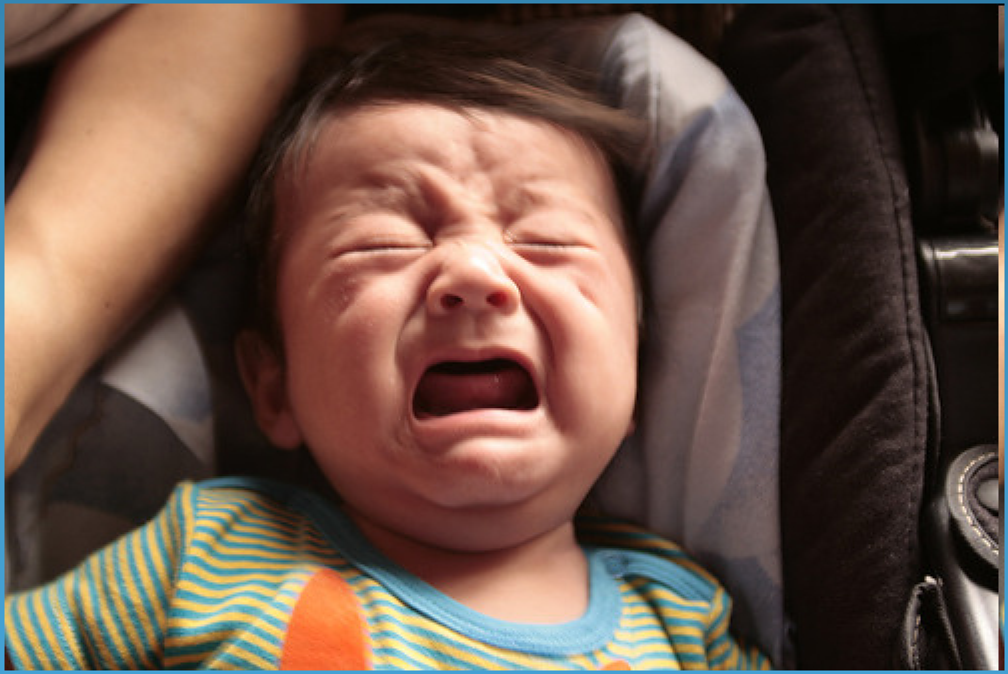
Noise



Common Types of Noise

Name	Example	Description
Impulse	Ignition, TVI	Not Random, Cure by Shielding,
Quantizing, Decoding, etc.	BER	Digital Systems, DAC's & ADC's. Often Bit Resolution and/or Bit Fidelity
Shot	Transistors	Corpuscular Current Flow, Lots of Impulses
Thermal	Resistors, Atmosphere	Thermal Agitation of Electrons Act Like Signal
Flicker (1/f)	Recombination	Low frequency, FET's

$\mathcal{H}$

Noise Voltage

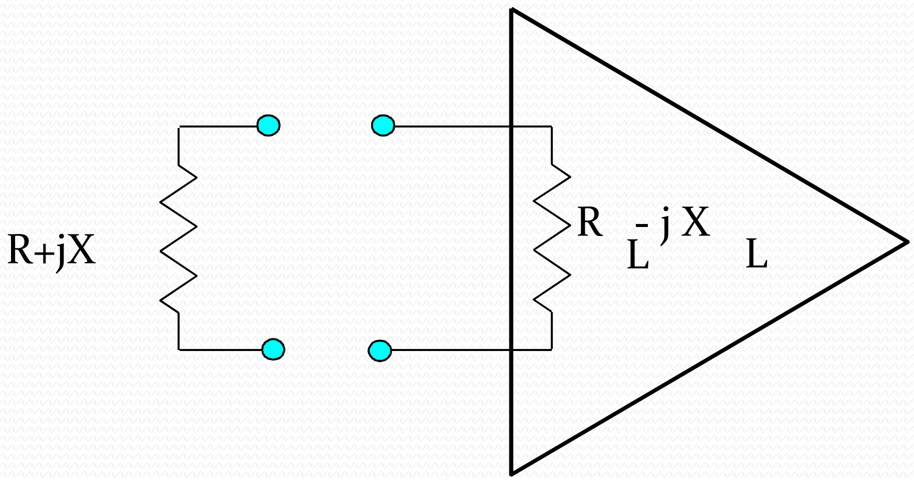
(Ref: JB Johnson/Nyquist :1928: Bell Labs)

Standard Equation for Noise Voltage
produced by a Resistor

$$e^2 = 4kTBR$$

k = Boltzman's constant (1.38x10-23 Joules/k)
T is absolute temperature
B is bandwidth (Hz)
R is resistor value in Ohms
e is rms voltage

kTB----***THE*** Noise Floor



k = 1.38 x 10 joule / k

T = Temperature (K)

B = Bandwidth (Hz)

Available Noise Power,

P_{av} = kTB

(Power Delivered to a Conjugate Load),

(i.e. R = R, X = X)

At Standard Temperature T (=290K) : kT = 4 x 10 $^{-21}$ W/Hz = *174dBm / Hz*

Across 50 Ohms

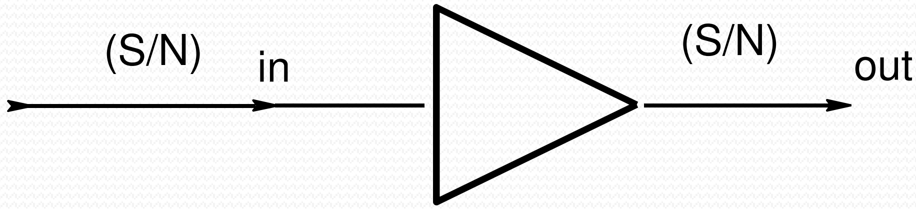
Noise Power is a Function of Bandwidth

$$\Delta \text{ Noise power} = 10 \log (BW_2/BW_1)$$

Bandwidth	**Noise power change**	**Noise power**
1 MHz	60 dB	-114 dBm
1 kHz	30 dB	-144 dBm
10 Hz	10 dB	-164 dBm
2 Hz	3 dB	- 171 dBm
1 Hz	0 dB	-174 dBm

What is Noise Figure?

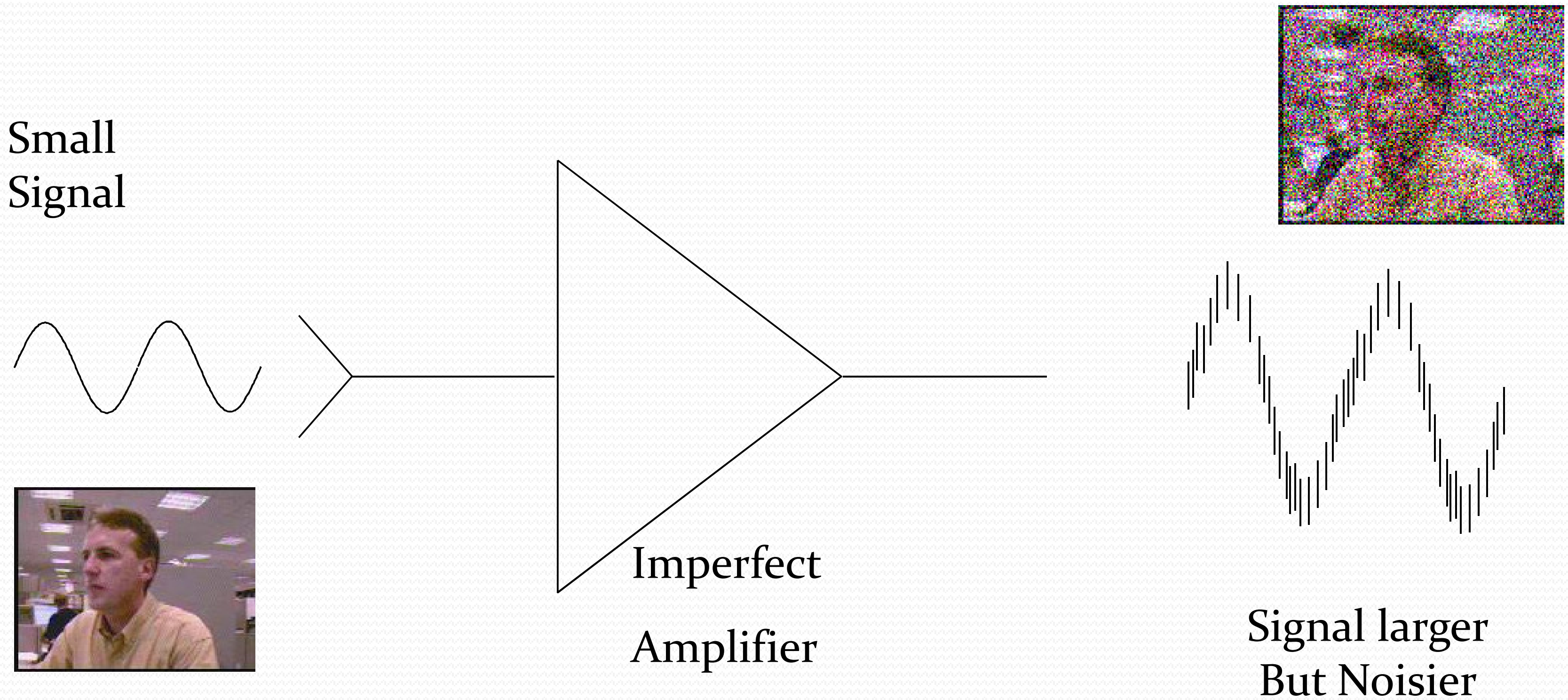
(Original Definition)



$$F(\text{dB}) = 10 \log \left. \frac{(S/N)_{in}}{(S/N)_{out}} \right|_{T_s = 290K}$$

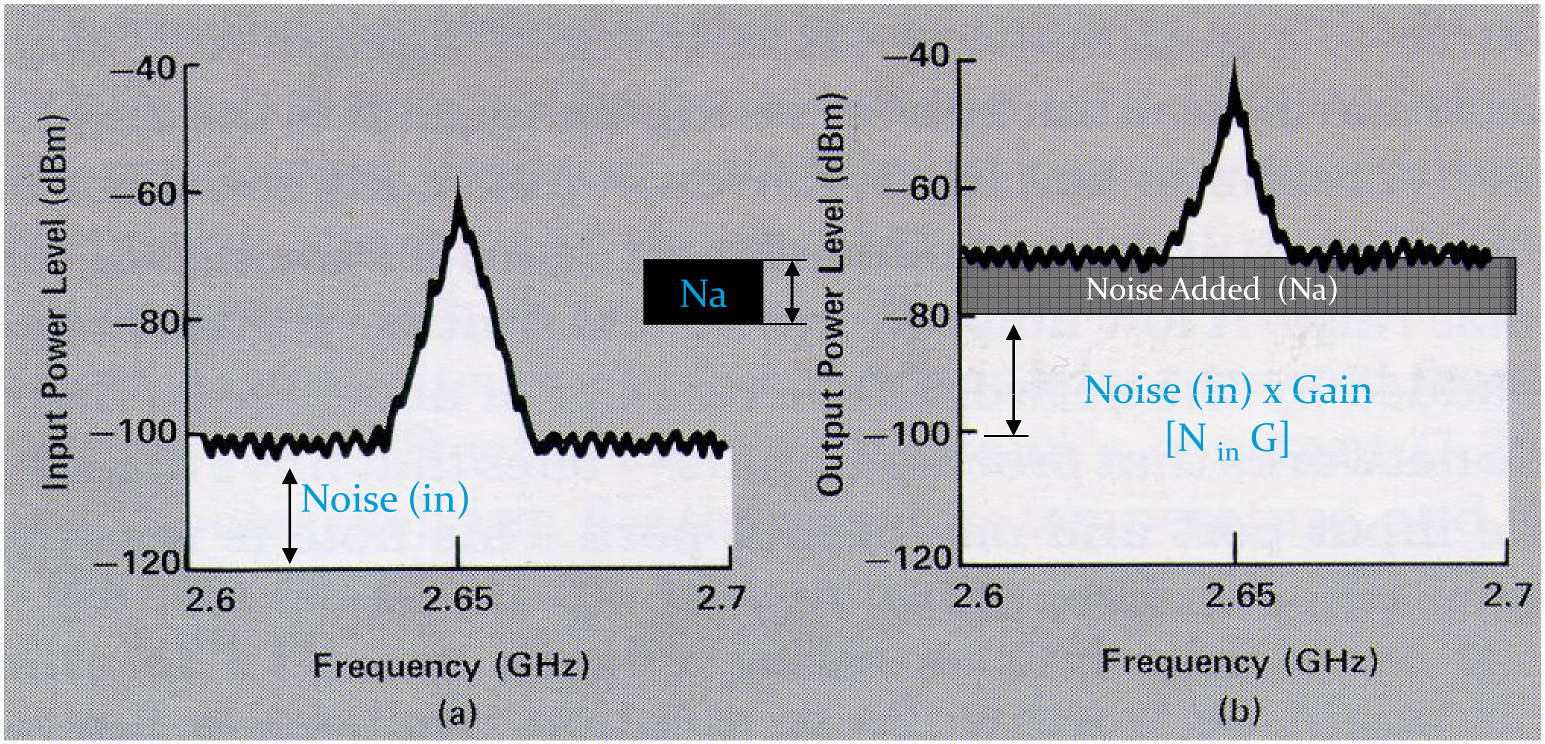
The linear ratio is known as "Noise Factor"

What is Noise Figure ?



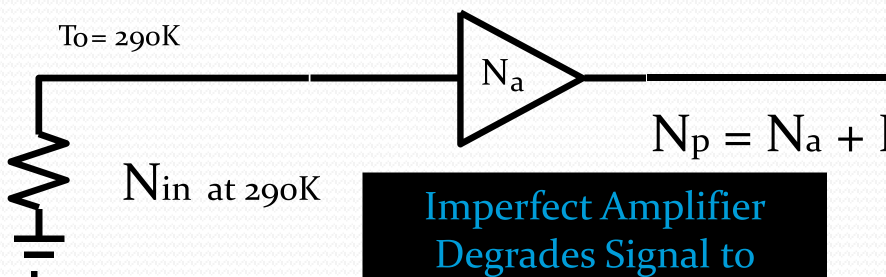
Thermal Agitation of Electrons adds noise to the signal

What is Noise Figure ? Noise added by Amplifier



Gain 20dB

NF 10dB



$N_p = N_a + N_{in} G$

Imperfect Amplifier Degrades Signal to Noise Ratio

What's the noise figure of an attenuator?

Does an attenuator ADD noise?
Does an attenuator attenuate noise?

How does loss impact the noise figure of my receiver system?

Why do we measure Noise Figure? Example…

Transmitter:

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

Receiver:

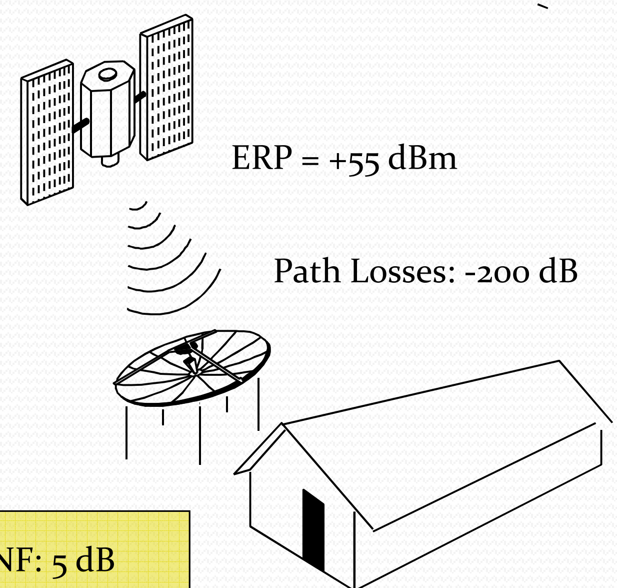
Noise Floor @ 290K	- 174 dBm/Hz
Noise in 100 MHz BW	+ 80 dB
Receiver N.F.	+5 dB
Receiver Sensitivity	-89 dBm

Link Margin: 4 dB

Power to Antenna: +40 dBm

Frequency: 12 GHz

Antenna Gain: +15 dB



Receiver NF: 5 dB

Bandwidth: 100 MHz

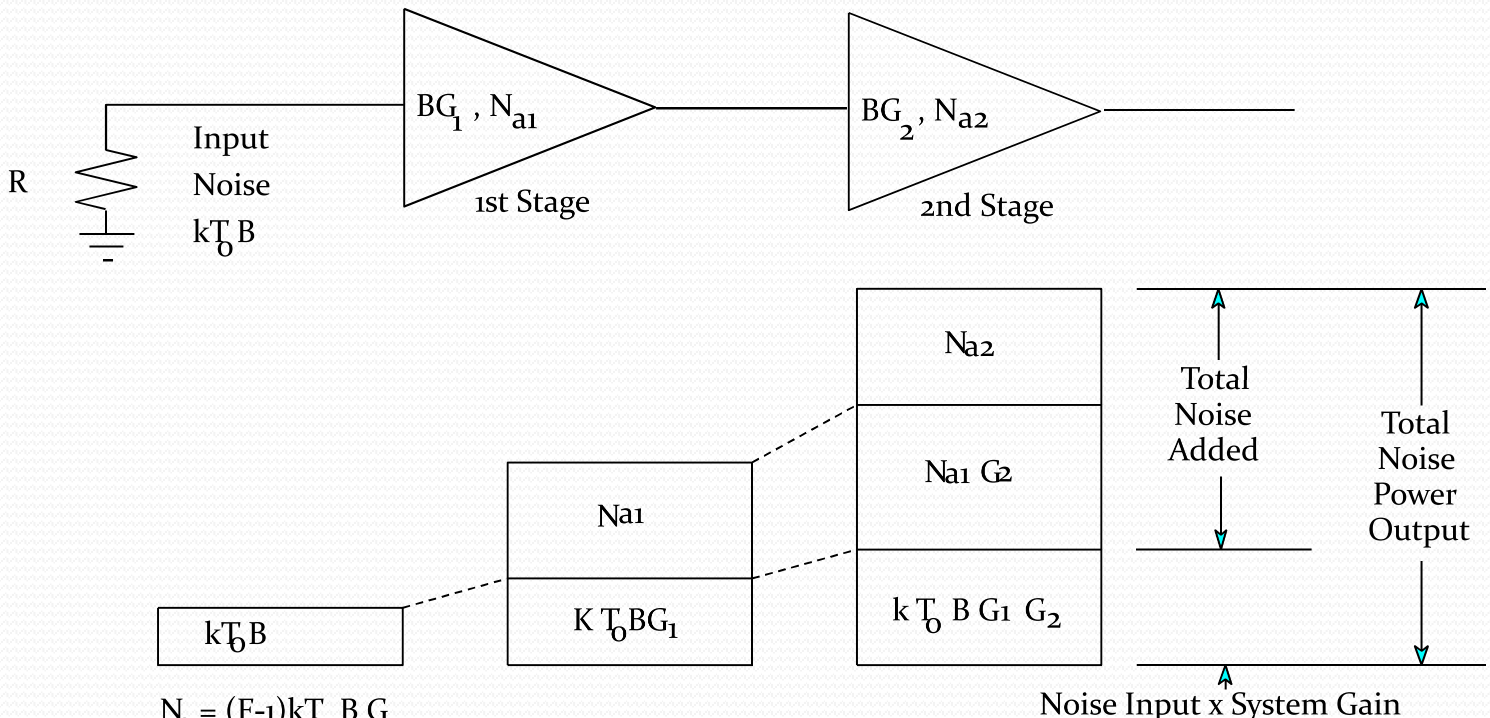
Antenna Gain: 60 dB

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

Effect of 2nd Stage Contribution
The Friis equation

$$F12 = F1 + \frac{F2 - 1}{G1}$$



$N_a = (F-1)kT_o\ B\ G$

$$F_{total} = F_1 + \frac{F_2 - 1}{G_1} + \cdots\cdots \frac{F_n - 1}{G_1 G_2 \cdots G_{n-1}}$$

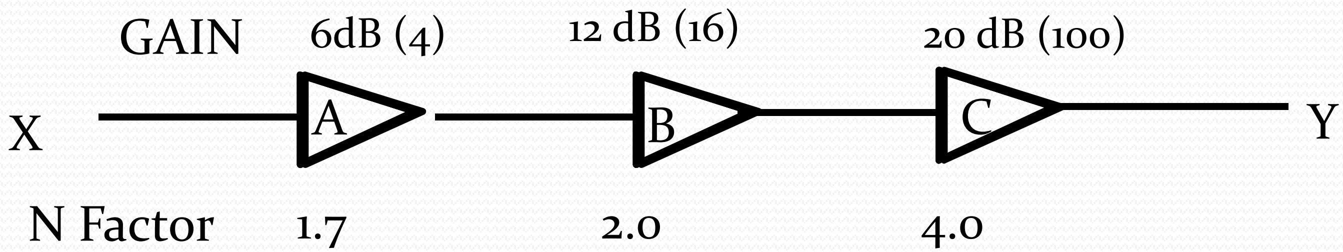
$$F_{12} = F_1 + \frac{F_2 - 1}{G_1}$$

Friis Equation

cascade or second stage

noise contribution

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



$$F_{ABC} = 1.7 + \frac{(2.0 - 1)}{4} + \frac{(4.0 - 1)}{4 \times 16} = 1.7 + 0.25 + 0.047 = 1.997 \quad (3\ \text{dB})$$

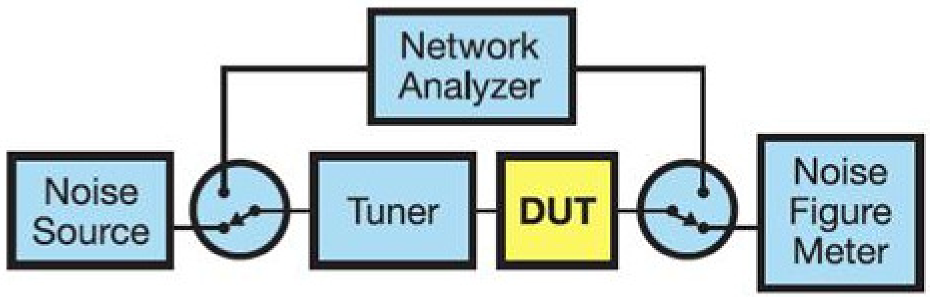
$$F_{ACB} = 1.7 + \frac{(4.0 - 1)}{4} + \frac{(2.0 - 1)}{4 \times 100} = 1.7 + 0.75 + 0.025 = 2.475 \quad (4\ \text{dB})$$

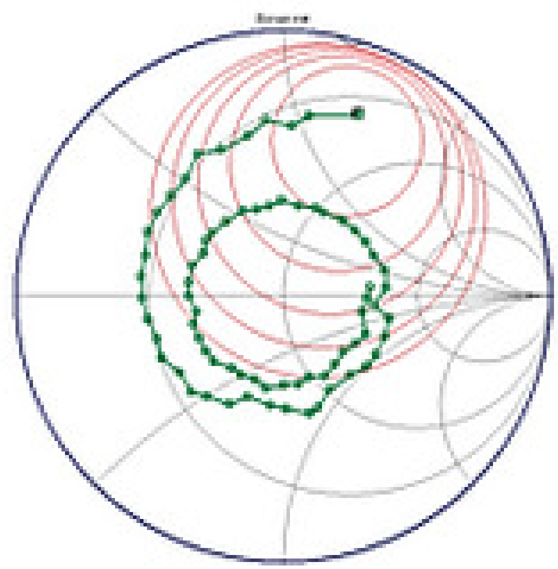
How Do We Get Low Noise Amps?

- Select or construct low-noise Transistors
  - High electron mobility materials- Gaas
  - low feedback and output resistance
  - Low base current/small signal= low temp
- Find optimum balance between match, gain and noise output

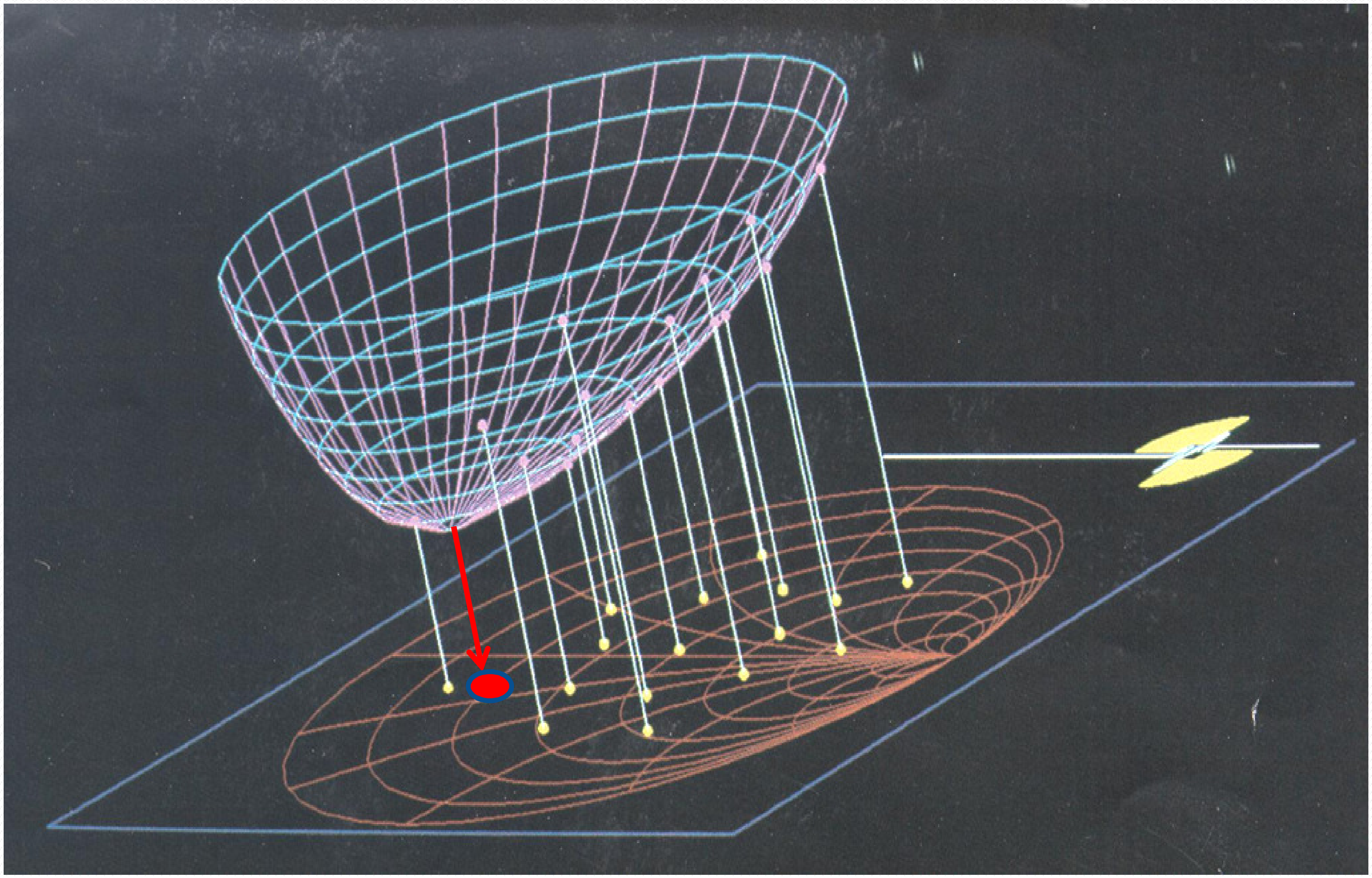
Transistor Noise Parameters

Finding the best balance between gain, match and noise





Noise Circles

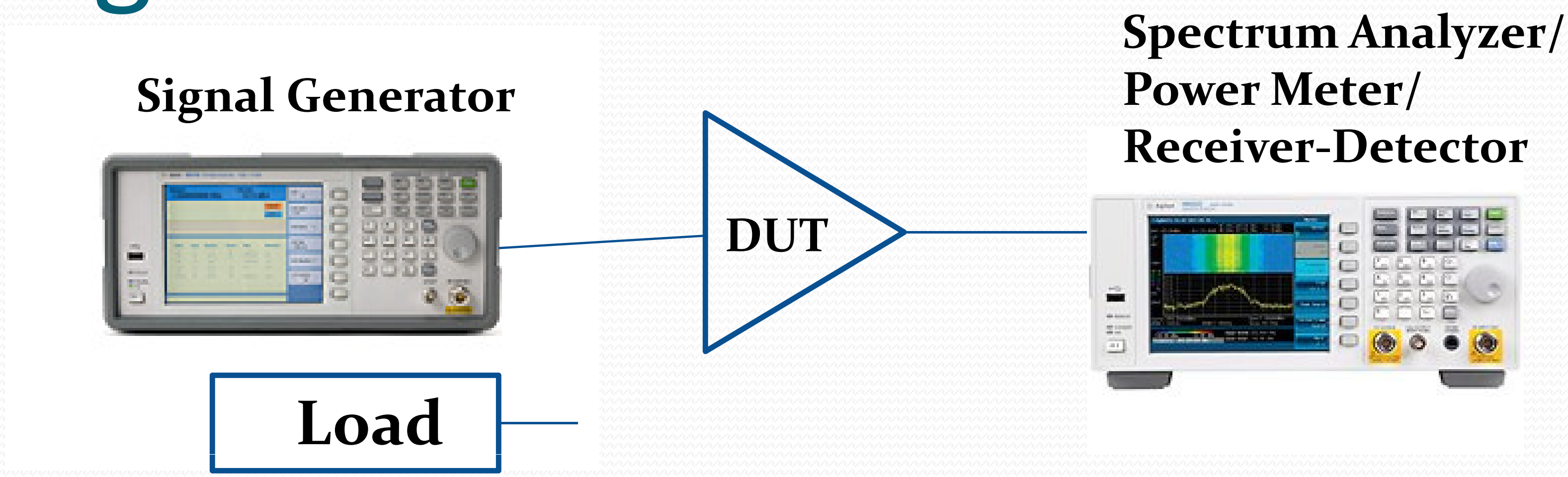


Gamma Optimum = Transistor match for minimum noise output

NF Measurement Techniques

- ✓ **Signal Generator Method**
- ✓ **Y-factor Method (Calibrated noise source)**
- ✓ **Y-factor without a calibrated noise source**

Signal Generator Method

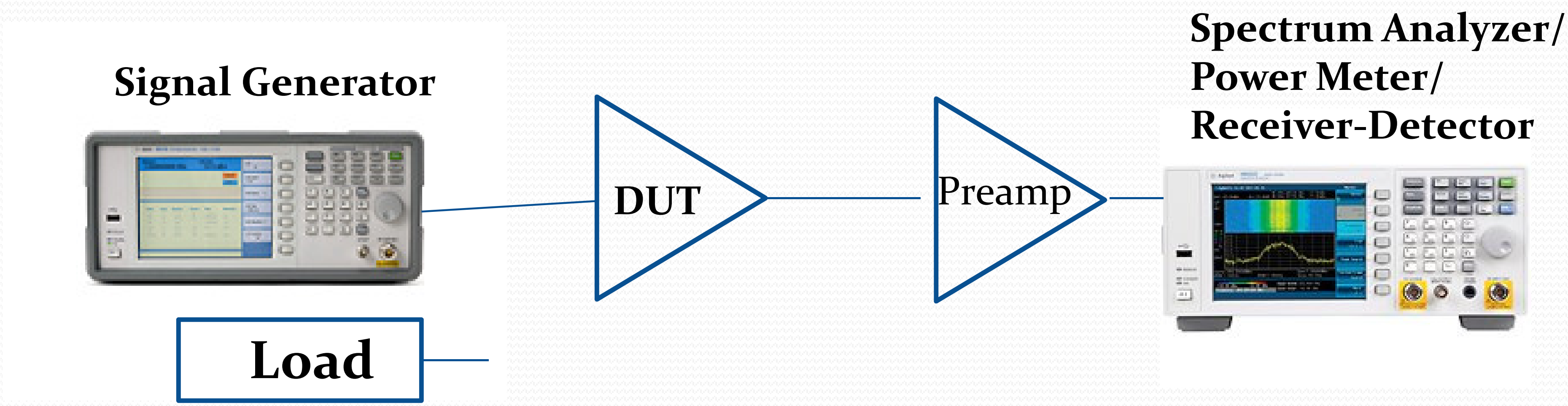


Steps

1. Measure SG Level output
2. Measure DUT output
3. Compute Gain
4. Terminate/Load Dut (KTB)
5. Measure Noise output of DUT
6. NFig = Noise Output - Gain + 174 dBm/Hz

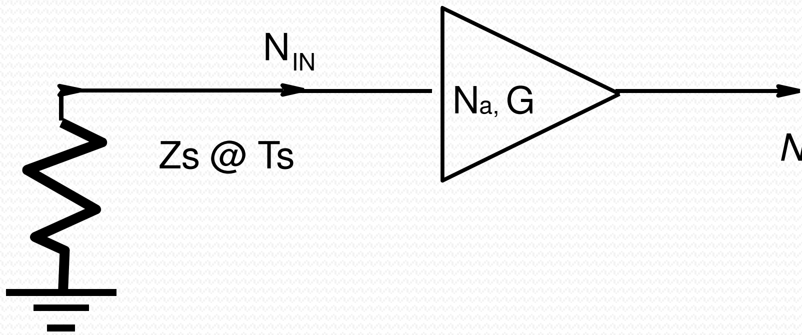
Signal Generator Method

Can't "see" the DUT noise? >Add a preamp



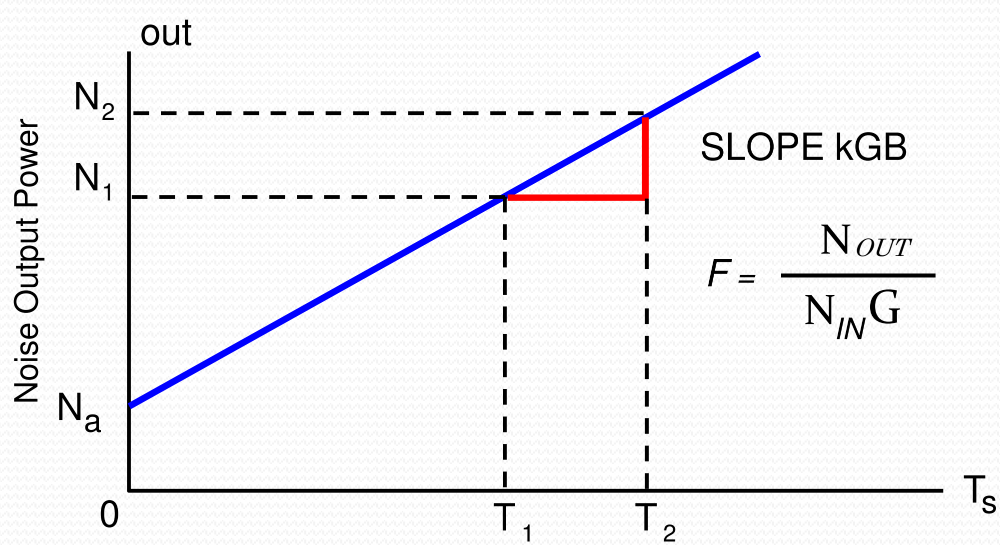
NF = Noise output - Gain(Dut) - Gain(Pre)+ 174 dBm/Hz

Noise Power is Linear with Temperature

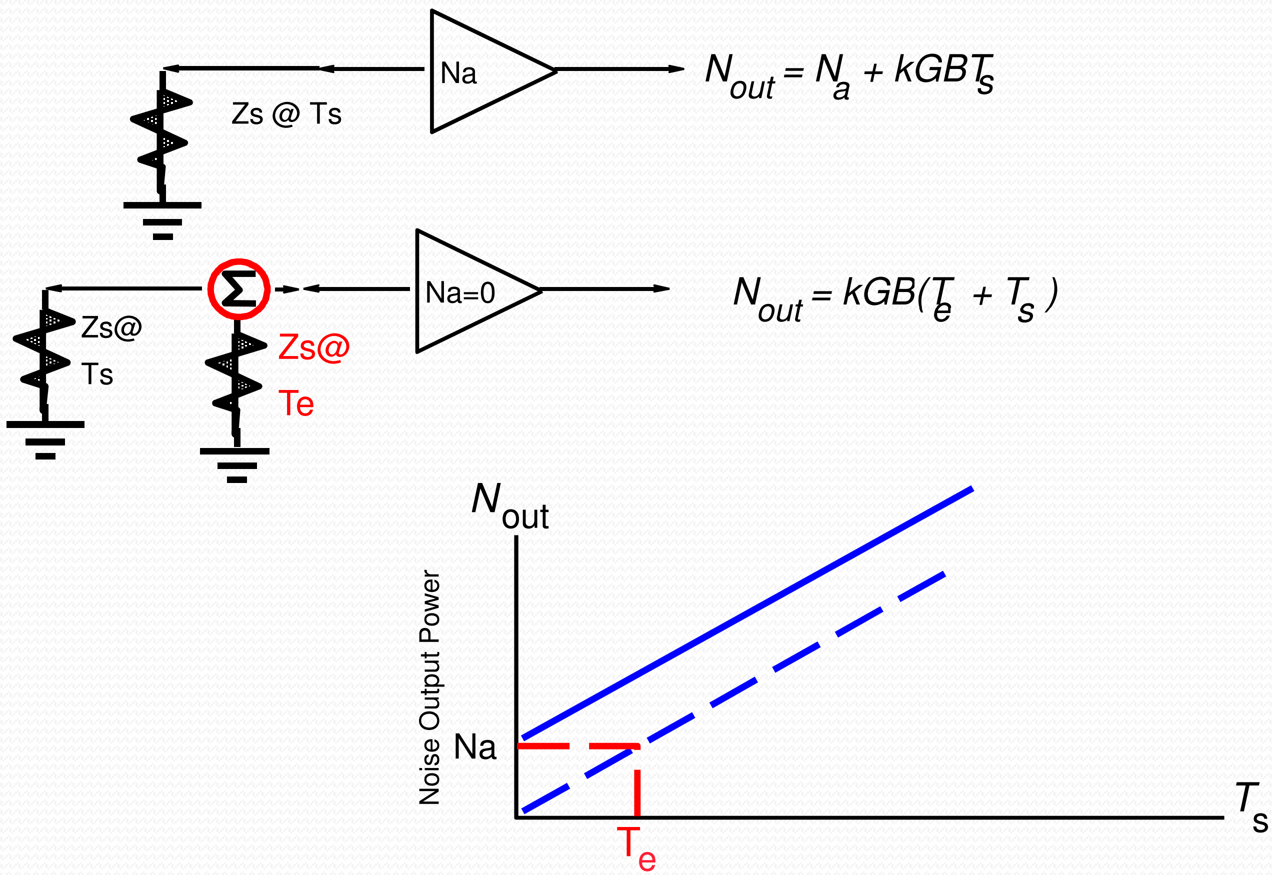


$$N_{out} = N_a + Gk(T_s)B$$

Added Noise (N_a); Input Noise, N_{IN} ($Gk(T_s)B$)

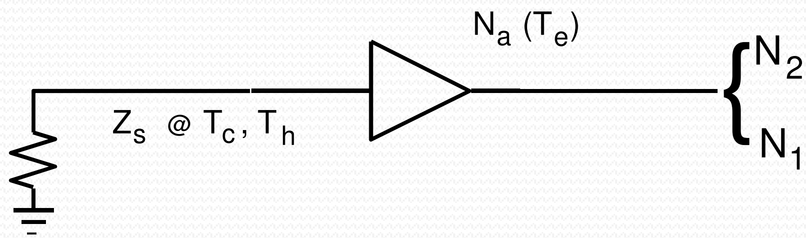


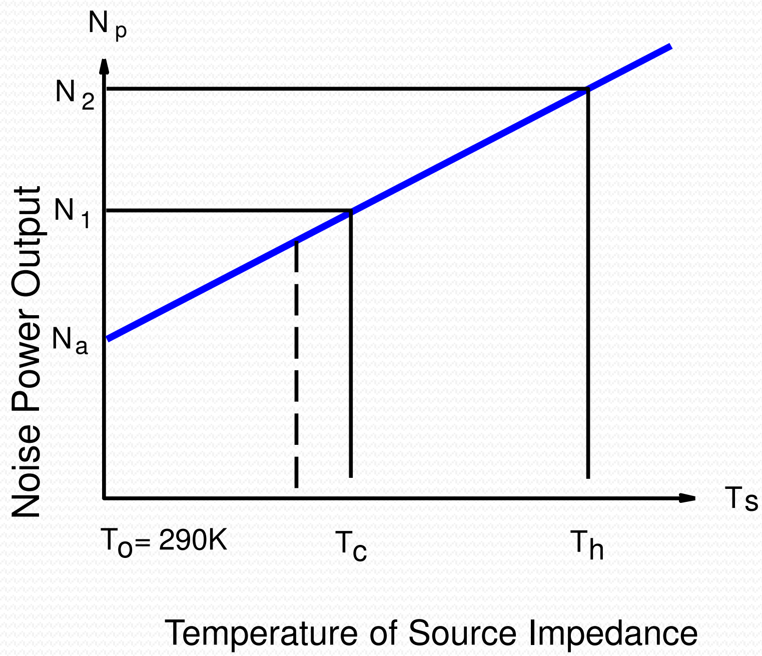
Definition of Effective Input Noise Temperature, T e



$\mathcal{H}$

Measurement of Noise





$$Y = \frac{N_2}{N_1} = \frac{kGB(T_h + T_e)}{kGB(T_c + T_e)}$$

$$T_e = \frac{T_h - YT_c}{Y-1} \qquad F = \frac{T_e + T_o}{T_o}$$

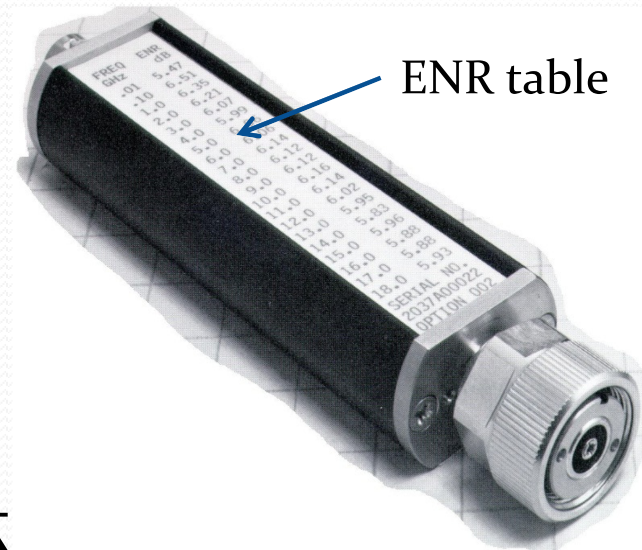
$$F = \frac{\left(\frac{T_h}{T_o} - 1 \quad - Y \quad \frac{T_c}{T_o} - 1 \right)}{Y - 1}$$

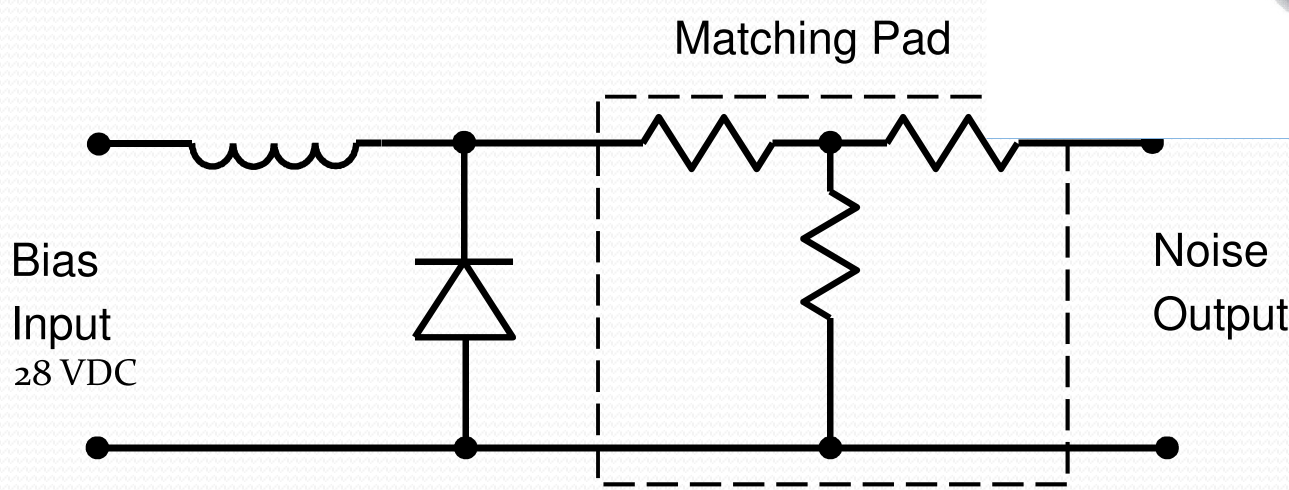
Where Do T_H and T_C Come From?

- *Noise Sources.....*

  - Gas Discharge Tubes
  - Load/Termination
  - Sun Noise (stars and galaxies, cold sky, cold load)
  - Diode Noise sources
    - Commercial and home-built

Avalanche Diode Noise Source



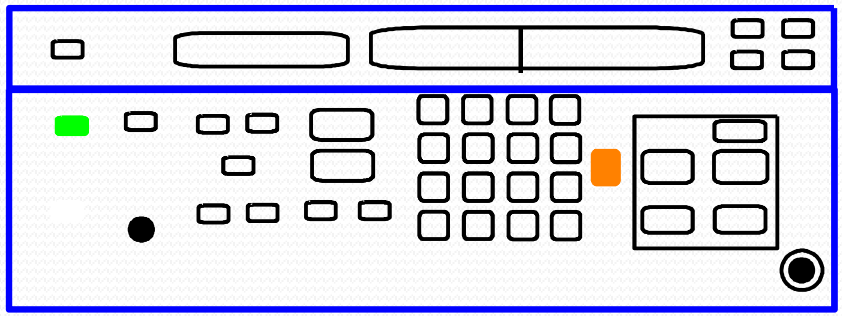


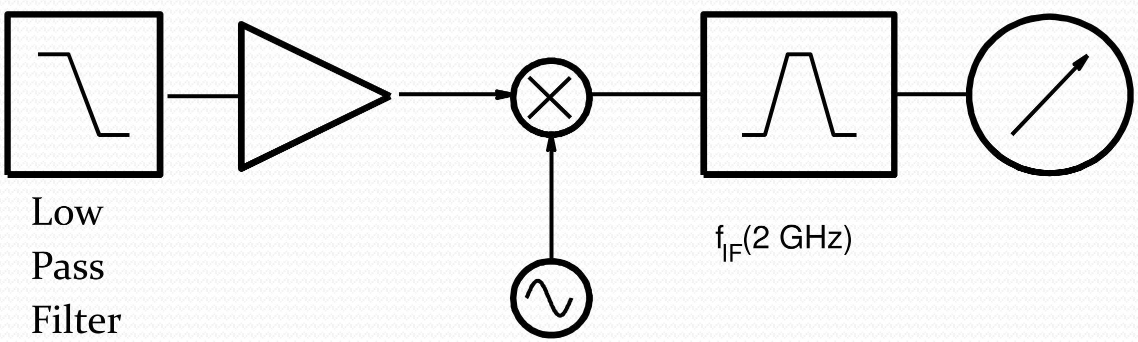
Excess Noise Ratio

$$ENR\ (\text{dB}) = 10 \log \left(\frac{Th - 290}{290} \right)$$

Model	**Frequency Range**	**ENR**
HP HP 346A	10 MHz - 18 GHz	6 dB
HP 346B	10 MHz - 18 GHz	15 dB
HP 346C	10 MHz - 26.5 GHz	15 dB
HP 346C/K01	1 - 50 GHz	20 to 7 dB
HP 346B/H42	10.5 - 13.5 GHz	5 dB

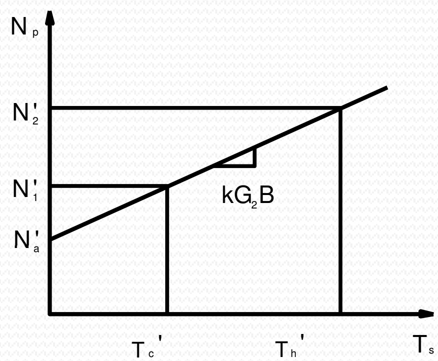
Noise Figure Meter





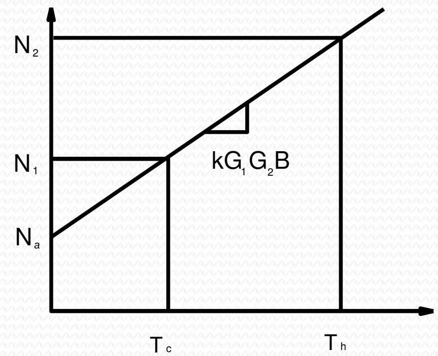
Making a Measurement

Calibration
(Measurement System)



$$slope = kG_2 B = \frac{N_2' - N_1'}{T_h' - T_c'}$$

DUT Measurement
(DUT & System)



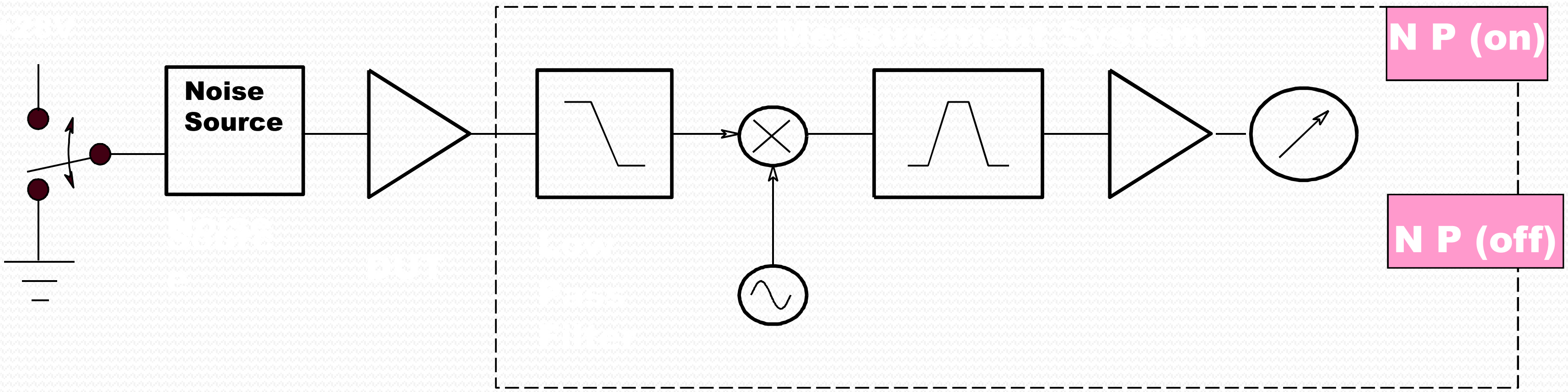
$$slope = kG_1 G_2 B = \frac{N_2 - N_1}{T_h - T_c}$$

Y = N2 / N1

$$G_{DUT} = \frac{\dfrac{N_2 - N_1}{T_h - T_c}}{\dfrac{N'_2 - N'_1}{T'_h - T'_c}}$$

$$F_{Meas} = F_{DUT} + \frac{F_{sys} - 1}{G_{DUT}}$$

Simpler Yet..........

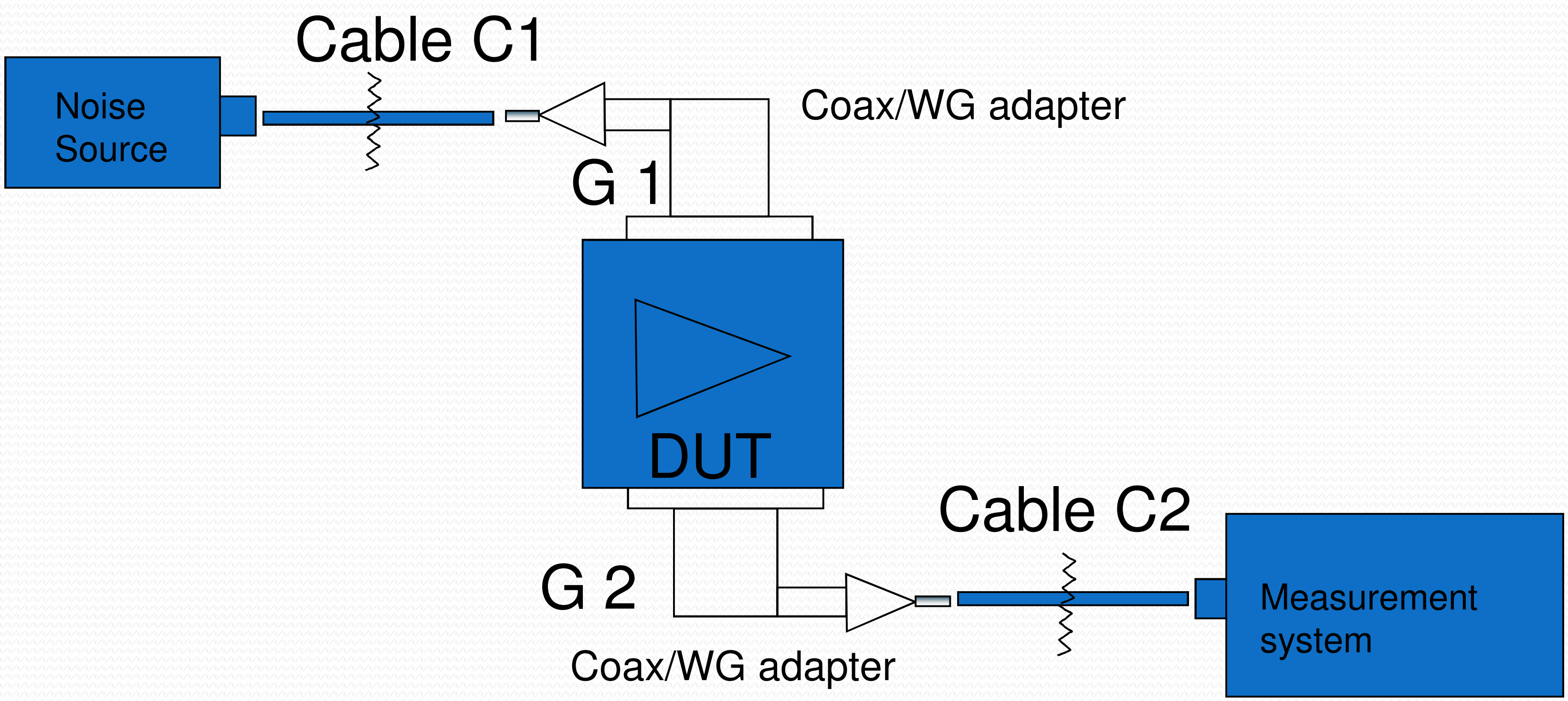


$$NF = ENR - 10 \log (Y-1)$$

$$Y = N_{Pon} / N_{Poff}$$

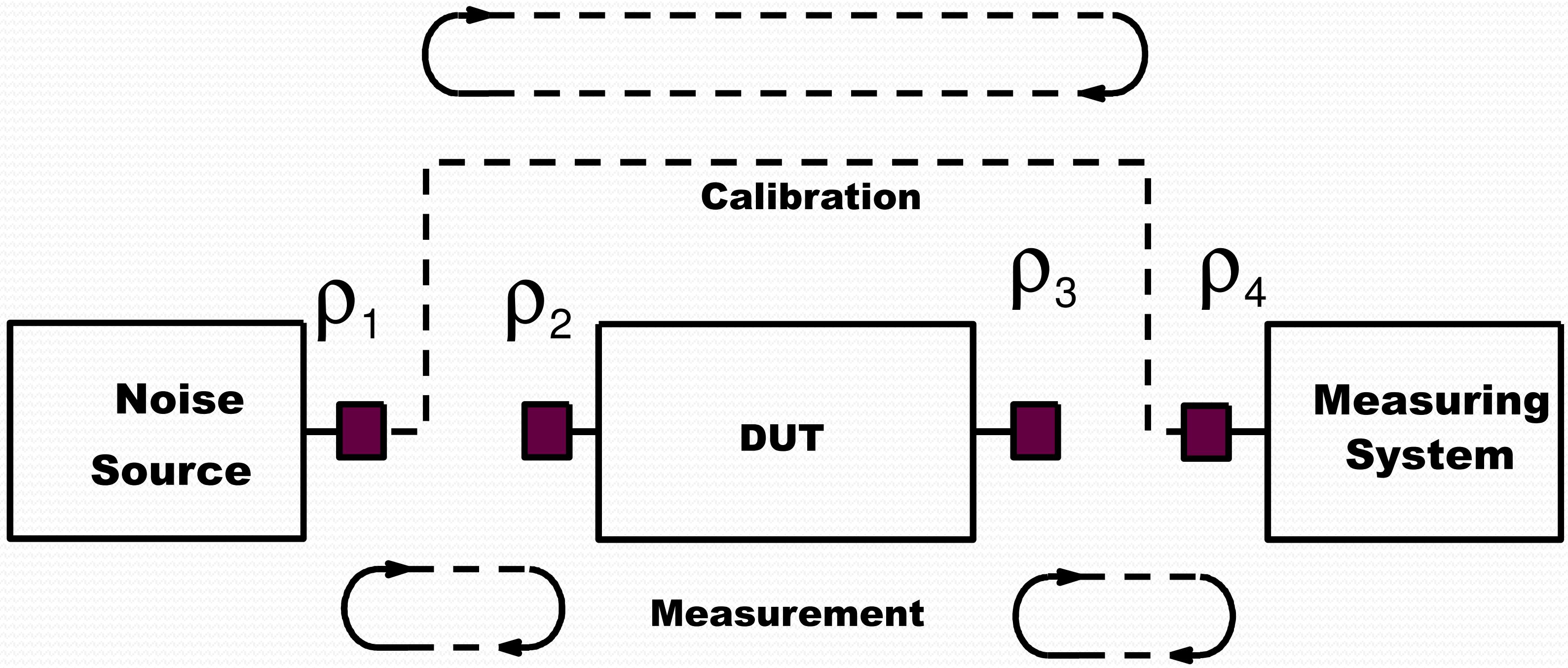
ERRORS!

Adapter and path losses



ERRORS!

Mismatch Uncertainty



ρ = reflection coefficient at a reference plane

Y-factor without a calibrated noise source

$$\text{Noise figure of DUT} = 10\log_{10}[\text{ENR}/(Y-1)]$$

$$\text{NFac} = \text{ENR}/(Y-1)$$

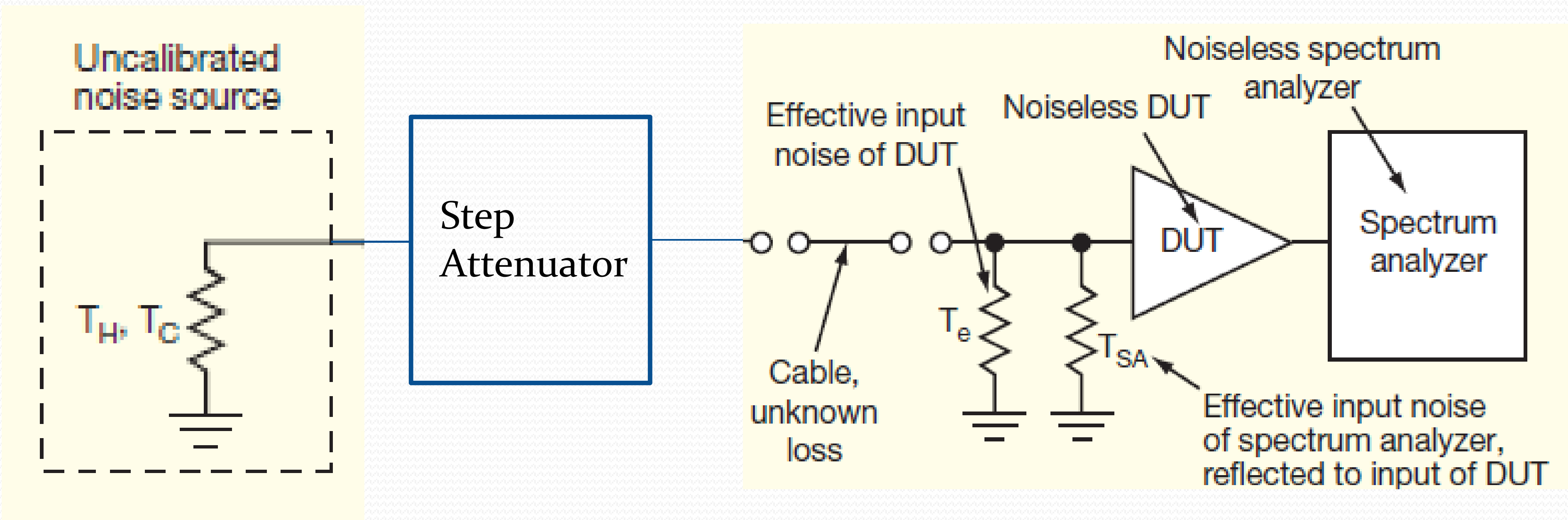
$$Y = \text{ENR}/\text{NFac} + 1$$

Differentiating

$$dY/d\text{ENR} = 1/\text{NFac}$$

$$\text{NFac} = 1/(dY/d\text{ENR})$$

Y-factor without a calibrated noise source



Y-factor without a calibrated noise source

$$P_{n1} = KB(T_{H1} + T_{DUT} + T_{SA})$$

$$P_{n2} = KB(T_{H2} + T_{DUT} + T_{SA})$$

$$\Delta P_n = KB(T_{H2} - T_{H1}) \rightarrow (T_{H2} - T_{H1} = \Delta P_n/KB$$

$$ENR_1 = (T_{H1} - 290)/290$$

$$ENR_2 = (T_{H2} - 290)/290 \rightarrow \Delta ENR = ENR_2 - ENR_1 = (T_{H2} - T_{H1})/290$$

$$\rightarrow \Delta ENR = \Delta P_n/(290KB)$$

$$Y_1 = 10^{(Pn1 - Pn0)/10)}$$

$$Y_2 = 10^{(Pn2 - Pn0)/10)}$$

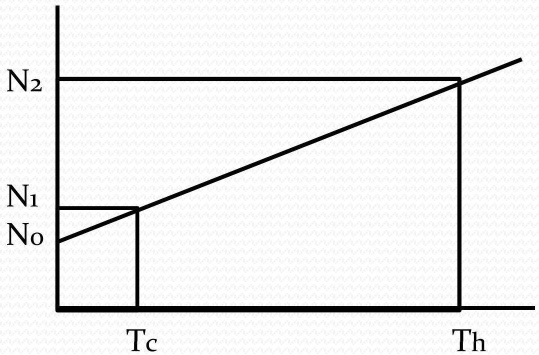
$$\rightarrow \Delta Y = Y_2 - Y_1$$

$$NF = \frac{1}{\Delta Y/\Delta ENR}$$

Conclusions

- kTB is THE noise floor at -174 dBm/Hz
- Noise figure = $Signal_{input}/Noise_{input}$ vs. $Signal_{output}/Noise_{output}$
- Noise figure is noise added by an amplifier or receiver
- Optimize noise figure by placing lowest noise/loss elements near antenna
- Second stage contribution is typically low
- There are several methods to measure noise figure
- The uncalibrated noise method could be very popular with hams

Noise Algebra



$$Y = \frac{N_2}{N_1} = \frac{kGB(T_e+T_h)}{kGB(T_e+T_c)}$$

$$T_e = \frac{T_h - YT_c}{Y-1}$$ **(Solve for Te)**

Using T e = (F -1) x To

$$F = \frac{\left(\frac{T_h}{T_o} - 1\right) - Y\left(\frac{T_c}{T_o} - 1\right)}{Y - 1}$$

$$F = \frac{\left(\frac{T_h}{T_c} - 1\right) - Y\left(\frac{T_c}{T_c} - 1\right)}{Y - 1}$$