Safety concerns for practical EMI line filters

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Safety Issues
The concept of safety and how it impacts the filter section are as follows

1. Any exposed metal (conducting) part (e.g. the chassis or output cables) is capable of causing an electrical shock to the user.

2. To prevent a shock, such parts must be Earthed and isolated from the high voltage parts of the power supply.

3. No single point failure anywhere in the equipment should lead the user to be exposed to an electrical shock. There should be two levels of protection, so that if one gives way, there is still a level of protection present.

4. Levels of protection that are considered essentially equivalent are a) Earthing of the exposed metal surface b) a certain physical distance (typically 4mm) maintained between any exposed metal and any part of the circuit containing high voltage c) a layer of approved insulator (minimum dielectric withstand capability of 1500VAC or 2121VDC) between any exposed metal and any part of the circuit containing high voltage.

5. So for example we could connect the enclosure to Earth. That gives us is one level of protection. But if the Earth connection failed, maybe due to something as simple as a loose contact, we would need to rely on one more level of protection. This could be simply the stipulated 4mm of separation. But what if we wanted to mount the Fet on to the enclosure for better heatsinking? The separation is now obviously going to be insufficient. We could then place one layer of approved insulator between the Fet and the enclosure. In this position, the insulator would serve as 'basic insulation'.

6. What if we have an exposed conductor which is not, or cannot be connected to Earth? This could be the case where we have floating output cables for example. Then we would need at least two levels of protection between the output and the high voltage Primary side. Besides the basic insulation, we would need another layer (with identical withstand properties) called the 'supplementary insulation'. Together these two layers are said to constitute 'double insulation'. We could also use a single layer of insulation, with dielectric withstand properties equivalent to double insulation (3000VAC or 4242VDC). That would be called 'reinforced insulation'.

7. If the equipment is by design, meant only for a two-wire AC cord, there is no Earth protection even present. In that case two layers of approved insulators will always be required from Primary side to any exposed metal.

8. Now we must understand why we connect the enclosure to Earth in the first place. Hypothetically, we could just use any two levels of protection, not necessarily including Earth. A prime reason for

using an Earthed metal enclosure is that we want to prevent radiation from inside the equipment from spilling out. Without a metal enclosure, whether Earthed or not, there is little chance that an off-line switching power supply can ever comply with the radiated emission limits. That is especially true when the switching speeds are within tens of nanoseconds. But the metal enclosure is naturally eyed as an excellent fortuitous heatsink by engineers. So power semiconductors are often going to be mounted on it (with insulation). However by doing this, we also create leakage paths (resistive/capacitive) from the internal subsystems/circuitry to the metal chassis. Though these leakage currents are small enough not to constitute a safety hazard, they can present a major EMI problem. If these tiny leakage currents are not 'drained out', the enclosure will charge up to some unpredictable/indeterminate voltage, and will start radiating. That would clearly be contrary to the very purpose of using a metal enclosure. So we need to connect the enclosure to Earth. We note that even if we didn't have power devices mounted on the enclosure, there could be other leakage paths present. Besides that, an unearthed enclosure would also inductively pick up and re-radiate the strong internal electric/magnetic fields.

9. Therefore, a) providing a good metal enclosure, and b) properly connecting it to Earth, is the most effective method to prevent radiated EMI. But by creating this galvanic connection to Earth, we also provide a multi-lane freeway for the conducted (common mode) noise to flow merrily into the wiring of the building. Now, to be able to stay within the applicable conducted emission limits, we would need to provide a common mode filter somewhere.

10. Generally, if the equipment is designed not to have any Earth connection (i.e. a two wire AC cord), there will usually be no metal enclosure present either. Keeping the issue of radiation limits aside for now, the good news here is that no significant common mode (CM) noise can be created, simply because CM noise needs an Earth connection by its very definition. Therefore a CM filter is superfluous and can be omitted. But conducted noise limits include not only common mode, but differential mode (DM) noise too. So irrespective of the type of enclosure and Earthing, DM filters are always going to be required.

11. One of the simplest ways of suppressing any noise is to provide decoupling between the nodes involved. For CM noise this means connecting high frequency ceramic capacitors between the L and E wires and also between the N and E wires, possibly at several points along the filter. But each of these CM line filter capacitors also unintentionally pass some of the AC line current into the chassis (besides the CM noise). To reduce the chances of a fatal electrical shock, safety laws restrict the total amount of current that can be injected into the Earth/enclosure. This in turn means that we have to limit the total CM filter capacitance. If the capacitance of an LC filter is restricted, we may need to increase the L to compensate. Therefore, the inductance used for the CM filter stage in off-line applications is usually fairly large (several mH).

Practical Line Filters

We can now look at a typical power supply line filter shown in Figure 2_1. Its overall purpose is to control conducted emissions, and therefore it has two stages (as highlighted) --- one for differential mode and one for common mode. Let us make some observations

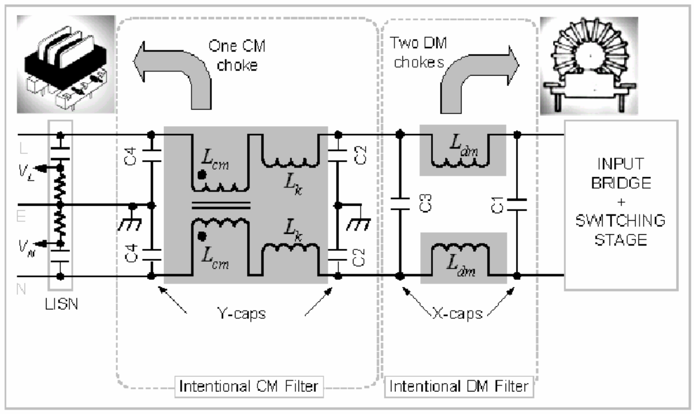


Figure 1: A typical off-line Input Filter

Both the CM and DM stages are usually pi-filters (LCL or CLC) especially in higher power converters, as they provide the desired attenuation characteristics. Sometimes T filters may be used. We could also just use a simple LC filter, or even a plain decoupling capacitor for low power applications. Tuned filter stages are occasionally seen. But under line transients or applied input surge waveforms as used for immunity testing, they can display severe unexpected oscillations, and so they are generally avoided.

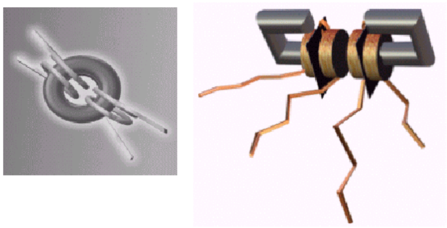
The filter is usually placed before the input bridge, because in that position it also suppresses the noise originating from the bridge diodes. Diodes have been known to produce a significant amount of medium to high frequency noise, especially at the moment they are just turning OFF. Small R-C snubbers (or just a C) are often placed across each diode of the input bridge. Alternatively, we can look for diodes with softer recovery characteristics. Input bridge packs, using ultrafast diodes are often peddled as offering a significant reduction in EMI. In practice they don't really make much difference, at least not enough to justify their additional cost. In fact typically, the faster a diode, the greater the reverse current and forward voltage spikes it produces at turn-off and turn-on. So very fast bridges may in fact produce worse results.

Typical practical values of the CM choke inductance are 10mH to 50mH (per leg) in high power converters. The DM choke is always much smaller (in inductance, not in size!). Typical values are 500uH to 1mH.

We have shown both the CM and DM filter stages as being symmetrical. We have for example, identical DM chokes on each of the L and N lines. We will later see that the DM choke is also part of the CM filter equivalent circuit. In general we try to maintain balanced impedances because any imbalance basically causes some of the CM noise to get converted to DM noise. When this happens the resulting EMI spectrum may be rather confusing to analyze and fix, except perhaps for really low power equipment.

As regards the CM noise, it is very important that we perform the attenuation equally in both the L and N lines. Otherwise we would have a leftover DM noise component. But if we try to achieve this by actually matching the CM filter inductance present on each line, our production is not going to like it. But what if we use the same core for both lines, i.e. a coupled inductor? That would automatically assure us a good inductance match (assuming of course that we have placed an equal number of windings per leg). If we are winding the CM choke ourselves, we must be clear that the relative direction of the windings is as indicated in Figure 3_2a. We can visualize easily that with this arrangement, the magnetic field inside the core cancels out for DM noise (as also for the input AC line current), but not so for the CM noise. The CM choke as shown in the figure, therefore presents an inductive impedance to the CM noise, but none (in theory) to the DM noise.

Note: The reader is cautioned that there are several widely used but confusing symbols for the CM choke in some schematics in related literature. Whatever the symbol, the direction of the windings must be as shown in Figure 3_2a.



(a) (b)

Figure 2: (a) Winding scheme for a CM choke (b) Split Windings for a CM choke

If we reverse any one of the windings of a CM choke then it can serve as a coupled DM choke for both the input lines. Though we have to check that the core is not saturating, because now differential currents no longer cancel out within the core (and that includes the input operating current of the power supply).

All DM chokes are necessarily physically large, despite their typically lower inductance. This is required because otherwise the core may saturate due to the input line current. CM chokes are also large, but that is necessitated by the typically higher inductance needed due to safety restrictions on the amount of capacitance we can use. The physical size (volume) of any magnetic element is related to its overall energy handling capability, and that is given by (1/2)LI^2. So if either L or I is increased, the size of the core must be correspondingly increased.

Pictures of sample CM and DM chokes are provided in Figure 3_1 for the purpose of easy identification. But we must not think that the CM choke cannot be a toroid for example, or that the DM choke cannot be a cheaper L or U type too. Either way, these chokes have to meet certain additional safety requirements, chiefly those relating to specified separation distances ('clearance' and 'creepage' requirements). As per safety standards, we cannot for example, just wind the two windings of an off-line CM choke carelessly overlapping on each other. We need to maintain a certain specified separation. Nor can we just use any bare toroid to wind them on. We need an approved coating, or a suitable designed bobbin.

A bare ferrite can be a very good electrical conductor, especially if it is the more commonly used manganese-zinc ferrite, as opposed to nickel-zinc formulations. This can be confirmed by simply pressing the tips of an ohmmeter at two points on the surface of a typical ferrite core lying around in the lab. Further, if we are trying to rely on the enamel coating of a typical copper magnet wire to protect from shorts, we should know that the coating is considered to be just operational/functional insulation, and is not approved as basic insulation.

Note that Lcm is the inductance of each leg of the CM choke. It is the inductance measured across any winding, with the other winding left open. Now, if we do the same measurement, but instead of keeping the other winding open, we short its ends together, what we measure is the leakage inductance Lk. By definition, the two leakage inductances in each leg are uncoupled and therefore they cannot be sharing any magnetic path or they would have interacted in some way. Therefore the leakage inductance of a CM choke will behave differently from the rest of the choke in that differential currents will no longer cancel out in this leakage inductance. This will therefore end up presenting an impedance to DM noise too, something that a CM choke is not designed or expected to do in principle. This leakage parasitic has been exploited by designers of EMI filters to serve as a formal DM choke. Therefore, in low power converters, we may not even find any explicit or intentional DM choke present. The good news here is that the leakage inductance is effectively an air-cored inductor, so it never saturates, even if for some reason, its parent CM choke saturates completely. Thus the efficacy of a leakage based DM choke is maintained at any current level.

The inter-winding capacitance of a choke affects its characteristics significantly at high frequencies. This can be intuitively visualized as providing an easy detour for noise to simply flow past the inductance. To minimize the overall end-to-end capacitance of a toroidal winding, it is recommended that the turns be placed single layer only. For the CM choke shown in Figure 3_1, a better type of bobbin is shown in the exploded view in Figure 3_2b. Note the additional split in each leg. This helps to reduce the end-to-end capacitance and also increases the leakage inductance (which helps reduce DM noise).

Line to Line capacitors are called 'X-capacitors'. X-caps when used before the input bridge (in off-line applications) must be safety approved, but after the bridge it's basically a 'don't care' situation. Being a front-end component, an approved X-cap is typically impulse tested up to 2.5kV peak. Line to Earth capacitors are called 'Y-capacitors'. An approved Y-cap is usually impulse tested up to 5kV peak. Y-caps used anywhere in the Primary side circuit (in off-line applications) must always be safety approved. Depending on the location in the power supply, we may even need two Y-caps in series, basically corresponding to double insulation. Sometimes we will find a Y-cap placed between the secondary ground and Earth/enclosure. In this position, it is usually acceptable to use any ordinary 500VAC rated capacitor.

Traditionally, off-line X-caps were of special metallized film+paper construction whereas Y-caps were a specially constructed disc ceramic type. However we can also find X-caps that are ceramic, just as we can find Y-caps which are film type. It's a choice dictated by cost, performance and stability concerns. Film capacitors are known to always provide much better stability over temperature, voltage, time, etc., than most ceramics. In addition, if they are of 'metallized' construction, they also possess self-healing properties. Ceramic capacitors do not have any inherent self-healing property, but as Y-caps, they are so designed that they never fail shorted under any condition.

However, if for any reason (such as filter bandwidth or cost), ceramic is preferred for the Y-caps, then we need to carefully account for its basic tolerance, its variation with respect to temperature and applied voltage, and all other long term variations and drifts. We must remember that the capacitance stated in the datasheet is not just a nominal (or typical) value, but in fact it happens to be a fairly misleading value. For example, if we look at the fine print, we will see that the test voltage at which the capacitance is declared is zero volts (or close to zero). So the actual capacitance it presents in a working circuit may be very widely different from its declared nominal value. This is especially true for ceramic capacitors which use a high dielectric constant ("high-k") material (e.g. Z5U, Y5V etc). Now, the total Y-capacitance that can be present is limited by certain safety concerns (to be explained later). Therefore to keep within the limits dictated by safety, we may need to specify a smaller nominal capacitance value than if we were using a film type Y-capacitor. In addition, since under certain conditions, the actual capacitance may be even less than the nominal value chosen, and we still need to keep within the legal EMI limits (now and in the future), we may need to start off with a much larger inductance. We note here that ceramic ages, unless it is of the COG/NPO type, which most Y-caps are not. A typical X7R capacitor ages 1% for every decade of time. So its capacitance at 1000 hours will be 1% less than what it was after 100 hours. Higher dielectric constant ceramics like Z5U can age 4 to 6% for every decade of time. So in effect our filter stage too, gets less efficacious with time. And we need to account for this in the initial design.

Note that SMD versions of off-line safety capacitors are also now appearing, for example from Wima, Germany (www.wima.com) and Syfer, UK (A HREF="http://www.syfer.com">www.syfer.com). But we must beware that it is not enough that the capacitor merely 'complies' with a certain safety standard. The capacitor must be actually approved by various safety agencies and carry their respective certification marks. From the electrical point of view, one of the great advantages of SMD components is their virtually non-existent lead inductance (ESL). This improves the high frequency performance in any filter application. On the flipside, some ESR or DCR is useful in helping damp out oscillations. Without any resistance, oscillations would last forever. That is one of the reasons why engineers sometimes pass one or both of the leads of a standard thru-hole Y-cap through a small ferrite bead (preferably with lossy characteristics). This may help suppress some particular high frequency resonance involving the Y-cap which is showing up in the EMI scan. But we must be careful that we are not landing up with a radiation problem instead.

Designers of low voltage, low power DC-DC converters may find the X2Y patented product range available from Syfer and from X2Y at www.x2y.com very useful if they need to miniaturize and lower the component count. This is a 3-terminal integrated SMD capacitor-based EMI filter that simultaneously provides line to line and also line to ground decoupling. Picor (a subsidiary of Vicor) at www.picorpower.com is also now selling what is billed as the industry's first active input EMI filter stage for standard 48V bricks. It may be a viable choice despite its roughly $20 cost, if board space is at a premium. Theoretical filter performance is based upon an assumption that we are using 'ideal' components. However, real-life inductors are always accompanied by some resistance (DCR) and some inter-winding capacitance. Similarly, real capacitors have an equivalent series resistance (ESR) and an equivalent series inductance (ESL). At high frequencies, inductance will dominate, and so a capacitor will basically no longer be functioning as one (from the signal point of view). But capacitors with smaller capacitances generally remain capacitive up to much higher frequencies than do larger capacitances. See Table 3_1 for some typical self-resonant frequencies (the point above which, capacitors start becoming inductive). Therefore, sometimes a smaller Y-cap may help where a large Y-cap is not yielding results. We can also consider paralleling a larger value Y-cap with a small Y-cap.

We also note that a Y-cap is always tested to higher safety standards than an X-cap, so we can always use a Y-cap at an X-cap position, but not vice versa. So, for example, we can place a ceramic Y-cap in parallel with a film X-cap, just to improve the DM filter bandwidth.

Generally, we try to maximize filter performance by increasing its 'LC' product as much as practically possible. Further, given a choice, we would prefer to harness that improvement by using large capacitances instead of impractically sized inductors. But the maximum Y-capacitance we can use is limited by safety considerations. X-caps too were limited for many years by sheer availability to a maximum value of 0.22uF (though occasionally 0.47uF was also seen). But now we can get up to 10uF. We should be conscious however that large input capacitances can cause undesirably high inrush surge currents at power-up. This may also cause eventual failure of the X-cap, especially if it is the very first component after the AC input inlet. Film caps may self-heal from such an event each time, but after every event, the capacitance gets degraded just a little. Finally, after many such events, there is a cumulative effect, and we would be left with a capacitor that is barely one. Therefore, despite EMI concerns, we should rather place X-caps after any input surge protection element (e.g. NTC thermistor or wirewound resistor), and perhaps even after a front-end choke.

Note: What were traditionally called X and Y capacitors are now more accurately called X2 and Y2 capacitors respectively. From the viewpoint of safety regulations (like impulse voltage rating etc.), the X1 and Y1 are virtually considered equivalent to two X2 and Y2 capacitors in series respectively. For example Y1 caps are impulse tested to 8kV. The original terms 'X-caps' and 'Y-caps' have recently started getting defaulted to refer to the more uncommonly used (higher voltage) X1 and Y1 capacitors instead.

Note: For better EMI suppression, we may decide to place Y-caps from the rectified DC rails (either or both) to Earth. Sometimes we place Y-caps from Primary ground to Secondary ground, or between the HVDC rail to Secondary ground. In either of these positions, a Y1 capacitor (or two Y2's in series) may be required.

Note: Safety regulations for Nordic regions (and Switzerland) may require each Y-cap shown in Figure 1 to be actually two Y2 capacitors in series (or a single Y1 capacitor). Historically, this has been necessitated by the fact that Earthing is poor in those geographical regions. In fact, it used to be pointed out that even the central meeting room of the Norwegian safety agency NEMKO (literally Norwegian Electric Material Control) did not have any Earth point in the wall outlets. Therefore, practically speaking, a lack of Earth is not considered a fault condition in many parts of the world, but is just a normal condition (this actually also includes about 1/3rd of homes in the US!). Therefore, very often, whether the equipment is supposed to be Earthed or not, it is expected to have reinforced insulation anyway. The Earthing if present, is just for helping out with EMI. We see that Y1 caps will often find use even in single-phase equipment. However, X1 caps are basically meant only for 3-phase equipment, since there is no pressing safety need for such a high voltage rating between the L and N wires in single phase equipment.

Safety Restrictions on the total Y-capacitance

Y-caps don't just bypass high-frequency noise, but also conduct some of the low-frequency line current. That is what the X-caps do too, the difference being that the Y-caps carry this current into the protective Earth/chassis. To prevent a fatal electric shock from occurring, international safety agencies limit the total RMS current introduced into the Earth by the equipment to a maximum of typically 0.25mA, 0.5mA, 0.75mA, or 3.5mA (depending on the type of equipment and its 'installation category' --- i.e. its enclosure, its Earthing and its internal isolation scheme). But somehow, 0.5mA seems to have become the industry default design value, even in cases where 0.75mA or 3.5mA may have been allowed by safety agencies. *It is important to know how high one can actually go in terms of ground leakage current, as this dramatically impacts the size and cost of the line filter, in particular the choke.*

Keeping the discussion here at a theoretical level, we can easily calculate that we get 79uA per nF at 250VAC/50Hz. This gives us a maximum allowed capacitance of 6.4nF for 0.5mA, or 44.6nF for 3.5mA. Typical configurations in off-line power supplies are four Y-caps, each being 1 or 1.2 or 1.5 nF, or only two Y-capacitors, each of value 2.2nF. Note that there may be other parasitic capacitances or/and filter capacitances present, which should be accounted for in computing the total ground leakage current, and thereby correctly selecting the Y-caps of the line filter. However we must keep in mind that if for better EMI performance/CM noise rejection, a Y-cap is connected from the rectified input DC rails to Earth (or from the output rails to Earth) there is no ground leakage current through these capacitors in principle. Therefore there is no limit on their size either.

Y-Capacitors		X-Capacitors	
Capacitance (pF)	Resonant Frequency (MHz)	Capacitance (µF)	Resonant Frequency (MHz)
1000	53	0.01	13
1500	42	0.022	9
2200	35	0.047	6.5
3300	29	0.1	4.5
4700	21	0.22	2.7
6800	19	0.47	1.9

Table 1: Typical Resonant Frequencies of X and Y-capacitors

Equivalent DM and CM Circuits

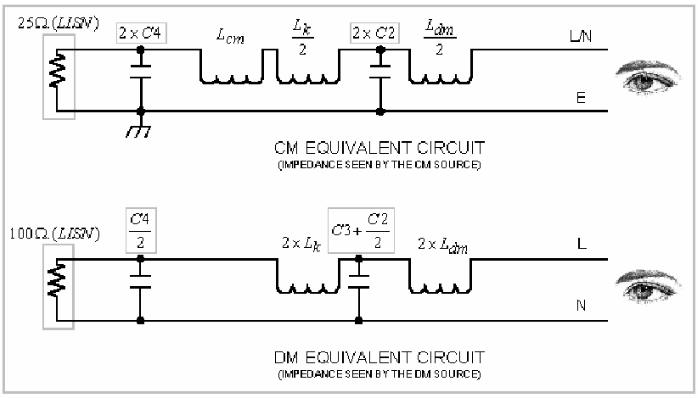


Figure 3: CM and DM equivalent circuits for the filter in Figure 1

The reason we had labeled the CM and DM stages as 'intentional' in Figure 3_1, is because 'unintentionally' they do interact. So looking at the equivalent circuits shown in Figure 3_3.

We see that the DM choke acts as a CM filter element too.

The leakage inductance of the CM choke appears as a DM filter element too.

Both the Y-caps also appear in the DM equivalent circuit (though arguably they will not add much to the heftier X-caps).

Considering that a very small value for Ldm is usually enough, no 'intentional' DM choke ever may be required. The leakage inductance of a common mode choke is roughly 1% to 3% of Lcm, depending on the construction, and this is enough to serve as an unintentional, but effective DM choke.

Theoretically, there is no need for any air gap in a common mode choke, because the flux due to the line current is expected to cancel out completely. In practice, it doesn't fully, particularly due to slight differences in the individual windings (that despite the equal number of turns). At a minimum, this causes the core to get DC biased in one direction, and thereby cause an imbalance in the inductance it presents in the two lines. This would naturally degrade the EMI performance. In the extreme case, the core may even saturate. Though this is not a catastrophic event like the saturation of the main inductor of the converter would be, it is serious from the viewpoint of EMI. Therefore, a small air gap is usually present even in a CM choke. This may be an actual visible air gap, or it may be a distributed gap as in powdered iron cores. This does lower the inductance somewhat, and therefore the effectiveness of the filter. But the resulting solution is much more immune to production variations, and also more stable over time. In general, whenever we put in an air gap, the core starts acquiring the properties of the interposing air, and since air never saturates, the air-gapped core too has a much softer saturation characteristic.

Better materials like amorphous cores or 'Kool Mu' are possible choices, so as to achieve higher inductance with higher saturation flux densities, and in a smaller size. Clearly they are more expensive.

Though CM chokes have a very high inductance usually, and that is certainly needed (particularly for complying with the CISPR 22 limits below 500 kHz), a good part of the CM noise is usually in the upper frequency range of 10-30 MHz. But not all ferrites have sufficient bandwidth to be able to maintain the inductance at such high frequencies. In fact materials with a high permeability tend to have a lower bandwidth, and vice versa (Snoek's law). Therefore a high inductance CM filter may look good on paper but be quite ineffective at high frequencies. See Table 2 for typical values of initial permeability vs. bandwidth (defined as a 6dB fall in permeability).

	Initial Permeability	Bandwidth (MHz)
Powdered Iron	60	10
	33	50
	22	100
	10	>100
Ferrite	15000	0.17
	10000	0.3
	5000	1.0
	3000	1.2
	2500	1.5
	1500	3.0

Table 2: Permeability and Bandwidth of popular materials

A DM noise generator is more like a voltage source. So putting in an LC filter works well for a DM source, as it simply presents a 'wall' of impedance which serves to block the DM emissions from entering the mains lines, and re-routes them accordingly. But this strategy is not by itself going to be effective for CM noise, whose source in a typical power supply behaves more like a current source. Current sources demand to keep their current flowing, and can surmount any impedance 'wall' we may throw at them (if there is no other route available). That is why in a power converter, we have to place a freewheeling diode otherwise the inductor current would punch a hole in our Fet the moment we tried to turn it OFF. We also know that pure reactances cannot dissipate any energy, only resistances do. All this leads to the following strategy when dealing with CM emissions--- a) we must allow it to flow b) we can re-route it thereafter by using impedance mismatching c) finally we do need to dissipate this energy by using resistive elements. As for the CM choke therefore, not only do we need high bandwidth, we should lower its Quality factor 'Q', especially at high frequencies. One way to achieve this is to increase the DC winding resistance, but this will impede the line current too and thereby lower the efficiency of the entire power supply via the IAC2 R losses. Another solution is to use a 'lossy' ferrite material for the CM choke. The usual ferrite used for power transformers and inductors is predominantly of manganese-zinc composition, but lossy ferrites of nickel-zinc composition are more helpful in 'killing' high frequency CM noise. Unfortunately, they also have such low initial permeabilities that they cannot replace the main high inductance CM choke. Therefore the lossy CM choke is usually an add-on, and may just be a small bead or toroid made of lossy material, slipped around the bunch comprising the L and N wires.

Engineers are often mystified to find that making the DM choke out of (low permeability) powdered iron or lossy ferrite helps too, when all else has failed, despite all the talk about DM noise being essentially a low-frequency emission. The reason seems to be as follows. The CM noise in a power supply is actually a nonsymmetric mode at its point of creation, though ultimately, by cross coupling it does tend to spread into both the lines equally. We can show that nonsymmetric noise can be considered to consist of part CM and part DM components. Therefore in practice, we do get a fair amount of high frequency DM noise too from nonsymmetric CM noise. That is where high bandwidth/low permeability/lossy materials help in DM noise suppression.

Most often, the DM and CM filters are laid out in the order shown in Figure 3_1. The idea seems to be that the last stage the noise encounters, as it travels from the power supply into the lines should be a common mode filter. Otherwise, if the CM stage looked into a DM stage which was not perfectly balanced (as it won't be unless the DM windings are on the same core), then the unequal impedances may cause the CM noise to effectively increase, or to produce new DM noise components. However, many successful commercial designs have reversed the order as shown in the figure, and so there may be no hard and fast rule here.

Backtrack: One of the most stubborn cases of conducted mode EMI failure was ultimately (and rather mysteriously) solved by simply reversing the orientation of the CM choke (turning it by 180 degrees). The leakage from the core was obviously being picked up by a nearby trace or component and the phase of the coupling was clearly mattering. Since most inductors do not have any identifiable marking to distinguish one end from the other, implementing such a fix is not easy in production. However nowadays, so many similar orientation cases are being reported, even relating to the main inductor of the converter, that some key inductor manufacturers are moving towards placing a 'polarity mark' on their newer inductors. Note that in another industry documented EMI problem, the inductor had to be rotated by only 90?. But that clearly is bad news, because it means the layout has to change. A possible location of an X-cap is directly on the prongs of the inlet socket at the entrance to the power supply. We must remember that in this position any capacitor is exposed to a huge surge current spike at power-up, and even if it self-heals a few times, we don't want to run it continuously in this slow degradation mode. If really unavoidable, it should be very small e.g. 0.047uF to 0.1uF, or we should try ceramic capacitors in this position (X-cap or Y-cap).

Similarly, the two front-end Y-caps shown as C4 in Figure 1, or two additional small Y-caps, can be connected directly onto the prongs of the AC inlet socket. This helps a great deal when the wire going from the PCB to the mains inlet socket is itself picking up stray fields and is therefore beyond assistance from the main filter stage which lies on the PCB.

Sealed chassis mountable line filters (sometimes with integrated standard IEC 320 line inlets) are available from several companies like Corcom (now part of Tyco Electronics) and Schaffner, Germany at www.schaffner.com. Such filters perform excellently but are less flexible to tweaking, and much more expensive than board-mounted solutions. Incidentally, Schaffner also makes some of the most widely used and standard test equipment for surge immunity testing.

Note that the performance of most commercially available line filters is specified with 50 ohms at both ends of the filter. Therefore its actual performance in a real power supply may be quite different from its datasheet.

In general, the traces on the PCB corresponding to the filter section should be thick and wide. The Earth trace should be connected to the chassis through several metal standoffs if possible. CM noise suppression is usually said to require a very 'good' connection to Earth. If the standoffs are not feasible, and the connection is to be made by means of a wire from the PCB to the IEC inlet, we must use thick braided wire to lower its inductance. A 'good' connection has also to be established between the chassis and the Earth prong of the IEC inlet. Here too, braided wire is recommended. Special custom-made metal brackets have also been in use by various power supply companies to connect the Earth prong of the IEC inlet socket to the enclosure. However, standard IEC 320 inlets with built-in metal brackets are now directly available from companies like Methode Electronics Inc., at www.methode.com.

References

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