

A Simple Analysis on the Dips of Radiation Efficiency in the Improved Wheeler Method

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1. Introduction

The Wheeler method is adopted for measuring the radiation efficiency in wide frequency range because of its simplicity and accuracy in spite of the dips of the measured efficiency at discrete frequencies [1]. In the Wheeler method, we can determine the radiation efficiency by only measuring two reflection coefficients in free space and with a radiation shield, but fail to estimate the efficiency at the resonant frequency of the radiation shield [2]. Recently, Huang et al clarify that the dips is caused by the loss of the wall of the radiation shield at the resonant frequency of the cavity [3]. In this paper, we will analyze the dips of the efficiency in the improved Wheeler method [4] using a transmission line model, where the moving shorts are modeled by lumped resistors with small resistance.

2. Outline of the Improved Wheeler Method [4]

An antenna under test (AUT) can be considered as a two-port network which is fed at port 1 and is connected to the load of the intrinsic impedance in free space at port 2. Then, the radiation efficiency can be given by

$$\eta = \frac{|S_{21}|^2}{1 - |S_{11}|^2}, \quad (1)$$

where $|S_{11}|$ can be obtained by measuring the reflection coefficient of the AUT in free space. $|S_{21}|$ can be determined by measuring three or more reflection coefficients of the AUT in the waveguide with two sliding shorts. Shifting the sliding shorts is equivalent to connecting a variable reactance circuit at port 2 of the AUT network. Then, the reflection coefficient is given by

$$\Gamma_{wg, i} = S_{11} + \frac{S_{21}^2 \Gamma_i}{1 - S_{22} \Gamma_i}, \quad (2)$$

where Γ_i is reflection coefficient of the reactance circuit and is located on an arc when varying the position of the sliding shorts. We can find the center z_0 and the radius r_0 of the arc by the method of least squares, and then $|S_{21}|^2$ is given by

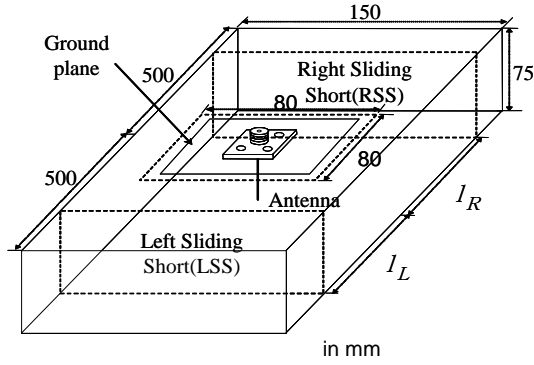


Fig.1: Waveguide with squared aperture.

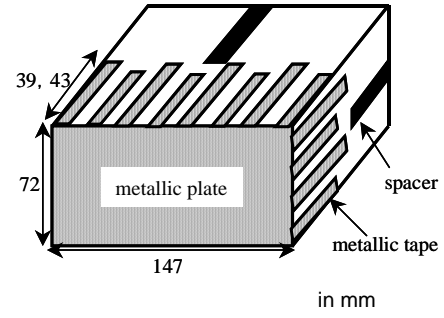


Fig.2: Sliding short with choke [4].

$$|S_{21}|^2 = r_0 - \frac{|z_0|^2}{r_0}. \quad (3)$$

In the measurement, we use a straight waveguide (150 x 75 x 1,000 mm, inner size) with a squared aperture (80 x 80 mm) in the wide wall for inserting the AUT and two sliding shorts (147 x 72 x 500 mm) with a choke [4] as shown in Figures 1 and 2. In this paper, a monopole with 40 mm length and 1 mm diameter is used as the AUT. S parameters are measured by using a vector network analyzer, Agilent 8720ES, with 32 averaging.

3. Transmission Line Model Analysis of the Efficiency Dips

An equivalent transmission line model of the waveguide with two sliding shorts and the AUT is shown in Figure 3. When two shorts are assumed to be lossless, the normalized admittance looking from port 2 of the AUT is given by

$$y_i = -j \cot \beta_g l_L - j \cot \beta_g l_R, \quad (4)$$

where l_L and l_R are the distance from the center of the AUT to the left and right shorts, respectively. And $\beta_g = 2\pi/\lambda_g$ is the phase constant of the TE_{10} waveguide mode and λ_g is the wavelength in the waveguide. If the values of y_i are not varied as l_L and/or l_R are varied, it is impossible to find the center and the radius of the arc. From (4), many combinations of l_L and l_R are possible for $y_i = 0$ or $y_i = \pm j\infty$. In the following, n , n_1 , and n_2 are positive integers.

(A) Case of $l_L + l_R = n\lambda_g/2$ and $l_L \neq n_1\lambda_g/2$ and $l_R \neq n_2\lambda_g/2$:

When $l_L + l_R$ is fixed and l_L and l_R are varied, the dip of the efficiency is caused at the resonant frequencies where the condition $l_L + l_R = n\lambda_g/2$ is satisfied. A simple way to avoid these dips is to except the data of the above condition in finding the center and the radius of the circle.

(B) $l_L = n_1\lambda_g/2$ or $l_R = n_2\lambda_g/2$:

When l_R is fixed and l_L is varied, the dip of the efficiency is caused at the frequencies where the condition $l_R = n_2\lambda_g/2$ is satisfied. A simple way to avoid these dips is to measure the reflection coefficients sliding both shorts.

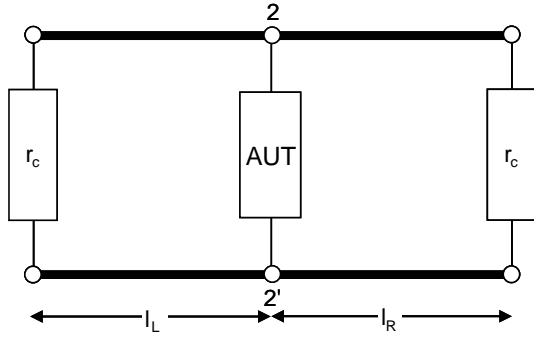


Fig.3: An equivalent transmission line model.

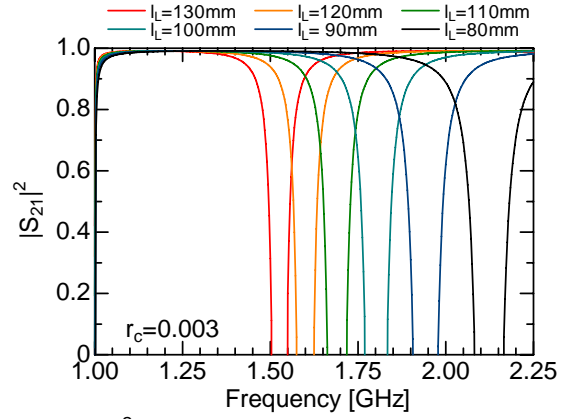


Fig.4: $|S_{21}|^2$ versus frequency when l_L is fixed and l_R is varied when $r_c=0.003$.

In practice, the dips of the efficiency are observed in a certain frequency range. For example, the above data exception must be done in $\pm 3\%$ range of the center frequency of the dip, because the contribution of the wall loss can not be ignored at the resonant frequency and in its neighborhood. The effect can be included in the transmission line model by replacing two shorts with two lumped resistors with small resistance, r_c . Then, the normalized admittance looking from port 2 of the AUT is given by

$$y_i = \frac{1 + jr_c \tan \beta_g l_L}{r_c + j \tan \beta_g l_L} + \frac{1 + jr_c \tan \beta_g l_R}{r_c + j \tan \beta_g l_R}. \quad (5)$$

This expression shows the bandwidth of the dips if the normalized resistance, r_c , is properly selected. The effect of the wall loss will be examined through following two examples.

(A) Case that one sliding short is fixed and the other is movable:

For simplicity, $S_{11}=0$ is assumed. In Figure 4, the relations between the frequency and $|S_{21}|^2$ are shown for $l_L=130, 120, 110, 100, 90,$ and 80 mm, when $r_c=0.003$. We can see that the bandwidth and the center frequency of the dip are dependent on the distance between the AUT and the sliding short. Therefore, the dips can be removed from the measured frequency band by adjusting the position of the sliding short. Figure 5 shows a comparison of our experimental result with the above result. We can find a good agreement with each other. This means that our transmission line model is valid for explaining the dips of the efficiency.

(B) Case that both sliding shorts are movable:

Δl denotes the distance from the center of the AUT to the center of two sliding shorts. For $n=2$, the normalized admittance given by (5) reduces to

$$y_i = \frac{2r_c(1 + \tan^2 \beta_g \Delta l)}{r_c^2 + \tan^2 \beta_g \Delta l}. \quad (6)$$

We can plot the relation between the reflection coefficient $\Gamma_i = (1 - y_i)/(1 + y_i)$ and the argument $\beta_g \Delta l$ as shown in Figure 6 (red solid line), when $r_c=0.003$. In the neighborhood of local maximums but except at the local maximums, we can find that

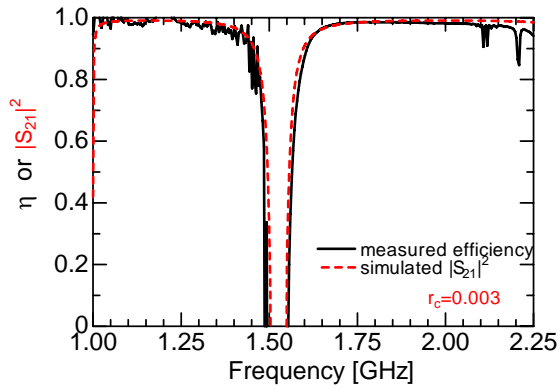


Fig.5: Comparison of measured efficiency with simulated $|S_{21}|^2$ when $l_L=130$ mm.

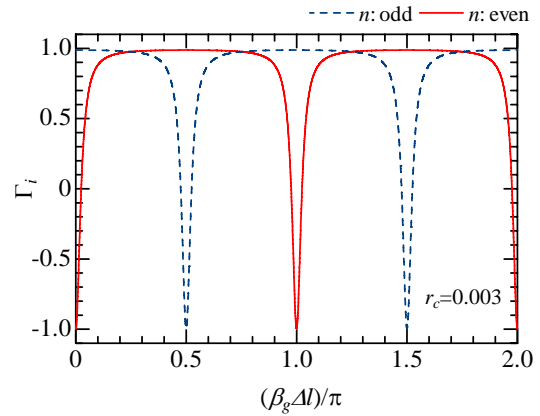


Fig.6: the distance between the center of the AUT and the center of two sliding shorts versus reflection coefficient of the reactance circuit.

the magnitude of the reflection coefficient $|\Gamma_i|$ is not equal to unity. This means that the dips of the efficiency are observed in the neighborhood of the nodes of the standing wave. Conversely, we can measure the efficiency without dips when $\Delta l = 0$, that is, $l_L = l_R$.

4. Conclusion

In this paper, we introduce a simple transmission line model to clarify the mechanism of the dips of the efficiency when using the improved Wheeler method. We have succeeded to explain the behavior of the dips by considering the loss of the short plane. And, the bandwidth of the dips can be also simulated by the model if the loss is properly estimated. Although many experimental data can not be included for the lack of the space, the results derived from the model are well consistent with our experimental results. This fact shows the validity of our transmission line model. In future, an efficiency measurement with no dips in a desired frequency range will be realized by restricting the moving range of the sliding shorts.

References

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