Radiation Efficiency Measurement Based on Wheeler Method Using Hybrid Coupler and Sliding Short

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Abstract

The use of the subtraction function of a 180-degree 3dB hybrid coupler is proposed in a method of removing the uncertainty of the reflection coefficient measurement. The authors have proposed and examined a technique of measuring arbitrary reflection coefficients using a hybrid coupler and a sliding short. It has a possibility of accurate measurement of the reflection coefficient whose magnitude is close to unity, because S parameters of the components used in the measurement system are measured. In this paper, we apply it to the measurement of the radiation efficiency of the antenna based on the Wheeler method and show the validity of the proposed technique.
Keywords : Hybrid coupler, Sliding short, Wheeler method, Small antenna, Radiation efficiency

1. Introduction

The Wheeler method is known as a simple method of measuring the radiation efficiency of small antennas [1]. In this method, the radiation efficiency can be evaluated by measuring reflection coefficients when the antenna under test is located in free space and is covered with the shield. In general, it is known that the uncertainty of the measurement increases when the magnitude of the reflection coefficient is close to unity with vector network analyzer (VNA). In this sense, it is desired to develop alternative method for the reflection coefficient when its magnitude is close to unity [2]. The technique that used a hybrid coupler was proposed by Randus et al. as a method of reducing the uncertainty of the reflection coefficient measurement when its magnitude is close to unity [3]. It uses an amplified subtraction function of the 180-degree 3dB hybrid coupler when measuring the transmission coefficient with a reference standard (RS). However, it is available only when $\Gamma_{RS} \approx \pm\Gamma_{\mathrm{DUT}}$, where Γ_{RS} and Γ_{DUT} are reflection coefficients of RS and device under test (DUT), respectively. Also, a predictive value of Γ_{DUT} could be known before the measurement.

To overcome the above difficulties, we have proposed a method of measuring the reflection coefficient of arbitrary DUT by two-port transmission measurement using the hybrid coupler [4]. In our method, a RS that $|\Gamma_{RS}|$ is constant but $\angle\Gamma_{RS}$ can be varied is used by a sliding short that is composed of short connected with the line stretcher. The locus of the reflection coefficient of RS draws a circle on the Smith chart because the phase can be changed by a sliding short. If well-chosen DUT and RS are connected into the hybrid coupler and the transmission coefficient between the unused two ports of the hybrid is measured, the locus of the transmission coefficient also draws a circle on the transmission coefficient plane. Then, the reflection coefficient of DUT, Γ_{DUT}, can be obtained by determining the center and radius of this circle by means of the least square method.

In this paper, our proposed method is applied to the measurement of the radiation efficiency of the antennas based on Wheeler method. We briefly introduce our proposed method with the 180-degree 3dB hybrid coupler and sliding short and experimentally confirm its validity by comparing the radiation efficiency obtained by our proposed method with directly measured by VNA.

2. Reflection Coefficient Measurement Using Hybrid Coupler and Sliding Short

2.1 Principle for ideal measurement system[4]

When RS is connected to port 3 of 180-degree 3dB hybrid coupler as shown in Fig. 1 and DUT is connected to port 4, the reflection coefficients of RS and DUT are given as $\Gamma_{ref} = a_3/b_3$ and

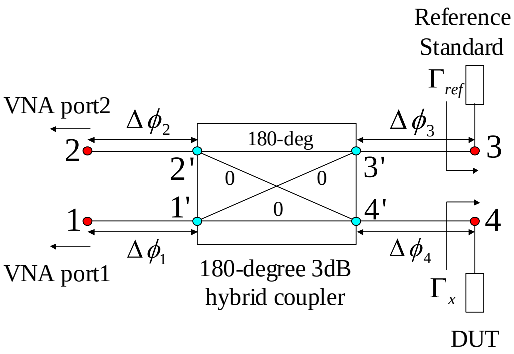

Fig. 1 Diagram of measurement system

$\Gamma_x = a_4/\mathrm{b}_4$, respectively. The transmission coefficient from port 1 to port 2 is given as $T_{21} = \mathrm{b}_2/a_1|_{a2=0}$. The hybrid coupler is assumed to be ideal. If $\Delta\phi_i$ denotes the phase difference between ideal port i' and real port i of the hybrid coupler, the transmission coefficient T_{21} is given as

$$T_{21} = \frac{1}{2} e^{-j(\Delta\phi_1 + \Delta\phi_2)} (\Gamma_{ref} e^{-j2\Delta\phi_3} - \Gamma_x e^{-j2\Delta\phi_4}) \tag{1}$$

If the value of Γ_{ref} is changed by moving a sliding short, Γ_{ref} draws a circle on the Smith chart. Also, T_{21} draws a circle on the transmission coefficient plane. The center and radius of the Γ_{ref} circle are denoted as z_{ref} and r_{ref}. Also the center and radius of the T_{21} circle are denoted as $z_c$and r_c. Then, the reflection coefficient of DUT, Γ_x, is given as

$$\Gamma_x = z_{ref} e^{j2(\Delta\emptyset_4 - \Delta\emptyset_3)} - 2z_c e^{j2(\Delta\emptyset_1 + \Delta\emptyset_2 + 2\Delta\emptyset_4)} \tag{2}$$

Thus, we should find z_{ref} and z_c by moving a sliding short to determine Γ_x. In practice, the center and radius of the circles can be found by measuring more than three reflection/transmission coefficients and using the least square method.

2.2 Measurement by using S parameters of components in measurement system [4]

Available 180-degree 3dB hybrid couplers are not ideal. In our measurement, we should pay attention to the insertion loss and phase difference due to the connectors and connecting cables. Therefore, it is required to measure all S parameters of the components in the measurement system shown in Fig. 1 and to calculate the reflection coefficient of DUT, Γ_x, according to the following procedure.

Transmission coefficient T_{21} in the measurement system shown in Fig. 1 is expressed as

$$T_{21} = \frac{F_1 + F_2\Gamma_{ref}}{1 - F_3\Gamma_{ref}} \tag{3}$$

where F_1, F_2 and F_3 are functions of Γ_x and algebraically calculated by using S parameters of the measurement system. If z_{ref} and $\mathrm{r}_{\mathrm{ref}}$ of Γ_{ref} circle can be estimated, then z_c and r_c of T_{21}circle can be determined by the following simultaneous equations,

$$z_c = \frac{(F_1 + F_2 z_{ref})(1 - \mathrm{F}_3 z_{ref})^* + r_{ref}{}^2 F_2 F_3{}^*}{|1 - F_3 z_{ref}|^2 - r_{ref}{}^2 |F_3|^2},\ \ r_c = \frac{r_{ref}|F_1F_3 + F_2|}{\left||1 - F_3 z_{ref}|^2 - r_{ref}{}^2|F_3|^2\right|}. \tag{4}$$

Note that all variables are known excluding Γ_x in the expressions of (4).

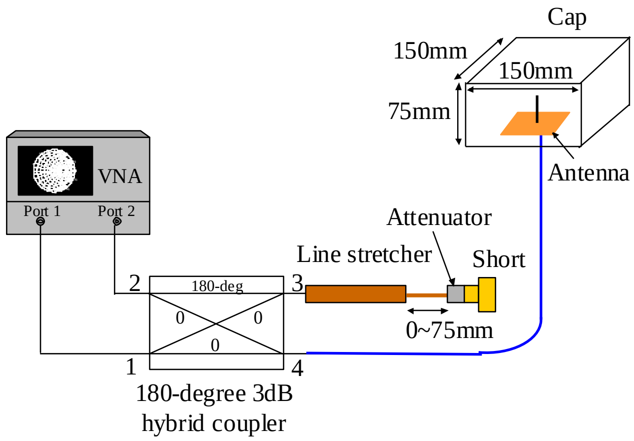

Fig.2 Measurement setup of radiation efficiency based on Wheeler method

3. Radiation Efficiency Measurement Based on Wheeler Method

3.1 Wheeler method

Our proposed method explained in the previous section can be applied to the radiation measurement based on the Wheeler method. The Wheeler efficiency η can be estimated as

$$\eta = \frac{|\Gamma^s|^2 - |\Gamma^f|^2}{1 - |\Gamma^f|^2}, \tag{5}$$

where Γ^f and Γ^s are reflection coefficients when the antenna is located in free space and covered with the shield, respectively.

3.2 Measurement Setup

Our measurement setup for the Wheeler efficiency measurement is shown in Fig. 2. A 180-degree 3dB hybrid coupler (Cernex, CHC0102U622T) is used.The antenna under test is a monopole antenna with a length of 40mm and the shield is a metallic cap of 150mm×150mm ×75mm. A 3dB attenuator is inserted between a fixed short and a line stretcher (Hirose, RS HLS-JJ-1(40)), which can vary its length from 0 to 75mm at intervals of 5mm. The measurement procedure is as follows. First, all S parameters of the four-port measurement system, $S_{ij}(i, j = 1,2,3,4)$, are measured by VNA. Next, T_{21}s are measured as the length of the line stretcher is changed when the antenna is located in free space. Γ_{ref}s are directly measured by VNA as the length of the line stretcher is changed. Then, Γ_x^f can be estimated. Similarly, Γ_x^s can be estimated when the antenna is covered with the shielding cap. Therefore, the Wheeler efficiency η_x can be estimated. For confirmation, η_x measured by our proposed method is compared with η_{VNA} measured directly by VNA.

3.3 Measurement Results

Fig. 3 shows $|\Gamma_x^f|$, $|\Gamma_x^s|$, $|\Gamma_{VNA}^f|$, and $|\Gamma_{VNA}^s|$ as a function of the frequency, where Γ_{VNA}^f and Γ_{VNA}^s are reflection coefficients measured directly by VNA when the antenna is located in free space and covered with the cap, respectively. Fig. 4 shows η_x and η_{VNA} as a function of the frequency. As shown in Fig.3, the averaged difference between $|\Gamma_x^f|$ and $|\Gamma_{VNA}^f|$ is 1.7% in the range of 1.0GHz to 2.0GHz. Also, the averaged difference between $|\Gamma_x^s|$ and $|\Gamma_{VNA}^s|$ is 0.5% in the same frequency range. This fact can lead to the validity of our proposed method. Although the large difference between η_x and η_{VNA} from 1.0GHz to 1.35GHz can be observed, η_x and η_{VNA} are in excellent agreement with each other and their averaged difference is 1.5% over 1.35GHz. This means that the Wheeler efficiency can be accurately estimated by our proposed method instead of the direct VNA measurement.

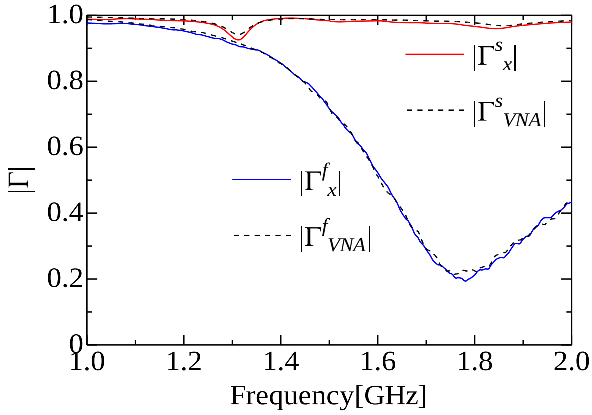

Fig3. |Γ| of AUT in free space and with the shielding cap

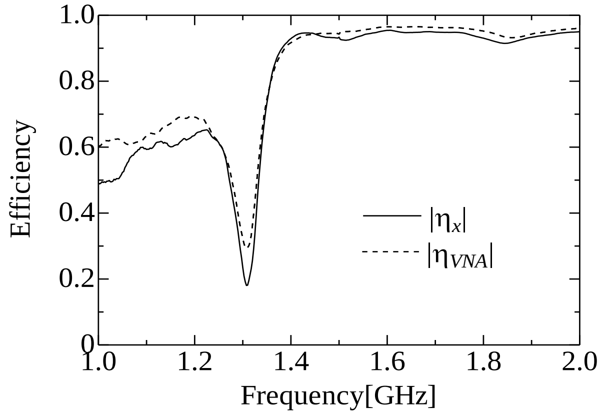

Fig4. Radiation efficiency η_x and η_{VNA}

4. Conclusions

Radiation efficiency η_x of a monopole antenna based on the Wheeler method is estimated by measuring the reflection coefficient using a 180-degree 3dB hybrid coupler and a sliding short. By comparing it with η_{VNA} directly measured by VNA, we confirm the validity of our proposed method. In the future, we will measure the radiation efficiency by the reflection method using our proposed method. And, we will estimate the uncertainties of the reflection coefficient and the radiation efficiency measurements by our proposed method.

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