COMPARISON OF METHODS FOR ADAPTER CHARACTERIZATION

J. Randa, W. Wiatr*, and R.L. Billinger

Radio-Frequency Technology Division
National Institute of Standards and Technology
Boulder, CO 80303

Abstract—**We review and compare three methods for characterization of precision adapters using a vector network analyzer. Two of the methods are one-port techniques, and the third is an established two-port adapter-removal technique. The intrinsic efficiencies of three adapters are measured with each technique, and the results are compared. The results generally agree within 0.005, which is within the estimated uncertainties of the techniques.**

I. INTRODUCTION

Availability of precision adapters greatly increases the versatility of measurement systems, permitting measurement of a device whose connector does not match that of the system. The use of adapters, however, usually requires that they be characterized to enable the user to correct for their effect. Accurate characterization of adapters remains a difficult task. As coaxial lines are pushed to ever higher frequencies (and higher waveguide bands), and the use of adapters increases, it becomes increasingly important to have reliable, automated, broadband methods for adapter characterization. Methods using a vector network analyzer (VNA) meet these needs.

In this paper we consider three different VNA-based techniques for characterizing adapters and compare their results for three representative adapters. The three are a one-port reflective-termination (RT) technique developed by Daywitt [1,2], a multiline one-port (ML1P) method developed by Wiatr [3,4], and the two-port adapter-removal (AR) technique described in the documentation [5] for the VNA which was used in the measurements. Each method will be briefly described, and their results compared. Because the RT technique does not determine the full scattering matrix and because our principal interest is in the use of adapters in noise and power measurements, the quantity which we choose for our comparison is the intrinsic efficiency of the adapter from plane 1 to plane 2, defined by

$$\eta_{21_0} = \frac{|S_{21}|^2}{1 - |S_{11}|^2}. \qquad (1)$$

In the next section we review each of the three methods and comment on their uncertainties. Section III presents and compares the results of the measurements on several adapters using each of the three characterization methods. Conclusions are presented in Section IV.

II. REVIEW OF METHODS

The general configuration for both one-port methods is shown in Fig. 1. In the RT technique [1,2], the VNA is first calibrated at plane 2 using a method prescribed by the manufacturer. The adapter is then connected to plane 2, and measurements of the reflection coefficient

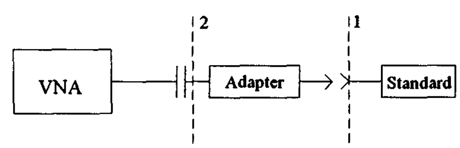

Figure 1. Measurement configuration for one-port characterization methods.

*Guest researcher; permanent address: Warsaw University of Technology, Warsaw, Poland.

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are made with the adapter terminated at plane 1 in two different reflective loads whose phases differ by 180°. The measured reflection coefficient is related to the intrinsic efficiency by

$$|\Gamma_2| \approx \eta_{21_0}|\Gamma_{rt}| - |\chi|\cos\phi, \quad \chi \approx S_{22}(1-\eta_{21_0}), \tag{2}$$

where Γ_{rt} is the reflection coefficient of the reflective termination ($|\Gamma_{rt}| \approx 1$), and ϕ is a phase angle which varies (approximately) linearly and relatively rapidly (compared to η_{21_0}) with frequency. The intrinsic efficiency can be obtained by taking an envelope average of $|\Gamma_2|$ and correcting for the small loss in the reflective termination (if an offset was used). In principle, the reflection coefficient with either reflective termination would be sufficient; in practice, both are used to facilitate the averaging and to provide redundancy. An example for a 2.4 mm coaxial to GPC-7 coaxial adapter is shown in Fig. 2. The two dashed curves are the reflection coefficients measured when the adapter's 2.4 mm port is terminated with an offset short and an offset open. (They have been corrected to account for the loss in the offset.) The solid curve is the average of the two measured curves and corresponds to the intrinsic efficiency η_{21_0}. In actual applications, a smooth curve is fitted to the average, but in the present comparison we use the unsmoothed average, since smoothing is not applied to the other methods. The RT method was developed for use in noise measurements and determines the intrinsic efficiency, but not the full scattering matrix of the adapter.

The ML1P method [3,4] uses reflective terminations with many different lengths of line to calibrate the VNA first at plane 2, and then at the output port of the adapter (plane 1) when it is connected to the VNA. The framework for the calibration procedure rests on a bilinear transformation of a measured reflection coefficient Γ_m referenced to the measured reflection coefficient Γ_{ml} of a matched load ($\Gamma_l = 0$),

$$w(\Gamma_m) = \frac{1-\Gamma_m\Gamma_{ml}^*}{\Gamma_m - \Gamma_{ml}}. \tag{3}$$

The actual reflection coefficient Γ is then related to $w(\Gamma_m)$ by [3]

$$w(\Gamma_m) = w_c + \frac{w_r}{\Gamma}, \tag{4}$$

where w_c and w_r are parameters determined in the calibration. In the complex w plane, w_c is interpreted as the position of the center of circles $|\Gamma| = const$, and w_r is interpreted as the radius of the circle $|\Gamma| = 1$. Measurements on several ($n = 1, 2, ..., N$) reflective terminations with different line lengths yield $\{w_n\}$ that lie on a spiral, as shown in Fig. 3. The center w_c is determined by fitting the spiral, and then w_r is given by $w_r = w_c - w_s$, where w_s is obtained from a measurement of a flush short. The full scattering matrix of the adapter is obtained with this method. If we use unprimed quantities to refer to the calibration at plane

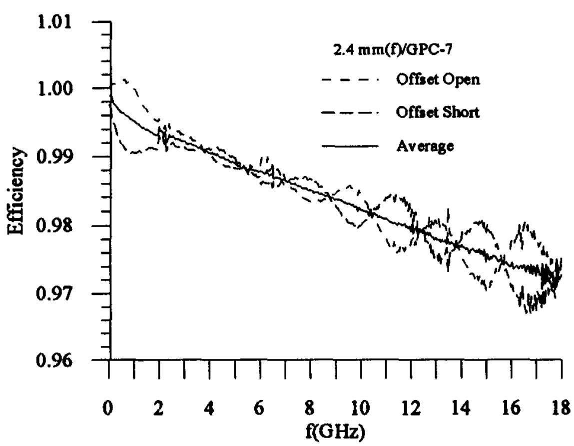

Figure 2. Efficiency (solid line) as determined in the reflective termination technique.

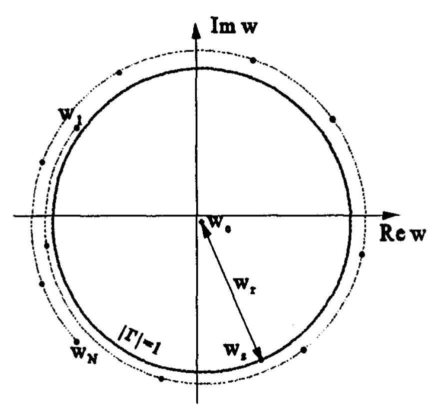

Figure 3. Representation of w plane for multiline one-port calibration.

2 and primed quantities for the calibration at plane 1, then the intrinsic efficiency is given by

$$\eta_{21_0} = \left|\frac{w_r}{w_r'}\right| \frac{\left(1 - |\Gamma_n|^2\right)}{|1 - w_c\Gamma_n|^2 - |w_c\Gamma_n|^2}, \qquad \Gamma_n \equiv \frac{\Gamma_{ml}' - \Gamma_{ml}}{1 - \Gamma_{ml}'\Gamma_{ml}^*}. \tag{5}$$

The two-port AR technique [5] uses a full two-port calibration on each side of the adapter, followed by a measurement through a reference adapter of known electrical length. This technique determines the full scattering matrix of the adapter, and the intrinsic efficiency is just calculated from Eq. (1).

Space limitations preclude presentation of details of the uncertainty analyses for the different techniques. The uncertainties in the RT method were treated in [6]. For typical cases the combined standard (1σ) uncertainty lies in the range 0.003 to 0.005. For the ML1P method, a detailed uncertainty analysis has not yet been published, but we have estimated the uncertainties and find that they are typically about 0.002 to 0.003, assuming certain favorable conditions. For the AR technique, the uncertainty in the intrinsic efficiency will be dominated by the uncertainty in $|S_{21}|^2$. We use the manufacturer's uncertainties for $|S_{21}|^2$, using the larger of the two values corresponding to the two different connector types in the one-port calibrations. For the adapters considered below, the standard uncertainties range from about 0.003 to about 0.012.

III. MEASUREMENT RESULTS

Several adapters were measured with each of these three methods, and we present three representative cases. The first is a GPC-7 coaxial to 2.4 mm coaxial adapter. Figure 4 shows the intrinsic efficiency of the adapter obtained with each of the three methods. The agreement among the results for the three different methods is excellent. The differences among the three methods are of the order of 0.001 or 0.002, considerably less than the estimated uncertainties, which are about 0.002 to 0.003, depending on frequency, for the RT method, about 0.002 for the ML1P method, and about 0.003 to 0.005 for the AR method, depending on the frequency.

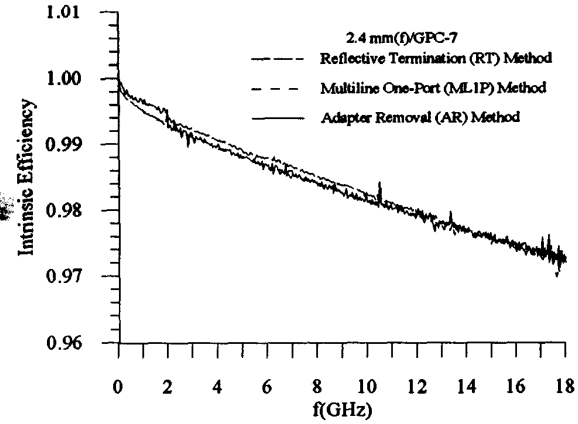

Figure 4. Comparison of results of three different methods for characterization of a 2.4 mm to PC-7 adapter.

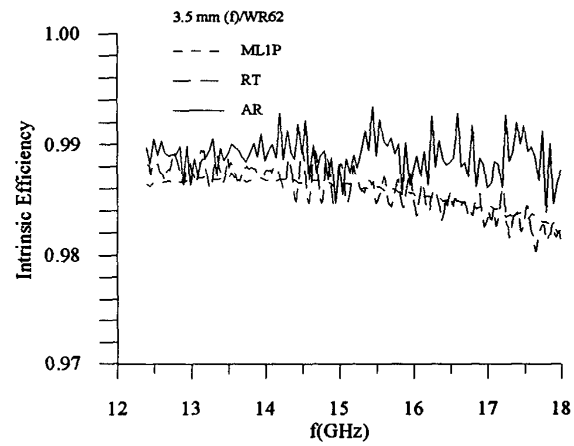

Figure 5. Comparison of results for intrinsic efficiency of a 3.5 mm coaxial to WR-62 waveguide adapter.

The second adapter is a 3.5 mm (slot) coaxial to WR-62 waveguide adapter. Results obtained with each of the three methods are shown in Fig. 5 for the WR-62 frequency range, 12.4–18 GHz. In this case the ML1P method and the RT method agree well, but the AR method deviates from the other two above about 16 GHz. The uncertainties are about 0.005 for the RT method, about 0.002 for the ML1P method, and about 0.006 for the AR method. Again the results of all three methods agree within the estimated uncertainties.

The final example we present is the worst case which we have encountered thus far. It is a 2.4 mm coaxial to

WR-42 waveguide adapter, and the results are shown in Fig. 6. The ML1P method and the AR method agree well up to about 24 GHz and differ by less than about 0.004 throughout the band. The RT method, however, is about 0.007 above the other two methods at the bottom of the frequency band and about 0.007 below the AR method at the top of the band. The standard uncertainties in this case are 0.005 for the RT method, about 0.003 for the ML1P method, and about 0.005 (up to 20 GHz) or 0.012 (above 20 GHz) for the AR method. Although the agreement in Fig. 6 does not look good, the discrepancies among the three methods are consistent with the uncertainties, and this is the worst disagreement we have encountered thus far.

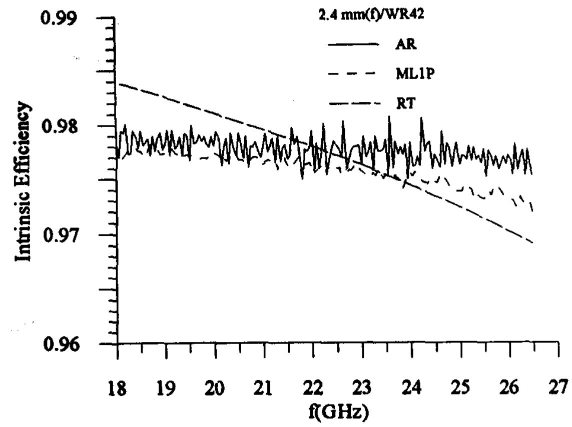

Figure 6. Worst disagreement encountered thus far among results of three methods.

IV. CONCLUSIONS

The intrinsic efficiencies measured with the three methods all agree within the estimated uncertainties. Each of the methods has its own advantages and disadvantages. The RT method is the quickest and easiest to use, requiring the fewest measurements and relatively little analysis. It does not measure the scattering parameters of the adapter, however, and it assumes that the adapter is reciprocal and has low loss. The ML1P method appears to achieve the smallest uncertainties and measures the full scattering matrix, assuming $S_{12} = S_{21}$. It is quite measurement intensive, however, and it requires more data analysis than the other methods. Also, its uncertainty analysis is still preliminary. The adapter-removal method measures the full scattering matrix without having to assume reciprocity, and the analysis is prepackaged. Its drawbacks are that it is measurement intensive, its uncertainties tend to be somewhat larger, and it is susceptible to additional errors due to cable movement and multiple connect-disconnects.

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