Measurement Jig Using Semi-Rigid Cable for Differential Impedance Measurement by S-Parameters

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***Abstract*— Recently, the S-parameter method using a vector network analyzer and a measurement jig instead of a balun was proposed whereby the differential input impedance of a balanced-fed antenna were obtained. As no balun is used, measuring impedance over a wide frequency bandwidth is now possible. To improve measurement accuracy of the S-parameter method, the dependence on thickness of the semi-rigid cable used for the measurement jig is obtained from the results of calculations using the FDTD method. Two types of jigs each made from semi-rigid cables of differing thickness were fabricated, and the input impedance of the dipole antenna calculated using the S-parameter method. The impedances were compared with those obtained from the available theories by King and calculation results of delta-gap-fed dipole antennas. Results from the S-parameter method agree with the available theories by King and the calculated results of the conventional model of a dipole antenna, over a range of about 6 GHz or less.**

Keywords—S-parameter method, balanced fed antenna, input impedance, modified open correction, measurement jig, semi-rigid cable

I. INTRODUCTION

As wireless handsets are often in contact with hands during use, the characteristics of conventional antennas, such as monopole antennas, change considerably [1], [2]. To mitigate this hand influence, a balanced fed antenna was proposed [3]. To measure the balanced impedance of the antenna, the S-parameter method has been developed that uses a jig instead of a balun, and the two ports of a vector network analyzer (VNA) [4], [5]. Because no balun is used, it is possible to measure impedances over a wide frequency bandwidth. However, if the measured frequency rises, measurement accuracy decreases because in measurements the influence of the jig cannot be disregarded. To account for this jig influence, we proposed a modified open correction that uses the ABCD-matrix [6].

To improve the measurement accuracy of the S-parameter method, the influence of thickness of the semi-rigid cables used for the measurement jig is assessed using calculations developed within the FDTD method. Two types of jigs were fabricated from semi-rigid cables of different thicknesses, and the input impedance of the dipole antenna calculated using the S-parameter method. The input impedance obtained by the S-parameter method is compared with the available theories developed by King and a calculation result of a dipole antenna fed by a delta-gap feed.

II. FORMULATION OF S-PARAMETER METHOD

A dipole antenna is one type of balanced-fed antenna (Fig. 1). Using the impedance matrix for a two-port network (Fig. 2), the dipole antenna satisfies the circuit equations

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

If the dipole antenna is fed by a balanced source, the currents that flow on the two radiating elements are $I = I_1 = -I_2$. Because the differential voltage is $V_d = V_1 - V_2$, the input impedance Z_{in} is expressible in terms of the impedance parameters or can be converted into the ABCD parameters, specifically

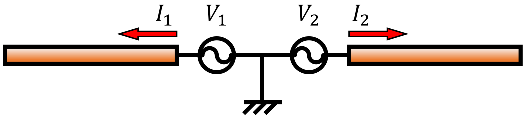


Fig. 1. Diagram of a dipole antenna.

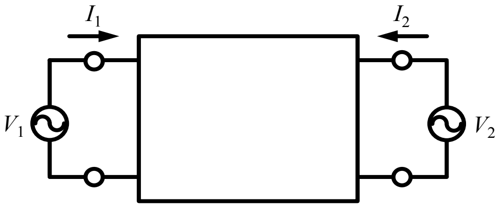


Fig. 2. Diagram of a two-port network.

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

Because a balanced-fed antenna has a symmetric geometry, the two-port network is both a symmetric circuit ($A = D$) and a reciprocal circuit ($AD - BC = 1$). Therefore, (2) reduces to

$$Z_{in} = \frac{2}{C}\left(A - 1\right). \tag{3}$$

III. CALIBRATION METHOD OF MEASUREMENT JIG

A diagram is given of the measurement system for the input impedance of a balanced antenna using the S-parameter method (Fig. 3). Each port of the balanced antenna is connected to one of the ports of the VNA using a measurement jig.

Figure 4 is a photo of a measurement jig which comprises jigs #1 and #2 made of semi-rigid coaxial cables. When the VNA is calibrated at the connector of the test cable using the SOLT calibration technique, the port extension which is a function of VNA or ABCD-matrix compensation is used to extend the measurement reference plane to the end of the jig. ABCD-matrix compensation, called the modified open correction, is performed to eliminate the influence of the measurement jig.

Figure 5 shows the circuit diagram of an antenna connected to a jig for measurement in a two-port network configuration. The ABCD-matrix K' representing transmission between the calibration planes can be determined by substituting the S-parameter measured by VNA in (4).

$$\mathrm{K}' = \begin{bmatrix} \dfrac{(1+S_{11})(1-S_{22})+S_{12}S_{21}}{2S_{21}} & \dfrac{(1+S_{11})(1+S_{22})-S_{12}S_{21}}{2S_{21}} \\ \dfrac{(1-S_{11})(1-S_{22})-S_{12}S_{21}}{2S_{21}} & \dfrac{(1-S_{11})(1+S_{22})+S_{12}S_{21}}{2S_{21}} \end{bmatrix} \tag{4}$$

In regarding Fig. 5, the characteristics of the jigs that are included in K'. Thus, the ABCD-matrix K of the antenna can be obtained by removing the ABCD-matrices of jigs #1 and #2, as given by

$$\mathrm{K} = \mathrm{K}_{\mathrm{J1}}^{-1}\,\mathrm{K}'\,\mathrm{K}_{\mathrm{J2}}^{-1}. \tag{5}$$

Consequently, the input impedance of a balanced antenna can be obtained when the ABCD-parameter of matrix K is substituted into (3).

In the modified open correction method, the ABCD-parameters of the jig is determined by using input impedance of transmission line terminated in an open circuit and load impedance at open end of the transmission line [6]. At the calibration plane, the input impedance Z_{in} of the transmission line looking toward the load impedance Z_L is

$$Z_{in} = Z_0 \frac{Z_L + Z_0 \tanh \gamma l}{Z_0 + Z_L \tanh \gamma l}, \tag{6}$$

where Z_0, γ, and l denote the characteristic impedance, propagation constant, and length of the transmission line, respectively. $Z_L = \infty$ is substituted in (6) in the open correction method. Although the load impedance is assumed to be infinite in the derivation of open correction, it actually has a finite value. We have proposed the modified open correction method, which does consider the influence of the load impedance Z_L. The ABCD-matrix that eliminates the influence of jig #*n* (*n*=1, 2) including the influence of the load impedance at the open end of the jig is given by

$$\mathrm{K}_{Jn} = \frac{1}{\sqrt{\left(Z_L{}^2 - Z_0{}^2\right)\left(Z_{Open-n}{}^2 - Z_0{}^2\right)}} \times \begin{bmatrix} Z_{Open-n}Z_L - Z_0{}^2 & Z_0{}^2\left(Z_L - Z_{Open-n}\right) \\ Z_L - Z_{Open-n} & Z_{Open-n}Z_L - Z_0{}^2 \end{bmatrix} \tag{7}$$

where Z_{Open-n} is an input impedance of the open end jig #*n*.

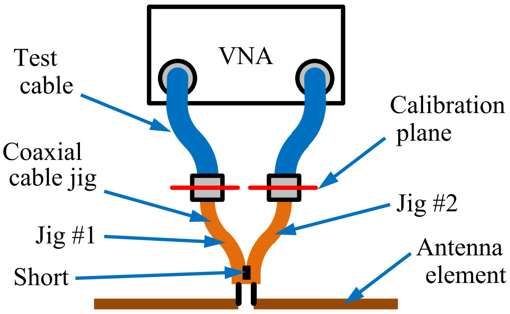


Fig. 3. Measurement system for input impedance of a balanced antenna.

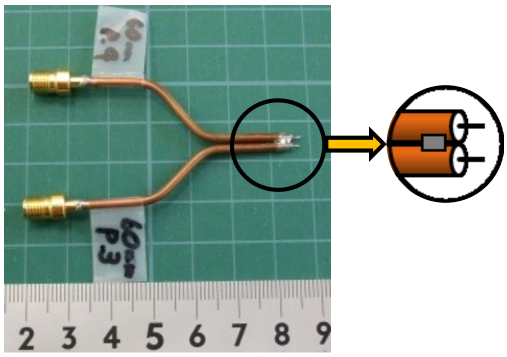


Fig. 4. Photo of a measurement jig.

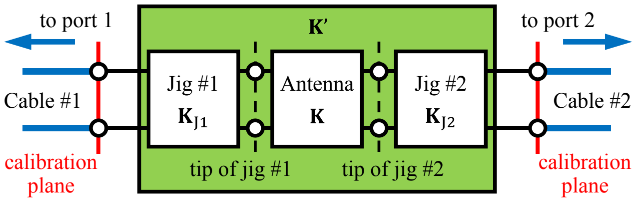


Fig. 5. Equivalent circuit diagram of an antenna with jig.

IV. MEASUREMENT RESULTS

The load impedance of the measurement jig used for the modified open correction method is calculated by the FDTD method. Figure 6 depicts the FDTD model of the semi-rigid coaxial cable for a measurement jig. To connect the antenna element, the inner conductor is longer than the outer conductor by 2 mm. The load impedance of the open end is calculated from the electric and magnetic fields at the end of the outer conductor.

Given the specifications of the semi-rigid cable (Table 1), we fabricated two types of jigs from semi-rigid cables with different thickness. Both numerical models are considered to be valid because the calculated values of the characteristic impedance are about 50 Ω.

Load impedances were obtained at the open end of the semi-rigid coaxial cable (Fig. 7). The resistances of RG405 and RG402 are 19.2 Ω and 13.1 Ω at 5 GHz, respectively. The resistance of a coaxial cable of thinner diameter is believed to be larger. Similarly, the corresponding reactance for RG405 and RG402 are 429 Ω and 317 Ω at 5 GHz, respectively. These values yield a capacitance of 0.074 pF and 0.100 pF. Note that the capacitance of the thinner-diameter coaxial cable is smaller.

To obtain the input impedance, an FDTD model of a dipole antenna is employed. Figure 8(a) and (b) shows the dipole elements with a measurement jig for the S-parameter method and a conventional dipole antenna model with a delta-gap feed, respectively. The cross-section of the conductive element is roughly circular of diameter 1 mm, and total length of about 71.2 mm. For the calculation model of S-parameter method, the two outer conductors of the RG405 and RG402 cables make contact with each other, and the radiating elements of the dipole antenna are connected to the inner conductors of the semi-rigid cables. The lengths of the coaxial cables of the jig were confirmed to be long enough using calculations involving changes in cable length. From the calculation model of a conventional dipole antenna, the total length is one cell longer than that given by the S-parameter method model because it is delta-gap fed. In addition, the diameter of the conductive element gradually thins near the delta-gap feed.

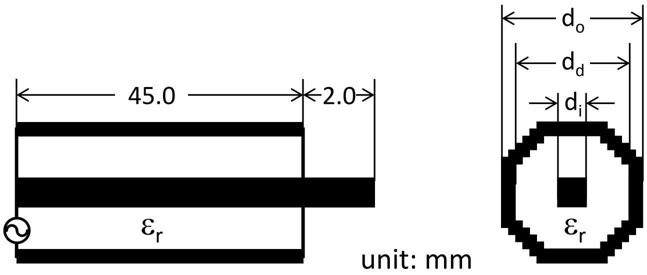
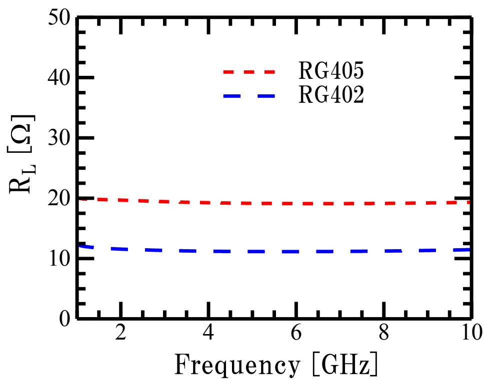


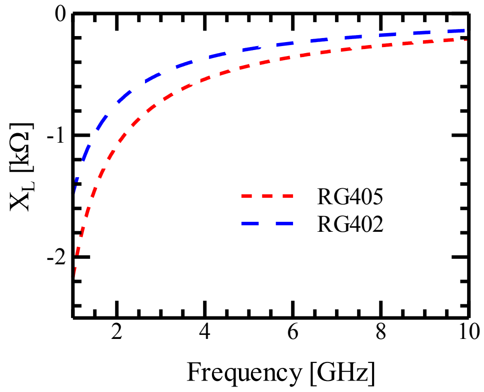
Fig. 6. Calculation model of an open end jig made of a semi-rigid cable.

TABLE I. SPECIFICATION OF SEMI-RIGID COAXIAL CABLE.

	RG405	***RG402***
Diameter of outer conductor: d_o	2.2 mm	3.6 mm
Diameter of insulation: d_d	1.7 mm	3.0 mm
Diameter of inner conductor: d_i	0.5 mm	0.9 mm
Relative permittivity	2.1	
tan δ	0.0002	
Characteristic impedance at 5GHz	47.4-*j*0.132 Ω	46.0-*j*0.128 Ω

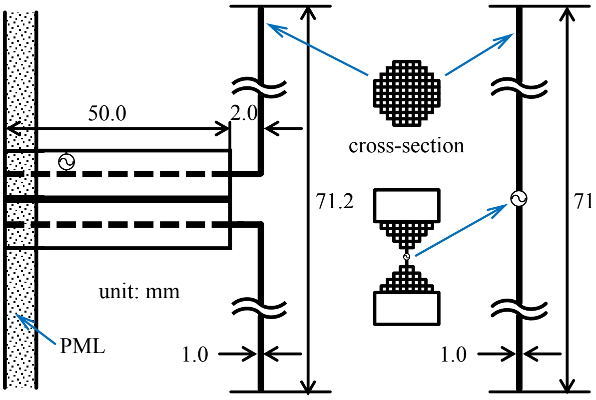


(a) Resistance.



(b) Reactance.

Fig. 7. Calculated load impedance at open end of the semi-rigid cable.



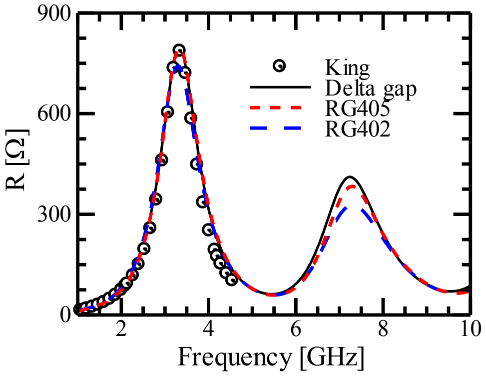
(a) S-parameter method. (b) Conventional model.

Fig. 8. Calculation model of a dipole antenna.

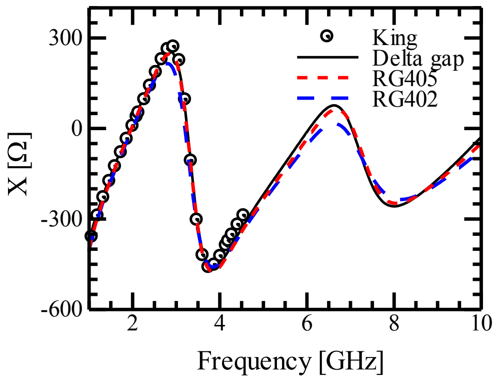
Figure 9 shows the calculated input impedance of the dipole antenna. Using the two types of jigs fabricated, the input impedance of the dipole antenna is calculated using the S-parameter method. The results were corrected using the modified open correction, and compared with the available theories by King and the calculated results of the conventional model of dipole antennas. At roughly 6 GHz and below, the two results of the S-parameter method correlate very well with those of King and conventional results. At frequencies of about 6 GHz and above, the result obtained from the S-parameter method using RG402 shifts from the conventional result more than that for RG405. The space of the radiating element of the dipole antenna is wider in the thicker-diameter coaxial cable of the jig.

V. CONCLUSION

To improve the measurement accuracy of the S-parameter method, we analyzed using calculations developed with the FDTD method the influence of semi-rigid cable thickness used for the measurement jig. First, we formulated the S-parameter method based on the two-port network. We analyzed a practical application where we eliminate the influence of a measurement jig on the measurement of the input impedance. Furthermore, to show the validity of the proposed approach to this measurement, results were given of input impedance using two types of jigs made from semi-rigid cables of different thickness. Both results of the S-parameter method were shown to agree with the available theories by King and the calculated results of the conventional model of dipole antenna, for frequencies below 6 GHz.



(a) Resistance.



(b) Reactance.

Fig. 9. Calculated input impedance of a dipole antenna.

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