Measuring True PAE Using A Maury Automated Tuner System

Authors: John Sevic, MSEE; Director, Device Characterization – Maury Microwave Corporation, and
Ray Qin, Automated Tuner System Test Engineer – Maury Microwave Corporation

Abstract: *Characterization and optimization of PAE is a common and useful application of loadpull. Based on the standard definition of PAE, using power gain, classical loadpull uses an incident power meter and reflected power meter, at the input of the source tuner, to approximate the power delivered to the DUT. However, since the source tuner is a lossy two-port, the return loss at its input is not an accurate representation of the return loss at the DUT reference plane, which is the necessary quantity to establish the DUT power gain and PAE. This results in a significant under estimation of true PAE, particularly in those situations where there is a large difference between transducer gain and power gain or when transducer gain is in the neighborhood of 10 dB or less, as found in many pulsed class C BJT applications. As well, a DUT under optimum linearity tuning frequently exhibits a low return loss, or equivalently, a large difference between transducer gain and power gain. Hence, accurate measurement of PAE is crucial for both saturation optimization as well as linearity optimization.*

Maury ATS provides for rigorous measurement of large signal input impedance at the DUT reference plane, thereby enabling characterization of true PAE. The present application note discusses the theory behind the measurement and shows how to configure both the Agilent 8753x series of VNAs and the Agilent 8510x series of VNAs for true PAE characterization. A plot is also given showing the error introduced by assuming transducer gain and power gain are equal, which is what loadpull systems provided by other manufacturers assume.

Defining PAE

PAE is defined as:

$$\eta_{PAE} = \eta\left(1 - \frac{1}{G_P}\right) \qquad (1)$$

where the η is the drain/collector efficiency and G_p is the power gain, defined as the ratio of the power delivered to the load by the DUT to the power delivered to the DUT by the source. In order for a loadpull system to accurately characterize η_{PAE} requires that the power delivered to the DUT be precisely known, not estimated, as done in many commercial loadpull systems. Classical loadpull either approximates DUT return loss at the input side of the source tuner using a directional coupler with incident and reflected power meters, or assumes $G_p = G_T$[1]. Both of these approximations result in significant under reporting of actual PAE, thereby giving the loadpull user an inaccurate characterization of a vitally important DUT metric.

Measuring PAE With a Loadpull System

There are three methods available for measuring PAE with a loadpull system:

1. *Assume $G_p = G_T$.* If the actual DUT input return loss is large and/or the transducer gain is in the neighborhood of 10 dB or less, this approximation results in a significant under estimate of the true PAE. **Figure 1** shows PAE under estimation introduced using this method. Note that as return loss degrades and/or as G_T drops below 10 dB that unacceptable error is introduced.

2. *Measure the return loss at the input side of the source tuner and assume it's the same as the return loss at the input of the DUT.* Using the mismatch invariance property[1] it can be shown that this method works only when the tuner is lossless and reciprocal. While a tuner is a reciprocal network, it is far from lossless,

particularly when it is synthesizing a large mismatch.

3. *Use a calibrated one-port vector receiver, e.g. a VNA, to measure the incident and reflected voltage waves at the input side of the source tuner and reset the calibration reference plane to the DUT reference plane.* This approach enables a rigorous and accurate method of measuring the input impedance of the DUT, at its reference plane, allowing calculation of the power delivered to the DUT to be made. Only in this fashion can true PAE be measured using a loadpull system. Note that this method also allows large signal input stability analysis to be performed. This method is adopted by Maury ATS, to give you optimum accuracy in characterizing PAE.

Measuring True PAE With Maury ATS

Maury ATS currently supports the Agilent 8753x series of VNAs and the Agilent 8510 series of VNAs, with a standard two-port test set, to measure large signal DUT input impedance. A standard SOL calibration is supported, with fixed or sliding load, at the input coupler reference plane. The input impedance is reported as the magnitude and phase of the large signal reflection coefficient seen at the input of the DUT, at the fundamental frequency. All standard characterization modes, such as source pull, loadpull, power sweep, and bias sweep are supported. In addition, when an 8753x VNA is used, large signal AM-PM can also be measured, as described in Maury application note 5C-029, ***Measurement of Large Signal Input Impedance During Loadpull***, which is found at the following URL: (http://www.maurymw.com/support/pdfs/5C-029.pdf).

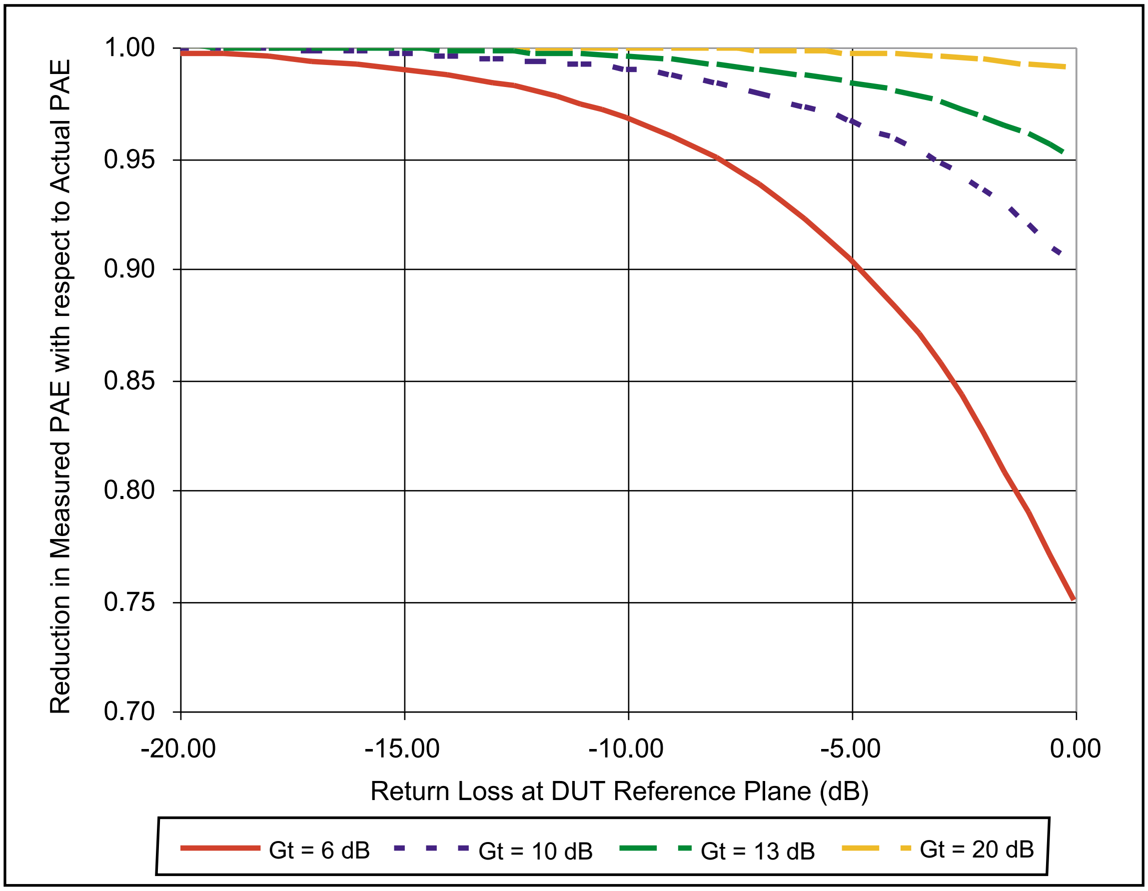

Figure 1. Reduction in Measured PAE by Assuming $G_p = G_T$. The Reduction is Shown as Apparent PAE with Respect to Actual PAE Versus DUT Input Return Loss and Transducer Gain, G_T.

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Figures 2 and **3** show the required ATS hardware configuration for the Agilent 8753x and Agilent 8510x VNAs, respecitvely. Ensure that the power limitation of the VNA is not exceeded, by inserting appropriate padding.

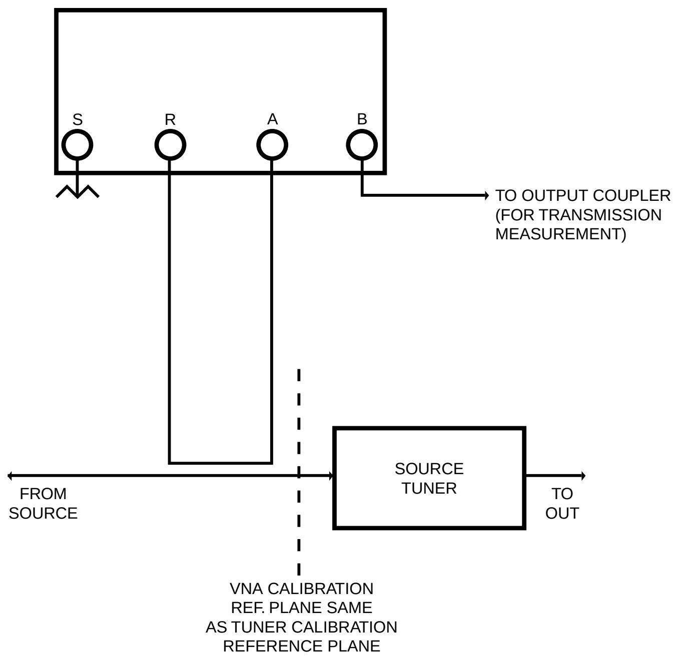

Figure 2. Required ATS hardware configuration for the Agilent 8753x.

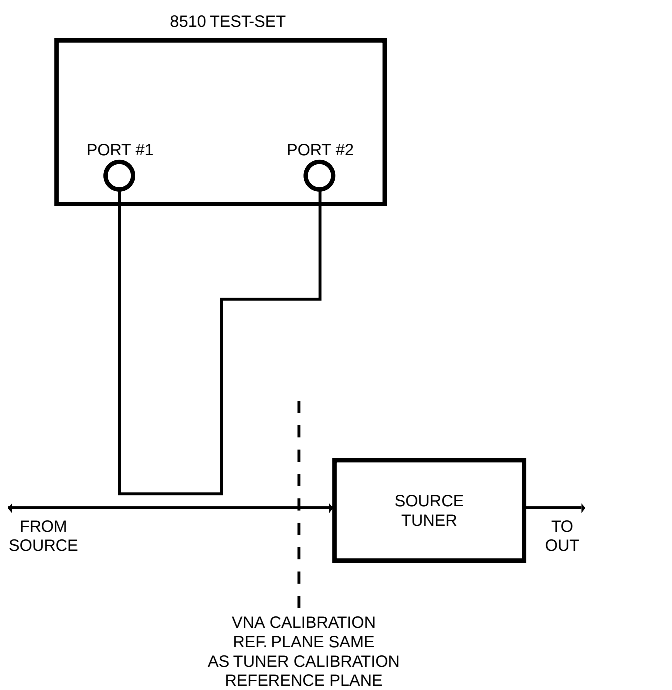

Figure 3. Required ATS hardware configuration for the Agilent 8510x.

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For true PAE measurement to be enabled, the vector receiver measurement option must be active, with either an 8753x or 8510x configured as shown in **Figures 2** and **3**, respectively. To configure the Maury ATS vector receiver measurement option, access the <instruments> options dialog, prior to starting a power calibration, and click on <Vector Receiver>. At the resultant dialog box, shown in **Figure 4**, enter the appropriate instrument driver and other information, such as GPIB address. The driver names of the supported instruments are:

- vna8753.exe (supports A and B models)
- vna8753d.exe
- vna8753e.exe
- vna8610c_vectorreceiver.exe (A, B, and C models)

Following configuration of the vector receiver, the ATS block diagram will appear as shown in **Figure 5**. As mentioned above, the 8753x series will also support measurement of AM-PM, if a sample of the output signal is taken, and applied to channel B of the VNA, as shown in the block diagram of **Figure 5**.

Next, execute either a standard CW calibration or CW calibration recall. Just prior to completing the calibration, a dialog box like the one shown in **Figure 6a** will appear. Choose either to recall an existing cal-set from the VNA (assuming it has already been done) or to perform a new SOL one-port VNA calibration. If the former is chosen, then the CW calibration is complete, and ATS is ready to make measurements.

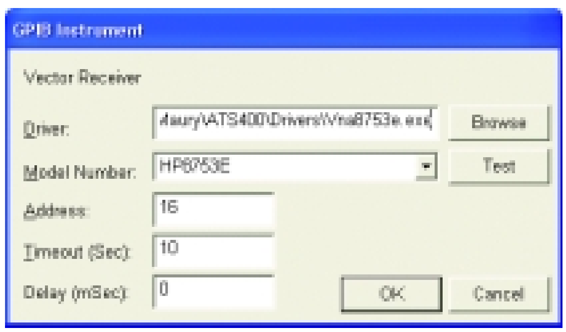

Figure 4. Dialog Box for Configuring Vector Receiver.

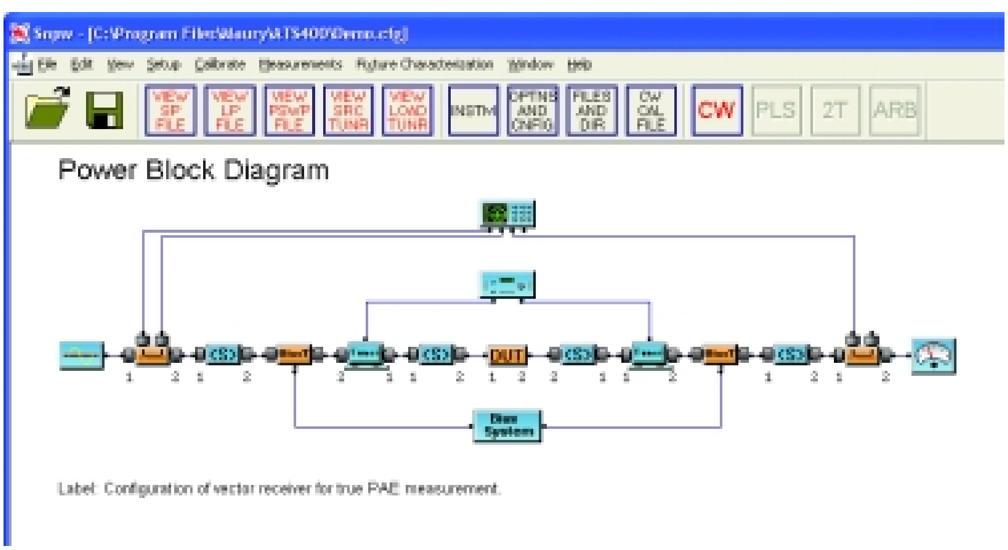

Figure 5. ATS Power Block Diagram View Showing Representation of Vector Receiver.

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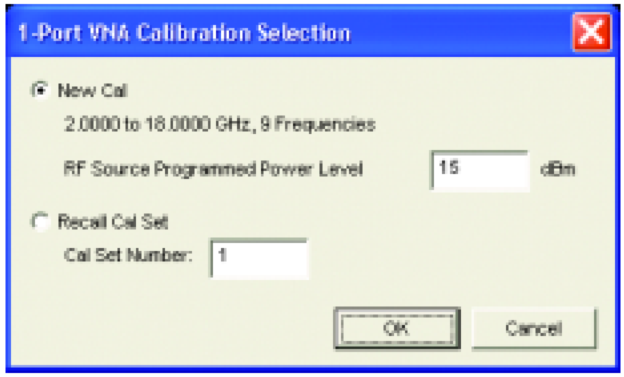

Figure 6a. Dialog Box to Chose Existing VNA Calibration Set or Perform New VNA Calibration.

If the latter is chosen, a dialog box like the one shown in **Figure 6b** will appear. A standard SOL calibration is supported, with REFLECT options for either a short or an open and LOAD options for either a fixed load or a sliding load. Fields exist also for the cal kit's upper frequency, the calibration reference impedance, and a cal kit label.

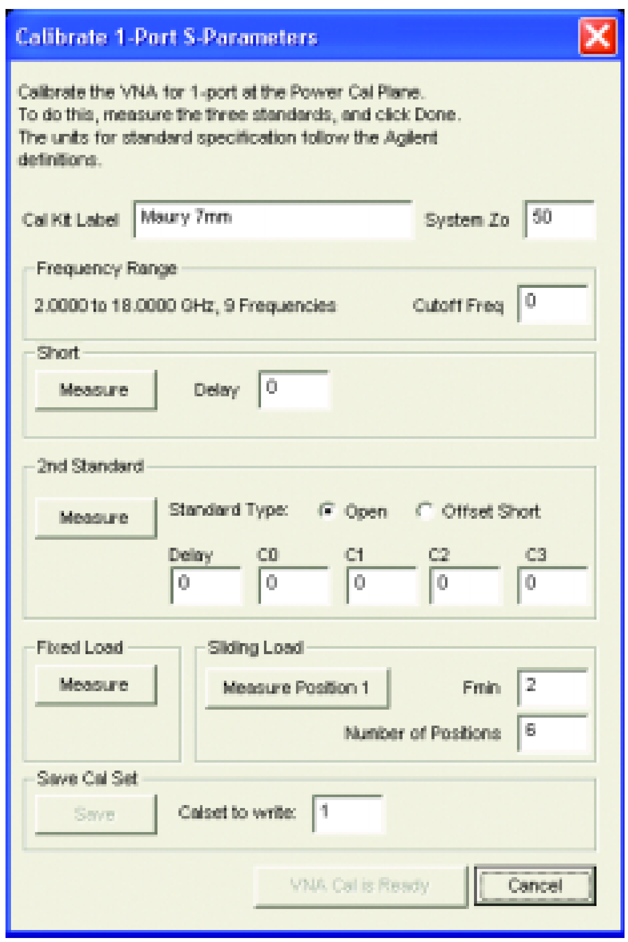

Figure 6b. Dialog Box Perform New VNA Calibration. Note That All Units Entered Follow Standard Agilent Definitions.

To execute the SOL calibration, attach and measure the appropriate standards. After each of the three calibration standards have been measured, the calibration will be written to the cal set specified, and ATS will be ready to make measurements.

ATS Post Processing With True PAE

All PAE calculations done subsequent to a vector receiver calibration will be referenced to power gain, G_p, thus providing true DUT PAE, not estimated PAE. In addition, four new variables are available, which are accessed from the <Measurement Parameters> dialog in the power measurement view. These variables are:

- Pin_del: True power delivered to DUT (dBm)
- Γ_{IN_MAG}: DUT large signal reflection coefficient magnitude
- Γ_{IN_PHASE}: DUT large signal reflection coefficient phase (deg)
- G_p: True DUT power gain (dB)

Each of these quantities is referenced to the DUT input side reference plane at the fundamental frequency. In addition, if an 8753x is used, then *Trans_pha*, is available, which represents AM-PM conversion at the input and output of the DUT at the fundamental frequency.

Note that it is possible to perform basic large signal stability analysis by plotting contours of the magnitude of the large signal input reflection and noting regions where its magnitude is greater than unity.

References

[1] Robert E. Collin, *Foundations for Microwave Engineering*, McGraw-Hill, New York, 1966.

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