1 Inductive components for electronic equipment

Especially in this age of fully-electronic and highly-integrated equipment, inductive components are indispensable. They are used to store energy intermittently in switch-mode power supplies and DC/DC converters, as parts of high-frequency circuits, as filter elements and last but not least as interference suppression components to ensure EMC.

Of course, the demands placed on inductors depend on how and where they are to be used. In HF circuits, coils with high quality factors and resonance frequencies are needed. In EMC applications, high inductances are required in order to achieve good interference suppression characteristics, low *Q* factors being more desirable here due to the need to avoid resonances.

EPCOS provides suitable inductive components for all applications. This data book contains a wide selection of standard components, from SMT types (starting with SIMID 0402) right up to the 4-line high-current inductors for power electronics applications.

Attention is drawn to the excellent HF characteristics and the extremely high reliability of the components, achieved thanks to large-scale production automation and many years of experience in the manufacture of this kind of components.

An overview of typical applications for inductors and chokes

Application	Inductance	Current rating	Resonance frequency	*Q* factor	DC resistance
HF circuits, resonant circuits	low	low	very high	very high	low
EMC	high	*	high	low	very low
Filter circuits	high	high	high	low	very low
Switch-mode power supplies, DC/DC converters	*	*	medium	high	low

* depends on the specific application

1.1 HF circuits

SMT styles (SIMID product range) and leaded RF chokes are especially suitable for RF and other high-frequency circuits. Typical applications are resonant circuits and frequency-selective filters of the type being increasingly used in telecommunications engineering and automotive electronics. In some cases, special demands on the inductive components arise, for example, when used in transmitter output circuits of mobile telephones (high *Q* factors and resonance frequencies) and in airbag control circuits (high pulse currents).

1.2 Filter circuits

When inductive components are used for filters in power supplies for electronics, high inductances, the lowest possible DC resistance and a low *Q* factor are required. The impedance should have a wideband frequency characteristic. In addition to the current rating, the maximum permissible pulse current (switching transient currents) and adequately high core material saturation are of importance.

Chokes belonging to all type series presented here can be used for this range of applications, from the SIMID types right up to chokes with powder cores and one or two lines.

1.3 Switch-mode power supplies, DC/DC converters

Inductive components are used for magnetic energy storage in all kinds of switch-mode power supplies and DC/DC converters. For example, the SIMID 1812 product range is used in low-power step-up converters in automobile electronics and in battery-powered equipment. They can be subjected for short periods to currents which are the quadruple of their current rating without any saturation effects occurring.

1.4 EMC applications

For broadband interference suppression, current-compensated chokes with ring cores or D cores and powder core chokes are especially suitable.

Apart from use as filters in mains and other power supply lines, such chokes are important for data lines as used in telecommunications engineering, e. g. in NTBAs (Network Termination Basic Access Units, ISDN), in line cards in telephone exchanges (ISDN and analog) and in the fast-expanding CAN bus application field (CAN = Controller Area Network) in automotive electronics.

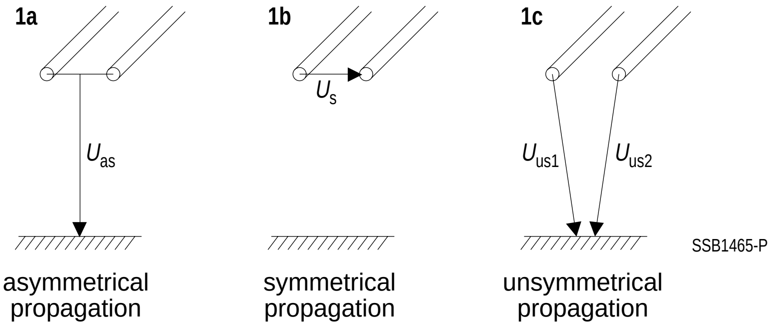
Almost all the component families are approved in accordance with the main international standards. All chokes for low-frequency mains networks are dimensioned and tested in compliance with the applicable EN and IEC standards.

Inductive components with particularly good RF characteristics are achieved by the use of ungapped cores. The manufacturing methods developed by EPCOS lead to good reproducibility of the attenuation characteristics and enable the production of high-quality components at a favorable price.

The company's many years of experience guarantee that customers quickly and economically obtain just the right solutions to their EMC problems. Our own EMC laboratory in Regensburg or one of our European EMC partner laboratories is at your disposal at all times to help with professional advice and in carrying out measurements (also refer to the chapter on "Services").

1.4.1 Propagation of interference

Interference voltages and currents can be grouped into common-mode interference, differential-mode interference and unsymmetrical interference:



$U = V =$ voltage

Fig. 1
Propagation modes

- Common-mode interference (asymmetrical interference):
  – occurs between all lines in a cable and reference potential (fig. 1a),
  – occurs mainly at high frequencies (from approximately 1 MHz upwards).
- Differential-mode interference (symmetrical interference):
  – occurs between two lines (L-L, L-N) (fig. 1b),
  – occurs mainly at low frequencies (up to several hundred kHz).

- Unsymmetrical interference:
  – This term is used to describe interference on a single line, relative to the reference potential (fig. 1c)

1.4.2 Characteristics of interferences

In order to be able to choose the correct EMC measures, we need to know the characteristics of the interferences, how they are propagated and the mechanisms by which they are coupled into the circuit. In principle, the interferences can also be classified according to their range (fig. 2). At low frequencies, it can be assumed that the interference only spreads along conductive structures, at high frequencies only by means of electromagnetic radiation. In the MHz frequency range, the term coupling is generally used to describe the mechanism.

Analogously, conducted interference on lines at frequencies of up to several hundred kHz are mainly symmetrical (*differential mode*), at higher frequencies, they are asymmetrical (*common mode*). This is because the coupling factor and the effects of parasitic capacitance and inductance between the conductors increase with frequency.

X capacitors and single chokes are suitable as suppression measures for the differential mode components. Where asymmetrical, i.e. common-mode interference has to be eliminated, current-compensated chokes and Y capacitors are mainly used, the prerequisite for this being, however, a well-designed, EMC-compliant grounding and wiring system.

The categorization of types of interference and suppression measures and their relation to the frequency ranges is reflected in the frequency limits for interference voltage and interference field strength measurements.

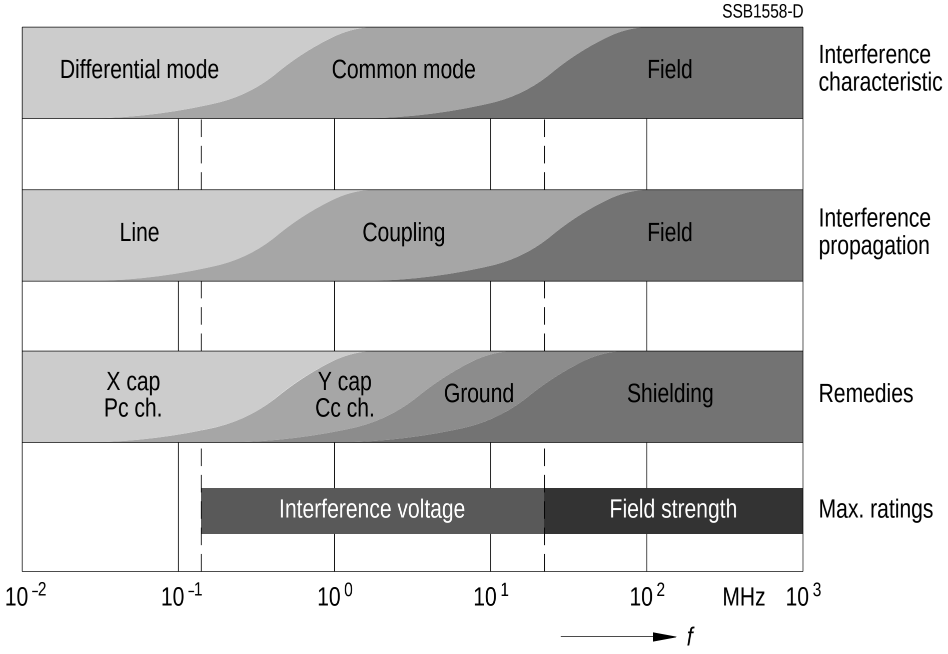


Fig. 2 Frequency range overview
Pc ch. = Iron powder core chokes, but also all single chokes/ X cap = X capacitors
Cc ch. = Current-compensated chokes / Y cap = Y capacitors

2 Electromagnetic compatibility (EMC)

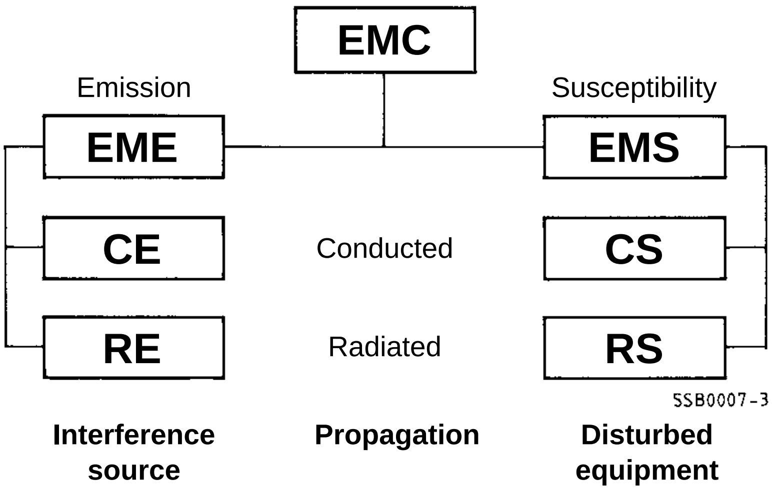
2.1 Introduction

For as long as electronic transmission equipment such as radio, television, and telephone has been in existence, it has had a history of susceptibility to interference from other electronic devices. Legal regulations on interference suppression (electromagnetic and radio frequency interference, EMI and RFI) have been in existence since 1928. These regulations protect transmission paths and reception equipment by limiting the emitted interference.

In view of the increasing number of electrical and electronic appliances in use, not only the principles of interference suppression must be observed, but also, in the sense of electromagnetic compatibility (EMC), it must be ensured that all equipment is able to operate simultaneously without problems. EMC is defined as the ability of electrical equipment to function satisfactorily in its electromagnetic environment without affecting other equipment in this environment to an impermissible extent.

The European Communities' EMC Directive (89/336/EEC) came into force on the 1. 1. 1996. It has been transformed into corresponding legislation in the individual EU (European Union) member states. With this, it has become mandatory to design electronic equipment to comply with the protection objectives of this Directive; i.e. to meet the requirements for electromagnetic emission and electromagnetic immunity as laid down in the corresponding EN standards (European Standards).

The concept of EMC includes both electromagnetic emission (EME) and electromagnetic immunity/susceptibility (EMS), see fig. 3.



EMC = Electromagnetic compatibility
EME = Electromagnetic emission
EMS = Electromagnetic immunity/susceptibility
CE = Conducted emission
CS = Susceptibility to conducted emission
RE = Radiated emission
RS = Susceptibility to radiated emission

Fig. 3 EMC terms

An interference source may generate conducted or radiated electromagnetic energy, i.e. conducted emission (CE) or radiated emission (RE). This also applies to the propagation paths and to the electromagnetic susceptibility of disturbed equipment.

In order to work out economical solutions, it is necessary consider both phenomena, i.e. propagation and susceptibility, to an equal extent, and not just one aspect, e.g. conducted emission.

EMC components are used to reduce conducted electromagnetic interference to the limits in an EMC plan or to reduce this interference below the limit values specified in the EMC regulations. These components may be installed either in the source of potential interference or in the disturbed equipment (fig. 4).

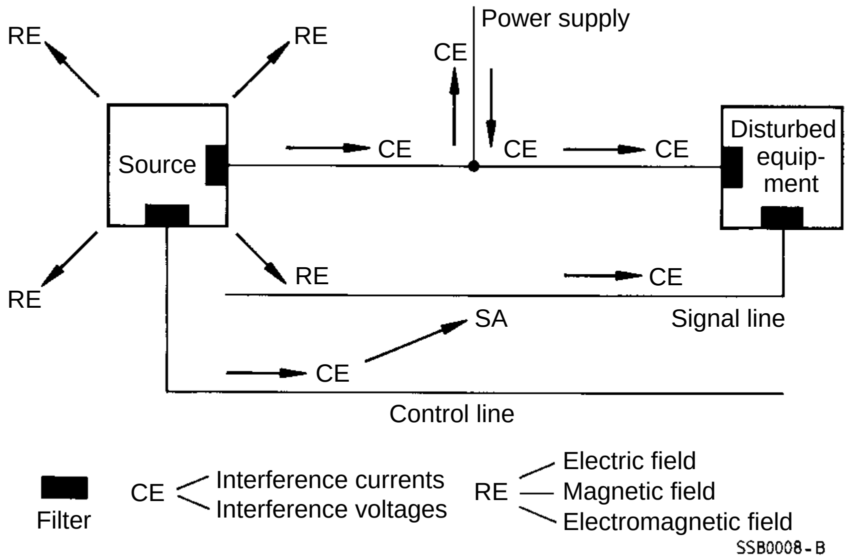


Fig. 4 Susceptibility model and filtering

EPCOS offers EMI suppression components with a well-balanced range of rated voltages and currents for power supply lines as well as for signal and control lines.

2.2 Interference sources and disturbed equipment

Interference source

An interference source is an electrical device or electrical equipment which emits electromagnetic interference. We can differentiate between two main groups of interference sources corresponding to the type of frequency spectrum emitted (fig. 5).

Interference source (emission)

Discrete frequency spectrum (Sine-wave, low energy)

- µP systems
- RF generators
- Medical equipment
- Data processing systems
- Microwave equipment
- Ultrasonic equipment
- RF welding apparatus
- Radio and TV receivers
- Switch-mode power supplies
- Frequency converters
- UPS systems
- Electronic ballast circuits

Continuous frequency spectrum (Impulses, high energy)

- Switchgear (contactors, relays)
- Household appliances
- Gas discharge lamps
- Power supplies and battery chargers
- Ignition systems
- Welding apparatus
- Motors with brushes
- Oscillating drives
- Atmospheric discharges

Fig. 5 Sources of interference

Interference sources with discrete frequency spectra (e.g. high frequency generators and microprocessor systems) emit interference energy which is concentrated on narrow frequency bands.

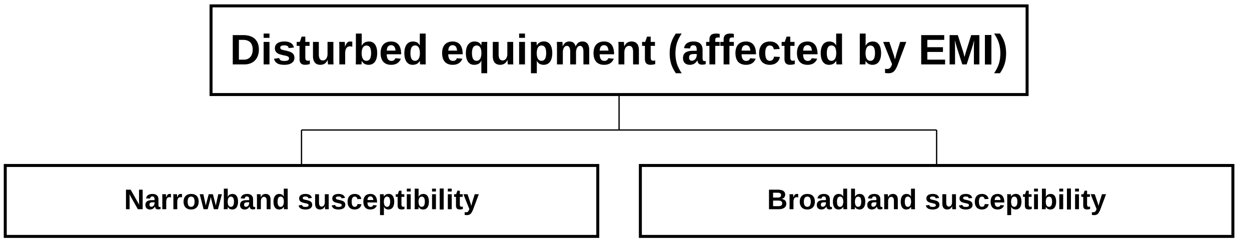
Switchgear and electric motors in household appliances, however, distribute their interference energy over broad frequency bands and are considered to belong to the group of interference sources having a continuous frequency spectrum.

Disturbed equipment

Electrical devices, equipment and/or systems subject to interference and which can be adversely affected by it are termed disturbed equipment.

In the same way as interference sources, disturbed equipment can also be categorized corresponding to frequency characteristics. A distinction can be made between narrowband and broadband susceptibility (fig. 6).

Narrowband systems include radio and TV sets, for example, whereas data processing systems are generally specified as broadband systems.



Narrowband susceptibility	Broadband susceptibility
Radio and TV receivers	Digital and analog systems
Radio reception equipment	Data processing systems
Modems	Process control computers
Data transmission systems	Control systems
Telemetric radio transmission devices	Video transmission systems
Frequency-coded signalling equipment	Interface lines

Fig. 6 Disturbed equipment

2.3 Propagation of electromagnetic interference and EMC measurement techniques

As previously mentioned, an interference source causes both conducted and radiated electromagnetic interference.

Propagation along lines can be detected by measuring the interference current and the interference voltage (fig. 7).

The effect of magnetic and electric interference fields on their immediate vicinity is assessed by measuring the radiated magnetic and electric field components. This method of propagation is also frequently termed electric or magnetic coupling (near field).

In higher frequency ranges, characterized by the fact that device dimensions are in the order of magnitude of the wavelength under consideration, the interference energy is mainly radiated directly (far field).

Conducted and radiated propagation must also be taken into consideration when measuring the susceptibility of disturbed equipment.

Interference sources e.g. sine-wave generators as well as pulse generators with a wide variety of pulse shapes are used for such tests.

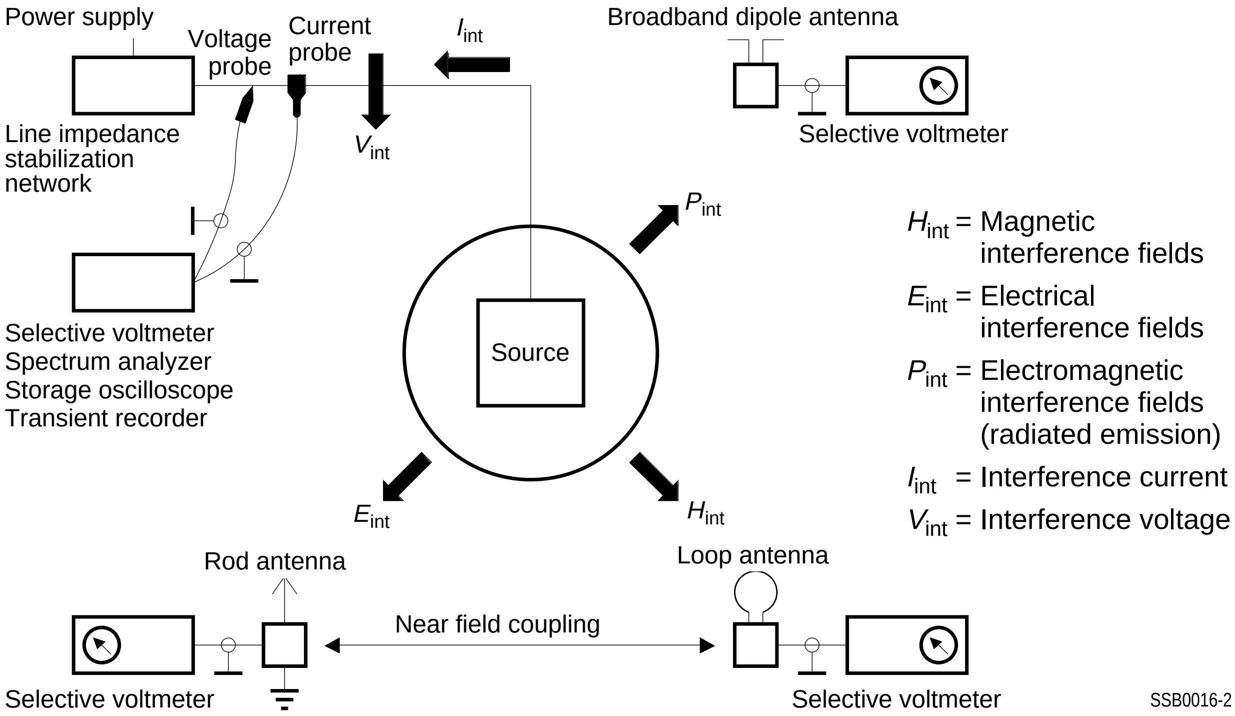


Fig. 7 Propagation of electromagnetic interference and EMC measurement techniques

2.4 EMC regulations und legislation

A wide range of legislation and of harmonized standards have come into force and been published in the field of EMC in the past few years. In the European Union, the EMC Directive 89/336/EEC of the Council of the European Communites has come into effect on the 1st of January 1996. As of this date, all electronic equipment must comply with the protection objectives of the EMC Directive. The conformity with the respective standards must be guaranteed by the **manufacturer or importer** in the form of a declaration of conformity. A CE mark of conformity must be applied to all equipment.

As a matter of principle, all electrical or electronic equipment, installations and systems must meet the protection requirements of the EMC Directive and/or national EMC legislation. A declaration of conformity by the manufacturer or importer and a CE mark are required for most equipment. Exceptions to this rule and special rulings are described in detail in the EMC laws.

New, harmonized European standards have been drawn up in relation to the EEC's EMC Directive and the national EMC laws. These specify measurement procedures and limit values or test severities, both for interference emission and for the interference susceptibility (or rather, immunity to interference) of electronic devices, equipment and systems.

The subdivision of the European standards into various categories (cf. following table) makes it easier to find the rules that apply to the respective equipment.

The generic standards always apply to all equipment for which there is no specific product family standard or dedicated product standard.

The basic standards contain information on interference phenomena and general measuring methods.

The following standards and regulations form the framework of the conformity tests:

EMC standards		Germany	Europe	International
Generic standards define the EMC environment in which a device is to operate according to its intended use				
Emission	residential	DIN EN 50081-1	EN 50081-1	—
	industrial	DIN EN 50081-2	EN 50081-2	
Susceptibility	residential	DIN EN 50082-1	EN 50082-1	—
	industrial	DIN EN 50082-2	EN 50082-2	
Basic standards describe physical phenomena and measurement procedures				
Basics		DIN VDE 0843	EN 61000	IEC 61000
Measuring equipment		DIN VDE 0876		CISPR 16-1
Measuring methods	emission	DIN VDE 0877		CISPR 16-2
	susceptibility		EN 61000-4-1	IEC 61000-4-1
Harmonics		DIN VDE 0838	EN 60555-2	IEC 61000-3-2
Interference factors e.g.	ESD	DIN VDE 0843-2	EN 61000-4-2	IEC 61000-4-2
	EM fields	DIN VDE 0843-3	EN 61000-4-3	IEC 61000-4-3
	Burst	DIN VDE 0843-4	EN 61000-4-4	IEC 61000-4-4
	Surge	DIN VDE 0843-5	EN 61000-4-5	IEC 61000-4-5
	Injection	DIN VDE 0843-6	EN 61000-4-6	IEC 61000-4-6
Product standards define limit values for emission and susceptibility				
ISM equipment	emission	DIN VDE 0875 T11	EN 55011	CISPR 11
	susceptibility	1)	1)	1)
Household appliances	emission	DIN VDE 0875 T14-1	EN 55014-1	CISPR 14-1
	susceptibility	DIN VDE 0875 T14-2	EN 55014-2	CISPR 14-2
Lighting	emission	DIN VDE 0875 T15-1	EN 55015-1	CISPR 15
	susceptibility	DIN VDE 0875 T15-2	EN 55015-2	IEC 3439
Radio and TV equipment	emission	DIN VDE 0872 T13	EN 55013	CISPR 13
	susceptibility	DIN VDE 0872 T20	EN 55020	CISPR 20
High-voltage systems	emission	DIN VDE 0873	EN 55018	CISPR 18
ITE equipment	emission	DIN VDE 0878	EN 55022	CISPR 22
	susceptibility	DIN VDE 0878	EN 55022	CISPR 22
Vehicles	emission	DIN VDE 0879	EN 72245	CISPR 25
	susceptibility	DIN VDE 0839		ISO 11451/ S2

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1) Is governed by the safety and quality standards of the product families.

The following table shows the most important standards in the field of immunity to interference.

Standard	Test characteristics	Phenomena
Conducted interference		
EN 61000-4-4 IEC 61000-4-4	5/50 ns (single impulse) 15 kHz burst	Burst Cause: switching processes
EN 61000-4-5 IEC 61000-4-5	1,2 / 50 ms (open-circuit voltage) 8 / 20 ms (short-circuit current)	Surge (high-energy transients) Cause: lightning strikes mains lines, switching processes
EN 61000-4-6 (ENV 50141) IEC 801-6	1 V, 3 V, 10 V 150 kHz … 80 MHz	High-frequency coupling Narrow-band interference
Radiated interference		
EN 61000-4-3 (ENV 50140) IEC 801-3	3 V/m, 10 V/m 80 … 1000 MHz	High-frequency interference fields
Electrostatic discharge (ESD)		
EN 61000-4-2 IEC 61000-4-2	Up to 8 kV 5 / 50 ns	Electrostatic discharge
Voltage dips, short interruptions and variations		
EN 61000-4-11 IEC 61000-4-11	0,4 V_R 1 … 50 ms 0,7 V_R optional $V_R = 0$ 10 ms	Electrostatic discharge

The IEC 1000 or EN 61000 series of standards are planned as central EMC standards into which all EMC regulations (e.g. IEC 801, IEC 555) are to be integrated in the next few years.

2.5 Propagation of conducted interference

In order to be able to choose suitable interference suppression components, the way in which conducted interference is propagated needs to be known (fig. 8).

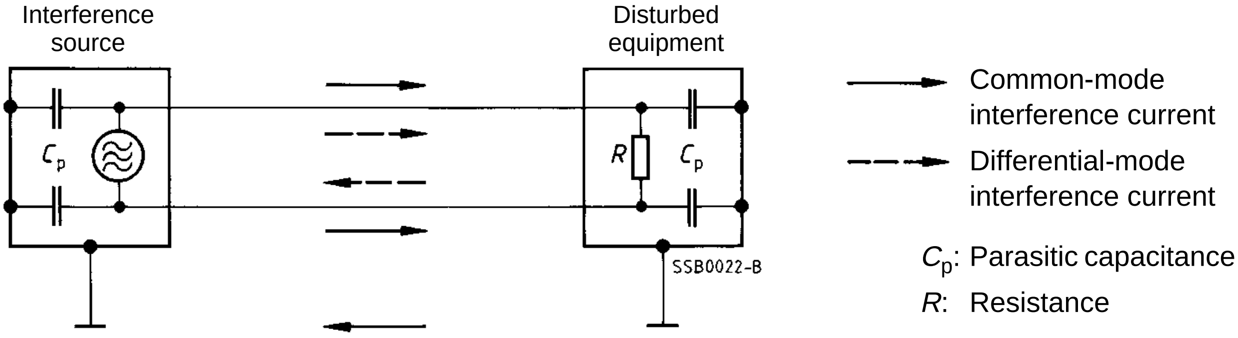


Fig. 8 Common-mode and differential-mode interference

An interference source which is at a floating potential primarily emits differential-mode, i.e. symmetrical interference which is propagated along the connected lines. On power lines, the interference current will flow towards the disturbed equipment on one wire and away from it on the other wire, just as the mains current does.

Symmetrical or differential-mode interference occurs mainly at low frequencies (up to several hundred kHz).

However, parasitic capacitances in interference sources and disturbed equipment or intended ground connections, also lead to an interference current in the ground circuit. This interference current flows towards the disturbed equipment through both the connecting lines and returns to the interference source through the ground lines.The currents on the connecting lines are in common mode and the interference is thus designated as common-mode or asymmetrical interference.

Since the parasitic capacitances will tend towards representing a short-circuit with increasing frequencies and the coupling to the connecting cables and the equipment itself will increase correspondingly, common-mode interference becomes dominant at multiple-MHz frequencies.

In European usage, the concept of an “unsymmetrical interference” is used, in addition to the two components described above, to describe interference. This term is used to describe the interference voltage between a line and reference ground potential.

2.6 Filter circuits and line impedance

Interference suppression filters are virtually always designed as reflecting lowpass filters, i.e. they reach their highest insertion loss when they are - on the one hand - mismatched to the impedance of the interference source or disturbed equipment and - on the other hand - mismatched to the impedance of the line. Possible filter circuits for various line, interference source and disturbed equipment impedance conditions are shown in fig. 9.

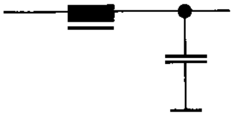
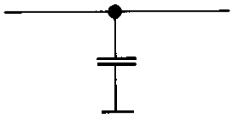
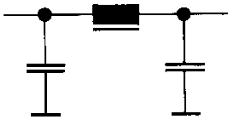
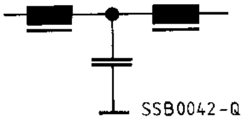
Line impedance		**Impedance of source of interference / disturbed equipment**
low		high
high		high
high unknown		high unknown
low		low
low unknown		low unknown

Fig. 9 Filter circuits and impedance relationships

It is, therefore, necessary to find out the internal impedances so that optimum filter circuit designs as well as economical solutions can be implemented.

The internal impedances of the power networks under consideration are usually known from calculations and extensive measurements, whereas the impedances of interference sources or disturbed equipment are, in most cases, not or only inadequately known.

For this reason, it is impossible to design the most suitable filter solution without measuring the equipment characteristics. In this context, we offer all our customers the competent assistance of our skilled staff, both on-site and in our EMC laboratory in Regensburg (also see chapter on “Services offered”, page 32).

3 Selection criteria for EMC components

To comply with currently valid regulations, a frequency range of 150 kHz to 1000 MHz has to be taken into consideration, in most cases, in order to ensure electromagnetic compatibility; in addition, however, factors such as low-frequency line interference should be considered.

EMC components must thus have favorable RF characteristics and are ususally required to be effective over a broad frequency range.

For individual components (inductors) the RF characteristics are specified by stating the impedance as a function of frequency.

4 Arrangement of EMC components

When designing filter circuits using individual components, observe the following basic rules:

- The components should be arranged along the lines (see example in fig. 10) to avoid capacitive and inductive coupling between components and between filter inputs and outputs.
- As insertion loss of a filter circuit in the MHz range is mainly determined by the capacitors connected to ground, the connecting leads of these capacitors should be as inductance-free as possible, i.e. short.
- Filter circuits which are to be installed in devices with limited space must be shielded.

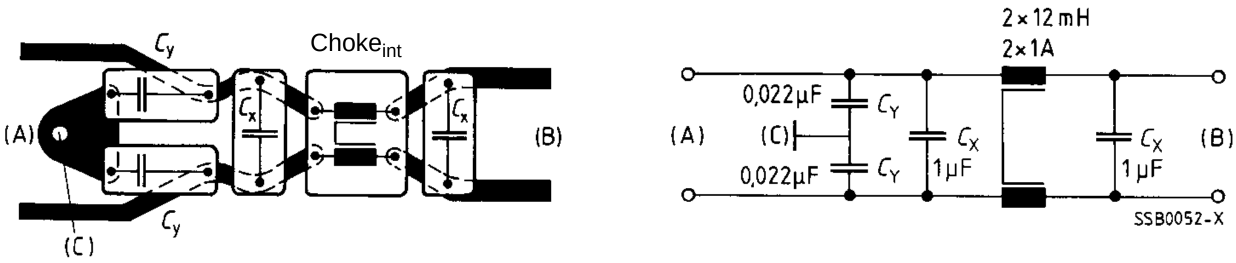


Fig. 10 Correct arrangement of filter components, e.g. on a PC board

When using off-the-shelf filters, observe the following rules:

- Ensure a proper electrically conductive connection between the filter case and/or filter ground and the metallic case of the interference source or disturbed equipment, and
- provide sufficient RF decoupling between the lines at the filter input (line causing the interference) and the filter output (filtered line), if necessary by using shielding partitions.

5 Approvals

All products by EPCOS AG are basically designed to conform to the German VDE regulations and/or EN standards. The respective regulations or standards are given for each component type. Many of our components have also been approval-tested in accordance with national and international regulations. The approval marks and quality assurance marks are listed in the data sheets.

Examples of approval marks:

VDE
Germany

UL
USA

Example of a quality assurance mark:

CECC quality assurance mark

In future, chokes will be tested in accordance with the new European standard EN 138 100. A uniform European mark of conformity has not yet been defined. For the time being the national marks of conformity are used (e.g. VDE) and the corresponding European standards is stated beside the mark.

6 Safety regulations

When selecting EMC components – in particular in case of power line applications – the safety regulations applicable to the relevant equipment must be observed.

7 Electrical characteristics

7.1 Rated voltage V_R

The rated voltage V_R is the maximum ac or dc voltage which can be continuously applied to the component at temperatures between the lower category temperature T_{min} and the upper category temperature T_{max}.

7.2 Test voltage V_T

The test voltage V_T is the ac or dc voltage which may be applied to the component for the specified test duration in the course of final inspection (100% end of line testing). This test may be repeated once as an incoming goods inspection test.

7.3 Rated current I_R

The rated current I_R is ac or dc current at which the component may be continuously operated under the nominal operating conditions.

For components with 1, 2 or 3 lines, the rated current is specified for simultaneous flow of a current of this value through all lines.

During ac operation, higher thermal loads may be caused due to waveforms which deviate from a pure sine wave. Where necessary, such cases must be taken into consideration.

7.4 Overcurrent

The rated current may be exceeded briefly. Details on permissible currents and load duration can be obtained upon request.

7.5 Pulse handling capability

Saturation effects (e.g in the ferrite cores used) may occur when high-energy pulses are applied to the components and these may lead to impaired interference suppression. The maximum permissible voltage-time integral area is used to characterize the pulse handling capability of chokes. For standard components a range from 1 to 10 mVs can be assumed. More specific data can be obtained upon request.

7.6 Current derating I_{op}/I_R

At ambient temperatures above the operating temperature stated in the data sheet, the operating current must be reduced according to the derating curve.

7.7 Rated inductance L_R

The rated inductance L_R is the inductance which has been used to designate the choke, as measured at the frequency f_L.

7.8 Stray inductance L_S

The stray inductance L_S (also termed leakage inductance) is the inductance measured through both coils when a current-compensated choke is short-circuited at one end. This affects symmetrical interference.

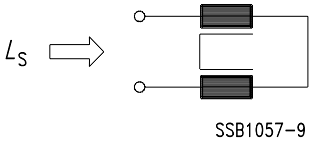


Fig. 11 Stray inductance

7.9 Inductance decrease $\Delta L/L_0$

The inductance decrease $\Delta L/L_0$ is the drop in inductance at a given current relative to the initial inductance L_0 measured at zero current. The data sheets specify this as a percentage. This decrease is caused by the magnetization of the core material, which is a function of the field strength, as induced by the operating current. Generally the decrease is less than 10 % .

7.10 DC resistance R_{typ}, R_{min}, R_{max}

The dc resistance is the resistance of a line as measured using direct current at a temperature of 20 °C, whereby the measuring current must be kept well below the rated current.

R_{typ}	typical value
R_{min}	minimum value
R_{max}	maximum value

7.11 Winding capacitance, parasitic capacitance C_P

Parasitic capacitances (C_P), which impair the RF characteristics of the components, are related to the component geometry. These capacitances may affect the two lines mutually (symmetrically) as well as the line-to-ground circuit (asymmetrically). The design of all EMC components supplied by EPCOS minimizes the parasitic effects. Due to this, these components have excellent interference suppression characteristics right up to high frequencies.

7.12 Quality factor Q

The quality factor Q is the quotient of the imaginary component of the impedance divided by the real component.

7.13 Measuring frequencies f_Q, f_L

f_Q is the frequency for which the quality factor Q of a choke is specified.
f_L is the frequency at which the inductance of a choke is determined.

7.14 Insertion loss

The insertion loss is a criterium for the effectivity of interference suppression components, as measured by using a standardized measurement circuit (fig. 12).

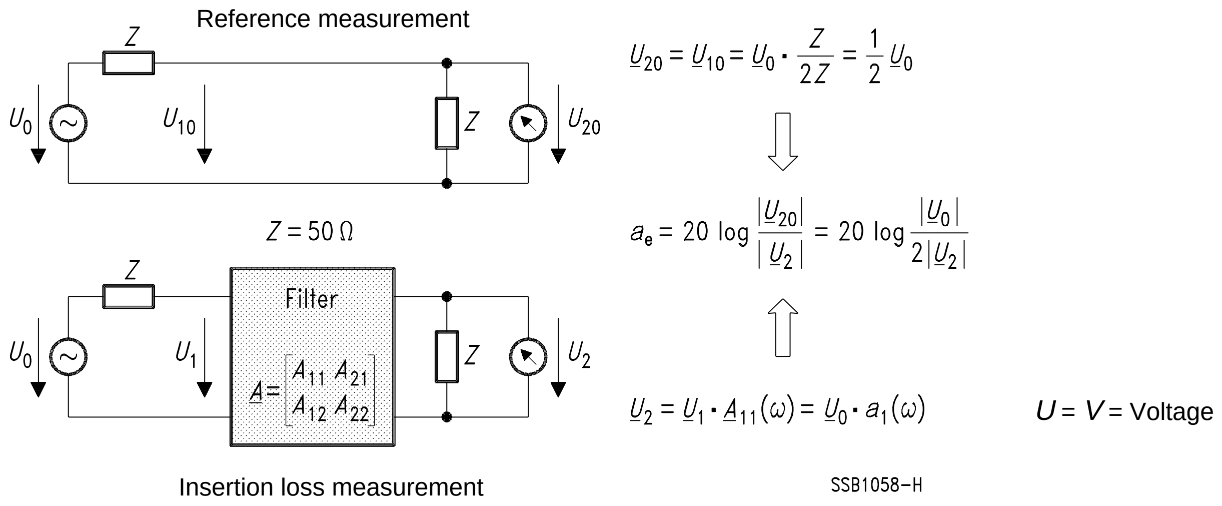


Fig. 12 Definition of insertion loss

The input terminals of the equipment under test are connected to an RF generator with impedance Z (usually 50 Ω) . At the output end of the component, the voltage is measured using a selective voltmeter having the same impedance Z. The insertion loss is then calculated from the quotient of the no-load generator voltage V_0 and half the output voltage V_2.

8 Mechanical properties

8.1 Potting (economy potting, complete potting)

We distinguish between economy potting and complete potting.

Economy potting is used to fix the the core and windings in the case and the windings on the core. This is an economical technique which enables a single resin casting procedure to be used. Because of this, most chokes supplied by EPCOS are produced using this method.

Complete potting is only required when the thermal conductitvity of economy potting is not adequate or if the customer has special demands. Complete potting requires several process steps to ensure complete embedding of the core and the windings.

Economy potting

Complete potting

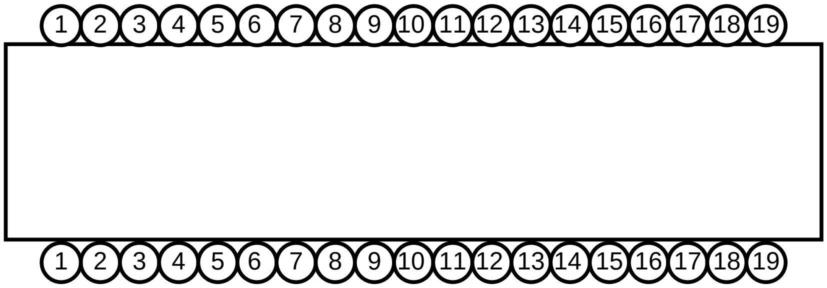
8.2 Types of winding

EPCOS uses different types of winding to suit the respective technical requirements:

- single-layer winding
- multilayer winding
- random winding

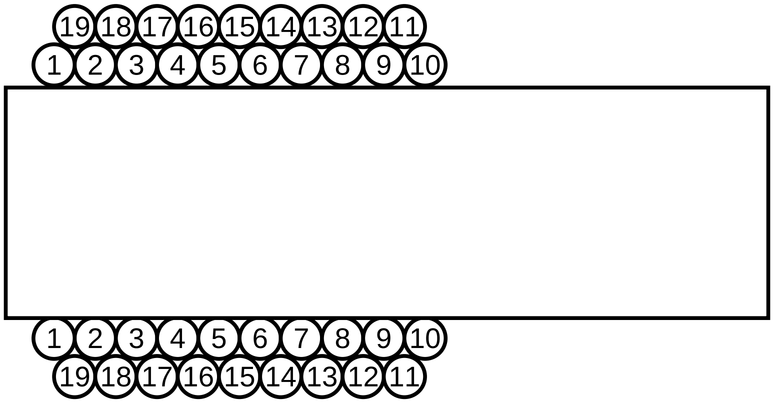
The different types of winding lead to different inductance characteristics, especially at high frequencies.

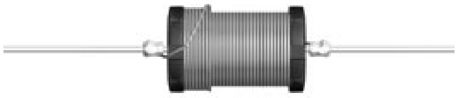
Single-layer winding:



The winding pitch is equal to or greater than the wire diameter. The coil is wound in one direction only. The only capacitances (parasitic capacitances) are those between one turn to the next. In comparison to all other types of winding, this type of winding leads to the lowest possible capacitances and thus the highest resonance frequencies.

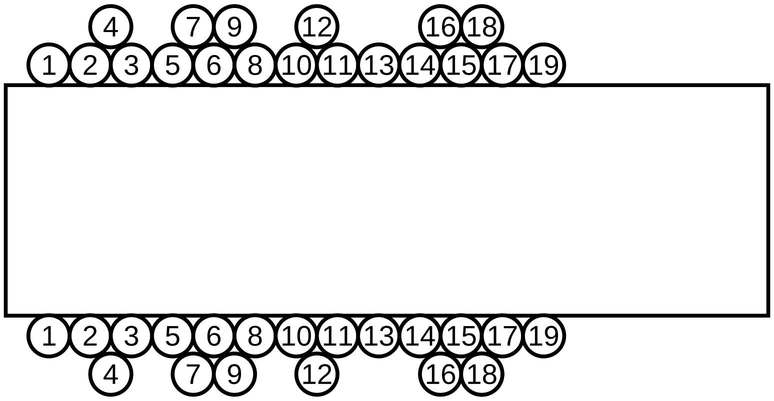
Multilayer winding:





The winding pitch is equal to the wire diameter. The coil is wound with several layers. This leads to parasitic capacitances between the layers in addition to the turn-to-turn capacitances. In comparison to all other types of winding, this type leads to the highest capacitances and thus the lowest resonance frequencies.

Random winding:



The winding pitch is smaller than the wire diameter. The coil is wound in one direction only. This method of winding a coil does not permit the final position of a turn to be predetermined exactly. The cross section of this type of winding clearly shows a disorderly, “random” arrangement of the turns. This leads to the parasitic capacitances being only minimally greater than those achieved by single-layer winding, and the resonance frequencies are equal to those achieved by single-layer winding.

8.3 RF characteristics of various types of winding

Figure 13 shows the relation between the impedance and the frequency for two chokes of equal inductance. One of the chokes has a two-layer winding and the other is randomly wound. The choke with random windings has a considerably higher first resonance frequency. The spurious resonances are very much higher than 10 MHz. The impedance at frequencies above the first resonance frequency is approximately five times higher. This leads to better interference suppression at high frequencies.

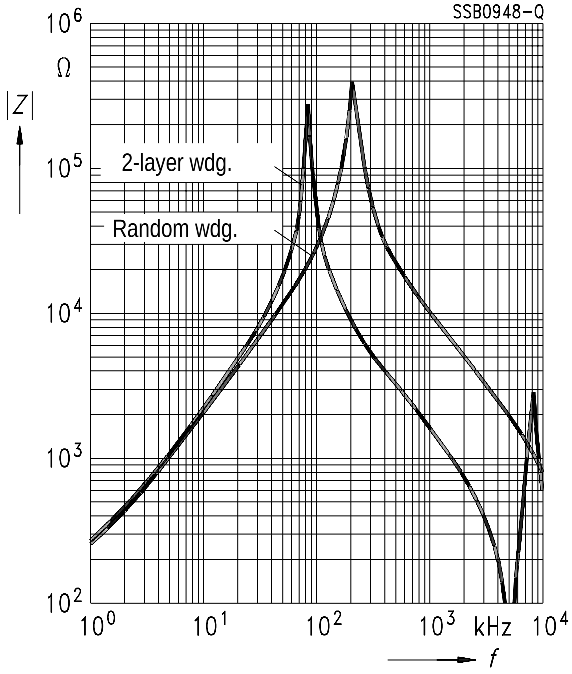


Fig. 13 Impedance $|Z|$ versus frequency f
comparison between two-layer winding and random winding

The RF characteristics of all chokes supplied by EPCOS are within the specifications and reproducible, as the winding processes which we have developed for single-layer, multilayer and random winding ensure that the characteristics of the inductors produced display very little variation.

The reproducibility of electrical characteristics of chokes is mainly determined by the production technique used. At EPCOS, coils are wound mainly by automatic machines (either fully or semi-automated). This permits even complicated winding patterns to be produced in large production runs with very little variation in product characteristics. In fig. 14, the impedance curves of several chokes, some wound manually and some by machine, are shown for comparison. With the random winding used in this comparison, the advantages of machine winding are clearly noticeable.

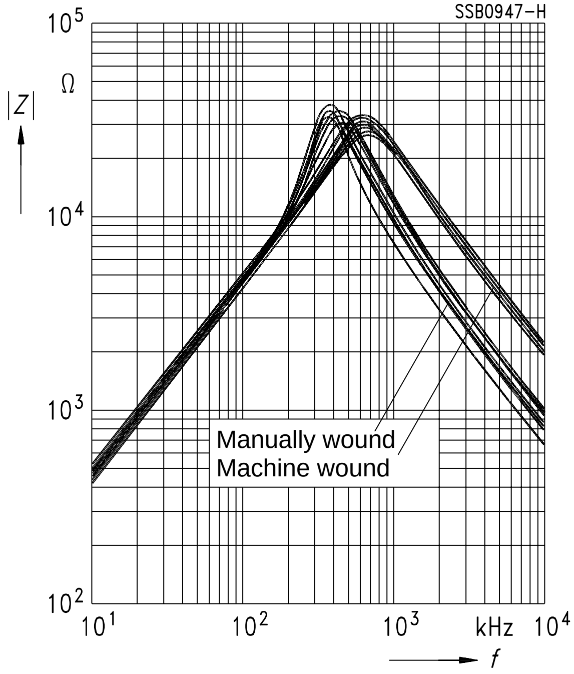


Fig. 14 Impedance |*Z*| versus frequency *f*
Reproducibility and scatter achieved by manual and by machine winding techniques.

9 Climatic characteristics

9.1 Upper and lower category temperature T_{max} and T_{min}

The upper category temperature T_{max} und the lower category temperature T_{min} are defined as the highest and the lowest permissible ambient temperatures, respectively, at which the component can be operated continuously.

9.2 Rated temperature T_R

The rated temperature T_R is defined as the highest ambient temperature at which the component may be operated under nominal conditions.

9.3 Reference temperature for measurements

Unless otherwise specified in the data sheets, the reference temperature for all electrical measurements is 20 °C in accordance with IEC 60068-1.

9.4 IEC climatic category

IEC 60068 -1, Appendix A, defines a method of specifying the climatic category by three groups of numbers delimited by slash characters.

Example: 55/085/56
– 55 °C
+ 85 °C
56 days

1st group of numbers:

Absolute value of the lower category temperature T_{min} as test temperature for
test Aa (cold) in accordance with IEC 60068-2-1

2nd group of numbers:

Upper category temperature T_{max} as test temperature for
test Ba (dry heat) in accordance with IEC 60068 -2-2
test duration: 16 h

3rd group of numbers:

Number of days denoting the test duration for
test Ca (damp heat, steady-state) in accordance with IEC 60068-2-3
at (93 + 2/– 3) % rel. humidity and an ambient temperature of 40 °C

10 Sizes

The sizes of surface-mount components SMD are encoded using a four-digit coding system. The code differs depending on the standard which it is based on.

The American EIA standards require the length and width to be stated in hundredths of an inch, in European standards and in the IEC draft standards, these dimensions are encoded in tenths of a millimeter. The following table sumarizes the sizes:

Length × width (mm)	EIA	IEC/EN
1,0 × 0,5	0402	1005
1,6 × 0,8	0603	1608
2,0 × 1,2	0805	2012
2,5 × 2,0	1008	2520
3,2 × 2,5	1210	3225
4,5 × 3,2	1812	4532
5,6 × 5,0	2220	5650

11 Dangerous substances in components

Dangerous substances (as defined by the German regulation “Gefahrstoffverordnung”) are only used in our production and to an extent where the state of the art leaves us no alternative. Wherever possible, we replace them by materials with safe characteristics. Where this is not possible, special staff entrusted with environmental protection and supervision of noxious materials monitor strict adherence to relevant laws and regulations in each of our factories.

As part of these efforts to manufacture our products without using dangerous substances as far as possible, we can guarantee for all components presented in this data book that they do not contain the following materials and compounds:

- acryl nitrile
- aliphatic chlorinated organic componds
- arsenic compounds
- asbestos
- lead carbonate and lead sulphide
- halogenated dioxines and furanes
- cadmium
- chlorinated fluorocarbons (CFC),

nor are they used in component manufacture.

Others,

- formaldehyde
- pentachlorophenol (PCB)
- polychlorinated biphenyles (PCB)
- polychlorinated terphenyles (PCT)
- mercury compounds
- creosote
- ugilec and DBBT (PCB substitutes)
- organic tin compounds
- vinyl chloride

may be used in manufacture but the components do not contain these.

The packaging of our components is generally suitable for ESD areas and free of pollutants. Full details are available from our sales offices.

12 Disposal

In the light of the facts stated above on the topic of dangerous substances, all components presented in this book can be disposed of without problems. Most of our components will be accepted by the respective electronic scrap recycling companies for material recycling and/or thermal decompositon. Of course the corresponding local regulations must be observed.