970 Montee de Liesse, #308
Ville St-Laurent, Quebec, Canada, H4T 1W7
Tel: 514-335-6227 Fax: 514-335-6287
Email focusmw@compuserve.com
Web Site: http://www.focus-microwaves.com

Application Note No 14

On Wafer Load Pull and Noise Measurements using Computer Controlled Microwave Tuners

This note describes an accurate method used to calibrate and operate On Wafer Device Load Pull and Noise Measurement Setups in the frequency range up to 40 GHz using coaxial programmable tuners (figures 1 and 2).

Introduction

Automatic Load Pull or Noise measurements require accurate knowledge of the tuner's and the setup's parameters. The classical technique used by Focus Microwaves consists in measuring each component separately on the Network Analyzer, including the tuners and the other passive components of the setup (bias tees, isolators, attenuators as well as test fixture). In the case of a wafer probe setup the test fixture consists of the two cables connecting the tuners to the probes and the probes themselves. The TRL software, used by Focus Microwaves permits to extract the S-parameters of the two halves of the "Wafer Test Fixture" and use them in the setup corrections and de-embedding.
This approach offers the advantage of not having to tie up a Vector Network Analyzer permanently to the setup during the measurement.

There is however justified concern about the accuracy of the measurement when the setup has to be broken apart after the calibration and put back together at another loca-tion using only the pre-calibrated tuner and setup data from files stored in the hard-disk. The possible error increases especially in the case of "on wafer" testing since the losses of traditional wafer probes are higher than the losses of test fixtures, and this implies also much higher reflective loss (At Γs=0.9 the reflective loss of the test fixture is about 10 times the S_{21} [1] and so is the uncertainty of the measurement, figure 3).

In the case of Noise measurements the measurement uncertainty at the input of the setup due to high loss can be eliminated using the "Cold Noise Source" method [2].

The setup and associated theory used to make accurate on wafer noise and load pull measurements are presented together with measured data.

 June 1994

Load Pull and Noise Measurement Setup

The measurement setups consist of two programmable tuners (model 1808 up to 18 GHz, model 2604 up to 26.5 GHz and model 4006 up to 40 GHz), a Vector Network Analyzer (Hewlett-Packard 8510 or Wiltron 360), two power meters, a power supply, a noise analyzer and noise source, all GPIB programmable, a wafer probe station and the required pas-sive components such as bias tees, isolators, LNA's, mixers and attenuators, all covering the frequency range of interest. The setup is remotely controlled by an IBM®PC compa-tible controller with tuner control and GPIB interface. For fully automatic operation two GPIB controllable RF switches can be inserted to permit in-situ S-parameter measu-rement of the DUT and tuner/setup calibration.

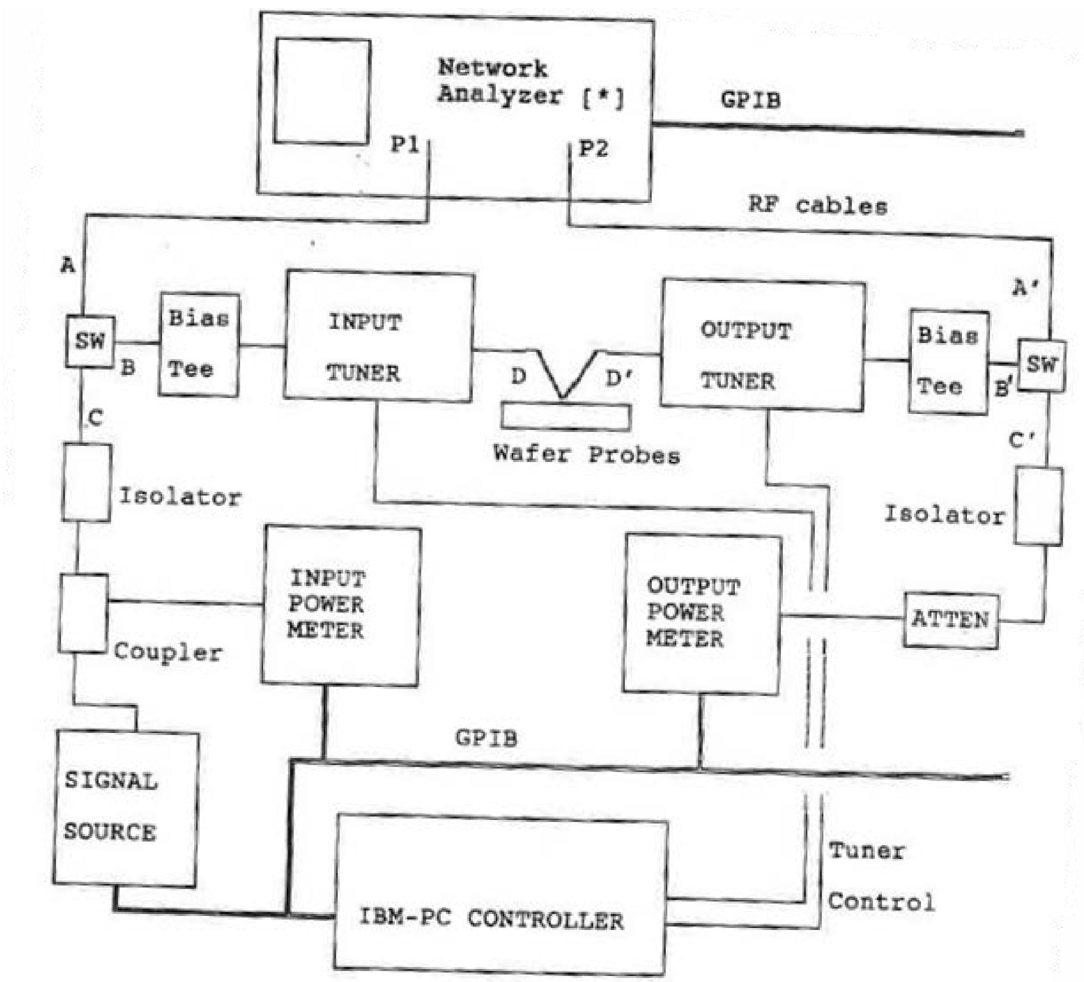

Figure 1: On Wafer Load Pull Setup

The Noise measurement setup uses a noise source instead of a signal source and a receiver (with optional Low Noise Amplifier - LNA) at the output, instead of the power meter. Also the output tuner is inactive at zero position, inorder to stabilize the DUT.
The loss in sensitivity for not prematching the receiver is in general compensated by the high gain of today's small signal transistors.

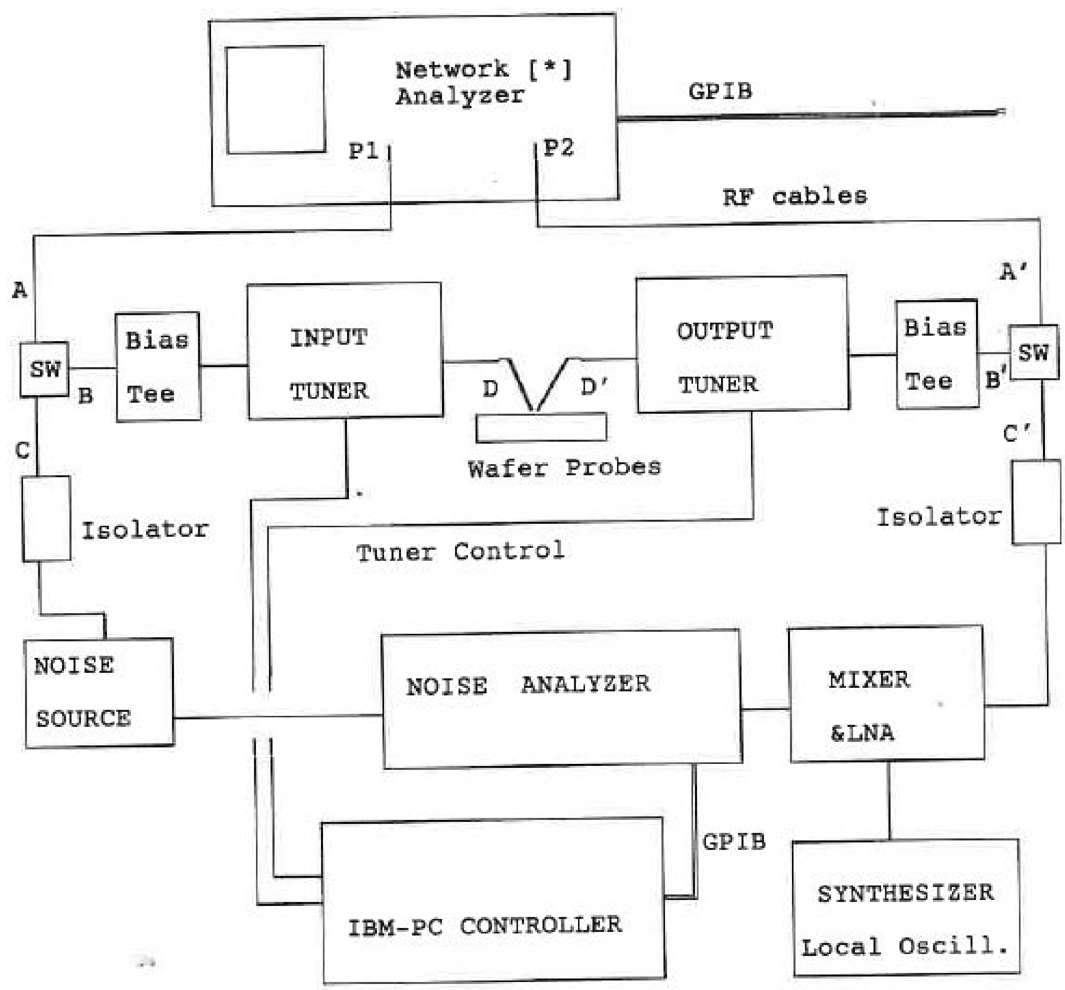

Figure 2: On Wafer Noise Parameter Measurement Setup. RF switches (SW) can be controlled by the AB08R interface from the PC.

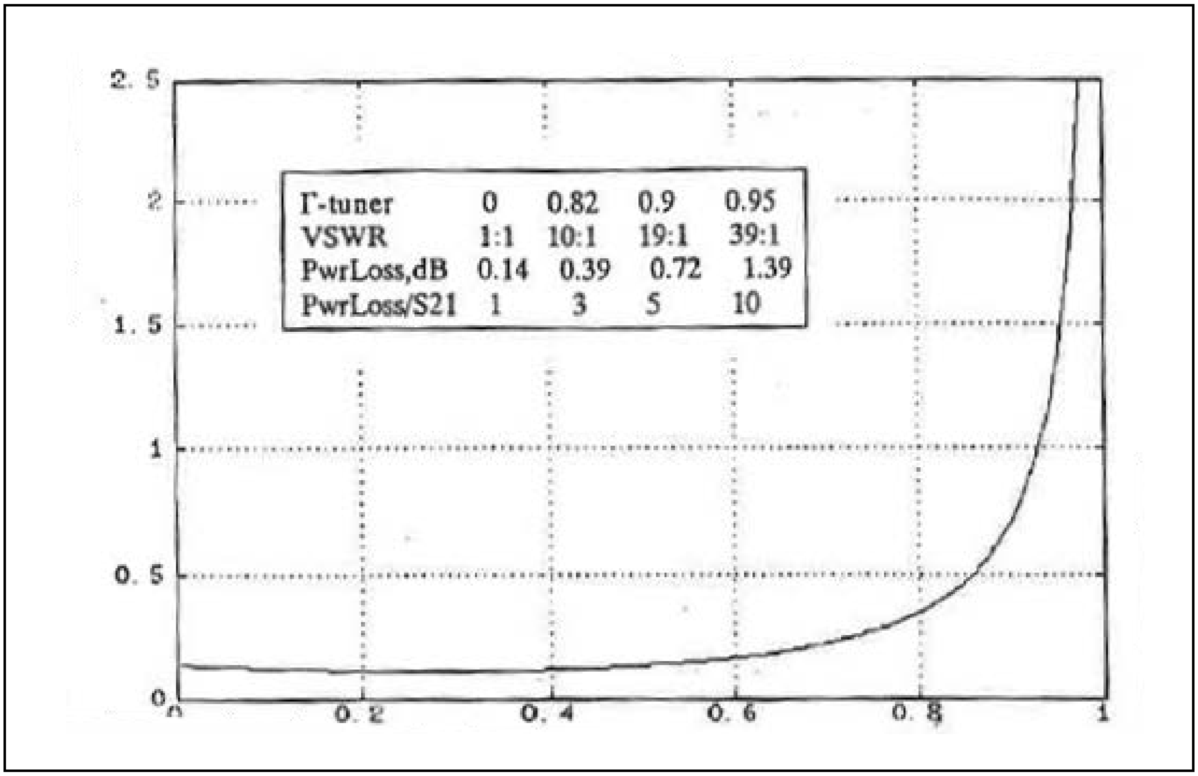

Figure 3: Available Loss of one Test Fixture section (S_{21}=0.14dB) as a function of the reflection factor presented to it by the input tuner.

System Calibration

In order to avoid the break-apart and reassembling errors of the setup we have to calibrate the critical sections between the bias tees and the wafer probe tips "in-situ".

The first step consists in performing an accurate coaxial calibration of the Network Analyzer on ports A and A'. For this we recommend to use, if possible coaxial TRL calibration kits, available from different vendors, such as Focus Microwaves [3] and Hewlett Packard [4].

We then connect both ports of the setup (B and B') to the Network Analyzer ports A and A' and characterize the complete setup as an extended test fixture using a modified version of Focus' SETUP software package.

This programm permits to characterize any test fixture by measuring the S-parameters of a Thru Line, a Delay Line and a Reflect, connected to the probe tips. All major wafer probe manufacturers supply this type of TRL standard for the various frequency ranges up to 40 GHz and above.

The result of the TRL characterization of the setup consists of two sets of S-parameters, one for the section between B and D and the other between D' and B' (figures 1 and 2) saved in binary form on the hard-disk as a function of frequency. For this step both tuners are set to zero (RF probe extracted) in which case they represent almost ideal 50 Ω transmission lines.

We then calibrate each tuner with the probe tips connected to a Thru Line and the other tuner in the zero position (50 Ω transmission).
During vertical scaling and tuner calibration the effect of the opposite setup side is simultaneously de-embedded, so we measure the four S-parameters of each half of the setup, including tuner, separately.

The calibration is fully compatible with existing tuner calibrations but the data are more accurate because we do not need to break the setup apart any more before we can proceed to measurements. We only have to disconnect the Network Analyzer cables from ports B and B' and connect them to C and C'. This can be done also automatically by using remote control SPDT RF switches (SW) as shown in figures 1 and 2.

Using RF switches or disconnecting the setup at points B and B' is not very critical, because the source and load impedances at these points of the setup are close to 50 Ω and we operate in a non-critical Loss region (figure 3).

This calibration method also permits to measure "in-situ" the S-parameters of the DUT, if we insert it in the wafer probe station and de-embed with the previously computed S-parameter matrices of the two halves of the setup. The S-parameters of the DUT are required in Noise Measurements in order to correct for the second stage noise contributio, following Friis' theorem

$$NF = NF1 + \frac{NF2 - 1}{Gav1(Sij,\Gamma s)} \qquad [1]$$

where
NF = total Noise Figure
NF1 = Noise Figure of first stage
NF2 = Noise Figure of second stage (receiver)
Gav1(Sij,Γs) = Available Gain of first stage=function of DUT S-parameter and source impedance.

Note: The Wafer Measurement software will soon be released as Windows Version within the TWIN (Tuner WINdows) Focus Microwaves upgrade.

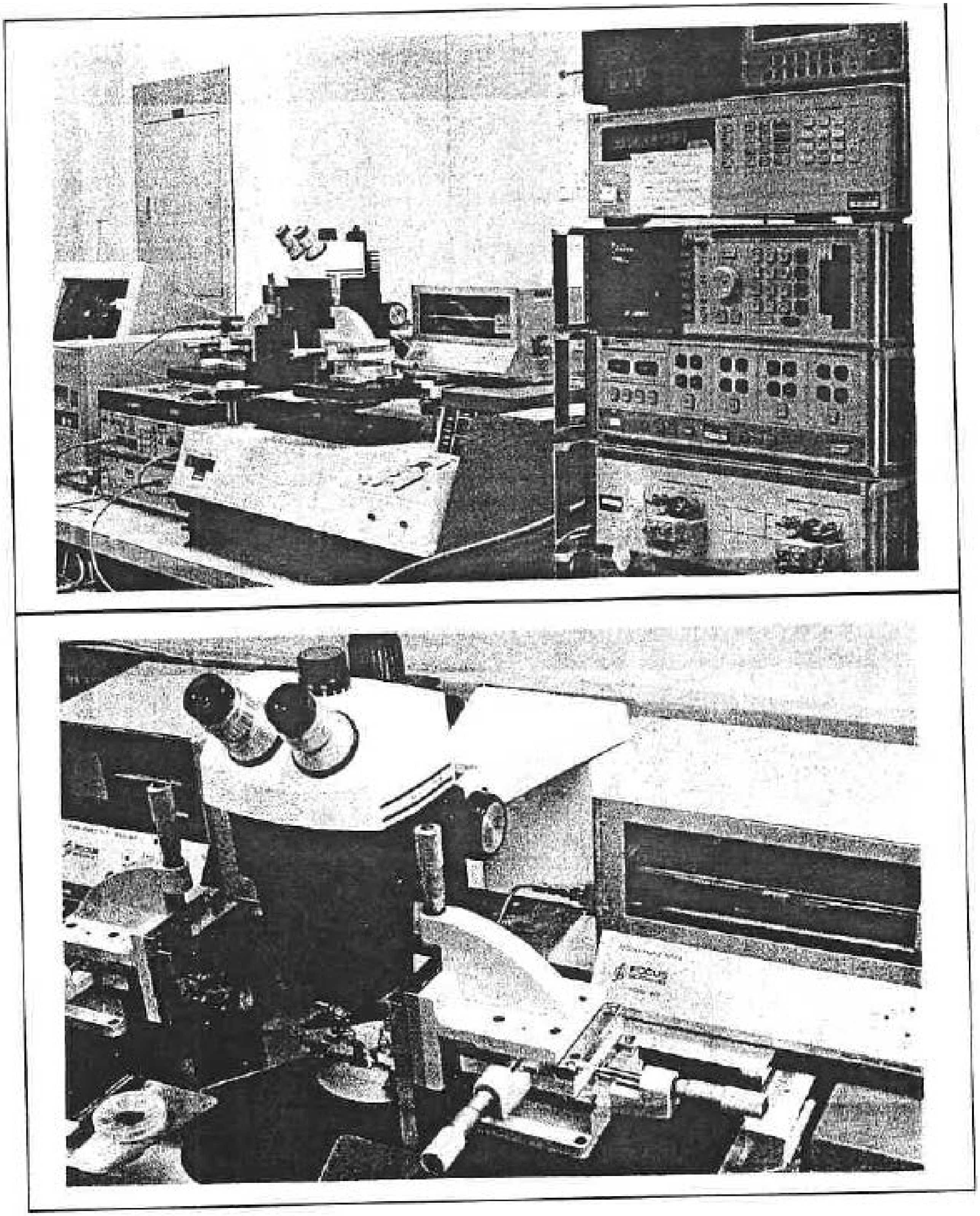

Figure 4: On Wafer Noise / Load Pull Setup using 1808 tuners and HP-8510B

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! Frequency : 10.50 GHz,  Comment :  Wafer cal (CasCade/GGB), Thu Mar 03 1994
!Limits: Xmin= 0,Xmax= 2405,Ymin= 0,Ymax= 2427 steps
!
!Point  |S11|  φ11   |S12|  φ12    |S21|  φ21    |S22|  φ22   Pwr.GAIN (dB)
!------------------------------------------------------------------------------------------------------------
001   0.116  179.3 °  0.852   17.6 °  0.864   18.1 °  0.095   27.5 °  -1.336
002   0.116 -145.5 °  0.858   16.4 °  0.865   16.4 °  0.113  -21.0 °  -1.271
003   0.196 -175.4 °  0.846   16.9 °  0.847   17.0 °  0.168   21.3 °  -1.286
004   0.163  156.3 °  0.844   17.4 °  0.853   17.4 °  0.127   60.0 °  -1.355
005   0.067  150.8 °  0.854   17.4 °  0.862   17.5 °  0.026   58.9 °  -1.350
006   0.169 -122.8 °  0.850   13.9 °  0.855   14.0 °  0.175  -41.8 °  -1.290
007   0.226 -150.7 °  0.843   14.2 °  0.844   14.3 °  0.228  -10.3 °  -1.258
008   0.259 -174.2 °  0.833   15.3 °  0.838   15.1 °  0.247   18.7 °  -1.287
009   0.250  163.4 °  0.825   15.9 °  0.833   16.2 °  0.228   47.2 °  -1.396
010   0.207  141.0 °  0.834   16.8 °  0.845   17.0 °  0.179   75.2 °  -1.387
011   0.129  115.4 °  0.848   16.3 °  0.852   17.2 °  0.114  111.8 °  -1.359
012   0.040   79.5 °  0.859   15.7 °  0.866   16.6 °  0.042 -172.0 °  -1.316
013   0.059 -101.8 °  0.858   15.2 °  0.868   15.8 °  0.086  -75.5 °  -1.313
014   0.235 -107.8 °  0.830   10.1 °  0.843   11.0 °  0.265  -59.1 °  -1.368
015   0.293 -132.6 °  0.818   10.6 °  0.826   11.2 °  0.300  -34.4 °  -1.353
016   0.327 -152.3 °  0.809   11.2 °  0.811   11.2 °  0.325  -11.3 °  -1.351
017   0.339 -172.5 °  0.800   12.4 °  0.807   12.1 °  0.337   11.6 °  -1.407
018   0.340  168.5 °  0.792   13.4 °  0.802   13.2 °  0.325   34.4 °  -1.496
019   0.319  150.7 °  0.798   14.3 °  0.805   14.5 °  0.299   57.0 °  -1.491
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169   0.730   20.6 °  0.316  -21.8 °  0.320  -18.5 °  0.772  115.7 °  -6.693
170   0.720    7.8 °  0.313  -22.3 °  0.327  -19.6 °  0.770  125.3 °  -6.907
171   0.726   -5.4 °  0.311  -24.9 °  0.329  -20.9 °  0.770  135.6 °  -6.900
172   0.734  -19.1 °  0.306  -26.2 °  0.326  -22.2 °  0.772  145.8 °  -6.926
173   0.742  -32.3 °  0.308  -26.3 °  0.329  -23.8 °  0.775  156.2 °  -6.745
174   0.753  -44.3 °  0.315  -28.7 °  0.328  -24.8 °  0.776  166.9 °  -6.411
175   0.756  -57.5 °  0.310  -30.0 °  0.323  -25.2 °  0.789  177.0 °  -6.513
176   0.773  -69.5 °  0.312  -31.0 °  0.315  -26.1 °  0.796 -172.9 °  -6.164
177   0.783  -80.9 °  0.297  -31.2 °  0.316  -27.8 °  0.805 -163.1 °  -6.437
178   0.785  -91.6 °  0.302  -32.4 °  0.314  -28.0 °  0.805 -152.9 °  -6.241
179   0.792 -101.2 °  0.302  -31.0 °  0.312  -28.1 °  0.820 -143.0 °  -6.119
180   0.802 -111.7 °  0.292  -31.3 °  0.300  -27.8 °  0.831 -132.9 °  -6.227
181   0.804 -121.0 °  0.290  -31.2 °  0.299  -27.4 °  0.841 -122.6 °  -6.221
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Table 1: Part of Tuner Calibration file (part) made using on wafer technique.
S11 is the reflection factor seen by the chip (includes wafer probe losses)

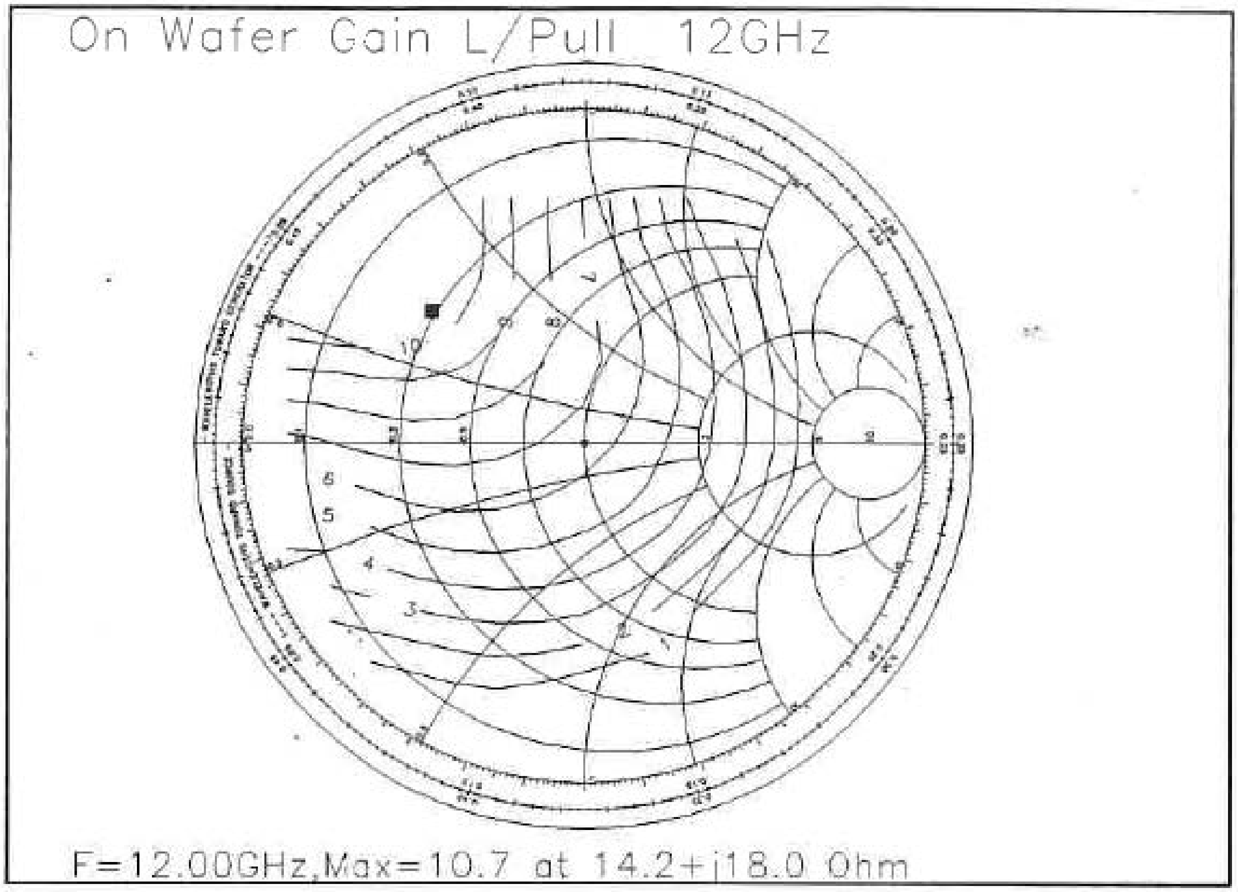

Figure 4: Load Pull contours, measured using on wafer setup

Freq [GHz]	Min NF[dB]	Equiv R [Ω]	Γ opt	ϕ opt [deg]	σ
8.500	1.12	14.2	0.642	55.4	0.14
9.000	1.21	11.9	0.645	59.0	0.08
9.500	1.32	10.7	0.678	63.5	0.06
10.000	1.44	10.3	0.598	65.4	0.11
10.500	1.53	11.4	0.661	69.9	0.09
11.000	1.64	11.9	0.594	71.5	0.07
11.500	1.75	12.5	0.556	76.0	0.11
12.000	1.84	13.6	0.571	77.9	0.10

Table 2: Noise Parameter of 0.5x300μm FET measured using on wafer setup