

Novel Techniques of Avoiding Dips of Radiation Efficiency Measured by Improved Wheeler Method

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1. Introduction

Improved Wheeler method is known as one of the simplest methods of measuring the radiation efficiency of the small antennas [1]. In this method, the reflection coefficients are required when the antenna under test (AUT) is located in free space and waveguide with both movable ends shorten, and the reflection coefficients in the waveguide with the shorts draw a circle on the reflection coefficient plane.

One of the problems for the improved Wheeler method is to encounter the cavity resonance when the distance between the two shorts is equal to half-integer multiple of the waveguide length. To find the cavity resonance, one can simply check this distance [2]. However, the clearance between the wall of the waveguide and the short plunger and the accuracy of the waveguide and shorts make the electrical distance between the two shorts perturbed. Therefore, some alternative techniques of checking the cavity resonance should be prepared. First technique we proposed is based on the fact that the magnitude of the reflection coefficients at the cavity resonance is smaller than that at no resonance [2]. It is easy to implement the code for estimating the radiation efficiency, because the judgment is simple and only the reflection coefficients at the cavity resonance should not be used when the radiation efficiency is estimated. Second technique is based on the fact that the changes in the reflection coefficients can be found at the cavity resonance when the frequency is swept [3],[4]. In this technique, we can check the changes in both the magnitude and phase or only magnitude of the reflection coefficients. However, it depends on selecting the frequency intervals; especially it is serious when the frequencies are selected at wide intervals.

The technique which focuses attention on the magnitude of the reflection coefficient assumes that the center of the circle is nearly equal to the origin of the reflection coefficient plane. If the power consumption at the AUT and peripheral material is low, the center of the circle is located near the origin and the radius of the circle or the magnitude of the reflection coefficient is nearly equal to 1 so that the technique could work well for excluding the reflection coefficients at the cavity resonance. However, when the loss due to the AUT or the peripheral material cannot be ignored, this technique should be further validated. This is because the center of the circle is off the origin and the radius is somewhat smaller than 1.

To overcome this difficulty, novel techniques for checking the cavity resonance are proposed in this paper. One is based on statistic approach for the magnitude of the reflection coefficients, which are about the same values except the cavity resonance. The other is based on the theorem that four points are along a circle on the complex plane if the cross-ratio for the four points is real. In the latter technique, the reflection coefficients at the cavity resonance are assumed not to be on the circle. Some examples are shown to validate the proposed techniques for a monopole antenna loaded with a resistor.

2. Improved Wheeler Method and Efficiency Misestimation

First, the reflection coefficient of the AUT in free space, Γ_f , is measured. Then, the AUT is installed in the waveguide with the two movable shorts to measure the reflection coefficient, $\Gamma_{w,i}$ ($i = 1, 2, \dots, N$). More than three combinations of the two shorts' locations ($N \geq 3$) should be required to draw a circle on the reflection coefficient plane. The center and radius of this circle denotes $\Gamma_f + z_c$ and r_c , then the radiation efficiency can be estimated as [2]

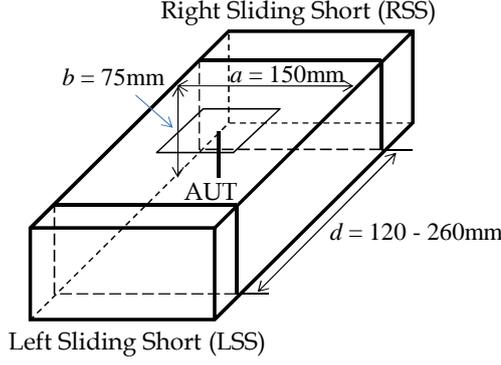


Figure 1: Waveguide and Sliding Shorts

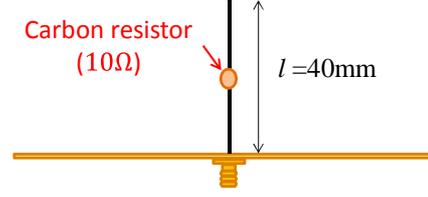


Figure 2: Monopole Antenna with Resistor

$$\eta = \frac{1}{1 - |\Gamma_f|^2} \left(r_c - \frac{|z_c|^2}{r_c} \right).$$

If the AUT is well matched, $\Gamma_f = 0$, and the center is located at the origin, $\Gamma_f + z_c = 0$, then the radiation efficiency can be reduced as $\eta = r_c$. This means that the efficiency is directly dependent on the radius, r_c , or the magnitude of the reflection coefficient, $|\Gamma_{w,i}|$. At the cavity resonance, $|\Gamma_{w,i}|$ is somewhat smaller than 1, then the center is off the origin and the radius becomes smaller than 1 so that the estimated efficiency can be apparently lower than real efficiency of the AUT. In other words, $\Gamma_{w,i}$ at the cavity resonance is located inside the circle formed by the other $|\Gamma_{w,i}|$ s.

3. Techniques for Excluding Cavity Resonance

As discussed above, some dips in the radiation efficiency estimated by the improved Wheeler method can be avoided by excluding the reflection coefficients, $|\Gamma_{w,i}|$ s, at the cavity resonance in determining the circle. In this paper, two techniques will be examined. The first technique can exclude $|\Gamma_{w,i}|$ s using the following criterion

$$|\Gamma_{w,i}| \leq e.$$

The criterion measure, e , can be determined as $e = m - 2\sigma$, where m and σ denote the average and standard variance of $|\Gamma_{w,i}|$ s, respectively. If $|\Gamma_{w,i}|$ s are normally-distributed, this criterion means that 95% of $|\Gamma_{w,i}|$ s would be used in determining the circle. Conversely, $|\Gamma_{w,i}|$ to remove would be included in the rest 5% of $|\Gamma_{w,i}|$ s. The second technique is based on the theorem that the cross-ratio of four $\Gamma_{w,i}$ s, that is, $\Gamma_{w,k}$, $\Gamma_{w,l}$, $\Gamma_{w,m}$, and $\Gamma_{w,n}$,

$$CR(k, l, m, n) = \frac{\Gamma_{w,k} - \Gamma_{w,m}}{\Gamma_{w,l} - \Gamma_{w,m}} \frac{\Gamma_{w,l} - \Gamma_{w,n}}{\Gamma_{w,k} - \Gamma_{w,n}},$$

is real if the four points are on a circle. The criterion to seek the cavity resonance is

$$\text{Arg}[CR(k, l, m, n)] > \phi_{\max},$$

for all the combinations of (k, l, m, n) , where k, l, m, n are integers that range from 1 to N . In practice, proper combinations should be selected to determine whether or not $\Gamma_{w,k}$ is on the circle. The above criterion can be also replaced by the Ptolemy's theorem for the cyclic quadrilateral.

4. Examples of Corrected Efficiency

4.1 Measurement Setup

Fig.1 shows a waveguide and two sliding shorts that used in our experiment. AUT is inserted into the tube and the both sliding shorts are moved 60mm to 130mm from the center of the

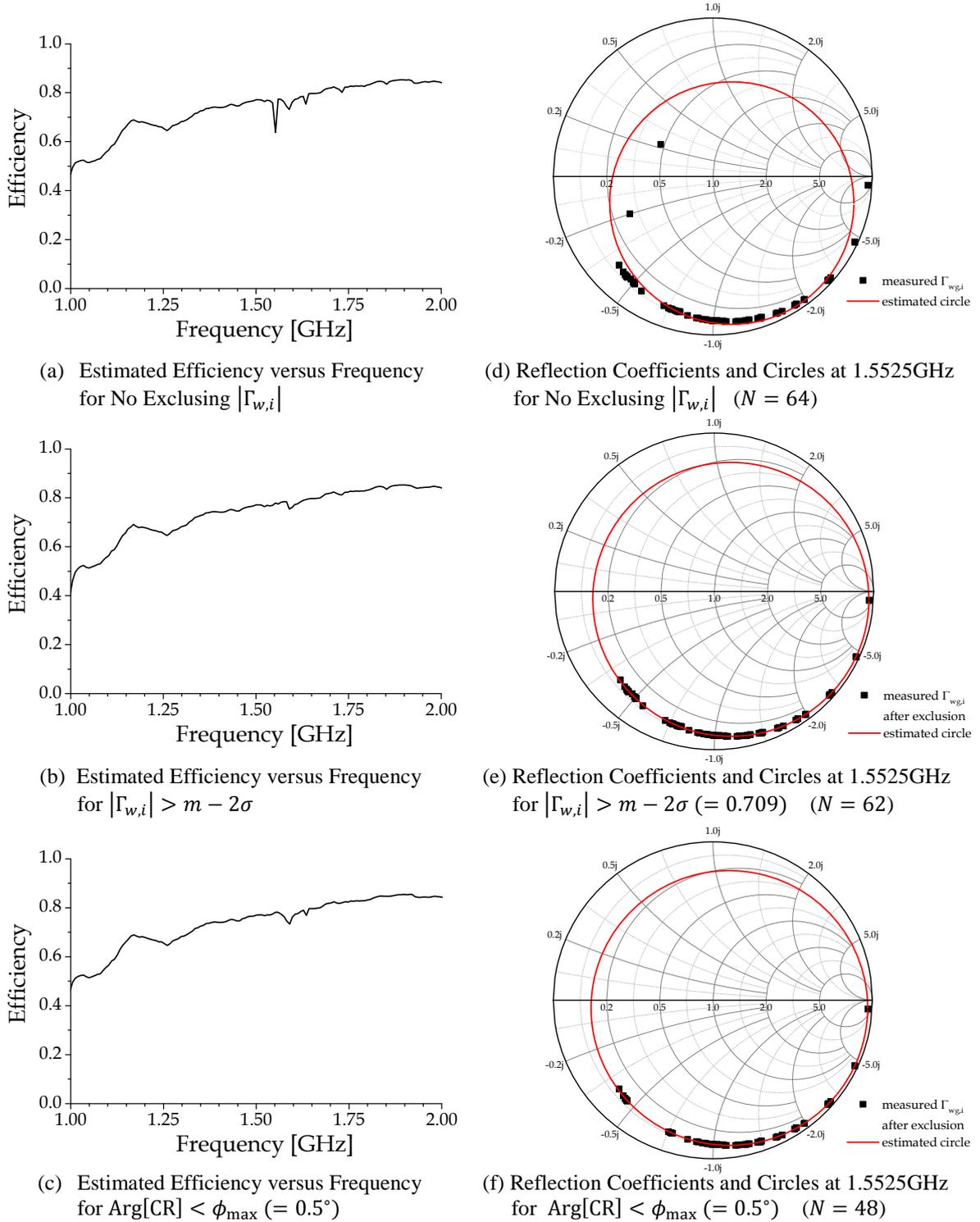


Figure 3: Estimated Efficiency versus Frequency and Circles on Smith Chart for 40mm Monopole Antenna with Resistor

AUT (i.e. feeding point) by use of stepper motor. Selected AUTs are 40mm monopole antennas with a 10Ω carbon resistor and near a wave absorber as shown in Fig.2. The reflection coefficients are measured by a vector network analyzer (Agilent N5230A) from 1GHz to 2GHz. The cavity resonance occurs when the distance between the two shorts, d , is equal to half-integer multiple of the waveguide length. In our configuration, it occurs experimentally at 1.5525GHz so that the dip in the estimated efficiency can be observed at this frequency.

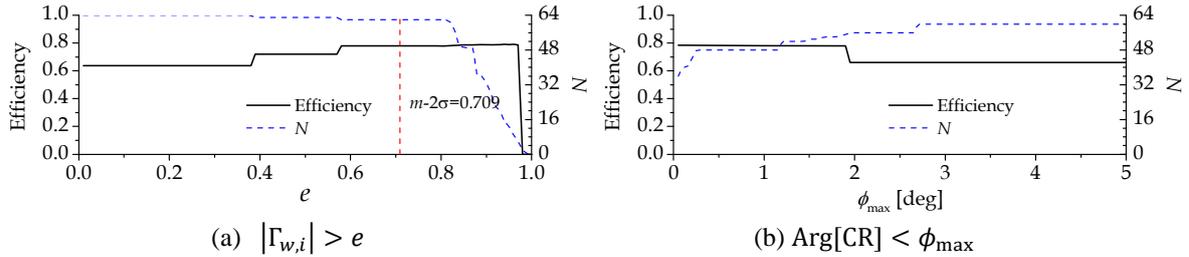


Figure 4: Criterion Values of Two Techniques for 40mm Monopole Antenna with Resistor

4.2 Some Examples of Corrected Efficiency

Estimated efficiency of 40mm monopole antenna with 10Ω resistor is shown in Fig.3(a)-(c), where Fig.3(a) is obtained with no exception in finding the circle, Fig.3(b) is obtained for the criterion of $|\Gamma_{w,i}| > m - 2\sigma$, Fig.3(c) is obtained for the criterion of $\text{Arg}[\text{CR}] < \phi_{\max} (= 0.5^\circ)$. A dip in the estimated efficiency in Fig.3(a) can be observed, however, no dips can be observed in Fig.3(b) and (c). Therefore, the two techniques work well for avoiding the dips at the cavity resonance. Measured $\Gamma_{w,i}$ s and three circles determined in Fig.3(a)-(c) at 1.5525GHz are shown in Fig.3(d). It can be found that two $\Gamma_{w,i}$ s inside black solid circle are disturbed to find the proper circle for no exception of $\Gamma_{w,i}$ s. The techniques can detect these two $\Gamma_{w,i}$ so that the dips in the estimated efficiency cannot be observed.

Of course, the two techniques depend on their criterion values. Fig.4 shows the relationship between the criterion values and estimated efficiency as well as the number of $\Gamma_{w,i}$ s used in determining the circles for the 40mm monopole antenna with the resistor. For the criterion of $|\Gamma_{w,i}| > e$, it is found that proper range to select e exists and criterion value of $m - 2\sigma$ is included in this range. For the criterion of $\text{Arg}[\text{CR}] < \phi_{\max}$, it is found that proper range to select e exists and criterion value of 0.5, which is used in Fig.3(c) and Fig.4(c), is included in this range. From comparisons with the number used in finding the circle, the technique by use of the cross-ratio is severer than that of $|\Gamma_{w,i}|$.

5. Conclusions

Novel techniques to exclude the dips in the estimated efficiency for the improved Wheeler method are proposed and examined: one is statistic approach for the magnitude of the reflection coefficients; the other uses the cross-ratio for four points along the circle on the reflection coefficient plane. These techniques are still valid to extract the reflection coefficient of the antenna with the resistor at the cavity resonance because they are useful for the circle off the origin on the reflection coefficient plane. Although the results for monopole antennas near a wave absorber and so on are not shown in this paper, due to the space limitation, however the two techniques can work well to remove the effects of the cavity resonance from the estimated efficiency.

References

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