Integrated Science

J Integr Sci Technol, 2014, 2(2), 37-41 Article

Journal of Integrated
SCIENCE & TECHNOLOGY

Power line Filter Design using equivalent circuit of passive lumped components

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ABSTRACT

A methodology to design power line filter, using the conventional technique of composite low pass filter has been presented. It is based on a model where common mode and differential mode interference is separately considered into the filter design. In this paper, the filter design process is carried out, by considering the effect of non-ideal behavior of passive lumped components. A proposed model of the power line filter design, based on the parasitic effect of the passive lumped elements is presented. The filter's circuits were first simulated using *Advanced design software* (ADS) based on S-parameter to verify the basic filter response. The simulation result is compared with the cases, where the parasitic effects of passive lumped elements are not taken into account.

Keywords: Power line filter, common mode,, differential mode, lumped components

INTRODUCTION

Switching and modulation techniques are used for efficient use of electrical power. Widely used *Switched mode power supplies* (SMPS) for powering today's electronics loads is a most common example. Unfortunately, all the power control techniques deliberately distort sinusoidal wave form of power frequency and generate unwanted interfering signals. Obviously, they all are often cited as one of the main source of conducted emission (CE). Usually the power supplies which are using controlling techniques cannot comply with the strict *electromagnetic compatibility* (EMC) regulations. In order to meet the limit set for conducted EMI, power supplies require a ***filter*** at its input. Conducted EMI generated by one equipment gets coupled to another equipment mostly through power line cables. CE can be controlled by using filters and increasing line impedance. Conducted EMI has two components: The common mode (CM) interference and the differential mode (DM) interference. The coupling mechanisms of these interferences are different.[1] The difference in the direction of propagation of these coupling currents along the phase and neutral line, leads to differential mode (I_{dm}) current and common mode mode (I_{cm}) current. Therefore design of EMI filters demand decoupling of these two modes.[2] This paper attempts to describe a design technique for *Power Line filter* using classical design technique. The main differences between an EMI filter and a conventional filter are as given below:

- Unknown noise source and load impedance.
- Two modes of propagation i.e.CM and DM are to be considered.
- High power handling capacity.

1.1 MODAL CHARACTERIZATION OF POWER LINE NETWORK

The signals in the single-phase power-line network (PLN) conductors [line (L), neutral (N), and ground (G)] can be characterized in two ways (fig1): circuitally (considering the physical signalsV_L,V_N,I_p, I_N) or modally (considering the modal signals V_{CM}, V_{DM}, I_{CM}, I_{DM})[3]. The currents flowing through the phase and neutral conductors are depicted as (I_p) and (I_n). These currents can be decomposed into two auxiliary currents, which are referred to as the common mode current (I_{cm}) and differential mode current (I_{dm}).[2] The propagation of interferences through phase, neutral and ground conductor is shown in the figure 1.[3]

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Cite as: *J. Integr. Sci. Technol.,2014, 2(2), 37-41.*

JIST ISSN 2321-4635

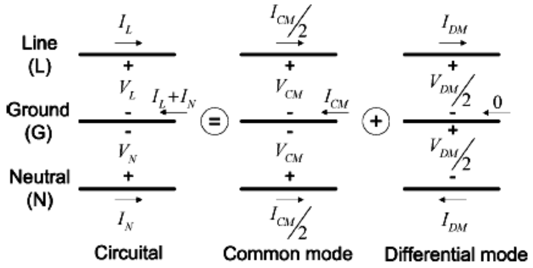

Figure 1. Relationship between circuital and modal voltages and currents.

The CM and DM currents separately can be determined from the conducted emission measurement data:

$$I_p = I_{cm} + I_{dm} \qquad I_n = I_{cm} - I_{dm} \tag{1}$$

$$I_{cm} = \frac{I_p + I_n}{2} \qquad I_{dm} = \frac{I_p - I_n}{2} \tag{2}$$

Input impedance of measuring instruments is mostly 50Ω. Therefore, the CM and DM Voltage can be defined as:

$$V_{dm} = 50\, I_{dm} = 50\left(\frac{I_p - I_n}{2}\right) = \frac{V_p - V_n}{2} \tag{3}$$

$$V_{cm} = 50 I_{cm} = 50\left(\frac{I_p + I_n}{2}\right) = \frac{V_p + V_n}{2} \tag{4}$$

The equivalent circuit for the conducted emission measurement setup is shown in the figure 2.[4]

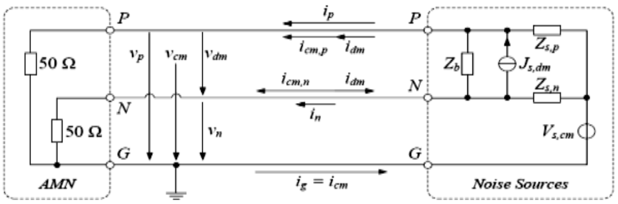

Figure 2. Equivalent circuit of the conducted emissions measurement.

1.2 CONDUCTED EMISSION MEASUREMENT

An example of a measurement setup for conducted emission tests according to CISPR 11/22 is carried out as shown in the above figure 3. The FCC and CISPR 22, limits on conducted emissions extend from 150 kHz to 30 MH. Measurement of CE for verification of compliance with the regulatory limits is to be measured with a line impedance stabilization network (LISN). It is inserted between the commercial power outlet and product's ac power cord. Measurement is carried out in frequency domain the graphical display of the conducted emission is shown in the *EMI Receiver* .

Figure 3. Measurement set up

Interference output from Line Impedance stabilising network (LISN) is viewed in the EMI Test Receiver. The measurement data of the test Receiver is shown in the fig (4). From the data of conducted emission test, it can be viewed that the peak level of emission exists at 80 dBμV. But according to the standard specification, the limitation of the emission is 40dB. Therefore according to the definition of Insertion loss, the filter must be designed in such a manner, that the IL of the power line filter must be more than 40dB.

1.3 MEASUREMENT OF PHASE & NEUTRAL LINE FOR CONDUCTED EMISSION

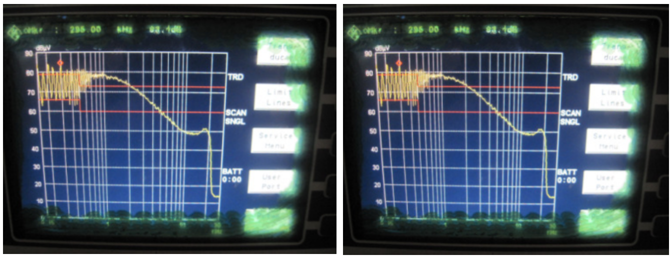

Figure 4. EMI Receiver data

2. DESIGN PROCESS

In this paper, we present a design methodology to realize low pass filter using a unique combination of constant-k, m-derived section. In this paper, we present a design methodology to realize low pass filter using a unique combination of constant-k, m-derived section. The significance of constant-k filter is such that the product of Z_1(series impedance) and Z_2(shunt impedance) is a constant real term. Hence the power delivered by the source is mostly absorbed by the load. But at the same time it has some demerits. So, the *m-derived* filter section is a modification of the constant-k section. With this, the sharpness of the cut-off is increased. And the prototype section (constant-k) provides the necessary attenuation at frequencies remote from cut off. This type of LPF is called *composite filter.*[5] It is designed separately for the differential mode filter in the frequency range of 150 kHz to 1 MHz and the common mode filter in the frequency range of 1 MHz to 30 MHz.

Constant-k Section: The value of Capacitance and Inductance is determined[3] as

$$L = \frac{Z_o}{\pi f_c} \quad C = \frac{1}{\pi f_c Z_o} \tag{5}$$

M-derived Section: The cut-off frequency (f_c) and the infinite attenuation occurred at frequency (f_∞) is defined as

$$f_\infty = \frac{f_c}{\sqrt{1-m^2}} \qquad f_c = \frac{1}{\pi\sqrt{LC}} \tag{6}$$

The independent element values of m-derived LPF is obtained as

$$L' = \frac{mL}{2} \tag{7}$$

$$C' = mC \tag{8}$$

$$L'' = \frac{1-m^2}{4m} \tag{9}$$

Matching section: This Circuit can be further modified using the Matching section i.e. bisected-π section of the M-derived section that are implemented as a terminating Half Section. The composite LPF is transformed into Common mode and Differential mode Power line section. The cut off frequency for the differential mode is f_c: 50 kHz and the infinite attenuation pole isf_∞: 1Mh.

The lumped elements of the terminating half sections at the input and output port of the low pass filter can be determined as

$$L' = \frac{ml}{2} \tag{10}$$

$$C' = \frac{mc}{2} \tag{11}$$

$$L'' = \frac{1-m^2}{2m} \tag{12}$$

2.1 DIFFERENTIAL MODE FILTER

The composite low pass section is now designed for the differential mode (DM) filter section with a cut off frequency (f_c) of 50 khz. It is chosen as one-third of the initial frequency of attenuation. The direction of propagation of DM current is considered while designing the circuit. The stop band attenuation is selected within the range of 150khz to 1 Mhz.

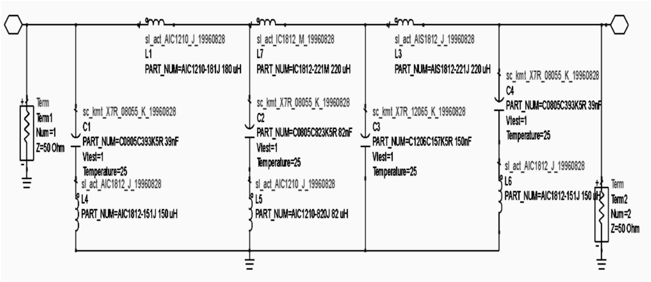

Figure 5. Circuit of lumped element DM composite filter.

2.2 COMMON MODE FILTER

In this section, the propagation direction of the CM current was being considered. The design is carried out at a cut off frequency(f_c): 333 kHz and maximum attenuation pole (f_∞):30 MHz. In this circuit, the series inductors of DM section are also connected in series with the CM filter section. The first inductor is the series inductor of the DM section.

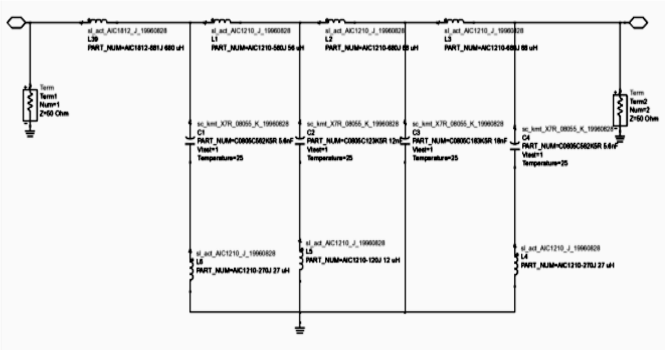

Figure 6. Circuit of lumped element CM composite filter.

Table 1 Design components of Filter circuit

Mode	L	*C*	f_0
DM	318.47µH	127.39 nF	50kHz
CM	47.77µH	19.1nF	333.33khz

2.3 DETERMINATION OF IL

Basic definition: The Insertion loss (IL) as a function of frequency is the most fundamental characteristic of a filter and is defined by[6]

$$\text{IL (dB)} = 20\, log_{10} \frac{V1}{V2} \tag{13}$$

Where, V_1= the output voltage of the signal source without the filter connected to the circuit
V_2 = the output voltage of the signal source at the output terminal of the filter with the filter inserted in the circuit.

2.4 ADS SIMULATIONS

The differential mode & common mode circuits are simulated in ADS based on S-parameter as shown in the figure. The simulation result of the DM filter has an attenuation of 84dB at the 1 MHz frequency. While the CM filter shows an attenuation of 125 dB at the frequency of 30 MHz.

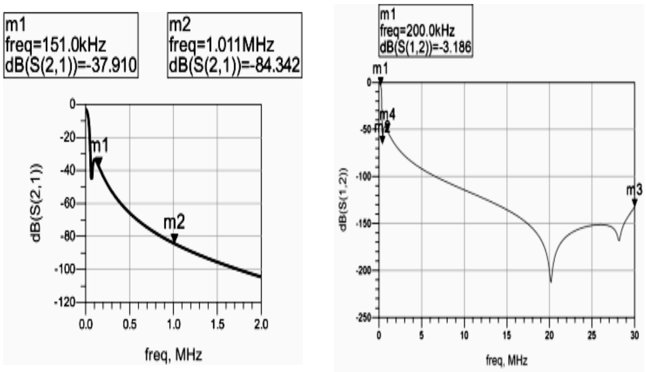

Figure 7. Simulation result for DM & CM composite filter.

3. ROLE OF PARASITIC EFFECTS OF PASSIVE ELEMENTS

Capacitor: The equivalent circuit of Capacitor consists of a series combination of series resistor (R_s), lead inductor (L_{lead}) and capacitor.[7] The mathematical models that yield considerable insight into the non ideal behaviour of components have been used. In the conducted emission range i.e. (150 kHz–30 MHz), the behaviour of these elements is far from the ideal as shown in figure 5.

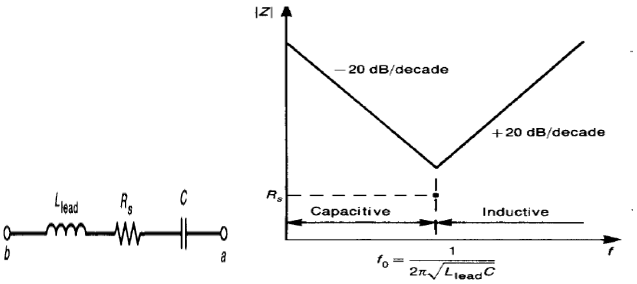

Figure 8. Equivalent circuit of capacitor including its non ideal effect.

At low frequency the impedance of the capacitor dominates and decreases linearly with increasing frequency at a rate of-20 dB/decade. With increasing frequency the impedance of the inductor increases until it equals that of the capacitive impedance at $(f_o) = 1/2\pi\sqrt{L_{lead}\,C}$. At this frequency the net impedance of the branch is Rs. The frequency ‘f_0’ is referred to as the self-resonant frequency (SRF) of the capacitor.[7] Hence the lead inductance of the capacitor can be determined from its *self resonant frequency* (SRF). The impedance of the capacitor is given by:

$$Z_c = R_s + jwl + \frac{1}{jwC} \tag{14}$$

where ‘*l*’ is lead inductance of the capacitor.

Inductor: The equivalent circuit of an inductor and the non ideal behaviour the inductor can be represented as shown in the (fig6)[7]. At low frequencies the resistance dominates, and the impedance is Rpar. As frequency is increased the impedance increases at 20 dB/decade.

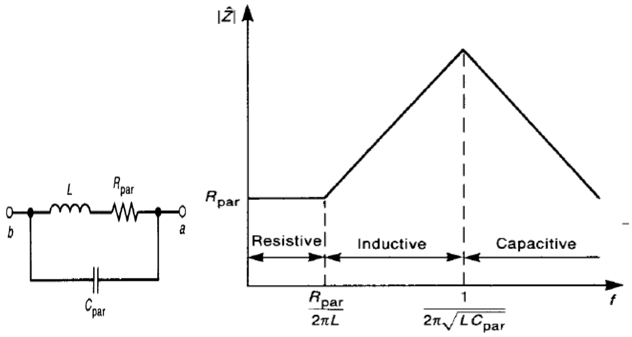

Figure 9. Equivalent circuit of an inductor including its non ideal effect.

As frequency is further increased, the impedance of the parasitic capacitance decreases until its magnitude equals that of the inductor impedance. This occurs at the self-resonant frequency of the inductor, $f_o = 1/2\pi\sqrt{L}C_{par}$ The impedance of the inductor is given by:

$$Z_l = \frac{R_{par} + jwl}{1 - w^2 jwLC + jwR_{par}\,C} \tag{15}$$

4. MODIFIED FILTER CIRCUIT

In order to obtain the desired frequency response and the Insertion loss of the differential mode filter (DM), the original circuit of the filter is modified by adding the parasitic components in the basic equivalent circuit of the passive lumped elements(inductor and capacitor).

The ADS schematic circuit of the differential mode filter designed as shown in the figure 10.

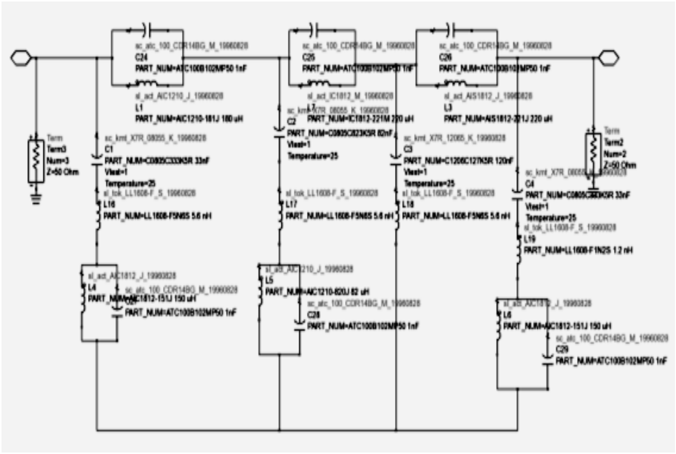

Figure 10. ADS schematic of DM filter

In the similar manner, Common mode section of the filter is also modified by considering the parasitic components of the passive lumped elements. The parasitic capacitor (C_{par}) is connected in parallel with the inductor and the lead inductor (L_{lead}) is connected in series with the capacitor, as per the equivalent model of passive lumped elements at high frequency. The parasitic values of the components are chosen from the manufacturer’s data sheet

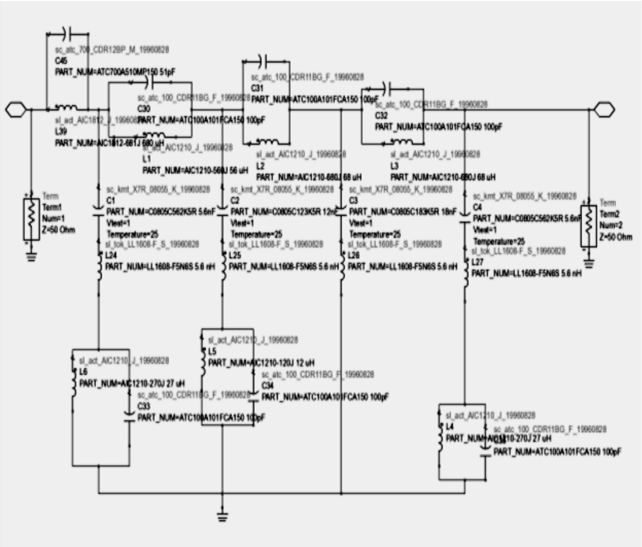

Figure 11. ADS schematic of CM filter

Table 2 Parasitic components of modified filter circuit

Components	L_{lead}	C_{par}
	5.6 nH	100pF

RESULT

In order to validate the filter design model, the simulated result of the modified circuit has been compared with the practical filter response. It is found from the simulation result that the DM insertion loss is lower compared to the CM insertion loss. It is due to the reason that generally DM current is dominant at low frequency i.e. up to 1Mhz where as CM current is dominant beyond 1Mhz and up to 30Mhz.[7]

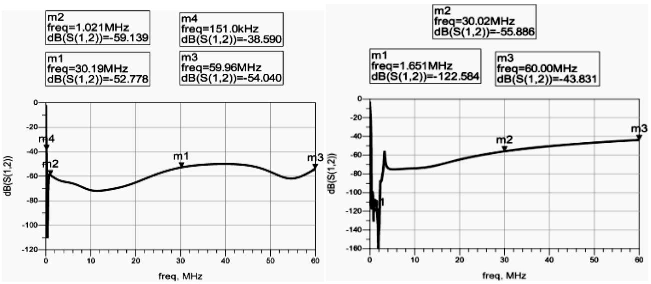

Figure 12. Simulation result of the modified DM and CM filter

CONCLUSION

- Design of power line filter using constant-k and m-derived composite low pass filter gives a better frequency response.
- The frequency response of the modified filter circuit has become equivalent to the practical filter response.
- The desired IL has been achieved within the CE range of frequency.

REFERENCE

1. Mohit Kumar, Vivek Agarwal. Power line filters Design for Conducted EMI using Time-domain measurements. IEEE transaction on electromagnetic compatibility, Vol.48, NO.1, February **2006**
2. V.Prasad kodali. Engineering Electromagnetic Compatibility. The institute of Electrical and Electronics Engineers, Inc : New York, **1996**.
3. Albert Miquel Sanchez, Joan Ramon Regue, Miquel Ribo, Pablo Rodriguez- Cepeda, Francisco Javier Pajares. A Modal Model of Common-Mode Chokes for Conducted Interference Prediction IEEE transaction, on electromagnetic compatibility, Vol.52, NO.3. August **2010**.
4. Konstantin Kostov. Design and characterization of single - Phase Power line filters. Helsinki University of Technology, **2009**.
5. D.M. Pozer. Microwave Engineering. J.Wiley & Sons,Inc,**2001**.
6. Konstantin Kostov, Jorma Kyyra. Insertion loss and Network parameters in the Analysis of Power Filters. Nordic Workshop on Power and Industrial Electronics, Espoo, Finland, June, **2008**.
7. Clayton R.Paul. Electromagnetic Compatibility. J.Wiley Sons Inc, **2006**.