Accurate Measurement of Small Input Resistances Using a Conventional Network Analyzer

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***Abstract*— Precise and accurate measurement of input resistance is essential to characterize small antennas whose input resistance is very small. However, this is very difficult because uncertainty, which includes imprecision and inaccuracy, sometimes exceeds the resistance being measured. In this paper, a method for precise measurement of small input resistance using a conventional network analyzer is presented. Inaccuracy, which includes an actual conductor loss of antenna under test (A.U.T.), manufacturing error, and the residual systematic errors is then estimated. The former two sources of inaccuracy are obtained by comparing a radiation efficiency measurement of a small loop antenna using the Wheeler cap method with a calculated radiation efficiency. Using these values in the calculation of the input resistance, a true input resistance is acquired. Finally, the actual value of the residual systematic errors for each instrument is estimated by comparison between the true input resistance and the measurement.**

***Index Terms*— Accurate measurement, small input resistance, small antennas, UHF antennas, Wheeler cap method.**

I. Introduction

OBTAINING precise and accurate values of input resistance is important for studies of small antennas [1]–[4]. However, this becomes very difficult when the input resistance is less than 1 Ω because the maximum uncertainty of a network analyzer in reflection measurements may correspond to over 1 Ω error in input resistance for a 50 Ω system.

Uncertainty includes imprecision and systematic errors of the measurement as listed in Table I, which gives the maximum uncertainties of three different network analyzers for S_{11} measurements. (These errors are after accuracy enhancement, i.e., postcalibration.)

In this paper, a method is presented first to reduce the imprecision of the measurement when using conventional instruments and techniques [5]. Secondly, accuracy of the measurement is confirmed using the Wheeler cap method, which is often used to measure radiation efficiency of small antennas.

II. Reducing Imprecision

Random errors and drift errors are causes of imprecision [6]. In practice, two main factors which cause imprecision are: 1) repeatability of connection and 2) drift of the instruments. To reduce their effects, we measured 30 reflections of a shielded open termination after 150 min of warm up and with use of a 10 Hz of IF bandwidth for the network analyzer. All measurement systems were put into an anechoic chamber to eliminate electromagnetic interference and to keep the temperature stable. As a result, an average imprecision of 0.000 05 was obtained for S_{11} measurement while the connection was loosened and tightened in each measurement.

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TABLE I
THE MANUFACTURER'S SPECIFICATION OF UNCERTAINTY IN S_{11} MEASUREMENT WHEN THE REFLECTION IS ALMOST UNITY. THE IF BANDWIDTH IS 10 Hz

Type	Uncertainty	Frequency range
HP 8719A	0.055	130MHz–13.5GHz
HP 8753B	0.044	300kHz–3GHz
HP 8753C	0.044	300kHz–3GHz

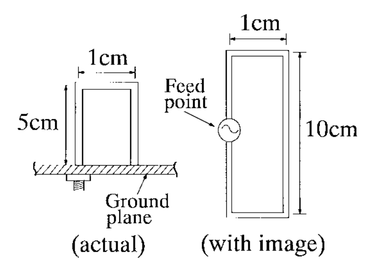

Fig. 1. A configuration of the small loop antenna.

III. Confirming Accuracy

In this part, the accuracy of the measured input resistance of a small loop antenna (Fig. 1) is evaluated. There are three causes of measurement deviation from calculation. They are the actual conductor loss of the measured antenna, manufacturing error, and the residual systematic errors. The values of the former two factors can be obtained by comparing measured radiation efficiency of the antenna under test (A.U.T.) by the Wheeler cap method with calculation. Then, using these values, a true input resistance as a standard for accuracy is calculated. The difference between the measurement and the true input resistance becomes the residual systematic errors of each instrument.

The residual systematic errors, however, are difficult for the user to remove because this is mainly due to imperfection of the calibration standard [6], [7]. Therefore, in this paper, we would rather estimate than eliminate them.

We first show a method to obtain the actual conductor loss and the manufacturing error of the A.U.T. Secondly, the true input resistance is acquired using these values. Finally,

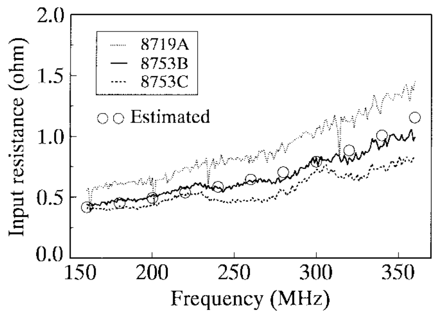

Fig. 2. The input resistance of the 1 cm × 10 cm loop antenna measured with three network analyzers and estimated value by the method of moments calculation.

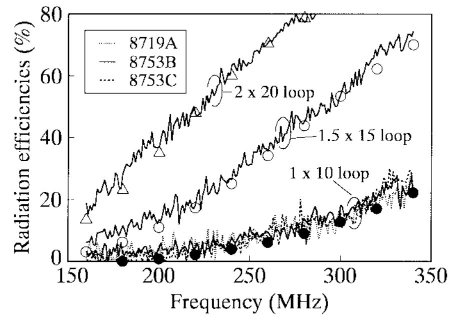

Fig. 3. Measured and calculated (dots) radiation efficiency of each size of antenna when $k_S = 1.5$. Efficiencies for 1 cm × 10 cm loop are measured with the three network analyzers.

actual values of the residual systematic errors are estimated by comparing the true input resistance with the measurement.

A. Measuring the Radiation Efficiency Without Systematic Errors

Radiation efficiency measured by using the Wheeler cap method is independent of the residual systematic errors of the instruments. The reason is explained in the following.

The radiation efficiency using the Wheeler cap (sized 40 cm × 50 cm × 20 cm) and an aluminum plate (sized 2 m × 2 m) for a ground plane is expressed as

$$\eta = \frac{R_0 - R_{\text{cap}}}{R_0}. \quad (1)$$

Here, R_0 and R_{cap} denote the input resistance without and with the cap, respectively. Then, we eliminated the soldering loss from (1) to compare it with calculation. Thus

$$\eta = \frac{(R_0 - R_{\text{sol}}) - (R_{\text{cap}} - R_{\text{sol}})}{R_0 - R_{\text{sol}}} = \frac{R_0 - R_{\text{cap}}}{R_0 - R_{\text{sol}}}. \quad (2)$$

Here, R_{sol} means the soldering resistance of joints altogether, which is about 0.1 Ω at 300 MHz.

We used three types of network analyzers: (A) HP 8719A; (B) 8753B; and (C) 8753C to estimate the effects of the residual systematic errors on the radiation efficiency by the Wheeler cap method. Fig. 2 shows the input resistance measured with these three network analyzers and the estimated true value by the method of moments [8], as explained in the next section. From Fig. 2, the increasing rates of the resistance differ from each other and are nearly constant with frequency. This stems from the residual systematic errors of each instrument. Therefore, we obtained the following relationships between the values measured by using the different instruments

$$R_A = k_A R_T, \quad R_B = k_B R_T, \quad R_C = k_C R_T \quad (k_A, k_B, k_C\text{: constants}). \quad (3)$$

Here, R_T denotes the true input resistance of the A.U.T. Then, as shown in Fig. 3, the radiation efficiency measured by (A) is

$$\eta_A = \frac{R_{A_0} - R_{A_{\text{cap}}}}{R_{A_0} - R_{A_{\text{sol}}}} = \frac{k_A R_{T_0} - k_A R_{T_{\text{cap}}}}{k_A R_{T_0} - k_A R_{T_{\text{sol}}}} = \eta_B = \eta_C. \quad (4)$$

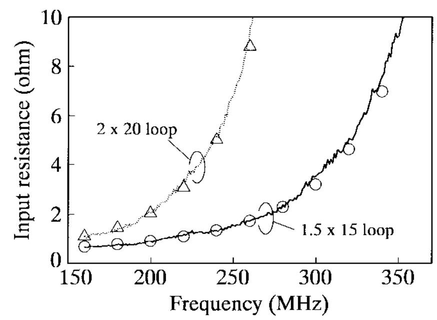

Fig. 4. Input resistance of antennas other than 1 cm × 10 cm loop when $k_S = 1.5$.

The difference in the residual systematic errors between the three instruments denoted as k_A, k_B and k_C is canceled out in the equation above.

B. Finding the True Input Resistance

The true input resistance is needed to estimate the conductor loss and the manufacturing error of the A.U.T. For this purpose, the calculated radiation efficiency was artificially adjusted to the experimental one by increasing the surface resistance of the antenna material because the measured radiation efficiency only includes the manufacturing error and the actual conductor loss, but not the residual systematic errors, as indicated by (4). In a sense, the conductor loss and the manufacturing error of the A.U.T. are represented in terms of an artificially increased surface resistance in the calculation. Actually, from Fig. 3, the ratio of the surface resistance of the A.U.T. to that of pure copper (denoted as k_S) was estimated to be about 1.5. Even for the different sizes of the loop antennas, 1.5 cm × 15 cm and 2 cm × 20 cm, good agreement is obtained between the calculations and experiments by putting $k_S = 1.5$. Then, using the proper value of k_S in the calculation of the input resistance, a true value is acquired and it can be a standard for the calibration of the instruments. In Figs. 2 and 4, good agreement between the calculations using $k_S = 1.5$ and the measurements is shown.

C. Estimating the Systematic Errors of Each Instrument

Understanding approximate values of the residual systematic errors of each instrument is helpful when considering measurement of small resistance although these errors are difficult to remove. The residual systematic errors are estimated from the difference in input resistance between the calculated value using $k_S = 1.5$ and the measured one because the calculation does not include them. In other words, they arise from calibration. From Fig. 2 and (3), actual value of the coefficients k_A, k_B and k_C are about 1.3, 1.0 and 0.85 on average, respectively. This indicates that the measurement by the instrument (B) is very close to the true value.

IV. Conclusion

The precise and accurate measurement of the input resistance of a small loop antenna has been considered. It was confirmed that even by using a conventional network analyzer, a small input resistance less than 1 Ω can be precisely measured. It has also been found that the residual systematic errors of each instrument do not much affect the measurement of radiation efficiency by the Wheeler cap method. In addition, accuracy of the measurement as well as the approximate values of the residual systematic errors were confirmed after obtaining the true input resistance by using the Wheeler cap method.

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