MEASUREMENT OF LARGE SIGNAL DEVICE INPUT IMPEDANCE DURING LOAD PULL

Abstract

Knowledge of device input impedance as a function of power level and load matching is useful to fully understand non-linear device behavior, and is also needed to rigorously determine the delivered input power for any arbitrary source tuner setting. This paper describes a technique of measuring the input impedance directly during a load or source pull using a vector network analyzer.

Introduction

Automated tuner systems provide a variable impedance environment for making measurements. One important application is characterization of non-linear RF power devices. The purpose is to provide information needed for design and optimization of power amplifiers and circuits.

Figure 1 shows a block diagram of a typical power measurement setup. A variety of parameters can be measured as a function of bias, frequency, drive power, and impedance. Some common parameters include available input power, delivered input power, delivered output power, transducer gain, power gain, and power added efficiency.

Device input impedance varies as a function of power level and load matching. Input impedance data can provide better understanding of device behavior, and it is also needed to rigorously determine delivered input power for arbitrary tuner settings. In the **Figure 1** setup, input impedance can be inferred indirectly from source pull data, but it cannot be measured directly.

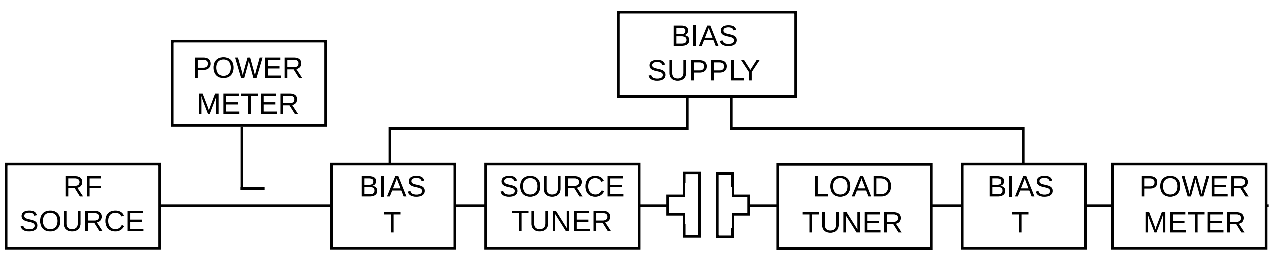

Figure 1: Block Diagram of a Basic Automated Tuner System for Power Measurements.

Types of Gain

The following three types of gain are of interest at RF/ microwave frequencies:

1. Available gain is defined as

$$\frac{\text{(available output power)}}{\text{(available input power)}}$$

It is a function of the device s-parameters and the source impedance. The equation is

$$Ga = f(\Gamma_s, [S]) = \frac{(1 - |\Gamma_s|^2)\, |S_{21}|^2}{|1 - S_{11}\Gamma_s|^2 (1 - |\Gamma_2|^2)}$$

where $\Gamma_2 = S_{22} + \dfrac{S_{12}\, S_{21}\, \Gamma_s}{1 - S_{11}\, \Gamma_s}$

2. Power gain is defined as

$$\frac{\text{(delivered output power)}}{\text{(delivered input power)}}$$

It is a function of the device s-parameters and the load impedance. The equation is

$$Gp = f([S], \Gamma_L) = \frac{|S_{21}|^2\ (1 - |\Gamma_L|^2)}{(1 - |\Gamma_1|^2)\ |1 - S_{22}\Gamma_L|^2}$$

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where $\Gamma_1 = S_{11} + \frac{S_{21}\ S_{12}\Gamma_L}{1 - S_{22}\Gamma_L}$

3. Transducer gain is defined as

$$\frac{\text{(delivered output power)}}{\text{(available input power)}}$$

It is a function of the device s-parameters and both the source and load impedances. The equation is

$$Gt = f(\Gamma_s, [S], \Gamma_L) = \frac{(1 - |\Gamma_s|^2)\ |S_{21}|^2\,(1 - |\Gamma_L|^2)}{|1 - S_{11}\Gamma_s|^2\ \ |1 - \Gamma_2\Gamma_L|^2}$$

Calculation of Delivered Input Power

The available power at the input of the source tuner is known from calibrated lookup tables or by measuring with the optional input power meter.

The available power at the Device-Under-Test (DUT) plane is found using the available gain of the source tuner. This can be calculated rigorously from pre-calibrated tuner s-parameters and the source impedance (looking back into the RF power source).

The delivered power at the DUT plane is found from the delivered power at the source tuner and the power gain of the source tuner. The approximate delivered power at the input of the source tuner is found by subtracting the reflected power from the incident power. But the power gain of the source tuner cannot be calculated rigorously without knowing the DUT input impedance.

This error (due to approximating the power gain of the source tuner) disappears in the region of maximum interest, which is the source impedance region where the DUT is matched. This can be found by doing a source pull. However, to rigorously find the delivered input power at an arbitrary source impedance requires knowledge of the DUT input impedance.

Measuring Non-Linear Input Impedance

The DUT input impedance can be measured directly during the load or source pull by adding a Vector Network Analyzer (VNA) as shown in **Figure 2**. An HP8753C VNA was used, and the incident and reflected powers were sampled with couplers. The VNA was operated in the receiver mode, since the external power source was used.

Source match and directivity errors are removed by standard VNA error correction techniques. The VNA is calibrated for a 1-port measurement at the input to the source tuner. This allows direct, error-corrected impedance measurements looking into the source tuner. The calibration remains valid over a wide power range.

With any arbitrary source and load tuner setting, the input impedance at the source tuner will be read from the VNA. The reference plane is then shifted to the DUT input plane using the known tuner s-parameters.

This input impedance data can then be presented in either rectangular or polar form, and is also used to accurately calculate delivered input power to the DUT. This in turn improves the accuracy of the power added efficiency calculation when the DUT sees large source mismatches.

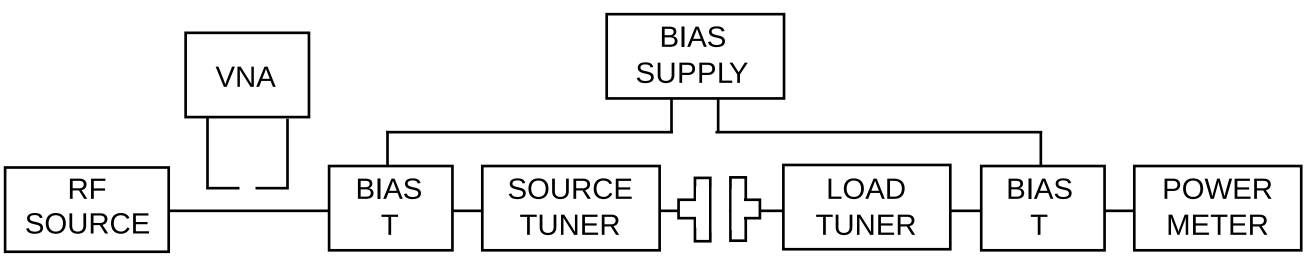

Figure 2: Block Diagram of an Automated Tuner System for Power Measurements, with a VNA to Measure DUT Input Impedance.

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Verification of Measurement Accuracy

To check the accuracy of the basic measurement, a fixed impedance was created with a passive thru, and the tuners set to fixed positions. The impedance was first measured with the HP8753 in the power setup. Then the couplers were disconnected, and a conventional HP8510, calibrated with the same 1-port cal kit, was connected instead. The two analyzer measurements were compared in this way at 12 source tuner settings, widely scattered over the Smith chart. The data in **Table 1** shows good agreement.

To check the accuracy as a function of power level, a power sweep was done with the passive thru, and the source and load tuners at fixed positions. The impedance (or reflection coefficient) was expected to remain constant versus power.

Over the range of -10 to +6 dBm, the worst case variation of measured reflection coefficient magnitude was .005 as shown in **Table 2**. Up to +11 dBm, the variation went up to .02. This should be checked when setting up the system to ensure that appropriate coupling values are used.

Gamma Measured at Tuner Input						
Tuner State Mag<phase	8510 System Real	8510 System Imag	8753 System Real	8753 System Imag	Delta Real	Delta Imag
.819<142	0.365	-0.549	0.367	-0.520	-0.002	-0.029
.673<108	0.553	-0.068	0.518	-0.037	0.035	-0.031
.624<55	0.404	0.429	0.365	0.418	0.039	0.011
.783<30	0.455	0.548	0.423	0.543	0.032	0.005
.362<136	0.250	0.020	0.247	0.019	0.003	0.001
.414<36.3	0.072	0.465	0.071	0.448	0.001	0.017
.601<12.2	0.050	0.619	0.030	0.584	0.020	0.035
.450<-143	-0.103	-0.284	-0.099	-0.276	-0.004	-0.008
.458<-42	-0.409	0.318	-0.389	0.305	-0.020	0.013
.818<-148	-0.468	-0.542	-0.452	-0.537	-0.016	-0.005
.686<-115	-0.583	-0.239	-0.545	-0.239	-0.038	0.000
.789<-52	-0.487	0.591	-0.480	0.563	-0.007	0.028

Table 1: Comparison of Direct Reflection Coefficient Measurements by the HP8753C in Receiver Mode vs. the Conventional HP8510.

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Input Power dBm	Measured Gamma Mag	Measured Gamma Phase
-10	0.0208	-14.86
-9	0.0196	-16.11
-8	0.0229	-11.24
-7	0.0207	-18.96
-6	0.0232	-16.17
-5	0.0215	-8.12
-4	0.0217	-10.78
-3	0.0214	-10.26
-2	0.0230	-12.73
-1	0.0227	-12.60
0	0.0224	-10.25
1	0.0237	-3.28
2	0.0231	1.08
3	0.0208	4.01
4	0.0258	0.70
5	0.0238	11.66
6	0.0247	14.37
7	0.0290	23.13
8	0.0317	31.91
9	0.0355	31.31
10	0.0388	40.21
11	0.0422	44.93

Table 2: Variation of Reflection Coefficient Data vs. Power.

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The final verification was to do the comparison with the HP8510 at the DUT plane for a wide range of source tuner settings. The data is shown in **Table 3**. The worst case was better than .02 magnitude, and this takes in the total error from the HP8753, the HP8510, and the tuner s-parameter accuracy and repeatability. This is excellent.

Gamma Measured at DUT Input						
Source State Mag<phase	8510 System		8753 System		Delta	
	Mag	Phase	Mag	Phase	Mag	Phase
.633<-175	.980	-162	0.985	-160.00	-0.005	-2.00
.482<134	.980	-162	0.984	-160.00	-0.004	-2.00
.510<82	.980	-162	0.988	-161.00	-0.008	-1.00
.523<49	.980	-162	0.994	-163.00	-0.014	1.00
.531<0	.980	-162	1.000	-162.00	-0.020	0.00
.681<-41	.980	-162	0.997	-162.00	-0.017	0.00
.502<-81	.980	-162	0.987	-161.00	-0.007	-1.00
.638<-136	.980	-162	0.988	-161.00	-0.008	-1.00

Table 3: Comparison of Reflection Coefficient Measurements at the DUT Plane by the HP8753C in Receiver Mode vs. the Conventional HP8510C.

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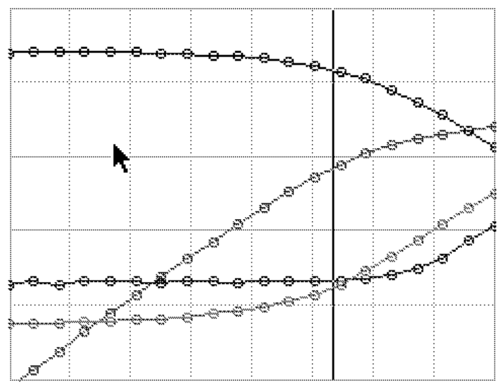
Measured Data With An Active DUT

Figure 3 shows a swept power plot of a GaAs FET. The plots shown include output power and transducer gain, and magnitude and phase of input reflection coefficient. The DUT input reflection does change with power level.

Power Sweep 2.0000 GHz
Γsource = (0.768< 151.21)
Γload = (0.497< 136.27)

Parameter	Scales	Marker
Pout:	0.00 to 20.00 dBm	11.33 dBm
Gt:	0.00 to 20.00 dB	16.58 dB
Γ2_mag:	0.95 to 1.00 mag	0.96 mag
Γ2_Phase:	-160.00 to -140.00 ang	-155.05 ang



Marker position: Pin_avail = -5.25 dBm

Pin_avail dBm	Pout dBm	Gt dB	Γ2_mag mag	Γ2_Phase ang
-5.00	11.503	16.503	0.963	-154.912
-4.00	12.098	16.098	0.963	-154.180
-3.00	12.536	15.536	0.964	-153.373
-2.00	12.879	14.879	0.965	-152.531
-1.00	13.146	14.146	0.966	-151.676
0.00	13.348	13.348	0.968	-150.836
1.00	13.493	12.493	0.971	-150.035

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Figure 3: Swept Measurement of DUT Input Impedance vs. Power.

Figure 4 shows contours of input reflection magnitude and phase as a function of load pull, overlaid on output power. The power was set to the 1 dB compression point for the matched load. The source tuner was approximately matched to the DUT.

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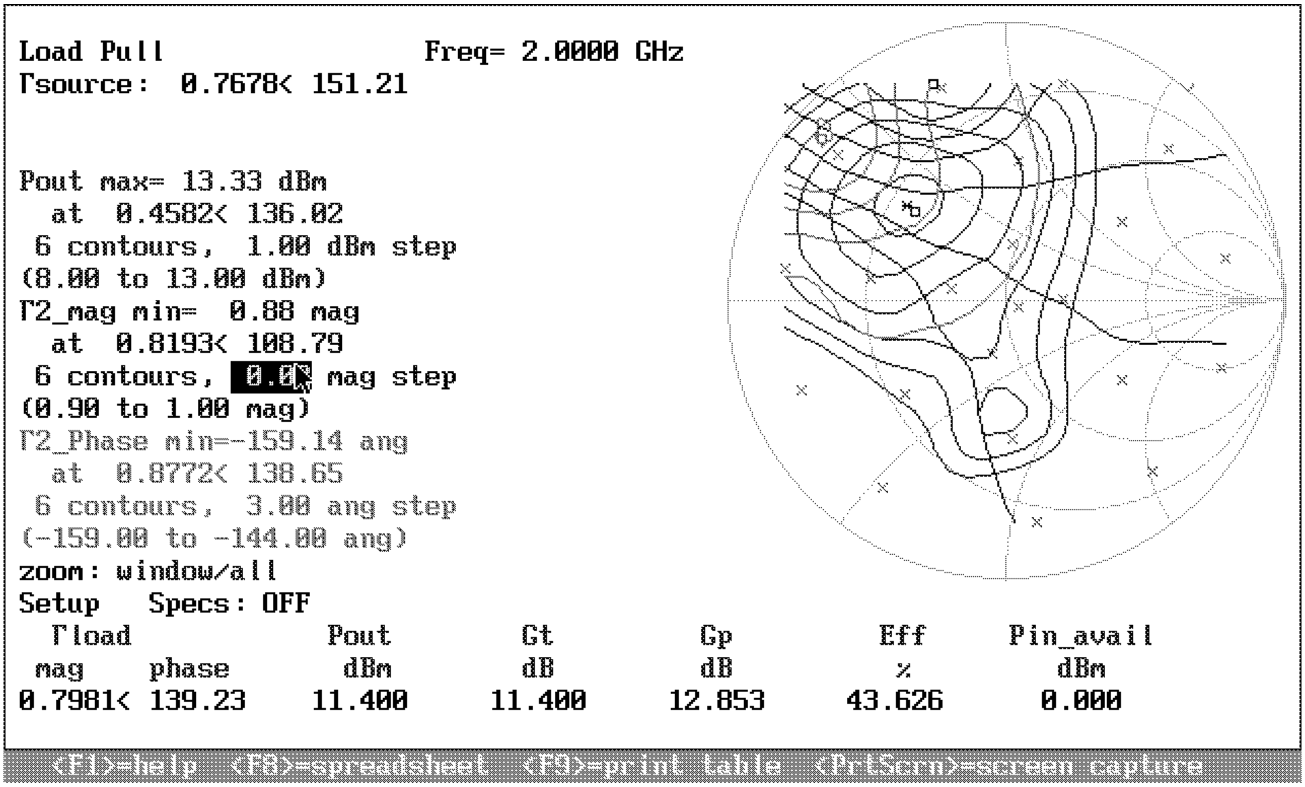

Figure 4: **Contours of DUT Input Reflection Coefficient Magnitude and Phase vs. Load Impedance.**

Summary

Connecting a vector network analyzer with couplers at the input of an Automated Tuner System allows the DUT input impedance to be accurately measured during load and source pull tests.

The input impedance data of the non-linear DUT as a function of power level and tuning should help provide better understanding of the non-linear behavior.

The direct measurement of DUT input impedance allows more accurate calculation of other parameters, such as delivered power and power added efficiency, at arbitrary source and load tuner positions.

Gary Simpson
Maury Microwave Corporation
Ontario, California

Mike Majerus
Maury Microwave Corporation
Ontario, California

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