

Understanding RFI Power Line Filters

What Is Radio Frequency Interference (RFI)?

RFI is unwanted electromagnetic energy in the frequency range generally used for radio communications. The frequency ranges of interest are 10kHz to 30MHz for conducted phenomena and 30MHz to 1GHz for radiated phenomena.

What are the modes of propagation of RFI?

RFI is propagated via radiation (electromagnetic waves in free space) and by conduction over signal lines and AC power systems.

Radiated - One of the most significant contributors to radiated RFI from electronic equipment is the AC power cord. The power cord is often an efficient antenna since its length approaches a quarter wave length for the RFI frequencies present in digital equipment and switching power supplies.

Conducted - RFI is conducted over the AC power system in two modes. Common mode (asymmetrical) RFI is present on both the line and neutral current paths with reference to the ground or earth path. Differential mode (symmetrical) RFI is present as a voltage between the line and neutral leads.

Why Be Concerned with RFI?

The designers and manufacturers of digital equipment must concern themselves with RFI for two reasons. (1) Their equipment must operate properly in the application environment, often in the presence of significant levels of RFI. (2) Their equipment must not emit RFI that interferes with RF communications often vital to health and safety. The necessity for reliable RF communications has given rise to legal regulations ensuring RFI control for electronic equipment.

What are the FCC requirements?

The U.S. Federal Communications Commission (FCC) has established regulations to reduce the interference potential of electronic computing devices (FCC Rules, Part 15, Subpart J). A computing device is defined as any electronic device or system that generates and uses timing signals or pulses at a rate in excess of 10,000 per second and that uses digital techniques. It is important to note that a switching power supply does not itself fall into this category, but that its emissions must still meet the limits when it is installed in a piece of equipment that is subject to the regulations.

The level of emissions the equipment must meet depends on whether it is marketed for use in a residential environment (Class B) or in a commercial, industrial, or business environment (Class A). The limits for Class B are more stringent than those for Class A (see Appendix A). Most Class B equipment must undergo certification, meaning that emissions

test data must be submitted to the FCC for type approval. Class A and all other Class B equipment must be verified—i.e. the manufacturer conducts his own emissions testing and verifies that he complies with the limits, but no forms need to be filed with the FCC.

Further details on FCC requirements can be obtained from the FCC, RF Devices Branch (Authorization and Standards Division), Washington, DC 20554, (301) 725-1585.

What are CE markings and RFI filters?

As of January 1, 1996, electrical and electronic equipment shipped to Europe is required to be labeled with the CE marking. In order to apply the CE marking, equipment must meet the General Product Safety Directive and Electromagnetic Compatibility Directive.

RFI power line filters are components and therefore not covered by the CE requirements, but they are used in electronic systems to meet EMC specifications.

Two of the most common emission specifications are EN 55011 for industrial, science, and medical equipment, and EN 55022 for information technology equipment. The conducted emission limits for these specifications are the same and broken down to Class "A" and Class "B" limits. Electronic equipment that may be connected to a power main shared with a residential area must comply with the more stringent Class "B" limits. The measurement technique is done using quasi-peak and average detection, with different limits for each measure in dB above one microvolt.

There are several immunity tests to which electronic equipment must comply, one of which is the electrically fast transient (EFT), IEC 61000-4-4. The equipment must continue to operate during this test. The transient wave form is a 5ns rise time with a 50ns duration. A burst is induced onto the power line at 1kV with a repetition rate of 5kHz lasting 15ms and repeated every 300ms. The test simulates switching of inductive loads and contacts.

To pass the EFT test, it is important that the RFI filter's enclosure have a good RF ground with the system's chassis ground. This provides a lower impedance path from the safety ground to the system ground. The shielding effect of the RFI filter's metal enclosure eliminates radiation into the system's cabinet induced by the conducted EFT burst. Stray capacitance may occur from any of the three input power wires to chassis ground where voltage can build up from the EFT burst and cause system interrupts. The RFI filter's inductor offers an impedance to the burst.

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In cases where the stray capacitances have caused multiple RF ground planes or where plastic enclosures are used, an inductive choke may be needed to provide isolation of the safety ground from the chassis ground.

What Is a Power Line Interference Filter?

A power line interference filter is a primary tool available to the designer of electronic equipment to control conducted RFI both into the equipment (potential equipment malfunction) and out of the equipment (potential interference to other system elements or RF communication). By controlling the RFI conducted onto the power cord, a power line filter also contributes significantly to the amount of radiated RFI.

A power line filter is a multiple-port network of passive components arranged as a dual low-pass filter; one network for common mode attenuation, another network for differential mode attenuation. The network provides attenuation of RF energy in the stopband of the filter (typically above 10kHz), while passing the power current (50-60Hz) with little or no attenuation.

How Does a Power Line Interference Filter Work?

Power line interference filters, as passive, bilateral networks, have complex transfer characteristics, which are extremely dependent upon source and load impedance. The magnitude of this transfer characteristic describes the attenuation performance of the filter. In the power line environment, however, the source and load impedances are not defined. Therefore the industry has standardized upon the practices of verifying filter uniformity through measurement of attenuation with 50 Ohm resistive source and load terminations. This measurement is defined to be the Insertion Loss (I.L.) of the filter.

$$I.L. = 10 \log \frac{P_L (Ref)}{P_L}$$

where $P_L (Ref)$ is the power transferred from the source to the load without the filter, and P_L is the power transferred when a filter is inserted between the source and load. The Insertion Loss may also be expressed in terms of voltage or current ratios as shown:

$$I.L. = 20 \log \frac{V_L (Ref)}{V_L}$$

$$I.L. = 20 \log \frac{I_L (Ref)}{I_L}$$

where $V_L (Ref)$ and I_L are measured without a filter and V_L and I_L are measured with a filter.

It is important to note that Insertion Loss does not describe the RFI attenuation provided by a filter in the power line environment. In the power line environment the relative magnitudes of the source and load impedances must be estimated and the appropriate filter configuration selected such that the greatest possible impedance mismatch occurs at each termination.

This dependence of filter performance on terminated impedances is the basis for the concept of “mismatching networks.”

What is the concept of power line filters as “Impedance Mismatching Networks”?

RFI power line filters can be thought of as “impedance mismatching networks” at higher frequencies in the attenuation band. Network analysis shows that the greater the mismatch of filter impedance to terminating impedance, the more effective the filter is in attenuating RF energies.

Common mode power line impedance is considered to be low (on the order of 50 Ohms). Thus, following the concept of an impedance mismatch, Corcom power line filters employ a high common mode impedance (series inductance) on the power line side of the filter.

For load (equipment) side common mode impedance mismatch, Corcom products are available with a high impedance (series inductance) or a low impedance (shunt capacitance).

High (common mode) impedance filters for use with low impedance equipment include the EP, H, 6A Q, R and V series. Low (common mode) impedance filters for use with high impedance equipment include the B, EC, ED, EF, G, K, N, 3A Q, S, SK, T, W, X, Y, and Z series.

Knowing the input impedance of your equipment, then, may be useful in initially selecting the filter series most likely to solve your RFI problems. However, since this impedance is almost certainly complex (having both resistive and reactive components), it may vary widely over the RFI frequency range. Hence a variety of series should be evaluated in your quest for the most effective filter in any one application.

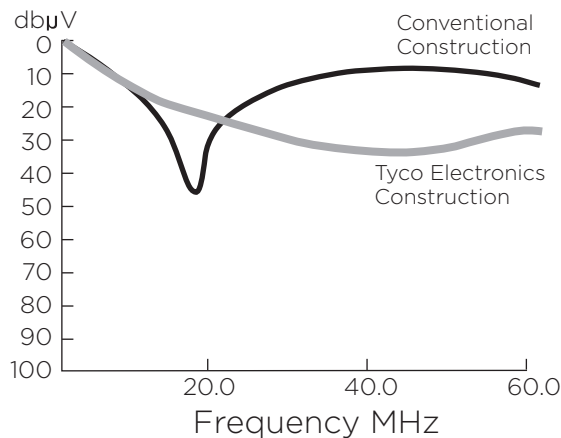
Do all filter networks with the same circuit and element values perform identically?

All filter networks with the same circuit and element values do not perform identically. Element values are specified and measured at a single frequency (usually 1kHz). Filter performance is required over the entire frequency spectrum, not just at the frequency of component measurement. The type of component construction and method of incorporation into a filter are extremely important to filter performance.

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Figure 1 illustrates the high-frequency performance difference between the three leaded capacitor construction employed by Tyco Electronics and a conventional method of construction. Both units would be specified by the same nominal 1kHz component value, approximately 5000pF.

Figure 1: Insertion Loss



How Do You Select a Power Line Interference Filter?

The only way to select and qualify a power line interference filter is to test the unit in your equipment. As mentioned above, the performance is highly dependent on equipment load impedance. Filter performance cannot be derived from single impedance (50 Ohm) insertion loss data. Performance is a complex function of filter element impedances and equipment impedances which vary in magnitude and phase over the frequency spectrum of interest. Filter selection testing should be performed in your equipment to your required level of performance for both conducted emission control (FCC, VDE) and susceptibility control.

How do you perform conducted emission tests?

Conducted emission testing requires a quiet RF environment—usually a shielded enclosure—a line impedance stabilization network, and an RF voltage instrument such as a tuned receiver or a spectrum analyzer. Additional testing information is given in Appendix A. The RF ambient of the test environment should be at least 20 dB below the desired compliance limit for accurate results. The line impedance stabilization network (LISN) is required to establish a desired source impedance for the power line input. This is an important part of the test procedure, since this impedance directly affects the measured emission levels. The correct bandwidth for the measurement receiver is also a critical test parameter.

How do you perform susceptibility testing?

Susceptibility testing involves injection of noise onto the power input lines while monitoring the equipment for proper operation. Quantification of the noise levels to be found in the equipment environment is difficult at best. Through analysis of solutions to specific susceptibility problems, Tyco Electronics has developed recommended noise injection levels, which proved a high level of confidence for reliable equipment operation in the real world environment. The test methods and injection noise levels are found in Appendix B.

Is installation important to filter performance?

Mounting and wiring of the filter are critical influences on its performances. A power line filter is best installed at the power line input point of your equipment. The filter is a barrier to high frequency signals. Its purpose must not be defeated by stray capacitance coupling the power input leads to the power output leads, or to any other conductors in the protected equipment.

Normally the case of the filter is bolted to the framework or chassis of the electronic equipment it protects. The line side leads should be kept short and well separated from the load side leads. The ideal isolation system is a bulkhead-mounted filter incorporating a line cord connector, such as the Corcom EC, ED, or EF power line filter series.

How Do You Know Which Filter To Test?

A filter, or ordered group of filters, likely to solve your interference control problem can be obtained by using the selector chart at the front of each section. Every Corcom filter series is available in a range of current ratings and packages. Detailed specifications, including prices, are listed on the individual series' catalog sheets referenced in the selector chart. Telephone numbers of distributors who stock all Tyco Electronics products are listed on the back cover of this catalog.

Why Be Concerned with Safety Agency Requirements?

All components in the AC power system, including power line filters, must be safe from potential fire and shock hazard. The standards set by the various safety agencies, like UL, CSA, VDE, and SEV, provide guidelines to assist the designer in specifying safe and reliable components. Components which carry the compliance symbols from these agencies have been designed and manufactured to comply with these standards. A summary of safety agency requirements can be found in Appendix C.



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What are the significant requirements of UL and CSA?

UL and CSA are primarily concerned with high potential withstand capability, temperature rise, creepage distances, and material temperature capability at the time of manufacture.

What are the additional aspects of VDE safety requirements?

In addition to the requirements of UL and CSA, VDE specifies limits of hipot, insulation resistance, and change of component values, at the conclusion of extreme environmental conditioning. The conditioning includes life tests at elevated temperatures, long term humidity, and temperature/humidity cycling. Components that bear the VDE symbol of safety have been designed and tested not only for initial safety but also for safety over the life of the product.

How Do You Specify a Power Line Filter?

The filter you have selected through system testing can best be specified by the data parameters found on the appropriate catalog page. Combining the product family parameters listed under the “specifi-

cations” with the package style and dimensional data from your specific filter will adequately define your selection.

Are there other parameters that need to be specified?

There are three additional requirements that are often specified. Below are our recommended values:

1. Insulation Resistance: 6000 MΩ @ 100VDC
2. Current Overload: 6 X rated current for 8 seconds
3. Humidity: 21 days at 40°C 95% RH

What are the test methods for verification of the important specification parameters?

Some filter specifications may be unfamiliar to you or may require slightly different measuring techniques than you have been using for other components. It is very important that supplier and customer use the same techniques for verification of electrical specifications, in order to assure an uninterrupted flow of quality components. Three specifications that must be clearly understood are hipot testing, leakage current, and insertion loss.

Understanding Hipot Testing

The term “hipot” is an acronym for “high potential.” Hipot testing stresses the insulation and capacitors of a filter assembly by applying a voltage much higher than is usually experienced in normal operation. The purpose of hipot specifications is to assure safety and reliability.

All the major safety agencies require hipot testing for qualification of power line filters, and also require that each production unit undergo hipot testing to verify the integrity of the line-to-ground components and insulation. Every Corcom filter is hipot tested twice: once during assembly and again after completion. Applying hipot testing as an incoming inspection procedure requires a thorough understanding of its uses and limitations.

Hipot test voltages are applied from each line (both lines tied together for VDE) to ground and from line-to-line. The line-to-ground voltages are always higher. Test voltages may be specified as AC or DC, with the DC voltages at least 1.414 times the AC voltages.

For incoming inspection testing, Tyco Electronics recommends using the voltages given as “hipot rating” for each filter in the catalog. These DC voltages will always be equal to or higher than the peak AC voltage carried by any safety agency whose approval the filter carries. A DC hipot test is generally used.

A variety of hipot testers is available from a number

of manufacturers. The tester chosen should have at least a 500VA rating.

The following precautions must be observed to insure the safety of the operator and the validity of the test:

1. THESE VOLTAGES CAN BE LETHAL—use the utmost safety precautions to protect the test operator.
2. The possibility of high surge currents and oscillatory overvoltage during sudden application of the test voltage requires some method of limiting the applied current or increasing the voltage comparatively slowly.
3. For AC hipot tests, use an oscillograph to monitor the applied voltage. The current limiting circuit may react with the filter circuit to distort the 60Hz waveform. This may produce a peak voltage that exceeds the expected peak value of a sinusoidal voltage having the specified rms value. The peak voltage should be 1.414 times the rms value. Higher voltages may cause unwarranted failures due to the peak currents exceeding the trip setting.
4. For line-to-line hipot testing, remember that most filters have a bleeder resistor (typical value 100kΩ to 10MΩ) to discharge the line-to-line capacitors. Be sure to set the trip point of the hipot tester above the current level that will flow through the bleeder resistor: 10mA is usually a safe value.

Understanding Leakage Current (Touch Current)

Leakage current (also referred to as “touch current”) is an important specification of power line filters. There has always been an undesired negative connotation to this term. Leakage current is not a function of the quality of components, but is a direct function of the line-to-ground capacitance value. The larger the capacitance, the lower the impedance to common mode currents, and the greater the common mode interference rejection. Hence, leakage current is a measure of filter performance—the higher, the better.

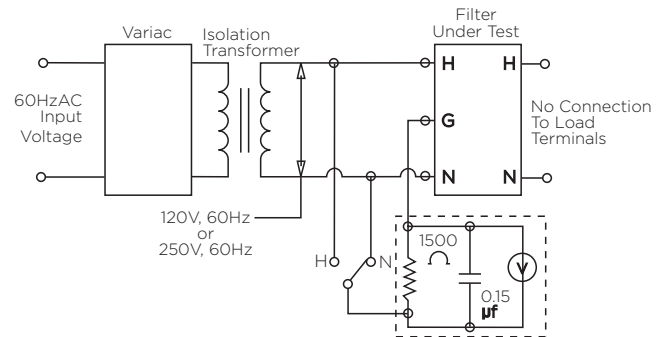
Why, then, do safety agencies specify a maximum allowable leakage current? This is done in order to limit the magnitude of expected ground return currents. The line-to ground capacitors provide a path for 50/60Hz current to flow to the chassis. As long as the equipment is grounded, these currents will flow in the ground circuit and present no hazard. However, in the unlikely but always possible circumstance where the ground circuit is faulty, the earth connection may be established by the body of a person. If this should occur, the maximum leakage current specification limits the ground return current to a safe value, typically 0.5 to 5.0mA. The limits set by safety agencies are based on end user equipment specifications, such as those given below.

Capacitive Current Limits

<u>Country</u>	<u>Specification</u>	<u>Limits for Class I Grounded Equipment</u>
U.S.A.	UL 60950	3.5 mA, 120V, 60Hz
Canada	C22.2 No. 60950	3.5 mA, 120V, 60Hz
Europe	EN 60950	3.5 mA, 250V, 50Hz

Since the largest component of leakage current is usually from the power line filter, it is prudent to set a maximum leakage current limit for the filter itself. There has been a tendency in the industry to specify the minimum leakage current to comply with all agency requirements, usually 0.5mA. This specification decision should not be made arbitrarily, because often the size and cost of the filter can be reduced by allowing a greater maximum leakage current.

Figure 2: Leakage Current Measurement



Note that filter case must be floating, not grounded.

The circuit of Figure 2 illustrates the measurement technique for leakage current. The leakage limits apply to each side of the line independently. The test circuit provides the correct value by shunting the line-to-ground path that is not being measured by the millimeter impedance. This test is realistic, because power to a system is provided by a hot line and a neutral line, with the neutral basically at ground potential, thus providing no addition to the leakage.

Note that the leakage current is directly proportional to line voltage and frequency. Hence, it is unwise to specify an operation frequency greater than 60Hz (e.g., 400Hz) when leakage current limits must also be met.

Understanding Insertion Loss

What is insertion loss?

Insertion loss is the ratio (expressed in dB) of the signal voltage transferred from source to load without a filter, to the signal voltage transferred from source to load when the filter is inserted. As discussed above (“How Does a Power Line Interference Filter Work?”), insertion loss is not a measure of filter performance in the power line equipment environment.

How is it measured?

If the terminating impedances are standardized, then it becomes meaningful to measure insertion loss, but the results so obtained can be applied only to an identical circuit. The most popular set-up is to make the source and load impedances each 50 Ohms, resistive.

The most important aspect of insertion loss measurement is consistency. It is particularly critical that supplier and user employ the same measurement techniques. The standard method of insertion loss measurement used by Tyco Electronics is as follows:

Insertion loss is easily measured with a spectrum analyzer or tuned receiver and a tracking generator. A zero dB reference is established without the filter. Then the filter is inserted, and the attenuation provided over the desired frequency range is recorded.

For a power line filter we are interested in signal attenuation in two different modes:

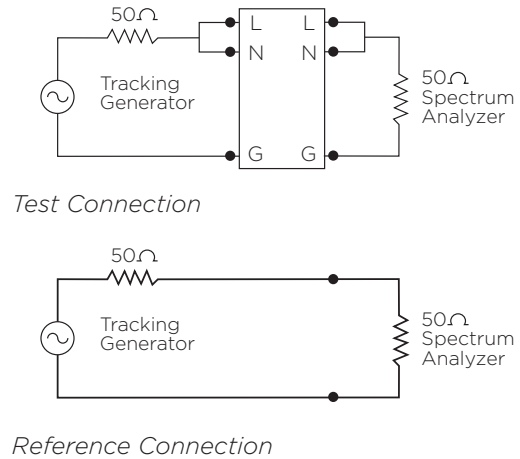
Common Mode (CM) — signals present on both sides of the line (hot and neutral) referenced to ground.

Differential Mode (DM) — signals present on one side of the line, referenced to the other.

Accordingly, we may deal with CM insertion loss or DM insertion loss or both.

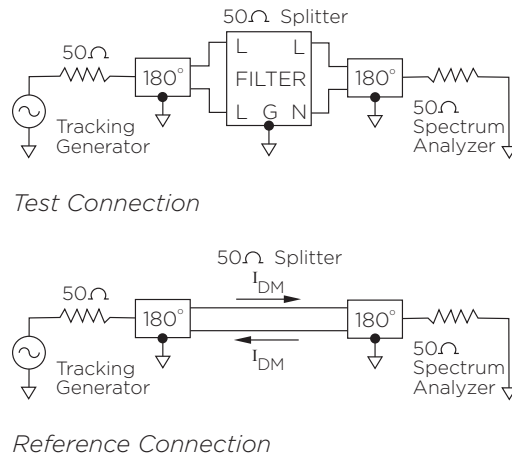
For the common mode, the line and neutral terminals are at the same potential (same magnitude and phase) and may be considered as being in parallel. CM current circulates between this pair and the common (ground) lead. CM insertion loss is measured by strapping the line and neutral terminals together on both sides of the filter (Figure 3). All CM insertion loss data published in the Corcom product catalog are measured this way. For differential mode, the signals on the line and neutral terminals are of the same magnitude but opposite phase. Current circulates between the line and neutral leads only. DM insertion loss is tested with 50 Ohm 180° power splitters as shown in Figure 4. All DM insertion loss data published in the Corcom product catalog are measured this way.

Figure 3: CM Insertion Loss Measurement



For differential mode, the signals on the line and neutral terminals are of the same magnitude but opposite phase. Current circulates between the line and neutral leads only. DM insertion loss is tested with 50 Ohm 180° power splitters as shown in Figure 4. All DM insertion loss data published in the Corcom product guide are measured this way.

Figure 4: DM Insertion Loss Measurement



Note that all signal leads in Figures 3 and 4 are 50 Ohm coaxial cables.

1. Make your 0dB reference measurement over the entire frequency range, not just at one or two points.
2. Make sure the filter case has a good RF ground connection.
3. Make sure the wiring to the load side of the filter is well separated from the wiring to the line side, to avoid RF coupling around the filter.

Understanding Insertion Loss *(continued)*

What can it be used for?

Standardized insertion loss data will not accurately predict a filter’s performance in your equipment. However, it does serve as an important tool for verifying product consistency through incoming inspection.

The criterion for acceptance would be that the measured insertion loss must either meet or exceed the

published data when tested in the standardized manner.

Accordingly, “typical” insertion loss data is not meaningful. The data to which you test should be minimum values. Most of the insertion loss data published by Tyco Electronics are guaranteed minimums, and as such can be tested for a positive indication of component consistency.

Appendix A - Conducted RFI Emissions Testing

Conducted RFI Emissions Testing

Since conducted emissions testing is usually done to insure that your equipment will comply with the limits of FCC Part 15 or EN55022, the test methods used should conform to the specifications of these two agencies. You will need the following equipment:

1. Shielded room, to allow measurement with minimal background interference.
2. Two 50 Ohm line impedance stabilization networks (LISNs), fixing the line-side impedances as mandated by FCC and CISPR.
3. Spectrum analyzer or tuned receiver, with CISPR quasipeak detector, covering the range from 10kHz to 30MHz.

Figure A2

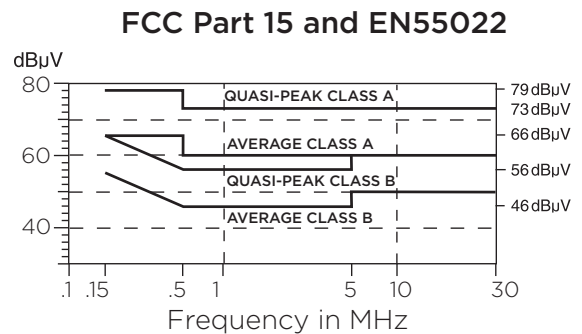
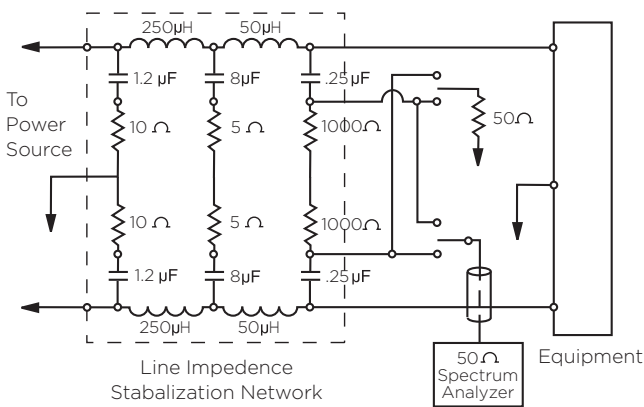


Figure A1



The limits for FCC Part 15 and EN55022 are shown in Figure A2. To which one or more of these limits you will test is determined by whether your equipment is marketed in the United States (FCC) or Europe (EN55022) and into which class of operation it falls at each agency.