

Practical Approach in Designing Conducted EMI Filter to Mitigate Common Mode and Differential Mode Noises in SMPS

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Abstract:

Fast switching in SMPS generate large amount of Electromagnetic Interference (EMI). The EMI consists of mainly common mode and differential mode noises. In the present work, conducted EMI is studied and a procedure for designing AC power line filter is proposed. As an application of this design procedure, conducted EMI noise measurement and filter design of a boost AC-DC converter with PFC has been achieved while successfully satisfying the CISPR22/EN55022 limit in the frequency range from 150KHz to 30MHz, which confirms the validity of the design procedure.

Key Words: Electromagnetic Interference, Differential Mode Noise (DM), Common Mode Noise (CM), Switch Mode Power Supply (SMPS), EMI Filter, (EMC) Electromagnetic Compatibility.

طريقة عملية في تصميم مرشح تداخلات مغناطيسية لتخفيف الضوضاء المشتركة والتفاضلية في
معدات القدرة ذات النمط المتقطع

الخلاصة:

تتسبب معدات القدرة ذات النمط المتقطع التي تعمل بترددات عالية على توليد مجالات كهرومغناطيسية ذات منسوب طاقة عالية نسبياً.. تعمل هذه المجالات على حث ضوضاء تداخل ذات نوعين، مشترك وتفاضلي. في هذا العمل جرت دراسة الضوضاء الكهرومغناطيسية بنوعيهما والمنقولة سلكياً واقتُرحت طريقة تصميم مرشح لمغذي القدرة المتناوب وجرى قياس ضوضاء التداخل وتطبيق تصميم المرشح على جهاز قدرة نوع (Boost AC-DC) ، وتم قياس الضوضاء بوجود المرشح وكان منسوبها ضمن حدود السماح للمواصفات القياسية (CISPR22) وضمن النطاق الترددي من 150KHz إلى 30MHz ، مما يؤكد صحة وفعالية طريقة التصميم المقترحة.

Introduction:

Most of the stationary information technology (IT) devices take their energy from the AC mains by means of the switch mode power supply. Unfortunately switch mode power supply energy conversion process produces powerful electromagnetic interferences (EMI) in broad radio frequency range. Which is considered a serious and increasing form of environmental pollution [1].

The threat of EMI is, controlled by adopting the practices of electromagnetic compatibility (EMC), which has two complementary aspects: It describes the ability of electrical and electronic systems to operate without interfering with other systems, and also describes the ability of such systems to operate as intended within a specified electromagnetic environment. Interference can propagate from a source to a victim via the mains distribution networks to which both are connected. This is not well characterized at high frequencies, especially since connected electrical loads can present virtually any R_F impedance at their point of connection[2].

The frequency ranges of EMI noise are 10KHz to 30MHz by conduction through wires and 30MHz to 1GHz by radiation [3]. Conventionally the total conducted EMI noise consists of two modes.

- Common mode (CM) interference is EMI noise present on the line and neutral referenced to safety ground.
- Differential (transverse) mode (DM) interference, is EMI noise present on the phase line reference to the neutral.

In order to achieve a solid EMC design, we must understand the EMC requirements. The International Electromechanical Commission (IEC) is responsible for deriving the European requirements, in saying that, the comite international special des perturbations radio electriques (CISPR) – International Special Committee on Radio Interference is responsible for the EMC requirements with (CISPR22) defining the strictest limit on conducted emissions. These limits (conducted emissions) are described in the product standards EN55022 limits for class B digital devises, in the frequency range of 150KHz to 30MHz.

The EMI issue is solved with introduction of EMI filters, which realize a very important task in modern power supplies – conducted high frequency noise suppression.

EMI in Switch Mode Power Supply (SMPS):

Switched mode power supplies are usually a part of a complex electronic system, the system operates with electric signals with much lower amplitude and energy compared to those on an SMPS. It means that usually the SMPS is the strongest electrical noise generator in the whole system. Especially the power switches with their high dv/dt and di/dt switching slopes are the

sources of EMI. The source of differential mode (DM) interference is the current switched by a MOSFET or a diode. High rates of dv/dt and parasitic capacitors to the ground are the reasons for common mode interferences.

EMI Types in SMPS:

As mentioned earlier, EMI is transmitted in two forms, radiated noise and conducted noise. Radiated noise occurs in the range of 30MHz-1GHz, which requires the measurement of magnetic or electric fields in free space, causing the testing to become much more complex, which is out of the scope of this paper. Besides that the conducted noise consist is higher than radiated noise. Conducted consist of two categories commonly known as differential mode noise (DM) and common mode noise (CM).

Differential Mode Noise (DM):

It is measured between each power line and neutral. DM is due to magnetic coupling, it is otherwise called as Normal-Mode or transverse mode noise. Current path of differential mode is shown in fig.(1). DM noise attempts to dissipate its energy along any path from line to neutral.

If the Normal-Mode noise has sufficient voltage (or energy), damage could first occur to the SMPS and then to the victim (ex. computer) circuitry. The p-n junction of the rectified diodes can break down due to the excessive biasing. The capacitors may degraded, if the noise is opposite in polarity or exceeds operating limits, transformers isolation may break down, if the noise peaks are excessively high.

The transmission of Differential Mode (DM) noise is through the input line to the utility system and through the DC-side network to the load on the power converter.

Differential Mode (DM) noise is presents on both the input and output lines.

Conducted EMI noise coupling through the 50Ω resistor of the line impedance stabilizing network (LISN) shown in fig.(2). The LISN is used in standard conducted EMI measurement and will be explained in the preceding sections.

Because of the switching nature of the MOSFET transistor, part of the switch current flows through the 50Ω resistors as indicated by the dash line. Since C_F is not perfect due to the existence of parasitic inductance L_F and the equivalent series resistance R_F , there is a certain amount of noise current flowing through the resistors in series. In general the Differential Mode (DM) noise current is load dependent and is affected by C_F and L_F [4].

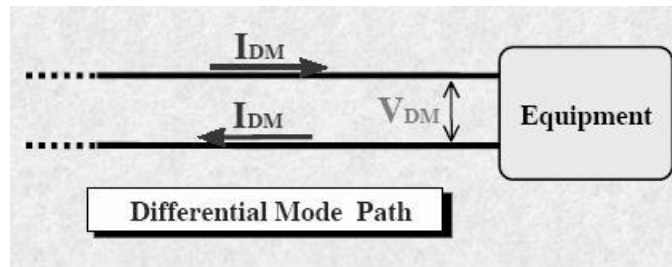


Fig.(1) Differential Mode Current Path

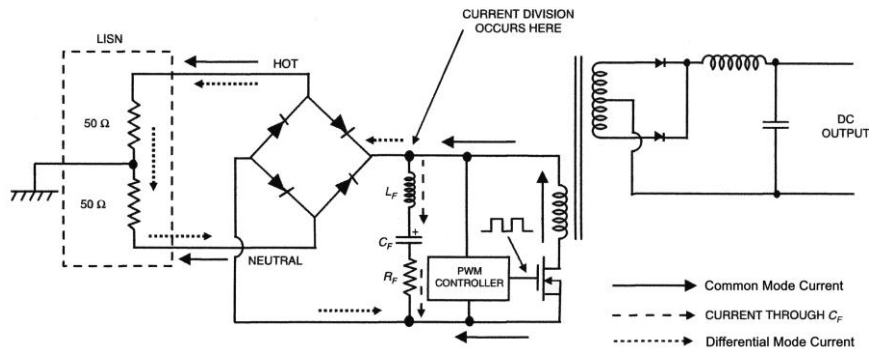


Fig.(2) SMPS showing differential mode and common mode – current paths

Common Mode Noise (CM)

Common Mode (CM) Noise is measured between line and ground. The major contributor to common-mode emission is the primary side parasitic capacitance to ground. The three contributors to this capacitance are switching transistor to heat sink capacitance, transformer inter winding capacitance, and stray primary side wiring capacitance as shown in fig.(3).

CM consist of high frequency impulses, there is a high probability that the noise will see the high frequency transformer just as a coupling capacitor and pass through unobstructed. Stray capacitor paths may exist within SMPS because they are smaller in physical size and more densely packaged as compared to other types of power supplies. Common mode noise is present on both input and output lines. The current path of common mode is shown in fig.(4)[4].

The transmission of CM noise is entirely through parasitic or stray capacitors and stray electric and magnetic fields, these stray capacitance exists between various system components and between component and ground.

The Common Mode (CM) noise is coupled through the parasitic capacitance between the drain of the MOSFET, since the MOSFET is operated as a switch, the drain voltage swings from low to high in half of the switching cycle. This voltage swing in turn causes the charging and discharging of the parasitic capacitance. The charging and discharging current will return through the ground path and show up the LISN resistors as CM noise.

The Common Mode (CM) noise path is illustrated with thin line in fig.(3). Notice that the noise current flow through the two 50Ω resistors in parallel.

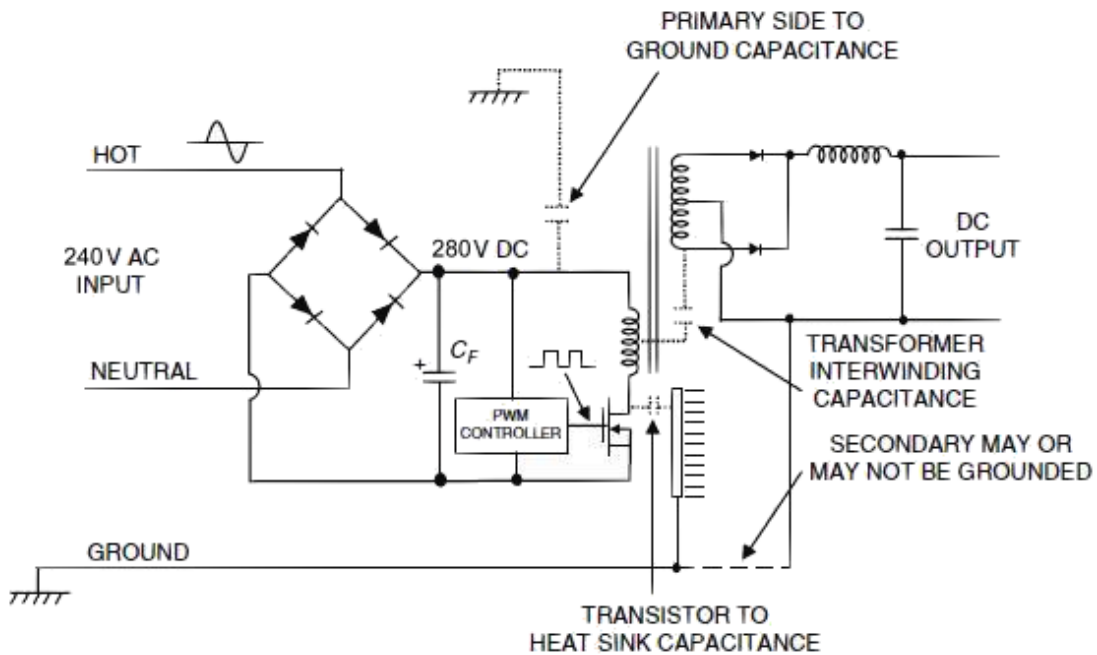


Fig.(3) Switched Mode Power Supply Showing parasitic Capacitance to Ground

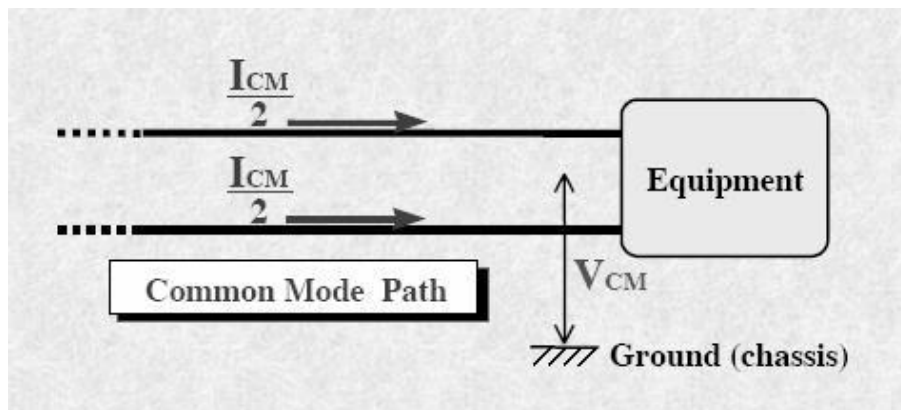


Fig.(4) Common Mode Current Path

Measuring Conducted EMI Noise:

Fig.(5) shows the typical schematic diagram for conducted EMI measurement for filter design system. The line impedance stabilization network (LISN) purpose is to provide stabilized impedance to conducted emissions, without interfering with the normal power flow required by the equipment under test (EUT). At the power line frequency the LISN provides a low impedance path from the power source to the load impedance and a high impedance path from

the load to ground. The 50Ω impedance to ground is actually the input impedance of the spectrum analyzer or EMI meter used to measure the noise, in other words, the LISN is buffer network which permits connecting the power leads of the test item to the power mains by, (1) passing only the dc or ac power to the test sample, (2) preventing the test sample's electromagnetic noise from getting back in to the power bus, (3) blocking the power mains R-F from coupling into the test sample. During the conducted emission test, a LISN is places between the product and the actual power line in order to present known impedance to the product's power line terminals over the frequency range of 150KHz to 30MHz. one LISN is inserted in the hot side of the power line, and one is inserted in the neutral side of the power line. The circuit of a 50μH LISN used for most conducted emission testing is shown in fig.(6). The 1μF capacitor C₂ on the power line side of the LISN shorts out the variable impedance of the actual power line so that it does not influence the test results. The 50μH inductor L₁ provides rising impedance with frequency. Capacitor C₁ is used to couple the conducted emission measuring instrument to the power line. The 1000Ω resistor R₁ discharges the LISN capacitors when the LISN is removed from the power line.

Usually the measurements are carried out using two LISN circuits as shown in fig.(5). Noise levels are measured separately for line and neutral. If any of them fails to comply with the standard, the equipment is not EMC compatible.

It is important to note that the DM noise current flows through two 50Ω resistors is series, resulting in 100Ω total load. On the other hand, for the CM EMI current, the two 50Ω resistors are in parallel, resulting in 25Ω total load for the CM noise.

The CM noise presents from line and neutral with the same magnitude and direction to the ground wire. The DM noise is flowed from the line to neutral wire with the same magnitude but in opposite direction that is shown in fig.(5). The conducted emission of the line and neutral can be expressed as:

$$V_{\text{LINE}} = V_{\text{CM}} + V_{\text{DM}} \quad \dots\dots (1)$$

$$V_{\text{NEUTRAL}} = V_{\text{CM}} - V_{\text{DM}} \quad \dots\dots (2)$$

Hence, we can calculate the common-mode noise V_{CM} and differential – mode noise V_{DM} as the following equation:

$$V_{\text{CM}} = (V_{\text{LINE}} + V_{\text{NEUTRAL}})/2 \quad \dots\dots (3)$$

$$V_{\text{DM}} = (V_{\text{LINE}} - V_{\text{NEUTRAL}})/2 \quad \dots\dots (4)$$

The spectrum analyzer receives the conducted noise from LISN. This noise need to be separated to CM and DM components using the equation (3) and (4), respectively.

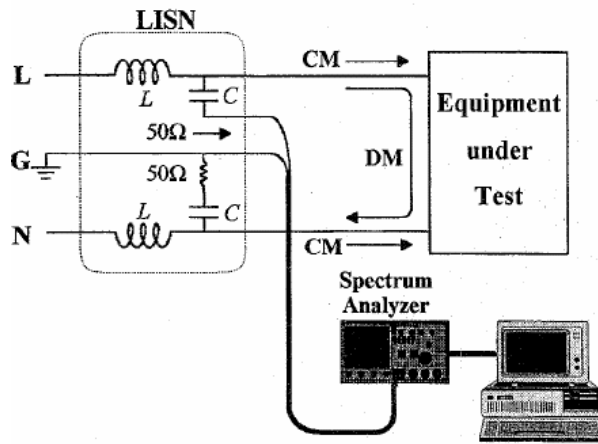


Fig. (5) Measuring conducted EMI from SMPS using LISNs

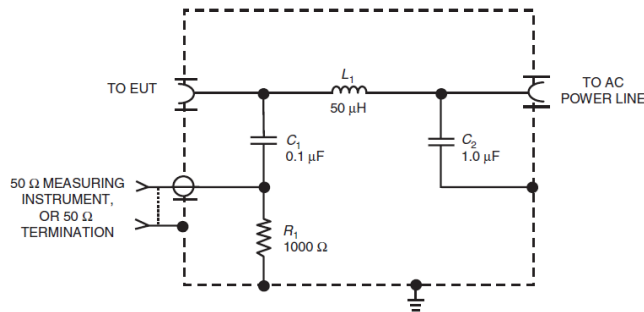


Fig. (6) Circuit of 50μH LISN used for conducted emission testing

Separation of CM and DM Noise

Usually the common mode and differential mode noises are separated by power combiners for EMI filter design [5]. The power combiners have two types of combiner, 0° and 180°, and wide frequency response.

Its operation principle is to combine two power inputs. Let the power of the input from the live (L) and the neutral (N) wire is denoted as P_L and P_N , respectively then the output power P_o of the combiner is [6].

$$P_o = (P_L + P_N) / 2 + \sqrt{P_L \cdot P_N} \cdot \cos\theta \quad \dots\dots (5)$$

The θ represents different phases of the power combiner. Specification. Then the output power P_o of the 0 degree power combiner can be expressed as:

$$P_o(0^\circ) = (P_L + P_N) / 2 + \sqrt{P_L \cdot P_N} \quad \dots\dots (6)$$

similarly the P_o of the noise separator from the passive 180 degree power combiner is:

$$P_o(180^\circ) = (P_L + P_N) / 2 - \sqrt{P_L \cdot P_N} \quad \dots\dots (7)$$

now

$$P_L = (V_{LINE})^2 / R$$

and $P_N = (V_{NEUTRAL})^2 / R$

Then substituting equation (1) and (2) in (6) and (7), we can obtain the following power equations:

$$P_L = (V_{CM} + V_{DM})^2 / R \dots\dots (8)$$

$$P_N = (V_{CM} - V_{DM})^2 / R \dots\dots (9)$$

Now, we can have P_o from 0° power combiner and P_o from 180° power combiner Via LISN

$$P_o(0^\circ) = 2V_{CM}^2 / R \dots\dots (10)$$

$$P_o(180^\circ) = 2V_{DM}^2 / R \dots\dots (11)$$

where R is the impedance for power combiner. So for, we can measure the V_{CM} and V_{DM} by spectrum analyzer.

For conducted EMI measurement, the micro-voltage (μv) is commonly used as the reference unit [7]. From equation (10) and (11) the output noise voltage from the noise separator will be measured by the spectrum analyzer in relative units of $dB\mu v$, with constant input impedance R and it is "+3dB" above from the measured data in the design calculations [6,8].

EMI Filter

A typical EMI filter topology to suppress Common Mode (CM) and Differential Mode (DM) noises in switching mode power supplies is shown in fig.(7-a).

Where L_{CM} is a common-mode choke and L_{DM} is a differential-mode choke, C_{X1} and C_{X2} are DM capacitors (called "x" capacitors) and C_y is a CM capacitor (called "y" capacitor). In contrast to the two opposite windings in the differential mode chock L_{DM} , the common-mode choke L_{CM} shown in fig.(7) has two identical winding that are wound on the same core. In practice, the magnitude of leakage inductance in a CM choke is usually about 0.5% to 2% of CM inductance [9,10].

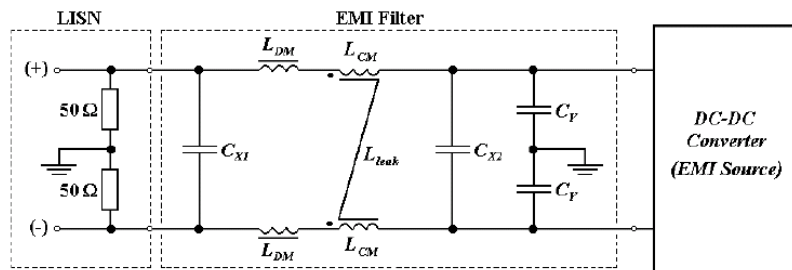


Fig. (7-a) A typical π filter configuration with it's components

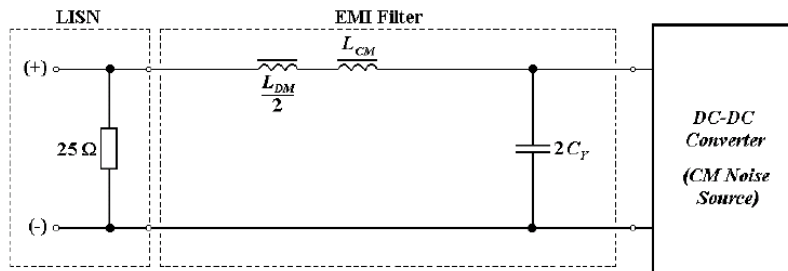


Fig.(7-b) Equivalent circuit for CM components

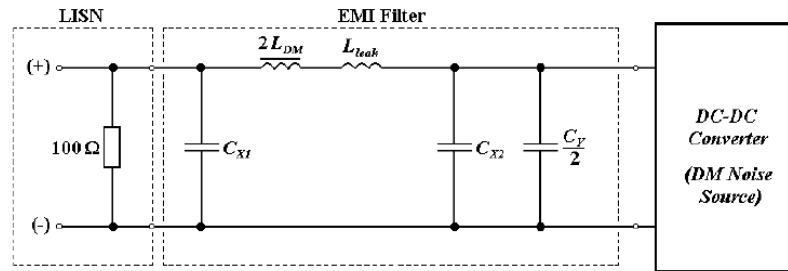


Fig.(7-c) Equivalent circuit for DM components

EMI Filter Design Procedure:

An EMI filter has to be designed so that the conducted emission of the product can satisfy the relevant regulatory limit. Fig.(8) shows the steps for the proposed filter design procedure.

1. The first step that must be considered in EMI filter design is accurate measurement of the base line (i.e without filter) common mode EMI noise spectrum, $(V_{CM,measured})_{dB}$ and differential-mode EMI noise spectrum, $(V_{DM,measured})_{dB}$ of the device under test by means of the measurement system. All details covered in previous section.

2. The second step is to determine the required CM-noise attenuation $(V_{req, CM})_{dB}$ and DM-noise attenuation $(V_{req, DM})_{dB}$ using the following two equations:

$$(V_{req, CM})_{dB} = (V_{CM, measured})_{dB} - (V_{limit})_{dB} + CF \dots\dots (12)$$

$$(V_{req, DM})_{dB} = (V_{DM, measured})_{dB} - (V_{limit})_{dB} + CF \dots\dots (13)$$

Where $(V_{CM,measured})_{dB}$ and $(V_{DM,measured})_{dB}$ are the base line noise voltage from first step. $(V_{limit})_{dB}$ is the required conducted EMI limit specified by CISPR22 (EN55022) class B standard as shown in fig.(9), [11].

CF (dB) denotes the correction factor of the designed method for avoiding design error. Usually "+6dB" is added to Eq.(12) and (13) because both the measured CM noise and DM noise using the present system are 3dB above the actual values, and because the measured CM and DM noise voltage may be in phase, which will cause a total error of 6dB in estimating the required attenuation [12].

3. The third step is to determine the minimum corner frequency of second order L-C filter for CM and DM according to the attenuation requirement for all frequency spectrum.

Fig.(7) (b) and (c) show the EMI equivalent circuits for the CM noise and DM noise respectively, which take into account the effect of the 50Ω input impedance of the spectrum analyzer. In fig.(7-b) the CM noise is affected only by the parallel effects of both "Y" capacitors and the two CM inductors. In fig.(7-c), both the inductance L_D of the DM chock and the leakage inductance L_l of the CM choke can attenuate the DM noise. Although the two "Y" capacitors also affect the DM noise, their effect on DM noise attenuation is negligible in comparison with that of the two "Y" capacitors with large capacitance. To reduce the EMI filter design cost and size, the effect of the DM inductance L_D shown in fig.(7-b) can be totally replaced by the leakage inductance L_l of the CM choke [12].

A side from the EMI filter components, the effectiveness of a conductance EMI filter also depends on the noise source impedance.

For a switched-mode power supply, it has been observed that the CM noise source can be modeled by a high impedance Z_{pc} in parallel with a current source, and that the DM noise source can also be modeled by a high impedance Z_{pd} in parallel with a current source, when the rectifier diodes are (on) and by a low impedance Z_{sd} in series with a voltage source when the diodes are (off). The DM noise equivalent circuit fluctuates between these two models every 2x (line frequency), and it is difficult to distinguish each individual contribution to the total DM noise. Thus it is troublesome to design a conductance EMI filter, if the effect of the conducted noise source impedance is not negligible.

In order to adopt a simple model for designing a conducted EMI filter that can ignore the effect of noise source impedance, the choice of the component value in the EMI filter in the present study must satisfy the following conditions [10]:

1. for a CM filter equivalent circuit. Fig.(7-b):

$$1/(2\omega C_y) \ll Z_{pc}, \omega (L_c + L_d/2) \gg 25 \text{ ohms} \quad \dots\dots (14)$$

2. for a DM filter equivalent circuit with:

$$C_{x1} = C_{x2} = C_x, \text{ fig.(7-c)}$$

I- if the rectifier diodes are off:

$$100\Omega \gg (1/\omega C_x) \gg Z_{sd} ;$$

II- if the rectifier diodes are on:

$$\omega(L_d) \gg 100\Omega$$

$$Z_{pd} \gg (1/\omega C_x) \gg 100\Omega \quad \dots\dots (15)$$

Where ω is the angular frequency of the CM or DM noise. When the above impedance condition are met, the equivalent filter circuits for both the CM and DM noise shown in fig.(7- (b) and (c)) can be simplified to the L-C filter depicted in fig.(8-b) and fig.(8-c).

By using the circuit reciprocity theorem. The ratio of the output power P_o from a noise source without an L-C filter to the output power P'_o from the same noise source with an L-C filter is defined as the attenuation (A) of this L-C filter. Since the output power is proportional to the square of the output voltage for the same load impedance, the attenuation (A) of an L-C filter in decibels (dBs) can be expressed as follows:

$$A(dB) = 10 \log_{10} P_o / P_o' = 20 \log_{10} (|V_o / V_o'|) \dots\dots (16)$$

Where V_o and V_o' are the output noise voltage without and with an L-C filter, respectively. For high frequency conducted noise with frequency $f \gg f_c$, where $f_c = 1/2\pi\sqrt{LC}$, it can be proved by means of circuit theory [10] that the attenuation (A) of a second order L-C filter in Eq.(16) can be simplified to:

$$A(dB) = 20 \log_{10} \{ |1 - (f/f_c)^2| \} = 40 \log_{10} (f/f_c) \dots\dots (17)$$

now the required attenuation of CM and DM can be expressed.

$$(V_{req,CM})dB = 40 \log_{10} (f/f_{R,CM}) \dots\dots (18)$$

$$(V_{req,DM})dB = 40 \log_{10} (f/f_{R,DM}) \dots\dots (19)$$

Thus, the two corner frequency $f_{R,CM}$ and $f_{R,DM}$ in equations (18) and (19) correspond to the minimum intersection of the 40dB/decade slope along the frequency axis fig.(10-d) and fig.(11-d).

4. The final step in designing is to determine the inductor and capacitor component values (L_{CM} , C_{CM}) and (L_{DM} , C_{DM}) of the conducted EMI filter from the corner frequencies ($f_{R,CM}$) and ($f_{R,DM}$) found on the previous step and refereeing to fig.(10-d) and fig. (11-d). [12]

$$f_{R,CM} = \frac{1}{2\pi\sqrt{L_{CM}.C_{CM}}} = \frac{1}{2\pi\sqrt{(L_C + \frac{1}{2}L_D).2Cy}}$$

if $L_C \gg \frac{1}{2}L_D$

$$f_{R,CM} = \frac{1}{2\pi\sqrt{L_C.2Cy}} \dots\dots (20)$$

for $f_{R,DM}$

$$f_{R,DM} = \frac{1}{2\pi\sqrt{L_{DM}.C_{DM}}}$$

where $L_{DM} = 2L_D + L_{leakage}$

$$f_{R,DM} = \frac{1}{2\pi\sqrt{(2L_D + L_{leakage}).C_{DM}}} \dots\dots (21)$$

for CM components, because of the restriction of the safety rule, "Y" capacitors cannot exceed in 5400pf [3,13]. So it is Cy choose to be 3300pf and the corner frequency $f_{R,CM}$ has been found in step 3, so we get the common mode inductor:

$$L_C = \left(\frac{1}{2\pi.f_{R,CM}} \right)^2 \cdot \frac{1}{2Cy} \dots\dots (22)$$

Consequently for DM component there is a freedom of choosing differential mode inductor L_{DM} so that:

$$C_{X1} = C_{X2} = C_{DM} = \left(\frac{1}{2\pi \cdot f_{R,DM}} \right)^2 \cdot \frac{1}{L_{DM}} \dots\dots (23)$$

To reduce cost and size of the filter we can use common mode inductor's leakage inductance $L_{leakage}$ as DM inductor so C_{DM} become:

$$C_{DM} = \left(\frac{1}{2\pi \cdot f_{R,DM}} \right)^2 \cdot \frac{1}{L_{leakage}} \dots\dots (24)$$

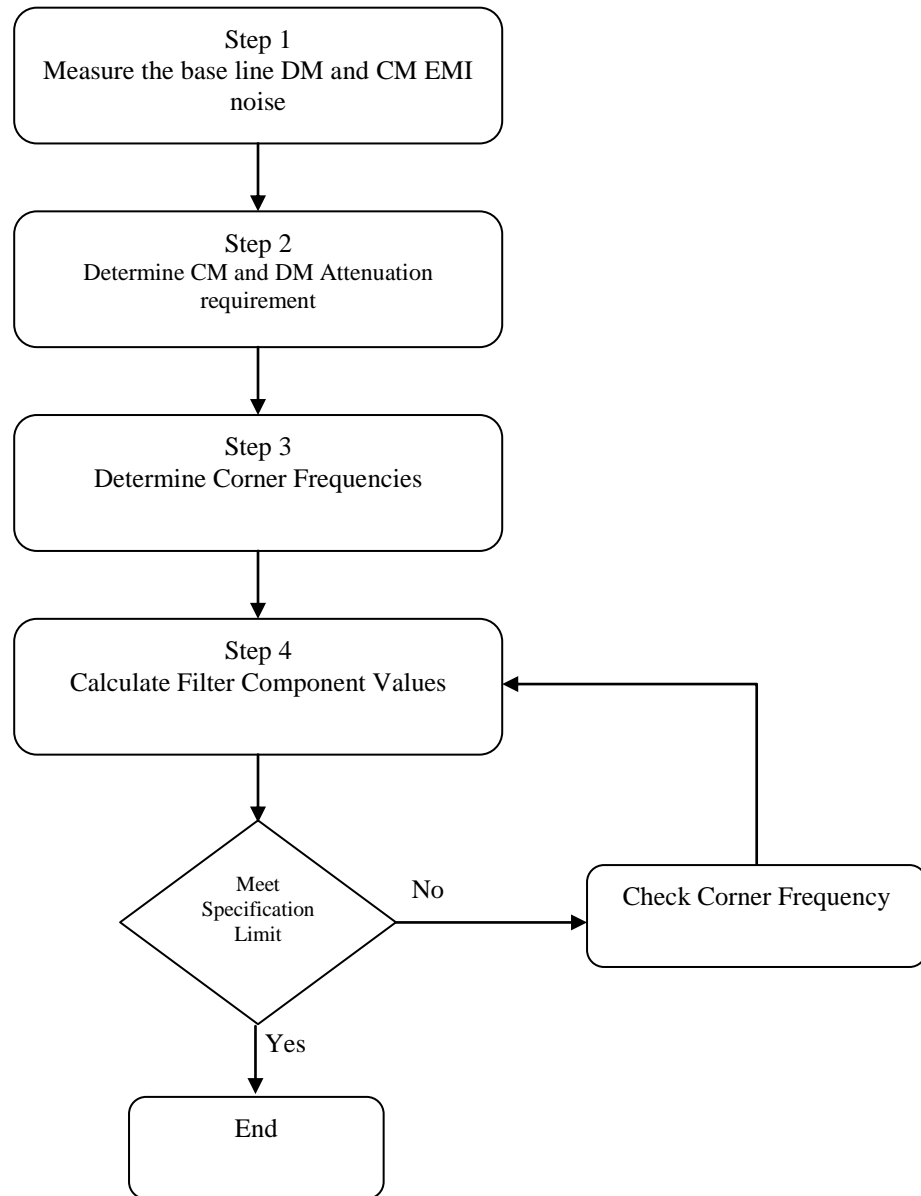


Fig.(8) A proposed design procedure for filter design

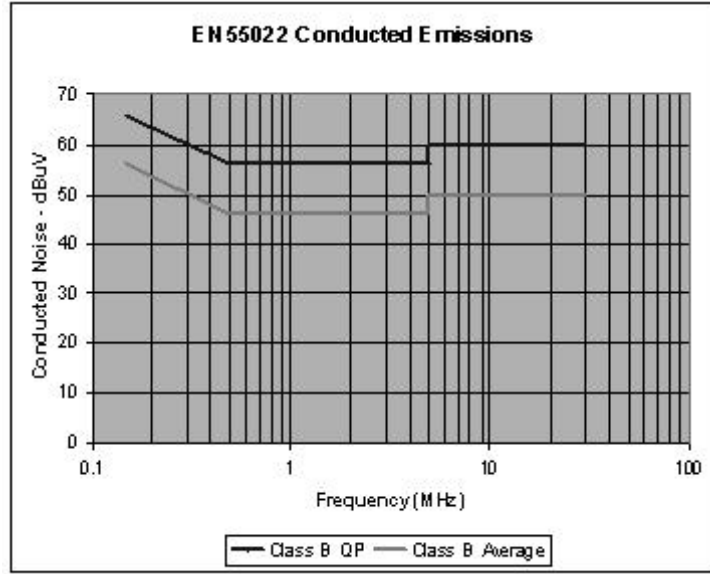


Fig.(9) EN 55022 Conducted Emissions.[11]

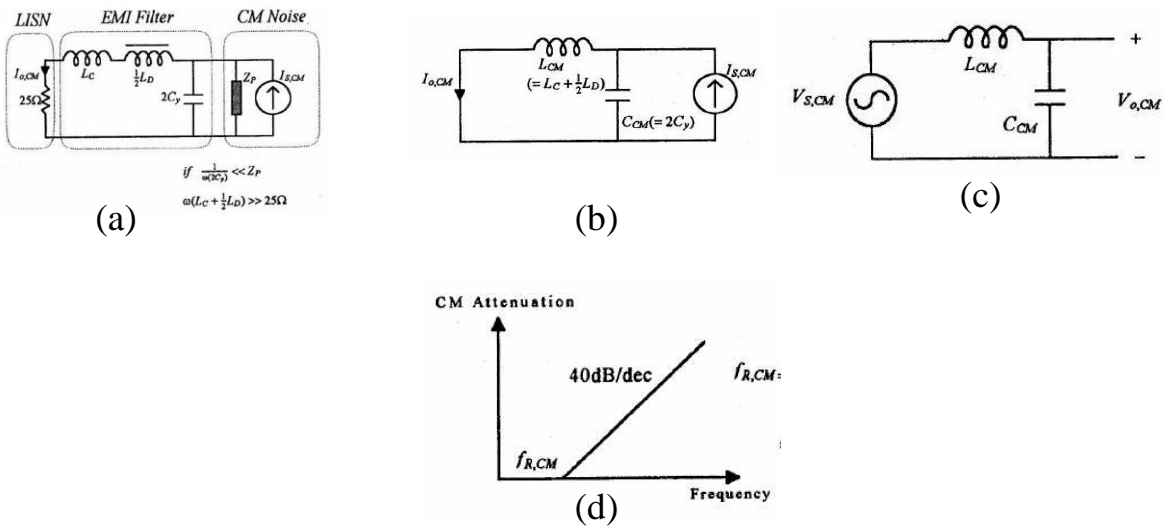


Fig.(10) (a,b,c) Modeling of equivalent circuit for CM noise
(d) Resulting attenuation and corner frequency

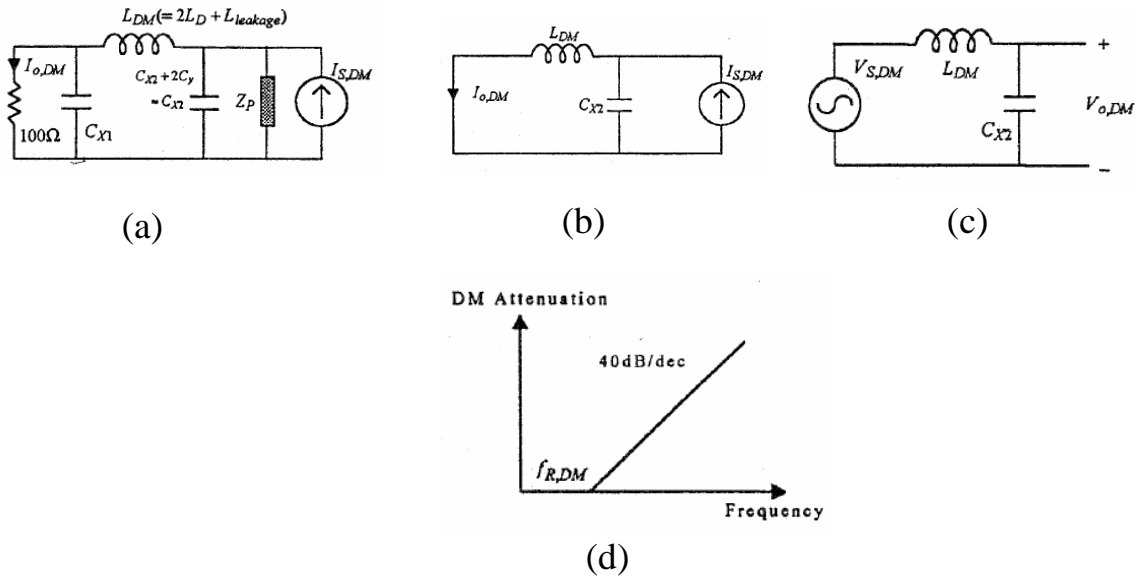


Fig.(11) (a,b,c) Modeling of equivalent circuit for DM noise
 (d) Resulting attenuation and corner frequency

Design Example and Experimental Results:

Based on the proposed design procedure, practical design example is given below to illustrate the steps described above. The ac-dc booster converter with PFC is the device under test in present application, the main specification of this boost converter are: input voltage 220V, switching frequency 94KHz, power factor 0.95, output voltage 200V, and output power 100W.

To obtain the CM and DM noises, a testing system is connected from L and N to the power combiner which inserted between LISN and the spectrum analyzer. The EMI from the boost converter was measured using quasi-peak (Qp) detector. Fig.(12) shows the base-line (without filter) EMI noise spectrum, fig. (12-a) being the total line measured, Fig.(12-b) and fig.(12-c) are the separated results having CM and DM noises, respectively using the power combiner. It can be seen that both well exceeds the CISPR22 class B standard limit.

The filter attenuation requirements can be determined by applying equations 12 and 13 so $(V_{req,CM})_{dB}$ and $(V_{req,DM})_{dB}$ is tabulated and drawn Vs the frequency for CM and DM noise as shown in fig.(13-a) and fig.(13-b). To obtain the corner frequency, a dashed line with 40dB/decade slope is drawn tangential to the attenuation requirement. The horizontal intercepts of the lines determine the corner frequencies $f_{R,CM}$ and $f_{R,DM}$ as shown in fig.(13-a) and fig.(13-b).

So that:

$$f_{R,CM} = 32KHz$$

$$f_{R,DM} = 21KHz$$

Then the parameter for the EMI filter can be calculate as the following:

I. For CM part and to meet safety leakage current requirement. C_y is choose to be 3300pf and L_c can be calculated from Eq.(22). [13]

$$L_c = \left(\frac{1}{2\pi f_{R,CM}} \right)^2 \cdot \frac{1}{2C_y}, \text{ where } f_{R,CM} = 32\text{KHz}$$

$$\therefore L_c = 3.7\text{mH}$$

II. For DM component values L_D and C_{x1} , C_{x2} in this design approach C_{x1} value is first assumed to obtain a simplified equation for corner frequency. Then L_{DM} and C_{DM} is decided according to Eq.(23).

Where

$$C_{x1} = C_{x2} = C_{DM} = \left(\frac{1}{2\pi \cdot f_{R,DM}} \right)^2 \cdot \frac{1}{L_{DM}}$$

generally the leakage inductance (L_l) of L_c is in the range of 0.5% - 2% of the Value [9,10].

$$\text{Let } L_l = 1\% * L_c = 37\mu\text{H}$$

Assume C_{DM} be 0.22 μF which is commonly available:

$$\therefore L_{DM} = 270\mu\text{H}$$

$$\text{and } L_D = (L_{DM} - L_l)/2 = 116\mu\text{H}, \text{ approximated to } 120\mu\text{H}.$$

Fig.(15) show the designed EMI filter composed of CM choke $L = 3.7\text{mH}$ (approximated to 4mH)

Y capacitor, $C_y = 3300\text{pf}$, L_D choke = 120 μH and $C_{x1} = C_{x2} = 0.22\mu\text{F}$.

Fig.(14-b), fig.(14-c) and fig.(14-a) show the measured CM noise, DM noise and total noise spectra respectively, when the final EMI filter is employed. In the present example both the CM and DM noises are nearly of the same order in magnitude and it is necessary to use both CM and DM filter components to suppress the total noise of the conducted emission of the supply with the designed line filter in order to comply with the CISPR22 class B standard.

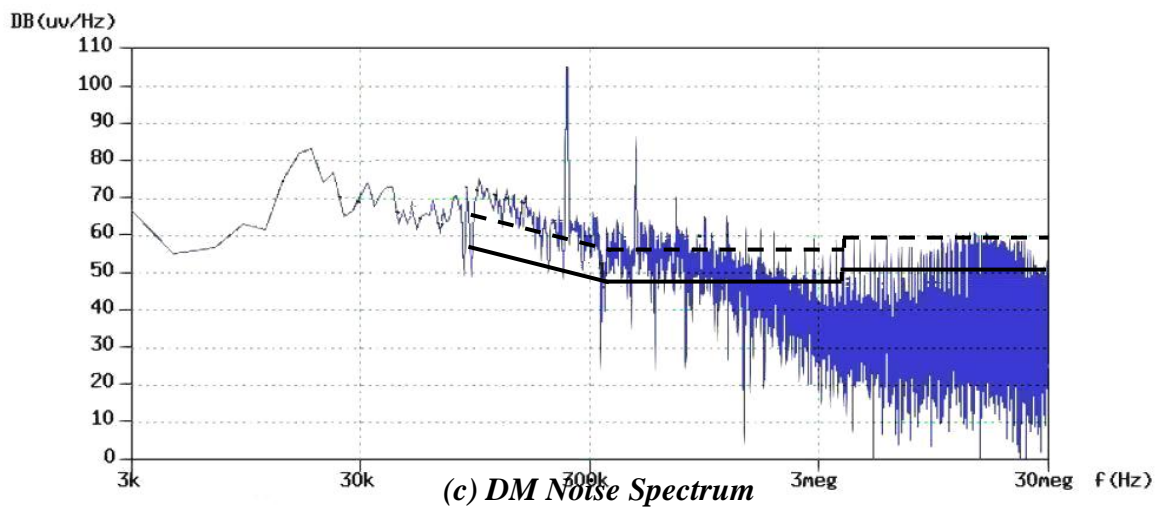
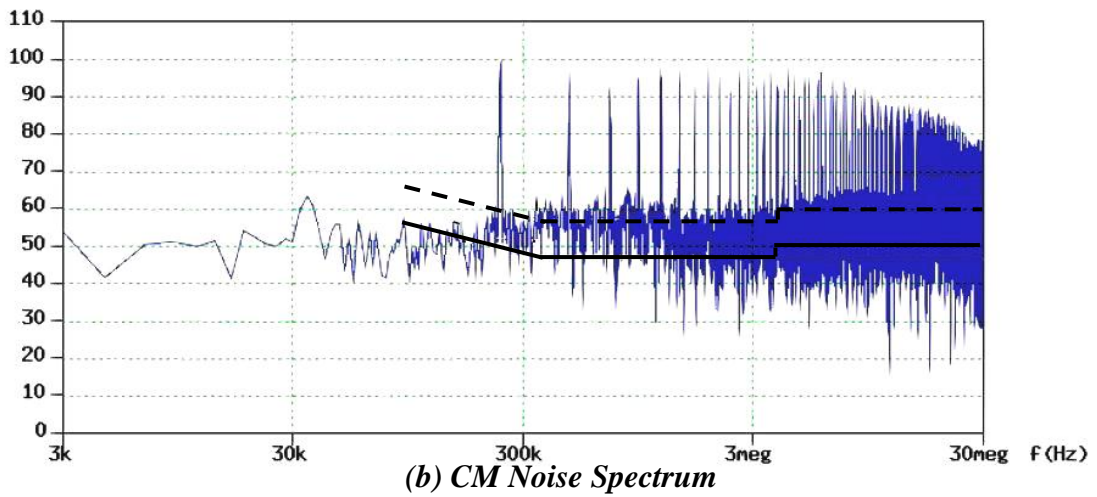
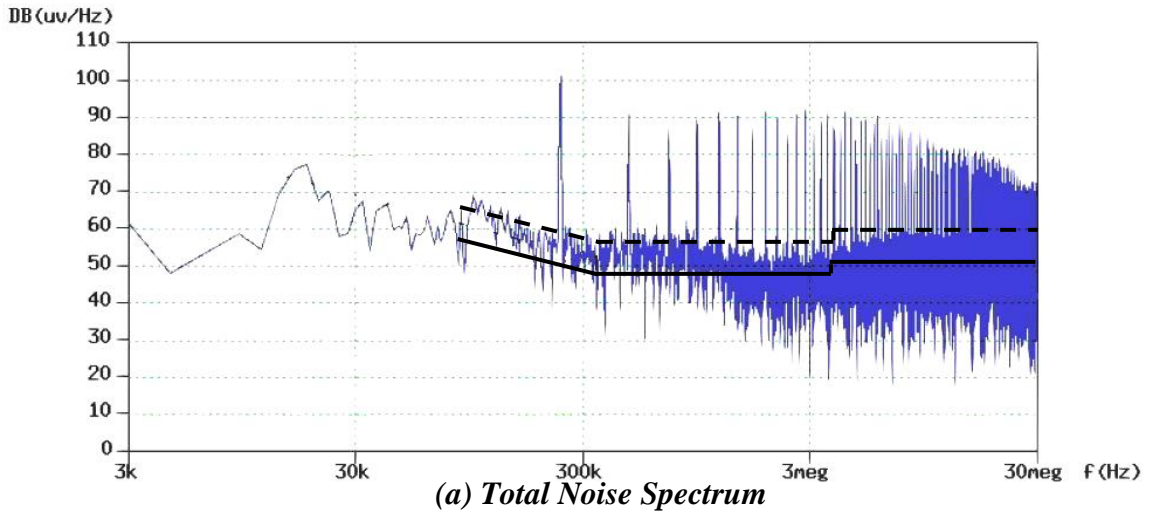
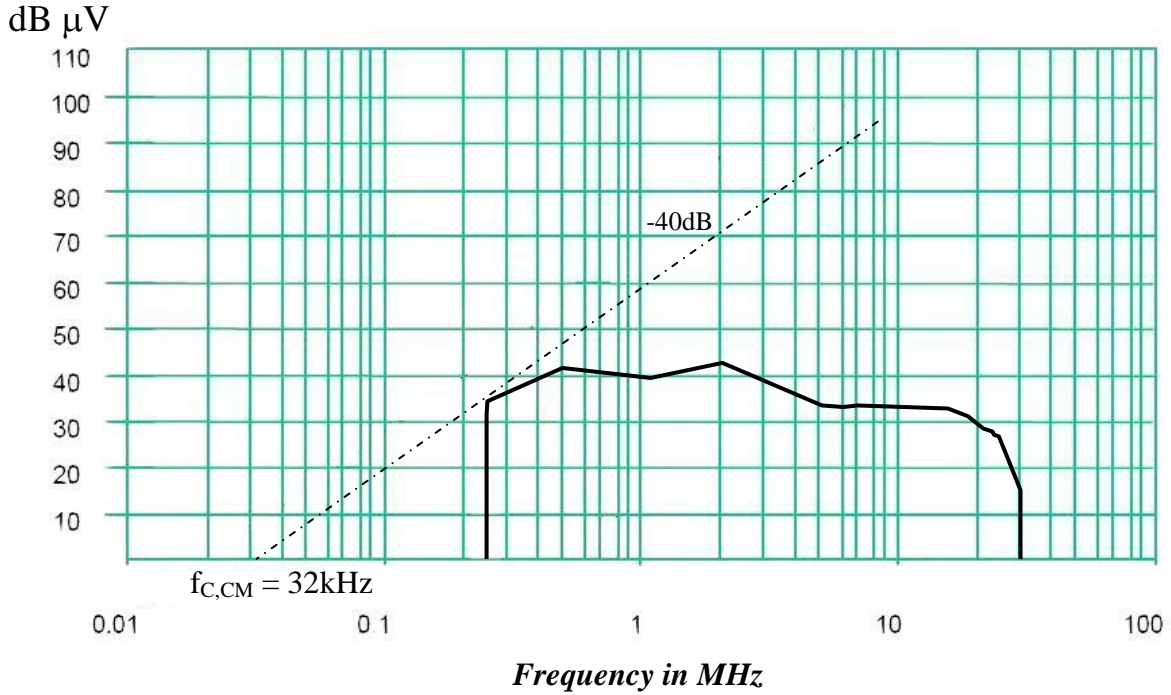
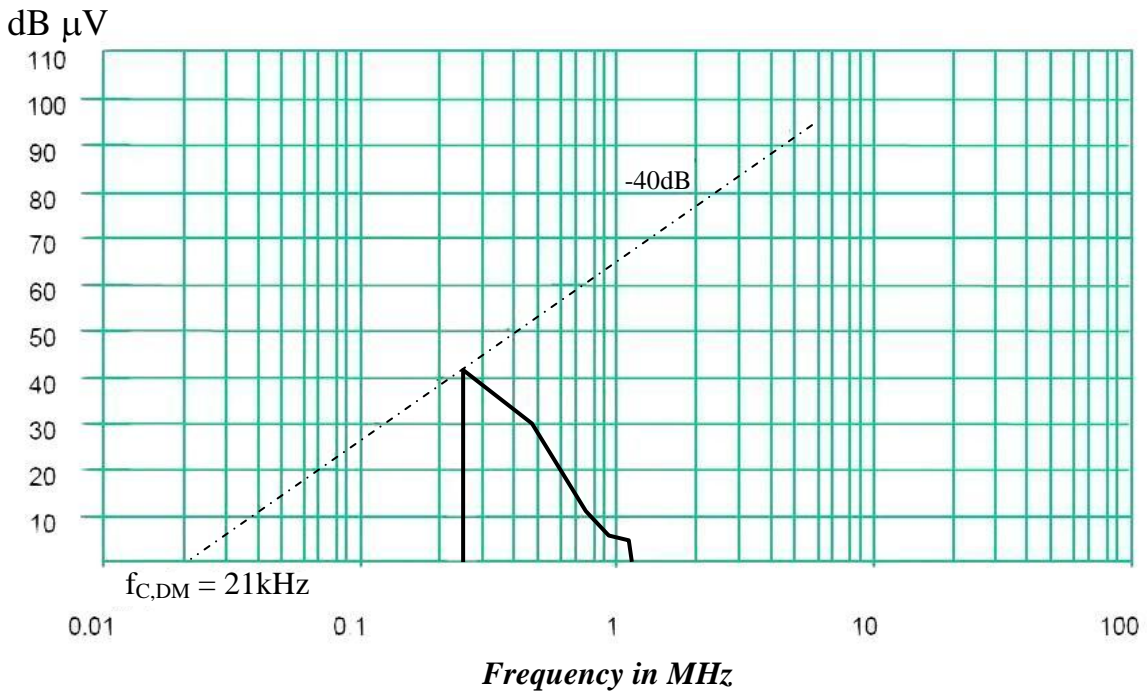


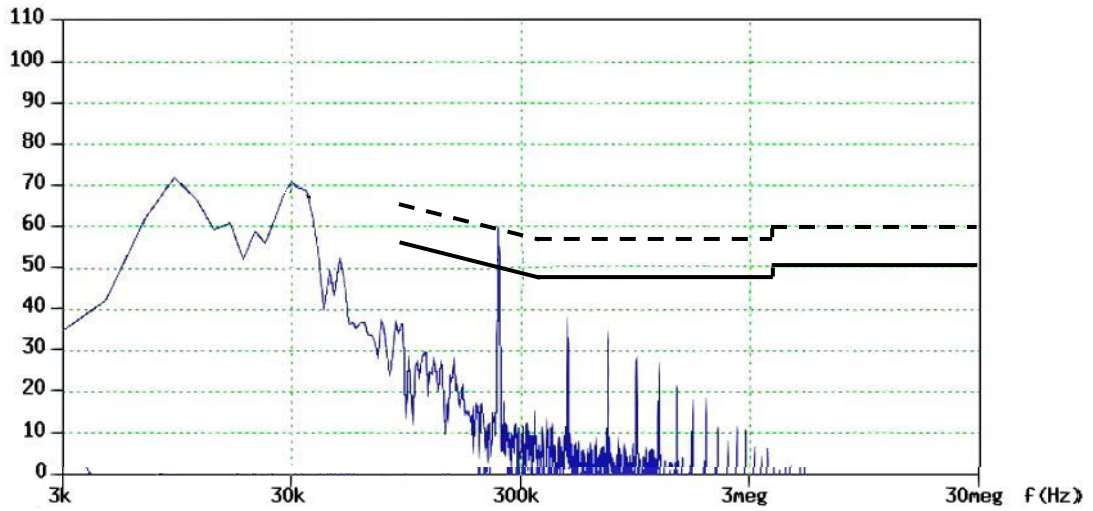
Fig. (12) Noise Spectrum for Original Design



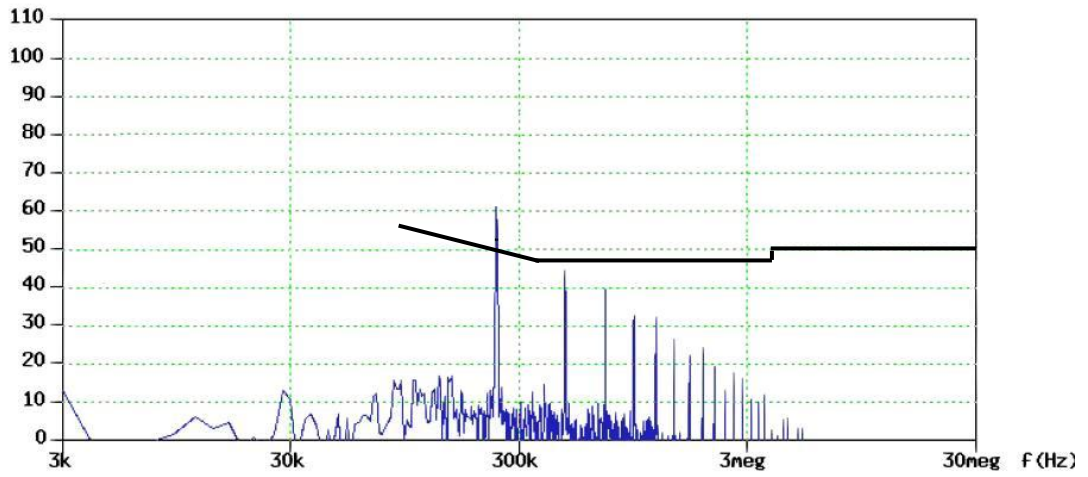
(a) CM Noise Attenuation



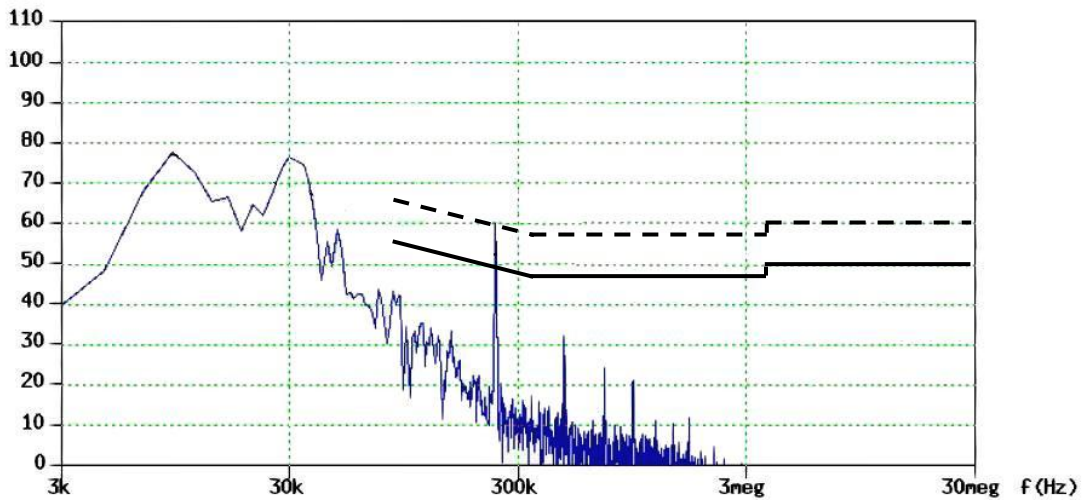
(b) DM Noise Attenuation



(a) Total Noise



(b) CM Noise



(c) DM Noise

Fig. (14) Noise Spectrum with the filter

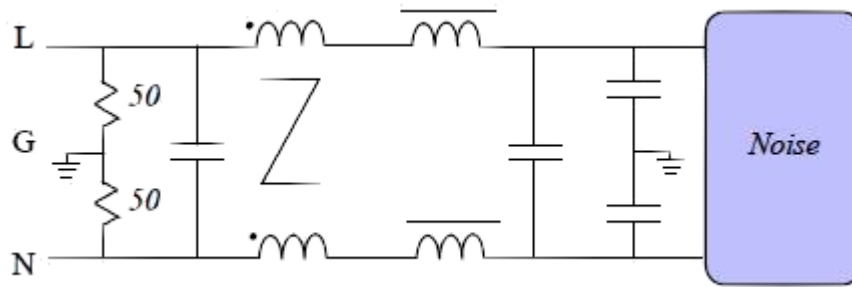


Fig.(15) Designed EMI Filte

Conclusions:

A practical procedure for design the EMI filter is presented. This procedure leads to:

1. A quick filter design that meet's low and high frequency part's of design specification.
2. This procedure facilitates the EMI filter design process and greatly reduces cut and trial effort.
3. The design procedure and the possibility to know the noise components make easier and optimized the filter design. So it is important to know in what proportion these EMI components are, in order to choose a filter, which will perform adequately.
4. The standard limits can be satisfied using this solution.

Finally the EMI filter should be designed case by case because the conducted EMI emission is depended upon many factors such as parasitic inductor and capacitor, ringing, voltage stress, etc. however, the aim of this paper is only to find out a suitable design procedure for EMI filter design to compliance with various standards and regulations.

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