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Determination of the Dissipative Loss of a Two-Port Network From Noise Temperature Measurements

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When radiometric equipment is available, noise temperature measurement techniques provide a convenient and accurate means for determining the dissipative component of the insertion loss of a two-port network. It is increasingly becoming the practice to ignore mismatch errors caused by multiple reflections between the source, the receiver, and the component whose dissipative loss is being measured. Mismatch errors are difficult to determine in practice because of the requirements of having full knowledge of the magnitudes of reflection coefficients and S-parameters. This article shows it is permissible to neglect the effects of mismatch errors if special conditions are met. These special conditions only require that the reflection coefficients of the source and load be made negligibly small and that the two-port network being evaluated has reciprocal and symmetrical properties.

I. Introduction

Noise temperature techniques have been employed successfully in the past for determining the dissipative losses of low-loss, two-port networks, including antenna waveguide components [1], dichroic plates [2], and radome materials.[1] Accuracies on the order of 0.002 dB have been achieved on a measurement of dissipative loss of 0.007 dB for a mode generator and quarterwave plate polarizer waveguide section [1].

Rigorous treatments of general case mismatch errors associated with noise temperature measurement techniques have been presented elsewhere [1,3]. In practice, reflection coefficient and S-parameter information required for mismatch error corrections are difficult to obtain. As a result, the matched case formulas are often employed without knowledge of the magnitude of mismatch errors involved. It is fortuitous that, in practice, attempts are still being made to reduce the reflection coefficients of the source and load (horn-receiver) to negligibly small values.

In the following section, it will be shown that for a special case where the source and load are Z_0-matched, it becomes possible to obtain a very simple mismatch error correction term that can be applied to the dissipative loss value calculated from matched case formulas. There is no restriction on the magnitude of the reflection coefficient of the two-port network, as long as the network is reciprocal and symmetrical. It will further be demonstrated that for most practical cases where the magnitude of the reflec-

[1] T. Y. Otoshi and M. M. Franco, "Results of Dielectric Constant and Radiometric Measurements on Radome Samples," JPL Memorandum 3328-92-041 (internal document), Jet Propulsion Laboratory, Pasadena, California, March 31, 1992.

tion coefficient is less than 0.1 [corresponding to a voltage standing-wave ratio (VSWR) of 1.2], the correction term is small and may be neglected.

II. Derivation

Insertion loss of a microwave component consists of both reflective and dissipative components of loss. Low dissipative loss in the passband is one of the more important properties that a component must have when it is used as part of the front end of a deep-space communications antenna receiving system.

For the purposes of this article, it will be assumed that the two-port network being considered is part of a basic receiving system, such as the one shown in Fig. 1. Applying the special case conditions that $\Gamma_g = \Gamma_r = 0$, $|S_{11}| = |S_{22}|$, and $S_{12} = S_{21}$ to the general case equations in [3], the total input noise temperature *delivered*[2] to the receiver (load) is

$$T_g' = T_g|S_{21}|^2 + T_n \tag{1}$$

where S_{11}, S_{12}, S_{21}, and S_{22} are the scattering parameters of the two-port network [4]; Γ_g and Γ_r are the voltage reflection coefficients of the generator and receiver, respectively; T_g is the source noise temperature *available* at port 1, in kelvins; and T_n is the noise temperature that is generated by the two-port network and *delivered* to the receiver at port 2, in kelvins. For the stated special case conditions,

$$T_n = \left(1 - |S_{11}|^2 - |S_{21}|^2\right) T_p \tag{2}$$

where T_p is the physical temperature of the network in kelvins.

Examples of two-port networks that meet the requirements of reciprocity and $|S_{11}| = |S_{22}|$ are dichroic plates and radome materials. It is of interest to express Eq. (1) in terms of power loss ratios associated with the reflective and dissipative attenuation of the signal. Attenuation is defined as the insertion loss of a network when the source and load reflection coefficients are zero [4]. The total attenuation of a network can be expressed as

$$A_T = -20\log_{10}|S_{21}| = -10\log_{10}\left(1 - |S_{11}|^2\right) + L_{\mathrm{dB}} \tag{3}$$

where L_{dB} is the dissipative component of attenuation expressed as

$$L_{\mathrm{dB}} = 10\log_{10} L \tag{4}$$

and

$$L = \frac{1 - |S_{11}|^2}{|S_{21}|^2} \tag{5}$$

The term L is the familiar dissipative power loss ratio (≥ 1), but differs from the matched load case formula in that $|S_{11}|$ (equal to $|S_{22}|$) is not zero. Use of Eq. (5) in Eq. (1) leads to

$$T_g' = T_g\left(1 - |S_{11}|^2\right) L^{-1} + T_n \tag{6}$$

where the expression for the delivered network noise temperature given by Eq. (2) now becomes

$$T_n = \left(1 - |S_{11}|^2\right)\left(1 - L^{-1}\right) T_p \tag{7}$$

Note that when $|S_{11}| = 0$, Eq. (6) becomes the familiar Z_0-matched case formula

$$T_g' = T_g L^{-1} + T_n \tag{8}$$

where the network generated noise temperature due to dissipative loss becomes

$$T_n = \left(1 - L^{-1}\right) T_p \tag{9}$$

It will now be assumed that the noise temperature T_n given by Eq. (7) has been measured radiometrically through the use of techniques similar to those described in [1] and [2]. It is now of interest to determine the associated dissipative component of attenuation. The procedure involves solving for L in Eq. (7), and then substituting the resulting expression into Eq. (4). These steps yield the desired result of

$$L_{\mathrm{dB}} = -10\log_{10}\left(1 - \frac{T_n}{T_p}\right) + C_{\mathrm{dB}} \tag{10}$$

where C_{dB} is a correction term derived to be

$$C_{\mathrm{dB}} = 10\log_{10}\left[1 + (L-1)|S_{11}|^2\right] \tag{11}$$

For low-loss cases, L is close to unity, so that the above correction term simplifies to

[2] Delivered and available noise temperatures at a particular port differ and are related by a mismatch factor [3].

$$C_{\text{dB}} \approx L_{\text{dB}} |S_{11}|^2 \tag{12}$$

when L_{dB} was defined by Eq. (4). It can now can be seen that for many practical cases involving low-loss components, the correction term will be very small. For example, if values $|S_{11}| = 0.1$ (corresponding to a VSWR = 1.2) and $L_{\text{dB}} = 0.1$ dB (corresponding to $L = 1.023$), the correction term from Eq. (12) is 0.001 dB. A second example is that when $L_{\text{dB}} = 0.1$ dB, but $|S_{11}| = 0.3$ (corresponding to a VSWR = 1.86), the correction term is still only 0.0091 dB [from Eq. (11)] and 0.009 dB [from Eq. (12)]. A third example is when the dissipative component of attenuation is only 0.01 dB. It can be seen from Eq. (12) that the correction term will still be negligibly small if $|S_{11}| < 0.3$.

It should be reemphasized that the above is a special case, where it is assumed that the generator and receiver reflection coefficients are zero. An attempt should be made in practice to achieve this condition as nearly as possible. The exact equations for the general mismatched case, with none of the above restrictions, can be found in [3].

III. Conclusions

For the special case conditions stated in this article, a simple correction term has been derived for applying it to the Z_0-matched case formula for determining the dissipative loss of two-port networks. It has been found that when the special case conditions are met, the correction term will typically be negligibly small.

References

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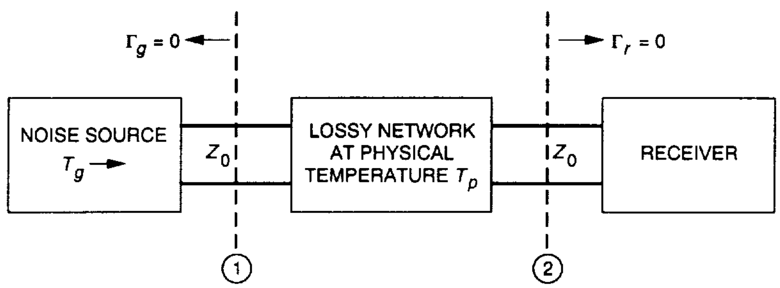

Fig. 1. A two-port lossy network in a receiving system having a matched generator and matched receiver ($\Gamma_g = \Gamma_r = 0$).