# A study of PLC Signal Influence on VDSL System by Induction between Indoor Power Line and Telecommunication Line

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**Abstract:** Due to the progress of information technology in recent years, power line communication (PLC) can be considered as a solution for configuring an indoor communication system. However, the influence on other systems caused by PLC signal induction has not yet been investigated. This paper presents a study on that influence. The induction voltage to a telecommunication line was analyzed by using an 8-port network. The calculation results nearly agree with the measurements. The investigation using a very high bit rate digital subscriber line (VDSL) modem indicates that the VDSL communication may not be degraded under normal conditions for the system using the experiment.

**Key words**: PLC, 8-port network, VDSL,

## 1. Introduction

Power line telecommunication (PLC) systems, which transmit over existing indoor power lines, have been developed. The first generation PLC, whose transmission rate is about 100 bps and the second generation PLC, whose transmission rate is 9600 bps, has been developed in Japan. Recently, a high-speed PLC system, whose transmission rate is more than 10 Mbps has been developed [1]. The influence on other communication systems should be evaluated from the EMC points of view, because the PLC uses the high frequency (HF) band signal.

There are three types of influences as shown in Fig. 1. The influence on the HF-radio communication caused by the radiated electromagnetic field due to the PLC signal transmission has been reported [2]. The influence on communication systems using untwisted pair (UTP) transmission lines caused by the induction voltage due to conductive coupling has also been evaluated [3]. However, the influence caused by the induction voltage due to the inductive coupling between cables has not yet been investigated.

In this paper, the induction voltage due to the inductive coupling is analyzed by using an 8-port network. The calculation results are compared with the measured data for a simple model. Then the influence on a VDSL system is examined.

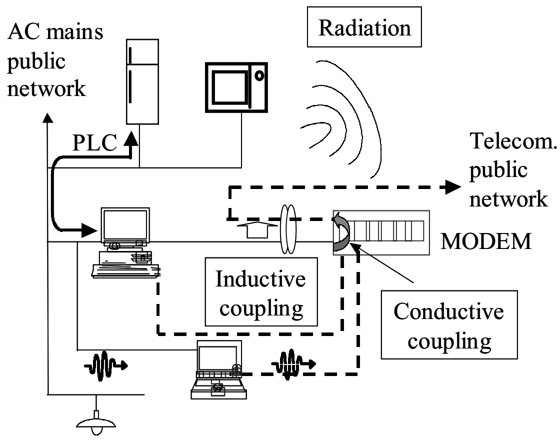


Fig. 1 Influence on other systems due to the PLC signal transmission

## 2. Analytical Method

The power line system and the telecommunication system, which are inductively coupled, are represented by the 8-port network as shown in Fig. 2.

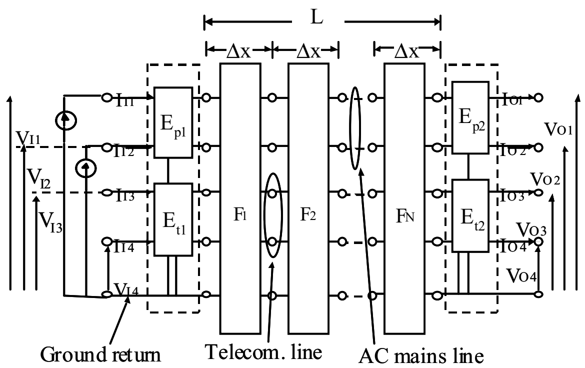


Fig.2 Analysis model of induction between power line and telecommunication line

The upper two wires are the power line, the next two wires are the telecommunication line and the lowest wire is the ground. $F_1,.....F_N$ are F-matrices representing transmission characteristics of an 8-port network consisting of a power line and a telecommunication line. The circuit diagram of the 8-port network is shown in Fig. 3. The capacitors, $C_{ij,k}$, indicate the capacitance between wires and the capacitance between wires and ground. The resistors, $R_{ii,k}$, indicate the resistance of each wire. The inductors, $L_{ii,k}$, indicate the self-inductance of each wire, and inductors, $L_{ij,k}(i \neq j)$, indicate the mutual inductance between wires. These parameters are investigated and reported in paper [4]. The Cs is the capacitor that represents the unbalance between the lines due to the imperfection of the configuration of the power line and the telecommunication line. In this paper, we use a Cs of 0.05 pF/m as the experimental value. In accordance with the equivalent circuit in Fig. 3, the F matrix is given by (1).

$$F_k = \begin{bmatrix} 1_4 & \left[\left(R_{ii,k} + j\omega L_{ij,k}\right)\cdot \Delta x\right] \\ \left[j\omega\left[C_{ij,k}\right]\cdot \Delta x\right] & 1_4 \end{bmatrix} \quad (1)$$

$$i, j = 1, 2, 3, 4$$

The Δx is the length of the line segment and $1_4$ is the 4 by 4 unit matrix.

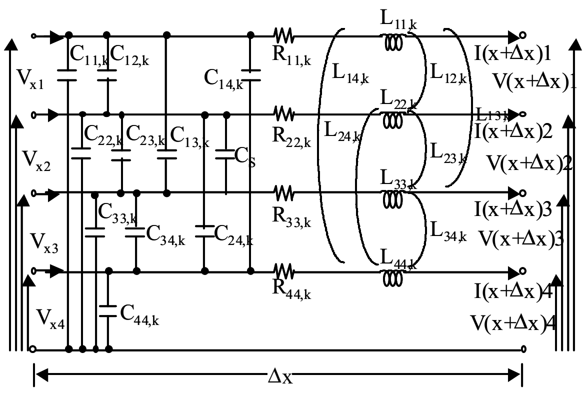


Fig. 3 Equivalent circuit of 8-ports network

The $E_{pn}$ and $E_{tn}$ (n=1,2) are the equipment connected to the wires. The electrical equipment and the artificial mains network having a pair of power ports and the telecommunication equipment having a pair of telecommunication ports are represented by 2-port networks. The telecommunication equipment also has a pair of power ports but we ignored the power ports on the basis of the assumption that the power port does not affect to the inductive coupling between the power line and the telecommunication line.

The 2-port network is replaced by the T-network as shown in Fig. 4. We assume that the equipment that terminates the lines is not connected to each other. The F-matrix for the terminal equipment is given by (2).

$$\mathbf{F}_{terminal} = \begin{bmatrix} \mathbf{1}_4 & \mathbf{0}_4 \\ \begin{bmatrix} Y_{p11} & Y_{p12} & 0 & 0 \\ Y_{p21} & Y_{p22} & 0 & 0 \\ 0 & 0 & Y_{t11} & Y_{t12} \\ 0 & 0 & Y_{t21} & Y_{t22} \end{bmatrix} & \mathbf{1}_4 \end{bmatrix} \quad (2)$$

in which $0_4$ is the 4 by 4 null matrix.
Here,

$$Y_{i11} = \frac{Z_{i2} + Z_{i3}}{Z_{i1}Z_{i2} + Z_{i2}Z_{i3} + Z_{i3}Z_{i1}}, Y_{i12} = \frac{-Z_{i3}}{Z_{i1}Z_{i2} + Z_{i2}Z_{i3} + Z_{i3}Z_{i1}}$$

$$Y_{i21} = \frac{-Z_{i3}}{Z_{i1}Z_{i2} + Z_{i2}Z_{i3} + Z_{i3}Z_{i1}}, Y_{i22} = \frac{Z_{i3} + Z_{i1}}{Z_{i1}Z_{i2} + Z_{i2}Z_{i3} + Z_{i3}Z_{i1}}$$

$$(i = p, t)$$

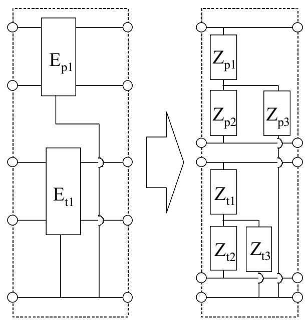


Fig. 4 Equivalent circuit model of terminal equipment

Finally, the relationships between input and output voltages and currents are represented by Eq. (3).

$$\begin{bmatrix} [V_{Ii}] \\ [I_{Ii}] \end{bmatrix} = [F_{terminal}] \cdot \left( \prod_{k=1}^{N} [F_k] \right) \cdot [F_{terminal}] \begin{bmatrix} [V_{Oi}] \\ [I_{Oi}] \end{bmatrix} \quad (3)$$

*k* is the number of the segment, $V_{Ii}$ and $V_{Oi}$ (*i*=1..4) are the voltages at both line ends and $I_{Ii}$ and $I_{Oi}$ (i=1..4) are the currents at both line ends.

From Eq. (3), we obtain the following relationship.

$$\begin{bmatrix} [V_{Ii}] \\ [V_{Oi}] \end{bmatrix} = [Z] \begin{bmatrix} [I_{Ii}] \\ [I_{Oi}] \end{bmatrix} \quad (4)$$

From Fig. 2, we can obtain $I_{I1}=I_{in}$, $I_{I2}=-I_{in}$, $I_{I3}=I_{I4}=0$, and $I_{Oi}=0$ (*i*=1..4). Then the voltages $V_{Ii}$ and $V_{Oi}$ can be calculated by Eq. (4).

## 3. Experiment and results

### 3.1 Measurement Setup

To confirm the analysis, the induction voltage was measured using the experimental setup shown in Fig. 5. A VVF cable whose conductor diameter was 1.6 mm and a single-pair UTP cable were used for the experiment. The length of both cables is 30 m. The cables are terminated by the balun. The center port of the balun was connected to the ground through a 150 Ω resistor to stabilize the common mode impedance. One conductor of the cable was grounded through a nominal resistor to adjust the unbalance of the telecommunication system. The voltage transfer ratio (VTR) is defined as the ratio between the input voltage $V_{in}$ and the output voltage $V_{out}$. The VTR is given by Eq. (5).

$$\mathrm{VTR(dB)} = 20\log\left|\frac{V_{l1}-V_{l2}}{V_{l3}-V_{l4}}\right| = 20\log\left|\frac{\eta V_{out}}{\eta V_{in}}\right| = 20\log\left|\frac{V_{out}}{V_{in}}\right| \quad (5)$$

In this equation, $\eta$ is the conversion factor of the balun. In the calculation, the balun was replaced by a T-network as shown in Fig. 3 and the parameters of the T-network were obtained by measurements [5].

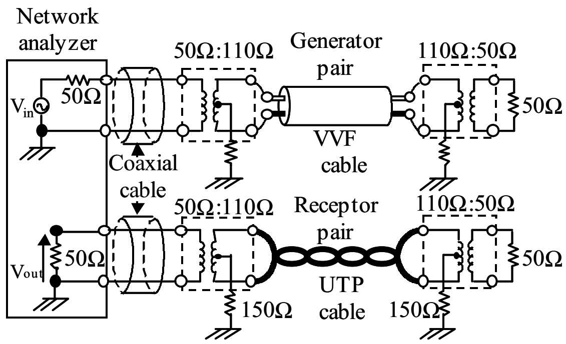


Fig. 5 Experimental setup for measuring induction voltage

### 3.2 Measurement results

The measurement and calculation results are shown in Fig. 6. Since the balance of the system is the important factor to evaluate the induction voltage, the balance of the cable was adjusted. The longitudinal conversion loss (LCL) value was used to evaluate the balance. In Fig. 6, the solid line and the broken line show measured values, and the inverse triangles and circles show the calculated values. These results are mostly in agreement.

The results indicate that the calculation model in Fig. 2 is effective for calculating the induction voltage.

## 4. Influence on VDSL communication

### 4.1 Estimation of the influence

The PLC signal influence on a telecommunication system was examined by using a model. The influence can be roughly estimated by using the desired and undesired signals (DU) ratio. The relationship between the VTR and the DU ratio when the telecommunication is not affected by the PLC is given by Eq. (6).

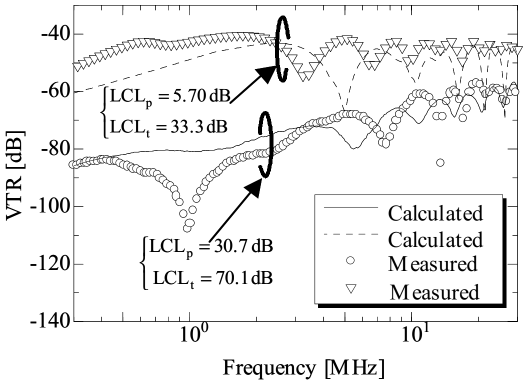


Fig. 6 Measured and calculated results of the VTR

$$VTR(dB) > S_{PLC}(dB) - S_{Tel}(dB) + DU(dB) \quad (6)$$

in which, $S_{PLC}$ is the input signal level of PLC, and $S_{Tel}$ is the receiving telecommunication signal level.

### 4.2 Experimental setup

The experimental setup for measuring the relationship is shown in Fig. 7. The cable layout was based on that in Fig. 5. The experiment was performed in a semianechoic chamber (5.2 m wide, 6 m long and 5 m high). So the cables were drawn in rectangular shape.

The measured VTRs are shown in Fig. 8. The results for straight cables are also shown in the figure for comparison. The results for the measured VTRs for the two cable layouts are nearly agreed.

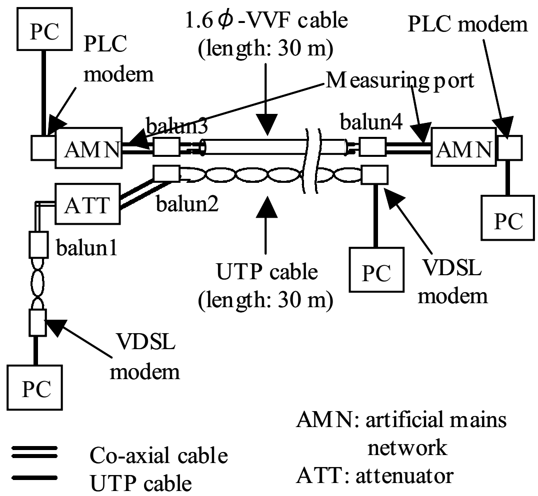


Fig. 7 Experimental setup for measuring influences on telecommunication system

The PLC modem used in the experiment does not have signal ports. The PLC signal was picked up by using the artificial mains network (AMN) and provided to the balun. The program for measuring the number of packets per second was used for maintaining normal communication conditions.

As for the VDSL communication system, using a variable attenuator (ATT) changes the receiving signal level and the throughput was measured.

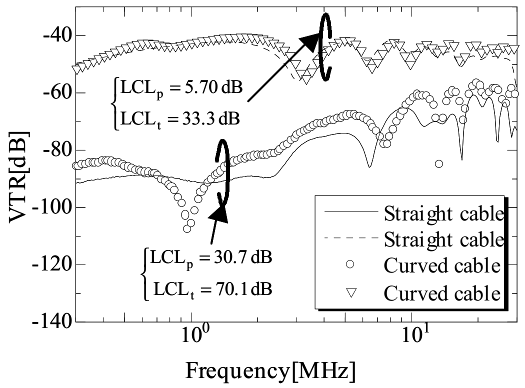


Fig. 8 Measured VTR for two cable layouts

The communication performance is estimated from Eq. (6). In the case of the setup in Fig. 7, $S_{PCL}$ is -50 (dBm/Hz), and $S_{Tel}$ is (-60-ATT) (dBm/Hz), and DU ratio is 20 (dB). The minimum VTR ($VTR_{min}$) for normal VDSL communication can be obtained by substituting these values into Eq. (6).

In order to validate the estimation, we measured the throughput of the VDSL communication under the two VTR conditions. VTR1 is smaller than $VTR_{min}$ and VTR2 is larger than $VTR_{min}$. Adjusting the LCL values of the power line and telecommunication line changed the VTR values. We used an $LCL_P$ of 19.6 dB and an $LCL_T$ of 33.5 dB for VTR1 and an $LCL_P$ of 19.6 dB and an $LCL_T$ of 46.8 dB for VTR2. The calculated VTR1 is 53.7 dB and VTR2 is 63.8 dB. These LCL and VTR values are the means value in the frequency range from 4.3 MHz to 12 MHz. The PLC and VDSL signals used in the experiment overlapped in this frequency range.

The measurement results are shown in Fig. 9. The vertical axis is the throughput normalized by the value of that when the PLC signal is not induced in the telecommunication line. Measurements were repeated five times for each condition, and the maximum, mean, and minimum values are shown in the figure. In this figure, the top of the bar indicates the maximum value, and the bottom of the bar indicates the minimum value, and squares and triangles indicate the mean value.

The throughput was not degraded in the case of VTR2 up to a transmission loss of 30 dB. When the ATT is 30 dB, $VTR_{min}$ is 60 dB. VTR2 (63.8 dB) is greater than $VTR_{min}$ and satisfies the condition of Eq. (6). On the other hand, in the case of VTR1, the throughput was degraded when ATT is greater than 26 dB. When the transmission loss is 26 dB, $VTR_{min}$ is 56 dB. VTR1 (53.7 dB) is smaller than $VTR_{min}$ and does not satisfies the condition of Eq. (6).

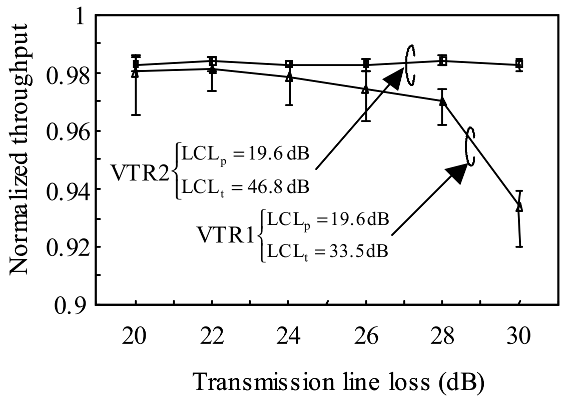


Fig. 9 Measurement result of throughput

These results suggest that we can estimate the influence of the inductive coupling between the power line and telecommunication line using the model in Fig. 2 if we know $S_{PLC}$, $S_{Tel}$, and the DU ratio.

## 5. Conclusion

The inductive coupling between power line and telecommunication line was analyzed by using an 8-port network. The calculation results almost agree with the measured values and the analysis method presented in this paper is effective for estimating the induction voltage on the telecommunication line.

The experiment of was performed using a PLC modem and a VDSL modem. The results indicate the influences can be estimated from the calculated VTR, the PLC signal level at the PLC modem port, the telecommunication signal level at the modem input port, and the DU ratio.

A Future issue is to confirm that the method is applicable for other conditions such as cable layout, the PLC systems, and the telecommunications systems.

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