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Reduction of Small Dips in Efficiency Estimated by Reflection Method

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1. Introduction

The reflection method is well known as a simple and low-cost measurement method of the radiation efficiency of the small antenna. In this method, it is required to measure the reflection coefficients of the antenna in free space and in the cavity formed by the waveguide and two sliding shorts [1]. However, some dips can be observed in the frequency response of the estimated efficiency [2]. We have studied the methods of avoiding these dips by use of the transmission line model [3]. Some serious dips are caused by the resonance between the antenna and the sliding shorts in the wide frequency range. To keep from these dips, the distance between the antenna and shorts should be carefully selected as the resonances are not encountered. On the other hand, it is possible to generate small dips of the efficiency due to the resonances between two sliding shorts. These dips are localized in the extremely narrow frequency range. To avoid the small dips, we exclude the ill-conditioned reflection coefficients according to the resonant condition of the cavity, and then evaluate the efficiency based on the principle of the reflection method. In this paper, an alternative method to avoid the small dips is proposed and examined.

2. Review of Measurement Principle and Equivalent Transmission Line

2.1 Measurement Principle

An antenna can be treated as a linear, passive, reciprocal two-port network that is fed at port 1 and is connected to the intrinsic impedance of free space at port 2 as shown in Fig. 1. Because the power radiated by the antenna can be wholly transmitted to free space, the reflection coefficient at port 2 of the network should be zero. Then, the radiation efficiency of the antenna can be described in terms of the *S* parameters of the network as follows:

$$\eta_{\mathrm{ant}} = \frac{|S_{21}|^2}{1-|S_{11}|^2}. \tag{1}$$

$|S_{11}|$ can be measured as the magnitude of the reflection coefficient of the antenna placed in free space. In the reflection method, $|S_{21}|$ can be determined by inserting the antenna into the hollow rectangular waveguide short-circuited by sliding shorts and measuring the reflection coefficients at port 1, $\Gamma_{wg,n}$, n=1,2,…, in more than three combinations of both sliding shorts, as shown in Fig. 2. In this paper, the waveguide and sliding shorts connected to port 2 is defined as a movable section. If the reflection coefficient seen looking to the movable section at port 2 is denoted as Γ_n, n=1,2,…, the reflection coefficient measured at port 1, $\Gamma_{wg,n}$,can be expressed by in terms of the *S* parameters of the network as follows:

$$\Gamma_{wg,n} = S_{11} + \frac{S_{21}^2\Gamma_n}{1-S_{22}\Gamma_n}. \tag{2}$$

Because the walls of the waveguide and sliding shorts have a finite conductivity, Γ_n, can be disturbed at the resonance of the cavity formed by the waveguide and sliding shorts. Then, the locus

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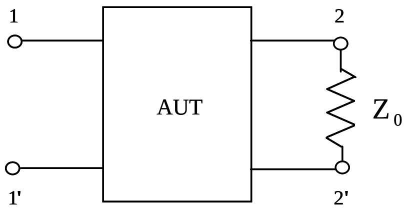

Figure 1: Two-port network

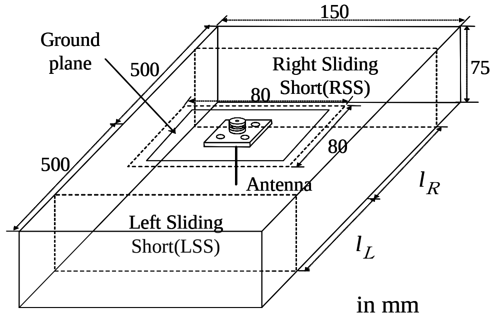

Figure 2: Waveguide and sliding shorts

of Γ_n draws a circle with a center of z_i and radius of r_i on the Smith chart, that is, $\Gamma_n = z_i + r_i e^{j\theta_i}$, where θ_i is the arbitrary phase angle. As seen from Eq. (2), $\Gamma_{wg,n}$ draws a circle with of S_{11}+z_o and radius of r_o on the Smith chart. After laborious calculation, $|S_{21}|$ can be given by

$$|S_{21}|^2 = \left(r_o - \frac{|z_o|^2}{r_o} \right) \Big/ \left(r_i - \frac{|z_i|^2}{r_i} \right). \tag{3}$$

Substituting Eq. (3) into (1), we can find the following relationship:

$$\eta_{\text{net}} = \eta_{\text{ant}} \cdot \eta_{\text{line}} , \tag{4}$$

where the efficiency in the whole network and the movable section can be defined as

$$\eta_{\text{net}} = \frac{1}{1 - |S_{11}|^2} \left(r_o - \frac{|z_o|^2}{r_o} \right), \tag{5}$$

$$\eta_{\text{line}} = r_i - \frac{|z_i|^2}{r_i} . \tag{6}$$

If the sliding shorts and waveguide has a perfect conductivity, the efficiency of the movable section is equal to unity, that is, $\eta_{\text{line}} = 1$ so that η_{net} can be considered as a true evaluation formula for the efficiency. Eq. (4) implies that the efficiency determined by measurand is a product of the true radiation efficiency of the antenna and the efficiency in the movable section.

2.2 Measurement Equipments

A hollow rectangular waveguide consists of two U-shaped casting and two plates, as shown in Fig. 2. The inside dimension of the cross-section is 150mm $\times$ 75mm and the length of the waveguide is 1000mm. An antenna under test can be inserted into the waveguide via a square hole in the board wall. Sliding short is shown in Fig. 3. The metal types in stripes on the side walls are attached to avoid the leakage from the clearance between the waveguide and sliding short. The reflection coefficients of a monopole antenna with a length of 40mm and a diameter of 1mm are measured by the network analyzer (Agilent 8720ES).

2.3 Equivalent Transmission Line Model

The movable section can be modeled by the equivalent transmission line terminated by two small resistances. The normalized resistance, r_c, can express the contribution of the sliding short. If the distance between the antenna and the left or right sliding short is denoted as l_L or l_R, the equivalent transmission line seen looking from port 2 of the network can be expressed as shown in Fig. 4.

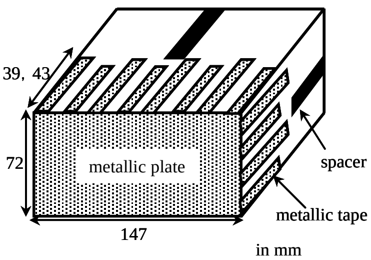

Figure 3: Sliding short

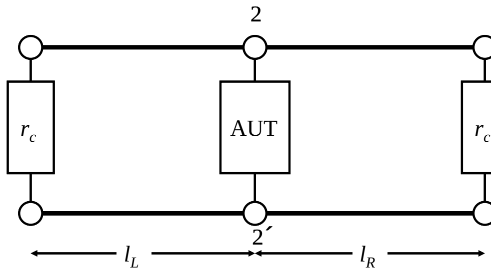

Figure 4: Equivalent transmission line

3. Cause Investigation of Small Dips in Estimated Efficiency

In our previous study, we theoretically clarified that there is no dip in the frequency response of the efficiency estimated by the reflection method when two sliding shorts are moved with $l = l_L = l_R$ [4]. In the corresponding measurement, two sliding shorts are moved from l=60mm to 130mm in increment of 10mm. Fig. 5 shows the estimated efficiency in the whole network. We can find some small dips of the efficiency. This contradiction is caused by a slight difference between l_L and l_R. To examine this hypothesis, we assume that $l_L = l - \Delta l$ and $l_R = l + \Delta l$, where l denotes the average of l_L and l_R and Δl denotes the deviation from l_L or l_R. Then, normalized admittance can be given by

$$y_n = \frac{1 + jr_c \tan\beta_g (l - \Delta l)}{r_c + j\tan\beta_g (l - \Delta l)} + \frac{1 + jr_c \tan\beta_g (l + \Delta l)}{r_c + j\tan\beta_g (l + \Delta l)}, \tag{7}$$

where $\beta_g = 2\pi/\lambda_g$ is the phase constant and λ_g is the guide wavelength for the TE_{10} mode of the hollow rectangular waveguide. Fig. 5 shows the efficiency in the movable section for $\Delta l = 1$mm, when r_c=0.003 [4]. We can find some dips for $\Delta l \neq 0$. In practice, we can see that these small dips of the efficiency can be observed because it is hard to control measurement accuracy of l_L and l_R.

4. Reduction of Small Dips in Estimated Efficiency

In this section, we propose and examine a new method of reducing the small dips in the frequency response as discussed in the previous section. In our previous study, we clarified that these dips are caused by the resonant condition of $l_L + l_R = n(\lambda_g/2)$, where n is integer, and propose an evaluation method with no use of the measured data satisfied with this condition. This method is required to know the information of l_L and l_R. Because of the index error of scale, the margin of error for l_L and l_R is assumed to be 3%. In practice, it overestimates the ill-conditioned data, because the uncertainty of l_L and l_R can not be reduced because the sliding shorts are manually moved. Therefore, another method for rejecting the ill-conditioned data should be proposed.

When the efficiency in the whole network has some dips, the radius of the circle for the reflection coefficient in the movable section, Γ_n, is smaller than unity. This is caused by some ill-conditioned Γ_n s whose magnitude is not nearly equal to unity. Therefore, we can avoid some small dips in the frequency response of the efficiency by excluding these ill-conditioned Γ_n s when determining the circle for Γ_n. Because of the relationship between Γ_n and $\Gamma_{wg,n}$ as shown in Eq. (2), some ill-conditioned $\Gamma_{wg,n}$ s exist. Our proposed method focuses attention on this fact. In general, the reflection coefficient of the antenna covered with the cavity, the magnitude of $\Gamma_{wg,n}$ is normally smoothly changed as the frequency is monotonously changed. However, the value of the ill-conditioned $\Gamma_{wg,n}$ is a bit different from the adjacent frequencies so that we should detect this

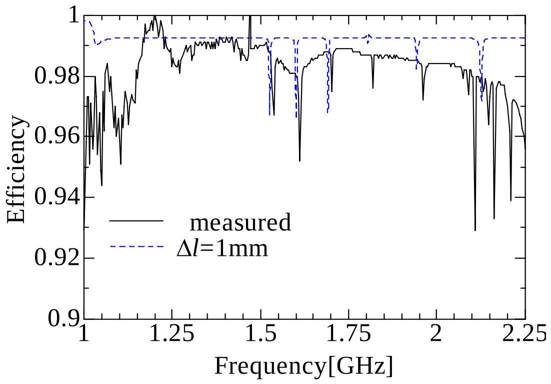

Figure 5: The efficiency in the whole network and the movable section for $\Delta l =$ 1mm.

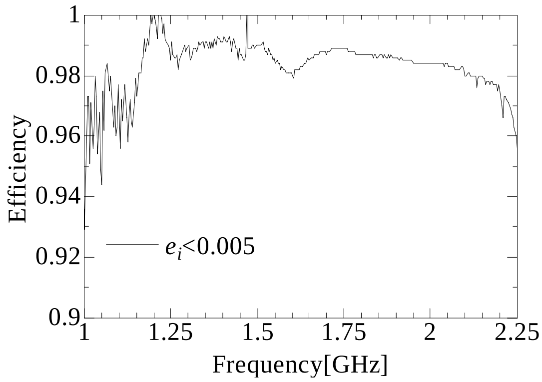

Figure 6: An example of avoiding some drops of the efficiency.

difference to find the ill-conditioned $\Gamma_{wg,n}$ which should be excluded in determining the circle for $\Gamma_{wg,n}$.

In practice, the following index should be evaluated to find the discontinuity of the frequency response of the reflection coefficient, $\Gamma_{wg,n}$,

$$d_i = \frac{\left| |\Gamma_{wg,n}(f_i)| - |\Gamma_{wg,n}(f_{i-1})| \right|}{|f_i - f_{i-1}|}, \quad (8)$$

where f_i, i=1,2,… is discretized frequency. For simplicity, we use the index $e_i = | f_i - f_{i-1} | d_i$ to find the discontinuity in this paper. Fig. 6 shows the efficiency in the whole network for $e_i < 0.005$. In this figure, we can see that some small dips can be reduced except some points which are concerned with the cutoff of the waveguide.

5. Conclusion

In the reflection method for measuring the radiation efficiency of the small antenna, there is a technique that both sliding shorts are equally moved for avoiding the small dips of the efficiency due to the resonance of the cavity. In theory, the efficiency does not have some dips and is constant for the change of the frequency. Actually, the dips are observed because of measurement error of scaling the distance between the antenna and sliding short. In this paper, we show that the dips can be observed if the two distances are slightly different from each other in the analysis using the transmission line model. We also propose an alternative technique for avoiding the dips by use of the discontinuities in the frequency response of the reflection coefficients.

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