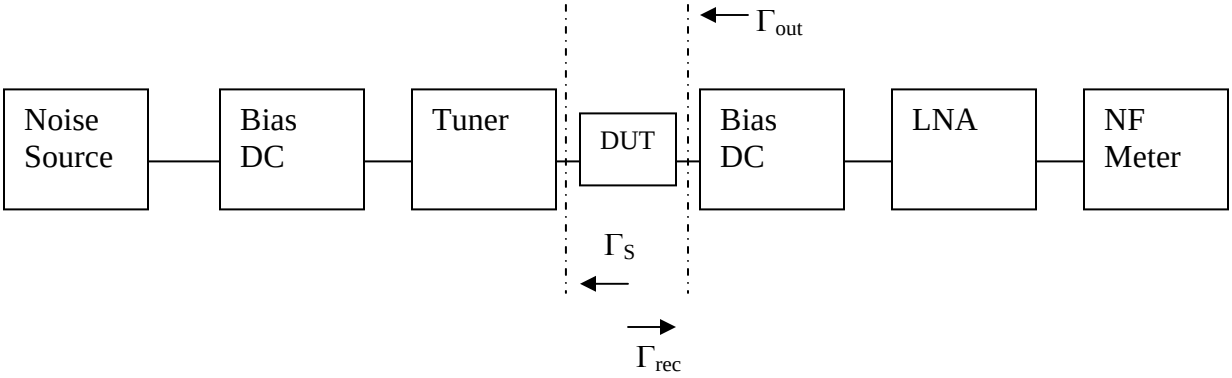
Noise Parameter Measurement using Cold Noise Source and TRL Setup Calibration

Introduction

In order to determine the four noise parameters of a DUT we need to measure its noise figure at several source impedance values; minimum is four, but for better accuracy we use between 7 and 11 points.
In the below described noise setup the noise figure of the DUT is calculated using the following formula:



$$\text{Noise Figure} = \frac{NP}{TokBG} * \frac{|1-S11*\Gamma_s|^2 * |1-\Gamma_{rec}*\Gamma_{out}|^2}{(1-|\Gamma_s|^2) * |S21|^2} - \frac{Tc}{To} + 1 \qquad [1]$$

NP = Noise Power (measured by the Noise Receiver)
Γs = Source reflection factor (seen by DUT)
Γout = DUT Output reflection factor (seen by DUT)
Γrec = Receiver Input reflection factor
kGB = Gain Bandwidth constant of receiver
Tc = actual Temperature (K)
To = standard Temperature (290K)
Sij = S-parameters of DUT

So, in order to obtain the DUT noise figure we need to build a good setup and then

1. Calibrate (using a VNA) all components of the setup from the noise source to the receiver input and the tuner (to get Γs, Γout and Γrec) and make a noise calibration of the receiver (to get TokGB). For noise calibration of the receiver we also need the ENR of the noise source (which is marked on the source itself) and its reflection factor Γns.
2. Verify the accuracy of the calibration using a THRU line as DUT (we should get ≈0dB noise figure all over the Smith Chart)
3. Insert and measure the S-parameters of the DUT in its actual bias conditions (to get Sij) and then measure the output noise power NP at different source impedances and compute its noise figure using formula [1].

In the following pages we try to explain, step by step how these tasks are accomplished, including all typical file names, their meanings and locations

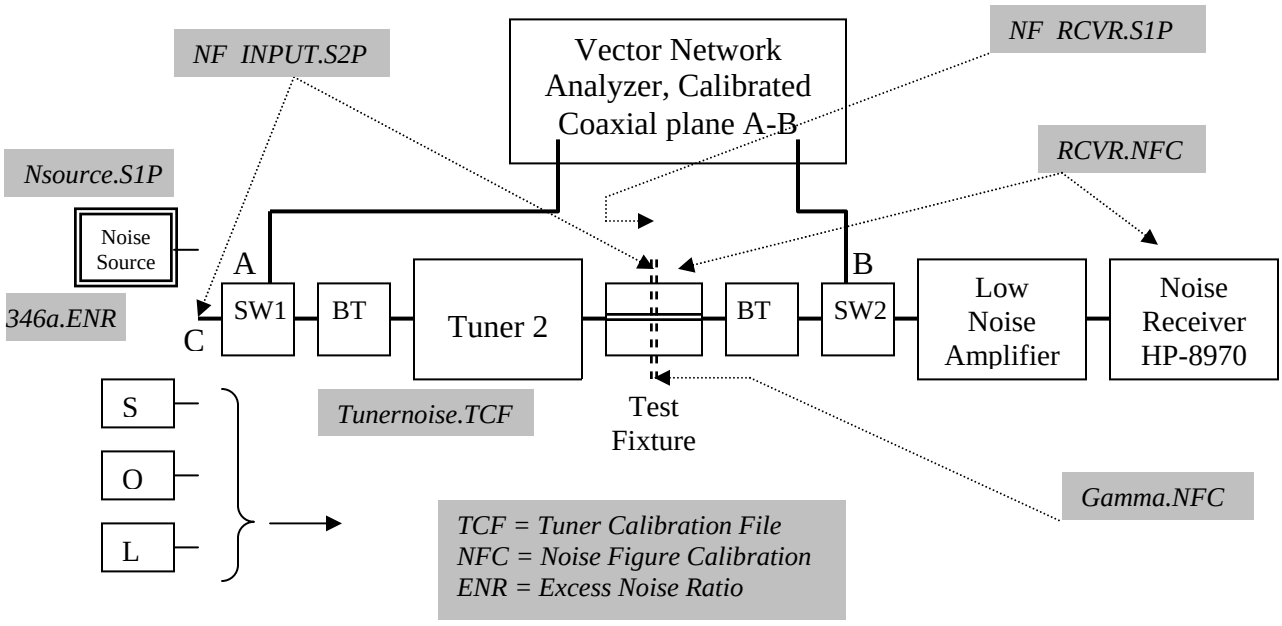
COLD_IN CALIBRATION & MEASUREMENT PROCEDURE
using TRL CALIBRATION

Noise measurements consist of two steps:

1. Hardware setup of the system and calibration of its components
2. Measurement of Noise Parameters.

Noise calibration and measurement, are controlled and executed by **setup files** which are very important. They are supposed to be edited and modified manually.
One file is **NF_CAL.TSF**, to be used for calibrating the setup and the noise figure meter, and the other file is **NF_MEAS.TSF** to be used for measuring noise parameters of a transistor (.TSF stands for Tuner Setup File). Take note of files being generated at each Calibration .

The calibration and measurement procedure is described below in detail: (we use 'cold-in mode', i.e. a "cold" noise source is connected at the input of the setup):



CALIBRATION:

1. **Assemble the components from left to right:**
Switch 1→bias T.1→tuner 2→test fixture→bias T.2→switch 2→LNA→Noise figure meter (or Spectrum Analyzer; in this case you need more gain in the LNA block).

2. **Configure the Switches:**

Start the Focus Shell (WinCCMT.exe), "File"→"configure"→"switch";
Switch-1, position 1→VNA IN;
Control mode → outputbus;
Address→550 (dipswitch position for 544 address+6 bits for switch);this address is by default, it can also be any other address used with adding 6 bits
Bit order→7; ! **depends on version of switch box**
Switch type→continue (some switches are 'pulse type'(**newer type**);
Bit value→ON
Save and test setup
position 2→noise in;
Control mode→ outputbus;
Address→550 (dipswitch position for 544 address+6 bits for switch);
Bit order→6;
Switch type→continue (some switch are pulse type);
Bit value→OFF
Save and test;

With pulsed type of switch boxes every position of the switch has different corresponding bit. If **PCI** card is used, the switch address is the address of the PCI card+6. The bits that respond are 4,5,6,7

Switch—2, position 1→VNA out;
Control mode →outputbus;
Address→550 (dipswitch position for 544 address+6 bits for switch);
Bit order→4;
Switch type→continue (some switches are pulse type);
Bit value→ON
Save and test

position 2→noise out;
Control mode→outputbus;
Address→550 (dipswitch position for 544 address+6 bits for switch);
Bit order→5;
Switch type→continue (some switches are pulse type);
Bit value→OFF
Save and test;

After configuration of the switches, you should verify their operation
Using the following method.

Go to Noise (WinNOISE.exe) →"options"→"switch control"; then test the switches separately (check with the response of the VNA or listen to switch.

3 Calibrate the VNA

at the coaxial reference plane A-B **using Focus' coaxial TRL calkit**. Set Delay for VNA readings if required – WinNoise-Options-Configurations-Options Parameters. Adjustment of Power level might be required depending on LNA in setup. If overdrive LNA in setup with DUT, results can be wrong.

4 Measure NOISE SOURCE impedance

No BNC cable connected to the Noise source):
Connect noise source to VNA port 2;
WinNOISE→Calibration→Component→1 port (S22);
Verify measurement by viewing S parameter plot using WinPlot
Save to file: **Nsource.S1P**
(Take Note of all Files created, for they will be used in the Noise Calibration setup file NF_CAL.TSF)

5 Measure INPUT LOSS (Loss of section between Noise Source and DUT)

You can use TRL method to get full S-parameters of input network.
Connect VNA port 1 to Switch 1 VNA IN ; Port 2 VNA Switch 2 VNA OUT
Switch Position changed from WinNoise –OPTIONS – SWITCH CONTROL
Set Switch 1→NOISE IN, Switch 2→VNA OUT;
Use the COAXIAL calibration of the VNA (on ref. plane A-B).
WinNOISE→calibration - components→TRL measure;

- THRU
- DELAY
- REFLECT PORT1
- REFLECT PORT 2

Select delay line used, type of Reflection – short or open,
Save two files **CONA.S2P** for Input and **CONB.S2P** for output file;
View the CONA.S2P and CONB.S2P S-parameters using WinPlot
Verify the TRL calibration by selecting TRL VERIFY this will
Create a **TEST.S2P** File.

6 Measure the Input Impedance of the Noise Receiver

Leave the THRU connection in the test fixture;
Switch on the LNA if included in setup.
Set Switch 1→VNA IN; Switch 2→NOISE OUT;
WinNOISE→Calibration→Component→S-PAR (de-embed)-S11 only
Choose CONA.S2P as the input de-embedding file
Save **file NF_RCVR.S1P**
Since everything from the middle of the test fixture to the right in the setup is considered as a receiver, CONA part of the calibration should be de-embedded.

7 Tuner 'in-situ' (on-wafer) calibration

Leave the THRU connection in the test fixture;
Noise Source to Switch 1 NOISE IN ; Port 2 VNA OUT
Switch 1→NOISE IN; Switch 2→VNA OUT;
WinNOISE→Calibration→Tuner →Tuner Calibration

FILE: Type or Retrieve the tuner output calibration
CONB.S2P with the correct location of the file.
FREQ: Sweep or List frequency
Enter Frequency F1,F2,F3…. You wish to calibrate tuner
MODE: **S22 only**
RESOLUTION: Medium (select to your requirements)
OPTIONS**:** De-embedded (CONB de-embed since the tuner is all input Section, from port 1 of the VNA to the middle of the test fixture)
MAX GAMMA: 0.9

****Define a Filename** especially for noise: example: **TunerNoise.TCF**

8 Edit Excess Noise Ratio (ENR) file

Use Notepad editor;
When doing that, the option "hide file extensions for known file types" from WinExplorer-->View-->Folder Options-->View should be checked out, otherwise *.txt file is created instead of *.nfc, and the extension txt is hidden which causes confusion
Enter frequency and ENR line by line;
The data can be found on the back of the Noise Source ;
For example, HP346A

```
!
0.01 6.09
0.1  6.67
1.0  6.47
2.0  6.08
3.0  5.95
4.0  5.97
```

Save this file as: **HP346a.ENR** (example).

9 Create\Edit the Noise Calibration setup file NF_CAL.STP

ATTENTION: You MUST use the internal editor of WinNoise (not Notepad.EXE):
Go: →File →New , and make a setup file;

(a) To Create a new Calibration setup file, use WinNoise editor as follows; WinNoise-File-New-, then type NF_CAL.TSF as the below example.
(b) To Edit an existing .TSF file, use WinNoise editor as follows; WinNoise-File-Open-select .TSF file to edit, then go to File-Edit Setup and proceed to edit file.

As an example: (noise calibration file for frequency 1 GHz)

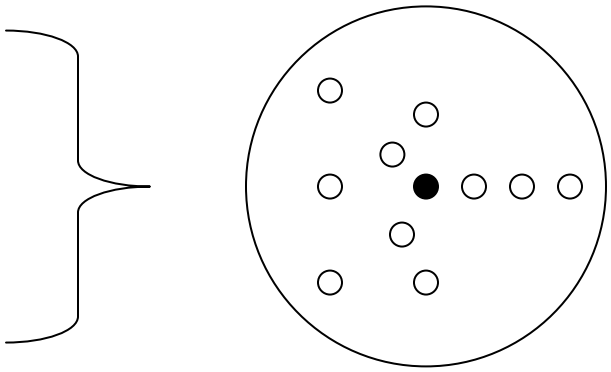
```
freq
fixed 1 ! – can choose also STEP or SWEEP  - value in GHz
!
nsource C:\focus\CAL\noise\NSOURCE.S1P
!
files
nf_input C:\focus\CAL\noise\CONA.S2P
!
input
tuner_2 C:\focus\CAL\NOISE\TUNERNOISE.TCF !replace by your tuner
!
load  c:\focus\CAL\noise\nf_RCVR.S1P
!
Instruments
HP8970 8 C:\focus\CAL\noise\HP346a.ENR  E0F3IF1000M
! last character string are initialization GPIB commands for NFM
! 8 is the address of the instrument used
```

-Save the created **NF_CAL.STP** (when a new file) If a edited File will save as a .TSF once edited

10 Define (create/edit) Gamma.NFC (Must be put in C:\Focus\Setup folder)
This file will be used when calibrating the Noise Receiver; ***(includes tuner positions for calibrating the Noise Receiver)***

The GAMMA.NFC file can be edited for various source impedances. The file is edited by using Windows NOTEPAD.
This should be done in the same way as it's explained in the section 8 .
For example,

```
! Gamma values for noise receiver calibration
! up to 16 values, mag/phase
 0.15 0
 0.15 120
 0.15 240
 0.5 0
 0.5 90
 0.5 180
 0.5 270
 0.7 0
 0.7 120
 0.7 240
```



11 Calibrate Noise Figure Meter (NFM)

Leave the THRU standard in the test fixture;
Set Switch 1→NOISE IN, Switch 2→NOISE OUT;
Make sure LNA block is in good condition; (enough gain); *(=up to 40dB when using NFM, up to 60dB when using Spectrum Analyzer)*
Usually 3 att. levels should be used (+20,+10,0 dB).

Connect BNC cable between Noise Source and Noise Figure Meter;
From WinNOISE menu select:
WinNOISE→calibration→noise receiver→receiver calibration;-options
Select COLD_IN method – Omit Gs Verification .
Select appropriate RF attenuation for the NFM.
After termination of the measurement: Save file as: **RCVR.NFC**

12. Edit/Create measurement setup file ***(example at 1GHz)***
WinNOISE→file→New
Edit using WinNOISE editor (→File→Edit Setup)

```
freq
fixed 1
```

!
nsource C:\focus\CAL\noise\NSOURCE.S1P
!
files
! USE real DUT S_PARAMETER to measure NF of device
DUT 0.00001 ! to measure on the THRU LINE S11==S22=0, S12=S21=1
! DUT C:\focus\cal\noise\dut.s2p ! testing a DUT
!
input
tuner_2 C:\focus\CAL\NOISE\TUNERNOISE.TCF !replace by your tuner
!
load c:\focus\CAL\noise\NF_RCVR.S1P
!
meas
nf noisefigure c:\focus\cal\noise\rcvr.nfc
!
Instruments
HP8970 8 C:\focus\CAL\noise\HP346a.ENR E0F3IF1000M !initialize the NFM

At last save the file another name: **NF_MEAS.STP** (Press OK, then File/Save As)

13. Verify Setup Calibration ;

Leave a THRU standard at the test fixture. This is to confirm Ref Plane of DUT
WinNoise – Measure – Trigger Test; Switch 2 – Noise Out ; Switch 1 – Noise In
Click on Smith Chart to view point. Ideally should measure close to zero. Space Bar will re-trigger measurement at the current point. If not satisfied with calibration repeat the calibration process – check all connections – No external interferences present – shield system setup.
Note; The measurement setup file (step 14 must contain DUT 0.00001 for only verification of setup)
Good calibration means 0dB all over the Smith Chart .
Suggestion: it is better to do the verification using attenuator (i.e. 3 dB), since with thrue the signal is too low for accurate measurement for the NF meter.
If the verification is good with 3 dB attenuator, it means that 3dB noise figure should be displayed in the middle of the Smith Chart.

14. Measure DUT S-parameter;

Insert DUT into Test Fixture *(or connect probes);*

Adjust Bias to turn on DUT.
Connect Port 1 VNA to switch one VNA IN and Port 2 VNA to switch 2 VNA OUT
Position Switch 1→VNA IN, Switch 2→VNA OUT;
WinNOISE→Calibration→S-PAR (de-embed)-S11 & S22
CONA and CONB should be de-embedded.
Save file DUT.S2P

15. MEASUREMENT:

1.WinNOISE→file→open NF_MEAS.STP

2.Follow menu…enter file DUT C: \focus\cal\noise\dut.S2P
Into setup under files section. See step 12

freq
fixed 1
!
nsource C:\focus\CAL\noise\NSOURCE.S1P
!
files
DUT C:\focus\cal\noise\dut.s2p ! testing a DUT
!
input
tuner_2 C:\focus\CAL\NOISE\TUNERNOISE.TCF !replace by your tuner
!
load c:\focus\CAL\noise\NF_RCVR.S1P
!
meas
nf noisefigure c:\focus\cal\noise\rcvr.nfc
!
Instruments
HP8970 8 C:\focus\CAL\noise\HP346a.ENR E0F3IF10M !initialize the NFM

At last save the file another name: **NF_MEAS.STP**

MEASUREMENT:
1)TRIGGER TEST
2)NOISE AUTO TEST
3)SOURCE PULL

(10/2001)