Study on Signal Attenuation Characteristics in Power Line Communications

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Abstract

In introducing power line communication systems, the fact that the "potential of practical application cannot be evaluated in advance" is a major impediment to practical application. Therefore, in this paper, in order to obtain a mathematical model for estimating signal attenuation characteristics from power line configuration conditions, we considered the relation between power line configuration and signal attenuation characteristics based on the measurement results in actual facilities, focusing on signal attenuation characteristics.

1. Introduction

Power line communications are expected to be used when accessing transmission lines and in-house LAN since they use existing power lines and there is no need to lay communication cables. In some parts of the United States and Europe they are already in a stage of practical use, with the inclusion of demonstration experiments.

In Japan, the limit on useable signal frequencies is prescribed in the Radio Law as 450 kHz or lower, and is used for practical/commercial uses such as controlling air-conditioning equipment or lighting. However, speeds are as slow as several Kbits/s since it is a narrow band frequency, and increasing its speed is difficult. Therefore, a new method using a high frequency of 1.7-30 MHz has been suggested with the purpose of realizing high-speed communication. This method can realize a high-speed communication of several tens Mbps/s since a broadband frequency is used and, therefore, relaxation of Radio Law regulations for practical application has been under consideration by the Ministry of Internal Affairs and Communications.

However, there are some major challenges for the realization of a power line communication system, one being the possibility of causing damage to other high frequency users. This is attributed to balance-to-ground deterioration and the leakage electric field generated as radiated emissions caused by superimposing high-frequency signals in power lines. It has been reported that the intensity of the leakage electric field is closely related to the common mode current that appears in the power wire. [1]

Another challenge is the liquidity of signal attenuation characteristics (transmission characteristics) due to using power lines as a communication channel. This means that the availability of the power line communication system cannot be judged by the configuration of power lines, impeding practical application a great deal.

Among these 2 technical challenges (leakage electric field, signal attenuation characteristics), we focused our attention on signal attenuation characteristics and considered relations between power line configuration and signal attenuation characteristics, based on the actual measurement results.

In this paper, we will show the results of measurements of signal attenuation characteristics conducted on 2 buildings with different power line configurations with changing power line configuration conditions (numbers of branches, lengths of power lines).

2. Signal Attenuation Characteristics

A power line is a transmission line designed for transmitting commercial power of 50 Hz and 60 Hz frequencies, not a line designed for communications. For this reason, the signal attenuation characteristics are affected to a greater extent by cable types or wiring methods and loads connected to the cable terminals (electric equipment, wall outlets, etc.), as compared to lines of coaxial cable or twist pair cable, etc., which are used for normal wire communications.

Reflection from the terminals of branch lines on the power line is one of the major factors in signal attenuation increases. In power lines, cable types are generally different in major lines and branch lines; therefore, they have different characteristic impedances, causing mismatching. Impedance of the loads connected to the terminals also varies, and terminals are often left open. Therefore, reflection of signals occurs at the connecting points of devices (opening points) or connecting points of power lines with different cable types.

Supposing that the signal transmission speed within the power line is approximately 60% of light speed, a return loss will occur at 450 m when the signal frequency is 100 kHz. Likewise, a return loss will occur at 4.5 m when the signal frequency is 10 MHz; therefore, it is assumed that signal attenuation occurs more easily on a MHz band than on a kHz band, due to reflection. Basically, reflection is assumed to be related to the distance from the branch line to the terminals; however, since the number of branches and the distance vary and they are intricately combined in the actual power line configuration, as was previously stated, reflection occurs on various frequencies. When these coincide, a great amount of unexpected signal attenuation will occur on certain frequencies.

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3. Measurement of Signal Attenuation Characteristics in the Actual Field

3.1. Measurement Environment

We have performed measurements on 2 buildings with different power line configurations in order to grasp the signal attenuation characteristics in the field. Although both of the 2 buildings can be considered large-scale residences, the power line configuration in Fig.1 has relatively few branches, with no branching from the distribution board on each floor to the individual rooms. On the other hand, the power line configuration in Fig.2 has a relatively high number of branches, with higher floors having more branches. This is because the power line is shared among groups of rooms divided vertically.

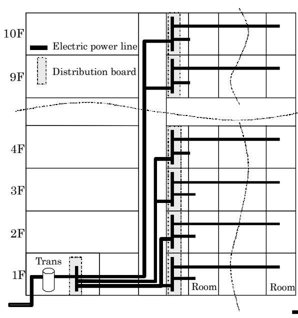

Fig.1 Power line configuration 1

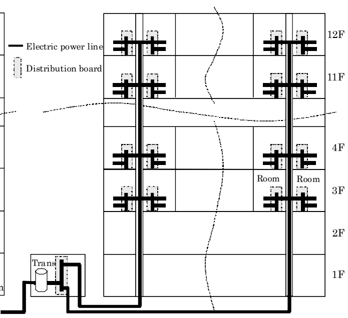

Fig.2 Power line configuration 2

3.2. Measurement Method

The measurement system described in Fig.3 was built in order to grasp signal attenuation characteristics. In this measurement system, multitone unmodulated signals simulating OFDM (Orthogonal Frequency Division Multiplexing) were input from a standard signal generator, and the signal level at each receiving point was measured to obtain the signal attenuation characteristics.

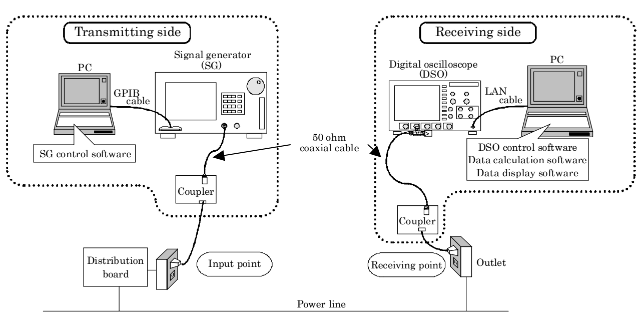

Fig.3 Measurement system

In this measurement system, the coupler acts as a balance-unbalance converter (balun). The power source for the digital oscilloscope was supplied by an outlet of a different system than that of the measurement target. The transmitting point and the receiving point were not synchronized in real-time, but were synchronized through numerical calculations.

The following are the details of the measurements.

(1) Frequency at the start of measurement 1.5 MHz
(2) Frequency at the end of measurement 30 MHz
(3) Number of measurement points 467 points (average value)
(4) Standard signal generator output 5 Vp-p (with a 50 ohm connection)

In this measurement system, the signal input point and the receiving point were altered as 23 patterns in power line configuration 1 (Fig.1) and 28 patterns in power line configuration 2 (Fig.2), and signal attenuation characteristics were obtained. Attenuation was between approximately -30 dB and -80 dB. We examined the impact of power line length and the number of branches on signal attenuation characteristics, based on the results.

4. Results

4.1. Signal Attenuation Characteristics Due to Power Line Length

In order to examine the relation between power line length and signal attenuation characteristics, 2 patterns, in which the power line length was changed in power line configuration 1 (Fig.1), were extracted. A model in which those 2 patterns were simplified so as to be compared more easily is contained in Fig.4.

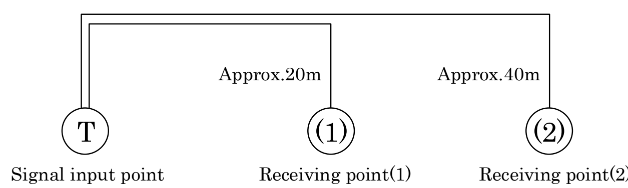

Fig.4 Differences in power line length (comparison model)

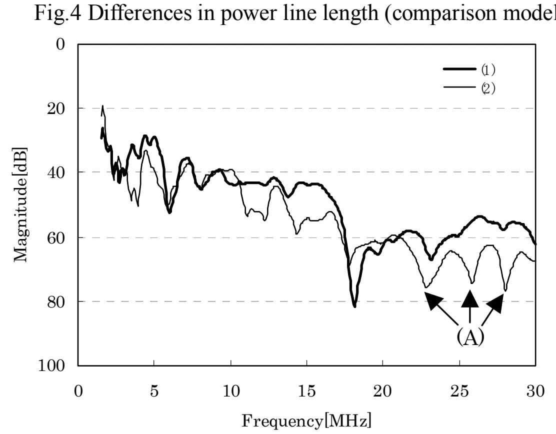

Fig. 5 Differences in power line length

A chart that shows the signal attenuation characteristics at receiving points (1) and (2), shown in Fig.4, on the same graph is shown in Fig.5. These 2 patterns have the same number of branches—almost none. (However, notice that the signal input point was the common distribution board and it has several branches around each receiving point.)

The 2 graphs show that signal attenuation is more significant when the power line is longer. Additionally, the signification attenuation of (A) is assumed to be due to reflection (multipath) at a branch point or connecting point of cables of different types. Significant signal attenuation was observed at 17-19 MHz in the graph of receiving point (1), and this is considered to be due to impedance change points or balance change points that exist in the power line.

4.2. Signal Attenuation Characteristics Due to the Number of Branches

Next, the signal attenuation characteristics of 3 patterns in power line configuration 2 (Fig.2), shown in Fig.6, were expressed on the same graph in order to examine the impact of the number of branches on signal attenuation characteristics.

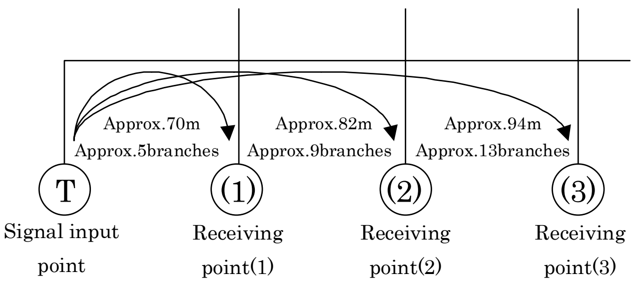

Fig.6 Difference in the number of branches (comparison model)

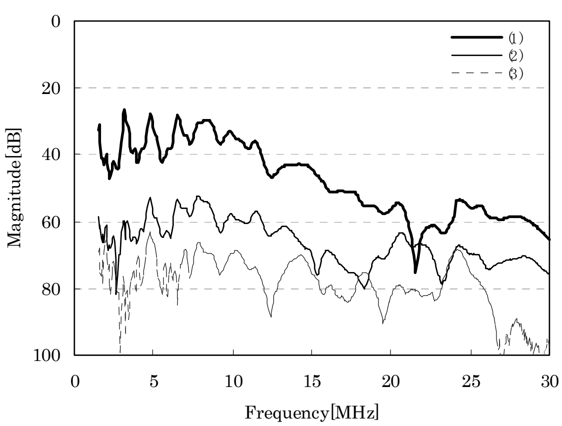

Fig.7 Difference in the number of branches

The length of the power line was changed with the changes in the number of branches; however, the change was around 12 m, and there was not much impact on signal attenuation characteristics when the difference in power line length was 20 m, as shown in Fig.5. Considering these facts, therefore, the patterns of Fig.6 seem to show the relationship between the number of branches and signal attenuation characteristics.

That signal attenuation is more significant when the number of branches is greater is shown in Fig.7. This is possibly because causes of reflection increased with the increase in the number of branches.

4.3. Signal Attenuation Characteristics When Maintaining the Same Power Line Length and Number of Branches

Subsequently, the signal attenuation characteristics of the patterns shown in Fig.8 were expressed in graphs in order to examine signal attenuation characteristics in power lines with an identical length and number of branches. Here, the measurement results from power line configuration 1 (Fig.1) were used.

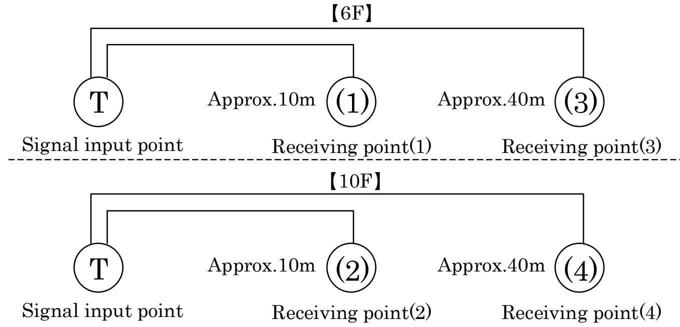

Fig.8 Identical power line length and number of branches (comparison model)

The signal attenuation characteristics on the power lines of 10 m length and 40 m lengths on the 6th and 10th floors are shown in graphs, in Fig.9 and 10 respectively.

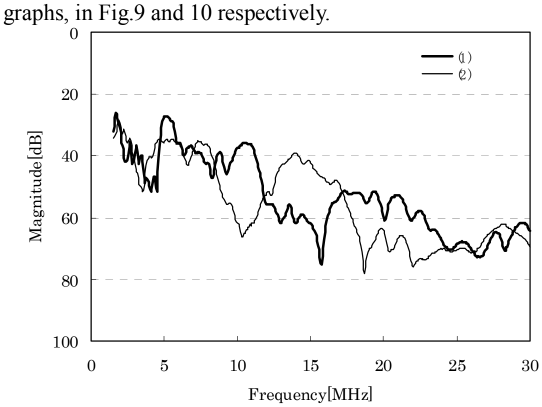

Fig.9 Identical power line length (10 m) and number of branches

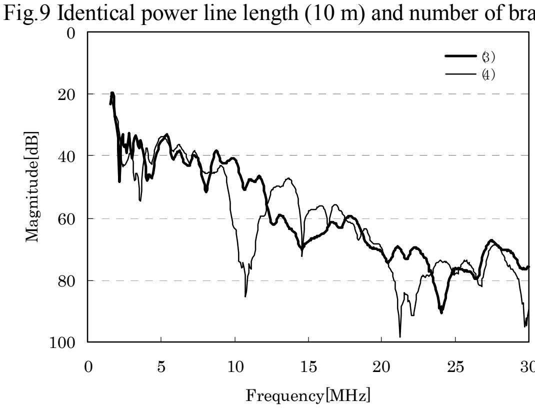

Fig.10 Identical power line length (40 m) and number of branches

Although the power line configuration conditions (power line length, number of branches) are the same in Fig.9 and Fig.10, the fluctuations of attenuation at each frequency are significantly different between them. This is likely to be attributed to the fact that signal attenuation characteristics were different due to the fact that the distribution lines and environment (time, electric equipment being operated) were not the same, even under the same conditions.

5. Discussion

5.1. Cases for Signal Attenuation

In order to discuss whether power line length or the number of branches, which had varying conditions in this study, has more impact on signal attenuation based on the measurement results, the graphs of Fig.5 and Fig.7 were expressed in linear approximation, as in Fig.11 and Fig.12 respectively.

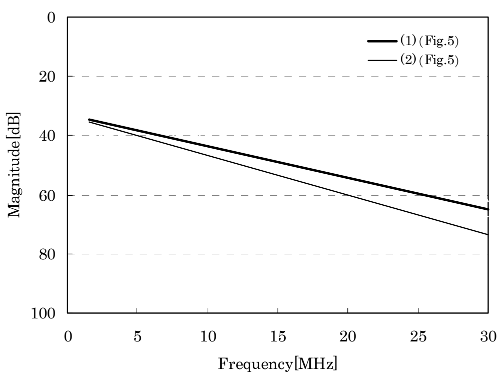

Fig.11 Linear approximation of Fig.5

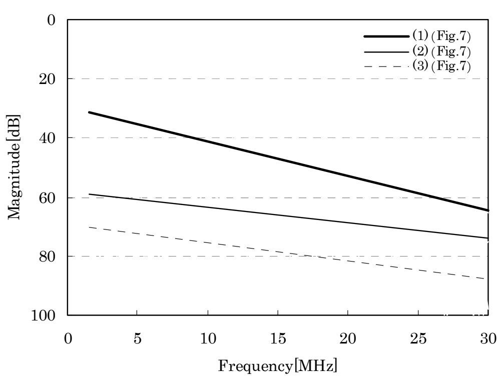

Fig.12 Linear approximation of Fig.7

Two patterns with the same number of branches but having a 20 m difference in power line length are shown in Fig.11. It is shown in the figure that attenuation is more significant when the power line is relatively long and when the frequency is higher. Three patterns are found in Fig.12 in which the number of branches is 5 for (1), 9 for (2) and 13 for (3). It is shown in the figure that attenuation becomes more significant with an increase in the number of branches. The increase of attenuation appears more significantly at lower frequencies as well, as compared to Fig.11.

Based on these facts, it can be assumed that the number of branches has a greater impact on signal attenuation when comparing power line length to the number of branches. This can be assumed from the previous statement that reflections occurring at branch points, etc., are one of the main causes for signal attenuation increase. However, the amount of data obtained at this time is not enough to verify this assumption; therefore, more actual measurement values need to be obtained for verification.

5.2. Tendencies of Signal Attenuation Characteristics When Maintaining the Same Power Line Length and Number of Branches

The signal attenuation characteristics of the power lines maintaining the same length and number of branches were shown in Fig.9 and 10. Linear approximations of those graphs are contained in Fig.13 and 14.

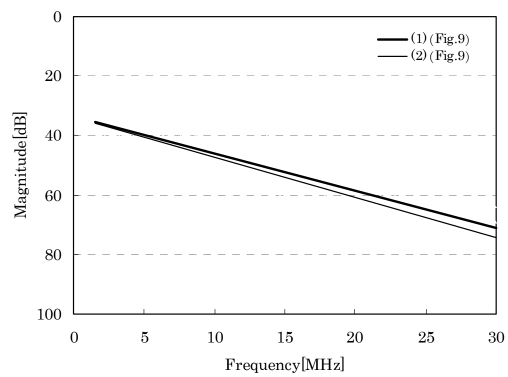

Fig.13 Linear approximation of Fig.9

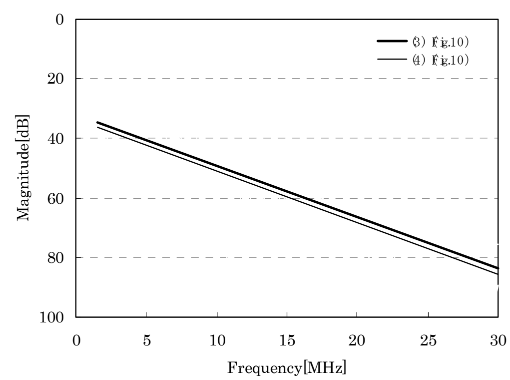

Fig.14 Linear approximation of Fig.10

The signal attenuation characteristics under power line configurations with the same number of branches are shown in Fig.13 and 14. The lengths of the power lines are 10 m in Fig.13 and 40 m in Fig.14. These graphs show that signal attenuation characteristics have very similar tendencies under the same conditions.

However, this tendency does not hold great significance in introducing power line communication systems. The reason being that, in actuality, signal attenuation fluctuates greatly due to the environment around the power lines (time, electric equipment being operated, etc.) even if the same signal attenuation tendency is shown under the same conditions and the available frequency band cannot be grasped, although the extent of signal attenuation in the available frequency band needs to be grasped so as to make a decision regarding introduction.

6. Conclusion

In introducing power line communication systems, the fact that the "potential of practical application cannot be evaluated in advance" is a major impediment to practical application. Therefore, in order to obtain a mathematical model for estimating signal attenuation characteristics from power line configuration conditions, we considered the relation between power line configuration and signal attenuation characteristics based on the measurement results in actual facilities, focusing on signal attenuation characteristics. As a result, it was found out that signal attenuation becomes more significant when power lines are longer and/or there are more branches. It also became clear that the number of branches has a greater impact on signal attenuation than power line length does.

Although the tendencies of signal attenuation are similar under the same power line configuration conditions (power line length, number of branches), the actual signal attenuation differs in each case. Therefore, conditions cause by the environment around the power lines (time, electric equipment being operated, etc.) need to be included in performing modeling.

We would like to add the connected loads (electric equipment, wall outlets, etc.) to conditions, as well as the power line length and number of branches and obtain signal attenuation characteristics, so as to propose mathematical models of signal attenuation characteristics.

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