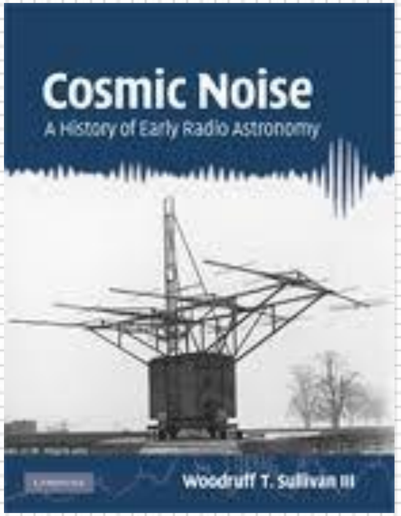
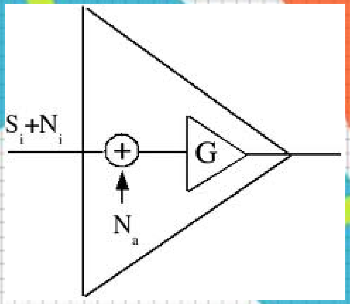
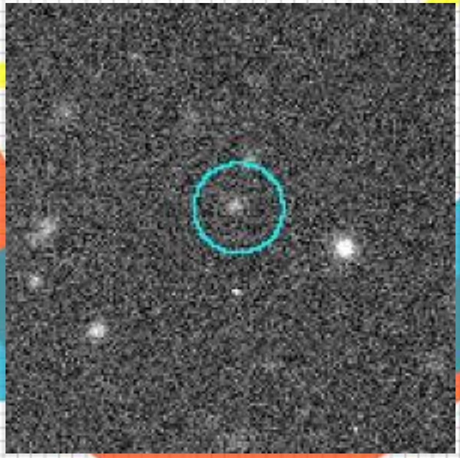


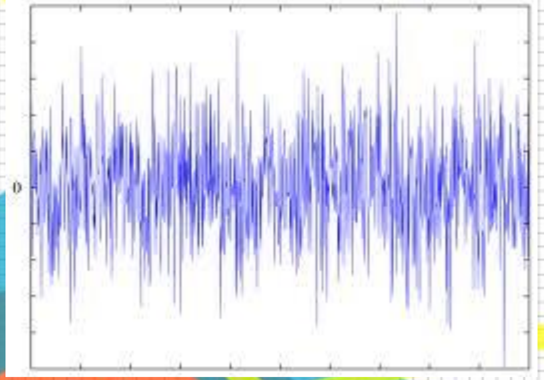
Noise Figure

Definitions and Measurements

What is this all about?...







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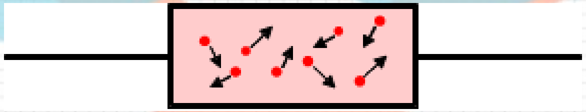
Today's Program on Noise Figure

- What is RF noise, how to quantify it,
- What is Noise Factor and Noise Figure,
- Evolution of NF over the years,
- NF in multiple stages,
- How to measure NF,
- Measurement Uncertainties,
- The challenges in designing for best NF.
- Hands on...

What is RF Noise?

- Various sources make RF Noise
  - **Thermal Noise** arises from vibrations of conduction electrons and holes due to their finite temperature.
  - **Shot Noise** arises from the quantized (not continuous) nature of current flow... electrons jump.
  - Other random Noises in electronic devices.
  - **Excludes man-made noise**
- Every real life device or component (active or passive) generates RF noise, especially if its temperature is above absolute zero K.
- Noise is what ultimately limits the performance of any system...



How to quantify RF noise?

- Thermal Noise Power

$P_N = kTB$

where P_N is the noise power (watts)
k is Boltzmann's constant, 1.38×10^{-23} J/K (joules per kelvin)
B is the bandwidth (hertz)

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

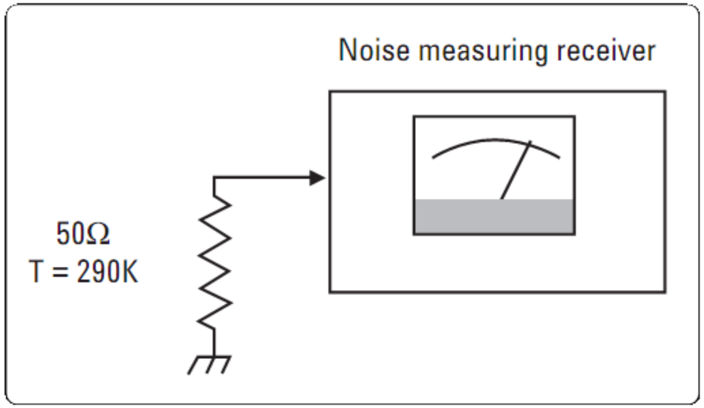


Figure 2-1 A resistor at any temperature above absolute zero will generate thermal noise.

- Equiv. Noise Temperature

$$T_e = \frac{N_a}{kGB}$$

Te = Equiv. Noise Temp. of DUT
G = Gain of DUT
Na = Additional DUT noise

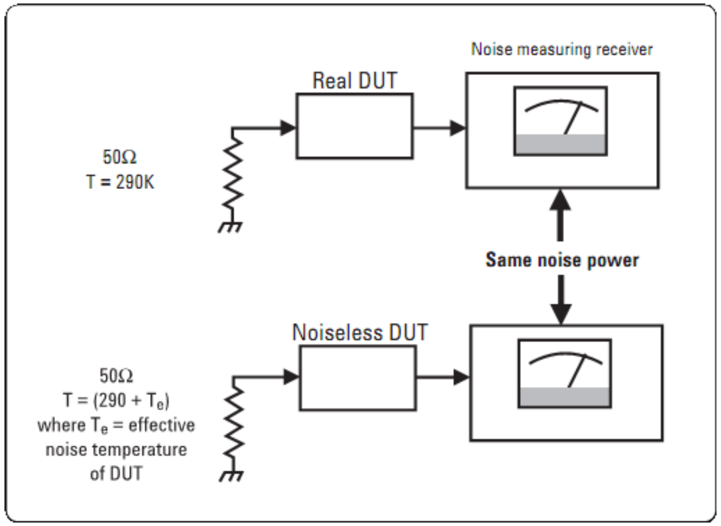
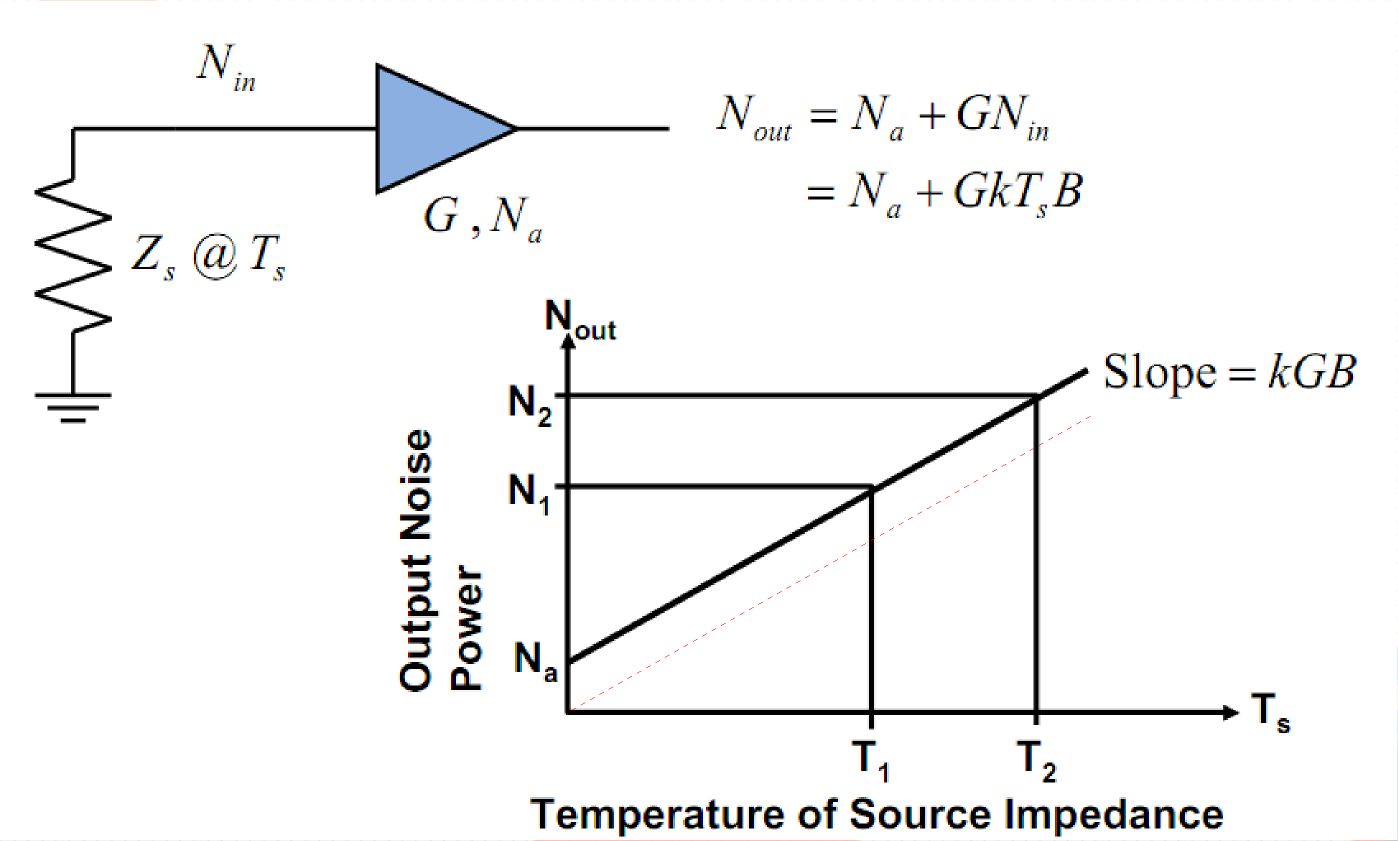


Figure 2-2 Effective noise temperature is the additional temperature of the resistor that would give the same output noise power density as a noiseless DUT.

- All types of RF noise are captured in the above definitions

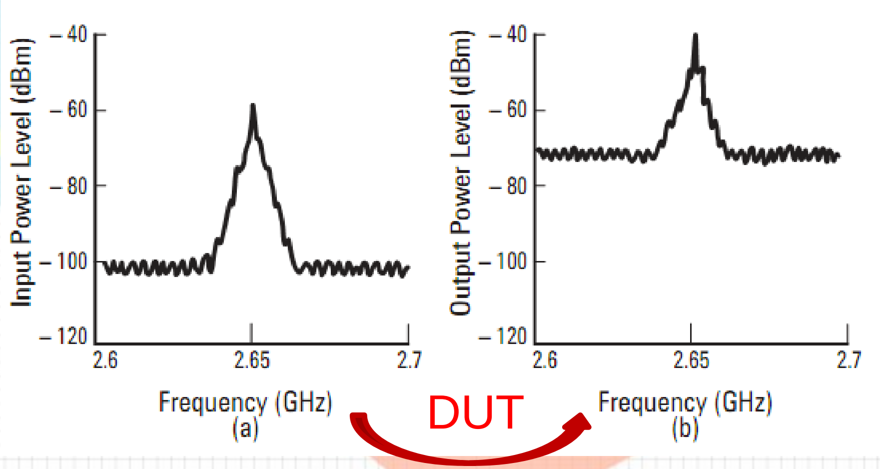
How to quantify RF noise?

- Noise Power is linear with temperature.
- DUT-added noise shifts the curve upward.



What is Noise Figure?

- Noise figure (NF) is a measure of degradation of the signal-to-noise ratio (SNR) caused by the noise generated within a system.
  - A perfect amplifier would amplify the noise at its input along with the signal, maintaining the same SNR at its input and output.
  - A realistic amplifier also adds some extra noise from its own components and degrades the SNR.



Gain = 20dB
NF = 10dB

What is Noise Figure?

- Mathematical representation

$$F = \frac{S_i/N_i}{S_o/N_o}$$

F = Noise FACTOR:
Signal-to-noise power ratio at the input divided by the signal-to-noise power ratio at the output. Always a positive value, >1.

$$F = \left(\frac{N_a + G \cdot N_i}{G \cdot N_i}\right)$$

$$NF = 10 \log F$$

NF = Noise FIGURE:
Logarithmic representation of Noise Factor, expressed in dB. Always a positive value, >0.

$$F = 1 + T_e / T_o$$

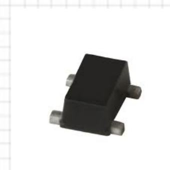
where T_o = 290 K

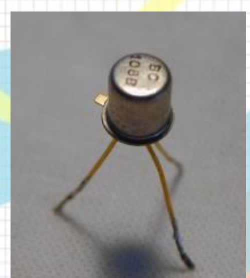
Noise figure NF	Noise factor F	Noise temperature T_e
0dB	1	0K (absolute zero)
1dB	1.26	75.1K
3dB	2.00	290K
10dB	10	2,610K
20dB	100	28,710K

An Idea of NF Over The Years

1940-1960:	Tubes, Nuvistor, BJT:	> 3dB
1960-1980:	BJT, FET, MOSFET:	1dB-3dB
1980-2000:	GaAs FET:	0.5dB-1dB
2000-...:	HEMPT, pHEMPT:	< 0.2 dB





NF in Multi-Stage Systems?

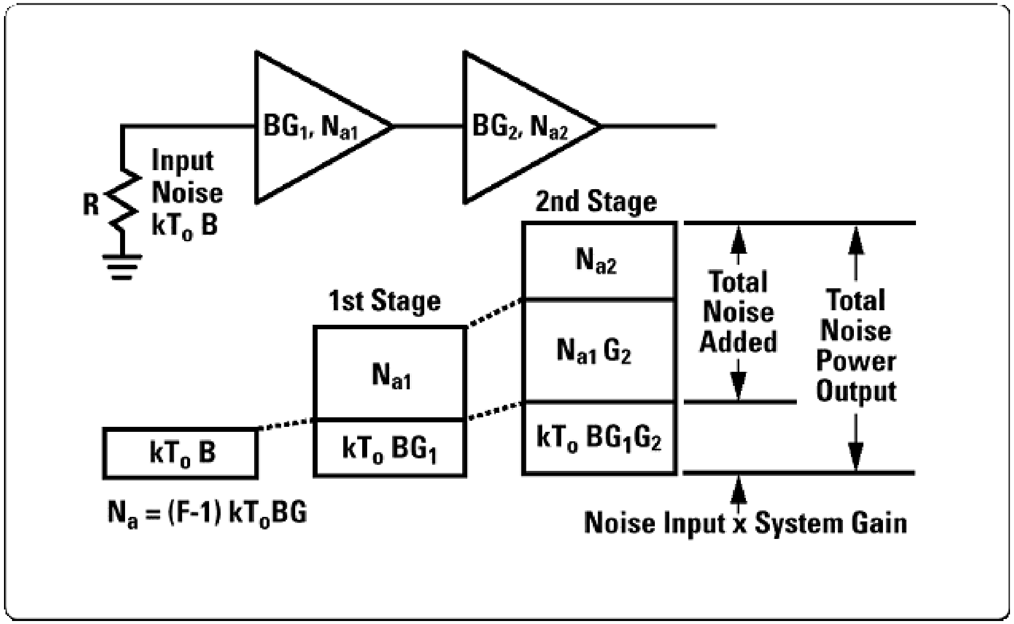


Figure 2-3. How noise builds up in a two-stage system.

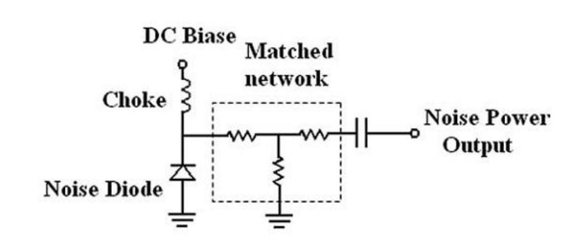
$$F_{sys} = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} + \ldots \frac{F_n - 1}{G_1 G_2 \ldots G_{n-1}}$$

If G_1 (gain of first stage) is sufficiently large, System NF is mostly dominated by first stage NF.

This is why Preamp NF is so important in low noise Rx applications (VHF/UHF/uWave)

How to Measure NF ?

- Easiest way to measure NF involves the use of a calibrated Noise Source
  - Usually made of a stable noise diode and attenuator.
  - Calibration data provides Excess Noise Ratio (ENR) expressed in dB.
    - ENR is the difference in Noise Power (N) between “ON” and “OFF” source conditions.
    - Sources typically come with ENR of 5dB or 15dB.
    - Expressed vs. Frequency (tabular).



$$ENR_{dB} = 10 \log \left(\frac{T_h - T_c}{T_o} \right)$$

T_h: T of active source
T_c: T of inactive source
T_o: 290° Kelvin

How to Measure NF ?

- What techniques used?
  - **Y Factor Method: The most used, accurate, repetitive.**
    - Noise Figure Meter: The simplest and fastest.
    - Spectrum Analyzer: More tedious and labor-intensive. Requires modern S.A. Not quite as accurate.
  - Signal Generator Twice-Power Method: OK for high NF
  - Direct Noise Measurement Method: OK for high NF
- What instruments required?
  - Noise Figure Meter: Best but more expensive -> dedicated.
  - Spectrum analyzer: More common but less accurate
  - Known bandwidth receiver: Much cheaper...
  - Build your own? See reference at end of presentation.

Y-Factor NF Measurement Method

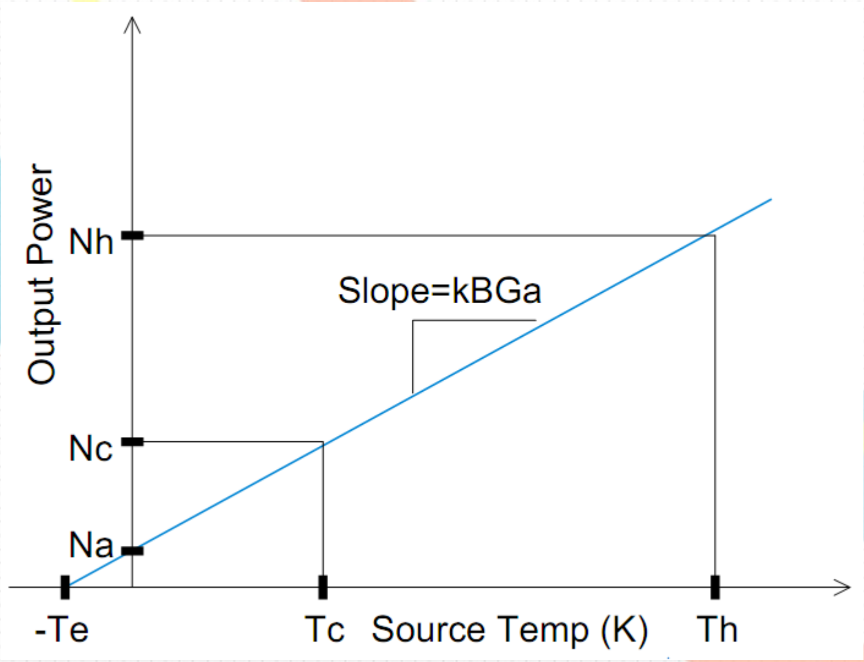
- Used by most NF meters and Spectrum Analyzers
- Can be automated or performed manually,
- Calibrated Noise Source required,
- DUT gain not required,
- Accurate, repetitive.

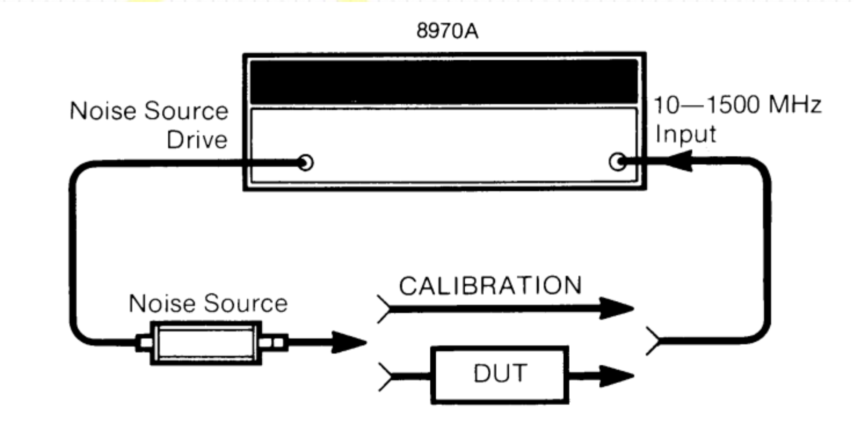
Y-Factor NF Measurement Method

- Two-Step Method
  - Calibration: Necessary to correct for the noise contribution of the test system and take temperature into account. Includes the input of the ENR data into the meter. Doing a “zero” by measuring Nh and Nc.
  - Measurement: Introduces the DUT. Again, measuring Nh and Nc. Yields NF and Gain.

$$Y = Nh / Nc = Th / Tc$$

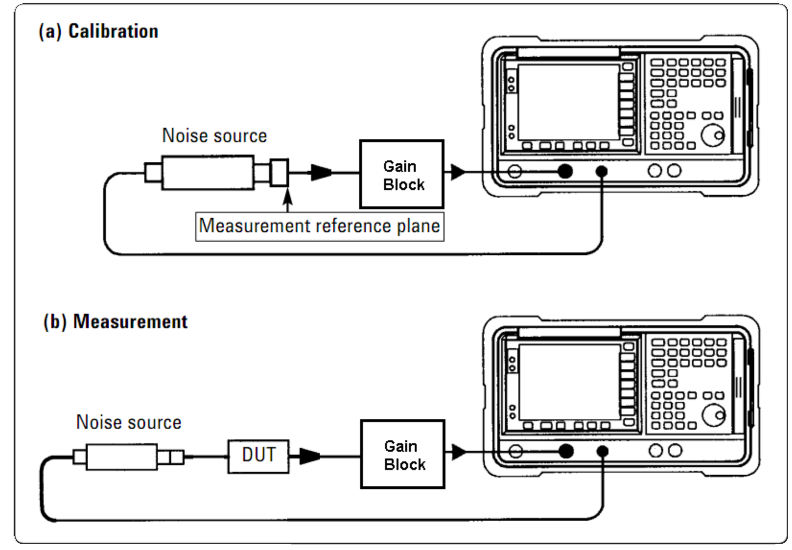
$$F = \frac{ENR}{Y-1}$$





Y-Factor NF Measurement Method

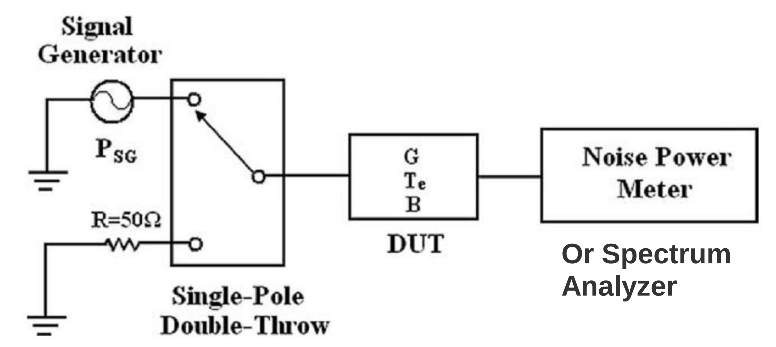
- ...Using a Spectrum Analyzer
  - Requires modern S.A that computes Noise Spectral Density dB/Hz of plotted spectrum (computerized S.A.).
  - Four measurements must be made.
  - Requires a calibrated noise head...
  - Requires the 1-3MHz Resolution Bandwidth option to pick up enough noise for a meaningful measurement.
  - Needs at least 30-40dB of low noise gain block ahead of the S.A. to compensate for its poor input noise figure.
  - Will work for NF values as low as a 1-2 dB. But likely not accurate/stable/linear enough for sub-dB NF measurements.



–See VE2AZX reference.

Other NF measurement Methods

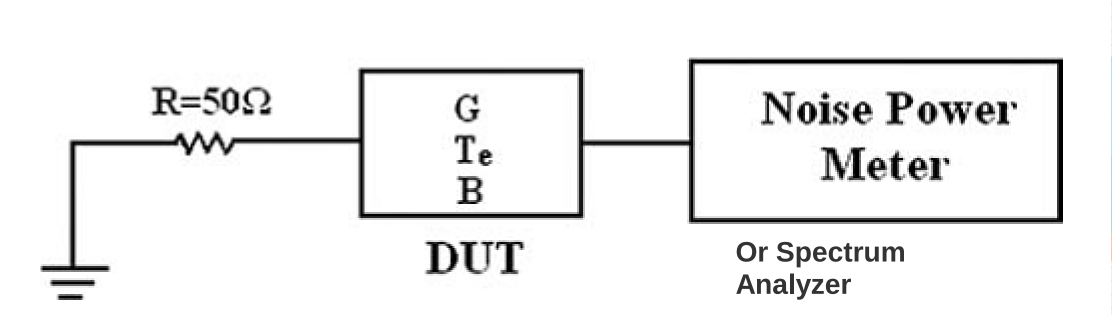
- Signal Generator Twice-Power Method
  - Does not require a Noise Source,
  - Useful for High NF devices,
  - Need to know Rx Bandwidth,
  - Two step Method
    - Measure output power of terminated input DUT @ ~290K.
    - Attach Signal Generator to input and adjust it to produce a 3dB increase in output power. The signal generator output power is equal to the total output noise power divided by the gain of DUT. Use formula below:



$$F_{sys} = \frac{P_{gen}}{kT_0B}$$

Other NF measurement Methods

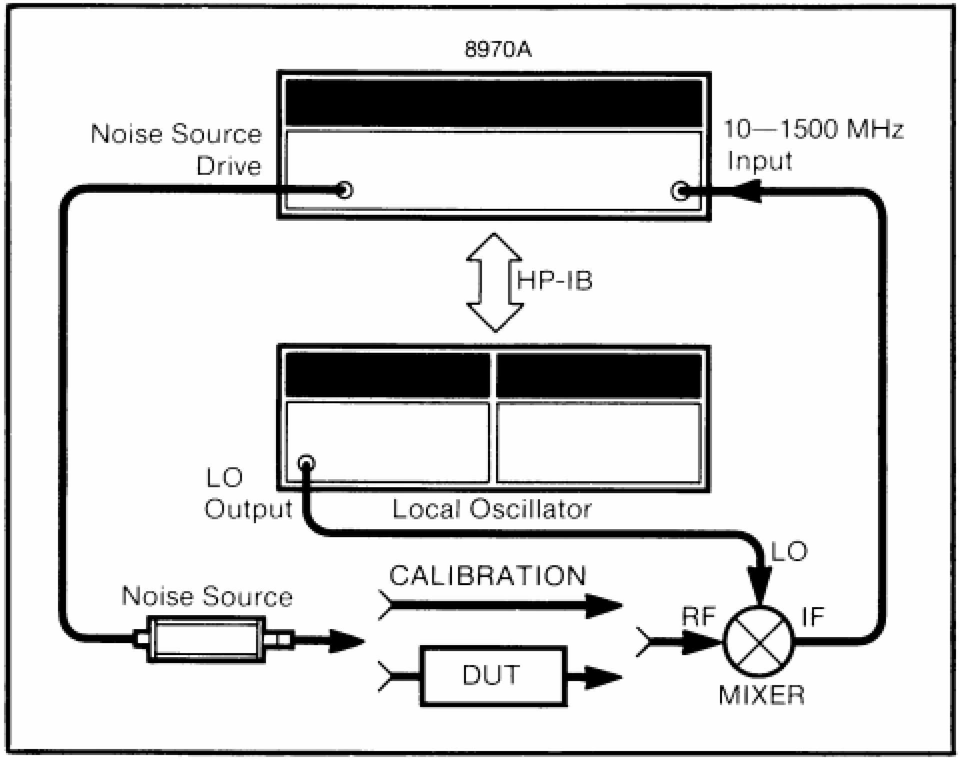
- Direct Measurement Method
  - Does not require a Noise Source.
  - Useful for High NF devices
  - Need to know DUT Gain, Rx Bandwidth
  - One step Method
    - Measure output power of terminated input DUT @ ~290K. Use formula below:



$$F_{sys} = \frac{N_o}{kT_oBG}$$

Measuring NF in the Microwaves?

- Use an external Microwave Signal Generator
- Add a Double-Balanced Mixer



Measurement Uncertainties?

- One must understand the potential measurement uncertainties.
  - Actual temperature at measurement time
  - Uncertainties increase as gain of DUT decreases
  - Uncertainties increase as NF of DUT increases
  - Externally induced noise (Lights, Power supplies, RF sources, noisy LO...)
  - Impedance mismatch between source and DUT.
  - Be careful with coaxial adapters and cables introduced or removed after calibration.

NF Meas. 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. See Agilent Calculation spreasheet.
- Minimize the number of adapters, and take good care of them.
- Avoid DUT non-linearities. Avoid S.A. non-linearities.
- Use Averaging to Avoid Display Jitter.
- Choose the Appropriate Bandwidth.
- Calibrate Noise Source ENR values regularly and use good pedigree calibration... (easier said than done!)

The Challenges in Designing for Best NF

- Stability: Be Careful!
  - Watch for excessive out-of-band gain, usually at the low end.
  - Scale back on gain to improve stability.
- Narrowband vs.Broadband
  - Best NF is usually not at a device input impedance of 50 Ohms.
    - Narrowband: Input/Output matching optimization for best NF “relatively” straightforward.
    - Broadband: Compromise on NF, Gain, S-Parameters, Stability...
- Keep Input Losses to Minimum
  - Every bit of attenuation is a direct hit on overall NF.

References

- Agilent, AN 57-1 Fundamentals of RF and Microwave Noise Figure Measurements
  - http://cp.literature.agilent.com/litweb/pdf/5952-8255E.pdf
- Agilent, AN 57-2 Noise Figure Measurement Accuracy – The Y-Factor Method
  - http://cp.literature.agilent.com/litweb/pdf/5952-3706E.pdf
- Agilent, Noise Figure Basics Presentation,Feb 24, 2009
  - http://www.ieee.li/pdf/viewgraphs/noise_figure_measurements.pdf
- Agilent, Spectrum and Signal Analyzer Measurements and Noise
  - http://cp.literature.agilent.com/litweb/pdf/5966-4008E.pdf
- Agilent, Online Noise Figure Uncertainty Calculator.
  - http://sa.tm.agilent.com/noisefigure/NFUcalc.html
- VE2AZX, Noise Figure Testing using a Spectrum Analyzer (spreadsheet)
  - http://ve2azx.net/technical/NoiseFigMeasure.xls
- VE2ZAZ, Amateur Radio and Electronics Website
  - http://ve2zaz.net
- VE5FP, An automatic Noise Figure Meter, Jim Koehler, QEX May/June 2007

Measurement Time!

- The HP 8970A
  - 10 MHz to 1500/1600 MHz, 1MHz increments,
  - Temperature compensated,
  - Calculates NF (0dB to +30dB)
  - Calculates Gain (-20dB to +40dB).
  - Accommodates typical Noise Sources on the market.
  - Rapidly turns on/off the noise source to perform calculations
- Hands on!

Thanks!