

Practical Design of a Passive EMI Filter for Reduction of EMI Generation

J. Jiraprasertwong, and C. Jettanasen

Abstract— Electromagnetic Interference (EMI) usually generated by a power converter can disturb or damage nearby sensitive electrical/electronic devices/equipment. The use of EMI filter inserted in the considered system is a classical technique for EMI reduction. In order to spend less time and have low cost, this paper proposes a user interface for practical EMI filter design. This interface is easy to use and able to rapidly find out the filter component values. The principle of this design is based on calculation from electromagnetic noises measured by spectrum analyzer, then the algorithm tries to find the cut-off frequency of the filter in order to obtain the attenuated noises respecting to an applied Electromagnetic Compatibility (EMC) standard. The performance of this practical EMI filter design is guaranteed by the real EMI emission measurement. Moreover, this user interface can be useful and used for other power converters, switching devices or EMI sources. Finally, it will reduce time consuming and cost when performing EMC testing in the real work.

Index Terms—EMC, EMI filter design, passive EMI filter, user interface

I. INTRODUCTION

T ODAY, electrical/electronic devices play an important role in everyday life. The electrical/electronic equipment has required EMC standard to confirm that the device can work without disturbing each other or immune to interference. To be compatible with other devices, electromagnetic compatibility must be taken into account when designing electronic devices since initial stage. However, in case of disrespecting of EMI level to the standard, EMI filter can be used for EMI reduction. Techniques for design of the passive EMI filter has been investigated and developed in past decade [1-2], and still have to be studied and designed continually [3-7].

When designing any electrical/electronic devices in terms of EMI/EMC, they must be tested by a spectrum analyzer in order to know their EMI generation behavior. The generated EMI is mandatorily compared with an EMC standard, such as FCC, EN, CISPR, VDE, and military standards. However, the spectrum analyzer is an expensive measuring apparatus. That is why many companies cannot measure or detect EMI

emissions during design phase. The EMI generation is usually measured or determined at the testing center when the device is already completed. Certainly, the cost of the testing is expensive and charge by the time of testing. Some electronic devices do not respect EMC standards, therefore, it is required to add or modify the EMI filter to limit conducted EMI issued from the device at the testing center, and measure electromagnetic noise again. Sometimes, it is only a single tune, and sometimes, it takes several times to adjust EMI filter component values to pass the EMC standard. Consequently, this paper will present an application with GUI interface for rapid practical design of passive EMI filter. By using the EMI spectrum results from the testing center for design, the component values of passive EMI filter will be obtained based on algorithm proposed in this paper. The technique uses the basic design already well understood with GUI interface for design and calculation. The purpose is to provide a quick and easy to fit real applications to reduce the testing time and the testing cost.

II. CONDUCTED ELECTROMAGNETIC INTERFERENCE

EMI is divided into two types: 1) conducted emission and 2) radiated emission. The EMI filter is designed to reduce conducted noise emission. Moreover, conducted EMI is separated into two modes; one is differential mode (DM) interference and another is common mode (CM) interference. The DM noise flows in line and returns by neutral whereas the CM noise flows in line and neutral and then, flows into ground. For specification of conducted measurement within the EMC standard, the noise is measured in the frequency range of 9 kHz to 30 MHz or 150 kHz to 30 MHz. The main equipment employed in noise measurement is LISN (Line Impedance Stabilization Network), spectrum analyzer and computer. LISN is normally placed between the electrical source and the device under test (DUT). It allows maintaining fixed input impedance in accordance with the EMC standard.

III. PASSIVE EMI FILTER

There are several types of filters, for example, passive EMI filter, active EMI filter, and hybrid EMI filter. However, the passive EMI filter is simpler than others. The main components of this filter are one common mode choke (coupled inductor: L_{CM}), two common mode capacitors (C_Y), one differential mode choke (L_{DM}), and two differential mode capacitors (C_X). The structure of the filter circuit is shown in Fig 1.

Manuscript received January 8, 2015.

J. Jiraprasertwong is presently a student in Electrical Engineering Master program at KMITL. His research interest is EMI/EMC in solar inverter and EMI filter design. (e-mail: j.jukkrit@gmail.com)

C. Jettanasen is currently an assistant professor in Department of Electrical Engineering, Faculty of Engineering, King Mongkut's Institute of Technology Ladkrabang (KMITL), Bangkok 10520, Thailand. His research interest is EMC in power electronic systems. (e-mail: kjchaiva@kmitl.ac.th)

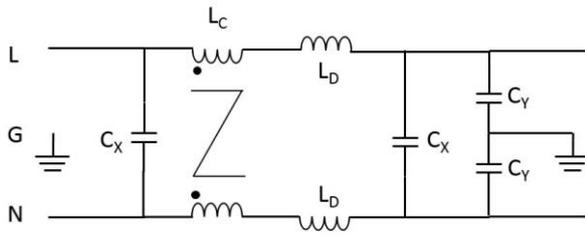


Fig. 1. Passive EMI filter equivalent circuit

A simple calculation of inductors and capacitors in the circuit can be found from (1)-(5). In (1)-(3), these equations are related to common mode noise. The $f_{R,CM}$ is the cut-off frequency of common mode filter. L_{CM} and C_{CM} are total CM inductor and CM capacitor in EMI filter. In (2), L_{CM} is represented by $L_C + \frac{1}{2}L_D$ and C_{CM} is represented by C_Y (L_C , L_D , and C_Y are shown in Fig. 1). Since L_C dominates L_D , the final equation in common mode path is simply expressed by (3).

$$f_{R,CM} = \frac{1}{2\pi\sqrt{L_{CM}C_{CM}}} \quad (1)$$

$$f_{R,CM} = \frac{1}{2\pi\sqrt{\left(L_C + \frac{1}{2}L_D\right) \times 2C_Y}} \quad (2)$$

$$f_{R,CM} = \frac{1}{2\pi\sqrt{L_C \times 2 \times C_Y}} \quad (3)$$

In (1)-(2), they are related to differential mode noise. The $f_{R,DM}$ is the cut-off frequency of differential mode filter. L_{DM} and C_{DM} are total DM inductor and DM capacitor in EMI filter. In (4), L_{DM} is represented by $((2 \times L_D) + L_{leakage})$ and C_{DM} is represented by C_X (L_D , and C_X are shown in Fig. 1). $L_{leakage}$ is leakage inductance of common mode choke. The final equation in differential mode path is expressed in (5).

$$f_{R,DM} = \frac{1}{2\pi\sqrt{L_{DM}C_{DM}}} \quad (4)$$

$$f_{R,DM} = \frac{1}{2\pi\sqrt{\left((2 \times L_D) + L_{leakage}\right) \times C_{DM}}} \quad (5)$$

Fig. 2 shows an example of the measured EMI emissions according to the EMC standard frequency range. The EMI spectrum is shown in red and green lines; red line represents EMI noise measured between Line and ground while green line represents EMI noise measured between Neutral and ground. An EMC regulation, which is herein EN55022 class B, is also presented and compared to the EMI level. The upper line is quasi peak and the lower line is average. Note that over the considered frequency range, EMI level exceeds the applied EMC standard. That is why, EMI filter is essential for EMI reduction.

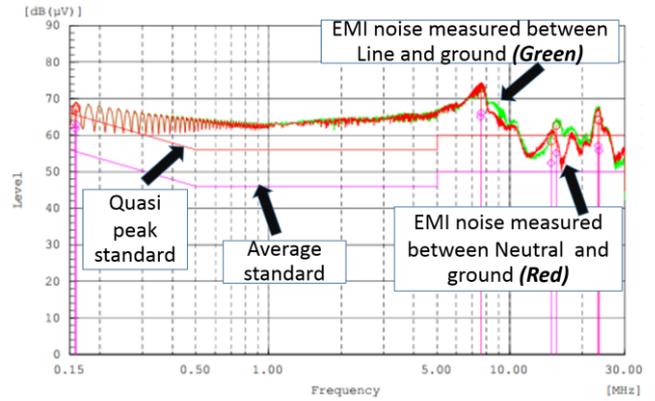


Fig. 2 EMI emissions measured from spectrum analyzer

Not only noise graph acquired, when the measurement is completed, we can extract data of critical points as marked on spectrum in fig. 2; these data are shown in Table I. These 4 points can be used to determine passive EMI filter element values using the proposed algorithm. The number of critical points is not fixed, it depends on the user. In the table, it presents data in 5 columns. The first column is frequency point that is marked in Fig. 2. The second column is quasi peak value of noise. The third column is average value of noise. The next column is margin of quasi peak value, subtracted from the standard and noise. For our data, they are all negative because the measured noises are over the standard. The final column is margin of average value between the standard and noise.

TABLE I
DATA FROM SPECTRUM ANALYZER

Frequency [MHz]	Reading QP [dB(µV)]	Reading CAV [dB(µV)]	Margin QP [dB(µV)]	Margin CAV [dB(µV)]
0.15769	56.9	51.6	-1.5	-6.2
7.5712	60.7	54.5	-11.2	-15.0
15.6068	52.0	44.4	-2.7	-5.1
23.2712	53.4	46.3	-4.2	-7.1

The filter must be able to reduce noise to be below the limit of standard. The simple calculation uses the cut-off frequency (f_c) of EMI filter. The selected f_c is determined from the measured noise. The cut-off frequency is the starting frequency of signal attenuation. With the structure in Fig. 1, EMI emissions can be attenuated approximately 40 dB per decade. The required attenuation (V_{reg}) is easily calculated by (6)-(7). $V_{reg,CM}$ and $V_{reg,DM}$ are required attenuation of CM noise and DM noise. V_{CM} and V_{DM} are the common mode noise and differential mode noise that are measured from spectrum analyzer. V_{limit} is defined as value of standard at the frequency of generated noise. Final parameter in equations is Margin; it is gap value for save when making design. Generally, the margin value is 3 dB, however, it can be higher if the user desires.

$$(V_{reg,CM})dB\mu V = (V_{CM})dB\mu V - (V_{limit})dB\mu V + (Margin)dB\mu V \quad (6)$$

$$(V_{reg,DM})dB\mu V = (V_{DM})dB\mu V - (V_{limit})dB\mu V + (Margin)dB\mu V \quad (7)$$

More details can be found in [1-7]. The calculation of the parameters mentioned in the above equations is simple calculation at low frequency range of EMI. It might not be

proper for higher frequencies owing to effects of parasitic elements of EMI filter and device components. To analyze the advanced design, it must carefully consider and take into account source and noise source impedances [8-9]. Analyzing with the mentioned technique can reduce cost of component. Sometimes, the EMI filter does not need high capacitance but appropriate capacitor is good enough to be used in the system for EMI reduction [10]. However, the EMI filter that is designed by the cut-off frequency technique has limitation in high frequency range. In practice, we can reduce parasitic elements by several methods such as shortening leg of the capacitor and resistor; furthermore, some winding inductance configurations can make self resonant frequency farther [11].

IV. QUICK DESIGN WITH USER INTERFACE

As previously mentioned, the user interface (GUI) is designed to be easy to use and works rapidly. The design principles and formulas used are previously presented. This simple and consistent GUI will be practically useful in design process for companies having no tools. This allows reducing the design time, costs of measurement, and production costs.

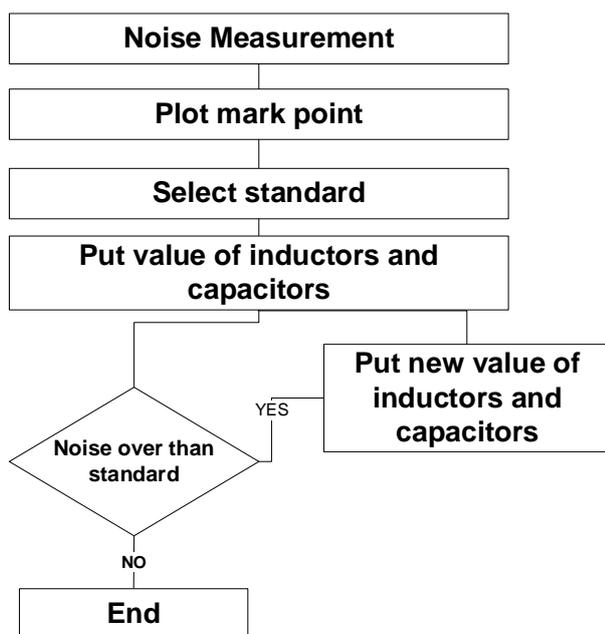


Fig. 3. Flow chart of user interface

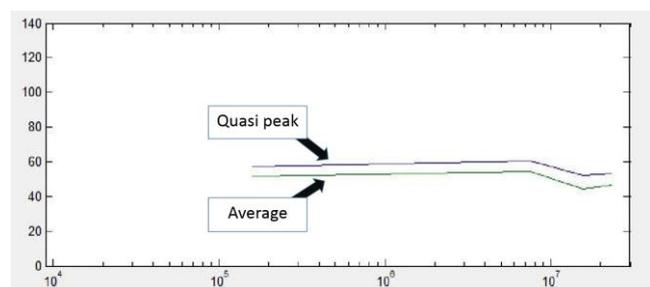


Fig. 4. Noises plotted from data

The flow chart of algorithm process is shown in Fig. 3. It starts with the noise measurement and brings value to put in user interface. The graph in Fig. 4 shows noises (4 points

presented in Table I) after putting their values in the user interface.

Then, we choose the standard and put value of capacitor and inductor. After that, the program will display the attenuation line and EMI estimated line after adding EMI filter. If margin is positive and more than minimum margin desired, the components can be used for reducing EMI noise.

The user interface contains 3 main parts as illustrated in Fig. 5. The part of standard selection is in part 1. The standard has two lines; quasi peak and average lines. The part 2 is data blank; they are blank for putting EMI data form measurement. In this part, five points can be put; it is sufficient for determining DM and CM cut-off frequencies. However, entering the minimum number of data is advantage because it is easy and fast. The main final part (part 3) is designing EMI filter part. In this section, the blank is allowed to put inductor and capacitor values. It is separated into two noise modes. Differential mode filter design must put L_D , $L_{leakage}$, and C_D . Then, algorithm will calculate DM cut-off frequency and show attenuation curve. Common mode filter design must put L_C , and C_C , then CM cut-off frequency will be calculated and show corresponding attenuation curve. In addition, user interface has list of CM and DM capacitors (C_Y , and C_X) existing in the market in order to ensure that the chosen value is able to be used for constructing real EMI filter. Finally, the reduced EMI is shown to visually compare with the standard. Moreover, for safety standard, the value of CM capacitor is recommended to not exceed 3.3 nF.

V. CONCLUSION

Passive EMI filters have been widespread use in the electromagnetic interference reduction. Filter design using cut-off frequency consideration is simple method, which is based on noises generated in the circuit. Some companies fabricating electrical/electronic devices/equipment do not have spectrum analyzer, so they must take product to testing center. The testing center will charge by the hour. Hence, this user interface can help to reduce design step, mistake in design and testing cost.

ACKNOWLEDGMENT

This work is financially supported by Faculty of Engineering, King Mongkut's Institute of Technology Ladkrabang (KMUTL), Thailand. The measurement of conducted electromagnetic interference is supported by the Electrical and Electronic Products Testing Center (PTEC), Bangkok, Thailand. The authors would like to thank for all supports.

REFERENCES

- [1] Shih, Fu-Yuan; Yie-Tone Chen; Yan-Pei Wu; Yie-Tone Chen, "A procedure for designing EMI filters for AC line applications," Power Electronics, IEEE Transactions on , vol.11, no.1, pp.170,181, Jan 1996.
- [2] Caponet, M.C.; Profumo, F.; Tenconi, A., "EMI filters design for power electronics," Power Electronics Specialists Conference, 2002. psc 02. 2002 IEEE 33rd Annual , vol.4, no., pp.2027,2032, 2002.
- [3] Hung-I Hsieh, "A procedure including mix-mode noise for designing EMI filters for off-line applications," Vehicle Power and Propulsion Conference, 2008. VPPC '08. IEEE , vol., no., pp.1,6, 3-5 Sept. 2008.
- [4] Raggl, K.; Nussbaumer, T.; Kolar, J.W., "Guideline for a Simplified Differential-Mode EMI Filter Design," Industrial Electronics, IEEE Transactions on , vol.57, no.3, pp.1031,1040, March 2010.

- [5] Drinovsky, J.; Zachar, J.; Kejik, Z.; Ruzek, V., "Impedance analysis of EMI filter circuitry used for estimation of the spurious components and boundings," Mixed Design of Integrated Circuits and Systems (MIXDES), 2011 Proceedings of the 18th International Conference , vol., no., pp.533,536, 16-18 June 2011.
- [6] Majid, A.; Saleem, J.; Bertilsson, K., "EMI filter design for high frequency power converters," Environment and Electrical Engineering (EEEIC), 2012 11th International Conference on , vol., no., pp.586,589, 18-25 May 2012.
- [7] Kotny, J.L.; Duquesne, T.; Idir, N., "Modeling and design of the EMI filter for DC-DC SiC-converter," Power Electronics, Electrical Drives, Automation and Motion (SPEEDAM), 2014 International Symposium on , vol., no., pp.1195,1200, 18-20 June 2014.
- [8] Fang Luo; Boroyevich, D.; Mattavelli, P., "Improving EMI filter design with in circuit impedance mismatching," Applied Power Electronics Conference and Exposition (APEC), 2012 Twenty-Seventh Annual IEEE , vol., no., pp.1652,1658, 5-9 Feb. 2012.
- [9] Kejik, Z.; Dřinovský, J.; Růžek, V., "Application optimization to search values of spurious elements of EMI filters," Mixed Design of Integrated Circuits and Systems (MIXDES), 2010 Proceedings of the 17th International Conference , vol., no., pp.505,509, 24-26 June 2010.
- [10] Tarateeraseth, V., "Effect of extra CX on EMI filter performances," Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology (ECTI-CON), 2012 9th International Conference on , vol., no., pp.1,4, 16-18 May 2012.
- [11] Saritsiri, K.; Khan-ngern, W., "Analysis of Conducted EMI Reduction on a Boost Converter Using Progressive Inductor Winding Technique," Power Electronics and Drive Systems, 2007. PEDS '07. 7th International Conference on , vol., no., pp.229,233, 27-30 Nov. 2007.

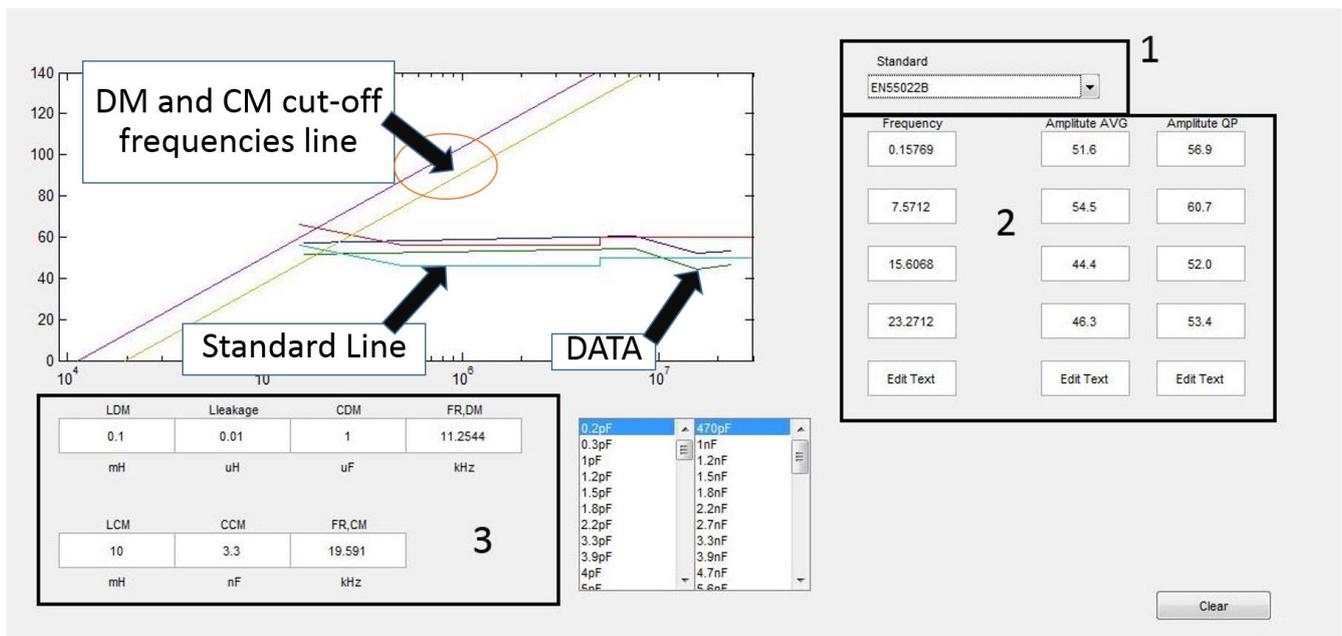


Fig. 5. User interface for passive EMI filter design