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Application Note No 10

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 $\Gamma s=0.9$ 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.

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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.

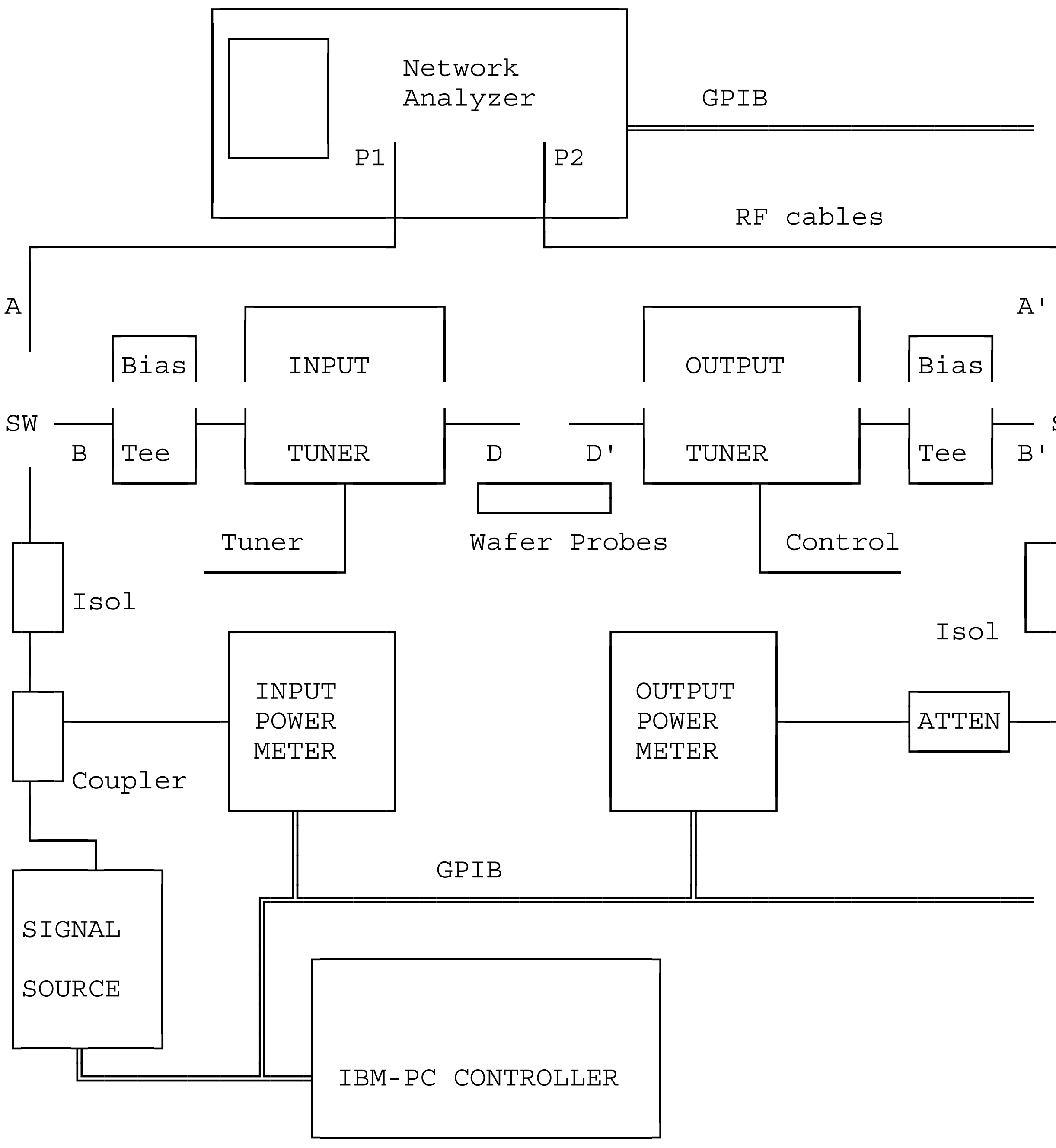

Figure 1: On Wafer Load Pull Setup

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.

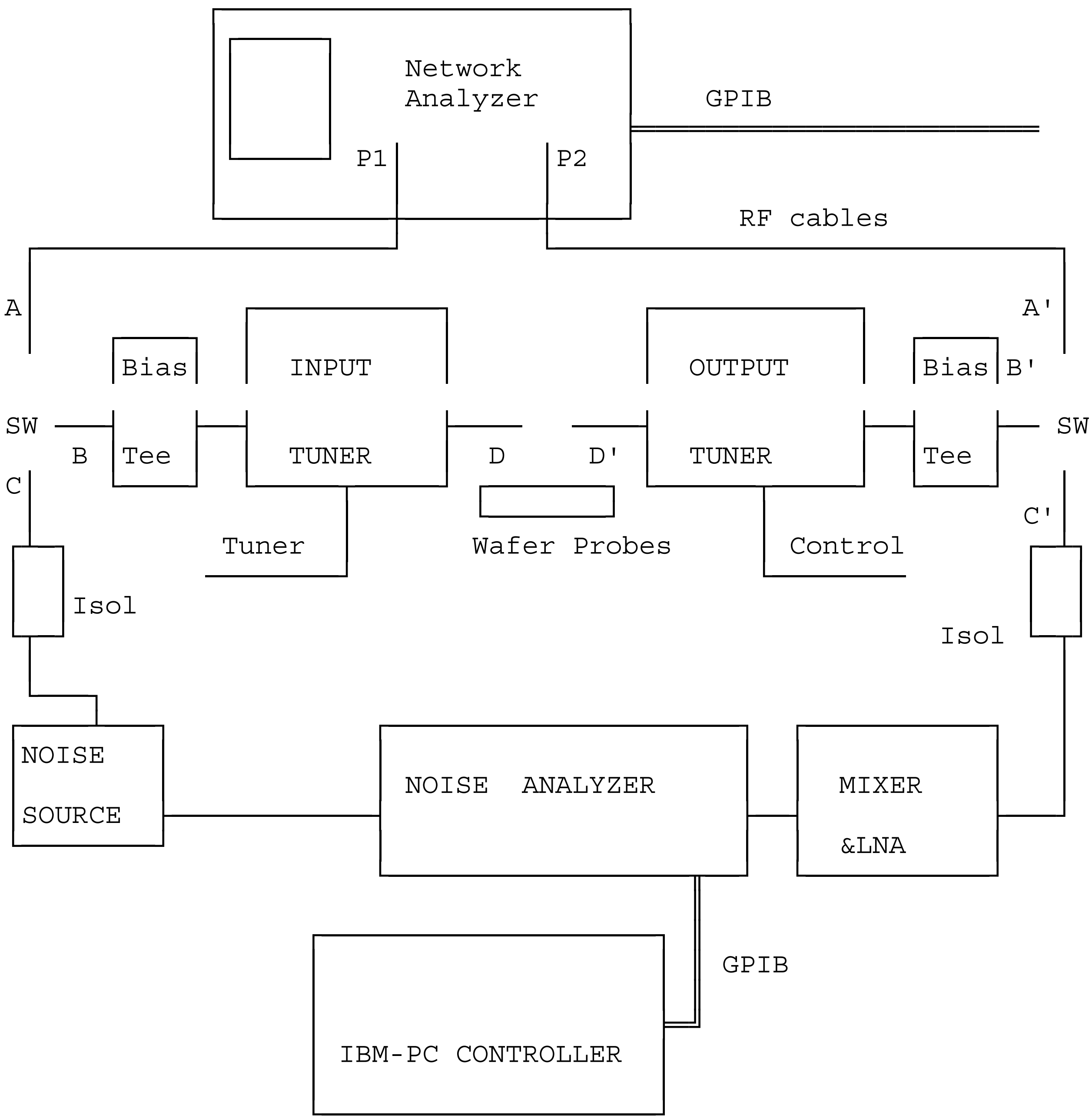

Figure 2: On Wafer Noise Parameter Measurement Setup

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 [2].

Example of Wafer Probe station programming
Photos of tuners on Wafer Probe station
Example of Tuner Cal file (part) made using on wafer technique