Development of circuit model of AC/coaxial adapter using for calibration of AMN

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Abstract: Transmission characteristics of an AC/coaxial adapter that is used for calibration of an AMN had been evaluated up to 30 MHz, which is the upper limit of frequency in the use of conventional AMNs. However, the new type AMNs for using over 30 MHz has been developed, thus the transmission characteristics of the adapter beyond 30 MHz should be evaluated. In this paper, a circuit model of the AC/coaxial adapter is developed in order to obtain easily its transmission characteristics up to 1 GHz. The calculated characteristics using the developed circuit model agreed well with that of simulated by using a numerical electromagnetic analysis.

Keywords: AC/coaxial adapter, circuit model, artificial mains network

Classification: Electromagnetic compatibility (EMC)

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1 Introduction

In recent years, energy-efficient equipment such as a power conditioner and LED bulbs have been rapidly spread by higher awareness for energy conservation. The energy is conserved by using a high-efficient power supply switching circuit in the equipment. However, the switching circuit often cause an electromagnetic disturbance over a wide frequency range from kHz to GHz [1]. Since this disturbance may interfere in the other electronics devices and broadcastings, the measurement of the disturbance is necessary.

An artificial mains network (AMN) [2] is used for measuring the conducted disturbance voltage below 30 MHz. Fig. 1(a) shows an example of conducted disturbance measurement using the AMN. As shown in the figure, an equipment under test (EUT) and a measuring receiver are connected to the AMN. The AMN supplies AC power to the EUT and transmits the disturbance occurring in the EUT to the measuring receiver. To obtain measurements result of the disturbance voltage, fundamental characteristics of the AMN such as the AMN impedance and the voltage division factor [2] need to be evaluated. Fig. 1(b) shows an example schema of AMN's characteristics measurement. As shown in the figure, the AC/coaxial adapter [3] is used for connecting the AC outlet of the AMN to a vector network analyzer. Thus, the measured characteristics of the AMN include the characteristics of the adapter. The characteristics of the adapter should be evaluated for obtaining the characteristics of the AMN without the adapter.

The characteristics of the adapter had been evaluated up to 30 MHz which is the upper limit frequency of the conducted disturbance measurement using the conventional AMN [3, 4, 5]. However, since the conducted disturbance measurement of over 30 MHz is required by the above background, new type AMN for using up to 1 GHz has been developed [6]. Therefore, the characteristics should be also evaluated beyond 30 MHz.

In this paper, we develop a new circuit model of the adapter for obtaining the transmission characteristics of the adapter beyond 30 MHz. Although the characteristics of the adapter can be also evaluated by using a 3D electromagnetic simulation, it is difficult to clarify the phenomenon from the result in the simulator. On the other hand, the circuit model can reduce a calculation cost for obtaining the characteristics and clarify the phenomenon. The characteristics obtained by the developed circuit model are compared with those of an electromagnetic simulation to clarify the validity of the developed circuit model.

Fig. 1. General outline of AMN and AC/coaxial adapter.

2 Developed circuit model of AC/coaxial adapter

2.1 Structure

Fig. 1(c) shows an AC/coaxial adapter. This adapter consists of two coaxial connectors, an AC plug, and a metal plate. The neutral and the phase lines connect directly each inner conductor of the connector. The protective earth (PE) line connects each outer conductors of the connector through the metal plate.

Fig. 2 shows the developed circuit model of the adapter. The AC plug can be treated as a transmission line because it consists of the conductors having uniform cross-section. There are three conductor lines #1, #2 and #3 above the infinite ground plane (GND) as shown in Fig. 2(a). The lines #1 and #2 represent the neutral and the phase lines, and the line #3 represents the PE line. Input ports of the lines #1, #2 and #3 are defined as port 1, 2, and 3, respectively. Output ports of the lines #1, #2 and #3 are defined as port 4, 5, and 6, respectively. The dimensions of the cross-section shown in Fig. 2(b) meet the JIS standard [7], and “ h ” is the height between the line #3 and GND. The two adapters which are connected as a back-to-back state will be measured because the ports of the adapter should be coaxial shape for connecting the vector network analyzer. Hence, a line length of the model is 34 mm which means the length of twice the AC plug. The equivalent circuit shown in Fig. 2(c) is lossless, and a telegrapher’s equation of the circuit is given by Eq. (1).

$$-\frac{d}{dx} \begin{bmatrix} V(x) \\ I(x) \end{bmatrix} = j\omega \begin{bmatrix} \mathbf{O} & \mathbf{L} \\ \mathbf{C} & \mathbf{O} \end{bmatrix} \begin{bmatrix} V(x) \\ I(x) \end{bmatrix} \quad (1)$$

Here, $\mathbf{O}$ is a square zero matrix. $V(x)$ and $I(x)$ are vectors of line voltages and currents, respectively. $\mathbf{L}$ and $\mathbf{C}$ are inductance and capacitance matrices, respectively.

Fig. 2. The developed circuit model of the adapter.

2.2 Evaluation method

The F matrix of the AC plug F is derived from Eq. (1) using the state variable method [8]. Here, the values of L and C are analyzed by “ANSYS Q3D Extractor” which is the commercially-available code of parameter extraction. When each input port’s voltages and currents are defined as V_1 , V_2 , V_3 , I_1 , I_2 and I_3 , and each the output port’s voltages and currents are defined as V_4 , V_5 , V_6 , I_4 , I_5 and I_6 , the relation between the voltages and the currents are given by Eq. (2).

$$\begin{bmatrix} V_1 \\ V_2 \\ V_3 \\ I_1 \\ I_2 \\ I_3 \end{bmatrix} = F \begin{bmatrix} V_4 \\ V_5 \\ V_6 \\ I_4 \\ I_5 \\ I_6 \end{bmatrix} \quad (2)$$

The adapter is excited by voltage difference between the neutral and PE lines or the phase and PE lines. The input voltages of the neutral and the phase lines are newly defined as V'_1 and V'_2 , and the output voltages are also defined as V'_3 and V'_4 . These defined voltages are given by Eq. (3).

$$\begin{aligned} V'_1 &= V_1 - V_3, & V'_2 &= V_2 - V_3 \\ V'_3 &= V_4 - V_6, & V'_4 &= V_5 - V_6 \end{aligned} \quad (3)$$

The currents which flow in the neutral and the phase lines return in the PE line. Therefore, the relation of the currents is shown Eq. (4)

$$I_1 + I_2 = -I_3, \quad I_4 + I_5 = -I_6 \quad (4)$$

Then, a new F matrix F' is derived by using Eqs. (3) and (4) that express the voltages and the currents conditions of the adapter. The relation between the voltages and currents using F' are given by Eq. (5).

$$\begin{bmatrix} V'_1 \\ V'_2 \\ I_1 \\ I_2 \end{bmatrix} = F' \begin{bmatrix} V'_3 \\ V'_4 \\ I_4 \\ I_5 \end{bmatrix} \quad (5)$$

The transmission characteristics of the adapter are evaluated by S matrix converted from F' .

3 Validation of developed circuit model

Fig. 3(a) shows an analysis model of the AC/coaxial adapters which are connected as a back-to-back state. All conductors of the analysis model are considered as perfect electric conductors. The dimensions of the coaxial connector are designed so that its characteristic impedance is 50 Ohm, and that of AC plugs are the same as the developed circuit model mentioned in Section 2. Also, the two inner conductors of the connectors are extended to avoid contact of the metal plate with the neutral/phase lines as shown in Fig. 3(a). The 4-port S-parameters of the analysis model are numerically simulated by using the 3D electromagnetic simulator “HFSS”, in a case of changing the height “ h ” between the PE line and the GND.

(a) An analysis model the adapters which are connected as a back-to-back state

(b) S-parameters at $h=10\text{mm}$

(c) S-parameters at $h=50\text{mm}$

Fig. 3. The calculated S-parameters of the adapter using the developed circuit model.

Fig. 3(b) and (c) show the calculated S-parameters of the adapter using the developed circuit model in cases of $h = 10$ mm and 50 mm. As shown in the figures, the calculated characteristics using the model agree with the simulated one using the electromagnetic simulation regardless of h . This result shows the validity of the developed circuit model. The transmission characteristic $|S_{31}|$ of the adapter keeps 0 dB in less than 30 MHz. Thus, the adapter affects hardly the characteristics of the conventional AMN. However, the characteristic $|S_{31}|$ decreases in a case where the frequency exceeds 30 MHz by increasing the reflection and the coupling between the neutral/phase lines. It is found that the adapter affect the characteristics of the new type AMN for using over 30 MHz.

4 Conclusions

In this paper, the circuit model of the adapter was developed for obtaining easily its transmission characteristics. The calculated S-parameters of the adapter using the developed circuit model were compared with the simulated one using the electromagnetic simulator. As a result, both S-parameters agreed well regardless of the height between the adapter and the GND. Therefore, the validity of the developed circuit model was indicated. Furthermore, it was found that the adapter affects the characteristics of the new type AMN for using over 30 MHz because the transmission characteristics of the adapter decrease due to its reflection and coupling characteristics. In future works, a balance and an impedance of the adapter will be evaluated by using the developed circuit model, and an influence of the adapter for the AMN will be evaluated.

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