Relation Between Balance-unbalance Conversion Factor and Leaked Electric Field in Power Line with Branch for PLC

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Abstract—In this paper, we calculated balance-unbalance conversion factor and leaked electric field in the power line with branch in high frequency. We paid attention to two typical branch such as outlet branch and lamp switch branch about the branch of the electricity distribution lines, and calculated the model which is combination of those divergences. To verify the validity of the calculation, we measured the model similar to the calculation, and compared with calculation results. As a result, the measurement and calculation values were approximated well both balance-unbalance conversion factor and leaked electric field, It was shown that the calculation model in the method of moments was effective to the analysis of the power line communication. And from the comparison of the calculation results, it was shown to have good correlation between balance-unbalance conversion factor and leaked electric field.

1. Introduction

The number of Internet users has recently seen explosive growth and demand for home LAN has increased, too. The means that the network can be easily constructed domestically is demanded. As one of the some solutions, there is a high-speed power line communication (PLC). PLC transmits data by using the conventional power line laid to supply commercial electric power both inside and outside the home in stead of telecommunication line. The practical application of PLC as realization approach of Home LAN is strongly hoped with the transmission speed improving in recent years. But there is a possibility that the leaked electromagnetic wave influences a radio service of high frequency band (3–30 MHz) by using PLC, because PLC uses this high frequency band. However, there is movement to develop the leaked electric field decreasing technology and to aim for realization of PLC, because the convenience of PLC is very large. From such a background, the Ministry of Internal Affairs and Communications (MIC) inaugurated the "Study Group for Power Line Communication Facilities" in April, 2002 [1]. And, High Speed Power Line Communication Promoters' Alliance of Japan (PLC-J) was established by the Japanese electric power company and the manufacturer, and they are doing various examinations of the leaked electric field decreasing technology. Now, various experiments are conducted [2], but it is difficult to verify all cases by experimental examination. Therefore, it is necessary to study a computer calculation method that can imitate the experiment.

In an experimental examination, the leaked electric field emitted from power lines has been analyzed quantitatively by using the degree of unbalance to ground, such as Longitudinal Conversion Loss (LCL) and common mode current, as an index [3]. Thus, the simulation method that can calculate LCL, common mode current, and leaked electric field is needed. There is a method of using four port network theory [4] about the calculation method, but we focused attention on method of moments (MoM) that was one of the electromagnetic field analysis method. We thought that the calculation was easily possible in a large-scale system, so that the MoM has the feature with comparatively short calculation time.

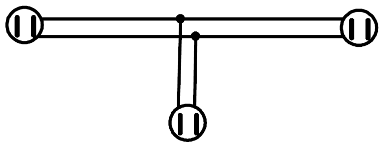
Based on above, in this paper, we report on the result of the calculation of LCL, the common mode current distribution, and the leaked electric field in the electric power line using the MoM. And, to verify the effectiveness of the calculation, we measured the characteristics of power line system with branch under PLC-J cooperation [5]. By comparing the measurement results with the calculation one, we will clarify the effectiveness of the calculation method as well as the relation between the balance-unbalance conversion factor and the leaked electric field.

2. Power Line Model

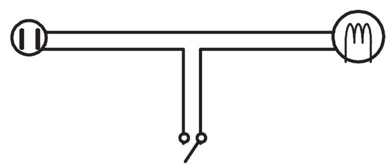
A general domestic power line has diverged variously, but it is possible to classify it into an outlet branch and a lamp switch branch by dividing a complex divergence of each element. In the outlet branch, both two lines of a pair line composing power line is diverged to make the outlet branch as shown in Figure 1(a), but in the lamp switch branch, only one line of the pair line is lengthened to make an ON / OFF switch as shown in Figure 1(b). In this paper, we paid attention to element of branch such as the outlet branch and the lamp switch branch, and "1 branch model" connected only the outlet branch line and "2 branch model" connected both the outlet branch line and the lamp switch branch line are measured and calculated respectively.

Figure 2 shows configuration of the 2 branch model, and size of the 2 branch model is shown in Figure 3. The outlet branch line of 5.6 m in total length and the lamp switch branch line of 4.0 m in total length are connected to the backbone line like a gate form. On the other hand, in the 1 branch model, the lamp switch branch line as shown in Figure 2 is not connected. The VVF (Vinyl insulated and Vinyl sheathed Flat type) cable with a conductor diameter of 1.6 mm is used for power line. And the size of this model reduces twice from the size of actual power line system, because an actual power line system is large-scale and then it is difficult to construct the power line model in a measurement site for radiated emission. To imitate the lamp, a terminal resistor of 100 Ω is connected in the lamp switch branch line. We connected the line of 1 m in length as a switch line, and connected the switch as the terminal. There is a possibility that ON / OFF of this switch influences the characteristic of the power line. Thus, we examined the changing characteristics to switching condition of ON/OFF. Each balun terminal has lengthened line to 40 cm in the height of 20 cm as shown in Figure 4, based on regulations of the line terminal in CISPR, and this size is also reduced to half.

In order to imitate the influence of grounding one wire of the pair line in pole transformer applied to Japanese power line, we grounded one wire of the pair line in balun on opposite side of the signal impression, that is, far end side from a domestic outlet. It is a factor that one of the pair line grounding lowers the balance-unbalance conversion factor of the power line. But, the structure to extend one wire of the pair line for the switch line is also cause of unbalance in the power line. We studied the model on the side where grounded line and switch line were the same in measurement and calculation, because the combination of the same sides acts additively to the characteristic of power line.



(a) Outlet branch.



(b) Lamp switch branch.

Figure 1: Classification of the branch.

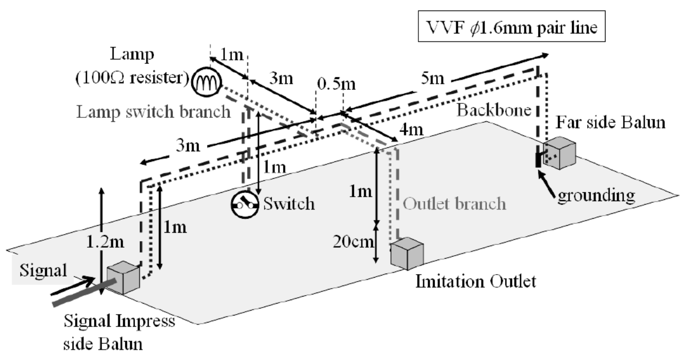


Figure 2: Configuration of the 2 branch model.

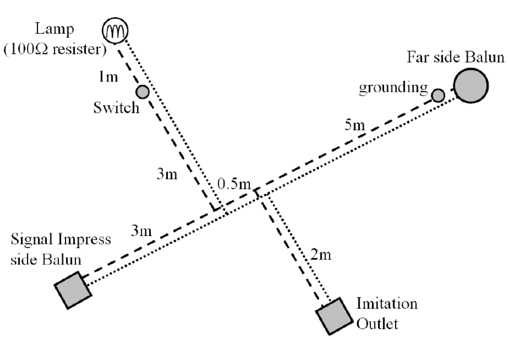


Figure 3: Size of the 2 branch model.

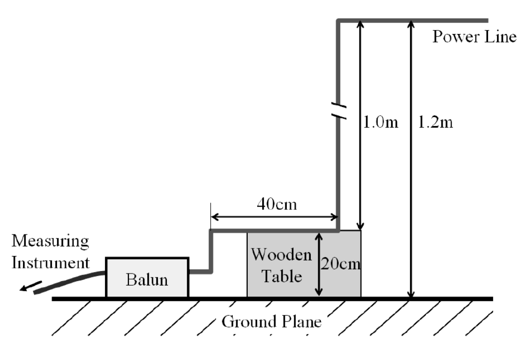


Figure 4: Configuration of power line terminal.

3. Measurement Method

3.1. LCL Measurement Method

In this paper, we paid attention to the value of balance-unbalance conversion factor, common mode current, and leaked electric field as EMC characteristics of the PLC, and measured these values and compared it with the calculation value. First, we measured LCL that was the ratio of the differential mode voltage and the common mode voltage in the input side as balance-unbalance conversion factor. LCL is defined by the following formula.

$$LCL = 20 \log_{10} \frac{V_{Cin}}{Din} \quad [dB] \tag{1}$$

Here, V_{Cin} is a common mode voltage in the input side, and V_{Din} is differential mode voltage in the input side. LCL was obtained by measuring the voltage appeared in the differential mode port when impressing the signal to common mode port of the balun, by using a network analyzer as shown in Figure 5.

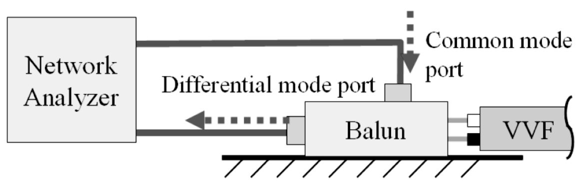


Figure 5: LCL measurement method.

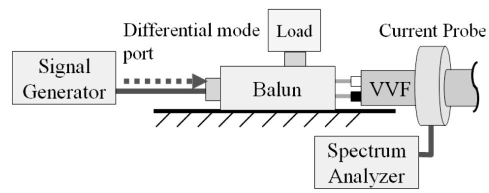


Figure 6: Common mode current measurement method.

3.2. Common Mode Current Measurement Method

We impressed the no modulated sine wave with power of 11 dBm from the signal generator to differential mode port of the balun, and measured the common mode current by using the current probe and spectrum analyzer synchronized the signal generator. Figure 6 shows the common mode current measurement system. The current distribution was obtained by measuring the current at intervals of 50 cm from signal input side balun.

3.3. Leaked Electric Field Measurement Method

In order to measure the leaked electric field from the power line, the power line model as shown in Figure 2 is set up on a large-scale turntable with radius of 5.0 m, and the no modulated sine wave signal of 11 dBm is impressed from the signal generator to differential mode port of balun. And we measured an electric field strength by a loop antenna, which is set at the point of 12 m from the center of turntable that arranged the power line model. We measured the electric field strength to horizontal, vertical and radial polarizations of loop antenna, and added all of three polarizations. The height of the antenna is 1.0 m. In the leaked electric field strength measurement, we rotated the turntable at intervals of 30 degrees. In frequency characteristics of the leaked electric field strength, the maximum value among many measured values obtained by rotating the turntable was adopted as the measured values at a frequency. Figure 7 shows the relation among arrangement of power line model and the receiving antenna position and the rotation angle of turntable.

4. Calculation Method

4.1. Calculation Model

The measurement system consisted of the power line as shown in Figure 2 was converted to an equivalent circuit of a differential transmission line to construct the calculation model by MoM as shown in Figure 8, and calculated each characteristics with MoM by using NEC2 as a calculation software [6]. Shape and size of the calculation model are completely equal to the measurement model. And we defined the model of the far end grounding by connecting the ground line of the impedance 0 Ω at far end side, because it is necessary to consider one wire grounding of pair line in the calculation model [7].

4.2. LCL Calculation Method

The electric field and magnetic field can be calculated by MoM as well as the current distribution along conductive wire, but the balance-unbalance conversion factor (for example LCL) cannot be calculated directly by MoM. However, as discussed previously, the method of simulation that can calculate LCL is demanded, because LCL is an important index of the characteristic of the power line. Thus, we devise a method of calculating LCL by the MoM. The method is shown here. First, to imitate the common mode input, we impressed the

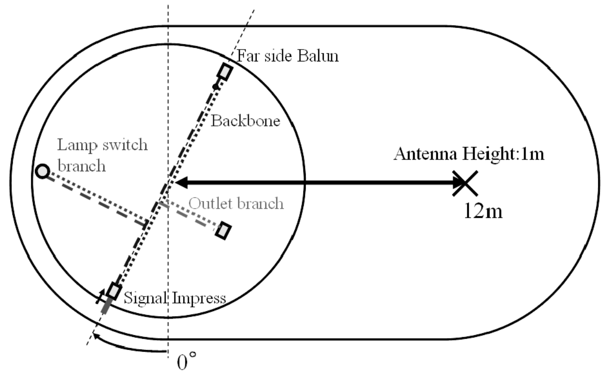


Figure 7: Configuration of power line model and receiving antenna on leaked electric field measurement systems.

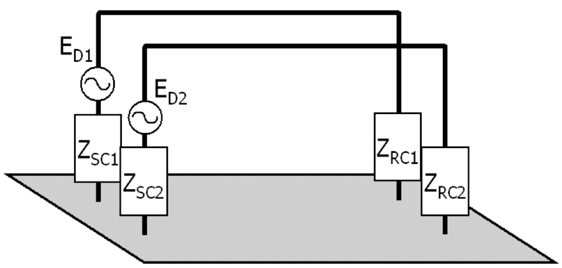


Figure 8: Calculation model by MoM.

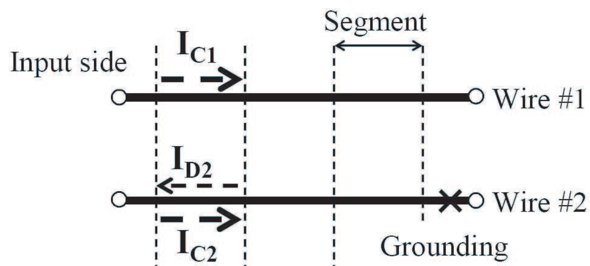


Figure 9: LCL calculation method by MoM.

in-phase voltage at the feeding point of two wires as shown in Figure 8, because LCL is a conversion ratio from the common mode signal to the differential mode signal at the input side. When grounding one wire of pair line at the far end, the current phase in an in-phase signal is greatly influenced by the grounding. Therefore, the difference of complex current appears in both lines on the segment of input side, and the subtracted value does not become 0, when one wire of the pair line is grounded on far end. This current can be considered as a differential mode current, and differential mode voltage (V_{Din}) is obtained by multiplying this differential mode current and differential mode impedance. LCL can be calculated from the ratio of V_{Din} and voltage (V_{Cin}) developed by one-quarter impedance of differential mode impedance.

4.3. Common Mode Current Calculation Method

We calculated the common mode current distribution by the method similar to the calculation of LCL, but, feeding power to each wire is impressed in reversed phase. A complex current is added to each segment at the same position of both lines, in order to calculate the common mode current distribution.

4.4. Leaked Electric Field Calculation Method

We calculated the leaked electric field at the point of 12 m from the center of power line model and 1m in height. The maximum value obtained by sweeping the angle at intervals of 30 degrees like measurement is adopted as a calculated value in calculation frequency range from 1 MHz to 30 MHz, according to the frequency range measurable by the loop antenna. And we calculated the magnetic field and converted it into the electric field by multiplying magnetic field and free space impedance.

5. Measurement and Calculation Results

5.1. LCL Calculation Result

Figure 10 shows LCL measurement and calculation results for the 1 branch model, and Figure 11 shows LCL for the 2 branch model. In Figure 10, the point is measurement value, and the solid line is calculation value. In Figure 11, Δ is measurement value for turning on switch (abbreviated as SW-ON), O is the one for turning off switch (abbreviated as SW-OFF). And the solid line is calculation value for SW-ON, the dotted line is the one for SW-OFF. From these figures, it is understood that average LCL for the 1 branch model is about 28 dB and the one for the 2 branch model is about 30 dB. In addition, it is also clear that LCL is not

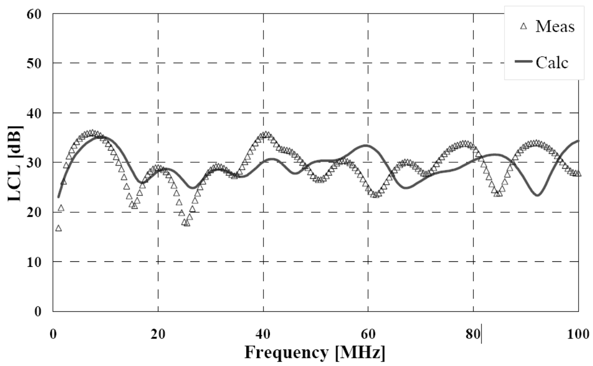


Figure 10: LCL for the 1 branch model.

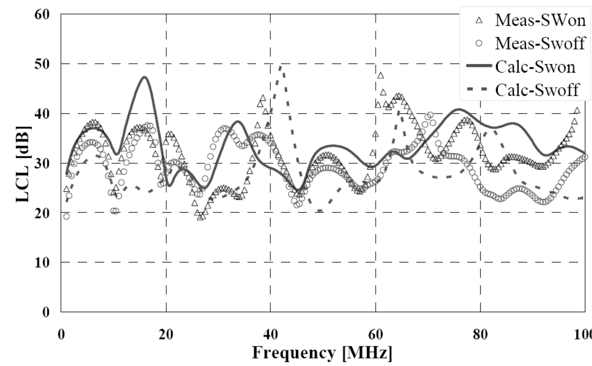


Figure 11: LCL for the 2 branch model.

so affected by switching condition, but the frequency appearing hump changes a little. From the comparison of these values, measurement and calculation values are almost corresponding though the hump position is different. The calculation value shifts the hump position to the high frequency side, and this cause is considered that dielectric constant of shielding material in each wire of the power line cannot be defined in the method of moment. Though the difference has extended in the 2 branch model, this cause is thought that the equivalent circuits for the switch and the lamp are not imitated accurately. However, it can be considered that the LCL calculation by MoM is effective, because measurement and calculation values are a similar tendency.

5.2. Common Mode Current Calculation Result

Figure 12 shows measurement and calculation values for the common mode current distribution along the backbone line in 1 branch model at frequencies of 1 MHz, 20 MHz, 40 MHz and 60 MHz. Figure 13 shows the current distribution along the outlet branch line in 1 branch model, and Figure 14 shows that along the backbone line in 2 branch model (SW-ON). The result in other cases was omitted, because the results were almost similar to that mentioned above.

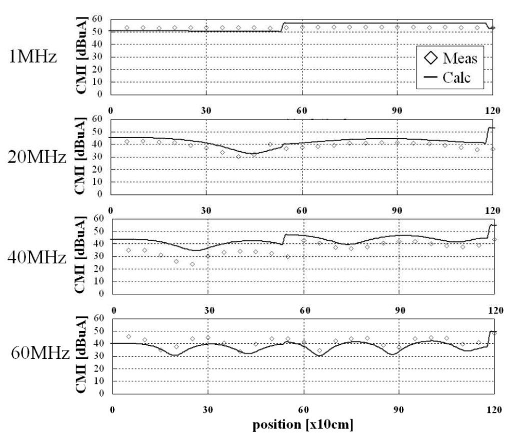


Figure 12: Common mode current for 1 branch model (backbone line).

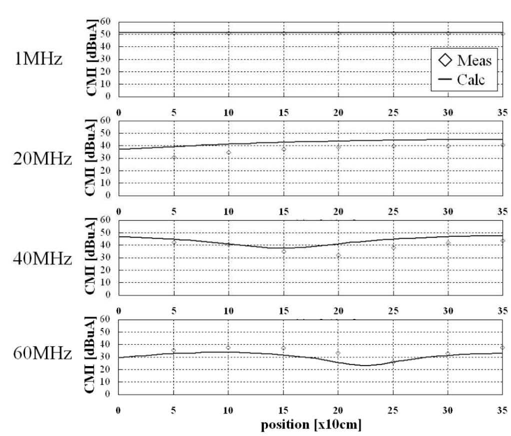


Figure 13: Common mode current for 1 branch model (outlet branch line).

From the current distribution along the backbone line shown in Figures. 12 and 13, in both the measurement and the calculation, the current has changed suddenly in 5.0 m. This position is the connecting point to each branch line and backbone line. Thus, it is understood that the common mode current flowing along the backbone line flows greatly to the line where common mode impedance is lower in the position of branch. From comparing the results, calculation values at the position of antinodes and nodes on the standing wave agree with measurement values, and the level of the common mode current is also almost equal to each other. Therefore, it was confirmed that the calculation of common mode current distribution by MoM was effective.

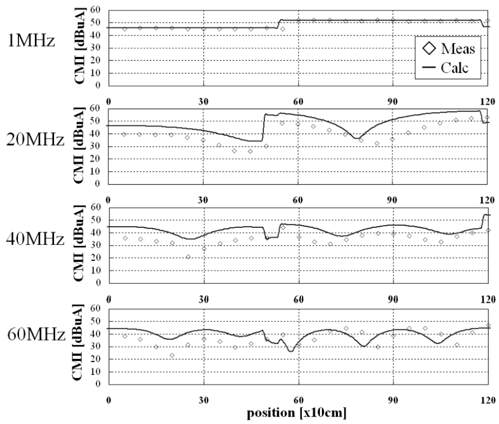


Figure 14: Common mode current for 2 branch model (backbone line).

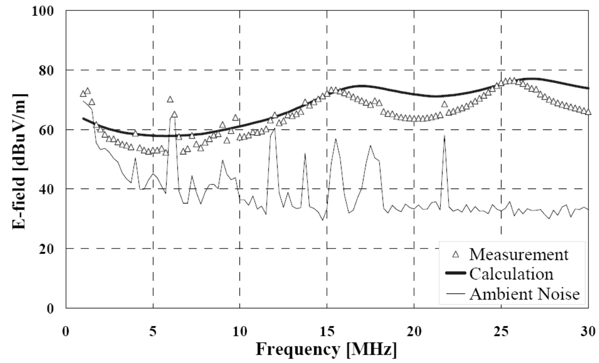


Figure 15: Leaked electric field for 1 branch model.

5.3. Leaked Electric Field Calculation Result

Figure 15 shows the value of leaked electric field for the 1 branch model. The leaked electric field for the 2 branch model (SW-ON) is shown in Figure 16, and that for the 2 branch model (SW-OFF) in Figure 17. A thin solid line in figures is ambient noise such as the broadcasting waves and noise level of the interference wave for the measuring instrument on an open area site. From those Figs. 15, 16, and 17, tendencies of the calculated frequency characteristics for the electric field strength are almost equal to measured ones. It is considered that the influence of dielectric material for power line appears as mentioned already for being a difference in the hump position, but it was revealed that the calculation for the leaked electric field by MoM was effective, because measurement and calculation values are a similar tendency.

5.4. Relation between Balance-unbalance Conversion Factor and Leaked Electric Field

Figure 18 shows a relation between balance-unbalance conversion factor and leaked electric field for the 1 branch model, and Figure 19 shows the relation for the 2 branch model. From comparing the relation between LCL and leaked electric field in these figures, if LCL reaches a low value, the leaked electric field becomes a high value, regardless of the switching condition. Conversely, if LCL reaches a high value, the leaked electric field becomes a low value. Thus, it is confirmed that there is relation of inverse proportion between LCL and leaked electric field. In addition, it is thought that such relation maintain regardless of the difference of the branch form and the switching condition.

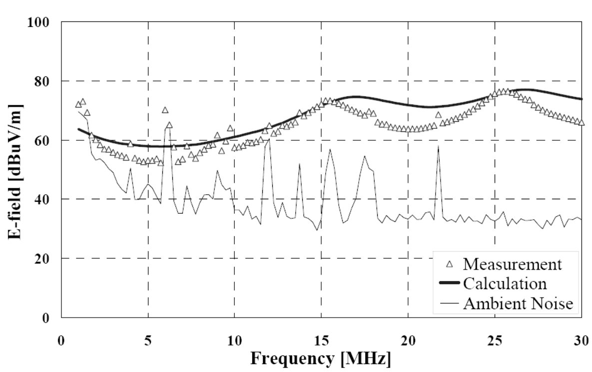


Figure 16: Leaked electric field for 2 branch model (SW-ON).

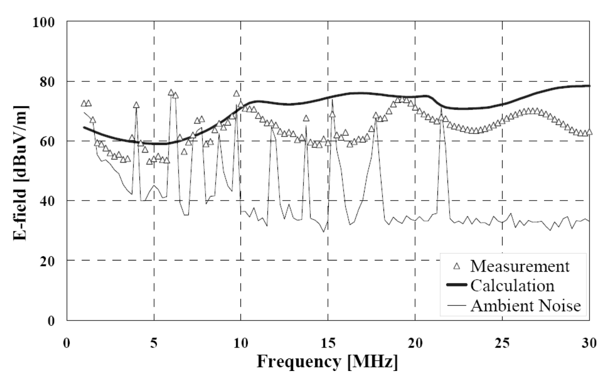


Figure 17: Leaked electric field for 2 branch model (SW-OFF).

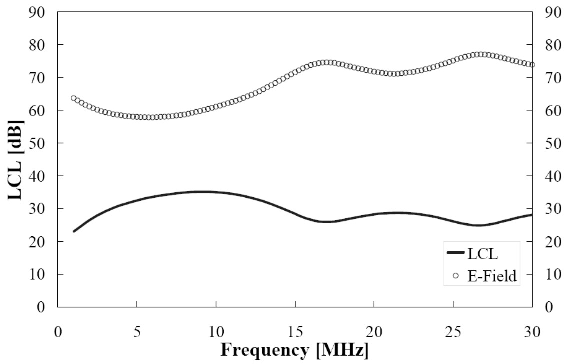


Figure 18: Relation (LCL-E-field) for 1 branch model.

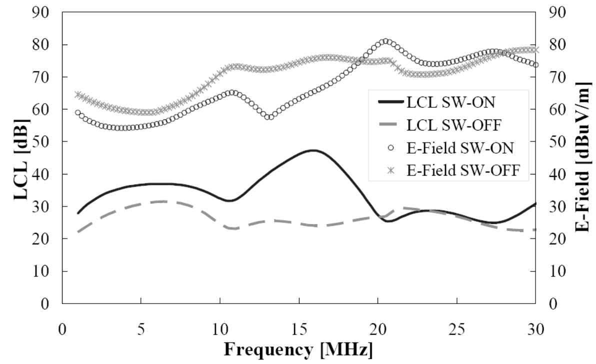


Figure 19: Relation (LCL-E-field) for 2 branch model.

6. Conclusion

In this paper, we focused attention on a power line communication using in high frequency band, and calculated balance-unbalance conversion factor and leaked electric field in the power line with branch by MoM. In order to confirm the validity of the calculation, we measured balance-unbalance conversion factor and leaked electric field for the same model as the calculation model, and compared the measurement value with the calculation value. As a result, the calculation value agreed well with measurement value, and then it was revealed that the calculation model of the PLC using the MoM was effective. In addition, it is confirmed that the influence of grounding one wire of the pair line in pole transformer applied to Japanese power line is small to LCL of the power line in the home, because LCL of the power line including each branch model is about 30 dB. Moreover, it was clear that there was a good correlation between LCL and the leaked electric field. The future task is expanding this branch model greatly, and applying it to power line model in the home.

REFERENCES

1. Power Line Communication Study Group in MIC, "Study group on Power Line Communication report," International Policy Division, International Affairs, Department Tele-communications Bureau, Ministry of Internal Affairs and Communications, Jul. 2003. (in Japanese)
2. Oka, N., A. Konemori, Y. Sasaki, H. Fukushima, M. Kato and S. Nitta, "Radiated emission from PLC and electrical unbalance of an artifical power distribution line," *2004 International Symposium on Electromagnetic Compatibility*, 4C3-2, Vol. 2, 841–844, Sendai, Japan, Jun. 2004.
3. Verpoorte, J., "Application of the LCL method to measure the unbalance of PLC-equipment connected to the low voltage distribution network," CISPR, SubCommittee I, Working Group 3 (CISPR/SCI/WG3), Feb. 26, 2003.
4. Miyoshi, K., N. Kuwabara, Y. Akiyama, and H. Yamane, "Calculation of radiating magnetic field from indoor AC mains cable using four-port network," *2005 IEEE International Symposium on Electromagnetic Compatibility, Proc.*, Vol. 3, 1002–1007, Aug. 2005.
5. Maegawa, K., N. Ishikawa, T. Shinpou, T. Inada, M. Maki, Y. Watanabe, and M. Tokuda, "Leaked electric field measurement from simplified power line model," *IEICE Technical Report*, EMCJ, EMCJ2005-67, in Japanese, 49–54, Sept. 2005.
6. http://www.nec2.org/.
7. Watanabe, Y., M. Shigenaga, and M. Tokuda, "Electromagnetic field near power line for a power line communication system," *2004 International Symposium on Electromagnetic Conpatibility*, Sendai, 4C3-3, 845–848, Jun. 2004.