EMI Filter Design for Conducted Interference Noise Reduction in Common-Mode and Differential-Mode

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Abstract

The demand for high-speed electronics at high frequencies is leading to increasing amounts of Electromagnetic Interference (EMI) which is in two forms - conducted and radiated. The mitigation of conducted interference is a major challenge today and the best solution is the use of EMI filters. This paper focuses on designing an EMI filter to reduce both common-mode and differential-mode noise using AWR microwave office and MATLAB. The comparison between inductor and choke filter for reducing common-mode noise is shown in this paper and a basic π filter has been designed for reducing differential-mode noise .The use of Microwave Office made the design easier and the availability of extensive tools in this software made the design more efficient and practical for use.

Keywords: Electromagnetic interference (EMI), Common-mode noise, Differential-mode noise, EMI filters, Choke, Insertion loss

Introduction

The use of sophisticated electronic equipment has led to rapid increase in Electromagnetic Interference (EMI). EMI is in two forms- conducted and radiated, of which the term conducted emissions refers to the coupling of electromagnetic energy produced by equipment to its power cord [1-3]. The conducted interference can further be classified into two types, namely common-mode and differential-mode.

Common-mode (CM) noise and Differential-mode (DM) noise

CM noise current flows in the same direction on both power conductors and returns via the ground conductor and can be suppressed by the use of inductors within an

EMI filter that are placed in series with each power line and by Y-capacitors that areconnected from both power line conductors to ground [4-6].Differential mode (DM) current flows through one ac conductor and returns along another [-9] and can be suppressed by the filter which contains an inductor in series and X-capacitorseen the connected in parallel bet w two current carrying conductors. The CM and DM noises exist as shown in Figure1.

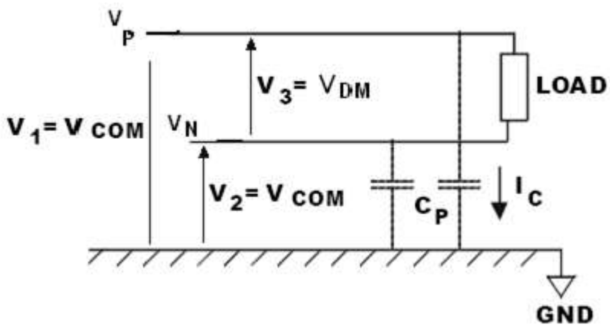

Figure 1: Common-mode and differential-mode noise.

Common mode noise is given as,

$$V_{cm} = \frac{\mathbf{V_P + V_N}}{\mathbf{2}} \tag{1}$$

and differential noise is given as,

$$V_{dm} = \frac{\mathbf{V_P - V_N}}{\mathbf{2}} \tag{2}$$

where, V_P is phase voltage and V_N is neutral voltage. The capacitors C_P are connected in shunt to the power lines to reduce CM noise and in order to reduce DM noise capacitors should be connected across the power line [9].

EMI Filters

EMI filtering circuits are employed so that the end product complies with the applicable EMC standards. Among the most frequently cited EMC standards are EN55022 or its equivalent CISPR 22 standard for IT equipment, EN55011 forindustrial equipment [7].

Table 1: CISPR 22 Conducted Emissions Limits for Class A Devices

Frequency (MHz)	µV QP (AV)	dB(µV) QP (AV)
0.15 - 0.5	8912.5 (1995)	79 (66)
0.5 - 30	4467 (1000)	73 (60)

Table 2: CISPR 22 Conducted Emission Limits for Class B Devices

Frequency (MHz)	µV QP (AV)	dB(µV) QP (AV)
0.15 - 0.5	1995-631 (631-199.5)	66-56 (56-46) (limit varies linearly)
0.5 - 5	631 (199.5)	56 (46)
5 - 30	1000 (316)	60 (50)

The frequency limits for conducted emissions are shown in Table 1 and Table 2 [4-5]. Conducted emissions are regulated by CISPR over the frequency range from 150 KHz-30MHz [10-12]. If the emissions are found to exceed the limits specified by EMC standards, then EMI filter would be designed in order to reduce the noise produced by the equipment under test.

Filter Design

The basic setup shown in Figure2 consists of Line Impedance Stabilization Network (LISN), Equipment under Test (EUT) which is a 2-transistor SMPS circuit, mains power supply and a noise separator circuit

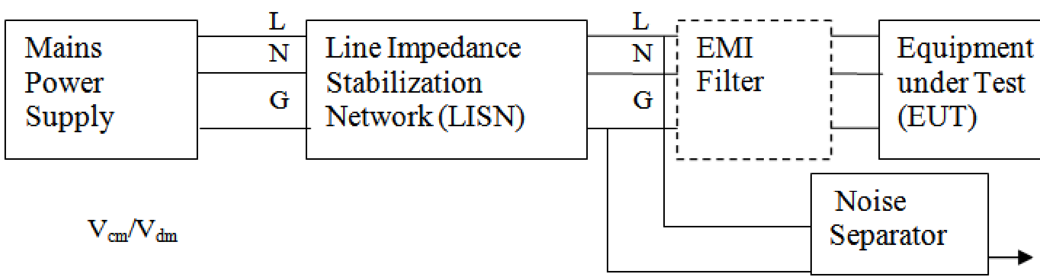

Figure 2: Conducted emissions measurement setup

Line Impedance Stabilization Network (LISN)

The conducted EMI measurement procedure requires a 50 W/ 50 mH Line ImpedanceStabilization Network (LISN) to be inserted between the equipment under test (EUT) and the ac utility line to provide specified measuring impedance for noise voltage measurement [5]. The basic schematic of LISN is shown in Figure3.

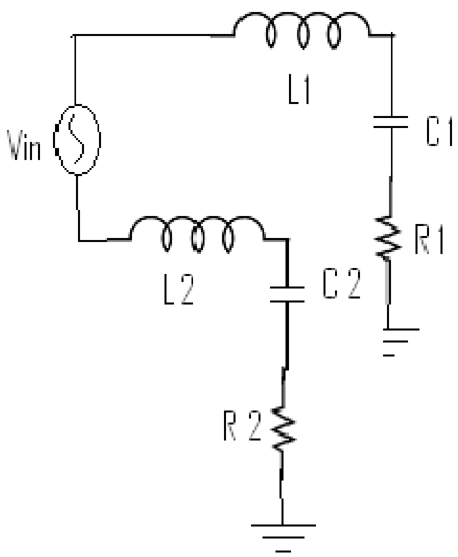

Figure 3: Schematic of LISN.

Euipment Under Test (EUT)

The EUT used in this setup is a 2-transistor SMPS circuit that consists of two transistors, diodes which act as noise sources from which conducted EMI is generated.

Noise Separators

The common mode and differential mode noises from the measured output are separated using a noise separator. DM noise rejection is done using a passive circuitwhile an active circuit is used for CM noise rejection.

Basic EMI filters

There are numerous EMI filters that could be considered for noise reduction, but the most popularly used are the LC inductor filter and the π filter for CM and DM noises respectively [13]. The aim is to obtain the maximum impedance mismatch between the filter and the outside system.

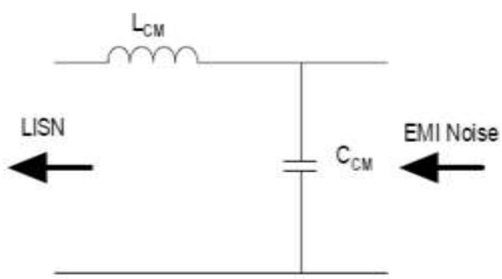

Figure 4: Inductor filter

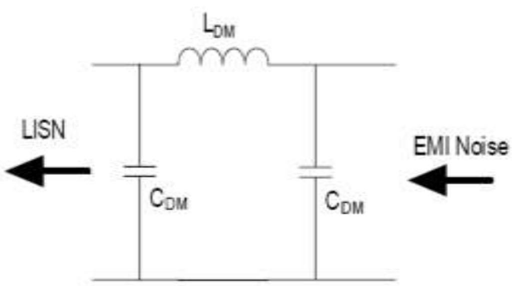

Figure 5: π filter

A better solution over the inductor filter is the choke filter. Chokes withstand high DC currents without degradation of filtering performance. Chokes reduce noise considerably over the entire desired frequency range.The components of inductor filter are designed such that

If $$\frac{1}{w(2C_{CM})} << Z_P \text{, then}$$

$$w(L_{CM}) >> 25\Omega \qquad (3)$$

Where L_{CM} and C_{CM} are inductor and capacitor used in the design of inductor filterand Z_P is the impedance of the euipment used [3].

The components of π filter are designed such that

If $$\frac{1}{w(C_{DM})} >> 100 \text{ and}$$

$$\frac{1}{w(C_{DM})} << Z_P \text{, then}$$

$$w(L_{DM}) >> 100\Omega \qquad (4)$$

Where L_{DM} and C_{DM} are inductor and capacitors used in the design of π filter andZ_P is the impedance of the equipment used [3].

Conducted Emissions Measurements

The experiment was initially conducted with the measurement setup shown in Figure2, but without filter across 150KHz-1.5MHz frequency range. The actual connected schematic has been shown in Figure6. The measured common-mode noise voltage, V_{cm} (dB) and DM noise V_{dm} (dB) across the noise separator, are shown in Figure7 and Figure8. Using these magnitudes, the insertion loss graphs were obtained in MATLAB. The simulation plots obtained in MATLAB showed that the $V_{cmdB\mu V}$ and $V_{dmdB\mu V}$ without filter have exceeded the $V_{limdB\mu V}$ set by the EMC standard for Class B equipment. Hence, the basic EMI filters were designed to be placed between the LISN and EUT and the noise outputs were once again measured and graphs were simulated.

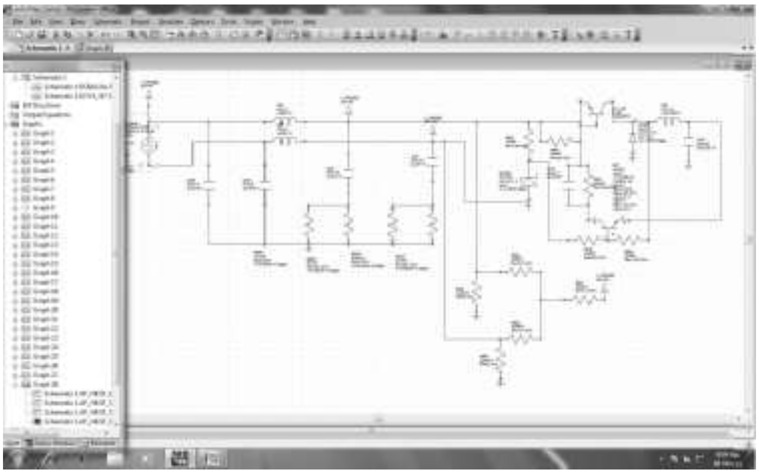

Figure 6: Conducted emissions measurement setup using AWR-Microwave Office.

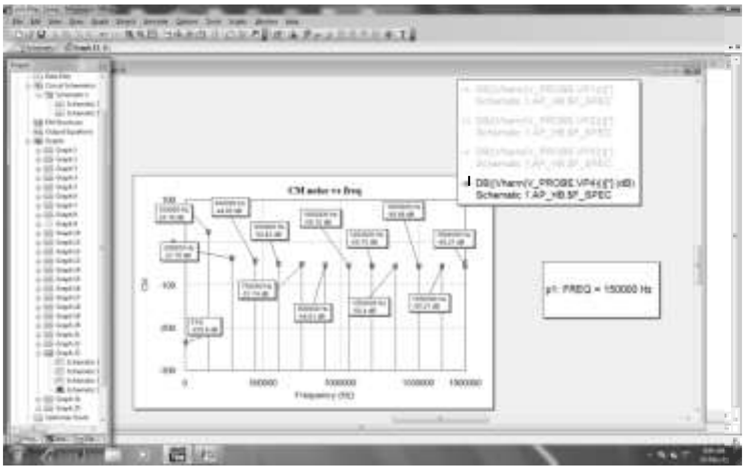

Figure 7: V_{cm}(dB) measured without filter across output of noise separator.

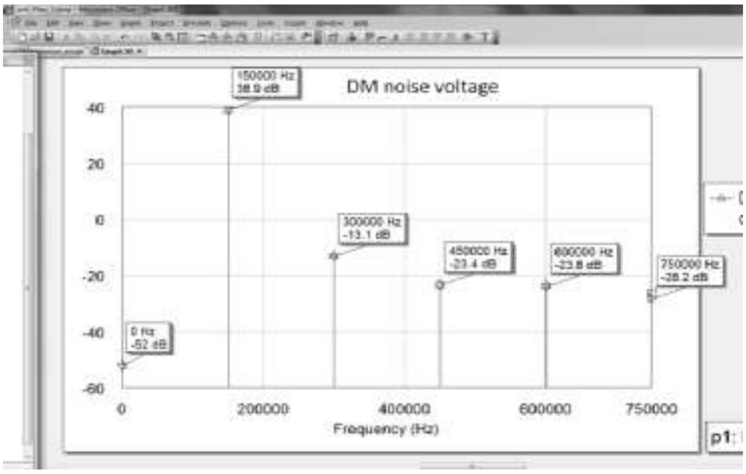

Figure 8: V_{dm}(dB) measured without filter across output of noise separator.

The Insertion loss without filter was calculated by,

$$IL_{cm\,dBuv} = V_{cm\,dBuV} - V_{\lim\,dBuv} \quad (5)$$

$$IL_{dm\,dBuv} = V_{dm\,dBuV} - V_{\lim\,dBuv} \quad (6)$$

where, V_{cm} is the common mode noise obtained in Microwave office whose magnitude is shown in Figure7, Vdm is the value differential mode noise obtained whose magnitude is shown in Figure8. V_{lim} is the EMC limit for conducted emissions which is in dBμV and hence the output noise obtained is converted into dBμV by adding 120 to output noise magnitude[5]. The aim was to design the filter to reducethe CM and DM noises and hence the design needs an insertion loss greater than that given equations 5 and 6.

Hence, the filter components were tuned in Microwave Office refereing to the equations 3 and 4 such that they produce noise voltages that would give an Insertion loss greater than that in equations 5 and 6. Once these components were tuned to give the required insertion loss, the same was simulated in MATLAB using the equations 7and 8 for inductor and π filter for CM and DM noises respectively. The obtained insertion losses using the filters is simulated using,

$$IL_{cmif\,\,dBuv} = V_{cm\,dBuV} - V_{cmif\,\,dBuv} \quad (7)$$

$$IL_{dmif\,\,dBuv} = V_{dm\,dBuV} - V_{dmif\,\,dBuv} \quad (8)$$

where, $V_{cmdB\mu V}$ and $V_{dmdB\mu V}$ are values obtained without using filter and V_{cmif} and V_{dmif} are the noise voltages obtained after tuning filter components for inductor and π filter respectively.

Inductor filter

The inductor filter was placed between the LISN and EUT and the filter circuit was tuned to obtain insertion loss greater than the loss obtained before embeding filter across the desired frequency range. The obtained CM noise voltage, V_{cmifdB} was measured across the output of noise separator in AWR-Microwave Office. It could be observed that noise output reduced considerably by using the inductor filter. Figure9(a) shows that for frequencies from 300KHz-1.5MHz, the noise is within the limits specified by EMC standards. To obtain desired insertion loss below 300KHz, the choke filter was used instead of inductor filter and the results were obtained as in Figure9(b).

Choke filter

It shows that by using choke filter there is a tremendous reduction in noise for frequencies less than 300KHz and over the entire range till 1.5MHz. The loss simulations are shown in Figure10.

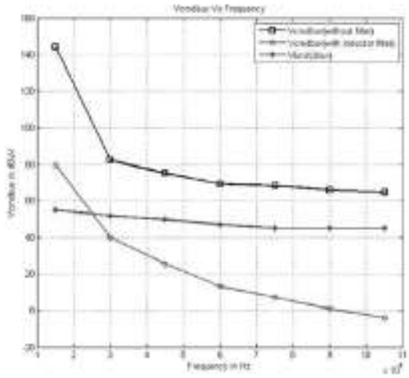

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Figure 9(a): Comparision of CM Voltage with and without filter with V_{lim} set by EMIstandards

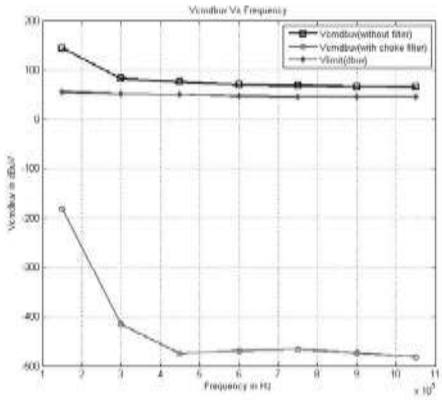

Figure 9(b): Comparision of CM voltage without filter and with choke with V_{lim} setby EMI standards

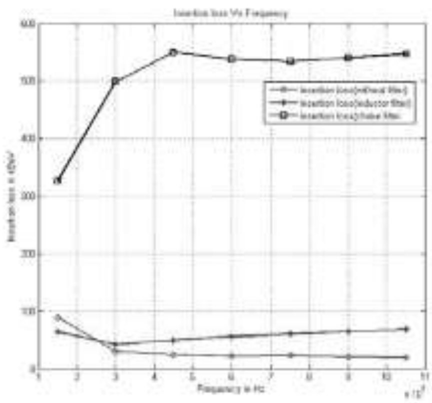

Figure 10: Insertion loss(dBuV) vs Frequency for inductor and choke filter in comparison to insertion loss without filter.

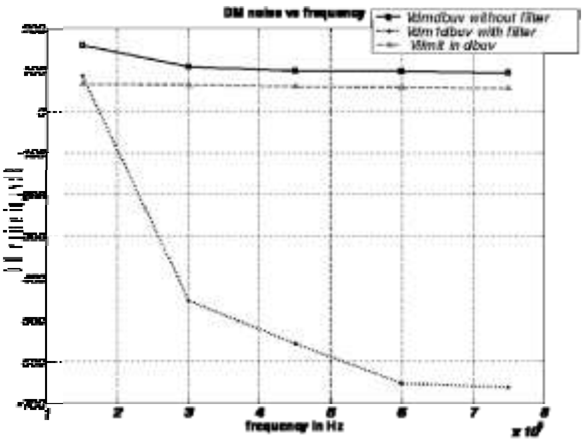

Figure 11: Comparison of DM output with and without filter with V_{lim} set by EMCstandards.

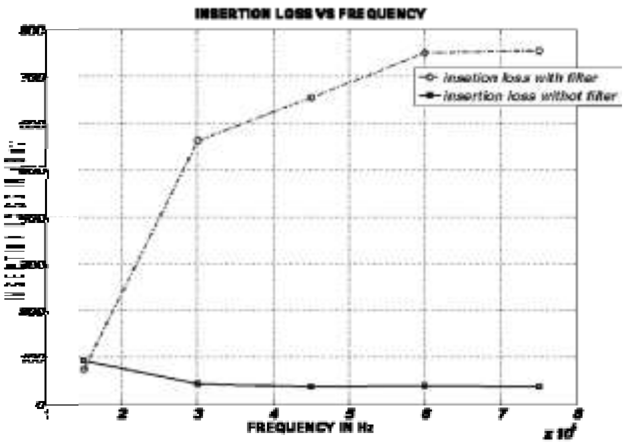

Figure 12: Insertion loss(dBμV) vs Frequency for filter in comparison to insertionloss without filter.

pi **filter**

To reduce the differential-mode noise, the filter was placed between the LISN and EUT and the filter was tuned to obtain DM noise voltage, whose insertion loss obtained is greater than the loss before embeding filter across the desired frequency range. The result obtained is shown in Figure11. Figure12 plots the insertion loss measurement with and without π filter

Results

The conducted emissions measurement setup without the filter produced an insertionloss of around 40-90dBμV for 150-300KHz frequency range and 30dBμV over the frequency range from 300KHz-1.5MHz for common mode noise. Insertion loss of 50-100dBμV was obtained over 150KHz-300KHz and 50dBμV over 300KHz-750KHz for differential mode. The designed filters pi, inductor and choke produced an insertion loss greater than the measurement setup without a filter. The inductor filter produced insertion loss of around 40-80dBμV from 300KHz-1.5MHz range and the choke filter produced loss of around 320-550dBμV over the frequencies from 150KHz-1.5MHz. The π filter produced an insertion loss of 80-560dBμV for 150KHz-300KHz and 550-750dBμV over 300KHz-750KHz. The use of AWR-Microwave Office made it much easier to tune the EMI filter to get the required Insertion loss.

Conclusion

The inductor filter produced desired insertion loss for frequencies from 300KHz- 1.5MHz, but the choke filter produced better results than the inductor filter and also the obtained noise reduced considerably over the entire considered frequency range from 150KHz-1.5MHz. The π filter is a good option for reducing the DM noise over the frequencies from 150KHz-750KHz. Hence, choke and pi filter are good EMI solutions over the conducted emissions range of 150KHz-1.5MHz.

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