Noise Figure Measurements

Feb 24, 2009

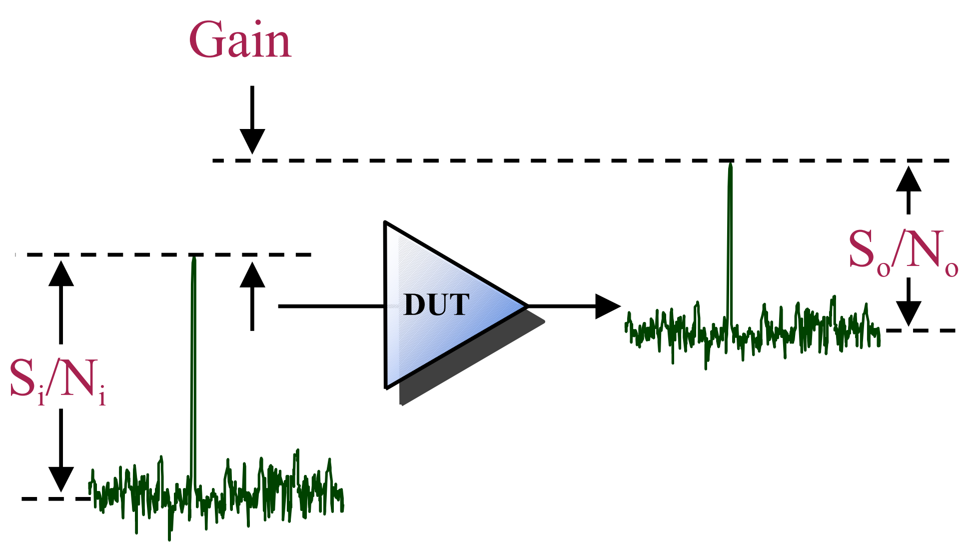
Account Manager : Peter Caputo

Presented by : Ernie Jackson

Agilent Technologies

Agenda

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



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

Why do we measure Noise Figure? Example...

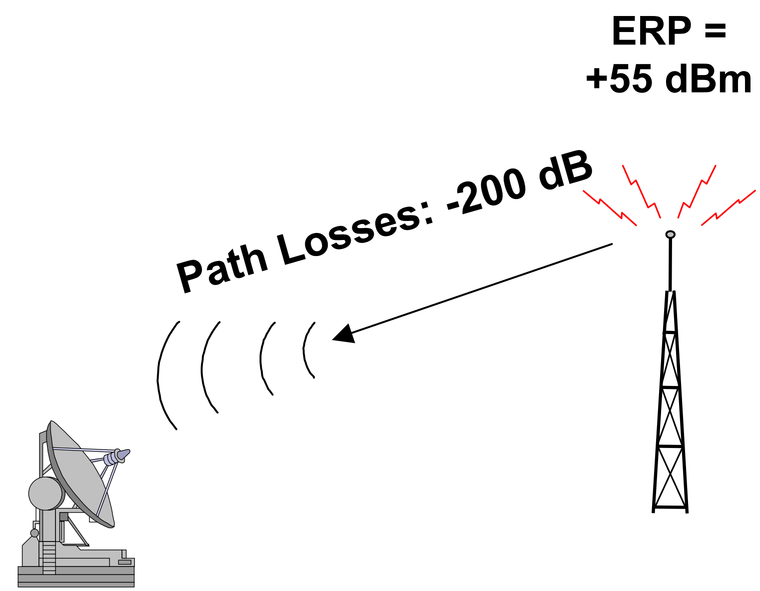
Transmitter:

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



Receiver NF: 5dB
Bandwidth: 100MHz
Antenna Gain: +60dB

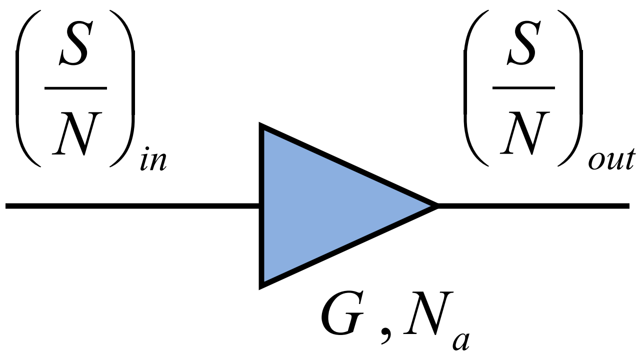
Power to Antenna: +40dBm
Frequency: 12GHz
Antenna Gain: +15dB

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

The Definition of Noise Factor or Noise Figure in Linear Terms

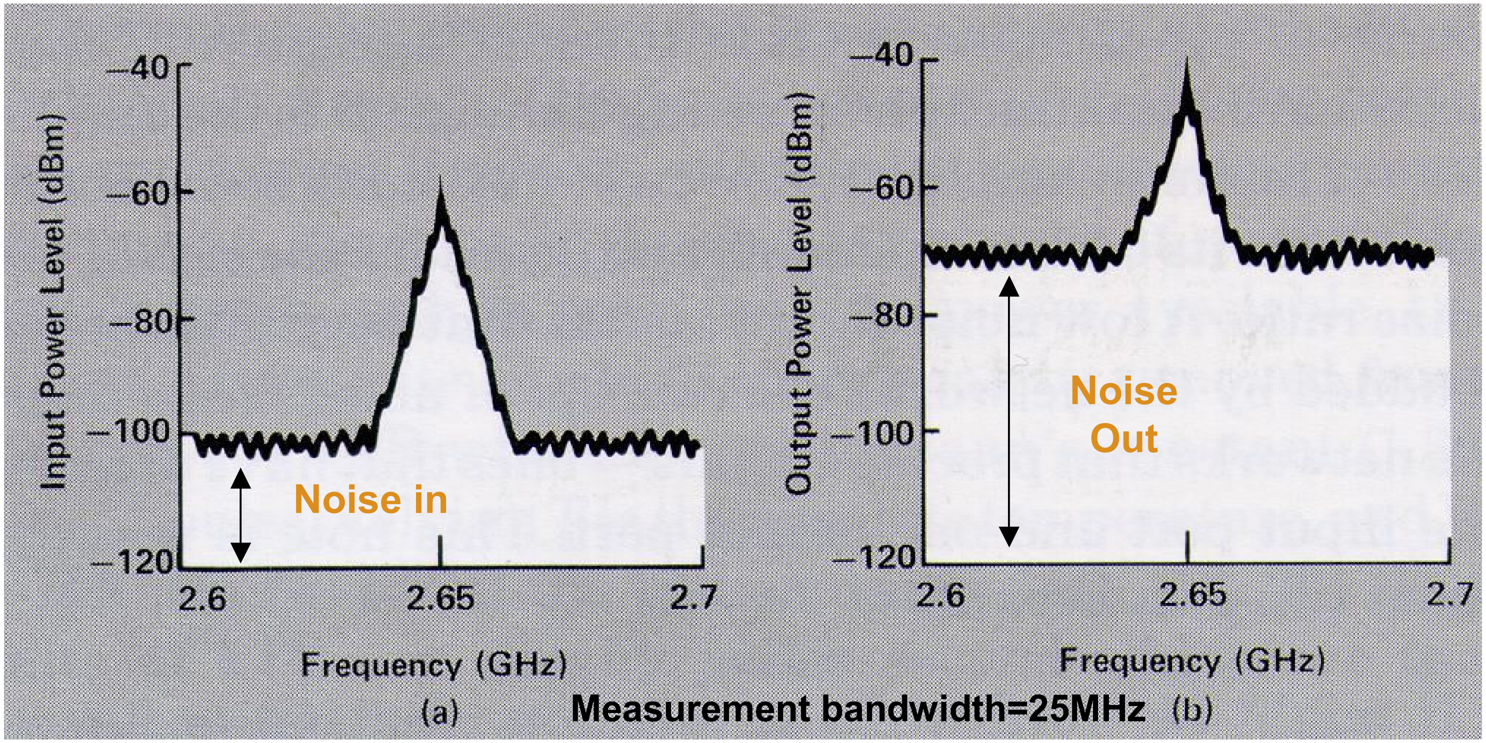
- **Noise Factor is a figure of merit that relates the Signal to Noise ratio of the output to the Signal to Noise ratio of the input.**
- **Most basic definition was defined by Friis in the 1940’s.**



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

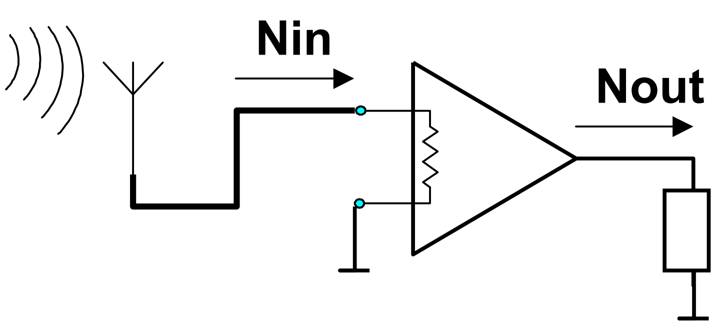
Reference: Harald Trap Friis: 1944: Proceedings of the IRE

What is Noise Figure ?

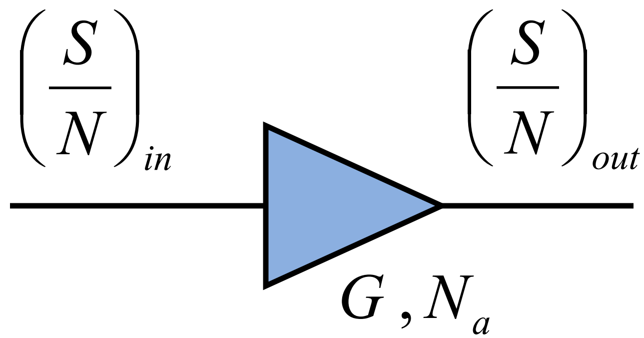


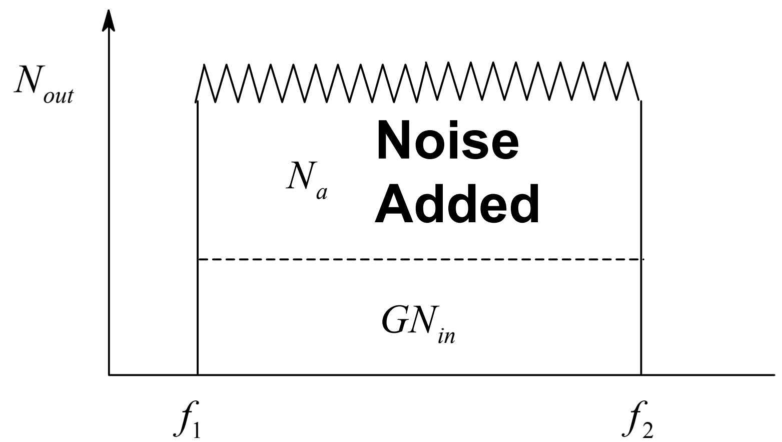
a) C/N at amplifier input

b) C/N at amplifier output



Definition of Noise Figure





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

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

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

Noise Factor

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

Noise Figure

Noise Voltage

Standard Equation for Noise Voltage produced by a Resistor

$$e^2 = 4kTBR$$

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

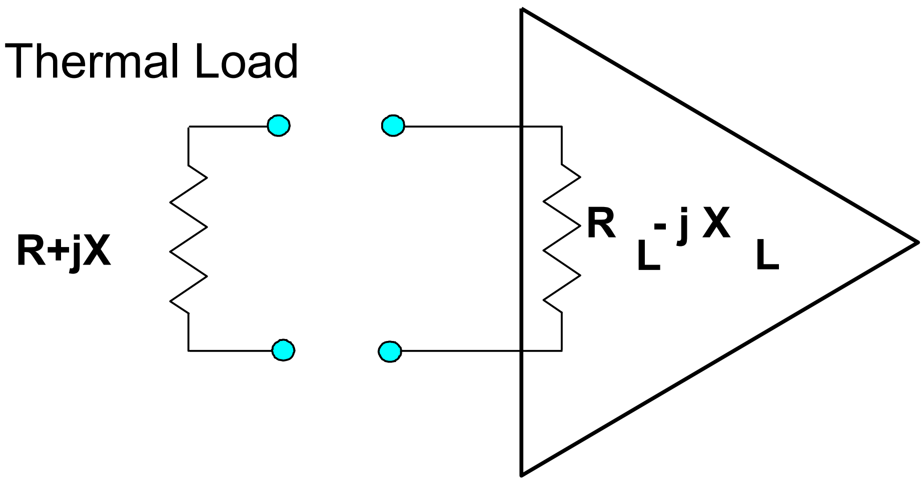
T is absolute temperature (°K)

B is bandwidth (Hz)

e is rms voltage

Reference: JB Johnson/Nyquist: 1928: Bell Labs

Noise Power at Standard Temperature



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

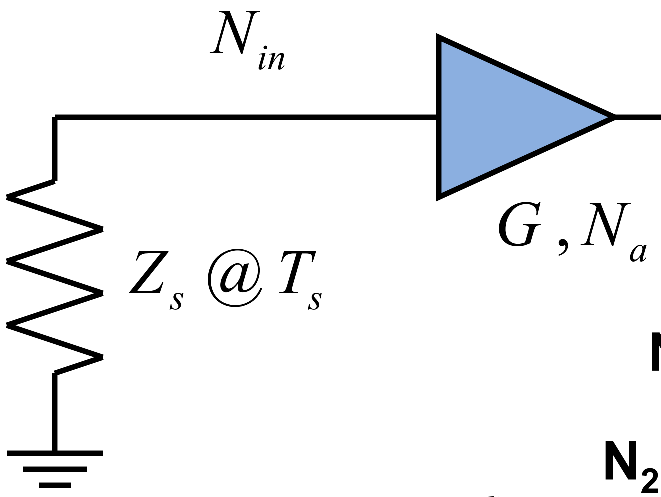
Available Noise Power Delivered to a Conjugate Load,

$$P_{av} = kTB$$

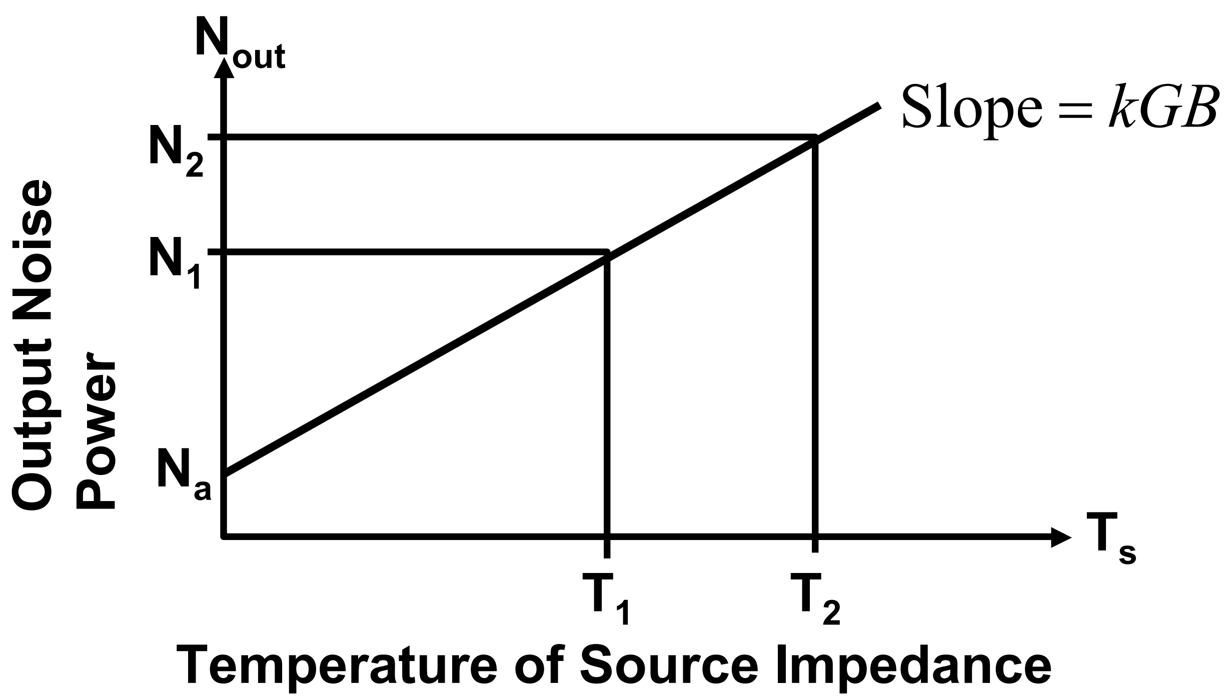
At 290K $P_{av} = 4 \times 10^{-21}$ W/Hz = -174dBm / Hz

In deep space kT = -198dBm/Hz

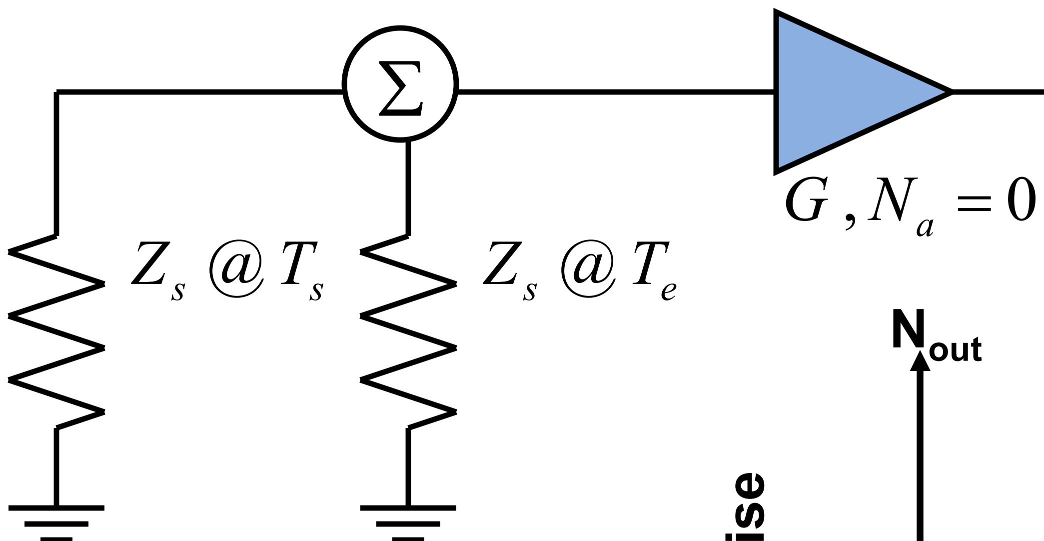
Noise Power is Linear with Temperature



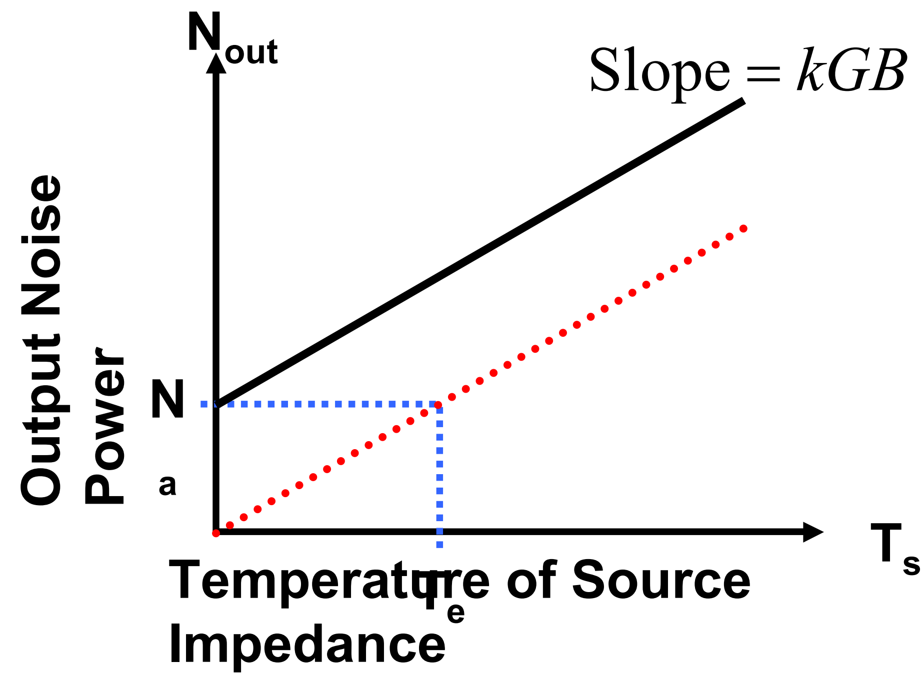
$$N_{out} = N_a + GN_{in}$$
$$= N_a + GkT_sB$$



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



$$N_{out} = N_a + GN_{in}$$
$$= GkT_eB + GkT_sB$$
$$= GkB(T_e + T_s)$$



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

and

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

Te or NF: which should I use?

•Use either - they are completely interchangeable

•Typically NF for terrestrial and Te for space

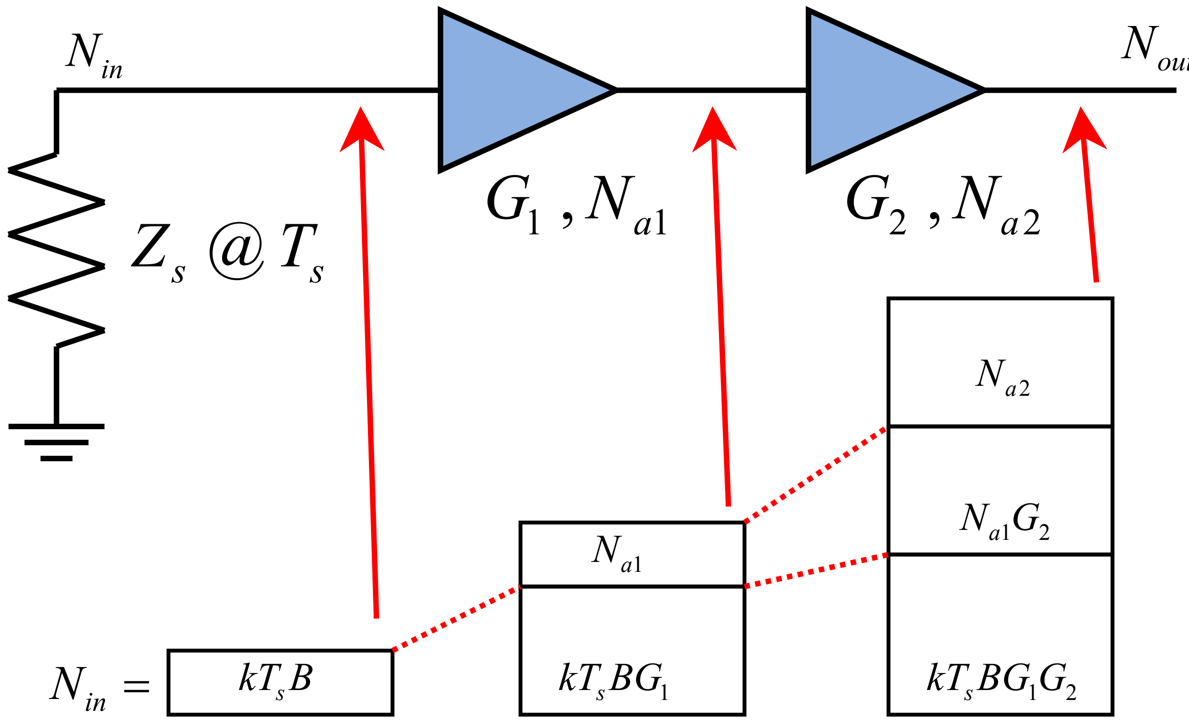
•NF referenced to 290K - not appropriate in space

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

•Te is easier to characterize graphically

Friis or Cascade Equation

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



$$N_{out} = N_{a2} + G_1N_{a1} + G_1G_2N_{in}$$

$$G = G_1G_2$$

$$N_{in} = kT_sB$$

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

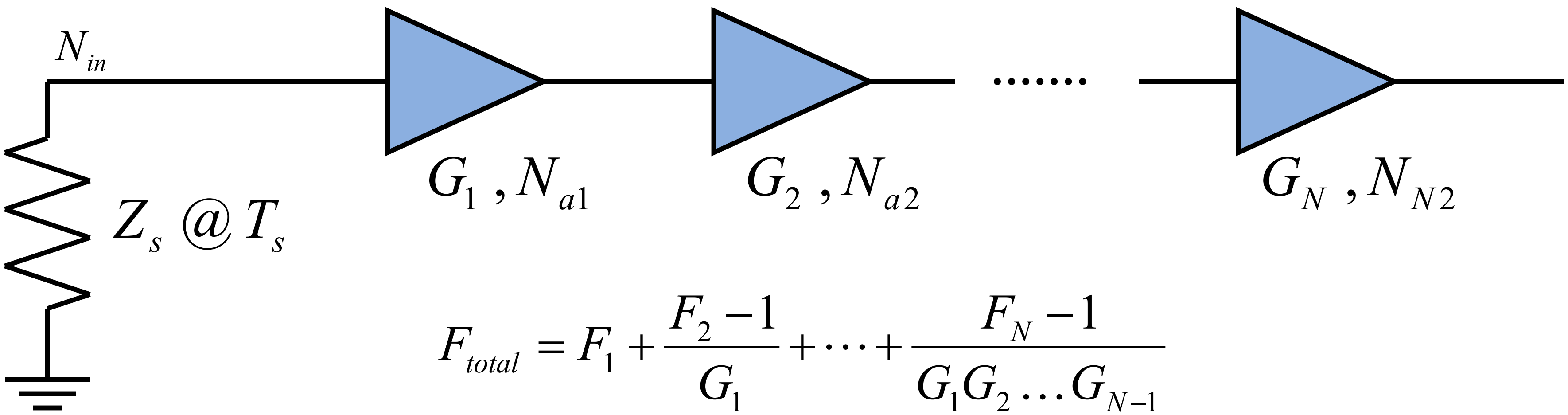
$$N_{a2} = kT_{e2}B = (F_2 - 1)kT_sB$$

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

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

Effects of Multiple Stages on Noise Factor

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

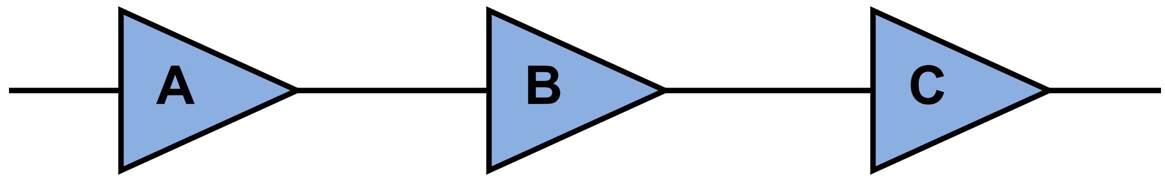


$$F_{total} = F_1 + \frac{F_2 - 1}{G_1} + \cdots + \frac{F_N - 1}{G_1 G_2 \ldots G_{N-1}}$$

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

Demo of Cascade Equation

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



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**

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

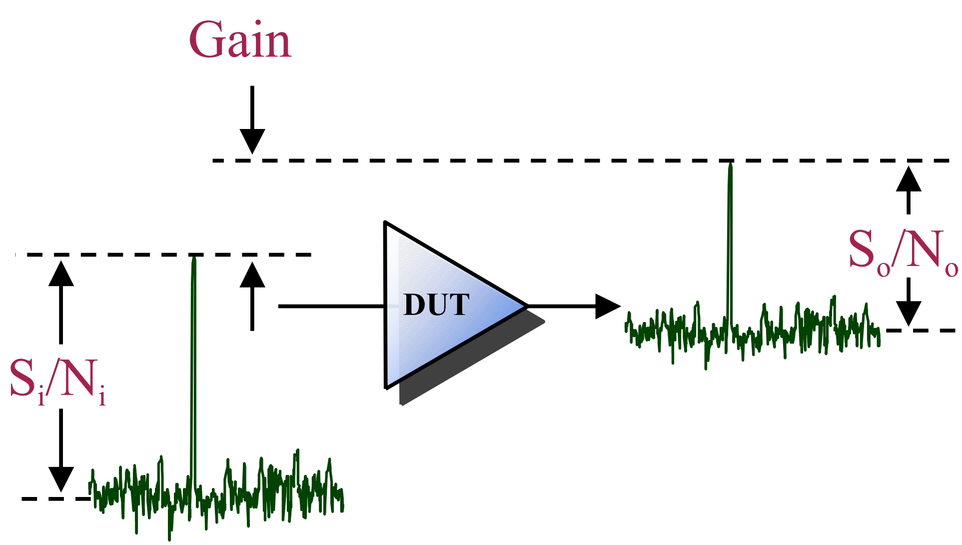
$$NF_{ABC} = 10\log(1.997) = 3.00\ \text{dB}$$

$$F_{ACB} = 1.7 + \frac{4.0 - 1}{4.0} + \frac{2.0 - 1}{4.0 \times 100.0} = 1.70 + 0.75 + 0.025 = 2.475$$

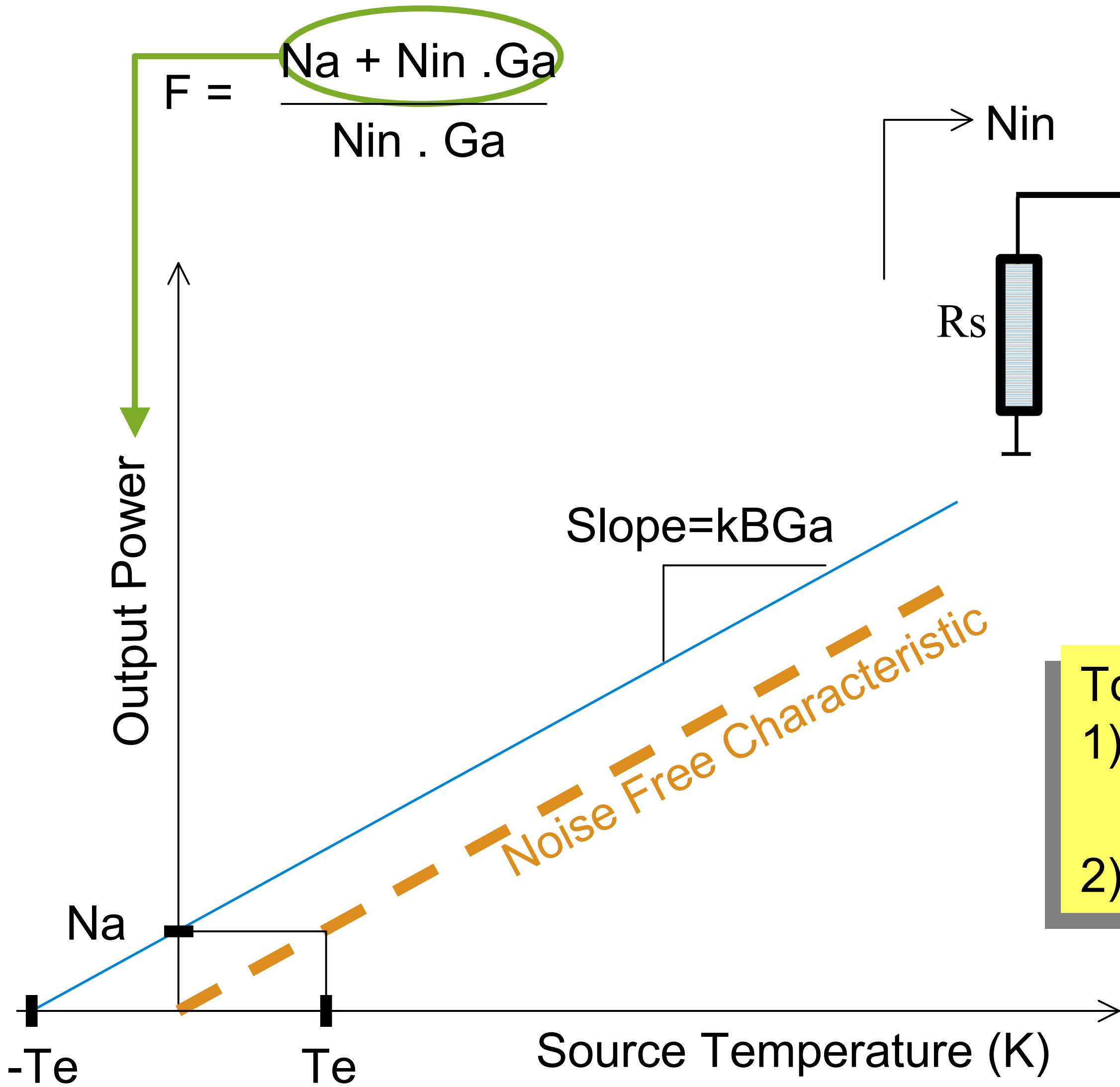
$$NF_{ACB} = 10\log(2.475) = 3.93\ \text{dB}$$

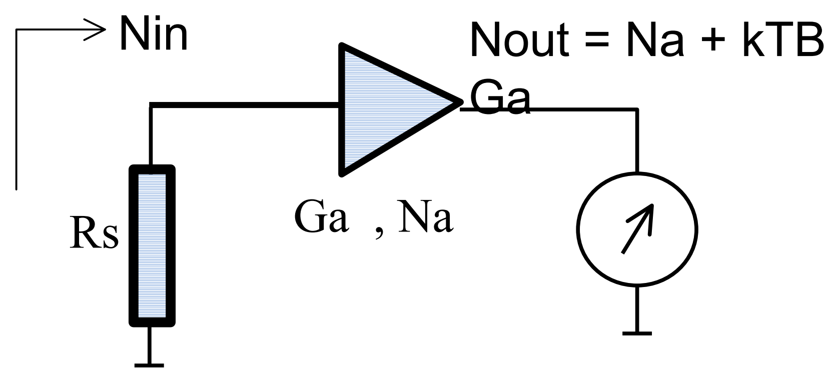
Agenda

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



Measuring Noise Figure



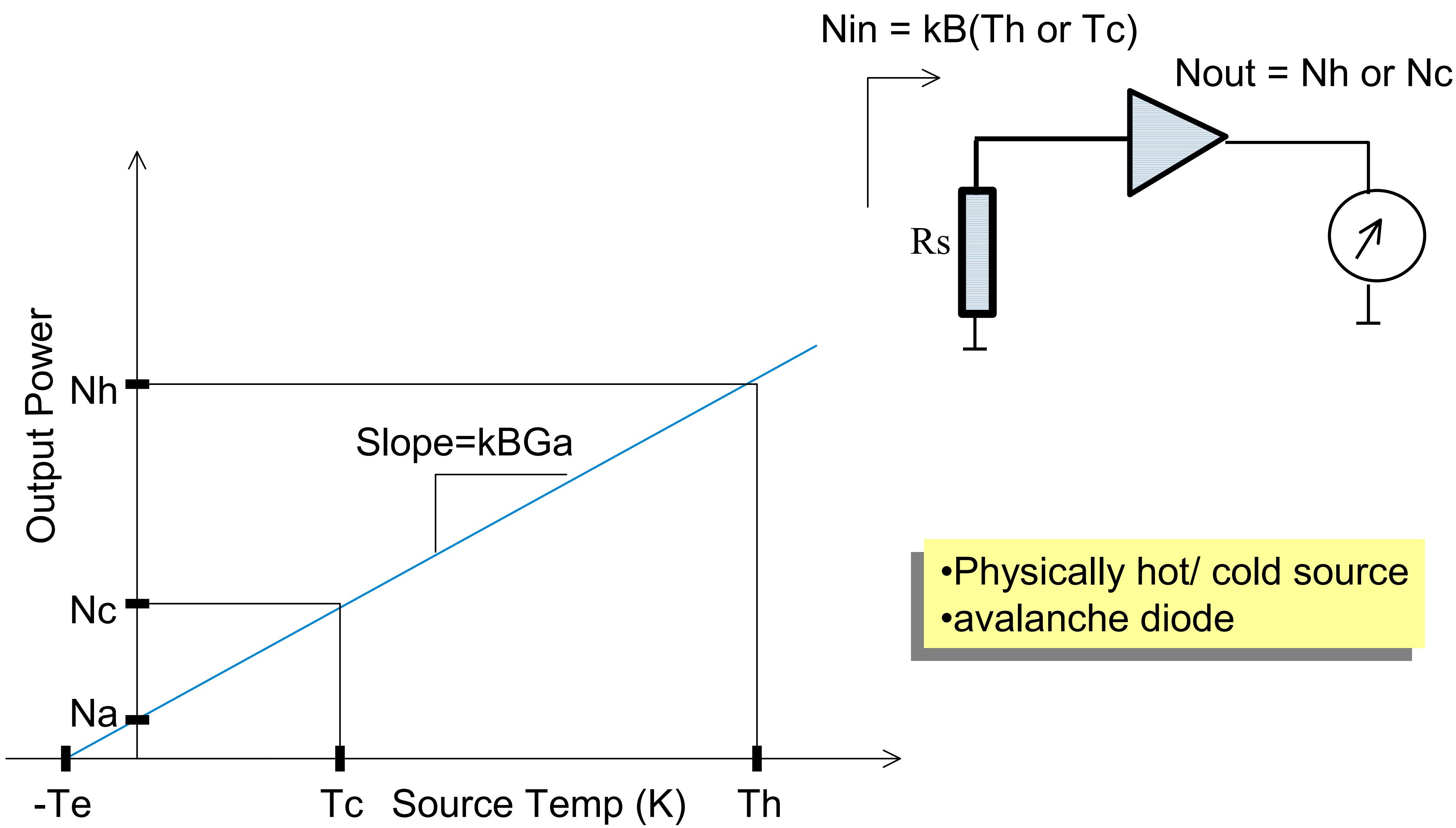


To solve for Na:
1) establish 2 points on curve

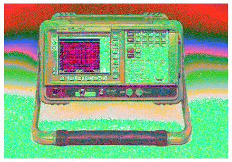
or

2) establish 1 point and gradient

Hot/Cold Technique

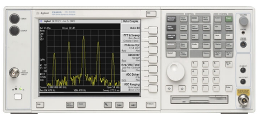


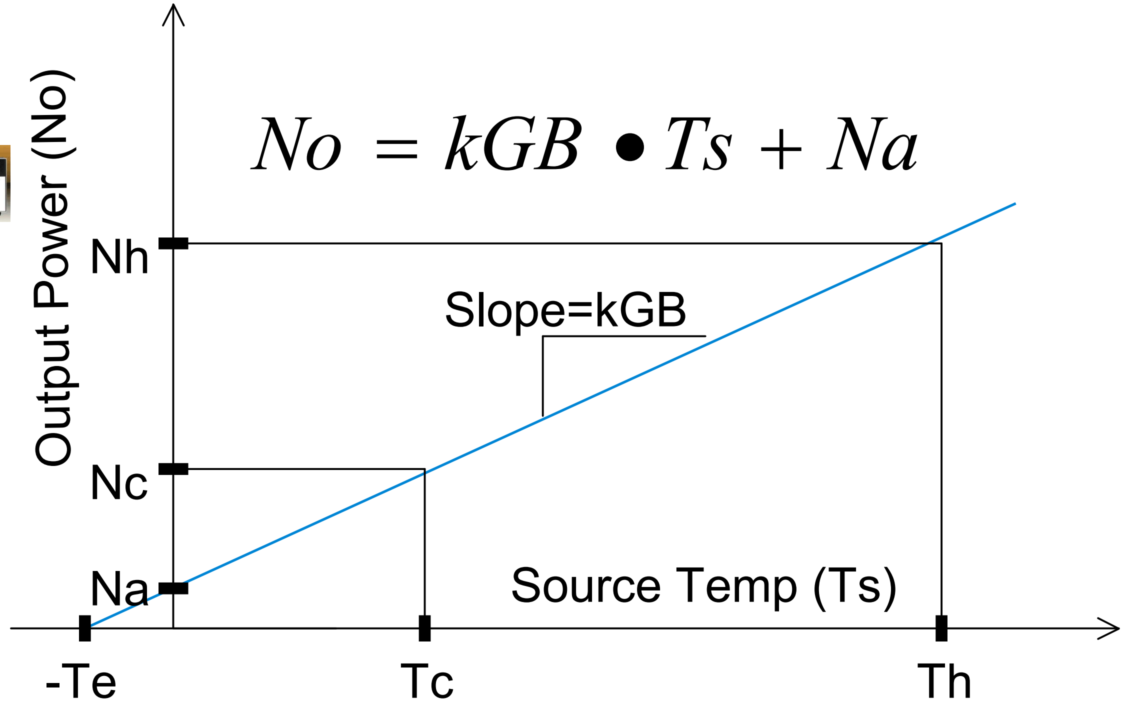
- Physically hot/ cold source
- avalanche diode




Measured

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





Input

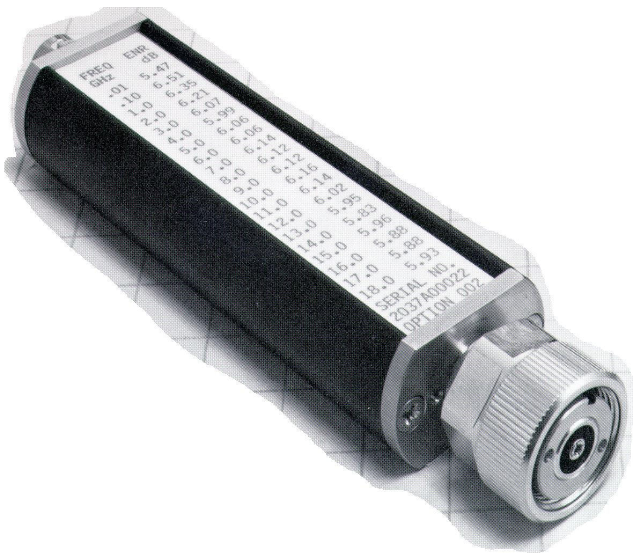
$$ENR = \frac{(Th - To)}{To}$$

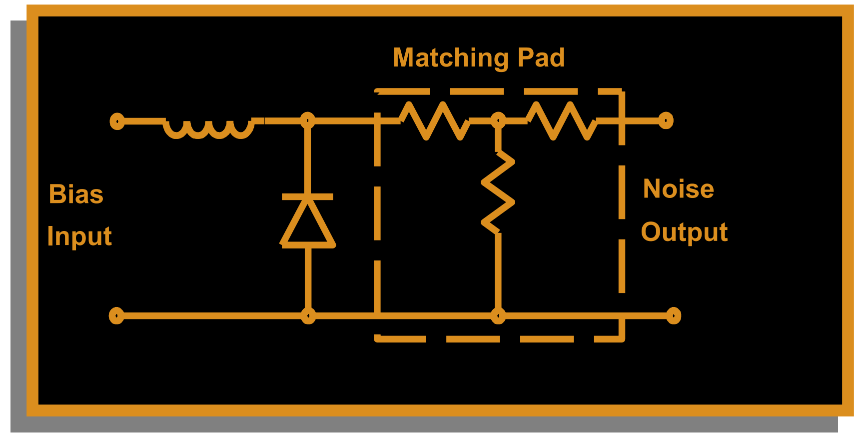
Calculated

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

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

Noise Source - the Avalanche Diode

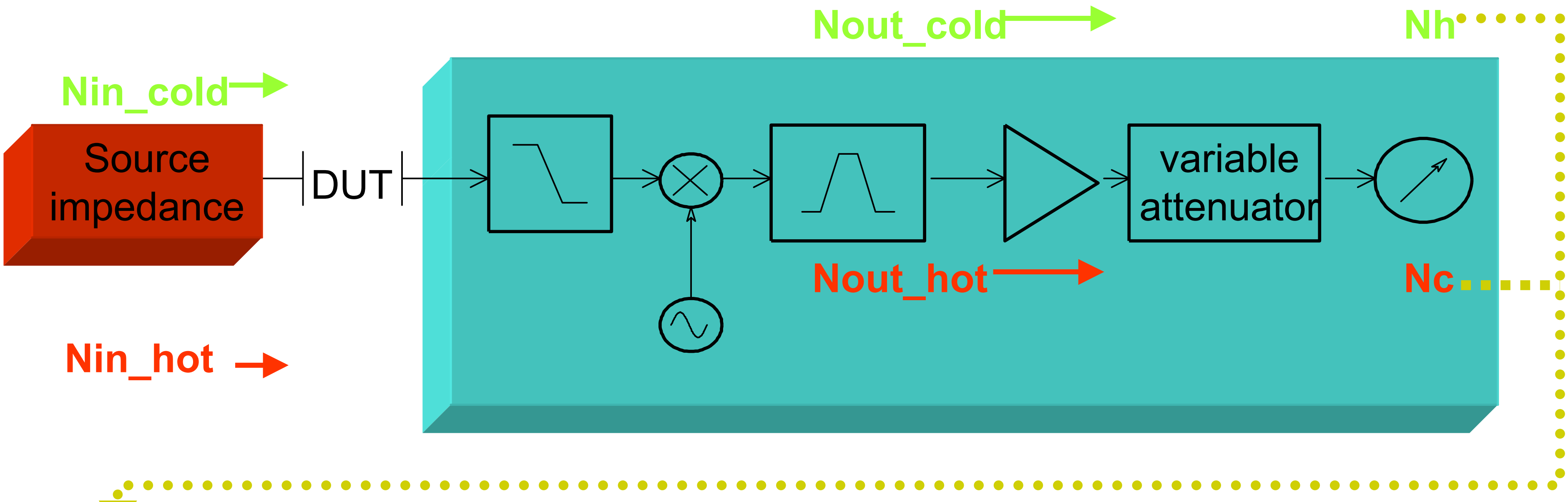




Excess Noise Ratio, $ENR\,(dB) = 10 \log_{10} \dfrac{(T_h - 290)}{290}$

Frequency	ENR dB
XXX	AAA
YYY	BBB
ZZZ	CCC
⋮	⋮

Noise Figure Analyzer

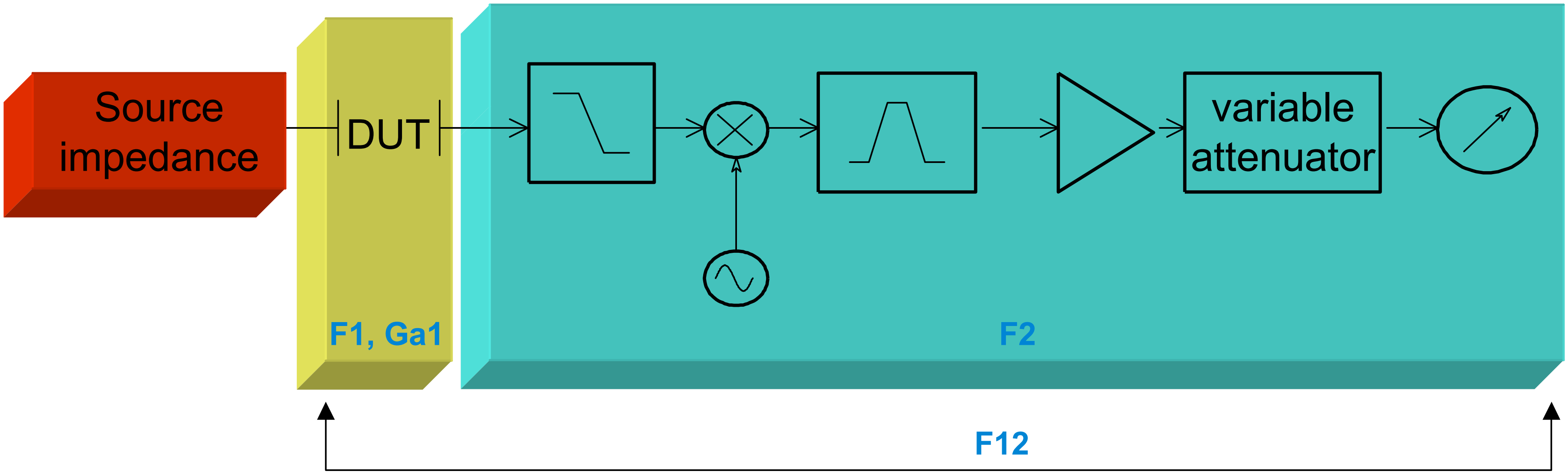


$$Y = \frac{Nh}{Nc} = \frac{kGB(Te + Th)}{kGB(Te + Tc)}$$

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

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

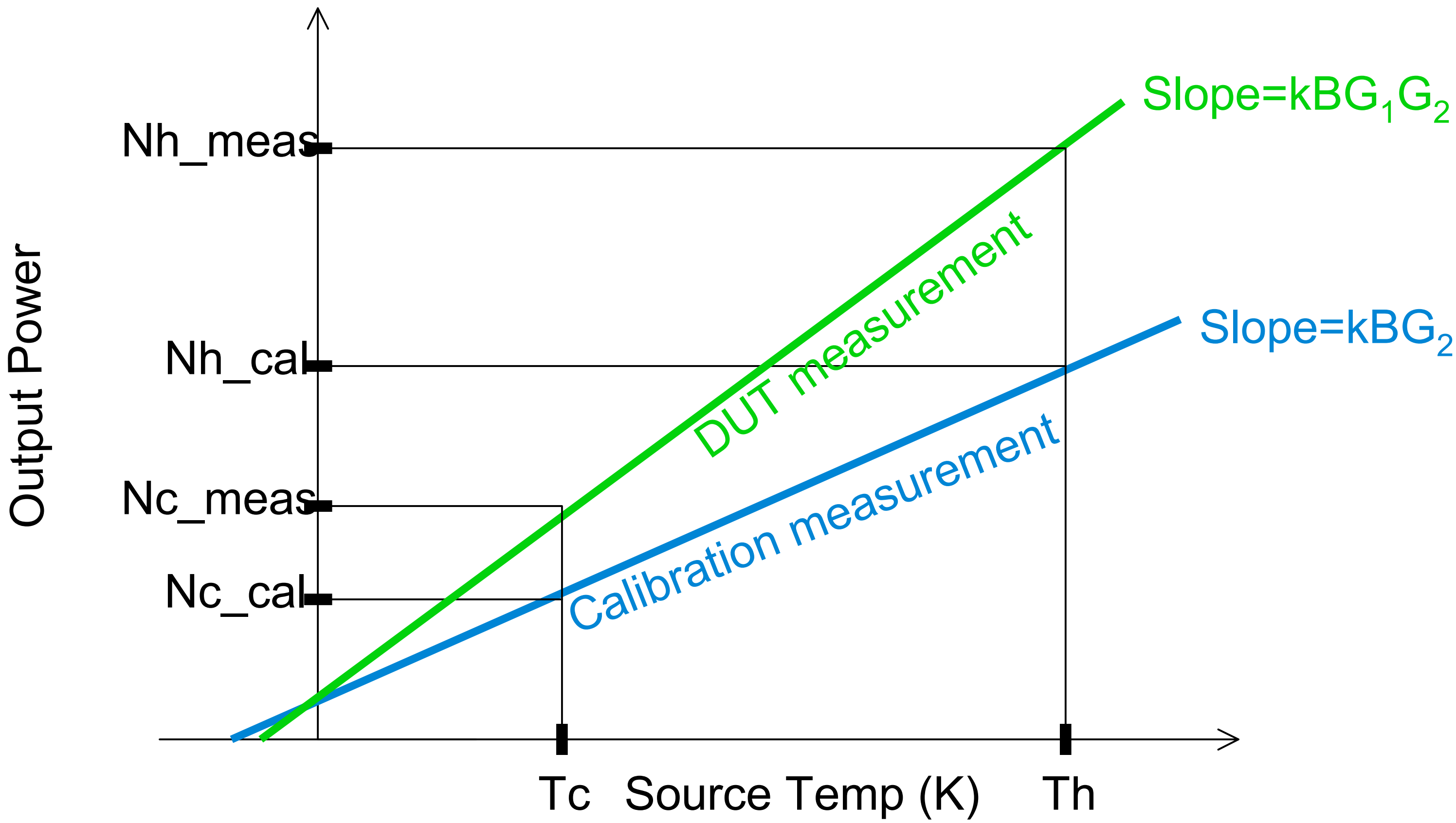
Calibrating out System NF



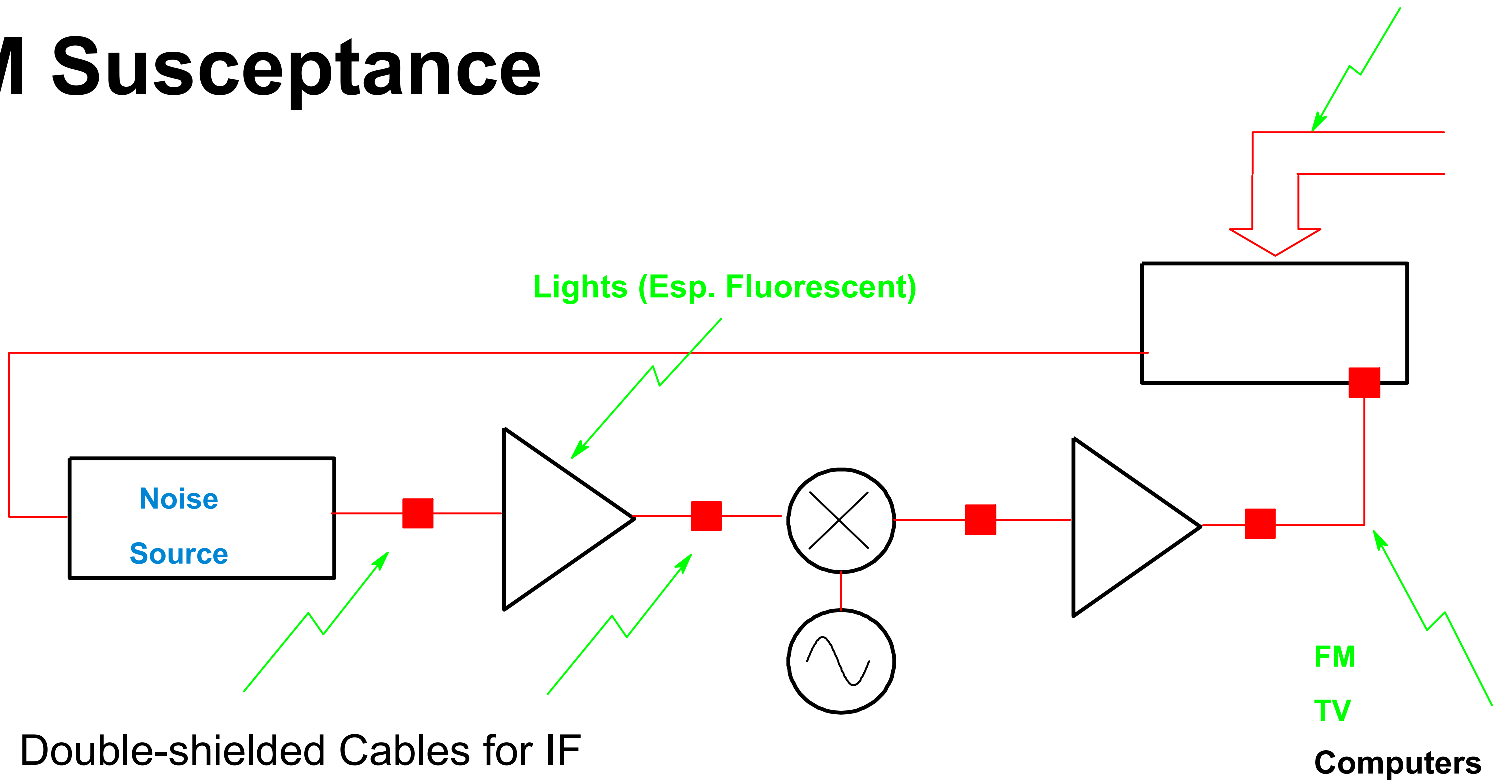
$$F_1 = F_{12} - \frac{F_2 - 1}{G_{a1}}$$

if $F_{12} \approx \frac{F_2 - 1}{G_{a1}}$ then uncertainty increases, so beware if F_1 and G_1 are low

How does the NFA measure gain



Avoidable Measurement Errors:
EM Susceptance

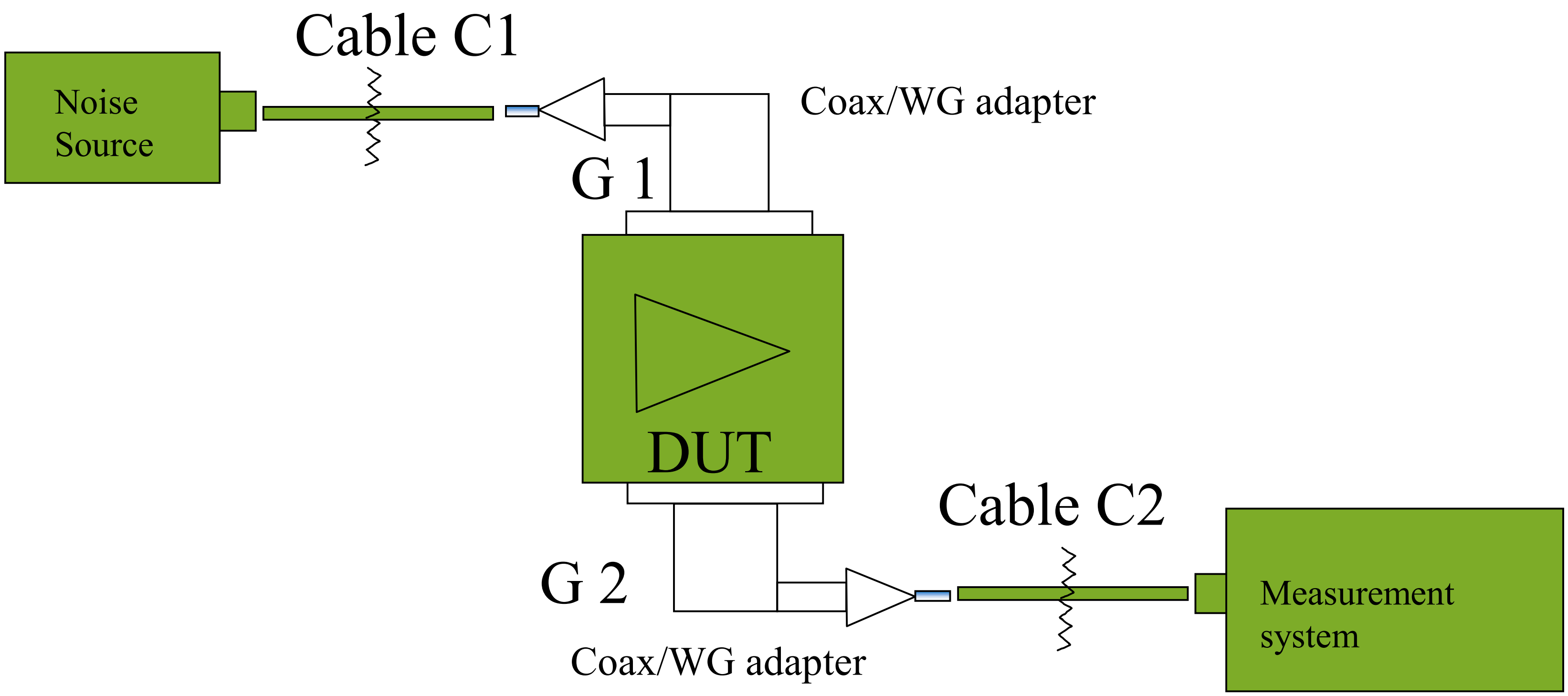


- Double-shielded Cables for IF
  (Ordinary Braid if porous)
- Shielded HP-IB Cables
- Enclose All Circuits
- Jiggle Connectors (Esp. BNC)
- Try snap-on ferrite cores on cables, dampen common-mode currents
- LO Contributes Spurious and Noise

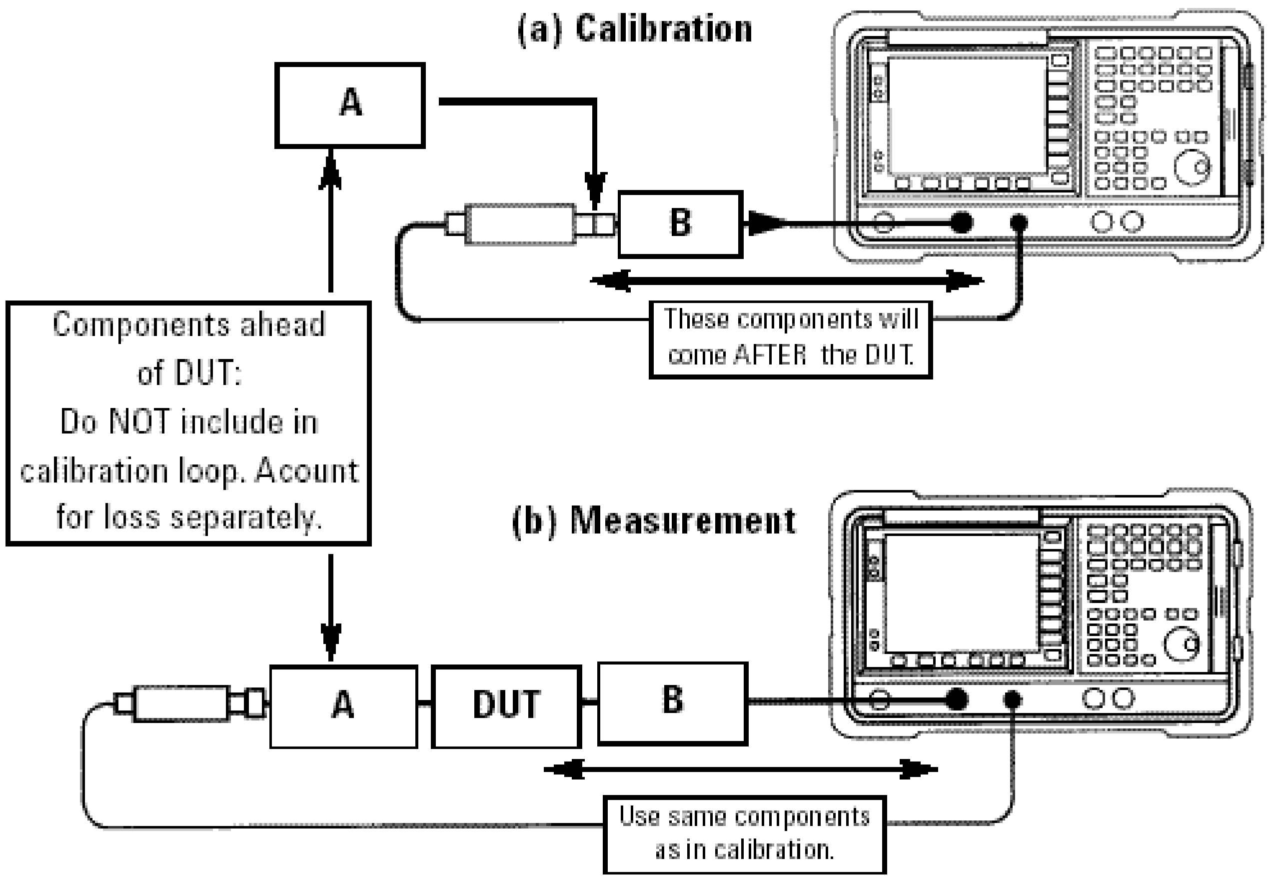
Avoidable Measurement Errors:
Choose the Appropriate Noise Source

- 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).

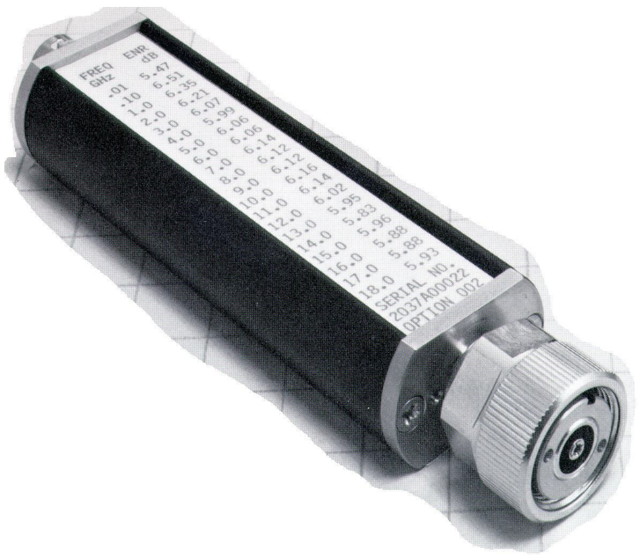
Avoidable Measurement Errors:
Accurate Loss Compensation

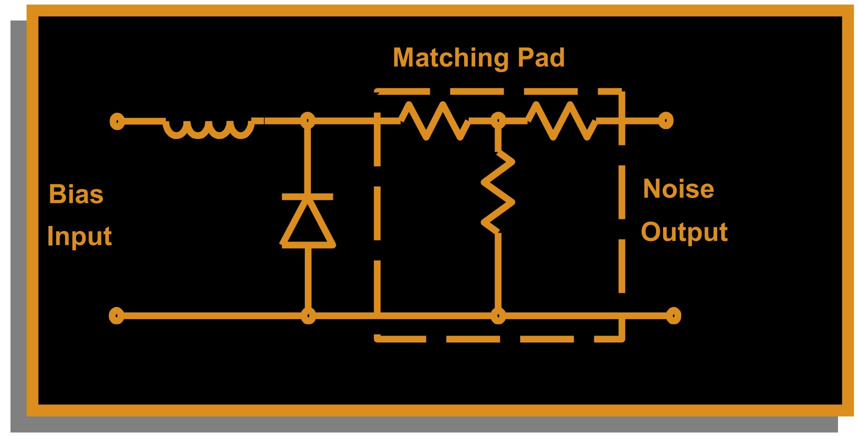


Avoidable Measurement Errors:
Loss Compensation and Calibration



Noise Source - the Avalanche Diode



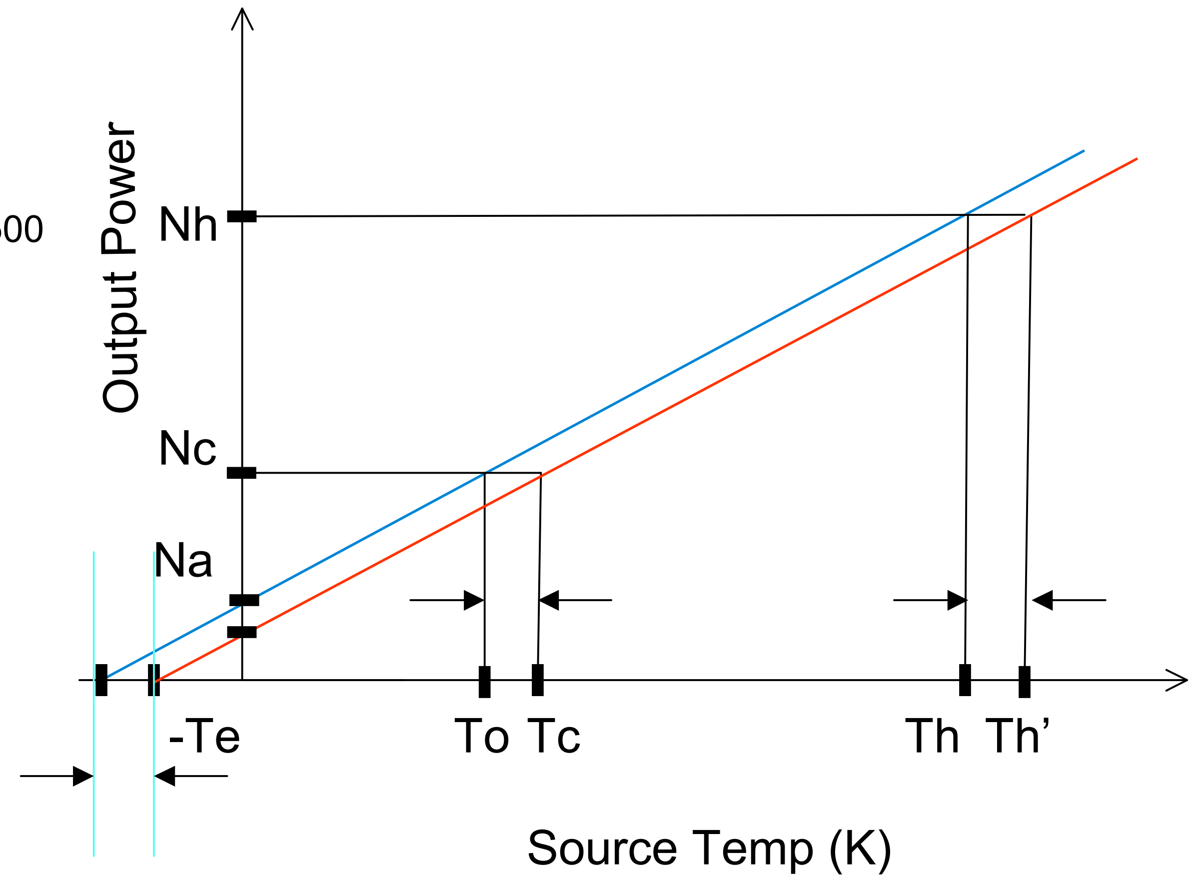


Excess Noise Ratio, $ENR\ (dB) = 10 \log_{10} \dfrac{(T_h - 290)}{290}$

Frequency	ENR dB
XXX	AAA
YYY	BBB
ZZZ	CCC
⋮	⋮

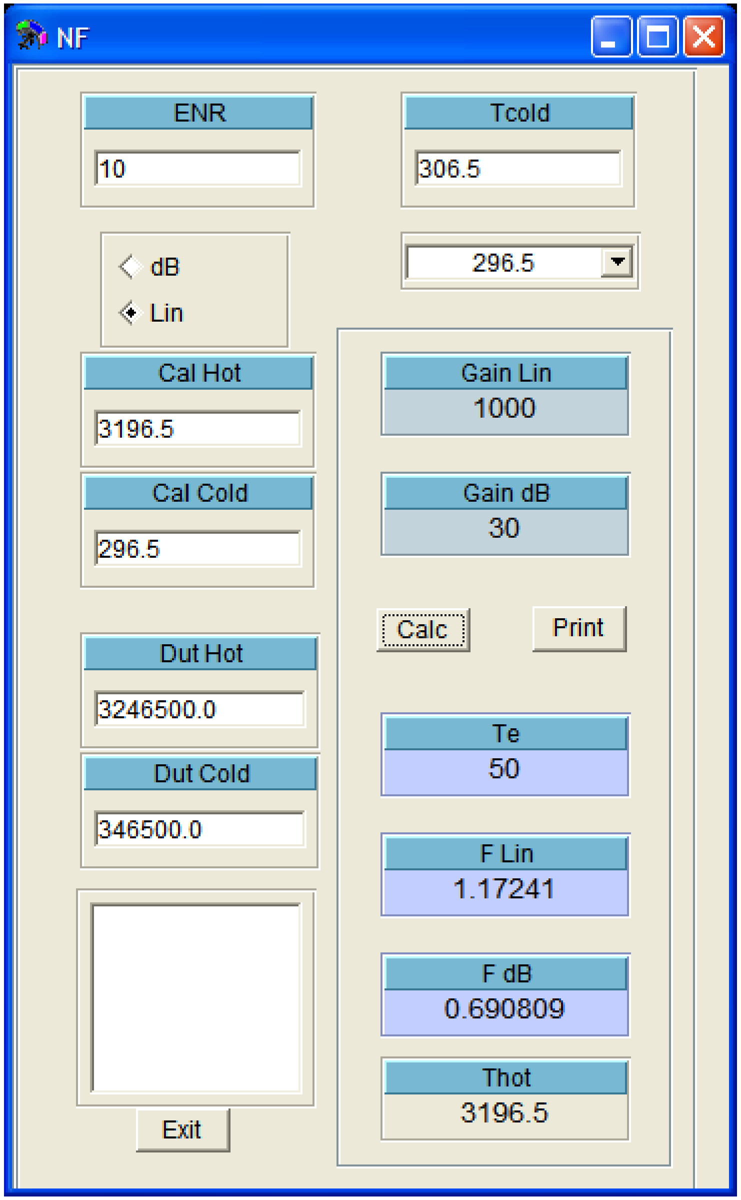
Avoidable Measurement Errors:
Temperature Considerations (Diode)

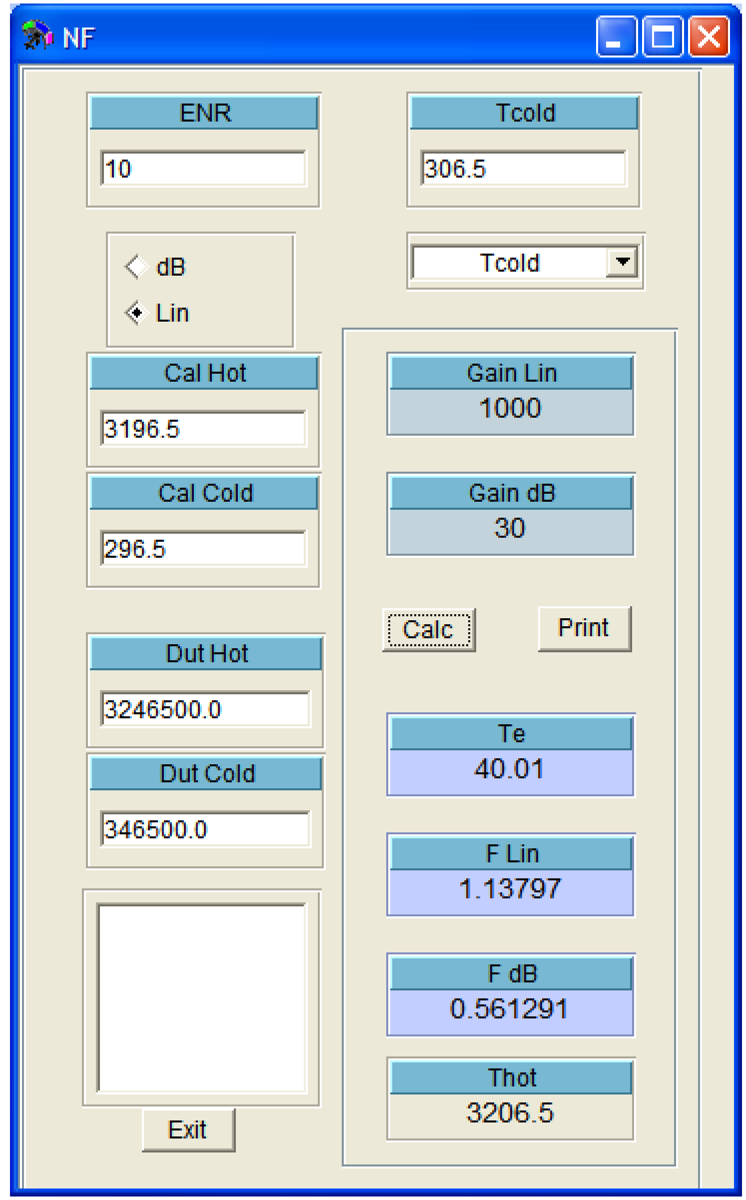
To=296.5 K
Th=10,000 or 1,500



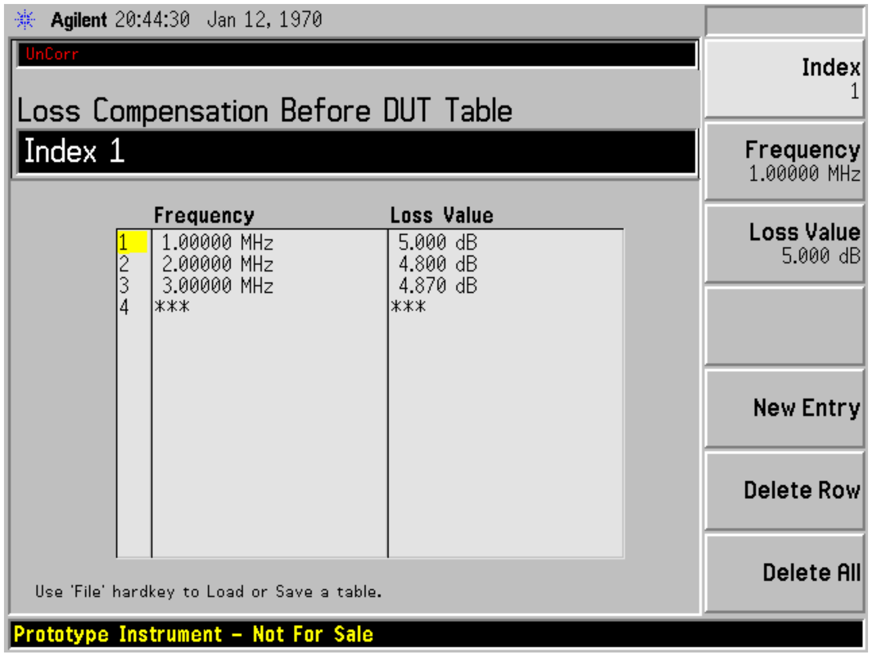
Report Ambient Temperature to Analyzer for Accurate ENR Interpretations

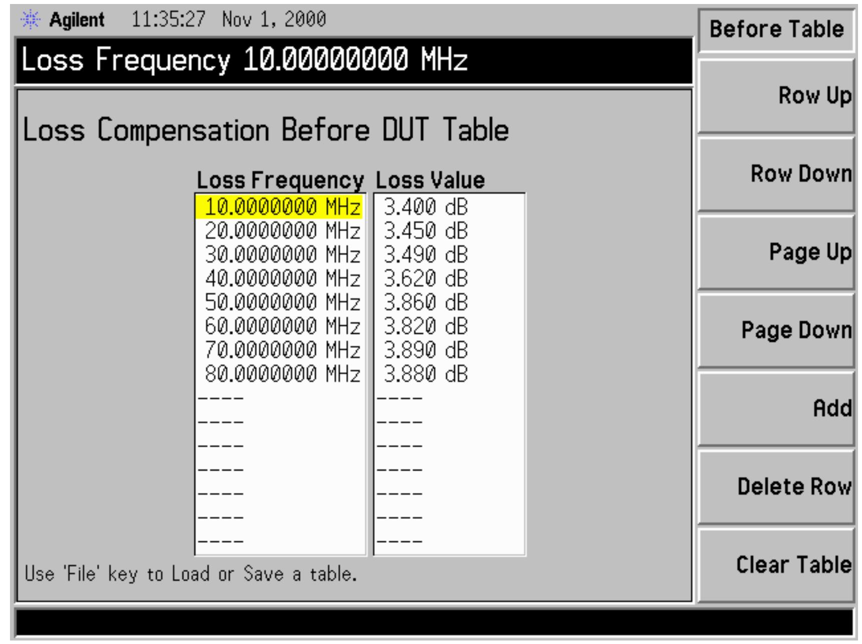
Agilent Technologies


NF
ENR
10
Tcold
306.5
dB
Lin
296.5
Cal Hot
3196.5
Gain Lin
1000
Cal Cold
296.5
Gain dB
30
Calc
Print
Dut Hot
3246500.0
Te
50
Dut Cold
346500.0
F Lin
1.17241
F dB
0.690809
Thot
3196.5
Exit


NF
ENR
10
Tcold
306.5
dB
Lin
Tcold
Cal Hot
3196.5
Gain Lin
1000
Cal Cold
296.5
Gain dB
30
Calc
Print
Dut Hot
3246500.0
Te
40.01
Dut Cold
346500.0
F Lin
1.13797
F dB
0.561291
Thot
3206.5
Exit

Avoidable Measurement Errors:
Loss and Temperature Corrections





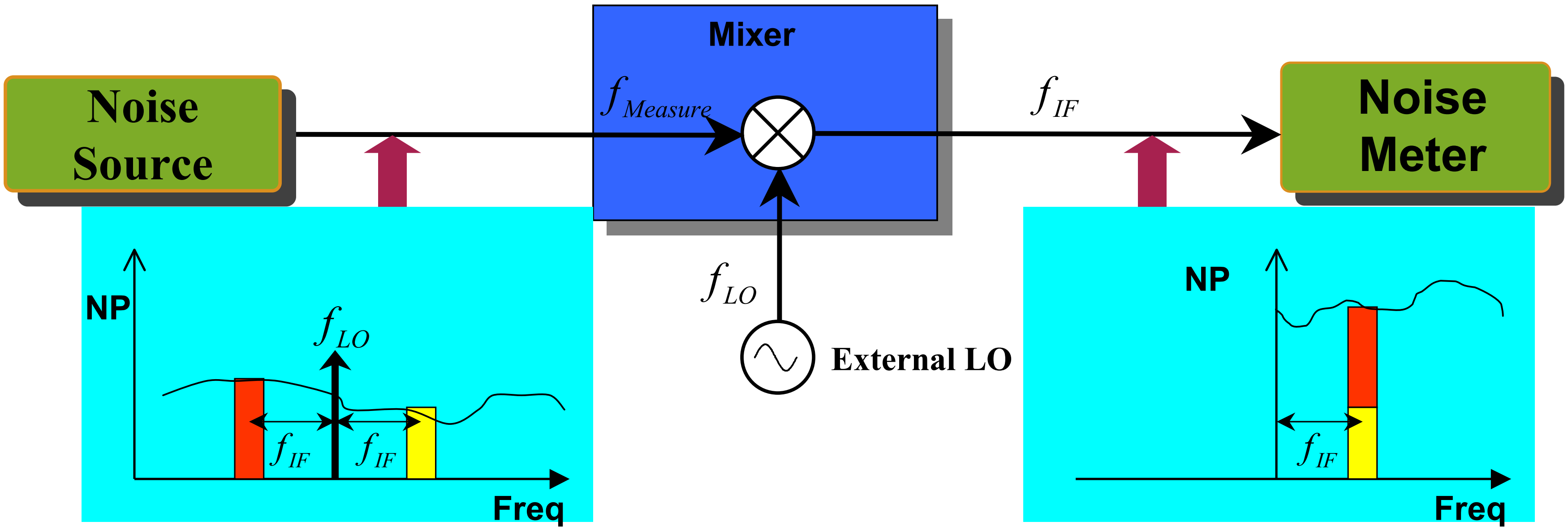
- **A temperature must be entered in Loss Compensation Setup for valid results**

  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)



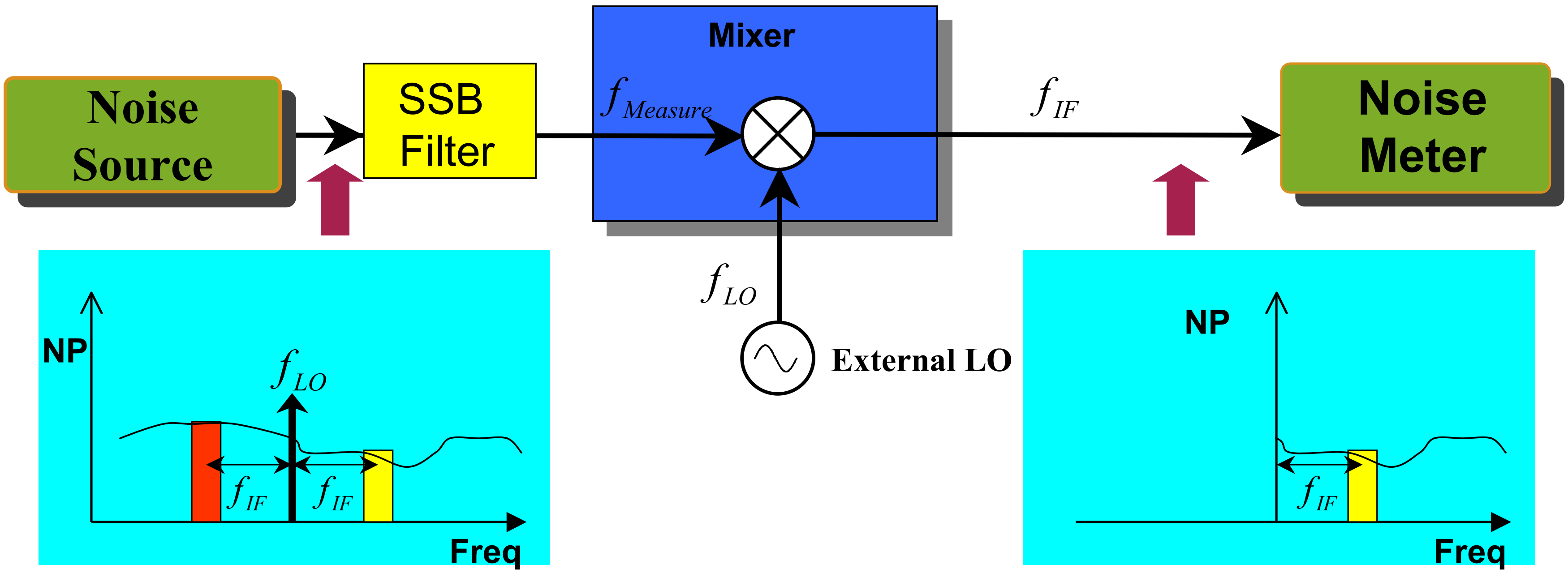
DSB is recommended when :

- **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

Avoidable Measurement Errors:

Account for Frequency Conversion (SSB Measurement)



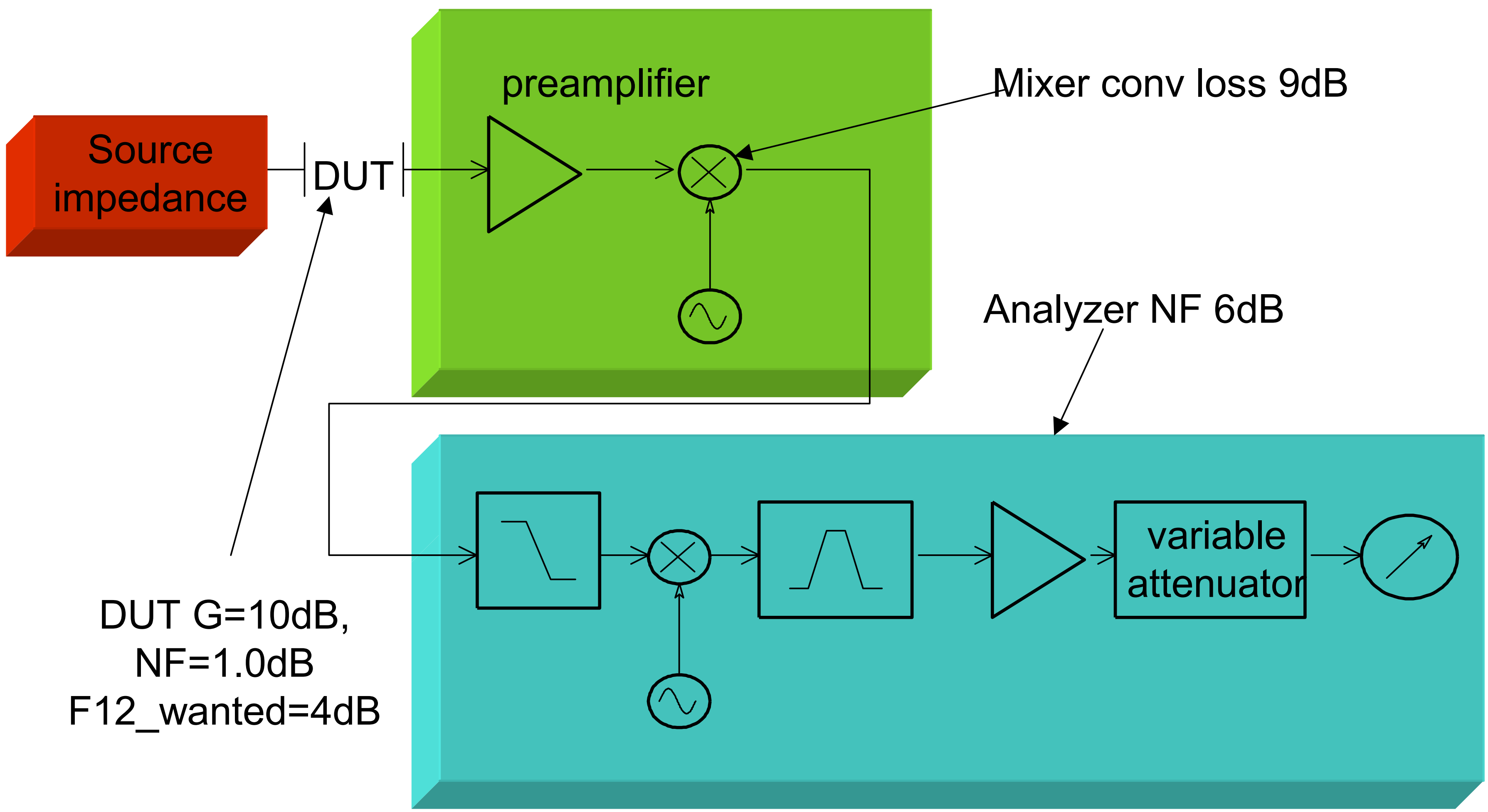
SSB is recommended when :

- **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.

Reduce Measurement System Noise Figure

Using a pre-amplifier to improve accuracy



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

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

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

$$F_1 = F_{12} - \frac{F_2 - 1}{G_{a1}}$$

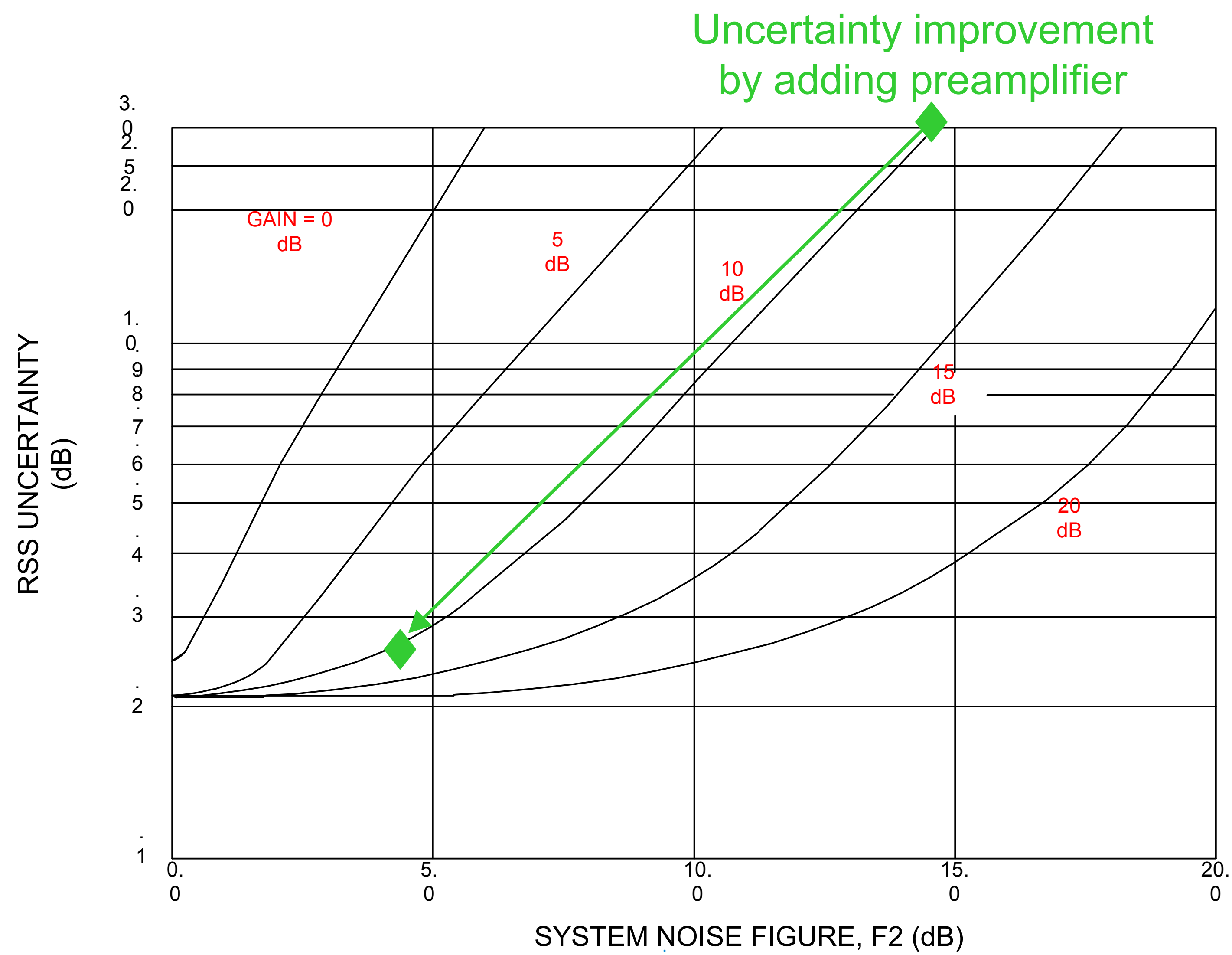
$$F2_{reduced} = F_{preamp} + \frac{F2_{current} - 1}{G_{pream}}$$

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

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

Reduce Measurement System Noise Figure (cont)

Error in 2nd Stage Correction

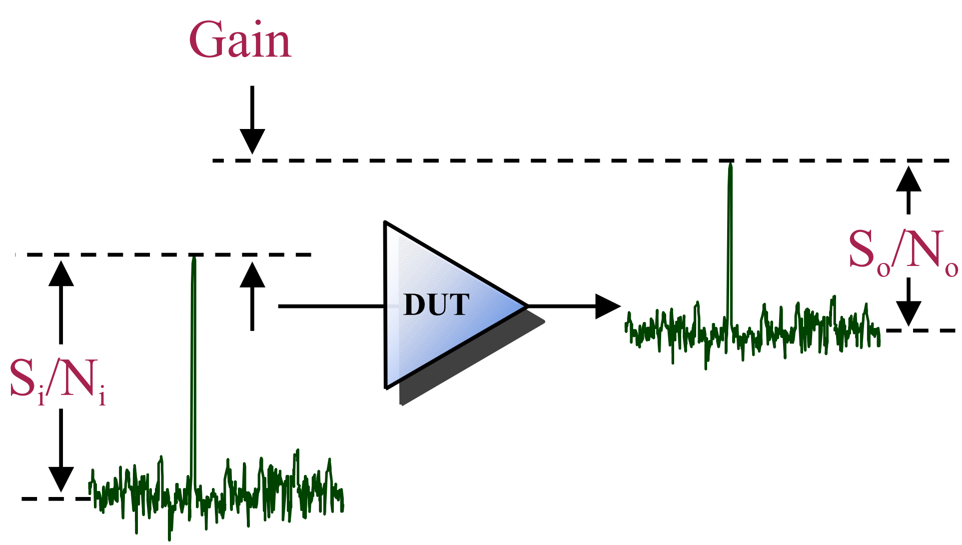


Additional Recommendations

- 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

Agenda

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



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								
3–7	This spreadsheet calculates the uncertainty of noise figure measurements. The numbers in yellow are user variables and the green area is a calculation area. The final uncertainty is shown in blue, this should be added to and subtracted from the result shown on the noise figure measurement instrument in order to give the 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

<u>Noise Figure Uncertainty</u>

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

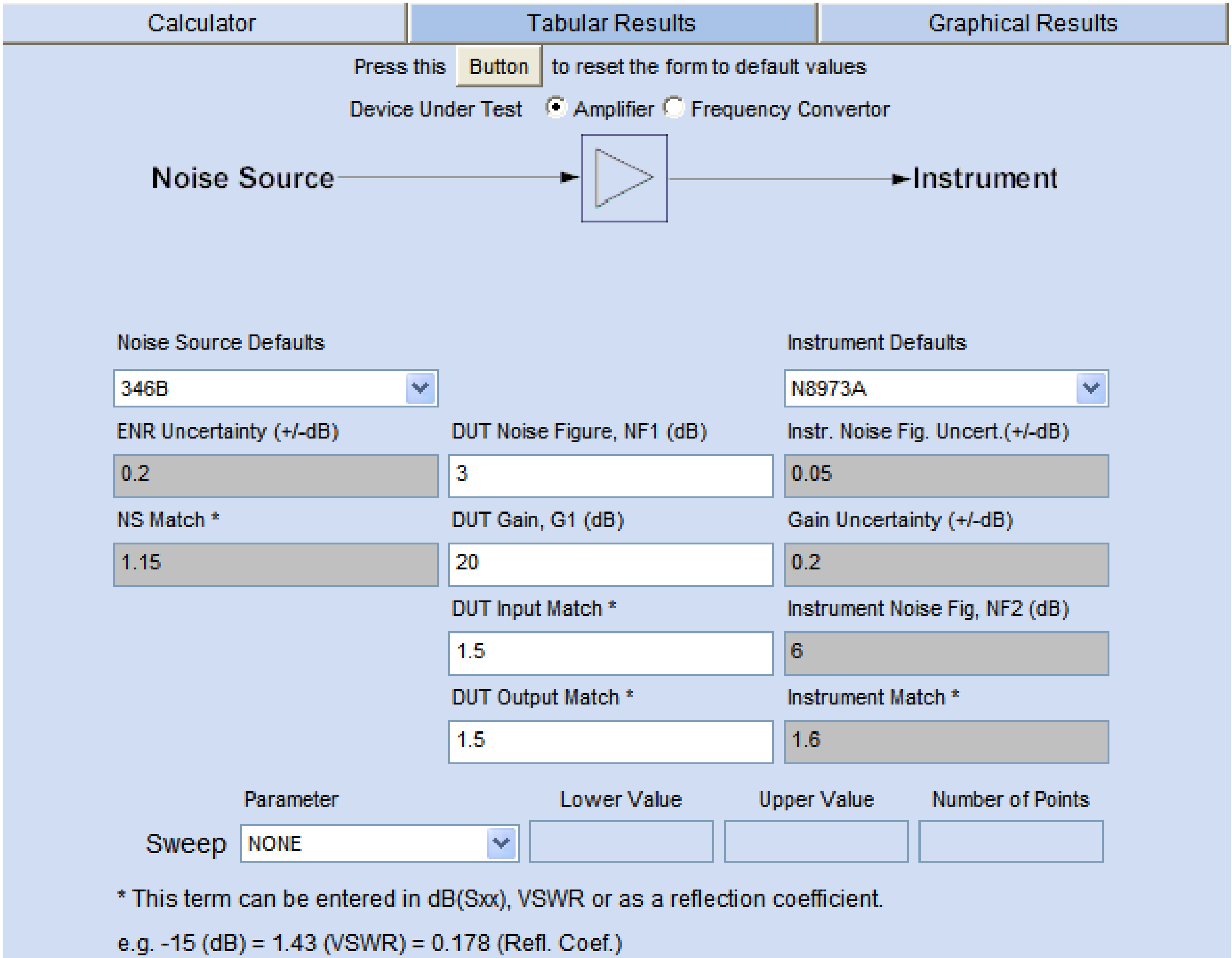
8970B/8971C = 0.423 dB N8975A = 0.353 dB

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

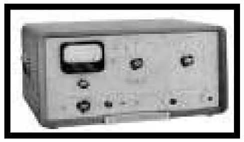

Calculator
Tabular Results
Graphical Results
Press this Button to reset the form to default values
Device Under Test Amplifier Frequency Convertor
Noise Source
Instrument
Noise Source Defaults
346B
Instrument Defaults
N8973A
ENR Uncertainty (+/-dB)
0.2
DUT Noise Figure, NF1 (dB)
3
Instr. Noise Fig. Uncert.(+/-dB)
0.05
NS Match *
1.15
DUT Gain, G1 (dB)
20
Gain Uncertainty (+/-dB)
0.2
DUT Input Match *
1.5
Instrument Noise Fig, NF2 (dB)
6
DUT Output Match *
1.5
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

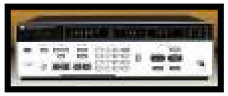
Coefficient	Contributors / Factors	Contribution (dB)
(F12/F1)	- Mismatch between the noise source and the DUT - Instrument noise figure measurement uncertainty	0.134
(F2/F1G1)	- Mismatch between the noise source and the instrument - Instrument noise figure measurement uncertainty	0.003
((F2 - 1)/(F1G1))	- 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



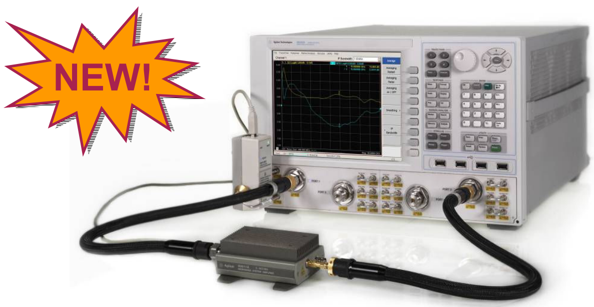
8970
1980

8560/90 with NF
1995

85120
1999

NFA
2000

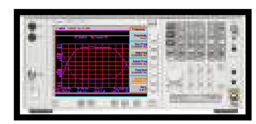
Nearly 50 years of Leadership



PNA-X with
NF
2007

MXA, EXA with
NF
2007

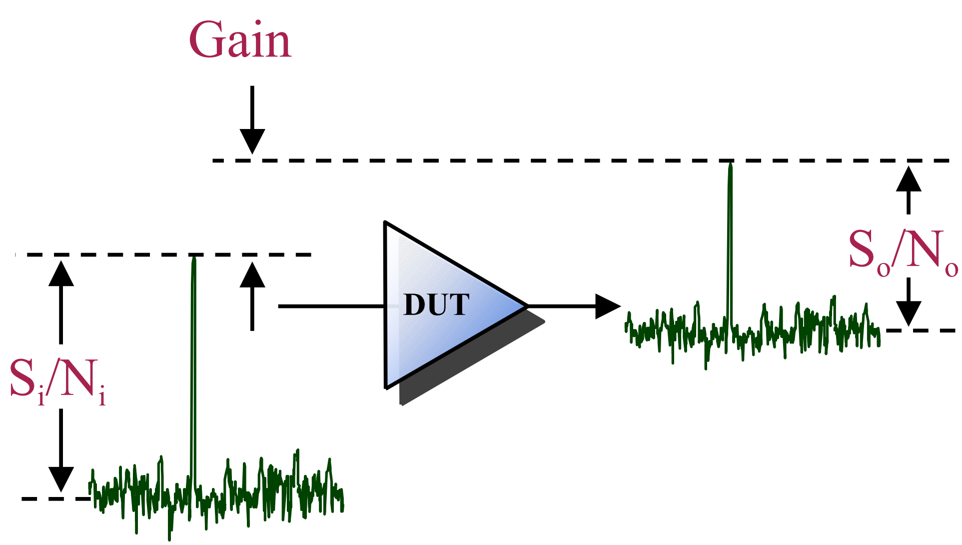
ESA with NF
2003

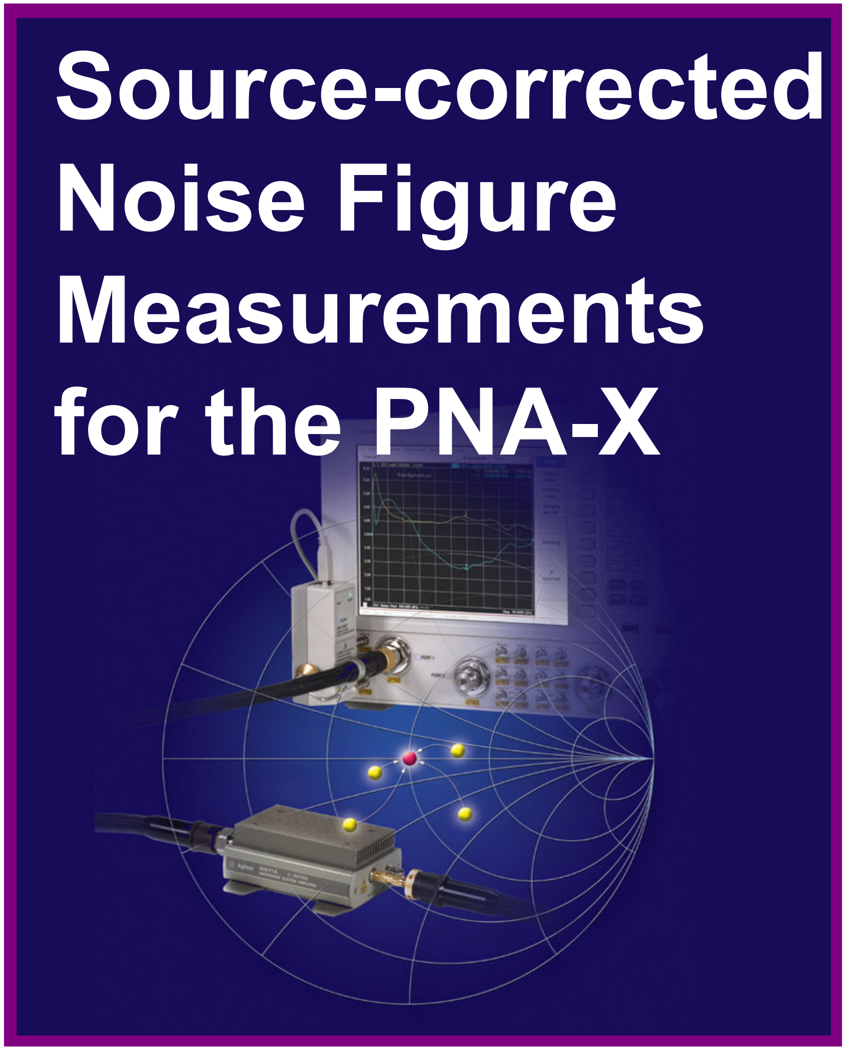


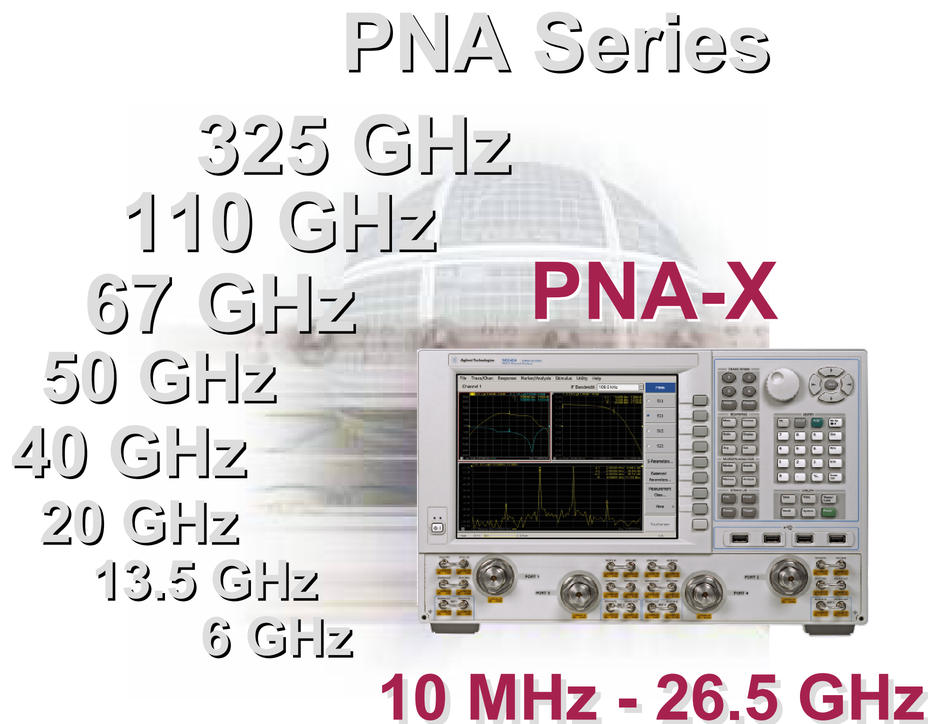
PSA with NF
2002

Agenda

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



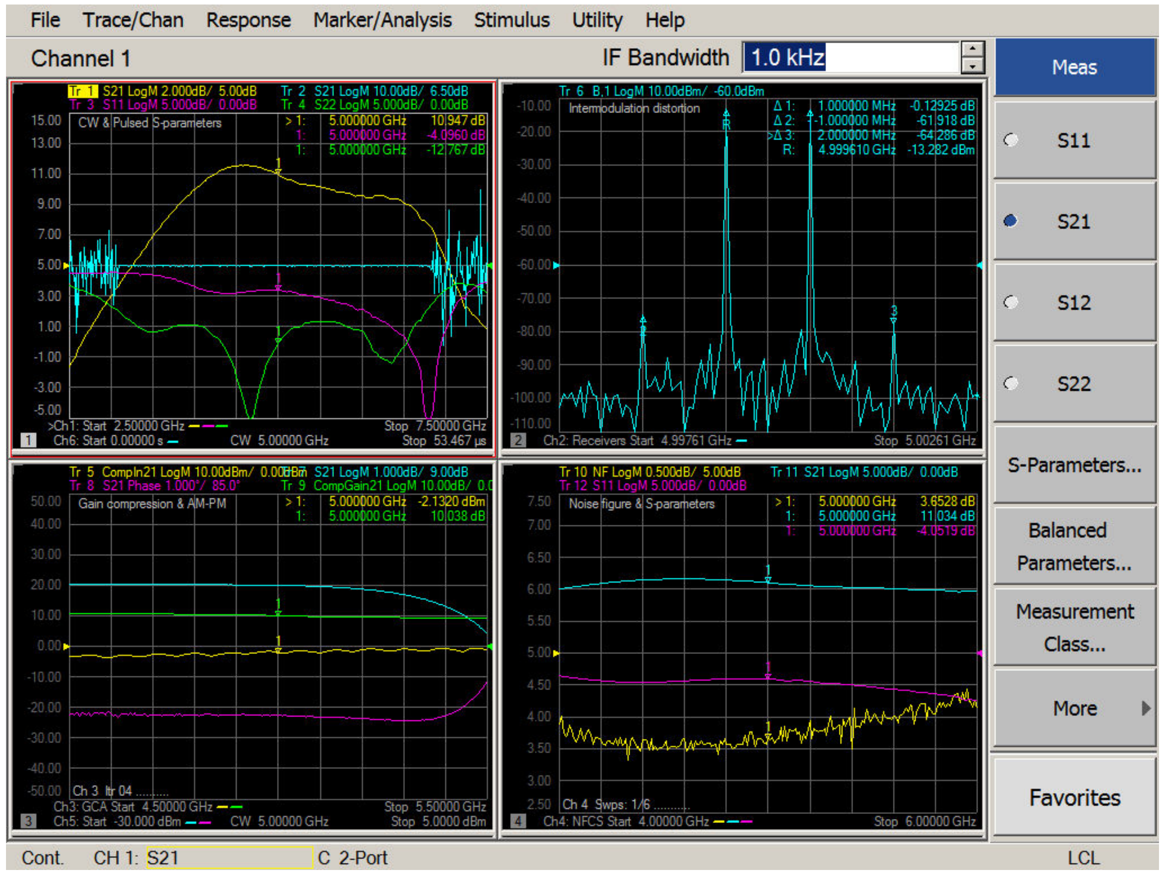

Source-corrected
Noise Figure
Measurements
for the PNA-X


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

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

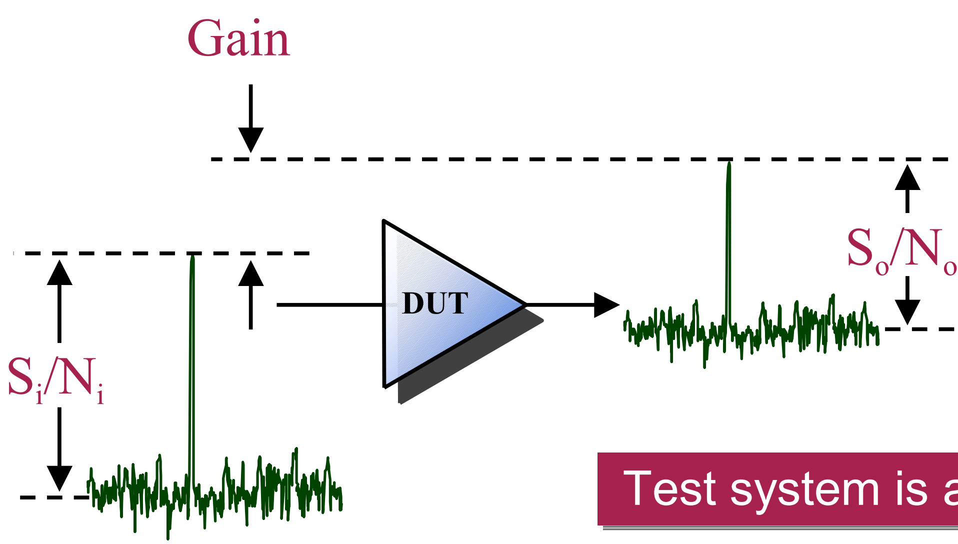


Noise Figure Definition

Noise figure is defined in terms of SNR degradation:

$$F = \frac{(S_i/N_i)}{(S_o/N_o)} = \frac{(N_o)}{(G \times N_i)} \quad \text{(noise factor)}$$

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



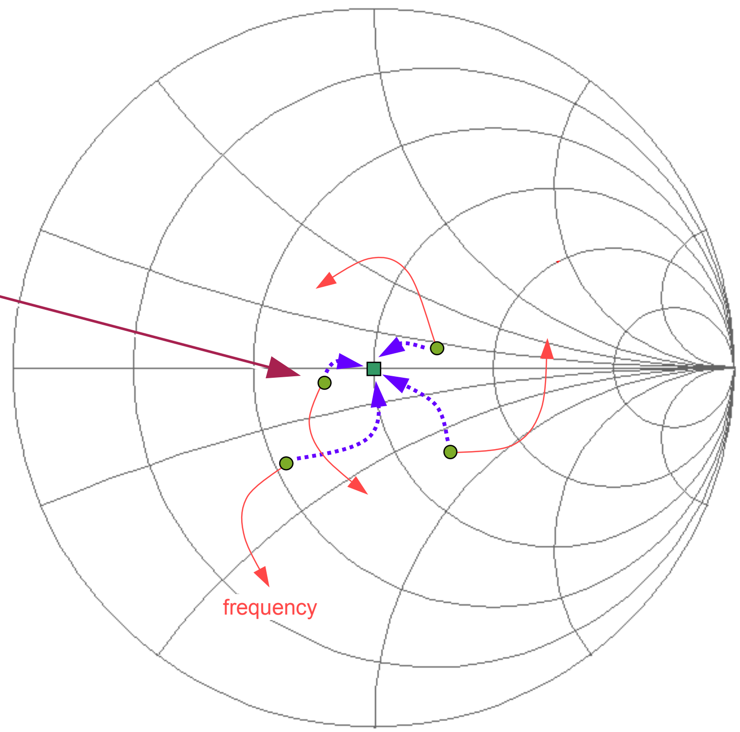
Test system is assumed to be 50 Ω

PNA-X's Unique Source-Corrected Technique

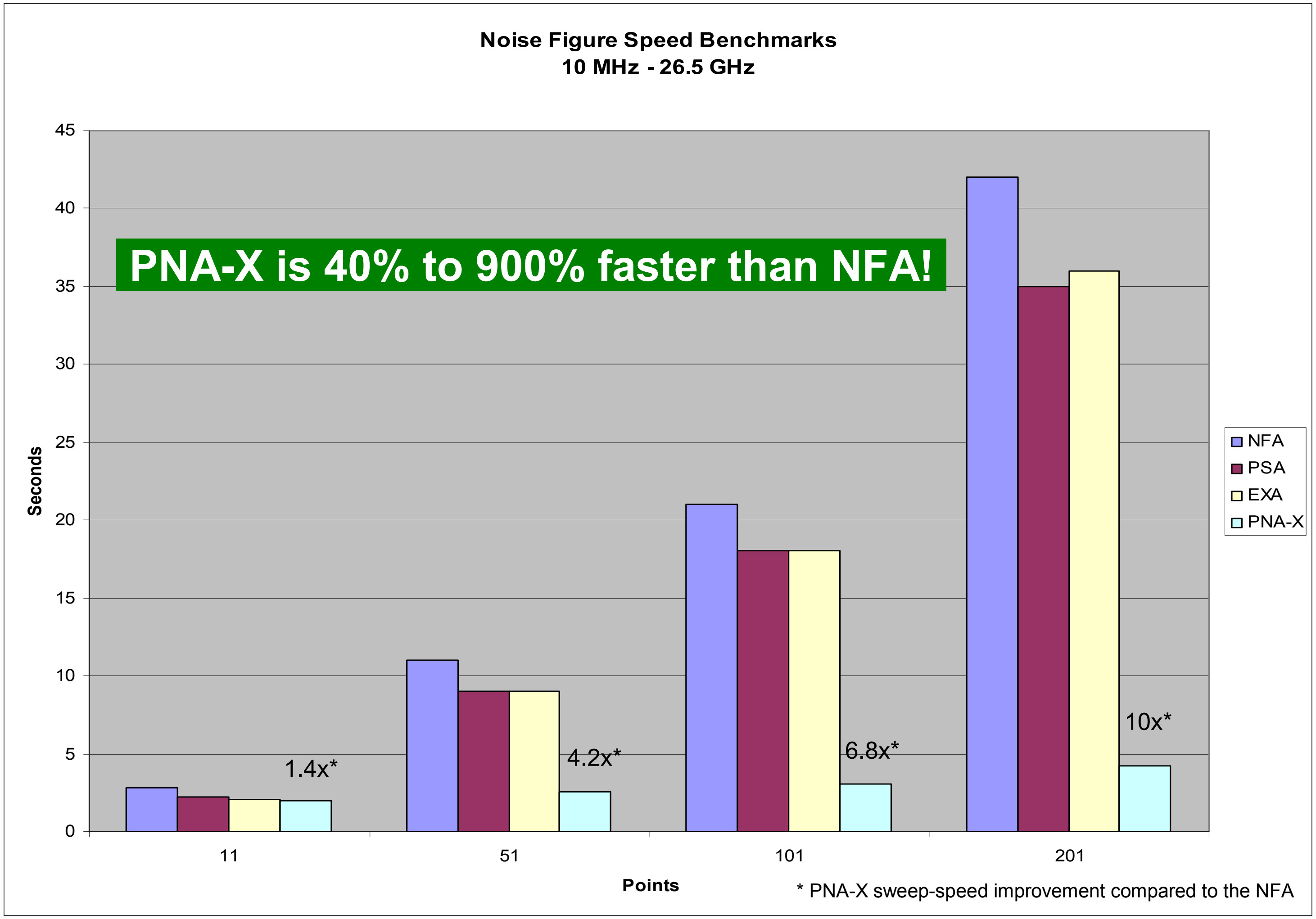
- **PNA-X varies source match around 50 ohms using an ECal module (source-pull technique)**
- **With resulting impedance/noise-figure pairs and vector error terms, very accurate 50-ohm noise figure (NF_{50}) can be calculated**
- **Each impedance state is measured versus frequency**

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

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

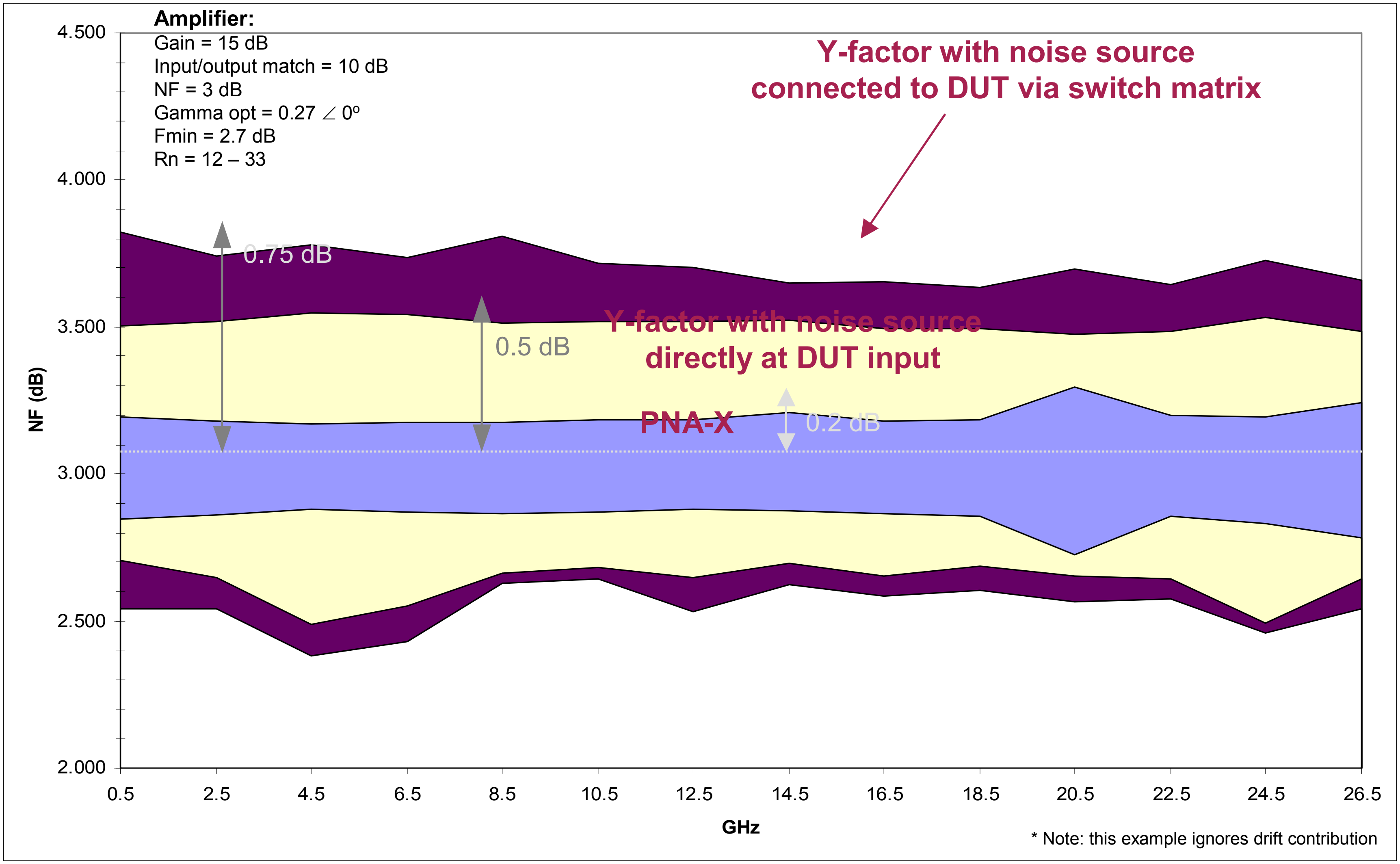


Speed Comparison: PNA-X Versus Y-Factor

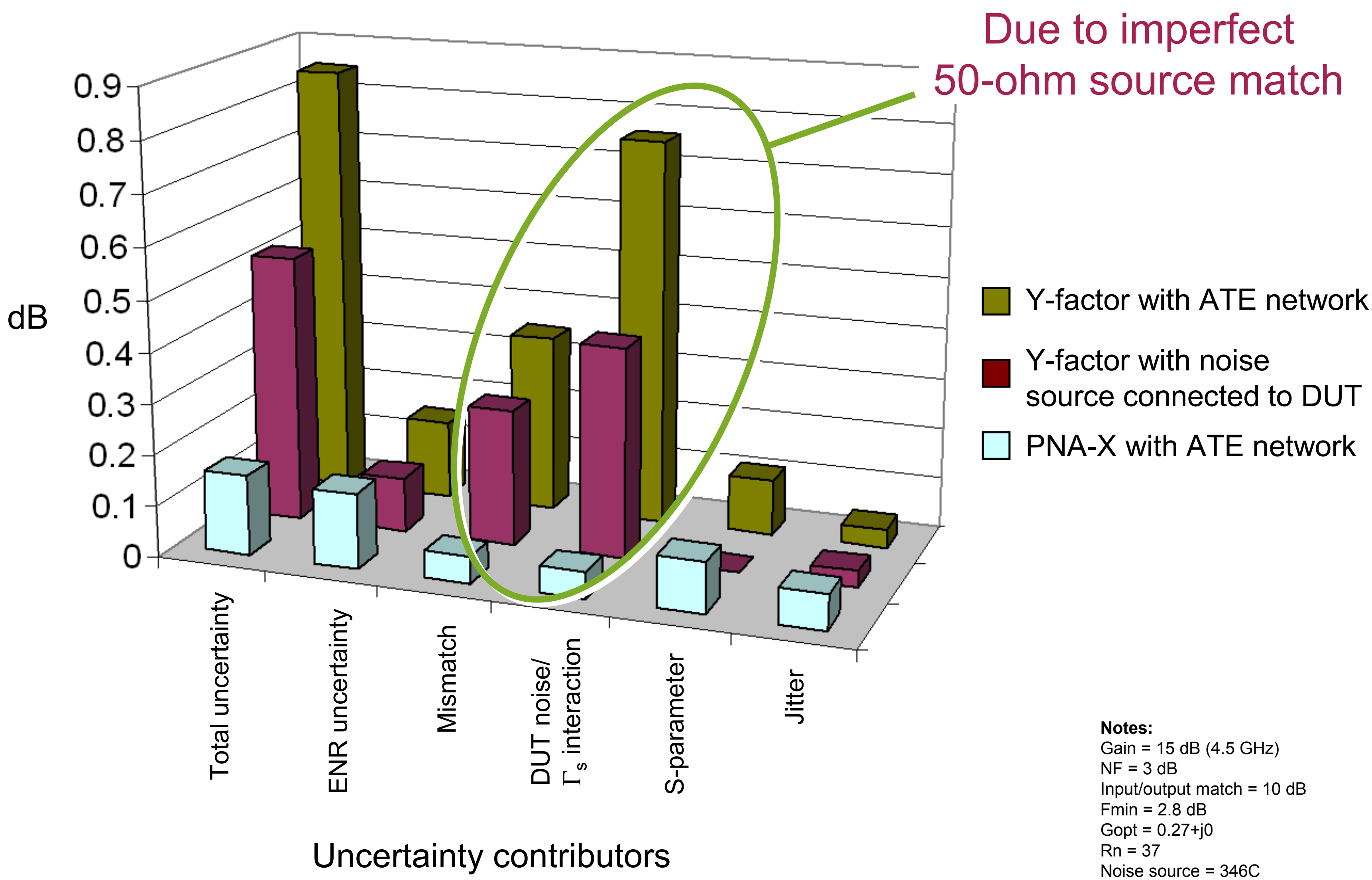


Agilent Technologies

Noise Figure Uncertainty Example (ATE Setup)

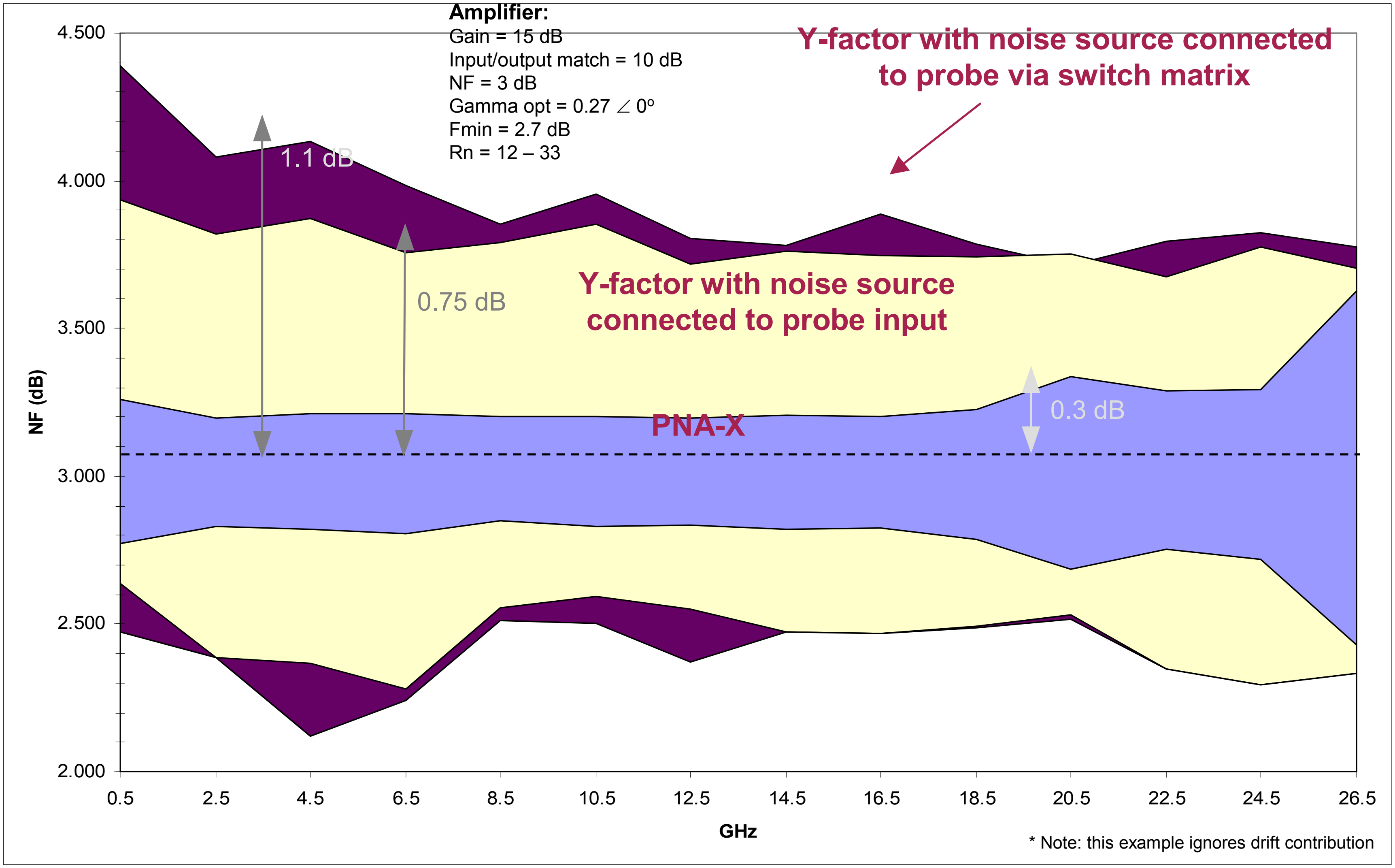


Uncertainty Breakdown (ATE Setup)

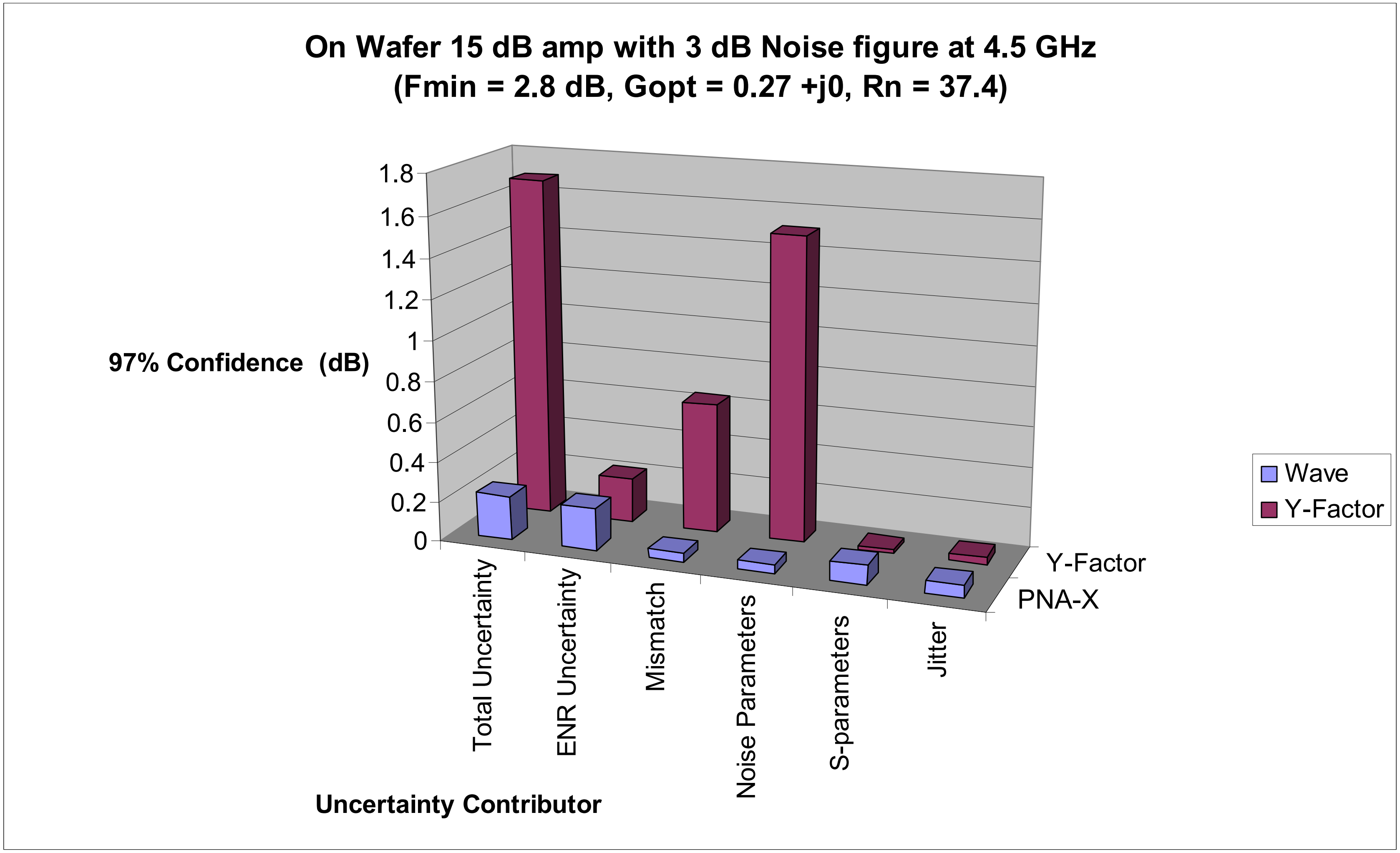


Notes:
Gain = 15 dB (4.5 GHz)
NF = 3 dB
Input/output match = 10 dB
Fmin = 2.8 dB
Gopt = 0.27+j0
Rn = 37
Noise source = 346C
97% confidence

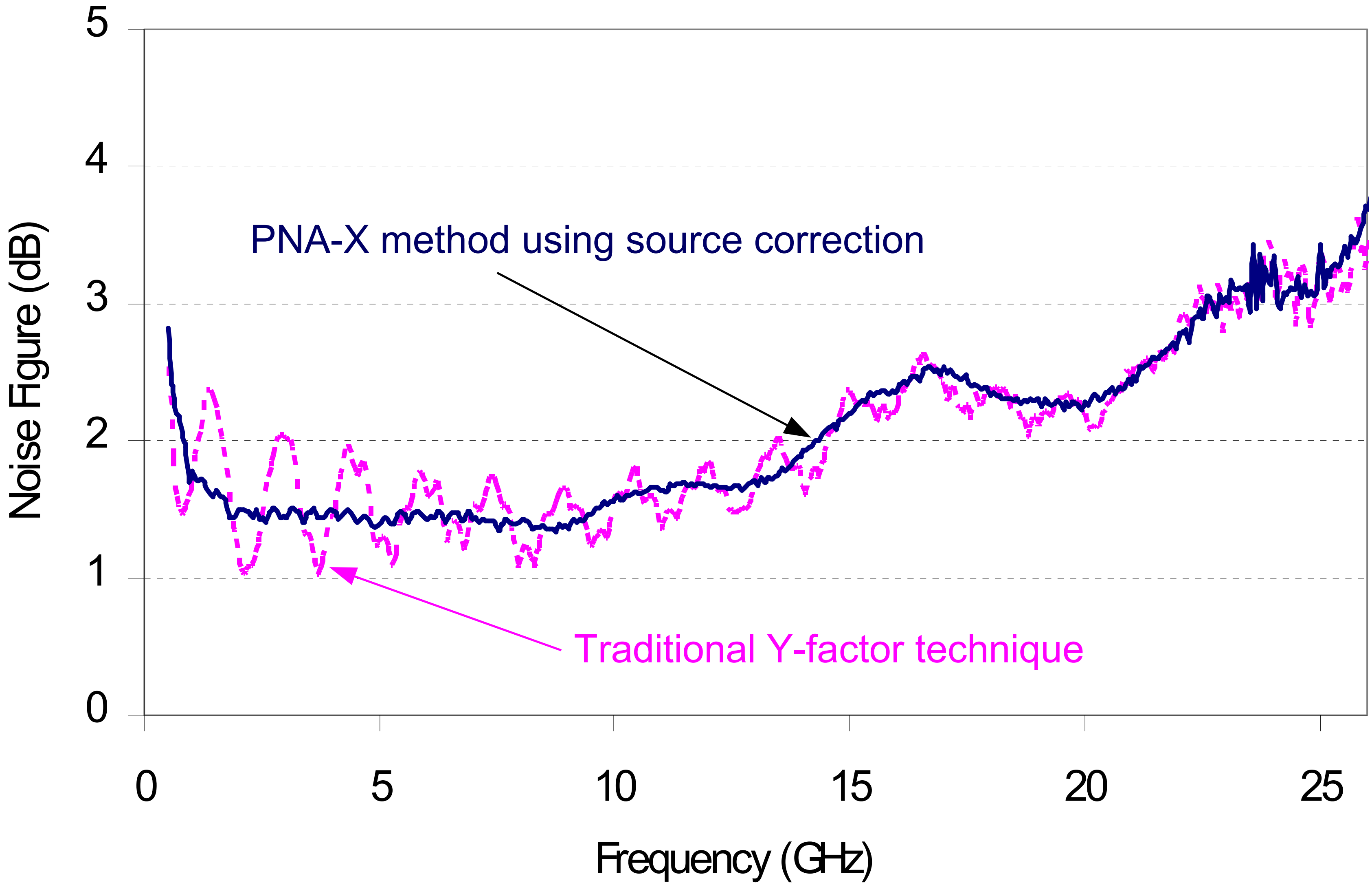
Noise Figure Uncertainty Example (Wafer Setup)



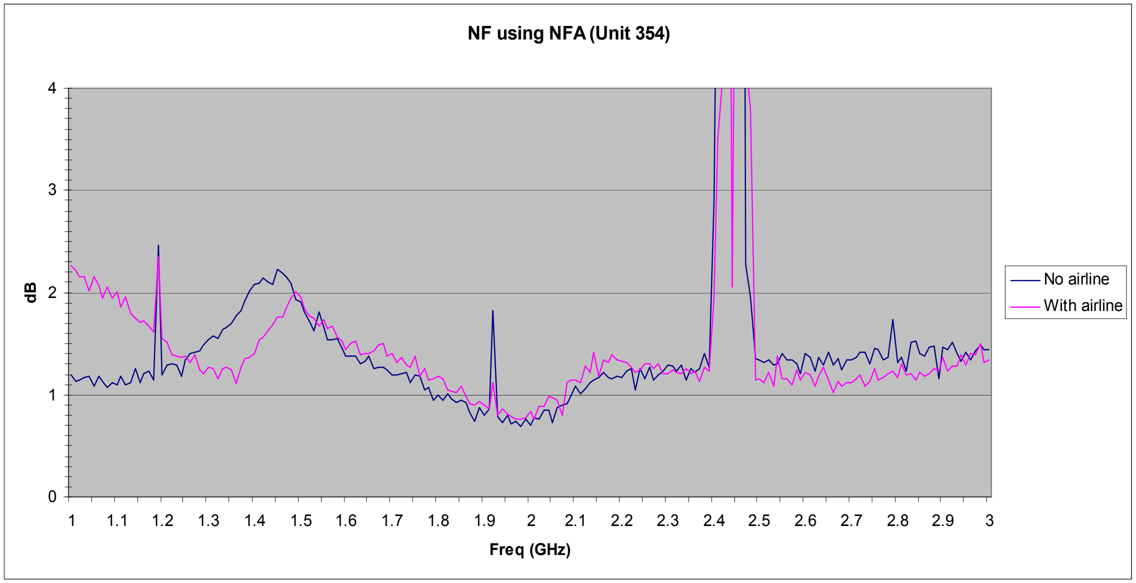
Uncertainty Breakdown (Wafer Setup)

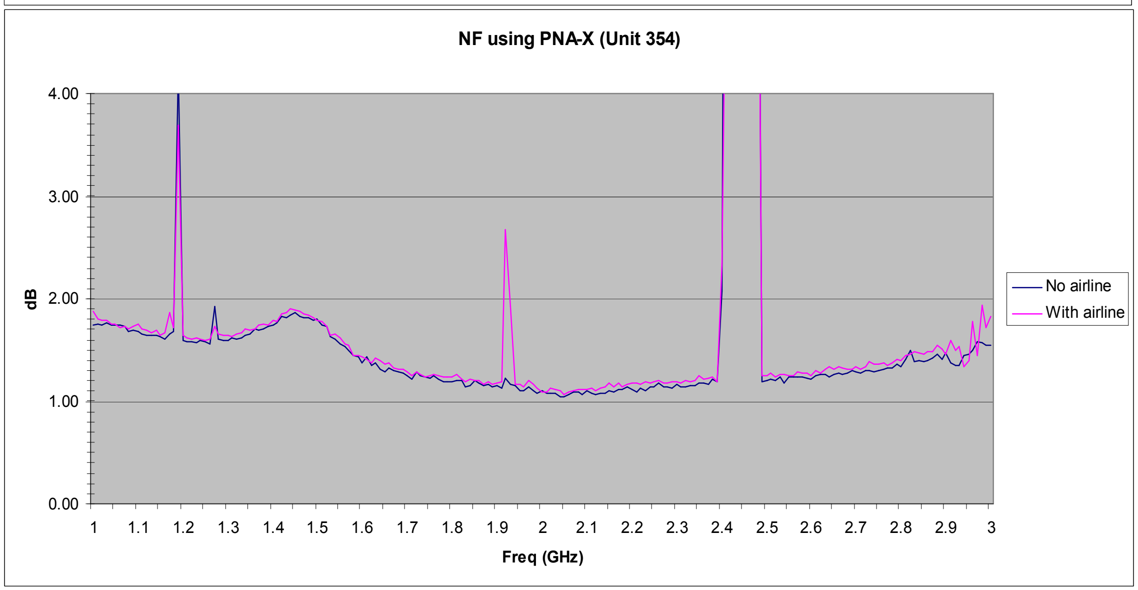


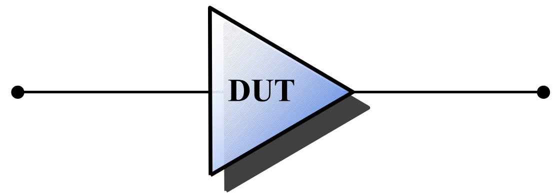
Example NF Measurements



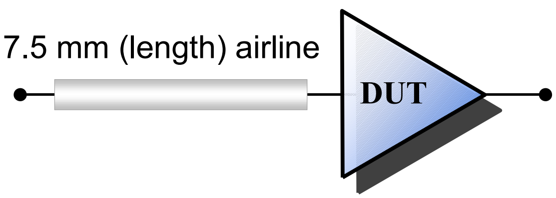
Airline Demonstration





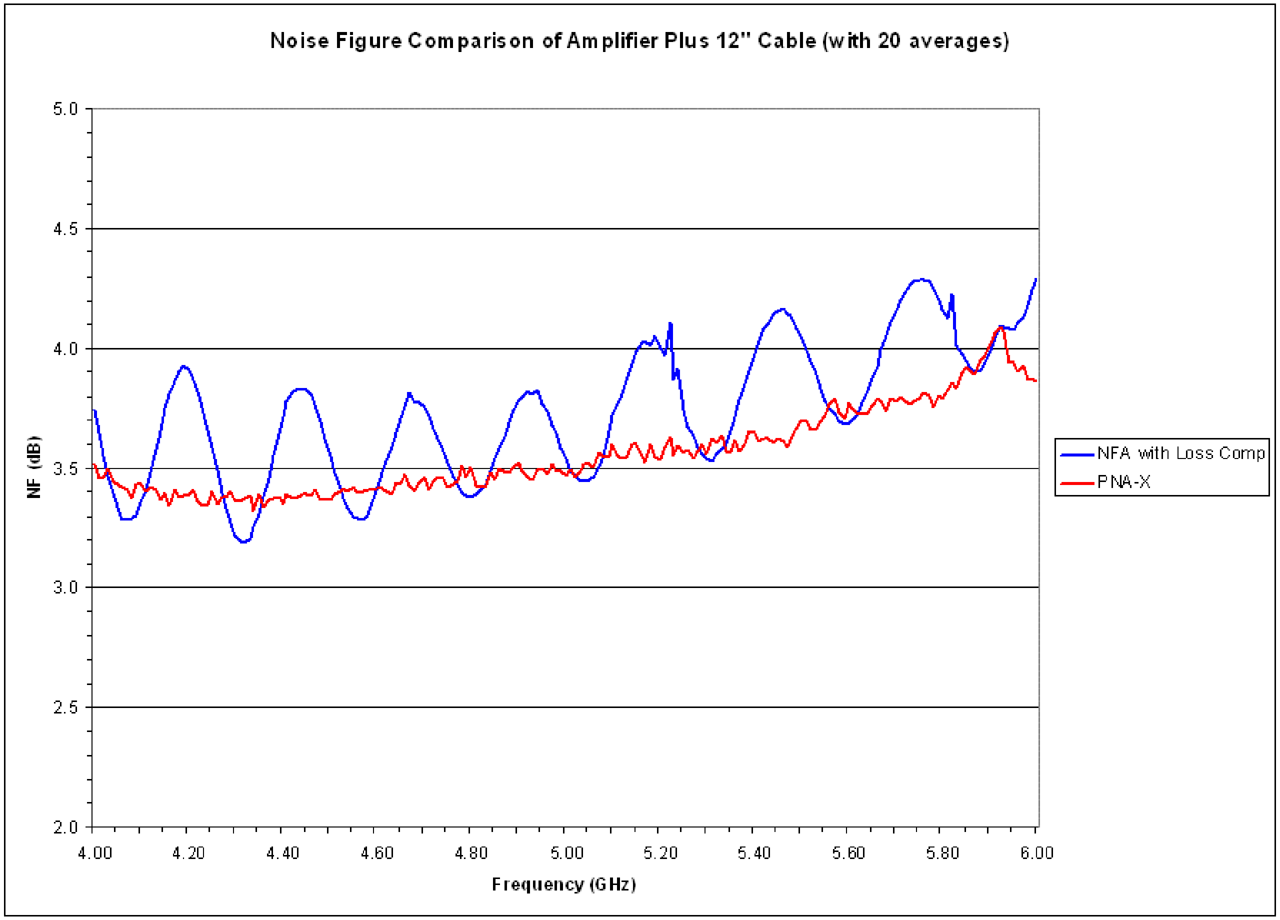


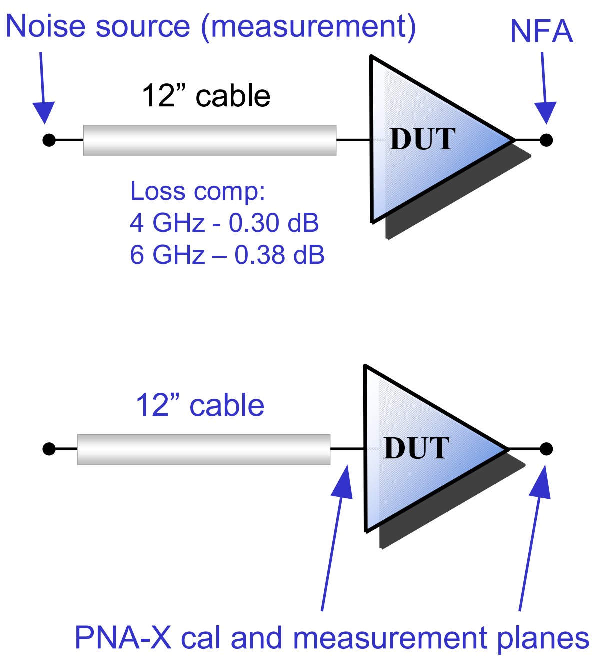
Measurement 1:
DUT alone



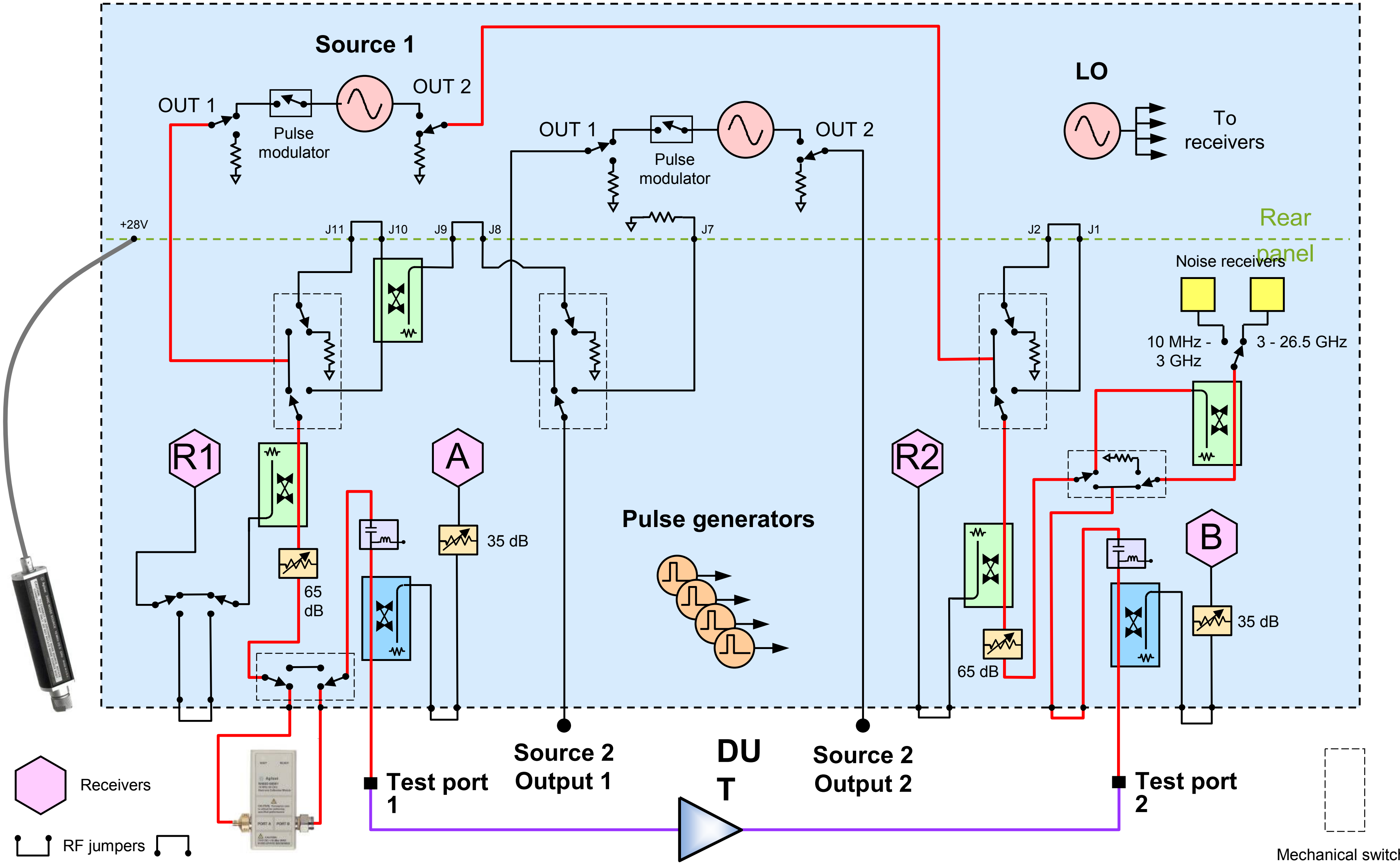
Measurement 2:
DUT with airline

NF Comparison in Pseudo ATE environment

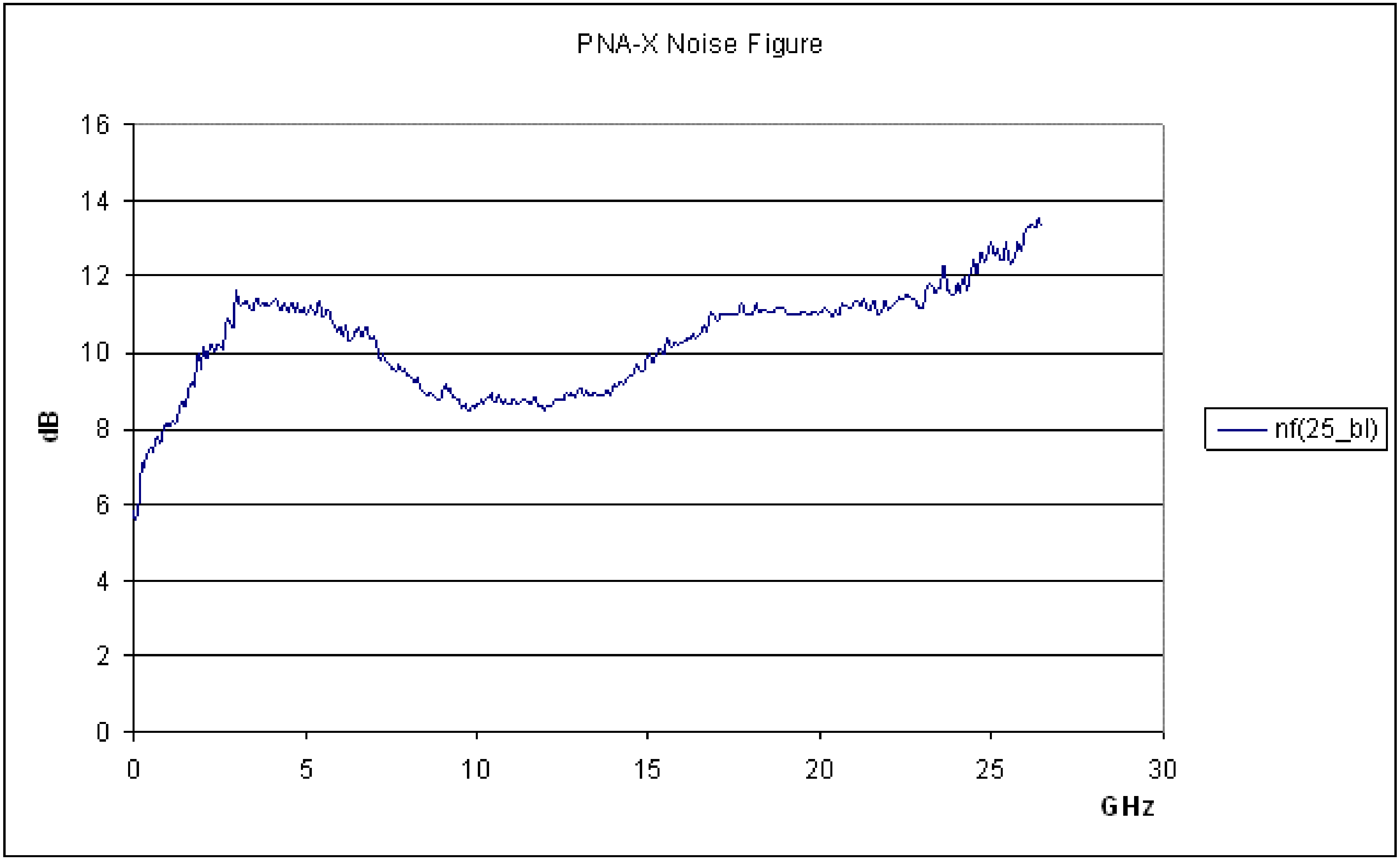




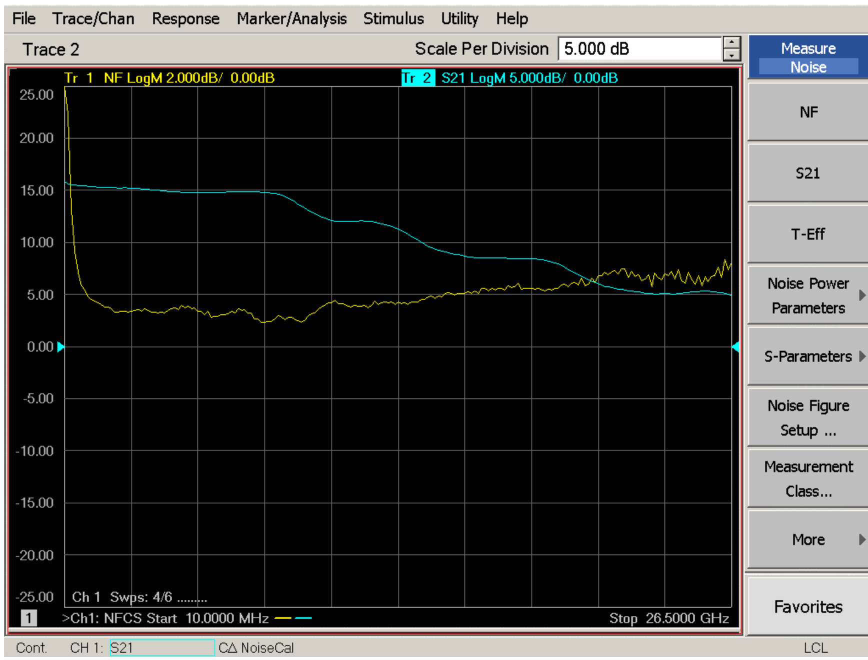
2-Port PNA-X Options 219, 224, 029

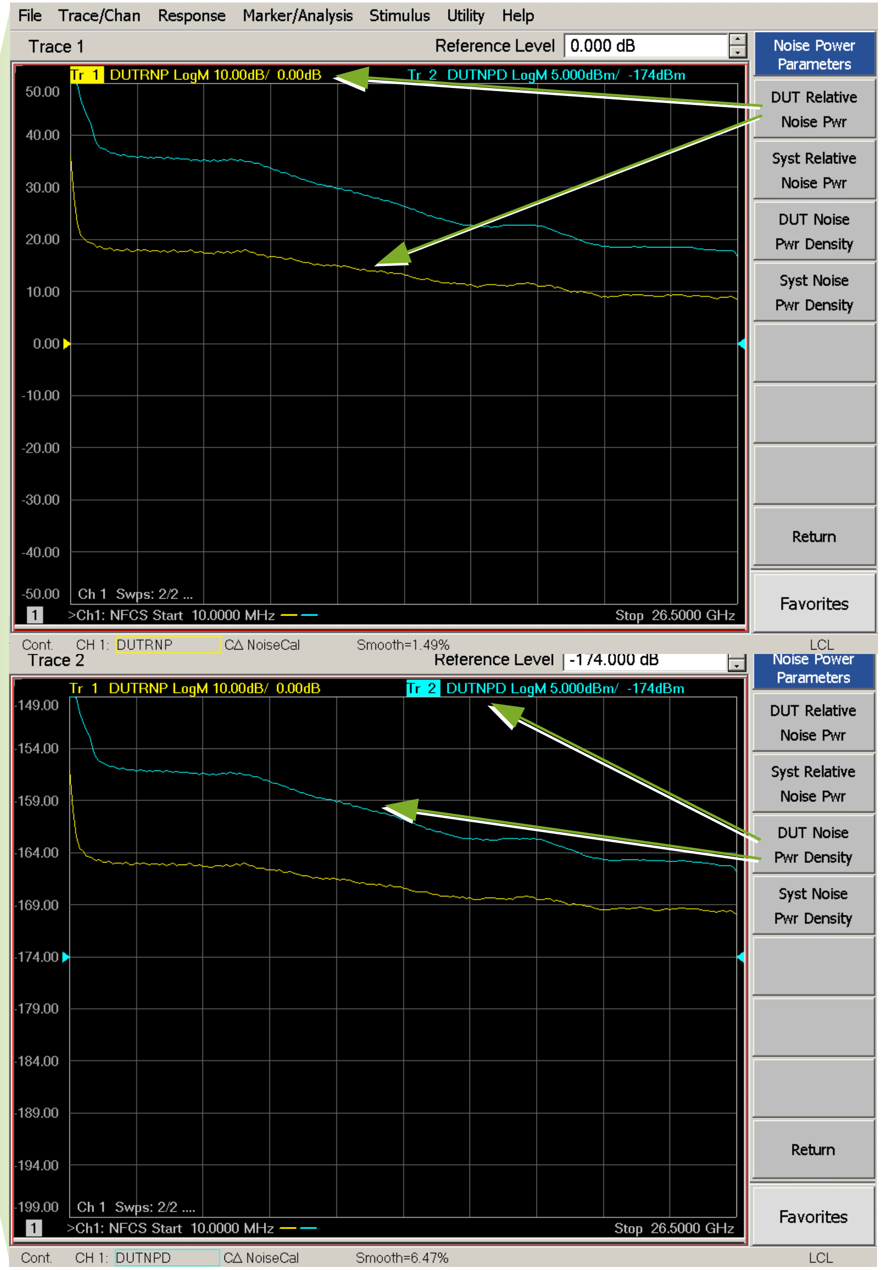


Typical Noise Figure of Port Two

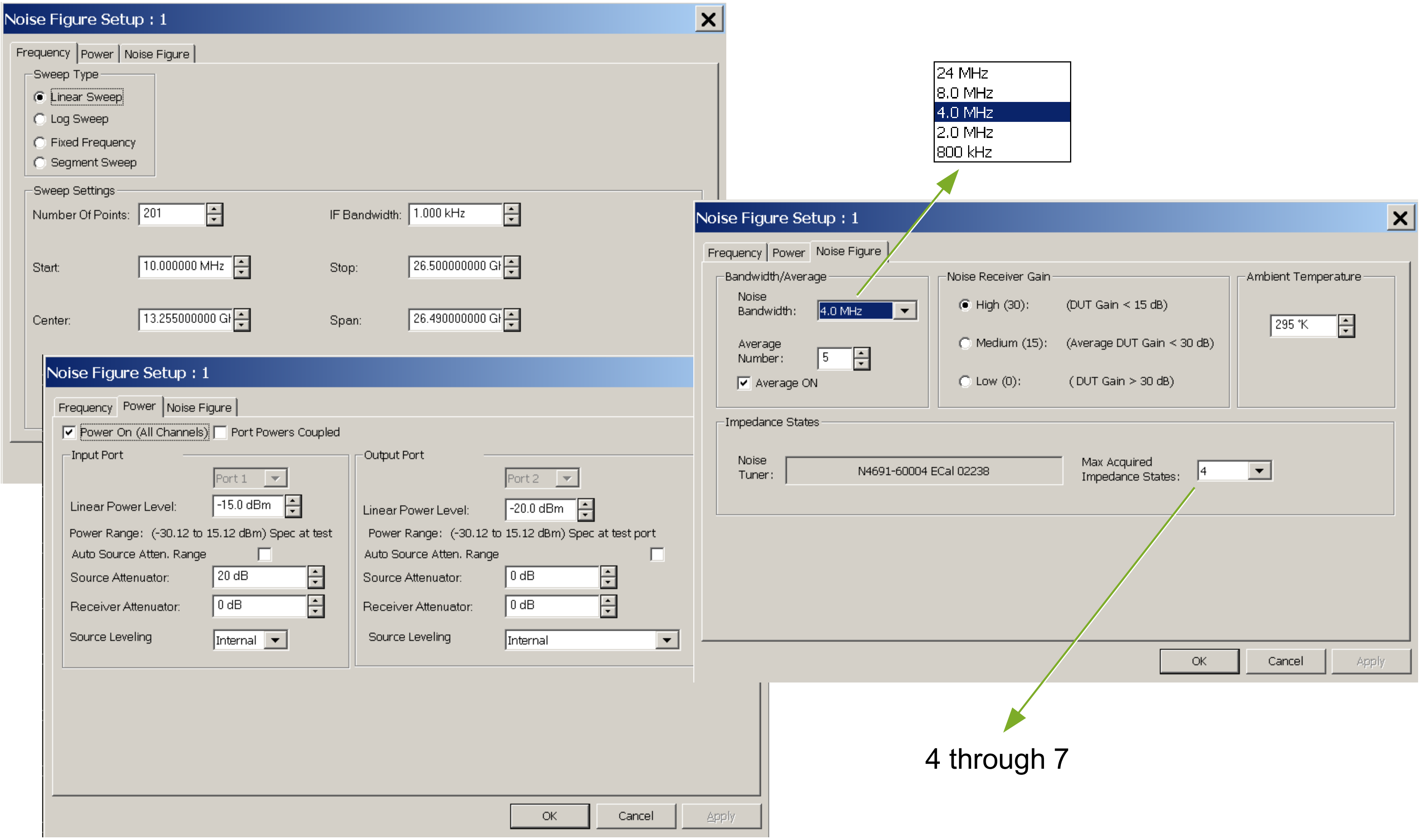


Noise Channel Parameters





Noise Figure Setup

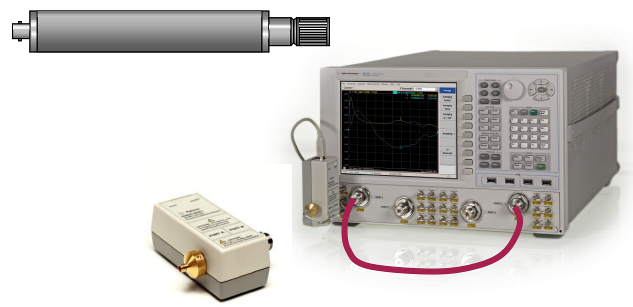


4 through 7

Calibration Procedure

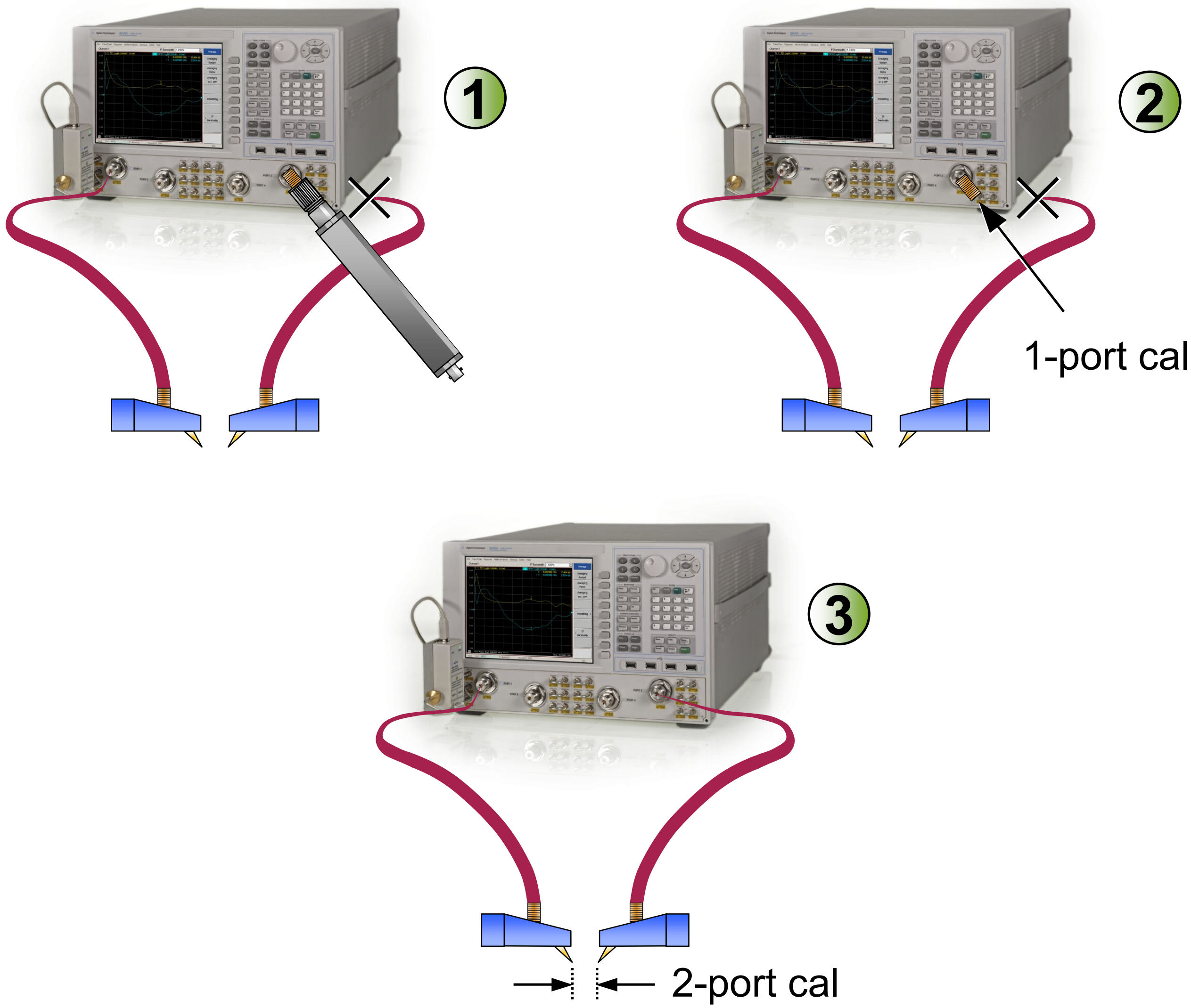
- Calibration uses sinusoidal and noise sources, plus cold terminations
- Some differences between high and low band calibrations
- Calibration sequence for simplest case (insertable)

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)

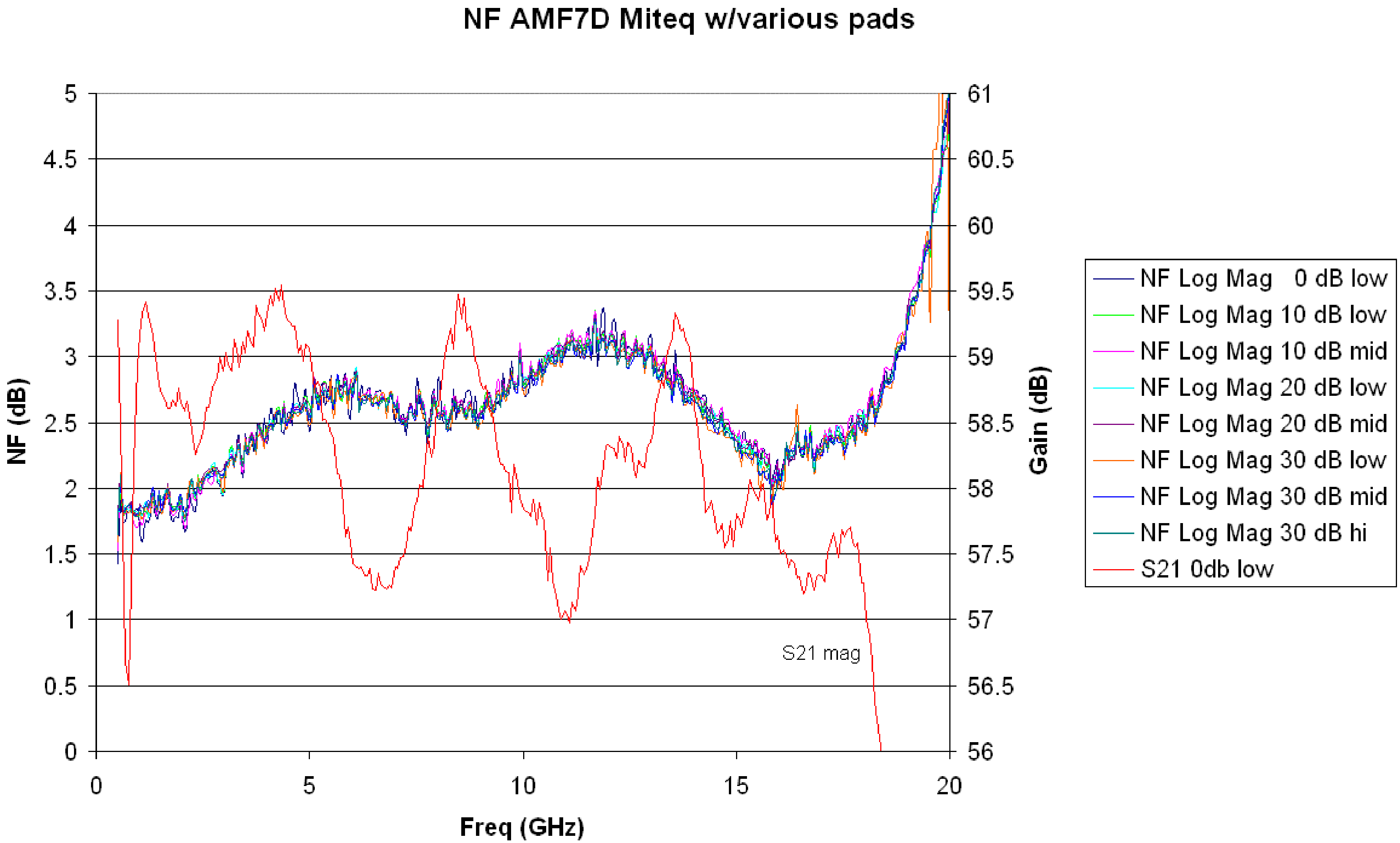


- Non-insertable cases require extra steps
    - additional 1-port calibration to account for adapter if noise source is non-insertable
    - additional S-parameter cal steps for non-insertable DUTs

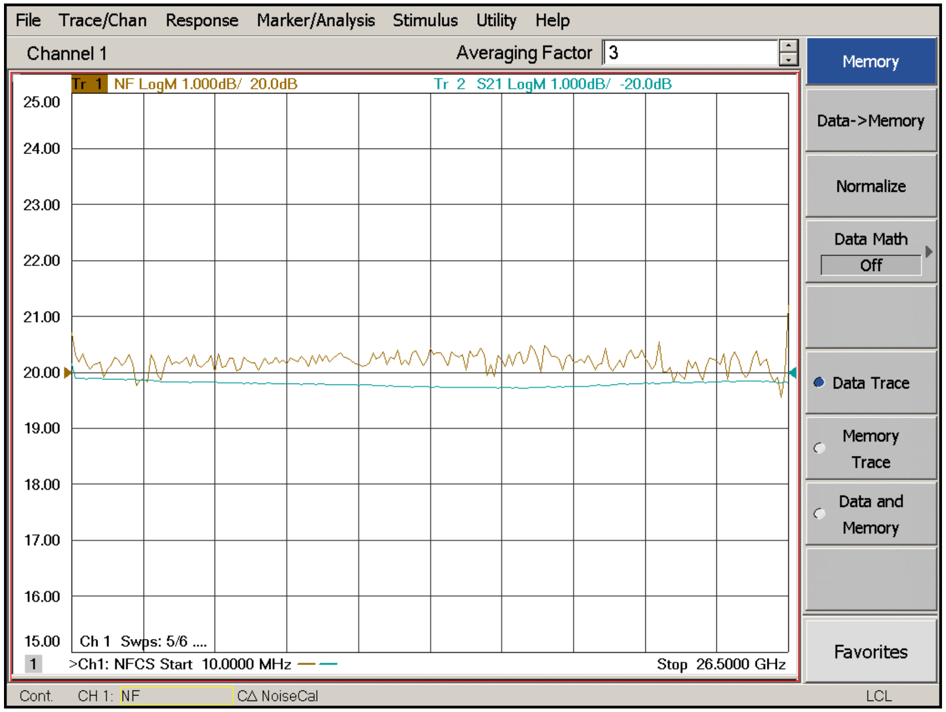
Calibrating On Wafer



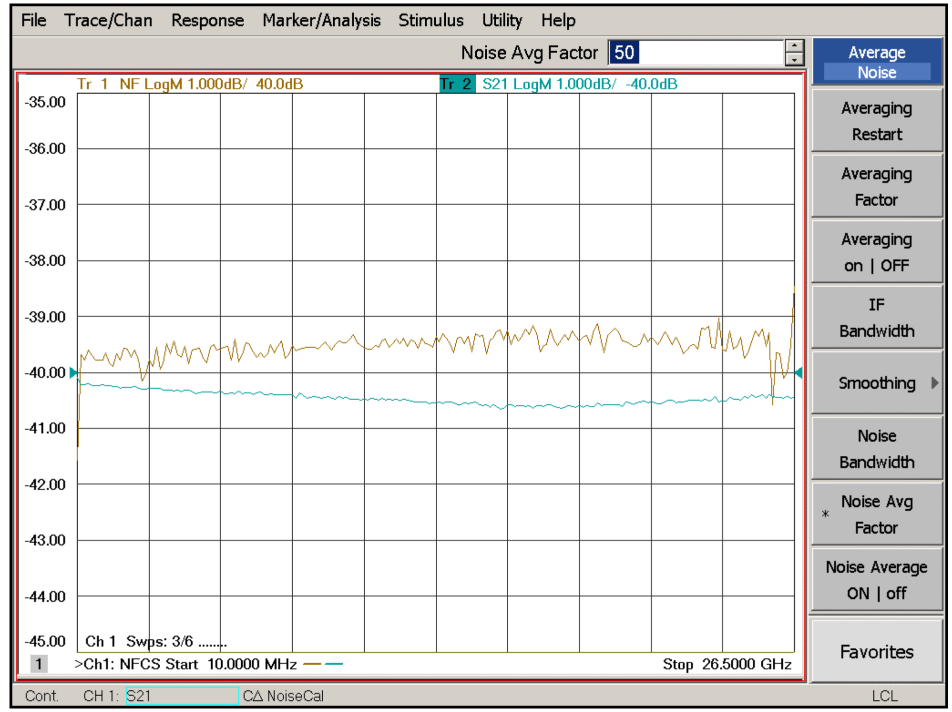
Comparison Between Gain Settings



Measuring Attenuators



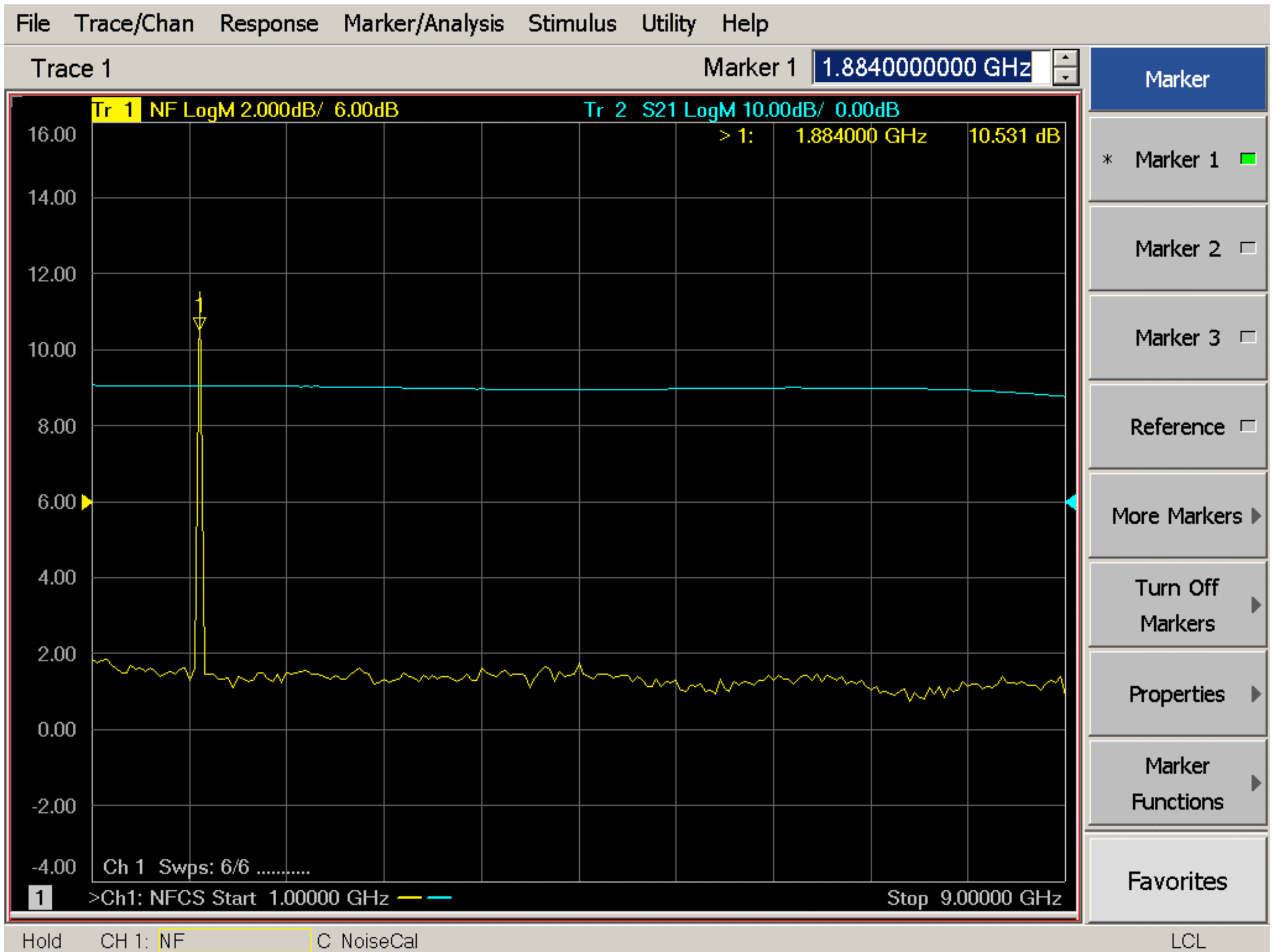
20 dB attenuator



40 dB attenuator

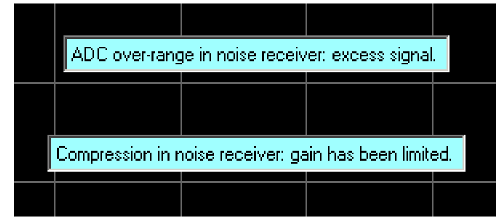
Interference

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

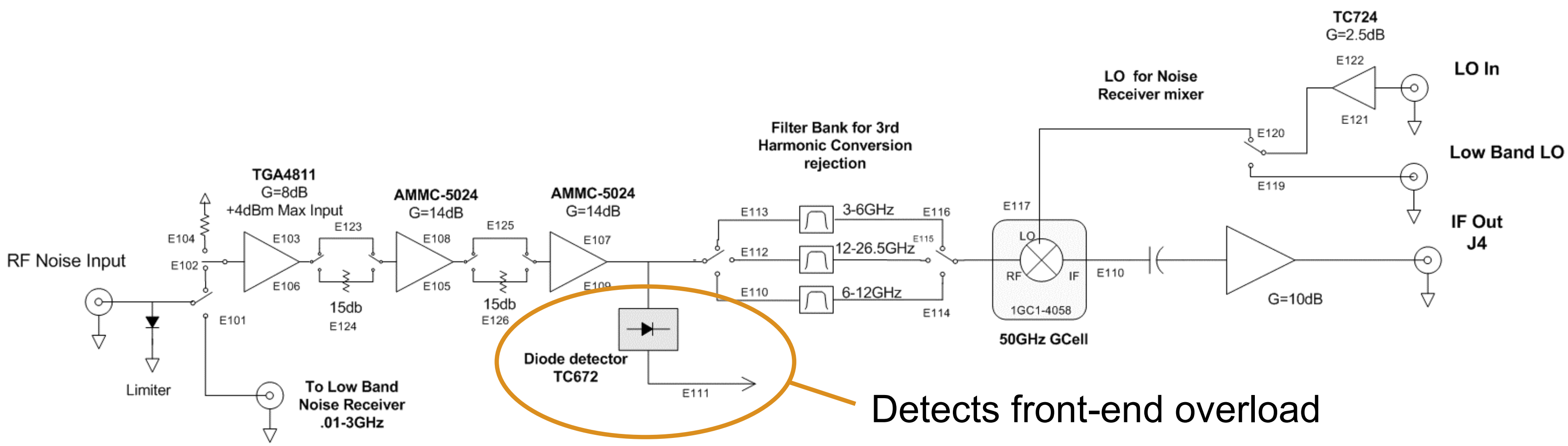


Agilent Technologies

Compression and Damage

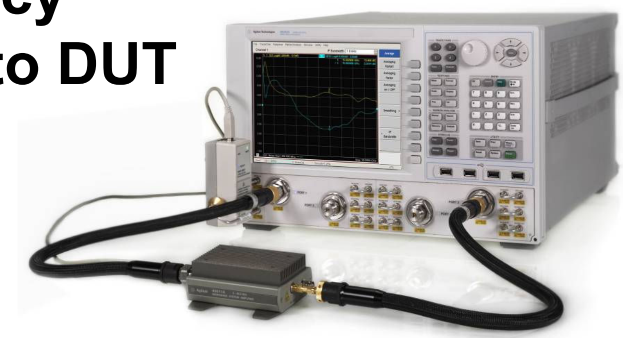


- **Compression in noise receivers:**
  - **Wideband noise compresses front-end amplifiers first**
  - **Narrowband noise likely to compress ADC before front-end amplifiers**
  - **PNA-X will report overload for both cases**
- **Damage level for noise receivers is lower than standard receivers**
  -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

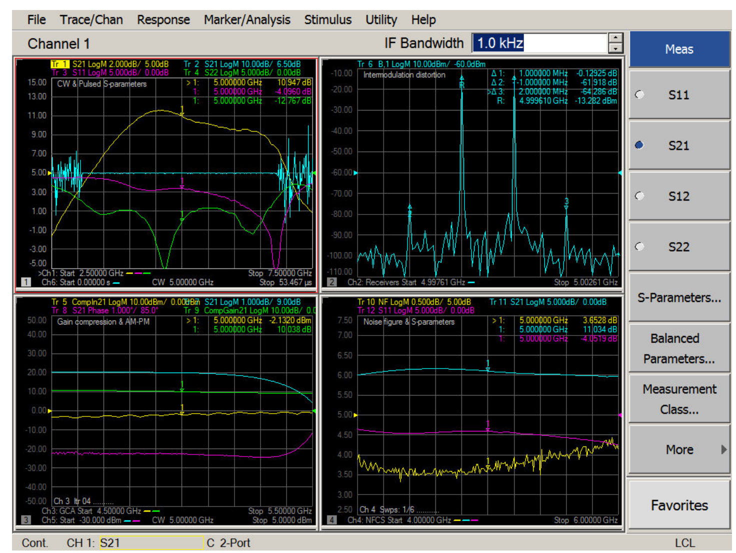


Summary

- **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