Noise figure measurments

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Summary

NF measurements

→ Noise Factor Review

→ Y Factor Method

→ Measurements Results

Noise Factor review

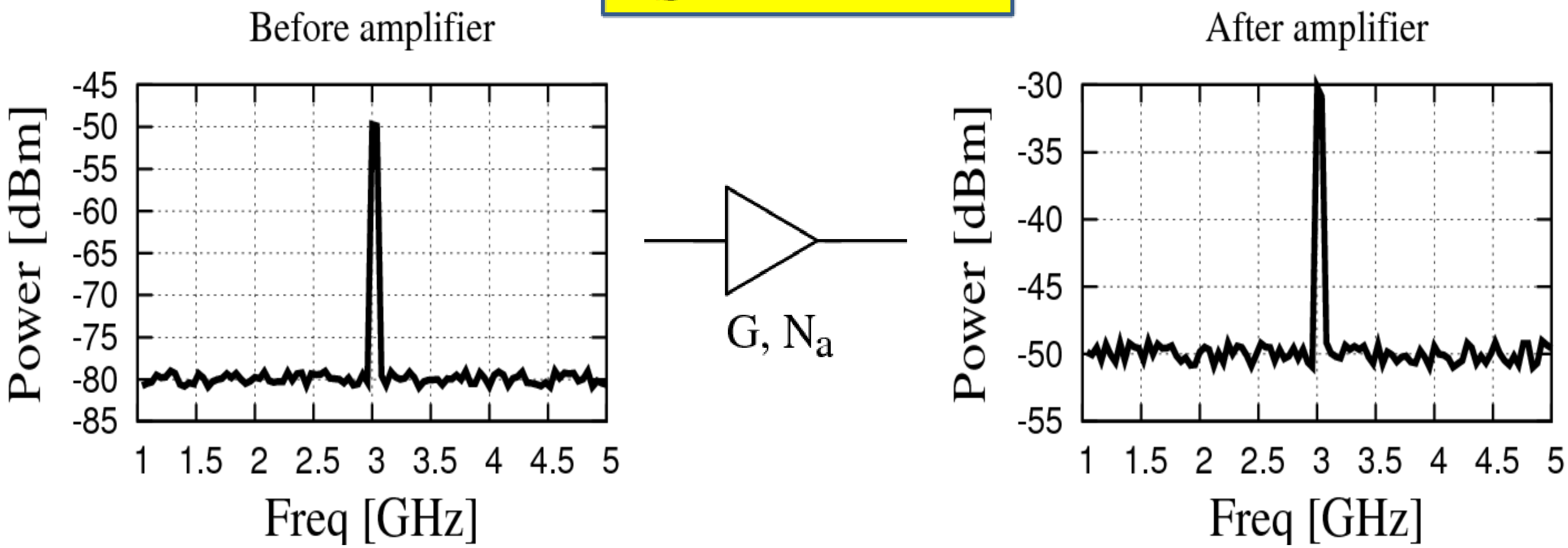
$$F = \frac{SNR_i}{SNR_o} = \frac{S_i/N_i}{S_o/N_o} = \frac{S_i/N_i}{GS_i/(N_a + GN_i)} = \frac{N_a + G\,N_i}{G\,N_i}$$

$$= \frac{N_a + G\,kT_0B}{G\,kT_0B} = \frac{N_{o(total)}}{N_{o(source)}}$$

where, $T_0 = 290\,\text{K}$

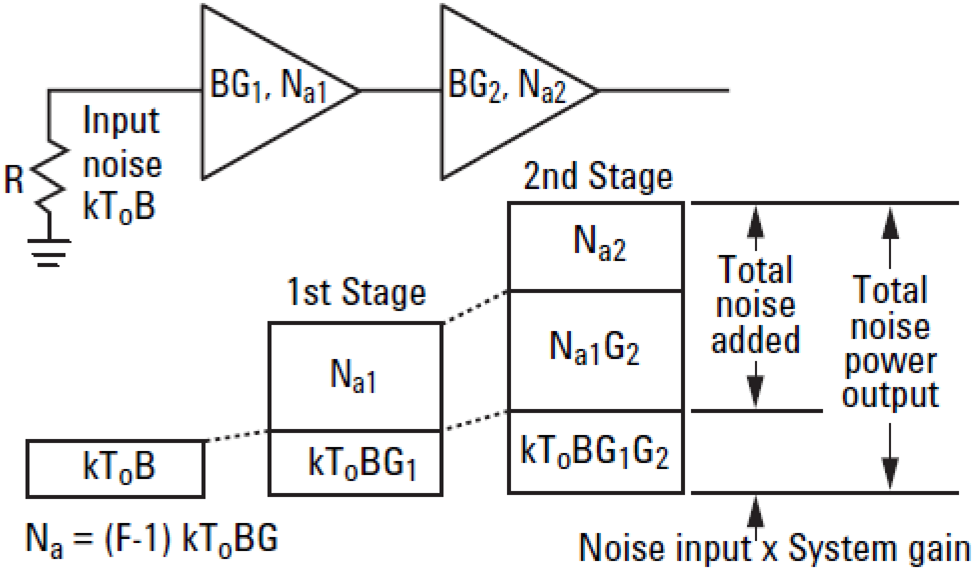
$k = 1.38 \times 10^{-23}\,\text{J/K}$

$$T_Q = (F-1)T_o$$



Noise Factor review

NF measurements



$$F_T = ?$$

$$F_T = \frac{N_{o(total)}}{N_{o(source)}}$$

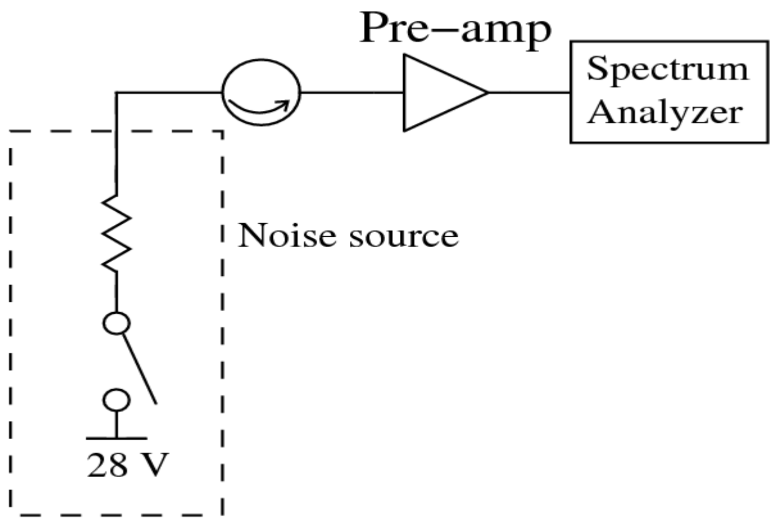
$$= \frac{kT_0BG_1G_2 + N_{a1}G_2 + N_{a2}}{kT_0BG_1G_2}$$

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

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

Noise Fig. measurements

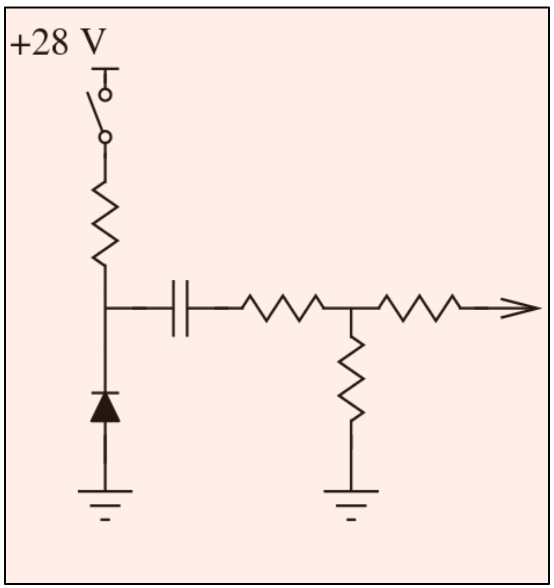
NF measurements



Noise source

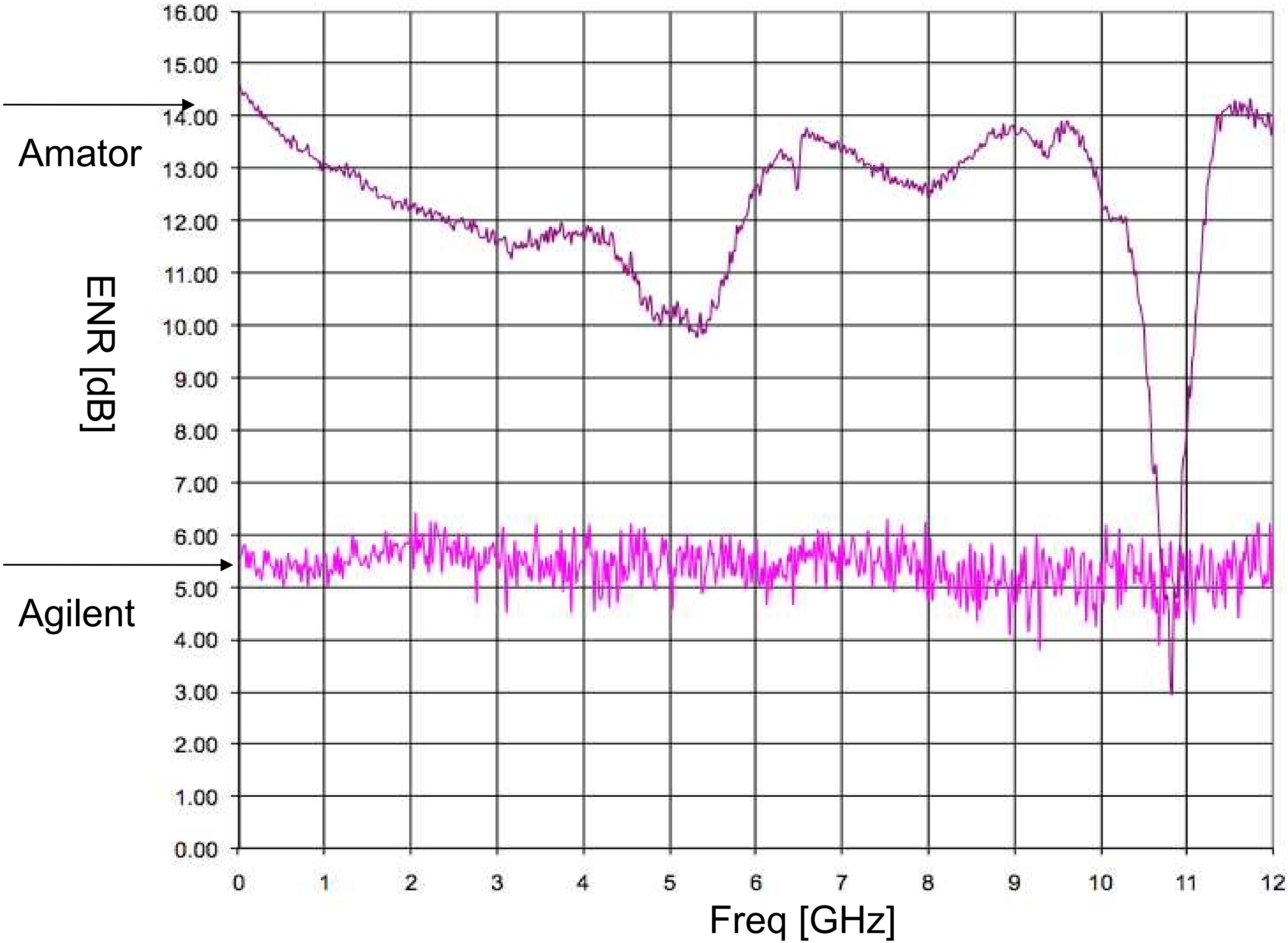
$$ENR = \frac{T_{hot} - T_{cold}}{T_0}$$

$$ENR_{dB} = 10\log(ENR)$$

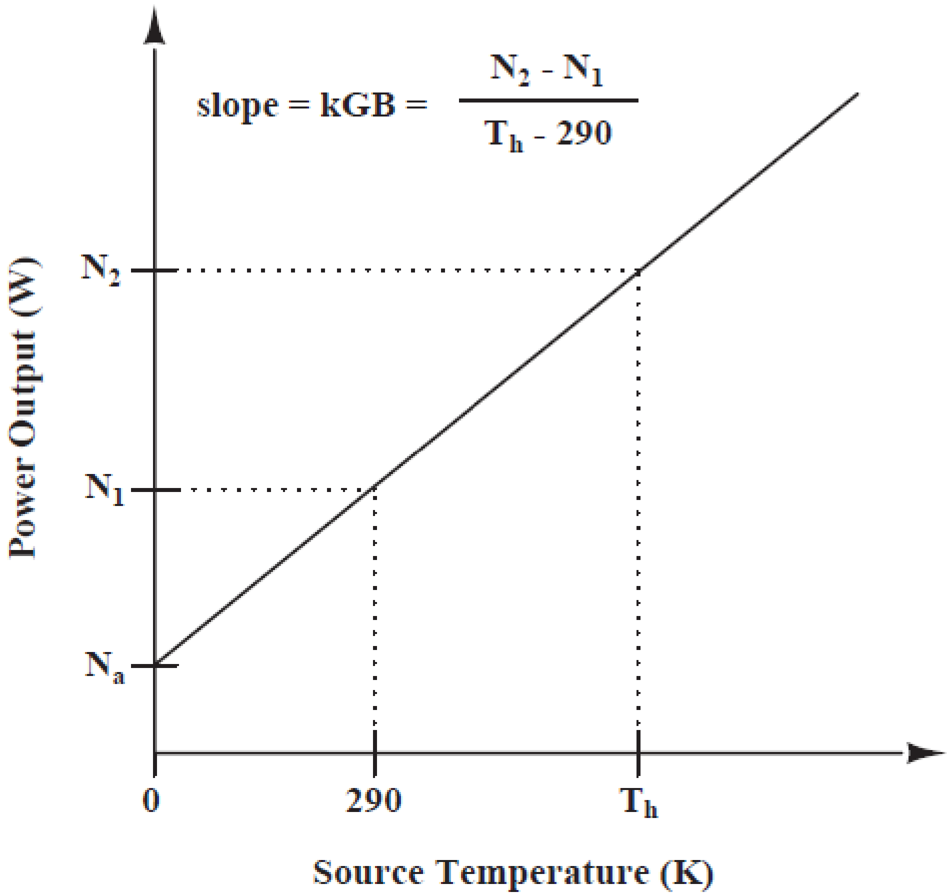


Noise Source	Frequency (GHz)	Typical ENR (dB)
346A / **346B**	0.01-18	5 / **15**
NC346D	0.01-18	19-25
NC346V	0.1-55	7-21
NC Test System	60-75	17

ENR example


Amator
Agilent
ENR [dB]
16.00
15.00
14.00
13.00
12.00
11.00
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
0
1
2
3
4
5
6
7
8
9
10
11
12
Freq [GHz]

Y-Factor Method

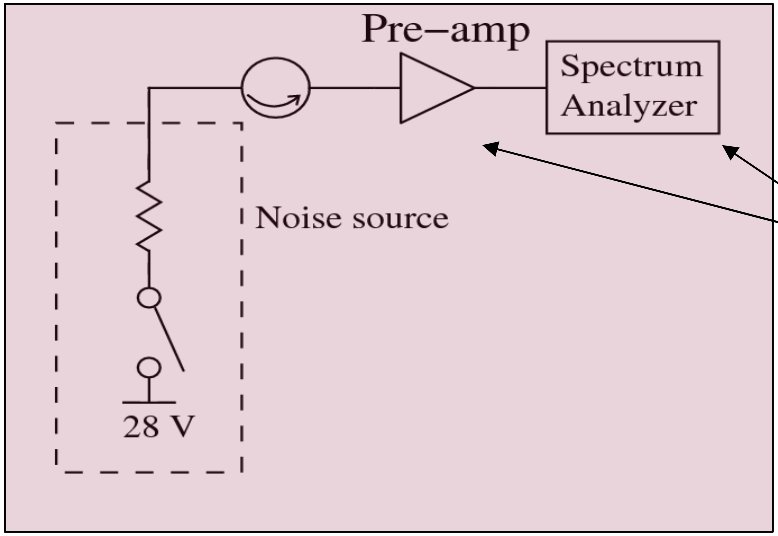


$$Y = \frac{N_2}{N_1}$$

$$Y - 1 = \frac{N_2 - N_1}{N_1} \qquad F = \frac{N_a + 290kGB}{290kGB} = \frac{N_1}{290kGB}$$

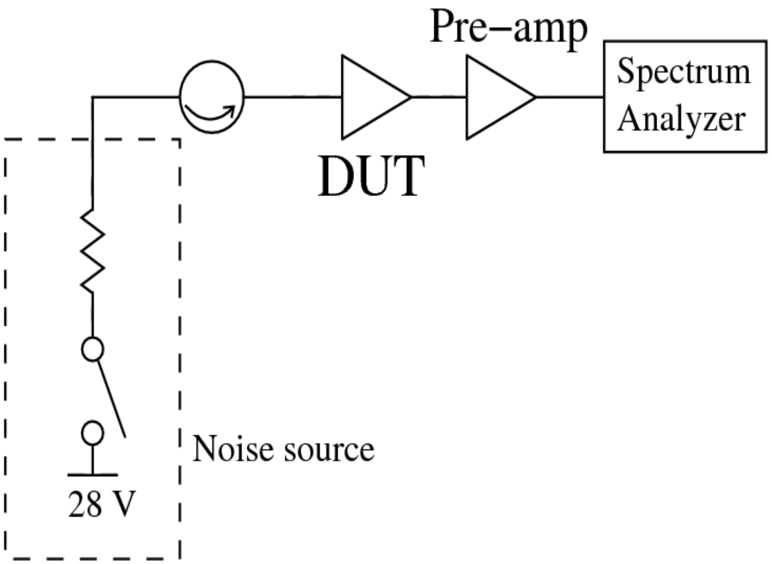
$$F = \frac{N_1}{290}\left(\frac{T_h - 290}{N_2 - N_1}\right) = \left(\frac{T_h - 290}{290}\right)\left(\frac{N_1}{N_2 - N_1}\right) = \frac{ENR}{Y - 1}$$

Noise Figure Measurements



They produce noise!

$$F_2$$



$$F_T = F_{DUT} + \frac{F_2 - 1}{G_{DUT}}$$

Connectorized LNA Tests

Features

- Ultra low noise figure, 0.8 dB typ.
- Output power, up to +18.5 dBm typ.
- Good output IP3, 31.5 dBm typ.
- Good return loss
- Unconditionally stable
- Protected by US patent 6,790,049

ZX60-272LN+

2300 to 2700 MHz

Electrical Specifications at 25°C

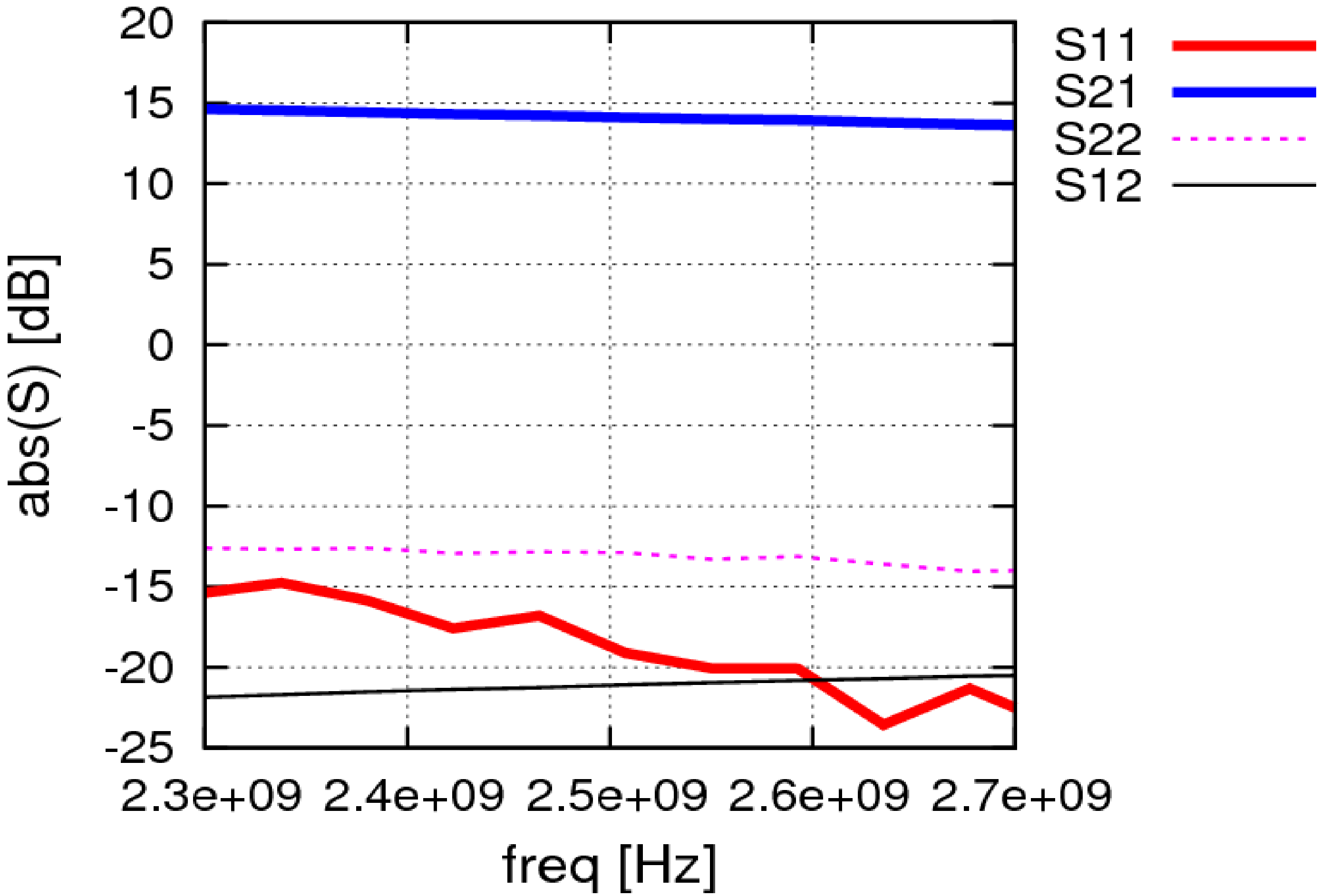
Parameter	Condition (MHz)	Min.	Typ.	Max.	Units
Frequency Range		2300		2700	MHz
Noise Figure	2300-2700		0.8	1.1	dB
Gain	2300-2700	11.5	14.0		dB
Gain Flatness	2300-2700		± 0.55	± 1.1	dB
Output Power at 1dB compression	2300-2700	16.0	18.5		dBm
Output third order intercept point (OIP3)	2300-2700		31.5		dBm
Input VSWR	2300-2700		1.2		:1
Output VSWR	2300-2700		1.6		:1
Active Directivity	2300-2700		7		dB
DC Supply Voltage			5.0		V
Supply Current			55	70	mA

Connectorized LNA Tests

ZX60-272LN+

2300 to 2700 MHz

NF measurements

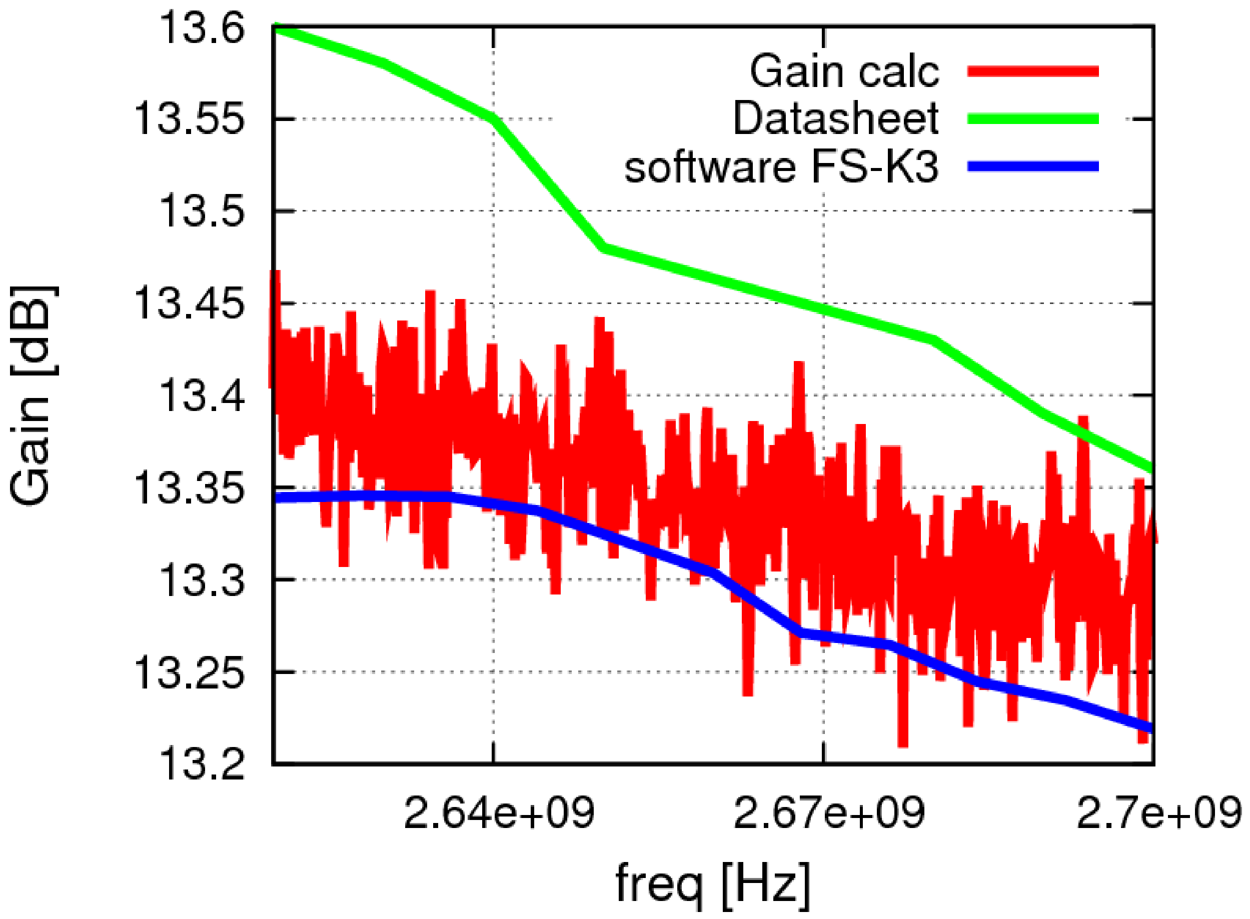


Measured S parameters of this LNA

Connectorized LNA Tests

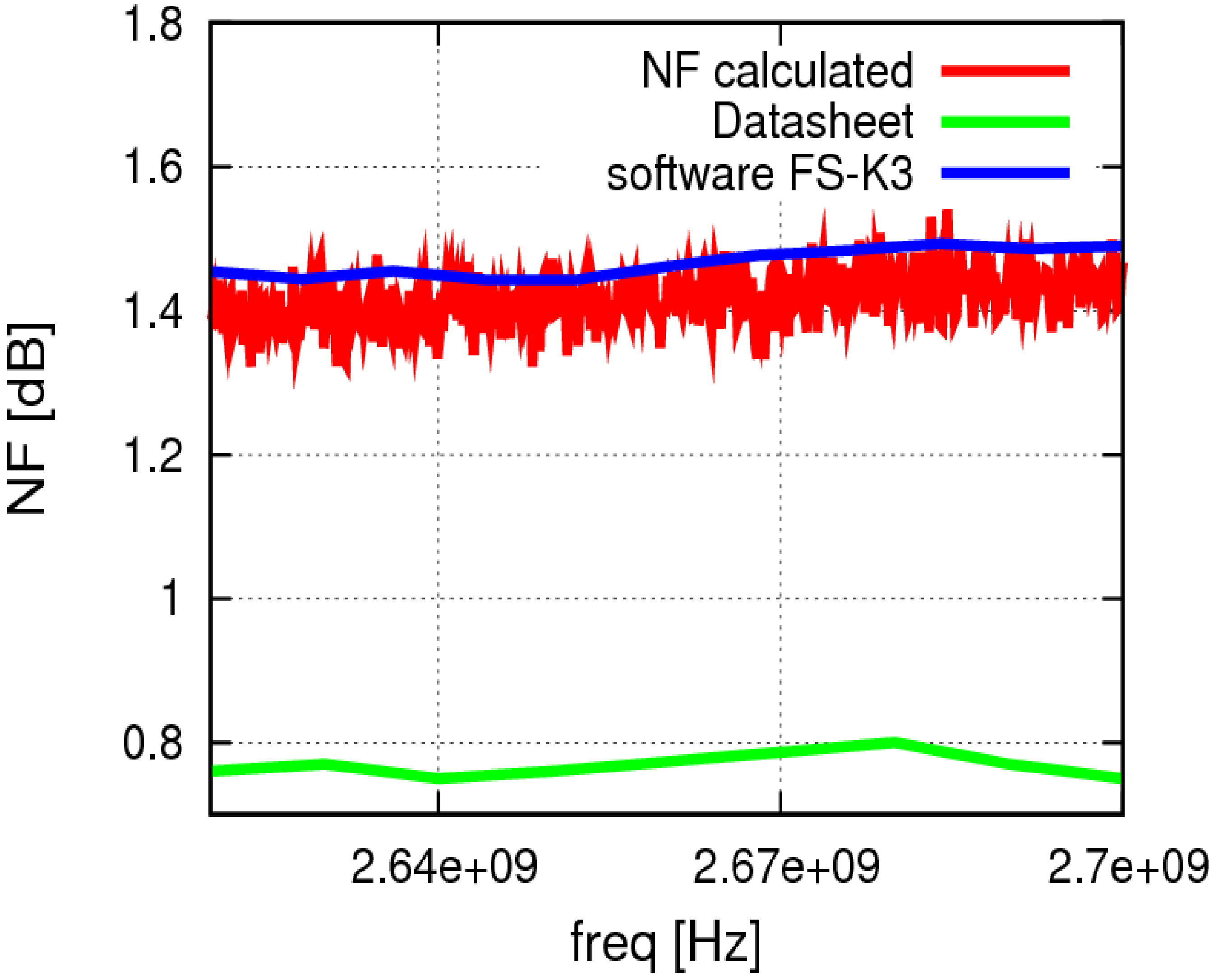
NF measurements

$$G_{ins} = \frac{P_{ON.DUT} - P_{OFF.DUT}}{P_{ON} - P_{OFF}}$$



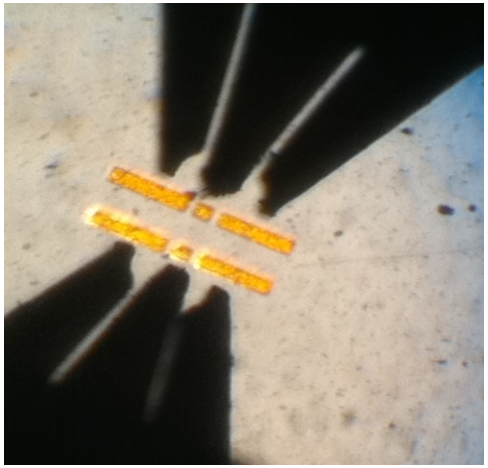
Connectorized LNA Tests

NF measurements

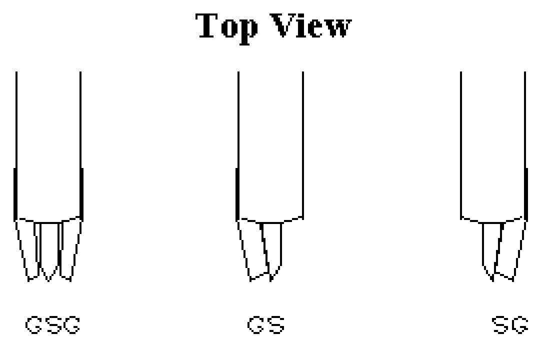


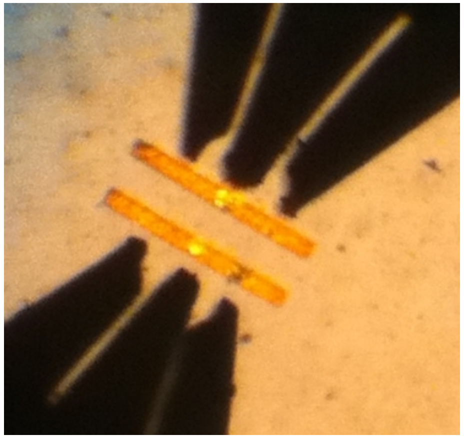
On Chip Tests – Probe & Calibration

NF measurements

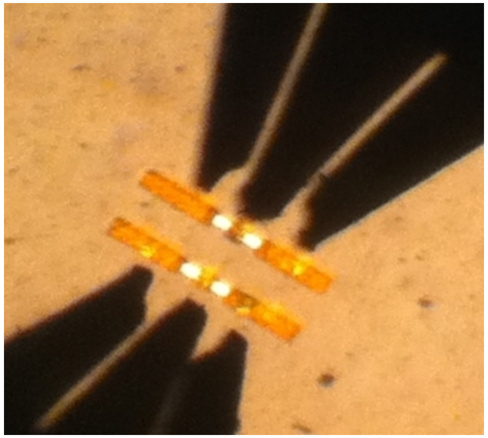


Open

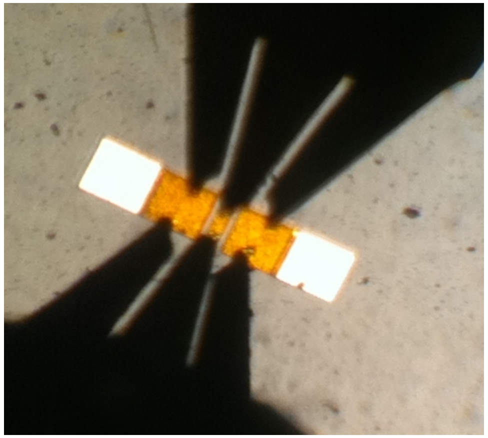




Short



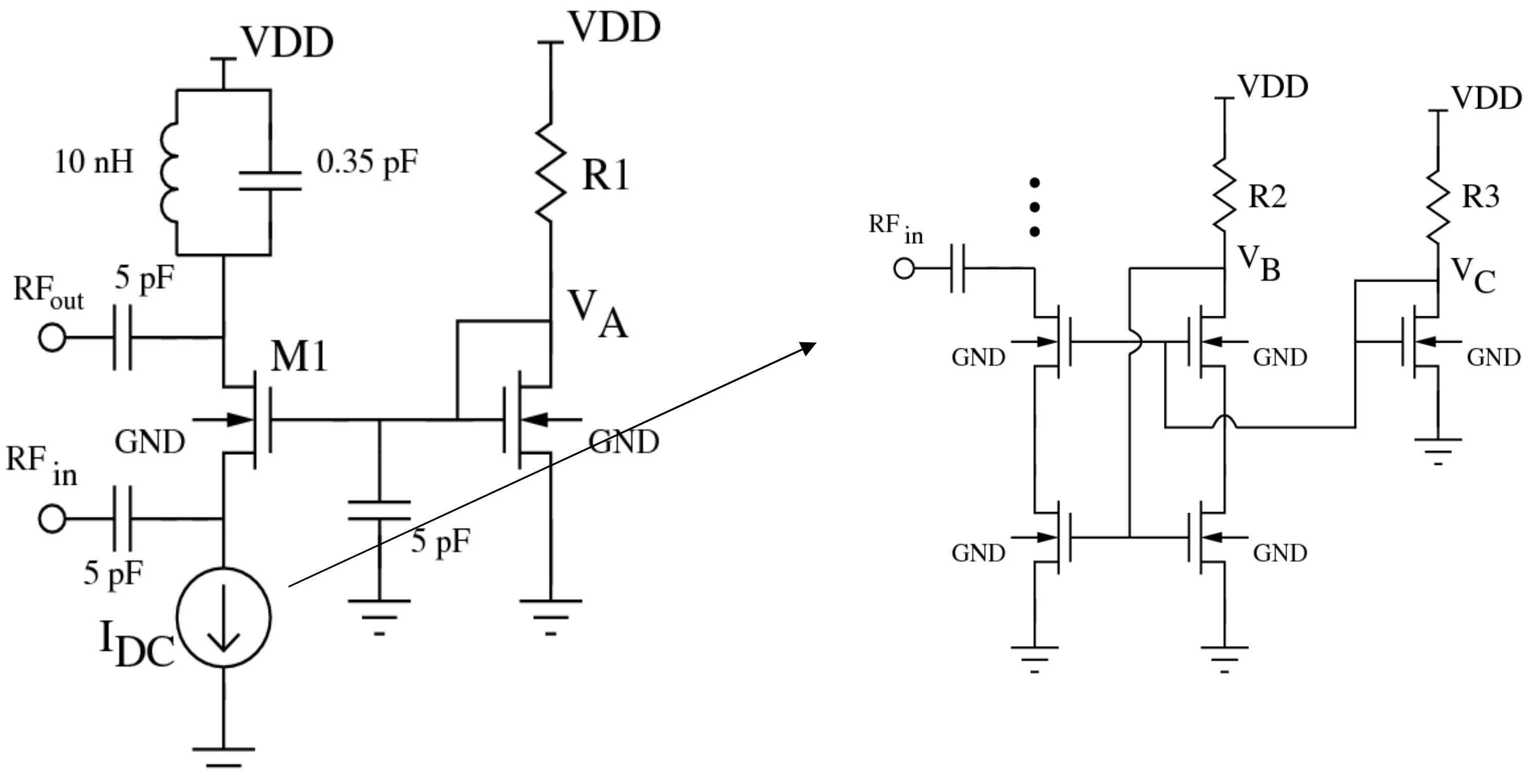
Load



Through

On Chip LNA Test (CMOS 0.35)

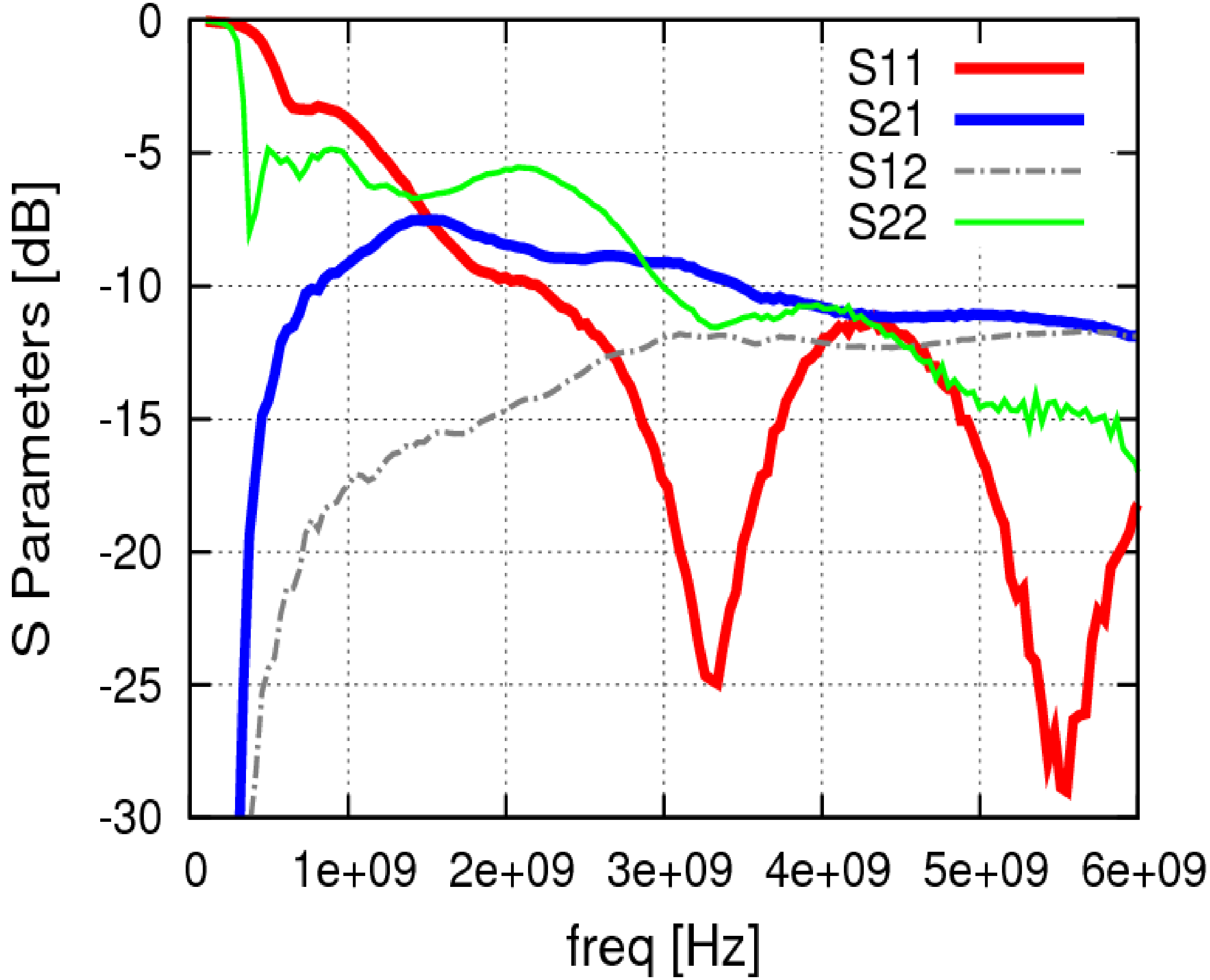
NF measurements



Specification	Value
Voltage Gain	$\geq 13\,\text{dB}$
S11	$\leq -12\,\text{dB}$
Noise Figure	$\leq 3\,\text{dB}$
Output 1 dB compression point	$\geq -10\,\text{dBm}$
Frequency of operation	2.4 GHz
Bandwidth	700 kHz

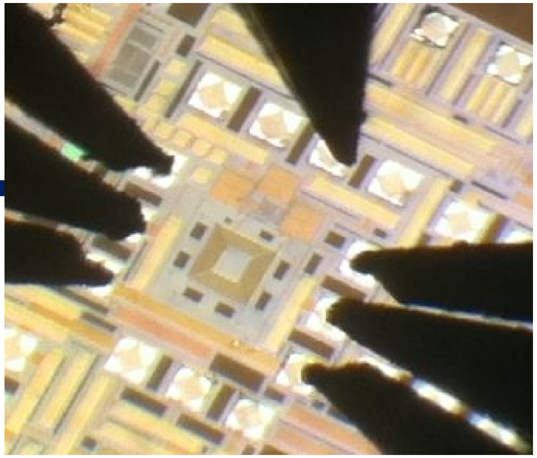
Parameter	Calculated	Measured
VA	2.4 V	2.4 V
VB	1.37 V	1.51 V
VC	2.0 V	2.1 V
I_{Tot}	4.3 mA	4.4 mA

On Chip LNA tests

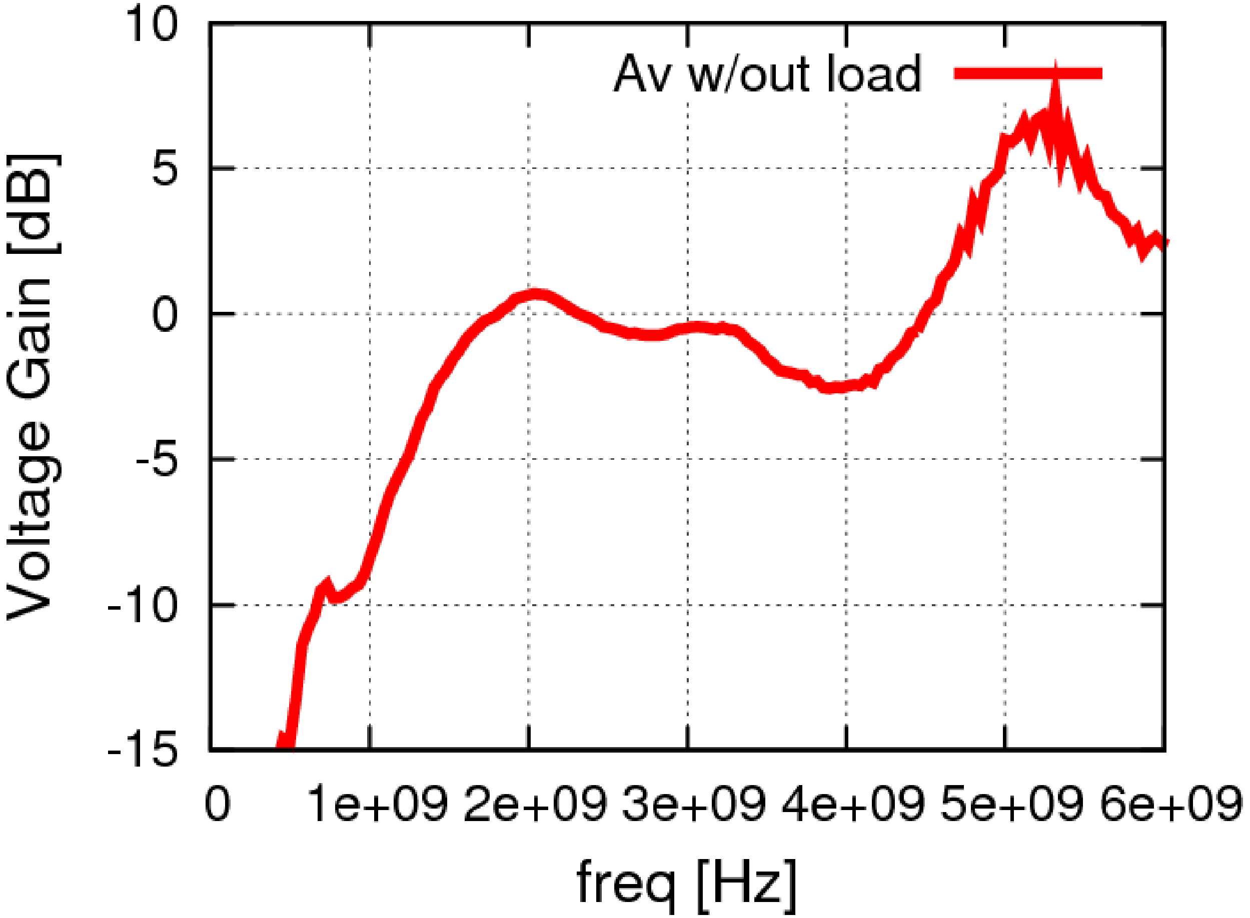


NF measurements

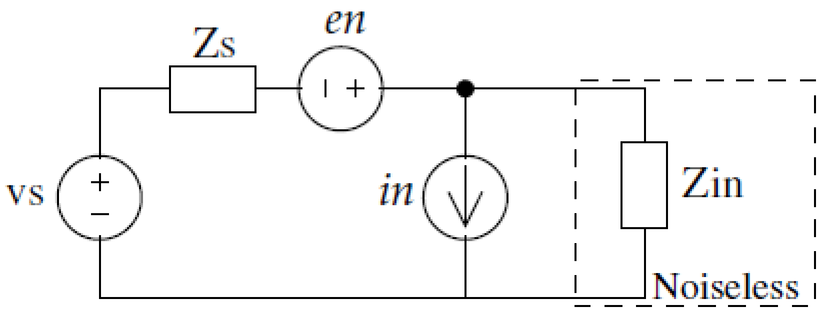
On Chip LNA tests



NF measurements



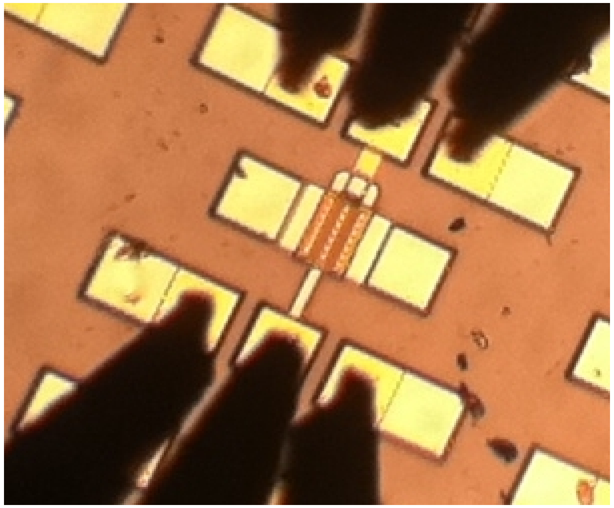
Two port NF parameter equation



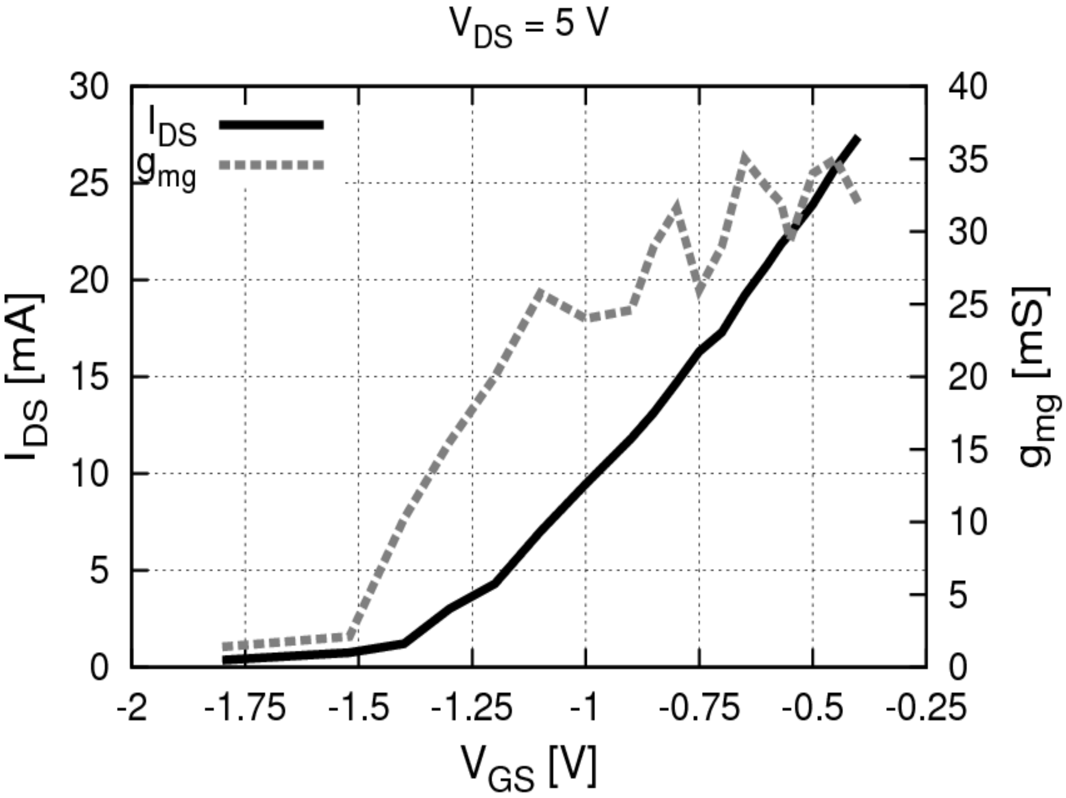
$$F = \frac{\overline{v_s^2}\left|\frac{Z_{in}}{Z_s+Z_{in}}\right|^2 + \overline{en^2}\left|\frac{Z_{in}}{Z_s+Z_{in}}\right|^2 + \overline{in^2}\left|\frac{Z_{in}Z_s}{Z_s+Z_{in}}\right|^2}{\overline{v_s^2}\left|\frac{Z_{in}}{Z_s+Z_{in}}\right|^2}$$

$$F = F_{MIN} + \frac{R_n}{G_s}\left|Y_s - Y_{opt}\right|^2$$

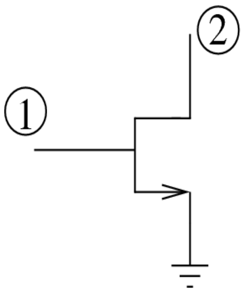
Transistor's DC behavior

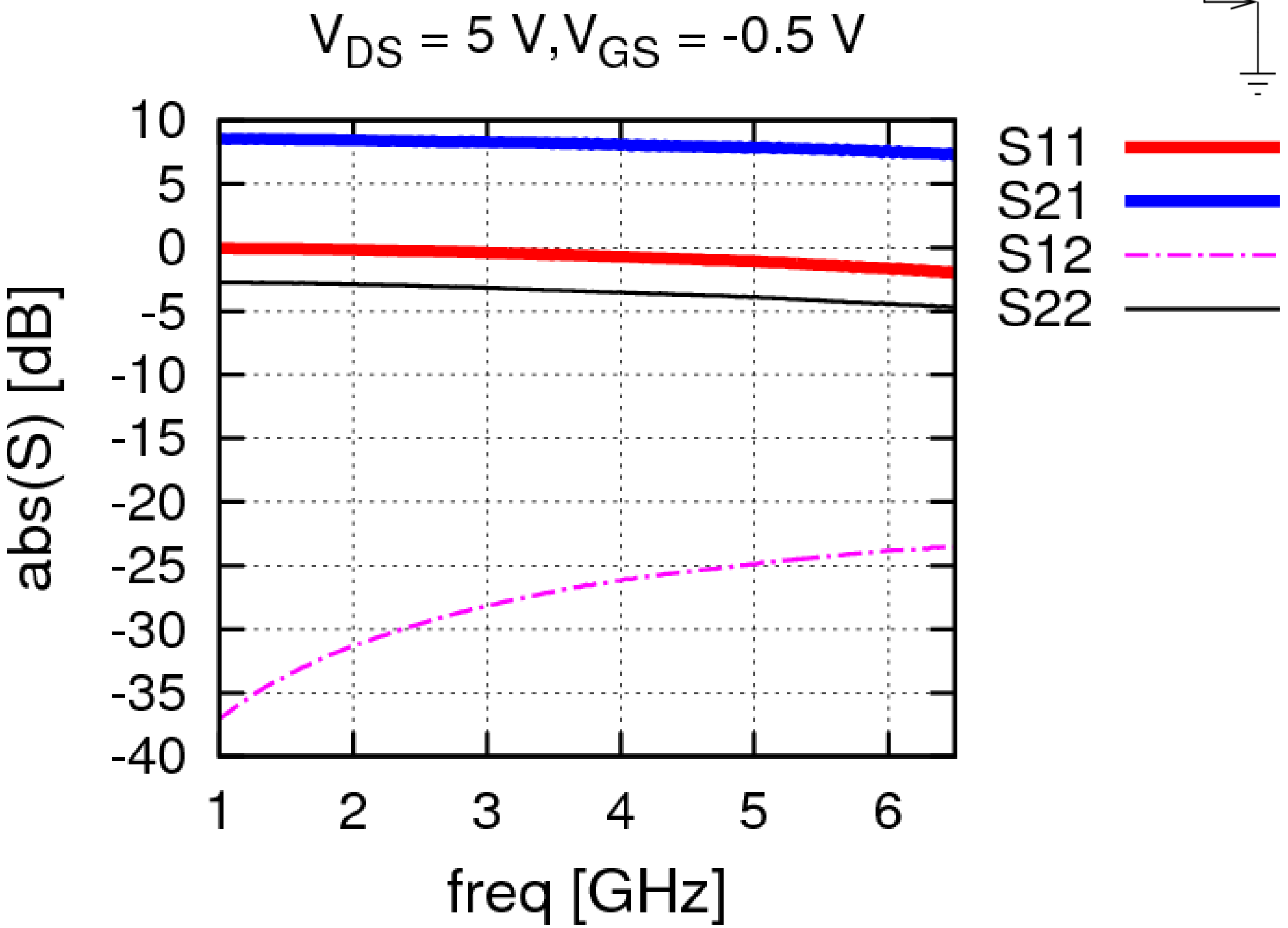


GaAs transistor

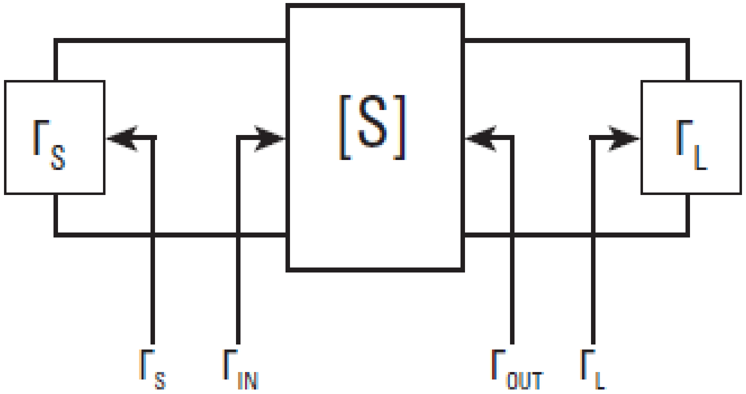


Transistor S params





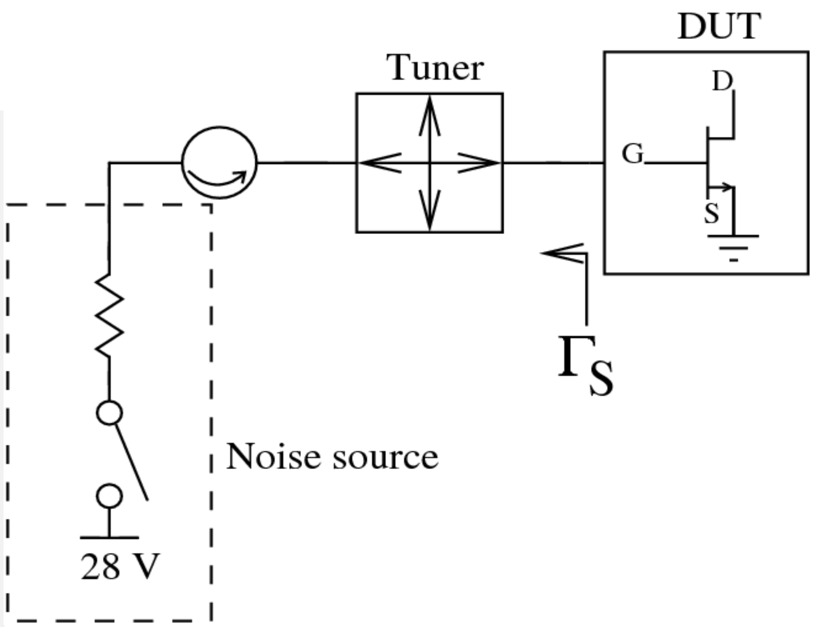
Available Gain calc



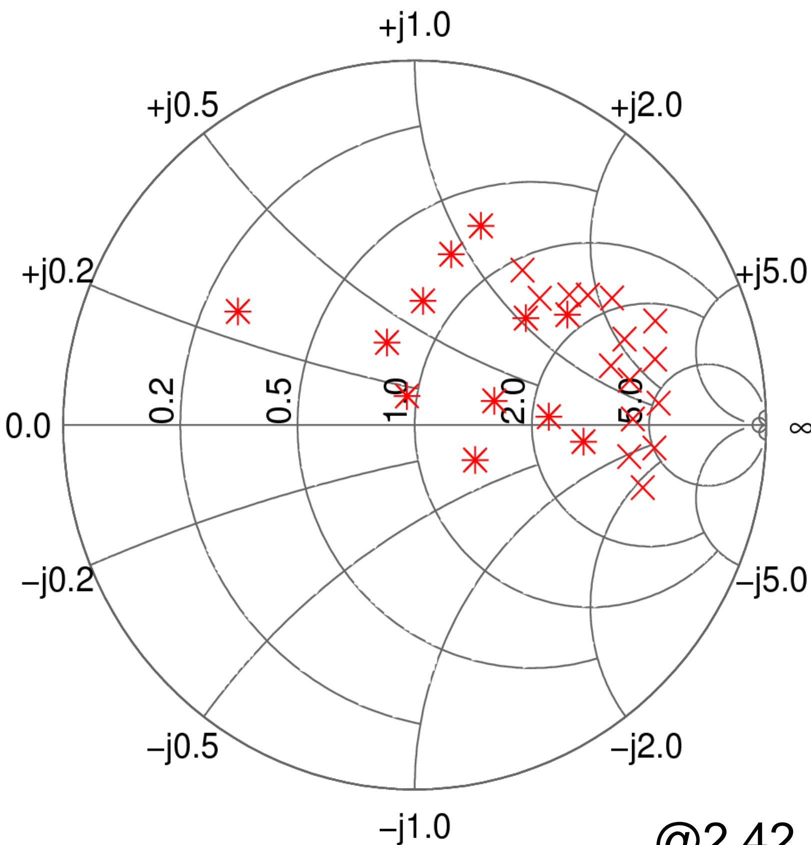
$$G_{Avbl} = |S_{21}|^2 \frac{1 - |\Gamma_S|^2}{|1 - \Gamma_S S_{11}|^2 (1 - |\Gamma_{out}|^2)}$$

$$\Gamma_{out} = S_{22} + \frac{S_{12} S_{21} \Gamma_S}{1 - S_{11} \Gamma_S}$$

Source impedance

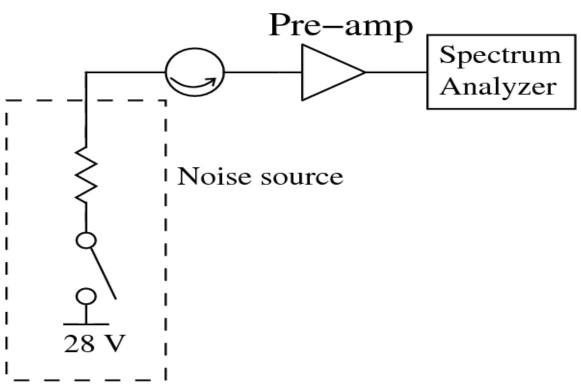


Consider the effect of:
probe+bias T+cable+tuner+circulator

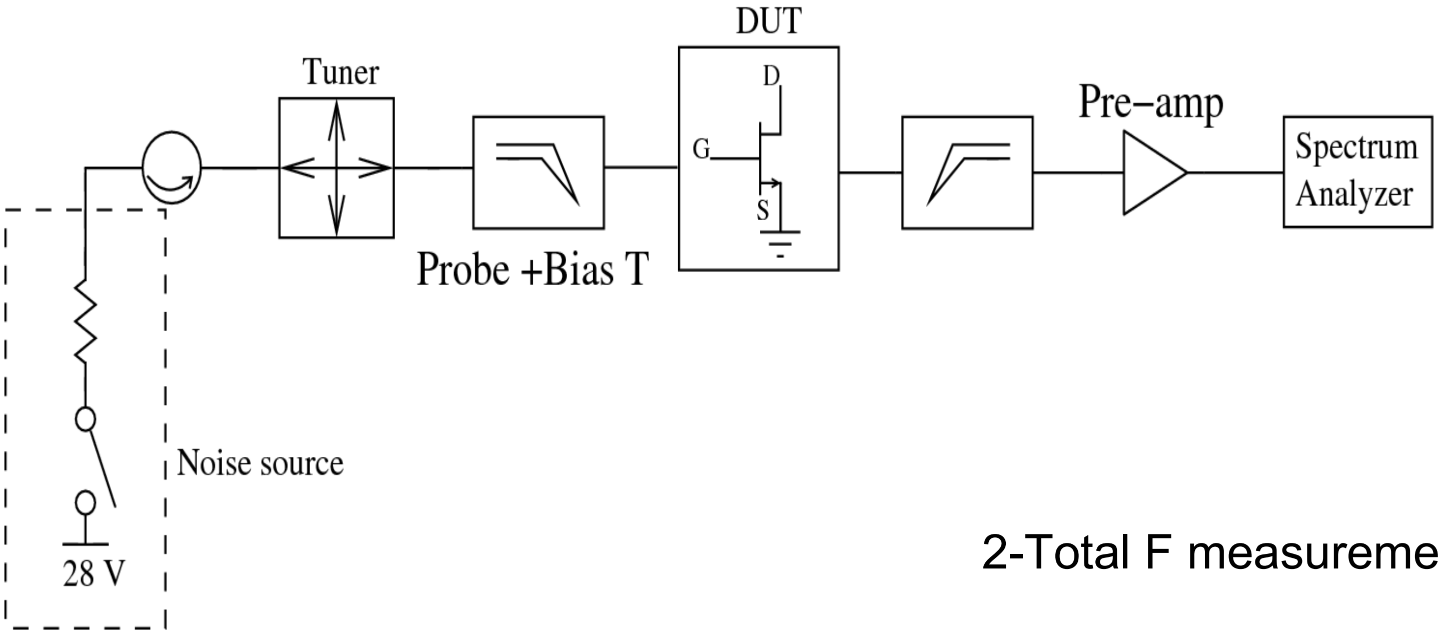


@2.42 GHz

Transistor NF measurement



1-Calibration Part



2-Total F measurement

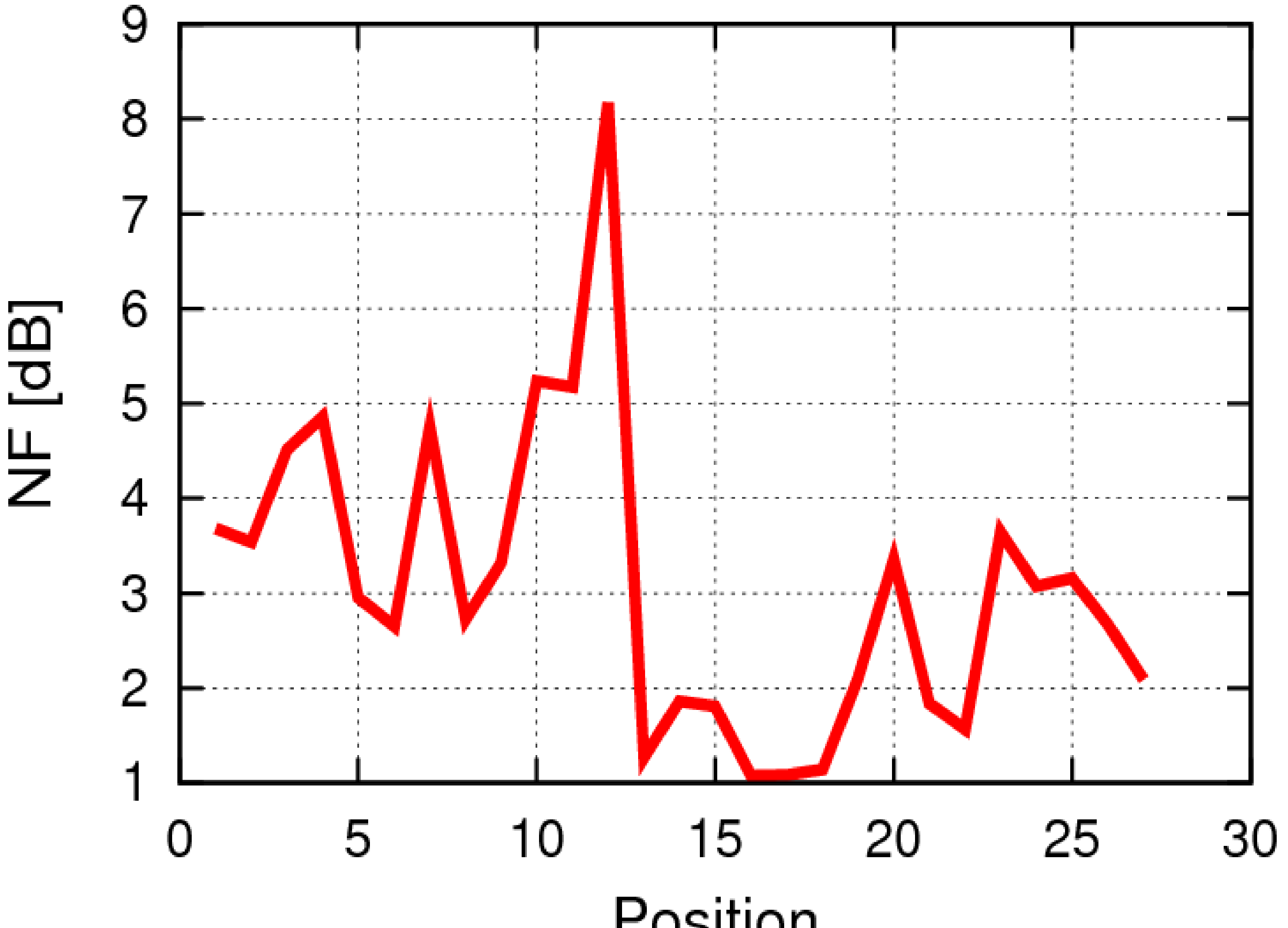
Must Find for DUT NF measurement

*S parameters of the system before the DUT.
(Can be found by making the Γs measurements and solving the system for open, short and through)

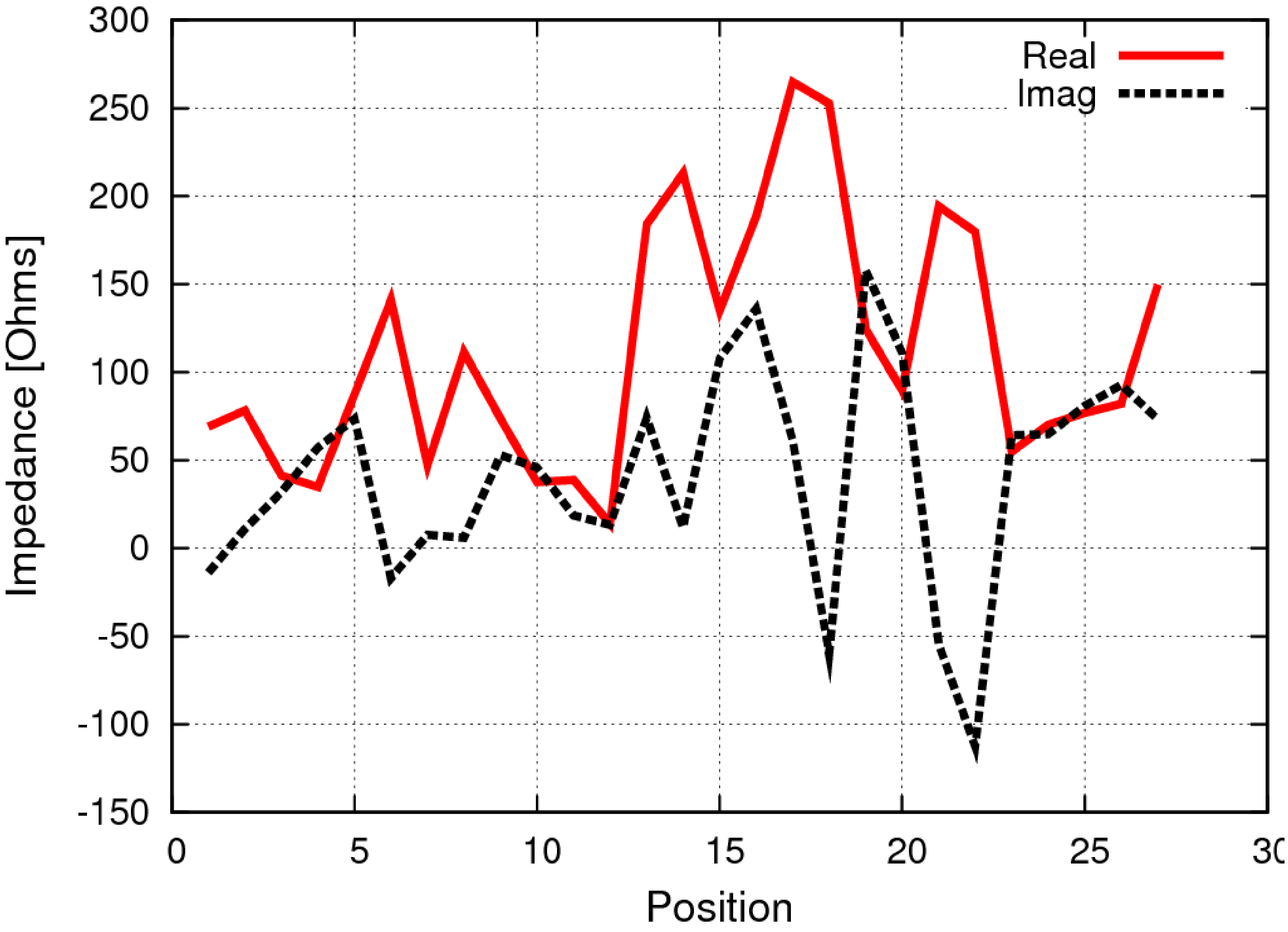
*Find the “probe+bias T” after the DUT S parameters.
(Can be found supposing that the 2 probes are equal.
Then, the S params of this system are aquired.
Convert them to T parameters and take the matrix sqrt.
Convert the result to the estimated S parameters of the Probe)

*Don't forget to consider all cables.

NF Values @ 2.42 GHz



Source Impedance Values @ 2.42 GHz



NF measurements

F parameters

$$F = F_{MIN} + \frac{R_n}{G_s} |Y_s - Y_{opt}|^2$$

Parameter	Value Obtained @2.42 GHz	Comparison @2 GHz [Gasmi]
NFmin (dB)	0.44	0.4
Rn/50	1.57	1.57
Module (Γopt)	0.99	0.93
Ang (Γopt)	3.43	8.35

Measurements tips

- The enviroment plays a big role on the NF measurements
- Choose the right ENR for each DUT
- Use average of the power signal to minimize display jitter
- Account for the losses

Conclusions

» Now we are able to make NF measurements on connectorized or on chip circuits.
» This will help also in circuit design.

References

[1] Noise Figure Measurement Accuracy – The Y-Factor Method Application Note 57-2. http://cp.literature.agilent.com/litweb/pdf/5952-3706E.pdf

[2] Fundamentals of RF and Microwave Noise Figure Measurements. http://www.home.agilent.com/agilent/redirector.jspx?ckey=1000001634:epsg:apn&action=ref&lc=e

[3] Maximizing Accuracy in Noise Figure Measurements. http://cp.literature.agilent.com/litweb/pdf/5091-4801E.pdf

[4] J. Rogers and C. Plett. Radio Frequency Integrated Circuit Design (Microwave Library). Artech House, 2003.

[5] A. Gasmi. Conception et réalisation de circulators actifs microondes en technologie monolithique MMIC: Calcul des paramètres de bruit des transistors pour l'optimisation des performances en bruit des circulateurs. Thèse, ENST 1997.