

An Adaptor Characterisation Technique used for Noise Measurements

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Introduction

The ability to measure the noise temperature of sources of one connector type on a radiometer with a different connector type is made possible through the use of calibrated adaptors. The adaptor's characteristics are determined, using an adaptor evaluation technique, and removed from the noise temperature measurement. Coaxial noise sources are often calibrated on waveguide radiometers through the use of such adaptors.

Using an adaptor in this way inevitably increases the uncertainty in the final coaxial noise temperature. The sizes of the contributions due to the adaptor are determined in the adaptor evaluation process, and for many processes are not well defined. The adaptor removal technique, which is part of the firmware of many ANAs, does not give any measure of the Type B uncertainties as the algorithms are generally not available to the user. Here we describe an adaptor evaluation technique to which an uncertainty budget has been ascribed, and discuss methods by which the uncertainties may be reduced.

The Method of Three Known Loads

This method uses the well-known expression, given in equation 1, for transforming the complex voltage reflection coefficient (VRC) of a one-port device from one measurement plane to another.

$$\Gamma_c = S_{11} + \frac{S_{12}S_{21}\Gamma_w}{(1 - S_{22}\Gamma_w)} \quad 1$$

It is written in terms of the S-parameters of the two-port network that separates the two measurement planes, and of the VRC of the one-port device being transformed, Γ_w , as shown in figure 1.

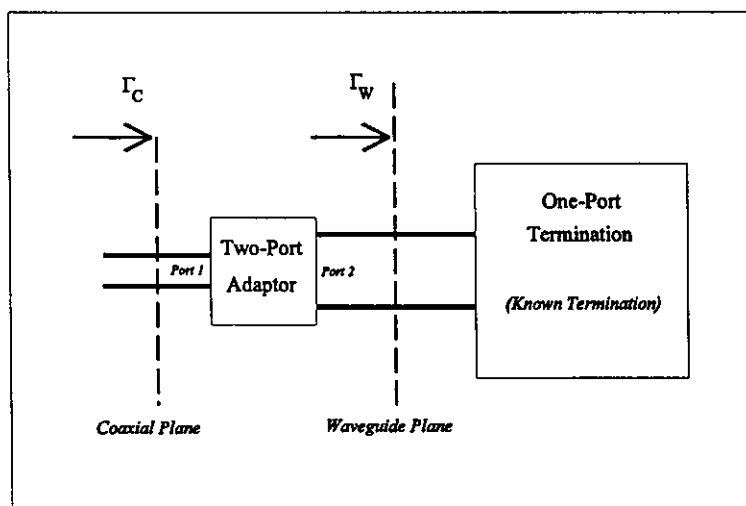


Figure 1

The three complex unknowns in equation 1, S_{11} , S_{22} and the product $S_{12}S_{21}$, can be found by measuring Γ_c when port 2 is connected to three one-port devices of known VRC. It is

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more sensible to talk of three known *terminations* rather than three known loads as the one-port items are deliberately chosen to be mismatched and the term *load* can be misleading. The solution is achieved by re-arranging equation 1 to give three simultaneous equations of the form of equation 2.

$$\Gamma_{c,i} = S_{11} + S_{22}\Gamma_{c,i}\Gamma_{w,i} + \Gamma_{w,i}(S_{12}S_{21} - S_{11}S_{22}) \quad i = 1, 2, 3. \quad 2$$

These are solved by creating the matrix given in equation 3 and inverting to yield the S parameter vector **S** and hence the required unknowns.

$$\Gamma_c = \begin{pmatrix} \Gamma_{c,1} \\ \Gamma_{c,2} \\ \Gamma_{c,3} \end{pmatrix} = \begin{pmatrix} 1 & \Gamma_{c,1}\Gamma_{w,1} & \Gamma_{w,1} \\ 1 & \Gamma_{c,2}\Gamma_{w,2} & \Gamma_{w,2} \\ 1 & \Gamma_{c,3}\Gamma_{w,3} & \Gamma_{w,3} \end{pmatrix} \begin{pmatrix} S_{11} \\ S_{22} \\ S_{12}S_{21} - S_{11}S_{22} \end{pmatrix} = M \cdot S \quad 3$$

The Uncertainty Budget

The matrix inversion is carried out numerically for each adaptor and produces a value for the S parameters that is dependent on the six complex quantities $\Gamma_{c,1} \dots \Gamma_{c,3}$ and $\Gamma_{w,1} \dots \Gamma_{w,3}$. The VRC data is presented as two real numbers: magnitude and phase, and hence each S parameter is a function of 12 real variables. Each of these variables is considered to be independent of the others and so their contributions to the S parameter uncertainty are orthogonal. Each contribution is evaluated by offsetting the parameter by its uncertainty and calculating the corresponding offsets in the S parameters. The overall S parameter uncertainty is given by the RSS of the 12 offsets.

It is obviously beneficial to reduce the uncertainty associated with each VRC in order to minimise the overall uncertainties. This is dependent on the determination of the VRCs themselves. The conventional method is to use an ANA, calibrated in the line type appropriate to port 2, to measure the VRCs of three different terminations: $\Gamma_{w,1}$ to $\Gamma_{w,3}$. The ANA is then recalibrated to measure the VRC of the adaptor when connected to each of the above known terminations, giving $\Gamma_{c,1}$ to $\Gamma_{c,3}$. This procedure has been used effectively when both ports are coaxial, but requires two ANA calibrations and six VRC measurements. Evaluation of coaxial-to-waveguide and waveguide-to-waveguide adaptors can make use of the waveguide port, as port 2, to reduce the number of ANA calibrations and VRC measurements. This is achieved by calculating the VRCs of the waveguide terminations from knowledge of their physical dimensions.

Calculated Reflection Coefficients.

The terminations that are most easily modelled are offset short circuits. The VRC of an offset short circuit is easily calculable from basic theory, assuming that the waveguide and the short circuit are ideal. The difference in calculated VRC for a lossless and a lossy offset short is at least an order of magnitude below the uncertainties ascribed in the VRC calculation and can be ignored. The uncertainties ascribed to the calculated VRCs are determined numerically by offsetting each of the physical dimensions by its mechanical tolerance.. The shifts in the VRC for all dimensional offsets are combined, as an RSS, to give the overall uncertainty.

A series of offset short circuits are not, however, the best terminations to use from a measurement point of view. Examination of equation 1 shows that the variation in Γ_c is dominated by Γ_w if $|\Gamma_w| \sim \text{unity}$. Physically Γ_c shows the interaction between a strong

reflection from the short circuit, and a weak reflection from the adaptor. The evaluation of the S parameters depends on the ability to resolve the variation of this interaction versus Γ_w , from the noise on the ANA measurement. An improvement can therefore be made by reducing the magnitude of the reflection from Γ_w to make it comparable to the adaptor's S_{11} . The use of a "lossy short", $|\Gamma_w| \sim 0.1$, and waveguide offsets would produce a significantly larger interaction and improve the evaluation of the S parameters. This would, however, necessitate measuring the VRCs of the waveguide terminations and incurring the penalty of higher uncertainties. Acceptable levels of measurement uncertainties can be achieved by measuring the waveguide terminations at a national standards laboratory.

S Parameter Results

Coaxial-to-waveguide adaptors have been evaluated using this technique in WG10, WG14, WG16, WG18, WG20, WG22 and WG23: covering 3GHz to 50GHz. The table below gives the uncertainty budget for the parameter S_{11} of a typical adaptor and shows the contribution due to each of the input variables. The mechanical tolerance, although a single parameter, affects the calculated phase in more than one way as this tolerance is applied independently to both the length and width of the waveguide offset.

Freq. 8.2GHz	Component Name	Component Uncertainty	Contribution to Uncertainty in S ₁₁	
			Magnitude	Phase
	First Load: Measured Magnitude	0.010 U	0.217 mU	23.94°
	First Load: Measured Phase	0.6°	5.32 mU	6.78°
	First Load: Known Magnitude	Mechanical Tolerance of 0.015mm	0 mU	0°
	First Load: Known Phase		1.82 mU	1.08°
	Second Load: Measured Magnitude	0.010 U	6.07 mU	18.96°
	Second Load: Measured Phase	0.6°	6.94 mU	14.68°
	Second Load: Known Magnitude	Mechanical Tolerance of 0.015mm	0mU	0°
	Second Load: Known Phase		1.96 mU	8.71°
	Third Load: Measured Magnitude	0.010 U	3.97 mU	5.24°
	Third Load: Measured Phase	0.6°	0.16 mU	18.27°
	Third Load: Known Magnitude	Mechanical Tolerance of 0.015mm	0 mU	0°
	Third Load: Known Phase		0.35 mU	5.99°
Total Uncertainty (RSS) at 95% CL			11.68 mU	40.84°

A Typical Uncertainty Budget for a Waveguide to Coaxial Adaptor

The resulting S parameters have been used to de-embed the effects of the adaptors from noise temperature measurements of a coaxial noise source made in bands WG10 to WG18.

De-embedding of Adaptors from Noise Temperature Measurements

The relationship between the noise temperatures at the coaxial and waveguide planes, T_c and T_w respectively, and their uncertainties δT_c and δT_w are given by equation 4, where α is

the available power transmission factor (APTF) of the adaptor. The APTF of the adaptor is determined from the adaptor's S parameters and the VRC of the coaxial noise source. The

$$T_c = \frac{(T_w - T_a)}{\alpha} + T_a \quad \text{and} \quad (\delta T_c)^2 = \left(\frac{\partial T_c}{\partial T_w} \delta T_w \right)^2 + \left(\frac{\partial T_c}{\partial T_a} \delta T_a \right)^2 + \left(\frac{\partial T_c}{\partial \alpha} \delta \alpha \right)^2$$

4

relative contributions to the coaxial source noise temperature are shown in the table below. The contribution due to the uncertainty in α is dominant, and is due mainly to the uncertainties in ANA measurements of the adaptor and the known terminations. This contribution increases at higher frequencies due to the higher levels of uncertainty attributed to ANA measurements in smaller coaxial lines.

Frequency = 8.2GHz	Measured T_{WG}	T_a	APTF (α)	Calculated T_c
Value of Component	9278.8K	297.9K	0.9868	9399.1K
Uncertainty of Component	62.1K	0.566K	0.013	
Contribution to T_c	62.9K	0.01K	117.8K	133.6K

Contributions to Coaxial Noise Temperature Uncertainty

Final Results and Concluding Remarks

The measurements of a coaxial noise source over bands WG10 to WG18 are shown in figure 2.

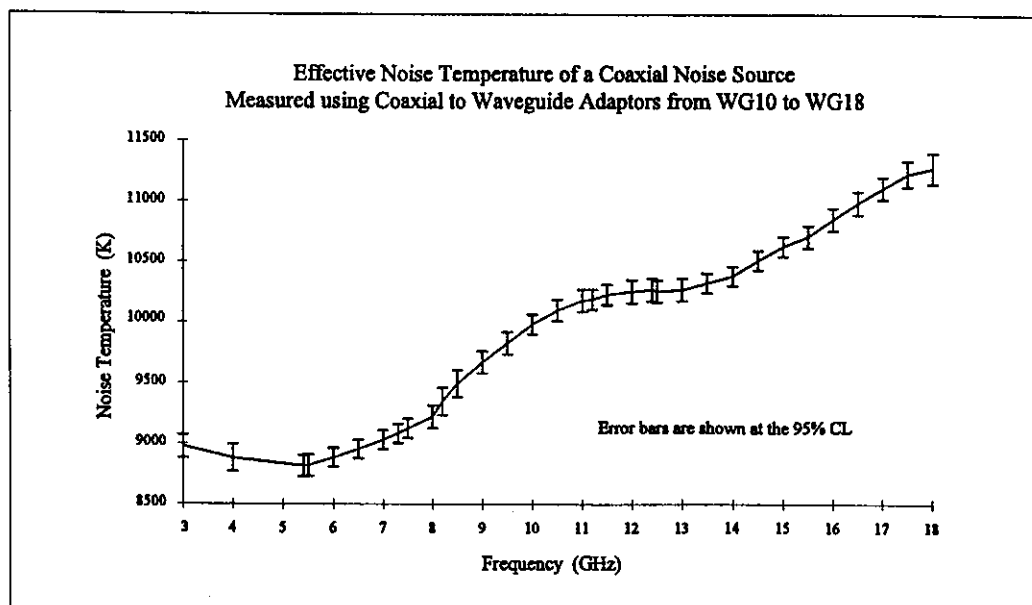


Figure 2

They compare well with results of the same source measured on a coaxial radiometer, using the UK coaxial primary standard. The levels of uncertainty are low enough to consider using this technique to provide traceability for coaxial radiometers above the frequencies currently covered by the UK primary coaxial standard, as well as providing a route to traceable coaxial measurements at frequencies above the limits of current coaxial radiometers.