NOISE FIGURE

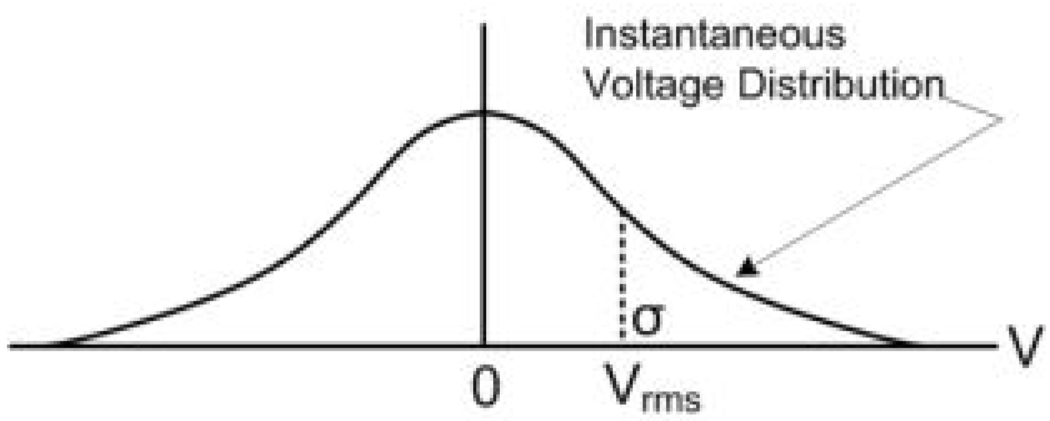
WHAT IS IT ?

WHY IS IT IMPORTANT ?

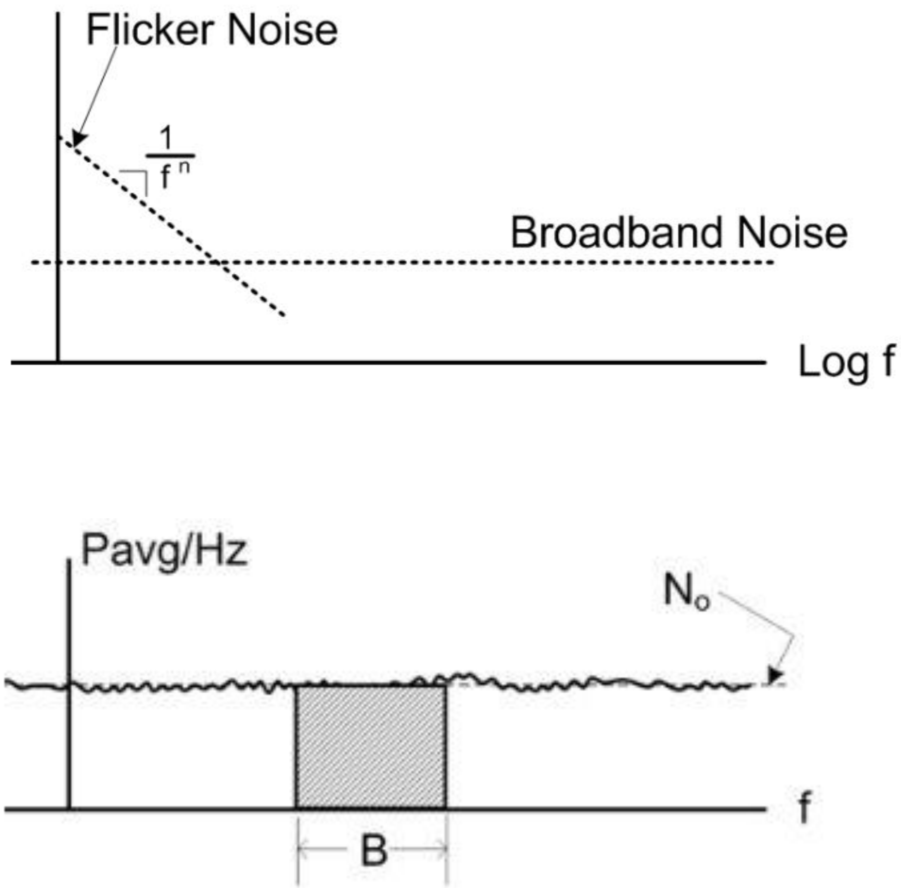
HOW TO MEASURE IT ?

WHAT IS NOISE ?

- Random motion of electrons in conductors (resistors)
  - Thermal energy powers this motion
  - Energy is proportional to temperature (° Kelvin)
  - Boltzmann's constant: $k=1.38 \times 10^{-23}$ Joules/K



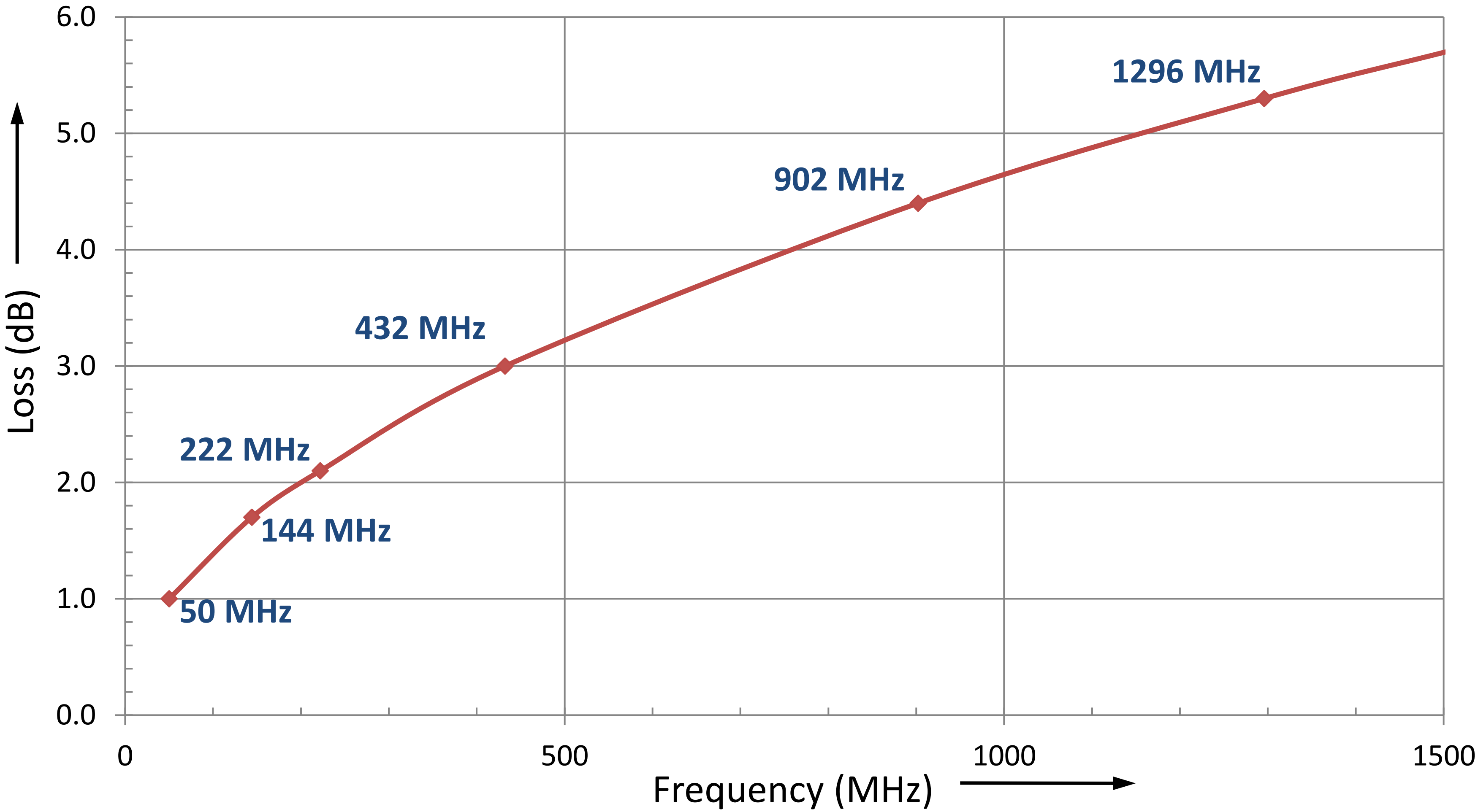
WHAT IS NOISE ?



- Thermal energy produces broadband noise
- Flicker noise variants originate in solid-state devices.
- Operational bandwidth sets how much noise power is captured.
- Narrowband modes can hear weaker signals than wideband modes. (CW vs SSB)

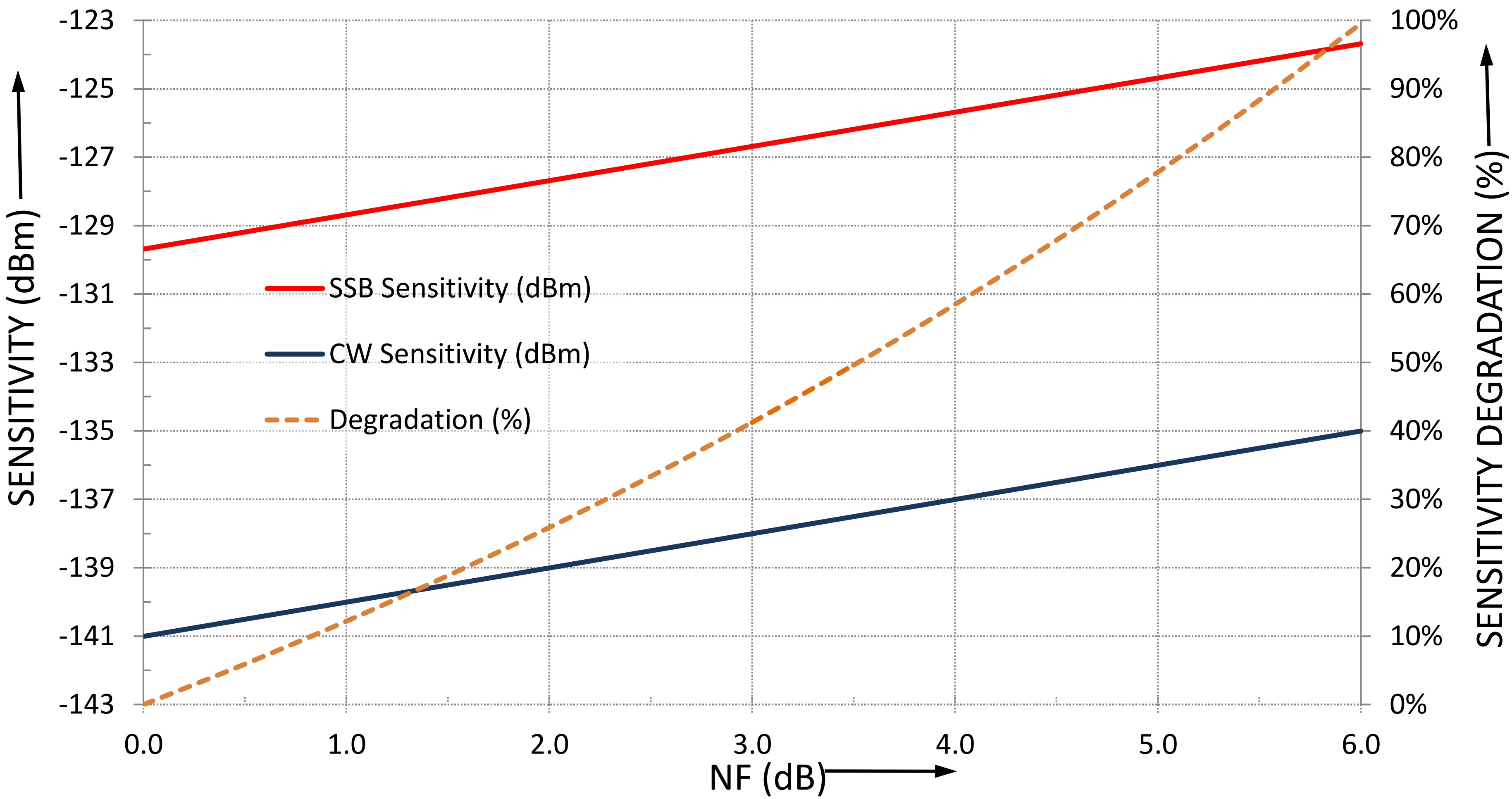
LOSS of LMR-400

(100 ft, with connectors)



SENSITIVITY vs NF

SSB: 2.7 KHz BW, 10 dB S/N, 50 Ω
CW: 500 Hz BW, 6 dB S/N, 50 Ω



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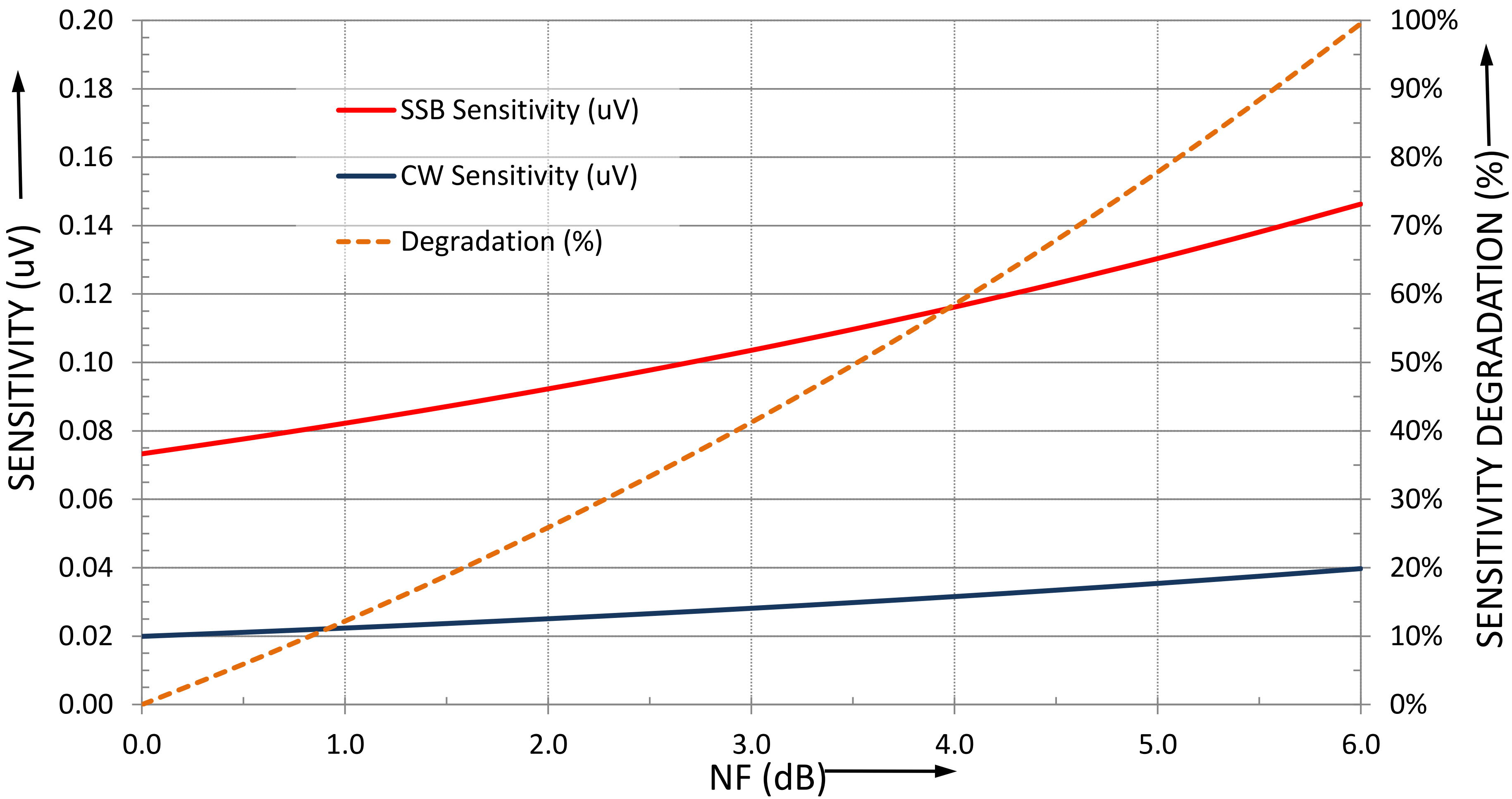
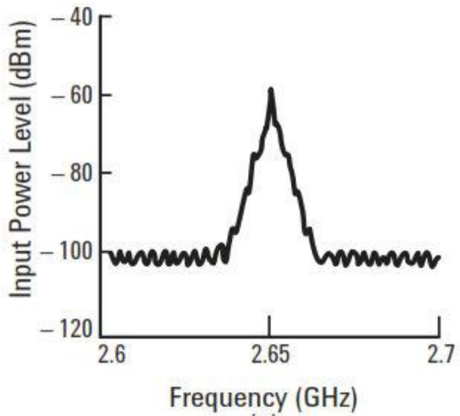


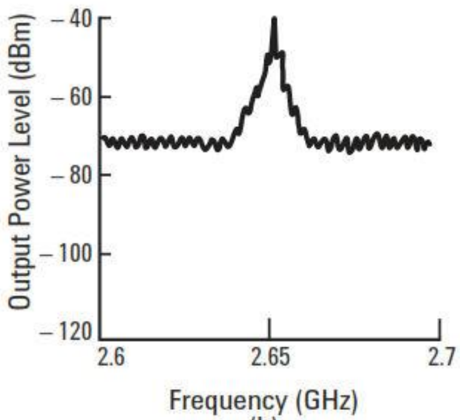
WHY IS NOISE IMPORTANT ?

- Dissipative (resistive) loss introduces thermal noise
  - Coax loss
  - Attenuators
  - Filters
  - Signal to noise ratio is degraded

- Amplifiers
  - Provide gain to both input signal and input noise
  - Add noise
  - Signal to noise ratio is degraded



(a)



(b)

THERMAL NOISE FLOOR

$$N_i = kTB$$

N_i:	Thermal noise power (input)
K:	Boltzmann's constant
T:	Temperature in Kelvin
B:	Bandwidth

NOISE FIGURE

- Original noise figure definition was based on power signal to noise ratio degradation:

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

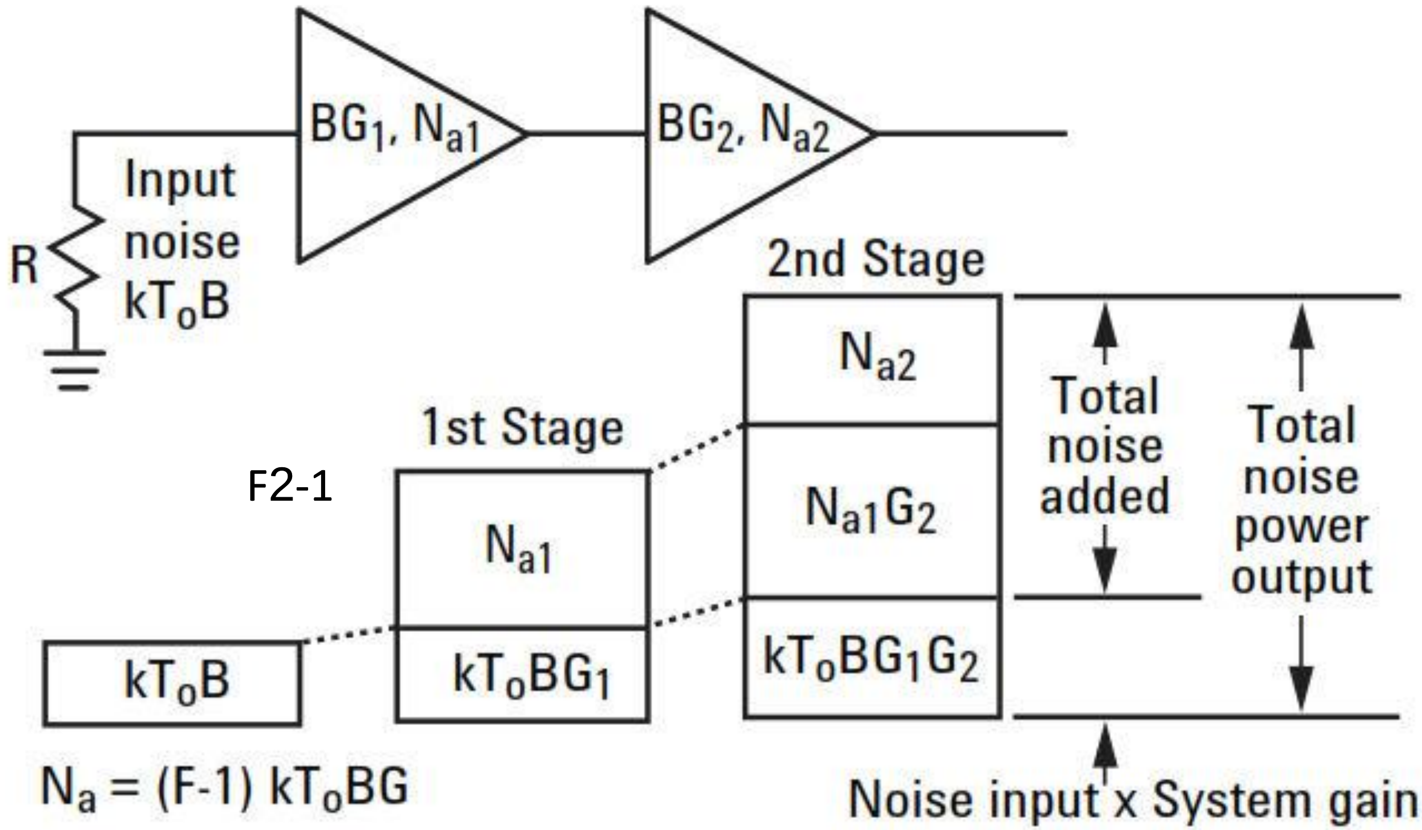
$$F = \frac{S_i/N_i}{G\,S_i/(N_a + G\,N_i)}$$

$$F = \frac{N_a + G\,N_i}{G\,N_i} = \frac{N_a + kTBG}{kTBG}$$

$$NF_{dB} = 10\log(F)$$

- Amplifiers contribute added noise, Na, in addition to gain, G.
- Noise figure of passive devices is simply the insertion loss.

NF of CASCADED STAGES



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

EFFECTIVE NOISE TEMPRATURE

- The *effective* input noise temperature, Te, of an LNA is sometimes used to describe the noise performance:

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

- The effective input noise temperature is related to noise figure by:

$$T_e = T_o\ (F - 1)$$

where To = 290° K (ambient temp).

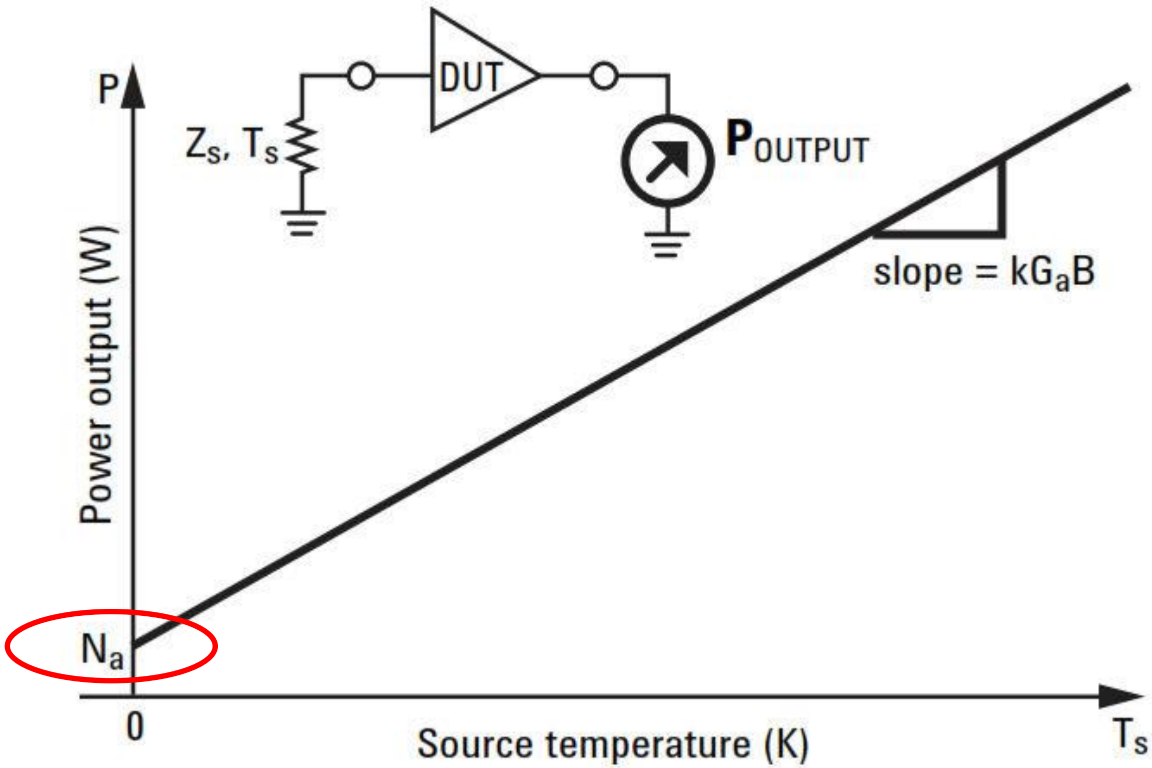
NF MEASUREMENT

$$ENR = \frac{T_{hot} - T_{cold}}{T_o}$$

$$ENR_{dB} = 10\,log(\frac{T_{hot} - T_{cold}}{T_o})$$

- A calibrated noise source is used to measure noise figure.
- The noise source provides two (hot and cold) states, calibrated over frequency.
- A pad can be used to provide a good source impedance. The Excess Noise Ratio (ENR) is reduced by the amount of the pad.

NOISE POWER LINEARITY



- A stepped source temperature with a known ENR allows the added noise, Na, to be determined.

Y FACTOR METHOD

$$Y = \frac{N_{hot}}{N_{cold}}$$

$$Y = 10^{\left(\frac{Y_{dB}}{10}\right)}$$

$$N_a = kT_o BG_1 \left(\frac{ENR}{Y-1} - 1\right)$$

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

- A stepped source temperature with a known ENR allows the added noise, Na, to be determined.
- Equations for $T_{cold} = T_o$.

NOISE MEASUREMENTS

- Use a spectrum analyzer with a high gain preamp.
- Measure NF of preamp.
- Measure system NF of cascade of preamp with DUT
- The DUT NF is calculated from the cascade measurement:

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

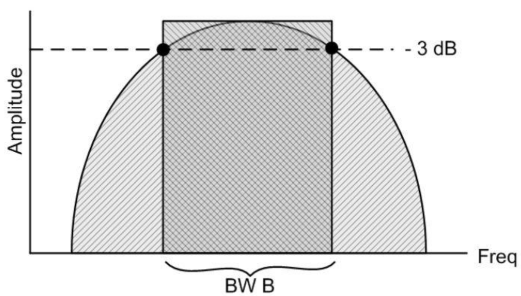
- Gain of DUT can be determined from ENR measurements:

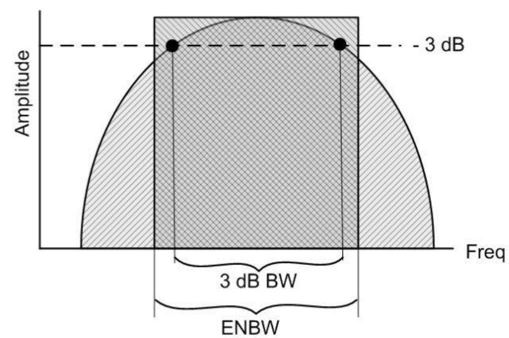
$$G_1 = \frac{N_{hot} - N_{cold}\ |output}{N_{hot} - N_{cold}\ |input}$$

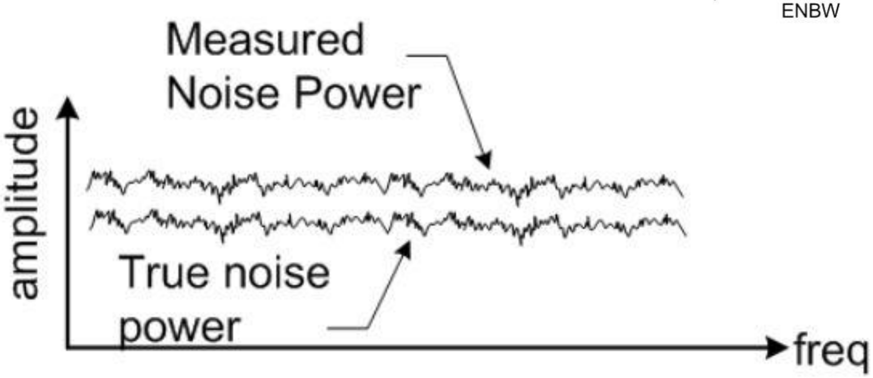
- The bandwidth of the spectrum analyzer is used in the noise factor calculations .

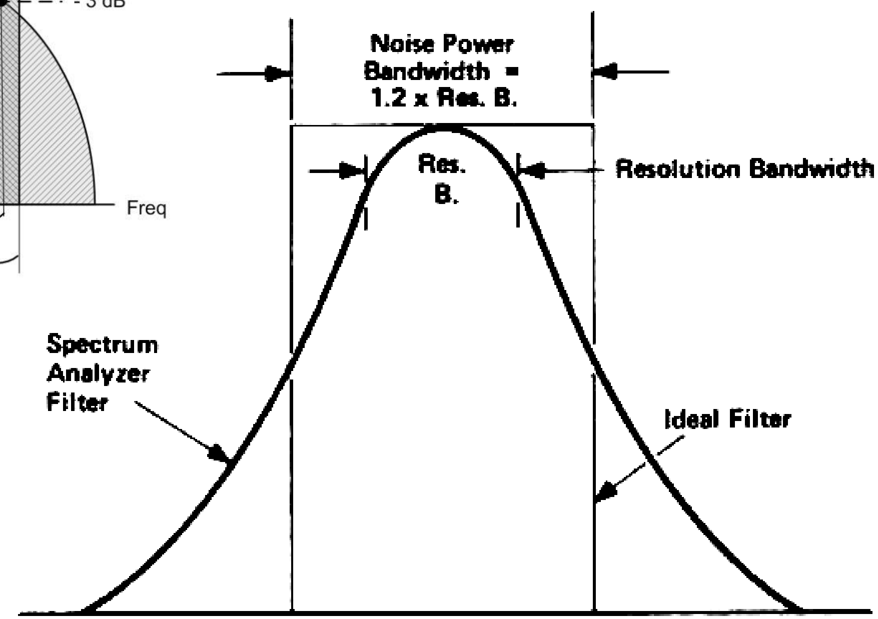
SPECTRUM ANALYZER EFFECTIVE NOISE BW

- Noise factor calculations are based on ideal filter shape.
- Actual filter shape in spectrum analyzer is not so sharp.
- HP suggests using a correction of 1.2 x *resolution BW*.

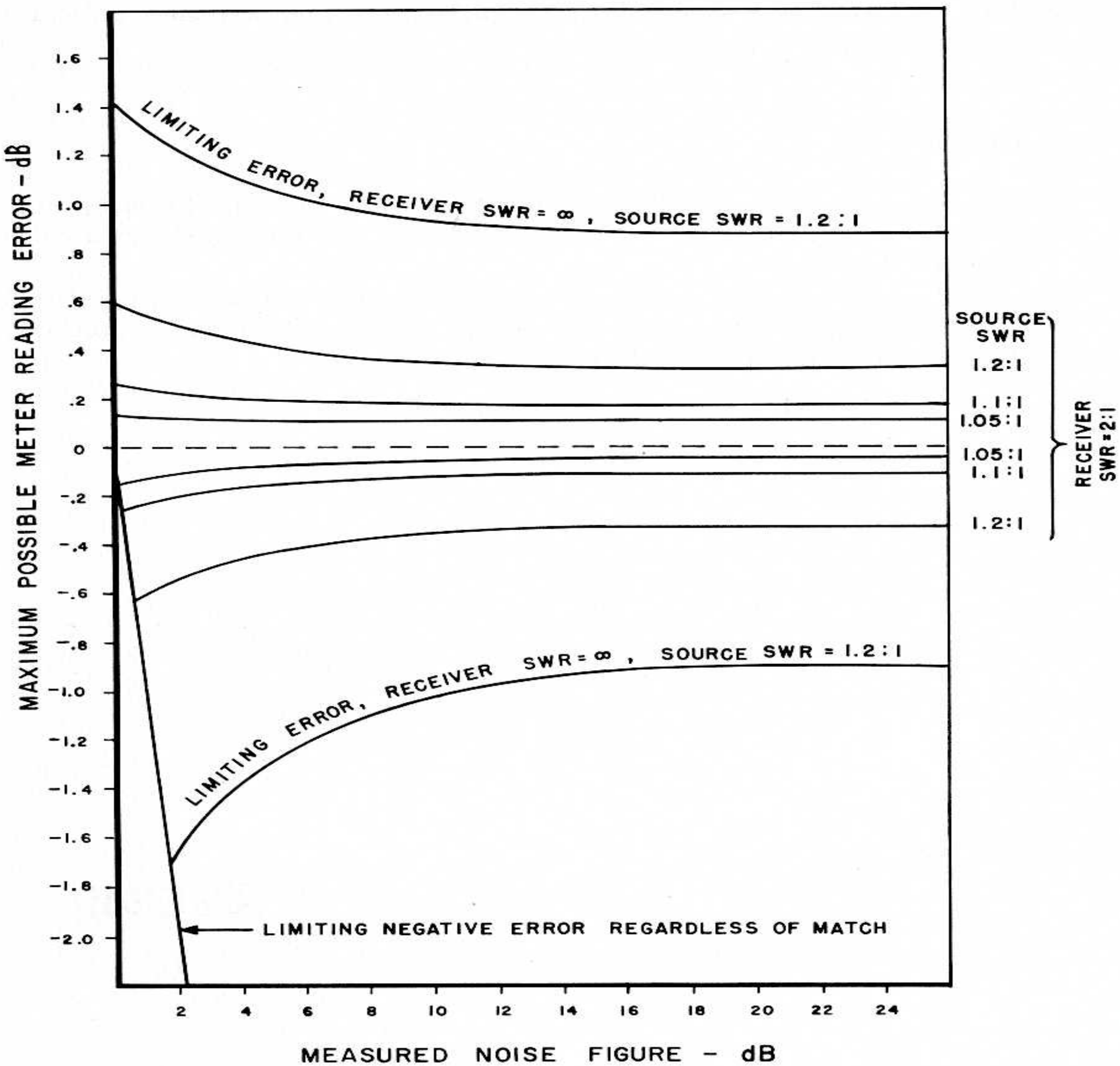




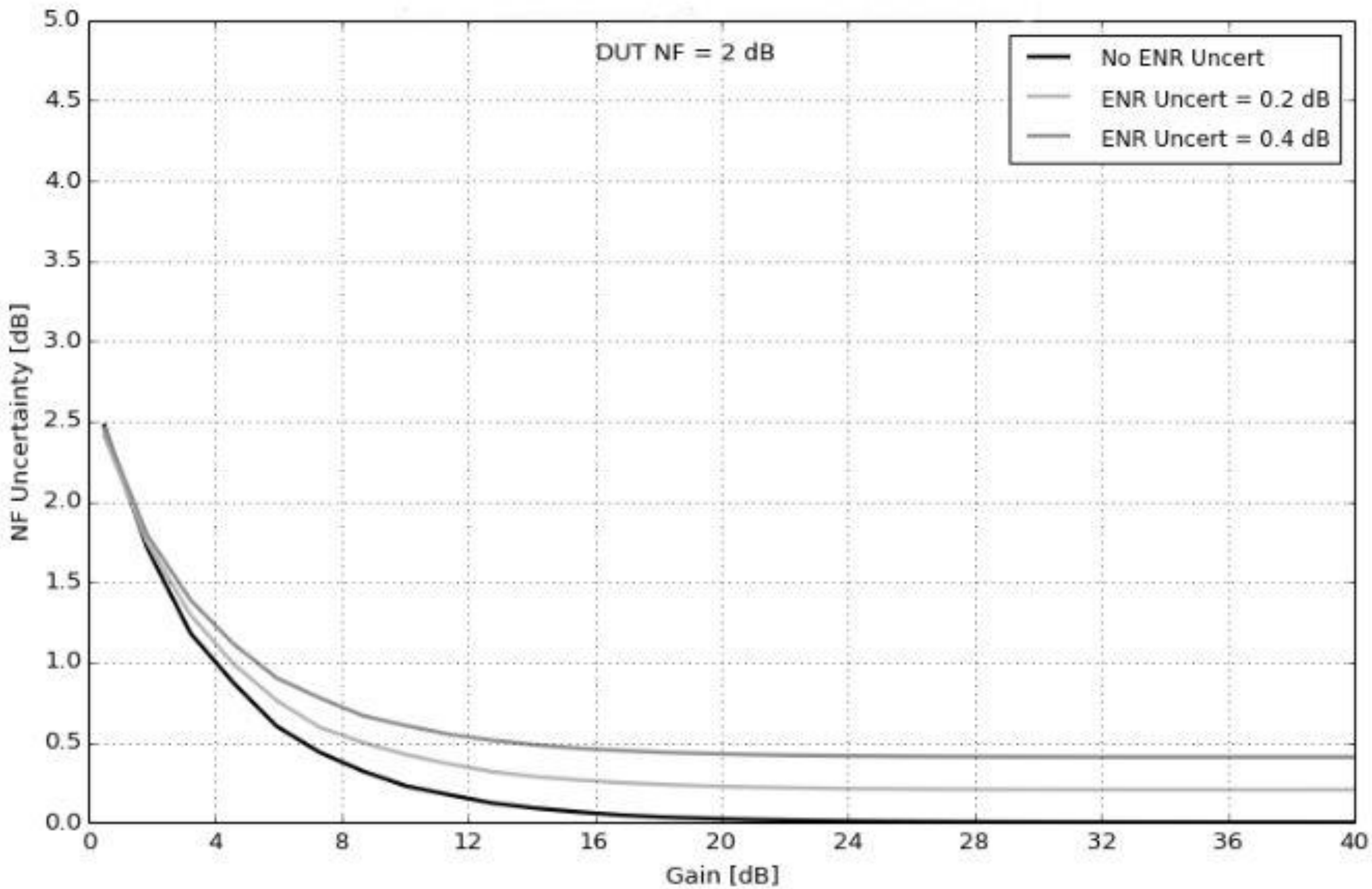




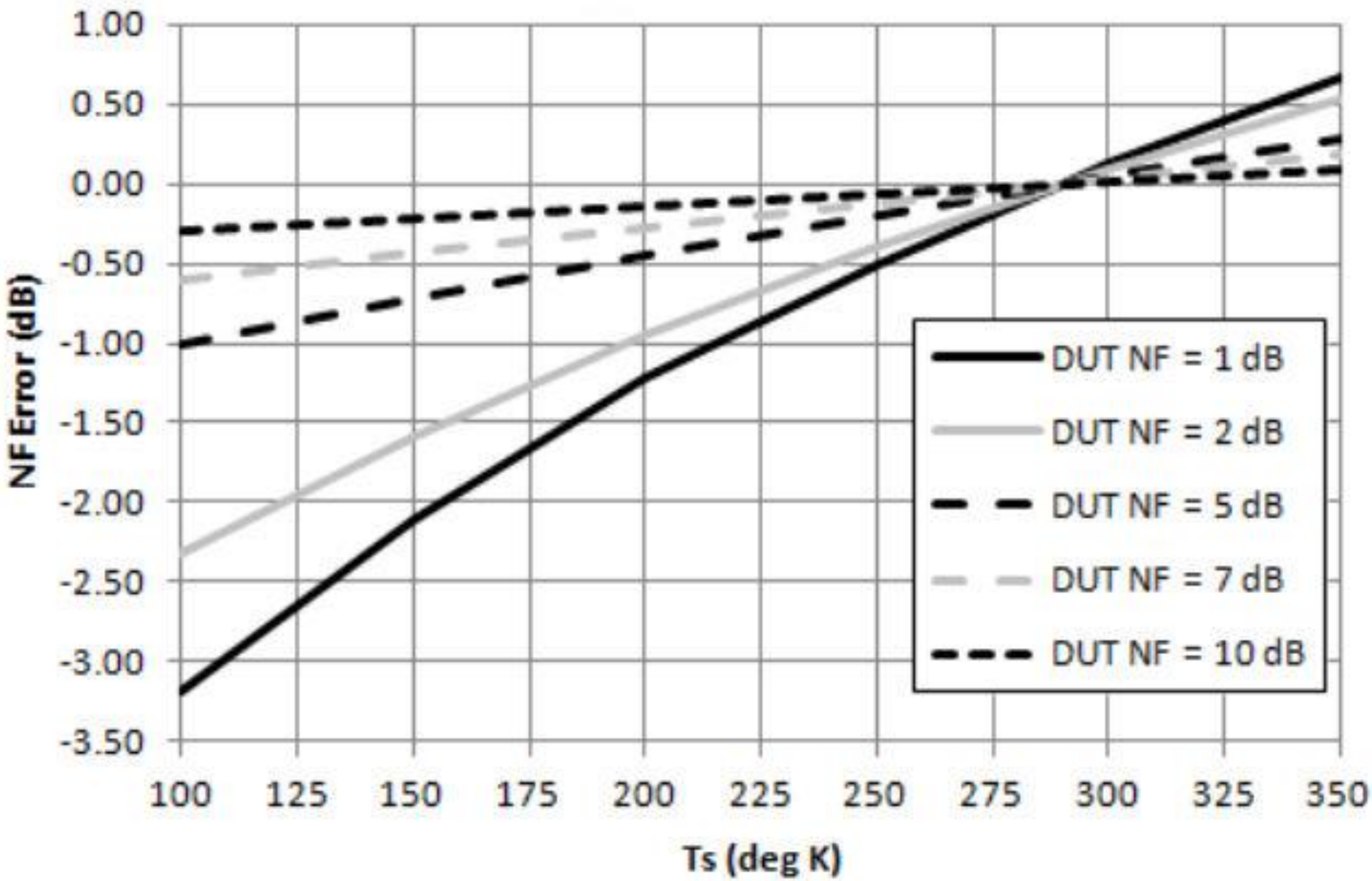
NF SOURCE MATCH ERROR



ENR ERROR


DUT NF = 2 dB
No ENR Uncert
ENR Uncert = 0.2 dB
ENR Uncert = 0.4 dB
NF Uncertainty [dB]
Gain [dB]
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
4
8
12
16
20
24
28
32
36
40

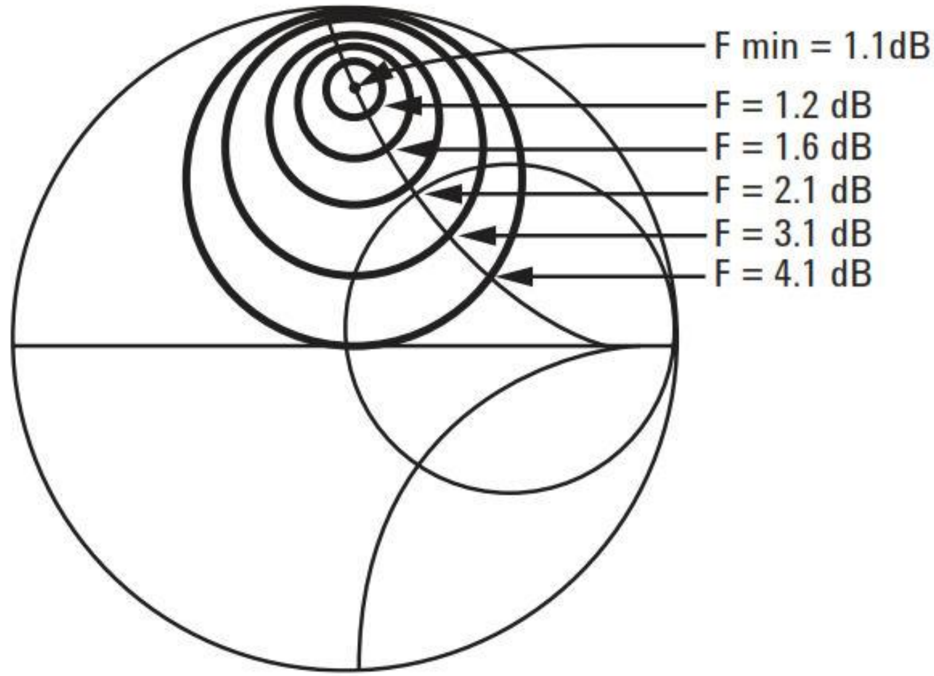
SYSTEM TEMP ERROR

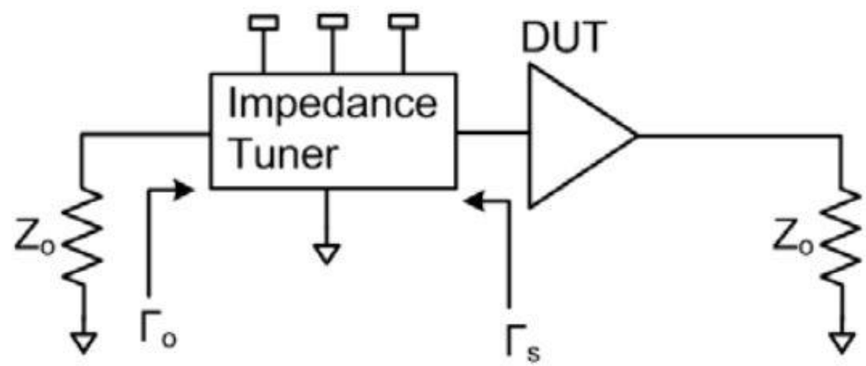


LNA DEVELOPMENT CONSIDERATIONS

- Source pull provides:
  - Optimum noise match impedance
  - Noise factor contours

- Input match is trade-off between noise match, reflection (gain) match, and stability analysis.





NF CALC SPREADSHEET

ORIG: NO5K

2-Sep-2022 Updated - K5TRA

Y FACTOR CALC	Measured				
FREQ(MHz):	1000 MHz	T_0:	295 K		
E.N.R:	4.66 dB	T_{hot} =	1,158 K		
N.S. ON:	-52.20 dBm	Y =	5.80 dB	3.80 lin	
N.S. OFF:	-58.00 dBm	NF =	0.19 dB	1.04 lin	13 K

Friis CASCADE		
NFdb 12 :	0.2	1.05 lin
NFdB 2 :	4.7	2.95 lin
GdB 1 :	21.4	138.04 lin
DUT-1 Noise =	0.14 dBF	1.03 lin

5623.000	fW	=	- 82.50 dBm
0.437	pW	=	-123.60 dBm
6.610	nW	=	-111.80 dBm
5.000	uW	=	-113.01 dBm
0.005	mW	=	-143.28 dBm

Degrees K	Deg F
300.0	80.3
289.8	62.0
NF dB NF:	0.2 dB
Te =	594 K

K= 1.381E-23

CASCADE	CALCULATION
System F (lin)	2.94
Cascade F (lin)	1.04
DUT Gain (lin)	137.88
System NF	4.7 dB NF
Cascade NF	0.2 dB NF
DUT Gain	21.40 dB
DUT F	1.03
DUT NF	0.13 dB NF

Device Under Test *AND* Spectrum Analyzer			
ENR:	4.66 dB	Th 1,158 K	0.2 dB NF
N.S. ON:	-52.20 dBm	6.0256E-09 W	3.80 lin Y
N.S. OFF:	-58.00 dBm	1.5849E-09 W	13 K
T_0 :	295 K		
Spectrum Analyzer Measured ALONE			
ENR:	4.66 dB	Th 1,158 K	4.7 dB NF
N.S. ON:	-71.90 dBm	6.46E-11 W	2.00 lin Y
N.S. OFF:	-74.90 dBm	3.24E-11 W	572 K
DUT NoiseTemp =	9 K	0.13 dB NF	
DUT Gain =	137.88	21.4 dB	

6.0256E-06 W	*Ylin*	*3.802*	
1.5849E-06 W	*3.802*	*Linear Y*	*ENR dB - "Y" dB*
Y - 1	*2.802*	*Lin Y - 1*	*= 0.19 dB NF*
10 log Y-1	*4.47 dB*	*10Log Lin Y - 1*	

ENR:	4.66 dB
4.60 dB Y	1.91 dB NF
4.30 dB Y	2.38 dB NF
4.00 dB Y	2.86 dB NF
3.50 dB Y	3.73 dB NF
3.00 dB Y	4.68 dB NF

Tdeg k :	295 K
Bw, Hz :	1
Gain dB :	40
T0 :	295 k
ENR:	15.5

kT =	-198.6 dBm/Hz
kTB =	-198.6 dBm
kTBG =	-158.6 dBm
P_{hot} Power Density	
-183.0 dBm/Hz	
10,762 deg K	

dBm/Hz :	-168.67	-108.0
BW, Hz :	↓ 1.00E+00 ↑	
dBm =	-168.7	-108

T_{hot} :	10500
T_{cold} :	295
ENR dB =	15.39 dB

ENR = (Thot / Tcold) - 1

-or-

ENR = (Th-To) / To

T_{hot}:	10500
T_{cold} :	295
ENR dB =	15.39 dB

NF dB NF :	4.7 dB	576 K
N Temp, K :	1249 K	7.2 dB NF

Noise Power :	-110 dBm
Measn BW :	1.00E+04
Est NFdB :	24.0 dB
Noise Energy:	-150.0 dBm/Hz

Noise Energy:	-159 dBm/Hz
BW :	1.00E+00
NFdB :	15.0 dB

DOWNLOAD: http://k5tra.net/TechFiles/NF_calc.xlsx