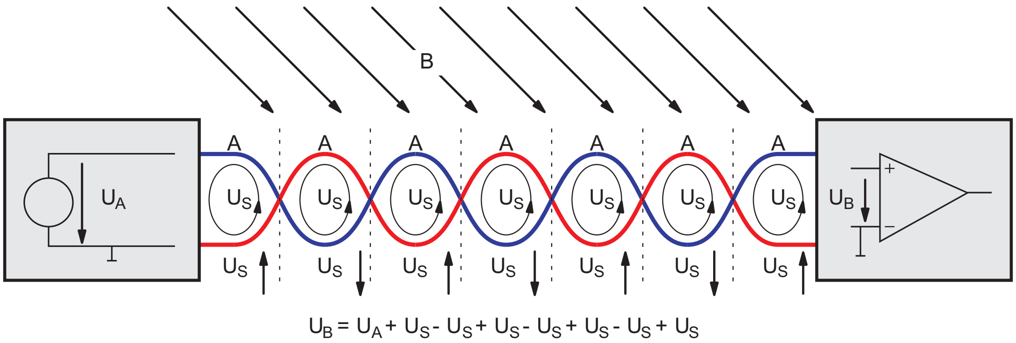
The following figure shows a layout in which a measuring circuit evaluates a voltage signal. A **non-twisted conductor** is exposed to magnetic field B.



234456459

The interference voltages U_S in the virtual subareas are added up because they have the same sign.

The following figure shows the situation when a **twisted conductor** is used:



234461067

The twisted conductors form many small subareas with opposite orientation. This means the loop area for coupling is much smaller. The interference voltages U_S add up to zero with alternating signs in an ideal case.

The interference voltage is normally not exactly zero because

- the loop areas A are not all the same size
- and because the magnitude of the magnetic field strength B in the loops varies (e.g. with different distances from the interference source).

The smaller the loop areas, the more effective the twisting. The user can achieve this with a higher number of loops per length unit (length of twist). Twisting conductors also significantly reduces the effective inductance of a conductor loop.

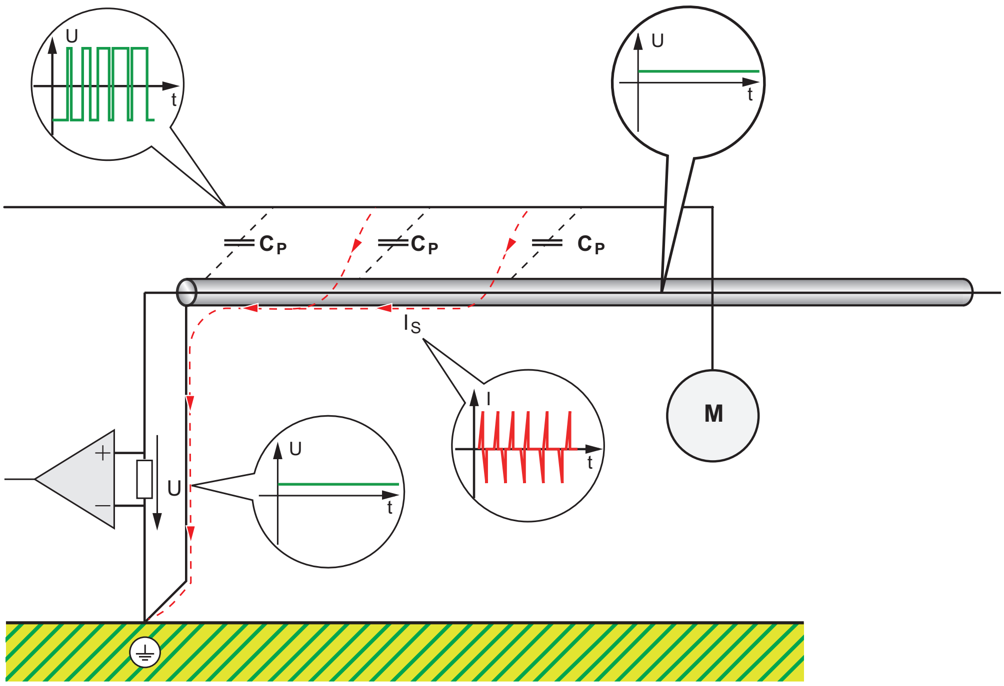
1.7 *Shielding*

A useful measure for reducing interference coupling is shielding components, units, and conductors. Basically, the shielded component is placed inside a Faraday cage. The quality of the shield depends on the integrity of the Faraday cage and its conductivity.

The following chapters describe the main aspects of cable and conductor shielding.

1.7.1 Single-sided shield grounding

The following figure shows an unshielded inverter output cable in parallel with a signal cable. The electrical coupling field causes parasitic capacitances. The single-sided shield forms the antipole of the parasitic capacitances. The interference current then flows away via the shield.



234545803

I_S	Interference current
C_P	Parasitic capacitance

With an ideal, impedance-free shield, there is no coupling with the inner conductor. In reality, however, the shield has an impedance, so that single-sided shielding against electric fields is only effective for short cables and low interference frequencies.

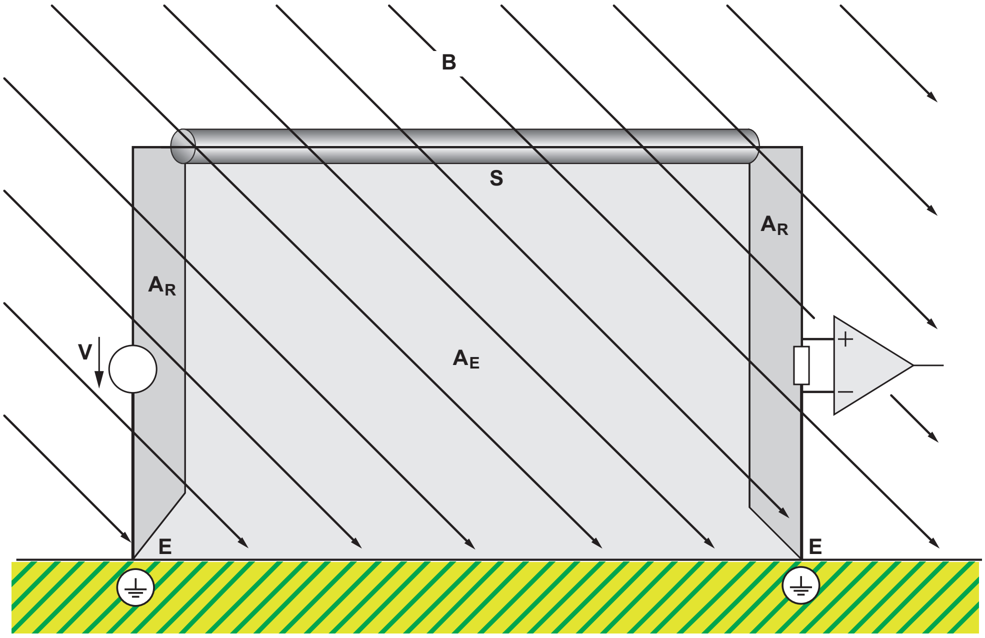
Single-sided shield grounding is ineffective against magnetic fields.

1.7.2 Double-sided shield grounding

From an EMC perspective, double-sided shield grounding is ideal for industrial environments because

- in the HF range, electric and magnetic fields always occur together
- and applications with a high power rating always cause magnetic interference fields.

The following figure shows an operational amplifier with measuring resistor that evaluates a signal voltage V under the influence of an outer magnetic field:



5582414219

B	Magnetic field	A_E	Ground loop area
E	Shield grounding	A_R	Residual loop area
S	Shield		

A magnetic alternating field penetrates the area between the signal conductor and ground. In this loop area, an interference voltage is induced that interferes with the measurement signal at the measuring resistor. The double-sided shield grounding of the signal conductor limits the effective area to the residual loop area A_R (see figure). The magnetic field induces a smaller interference voltage than without shield.

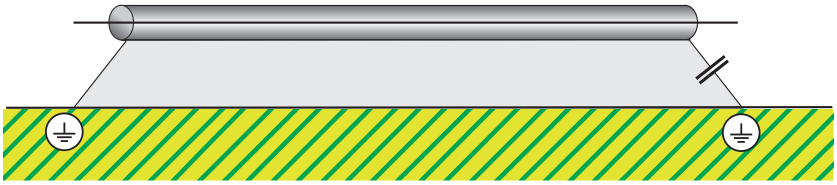
The part of the residual loop area A_R between the signal conductor and the shield only contributes to the coupling if the shield can be penetrated by the interference field.

The ground loop area A_E is exposed to the alternating magnetic field despite the shield. However, the interference current induced here can short via the shield, the shield connection and ground without generating interfering voltage drops.

This results in the following requirements for EMC-compliant installation of cable shields:

- Minimizing the area between free conductor ends and the shield or ground
- Appropriate shield quality
- Low-impedance, HF-capable connection of the shield ends with ground

In those rare cases in which direct shield grounding is not possible on both sides, one shield end can be grounded with a capacitor:



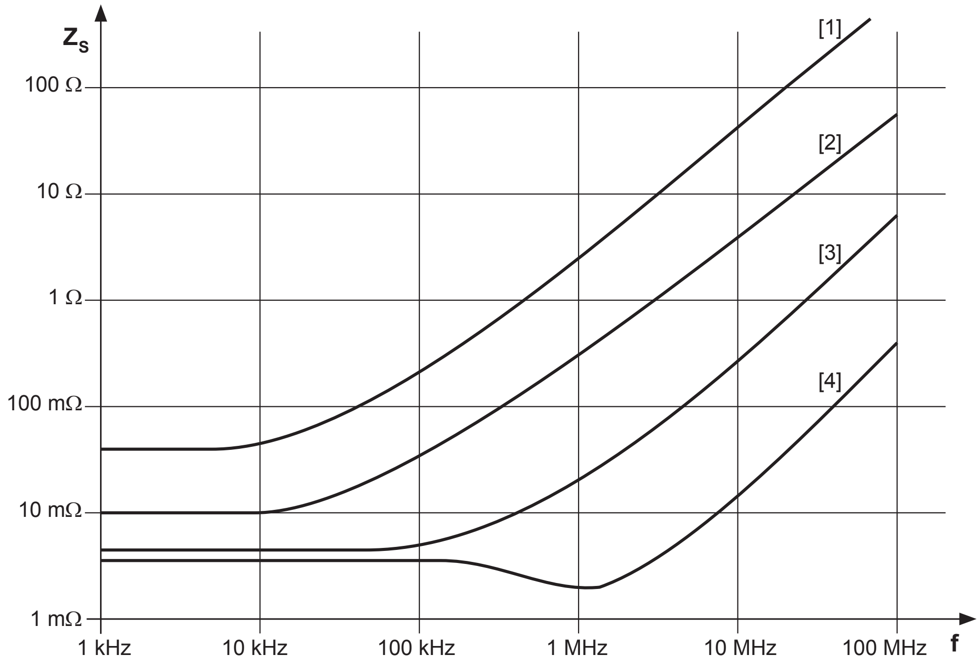
234485771

As an alternative, you can use a double-shielded cable, for which one shield is connected at each cable end.

1.7.3 Influence of the shield connection

EMC-compliant realization of the shield connection is especially important for the effectiveness of the shield. When the shield is connected by twisting the shield end (so-called "pigtail"), the length of the shield connection, i.e. its inductive component, limits the entire shield function.

The following figure shows that the shielding effect can be strongly reduced or even eliminated by incorrect shielding connections in the EMC-relevant frequency range above 1 MHz.



235722507

[1] Shield connection length 1000 mm
[2] Shield connection length 50 mm
[3] Shield connection length 4 mm
[4] Shield bonded over entire circumference (concentric gland)

Shield connection length = Length of cable connected to shield tail

Conclusion

EMC-compliant shield grounding is installed on both sides. The shield is bonded over the entire circumference to establish a HF-capable connection over a large surface area.

1.8 Standards and regulations

The legal basis for EMC in the European Union is the EMC Directive and its implementation in national laws of the EU member states.

Notes on the application of the EMC Directive can be found in the "Guide for the EMC Directive".

For electric drive systems, the EMC product standard EN 61800-3 is effective in Europe. It includes all relevant EMC requirements for electrical power drive systems (PDS) and takes precedence over generic standards.

For exports of units or plants into other economic regions, e.g. USA, China, or Australia, the relevant national regulations must be observed.

2 EMC-Compliant Installation in Practice

Electromagnetic compatibility (EMC) denotes the capability to operate several electrical and electronic components together and next to each other within a certain environment without any interference.

This chapter will help you to optimize the EMC of your plant and to correct any existing EMC problems.

The notes in this chapter are not legal regulations; they are merely hints for improving the EMC of your plant. For unit-specific notes and instructions, refer to the operating instructions of the unit.

Observe the following guidelines and notes for electrical installation:

- General guidelines and instructions of the plant manufacturer
- General safety notes of the respective units
- Permitted conditions at the installation site
- Assembly notes and installation instructions of the respective units

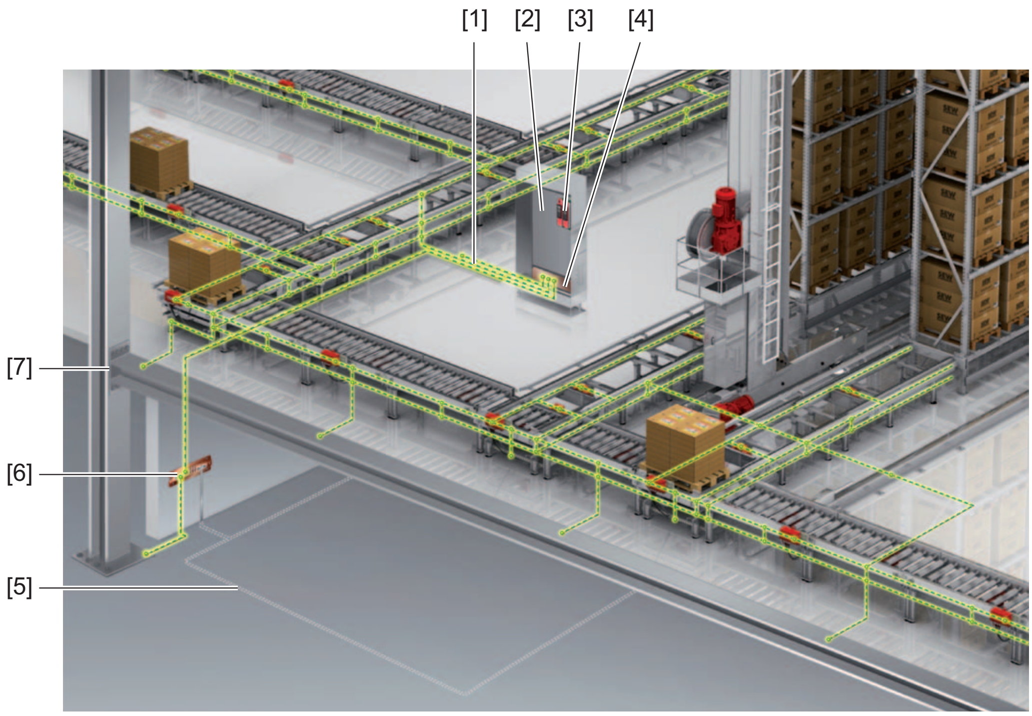
2.1 *Grounding via interconnected EMC concept*

Grounding is particularly important for fault-free operation of a plant.

Note the following:

- All components of the plant must be grounded via low resistance connections both in the low frequency (LF) and high frequency (HF) range. This is why the plant must have a grounding network with a consistent reference potential also for high frequencies.
- For electromagnetic interference mechanisms, the PE conductor represents a high HF impedance. Grounding cables are only effective in the HF range if they are **interconnected**. This **parallel connection** reduces the conductor resistance.

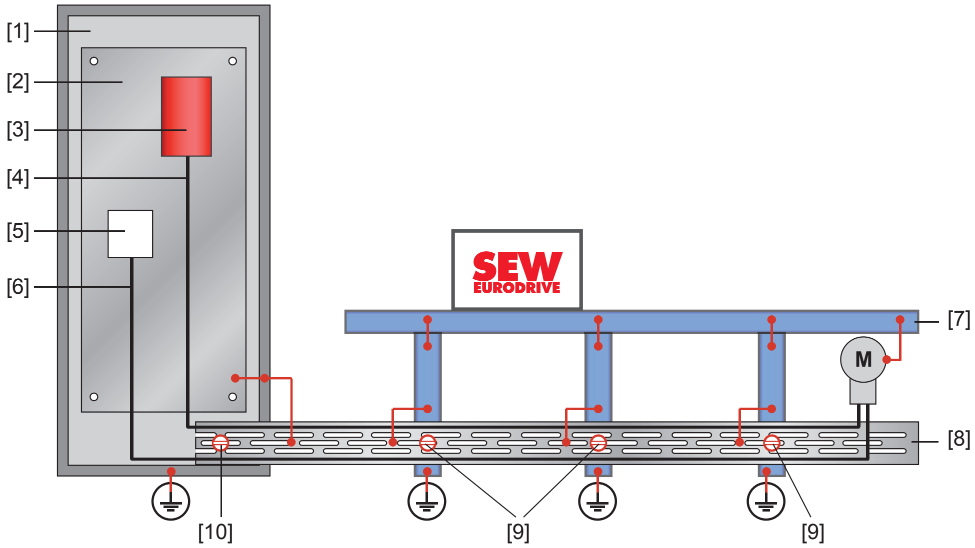
The following figure shows an example of the components of a plant that must be considered for grounding.



3771657867

[1] Sheet metal cable duct
[2] Mounting plate in the control cabinet
[3] Frequency inverter
[4] Equipotential bonding bar (PE bar)
[5] Foundation ground electrode
[6] Equipotential bonding point
[7] Steel frame

The following figure shows the equipotential bonding measures of a transportation system with one drive:



462823435

[1] Control cabinet
[2] Mounting plate
[3] Inverter
[4] Motor cable
[5] PLC
[6] Signal cable
[7] Metallic frame
[8] Sheet metal cable duct
[9] Sheet metal cable duct connected to the metallic machine frame over a large surface area
[10] Sheet metal cable duct connected to the back wall of the control cabinet over a large surface area

2.1.1 Leakage currents

A controlled drive system always generates cable-conducted LF and HF interference. Suitable EMC measures reduce these interferences significantly, partly dissipating them as leakage currents to the ground potential.

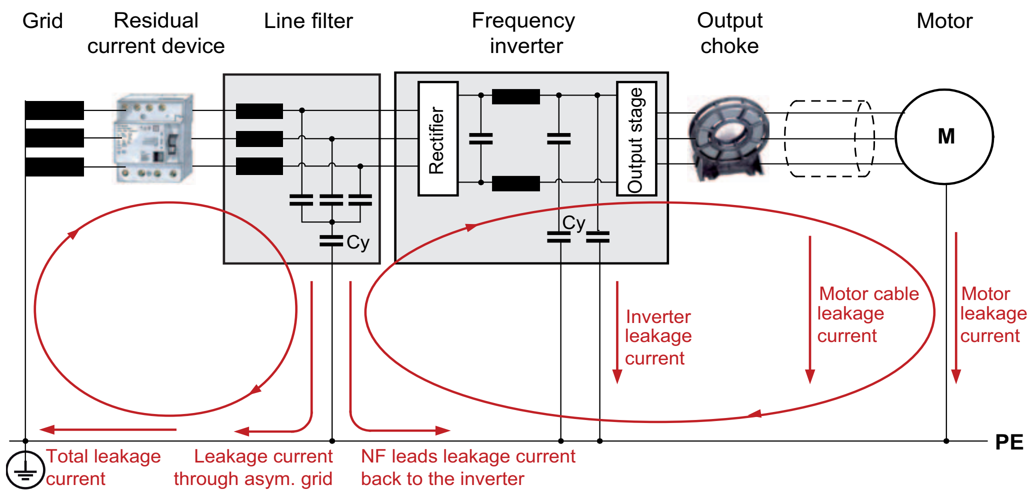
- The largest part of the leakage currents should flow back to the frequency inverter.

  This is why good, **low-resistance grounding** is particularly important. It prevents the leakage currents from taking another path and thus interfering with other units.

- The inductance of a **line filter** works against the leakage current in the kHz range and feeds a large part of the leakage current back to the frequency inverter via the Y capacitor.

  The line filter keeps back the leakage currents generated by the frequency inverter and the interference voltages from the power supply system and feeds them back to the frequency inverter (interference source).

The following figure shows the leakage currents of a controlled drive with suitable EMC measures.



3875098123

Conclusion

The largest part of the leakage currents should flow back to the frequency inverter to keep them from interfering with other units.

INFORMATION

Detailed information about leakage currents from frequency inverters are available from SEW-EURODRIVE on request.

2.2 *Voltage supply*

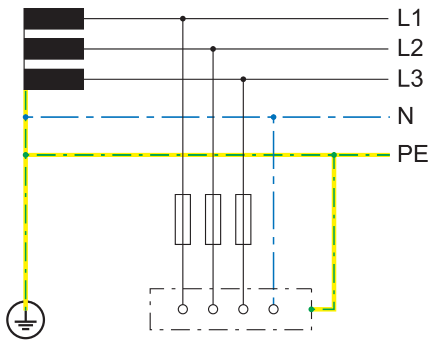
The equipment in a plant must be connected to the supply source in a star-type configuration. Sensitive equipment and equipment with high power ratings require separate supplies.

2.2.1 Supply system selection

Different supply systems are permitted for supplying the units. The supply system type has a significant influence on the EMC behavior of a plant.

The following figure shows the wiring diagrams of the supply system types.

TN-S network



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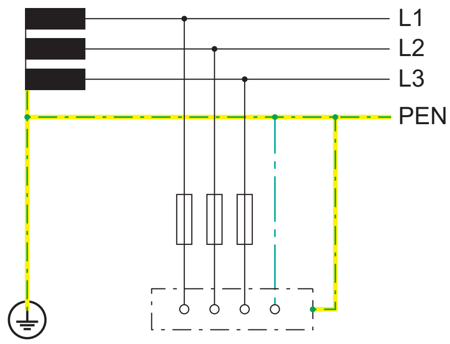
TN-C network



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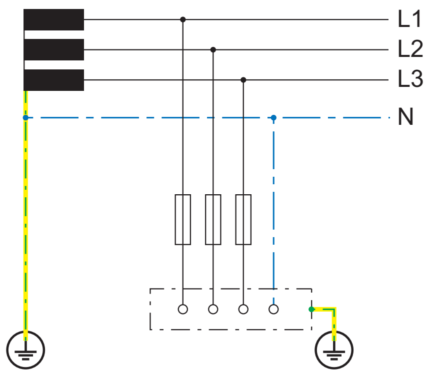
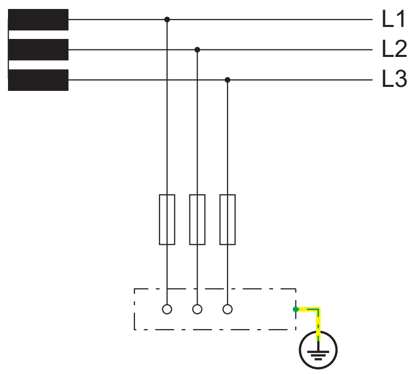
TT network



3773250571

IT network



3773369611

The following table shows the EMC properties of the different supply systems.

Network configuration:	EMC characteristics
TN-S network	Very good
TT network	Good
TN-C network	Poor
IT network	Poor

The TN-S network with 5 conductors has the best EMC characteristics. The advantage of the TN-S network is the **separate routing of N and PE conductors**. Both conductors are only connected at a central point in the building. The PE conductor is usually only used for dissipating interference currents.

The isolated IT network has the poorest EMC characteristics.

2.2.2 Extra-low voltage

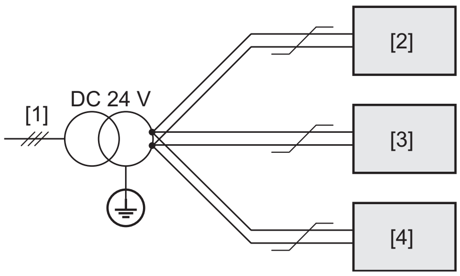
For extra-low voltages (e.g. 24 V), it is important that

- analog consumers (e.g. measuring sensors, proximity switches, etc.)
- and consumers with high power rating (e.g. contactors, brakes, etc.)

are connected to different power supply units or at least different lines. These lines must lead to the power supply unit in a star-type configuration.

Supply and return conductors must always be laid together.

The following figure shows a the supply concept for extra-low voltages.



3771657867

[1] Supply cable

[2] Power components with high power rating e.g. contactors, brakes

[3] Power components with small power rating, e.g. relays

[4] Extra-low voltage components, e.g. measuring sensors, proximity switches, etc.

2.2.3 24 V brake control

In motors with a DC 24 V brake that is not controlled by a brake control unit (BMV or BSG), burned relay contacts and EMI can occur in the 24 V supply.

SEW-EURODRIVE recommends to always use a BMV (in the control cabinet) or BSG (in the terminal box) brake control unit for 24 V brakes.

Brake with brake control unit (BMV or BSG)

The BMV and BSG brake control units are wear-free electronic switches. They prevent EMI coming from contact-breaking sparks when switching off the brake. The brake control unit protects the brake from overvoltages.

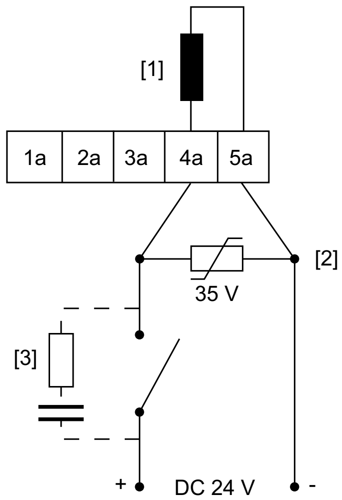
Brake without brake control unit

If the brake is not switched by a brake control unit (BMV or BSG), you must use a contactor or relay that is suitable for switching inductive DC loads. In this case, the 24 V brake needs a **35 V varistor** connected in parallel with the brake coil for overvoltage protection and for EMI suppression of the 24 V supply, see figure below.

For brakes with a DC supply higher than 24 V, use a 300 V varistor.

If EMI still occurs, you can additionally connect an RC element in parallel with the contactor.

The following figure shows a 24 V brake with EMI suppression:



[1] Brake coil
[2] Varistor (Example: SIOV S 10 K 35 => **35 V** from the company EPCOS)
[3] RC element (Example: RC BUG2/24-48V DC/DC from the company Murr)

Conclusion

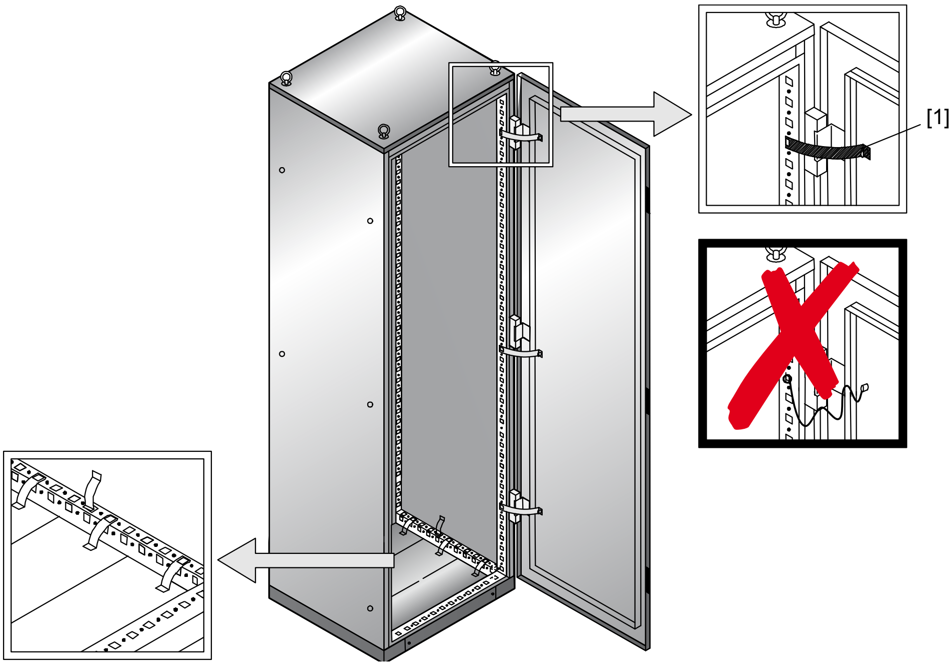
Compared with contactors or relays, the BMV and BSG brake control units offer the following advantages:

- Much higher system availability
- Much better EMC
- Much longer service life

2.3 *EMC in the control cabinet*

2.3.1 Sheet steel control cabinet

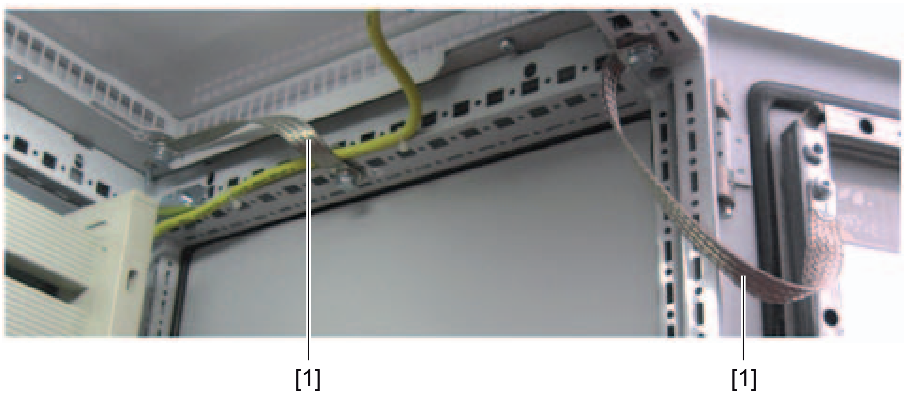
A control cabinet made of sheet steel is a good solution from an EMC viewpoint because it offers excellent shielding against magnetic interference fields.



401657483

[1] HF braids

The following figure shows the HF equipotential bonding between doors, sheet metal, and the mounting plate:



3773699467

[1] HF equipotential bonding between doors, sheet metal, and mounting plate

The control cabinet helps to reduce radiation. Optimum equipotential bonding improves the shielding of the control cabinet. Integrating the doors and the cable ducts is important.

2.3.2 Mounting plate in the control cabinet

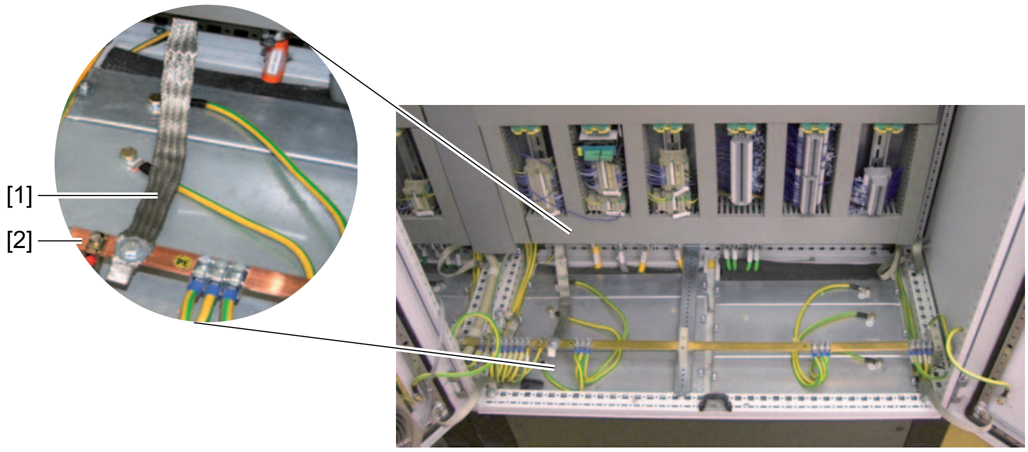
Apart from providing for an installation place for components, the control cabinet mounting plate is also used to ground components with metal housing over a wide area. Galvanized steel plates are most suitable for this purpose. The mounting plate must have a large-area connection with the machine hall construction. This connection is realized with an HF braid between the mounting plate and the PE busbar.

Nowadays, you can also use mounting systems instead of mounting plates. However, this offers disadvantages as the connections with the inverter housings are not over a wide area. If the grounding resistance increases with the use of a mounting system, this has a negative effect on EMC as well. This is why for mounting systems, all components such as frequency inverters, filters and shields must be connected over a wide area to a mounting plate integrated in the system.

2.3.3 PE busbar

The PE busbar is the central connection point for the PE conductors of the individual units in the control cabinet (star-type grounding). The PE conductor replaces neither HF grounding nor shielding. It is mandatory for protective earthing for safety reasons.

The following figure shows the PE busbar and the HF equipotential bonding between the mounting plate and the PE busbar in the control cabinet:



3773666827

[1] HF equipotential bonding between the mounting plate and the PE busbar
[2] PE busbar

Conclusion

From an electrical safety perspective, the PE busbar is the star point.

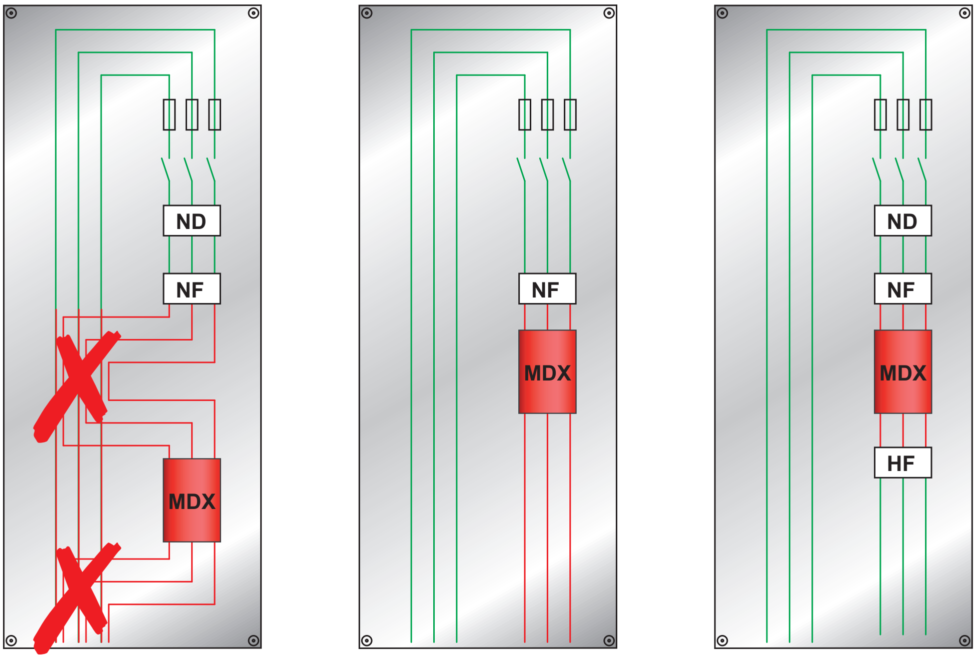
In terms of EMC, it is advantageous if the mounting plate is used as a star point with respect to HF equipotential bonding.

2.3.4 Arrangement of the EMC components

You can install EMC components to improve electromagnetic compatibility. **EMC components, such as line filters and output filters, require a large-area, metallic contact with the inverter via a shared mounting plate.**

They must be placed as close to the corresponding unit as possible in order to keep the lines short between the EMC component and the unit (max. 50 cm).

Stick to the following order of the components in the control cabinet:



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ND	Line choke	Green cable	= Cable without EMI
NF	Line filter	Red cable	= Cable with EMI
MDX	Inverter		
HF	Output filter		

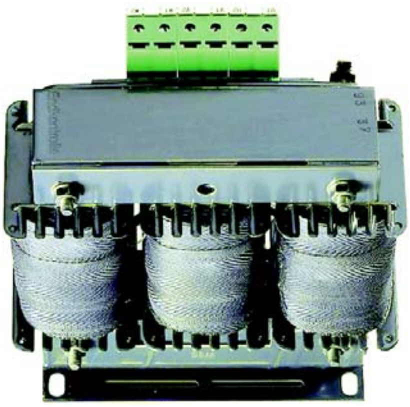
Make sure that the supply from the grid (before the line filter) does not run in parallel with the cable with EMI (after the line filter). Otherwise, the already filtered cable is exposed again to EMI.

If these requirements cannot be met, it makes sense to use shielded cables. To eliminate inductive coupling, you should not use single conductors for connection.

If you install EMC components on the base plate of the control cabinet due to their high weight (not ideal in terms of EMC), you must connect the base plate with the mounting plate using an HF braid.

2.3.5 Line choke

A line choke dampens voltage and current peaks. As a result, the line harmonics are also dampened.



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Power line harmonics

During operation, an inverter always generates line harmonics. An optimization of the inverter can limit or reduce these harmonics already when they are generated.

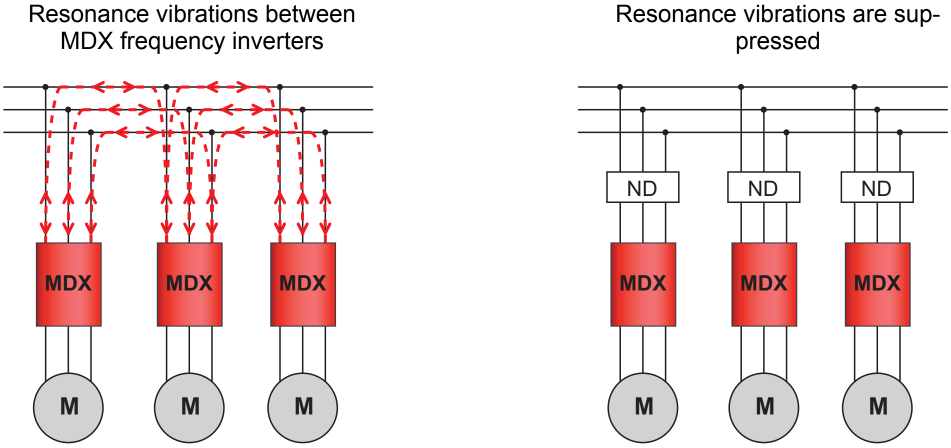
Line chokes are fitted ahead of inverters with high line current distortion. They smoothen the input current to an almost sinusoidal waveform, reducing the amplitude of the line harmonics.

SEW inverters

In modern frequency inverters with lean DC link (e.g. inverters from SEW-EURODRIVE), the harmonics are usually low enough so that a line choke is not necessary.

Resonance vibration

When several frequency inverters are installed next to each other and supplied via very short cables, resonance vibrations can occur between the inverters.



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The resonance vibrations can put a strain on the rectifiers at the inverter input and cause premature aging.

In such cases, a line choke must be connected before each frequency inverter. These line chokes dampen the harmful resonance vibrations.

Voltage spikes

Switching high power contactors causes voltage spikes in the supply system. These spikes can cause the inverter to shut down or even destroy it.

A line choke protects the inverter from these voltage spikes. In case of critical supply system conditions, in which voltage spikes are expected, SEW-EURODRIVE recommends using a line choke for inverter protection.

Inrush current spikes

When several frequency inverters are switched on at the same time, the total inrush current adds up. Especially in the case of small supply system contactors, too high an inrush current can lead to sticking or welding of the contacts.

Conclusion

If several frequency inverters are to be switched on simultaneously, you should connect a line choke before each frequency inverter.

2.3.6 Line filter

The line filter keeps back the interference voltages generated by the frequency inverter from the power supply system and feeds them back to the frequency inverter.

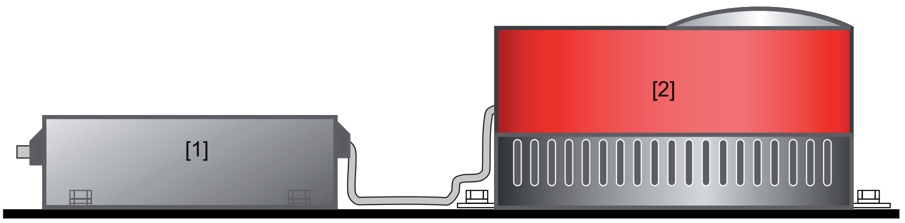
5552897931

Note the following:

- The selection of the line filter depends on the inverter current and the line voltage of the frequency inverter.
- The line filter is selected according to the recommendation of the component manufacturer, who has proven compliance with the limit values in typical configurations. Proof for the variety of possible combinations of grid conditions, line filters, inverters, motor cables, and motors is not stipulated in the standards.

  It is <u>not</u> recommended to select line filters according to damping curves, because they only apply for idealized measurement conditions and can deviate considerably from that in specific applications.
- Install one line filter just before each frequency inverter.
- As an alternative, you can also use a shared line filter for the entire control cabinet. The common line filter is selected on the basis of the total current of all inverters.
- Do not install any switching element (e.g. contactor) between the line filter and the frequency inverter.

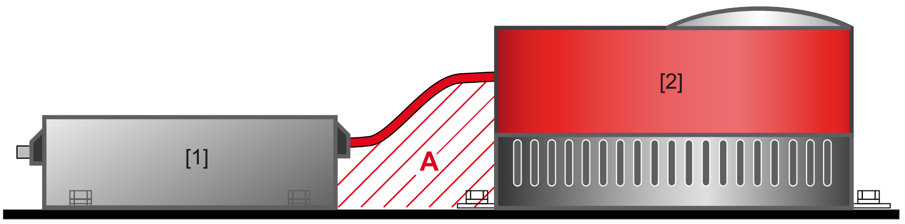
- Route the cable between the filter [1] and the frequency inverter [2] as closes as possible to the mounting plate.



Metallic contact over a large area at the common mounting plate.

237370123

If you install the cable at a large distance from the mounting plate, the radiation area increases and so does EMI.



Radiation area between cable and mounting plate   Common mounting plate

3774704907

- For this reason, route the cables as close to the reference potential (mounting plate).

  Suspended cables act as active and passive antennas.

Use

The use of line filters is recommended for the following requirements:

- Reduced EMI via the line cable
- Compliance with limit values
- Reduced equipotential bonding currents
- Reduced leakage currents in case of long motor cables

2.3.7 Output choke (ferrite core choke)

An output choke is a cost-effective measure to reduce the EMI potential of the motor lead of the inverter.

The emission limits for radio interference suppression are met if the output choke is suitably sized.

SEW-EURODRIVE offers output chokes for different core cross sections (open variants HD001, HD002, HD003) and for inverter variants (HD012, HD004, HD005).

An output choke has the advantage that no additional voltage drop is caused at the inverter output. Usually, 3 – 5 turns around a toroidal core are sufficient.

Output chokes are usually used with unshielded motor cables.

Special case: Shielded motor cables with several plug connectors

INFORMATION

Plug connectors within a shielded motor line are not ideal with respect to EMC.

However, plug connectors are often a requirement in the automotive industry to avoid downtimes in case of failures.

If the shielded motor line has several plug connections, the shielding effect might deteriorate. In such cases, an output choke can also be used in combination with a motor cable shield. The leakage currents dissipated via the motor cable shield place an additional load on the output choke. This leads to a higher temperature.

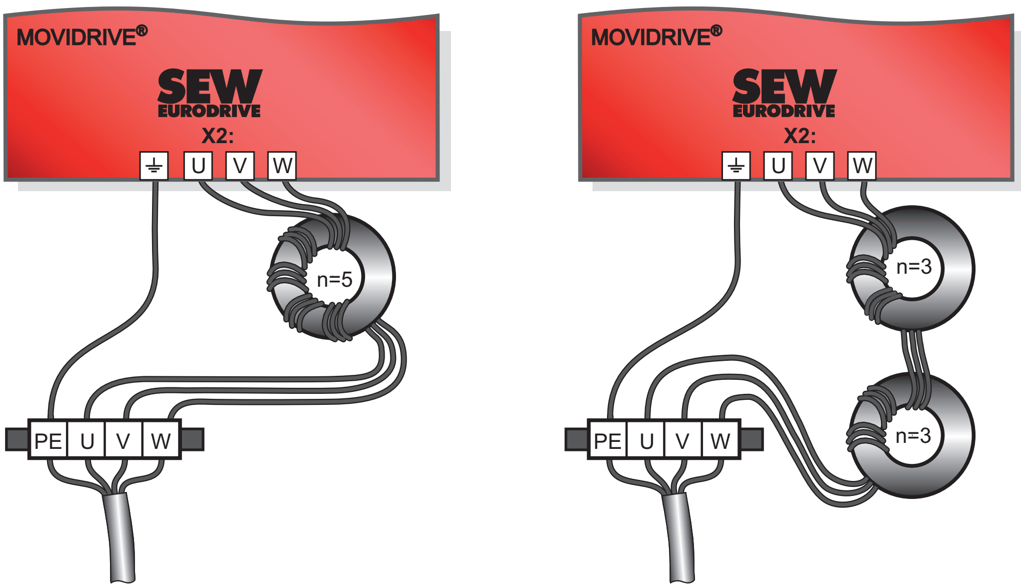
High operating temperature

The output choke can have high operating temperatures (above 100 °C) at the toroidal core. In open variants, a plastic guard protects the core insulation of the motor cables. If the application requires lower temperatures, the temperature can be reduced by using a second output choke.

When installing a second output choke, you must reduce the number of conductor windings on the ferrite core.

1 output choke with 5 windings

2 output choke with 3 windings



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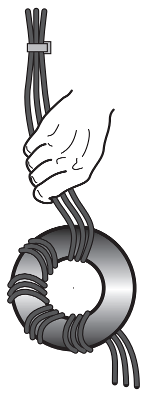
Installation

Always wind the motor conductors together on the output choke as follows:

1. Take the three conductors into one hand.
2. Secure the beginning of the three conductors with a cable tie.
3. Wind the three conductors together through the ring core five times.

Now all three conductors are routed in parallel around the ring core.



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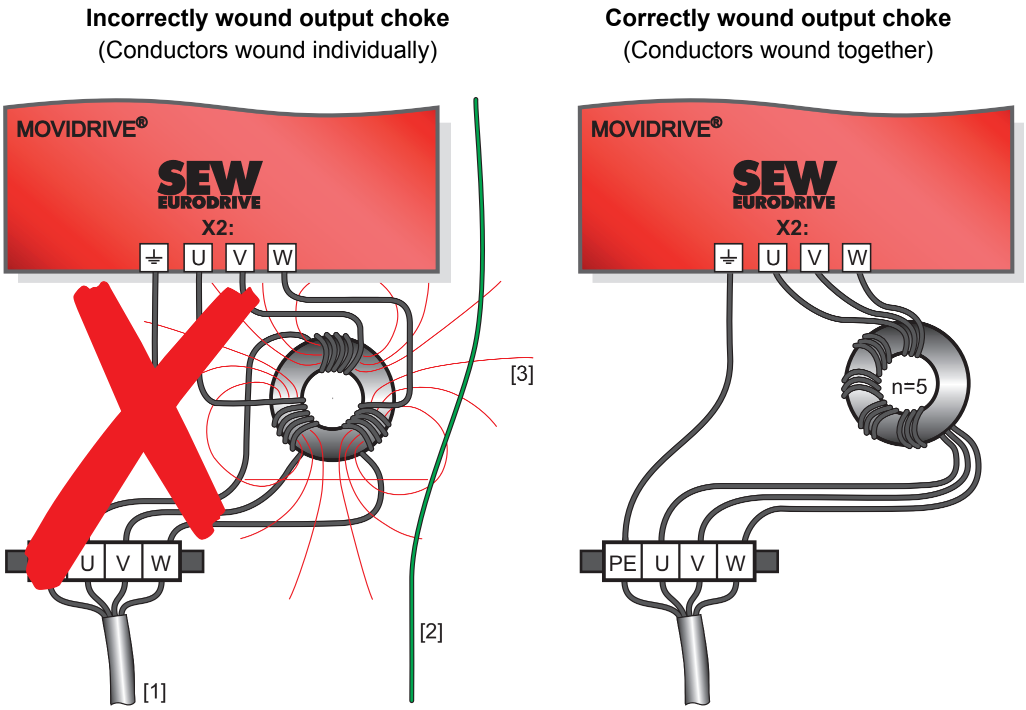
Note the following:

- Wind all three conductors in the same direction.
- Do not mix up the beginning and the end of the conductor. Otherwise this will cancel the effect of the choke.
- If you wind each conductor around the ring core individually, there is a risk that the winding direction or the beginning and end of the conductor are mixed up.

  There is also a risk of an increased stray field forming around the areas of the ring core that are not wound. This stray field can interfere with sensitive conductors.

The following figure shows how to connect the output choke:



5382193419

[1] Motor cable
[2] Sensitive signal conductor
[3] Stray field

Use

An output choke suppresses interference at the inverter output.

An individual output choke is quickly overloaded by a group drive.

2.3.8 Output filter (sine filter)

The output voltage of an inverter is formed from square-wave pulses.

An output filter converts this square-wave output voltage to an almost sinusoidal voltage, see following figure.

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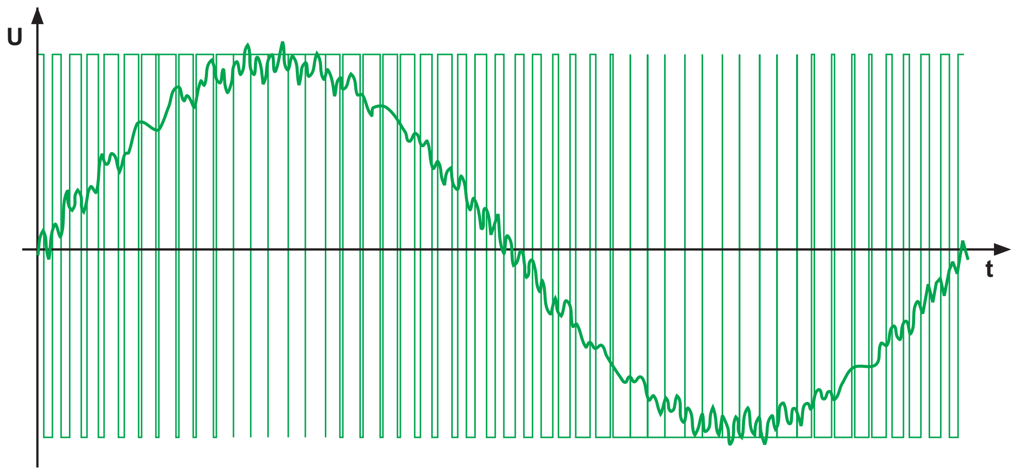

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Group drive

The square-wave output voltage of the inverter generates leakage current spikes in the parasitic capacitances of the motor cable and motor windings. In group drives, these leakage current spikes add up and can reach values that are not permitted for the inverter.

The leakage current spikes depend on:

- The number of motors connected in parallel,
- The type and length of the cable at the inverter output,
- And the size of the motors.

When using an output filter, these leakage current spikes are significantly reduced due to its sinusoidal output voltage. The output filter loads the inverter with a filter current component, which is independent of external factors such as number of motors, cable type, and cable length.

Motors that are not designed for inverter operation

The square-wave output voltage of the inverter can cause overvoltages in the motor, see chapter "Voltage load of the motor caused by inverter pulsing". In motors that are not designed for inverter operation, these overvoltages can destroy the winding insulation of the motor. Using an output filter solves this problem reliably. Thanks to the sinusoidal voltage after the output filter, the overvoltage is significantly reduced. This takes load off the insulation system of the motors. To avoid overvoltages caused by resonance against ground (e.g. in case of long cables), the output filter should also filter against ground. This is realized by feeding the signal back to the DC link (U_Z connection).

Noise filtering

The square-wave pulses of the inverter output cause audible noise in the motor. This noise in the range of the inverter pulse frequency can be very unpleasant. The output filter dampens this noise in the motor considerably. The filter itself creates noise in the range of the inverter pulse frequency.

Radio interference suppression

The use of an output filter enables operation without shielded motor cable also in applications that stipulate limit values.

Output filter without DC link connection

An output filter **without** DC link connection converts a pulsed inverter voltage to a sinusoidal voltage when connected phase-to-phase.

When connected phase-to-ground, it has a considerably reduced filter effect.

Output filter with DC link connection

An output filter **with** DC link connection converts a pulsed inverter voltage to a sinusoidal voltage when connected phase-to-phase and phase-to-ground.

When connecting the output filter to the DC link, you must increase the pulse frequency. With a pulse frequeny of 12 kHz, the inverter only delivers about 70% of its nominal power.

Dimensioning

The selection of the output filter depends on the nominal current and the nominal voltage of the inverter.

If the nominal current of the motor is smaller than the nominal current of the inverter, you select the output filter based on the motor current.

When operating several motors in parallel, select the output filter based on the total motor current.

Note the voltage drop at the output filter as specified under "Technical data". This voltage drop reduces the voltage that is available to the motor.

Motor cable

Only connect unshielded cables as motor cables to the output of the output filter.

Shielded cables can cause resonance vibrations between the shield capacitance and the capacitance of the output filter. These resonance vibrations can damage the output filter.

Use

The use of output filters is recommended for the following applications:

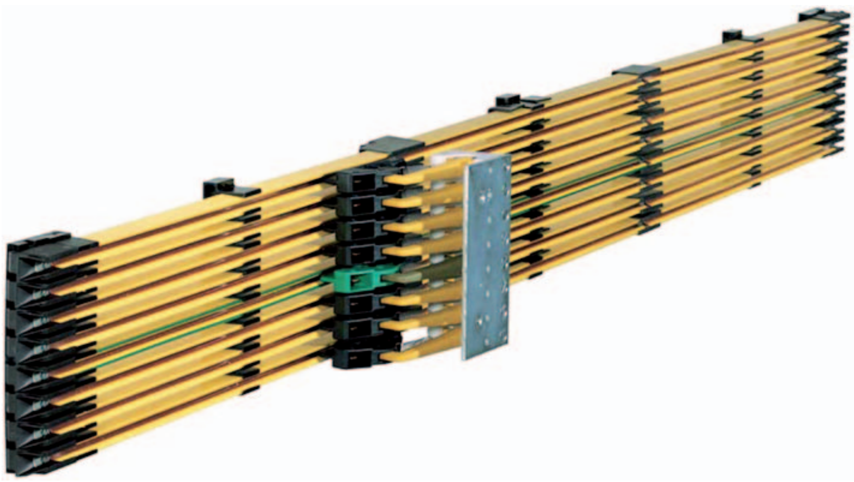
- Group drive (several motors connected to one inverter)
- Noise filtering
- Interference suppression with unshielded motor cables
- Protection from voltage spikes

Price

The purchase price, size, and energy loss of an output filter and an inverter are similarly high. This is why many project planners try to avoid using an output filter, even though the output filter is an almost ideal solution from an EMC perspective.

Conductor rail as motor supply

If you are using insulated conductor rails after a frequency inverter as a motor supply (e.g. from companies Wampfler or Vahle), SEW-EURODRIVE recommends using an output filter. A shielded cable is not possible in this case.



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The output filter offers protection from EMI. It also protects the output stage of the inverter in case of problems with the current collectors. The output filter acts like a buffer here.

Only use conductor rails with double current collectors (2 brushes in series).

For the PE conductor, use 2 current collectors with two separate holders.

2.4 *Control cabinet components*

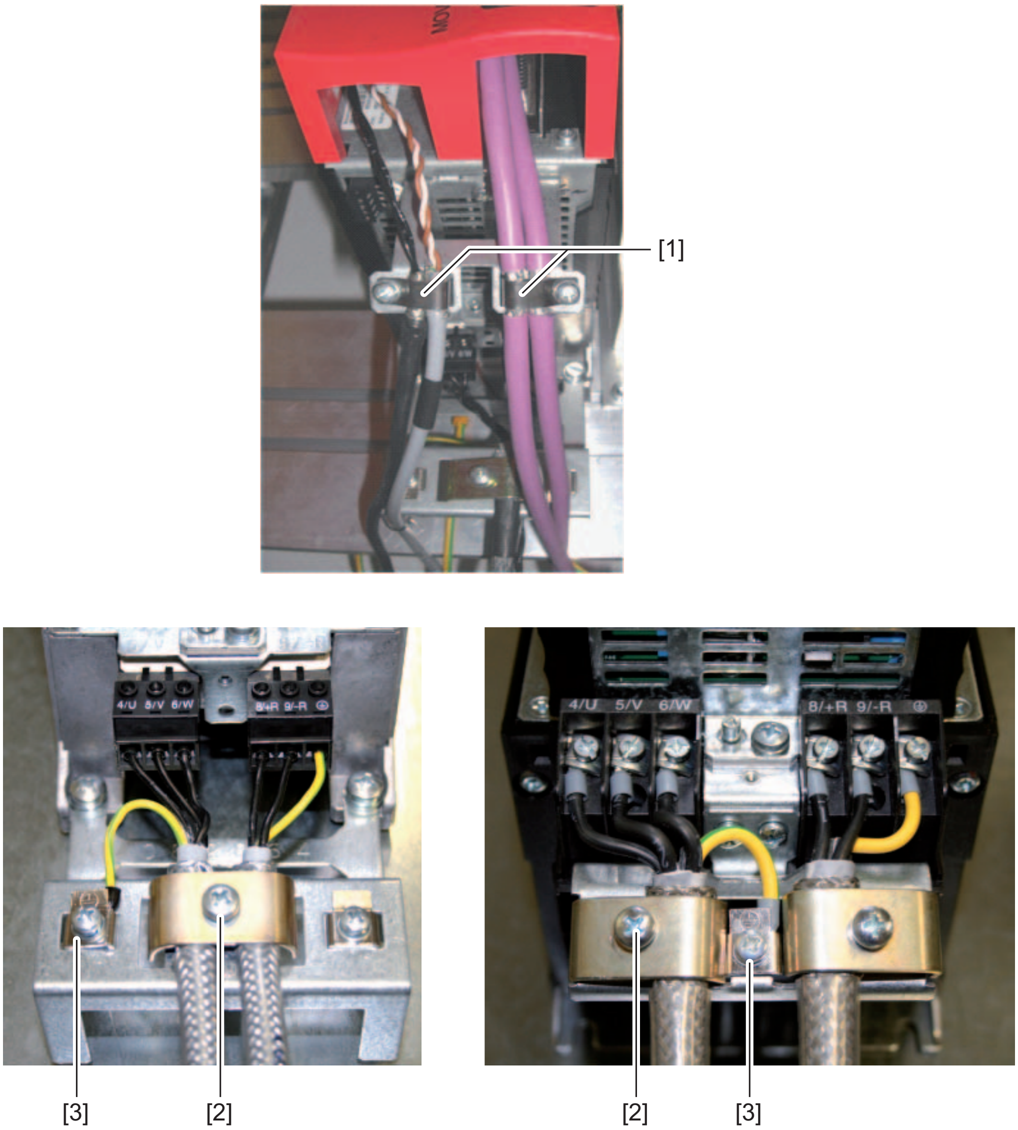
The following chapters exemplify equipotential bonding of the components in the SEW-EURODRIVE control cabinet.

2.4.1 MOVIDRIVE® MDX

Connection of braided shield of MOVIDRIVE® size 1 and 2

The following figures show the connection of braided shields to the MOVIDRIVE® MDX frequency inverter, size 1 and 2:

Control unit



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Power section
Size 1

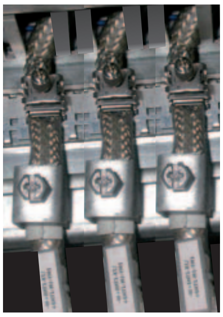
Power section
Size 2

[1] Connection of braided shield of signal cables (24 V cable, encoder cable and bus cable)
[2] Connection of braided shield of power cables (power section shield clamp)
[3] PE connection

Connection of braided shield of MOVIDRIVE® size 3 to 6

The following figure shows the connection of the braided shields of 3 MOVIDRIVE® MDX frequency inverter of size 3 – 6:

Connect the braided shield of the motor cable on the input side shield plate of the control cabintet according to the following figure:



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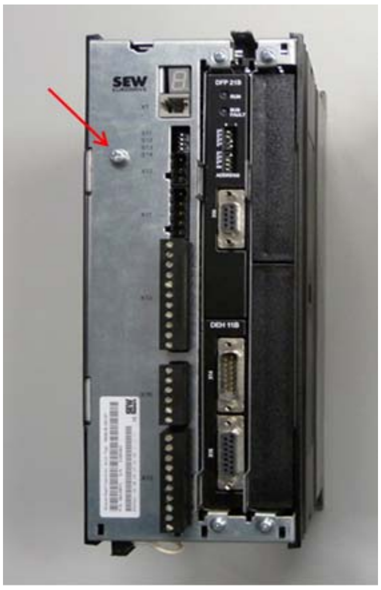
Increased encoder availability due to grounding screw of MOVIDRIVE® control unit

By using the grounding screw at the MOVIDRIVE® control unit, the reference potential of the 24 V supply can be separated from the PE conductor.



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- Grounding screw screwed in → direct connection with 0 V of 24 V supply

  DGND (X10, X12, X13, X16, X17) is connected with PE

  This means the MOVIDRIVE® inverter has increased protection against encoder errors.
- Without screw → high insulation resistance

  Removing the M4 grounding screw creates electrical isolation.

  Ground connection is now via 4 capacitors and a high resistance to ground.

Example: Insulation monitor in 24 V supply

For additional operating reliability, the 24 V supply is partly monitored by an insulation monitor (e.g. in the chemical industry). This monitoring offers additional protection from malfunctions of the plant in case of faulty insulation in the 24 V control circuit.

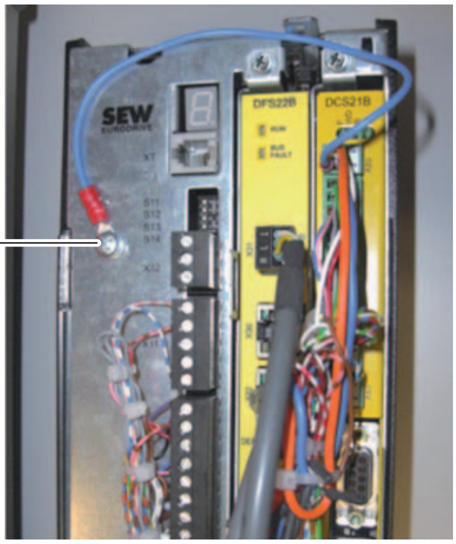
If electrical isolation is not possible in a unit, you must provide a separate 24 V supply.

Equipotential bonding of the DCS21/31B option card

The following figure shows the equipotential bonding of the DCS21B/31B option card at the MOVIDRIVE® MDX frequency inverter of size 1 to 6:

MOVIDRIVE®
with grounding screw

[1]



3851412747

[1] Equipotential bonding of the option card using a grounding screw

INFORMATION

If you install the DCS21B/31B option in a MOVIDRIVE® MDX B frequency inverter without tapped hole, proper operation cannot be ensured.

SEW-EURODRIVE recommends to replace the MOVIDRIVE® MDX B frequency inverter without tapped hole by a MOVIDRIVE® MDX B frequency inverter with tapped hole.

2.4.2 Braking resistor

Braking resistor cables

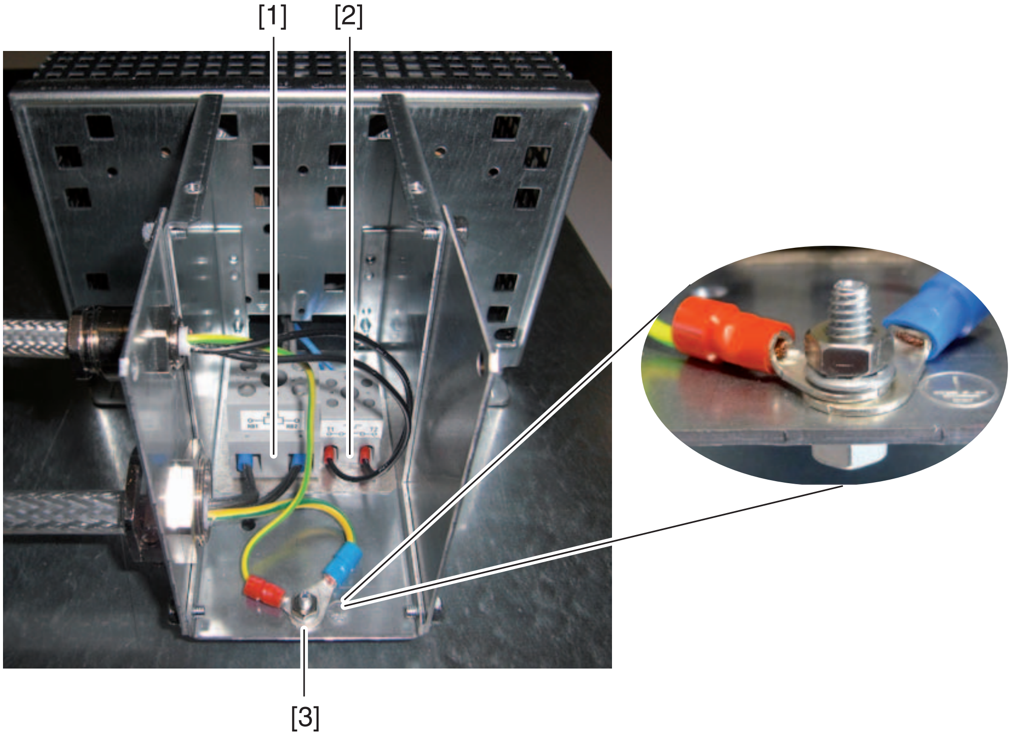
For connecting braking resistors to the inverter, use two closely twisted cores or a shielded power cable.

The nominal voltage of the braking resistor cable must be at least U_0 / U = 300 V / 500 V according to DIN VDE 0298.

Installation of steel-grid braking resistor

Install the braking resistor over a large, non-painted area, if possible. If this is not possible, you can also mount the braking resistor to the control cabinet panel using tooth lock washers.

The following figure shows the connection of a steel-grid braking resistor with temperature sensor or temperature switch:



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[1] Braking resistor connection
[2] Connection of TH temperature switch
[3] PE connection

2.5 *Cables*

2.5.1 Routing

Observe the following notes:

- Route the supply and return cables together.
- Avoid spare loops in all connection cables.
- Unused conductors must be grounded at both ends.
- Preferably route conductors emitting EMI in the corners of a metal cable duct or corner profile. This reduces the radiation of the conductor.

235879819

K	Cable duct
E	Corner profile
S	Shielding effect

The shielding effect is improved significantly by using enclosed cable ducts.

Distance between conductors

The greater the distance between conductors, the smaller the parasitic capacitance and the smaller the interference current.

The parasitic capacitance (interference capacitance) increases

- with decreasing distance between conductors
- with increasing length of conductors routed in parallel

The interference current increases with increasing voltage in the interference-source cable.

Distance from the reference potential

Route the cables as close as possible to the reference potential, such as the mounting plate, metal cable duct, or grounded machine support.

Suspended cables act as active and passive antennas.

Cable groups

The interference source (e.g. motor cable) is usually coupled with the susceptible equipment (e.g. sensitive conductor, device) via the connected circuits. This is why cable routing and the type of cable play an important role in EMC.

For systematic cable routing, the cables are classified into groups according to the signals they transmit. This classification makes it possible to define general, practical rules for cable routing.

In practice, a classification into 4 cable groups has proven useful. The cable groups can be characterized as follows:

Cable group	Examples
Group 1 Very sensitive	Encoder cable Analog sensors Measuring line Capacitive proximity switches Bus cable
Group 2 Sensitive	Small signal cables Small signal supply (10 V, 24 V)
Group 3 Interference sources	Control cables for inductive loads (brakes, contactors, relays) Interference-suppressed power cables Power supply cables (unswitched)
Group 4 Strong interference sources	Power circuits Switched power cables (inductive loads, e.g. contactors) Pulsed power cables (inverter)

This group classification is the basis for the following rules of thumb for cable selection:

<table>
<tr><th>Cable group</th><th>In the control cabinet</th><th>Outside the control cabinet</th></tr>
<tr><td>Group 1</td><td colspan="2">Shielded, low-capacitance cable
Without interruptions up to the unit, if possible
Routed at some distance to groups 3 and 4</td></tr>
<tr><td>Group 2</td><td rowspan="2">Unshielded cable
Separate from groups 3 and 4</td><td rowspan="2">Cable
Routed at some distance to groups 3 and 4</td></tr>
<tr><td>Group 3</td></tr>
<tr><td>Group 4</td><td colspan="2">Shielded or filtered cable</td></tr>
</table>

Parallel, safe routing of cables from different groups is only possible with additional measures, such as shielding, filtering, or spacing.

In the control cabinet, power and signal cables must be branched off or split up several times. The cables are rather short. Radiation to the outside is reduced by the shielding effect of the control cabinet.

In the control cabinet, it is not always possible to route cables of groups 1 and 2 separately from cables of groups 3 and 4. However, parallel routing should be reduced to the necessary minimum.

- Motor cables in the control cabinet

  If you want to route an unshielded and unfiltered motor cable in the control cabinet, you have to twist the cores of the three phases and route them separately from sensitive conductors. However, this solution is only a compromise and should not be used in control cabinets with sensitive conductors.

- Braking resistor in the control cabinet

  Use only shielded cables or twisted-pair cables as braking resistor cables. Always route twisted-pair cables separately from sensitive conductors.

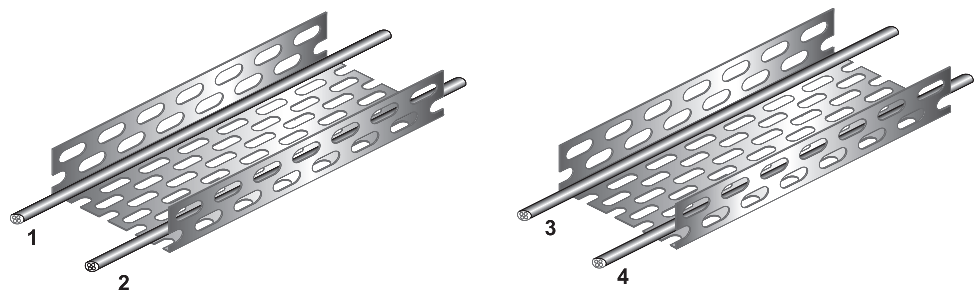
Outside the control cabinet, cables are often routed in parallel over long distances with little space in between. In case of non-EMC-compliant cable routing, this leads to increased coupling between the transmitted signals.

Outside the control cabinet, a distance of 20 cm between cables of group 1 or 2 and cables of group 3 or 4 is usually sufficient.

Installing cables from different groups

When installing cables from different groups, note the following:

- Always install cables of groups 1 and 2 as far from cables of groups 3 and 4 as possible, or separate them by means of a metallic partition.



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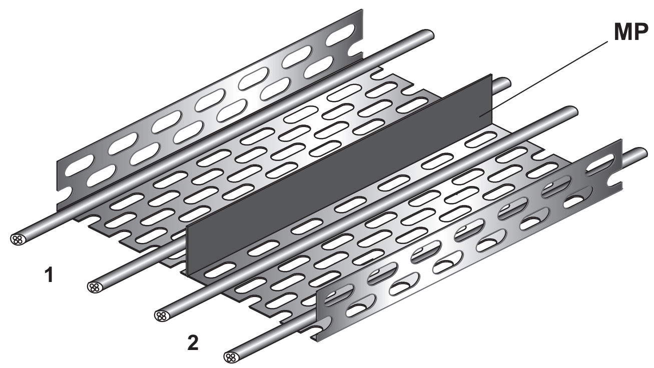
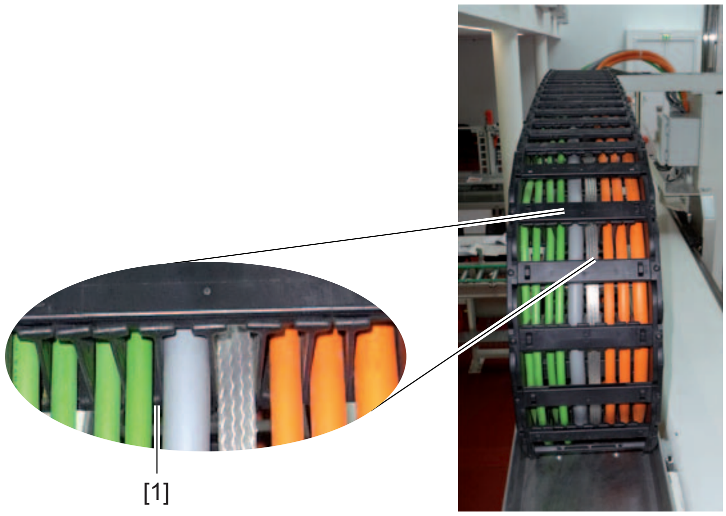


235452043

MP Metal partition

- The motor cables behind an output filter can be routed in the same cable duct as cables of other groups.

- Only use cable carriers with dividers [1].



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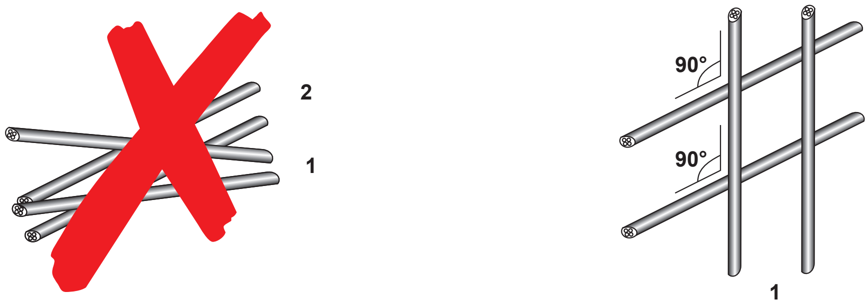
- Cross cables of groups 1 and 2 with cables of groups 3 and 4 at a right angle, if possible.



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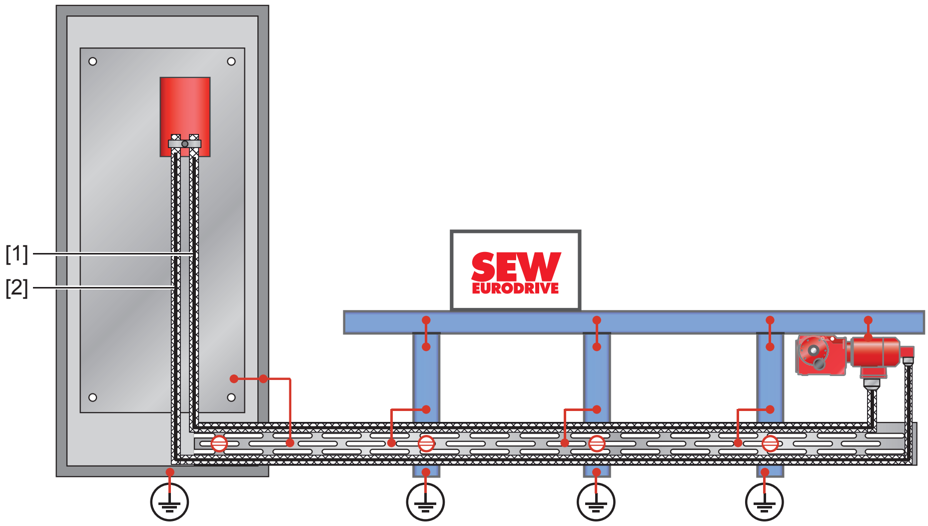
2.5.2 Shielding

Observe the following notes for shielding:

- Every conductor can emit or receive a magnetic field. This means that every conductor can act both as a transmitting and a receiving antenna.
- A single unshielded or unfiltered cable can nullify all the other measures taken.
- Single-sided shielding of a cable is only effective against capacitive coupling of parallel cables but not against magnetic fields.
- You always have to connect the shield on both ends against magnetic radiation. The shield should be made of copper.



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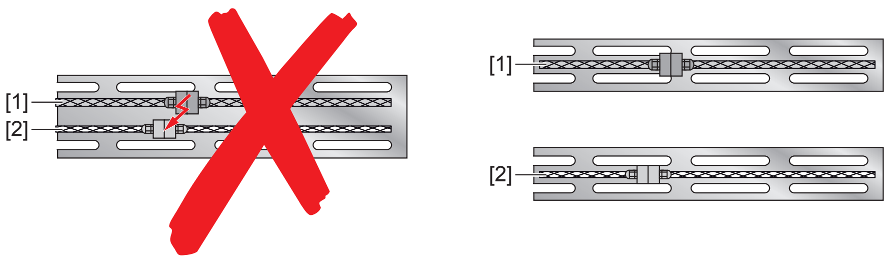
[1] Motor cable (grounded on both ends)
[2] Encoder cable (grounded on both ends)

Exception:

- Routing the cable in a metal duct dampens radiation as well, but not as effectively as a copper shield.
- Metal pipes are good shields. Special attention must be paid to the connection of the shield at both pipe ends.
- Shielded cables from different groups that are grounded on both ends can be routed in the same cable duct.

  However, cables that have been extended with plug connectors must be routed in separate cable ducts. Otherwise, interference can be transmitted via the plug connectors.



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[1] Motor cable
[2] Encoder cable

Practical experience

- Often, non-EMC-compliant plug connectors are used for extended shielded encoder or motor cables.
- The plug connectors of extended cables are often not assembled in line with EMC requirements.

Use only prefabricated cables from SEW-EURODRIVE for extended encoder and motor cables.

Shield types

In practice, different shield types are used for electric conductors. The following table shows the characteristics of the different shield types:

Shield type	Characteristic
Foil shield	Foil shields are often used for signal cables. Their advantage is the high degree of shield coverage of 100%. As the conductive layer is very thin, the effectiveness of foil shields is limited, especially in case of: • Strong magnetic interference fields • Higher interference currents due to small cross sections Make sure that the shield foil is not damaged by bending.
Braided shield	Braided shields are usually used for power cables. The higher shield cross section of braided shields offers better protection from high interference currents and strong magnetic fields. Optical shield coverage is an important characteristic of this type of shield. For EMC purposes, it must be at least 85%. Cables with iron armoring are not suitable for EMC purposes.
Multi-shields	Multiple shield cables offer better shield damping compared with single-shield cables. The combination of foil and braided shields offers the advantages of both types. As the manufacturing of such cables is very complex, they are usually only used for transmitting sensitive signals.
Piping	A special type of shielding is routing cables in metallic pipes. Metal pipes offer a large shield cross section and a shield coverage of 100%. This is why metal pipes are well-suited for shielding purposes. Special attention must be paid to the connection of the shield at both pipe ends and to the coupling between cables that are routed together in the pipe.
Ferrite coating	For power cables, there are sheath materials available with integrated ferrite particles for dampening interference currents. These cables are not very significant in practice due to their length-dependent damping and effectiveness. Especially with respect to longer cable lengths and the complex manufacturing technique, these cables are not very common.

Encoder cables

Only use cables with the following characteristics as encoder cables:

- Low capacitance (capacitance between the cores $C_{core-core}$ ≤ 70 nF/km (70 pF/m))
- With braided shield
- Twisted pair

Recommendation:

Only use prefabricated encoder cables from SEW-EURODRIVE.

If you prepare the encoder cable yourself, note the following guide values:

Unit	Capacitance $C_{core-core}$ of the encoder cable
MOVIDRIVE® drive inverters	≤ 120 nF/km (up to 50 m cable length) ≤ 70 nF/km (more than 50 m cable length)
MOVISAFE® safety module (MOVIDRIVE® option)	≤ 70 nF/km
MOVIAXIS® servo inverter	≤ 70 nF/km

Example: Encoder cables from the company HELUKABEL®

HELUKABEL® type	Use
Li**9Y**CY	SEW-EURODRIVE uses this cable (70 nF/km) as standard low capacitance encoder cable.
Li**2Y**CY	This cable can also be used as encoder cable. $C_{core-core}$ = 70 nF/km
Li**Y**CY	This cable is also often used as encoder cable. This cable is not a low capacitance conductor. $C_{core-core}$ = 120 nF/km

Long, shielded cables

Observe the following notes for long shielded cables;

- The shielding effect decreases with increasing cable length. You can improve the shielding of longer cables by grounding the shield at regular intervals with several cable clamps.
- Each cable has a parasitic capacitance that drains off earth-leakage currents to ground. Shielding significantly increases this parasitic capacitance.
- In long shielded motor cables, the high leakage currents can cause considerable interference. Use output filters or ferrite cores instead of the shielded cable in such cases.

If the shield of an already installed shielded cable is not wanted, there is no need to replace this cable.

You can also disconnect and insulate the shield on both ends. Make sure that the insulation is sound, e.g. with shrinking tubing. In case of poor insulation, sparks can be created at the shield ends against ground or other conductive objects.

Disconnecting the shield can be necessary for the following reasons.

- Subsequent installation of an output filter
- Increased leakage current
- Capacitance of long cable is too high
- Group drives

No shielded cables in case of group drives

Group drives have increased leakage currents as the capacitance of the motor cables and motors increases with parallel connection. The leakage currents put an additional load on the output stage of the frequency inverter.

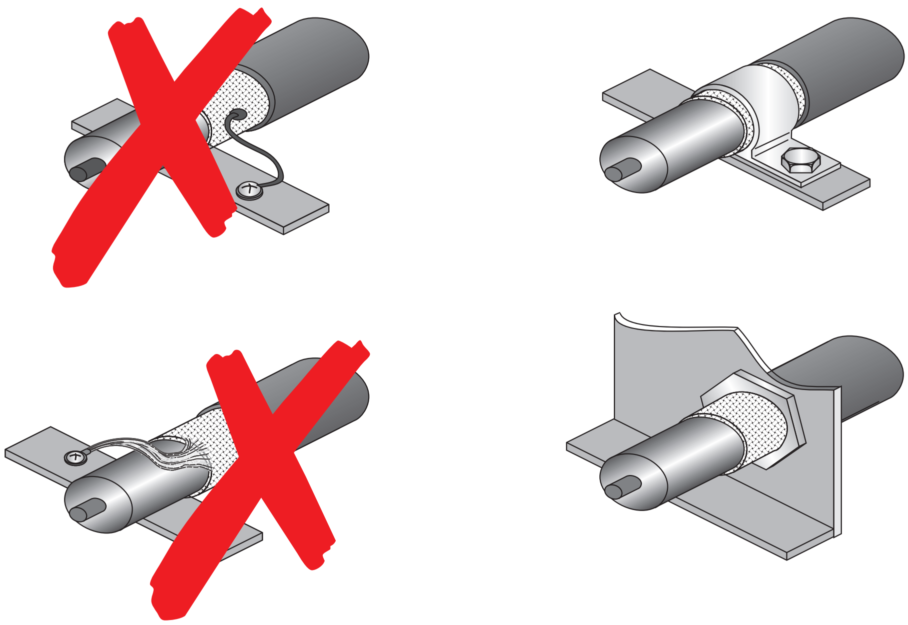
These leakage currents strongly increase when shielded motor cables are used. They can also trip the motor protection switch that is usually used in group drives. This is why you should preferably use unshielded cables for group drives. If the plant must meet EMC limit values, install an output filter instead.

Braided shield connection

Connect the braided shield over its entire circumference using grounding clamps or EMC cable glands.

Do not connect the shield via a twisted braid (so-called pigtail) or a wire extension. This can reduce the shielding effect by up to 90%.

The following figure shows the different options for connecting the shield:



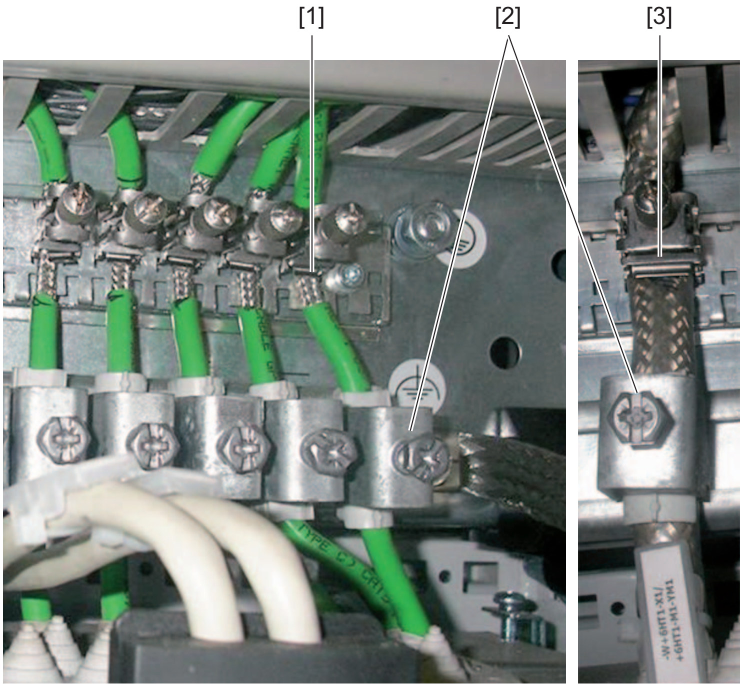
235857803

Incorrect shield connection
via wire extension
or twisted braiding

Correct shield connection
over entire circumference to housing
or grounded surface

Practice

The following figures show braided shield connections in practice:



3779830539

[1] Shield of encoder cable connected to shield plate of control components
[2] Mechanical cable relief
[3] Shield of motor cable connected to shield plate of power components

Note the following:

- Connect the braided shields of the encoder and bus cables to the shield plate of the control components [1].
- Connect the braided shield of the motor cable to the separate shield plate for power components [3].
- Fix the cables in position with mechanical cable reliefs [2].
- If the shield plate is not directly connected to the uncoated mounting plate, you have to establish an HF connection to the PE busbar in the control cabinet.
- The braided shield can also be connected directly at the frequency inverter.

EMC cable glands

Use an EMC cable gland of the following type for routing the cable into a housing:

3880956939

For example:

Manufacturer	Sales	Thread	Type
Jacob	Sonepar	Mxx	50.6xx M / EMC
		M20	50.620 M / EMC

You can also use EMC cable glands from the company Hummel:

HSK-M-EMV: Type comparable with 50.6xx M / EMC from the company Jacob

HSK-MZ-EMV: With integrated strain relief and bending protection

HSK-M-EMV-D: For leading through the braided shield

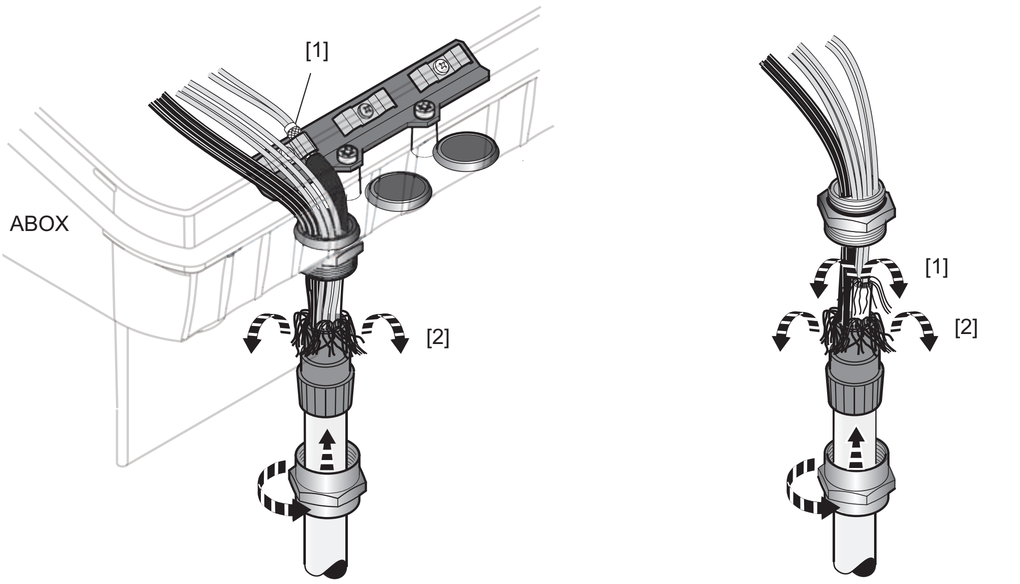
Shielding of hybrid cables

Each shield of a hybrid cable must be connected on both ends.

Example with MOVIFIT®

Connecting the 2nd braided shield of a hybrid cable to the shield plate

Connecting the 2nd braided shield of a hybrid cable with an EMC cable gland



3780284427

[1] Inner shield
[2] Outer shield

If there is no shield clamp for another braided shield of a hybrid cable, you must connect all braided shields to the EMC cable gland together.

Faulty prefabrication of hybrid cables

Prefabricated hybrid cables are often shortened on the motor end by customers or assembled by the customers themselves.

The following error is made often here:

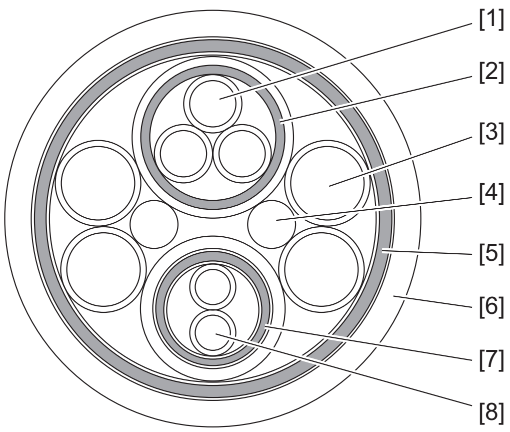
- The outer shield is connected correctly.
- The inner shield is connected correctly on the inverter end.
- **Error:** The inner shield is **not** connected correctly on the motor end.

Example of motor/brake cable:

If the brake cable of an hybrid cable is connected only on one end, the shielding effect is not sufficient.

In case of a pulsed motor cable with insufficient shielding, HF interference peaks are induced the brake cable. These HF interference peaks in the brake cable put an impermissibly high load on the brake rectifier, so that it ages more quickly.

The following figure shows the cross section of a hybrid cable (SEW-EURODRIVE, type D) with cores for connecting the motor [3], the brake [1], and the temperature sensor [8]:



3780763403

[1] Brake cable
[2] Brake cable shield
[3] Phase of motor cable
[4] Filling element
[5] Outer shield
[6] Outer cable sheath
[7] TF cable shield
[8] TF cable

- Connecting the inner shield of the brake cable in the hybrid cable on one end only can damage the brake rectifier and subsequently the brake coil in the long run.
- If the shield of a TF cable is not grounded on both ends, encoder errors can be triggered.

Connect each shield of the hybrid cable and TF cable on both ends.

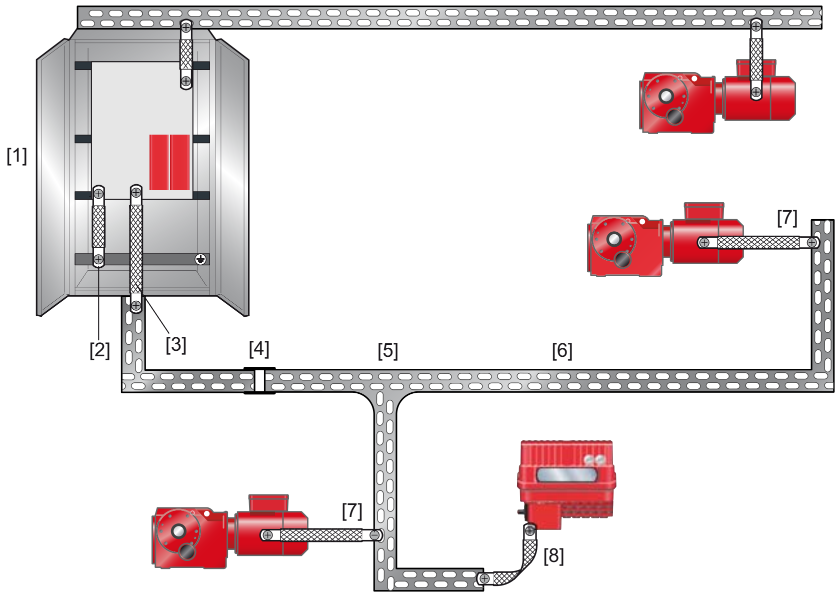
2.6 *Equipotential bonding in the plant*

2.6.1 Interlinked equipotential bonding

If you interlink several machines, you must provide for equipotential bonding between the control cabinet, conveyor elements, cable ducts, and resources.

- From an electrical safety perspective, the PE busbar is the star point.
- In terms of EMC, it is advantageous if the mounting plate is used as a star point with respect to HF equipotential bonding.

The following figure shows an example of interlinked equipotential bonding between several components:



3853533579

[1] Control cabinet with PE busbar
[2] Connection between the mounting plate and the PE busbar
[3] HF-capable connection of cable duct to PE busbar
[4] Connection between cable ducts over a large area
[5] Branches with extensive angles
[6] Cable duct made of sheet metal
[7] HF-capable equipotential bonding of the gearmotor to the cable duct
[8] HF-capable equipotential bonding of the MOVIFIT® unit to the cable duct

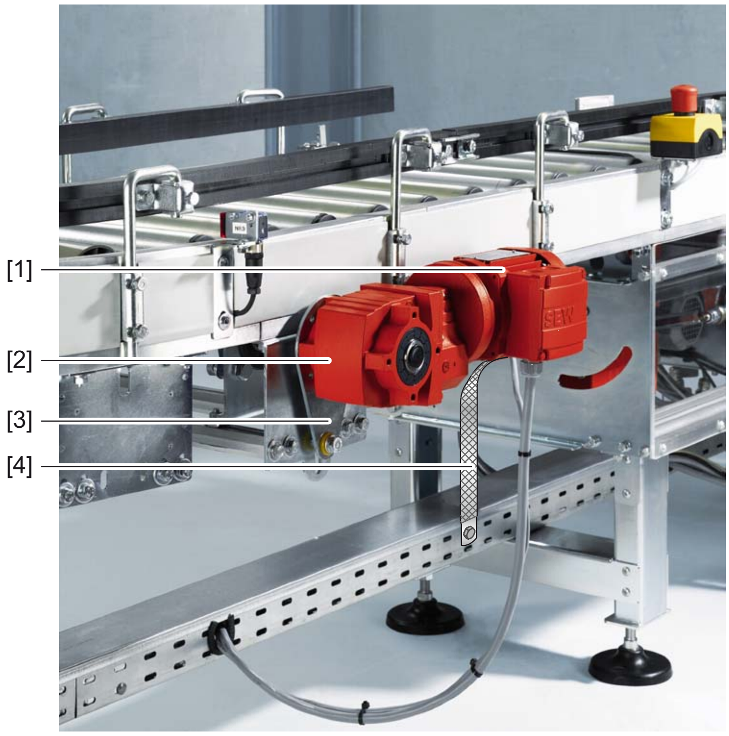
Observe the following notes when establishing equipotential bonding:

- Install the control cabinet with PE busbar according to the illustration above.
- Connect the cable duct to the control cabinet over a large area.
- Connect the cable duct with the mounting plate in the control cabinet [3] using an HF braid.
- Connect the PE busbar with the mounting plate [2] over a large area (HF connection).
- Connect the parts of the sheet metal cable duct with each other [4] over a large area.
- Connect cable ducts that branch off with large-area brackets [5] or with HF braids.
- Connect the PE connection of MOVIFIT® with the cable duct [8] using an HF braid.
- Connect the gearmotor with the cable duct [7] in the same way.

2.6.2 Example: Drive with shaft-mounted gear unit

Equipotential bonding for protection of the brake rectifier

A drive with shaft-mounted gear unit is mechanically connected to the plant only via the shaft and a torque arm.



5374678539

[1] Motor
[2] Shaft-mounted gear unit
[3] Torque arm with rubber bushing
[4] HF braid

The bearings of the gear unit offer no sufficient equipotential bonding for the drive. The torque arm is often equipped with an elastic rubber bushing that electrically isolates the drive from the plant. This means the drive has no HF-capable equipotential bonding.

Due to this insufficient equipotential bonding, some of the leakage currents from the motor flow back to the inverter in the control cabinet via the brake cable. This means the leakage currents flow through the brake rectifier, where they damage the electronic components of the brake rectifier. This can lead to accelerated aging and to an early failure of the brake rectifier.

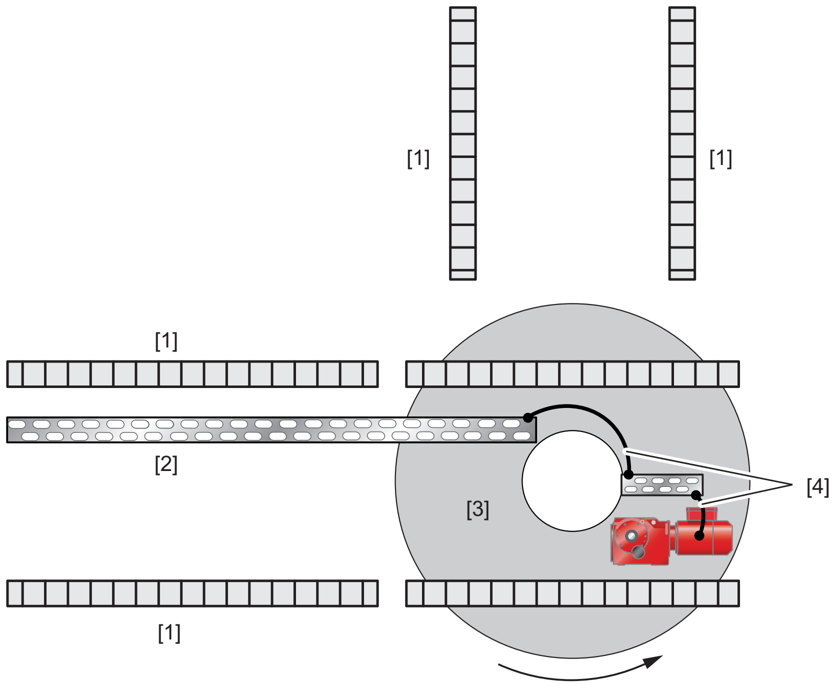
In hoists and rotary tables, the equipotential bonding of the mobile drive might also be unsuitable for HF. The insufficient equipotential bonding of mobile drives of hoists and rotary tables can also lead to an early failure of the brake rectifiers.

Conclusion

Always install an HF braid between the motor and the plant in case of shaft-mounted gear units, hoists, and rotary tables. The leakage currents then flow to ground via the HF braid.

2.6.3 Example: Rotary table

The following figure shows the equipotential bonding of a rotary table:



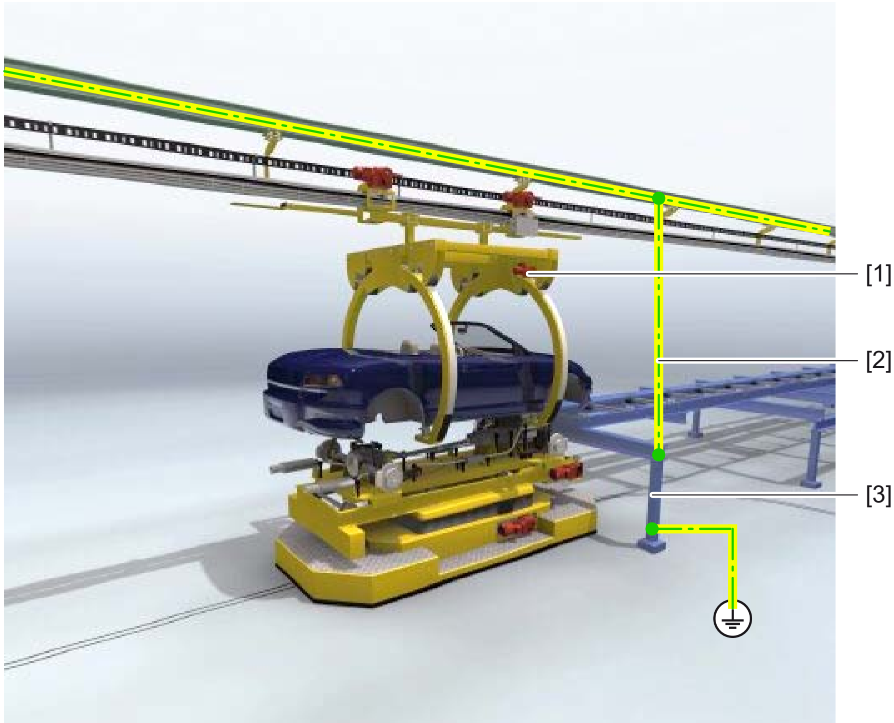
3854592267

[1] Chain of the chain conveyor
[2] Cable duct made of sheet metal
[3] Rotary table
[4] Equipotential bonding between stationary and mobile cable ducts and motor

Establish equipotential bonding between the stationary cable ducts, mobile cable ducts, and the motor as shown in the figure above [3].

2.6.4 Example: Electrified monorail system

The following figure shows the equipotential bonding at the docking station of an electrified monorail system:



3855975947

[1] Frequency inverter of the turning device with line filter
[2] Equipotential bonding of PE busbar to docking station
[3] Docking station

- Mobile drive on the electrified monorail unit

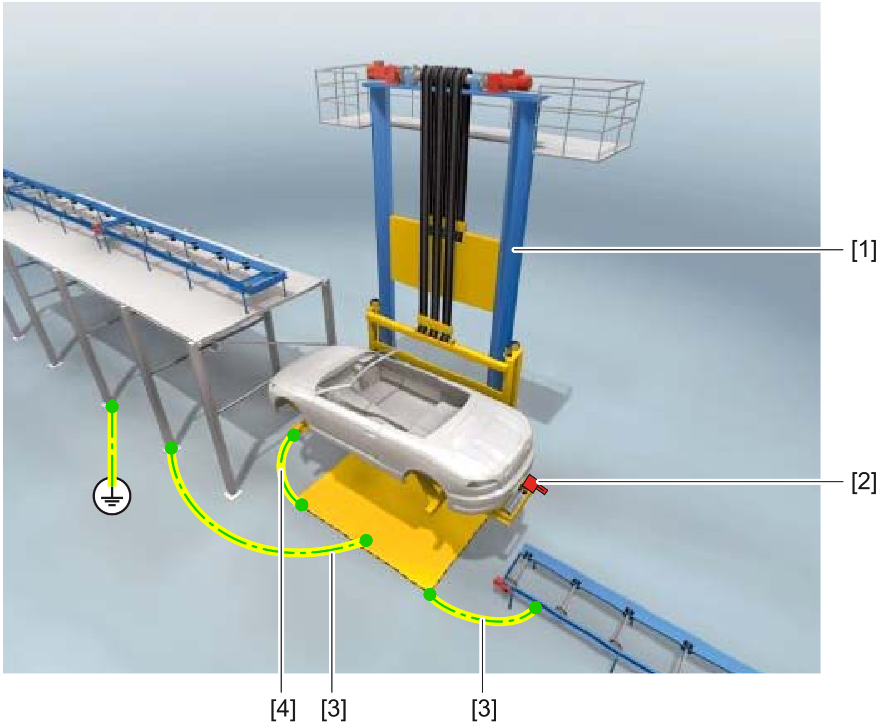
  If a controlled drive travels on an electrified monorail unit, the mobile drive must be equipped with a line filter. In smaller frame sizes, the line filter is already integrated. The line filter feeds the largest part of the leakage currents back to the frequency inverter. This reduces the risk of leakage currents dissipating via other components and interfering with equipment or communication.

- Equipotential bonding of the electrified monorail system at the docking station

  If an electrified monorail system is supplied with power via a conductor rail system, you must install an equipotential bonding cable between the PE busbar of the conductor rail system and the stopping point of the docking station. This ensures that no potential difference can occur between the electrified monorail system and the docking station. This prevents electrical hazards to persons.

2.6.5 Example: Hoist with integrated roller conveyor

The following figure shows the equipotential bonding of a hoist with integrated roller conveyor:



3857042187

[1] Hoist
[2] Mobile drive
[3] Equipotential bonding
[4] Equipotential bonding (traveling cable) of the fork

If a controlled drive [2] travels on a hoist, the mobile drive must be equipped with a line filter. In smaller frame sizes, the line filter is already integrated. The line filter feeds the largest part of the leakage currents back to the frequency inverter. This reduces the risk of leakage currents dissipating via other components and interfering with equipment or communication.

If the frequency inverter and the bus module of a roller conveyor drive are both installed on the fork of the hoist, correct equipotential bonding of the fork is especially important.

The following cables are suitable as traveling cables [4]:

- Round, tinned copper strip, e.g. RTCB from the company ERICO.

  This is the best solution with respect to EMC.
- Separate PE conductor with larger cable cross section, e.g. 16 mm^2.

2.6.6 ESD – electrostatic discharge

Electrostatic discharge (ESD) is a disruptive discharge or spark that is created by high potential differences in an electrically insulating material. ESD causes a very short, high electrical current impulse that strongly interferes with the components in the plant.

Cause

The cause for the high potential difference is usually continuous charging due to the triboelectric effect, e.g.:

- Walking on a rug with insulating shoes
- Handling plastic parts
- Pulling off plastic or paper webs from reels
- When using plastic rollers, e.g. in roller conveyors or hoists

Effects

- Interference with electronic equipment, especially in case of bus communication
- Damage to semiconductors, creeping defects
- Encoder malfunctions

Remedy

You can protect the plant from ESD by installing components for dissipating the charge at all points where insulating materials rub against each other.

The following measures are suitable for dissipating charges within the plant:

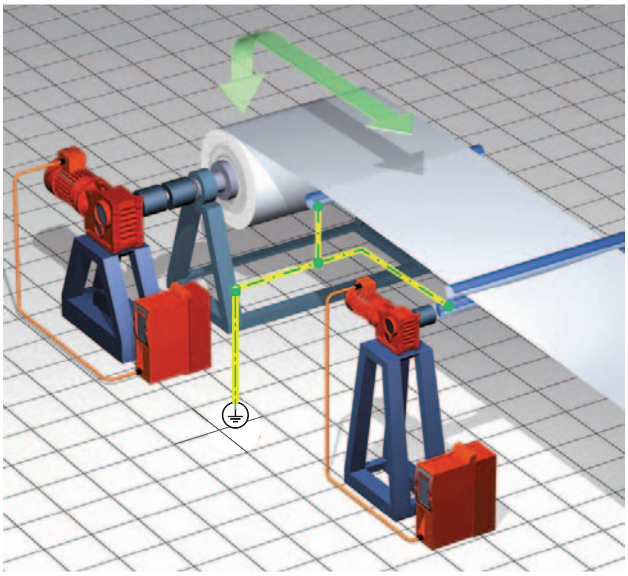
- Conductive combs
- Brushes, metal filaments
- Sliders, metal rollers, metal drums, etc.

These protective measures are especially important for the following applications:

- Conveyor belts
- Pulling off plastic or paper webs from reels.

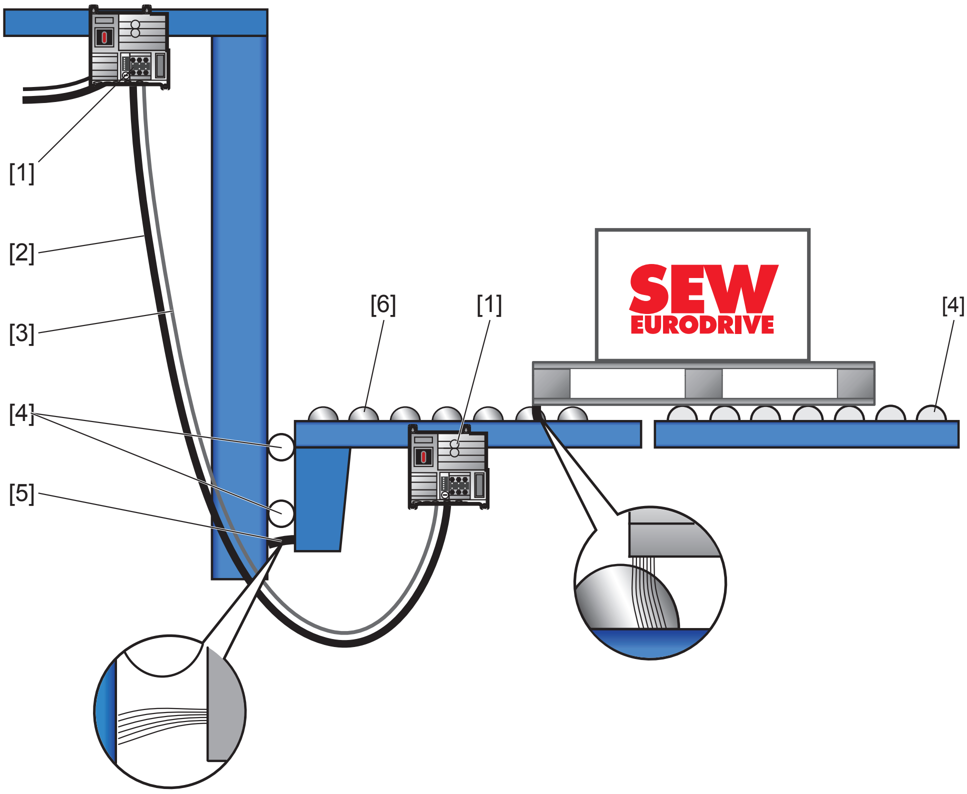
In large moving objects (e.g. winders), the charges can become so high that ESD protection is necessary for reasons of operator protection alone.

The following figure shows ESD protection of a winding machine:



3857042187

The following figure shows ESD protection of a hoist and a roller conveyor with metal and plastic rollers:



301406603

[1] Susceptible field distributor with inverter
[2] Hybrid cable (power, bus communication)
[3] EMC-compliant equipotential bonding conductor
[4] Plastic rollers (made of PVC)
[5] Metal comb
[6] Metal rollers

The charges of the mobile part are dissipated continuously via the metal comb to the frame of the hoist. This prevents electrostatic charging of the transported goods.

Conclusion

Plants that are vulnerable to ESD need ESD protection measures in addition to EMC-compliant equipotential bonding.

The following measures are required:

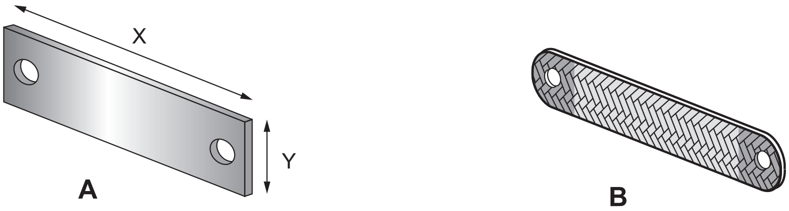
- EMC-compliant **equipotential bonding** against EMI
- **ESD protection** as unit protection

  In case of large, moving objects, ESD protection is necessary also for operator safety reasons.

2.6.7 Low-resistance ground reference

For optimized equipotential bonding in the HF range, a low-resistance ground reference is obligatory.

The following connection elements ensure low-resistance ground reference:



235057163

A Connection over a wide area (1:3 < X:Y < 3:1)
e.g. for connecting sheet metal ducts

B HF braid

Connection over a wide area

To connect individual machine parts or sheet metal ducts, you can use a wide metal plate [A].

Connect it to the reference potential at both ends over a large area.

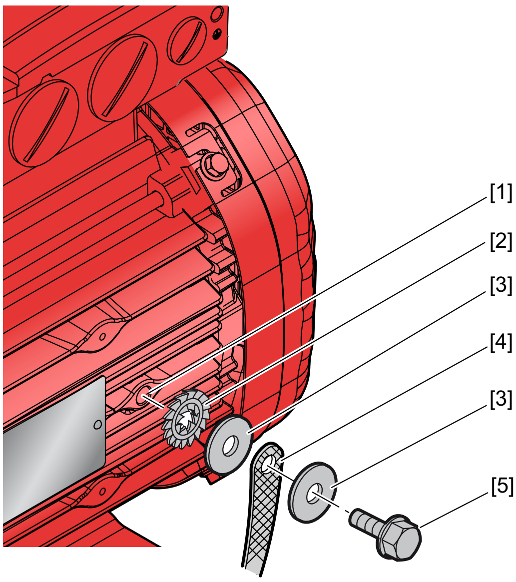
HF braids

If it is not possible to use metal plate connections, you can also use flexible HF braids [B].

According to **EN 60204-1**, chapter 13.2.2 from 2006, HF braids may also be used as PE conductor if the connection points are marked with the ground symbol.

Protect the HF braid with 2 washers to avoid damage to it from the screws or vibrations. Note the structure of the screw connection below.

The following figure shows an example of how the HF braid is installed to a DR.100M motor:



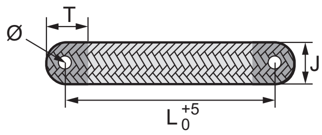
9007204735364875

[1] Hole
[2] Serrated lock washer
[3] Washer for protecting the HF braid
[4] HF braid
[5] Self-tapping screw

SEW-EURODRIVE recommends the following HF braids from the company ERICO for equipotential bonding:

- For the standard equipotential bonding connection of SEW components such as motors and decentralized controllers, use an HF braid with a hole diameter of 6.5 mm.
- For the "Improved grounding" option for DR motors (see chapter "DR motors" (page 89), use an HF braid with a hole diameter of 8.5 mm.

The following figure shows the HF braid from the company ERICO:



3566927115

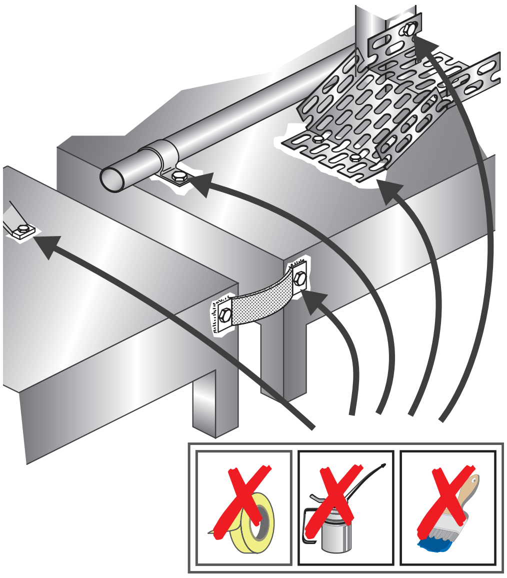
The following table shows the technical data of the HF braids:

	SEW standard connection for equipotential bonding	"Improved grounding" option
Item number (ERICO)	556610	556660
Type	MBJ 10-300-6	MBJ 16-300-8
[L] length	300 mm	300 mm
[J] Width	12 mm	15 mm
[Ø] Hole diameter	6.5 mm	8.5 mm
[T] Minimum contact length	22 mm	25 mm
Current carrying capacity	Max. 75 A	Max. 120 A
Cable cross section	10 mm^2	16 mm^2

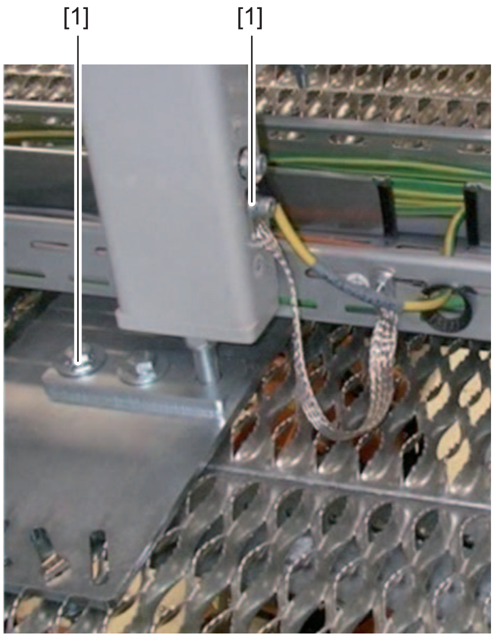
2.6.8 Contact

The contacts of the grounding connections have a significant influence on the quality of the grounding connection. The effectiveness of the best ground conductor can be nullified by careless or unsuitable contacts.

The following figures show examples of suitable contact options:



235062283



3879515275

[1] Contact options

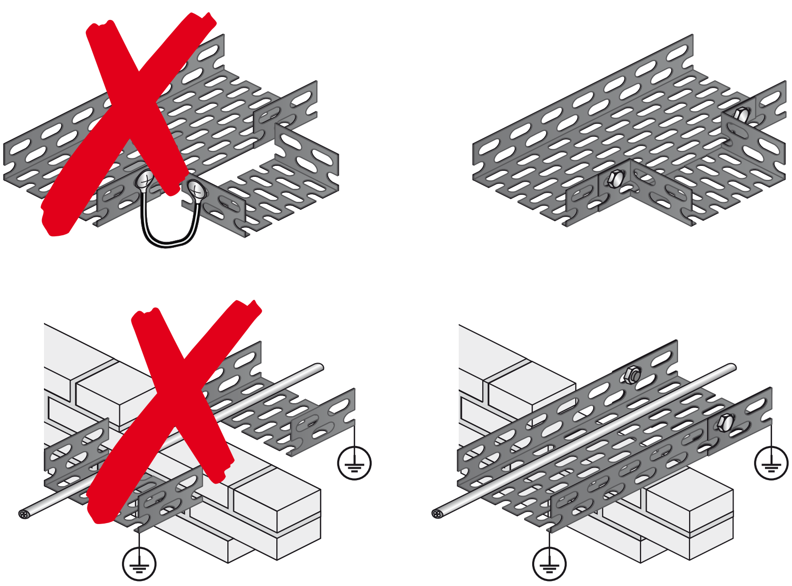
2.6.9 Cable duct connections

Observe the following notes for the installation of cable ducts:

- Ensure connection over a large area by using metal brackets for the cable ducts.
- A continuous ground reference surface (sheet metal duct) must exist between two plant components.
- Route all cables along the ground reference surface.
- Make sure that the contact points pose no tripping hazard.

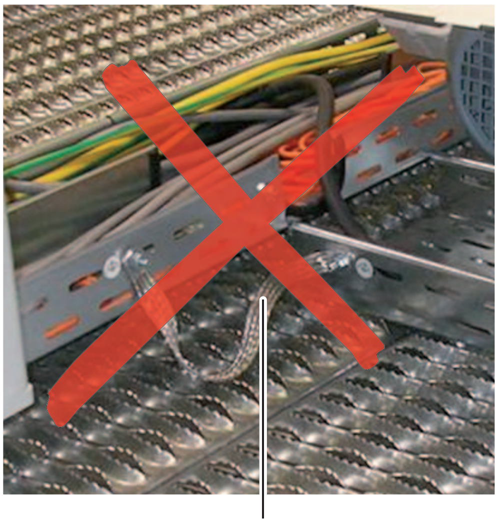
The following figures show examples of suitable contact options:

Non-recommended connections	**Recommended connections**



235092491

The following figures show negative examples of contact options:



[1]

[1]

[1] Connection poses a tripping hazard

Do **not** establish connections [1] as shown in the pictures above, as they do not offer contact over a large area and pose a tripping hazard.

2.7 Equipotential bonding of decentralized components

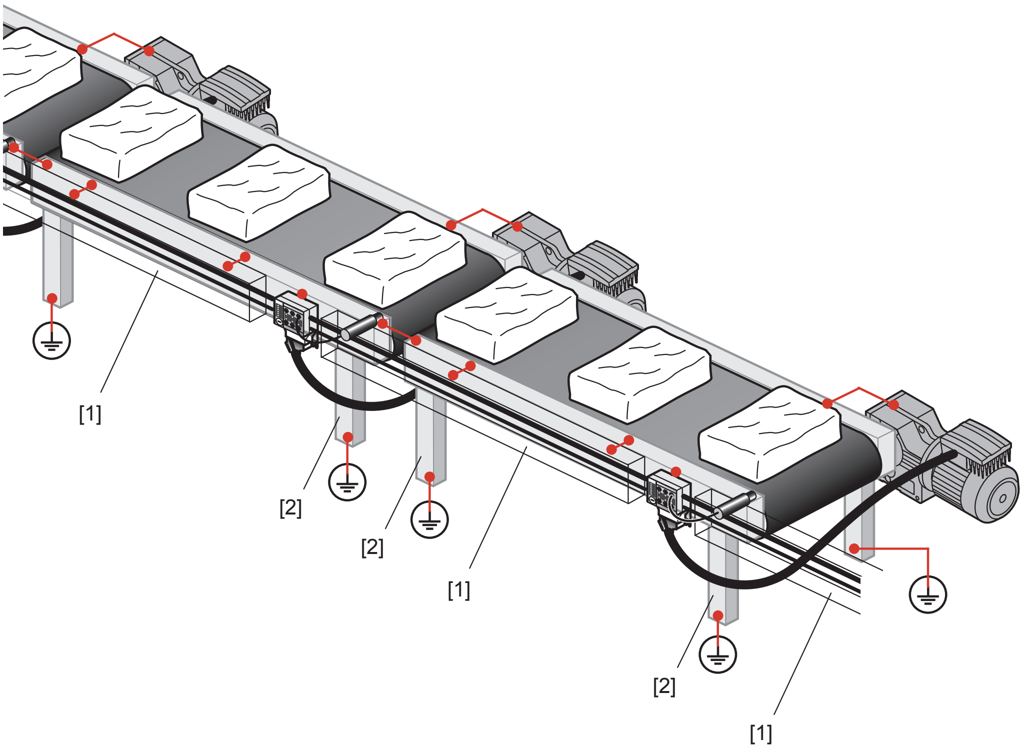
In decentralized applications, bus communication is distributed in the field. This is why HF-capable equipotential bonding is particularly important.

In addition to the PE connection, you must install low-resistance, HF-capable equipotential bonding (e.g. HF braid).

The following chapters exemplify equipotential bonding of the decentralized components from SEW-EURODRIVE.

2.7.1 MOVIMOT® with field distributor

The following figure shows the equipotential bonding measures of a transportation system with several MOVIMOT® drives: Signal transmission and supply is via field distributors:



462884107

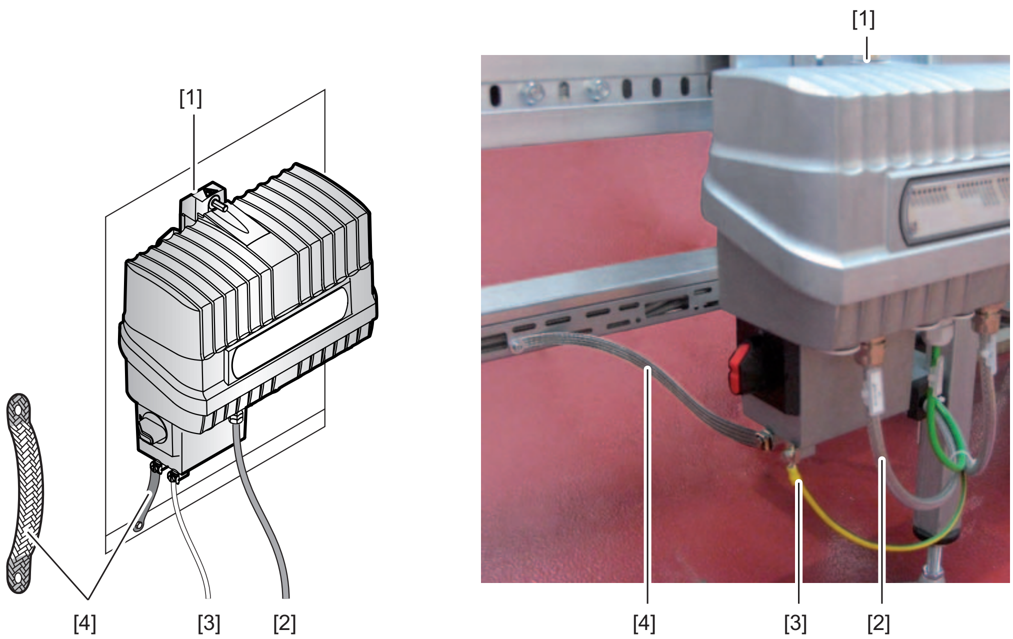
[1] Cable duct
[2] Metallic frame

The cables for fieldbus systems and rotary and position encoders transmit sensitive signals, and due to the decentralized principle, they are routed in parallel with power cables, e.g. from frequency inverter to the motor.

To ensure the necessary protection from HF interference, these systems are equipped with high-quality HF shields. In such systems, equipotential bonding via cable ducts and the metal structure of the machine is especially important. Otherwise, different potentials are mainly equalized via the signal cables, which causes interference.

2.7.2 MOVIFIT®

The following figure shows the PE conductors and EMC-compliant equipotential bonding of MOVIFIT® units:



3880956939

[1] Conductive connection over a large area between MOVIFIT® and the mounting rail
[2] PE conductor in the supply cable
[3] 2. PE conductor via separate terminals
(double safety for leakage currents > 3.5 mA according to EN 61800-5-1)
[4] EMC-compliant equipotential bonding via HF braid

INFORMATION

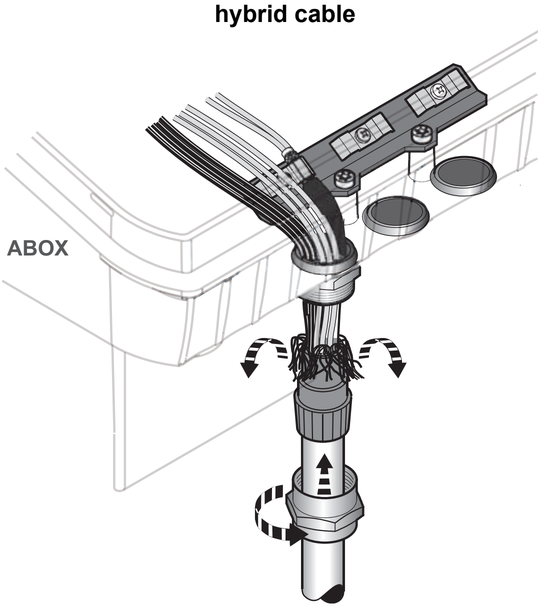
- **Metallic cable ducts may not be used as PE conductors** for electrical safety reasons.
- However, **from an EMC perspective**, a low-resistance connection between the control cabinet, the metal cable duct, and the motor for equipotential bonding **offers the following advantages**:
  – The metal cable duct is always installed in parallel with the cables.
  – It can easily be checked for interruptions.

Observe the following notes when establishing equipotential bonding for MOVIFIT® units:

- Establish a large-area connection between the MOVIFIT® unit and the grounding point of the plant.
- To do so, connect an HF braid between the MOVIFIT® unit and the grounding point of the plant.

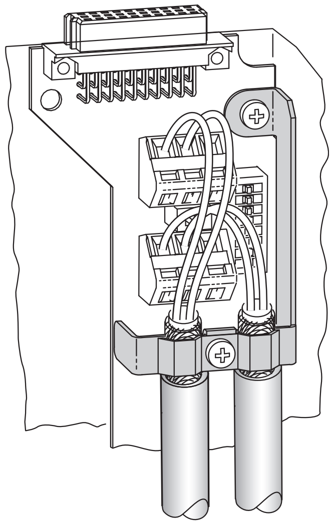
The following figures show the braided shield connection of hybrid and PROFIBUS cables at MOVIFIT® units:

Connection of hybrid cable



5461694475

Connection of PROFIBUS



5449603851

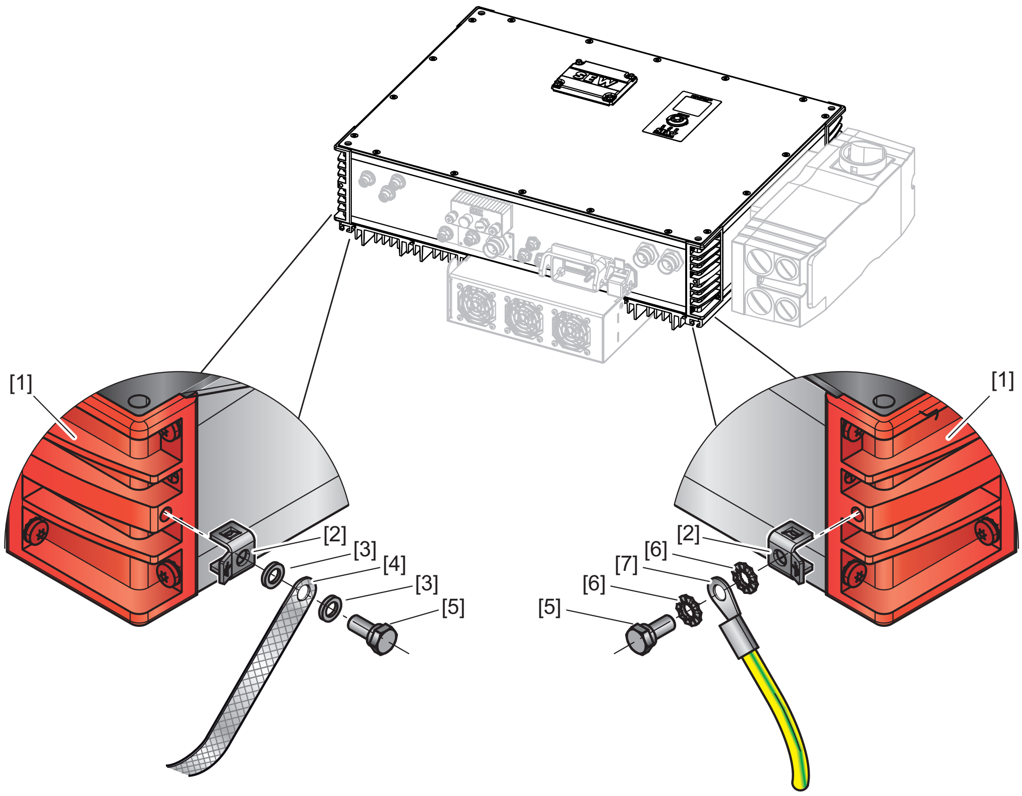
Use only EMC cable glands for connecting the hybrid cable to the MOVIFIT® unit, see chapter "EMC cable glands" (page 69).

2.7.3 MOVIPRO®

Grounding kit

The scope of delivery of MOVIPRO® includes two grounding kits.

The following figure shows the positions of the connection points and the sequence in which to install the individual parts:

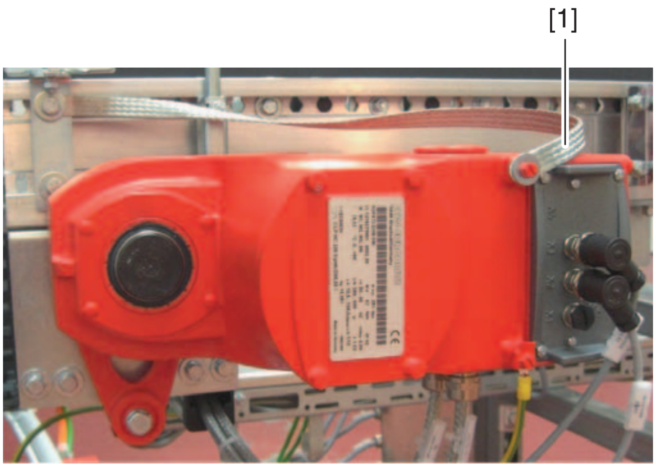


5462396939

[1] Housing corner
[2] Terminal clip
[3] Washer for M5
[4] HF braid
[5] M5 screw, self-tapping
[6] Tooth lock washer
[5] Ring cable lug for PE copper conductor

2.7.4 MOVIGEAR®

The following figure shows the equipotential bonding of MOVIGEAR® drive units:



3882314891

[1] Equipotential bonding of MOVIGEAR® drive unit

Observe the following notes when establishing equipotential bonding for MOVIGEAR® drive units:

- Establish a large-area connection between the MOVIGEAR® drive unit and the grounding point of the plant.
- To do so, connect an HF braid between the MOVIFIT® unit and the grounding point of the plant.

2.8 *Equipotential bonding of AC motors*

2.8.1 Connection of options

Temperature sensor connection

Route the cable of the TF temperature sensor separately from other power cables.

Keep a minimum distance of 200 mm.

The cables can only be routed together if either the TF cable or the power cable is shielded.

Brake connection

Route the brake cable separately from other power cables.

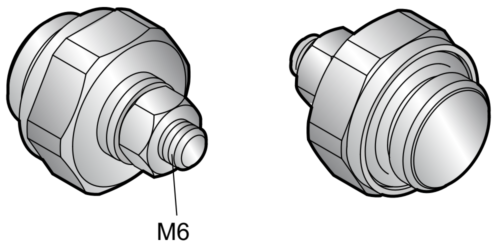
Keep a minimum distance of 200 mm.

The cables can only be routed together if either the brake cable or the power cable is shielded.

Use varistors for connections in the DC circuit of disk brakes. The varistors prevent harmful overvoltages. Brake control systems from SEW-EURODRIVE are equipped with varistors as standard.

2.8.2 Equipotential bonding / HF grounding at the connection box

Another option for HF-capable equipotential bonding at a connection box is the following cable gland with M6 threaded bolt.



3884960907

	Part number
M16 cable gland with M6 threaded bolt	0 818 923 4
M25 cable gland with M6 threaded bolt	0 819 268 5

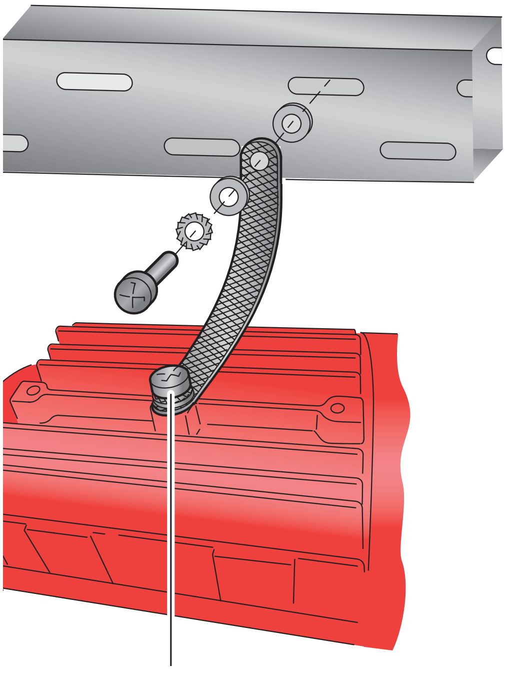
You can install this cable gland at a connection box that still has a free cable entry hole of size M16 or M25.

Screw the cable gland into the free hole and install the grounding cable (with ring cable lug) or the HF brand at the M6 threaded bolt.

2.8.3 DT/DV motors

Size DT71 – DV132

The following figure shows the equipotential bonding connection with suitable screws and serrated lock washers:



3884799499

[1] Self-tapping screw and 2 serrated lock washers

Use the following screws and serrated lock washers for equipotential bonding for the respective size:

- **Size DT71 – DV132S:**

  1 self-tapping screw M5 x 10 and 2 serrated lock washers [1]

- **Size DV112M – DV280:**

DV112 / DV132S:	M8 screw	+ 2 serrated lock washers
DV132M – DV180L:	M12 screw	+ 2 serrated lock washers
DV200 – DV280:	M16 screw	+ 2 serrated lock washers

2.8.4 DR motors, exterior LF grounding

In addition to the interior PE connection, a LF (low frequency) grounding cable can be attached to the outside of the terminal box. LF grounding is not installed as standard.

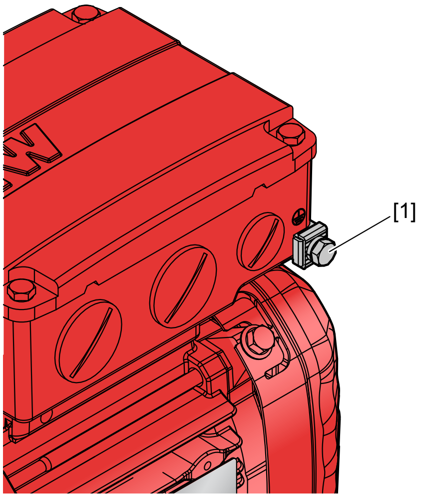
LF grounding can be ordered as completely pre-installed at the factory. For DR.71 – 132 motors, this requires a brake or gray-cast terminal box. For DR.160 – 225 motors, this option can be combined with all terminal box types.

The option can be combined with HF grounding.

INFORMATION

All parts of the LF grounding kit are made from stainless steel.

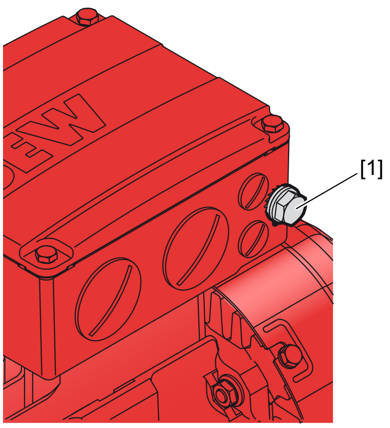
Size DR.71 – DR.132



9007204717158539

[1] LF grounding at the terminal box

Sizes DR.160 – DR.225



9007204718646539

[1] LF grounding at the terminal box

2.8.5 "Improved grounding" option (HF grounding) for DR motors

For improved, low-impedance grounding at high frequencies, we recommend using the following connections: SEW-EURODRIVE recommends to use corrosion-resistant connection elements.

HF grounding is not installed as standard.

The HF grounding option can be combined with LF grounding at the terminal box.

If you require LF grounding in addition to HF grounding, you can connect the conductor to the same point.

The HF grounding option can be ordered as follows:

- Completely pre-installed at the factory, or as
- "Grounding terminal" kit for customer installation; part numbers listed in the following table.

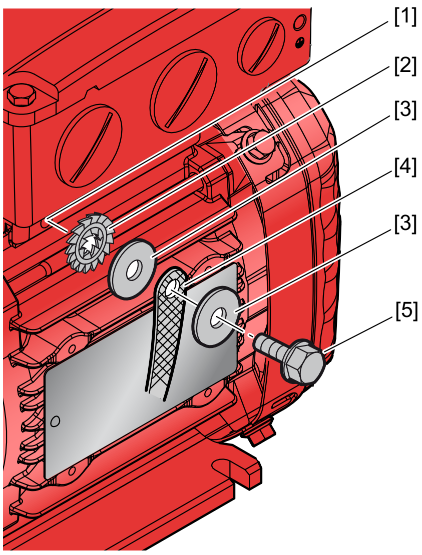
Motor size	Part number of "Grounding terminal" kit
DR.71S / M DR.80S / M	1363 3953
DR.90M / L	
DR.100M	
DR.100 L – DR.132 with aluminum terminal box	1363 3945
DR.160 – DR.225 with aluminum terminal box	

INFORMATION

All parts of the kit are made from stainless steel.

Size DR.71S / M and DR.80S / M

The following figure shows how the grounding kit is installed:



9007204719329675

[1] Use of the pre-cast bore at the stator housing

[2] Serrated lock washer

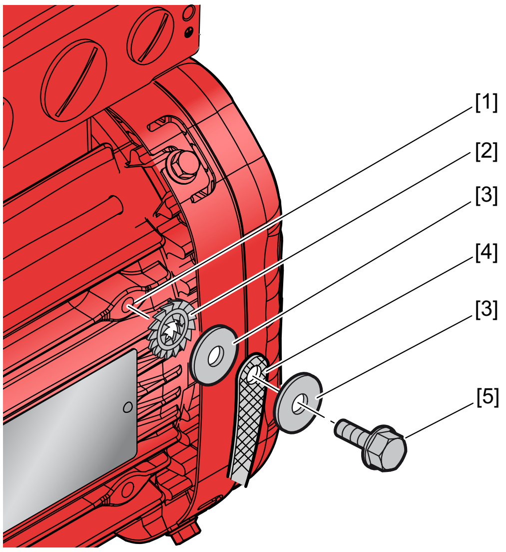
[3] Disk 7093

[4] Ground strap (not included in the scope of delivery)

[5] Self-tapping screw DIN 7500 M6 x 16, tightening torque 10 Nm (88.5 lb-in)

Size DR.90M / L

The following figure shows how the grounding kit is installed:



9007204722451083

[1] Use of the pre-cast bore at the stator housing

[2] Serrated lock washer

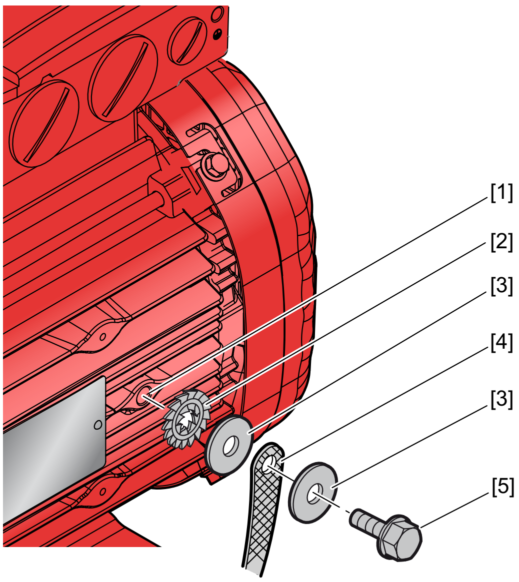
[3] Washer 7093

[4] Ground strap (not included in the scope of delivery)

[5] Self-tapping screw DIN 7500 M6 x 16, tightening torque 10 Nm (88.5 lb-in)

Size DR.100M

The following figure shows how the grounding kit is installed:



9007204735364875

[1] Use of the pre-cast bore at the stator housing

[2] Serrated lock washer

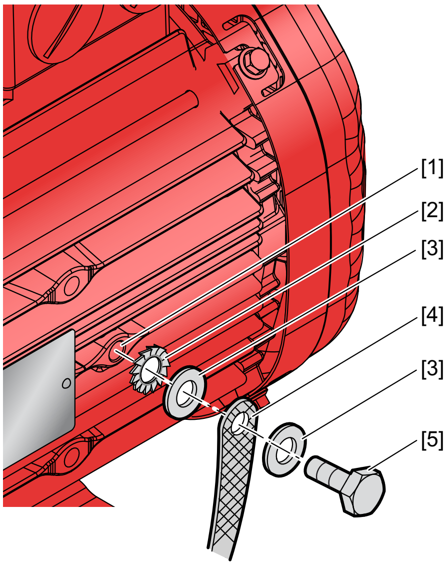
[3] Washer 7093

[4] Ground strap (not included in the scope of delivery)

[5] Self-tapping screw DIN 7500 M6 x 16, tightening torque 10 Nm (88.5 lb-in)

Size DR.100L – DR.132

The following figure shows how the grounding kit is installed:



9007204735369227

[1] Use of tapped hole for lifting eyes

[2] Serrated lock washer DIN 6798

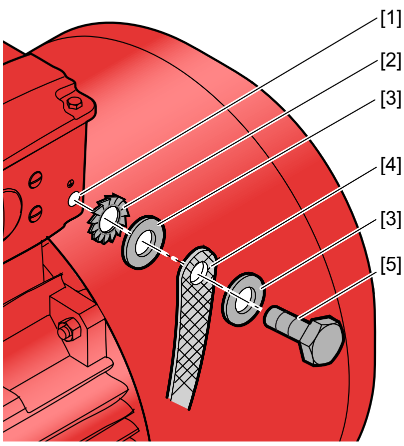
[3] Washer 7089 / 7090

[4] Ground strap (not included in the scope of delivery)

[5] Hexagon screw ISO 4017 M8 x 18, tightening torque 10 Nm (88.5 lb-in)

Sizes DR.160 – DR.315

The following figure shows how the grounding kit is installed:



9007204735374603

[1] Use of the tapped holes at the terminal box
[2] Serrated lock washer DIN 6798
[3] Washer 7089 / 7090
[4] Ground strap (not included in the scope of delivery)
[5]
- Hex head screw ISO 4017 M8 x 18 (with aluminum terminal boxes of size DR.160 – 225), tightening torque 10 Nm (88.5 lb-in)
- Hex head screw ISO 4017 M10 x 25 (with gray cast iron terminal boxes size DR.160 – 225), tightening torque 10 Nm (88.5 lb-in)
- Hex head screw ISO 4017 M12 x 30 (terminal boxes of size DR.250 – 315), tightening torque 15.5 Nm (137.2 lb-in)

3 Electromagnetic Interference

3.1 Fault diagnosis

Careful observation and documentation of the errors that occurred will help you to determine the cause of the fault. The more detailed the error description, the more quickly and easily the fault can be eliminated. Make sure that the error description cannot be misinterpreted.

Identification of interference source

- Do the malfunctions occur permanently or only from time to time?
- Is there a connection between the occurrence of the malfunction, the error rate, and the operating modes of the malfunctioning system when other units are operated?
- Identify the interference source by successively switching off units in the system.
- Check the supply voltages.

Identification of susceptible equipment

- Can you clearly rule out a malfunction due to hardware or software errors?
- Are there units or system components that are malfunctioning, but the malfunction cannot clearly be determined? For example, an encoder that can affect the entire system?
- Use the diagnostics options of the system (LEDs, error display, error counter, etc.) to identify the affected unit.
- Selective shutdown, disconnection, or replacement of system components helps you to locate the affected unit. Disconnection, for example, by
  – Changing the operating mode
  – Deactivating functions

3.2 Fault clearance

To clear faults that result from poor EMC, you can do the following:

- Eliminate or reduce the noise emitted by the interference source by means of coils, filters, or shield plates.
- Increase the interference immunity of the affected unit by using filters and/or shielded housings.
- Eliminate coupling sections to prevent the noise getting from the interference source to the susceptible equipment, e.g. by
  – Keeping sufficient distance between power and signal cables
  – Using shielded cables
  – Routing cables near ground
- Check compliance with the requirements described in this document and in the relevant product documentation.

3.3 Fault list

The following fault list helps you to identify EMI-related faults.

Malfunction	Cause	Solution
Sporadic malfunction	No interference suppression circuits (spark quenching) for coils of contactors, valves, or horns installed.	Install interference suppression elements (spark quenchers) for the coils. Use the interference suppression circuits recommended by the manufacturer.
	Spark-producing machines (e.g. welding machines)	Check/correct the routing of the control cables of the interference-emitting machine. Increase the distance to the interference-emitting machine.
	Radio transmitter, ripple control system	Install additional shielding.
	Cables with poor shield connections, incorrect conductor twisting, or incorrect characteristic values	Use original part cables. Check the conductor assignment.
	Interruptions in the cable shield, e.g. cable branching	Connect the cable shields of the incoming and outgoing cables with each other by connecting them either to a common large metal surface or an EMC shield cable gland or a shield plate.
	Incorrectly installed equipotential bonding cable	Re-install the equipotential bonding cable, see previous chapters.
	Dirt in the controller	Clean the dirty controller and assemblies. Ensure clean air supply.
Permanent axis offset	See "Sporadic malfunction"	
	No/insufficient equipotential bonding of the actual value conductor of an encoder	Install an equipotential bonding conductor between the encoder housing and the controller housing. Improve the equipotential bonding connection.
Encoder error	Shield of encoder cable interrupted	Replace the encoder cable with an original part encoder cable (product-specific).
	Encoder cable with poor shielding properties	
	Encoder cable shield connected via separate wire/conductor	Connect the shield of the encoder cable to an EMC shield clamp / shield glands on both ends.
	Encoder cable with incorrect characteristic values used	Use the encoder cable type recommended by the manufacturer or replace the encoder cable with an original part encoder cable (product-specific).
	Encoder track cores not twisted in pairs	Only use twisted pair cables as encoder cables: Connect them in pairs according to the wiring diagram.
	Shield of TF cable not grounded on both ends	Always use shielded cables as TF cables. Connect the shield of the TF cable on both ends.

Malfunction	Cause	Solution
Sporadic malfunction of stations in bus systems (e.g. PROFIBUS)	Incorrect terminating resistor e.g. PROFIBUS: 220 Ω CAN bus (SBus): 120 Ω	Measure with the ohmmeter whether the two terminating resistors are active in the bus segment. **Example:** PROFIBUS terminating resistor 220 Ω The two terminating resistors must be active at the start and end of the bus segment. Both terminating resistors are connected in parallel through the bus conductors. Resistance measurement between "Data+" and "Data -" (or "A" and "B") must produce about half the value of a terminating resistor (with PROFIBUS: about 95 – 110 Ω).
	Terminating resistor in the wrong place	During the resistance measurement, check whether the terminating resistor is in the right place by switching it off and on.

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