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A Study on Jig Fabricated by Microstrip Line for S-Parameter Method

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1. Introduction

In recent years, many wireless telecommunication services have spread over the world. It is known that the characteristics of conventional antennas, such as monopole antennas, change considerably when the body of the handset is touched by the hand. This is caused by the variation of the current on the surface of the conducting box used for the handset due to human body influence. To decrease the influence of the human body, a balanced fed antenna is suggested [1]. The input impedance of the balanced antenna is measured conventionally by using a balun that forces opposite currents into each part of the radiation element. Generally, due to the narrow available bandwidth, balun is not suitable for the measurement of the wideband balanced antenna. Recently, the S-parameter method is proposed to measure the balanced impedance of the antenna using a jig instead of the balun, and two ports of a vector network analyzer (VNA) [2-3]. We examined the S-parameter method with calibration cables and a jig fabricated by semi-rigid cable [4].

In this paper, to improve the measurement precision, a jig fabricated by microstrip line is examined. The microstrip line fabricated using a milling machine increases machining accuracy and reproducibility. Three compensating methods using ABCD-matrix, called open-correction, short-correction, and open-short-correction, are applied to eliminate the influence of the jig for the S-parameter method. The wideband input impedance of a dipole antenna, which is one of typical balanced fed antennas, is measured using our proposed methods, and are compared with a measured result using a jig fabricated by semi-rigid cable and a calculated results using the moment method.

2. S-Parameter Method

Figure 1 shows the dipole antenna, which is one of the balanced fed antennas. Using the impedance matrix of the two-port network as shown in Fig. 2, the equation for the dipole antenna is given by

$$\left.\begin{aligned} V_1 &= Z_{11}I_1 + Z_{12}I_2 \\ V_2 &= Z_{21}I_1 + Z_{22}I_2 \end{aligned}\right\}. \tag{1}$$

When the dipole antenna is fed by a balanced source, the currents that flow on the two radiation elements are $I = I_1 = -I_2$. Because the differential voltage is $V_d = V_1 - V_2$, the input impedance Z_{in} is expressed as follows using the Z-parameter, in addition, this can be converted into S-parameter and ABCD-parameter.

$$\begin{aligned} Z_{in} &= V_d / I = Z_{11} - Z_{12} - Z_{21} + Z_{22} \\ &= 2Z_0 \frac{(1-S_{12})(1-S_{21}) - S_{11}S_{22}}{(1-S_{11})(1-S_{22}) - S_{12}S_{21}} \\ &= \frac{1}{C}(A + D - AD + BC - 1) \end{aligned} \tag{2}$$

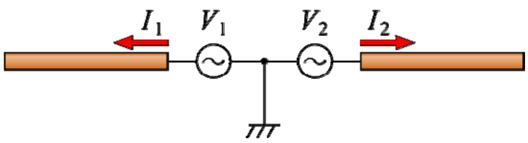


Figure 1: Dipole antenna.

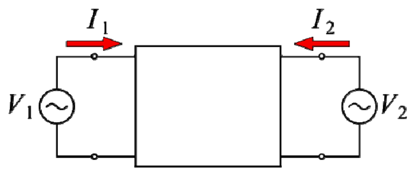


Figure 2: Two-port network.

3. Measurement Method

Figures 3 and 4 show the geometry of jig for measurement and the fabricated jig. The jig is composed of two dielectric substrates with dimension of 24 x 11 x 0.4 mm^3 , the dielectric constant of 2.25. A microstrip line with the characteristic impedance of 50 Ω is printed on the dielectric substrate, and a SMA receptacle is soldered to one end of the microstrip line. Four corners of the dielectric substrates facing the ground each other are fixed with the screw, as shown in Fig. 4. Then, the radiation element of the balanced antenna is soldered to the other end of the microstrip line, as shown in Fig. 5. In this study, the jigs connected to port 1 and port 2 of VNA are called jig #1 and #2, respectively.

Figure 6 shows the circuit diagram with an antenna connected to the jig for measurement in a two-port network configuration. The ABCD-matrix K of the antenna is obtained by removing the ABCD-matrices of the jigs K_{J1} and K_{J2}, from the ABCD-matrix K' that is between the calibration planes. The matrix K' can be determined by substituting the measured results of the S-parameter at the calibration planes in Eqn. (3).

$$K' = \begin{bmatrix} \dfrac{(1+s_{11})(1-s_{22})+s_{12}s_{21}}{2s_{21}} & \dfrac{(1+s_{11})(1+s_{22})-s_{12}s_{21}}{2s_{21}} \\ \dfrac{(1-s_{11})(1-s_{22})-s_{12}s_{21}}{2s_{21}} & \dfrac{(1-s_{11})(1+s_{22})+s_{12}s_{21}}{2s_{21}} \end{bmatrix} \qquad (3)$$

Therefore, the matrix K of the antenna is determined from Eqn. (4) using K_{J1} and K_{J2} explained in next section.

$$K = K_{J1}^{-1} K' K_{J2}^{-1} \qquad (4)$$

Finally, the input impedance of the balanced antenna can be obtained by substituting the ABCD-parameter of Eqn. (4) in Eqn. (2).

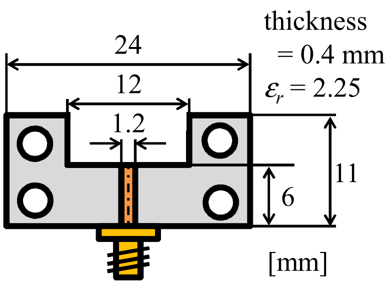


Figure 3: Geometry of jig.


Figure 4: Fabricated jig.

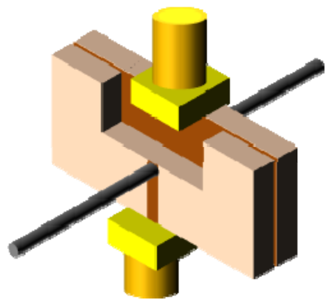


Figure 5: Antenna with jig.

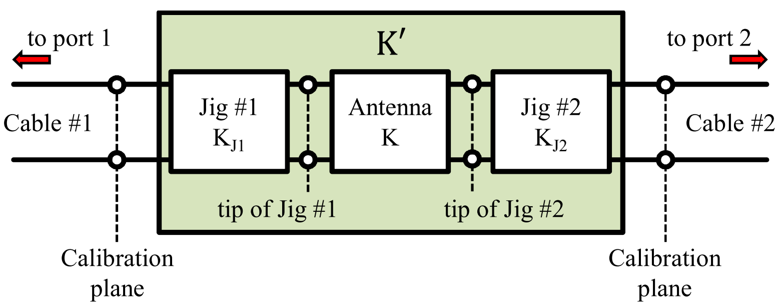


Figure 6: Equivalent circuit diagram of antenna with jig.

3.1 Open-correction

Open-correction is a method for determining the ABCD-parameter using the input impedance of the jig terminated in an open circuit and the characteristic impedance of the cable for the jig. Accordingly, it is necessary to make the jig of two transmission lines.

Figure 7 shows the circuit diagram of the jig considered as two transmission lines. The complex propagation constant and characteristic impedance of both cables are γ and Z_0. The lengths of the cables are l_1 and l_2. When the jig #1 is terminated in load impedance Z as shown in Fig. 7, the input impedance Z_1 of jig #1, seen looking toward the load from the calibration plane, is expressed in Eqn. (5).

$$Z_1 = Z_0 \frac{Z + Z_0 \tanh \gamma l_1}{Z_0 + Z \tanh \gamma l_1} \tag{5}$$

When the jig is terminated in an open circuit, the measured input impedance of jig #1, is defined as Z_{1O}. Because $Z = \infty$ is substituted in Eqn. (5), Z_{1O} can be expressed as follows.

$$Z_{1O} = Z_0 / \tanh \gamma l_1 \tag{6}$$

The hyperbolic functions $\sinh \gamma l_1$ and $\cosh \gamma l_1$ can be derived using $\cosh^2 \gamma l_1 - \sinh^2 \gamma l_1 = 1$ and Eqn. (6). Thus, the ABCD-matrix of the jig #1 can be written as Eqn. (7).

$$\mathrm{K_{J1}} = \frac{1}{\sqrt{Z_{1O}{}^2 - Z_0{}^2}} \begin{bmatrix} Z_{1O} & Z_0{}^2 \\ 1 & Z_{1O} \end{bmatrix} \tag{7}$$

This method, used to obtain the ABCD-matrix of the jig, is called the open-correction method, since the input impedance for the open circuit load and the characteristic impedance are used to drive the matrix. The ABCD-matrix of the jig #2 $\mathrm{K_{J2}}$ can be obtained as $\mathrm{K_{J1}}$.

3.2 Short-correction

Similarly, when the jig #1 is terminated in a short circuit, the measured input impedance of jig #1 is defined as Z_{1S}. Because $Z = 0$ is substituted in (5), Z_{1S} can be defined as follows.

$$Z_{1S} = Z_0 \tanh \gamma l_1 \tag{8}$$

Thus, by using the measured input impedance for short-circuited jig and the characteristic impedance of the jig, the ABCD-matrix of the jig #1 for the short-correction can be written as (9).

$$\mathrm{K_{J1}} = \frac{1}{\sqrt{Z_0{}^2 - Z_{1S}{}^2}} \begin{bmatrix} Z_0 & Z_0 Z_{1S} \\ Z_{1S}/Z_0 & Z_0 \end{bmatrix} \tag{9}$$

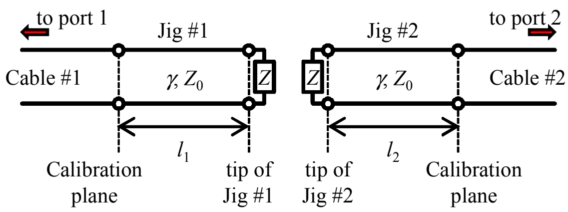


Figure 7: open-correction and short-correction.

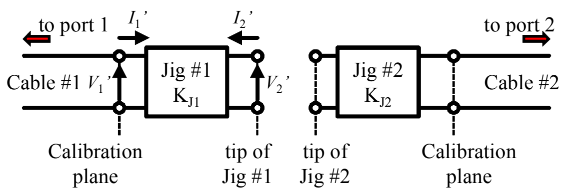


Figure 8: open-short-correction.

3.3 Open-Short-correction

Open-short-correction is a method for determining the ABCD-matrices $\mathrm{K_{J1}}$ and $\mathrm{K_{J2}}$ using the input impedance when the jig is terminated in an open and a short circuit. Figure 8 shows the circuit diagram of a measuring jig expressed by the ABCD-matrix. The input impedance Z_1, with respect to the calibration plane, is expressed as follows.

$$Z_1 = \frac{V_1'}{I_1'} = \frac{A_1 V_2' + B_1 I_2'}{C_1 V_2' + D_1 I_2'} \tag{10}$$

When the jig terminated in an open circuit, $I_2' = 0$, and the corresponding input impedance is $Z_{1O} = A_1 / C_1$. On the other hand, when the jig terminated in an short circuit, $V_2' = 0$, and the corresponding input impedance is $Z_{1S} = B_1 / D_1$. Because the jig is a symmetrical circuit $(A_1 = D_1)$, the ABCD-matrix $\mathrm{K_{J1}}$ is given by (11).

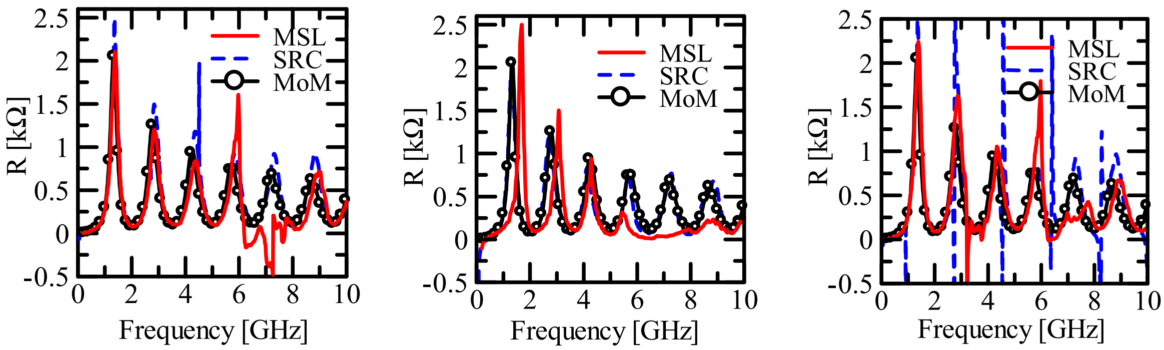
$$\mathrm{K_{J1}} = A_1 \begin{bmatrix} 1 & Z_{1S} \\ 1/Z_{1O} & 1 \end{bmatrix} \tag{11}$$

Because it is also a reciprocal circuit $(A_1 D_1 - B_1 C_1 = 1)$, we have $A_1 = \sqrt{Z_{1O} / (Z_{1O} - Z_{1S})}$.

4. Results and Discussion

Typical results for the S-parameter method are presented for a dipole antenna. Two pieces of copper wire with length of 99.6 mm and diameter of 0.35 mm are soldered onto the microstrip line of jig #1 and #2 fabricating the dipole antenna to be measured. To discuss the accuracy of the measured result of the S-parameter method using the jig fabricated by microstrip line (MSL), the calculated result using the method of moments (MoM) and the measured result of the S-parameter method using the conventional jig fabricated by semi-rigid cable (SRC) [4] are also shown. Same measured input impedance of the jig for the open circuit load and short circuit load, and same measured S-parameter of the dipole antenna are used to obtain the result of the S-parameter method compensated by the three correction methods.

Figure 9 shows the real part of the input impedance of the dipole antenna. It is seen in Fig. 9 (a) that the measured result of the S-parameter method calibrated by the open-correction agrees with the simulated result at less than about 5.5 GHz. The measured result using SRC has periodical discrepancy at higher resistance and a sharp peak at 4.5 GHz. Regarding the short-correction, the measured result using MSL corresponds approximately with the simulated result at about 4 GHz. It seems that there is a problem in the short circuit load of microstrip line. On the other hand, the result of SRC and the simulated result are in very good agreement. Regarding the open-short-correction, it is observed that sharp peaks are occurred in both jigs.



(a) Open-correction (b) Short-correction (c) Open-Short-correction

Figure 9: Measured input resistance of S-parameter method.

5. Conclusion

In this paper, to improve the measurement precision, a jig fabricated by microstrip line for the S-parameter method was examined. Three compensating methods called open-correction, short-correction, and open-short-correction, have been adopted to compensate for the influence of the jig. The effects of the jig were examined by comparing them with measured results using a jig fabricated by semi-rigid cable and a calculated result using the method of moments.

References

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