Noise Figure Measurements

Feb 24, 2009

Account Manager : Peter Caputo
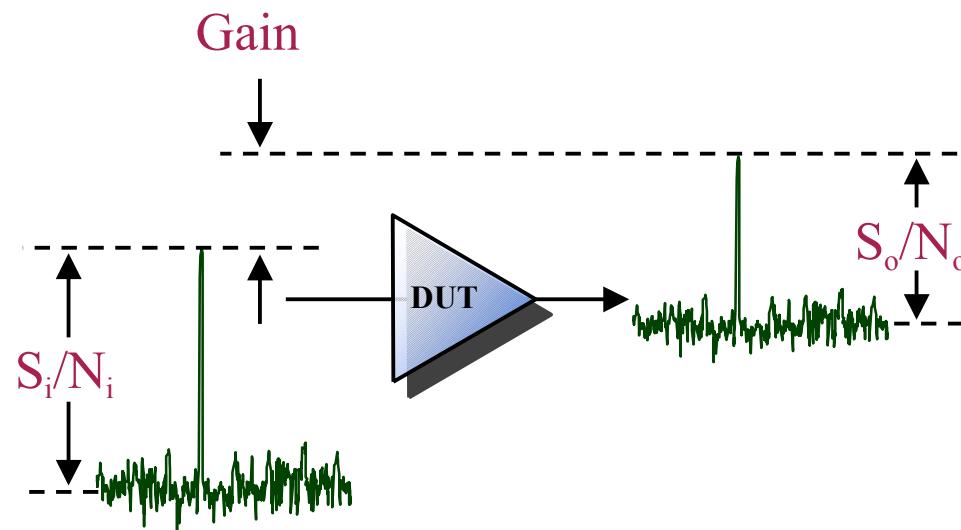
**Presented by : Ernie Jackson**

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Agenda

➡️ • **Overview of Noise Figure**
- **Noise Figure Measurement Techniques**
- **Accuracy Limitations**
- **PNA-X's Unique Approach**

Gain

S_o/N_o

DUT

S_i/N_i

Noise Contributors

Thermal Noise: (otherwise known as Johnson noise) is the kinetic energy of a body of particles as a result of its finite temperature

$$P_{therm}=kTB$$

Shot Noise: caused by the quantized and random nature of current flow

Flicker Noise: (or 1/f noise) is a low frequency phenomenon where the noise power follows a $1/f^{\alpha}$ characteristic

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Why do we measure Noise Figure? Example...

Transmitter:

ERP	+ 55 dBm
Path Losses	-200 dB
Rx Ant. Gain	60 dB
Power to Rx	-85 dBm
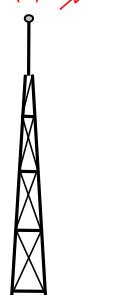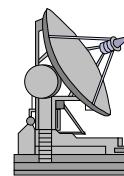
Receiver:

Noise Floor@290K	-174 dBm/Hz
Noise in 100 MHz BW	+80 dB
Receiver NF	+5 dB
Rx Sensitivity	-89 dBm

C/N= 4 dB

ERP = +55 dBm

Path Losses: -200 dB

Choices to increase Margin by 3dB
1. **Double transmitter power**
2. **Increase gain of antennas by 3dB**
3. **Lower the receiver noise figure by 3dB**
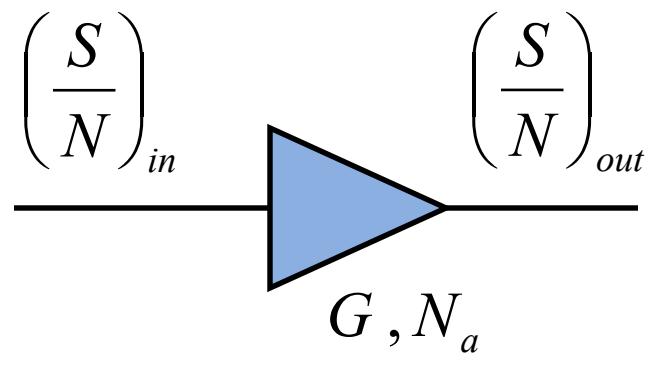
Receiver NF: 5dB
Bandwidth: 100MHz
Antenna Gain: +60dB

Power to Antenna: +40dBm
Frequency: 12GHz
Antenna Gain: +15dB

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The Definition of Noise Factor or Noise Figure in Linear Terms

- **Noise Factor is a figure of merit that relates the Signal to Noise ratio of the output to the Signal to Noise ratio of the input.**

- **Most basic definition was defined by Friis in the 1940's.**

$$\left(\frac{S}{N}\right)_{in} \quad \triangleright \quad \left(\frac{S}{N}\right)_{out}$$

$$G, N_a$$
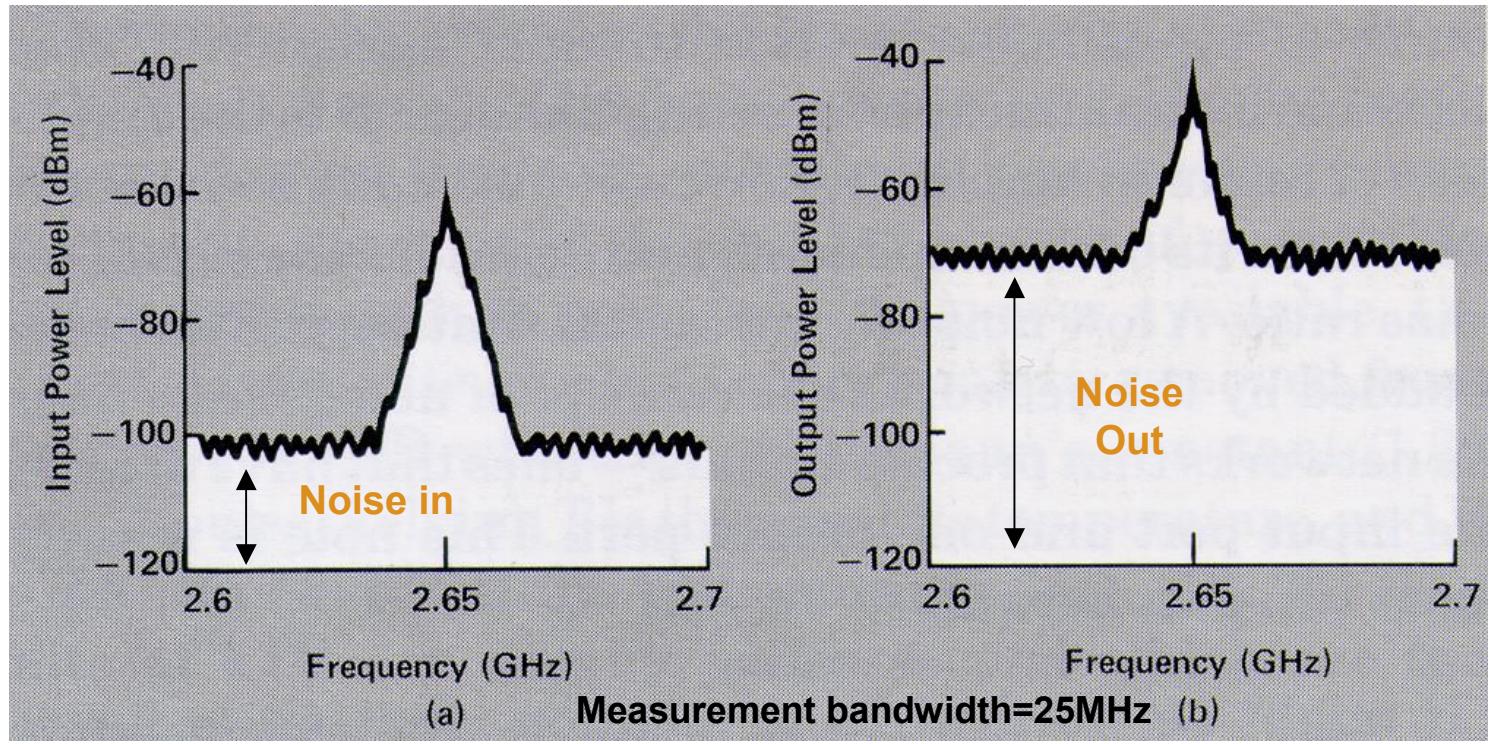
$$F = \frac{\left(\dfrac{S}{N}\right)_{in}}{\left(\dfrac{S}{N}\right)_{out}}$$

Reference: Harald Trap Friis: 1944: Proceedings of the IRE

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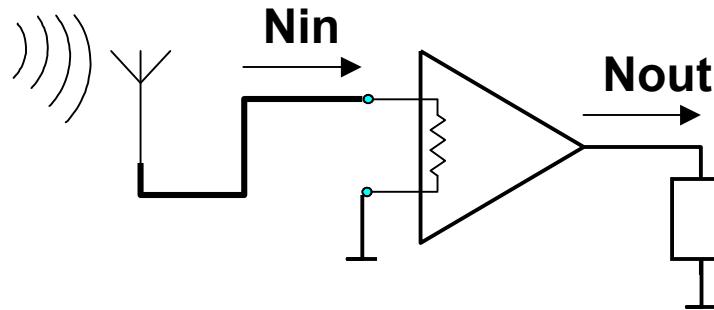
What is Noise Figure ?
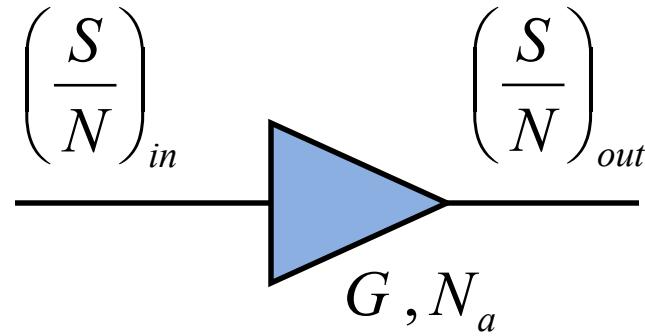

a) C/N at amplifier input   b) C/N at amplifier output
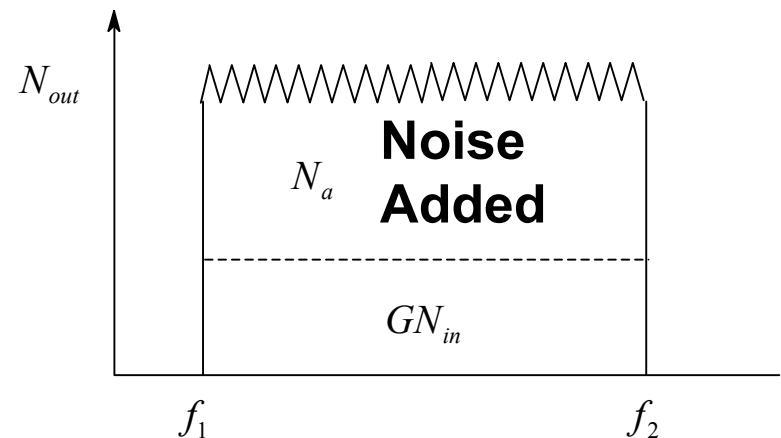
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Definition of Noise Figure

$$\left(\frac{S}{N}\right)_{in}$$

$$\left(\frac{S}{N}\right)_{out}$$

$$G, N_a$$

N_{out}

N_a **Noise Added**

GN_{in}

f_1 f_2

$$Gain = G = \frac{S_{out}}{S_{in}} \qquad N_{out} = N_a + GN_{in}$$

$$F = \frac{\left(\frac{S}{N}\right)_{in}}{\left(\frac{S}{N}\right)_{out}}$$

$$F = \frac{N_{out}}{GN_{in}} = \frac{N_a + GN_{in}}{GN_{in}} \qquad \textbf{Noise Factor}$$

$$NF \text{ (dB)} = 10\log\left(\frac{N_a + GN_{in}}{GN_{in}}\right) \qquad \textbf{Noise Figure}$$

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Noise Voltage

Standard Equation for <mark>Noise Voltage produced by a Resistor</mark>

$$e^2 = 4kTBR$$

$k = \text{Boltzman's Constant} = 1.38 \times 10^{-23} \text{ Joules/°K}$

$\text{T is absolute temperature (°K)}$
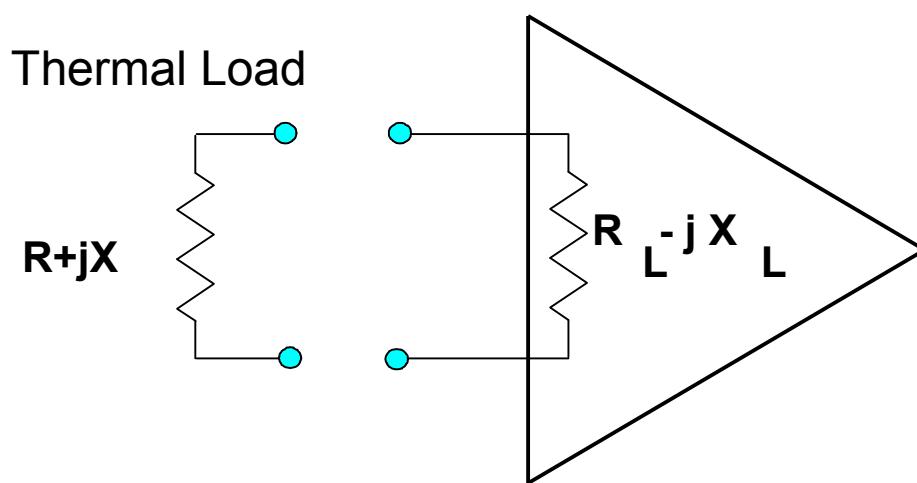
$\text{B is bandwidth (Hz)}$

$e \text{ is rms voltage}$

Reference: JB Johnson/Nyquist: 1928: Bell Labs

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Noise Power at Standard Temperature

Thermal Load

$R+jX$

$R_L -jX_L$

k = 1.38 x 10^{-23} joule / k
T = Temperature (K)
B = Bandwidth (Hz)

Available Noise Power Delivered to a Conjugate Load,
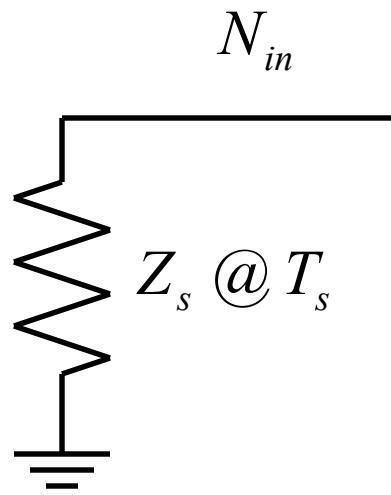
$$P_{av} = kTB$$

At 290K P_{av} = 4 x 10^{-21} W/Hz = <u>-174dBm / Hz</u>
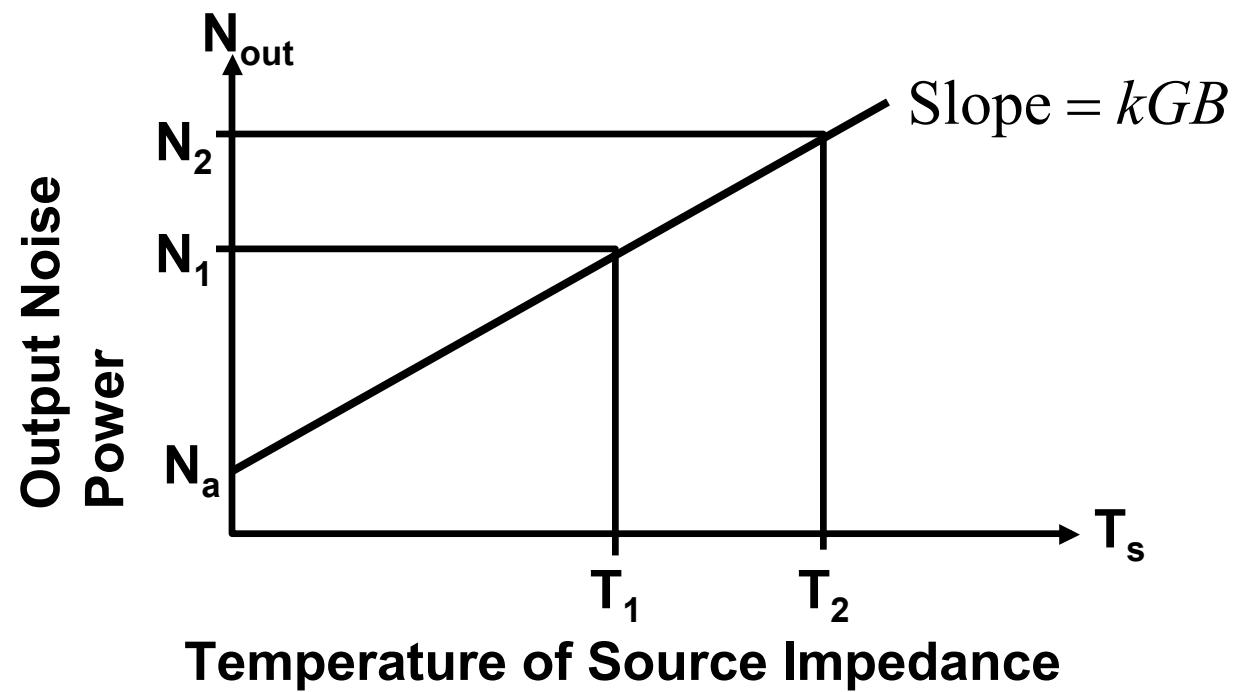
In deep space kT = <u>-198dBm/Hz</u>
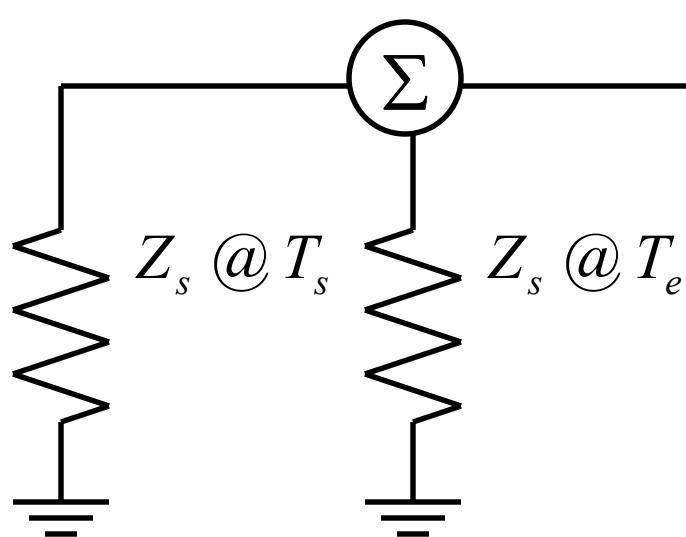
Noise Power is Linear with Temperature

N_{in}

$$N_{out} = N_a + GN_{in}$$
$$= N_a + GkT_sB$$

$Z_s @ T_s$

G, N_a

Output Noise Power

N_{out}

Slope $= kGB$

N_2

N_1

N_a

T_1 T_2 T_s

Temperature of Source Impedance

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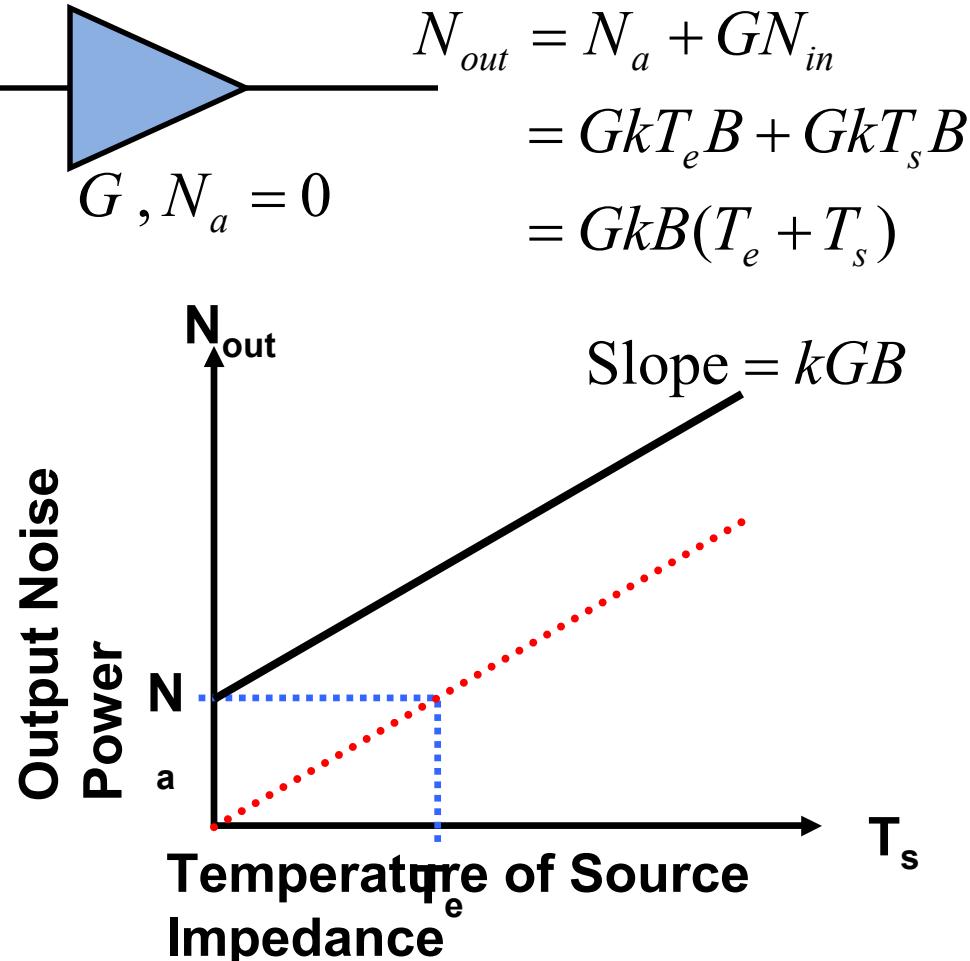
An Alternative Way to Describe Noise Figure:
Effective Input Noise Temperature (T_e)

$$N_{out} = N_a + GN_{in}$$

$$= GkT_eB + GkT_sB$$

$$= GkB(T_e + T_s)$$

$$G,\ N_a = 0$$

$$Z_s\ @\ T_s \qquad Z_s\ @\ T_e$$

$$T_e = (F-1)T_s$$

and

$$F = \frac{T_e + T_s}{T_s}$$

N_{out}

Slope $= kGB$

Output Noise Power

N
a

**Temperature of Source Impedance**

T_e

T$_s$
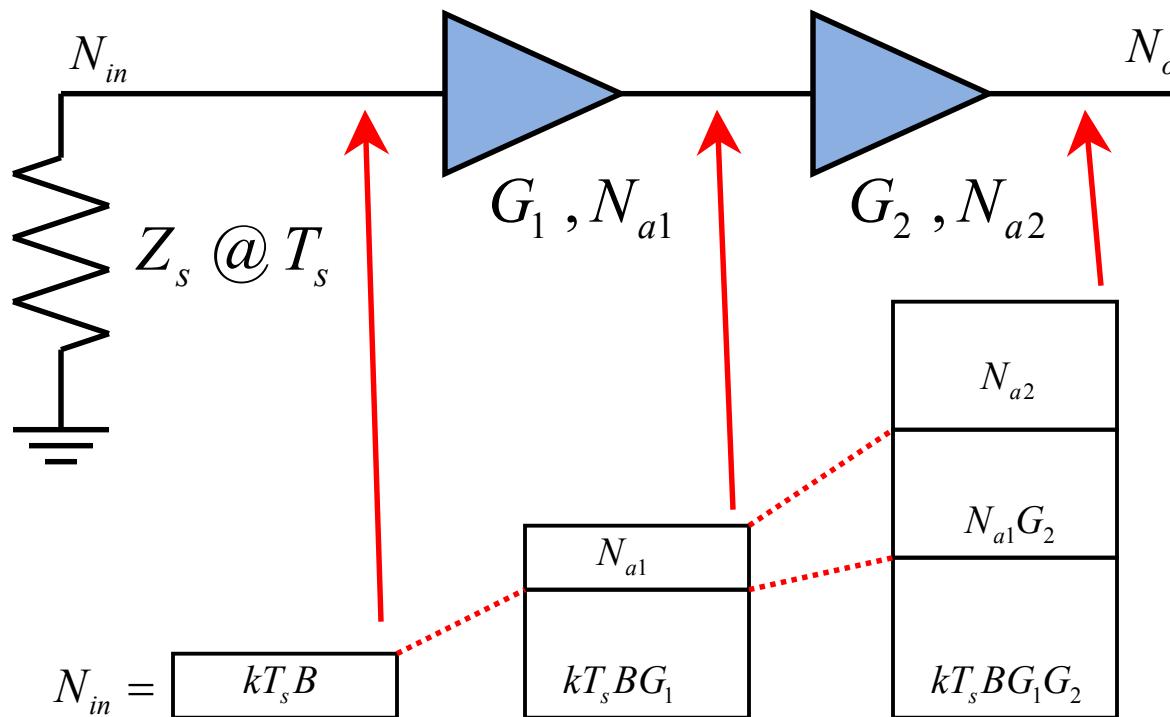
Te or NF: which should I use?

- Use either - they are completely interchangeable

- Typically NF for terrestrial and Te for space

- NF referenced to 290K - not appropriate in space

- If Te used in terrestrial systems, the temperatures can be large (10dB=2610K)

- Te is easier to characterize graphically

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Friis or Cascade Equation

- **Here we see what contribution a second amplifier has on the overall noise factor.**

$$N_{out} = N_{a2} + G_1 N_{a1} + G_1 G_2 N_{in}$$

$$G = G_1 G_2$$

$$N_{in} = kT_s B$$

$$N_{a1} = kT_{e1}B = (F_1 - 1)kT_s B$$

$$N_{a2} = kT_{e2}B = (F_2 - 1)kT_s B$$

$$F = \frac{N_{out}}{GN_{in}}$$

N_{in}

$Z_s @ T_s$

G_1 , N_{a1}

G_2 , N_{a2}

N_{a2}

$N_{a1}G_2$

N_{a1}

$N_{in} = \boxed{kT_s B}$

$\boxed{kT_s BG_1}$

$\boxed{kT_s BG_1 G_2}$

$$F_{12} = F_1 + \frac{F_2 - 1}{G_1}$$

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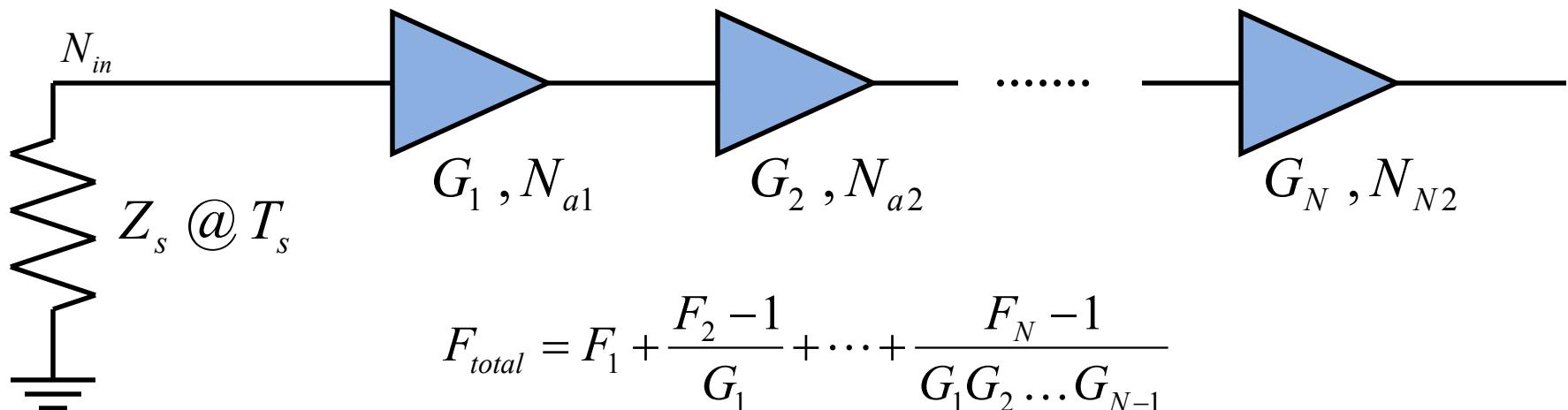
Effects of Multiple Stages on Noise Factor

- **The cascade equation can be generalized for multiple stages**

N_{in}

$Z_s @ T_s$

G_1 , N_{a1}

G_2 , N_{a2}

....

G_N , N_{N2}

$$F_{total} = F_1 + \frac{F_2 - 1}{G_1} + \cdots + \frac{F_N - 1}{G_1 G_2 \ldots G_{N-1}}$$

$$F_{total} = F_1 + \sum_{i=2}^{N} \left(\frac{F_i - 1}{\prod_{j=i}^{N} G_{j-1}} \right)$$

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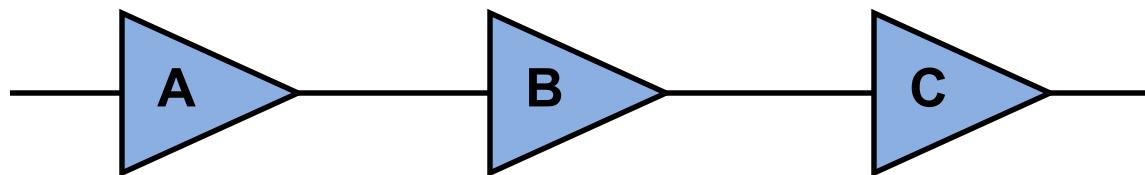
Demo of Cascade Equation

$$F = F_1 + \frac{F_2 - 1}{G_1}$$

	A	B	C
Gain (dB)	6.0	12.0	20.0
Gain	4.0	16.0	100.0
Noise Figure(dB)	2.3	3.0	6.0
Noise Factor	1.7	2.0	4.0

$$F_{ABC} = 1.7 + \frac{2.0 - 1}{4.0} + \frac{4.0 - 1}{4.0 \times 16.0} = 1.70 + 0.25 + 0.047 = 1.997$$

$$NF_{ABC} = 10\log(1.997) = 3.00 \text{ dB}$$
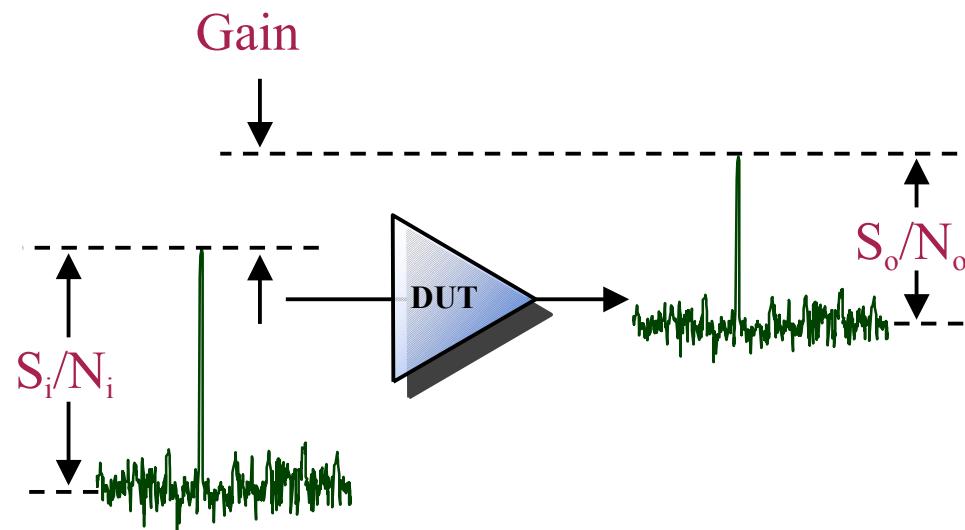
$$F_{ACB} = 1.7 + \frac{4.0 - 1}{4.0} + \frac{2.0 - 1}{4.0 \times 100.0} = 1.70 + 0.75 + 0.025 = 2.475$$

$$NF_{ACB} = 10\log(2.475) = 3.93 \text{ dB}$$
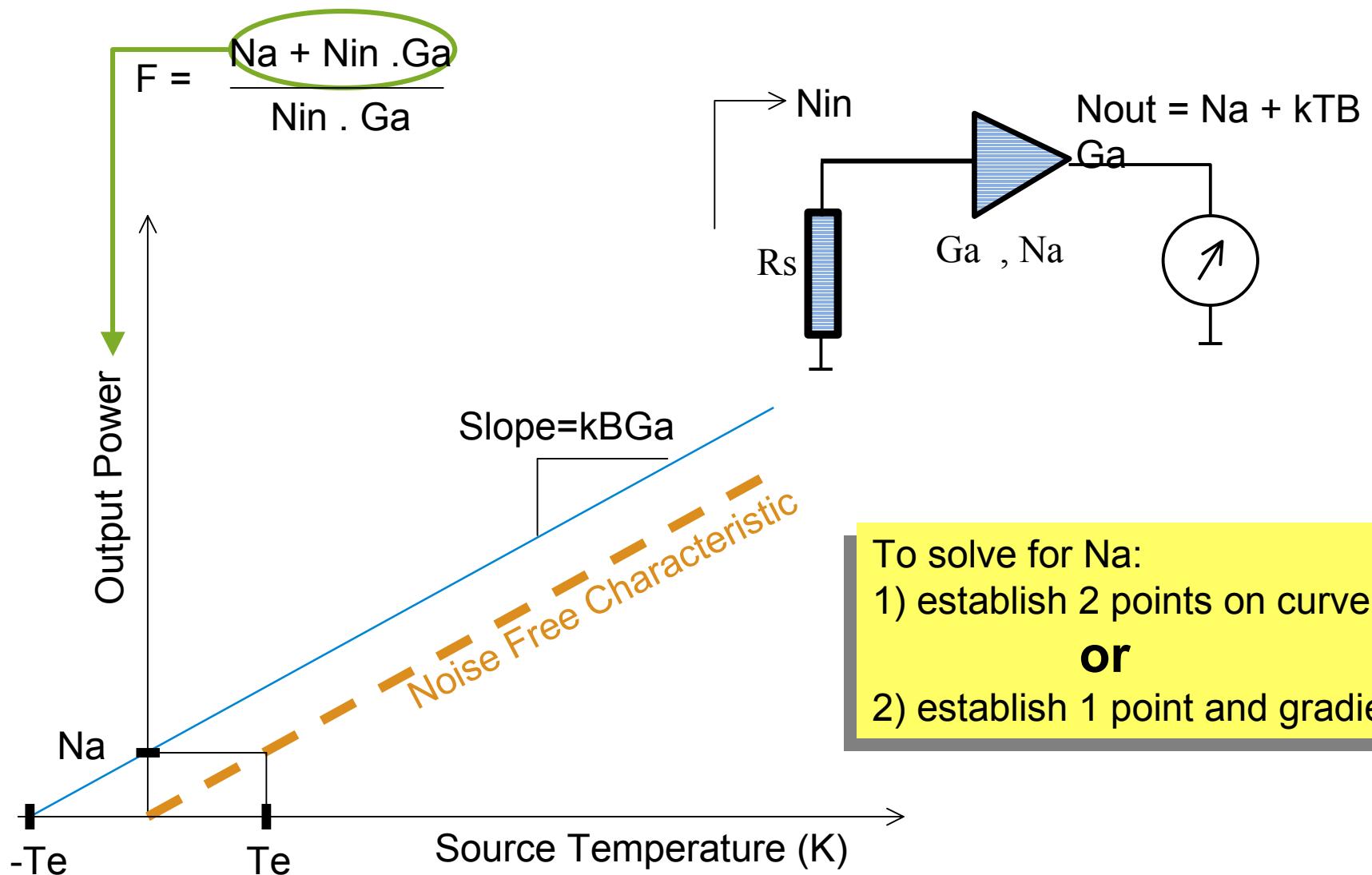
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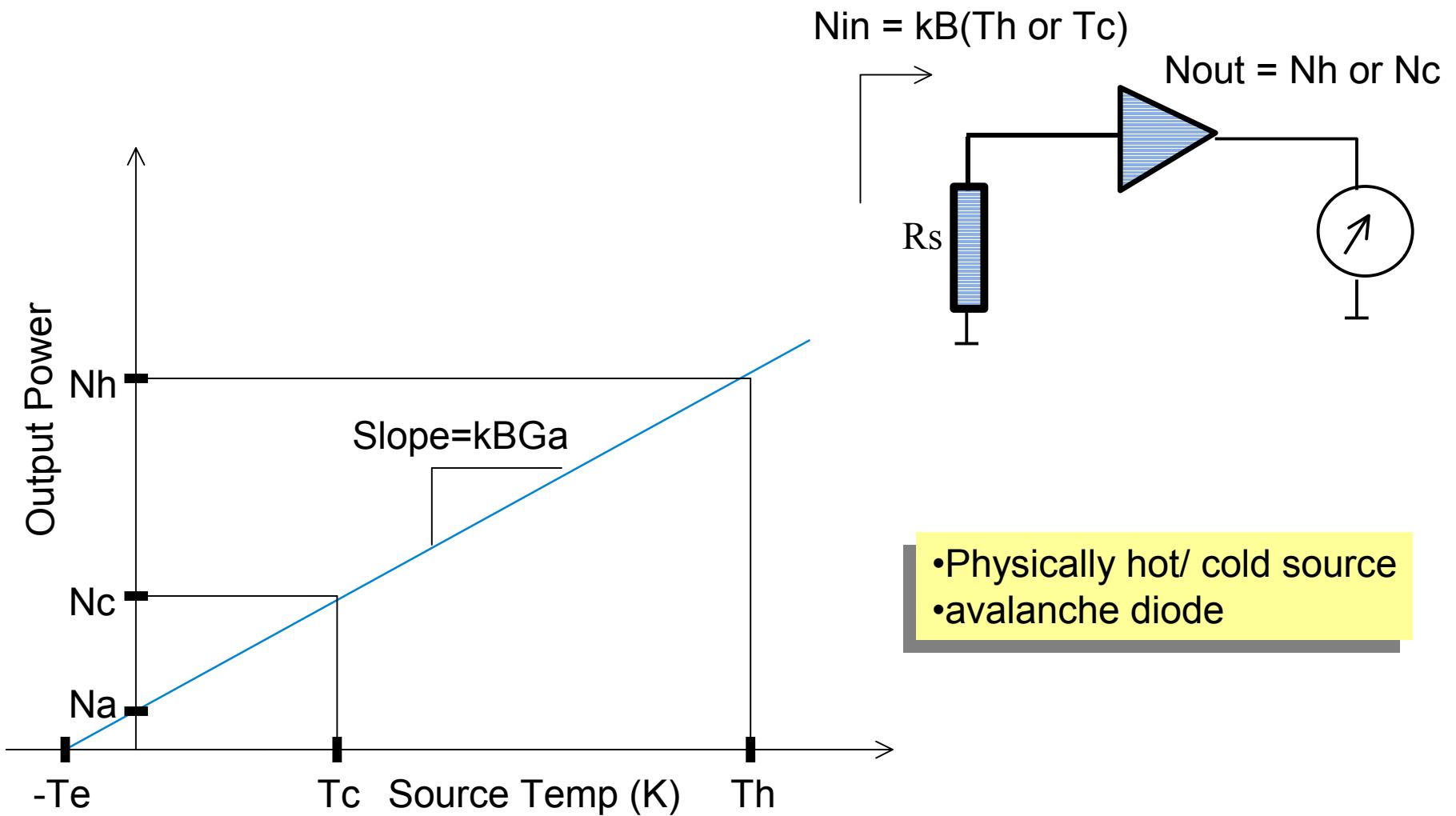
Agenda

- **Overview of Noise Figure**
- **Noise Figure Measurement Techniques**
- **Accuracy Limitations**
- **PNA-X's Unique Approach**

Gain

S_o/N_o

DUT

S_i/N_i

Measuring Noise Figure

$$F = \frac{Na + Nin \cdot Ga}{Nin \cdot Ga}$$

Nin

$Nout = Na + kTB$

Ga

Rs

Ga , Na

Output Power

Slope=kBGa

Noise Free Characteristic

To solve for Na:
1) establish 2 points on curve

or

2) establish 1 point and gradient

Na

-Te

Te

Source Temperature (K)

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Hot/Cold Technique

$$Nin = kB(Th \text{ or } Tc)$$

$$Nout = Nh \text{ or } Nc$$

Rs

- Physically hot/ cold source
- avalanche diode

Output Power

Nh

Slope=kBGa

Nc

Na

-Te   Tc   Source Temp (K)   Th

Measured

$$Y = \frac{Nh}{Nc}$$

$$No = kGB \bullet Ts + Na$$

Output Power (No)

Nh

Slope=kGB

Nc

Na

Source Temp (Ts)

-Te   Tc   Th
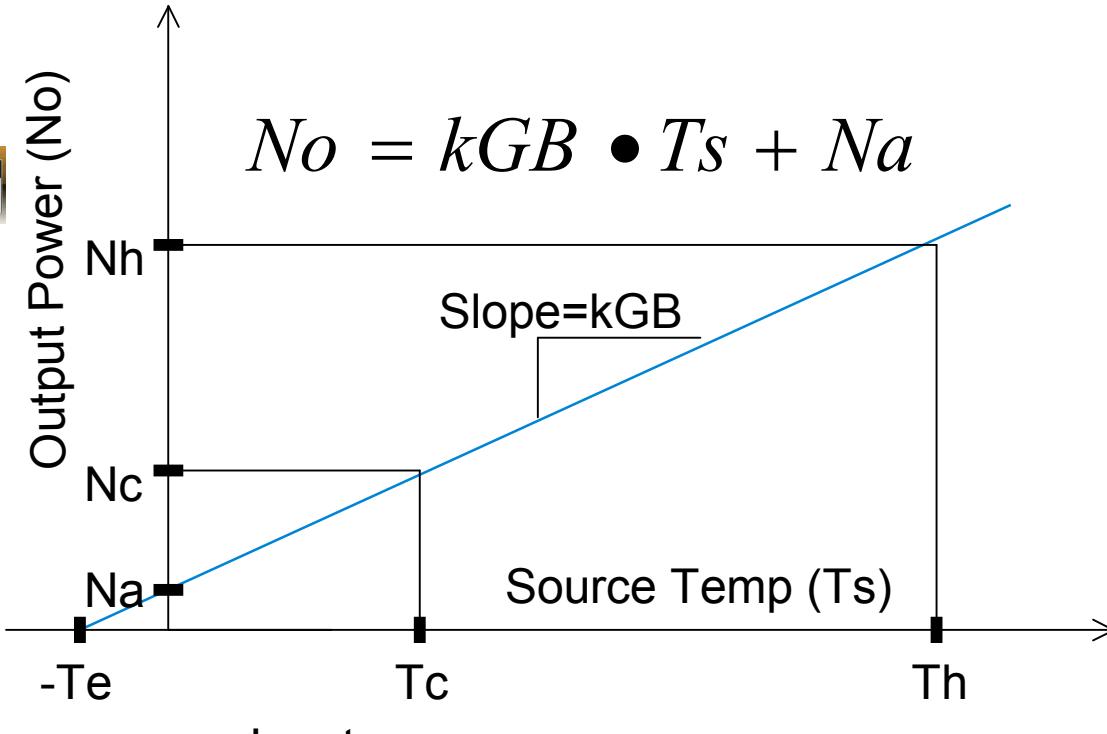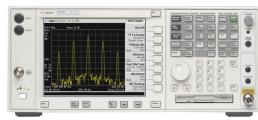
Input

$$ENR = \frac{(Th - To)}{To}$$

Calculated
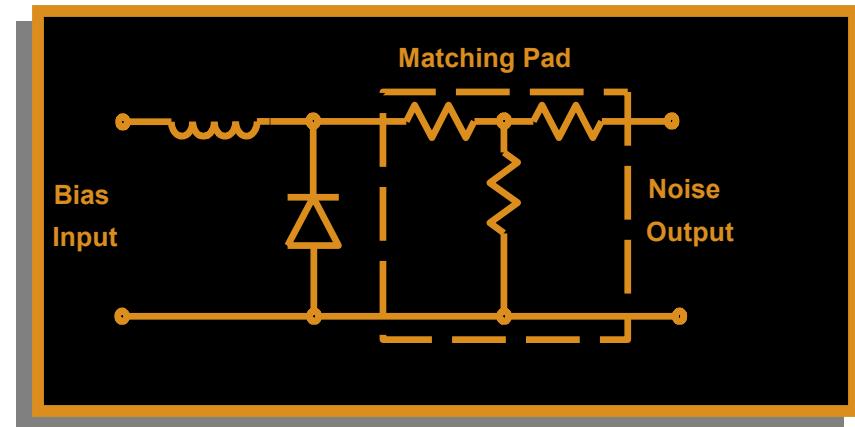
$$Na = kBGTo\left(\frac{ENR}{Y-1} - 1\right)$$

$$Te = \frac{Na}{kGB}$$

$$F = \frac{Na + kGBTo}{kGBTo} = \frac{ENR}{Y-1} = \frac{Te + To}{To}$$

$$Te = To(F - 1)$$

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Noise Source - the Avalanche Diode
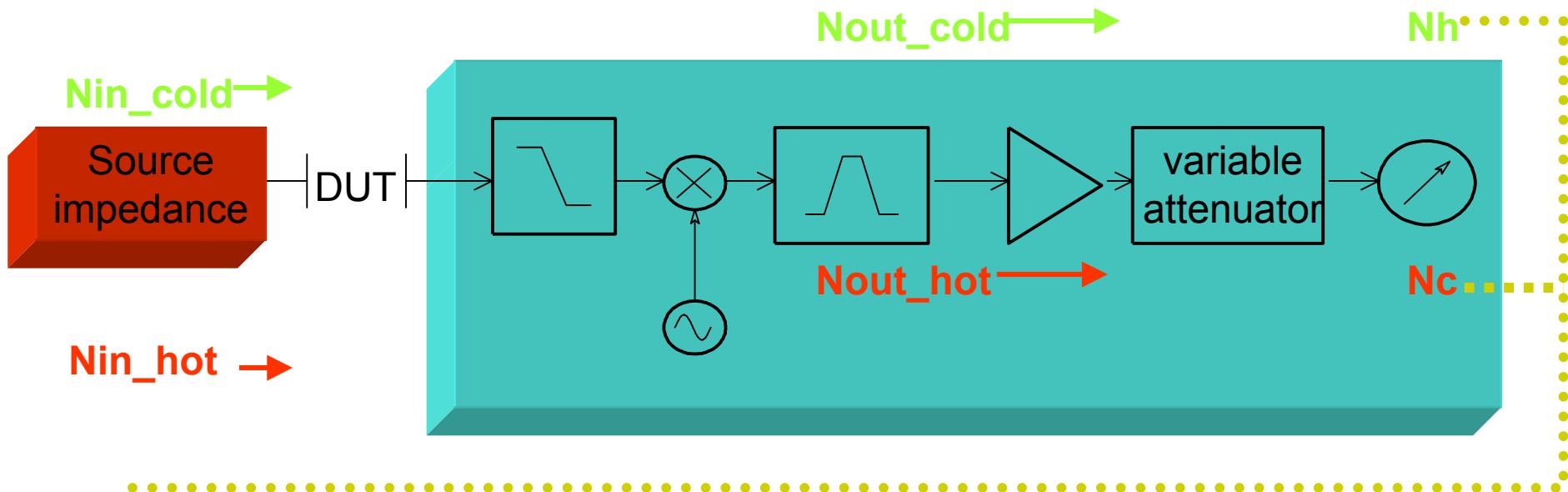
Excess Noise Ratio, ENR (dB) = 10 Log $_{10}$ $\dfrac{(T_h - 290)}{290}$

Frequency	ENR dB
XXX	AAA
YYY	BBB
ZZZ	CCC
⋮	⋮

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Noise Figure Analyzer
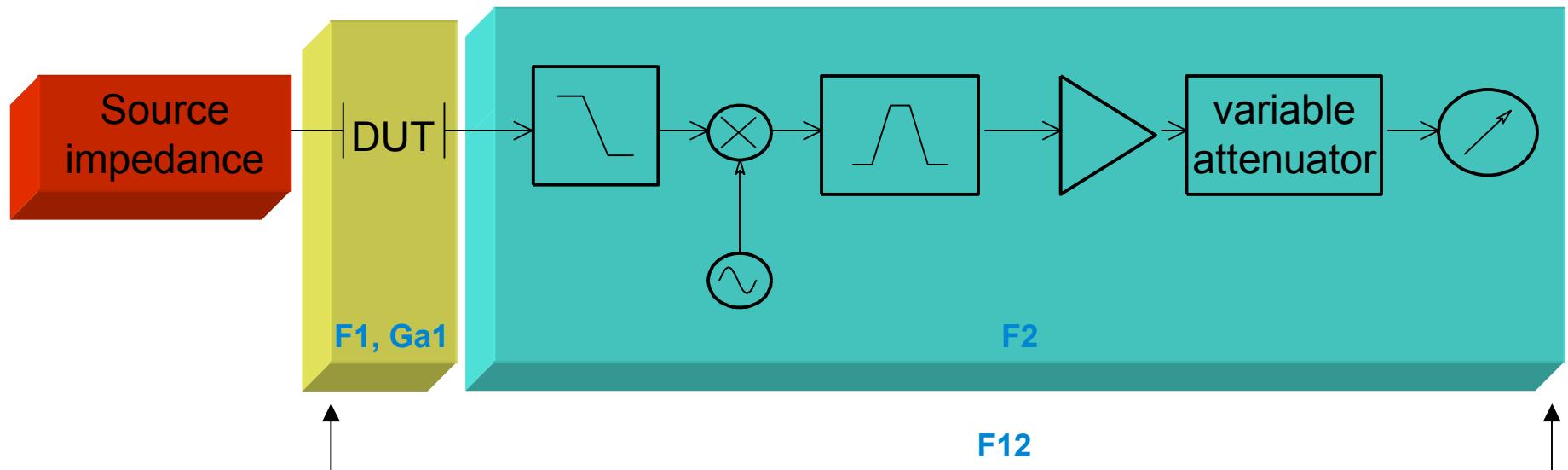


$$Y = \frac{Nh}{Nc} = \frac{kGB(Te + Th)}{kGB(Te + Tc)}$$

$$Te = \frac{Th - Y\,Tc}{Y - 1} \quad \text{(solve for Te)}$$

$$F = \frac{Te + To}{To}$$

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# Calibrating out System NF
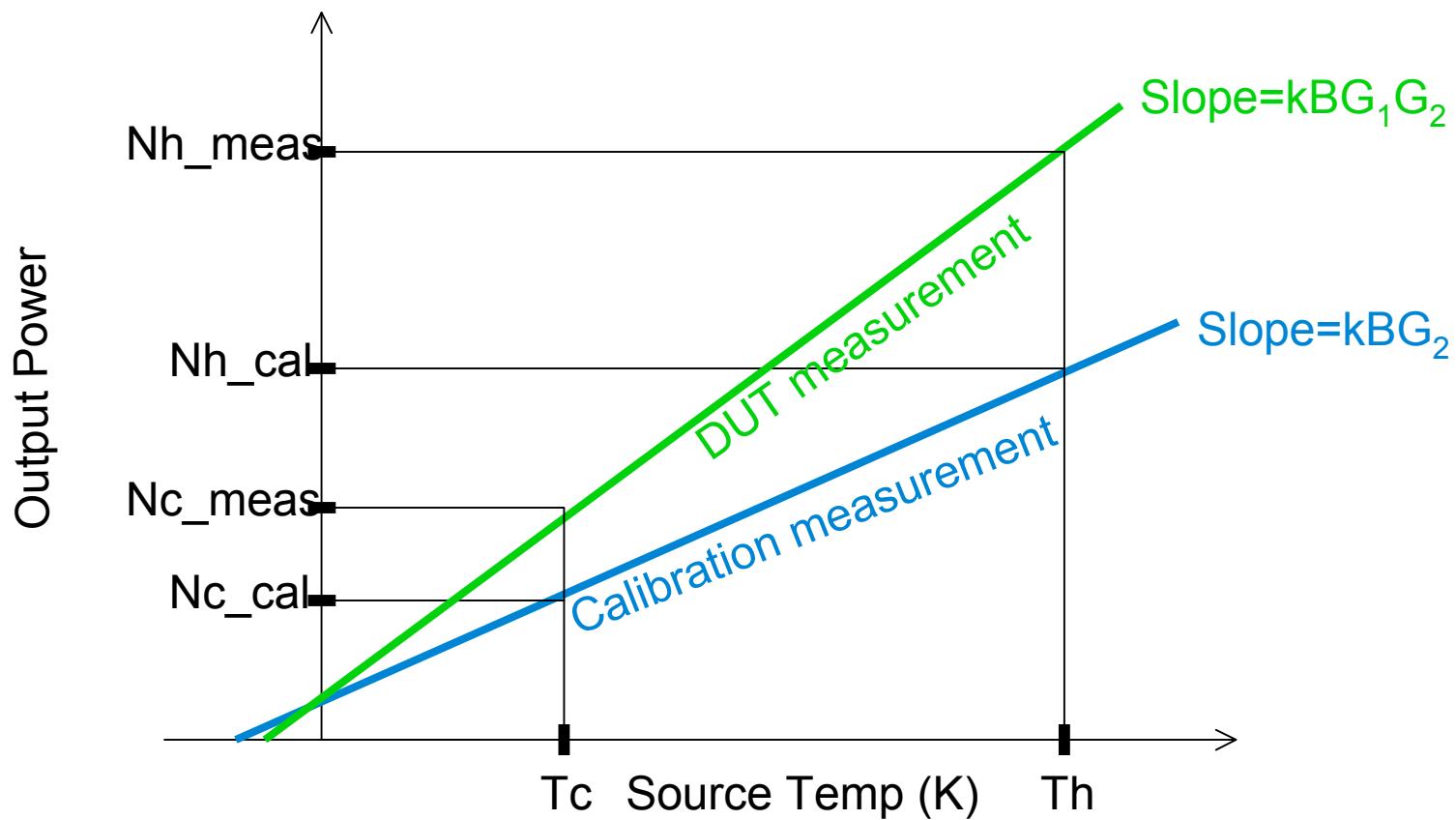
$$F_1 = F_{12} - \frac{F_2 - 1}{G_{a1}}$$
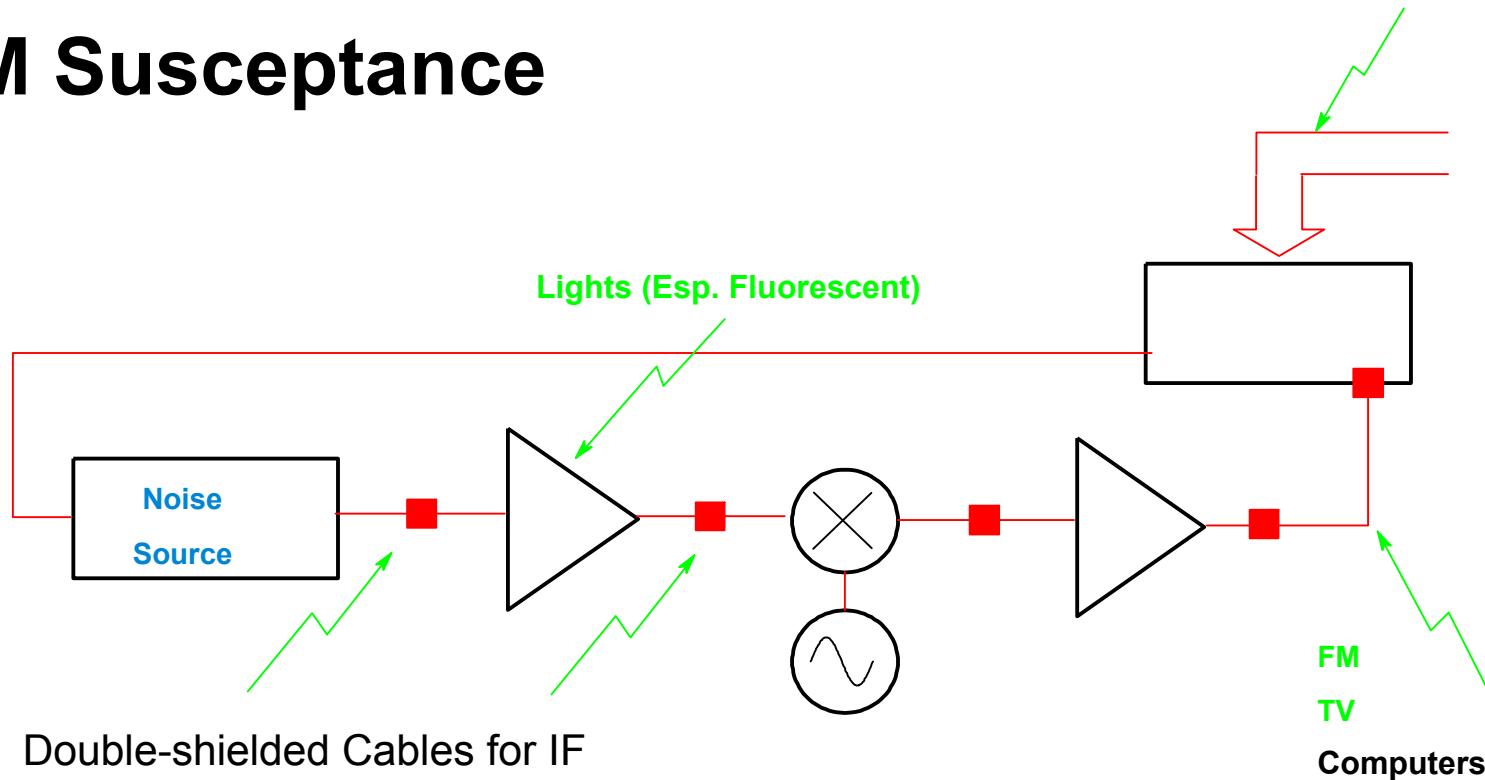
if $\quad F_{12} \approx \dfrac{F_2 - 1}{G_{a1}} \quad$ then uncertainty increases, so beware if F_1 and G_1 are low

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How does the NFA measure gain

Avoidable Measurement Errors:
EM Susceptance

Lights (Esp. Fluorescent)

Noise Source

FM
TV
Computers

* Double-shielded Cables for IF
  (Ordinary Braid if porous)
* Shielded HP-IB Cables
* Enclose All Circuits
* Jiggle Connectors (Esp. BNC)
* Try snap-on ferrite cores on cables, dampen common-mode currents
* LO Contributes Spurious and Noise

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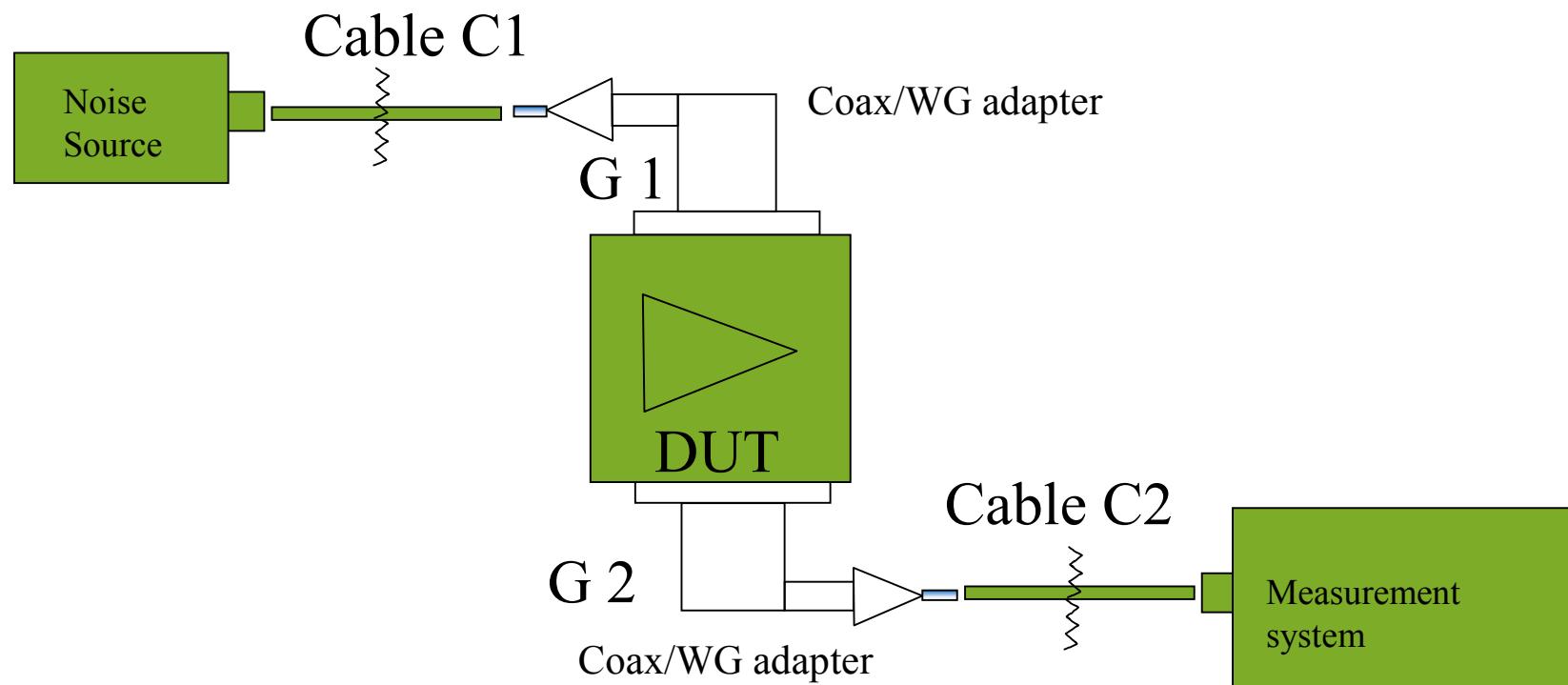
Avoidable Measurement Errors:
## Choose the Appropriate Noise Source
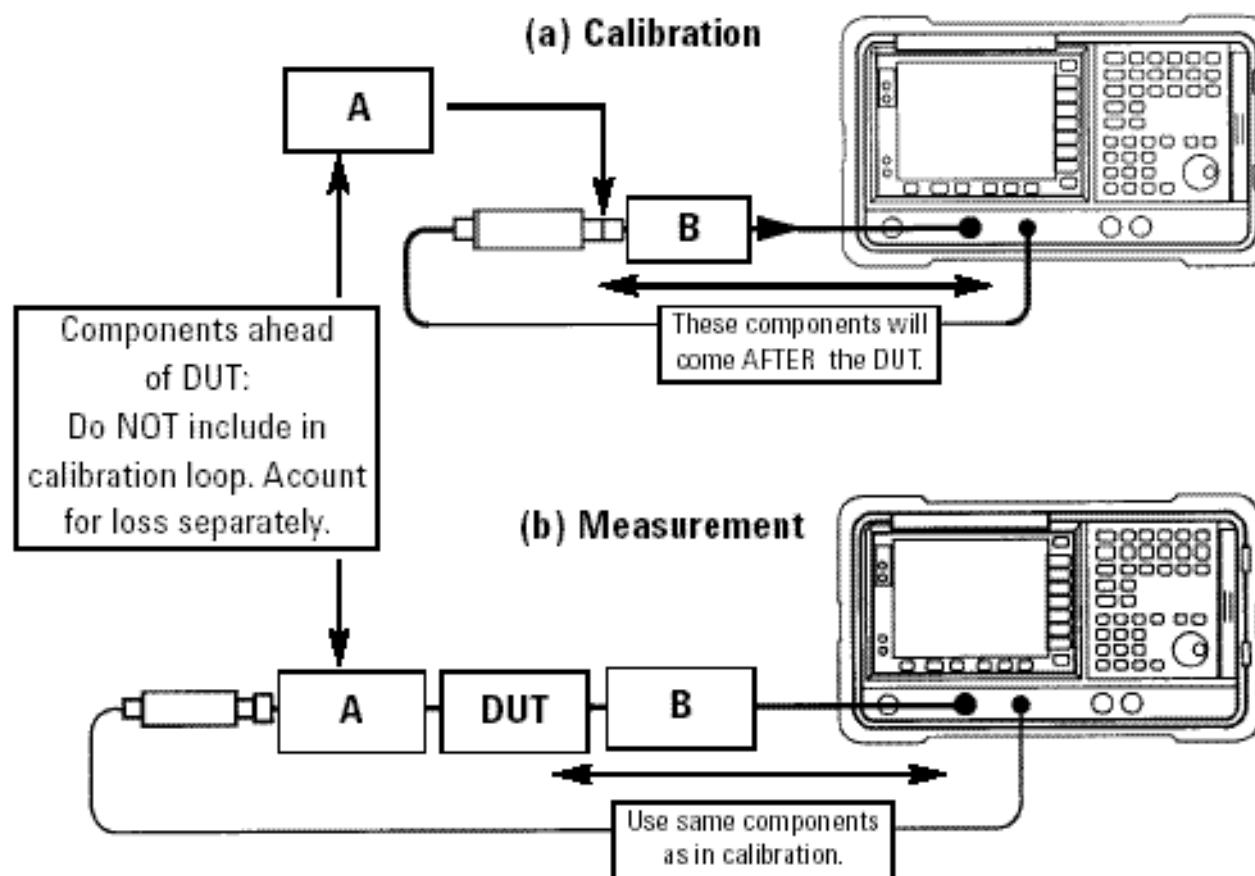
•15dB ENR noise source to measure NF of up to 30dB (eg N4001A, N4002A, 346B/C)

•Use 6 dB ENR for very low noise figure devices to keep noise detector linearity issues to a minimum (eg N4000A, 346A).

•Use a Noise Source with greater internal attenuation if the DUT is match sensitive (eg N4000A, 346A).

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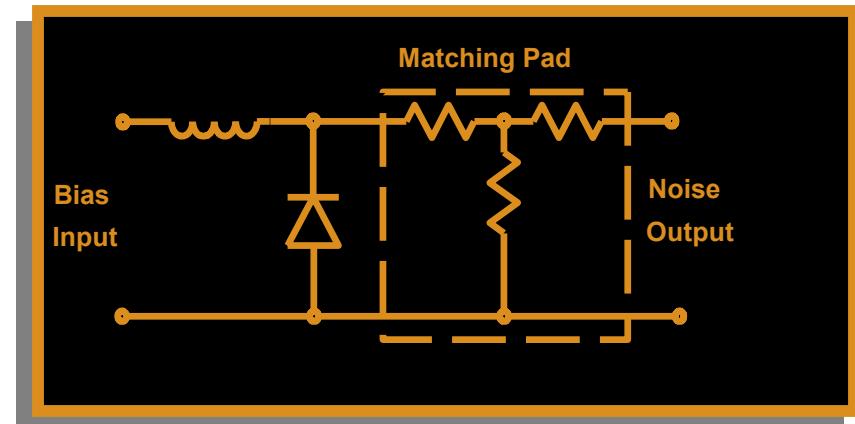
Avoidable Measurement Errors:
Accurate Loss Compensation

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Avoidable Measurement Errors:
Loss Compensation and Calibration

(a) Calibration

A

B

Components ahead of DUT:
Do NOT include in calibration loop. Acount for loss separately.

These components will come AFTER the DUT.

(b) Measurement

A   **DUT**   **B**

Use same components as in calibration.

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Noise Source - the Avalanche Diode

Excess Noise Ratio, ENR (dB) = $10 \log_{10} \dfrac{(T_h - 290)}{290}$

Frequency	ENR dB
XXX	AAA
YYY	BBB
ZZZ	CCC
⋮	⋮

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Avoidable Measurement Errors:
Temperature Considerations (Diode)

To=296.5 K
Th=10,000 or 1,500

Report Ambient Temperature to Analyzer for Accurate ENR Interpretations

Left window — NF

ENR	Tcold
10	306.5

◁ dB
◆ Lin

296.5 ▼

Cal Hot	Gain Lin
3196.5	1000

Cal Cold	Gain dB
296.5	30

Calc   Print

Dut Hot
3246500.0

Dut Cold	Te
346500.0	50

F Lin
1.17241

F dB
0.690809

Thot
3196.5

Exit

Right window — NF

ENR	Tcold
10	306.5

◁ dB
◆ Lin

Tcold ▼

Cal Hot	Gain Lin
3196.5	1000

Cal Cold	Gain dB
296.5	30

Calc   Print

Dut Hot
3246500.0

Dut Cold	Te
346500.0	40.01

F Lin
1.13797

F dB
0.561291

Thot
3206.5

Exit

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Avoidable Measurement Errors:
Loss and Temperature Corrections

- **A temperature must be entered in Loss Compensation Setup for valid results**

  NFA & PSA **Default = 0 degrees K**

- **The NFA and PSA accept S2P files from a Network Analyzer for the Loss Compensation table**

Avoidable Measurement Errors:

## Account for Frequency Conversion (DSB Measurement)
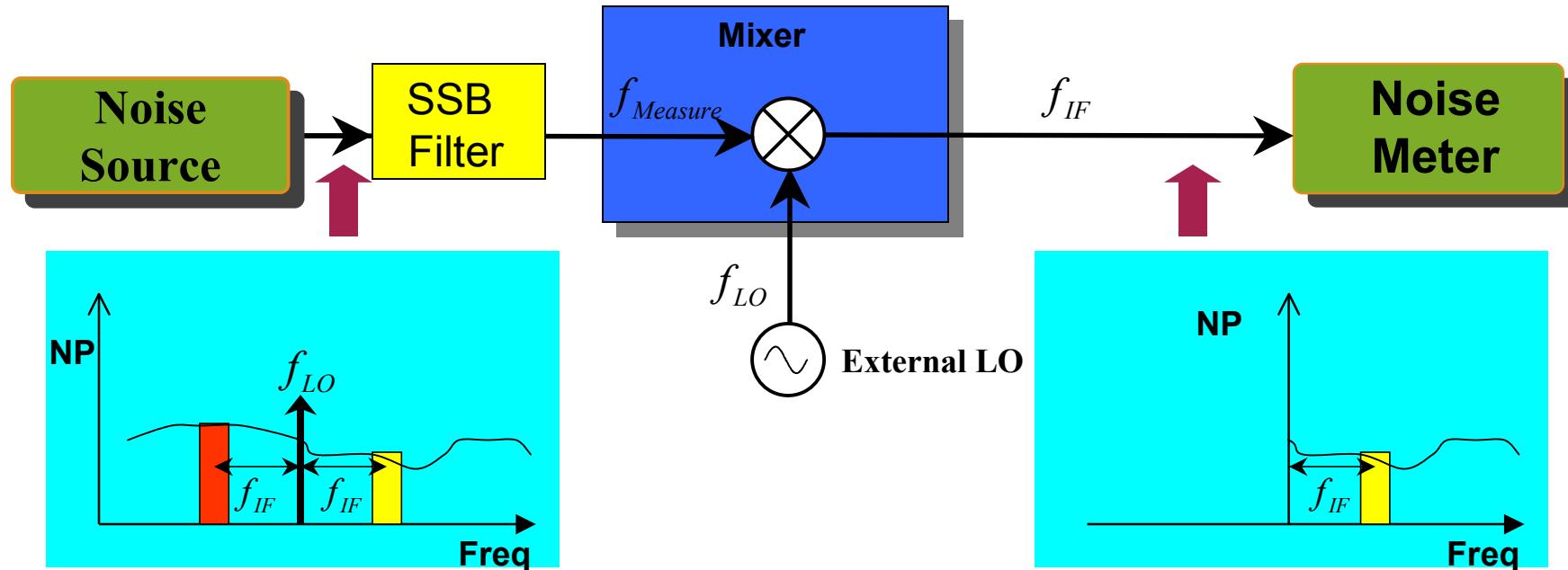
DSB is recommended when :
- **The application is DSB**
- **The DUT is broadband**
- **No SSB filter is available**
- **The frequency range make SSB filters impossible/impractical**

Loss compensation of 3dB (under perfect conditions) needs to be entered to account for doubling of power during measurement

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Avoidable Measurement Errors:

## Account for Frequency Conversion (SSB Measurement)

SSB is recommended when :
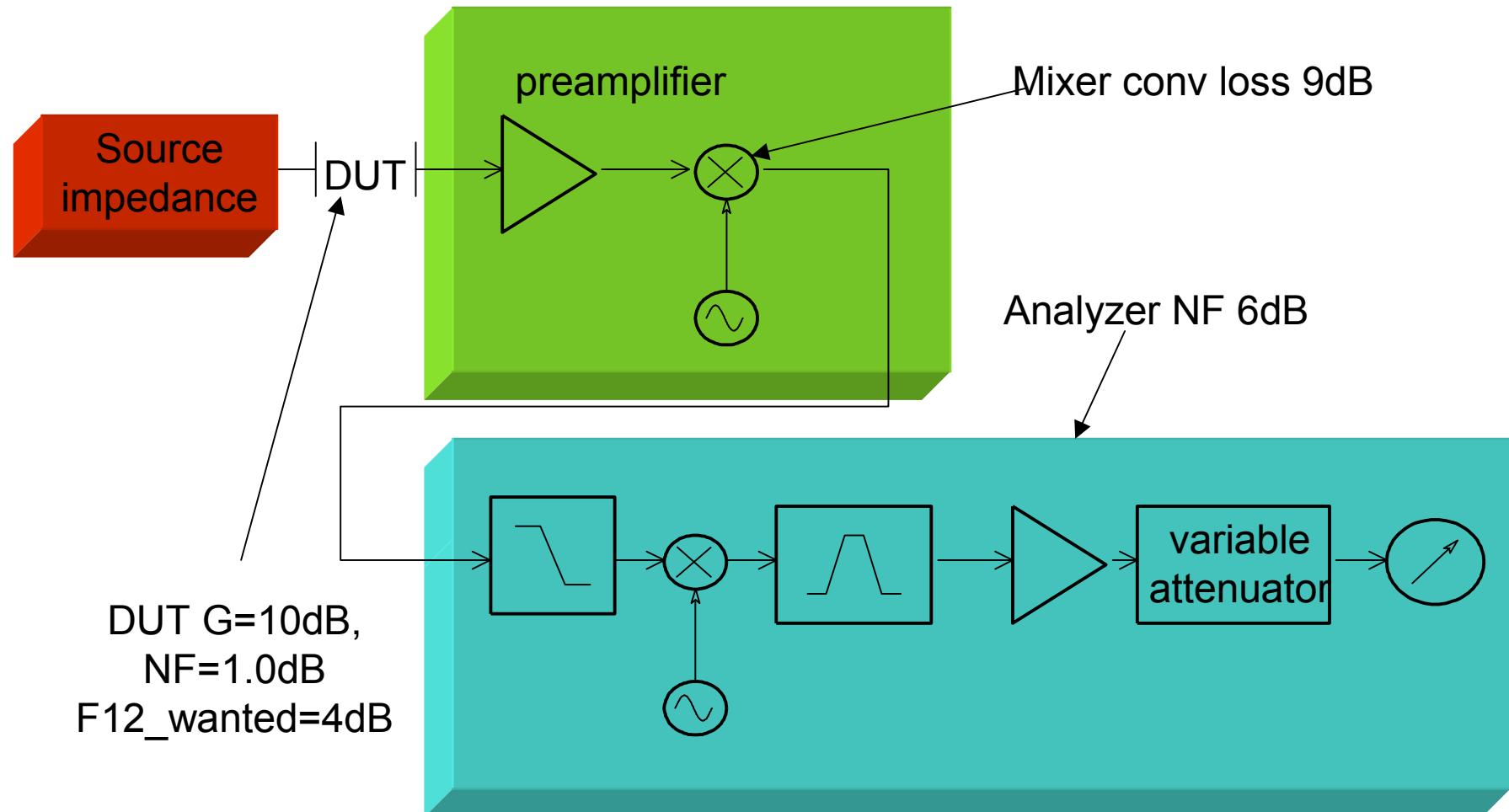
• The application is SSB

• The DUT is narrowband

If down conversion is part of the measurement system, filters should be included in calibration path and measurement path because the calibration and measurement are performed at the same frequencies.

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Using a pre-amplifier to improve accuracy

preamplifier

Mixer conv loss 9dB

Source impedance

DUT

Analyzer NF 6dB

variable attenuator

DUT G=10dB,
NF=1.0dB
F12_wanted=4dB

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Minimise Errors which cannot be eliminated:
Reduce Measurement System Noise Figure

- **Most important of all uncertainties**
- **if DUT has low gain/ low NF - watch out!**
- **NF2 $\leq$ (NF1 + G1) - 5dB for accuracy**
- **work out new system NF with preamp**
- **work out preamp gain**
- **avoid overload**

$$F = F_1 + \frac{F_2 - 1}{G_1}$$

$$F_1 = F_{12} - \frac{F_2 - 1}{G_{a1}}$$
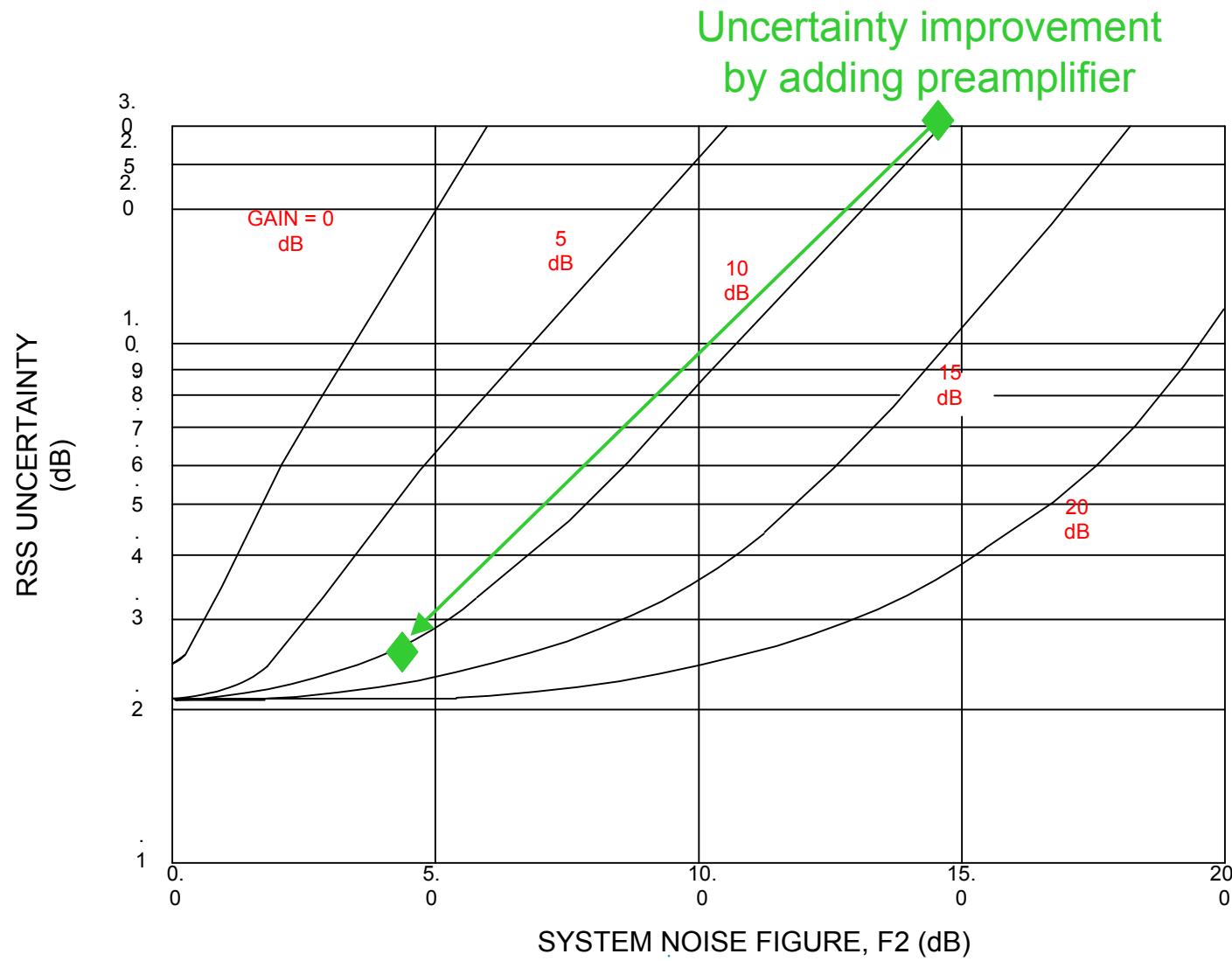
$$F2_{reduced} = F_{preamp} + \frac{F2_{current} - 1}{G_{pream}}$$

$$G_{preamp} = \frac{F2_{current}^p - 1}{F2_{reduced} - F_{preamp}}$$

Pin = -174dBm/Hz + ENR(dB) + 10log(BW) +
NF1 +G1(dB) + Gpre(dB)

Reduce Measurement System Noise Figure (cont)
Error in 2nd Stage Correction

Uncertainty improvement by adding preamplifier

RSS UNCERTAINTY (dB)

GAIN = 0 dB

5 dB

10 dB

15 dB

20 dB

SYSTEM NOISE FIGURE, F2 (dB)

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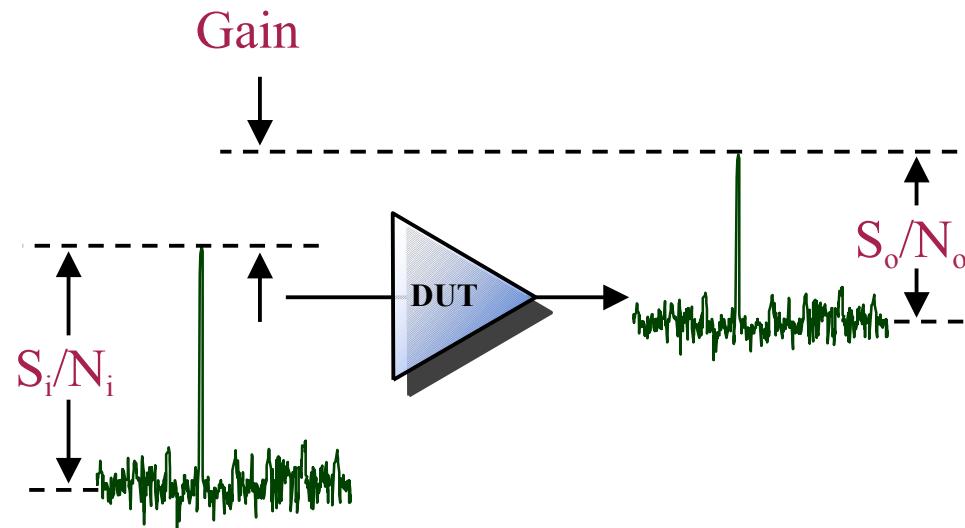
Additional Recommendations

- **Minimize the noise figure of the test system (especially when measuring low gain DUTs).**

- **Reduce the magnitude of all mismatches by using isolators or pads**

- **Minimize the number of adapters, and take care of them**

- **Calibrate Noise Source ENR values regularly and use good pedigree calibration**

- **Use Averaging to Avoid Display Jitter**

- **Choose the Appropriate Bandwidth**

- **Avoid DUT non-linearities**

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Agenda

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- **Noise Figure Measurement Techniques**
- **Accuracy Limitations**
- **PNA-X's Unique Approach**

Gain

DUT

S_o/N_o

S_i/N_i

Calculating Unavoidable Uncertainty

Available at : www.agilent.com/find/nfu

Microsoft Excel - NF Uncertainty Calculator.xls:1

File Edit View Insert Format Tools Data Window Help

	A	B	C	D	E	F	G	H
1	© 1999 - 2002 Agilent Technologies							
2								
3								
4	This spreadsheet calculates the uncertainty of noise figure measurements. The numbers in yellow are user							
5	variables and the green area is a calculation area. The final uncertainty is shown in blue, this should be added							
6	to and subtracted from the result shown on the noise figure measurement instrument in order to give the							
7	spread of possible values.							
8								
9		dB	Linear					
10	DUT NF, F1=	9	7.943282		F12/F1=	1.003083		
11	Instrument NF, F2=	16	39.81072		F2/F1G1=	0.003162		
12	DUT GAIN, G1=	32	1584.893		(F2-1)/F1G1=	0.003083		
13	Combined NF, F12=	9.013368	7.96777		(F12/F1)-(F2/F1G1)=	0.999921		
14								
15	Match	Units*	Refl Coef			Negative	Positive	Max
16	Noise Source=	1.35	0.148936		Uncert NS-DUT IN=	0.26266	0.25495	0.26266
17	DUT Input=	1.5	0.2		Uncert NS-NFA=	0.54971	0.516981	0.54971
18	DUT Output=	1.5	0.2		Uncert DUT OUT-NFA=	0.746486	0.687378	0.746486
19	Instrument=	2.4	0.411765					
20								
21	Uncertainties	dB						
22	Instrument NF=	0.15			Uncert NF12=	0.300198		
23	Instrument Gain=	0.17			Uncert NF2=	0.5669		
24	Noise Source ENR=	0.2	(Amplifiers Only)		Uncert G1=	0.94335		
25	Noise Source ENR=	0	(Receivers Only)		Uncert ENR=	0.2		
26								
27					Noise Figure Uncertainty =	0.357835 dB		
28					Frequency measurement Range = 20 to 26.5 GHz			
29	* This term can be entered in dB (Sxx), VSWR or as a reflection coefficient.					D.Boyd 1999		
30	e.g. -15dB = 1.43 VSWR = 0.178 reflection coefficient							
31								

N8975A with 346C / N8975A with N4002A / E4448A with

Measurement Uncertainty Case Studies

Noise Figure Uncertainty

The uncertainty of the overall noise system is related to the noise source (match and ENR uncertainty), device under test (noise figure, gain , i/p and o/p match) and instrument parameters (noise figure uncertainty, gain uncertainty, level of noise figure and match).

See http://www.agilent.com/find/nfu
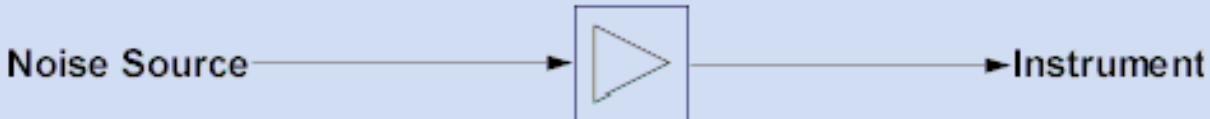
Example 1. @ 1GHz DUT Noise Figure = 1dB   DUT Gain = 20dB
**   DUT i/p match = 1.5   DUT o/p match = 1.5**
PSA = 0.167 dB   8970B = 0.19 dB;   N8973A = 0.167 dB
12% less RSS noise figure uncertainty with NFA or PSA

Example 2. @ 6GHz DUT Noise Figure = 6dB   DUT Gain = 15dB
**   DUT i/p match = 1.5   DUT o/p match = 1.5**
PSA = 0.186 dB   8970B = 0.327 dB   N8973A = 0.186 dB
43% less RSS noise figure uncertainty with NFA or PSA

Example 3. @ 12GHz DUT Noise Figure = 4dB   DUT Gain = 20dB
**   DUT i/p match = 1.8   DUT o/p match = 1.8**
                    8970B/8971C = 0.423 dB   N8975A = 0.353 dB
16% less RSS noise figure uncertainty with NFA

Example 4. @ 20GHz DUT Noise Figure = 4dB   DUT Gain = 20dB
**   DUT i/p match = 1.8   DUT o/p match = 1.8**
                    8970B/8971C = 0.945 dB   N8975A = 0.409 dB
57% less RSS noise figure uncertainty with NFA
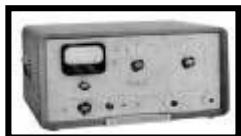
Calculator	Tabular Results	Graphical Results

Press this [Button] to reset the form to default values

Device Under Test   ⊙ Amplifier ○ Frequency Convertor

Noise Source ──────────▷─────────►Instrument

Noise Source Defaults

346B ▾

ENR Uncertainty (+/-dB)

0.2

NS Match *

1.15

DUT Noise Figure, NF1 (dB)

3

DUT Gain, G1 (dB)

20

DUT Input Match *

1.5

DUT Output Match *

1.5

Instrument Defaults

N8973A ▾

Instr. Noise Fig. Uncert.(+/-dB)

0.05

Gain Uncertainty (+/-dB)

0.2

Instrument Noise Fig, NF2 (dB)

6

Instrument Match *

1.6

	Parameter	Lower Value	Upper Value	Number of Points
Sweep	NONE ▾			

* This term can be entered in dB(Sxx), VSWR or as a reflection coefficient.

e.g. -15 (dB) = 1.43 (VSWR) = 0.178 (Refl. Coef.)

	Calculator	Tabular Results	Graphical Results

Contributors | Contribution (dB)

Coefficient	Factors	
(F12/F1)	- Mismatch between the noise source and the DUT - Instrument noise figure measurement uncertainty	0.134
(F2/F1G1)	- Mismatch between the noise source and the instrument - Instrument noise figure measurement uncertainty	0.003
((F2 - 1)/(F1G1))	- Mismatch between the noise source and the DUT - Mismatch between the noise source and the Instrument - Mismatch between the DUT and the instrument - Instrument gain measurement uncertainty	0.007
(F12/F1)–(F2/F1G1)	- Noise source ENR uncertainty	0.199

RSS Noise Figure Measurement Uncertainty (+/-dB)   0.238

Agilent's Noise Figure Legacy

340A
1958

8970
1980

8560/90 with NF
1995

85120
1999

NFA
2000
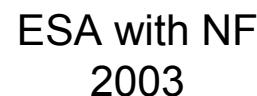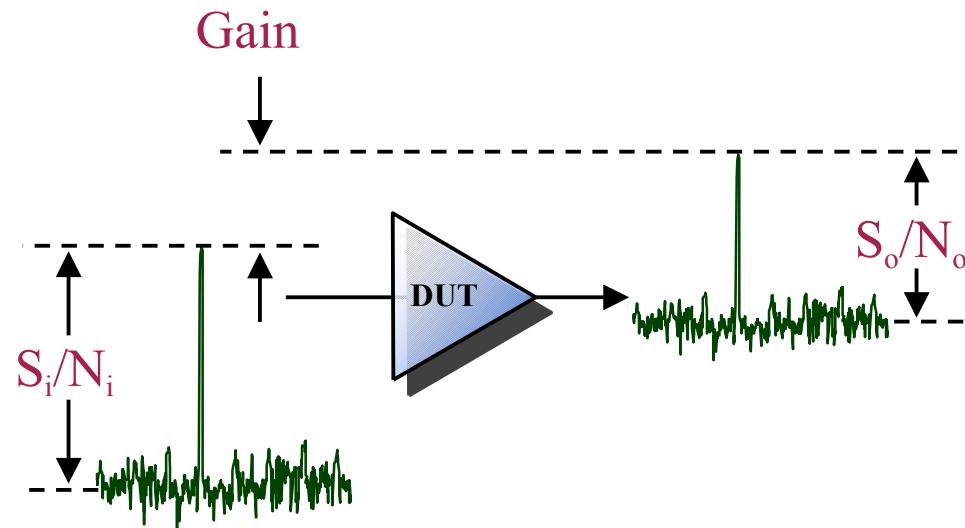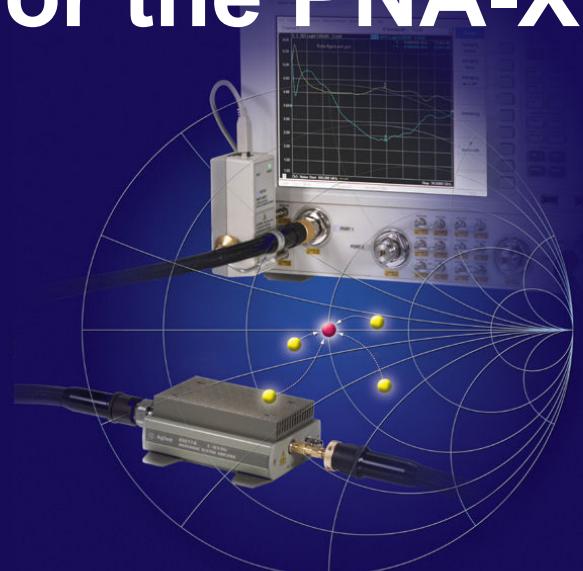
Nearly 50 years of Leadership

NEW!

PNA-X with
NF
2007

NEW!

MXA, EXA with
NF
2007

ESA with NF
2003

PSA with NF
2002

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Agenda

- **Overview of Noise Figure**
- **Noise Figure Measurement Techniques**
- **Accuracy Limitations**
➡ - **PNA-X's Unique Approach**

Gain

DUT

S_o/N_o

S_i/N_i

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Source-corrected Noise Figure Measurements for the PNA-X

PNA Series

325 GHz
110 GHz
67 GHz
50 GHz
40 GHz
20 GHz
13.5 GHz
6 GHz

PNA-X

10 MHz - 26.5 GHz

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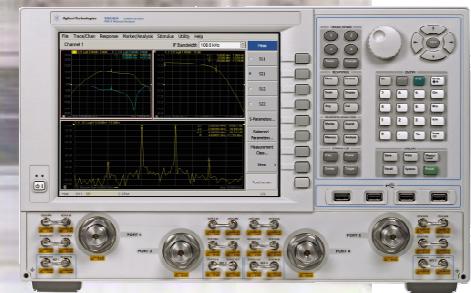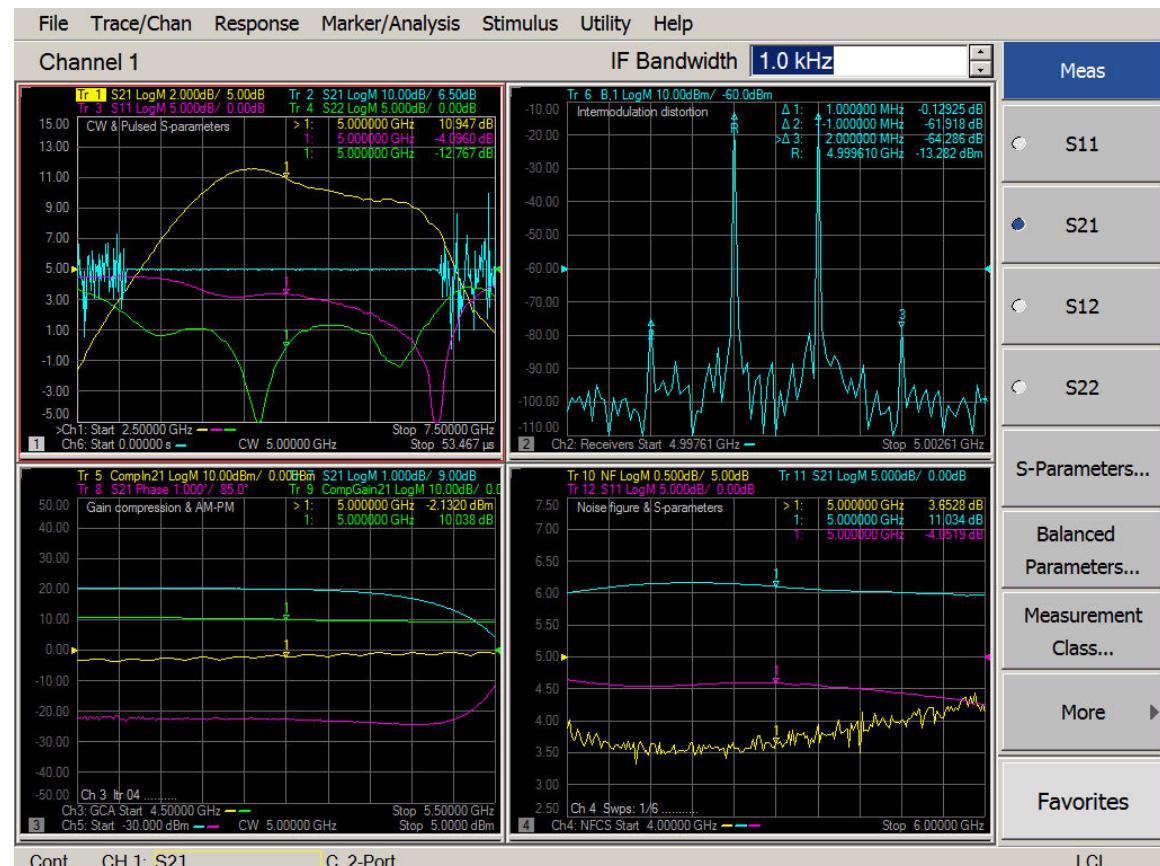
Single Connection, Multiple Measurements

- Easily switch between measurements:

- One signal source
  - **CW S-parameters**
  - **Pulsed S-parameters**
  - **Gain compression**
  - **AM-to-PM conversion**
  - **Harmonics**
- Two signal sources
  - **Intermodulation distortion**
  - **Hot-S_{22}**
  - **Phase versus drive**
  - **True-mode stimulus**
  - **Conversion loss/gain**
- Noise figure

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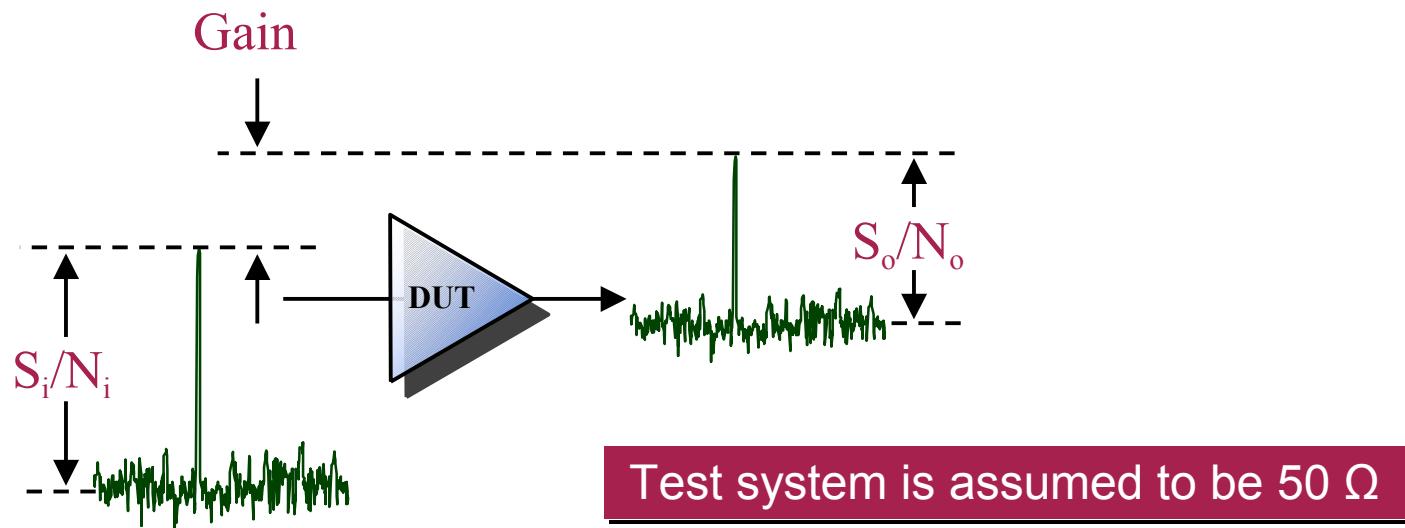
Noise Figure Definition

Noise figure is defined in terms of SNR degradation:
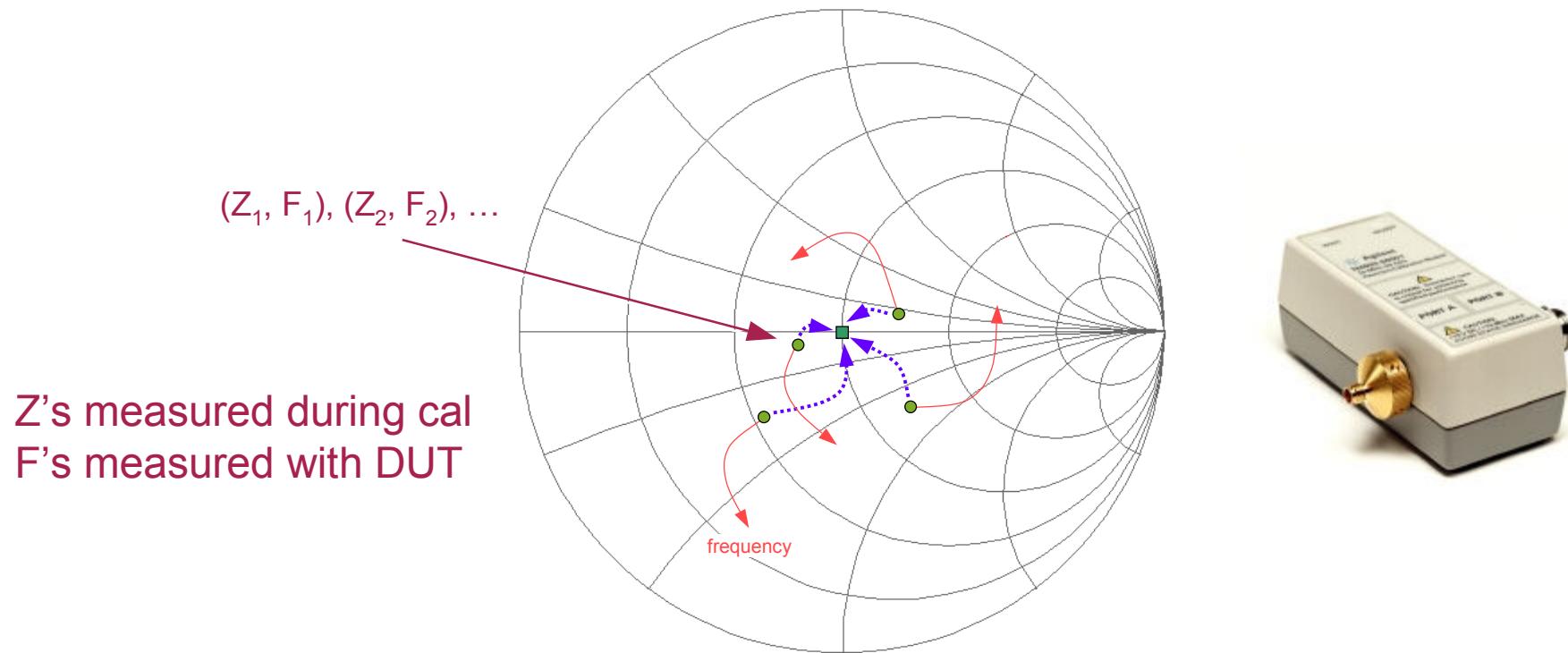
$$F = \frac{(S_i/N_i)}{(S_o/N_o)} = \frac{(N_o)}{(G \times N_i)} \quad \text{(noise factor)}$$

$$NF = 10 \times \log(F) \quad \text{(noise figure)}$$

Gain

S_o/N_o

DUT

S_i/N_i

Test system is assumed to be 50 Ω

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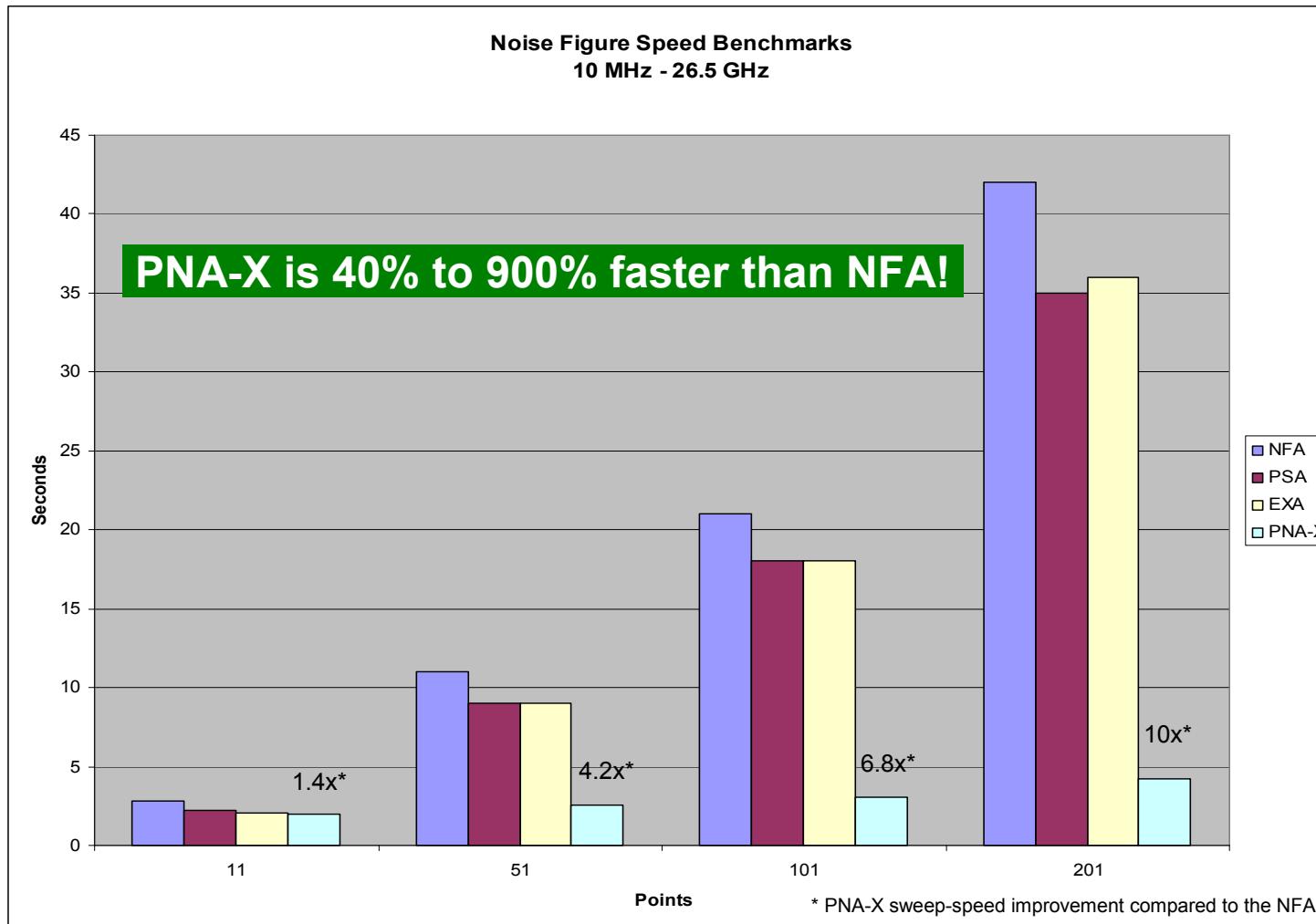
PNA-X's Unique Source-Corrected Technique
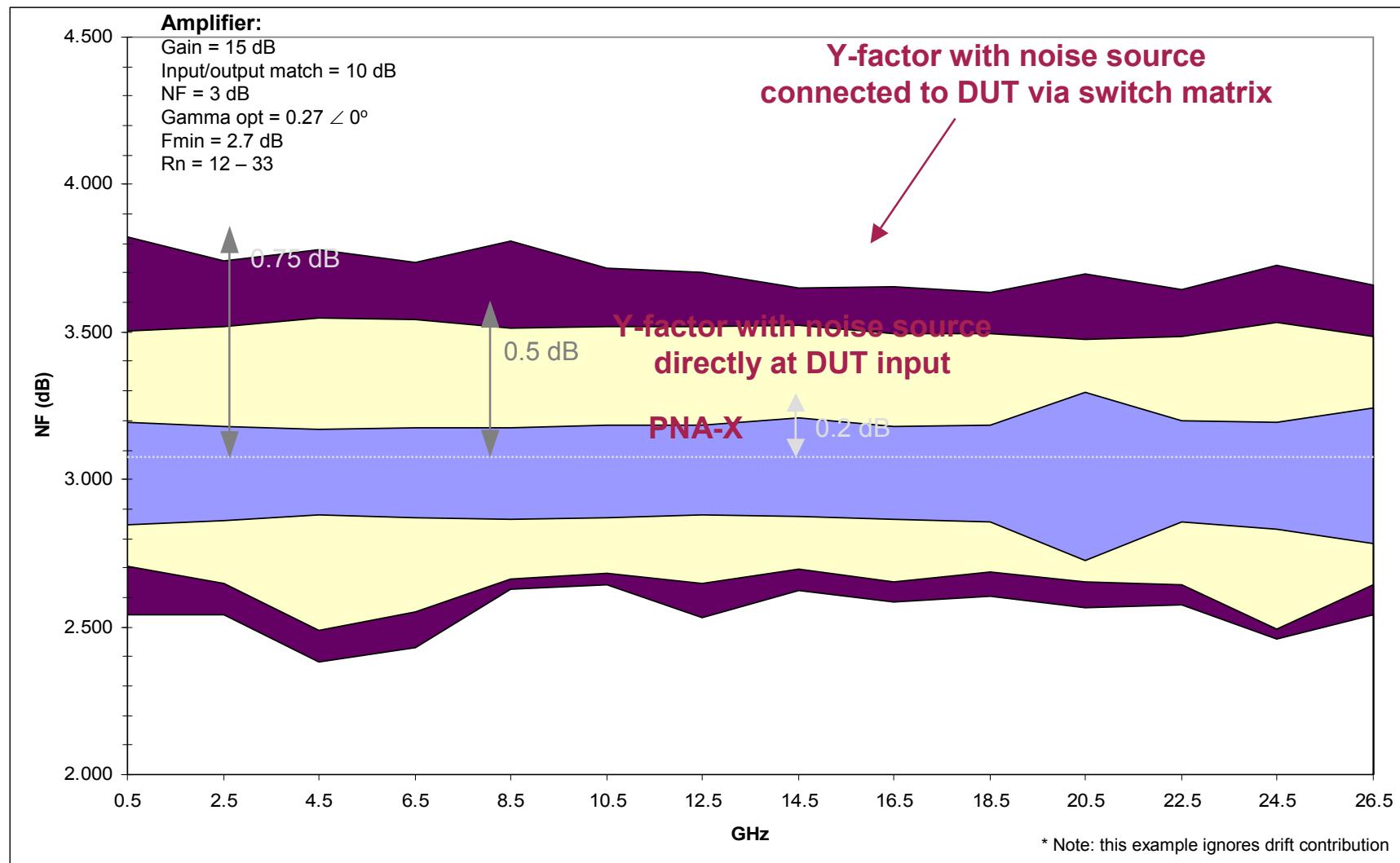
- **PNA-X varies source match around 50 ohms using an ECal module (source-pull technique)**

- **With resulting impedance/noise-figure pairs and vector error terms, very accurate 50-ohm noise figure (NF_{50}) can be calculated**

- **Each impedance state is measured versus frequency**

$(Z_1, F_1), (Z_2, F_2), \ldots$

Z's measured during cal
F's measured with DUT

frequency

Agilent Technologies
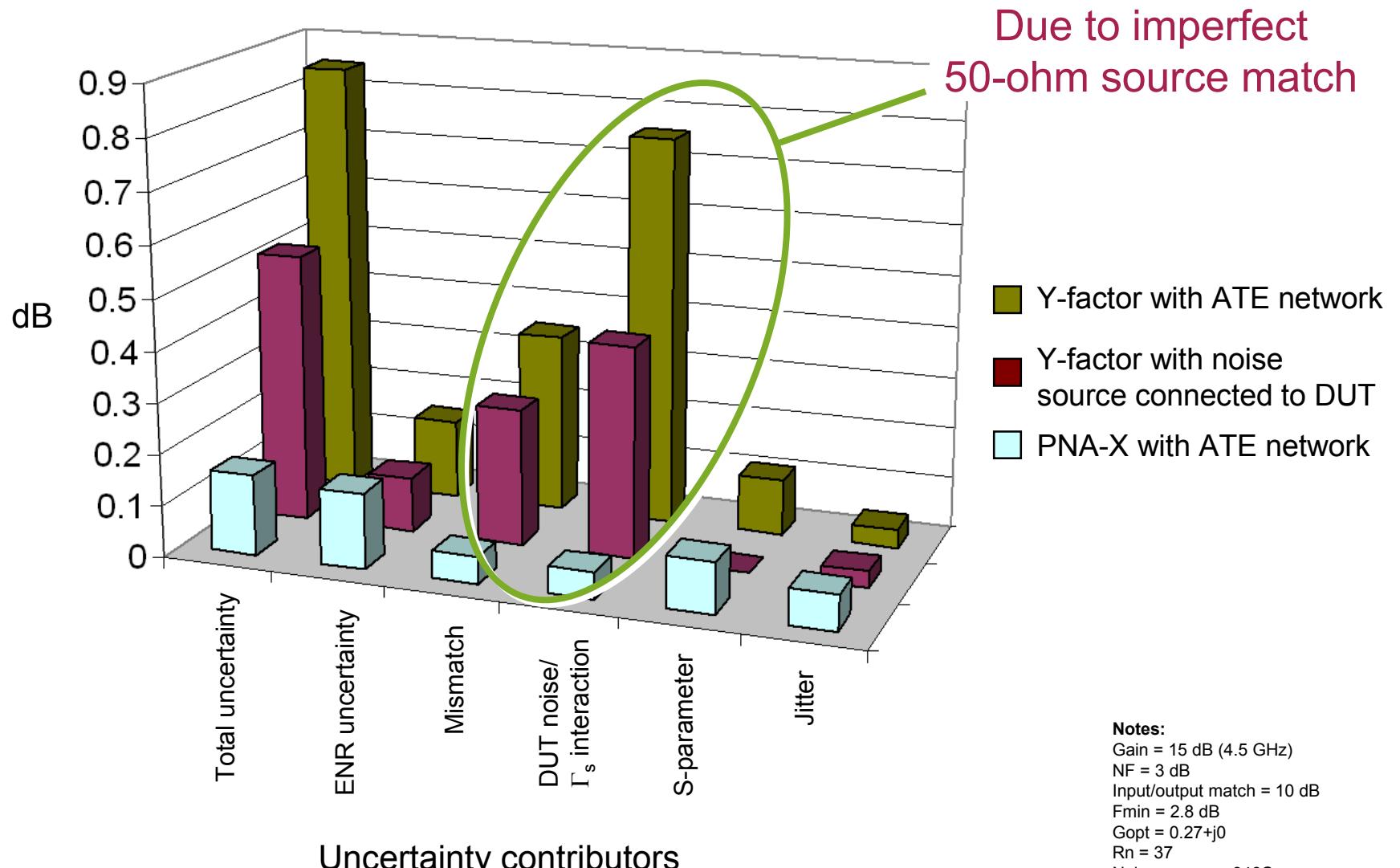
Speed Comparison: PNA-X Versus Y-Factor

Noise Figure Speed Benchmarks
10 MHz - 26.5 GHz

PNA-X is 40% to 900% faster than NFA!

Legend: NFA, PSA, EXA, PNA-X

1.4x* 4.2x* 6.8x* 10x*

Points

* PNA-X sweep-speed improvement compared to the NFA

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Noise Figure Uncertainty Example (ATE Setup)

Amplifier:
Gain = 15 dB
Input/output match = 10 dB
NF = 3 dB
Gamma opt = 0.27 ∠ 0°
Fmin = 2.7 dB
Rn = 12 – 33

Y-factor with noise source connected to DUT via switch matrix

Y-factor with noise source directly at DUT input

PNA-X

0.75 dB

0.5 dB

0.2 dB

* Note: this example ignores drift contribution

NF (dB)

GHz

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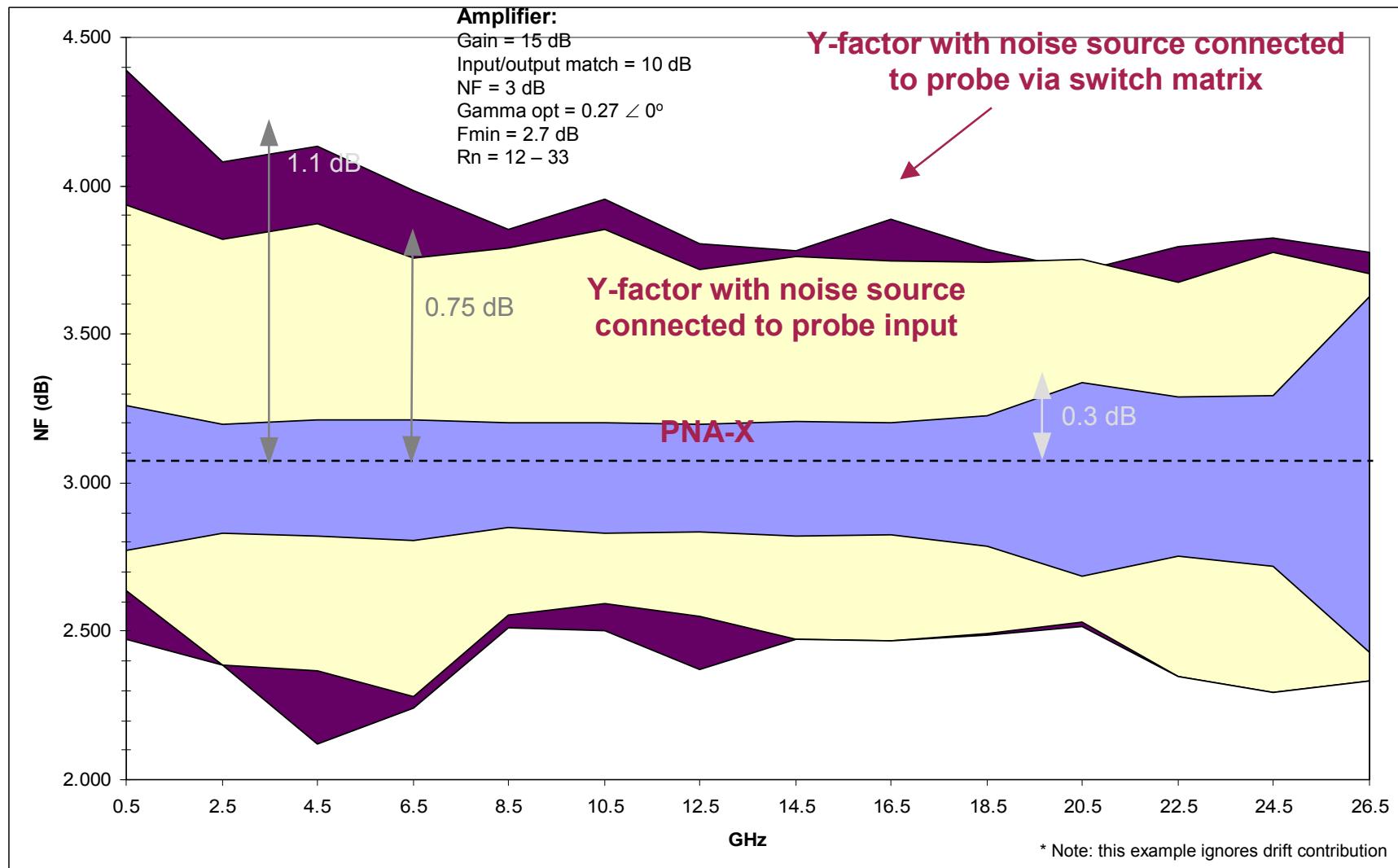
Uncertainty Breakdown (ATE Setup)

Due to imperfect
50-ohm source match

Legend:
- Y-factor with ATE network
- Y-factor with noise source connected to DUT
- PNA-X with ATE network

Y-axis: dB (0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9)

X-axis categories: Total uncertainty, ENR uncertainty, Mismatch, DUT noise/Γ_s interaction, S-parameter, Jitter

Uncertainty contributors

Notes:
Gain = 15 dB (4.5 GHz)
NF = 3 dB
Input/output match = 10 dB
Fmin = 2.8 dB
Gopt = 0.27+j0
Rn = 37
Noise source = 346C
97% confidence
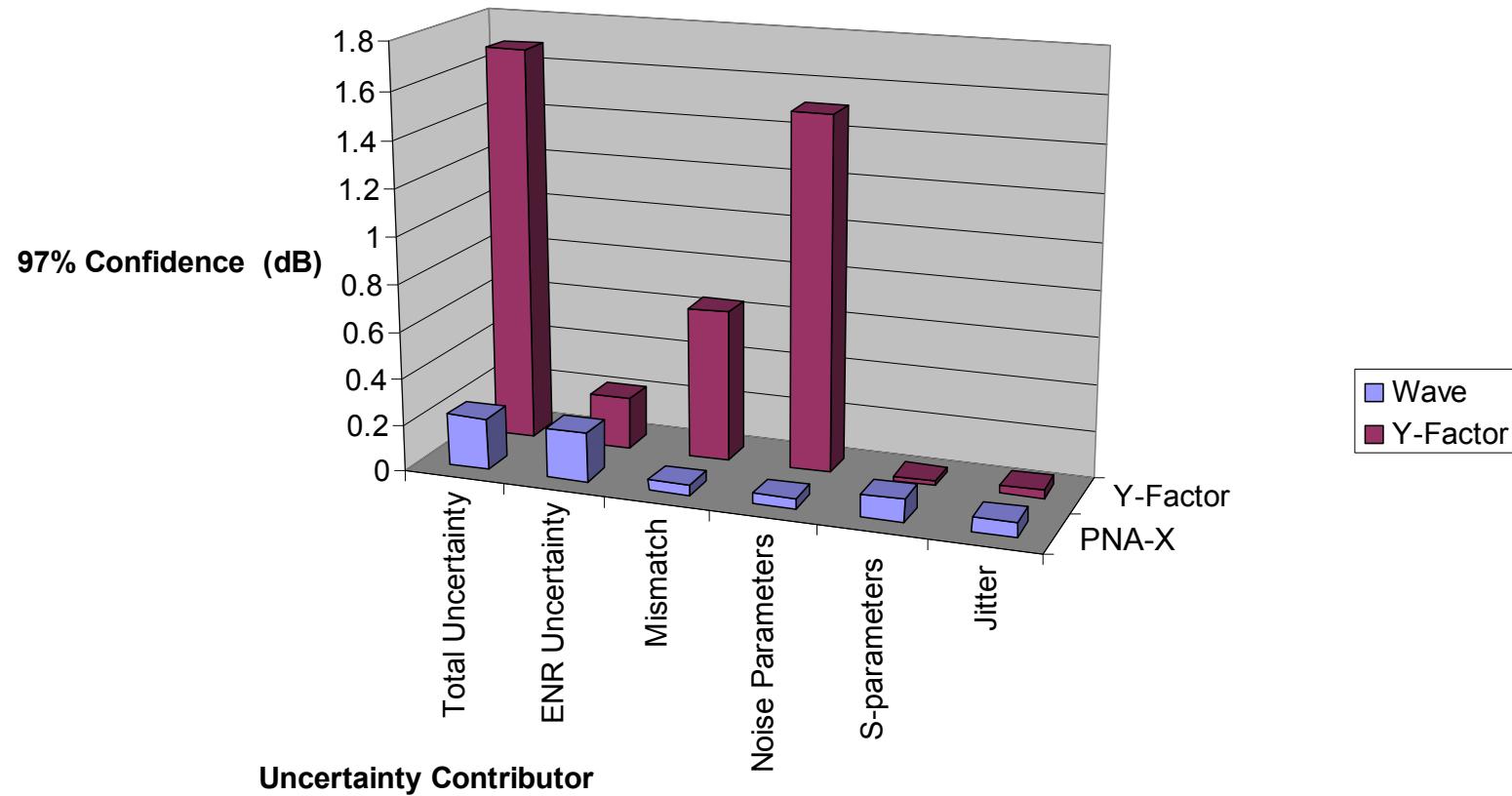
Noise Figure Uncertainty Example (Wafer Setup)

Amplifier:
Gain = 15 dB
Input/output match = 10 dB
NF = 3 dB
Gamma opt = 0.27 $\angle$ 0º
Fmin = 2.7 dB
Rn = 12 – 33

Y-factor with noise source connected to probe via switch matrix

1.1 dB

0.75 dB

Y-factor with noise source connected to probe input

PNA-X

0.3 dB

NF (dB)

GHz

* Note: this example ignores drift contribution
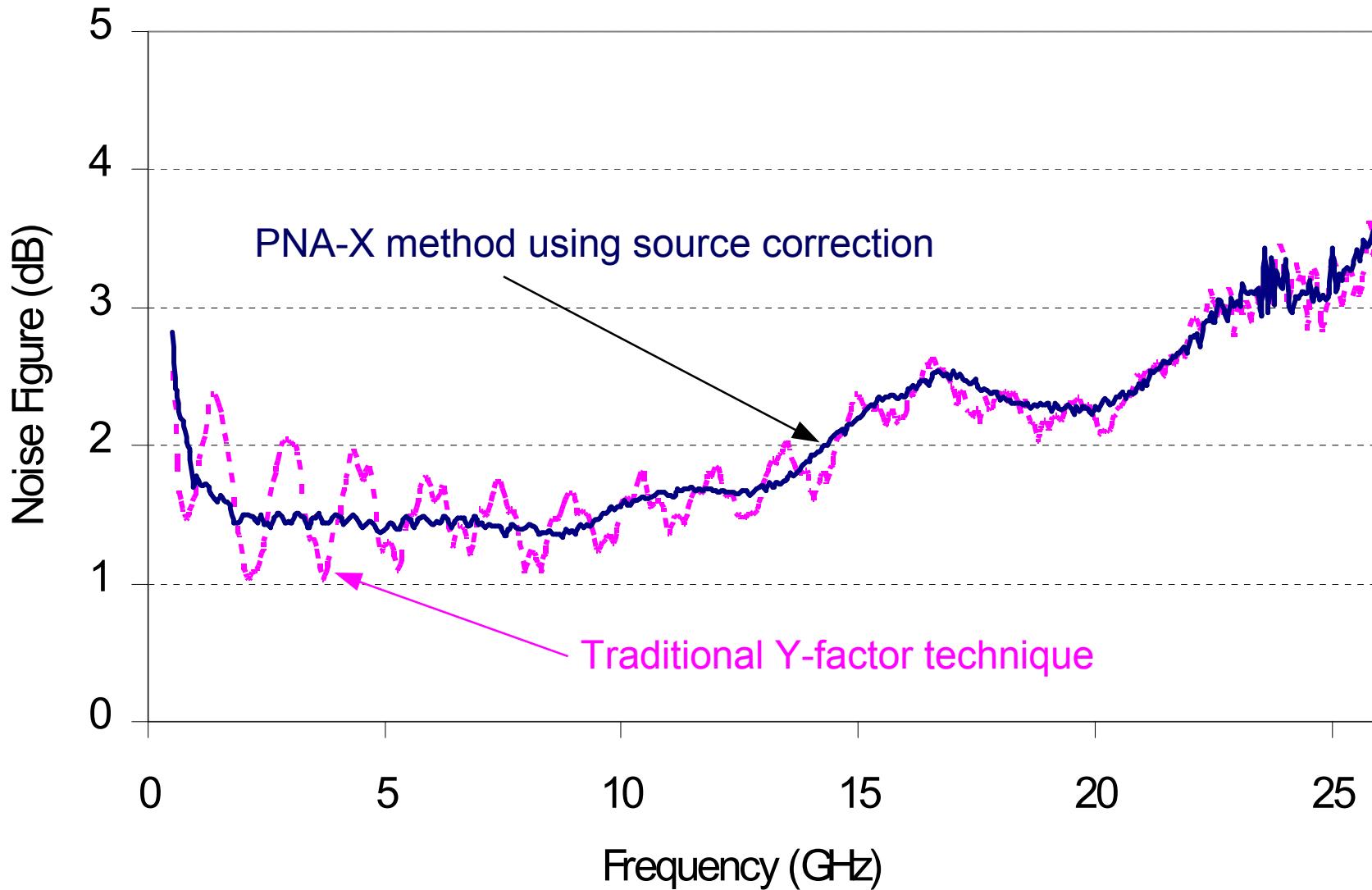
Uncertainty Breakdown (Wafer Setup)
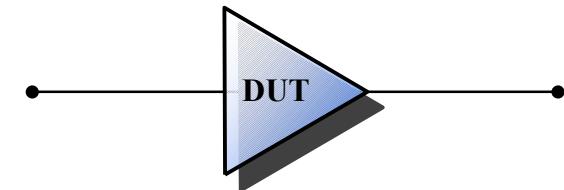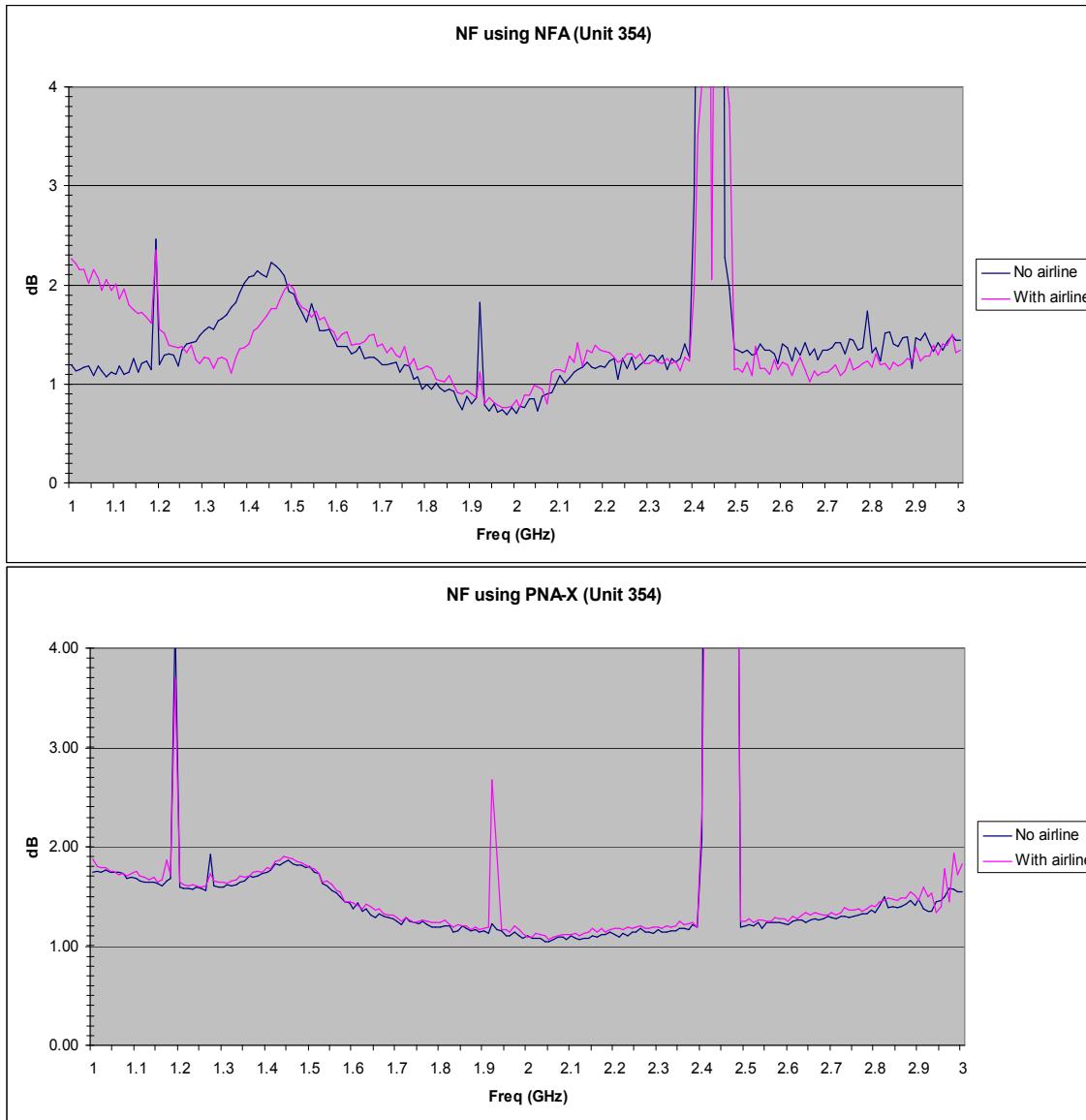
On Wafer 15 dB amp with 3 dB Noise figure at 4.5 GHz
(Fmin = 2.8 dB, Gopt = 0.27 +j0, Rn = 37.4)
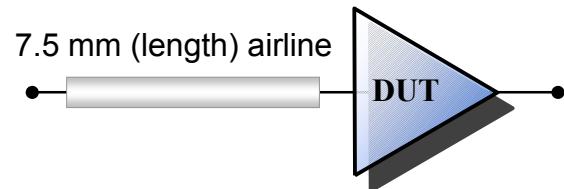
Example NF Measurements

PNA-X method using source correction

Noise Figure (dB)

Traditional Y-factor technique

Frequency (GHz)

Airline Demonstration

NF using NFA (Unit 354)

Legend: No airline / With airline

NF using PNA-X (Unit 354)

Legend: No airline / With airline
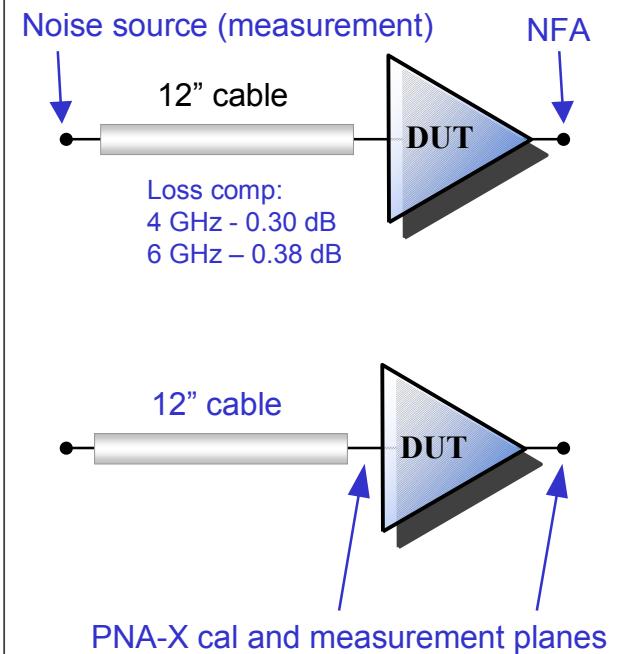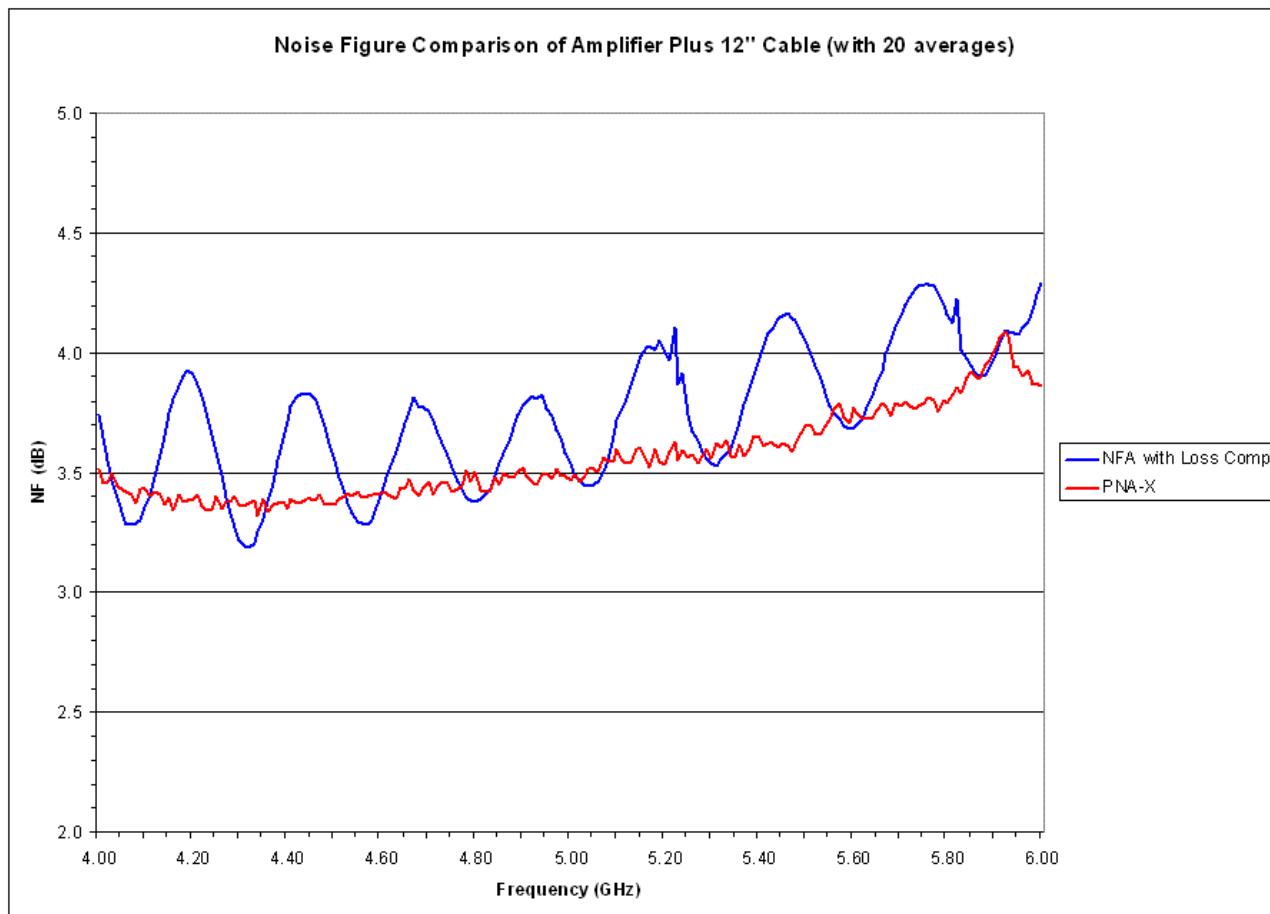
Measurement 1:
DUT alone

7.5 mm (length) airline
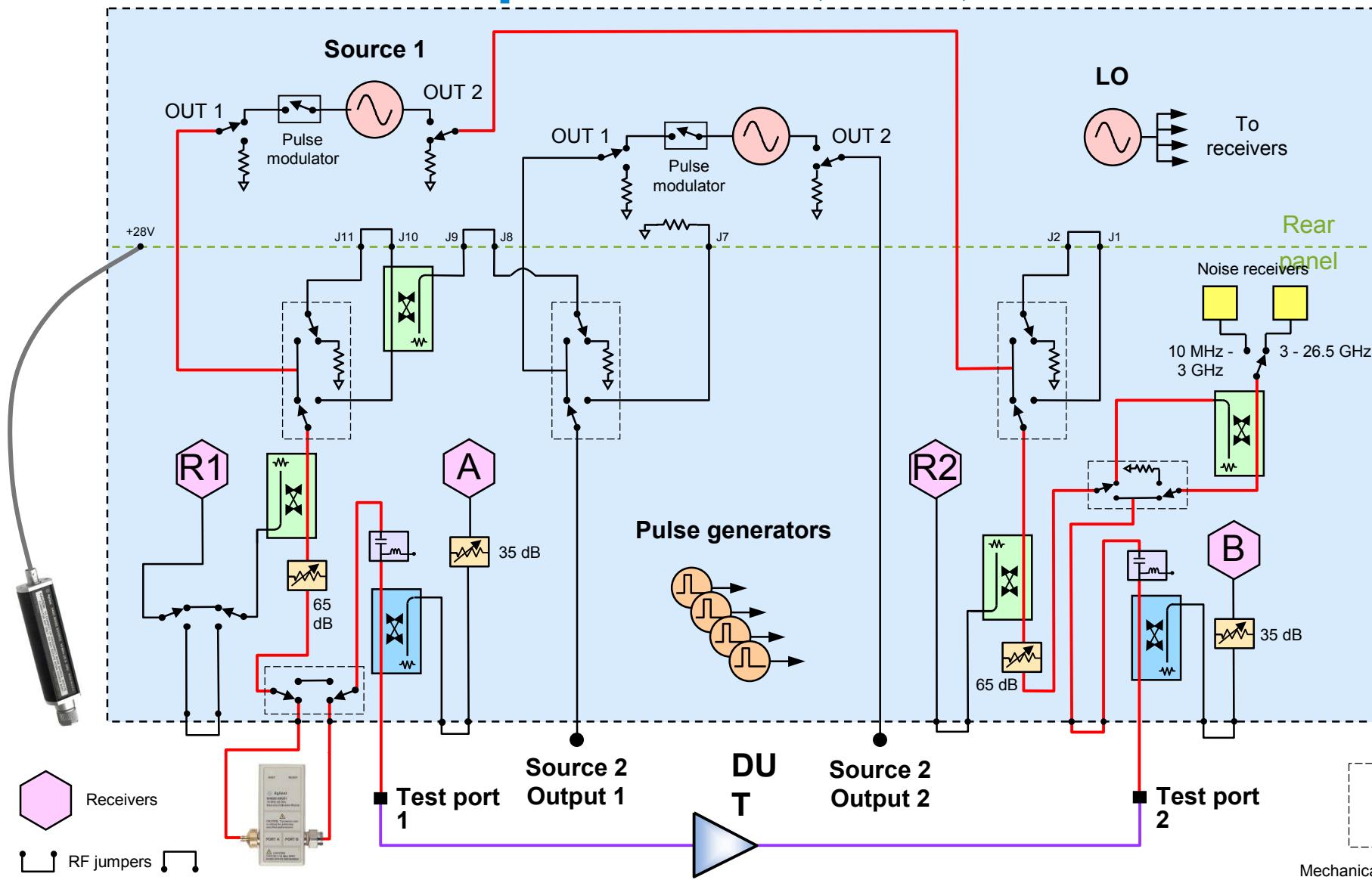
Measurement 2:
DUT with airline

Agilent Technologies
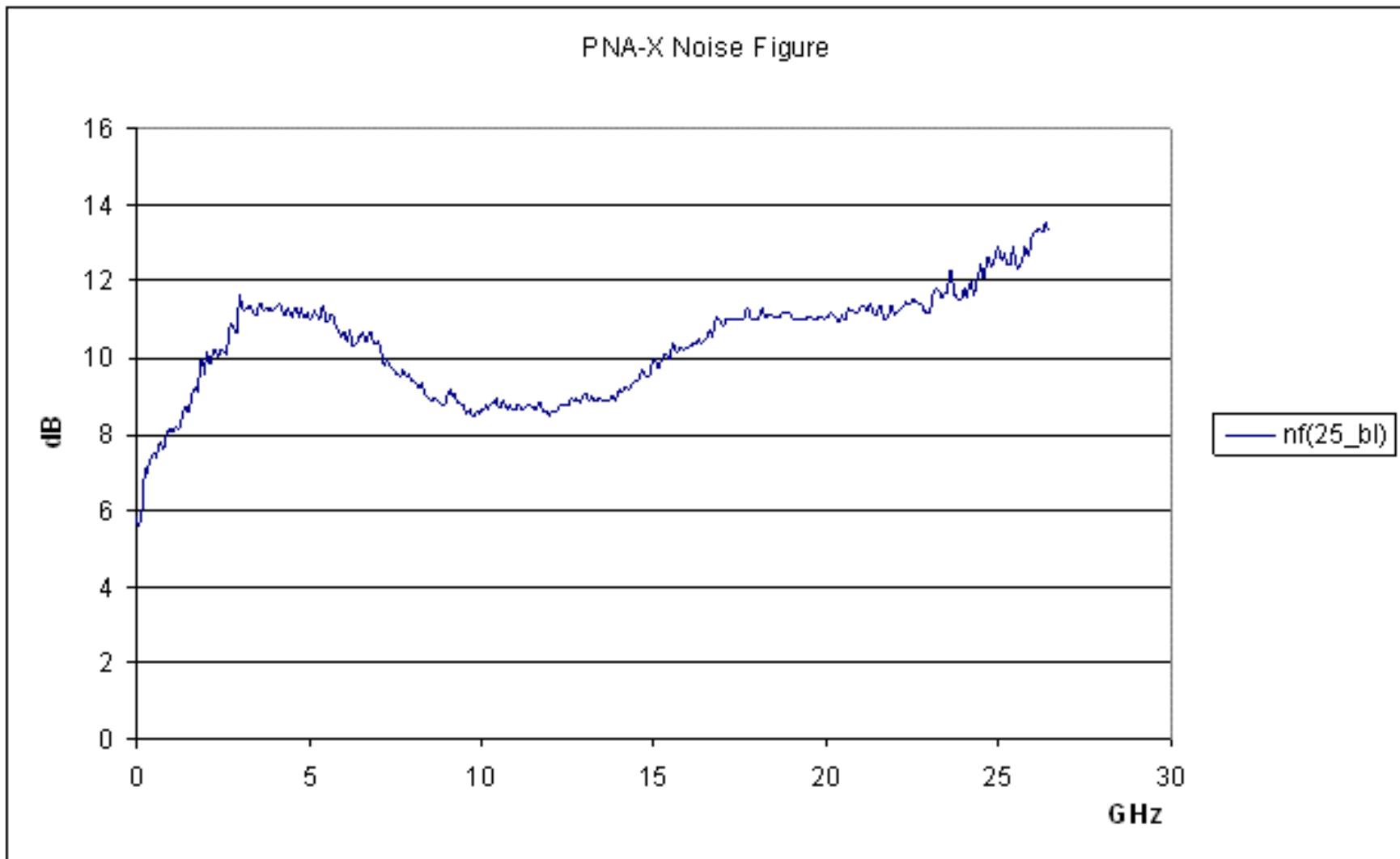
NF Comparison in Pseudo ATE environment

Noise Figure Comparison of Amplifier Plus 12" Cable (with 20 averages)

NFA with Loss Comp
PNA-X

Noise source (measurement)   NFA

12" cable   DUT

Loss comp:
4 GHz - 0.30 dB
6 GHz – 0.38 dB

12" cable   DUT

PNA-X cal and measurement planes

Agilent Technologies
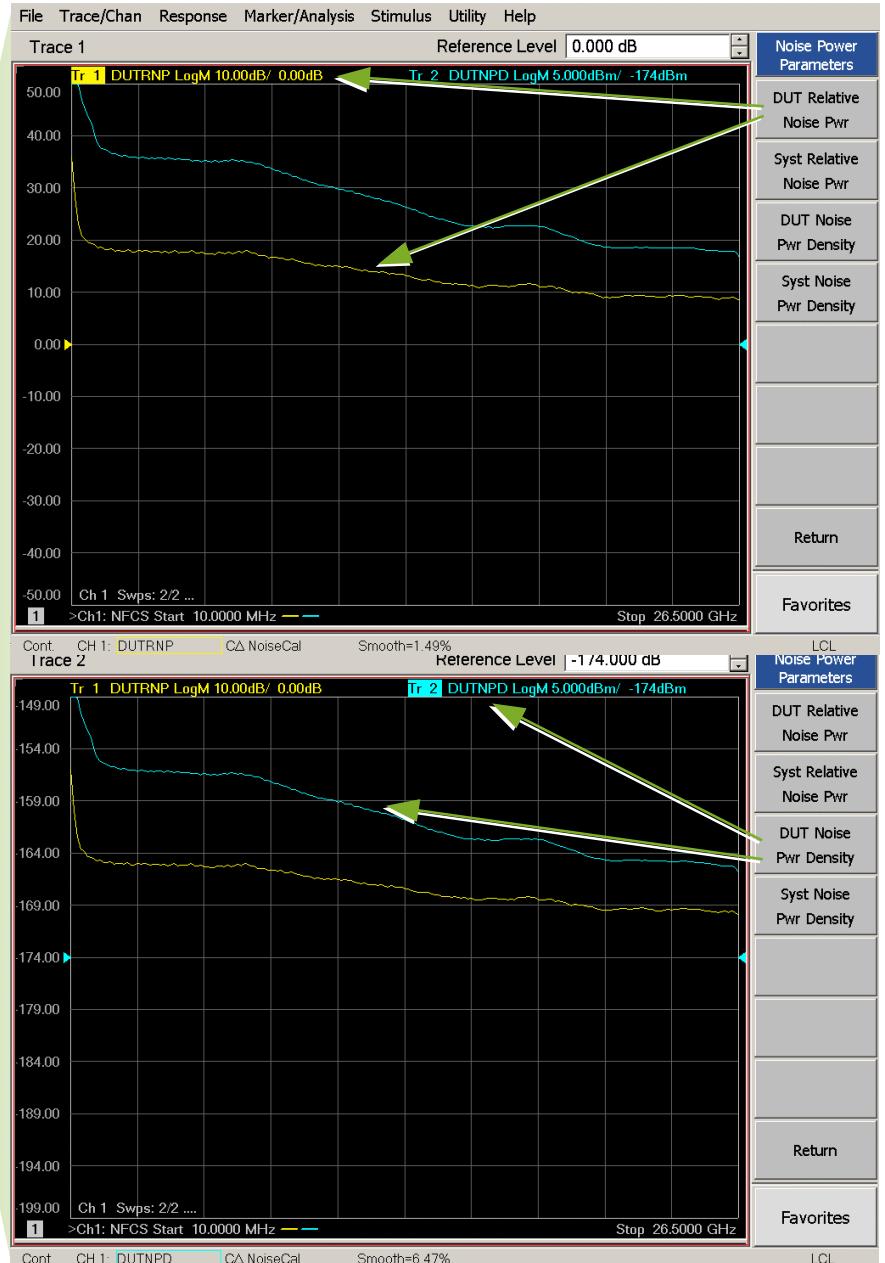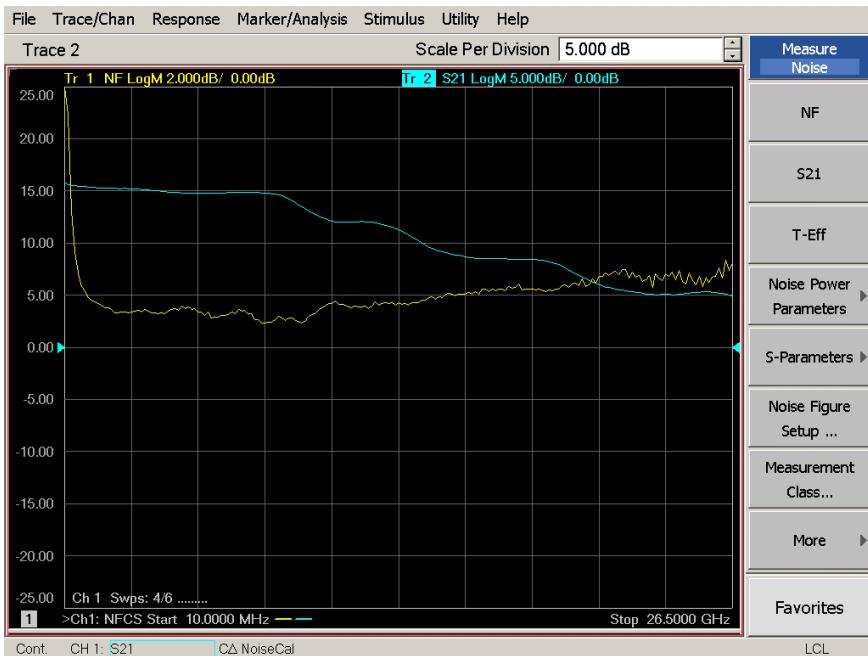
2-Port PNA-X Options 219, 224, 029

Source 1

LO

OUT 1

OUT 2

Pulse modulator

OUT 1

OUT 2

Pulse modulator

To receivers

+28V

J11 J10 J9 J8

J7

J2 J1

Rear panel

Noise receivers

10 MHz - 3 GHz

3 - 26.5 GHz

R1

A

35 dB

65 dB

R2

B

35 dB

65 dB

Pulse generators

Source 2 Output 1

DUT

Source 2 Output 2

Test port 1

Test port 2

Receivers

RF jumpers

Mechanical switch

Agilent Technologies
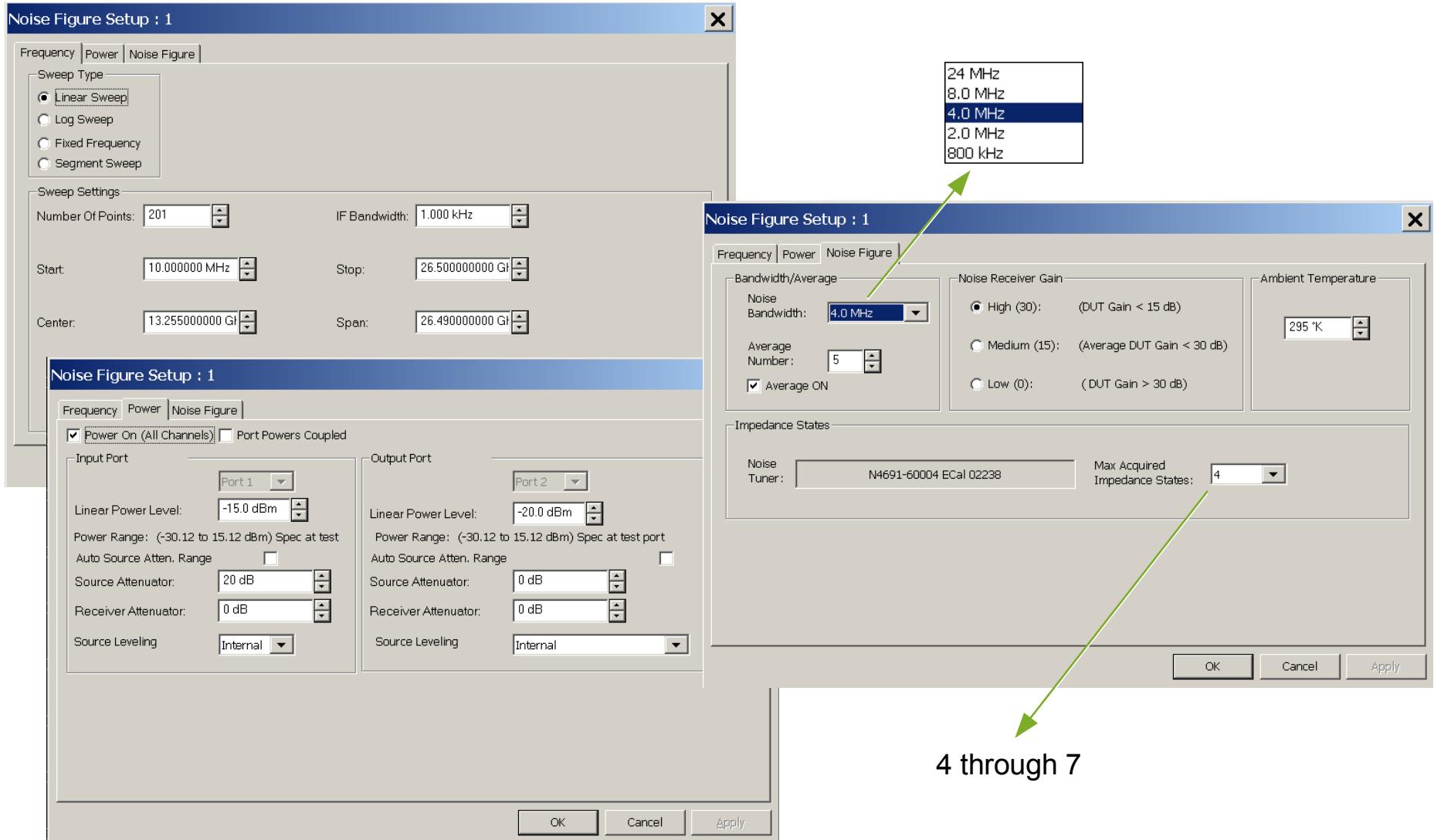
Typical Noise Figure of Port Two

PNA-X Noise Figure

nf(25_bl)

Noise Channel Parameters

Noise Figure Setup

4 through 7

Calibration Procedure

- **Calibration uses sinusoidal and noise sources, plus cold terminations**
- **Some differences between high and low band calibrations**
- **Calibration sequence for simplest case (insertable)**

  1. Connect noise source to port 2
     - **Measure hot and cold noise power**
     - **Measure hot and cold match of noise source**

  2. Connect through (ports 1 and 2)
     - **Measure gain differences between 0, 15, 30 dB stages**
     - **Measure load match of noise receivers**
     - **Measure Γ_s values of ECal used as impedance tuner**
     - **Measure receiver noise power with different tuner Γ_s values (mechanical cal only)**

 3. Connect calibration standards (ports 1 and 2)
     - **Measure normal S-parameter terms**
     - **Measure receiver noise power with different Γ_s values (use ECal or mechanical standards)**
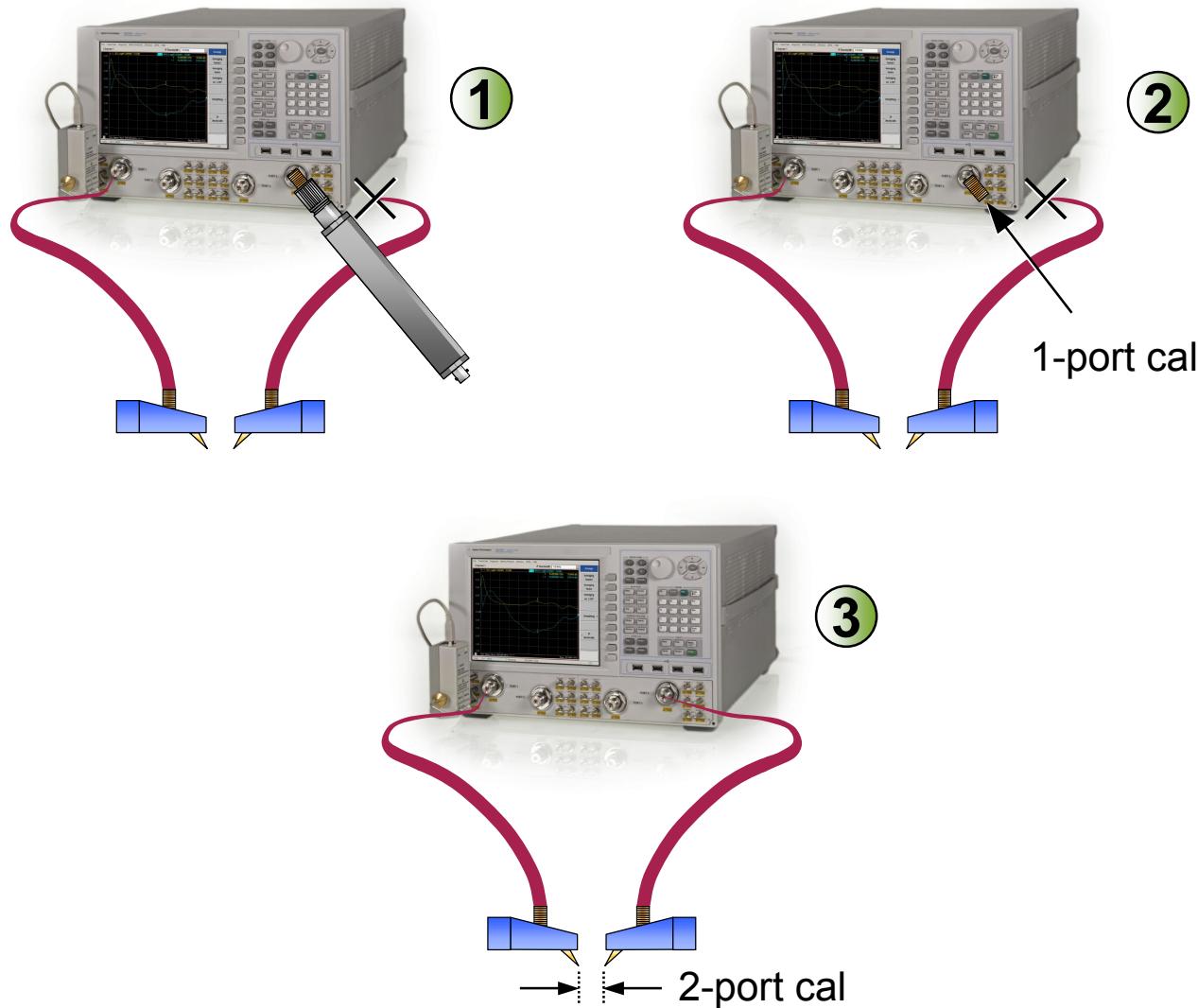
- **Non-insertable cases require extra steps**
  - **additional 1-port calibration to account for adapter if noise source is non-insertable**
 - **additional S-parameter cal steps for non-insertable DUTs**

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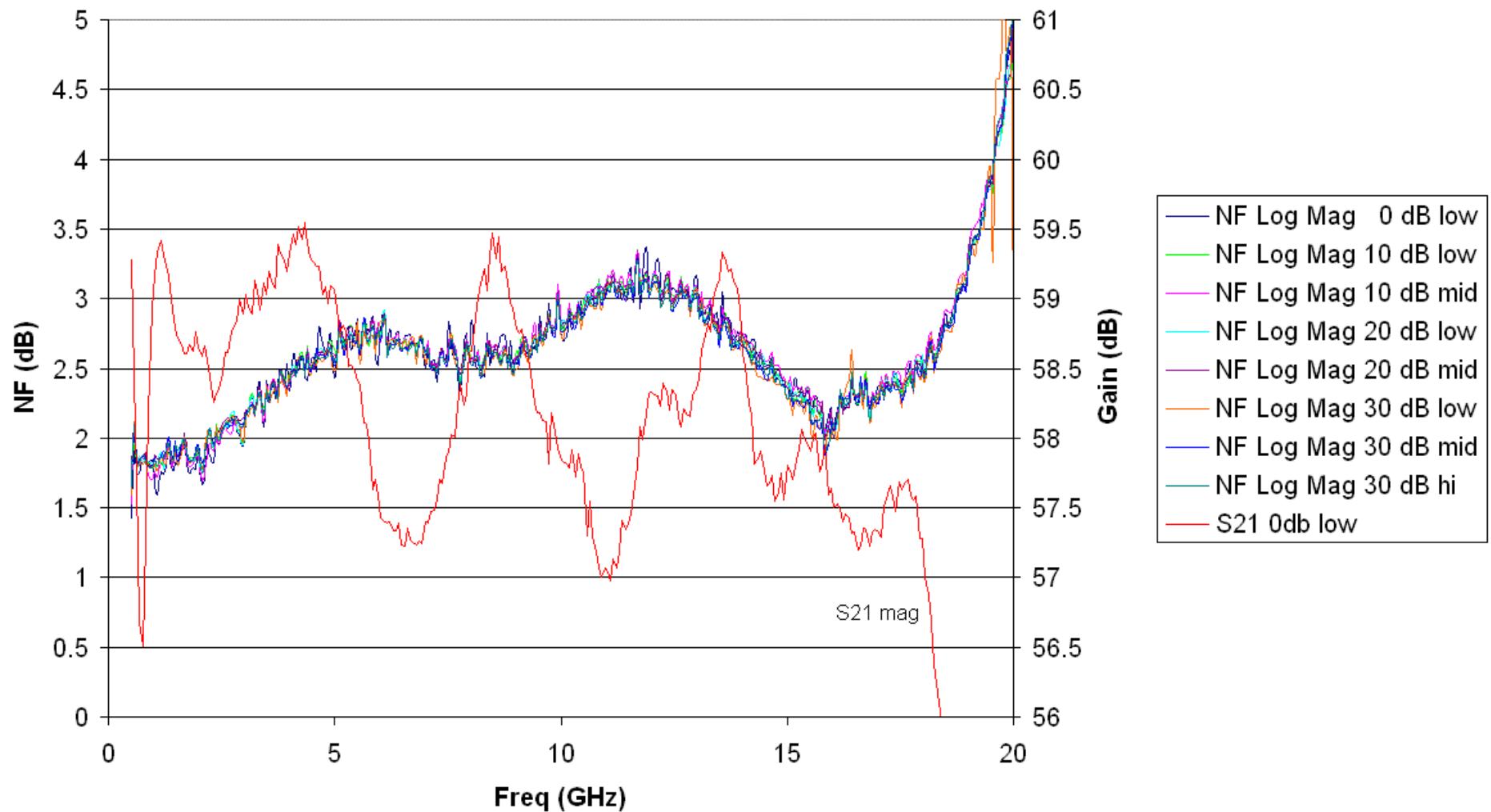
Calibrating On Wafer


① ② ③

1-port cal

2-port cal
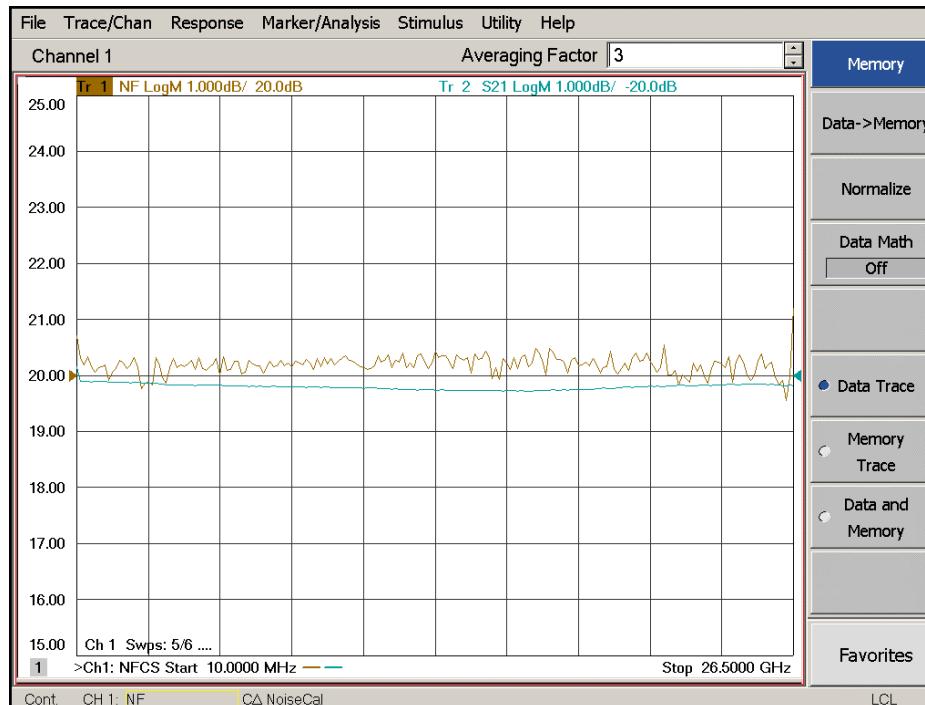
Comparison Between Gain Settings
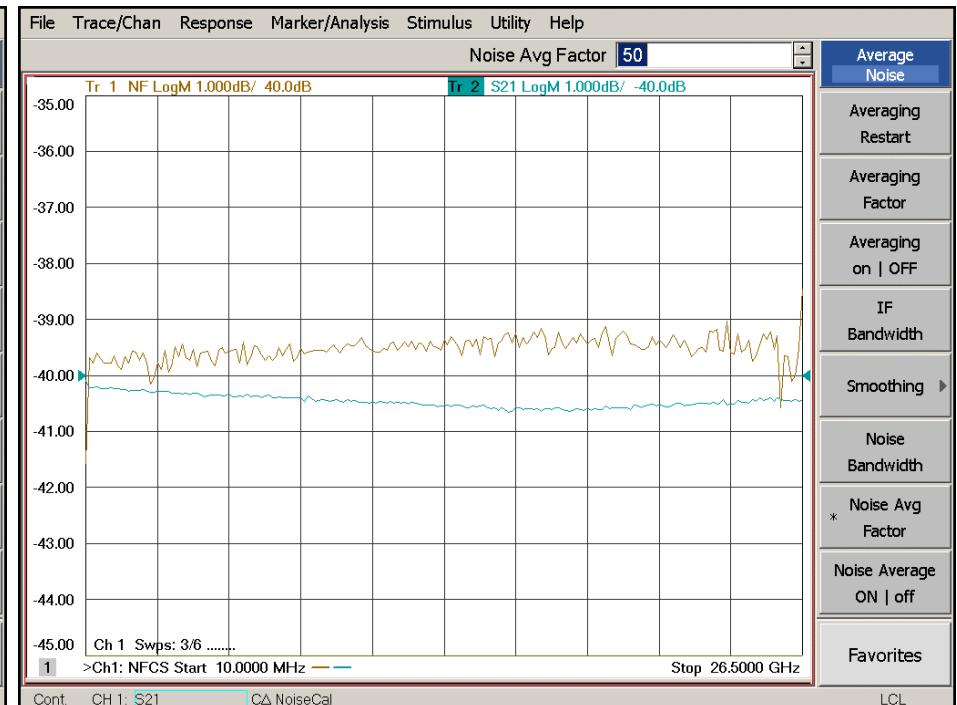
NF AMF7D Miteq w/various pads

Measuring Attenuators

20 dB attenuator

40 dB attenuator

Agilent Technologies
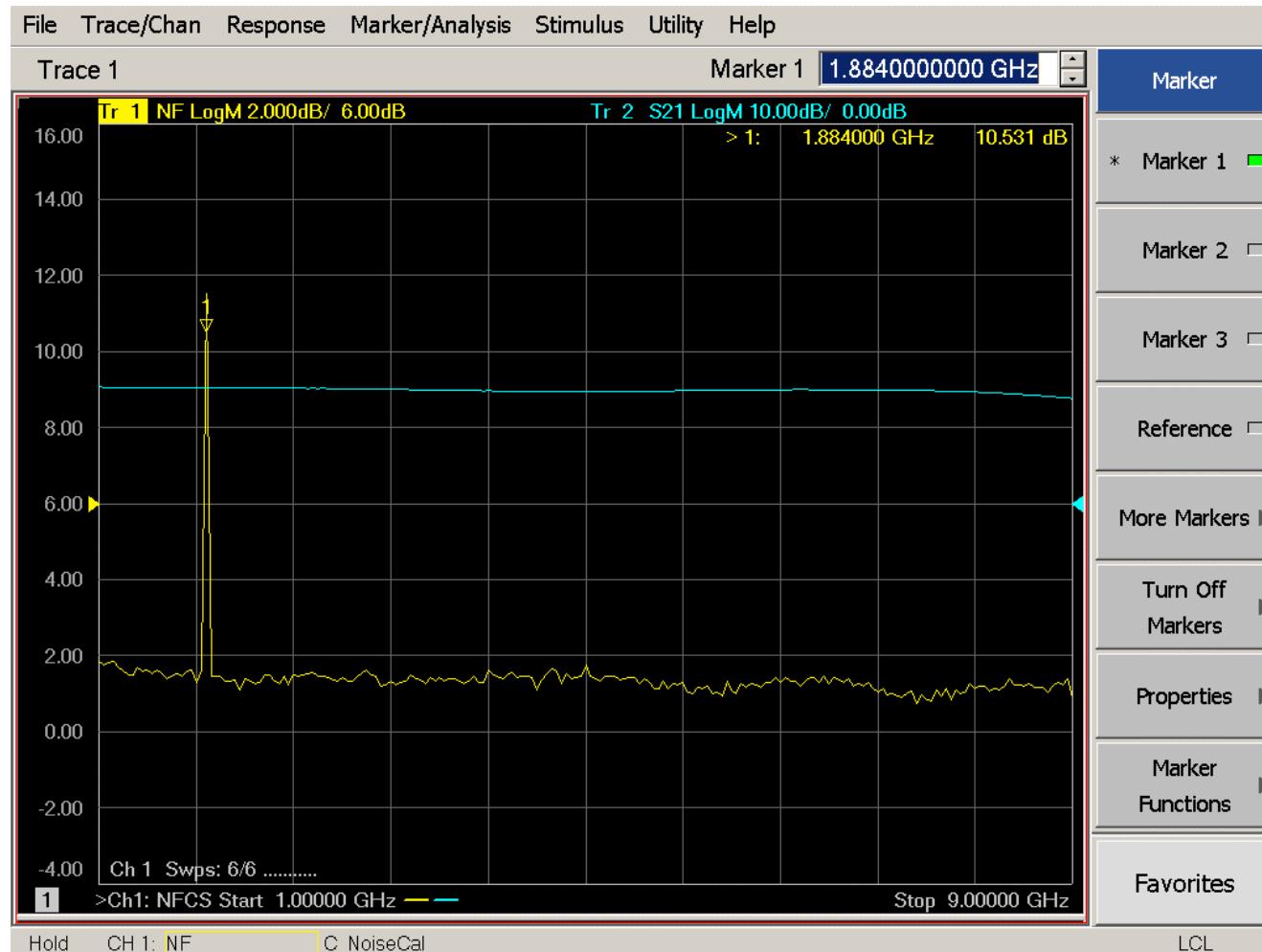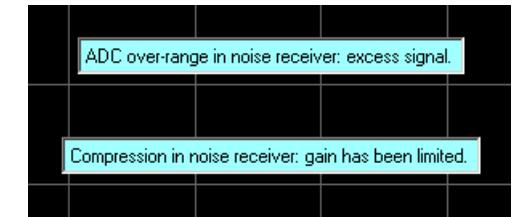
Interference
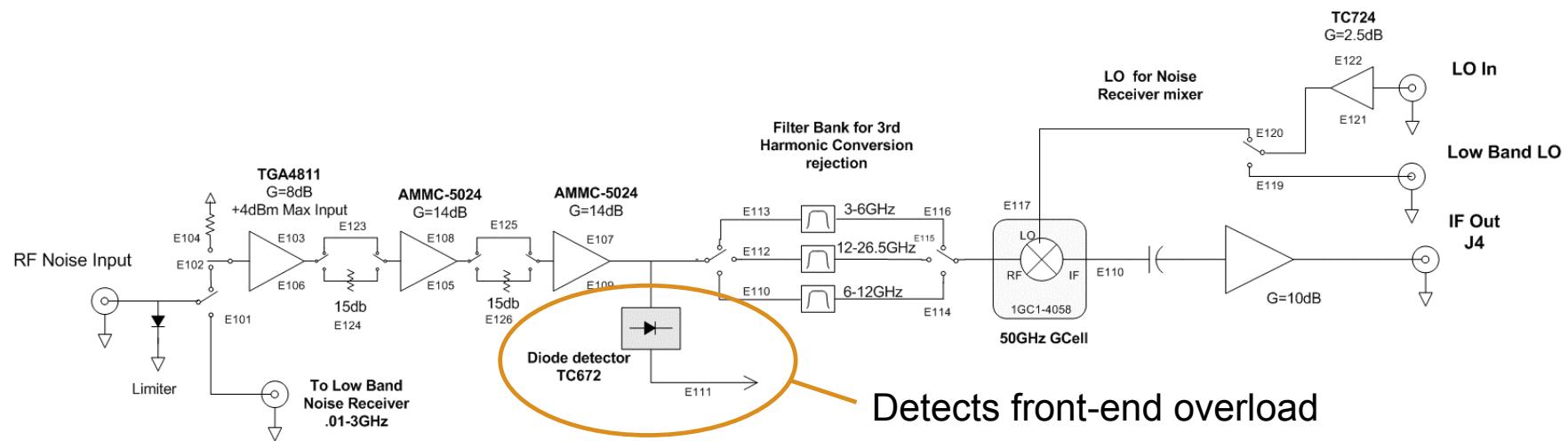
Beware of unshielded devices, especially near 0.9, 1.8, 2.4, 5.5 GHz!

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Compression and Damage

ADC over-range in noise receiver: excess signal.

Compression in noise receiver: gain has been limited.
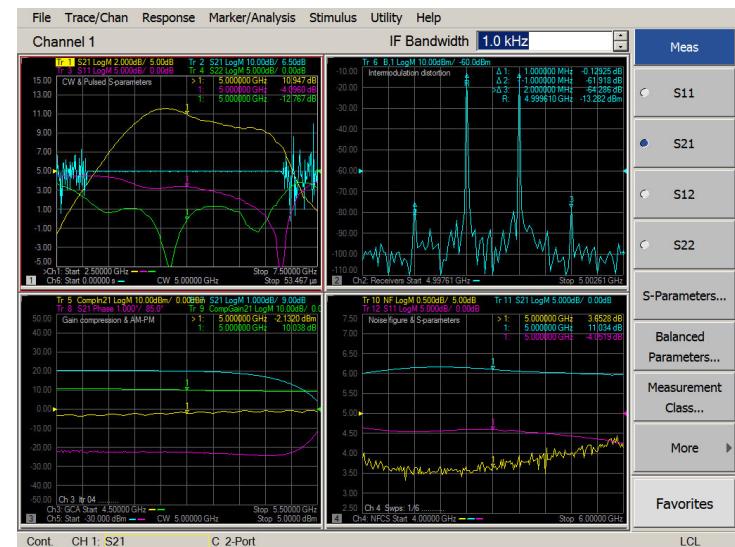
- **Compression in noise receivers:**
  - **Wideband noise compresses front-end amplifiers first**
  - **Narrowband noise likely to compress ADC before front-end amplifiers**
  - **PNA-X will report overload for both cases**
- **Damage level for noise receivers is lower than standard receivers**
  - **Front-panel specification is +25 dBm in noise mode**
  - **Firmware checks power before switching in 30 dB stage**

Detects front-end overload

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Summary

- **Y-factor method offers reasonable accuracy when noise source is connected directly to DUT**

- **Source-corrected cold-source technique:**

  - **Offers best accuracy in all cases**

  - **Works in fixtured, on-wafer, and ATE environments**

  - **Is 1.4 to 10 times faster than NFA**

- **PNA-X offers** highest accuracy **as well as** speed **and** convenience **of** single connection **to DUT for a variety of amplifier measurements**

References

- **Applications Notes**

  - **Fundamentals of RF and Microwave Noise Figure Measurements, AN 57-1, Publication Number 5952-8255E**

  - **Noise Figure Measurement Accuracy - The Y-Factor Method, AN 57-2, Publication Number**

  - **10 Hints for Making Successful Noise Figure Measurements, AN 57-3, Publication Number 5980-0288EN**

- **Web Links**
  http://www.agilent.com/find/nf

  NFA : http://www.agilent.com/find/nfa

  PSA : http://www.agilent.com/find/psa
  NF Uncertainty Calculators: http://www.agilent.com/find/nfu

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