Comparative analysis of various AC/coaxial adapters for LISN calibration up to 1 GHz

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Abstract: There are various types of AC/coaxial adapter for line impedance stabilization network (LISN) calibration because the AC plug used differs among countries. The difference in the characteristics of the adapters may be large at a high frequency such as 1 GHz; thus, their characteristics should be compared. In this paper, the transmission characteristics of one-phase AC/coaxial adapters for Japan (A-type) and UK and some Asian countries (BF and B3-types, respectively) are compared using their equivalent circuit models. The following two results are obtained: (1) the BF-type most strongly affects the LISN calibration, and (2) the transmission coefficient of the A-type is the least affected by the reference ground.

Keywords: AC/coaxial adapter, calibration, equivalent circuit, line impedance stabilization network (LISN), transmission line theory

Classification: Electromagnetic Compatibility (EMC)

References


1 Introduction

A line impedance stabilization network (LISN) is used for conducted disturbance measurement on mains lines, and its upper limit frequency is 30 MHz [1]. In recent years, however, the LISN for measurements up to 1 GHz has been studied because measurements above 30 MHz have also been required owing to the electromagnetic interference over a wide frequency range from kilohertz to gigahertz caused by green electronics [2]. LISN calibration is important to obtain accurate disturbance measurement results. As an example of the calibration, an LISN impedance measurement setup is shown in Fig. 1. In the measurement, the AC/coaxial adapter shown in the figure is needed to connect a vector network analyzer to the AC outlet of the LISN. Since the measured LISN characteristics include the adapter characteristics, the latter should be evaluated and eliminated from the measured LISN characteristics for the accurate LISN calibration.

Although various studies on the evaluation of adapters up to 30 MHz have been reported [3, 4], the evaluation above 30 MHz has hardly been carried out. Moreover, there are various types of adapter because the AC plug used differs among countries, but their characteristics have hardly been compared. The characteristics differ for each adapter, and the difference in these characteristics may become large with increasing frequency; thus, their comparison at high frequencies is important.

The authors proposed an equivalent circuit model of an adapter up to 1 GHz [5]. The proposed model treats the one-phase AC plug for Japan as the transmission line model because it consists of three-conductors with a uniform cross-section. The AC plugs used in other countries also consist of conductors with a uniform cross-section as with the Japanese AC plug; therefore, the proposed model is useful for the characterization of various adapters.

In this paper, the transmission characteristics of three one-phase adapters are compared using the proposed model.
2 Equivalent circuit model of AC/coaxial adapter

Fig. 2(a) shows the structure of an AC/coaxial adapter. This adapter consists of two coaxial connectors, an AC plug, and a metal plate with two strip lines. The strip lines embedded in the metal plate connect the neutral/phase lines (#1 and #2) and each inner connector. The protective earth (PE) line (#3) connects the outer conductors of the connectors via the metal plate. Fig. 2(b) shows the dimensions of three AC plugs. As an example, the three adapters for Japan (A-type) and UK and some Asian countries (BF- and B3-types, respectively) are chosen. Here, $h$ is defined as the height between the PE line and the reference ground (GND). Fig. 2(c) shows the equivalent circuit of the adapter [5]. This equivalent circuit is the cascade arrangement of three circuits: the coaxial connector, the metal plate, and the AC plug. The AC plug is represented as the three-conductor transmission lines above the GND, in which the currents flowing in the neutral/phase lines return to the PE line. The circuit of the metal plate consists of the two strip lines and the two capacitors $C_{NM}$ and $C_{PM}$ respectively expressing the coupling between the neutral/phase lines and the metal plate. In this paper, the equivalent circuit is considered as a lossless.
3 Comparison of transmission characteristics

3.1 Evaluation method

To obtain the matrix of the \( \text{ABCD} \) parameters for the adapter \( F_{\text{adapter}} \), the matrices of the \( \text{ABCD} \) parameters for the coaxial connector, the metal plate, and the AC plug, namely, \( F^c \), \( F^M \), and \( F^p \), respectively, are derived [5]. The matrix of the \( \text{ABCD} \) parameters for the transmission line can be derived by the state variable method [6]. When \( x^p \) is the line length of the AC plug, \( F^p \) is given by

\[
F^p = \exp \left( j \omega x^p \begin{bmatrix} O & L^p \\ C^p & O \end{bmatrix} \right)
\]

(1)

where \( O \) is the square zero matrix; \( L^p \) and \( C^p \) are the per-unit-length inductance and capacitance matrices of the AC plug given by the following symmetric matrices:

\[
L^p = \begin{bmatrix} L^p_{11} & L^p_{21} \\ L^p_{21} & L^p_{22} \end{bmatrix}, \quad C^p = \begin{bmatrix} C^p_{11} + C^p_{21} & -C^p_{21} \\ -C^p_{21} & C^p_{22} + C^p_{21} \end{bmatrix}
\]

(2)

with the self- and mutual inductances \( L_{ij}^p \) and the capacitances \( C_{ij}^p \). In the same manner, \( F^c \) is given by
\[ F_c = \exp\left(j\omega x^c \begin{bmatrix} O & L^c \\ C^c & O \end{bmatrix}\right) \]  
(3)

where \( x^c \) is the line length of the coaxial connector; \( L^c \) and \( C^c \) are the per-unit-length inductance and capacitance matrices of the two coaxial connectors:

\[ L^c = \begin{bmatrix} L^c & 0 \\ 0 & L^c \end{bmatrix}, \quad C^c = \begin{bmatrix} C^c & 0 \\ 0 & C^c \end{bmatrix}. \]  
(4)

Moreover, \( F^M \) can be obtained as the following equation from the circuit of the metal plate shown in Fig. 2(b):

\[ F^M = \exp\left(j\omega x^s \begin{bmatrix} O & L^M_s \\ C^M_s & O \end{bmatrix}\right)\begin{bmatrix} U & O \\ j\omega C^M & U \end{bmatrix}. \]  
(5)

Here, \( U \) is the unit matrix; \( x^s \) is the line length of the strip line; \( L^M_s \) and \( C^M_s \) are the per-unit-length inductance and capacitance matrices of the two strip lines; \( C^M \) is the matrix of the two capacitors \( C^M_N \) and \( C^M_P \). \( L^M_s \), \( C^M_s \) and \( C^M \) are given by

\[ L^M_s = \begin{bmatrix} L^M_s & 0 \\ 0 & L^M_s \end{bmatrix}, \quad C^M_s = \begin{bmatrix} C^M_s & 0 \\ 0 & C^M_s \end{bmatrix}, \quad C^M = \begin{bmatrix} C^M_N & 0 \\ 0 & C^M_P \end{bmatrix}. \]  
(6)

Therefore, \( F^{\text{adapter}} \) is obtained using the following matrix:

\[ F^{\text{adapter}} = F_c \cdot F^M \cdot F^p. \]  
(7)

Finally, the matrix of the S-parameters for them when the reference impedance is 50 ohm is derived from \( F^{\text{adapter}} \).

### 3.2 Evaluation result

Fig. 3(a) shows the calculated transmission characteristics of the three AC/coaxial adapters at \( h = 10 \) mm. Here, the circuit parameters of the coaxial connector and the strip line are selected so that their characteristics impedance is 50 ohms. The two capacitances \( C^M_N \) and \( C^M_P \) between the neutral/phase lines and the metal plate are 1 pF, as an example, and the circuit parameters of the three AC plugs are obtained using the circuit parameter extraction simulator Q3D Extractor [7]. Since the three transmission coefficients \( |S_{31}| \) remain at 0 dB up to 100 MHz, the three adapters hardly affect the LISN calibration below 100 MHz. In contrast, above 100 MHz, their coefficients decrease with increasing frequency, so the three adapters seriously affect the LISN calibration. Moreover, it has been found that these decreases differ for each adapter, where that of the BF-type is the largest. Therefore, the BF-type is the most strongly affects the LISN calibration.

The impact of the GND on the adapters is also investigated. Fig. 3(b) shows the deviations in each transmission coefficient at \( h = 10 \) mm from the coefficient of each adapter without the GND. Here, a large deviation value means that the GND strongly affects the coefficient. As shown in the figure, since the deviation of the A-type is the smallest, it has been found that the A-type is the least affected by the GND.
In this paper, the transmission characteristics of three one-phase AC/coaxial adapters for Japan (A-type) and UK and some Asian countries (BF and B3-types, respectively) were compared using their equivalent circuit models formed by the transmission line theory. It was found that the three adapters affected the LISN calibration above 100 MHz. It was also found that the impact of the calibration differs for each adapter and that the BF-type most strongly affects the calibration. Moreover, the impact of the reference ground on the adapters was investigated. The result indicated that the A-type is the least affected by the ground. In future works, the impact of the difference in these characteristics on the calibration will be evaluated.

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