Measurement of Common-Mode and Differential-Mode Noise Source Impedances Using a Current Probe and Single Path LISNs

Jinlong Li, Shiping Ma, Xuebin Yin, Xiazhen Qin
EMC Laboratory, Fundamental Performance Test Center
Shanghai Institute of Measurement and Testing Technology
Shanghai, 200233, China
E-mail: lijl@simt.com.cn

***Abstract*—A measurement method of common-mode (CM) and differential-mode (DM) noise source impedances is presented and validated using a current probe and two single path LISNs. By this method, the noise source impedances and current amplitude of CM and DM conducted noises can be obtained simultaneously, without interrupting the normal operation of the equipment under test (EUT). The experiment results show that this method is quick and effective in noise source impedance measurement and suitable for electromagnetic conductive interference filter design.**

Keywords—common-mode (CM); differential-mode (DM); noise source impedance; electromagnetic interference; filter

I. INTRODUCTION

Conducted electromagnetic interference (EMI) test is a key test item in electromagnetic compatibility (EMC) test for electronic and electrical products. According to the relevant EMC test standards [1], the test frequency range is generally 150 kHz to 30 MHz. In automotive components test standards [2], the test frequency is extended to up to 108 MHz. In EMC design, the EMI filter is one of the effective means to suppress conducted EMI noise. In order to achieve the maximum attenuation of the EMI noise by the EMI filtering network, it is necessary to consider the matching of the noise source impedance and the load impedance so that the designed filter can achieve the maximum impedance mismatch [3]. On the other hand, different suppression methods are needed according to different common-mode (CM) noise and differential-mode (DM) noise transmission paths. Therefore, both CM and DM noise source impedances need to be extracted from the transmission path to provide an accurate reference for the design of EMI filters.

As a standard measurement equipment, line impedance stabilization networks (LISNs) specified by international standards [4] is only capable of measuring the mixed signals of CM and DM components, and cannot separately detect the specific components of CM and DM signals. At present, separation of conducted EMI noise modes is mainly achieved by a noise separation network [5-7] or a current probe [8]. The noise source impedance extraction methods mainly include insertion loss method [9], dual current probe method [10], single current probe method [11], and scattering parameter (S-parameter) method [12, 13]. These methods provide a relatively accurate measurement scheme for source impedance measurement, but the implementation of the measurement is complex and demanding.

In this work, a quick measurement method of CM and DM noise source impedances is presented and validated using a current probe and two single path LISNs. First, the test system configuration of CM and DM noise source impedances measurement is introduced. Then, the measurement method is theoretically analyzed. Finally, the results are experimentally verified.

II. TEST SYSTEM CONFIGURATION

A. Current definitions

Fig. 1 shows the definitions of CM and DM current during a conducted EMI test. In a conventional conducted emission test, two single path LISNs are inserted between the EUT and power grid by connecting them with two power supply wires, respectively. The equivalent circuit of LISNs in CM and DM signal paths is shown in Fig. 1. The R_p is the terminal resistance of the LISN measurement port. Usually, The R_p is equal to 50 ohms. The interference current generated by the EUT consists CM and DM components. DM currents flow between the two power supply wires, while CM currents take the two power supply wires as one single outgoing route and return via the ground wire or ground plane loop.

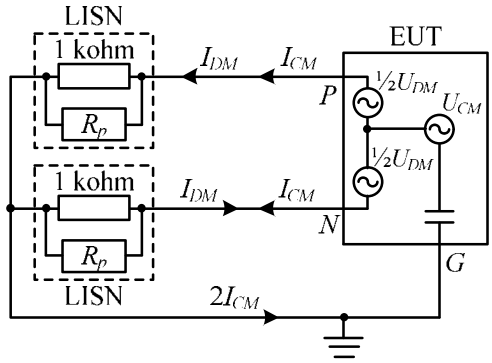

Fig. 1. Definitions of CM and DM current during a conducted EMI test

B. Measurement arrangement

The wire arrangements for CM and DM interference measurements are shown in Figure 2 and Figure 3 respectively. The conducted interferences are measured by a current probe. The output port of the current probe is connected to a measurement receiver. In the two power supply wires, the CM current flows in the same direction, while the DM current flows in the opposite direction. Therefore, the CM current is obtained by measuring the two wires simultaneously through the current probe in a parallel manner as shown in Fig. 2. The DM currents cancel each other out in the current probe. Therefore, the current measured by the current probe is twice the CM current amplitude of each wire (2 I_{CM}).

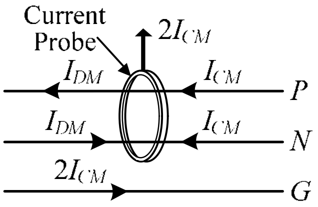

Fig. 2. Arrangement for the CM current measurement

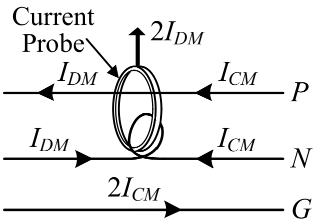

Fig. 3. Arrangement for the DM current measurement

Similarly, the DM current is obtained by wrapping one of the two wires around the probe before passing through the current probe as shown in Fig. 3. The CM currents now cancel each other out in the current probe. Therefore, the current measured by the current probe is twice the DM current amplitude of each wire (2 I_{DM}).

III. Theoretical Analysis

In the transmission circuit of the CM / DM signals, the impedance in the CM current path includes a parallel impedance of the two LISN impedances (approximately 0.5 R_p) and a CM source impedance Z_{SCM}. The impedance in the DM current path includes a series impedance of the two LISN impedances (approximately 2 R_p) and a DM source impedance Z_{SDM}. Hence, the CM and DM currents in the transmission circuit can be expressed respectively as follows

$$2I_{CM} = \frac{U_{CM}}{\frac{1000R_P}{2(1000+R_P)} + Z_{SCM}} \tag{1}$$

$$I_{DM} = \frac{U_{DM}}{\frac{2000R_P}{1000+R_P} + Z_{SDM}} \tag{2}$$

where U_{CM} and U_{DM} are the equivalent CM and DM voltages generated by the EUT.

In order to obtain Z_{SCM} and Z_{SDM}, we assume that R_p is equal to 0 ohm and 50 ohm, respectively. That is, the measurement ports of the single path LISNs are terminated by shorted terminations and 50 ohm terminations, respectively. For simplicity, Z_{SCM} and Z_{SDM} are expressed in absolute values during analyses. Substituting the two R_p values into Equation (1) and (2) to solve the equations, $|Z_{SCM}|$ and $|Z_{SDM}|$ can be expressed approximately as

$$|Z_{SCM}| \approx \left| \frac{25I_{CM50}}{I_{CM0} - I_{CM50}} \right| \tag{3}$$

$$|Z_{SDM}| \approx \left| \frac{100I_{DM50}}{I_{DM0} - I_{DM50}} \right| \tag{4}$$

where I_{CM0} and I_{DM0} are the CM current amplitude and the DM current amplitude respectively, when R_p = 0 ohm. I_{CM50} and I_{DM50} are the CM current amplitude and the DM current amplitude respectively, when R_p = 50 ohm. It can be seen that we only need to measure two sets of CM or DM current amplitude data with two different R_p values, then we can get the corresponding $|Z_{SCM}|$ and $|Z_{SDM}|$.

IV. Experimental Results

In the calculation during the entire theoretical analysis, we ignore the influence of parasitic parameters. In order to minimize parasitic parameters, we use wire harness as short and as far away from each other as possible during the measurement test implementation. The test herein refers to the test arrangement of CISPR 25 [2]. The length of the wire harnesses between the LISNs and the EUT is about 20 cm. The wire harnesses and EUT are placed on a non-conductive, low relative permittivity material ($\varepsilon_r \leq 1.4$) about 5 cm above the reference ground plane.

A. CM Noise Source Impedances

The CM current amplitude is measured using the arrangement shown in Fig. 2. Fig. 4 shows the measurement spectrum of CM current amplitude (2 I_{CM}). The measured current amplitude is twice the amplitude of the CM current.

When the measurement ports of both LISNs are terminated by two shorted terminations, i.e. R_p = 0 ohm, the measured CM current amplitude (2 I_{CM0}) spectrum is shown in Fig. 4 (a). When the measurement ports of both LISNs are terminated by two 50 ohm terminations, i.e. R_p = 50 ohm, the measured CM current amplitude (2 I_{CM50}) spectrum is shown in Fig. 4 (b). It can be seen that the measured current amplitude 2 I_{CM50} is significantly reduced in some frequency bands.

Based on the measured CM current amplitude data shown in Fig. 4, we convert the unit of the current amplitude level form dBμA to A. By excluding the background noise data, only peak values in Fig. 4 are used in calculation. On the other hand, it's important to note that if I_{CM0} and I_{CM50} are close to each other for peak part in the graphic, the denominators $|I_{CM0} - I_{CM50}|$ will be a small value causing a abrupt amplitude step in the impedance. Moreover, impedance is usually continuous. As a result, the anomalous signals mentioned above are eliminated through software algorithm. Substituting the optimized measured I_{CM0} and I_{CM50} into Equation (3), the spectrum of the CM noise source impedance is shown by the solid line in Fig. 5. The dotted line represents the measurement results obtained by the S-parameter method. The comparison results show that the results of the two measurement methods are in good agreement, which proves that the measurement method of this paper is valid.

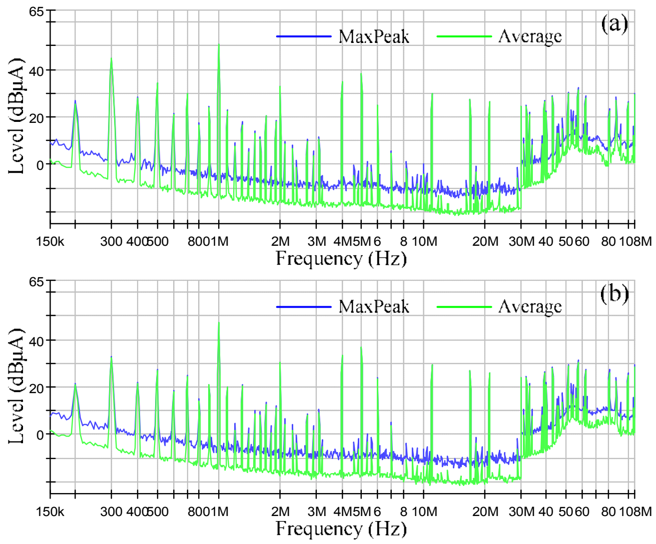

Fig. 4. Measurement spectrum of CM current amplitude (2 I_{CM})

As can be seen from Fig. 5, at frequency range from about 18 MHz to 40 MHz, the test results obtained by the two measurement methods have relatively large difference in amplitude. But this difference does not affect the qualitative judgment of the CM noise source impedances in the EMI filter design. A very similar CM noise source impedance value is obtained using two measurement methods at the frequency ranges from 150 kHz to 18 MHz, 40 MHz to 50 MHz and from 90 MHz to 100MHz, respectively.

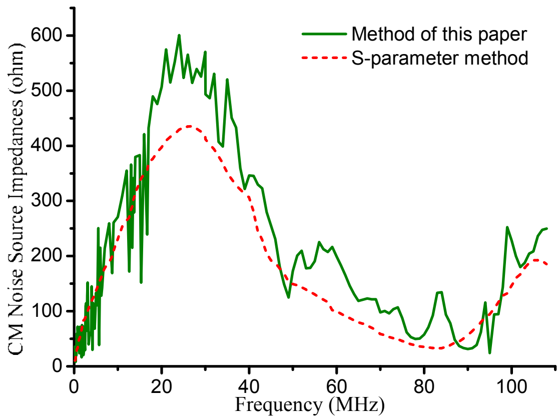

Fig. 5. Measured CM noise source impedances ($|Z_{SCM}|$)

B. DM Noise Source Impedances

Similar to the CM noise source impedance measurement procedure, the DM current amplitude is measured using the arrangement shown in Fig. 3. Fig. 6 shows the measurement spectrum of DM current amplitude (2 I_{DM}). The measured current amplitude is twice the amplitude of the DM current.

When the measurement ports of both LISNs are terminated by two shorted terminations, i.e. R_p = 0 ohm, the measured DM current amplitude (2 I_{DM0}) spectrum is shown in Fig. 6 (a). When the measurement ports of both LISNs are terminated by two 50 ohm terminations, i.e. R_p = 50 ohm, the measured DM current amplitude (2 I_{DM50}) spectrum is shown in Fig. 6 (b). It can be seen that the current amplitude 2 I_{DM50} is also significantly reduced in some frequency bands.

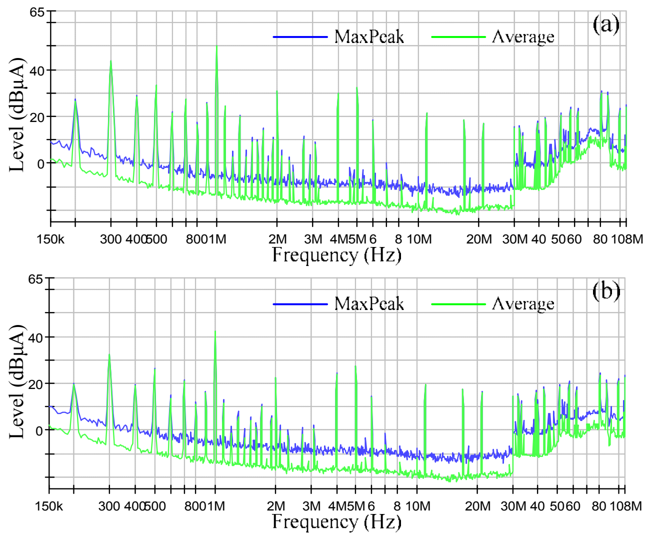

Fig. 6. Measurement spectrum of DM current amplitude (2 I_{DM})

Based on the measured DM current amplitude data shown in Fig. 6, we also convert the unit of the current amplitude level from dBµA to A. By excluding the background noise data, only the peak values in Fig. 6 are used in calculation. These anomalous signals where I_{DM0} and I_{DM50} are close to each other for peak part in the graphic, causing a abrupt amplitude step in the impedance, are eliminated through software algorithm to make the impedance continuous.

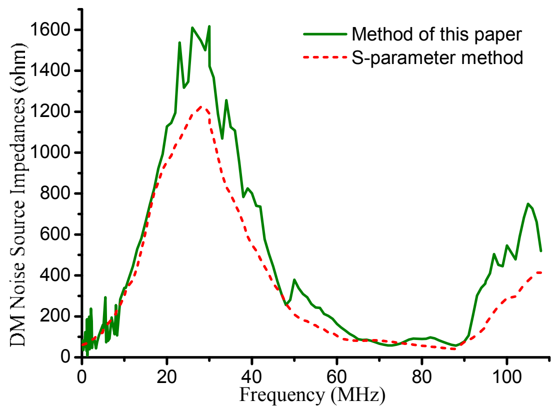

Fig. 7. Measured DM noise source impedances ($|Z_{SDM}|$)

Substituting the optimized measured I_{DM0} and I_{DM50} into Equation (4), the spectrum of the DM noise source impedance is shown by the solid line in Fig. 7. The dotted line represents the measurement results obtained by the S-parameter method. The comparison results show that the results of the two measurement methods are in good agreement, which proves that the measurement method of this paper is valid.

At frequency range from about 20 MHz to 35 MHz, the test results obtained by the two measurement methods have relatively large difference in amplitude. But this difference does not affect the qualitative judgment of the DM noise source impedances in the EMI filter design. At the frequency ranges from 150 kHz to 20 MHz and from 35 MHz to 90MHz, it is very similar of these measurement results using two measurement methods.

In Fig. 5 and Fig. 7, the large fluctuations in the measurement result curves are caused by the influence of parasitic parameters such as the wire harness and the instability of the conducted emission noise with time. In practice, we can take multiple measurements to average the results in order to optimize the measurement results. In addition, we can separately measure the CM and DM noise source impedances in these frequency bands or frequency points, where the measured level in conducted emission test is beyond the limit requirements. This is sufficient to improve the EMI filter design of the EUT when seeking to pass the conducted emission test.

For direct, we can measure the amount of change in the current amplitude at the frequency band with high level EMI emission noise, providing that the measurement ports of both single path LISNs are simultaneously terminated first by shorted terminations and then by 50 ohm terminations. The noise source impedance can be considered to be low impedance when this current amplitude changes significantly. Similarly, the noise source impedance can be considered to be high impedance when this current amplitude change is small. More importantly, with the measurement method described herein, since the measurement arrangement is based on a normal conducted emission test setup itself, the entire measurement process requires very little time and no additional test equipments. Therefore, it is very quick, convenient and efficient.

V. CONCLUSION

In a nutshell, a quick measurement method of CM and DM noise source impedances is presented and validated using a current probe and two single path LISNs. The separation of the CM and DM noise components is based on measuring the wire harness with different routing manners through a current probe. Two sets measurement data of CM / DM current amplitude are obtained by using the single path LISNs with different terminations on their measurement ports, and the CM / DM noise source impedances are further calculated. The experiment results show that the measurement results using the method of this paper are consistent with the results measured by the S-parameter method. The measurement system can be adopted to get the noise source impedances and current amplitude of CM / DM conducted noises at the same time, without adding an extra analog circuitry that can limit the bandwidth. The CM / DM noise source impedance measurement results can be used in the EMI filter circuit design for the EUT in conducted emission testing. What's more, for EUTs with more than two wires, the method of this paper can be extended by using a current loop and a corresponding number of single path LISNs. These LISNs may also be matching signal wire artificial networks when the measured wires are signal wires.

ACKNOWLEDGMENT

The author would like to thank the support of the Secretariat of Subcommittee 1 on High Frequency Phenomena of National Technical Committee 246 on Electromagnetic Compatibility of Standardization Administration of China.

REFERENCES

[1] CISPR 16-2-1: 2017-06, Specification for radio disturbance and immunity measuring apparatus and methods – Part 2-1: Methods of measurement of disturbances and immunity – Conducted disturbance measurements.

[2] CISPR 25: 2016-10, Vehicles, boats and internal combustion engines - Radio disturbance characteristics - Limits and methods of measurement for the protection of on-board receivers.

[3] A. Pérez, A. Sánchez, J. Regué, M. Ribó, P. Rodríguez-Cepeda and F. Pajares, "Characterization of Power-Line Filters and Electronic Equipment for Prediction of Conducted Emissions," IEEE Trans. on Electromagnetic Compatibility, vol. 50, pp. 577-585, August 2008.

[4] CISPR 16-1-2: 2017-11, Specification for radio disturbance and immunity measuring apparatus and methods – Part 1-2: Radio disturbance and immunity measuring apparatus – Coupling devices for conducted disturbance measurements.

[5] C. Paul and K. Hardin, "Diagnosis and reduction of conducted noise emissions," IEEE Trans. on Electromagnetic Compatibility, vol. 30, pp. 553-560, November 1988.

[6] K. See, "Network for conducted EMI diagnosis," Electronics Letters, vol. 35, pp. 1446-1447, August 1999.

[7] T. Guo, D. Chen and F. Lee, "Separation of the common-mode- and differential-mode-conducted EMI noise," IEEE Trans. on Power Electronics, vol. 11, pp. 480-488, May 1996.

[8] Q. Feng, C. Liao and X. Xiong, "A Novel Measurement System for the Common-Mode- and Differential-Mode-Conducted Electromagnetic Interference," Progress in Electromagnetics Research Letters, vol. 48, pp. 75-81, August 2014.

[9] D. Zhang, D. Chen, M. Nave and D. Sable, "Measurement of noise source impedance of off-line converters," IEEE Trans. on Power Electronics, vol. 15, pp. 820-825, September 2000.

[10] K. See and J. Deng, "Measurement of noise source impedance of SMPS using a two probes approach," IEEE Trans. on Power Electronics, vol. 19, pp. 862-868, May 2004.

[11] X. Qiu, Y. Zhao, K. See and X. Shen, "An Efficient Noise Source Impedance Estimation Approach Applied in Electromagnetic Compatibility," Chinese Journal of Electronics, vol. 18, pp. 744-748, October 2009.

[12] Y. Zhao, X. Lu, Y. Dong, Y. Luo, W. Yan and R. Rong, "Study on impedance extraction methods applied in conductive EMI source modeling," 2010 Asia-Pacific Int. Symp. on Electromagnetic Compatibility, pp. 998-1001, Beijing, China, April 2010.

[13] V. Tarateeraseth, B. Hu, K. See and F. Canavero, "Accurate extraction of noise source impedance of an SMPS under operating conditions," IEEE Trans. on Power Electronics, vol. 25, pp. 111-117, January 2010.

