Small Loop Antenna for EMI Controlled and Monitoring

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Abstract: This paper presents conducted emission noise measurement from electronic equipment in frequency range of 1 MHz up to 30 MHz by small loop antenna. Small loop antenna measurement method can measure common-mode (CM) and differential-mode (DM) component of the noise on a pair of power line at the same time. The CM and DM can be measured separately. The theory of this measurement method is introduced and analyzed. The measured results were compared with the conventional measurement by Line Impedance Stabilization Network (LISN) and result a good trend between those methods.

Keyword: Small Loop Antenna, common mode, differential mode, conducted EMI emission, Hybrid junction

1. Introduction

Recently, the introduction of the power line communication (PLC) system has been discussed eagerly in many countries. There are two controversial problems concerning the PLC, that is, the interference with existing radio stations caused by the PLC common mode current, and immunity of the PLC to the difference- mode disturbances produced by tremendous numbers of house hold appliances connects to the power- lines [1].

With respect to conducted disturbance on power-line cables at frequency from 0.15 to 30 MHz, the CISPR sets forth the limits and the measurement methods for the main terminal voltage as specified in the standard CISPR 22 [2].

There is a problem for conducted emission measurement on power lines of electrical and communication equipments that the noise measurement cannot separate the common mode (CM) and differential mode (DM) noise. The conventional measurement need to use the LISN. This method can measure the total noise only. For this reason, a new measurement method by small loop antenna [3] is developed by Research Institute of Electrical Communication, Tohoku University; Sendai, Japan to measure the conducted EMI on the power lines instead of the LISN. The CM and DM can be measured separately and at the same time.

The EMI measurement has been investigate and analyzed by step of transformation.

2. Theory

The noise current composes of common mode and differential mode noise. The noise current in power line 1 and power line 2 are equal to i_1 and i as shown in Eqs. 1 and 2 respectively.

$$i_1 = \frac{i_C}{2} + i_d \tag{1}$$

$$i_2 = \frac{i_C}{2} - i_d \tag{2}$$

The common mode current is defined by

$$i_C = i_1 + i_2 \tag{3}$$

The differential mode current is defined by

$$i_1 - i_2 = 2 i_d \tag{4}$$

$$i_d = \frac{i_1 - i_2}{2} \tag{5}$$

i_1 and i will be transferred to I_1 and I_2 by radiated induction process through the antennas which have the transfer coefficient F .

Common mode current noise is defined below

$$i_C = i_1 + i_2 = \frac{V_1 - V_2}{F_i} = \frac{V_C}{F_i} \tag{6}$$

where,

$$F_i = \frac{F_{i1} + F_{i2}}{2} \tag{7}$$

Differential mode current is defined below

$$i_d = \frac{1}{2}(i_1 + i_2) = \frac{1}{2}\left(\frac{V_1 + V_2}{F_S}\right) = \frac{1}{2}\left(\frac{V_d}{F_S}\right) \tag{8}$$

where,

$$F_S = \frac{F_{S1} + F_{S2}}{2} \tag{9}$$

The conventional differential mode and common mode voltage noise [4] as shown in Eqs. (10) and (11).

$$V_{CM} = I_C Z_{CP} \tag{10}$$

$$V_{DM} = I_d Z_{EUT} \tag{11}$$

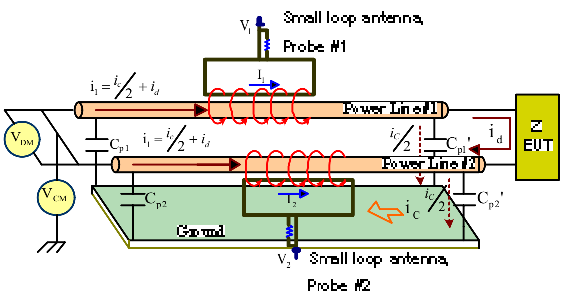


Figure 1: Concept of common mode and differential mode measurement.

Eq. 6 substitutes to Eq. 10 to determine the relative of common mode voltage.

$$V_{CM} = \frac{V_C}{F_i} Z_{CP} \tag{12}$$

Eq. 12 shows the directly proportional relation between V_C and V_{CM} as shown

$$V_{CM} \quad V_C$$

In the same concept, the differential mode voltage is equals to Eq.   which is substituted to Eq. (11).

$$V_{DM} = \frac{1}{2}\left(\frac{V_d}{F_S}\right) Z_{EUT} \tag{13}$$

Eq. (13) shows the directly proportional relation between V_d and V_{DM} as follows:

$$V_{DM} \quad V_d$$

V_{DM} and V_{CM} get from measurement by the LISN.
V_d and V_C get from measurement by the small loop antenna.

when,
i_1: current flows on power line 1 follow figure 1
i_2: current flows on power line 2 follow figure 1
I_1: current signal is induced by i_1
V_1: voltage signal transfer from I_1
I_2: current signal is induced by i_2
V_2: voltage signal transfer from I_2
I_C: common mode current
V_C: common mode voltage gets from I_C
I_d: differential mode current
V_d: differential mode voltage gets from I_1
V_{DM}: differential mode voltage
V_{CM}: common mode voltage
C_{p1}, C_{p2}, C_{pl} , C_{p2} : parasitic capacitor between power line 1, 2 and ground
Z_{EUT}: impedance of equipment under test (EUT)
Z_{CP}: total impedance of parasitic capacitor
F_S: transfer coefficient of the antenna
F_i: transfer coefficient of the antenna

3. Measurement

The conducted EMI emission measurement using the LISN suggested by CISPR 16-2 [5] is shown in fig (2) and the conducted EMI emission measurement using the small loop antenna is shown in fig. (3). The detail of LISN is shown in fig. (4). In this case, equipment under test (EUT) is the inverter, where output signal is sent to EMI receiver to monitor. The detail of EMI receiver is shown in fig (5). The hybrid junction for isolation or summation the noise is shown in fig. (6).

EUT for experimental is the switching-mode dc-to-ac inverter that is used in ac motor drives and uninterruptible ac power supplies where the objective is to produce a sinusoidal ac output whose magnitude and frequency can both be controlled. Inverter picture is shown in fig. (7).

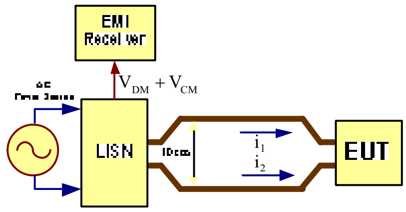


Figure 2: The structure of conducted EMI measurement by LISN.

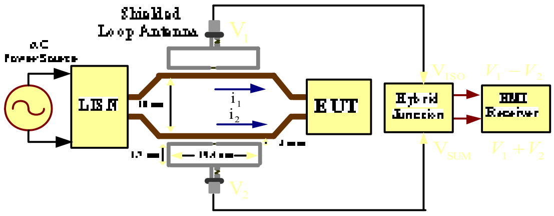


Figure 3 : The structure of conducted EMI measurement by small loop antenna.

Figure 4: LISN EMCO model 3810/2

LISN Specifications
Network Inductance Impedance 50Ω, 50/250 H
Frequency Range: 9 kHz to 30 MHz
Continuous Current Rating: 10 A

Figure 5: EMI receiver

Agilent model E7401A 9 kHz-1.5 GHz

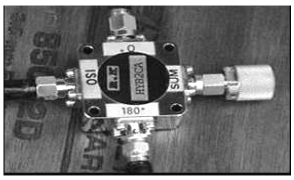


Figure 6 : Hybrid junction for isolation or summation the noise.

Hybrid unction Specifications
Frequency Range 0.1MHz   150 MHz
Maximum RF Input Power 1W
Impedance 50 Ohms
Connectors BNC

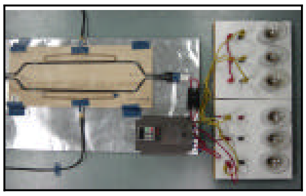


Figure 7: The experimental of conducted EMI measurement by small loop antenna

Inverter Specifications
Operating Frequency: 50 Hz
Switching Frequency: 16 KHz
Current Rating: 0.7 A
Power: 600 Watt
Load: R load

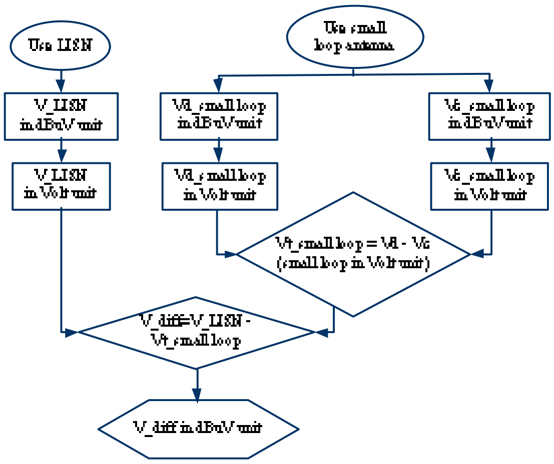
The new proposed method for conducted EMI measuring setup is shown in fig. (3) and the experimental of conducted EMI measurement by small loop antenna is shown in fig. (7). It consists of two small loop antennas attached closed to power lines. As the currents (i_1, i_2) flow through the line1 and line2 which induced the magnetic field to the loops then they cause current (I_1, I_2). These currents pass through the loop impedance. After that they are transformed to be the voltage signals (V_1, V_2). These signals are fed to 0 and 180 degrees hybrid junction respectively for summation or isolation then sent the signal to EMI receiver for display. The hybrid junction is shown in fig. (6). Finally, these signals are transformed to i_d, i_c by Eqs. (1)-(5) respectively.

4. Experimental results

The step of transformation the unit is shown in fig. (8). The step composes of two paths. The one path is using LISN while another path is using small loop antenna. The first paths, total noises (V LISN) are measured by the LISN in dBuV unit to make the comparison. The second path, noises are measured by small loop antenna which compose of two paths. There are differential mode voltage (Vd small loop antenna) and common mode voltage (Vc small loop antenna) in dBuV unit. Then they are also transformed in volt unit. They will be combined to total voltage noise (Vt small loop antenna). These values will be compared with V LISN. Finally, this result will be transformed in dBuV unit.

The small loop antenna can measure the common-mode (CM) and differential-mode (DM) component of the total noise on a pair of power line which can be measured separately and are shown in fig. (9). The trends of noise level of Vc small loop antenna are higher than Vd small loop antenna such as at frequency range 17MHz Vc small loop noise equals to 36.4dBuV and Vd small loop noise equals to 17.8dBuV. In fig. (9), the lowest noise line is noise floor of small loop antenna during no EUT. The comparison of measured result of using LISN and the antenna are shown in fig. (10). The Vt small loop antenna is generated by step of transformation is shown in fig. (8).

The trend of noises from measurement by small loop antenna (Vt small loop antenna) is a good trend to the LISN (V LISN) at frequency range 17 MHz to 30 MHz. There are differential of noises level from measurement between of LISN and small loop antenna are shown on fig. (11). The antenna factor is not focused on this studied. Then the comparison shows a large margin. The differential level has uppermost level at about 70 dBuV and lowest level at -30 dBuV.



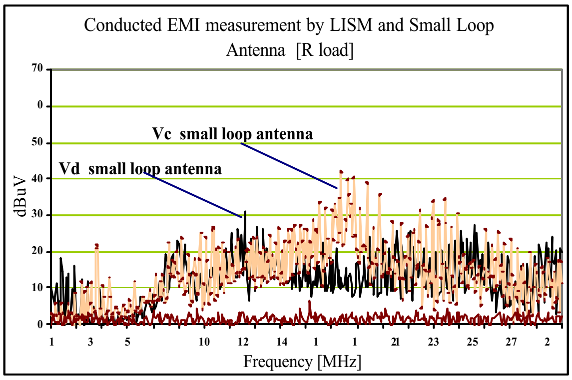


Figure 9: Measured result of CM and DM noise by small loop antenna.

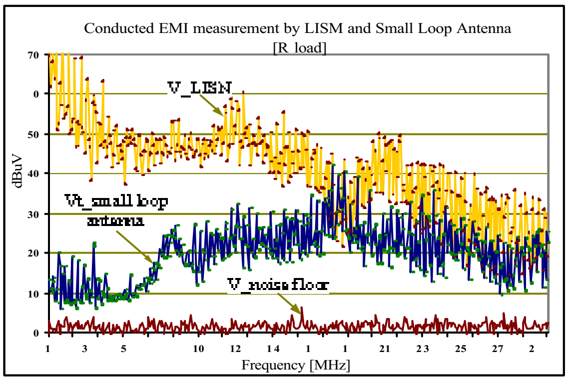


Figure 10: Comparison of voltage noise between using the LISN and small loop antenna.

when,
Vt small loop antenna: Total voltage noise from measurement by small loop antenna.
V LISN: Total voltage noise from the measurement by LISN.
Vd small loop antenna: Differential mode voltage noise from the measurement by small loop antenna.
Vc small loop antenna: Common mode voltage noise from the measurement by small loop antenna.

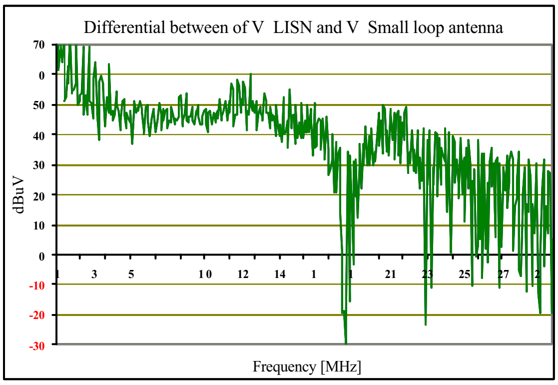


Figure 11 : Differential result between total voltage noise measurement by LISN and the small loop antenna.

5. Analysis

The trends of common mode (CM) and differential mode (DM) noise from measurement by small loop antenna that is investigated by theory and the experiment. At frequency range 8 MHz to 30 MHz, the CM noise level is equals to 10 - 40 dBuV and DM noise is equals to 10 30 dBuV. These results are transformed to V_d, V_c by Eqs. (6)-(13) respectively. The common mode voltage (V_{CM}) dependent on F_i, V_c, and Z_{CP}. The differential mode voltage (V_{DM}) dependent on F_S, V_d, and Z_{EUT} which are shown in Eqs. (6)-(13).

The measured results of small loop antenna are different in measured results of LISN . However, the trend of conducted EMI is quite good agreement which a good trend at frequency range grater than 17 MHz. The output difference may be caused by many parameters such as the loop type, loop shape, signal strength, the distance between the power line and small loop antenna and antenna factor. Then, the solution for small loop antenna should be laid closed to the power line or should be designed of optimum loop shape for sensor effectively and should be added amplifier for increasing the signal strength. At frequency range 1 MHz to 30 MHz must be improved by redesign the antenna size.

. Conclusion

The new method the conducted EMI measurement by small loop antenna is presented and compared with the conventional LISN. The trend of measured result is quite good agreement to the conventional method by LISN at frequency range the 17 MHz to 30 MHz. The measurement method can measure separately the common mode and differential mode component of noises on a pair of power lines at the same time. The good calibration is also needed.

7. Future work

There is a need for improvement in accurate measuring result of small loop antenna to cover at frequency range 1 MHz to 30 MHz The error signal should be compensated by adding the amplifier. It should be found that the suitable gab of length between the loop antennas and power line which have the effects of parasitic capacitance is one of the key factor.

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