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Investigation of Electromagnetic Noise Transmission Characteristics from AC Mains Port to Telecommunication Port

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Abstract

A method of evaluating the isolation factor from an AC mains port to a telecommunication port was investigated. Telecommunication equipment was represented by a 4-port network consisting of a pair of wire and ground. The relationship between input and output signals of the network was represented by an F-matrix and the isolation factor (ratio of input to output signals) was derived from the matrix. We developed a method of measuring the parameters and the measured values for a resistance-network agree well with calculated ones. The evaluation results of the isolation factor for three types of telecommunication equipment show that isolation for differential-mode noise from AC mains to telecommunication ports is larger than that for common-mode noise.

Key words: EMC, isolation, 4-port network, PLC, telecommunication equipment

1. INTRODUCTION

Many types of electrical equipment, which generate conducted emission, are connected to an indoor AC mains line, so electromagnetic noise (EM noise) exists on the line [1]. In addition, the electromagnetic energy on the line may increase as power line communication (PLC) systems become more common [2].

The EM noise conducted from an AC mains port to a telecommunication port of telecommunication equipment may cause some degradation in the quality of the telecommunication service because of interference between the telecommunication signal and the noise. It is important to estimate the EM noise level at the telecommunication port in order to evaluate the quality of telecommunication. However, no method of evaluating transmission characteristics between the AC mains and telecommunication ports of the equipment has yet been developed.

This paper presents a method of evaluating the transmission characteristics. Equipment having both AC mains and telecommunication ports is represented by a 4-port network and the relationship between input and output signals at each port is represented by the F-matrix. The transmission characteristics are derived from signals. The parameters of the matrix are obtained through measurement in a typical condition. The isolation factor, which means the ratio between the input signal at the AC mains port and the output signal at the telecommunication port was estimated for a PC with modem, a telecommunication terminal equipment, and a facsimile machine.

2. ANALYSIS MODEL FOR CONDUCTIVE DISTURBANCES

Figure 1 shows the indoor electromagnetic environment of the AC mains and telecommunication lines. As many types of electrical equipment are connected to an AC mains line, common-mode EM noise appears on the line. The noise propagates to a telecommunication port via the AC mains port of the telecommunication equipment (TE). Also, the communication signals of PLC systems propagate to the telecommunication port as differential-mode EM noise.

The differential-mode telecommunication signal from a telecommunication center is usually attenuated because the transmission line length from the center to a customer is longer than that of indoor communication. We should, therefore, study the transmission characteristics of the EM noise from AC mains to the telecommunication ports.

Figure 2 shows a 4-port network model for the telecommunication equipment having an AC mains port and a telecommunication port. Telecommunication equipment usually has several telecommunication ports, but we consider the simplest case in this paper.

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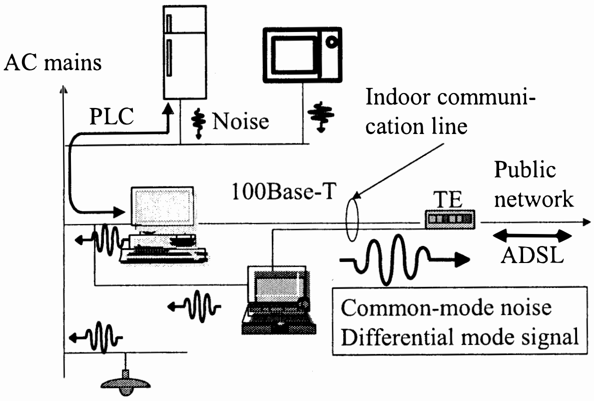


Fig. 1 Electromagnetic environment of the AC mains and

telecommunication lines.

The lines labeled #a and #b in Fig. 2 are the conductors of the AC mains cable, and the lines #c and #d are conductors of the telecommunication lines. Pairs of the lines #a and #b and lines #c and #d provide differential-mode transmission and pairs of each line and the ground provide common-mode transmission.

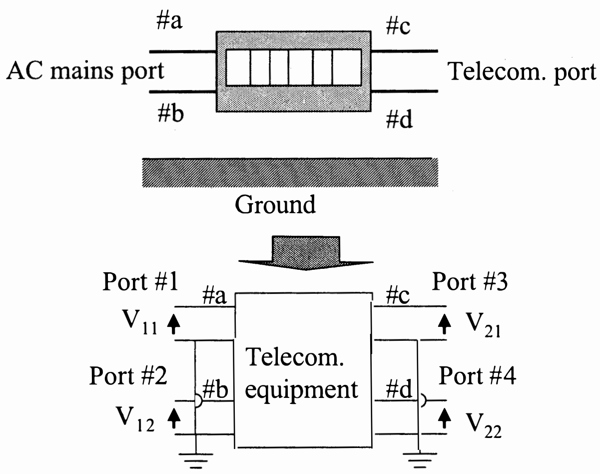


Fig. 2 4-port network model for telecommunication equipment.

At the AC mains port, the common-mode voltage V_{c1} is defined by

$$V_{c1} = \frac{V_{11}+V_{12}}{2}, \quad (1)$$

where V_{11} and V_{22} are the voltages at ports #1 and #2, respectively. The differential-mode voltage V_{d1} is defined by

$$V_{d1} = V_{11} - V_{12}. \quad (2)$$

In the same way, the differential-mode voltage V_{d2} at telecommunication port is defined by

$$V_{d2} = V_{21} - V_{22}, \quad (3)$$

where V_{21} and V_{22} are the voltages at ports #3 and #4.

From equations (1) through (3), the isolation factor (F_{cd}) for the common-mode EM noise at the AC mains port and differential-mode EM noise at the telecommunication port is given by

$$F_{cd}(dB) = 20\log_{10}\left|\frac{V_{c1}}{V_{d2}}\right|. \quad (4)$$

Using equations (2) and (3), we get the isolation factor (F_{dd}) for differential-mode EM noise at the AC mains and telecommunication ports as

$$F_{dd}(dB) = 20\log_{10}\left|\frac{V_{d1}}{V_{d2}}\right|. \quad (5)$$

3. ANALYSIS OF ISOLATION FACTOR

The model of analyzing the isolation factor is illustrated in Fig. 3. In this model, ground lines at the AC mains and telecommunication ports are represented by one common line. The EM noise at the AC mains port represented two current sources and a T-shaped network represents the internal impedance of AC mains line. The telecommunication ports are terminated by an impedance network representing the telecommunication line, and it can be represented by a 2-port network as shown in Fig. 3. The relationships between voltages and currents at the ports are represented by the F-matrix[3], which is given by

$$\begin{bmatrix}[V_1]\\[I_1]\end{bmatrix} = \begin{bmatrix}V_{11}\\V_{12}\\I_{11}\\I_{12}\end{bmatrix} = \begin{bmatrix}A_{11} & A_{12} & B_{11} & B_{12}\\A_{21} & A_{22} & B_{21} & B_{22}\\C_{11} & C_{12} & D_{11} & D_{12}\\C_{21} & C_{22} & D_{21} & D_{22}\end{bmatrix}\begin{bmatrix}V_{21}\\V_{22}\\I_{21}\\I_{22}\end{bmatrix} \quad (6)$$

$$= \begin{bmatrix}[A] & [B]\\[C] & [D]\end{bmatrix}\begin{bmatrix}[V_2]\\[I_2]\end{bmatrix}$$

We should get the relationship between the current source and voltages at the ports to calculate the isolation factor. The model is simplified to calculate the relationships as shown in Fig. 4. The internal impedance of AC mains line is included in the telecommunication equipment box.

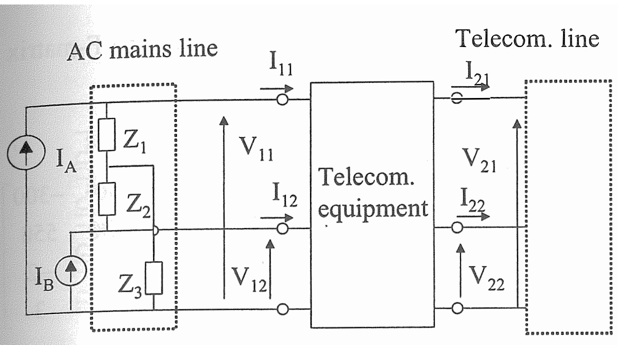


Fig. 3 Analysis model for isolation factor.

The 2-port network representing telecommunications line is converted to a 4-port network as shown in Fig. 4. In this model, the relationships between voltages and current at each port are given by

$$\begin{cases} V_{21} = V_{31} = V_a \\ V_{22} = V_{32} = V_b \\ I_{21} = I_a + I_{31} \\ I_{22} = I_b + I_{32} \end{cases} . \qquad (7)$$

From equation (7), the F-matrix of the 4-port network is given by

$$\begin{bmatrix} V_{21} \\ V_{22} \\ I_{21} \\ I_{22} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ Y_{11} & Y_{12} & 1 & 0 \\ Y_{21} & Y_{22} & 0 & 1 \end{bmatrix} \begin{bmatrix} V_{31} \\ V_{32} \\ I_{31} \\ I_{32} \end{bmatrix}, \qquad (8)$$

where Y_{**} is the admittance matrix of the 2-port network. It is defined by

$$\begin{bmatrix} I_a \\ I_b \end{bmatrix} = \begin{bmatrix} Y_{11} & Y_{12} \\ Y_{21} & Y_{22} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \end{bmatrix}. \qquad (9)$$

The relationships between V_{11}, V_{12}, V_{31}, and V_{32} can be obtained by connecting the two series F-matrices, giving by

$$\begin{bmatrix} [V_1] \\ [I_1] \end{bmatrix} = \begin{bmatrix} [A] & [B] \\ [C] & [D] \end{bmatrix} \begin{bmatrix} [E] & [0] \\ [Y] & [E] \end{bmatrix} \begin{bmatrix} [V_3] \\ [0] \end{bmatrix} = \begin{bmatrix} [A]+[B][Y] & [B] \\ [C]+[D][Y] & [D] \end{bmatrix} \begin{bmatrix} [V_2] \\ [0] \end{bmatrix} \qquad (10)$$

where $[E]$ indicates the unit matrix, [0] indicates zero matrix, and $[I_1]$ is the current source, which is given by

$$[I_1] = \begin{bmatrix} I_A \\ I_B \end{bmatrix}. \qquad (11)$$

Then, voltage $[V_2]$ can be obtained as

$$[V_2] = \left[[C]+[D][Y]\right]^{-1}[I_1]. \qquad (12)$$

Using equation (10), voltage $[V_1]$ is also obtained as

$$[V_1] = \left[[A]+[B][Y]\right]\left[[C]+[D][Y]\right]^{-1}[I_1]. \qquad (13)$$

In this paper, we use $I_A = -I_B = 1$ for calculating F_{dd}, and $I_A = I_B = 1$ for calculating F_{cd}. The isolation factor is derived from equations (4), (5), (12), and (13). [A], [B], [C], [D], and [Y] in equations (12) and (13) are measured for a typical line condition.

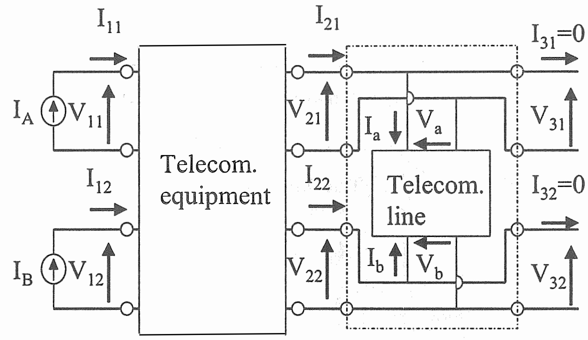


Fig. 4 Simplified model for calculating isolation factor.

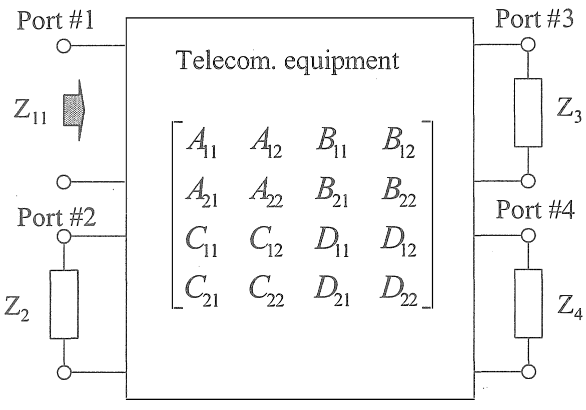
4. MEASUREMENT

4.1 Method of measuring F-matrix parameters

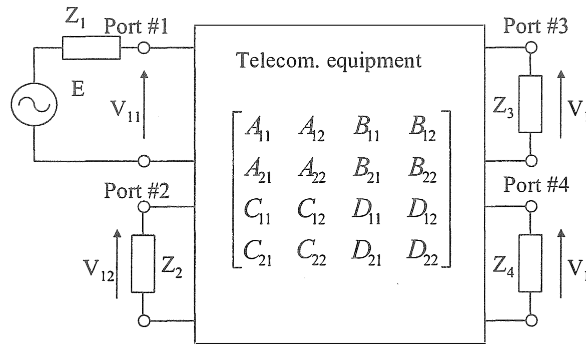
The method of measuring F-matrix parameters is shown in Fig. 5. First, we measure the input impedance Z_{11} at port #1 when other ports are terminated by impedance as shown in Fig. 5(a). Next, we measure the transmission characteristics from port #1 to ports #2, #3, and #4, as shown in Fig. 5(b) and get the following four equations.

$$\begin{cases} \dfrac{Z_{11}}{Z_o + Z_{11}} = A_{11}\dfrac{V_{21}}{E} + A_{12}\dfrac{V_{22}}{E} + B_{11}\dfrac{V_{21}}{EZ_3} + B_{12}\dfrac{V_{22}}{EZ_4} \\ \dfrac{V_{12}}{E} = A_{21}\dfrac{V_{21}}{E} + A_{22}\dfrac{V_{22}}{E} + B_{21}\dfrac{V_{21}}{EZ_3} + B_{22}\dfrac{V_{22}}{EZ_4} \\ \dfrac{1}{Z_o + Z_{11}} = C_{11}\dfrac{V_{21}}{E} + C_{12}\dfrac{V_{22}}{E} + D_{11}\dfrac{V_{21}}{EZ_3} + D_{12}\dfrac{V_{22}}{EZ_4} \\ -\dfrac{V_{12}}{EZ_2} = C_{21}\dfrac{V_{21}}{E} + C_{22}\dfrac{V_{22}}{E} + D_{21}\dfrac{V_{21}}{EZ_3} + D_{22}\dfrac{V_{22}}{EZ_4} \end{cases} \qquad (14)$$

Equation (14) indicates that we can use the measurement results for the conversion factor which are more accurate than the voltage measurements. In the same way, we get four independent equations for ports #2, #3 and #4. Finally, we get sixteen independent equations. Solving these equations, we can determine the F-matrix parameters.



(a) Input impedance measurement method



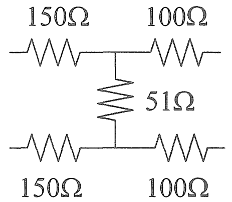
(b) Transmission characteristics measurement method

Fig. 5 Method of measuring 4-port network parameters.

4.2 Validation of the F-matrix parameters measurement method

To validate the method of measuring the F-matrix parameters, we measured the parameters of the resistance-network shown in Fig. 6 and compared to theoretical values also shown in Fig. 6.

The measurement results are shown in Fig. 7. A gain-phase analyzer (HP4194) with impedance probe was used to measure the input impedance and conversion factor. Measurements were carried out from 10 kHz to 100 MHz. Figure 7(a) through 7(d) show absolute values of A_{11}, A_{12}, A_{21}, and A_{22}, B_{11}, B_{12}, B_{21}, and B_{22}, C_{11}, C_{12}, C_{21}, and C_{22}, and D_{11}, D_{12}, D_{21}, and D_{22}, respectively. Phase angles of the parameters are within 10 degrees up to 30 MHz. The measured values agree well with the calculated values. This means that the method presented in this paper is suitable for measuring the F-matrix parameters.



$$\begin{bmatrix} 4 & -3 & 550 & -300 \\ -3 & 4 & -300 & 550 \\ 0.02 & -0.02 & 3 & -2 \\ -0.02 & 0.02 & -2 & 3 \end{bmatrix}$$

Fig. 6 4-port network for the measurement method validation.

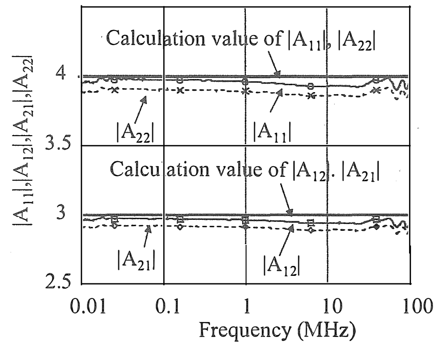


Fig. 7(a) Measured values of 4-port parameters ($|A_{11}|$, $|A_{12}|$, $|A_{21}|$,$|A_{22}|$ values).

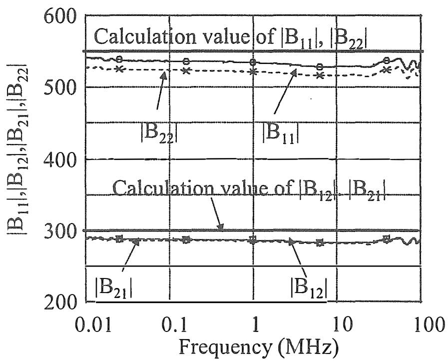


Fig. 7(b) Measured values of 4-port parameters ($|B_{11}|$, $|B_{12}|$, $|B_{21}|$,$|B_{22}|$ values).

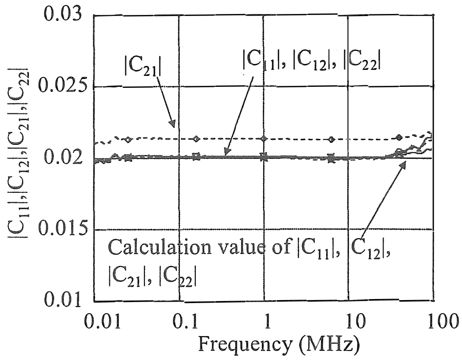


Fig. 7(c) Measured values of 4-port parameters

(|C_{11}|, |C_{12}|, |C_{21}|,|C_{22}| values).

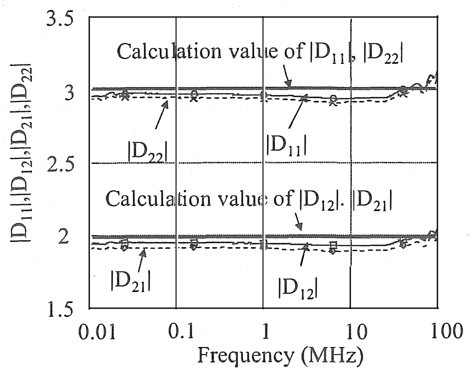


Fig. 7(d) Measured values of 4-port parameters (|D_{11}|, |D_{12}|, |D_{21}|,|D_{22}| values).

4.3 Isolation factor of the network

The isolation factor of the resistance-network was calculated using measured F-matrix parameters. We used a T-shaped network consisting of three impedances to represent the telecommunication line as a 2-port network. Common-mode and differential-mode impedances of the T-shaped network were 150 Ω and 100 Ω, respectively. Since the isolation factor is significantly affected by the parameters representing the telecommunication line, the value of longitudinal conversion loss (LCL) [4] is considered to determine the impedance elements of the T-shaped network.

The impedance value of the T-shaped network, Z_1, Z_2, and Z_3 and the LCL value are determined by

$$Z_1 + Z_2 = 100 \quad (15)$$

$$Z_3 + \frac{Z_1 Z_2}{Z_1 + Z_2} = 150 \quad (16)$$

$$LCL = 20\log\left|-\frac{Z_1 - Z_2}{2(Z_1 + Z_2)} + \frac{2(Z_1 + Z_2) + 4Z_3}{Z_1 - Z_2}\right|. \quad (17)$$

LCL values of 80 and 30 dB were selected for the calculation.

Calculated results are shown in Fig. 8. The calculated values were obtained using the theoretical F-matrix parameters shown in Fig. 6. The calculated value of F_{cd} for LCL of 80 dB is quite different from the measured value (Fif. 8 (b)). We think the difference originates from the deviation in resistance values between theoretical and measurement conditions. The calculated values for LCL of 30 dB, where the influence of the resistance value deviation is small, almost agree with the measured values. As for the F_{dd} value, the influence of the LCL value is very small.

Taking the comparison results into consideration, the method described in this paper is suitable for estimating the isolation factor of the telecommunication equipment.

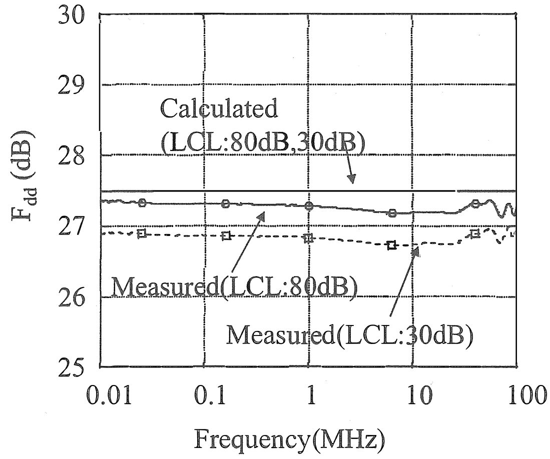


Fig. 8(a) Calculated values of F_{dd} values for the network shown in Fig. 6.

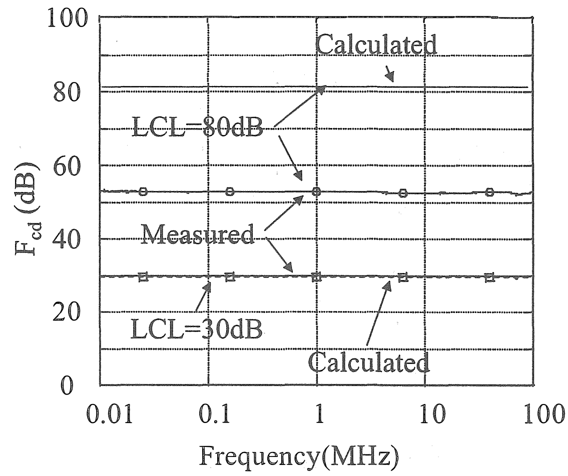


Fig. 8(b) Calculated values of F_{cd} values for the network shown in Fig. 6.

5. ISOLATION FACTOR FOR SAMPLE EQUIPMENT

We measured F_{dd} and F_{cd} are measured for three types of telecommunication equipment: a personal computer with an analog modem (EUT1), an ADSL modem (EUT2) and a facsimile machine (EUT3) to evaluate the isolation of actual equipment.

Figure 9 shows the measured isolation factor between the differential-mode noise at AC mains and telecommunication ports. EUTs were placed 40 cm above a metallic ground plane. The reference plane for the measurement was placed 80 cm away from the EUT on the ground plane. The same setup was used for measuring the network shown in Fig. 6. The F-matrix parameters were measured from 10 kHz to 100 MHz.

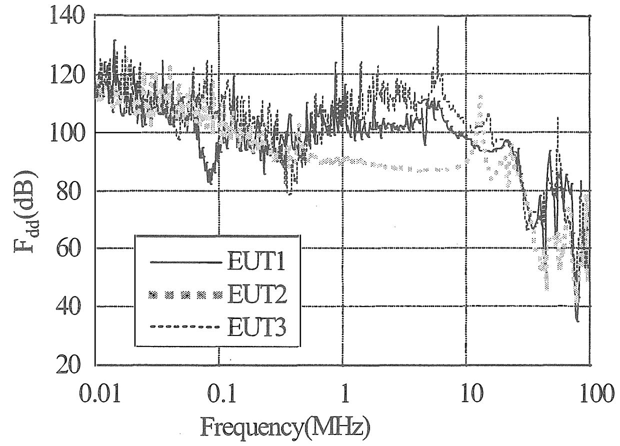


Fig. 9 Evaluation results for isolation factor between differential-mode EM noise at AC mains and telecommunication ports.

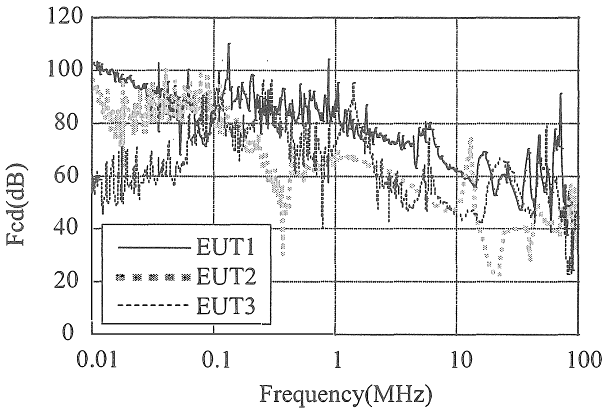


Fig. 10 Evaluation results for the isolation factor between common-mode EM noises at AC mains and telecommunication ports.

Figure 9 shows that the differential-mode isolation factors of the EUTs are almost the same and are less than 80 dB up to 20 MHz. This means that the isolation for the differential-mode noise transmission is sufficiently high.

Figure 10 shows that the common-mode isolation factors are more than 40 dB up to 20 MHz. The isolation factor of EUT1 is the highest. The reason may be became EUT1 uses an AC adaptor.

Figures 9 and 10 show that the common-mode noise at the AC mains port is more important than the differential-mode noise with regard to interference between the telecommunication signal and the types of noise.

6. CONCLUSION

We investigated a method of evaluating the isolation factor between AC mains and telecommunication ports of telecommunication equipment.

Telecommunication equipment was represented by a 4-port network. The F-matrix of the network shows the relationships between the input and output signals. F-matrix parameter measurement method was developed based on network theory, and was validated by comparing measured and theoretical values of the resistance-network.

The isolation factors for three types of telecommunications equipment were measured. The results show that the differential-mode and common-mode isolation factors were more than 80 and 40 dB, respectively, up to 20 MHz and common-mode noise at the AC mains port is more important than differential mode noise for the interference between telecommunication signals and the noise at the telecommunication port.

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