TWO TYPES OF THE LCL PROBE FOR MEASURING LCL ON THE POWER LINES

Yuji Ando, Akio Konemori, Naoto Oka
Mitsubishi Electric Corporation, Information Technology R&D Center, EMC Technology Center
5-1-1 Ofuna, Kamakura, Kanagawa 247-8501, JAPAN

Abstract: In order to measure the longitudinal conversion loss (LCL) on power lines, we assembled LCL probes and evaluated their performances of LCL measurement. We confirmed that the performance of LCL probes was improved by putting together different types of transformers. And LCL measurement on the artificial power lines was performed using these LCL probes. In case of power lines which had LCL of below 50 dB, we confirmed that the LCL probes in this paper were useful for the LCL measurement at the frequency range 2 to 30 MHz.

Key words: Power Line Communication, Longitudinal Conversion Loss, LCL probe, Electrical Unbalance

1. Introduction

High-speed power line communication (PLC) applies multiplexing modulation technology and various modulation technologies, and can make the access rate of dozens Mbps using the frequency range of 2-30 MHz. The field trials for practical use of PLC have already been performed in Europe and U.S.A. But in Japan, the field trials have not been performed because of insufficiency of investigation for radiated emission from PLC. In order to study and reduce radiated emission from PLC, LCL is evaluated as electrical unbalance of power-lines.

For LCL measurement of balanced network, an LCL probe was reported [1]. And, the study of influence of transformers in a LCL probe on measurement dynamic range was reported [2].

However, the commercial LCL probes are not available now. It is necessary to assemble LCL probes in order to measure LCL on power-lines. In this paper, we assembled two types of LCL probes and evaluated their performances of LCL measurement based on the references [1,2]. Moreover, we located the artificial power-lines in the EMI-anechoic chamber. And we measured the LCL of the lines using these LCL probes.

2. Assembling of LCL probes

The circuit schematic of the LCL probe is shown in Fig. 1[1]. T1 and T3 are the transformers in order to reject differential mode signal (the differential mode choke), and T2 and T4 are the transformers in order to reject common mode signal (the common mode choke). C1 and C2 are the capacitors that isolate measurement systems from AC mains voltage, and these capacitances are 470 nF in this study.

For LCL measurement, voltage (El) is applied to the input port "IN", and the voltage is transferred to the balanced test port (c, d) as the common mode voltage. When the device under test connected to the balanced test ports (c, d), differential mode voltage (Vt) appears among terminals of the balanced test ports (c, d) corresponding to electrical unbalance of the device. The LCL shows the electrical unbalance and is it calculated by the equation (1).

$$LCL = 20\log_{10}\left|\frac{El}{Vt}\right| = 20\log_{10}\left|\frac{El}{2Vp}\right| \quad [dB]\ldots(1)$$

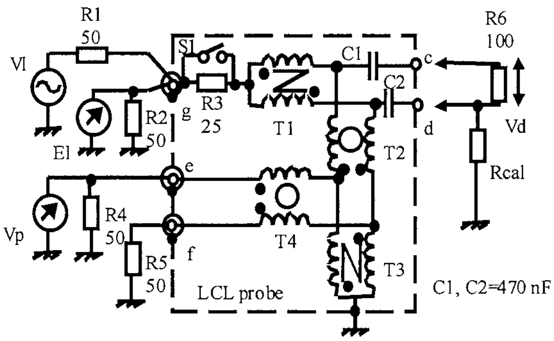

Fig.1 Schematic of LCL Probe and LCL measurement

The toroidal cores were used for the transformers of T1 to T4, and they were winded with twisted pair lines. The details of the transformers are shown in Table 1, the inductance characteristics of the transformers are shown in Fig. 2, and the impedance characteristics are shown in Fig. 3.

Some combinations of the transformers in the LCL probe were examined with frequency range from 100 kHz to 100 MHz, and the calibration results were reported [2].

Table 1 Transformers Detail

	Core size [mm]	N [turns]
Trans. (a)	14.3×3.2×6.5	10
Trans. (b)	14.3×3.3×6.4	10

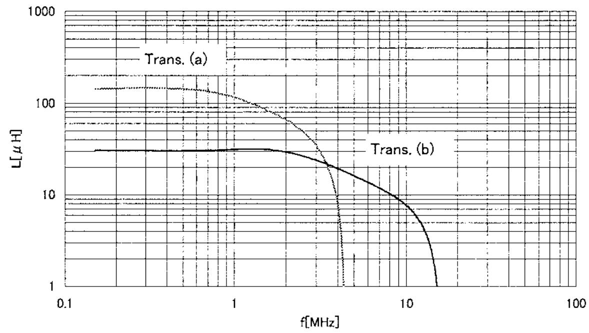

Fig.2 Inductance of Transformers

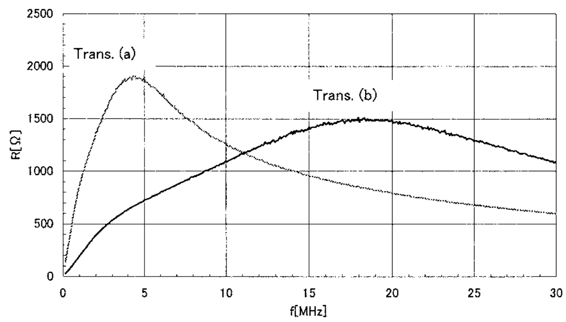

Fig.3 Impedance of Transformers

In this study, the LCL probes were assembled for the purpose of covering the frequency range from 2 - 30 MHz. This frequency range is used for PLC communication. The combinations of the transformers used to the LCL probes in this paper are shown in Table 2. Probe (1) has only the transformers (b). The transformer (b) has lower inductance and impedance than those of transformer (a) below the frequency about 3.5 MHz and 11 MHz. But it has higher inductance and impedance than those of transformer (a) over the frequency between 3.5 MHz and 11 MHz, respectively. Probe (2) has two transformers (a) for the transformers of T1 and T2, and has two transformers (b) for the transformers of T3 and T4.

Table 2 Combinations of transformers

	T1	T2	T3	T4
Probe(1)	Trans. (b)	Trans. (b)	Trans. (b)	Trans. (b)
Probe(2)	Trans. (a)	Trans. (a)	Trans. (b)	Trans. (b)

3. Evaluation of LCL probes

These LCL probes were evaluated by using the calibration method described by reference [1]. This evaluation method of LCL probes is shown in Fig. 4. For the differential mode impedance, R6, it was the resistor of 100 ohms, was set to the balanced test ports (c, d) of the LCL probe. Rcal was set to open, 470 ohm and short, in order to obtain known values of LCL at the test port. Then LCL was measured using a network analyzer at the conditions.

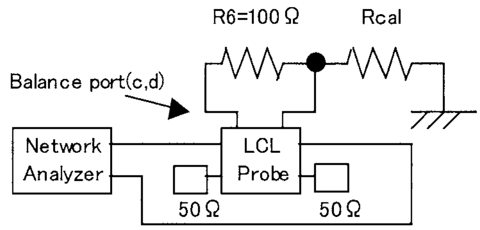

Fig.4 Evaluation method of LCL probe

The equation, which calculates LCL from Fig. 1 and Fig. 4, is shown in equation (2). [1] (The capacitors C1 and C2 are not taken into consideration.)

$$LCL = 20\log_{10}\left|\frac{El}{Vt}\right|$$

$$= 20\log_{10}\left|\frac{[R6//(R4+R5)]+4Rcal+4R3}{2[R6//(R4+R5)]}\right|[dB]\ldots(2)$$

The measurement results by using the evaluation method of Fig. 4 and calculation results are shown in Fig. 5-1 and 5-2. The results of LCL probe (1) are shown in Fig. 5-1.
In the case of LCL probe (1), the maximum value of LCL at the Rcal set "open " was about 70 dB. And, at the Rcal is 470 ohm and "short", the LCL values in the lower frequency range were different from the theoretical values.

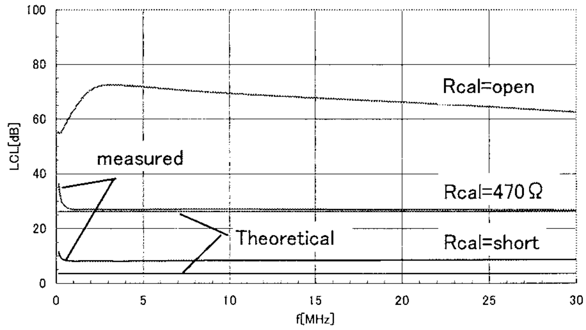

Fig.5-1 Measurement result of LCL in Fig.4 at LCL Probe(1)

Next, the improvement of dynamic range of the Probe (1) was tried at the frequency range on target. All of transformers of the probe (1) are the transformer (b). In the reference [2], the dynamic range of LCL probes was improved by setting inductance of T1 and T2 higher than the inductance of T3 and T4. Then for the probe (2), transformers (a) are used to the transformers as T1 and T2.
The evaluation results of LCL probe (2) are shown in Fig. 5-2.

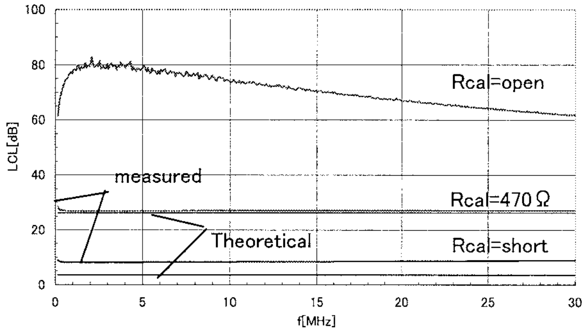

Fig.5-2 Measurement result of LCL in Fig.4 at LCL Probe(2)

In the case of LCL probe (2), the maximum value of LCL at the Rcal set "open" was about 80 dB. And, at the Rcal is 470 ohm and "short", the LCL values in the lower frequency range were improved considering the theoretical values as reference. The results of the Probe (2) are better than those of the Probe (1) in lower frequency range. And, the dynamic range of the Probe (2) was improved.

4. The LCL Measurement on the artificial power-lines

The cross-section drawing of artificial power-lines are shown in Fig. 6-1. These power-lines were located in the EMI-anechoic chamber and we measured LCL on the line by using probes (1) and (2). The measurement layout is shown in Fig. 6-2. The artificial power-line was stretched horizontally by length of 10 m, and the height from the chamber's ground plane was 0.3 m. In order to reject the influence of vertical part of the wires, ground of the LCL probe and the receiving end of the wire were put on vertical ground planes. The vertical ground planes were connected to the chamber's ground plane. The termination of receiver side was configured as T type resistor network. In this case, LCL value of the resistor network was calculated by the equation (3) [1]. The LCL of the termination was changed with the value of resistors Za, Zb and Zc. The LCL of the resistor network is shown in Table 3.

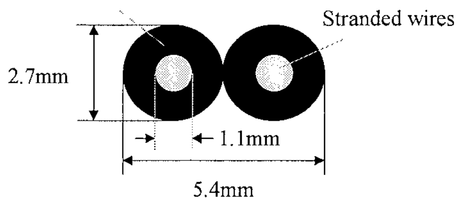

Fig.6-1 Cross-section drawing of artificial power-lines

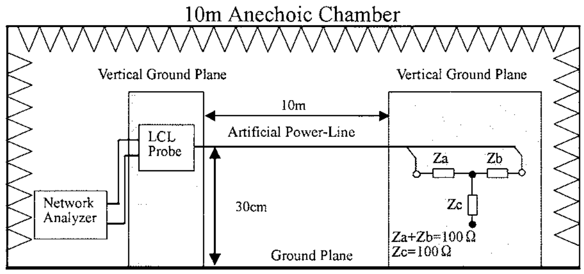

Fig.6-2 LCL Measurement on the artificial power-lines

$$LCL = 20\log\left|\frac{2Zo + 4Zc}{|Za - Zb|} - \frac{|Za - Zb|}{2Zo}\right|[dB]\ldots(3)$$

Zo=100 [Ω]

Table 3. Calculated LCL of the resistor network in Fig.6

Za[Ω]	Zb[Ω]	Zc[Ω]	LCL[dB]
51	51	100	Infinity
47	56	100	36.6
33	68	100	24.6
15	82	100	18.6

5. Results

The measurement results of LCL on artificial power lines are shown in Fig. 7-1 and 7-2. These results show followings.

1) The measurement results and the calculation results were in agreement in order. And, the rate of change of the measurement results and that of the calculation results were almost equal.
2) The maximum LCL value measured by the probe (1) was 63 dB, and that measured by the probe (2) was 67 dB; at the frequency range of 2 - 30 MHz.

3) When the probe (1) was used, or when the probe (2) was used, the measured LCL values on unbalance condition of the termination were almost equal.
4) It was considered that the measurement results of LCL contained influence of impedance of the power line.

If the probe (1) is compared with the probe (2), the measurement limit of LCL of the probe (2) is higher than the probe (1), so the probe (2) measures higher LCL values than the probe (1). Especially at the condition of high values of LCL (Za=Zb=51 ohm, in this case), the probe (2) showed higher values of LCL than the probe (1).
Moreover, at the condition that LCL was from 20 to 50 dB, ((Za,Zb)=(47 ohm, 56 ohm), (33 ohm, 68 ohm) and (15 ohm, 82 ohm),in this case), measured LCL values which used the probe (1), and the result which used the probe (2) were almost equal.
As mentioned above, when measuring power lines with LCL less than 50 dB, both the probe (1) and (2) were seemed to be appropriate to measure LCL. But in measuring of balancing lines, the probe (2) was preferable to measure them. Moreover, the power lines measured in this paper had attained LCL over 40 dB, when it configured as Za=Zb=51 ohm in the case, and it was checked that these power lines were thought as the sufficiently high degree of balancing. This showed the validity as artificial power lines.

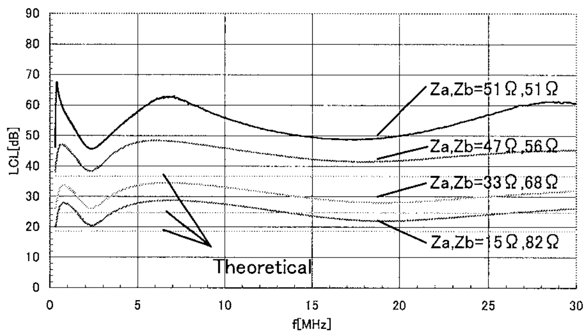

Fig.7-1 Measured LCL on the artificial power-lines by using Probe (1).

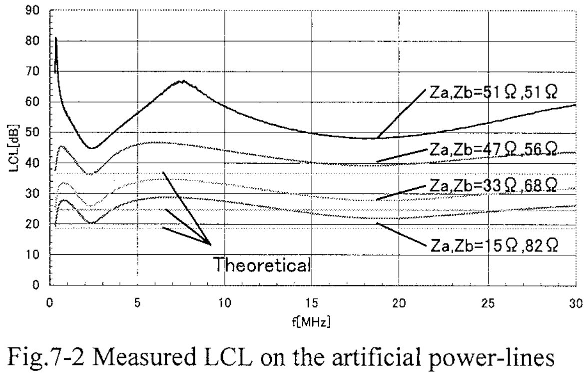

Fig.7-2 Measured LCL on the artificial power-lines by using Probe (2).

6. Conclusions

In order to measure LCL of power-lines, we assembled LCL probes in accordance with references [1,2], and evaluated them. Consequently, we confirmed that the measurement of dynamic range of LCL probe could be wider by putting together different types of transformers. And we confirmed that LCL of below 50 dB could be measured by using the two types of LCL probes at the frequency range of 2 - 30 MHz. That is, we confirm that the LCL probes in this paper are preferable to measure LCL on power lines. From now on, we will measure also about several types of power lines, power lines with branch and also real power lines. Moreover, we are due to study correlations between their LCL and radiated emission from the artificial power lines.

Reference

[1] Ian P. Macfarlane, “A Probe for the Measurement of Electrical Unbalance of Networks and Devices”, IEEE Trans. On Electromagnetic Compatibility, Vol. 41, No. 1, (1999-2)
[2] Y.Kawakami, S.Tsuzuki, M.Wasaki, Y.Yamada, “Producing an LCL Probe for Residential Power-lines”, Proc. Electronics, Information and Systems Conference, Electronics, Information and Systems Society, I.E.E. of Japan, OS1-6, pp.276-281 (2003-8)
[3] N.Oka, A.Konemori, Y.Sasaki, H.Fukushima, M.Kato, “Radiated Emission from PLC and Unbalance of Power Distribution Network”, Proc. Electronics, Information and Systems Conference, Electronics, Information and Systems Society, I.E.E. of Japan, OS1-5, pp.274-275 (2003-8)