Calibration of Impedance Measurement of a Balanced Antenna Using the 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. Therefore, the measured result of the input impedance of the balanced antenna includes the influence of the balun. However, an S-parameter method is suggested 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].

In this paper, three methods, open-correction, short-correction, and open-short-correction are suggested for compensating for the influence of a jig on the measurement by the S-parameter method. The effects of the three methods are examined by comparing them with the calculated result using the moment method for the input impedance of a dipole antenna. In addition, errors that occur because of the length of the jig are removed by making calibrations using a calibration cable that is almost the same length as the jig.

2. S-parameter method

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

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

When the dipole antenna is fed by a balanced source, the currents that flow in 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.

$$Z_{in} = V_d / I = z_{11} - z_{12} - z_{21} + z_{22}. \tag{2}$$

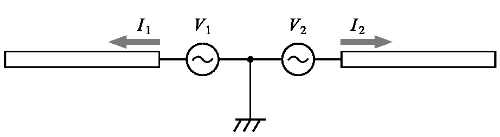


Figure 1: The dipole antenna.

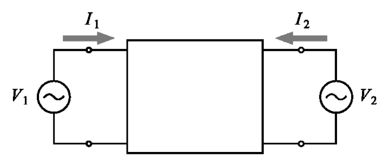


Figure 2: The two-port network.

3. Measurement method

3.1 Structure of the jig

Figure 3 shows the jig used in this study for measurement using the S-parameter method. The jig is made up of two RG405 semi-rigid cables. The cable is connected with an SMA connector to one end, while the other end has its inner conductor exposed. The jig is then formed by soldering the outer sleeves of the two cables together, as shown in Figure 3. As shown in Figure 4, the connectors of the jig are connected to the cable, and the exposed inner conductors of the jig are soldered to the radiation elements of the dipole antenna.

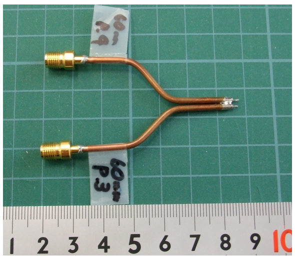


Figure 3: Jig for measuring.

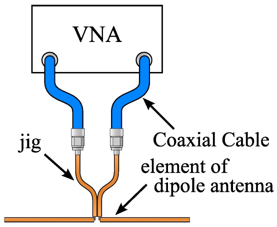


Figure 4: Measuring the dipole antenna.

3.2 Calibration of the influence of the jig

Figure 5 shows the circuit diagram with an antenna connected to the jig for measurement in a two-port network configuration. In this paper, the cascade matrix K of the antenna is obtained by removing the cascade matrices of the jigs K_{J1} and K_{J2}, from the cascade matrix K' that is between the calibration surfaces. The matrix K' can be determined by substituting the measured results of the S parameters at the calibration surfaces in Equation (3).

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

Therefore, the matrix K of the antenna is determined from Equation (4) using K_{J1} and K_{J2}.

$$\mathrm{K} = \mathrm{K}_{\mathrm{J1}}^{-1}\,\mathrm{K}'\,\mathrm{K}_{\mathrm{J2}}^{-1}. \tag{4}$$

In the next section, we explain three methods for determining the cascade matrices K_{J1} and K_{J2}.

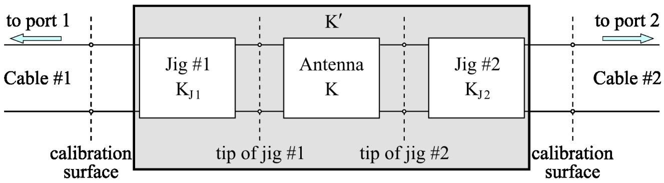


Figure 5: Equivalent circuit schematic of the antenna with the measuring jig.

3.2.1 Open-correction and short-correction

Open-correction and short-correction are methods for determining the cascade matrices K_{J1}, K_{J2} using the input impedance when the jig is terminated in an open or a short circuit, respectively.

Figure 6 shows the jig considered as a transmission line. As mentioned above, the jig is made up of two cables jig #1 and #2. 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. The input impedance Z_1 of jig #1, seen looking toward the load, is expressed in Equation (4).

$$Z_1 = Z_0 \frac{Z + Z_0 \tanh \gamma l_1}{Z_0 + Z \tanh \gamma l_1}. \tag{4}$$

The measured input impedance of jig #1, when the jig is terminated in an open circuit, is defined as Z_{1O}. Because $Z = \infty$ is substituted for Equation (4), Z_{1O} can be expressed as follows.

$$Z_{1O} = Z_0 / \tanh \gamma l_1 . \tag{5}$$

Thus, $\tanh \gamma l_1$ can be determined as

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

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 Equation (6). The matrix K_{J1} of the jig #1 can be determined by substituting these hyperbolic functions in Equation (7).

$$\mathrm{K}_{\mathrm{J1}} = \begin{bmatrix} \cosh \gamma l_1 & \sinh \gamma l_1 \\ \sinh \gamma l_1 & \cosh \gamma l_1 \end{bmatrix}. \tag{7}$$

This method, used to obtain the cascade matrix of the jig, is called the open-correction method, since the input impedance for the open circuit load is used to drive the matrix.

Similarly, when the jig #1 is terminated in a short circuit, the measured input impedance is defined as Z_{1S}. Because $Z = 0$, $\tanh \gamma l_1$ can be expressed in Equation (8) from Equation (4).

$$\tanh \gamma l_1 = \sinh \gamma l_1 / \cosh \gamma l_1 = Z_{1S}/Z_0 . \tag{8}$$

The matrix K_{J1} can be determined by substituting the hyperbolic functions $\sinh \gamma l_1$ and $\cosh \gamma l_1$ in Equation (7). This method is called the short-correction.

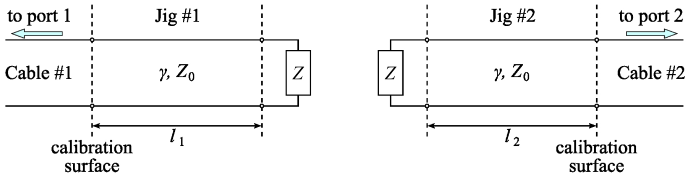


Figure 6: Circuit diagram of open-correction and short-correction.

3.2.2 Open-short-correction

Open-short-correction is a method for determining the cascade matrix of the jig using both input impedances for the open circuit load, and short circuit load. The equivalent circuit of the jigs is supposed that is an L-type circuit as shown in Figure 7. When the tip of the jig is short-circuited, the corresponding input impedance is Z_{1S}. And when the tip of the jig is open-circuited, the corresponding input impedance is Z_{1O}. For the jig #1, the Z-matrix of the L-type circuit is expressed by Equation (9).

$$\mathrm{Z}_{\mathrm{J1}} = \begin{bmatrix} Z_{1S} + Z_{1O} & Z_{1O} \\ Z_{1O} & Z_{1O} \end{bmatrix}. \tag{9}$$

When this is converted into a cascade matrix, we obtain Equation (10).

$$\mathrm{K}_{\mathrm{J1}} = \begin{bmatrix} (Z_{1S} + Z_{1O})/Z_{1O} & Z_{1S} \\ 1/Z_{1O} & 1 \end{bmatrix}. \tag{10}$$

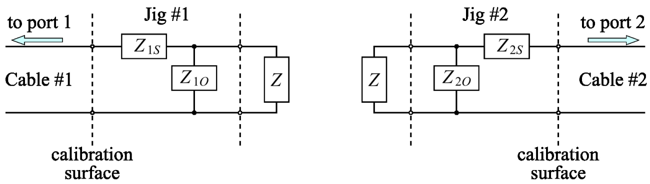


Figure 7: Circuit diagram of open-short-correction.

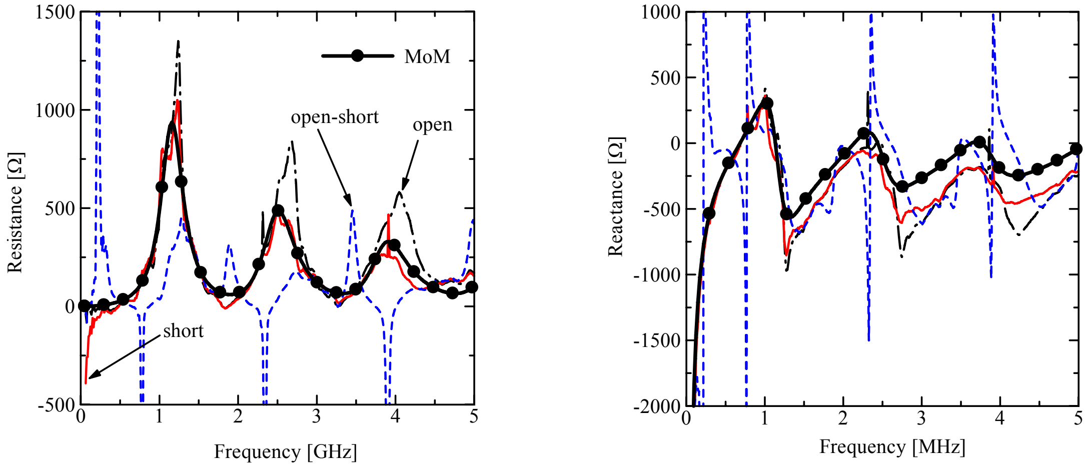
4. Measurement Results

Figure 9 shows the compensated results of the input impedance of the dipole antenna using three methods. The total length and the diameter of the radiation elements of the dipole antenna are 206 mm and 2 mm. Three types of compensation are performed using the same measured data. A calculated result using the moment method is also shown for comparison. It can be seen that the error grows large where the resistance becomes large due to anti-resonance. It is difficult to remove error using the S-parameter method since the measured results of the VNA, which is a 50 Ω system, tend to include the error at high-resistance from the start. In addition, peak-shaped errors can be observed at 750 MHz, 2,400 MHz, and 3,900 MHz. It is understood that the anti-resonance frequency is larger when the cable length of the jig is shorter. In this paper, to remove the error at the anti-resonance frequency, we calibrate the VNA using two calibration cables that are almost the same length as the cable of the jig, with SMA connectors at both ends of the calibration cables.

Figure 10 shows the measured input impedance of a dipole antenna, when the calibration cables are used for the calibration. A calculated result using the moment method is also shown for comparison. It is obvious that the peak-shaped errors at the anti-resonance frequencies have disappeared. The compensated results of the short-correction and the open-short-correction tend to agree well with the calculated results using the moment method over the wider range of frequencies.

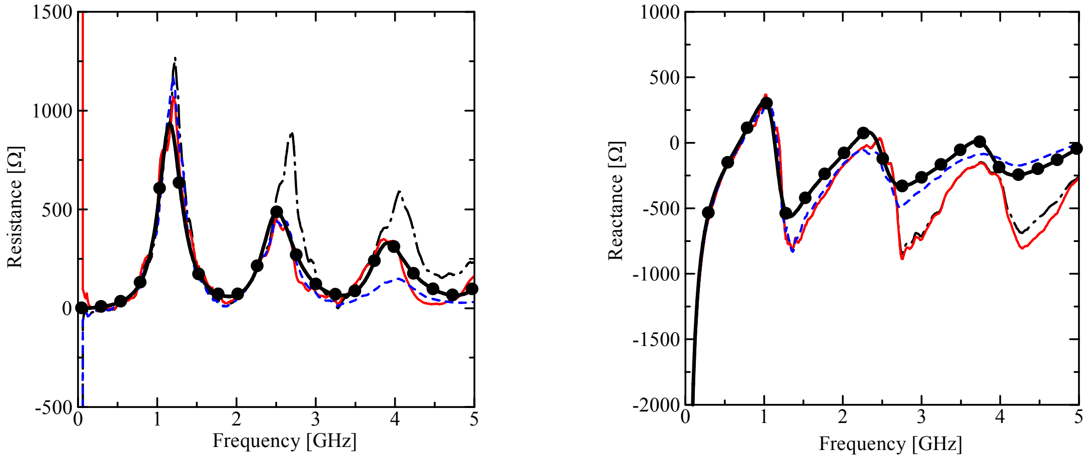
5. Conclusions

In this paper, three methods have been proposed to compensate for the influence of a jig on measurements by the S-parameter method. The effects of the three methods were examined by comparing them with the calculated results using the moment method for the input impedance of a dipole antenna which is one of the balanced fed antennas. In addition, errors caused by the anti-resonance of the jig were removed by carrying out a calibration using the calibration cable. The results of the short-correction and the open-short-correction agreed quite well with the calculated results using the moment method over the wider range of frequencies.



(a) Resistance (b) Reactance

Figure 9: The input impedance of the dipole antenna.



(a) Resistance (b) Reactance

Figure 10: Input impedance when used as a cable for calibration.

References

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