Measurement of Japanese Indoor Power-line Channel

Shinji TSUZUKI, Shinji YAMAMOTO, Takashi TAKAMATSU, Yoshio YAMADA

Dept. of Electrical & Electronic Eng., Ehime University
3-Bunkyo, Matsuyama, 790-8577, JAPAN
tsuzuki@ee.ehime-u.ac.jp

Abstract The impedance characteristics of household-appliances and power-line channels in the Japanese environment are measured in the high-frequency band, i.e., from 70kHz to 35MHz. The transfer function of the channels is also measured and these results are shown. The power-line channel can be treated as a distributed constant circuit at the high frequency band. In this paper, the distributed constants of a VVF cable with two wires, which is widely used for the indoor power-line in Japan, are obtained by measuring the relative dielectric constant (ε_r) and the dielectric loss-tangent (or dissipation-factor, $\tan\delta$).

Keyword: measurements and channel characterization, impedance characteristic of household appliances and power-line, transmission characteristic, distributed constants of VVF cables

1 Introduction

The research and development of high-speed power-line communications (PLC) of around 10M bps using the high-frequency band under 30MHz have become active. To realize the high-speed PLC, it is important to know the characteristics of power-line as a communication channel. Considering the Japanese PLC environment, the allowed band is from 10kHz to 450kHz. Therefore, the channel characteristics of Japanese power-line environments in the high-frequency band have not yet surveyed sufficiently.

In this paper, the impedance characteristics of household-appliances and power-line channels are measured in the high-frequency band, i.e., less than 35MHz. And the transfer function of the channels is measured and these results are shown[1].

The power-line channel must be treated as a distributed constant circuit at the high-frequency band. In this paper, the distributed constants of a VVF (Vinyl insulation, Vinyl sheath, Flat) cable with two wires of ϕ1.6mm, which is widely used for the residential power-line in Japan, are obtained by measuring the relative dielectric constant (ε_r) and the dielectric loss-tangent (or dissipation-factor, $\tan\delta$)[2].

2 Impedance of household-appliances

Figure 1 shows our impedance-measurement scheme. The impedance was calculated from the S-parameter of S_{11} measured by a network analyzer (HP4395A). The calibration was done at the outlet as shown in the figure. The impedance of an appliance was calculated from that of the AC-power-line itself and parallel-impedance of the AC-line and the appliance.

The result is shown in Fig.2. The 54 kinds of appliances with 89 power-on/off states were measured. The frequency range in log-scale was segmented into 40 sub-bands, and the maximum and minimum impedance-values of each appliance in the respective band were measured. The measured values were plotted as a probability distribution. For example, 78.8% appliances are included in the darkest-shadowed area.

One of the difficulty of PLC in the low frequency-band (less than 450kHz) is the dispersion of individual appliances' impedance. However, it is measured that the dispersion tends to decrease gradually in the range from 500kHz to 10MHz. When the frequency is higher than 10MHz, it changes to increase again. Therefore, the frequency band where the influence of the dispersion of appliances' impedance is the least, is around 10MHz.

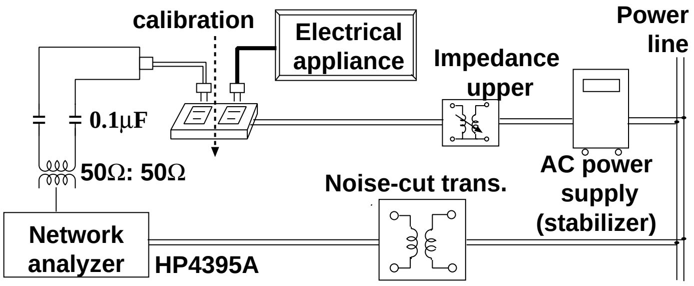


Figure 1: Impedance measurement

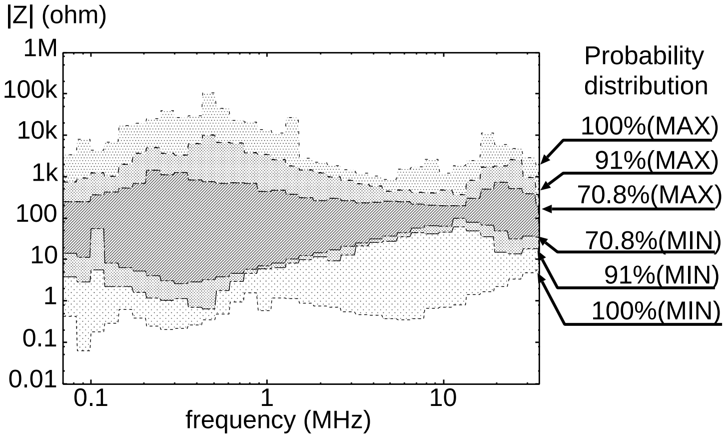
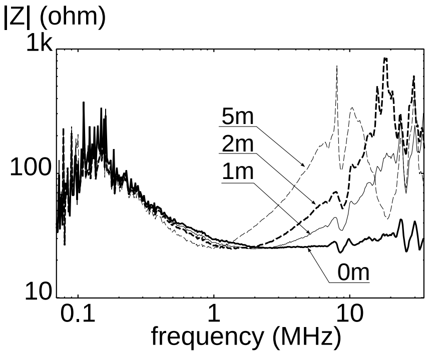
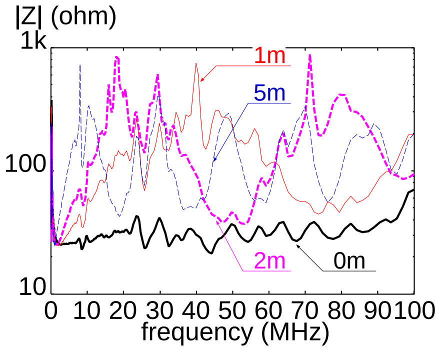


Figure 2: Impedance of appliances and its dispersion. (54 appliances, 89 states)



(a) Frequency axis in log scale



(b) Frequency axis in liner scale

Figure 3: Influence of the length of AC-power-supply cord on the appliance's impedance.

At the frequency less than 10MHz, the impedance of appliance itself is dominant. On the other hand, when higher than 10MHz, an influence of an attached AC-power-supply cord, which must be treated as a distributed constant circuit, becomes dominant as shown in Fig.3 (a). This phenomenon agrees with that of impedance-dispersion increase beyond 10MHz shown in Fig.2.

Figure 3 (a) shows the impedance of a battery charger without the AC cord and with a 1m, 2m, and 5m cord, respectively. Figure 3 (b) is the same as (a), but the frequency axis is changed to a liner scale and the highest frequency is extended from 35MHz to 100MHz. When the length of the cord is 0m, i.e., without the cord, the impedance is almost constant to be around 30 ohm. However, when the cord is connected, the impedance resonates. When the cord length is 1m, the resonance occurs once at the frequency 40MHz. When 2m, it occurs twice at the frequencies 25M and 75MHz. When 5m, it occurs five times at the frequencies 10M, 30M, 50M, 70M and 90MHz. These resonance can be explained by the theory of the distributed constant circuit.

From these observations, the equivalent circuit of the appliance (in this case, the battery charger)'s impedance is given as Fig.4. The AC cord is given as a four terminal network, denoted by $Z^{(1)}$, composed of a distributed constant circuit, where γ is the propagation constant, l is the length of the cord, and Z_0 is the characteristic impedance. The appliance itself is given as a two terminal network, denoted by $Z^{(2)}$, composed of lumped constants. Then, the total impedance of the appliance with the AC cord is given as a cascade connection of $Z^{(1)}$ and $Z^{(2)}$. The distributed constants of $Z^{(1)}$ are as follows; R=0.400$[\Omega/m]$, L=650$[nH/m]$, G=0.600$[m\mho/m]$, C=40.3$[pF/m]$. These values are based on the result of Sec.4, and modified to fit with the measurement results.

Figure 5 compares the impedance-model given in Fig.4 with the measurement. The 0m's lines shows the value of $Z^{(2)}$. The model values of l = 0m and 5m fit well with the measured values. Even when the length l is changed to 1m and 2m, they fits well, where the distributed constants are the same as those of 5m.

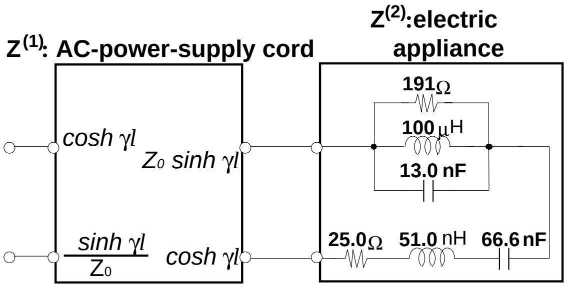
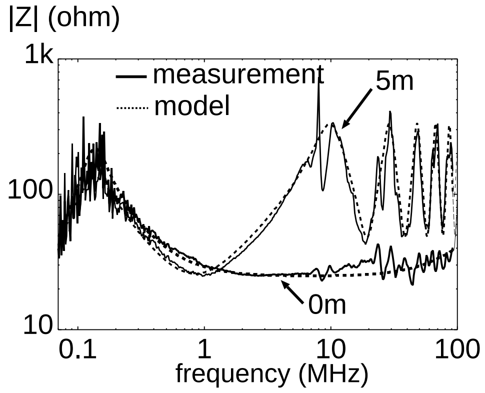
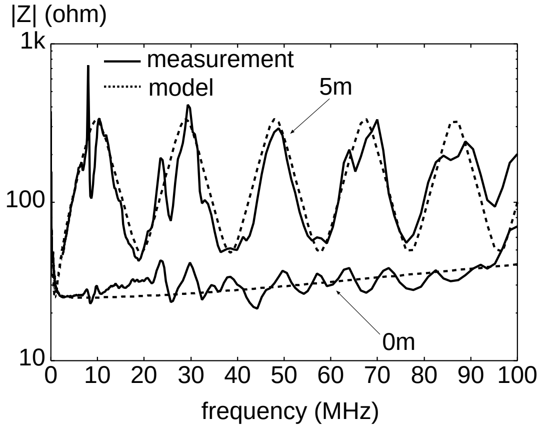


Figure 4: Equivalent circuit of a battery charger.



(a) Frequency axis in log-scale



(b) Frequency axis in linear-scale

Figure 5: Comparison of the impedance model and the measurement. (A battery charger)

○ the same phase with the outlet 1

● the opposite phase to the outlet 1

□ the different distribution power-line from the outlet 1

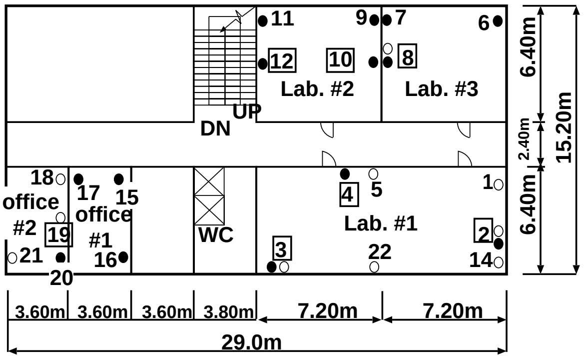


Figure 6: The outlets where the line-impedance was measured.

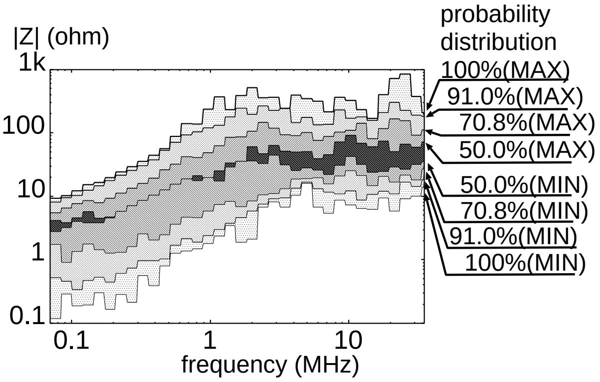


Figure 7: Impedance property of power-line. (24 outlets)

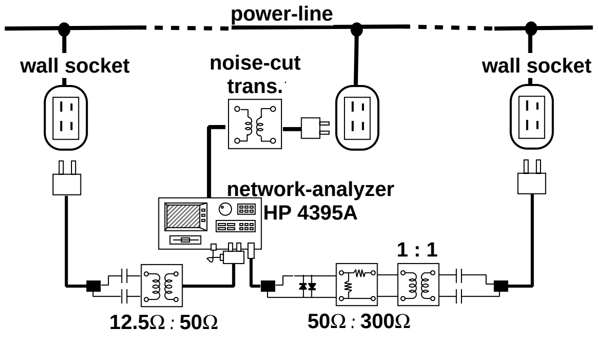


Figure 8: Measurement scheme of the transfer function between two outlets.

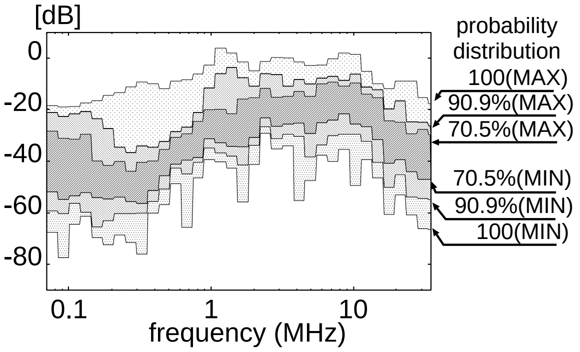


Figure 9: Transfer function between the same-phase outlets. (44 cases)

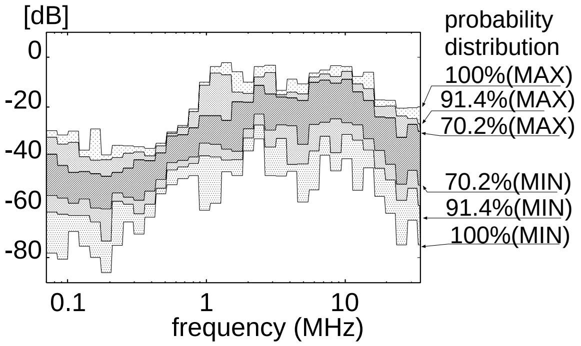


Figure 10: Transfer function between different-phase outlets. (47 cases)

3 Characteristics of power-line

The impedance of 24 outlets of our laboratory shown in Fig.6 was measured. The result is shown in Fig.7. The impedance of power-line, to which a lot of electric equipment are connected, changes from an increasing function to a flat one, which fluctuates around 40 ohm in our measurement, when the frequency is higher than 2MHz. This fluctuation is the same reason as shown in Fig.3.

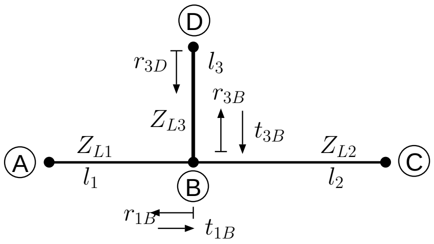
Another difficulty of PLC in the low frequency-band is the signal attenuation due to the phase-coupling loss[3]. This is encountered when the communication signal must cross the opposite phase. In Japan, electric power distribution containing center tap transformers is provided for residential use. With this type of distribution network, if two nodes on the communication channel are on opposite phases, a cross-phase coupling device consisting of a high pass filter is often needed. However, it is observed from Fig. 9 and Fig. 10 that the transfer function of the channels crossing phases is almost the same as that with the same phase, when the frequency is higher than 1MHz. It means the coupling device is not needed in the higher frequency-band. The signal seems to transfer to the opposite phase owing to the crosstalk at the power distribution line of 3-wire VVF cable.

4 Distributed constants of a VVF cable

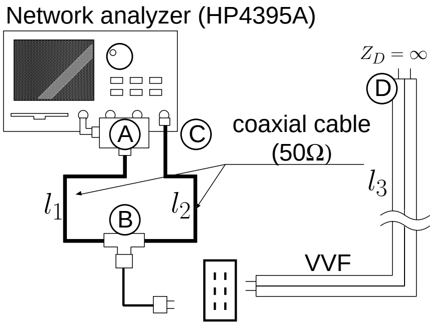
Distributed constants of a VVF cable manufactured by Suganami Electric Wire Co., Ltd. was measured experimentally as shown in Fig.11. The impedance of the transmitting point A and the receiving point C are matched to the coaxial cable of 50Ω. At the branch point B, a VVF cable is connected. The opposite end D of the VVF cable is opened, so that all signals reflect with the reflection factor $r_{3D} = 1$. At another unmatched point B, signals reflect and transmit with the reflection factor r_B and the transmission factor t_B $(= 1 - |r_B|)$. The transfer faction from A to C was measure as shown in Fig.11(b), where its theoretical value is given in [4]. The distributed constants of the VVF cable were selected to fit to the measurement result[2].

In Fig.12, the theoretical value of the transfer function $|H(f)|$ with the VVF cable length $l_3 = 38.7m$ is compared to the measured value. Even when the length l_3 was changed to 12.1m and 22.7m, the theoretical value agrees with the measured value.

From Fig.13 to 15, the obtained distributed constants of the VVF cable are shown. The relative dielectric constant ε_r shown in Fig.13 and the dielectric loss $\tan\delta$ shown in Fig.14 are of the vinyl insulation of the VVF cable. They are approximated by one or two linear function(s), respectively. The inductance L of the distributed constant was obtained to be $0.52\mu H/m$.



(a) Multipath signal propagation channel



(b) Measurement scheme

Figure 11: Measurement of distributed constants of a VVF cable.

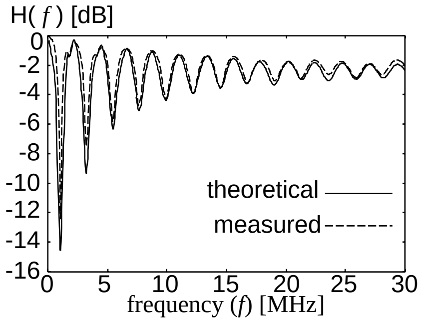


Figure 12: Transfer function from A to C. ($l_3 = 38.7m$)

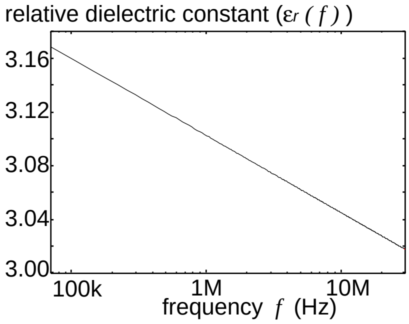


Figure 13: Relative dielectric constant ε_r of the VVF cable.
$varepsilon_r(f) = -5.733e^{-2} \log_{10} f + 3.444$

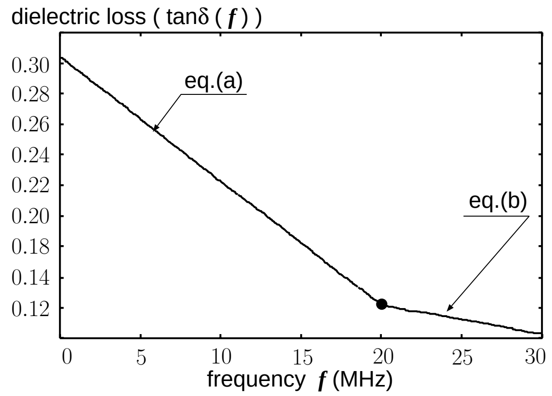
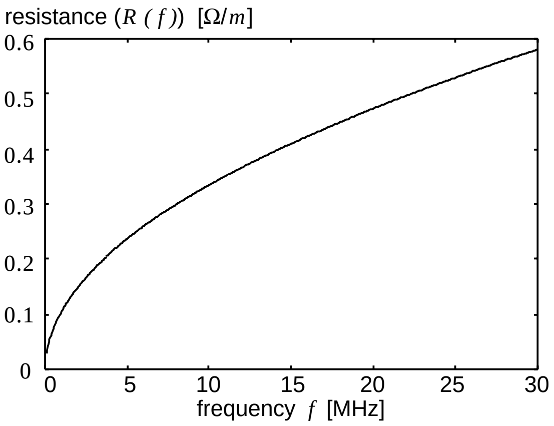
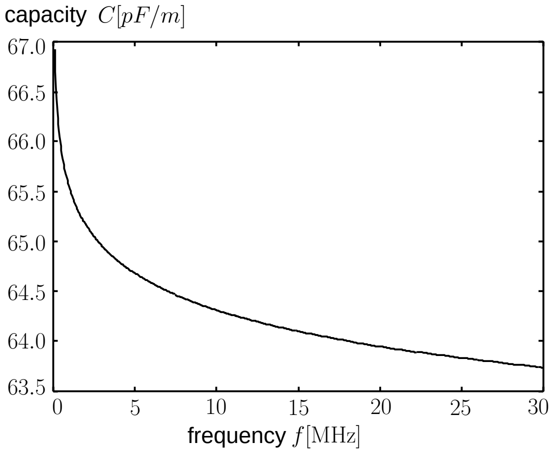


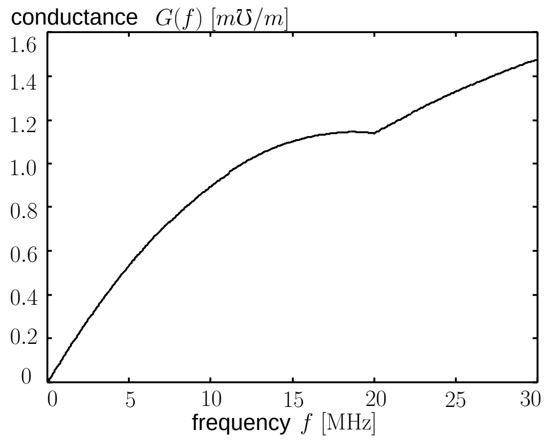
Figure 14: Dielectric loss $\tan \delta$ of the VVF cable.
eq.(a): $\tan \delta(f) = -8.119e^{-9} f + 0.3041$
eq.(b): $\tan \delta(f) = -1.872e^{-9} f + 0.1791$



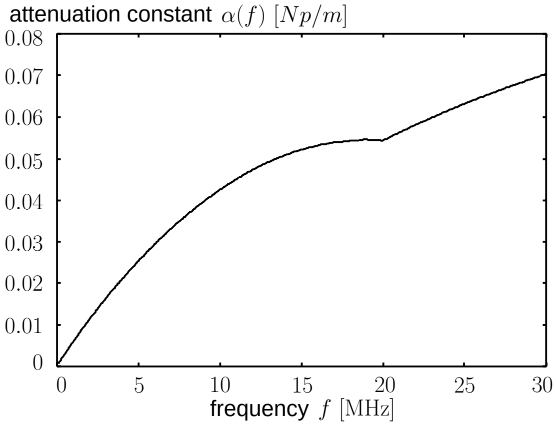
(a) Resistance R



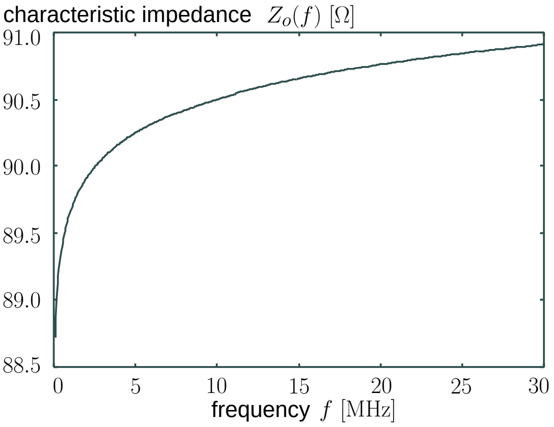
(b) Capacity C



(c) Conductance G



(d) Attenuation constant α



(e) Characteristic impedance Z_0

Figure 15: Distributed constants of the VVF cable.

5 Conclusion

In this paper, the impedance characteristics of household-appliances and power-line channels are measured in the range from 75kHz to 35MHz. It is measured that the dispersion of the individual appliances' impedance tends to decrease gradually in the range from 500kHz to 10MHz. Beyond 10MHz, the influence of an attached AC-power-supply cord appears, and the dispersion changes to increase again. The impedance of power-line changes from an increasing function to a flat one, which fluctuates around 40 ohm in our measurement, when the frequency is higher than 2MHz. It is measured that the transfer function of the channels crossing phases is almost the same as that with the same phase, when the frequency is higher than 1MHz.

The distributed constants of a VVF cable were obtained. They will be used to predict power-line channel properties from its wiring configuration.

References

[1] S.Yamamoto, S.Tsuzuki, Y.Yamada, Measurement of characteristic on indoor power-line channel, IEICE Technical Report, SST2000-55, 2000-12. (In Japanese)

[2] T.Takamatsu, S.Tsuzuki, Y.Yamada, Measurement of distributed constants of VVF Cable, IEICE Technical Report, SST2000-56, 2000-12. (In Japanese)

[3] Phase Coupling for Power Line Communications, Intellon, Application Note No.0050, http://www.intellon.com/docs/appnotes/26001087.pdf.

[4] M.Zimmermann, K.Dostert, A multi-path signal propagation model for power line channel in the high frequency range, Proc.ISPLC'99, pp.45-51, Mar./Apr., 1999.