



EMC filters

Application notes

Date: January 2006

1 Filters for converters with an active front end (AFE)



In contrast to conventional converters, AFE converters use semiconductor switches (such as IGBTs¹⁾) as rectifiers instead of the diode bridges which are otherwise generally used. The switches can be turned on or off at any time. If they are controlled in an appropriate way, the amplitude of the generated harmonics is reduced and the current drawn by the converter is approximately sinusoidal. Another advantage is that the DC link voltage can be varied up to the peak value of the line voltage.

Many AFE converters can also feed energy back into the power supply network from the DC link circuit, for instance when a motor is decelerated.

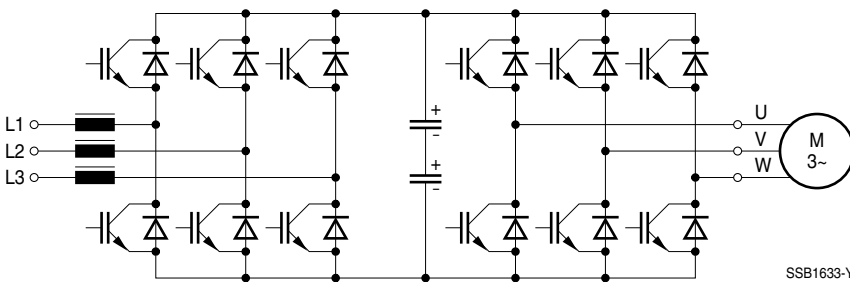


Figure 1 Basic circuit diagram of an AFE converter

1) IGBT = Insulated Gate Bipolar Transistor

However, the switching frequency of the semiconductor switch causes interferences on the line side of the frequency converter. A considerable voltage ripple occurs between the individual phases. In addition, common-mode currents whose size depends on the total length of the motor cable flow between converter and network. The effects are boosted in return-feed operation.

The use of a suitable filter from EPCOS attenuates these interferences so that mutual effects between the converter and adjacent equipment are excluded. Compliance of the limit values of the interference voltage is secured. EPCOS has developed solutions (patent pending) for special requirements, such as maximum permissible common-mode currents or maximum leakage currents.

Application examples

In view of the diverse applications of AFE converters, two different application examples will be used to show what filter solutions for such converters might look like.

The first example shows a converter with a feed-in/energy recovery unit to which up to twelve drive modules with a total motor cable length of up to 500 m can be connected (see Figure 2). The common-mode currents occurring in this case drive every conventional filter choke to saturation. To this must be added the extra stress caused by regenerating operation. We have elaborated several solutions in order to offer a suitable filter for such extreme applications. Some of these have already been patented while in other cases the patents are currently pending.

(See also data sheet example in the Chapter “Customer-specific filters”.)

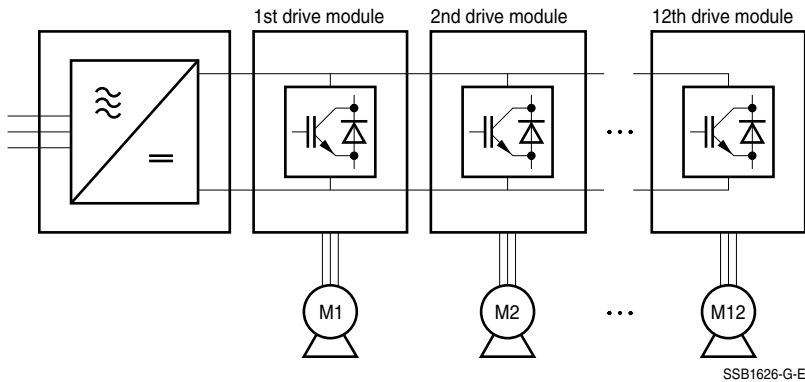


Figure 2 Application example of converter with feed-in/energy recovery unit

The second example was developed for a single AFE converter of the kind frequently used to drive elevators, for example. In this case, motor cables of up to 20 m length are typically used. Nevertheless, the particular interference characteristics of this converter type must also be considered. In order to suppress the interferences of this unit, a conventional ring core choke with a highly saturable core material was used and a sophisticated capacitor circuit was selected. (See also data book example in the Chapter “Customer-specific filters”.)

Please contact us about optimized filter solutions for AFE applications. EPCOS has developed numerous different solutions over the years. In view of the complexity of the application, a technical discussion may be needed in order to quickly define the correct EMC filter design. Our experts will be pleased to support you in this matter.

2 An example of environmentally friendly power generation



As a market leader in the sector of passive components in Europe, EPCOS also makes its contribution to an appropriate environmental policy. We feel a responsibility to preserve our environment and use natural resources sparingly. This attitude applies both to our manufacturing processes and our products.

We have consequently supplied numerous solutions to customer applications in the sectors of environmentally friendly power generation and renewable sources of energy. These have involved not only EMC components but also power capacitors. Thus a special capacitor was also developed for wind-driven power applications whose trademark *WindCap* (B25668 series) is protected.

Typical examples of these applications are wind generators, the generation of energy from waste-dump gas as well as engine-based cogeneration plants. In all these cases, the energy produced is fed into the public supply network. Compliance with the specifications of the power utilities with respect to power line quality is mandatory. These requirements ensure that loads connected to the supply network, such as households, are not disturbed.

Application examples include filters located between the power-line side and the wind-driven power generator. The power is supplied by connecting an asynchronous generator directly to the power network or by setting up an indirect connection via converters and DC link voltages. Depending on the type of design, the relevant specifications of the power supply companies must be observed and the electromagnetic compatibility levels within the wind generator must be respected in order to ensure the reliable operation of all components.

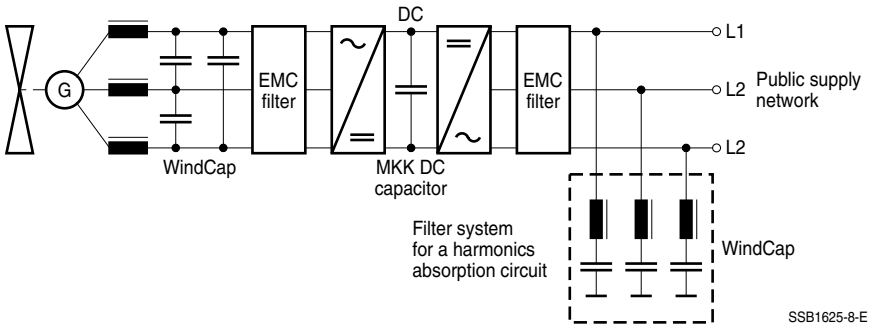


Figure 3 Block diagram of a wind generator

An example drawn from the practical experience of EPCOS EMC engineers is described below: Private households located in the proximity of wind generators suffered from interferences. Thus a resident complained to his local power utility that his electronic alarm clock continually ran two hours fast and woke him too early. The beginning of the irregularities correlated closely with the operational start of the neighboring wind generator, and the power utility soon identified this as the cause of the disturbance.

In this case, the wind-driven generator was connected indirectly to the public supply network via a converter. The necessary EMC measures were discussed and tested jointly with the plant manufacturer and were included in the subsequent series production of these plants.

The EMC measurements confirmed the effectiveness of the EMC filters from EPCOS and that sufficient distance was maintained to the permissible compatibility levels.

The manufacturer opted to use our EMC filters in his wind generators for the following reasons:

- The high technical competence of EPCOS
- The low unit volume of the filters
- Their low power losses
- Their high insertion loss
- Their good price-performance ratio
- EPCOS is a competent and one of the world's largest suppliers

If you encounter any EMC problems, please feel free to approach our sales staff. They will be pleased to inform you about our range of EMC components, send you information material or set up contacts to our EMC laboratory or our development engineers if desired.

If you wish, we will provide you with technical advice: we may then have to take measurements at your premises and find a special solution to suit your needs. We will also deal with any questions pertaining to shaping voltage curves via output filters, improving the power factor or reducing harmonics.

Details of our filters for converters and power electronics (2, 3 and 4-line filters) may be obtained from the relevant data sheets in the data section of this book.

3 Application example – rolling mill



Variable-speed drives are increasingly used in industry to improve the control of technological parameters. Ever more advanced active components such as latest-generation IGBTs make available powers up to the megawatt range for converter drives. In addition to the technological advantages of variable speeds, they also result in significant energy savings and thus ecological benefits. In many cases the economic savings are so great that new investments already become profitable after a few years of use.

High-power drives are mostly operated in industrial networks, so they are not a feature of public power supply systems. This implies that higher interference limits are permissible. However, false economies are often made particularly at this point where operators are too tolerant with respect to interferences.

Modern industrial environments are characterized by the presence of a large number of items of equipment, installations and machines linked to both electronic control and computer systems. These react with mutual sensitivity to electromagnetic interferences and require special EMC protection in view of the diverse combinations of high-level noise signals which occur. It is recommended that **EMC filters be planned-in from the very beginning**, as the consequential costs caused by disturbance of external equipment are significantly higher in practice than the investment costs for EMC filters. Consequential costs may be caused by troubleshooting, down times of production plant in order to effect subsequent improvements right up to delivery delays.

This situation may be illustrated by an example taken from practice.

Our EMC test engineers were called to a large rolling mill because disturbances repeatedly affected the measurement sensors and interfered with operations. Sporadic errors also occurred in the control system; they were also suspected to be caused by interferences. These problems became manifest after the installation was redesigned and some of the drives were replaced.

EMC filters

Industry

An on-site analysis showed very high inrush currents at the start-up of some of the large drives and a very high dv/dt of the output signal from the converter drives. The drives were installed in protected areas because of the harsh operating environment so that the motor cables were very long. This led to high leakage currents caused principally by the parasitic capacitances of the shielding of the long cables to the drive motors. Laying the cables in protected ducts favored the overcoupling of interferences.

The development engineers found a well-matched solution which reliably eliminated all existing problems by using standard filters.

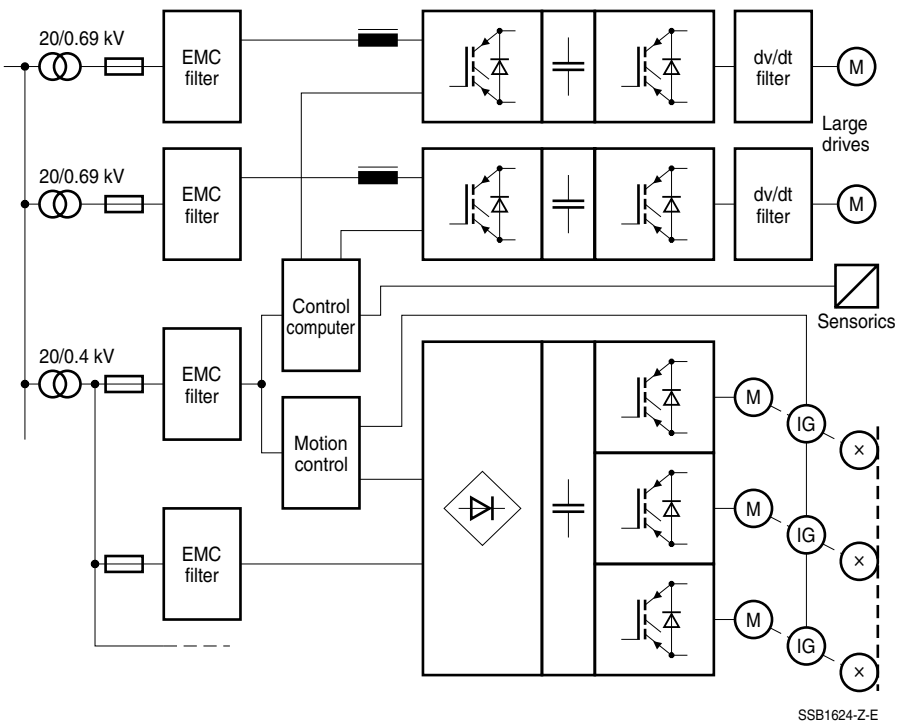


Figure 4 Block diagram, section of rolling mill drives

The example of drives in a rolling mill shown in Figure 4 not only involved the need to comply with the applicable standards; it was also necessary to take note of **safety aspects**. In such cases, electronic devices control large drive systems whose malfunction would release large forces and thus represent a great potential danger. As in many other application areas, in this case too electromagnetic compatibility implied safety for the employees.

The EPCOS filters used here not only proved their worth for many years in a harsh industrial environment but also solved the problem of high common-mode current and **reliably reduced** the interferences on the line side. The **dv/dt filters** used on the output side of the converter **limit the voltage rise time** at the motors to permissible values (in this case 500 V/ μ s). This action reduces both the stress on the insulation within a phase winding and the voltage reflections. But it also reduces the failure rate of the drive motors, a result which is reflected in the higher availability of the installations in terms of cost efficiency. To complete these actions, proposals by our EMC system engineers on earthing, grounding and cable laying were implemented at relatively low cost. The result is interference-free operation of a large installation and a satisfied customer.

The following were among the principal reasons why the customer decided to opt for EMC filters from EPCOS:

- The company's many years of experience in the field of filters with high currents
- Coverage of the entire product range by a single manufacturer
- A single contact partner for all problems, from the cause of interference via the supply of the components up to acceptance measurements by an accredited laboratory
- The use of high-quality components in the filter itself
- Advice on interference suppression by the team of the EMC laboratory

In this application too, the components used have operated free of faults for many years, which says a great deal about the quality of our products. The calculated low failure rates were also corroborated in practice by the extremely infrequent complaints in view of the large number of filters in operation. The customer confirmed that he had made the right choice for this harsh operating environment by opting for EMC filters from EPCOS.

It has now become standard practice for many industrial companies and handicraft business **to make exclusive use of equipment and installations bearing proof of compliance with the EMC requirements relating to interference emissions and immunity**. The correct operation of the equipment is then assured and its reliability significantly increased. Although this measure is admittedly somewhat more expensive in the investment phase, we were assured that it is certainly worthwhile in the long run.

A more detailed description of some of the filters of the B84143B*S02* series used in this application can be found in the data sheet (B84143B*S020 ... S024).

4 Application example – supply ship



The history of large electrical drives in marine engineering goes back to the first half of the last century. Thus the first diesel-electric icebreaker “Ymer I” started operations in Swedish waters in 1933. Recently developed drives for motors with high power/weight ratios and thus large volumetric efficiency as well as new technologies for converters have now become standard in a number of marine applications. Thus diesel-electric drives are among the convenience features found on large passenger liners and are indispensable whenever high levels of maneuverability are required such as for drilling ships.

State-of-the-art systems have significantly improved efficiencies at partial loads and have permitted uniform power output irrespective of the continuously variable motor speed as well as the rapid response required for thrust reversal, to name only a few examples.

In many cases, the conditions prevailing in marine power supply systems resemble those for **IT networks** so that the EMC filters used should also satisfy the requirements of the latter. However, EPCOS also offers solutions with extremely **low leakage currents**. These are sometimes needed in marine applications in order to ensure the **safety of the crew** in view of the ship’s metal hull.

The specialists involved are aware that it is no simple task to plan projects for large drives in the megawatt range operated at several kilovolts in conjunction with sensitive control and signal technology – and all enclosed within a ship’s metal hull. A project manager with a due sense of responsibility will therefore **plan electromagnetic compatibility** into the system from the beginning in the knowledge that the safety of human lives may be endangered by the failure of control, radio or echo-sounding equipment under stormy sea conditions.

An example taken from practice illustrates the diversity of the possible EMC problems which may occur: Employees of the EPCOS EMC laboratory were called to an unusual location when interference problems occurred on a small supply ship. Among the tasks of this vessel was to secure the provision of supplies to drilling platforms even in very heavy seas. To improve maneuverability, the ship was equipped with diesel-electric engines which could also be controlled from a remote console away from the command bridge. In particular, tasks such as approaching tricky mooring points or unloading provisions without mooring in heavy seas at drilling platforms were disturbed. On-board measurements showed impermissible conducted interferences at low frequencies and radiated emissions at specific high frequencies. An examination of the earthing concept led to a suspicion of potential carry-overs.

On the recommendation of our EMC system engineers, EMC filters with low leakage currents were used to decouple both the converters from the ship's power system and equipment with higher internal operating frequencies. Moreover, the earthing concept was changed throughout, contacts were set up across the entire surface of the cable shields and several low-pass filters with discrete components were installed in the control sector.

Additional mechanical components from EPCOS (cases and fittings; see Figure 5) boosted the attenuation in the upper frequency range. Use was also made of cost-effective EMC filters from our standard program.

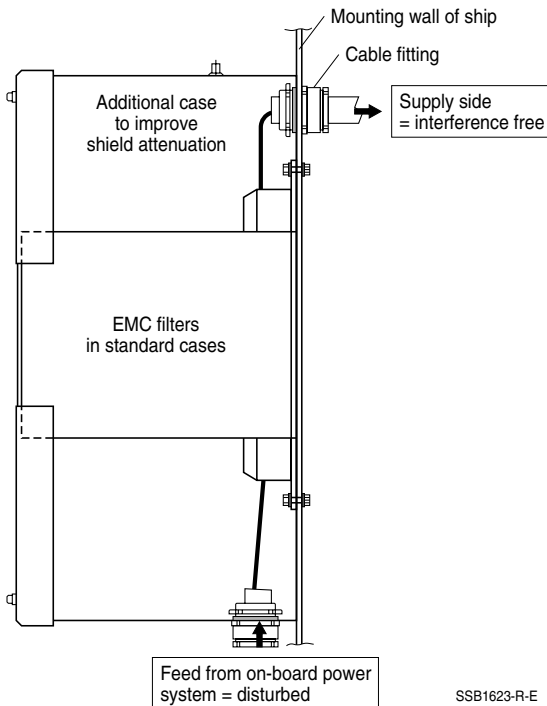


Figure 5 Example of mounting a filter into a ship electrical system

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EMC filters

Marine

EPCOS succeeded not only in assuring compliance with the permissible EMC levels but also in keeping the low and high controller levels within the permissible limits so that the functional interferences of all the ship's operating conditions was eliminated.

The following reasons were decisive for the use of EPCOS components:

- Very rugged filter construction
- Resistance to humidity
- Small unit volume
- Suitability of the filters for this IT network application
- Very low leakage currents
- Thanks to supplementary mechanical parts for the filters, shielding was set up throughout between the filter input and output.

EPCOS products range from **input filters** for various equipment in marine on-board power systems (also for military applications) up to **output filters** with high powers, currents and voltages (0.07 ... 5 MW; 100 ... 1000 A; 0.4 ... 6 kV).

Factors other than interference suppression play a part in output filters. They include:

- the reduction of common-mode current by using ground connections,
- shielding of the motor cables is undesired, and above all
- low stress on motor due to voltage peaks.

In many cases, the last point means **higher reliability and a longer operating life of the drives.**

It is part of the corporate philosophy of EPCOS to maximize customer satisfaction. That's why we sometimes implement solutions to enquiries which may appear unusual at first sight. As a result, we can demonstrate very demanding technical solutions such as a current-compensated choke for 750 A and 5000 V with **extremely low partial discharge** (see Figure 6).

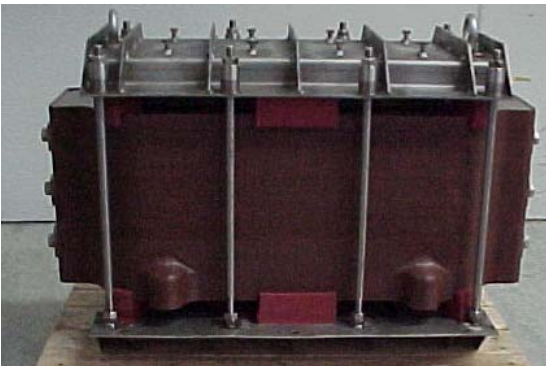


Figure 6 Current-compensated choke for
3 × 750 A and 5000 V

Details of our filters for converters and power electronics (2, 3 and 4-line filters) may be found in the relevant data sheets in the data section of this book.

5 Application example – traction

The requirements of traction applications such as streetcars, trolleybuses, electric locomotives and modern railcars often differ from those of other industrial applications. These differences relate both to the electrical parameters and to the environmental requirements in terms of impact, vibration, mechanical stability, soiling and dew formation.

EMC filters from EPCOS are available as standard products for a number of application areas, such as input filters for voltages up to 2000 V DC and currents up to 1000 A. But numerous special types are also offered outside the range covered by the data book. If required, we will develop a matching solution together with the customer.

5.1 Streetcars

Figure 7 shows an overview circuit diagram illustrating the use of EPCOS EMC filters in the power supply system of a modern municipal rail system with converter drives.

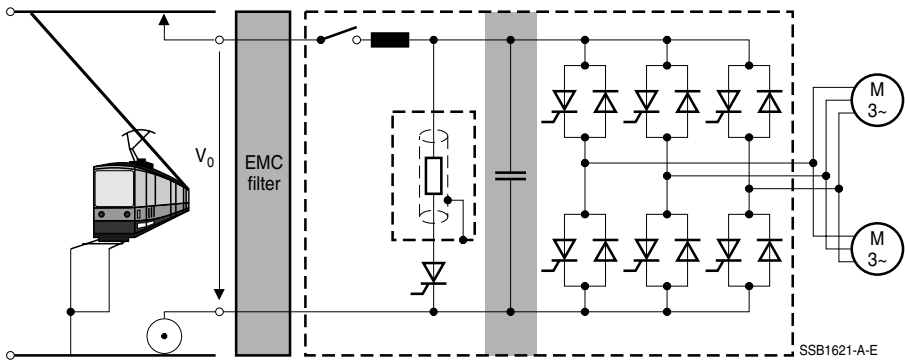


Figure 7 Power supply system of a modern municipal rail system with converter drives

The following criteria were decisive for the customer in this case:

- Compliance with the mechanical and climatic properties required for operation
- High insertion loss
- Low leakage current
- Small unit volume
- Low power losses
- Low weight

5.2 Omnibus systems

Filters with low leakage currents which satisfy the more stringent safety requirements of omnibus systems are a typical example of customer-specific solutions.

Although special frame-connection and grounding conditions had to be considered because of the rubber tires of the vehicles, a solution based on EPCOS components was also found for this application.

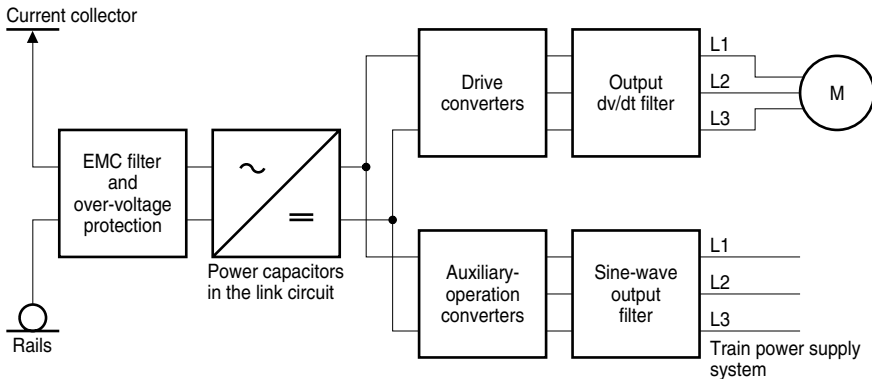
5.3 Modern long-haul trains

Another example of a customer-specific solution is that of sine-wave **output filters** for onboard power supply systems. These convert the square-wave output voltage of the auxiliary converter into an on-board voltage of high power-line quality. As a result, users can operate standard equipment and even laptops when traveling on modern long-haul trains. In this specific case, sinusoidal output filters were implemented with voltages up to 2.4 kV and currents up to 500 A.

A sinusoidal output voltage is also mandatory for complying with the EMC limits on board a train, as shielded cabling cannot be used in most cases.

For **locations where safety is a factor**, such as below-floor mounting, the design must conform to the requirements and mounting conditions of the relevant transport medium. Stabilities, material fatigue and oscillation characteristics may be verified by means of finite-element calculations and/or tests. Any required welding work is performed by welding operators who have been approved for railroad applications.

Figure 8 shows a block diagram for modern Inter-City trains based on EPCOS components.



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Figure 8 Block diagram (Inter-City train)

Close and confidential cooperation between the customer and the filter manufacturer is required to solve the diverse and complex electrical, mechanical, acoustic and oscillation problems occurring in conjunction with the other parts of long-distance trains.

We see ourselves as a EMC service provider who solves your EMC problems and establishes the associated safety aspects of your railroad application. We provide the relevant verifications and carry out the required tests (in the form of type and series tests with corresponding protocols).

However, our service offer does not end with the supply of the filters, but includes optional services such as multi-lingual documentation or the provision of spares over long time periods.

We present a number of filters for converters in traction systems in this data book. Please refer to the data sheets B84142A*S002 ... S018 and B84143-TRAC.

6 Output filters for converters



Frequency converters, and particularly voltage-controlled converters with IGBTs¹⁾, are used increasingly in industry, as they allow the manufacture of rugged and outstanding drive systems in conjunction with three-phase asynchronous motors.

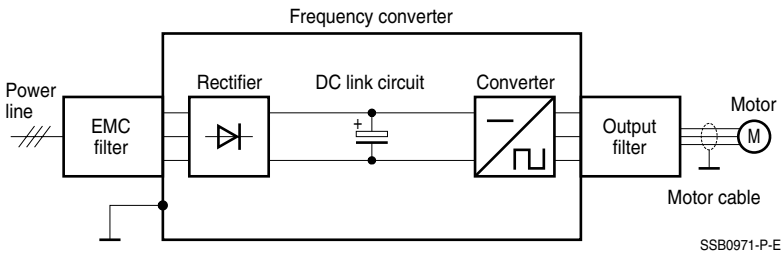


Figure 9 Block diagram of a converter with input EMC filter and and output filter

¹⁾ Insulated Gate Bipolar Transistor

A converter uses an supply with constant voltage and frequency to generate an output voltage whose amplitude and frequency can be modified within broad limits. For this purpose, the input voltage is rectified and smoothed by a DC link circuit. The DC link voltage is then fed into a semiconductor bridge circuit. The turn-on duration of the semiconductors is controlled by the converter control circuit so that the filtered mean value of the output voltage is sinusoidal (pulse width modulation = PWM). The individual half-bridges are driven as to obtain a three-phase AC voltage at the converter output.

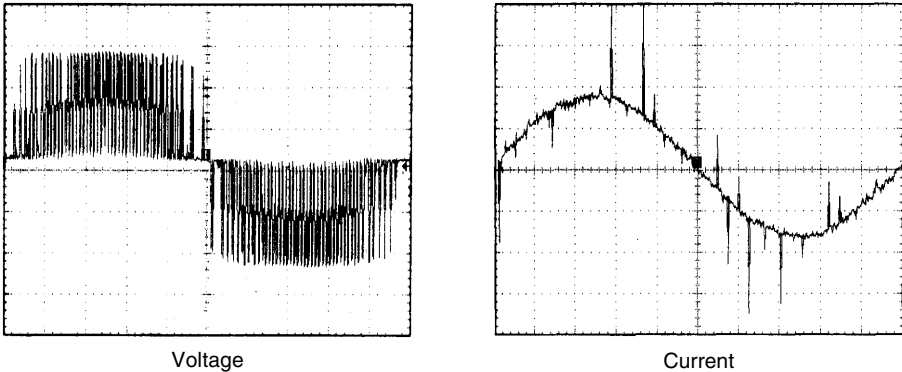


Figure 10 Voltage and current at the converter output without a filter

Few problems occur if the converter and motor are integrated in a single unit. In practice, however, they are usually connected via a long cable.

The cable has parasitic capacitances between the conductors and with respect to ground. Because the rise time of the square-wave pulses of the converter output voltage is between some 5 and 10 kV/ μ s, high-frequency currents flow in the cable every time that switching takes place. In long cables, these can become so large that they trigger the surge-current protection circuit of the converter. However, they always reduce the current available to the motor, so the converter must be more generously dimensioned. In addition, these currents generate losses in the cable and motor because of their high amount of harmonics.

Because a part of these high-frequency currents flows to ground, common-mode interferences are produced. If the motor cables are unshielded, impermissibly high interference fields are generated. Shielding the cables reduces the emissions significantly.

The high dv/dt of the converter voltage stimulates parasitic resonance circuits consisting of cable and motor capacitances and line inductances whose ringing voltages are superimposed onto the converter output voltage.

As a result, short overvoltages occur which can greatly exceed the rated voltage of the motor, particularly on the motor side (Figure 11). These overvoltages stress the motor insulation with partial discharges and cause premature failure, especially in the case of older motors.

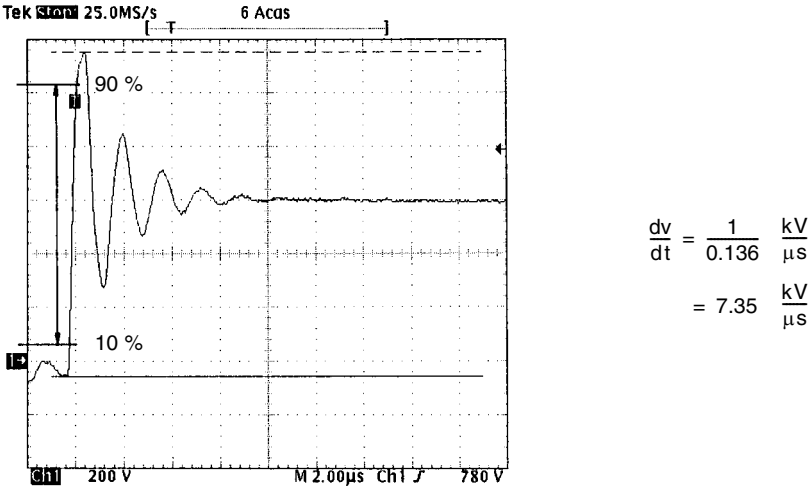


Figure 11 Overvoltage through a motor cable

The following effects are thus produced when converters are operated:

- Large high-frequency reactive currents in the motor cable
- Overvoltages at the motor as a result of the high dv/dt and the long motor cable
- Bearing damage due to leakage currents flowing through the bearings
- Motor noise
- EMC problems
- Damage to the motor insulation

Three filter types are used to reduce these problems:

1. dv/dt filters
2. Sine-wave filters
3. EMC sine-wave filters

Note for users:

Output filters must be matched to the converter and the motor, as they can be excited to self-oscillate under particular operating conditions. The filters described in this data book were tested on various converters. They are merely examples. Additional filters are available upon request.

6.1 dv/dt filters

A dv/dt filter is essentially an LC low-pass filter whose cut-off frequency exceeds the switching frequency of the converter (basic diagram, Figure 12).

The filter increases the rise time of the voltage pulses on the line, reduces the voltage peaks at the motor and causes the dv/dt of the output voltage to drop. This assures compliance with the recommendations with respect to the amplitude and rise time of the line voltage.

The effect of the filter is limited to the dv/dt between the lines. The filter has practically no effect with respect to protective ground. The leakage current and radiated emissions are not reduced.

- Motor cables may be up to 100 m in length
- The motor cable must be shielded
- There is hardly any improvement in EMC interferences

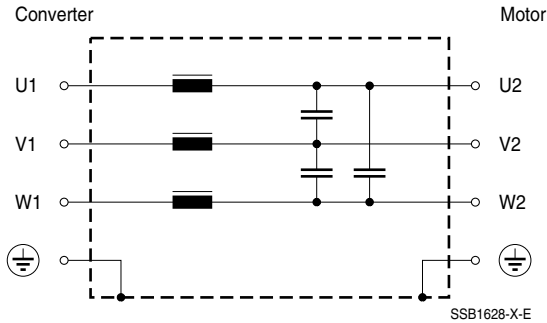


Figure 12 Basic diagram of the dv/dt filter and the sine-wave filter

6.2 Sine-wave filters

A sine-wave filter has the same basic circuit as a dv/dt filter (Figure 12), but the cut-off frequency lies between the output frequencies and converter switching frequencies. Although this makes it necessary to use larger inductances and capacitances, the filter is also more effective. The switching frequency disappears almost completely from the line voltage (Figure 13).

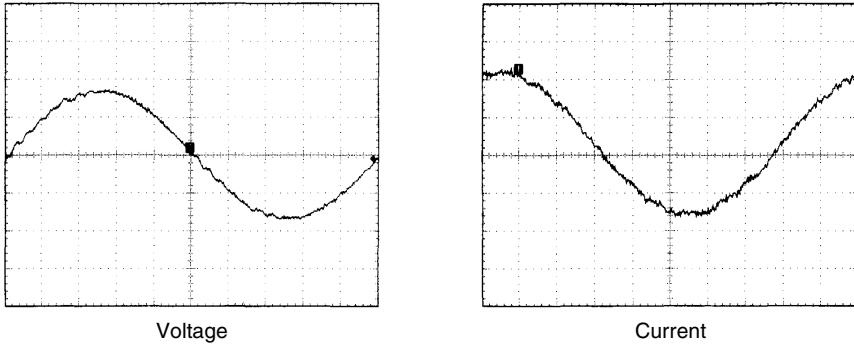


Figure 13 Line voltage and current after the sine-wave filter

As the sine-wave filter mainly affects the differential-mode interferences between the lines, common-mode interferences are hardly reduced at all (Figure 14).

- Motor cables may be longer than 100 m
- Shielding of the motor cable cannot be dispensed with
- Motor noise and eddy current losses are reduced
- The EMC input filter can be down-sized

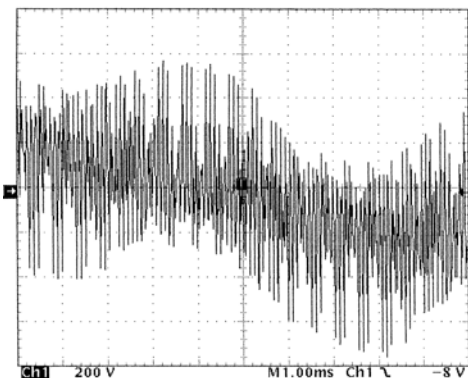


Figure 14 Common-mode line voltage after the sine-wave filter

For data sheets for sine-wave filters see B84143V*R027 and B84143-TRAC.

6.3 EMC sine-wave filters

An EMC sine-wave filter must be used to eliminate the common-mode interferences on the motor cable. It contains a sine-wave filter and an additional current-compensated choke with capacitors between the lines and ground.

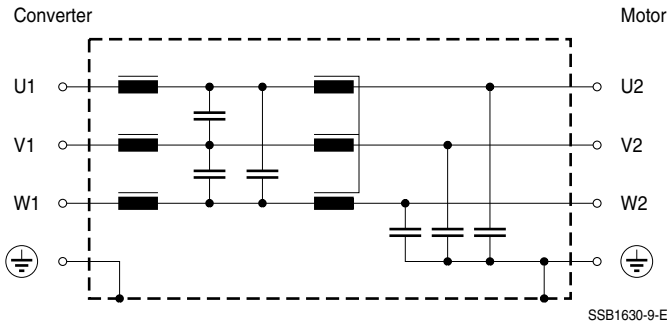


Figure 15 Basic circuit diagram of the EMC sine-wave filter

In this filter, both the voltages between the lines and line to ground are practically free of high frequencies. This offers further advantages over the sine-wave filter:

- Compliance with the EMC specifications is possible without shielded motor cables
- The length of the motor cable is limited only by the motor current
- The EMC input filter can be significantly downsized
- Significant cost savings are achieved by using unshielded lines.

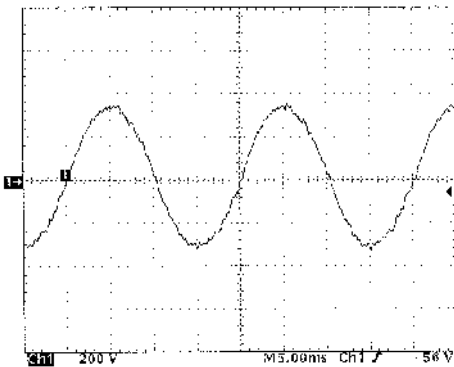


Figure 16 Voltage line to ground after the EMC sine-wave filter

In the ideal case of a sinusoidal output voltage, but depends strongly on the application. The aim is to observe the limits for radiated interferences without shielded motor cables.

6.4 Conclusions

The following conclusions can be drawn:

- The dv/dt filter reduces the rate of rise of the output voltage (line/line), thus reducing the failure probability of the motor.
- The sine-wave filter generates a sinusoidal line-to-line voltage at little extra cost. The common-mode RF interference voltage is somewhat reduced at the same time.
- The EMC sine-wave filter represents the best but also the most expensive solution. However, the EMC sine-wave filter minimizes EMI suppression and shielding expenditures. In addition, motor cable costs are significantly reduced.

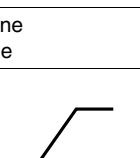

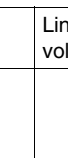
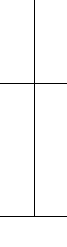
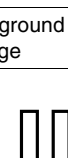

| | Line/line voltage | Line/ground voltage | Radiated emissions |
|----------------------|---|--|---------------------------|
| dv/dt filter |  |  | almost no improvement |
| Sine-wave filter |  |  | slight improvement |
| EMC sine-wave filter |  |  | almost totally eliminated |

Figure 17 Summary of filter properties

7 Filters for switch-mode power supplies



Switch-mode power supplies are increasingly replacing conventional power supply systems in electrical applications based on power transformers and linear controllers. These are usually reasonably priced, but the volume is bigger and the efficiency is lower.

In switch-mode power supplies, the input voltage is rectified and then smoothed in a DC link circuit. Semiconductor switches then chop this DC voltage again, and it is finally transformed, rectified and smoothed. The frequency of the generated AC voltage is usually between approximately 20 and several hundred kHz. This allows the dimensions of the transformers and filter circuits to be minimized. Because only switching and forward losses occur, the efficiency is very high compared with linear solutions.

In the first instance, a distinction is made between primary-switched and secondary-switched converters. Primary-switched converters are further subdivided into flyback converters, single-phase forward converters and push-pull forward converters. The main representatives of the secondary-switched converters are buck and boost converters. All converters have a specific switching characteristic which is reflected in different voltage and current curves generated during switching.

The benefits resulting from this switching technology in terms of size, efficiency and load regulation must be traded off against increased EMC problems. The main interference sources are the semiconductor switches, the output rectifiers, the power rectifiers and not least the control circuits containing components such as microcontrollers. The base interference frequency is the switching frequency of the converter.

A large part of the losses occur when the semiconductor switches are turned on and off. At these times, the semiconductors briefly traverse a linear state in which high voltages are built up and current flows. To minimize these times, the semiconductor switches are switched very fast, i.e. they change from the blocking to the conducting state in about 50 to 100 ns.

EMC filters

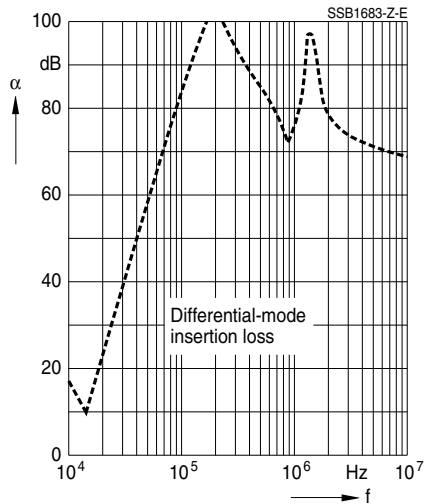
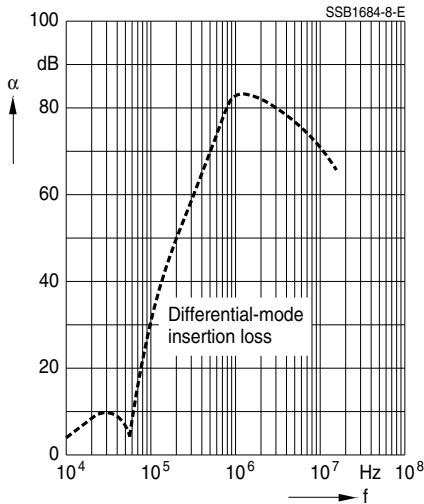
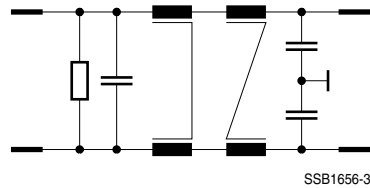
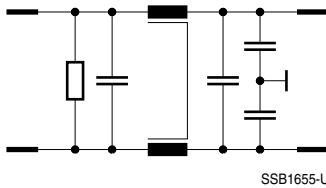
Filters for switch-mode power supplies

These circumstances result in rates of voltage rise dv/dt of several $kV/\mu s$. The RF spectrum extends to several MHz.

If the voltage at the rectifier diodes changes from the forward to the reverse direction, the diode current continues to flow for a short time as a result of the charge carrier storage effect until it suddenly drops to zero when the carriers have decayed. This current drop in conjunction with a simultaneously applied reverse voltage generates an interference voltage with base frequencies in the region of several MHz.

In the range up to several hundred kHz, differential-mode interferences between the lines are predominant. It is attenuated by the leakage inductances of the current-compensated chokes of the filter and by the X capacitors.

If the differential-mode insertion loss in the region below 100 kHz is insufficient, it can be increased by adding powder core chokes with high differential-mode insertion loss (Figure 18).



Filter without differential-mode choke
B84114D*A030

Filter with an additional differential-mode choke
B84115E*A030

Figure 18 Comparison of two filters, with and without differential-mode (powder core) choke

EMC filters

Filters for switch-mode power supplies

At frequencies beyond about 1 MHz, common-mode interferences are dominant. Interference currents then flow between the lines and the reference ground. Semiconductors act as interference sources because they have a high coupling capacitance with respect to ground due to their heat sink as well as a high dv/dt with respect to the case.

Current-compensated chokes are used for interference suppression. The useful current then flows through the choke windings so that the magnetic fluxes in the core are compensated. The full inductance acts for common-mode interferences. Y capacitors are included to short-circuit the interference currents with respect to ground. They are connected to the reference ground principally on the side of the filter facing the interference source (Figure 19).

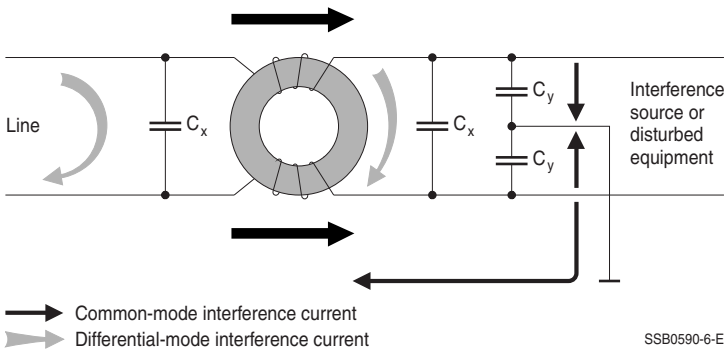


Figure 19 Circuit layout of an EMC filter with current-compensated choke

Because the leakage current of the equipment is limited (e.g. to 0.5 or 3.5 mA) by standards in many applications, the capacitance of the Y capacitors is also limited. A high-inductance choke must therefore be used to produce the desired interference suppression effect.

At frequencies of several MHz, some of the interferences are radiated by electromagnetic fields. In order to achieve high insertion loss, the filter and often also the power supply system must be shielded because the RF interferences can couple over to the input line.

With the SIFI series, EPCOS offer a modular system with various insertion loss and current values. In a word: Standard solutions for almost every application.

EMC filters

Filters for switch-mode power supplies

To ensure that the filter continues to operate at high frequencies, it must be connected to the reference ground with low inductance. It is not sufficient to connect the filter ground connection to the reference ground via a conductor, as the filter then becomes almost ineffective at higher frequencies (Figure 20). The aim should be to use a plane connection between the filter case and the reference ground.

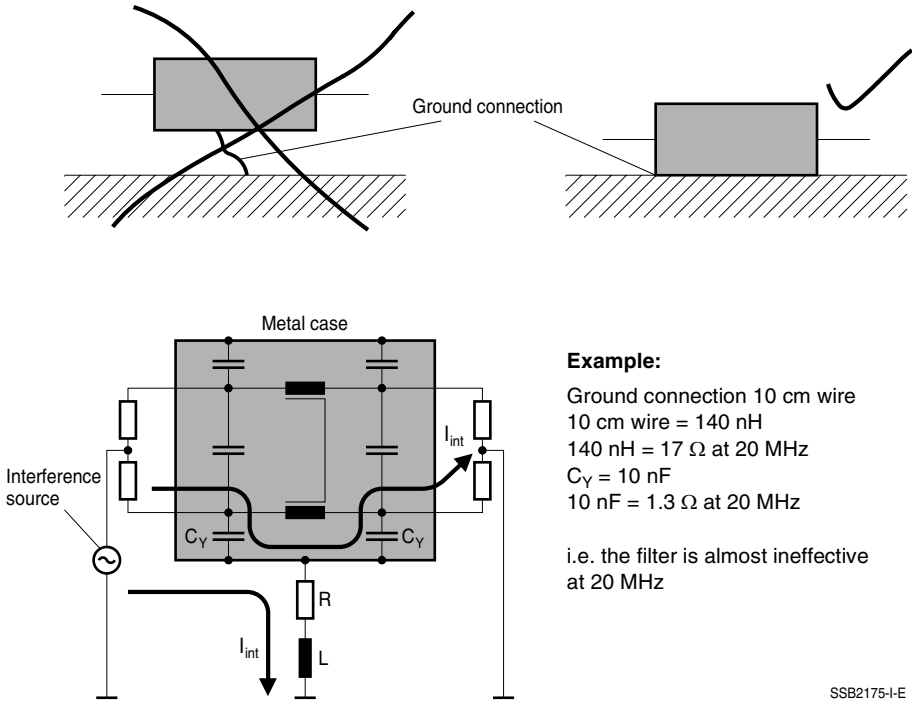


Figure 20 Effects of incorrect filter mounting

The following points must therefore be considered when selecting a filter:

- The switching frequency determines the characteristic of the EMC filter at low frequencies.
- The rate of voltage rise dv/dt of the semiconductor switches as well as any fast-clocked micro-controller circuits which may be present determine the insertion loss needed at high frequencies.
- EMC filters and power supply systems must be regarded as a single unit. Often, even small changes in the circuit (such as altered interconnection layouts or somewhat longer turn-on times) can allow the use of a smaller and less expensive EMC filter.

8 Interference suppression of installations



All equipment containing electrical or electronic components is subject to the EMC Directive and the national EMC laws. These make it mandatory to comply with the protection objectives which can be derived from standards.

If no EMC product standard exists for a certain type of equipment, the relevant product family standard, which describes the limits as well as the applicable measurement configurations and methods, will apply. Installations (such as large printing machines, assembly lines etc.) to which no product or product family standards can be assigned are subject to the generic standards (see tables in Chapter "EMC basics", Section 1.9).

The German EMC law, status September 3, 1998, § 6, paragraphs 6 and 7, contains the following wording:

- (6) Installations containing appliances, systems or components within the meaning of (3) which are in conformity with the requirements according to § 3(1) and § 4(1) shall be **deemed to satisfy the protection requirements** if

1. the information on the **intended use** of those parts, and
2. the rules of **good engineering practice**

have been respected.

§ 4(1) sentence 1 subparagraphs 1 to 3 and 5 shall not apply to installations according to sentence 1.

- (7) Installations also containing appliances, systems or components within the meaning of (3) which have been produced solely for use in these installations and are not in accordance with the provisions of § 4(1) or (2) shall, where neither the presumption according to § 3(2) applies nor documents according to § 3(3) have been provided, be **deemed to satisfy the protection requirements** if

1. they have been provided by firms or persons with **expertise in the field of electromagnetic compatibility**,

EMC filters

Interference suppression of installations

2. the information on the **intended use** of the components has been respected,
3. the rules of **good engineering practice** have been respected, and
4. the installations are **electromagnetically compatible** with other apparatus used in their **environment**.

The manufacturer shall provide the operator with a technical construction file on installations according to sentence 1 above when they are taken into service. Such file shall include:

1. a description of the installation,
2. details of the installation site, and
3. information on the measures to ensure the protection requirements.

After the installation has been taken into service, the operator shall hold the technical construction file with the contents specified in sentence 3 at the disposal of the Regulatory Authority for the period of its use.

§ 4(1) sentence 1 subparagraphs 1 to 3 and 5 shall not apply to installations according to sentence 1.

This means that installations which are set up on site from individual items of equipment bearing a CE mark, in accordance with their intended use and in a technically competent way, are not subject to mandatory marking.

In the same way, installations which are not set up with CE-marked equipment but are manufactured, operated and documented in a technically competent way, can also be operated without CE marking. However, electromagnetic compatibility can only be secured by means of a test.

It is as a rule difficult to estimate the EMC of installations because the equipment standard was designed only for generally available equipment and takes the entire electromagnetic environment into account. No generally applicable standard exists for installations. The EMC must consequently be checked and secured for each individual case. If problems occur in operating the equipment, an attempt must be made to identify the disturbing source and to suppress the interferences until its effects are completely eliminated.

In principle, installation operators should urge their installation suppliers, and these their equipment suppliers, to make exclusive use of EMC-compliant equipment to ensure the operational safety of their installations and to document this status in a verifiable way by means of appropriate tests.

The specifications laid down in agreements designed to comply with EMC apply prospectively to all parties involved. The effort and expense required to subsequently correct noisy installations is incomparably greater than that expended in including EMC components and filters as early as the planning phase.

To ensure an optimum and cost-effective EMC solution, the installation must be examined by the manufacturer and by EMC experts, and suitable EMC measures (e.g. filters, cable laying, maintenance) must be taken. The filters described in this data book as well as customer-specific filter solutions are available for this purpose.

Suitable filters designed to suppress the interferences of individual items of equipment in the installation may be selected from the relevant tables and application notes in this data book. An EMC filter can be matched in a customer-specific way, if required. The filters must obviously satisfy the requirements of the relevant application.

9 Filters for power line communication (PLC)



What is PLC?

Power line communication refers to the transmission of data via the power supply network. In this process, the data stream to be transmitted modulates one or several RF carriers in an appropriate way. The RF signal is coupled into the power line and subsequently tapped, demodulated and evaluated at another point.

In principle, a distinction is made between broadband and narrowband communication techniques.

Applications

- Networking of POS (point of sale) systems, automatic vending machines
- Time recording and access monitoring
- Control and monitoring of processes and machines
- HVAC (heating, ventilation and air-conditioning)
- Remote maintenance and diagnosis of domestic appliances
- Connection of sensors and actuators
- Permanent Internet access (fixed connection)
- Alternative to telecommunications providers in local networks

Benefits

- Existing power infrastructure can be used for transmission, both outside and inside the house
- Simple retrofitting (only one access router per house)
- Available throughout the world

Drawbacks

- Difficult to ensure compliance with EMC limits
- Bandwidth is limited (10 MBps)
- Many households are connected to a low-voltage cable; bandwidth is reduced as the number of subscribers increases
- No uniform transmission standards yet exist for terminals (compatibility problems when moving house)

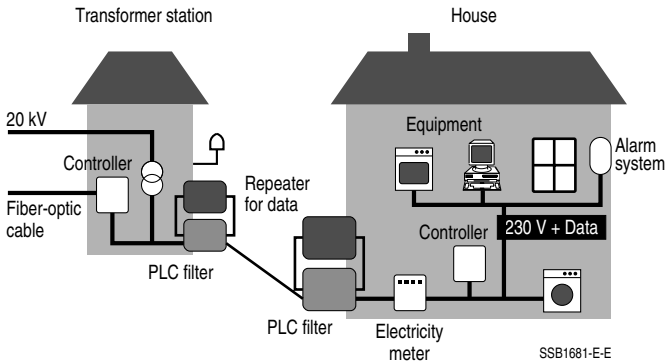
9.1 Broadband communication within a house and between a house and the transformer station (Internet from the power socket)


Figure 21 Broadband communication within a house and between the house and transformer station

Data are transmitted between a transformer station and the end user in the frequency range of several MHz at a rate up to 10 MBps. Repeaters are connected at the ends of the lines in order to increase the signal level.

The PLC filter is used to:

- couple the RF data signal into the line;
- allow the repeater input and output to be decoupled while using only a single frequency range;
- to attain a defined value for the characteristic impedance at the house terminal;
- to extend the range (the power network at the house terminal has a very low impedance without a filter; short circuiting of the wanted signal);
- To avoid collisions of data packets in the event of high user density.

A special form of this technology is represented by data distribution along the medium-voltage line on which only transformer stations are interconnected.

9.2 Narrowband communication within a house

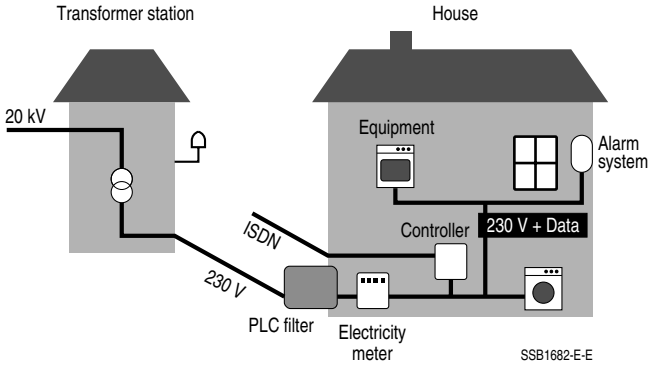


Figure 22 Narrowband communication within a house

Data are exchanged only between the controller and intelligent equipment. A PLC filter ensures that the data does not leave the house. Communication to the outside are sent via the existing telephone line. A narrowband transmission in the frequency range up to approximately 150 kHz is sufficient for this kind of communication.

9.3 Filters for PLC

EPCOS offers filters for PLC applications in homes and transformer stations. An example of a PLC filter for use in the sector of broadband communication is shown in the Chapter “Customer-specific filters” (data sheet B84131-PLC).