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Application Note 31

Accurate Noise Parameter Measurements Using a Spectrum Analyzer as Noise Receiver

A "Cold Noise Source" method uses a Spectrum Analyzer and FOCUS Microwaves programmable tuner to effectively and accurately measure the four noise parameters of RF and microwave transistors. The spectrum analyzer improves both the systematic accuracy and the flexibility of the system: <u>Accuracy</u> is improved because we are able to make Single Sideband noise measurements and <u>simplicity</u> because the spectrum analyzer includes filtering, tuning, mixing and L.O. components in one instrument. The spectrum analyzer is also used to detect parasitic oscillations which otherwise would falsify the measurement; it is also easier to find a general utility instrument such as a spectrum analyzer in the lab than a dedicated noise receiver. The "high gain – low noise" preamplifier used to increase the noise floor to an easily detectable level is also necessary in the case of a direct mixer. FOCUS "WinNoise" software controls all the components of the setup, such as tuners, spectrum analyzer, remote switches and network analyzer and enables "in-situ" calibrations and measurements. The graphics utility "WinPlot" generates plots and printouts of all measured parameters over frequency or DC bias.

<u>Components required for the Noise Measurement System (NMS):</u>

- Vector Network Analyzer (for Calibration and DUT S-parameter measurements)
- IBM-PC* with GPIB* and Tuner Control Interface* (the latter also controls the switch control box)
- Test fixture* or probe station with TRL standards*, DUT
- Switch Control Box (SCB*) with output for noise source ON/OFF control
- One programmable tuner*, Model CCMT-xxyy (xx = Max Freq, yy = Min Freq in GHz)
- WinNoise and WinPlot software*
- Noise source (for Receiver Cal only)
- Low Noise Preamplifier, LNA
- Spectrum analyzer
- Two remote switches, SW-1,-2*
- Two bias tees, BT*

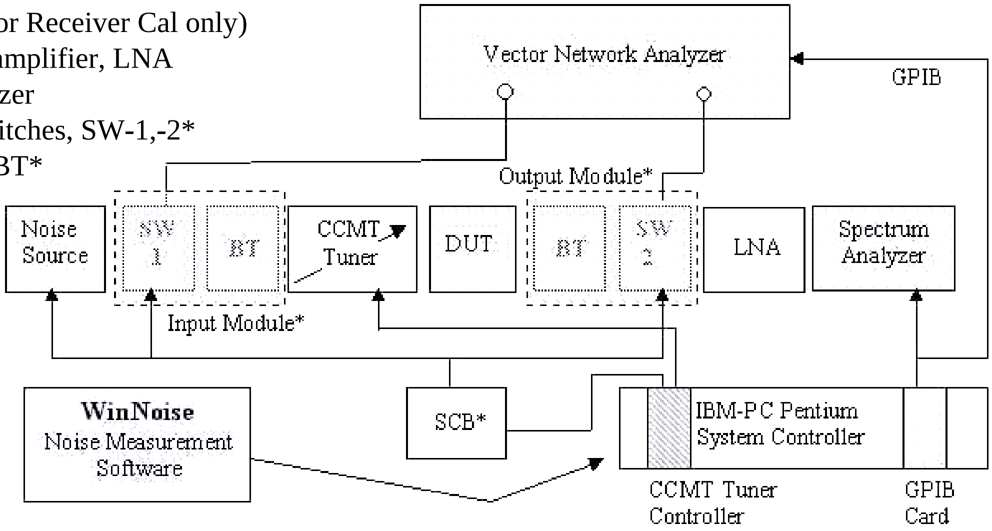


Figure 1: Noise Measurement System (NMS) using the "Cold Noise Source" method and a Spectrum Analyzer as noise receiver

*(*) Items marked with * can be supplied by FOCUS for an integrated turnkey NMS*

The "Cold Noise Source" measurement method

This method requires a "hot-cold" noise source only in order to calibrate the noise receiver. During transistor noise measurements the noise source itself is not used, only its internal 50Ω resistance. The thermal noise of this source resistance, combined with the noise power generated by the DUT are reflected at the source impedance and the combination is amplified by the DUT and generates the Output Noise Power (NP), which is amplified by the LNA and detected by the Spectrum Analyzer. The following relation applies:

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

Where
NP = Noise Power at DUT output;
Γ_s = Source Reflection Factor;
Γ_{out} = Reflection Factor at DUT output;
Γ_{rec} = Input Reflection Factor of Noise Receiver; kGB = Gain Bandwidth constant of Receiver ; Tc = Room Temperature;
To = Standard Temperature (290K);
Sij = Scattering parameters of DUT

System Calibration

The Noise Measurement System is calibrated both for S-parameters of the setup and the Tuner as well as for Noise parameters of the receiver, before executing noise measurements.

Step 1: Calibration of the Network Analyzer at DUT reference plane. Both switches are set to VNA, the tuner is initialized (=Through-Line) and a TRL calibration is performed, using TRL standards either on-wafer or in fixture. This permits direct measurement from the DUT terminals towards the tuner and the receiver.

Step 2: 3T (Three Termination) calibration of the section between Noise Source and DUT input: Using pre-characterized standards (Short – Open – Load) and with SW1 on Noise Source we measure S22 on the calibrated VNA via a THRU-Line in place of the DUT and determine, using FOCUS software, the loss of this section with the tuner initialized.

Step 3: Tuner Calibration: Using FOCUS software we calibrate (=characterize) the tuner "in-situ", by measuring S22 for 200 to 400 tuner positions for a number of user defined frequencies. The data is saved in tuner cal-files on the hard-disk.

Step 4: Receiver Noise Calibration: The noise source is switched ON and OFF once with SW2 connected to the noise receiver (LNA). This provides the Gain-Bandwidth Constant (kGB) of the receiver. After this the tuner is used to synthesize automatically 11 preselected impedances and to measure the noise figure of the receiver using equation [1] (with Sij = S-parameters of a Thru-Line) and the input section loss determined in step 2. This data allows the calculation of the four noise parameters of the noise receiver over a user defined frequency range.

After the calibration procedure is terminated the DUT is inserted, biased and its S-parameters measured by switching SW1 and SW2 back to VNA. Then the noise parameters can be measured either automatically, in which case the software selects an optimum set of source impedances, or manually by tuning using the mouse.

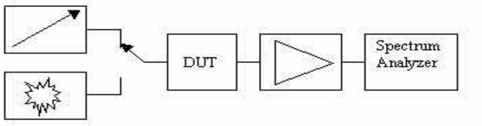
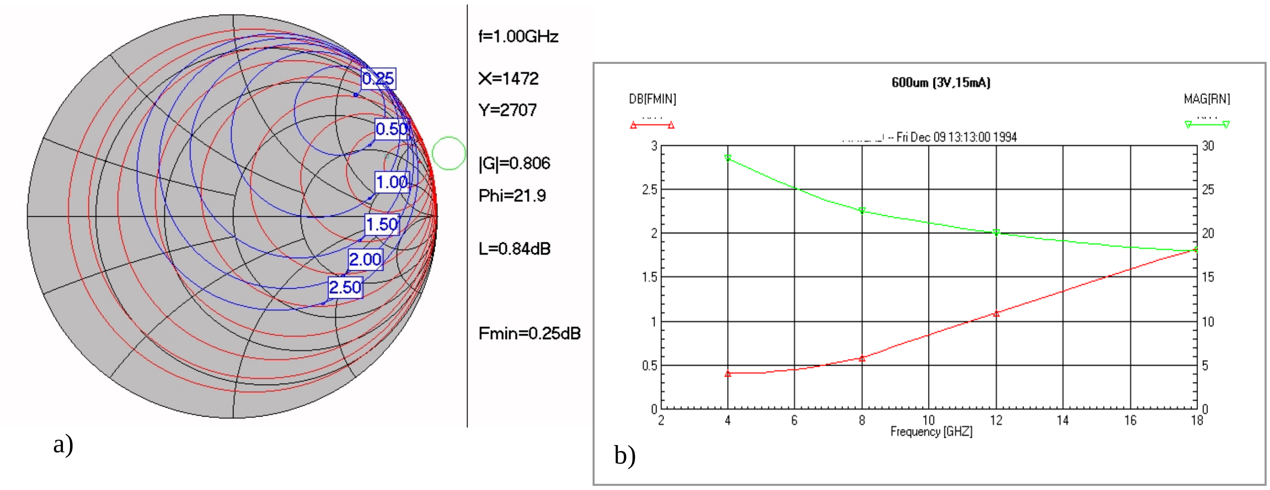


Fig 2: Cold Noise Source measurement principle

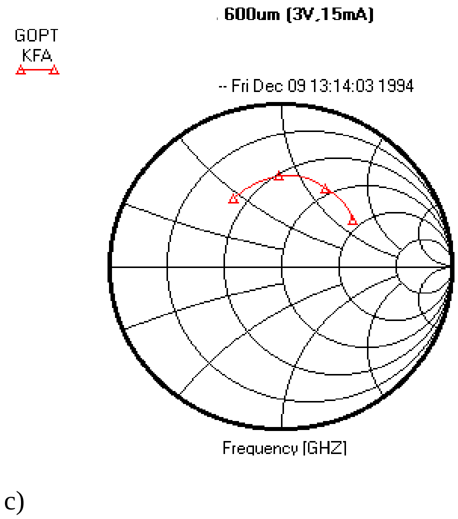
Noise Measurements

The results can be exported in table-form, Noise Circle or Cartesian plots over frequency. For a given frequency the software can be directed to measure the four noise parameters as a function of DC bias and generate corresponding listings or plots.

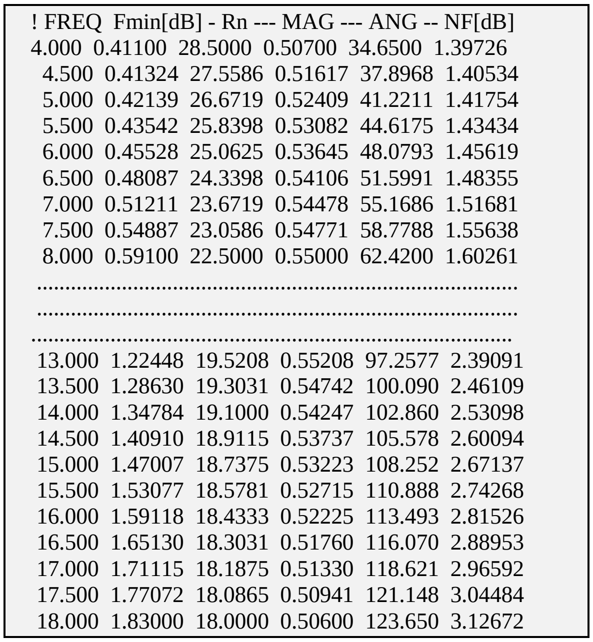


a)

b)



c)



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! FREQ  Fmin[dB] - Rn --- MAG --- ANG -- NF[dB]
4.000  0.41100  28.5000  0.50700  34.6500  1.39726
 4.500  0.41324  27.5586  0.51617  37.8968  1.40534
 5.000  0.42139  26.6719  0.52409  41.2211  1.41754
 5.500  0.43542  25.8398  0.53082  44.6175  1.43434
 6.000  0.45528  25.0625  0.53645  48.0793  1.45619
 6.500  0.48087  24.3398  0.54106  51.5991  1.48355
 7.000  0.51211  23.6719  0.54478  55.1686  1.51681
 7.500  0.54887  23.0586  0.54771  58.7788  1.55638
 8.000  0.59100  22.5000  0.55000  62.4200  1.60261
 ..............................................................................
 ..............................................................................
...............................................................................
 13.000  1.22448  19.5208  0.55208  97.2577  2.39091
 13.500  1.28630  19.3031  0.54742  100.090  2.46109
 14.000  1.34784  19.1000  0.54247  102.860  2.53098
 14.500  1.40910  18.9115  0.53737  105.578  2.60094
 15.000  1.47007  18.7375  0.53223  108.252  2.67137
 15.500  1.53077  18.5781  0.52715  110.888  2.74268
 16.000  1.59118  18.4333  0.52225  113.493  2.81526
 16.500  1.65130  18.3031  0.51760  116.070  2.88953
 17.000  1.71115  18.1875  0.51330  118.621  2.96592
 17.500  1.77072  18.0865  0.50941  121.148  3.04484
 18.000  1.83000  18.0000  0.50600  123.650  3.12672
```

d)

Figure 3a-d: WinNoise operation and Noise Parameter presentation: a) During the measurement (Noise and Gain Circles), b) as function of frequency, c) Optimum Γ_s on Smith Chart and d) in form of a listing

Critical Review and Comparison of the methods used

In this note we described the use of the "Cold Noise Source" method and a Spectrum Analyzer for noise measurements. The advantages of each are:

1. The "Cold Noise Source" method does not require the loss and thus the full set of S-parameters of the tuner but only its S22. This simplifies the tuner characterization and enhances the measurement accuracy, since the tuner can easily be re-characterized "in-situ". The absence of the tuner loss adds to the accuracy, since it would have to be subtracted from the "hot" noise power of the source when we use the "hot-cold" method. However, the disadvantage is that the S-parameters of the DUT are critical for the noise figure measurement [eq. 1]. So, the actual S-parameters of the DUT have to be measured "in-situ", which means that remote switches and a network analyzer need to be part of the setup. In the case of "hot-cold" noise source the loss of the tuner has to be known, but the S-parameters of the DUT interfere only via Friis' formula, i.e. in the second stage correction factor [eq. 2].

$$NF(\Gamma s) = NF_{total} - (NF_{rec} - 1) / G_{dut}(Sij) \quad [2]$$

This means that DUT S-parameter sets measured previously and saved in files can be used without sensitive loss of accuracy, especially if NF_{rec} is low (~1dB) and the VNA and switches need not be part of the setup. However this technique is, for very low noise figures, not so accurate as the "cold noise source" method, it can be used with confidence for minimum noise figures larger than 1dB, whereas the "cold" method is reliable for noise figures as low as 0.2 dB.

2. The Spectrum Analyzer combines filtering, mixing and data processing (averaging) in one instrument. If a standard local oscillator combination would be used then only Double Sideband (DSB) noise measurements would be possible. The corresponding Single Sideband (SSB) noise modules (HP-8970B & 8971C) are limited in frequency (26.5 GHz max) and have noise figure between 10 and 14 dB. In both cases a low noise preamplifier is needed, as is also the case for the spectrum analyzer.
DSB noise measurements entail potential measurement errors, in that the source impedance and the gain of the DUT are different for the upper and lower sideband. There is no simple technique to account for this error, which may be significant, especially when the electrical length between DUT and tuner probe is big, as is the case in wafer probe tests.
The difference in the phase of the source reflection factor between upper and lower sideband can be calculated from:

$$\Delta\Phi = 0.024 * Lel\,(cm) * \Delta f\,(MHz) \quad [3]$$

A typical electrical length for a wafer probe setup is 20 cm and a typical upper-lower sideband frequency difference is 60 MHz; this creates a phase difference of ~30°, which may cause significant errors if the source impedances are not placed tangentially to the gain circles of the device. WinNoise includes a feature, which warns the user for source impedances at which this error becomes significant (gain difference between sidebands more than 0.5dB), but this is in conflict with fast automatic frequency sweeps; therefore the importance of SSB noise measurements.

Supported Spectrum Analyzers

1. Video Bandwidth = 1 Hz
2. Marker reading resolution = 0.01 dB.

The following spectrum analyzers are suitable and supported:

1. Anritsu MS-2665 and similar
2. Hewlett-Packard 85xx, series E
3. Rohde & Schwarz, series FS

Custom drivers can be added on request.