Practical Noise Figure Measurements

Including an example LNA design

Duncan Boyd

Power & Noise PGU, South Queensferry, Scotland

Agilent Technologies
Innovating the HP Way

Agenda

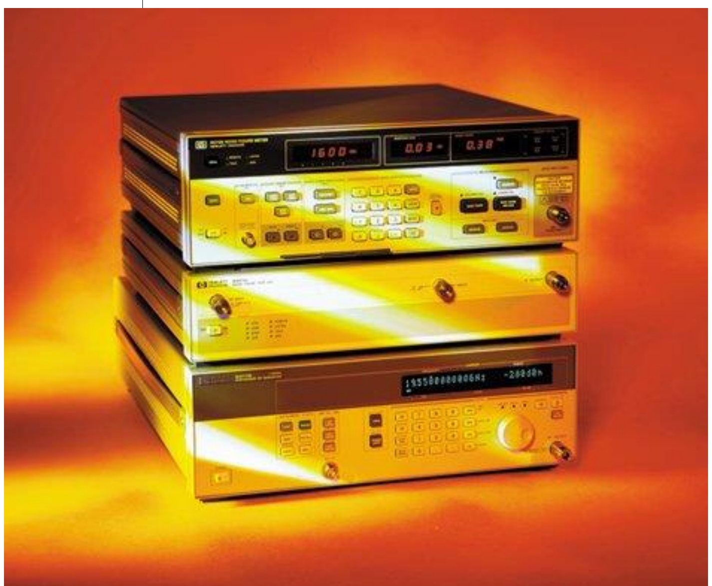
- Motivation
- Model a low noise amplifier block on ADS
- Practical noise figure measurements of the prototype amplifier using Agilent's N8973 Noise Figure Analyzer
- Narrow band noise figure measurements
- Measuring noise figure at microwave frequencies
- Measurement Uncertainty

Motivation

- RF Communications
  - Mobile Phones and Cordless Phones
- Point to Point Radio
- Satellite Communications
- Wireless LAN
- Global Positioning System
- Bluetooth
- Defense and Radar

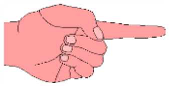
New Test Solution from Agilent

- Industry Standard 8970 Noise Figure Meter, 1981-2000



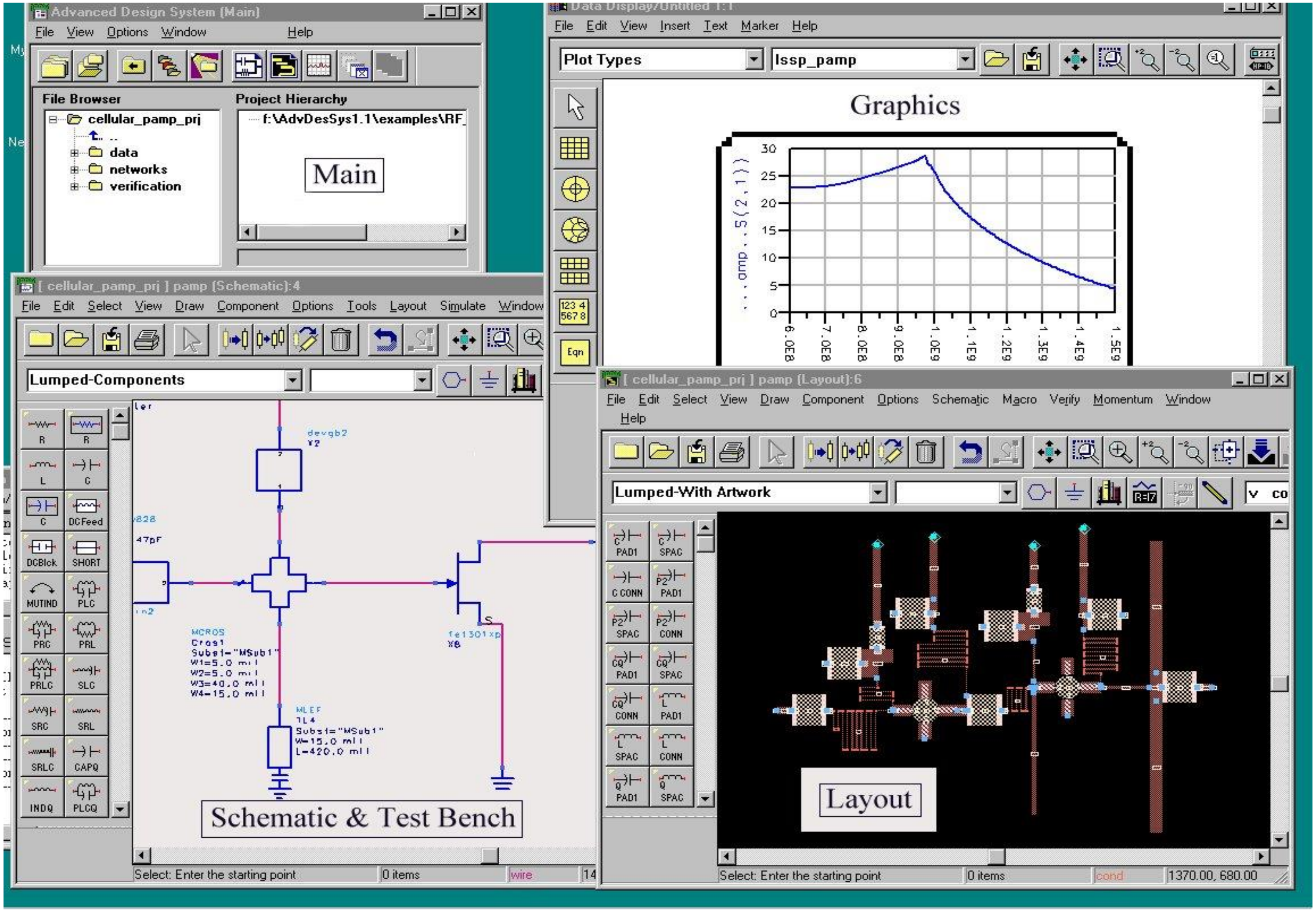
- New Generation NFA Series Noise Figure Analyzers, 2000 and beyond

Agenda

- Motivation


- Model a low noise amplifier block on ADS
- Practical noise figure measurements of the prototype amplifier using Agilent's N8973 Noise Figure Analyzer
- Narrow band noise figure measurements
- Measuring noise figure at microwave frequencies
- Measurement Uncertainty

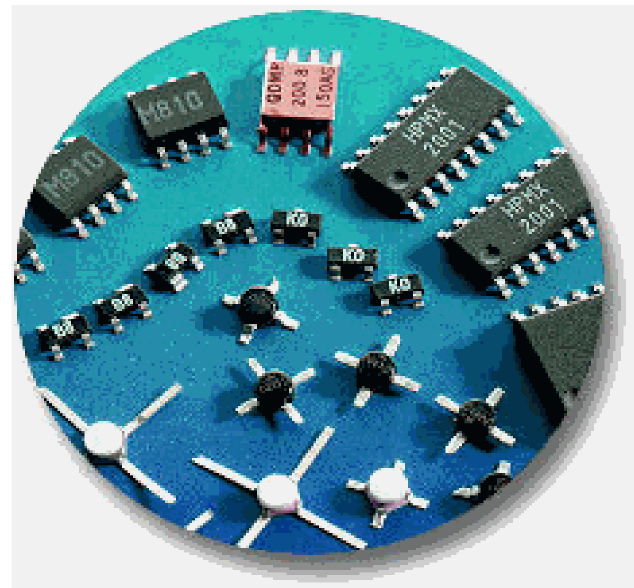
ADS Presentation Windows



Example Low Noise Amplifier Design using ADS

Design Process

- Functional Requirements
- Device selection
- Design
  - Bias
  - Synthesize matching networks
- Layout
  - Choose vendor parts with artwork
  - Generate layout
- Performance analysis and optimization



Amplifier Functional Requirements

- Frequency Range of 1.5-2.5GHz covering the 1.8 and 2.3GHz Mobile Phone bands
- Noise figure <1dB
- Gain >10dB
- VSWR <2.0:1
- Low voltage supply, ideally 3v
- Distributed matching (microstrip) to reduce cost

Device Selection

- GaAs, SiGe, HEMPT, PHEMPT?
  - Many modern technologies have sub1dB noise figures
- Suppliers have web pages with downloadable datasheets as well as downloadable S-Parameter/ Noise Parameter data
- Choose ATF34143 PHEMPT from Agilent
  - 0.5dB Noise Figure
  - Good Dynamic Range
  - Reasonably easy to match

- Noise and S-Parameters File

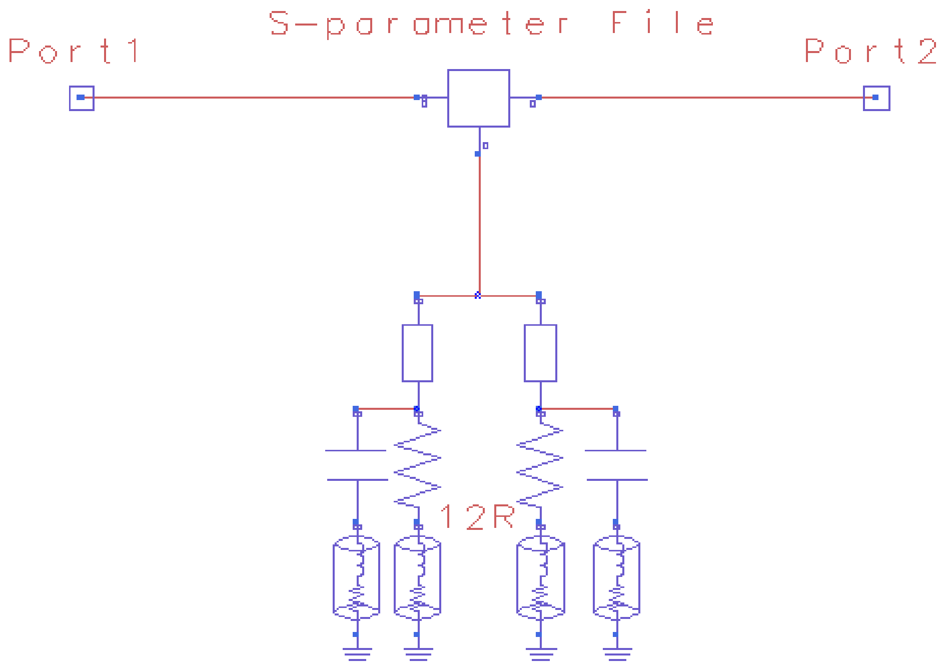
! ATF-34143 S PARAMETERS
! Id = 20 mA LAST UPDATED 2/6/99

!FREQ	S11		S21		S12		S22	
!GHz	MAG	ANG	MAG	ANG	MAG	ANG	MAG	ANG
0.50	.96	-37	10.08	153	.035	68	.4	-35
0.80	.91	-60	9.642	137	.050	56	.34	-56
1.00	.87	-76	8.867	126	.061	48	.32	-71
1.50	.81	-104	7.443	106	.077	34	.29	-98
1.80	.78	-115	6.843	98	.083	28	.28	-110
2.00	.75	-126	6.306	90	.088	23	.26	-120
2.50	.72	-145	5.438	75	.095	15	.25	-140
3.00	.69	-162	4.762	62	.102	7	.23	-156
4.00	.65	166	3.806	38	.111	-8	.22	174

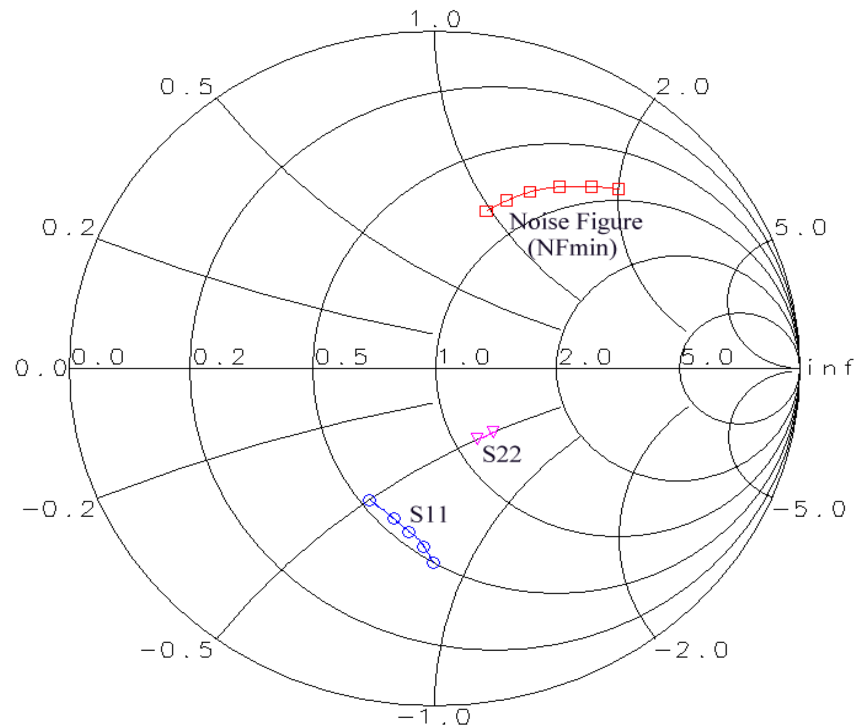
!FREQ	Fopt	GAMMA OPT		RN/Zo
!GHZ	dB	MAG	ANG	-
0.5	.10	.90	13	.16
0.9	.11	.85	27	.14
1.0	.11	.84	31	.13
1.5	.14	.77	48	.11
1.8	.17	.74	57	.10
2.0	.19	.71	66	.09
2.5	.23	.65	83	.07
3.0	.29	.59	102	.05
4.0	.42	.51	138	.03

Modeling the raw device

- Model of raw device with Source Resistance for self bias



- Noise and S-Parameters

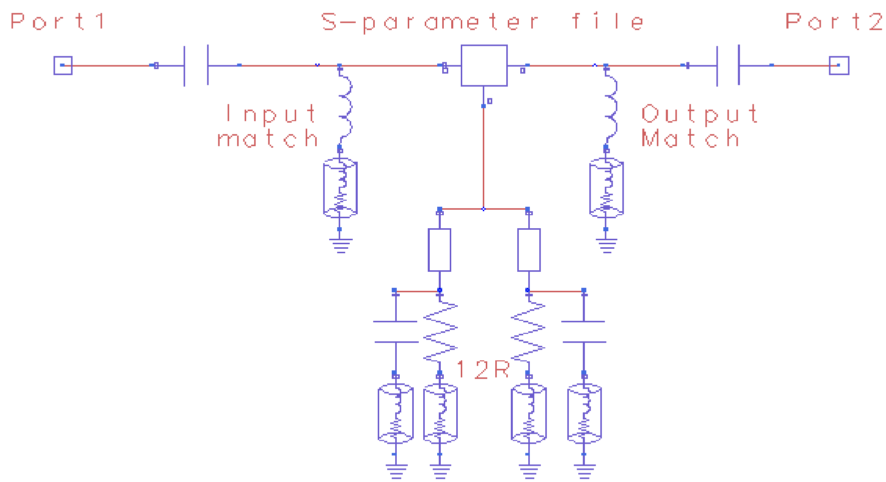


Agilent Technologies

Matching the device

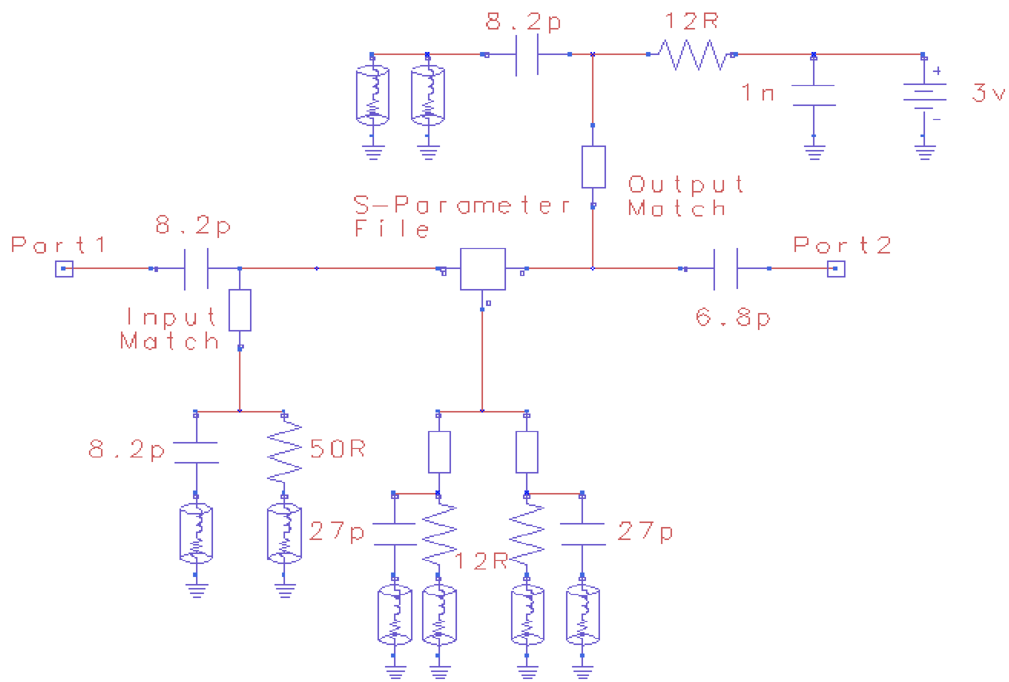
- Circuit looks capacitive
  - Use High-pass arrangement shown
- There are many ways to synthesize matching networks
  - Calculator
  - Smith chart
  - Use Esyn in ADS
  - Use optimizer in ADS

- Simple high-pass impedance match



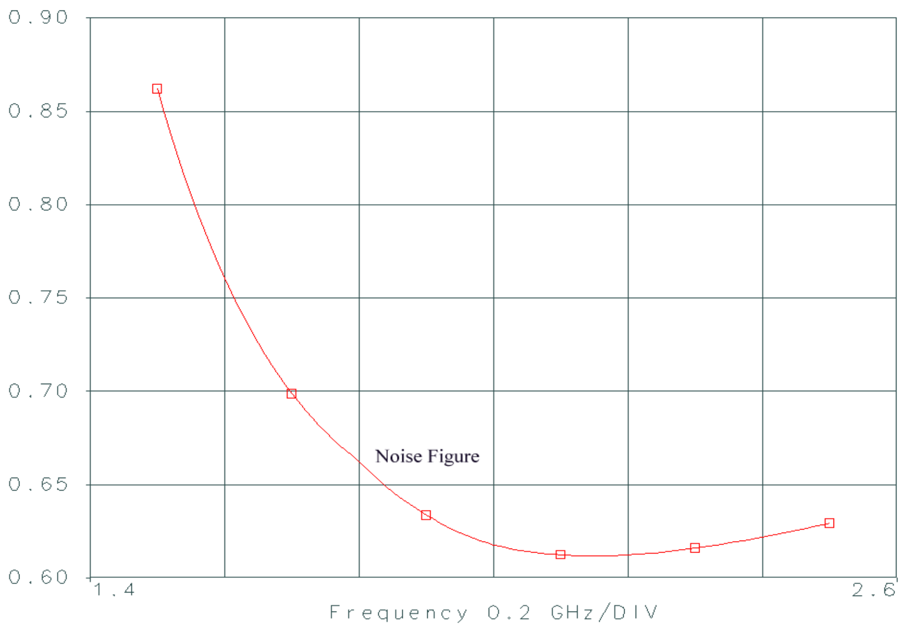
Complete Model of the Amplifier

- Inductors replaced by distributed elements
- Discretes replaced by vendor parts
- Output match inductance used to de-couple power supply
- Through hole vias included in model
- Some stabilization added
- ADS Optimizer used to re-tune values

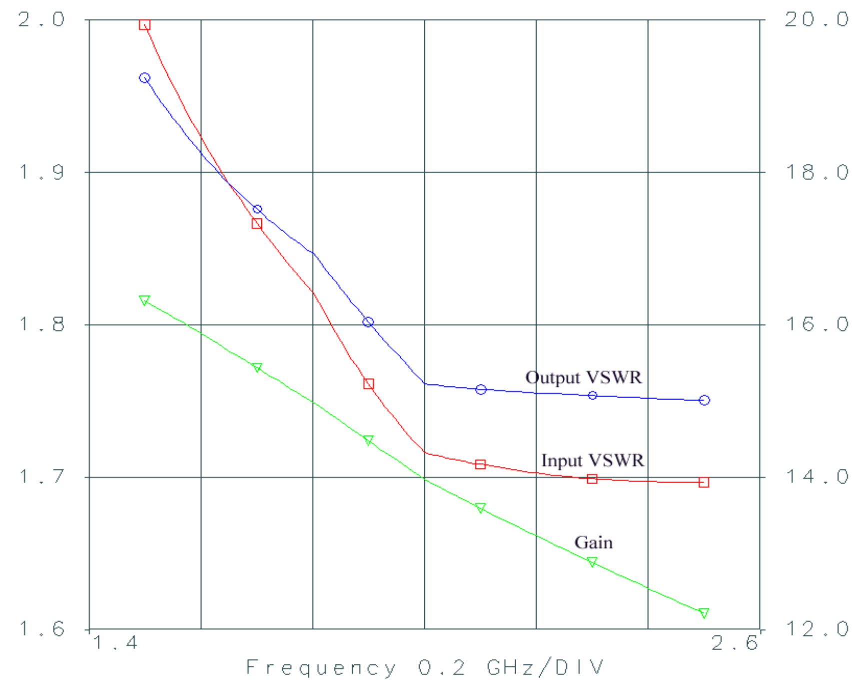


Simulation Results

- Noise Figure

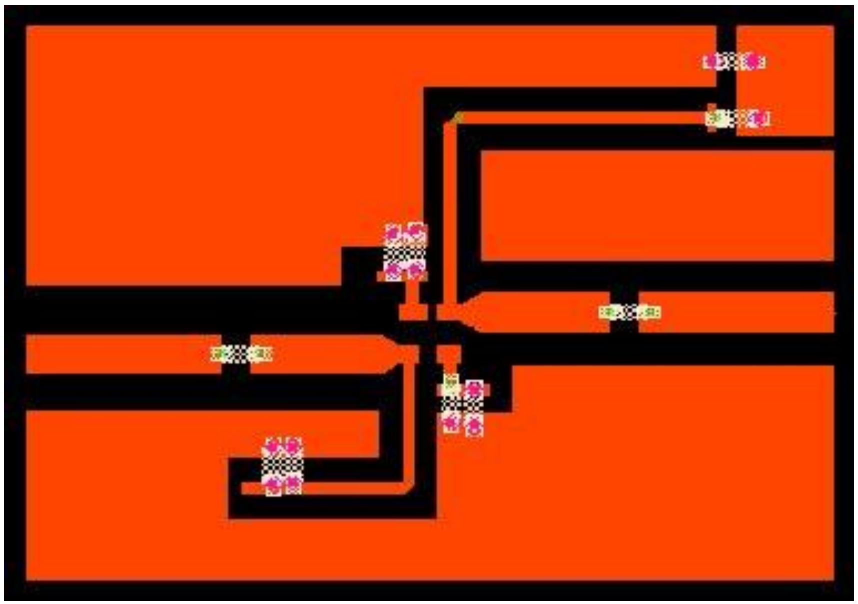


- Gain and Match

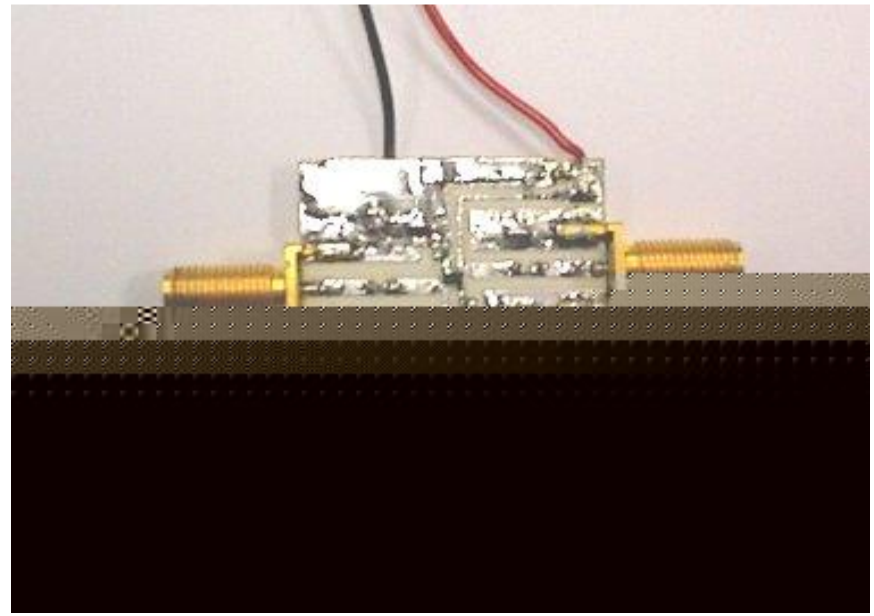


Layout and Prototype

- Layout generated from schematic



- Breadboard amplifier

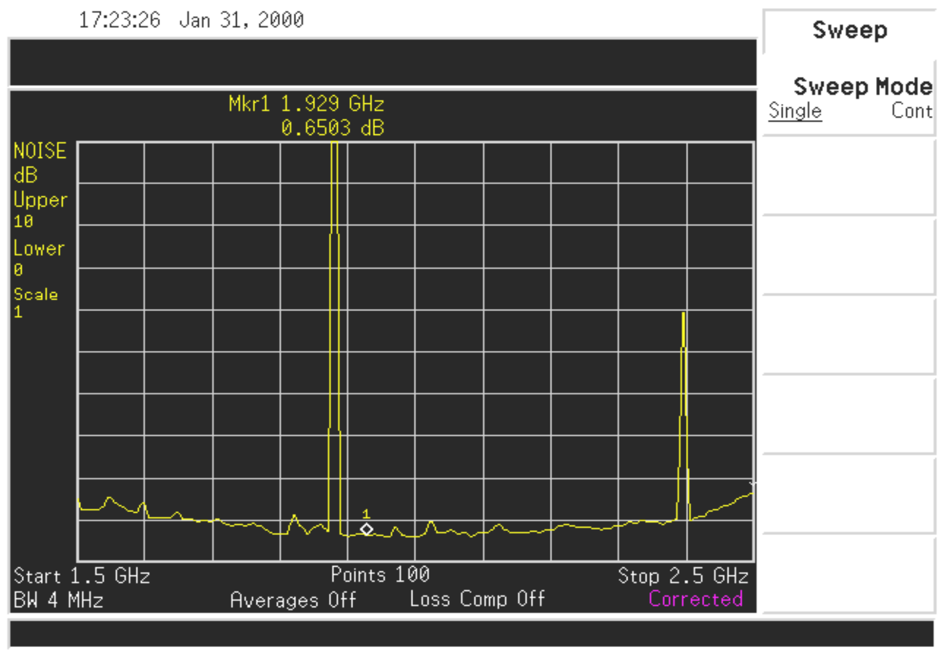


Agenda

- Motivation
- Model a low noise amplifier block on ADS
- Practical noise figure measurements of the prototype amplifier using Agilent's N8973 Noise Figure Analyzer
- Narrow band noise figure measurements
- Measuring noise figure at microwave frequencies
- Measurement Uncertainty

Noise Figure Measured on the N8973 NFA

- Connect the noise source directly to the instrument and perform a user calibration
  - Measures the noise figure instrument at selected attenuator settings
- Connect the LNA prototype between the noise source and the instrument
  - Measure corrected Noise Figure, Y-Factor, gain, effective temperatures etc.
- Spikes are mobile phone transmissions getting into the unscreened circuit

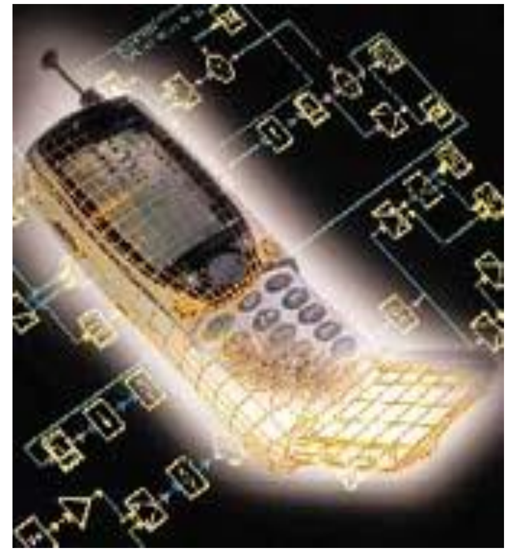


Agenda

- Motivation
- Model a low noise amplifier block on ADS
- Practical noise figure measurements of the prototype amplifier using Agilent's N8973 Noise Figure Analyzer
- Narrow band noise figure measurements
- Measuring noise figure at microwave frequencies
- Measurement Uncertainty

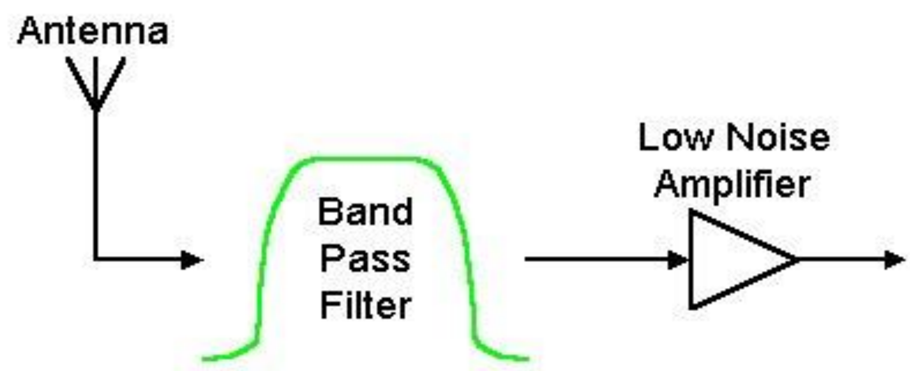
Narrow Band Noise Figure

- Noise Figure has traditionally been measured in a 4MHz band
  - Measurement time
  - Accuracy
  - Device Bandwidth
- Modern applications are much more demanding
  - Measurement Bandwidth much more important
  - Narrow band measurement technique required



Base Station/Mobile Phone Front-end

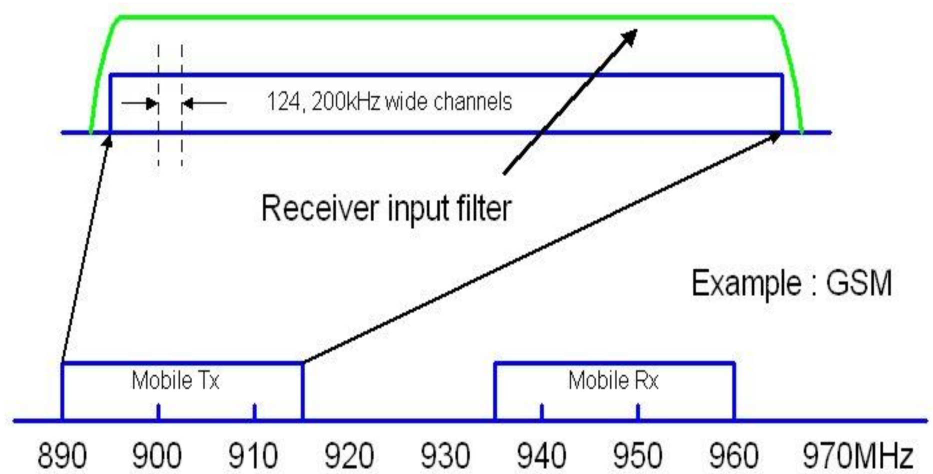
- Noise Figure of Front-end absolutely critical
  - Isolator
  - High Q bandpass filter
  - Very low noise amplifier
- Beyond Front-end, Noise Figure not so important
  - Front-end gain reduces the effects



Simplified Receiver Front-end

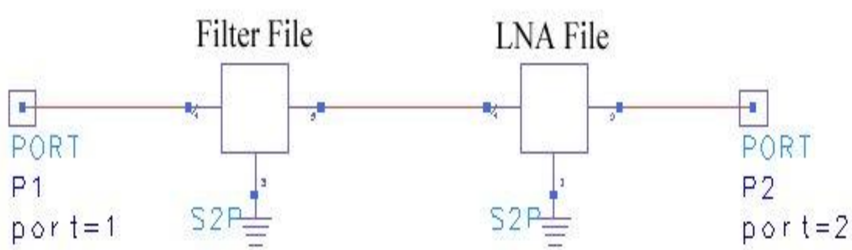
Why are Narrow Band measurements important?

- Using GSM as an example
  - Band is 25MHz wide
  - 124, 200kHz wide channels
- Filter rolls off at band edges
  - Risk of higher loss before LNA
  - Risk of higher noise figure
  - Risk of poor performance in channels near band edges

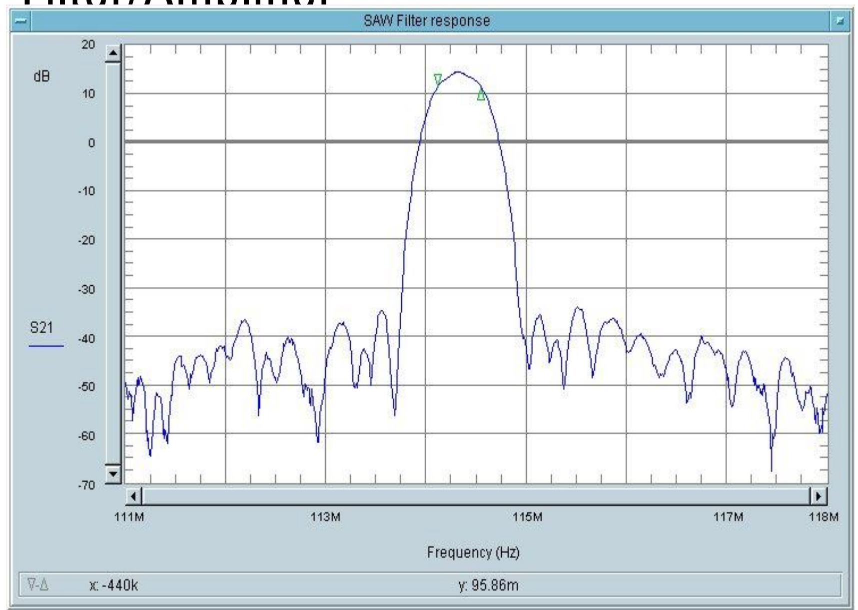


Narrow Band Example

- Combine a narrow band filter (~440kHz) with an amplifier
- Model using ADS
- Check the response on a network analyzer for reference

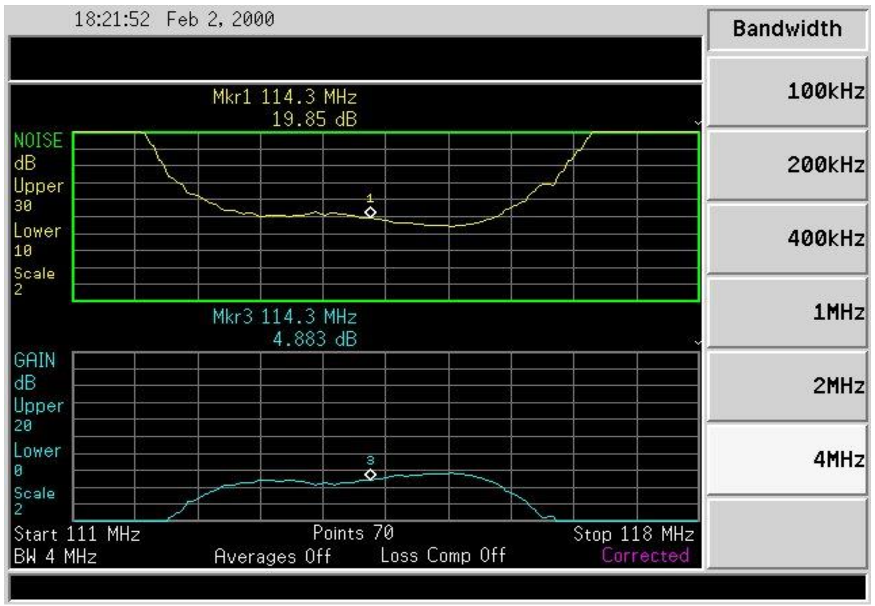


- Network measurement of Filter/Amplifier

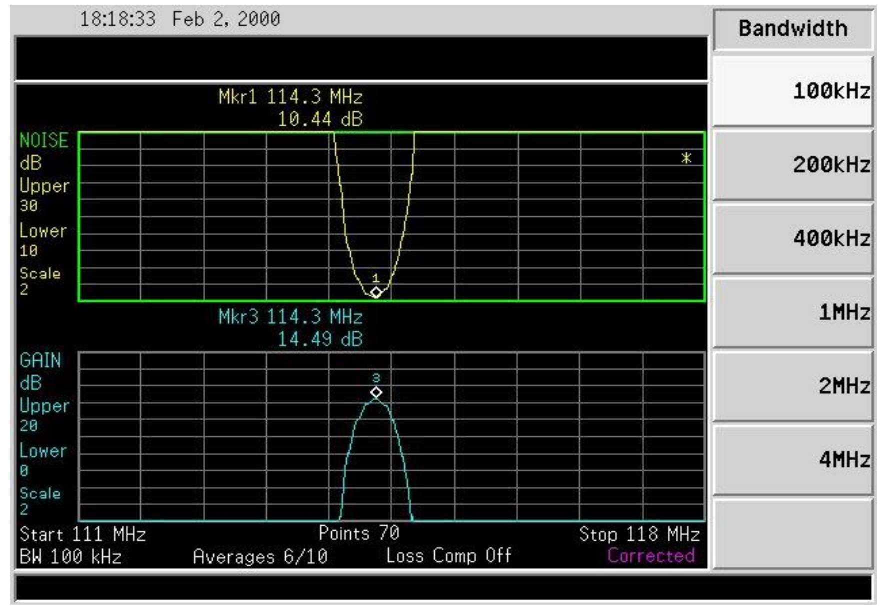


Measuring Narrow Band NF on the N8973 NFA

- Measurement with 4MHz bandwidth



- Measurement with100kHz bandwidth

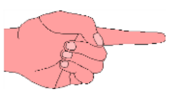


Agenda

- Motivation
- Model a low noise amplifier block on ADS
- Practical noise figure measurements of the prototype amplifier using Agilent's N8973 Noise Figure Analyzer
- Narrow band noise figure measurements
- Measuring noise figure at microwave frequencies
- Measurement Uncertainty

Agenda

- Motivation
- Model a low noise amplifier block on ADS
- Practical noise figure measurements of the prototype amplifier using Agilent's N8973 Noise Figure Analyzer
- Narrow band noise figure measurements
- Measuring noise figure at microwave frequencies



- Measurement Uncertainty

Measurement Uncertainty

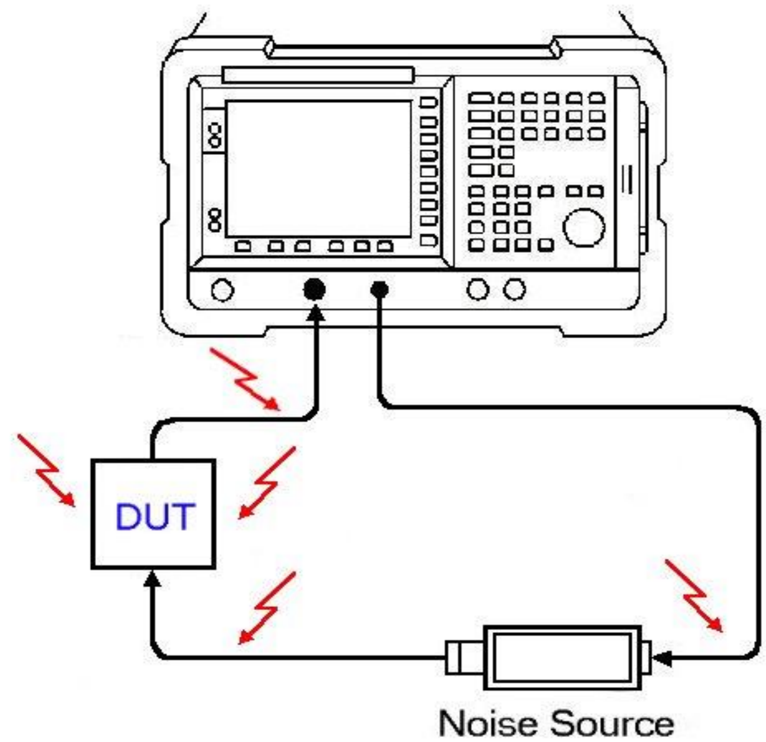
- Factors Affecting Measurement Accuracy
  - Extraneous Signals
  - Non-linearity's
  - Instrumentation Uncertainty
  - ENR Uncertainty
  - Mismatch
  - Measurement Architecture
  - Instrument Noise Figure
  - Unwanted in-band power
    - Many Other Factors

- Uncertainty Equation

$$\left\{\left[\left(\frac{F_{12}}{F_1}\right)\delta NF_{12}\right]^2 + \left[\left(\frac{F_2}{F_1 G_1}\right)\delta NF_2\right]^2 + \left[\left(\frac{F_2 - 1}{F_1 G_1}\right)\delta G_1(dB)\right]^2 + \left[\left(\frac{F_{12}}{F_1} - \frac{F_2}{F_1 G_1}\right)\delta ENR\right]^2\right\}^{0.5}$$

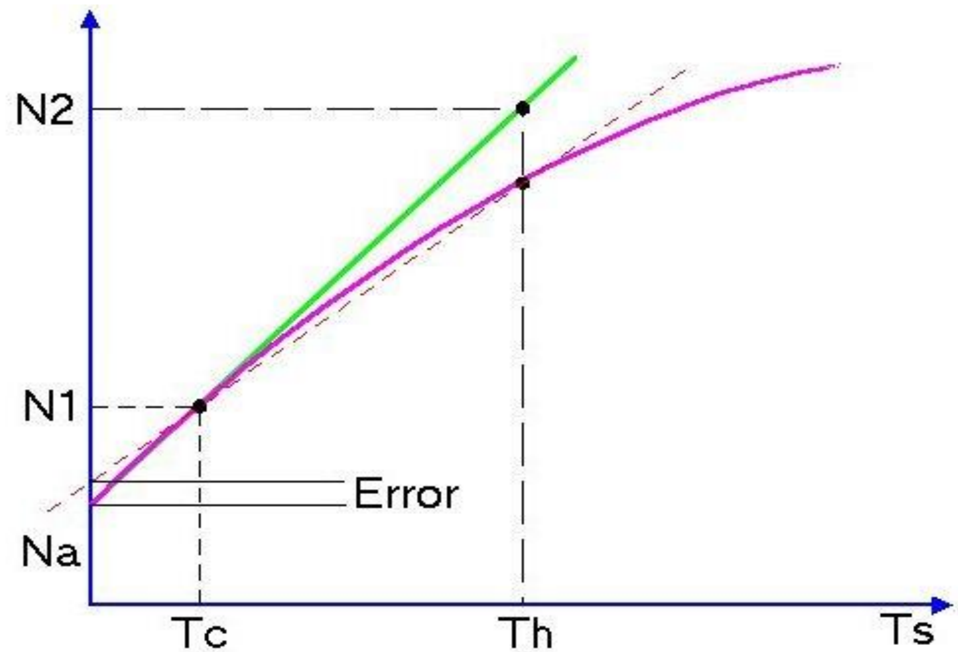
Extraneous Signals

- Pocket Pagers
- Security communication systems
- Mobile/Cordless Phones
- WLAN
- Choice of measuring instrument!
  - DUT's are often connected directly to the instrument
  - Good instruments have very low emissions in the near field



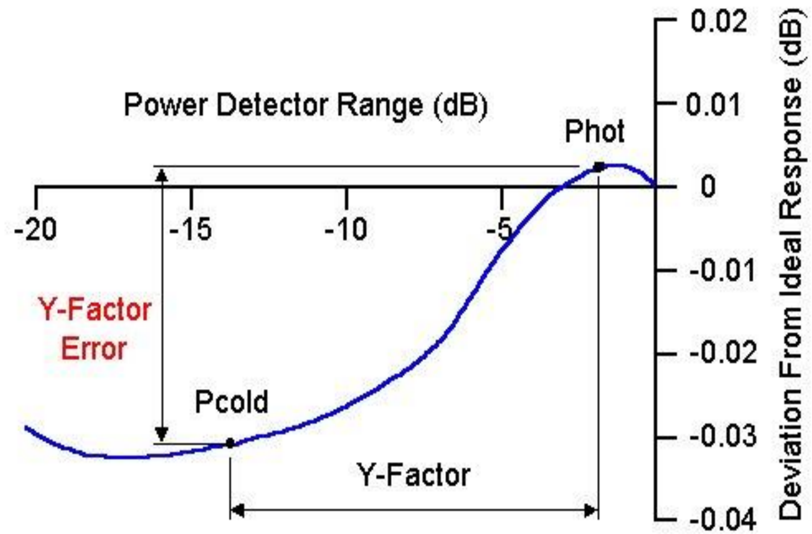
Non-linearities

- Non-linearities distort the Y-Factor
  - This translates through to the Noise Figure
- No Saturation in Amplifiers or Mixers
- No AGC or Limiters
- No Squelch
- Measure sub-circuitry before loops, AGC etc are added



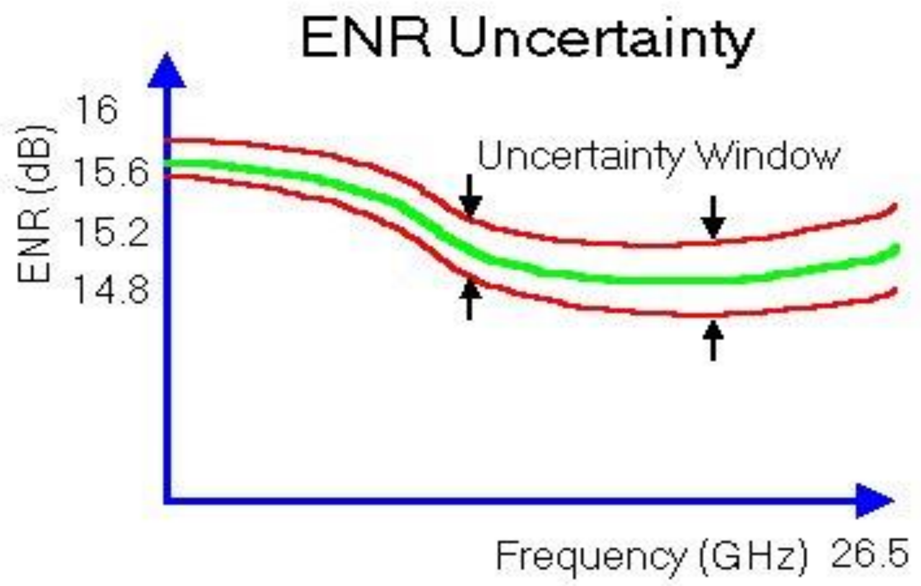
Instrumentation Uncertainty

- Detector linearity is a prime contributor to the overall uncertainty
- Effect, not reduced by DUT gain
- Differences of as little as 50mdB between different instruments have a significant effect
- Principal Spec when choosing an instrument
  - Measure of raw performance



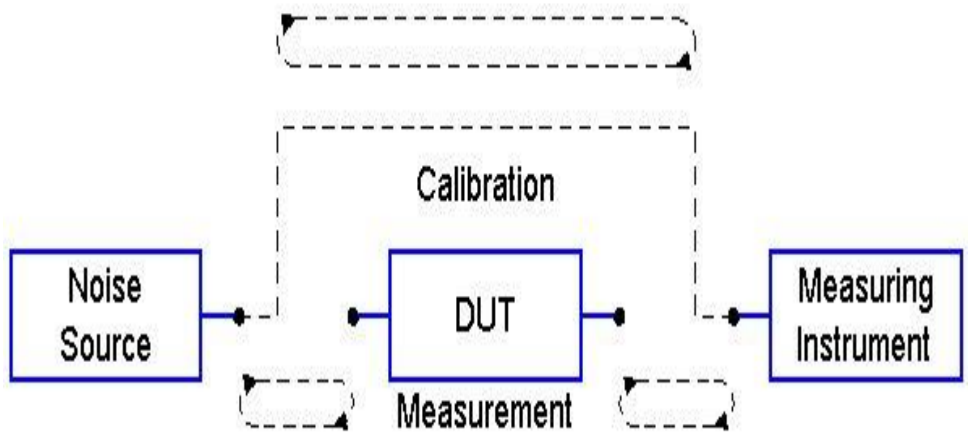
Excess Noise Ratio (ENR) Uncertainty

- Uncertainty in the noise power from the noise source is a very big player
- Referenced to National Institute of Standards and Technology (NIST)
- Ensure the ENR table in the instrument is for the source in use
- Ensure there are no errors in the table entries
    - NFA series allows the table to be loaded from disk or GPIB



Mismatch Uncertainty

- Complicated subject in the context of noise figure
- Noise source VSWR is a big player
- Isolators between the noise source and DUT can help but bring other uncertainties
- Effects reduce with increased DUT gain
- Using S-Parameters may cause further errors unless accompanied by noise parameters



Instrument Architecture

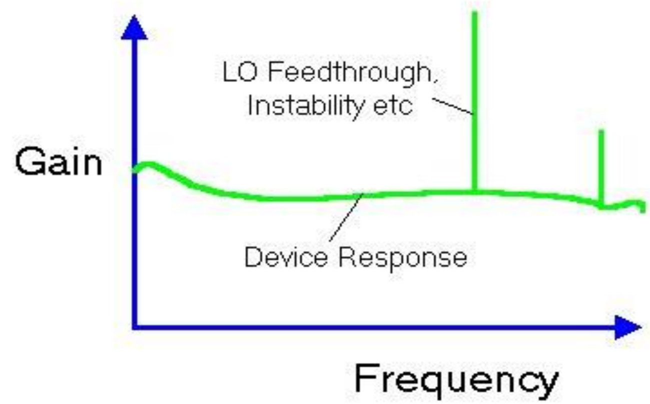
- SSB or DSB Instrument Architecture?
- The power in the undesired sideband of a DSB instrument will introduce an uncertainty - possibly a significant one
- With the SSB architecture the power in the unwanted sideband is heavily filtered
- For the most exacting measurements a SSB instrument should be used
    - NFA series instruments are SSB

Instrument Noise Figure

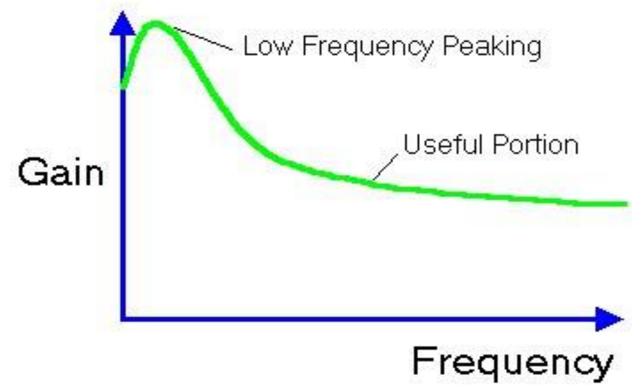
- The ratio (F_{12}/F_1) seen in the uncertainty equation can never be smaller than 1
    - F_{12} is the noise factor of the DUT and Instrument combined
- Ratios much higher then 1 impair the measurement uncertainty
    - To keep F_{12} near F_1 the noise figure of the instrument should be low
    - High DUT gain also helps

Unwanted in-band Power

- High levels of unwanted in-band power will cause the analyzer to select a poor range for the measurement
  - High instrument noise figure
- Keep LO's well out of the band of the instrument
- Ensure devices are stable and free from oscillations
- Filter unwanted amplifier responses



GaAs Amplifier Response



The Path to Overall Uncertainty

- Individual uncertainty components are all very well but it is the overall uncertainty that is important
    - Need a model for calculating the overall uncertainty
- Apply some differential calculus to the noise figure equations to derive an uncertainty equation
    - Generate an uncertainty calculator

Agilent Technologies
Innovating the HP Way

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.

	dB	Linear				
DUT NF, F1=	3	1.995262	F12/F1=	1.045107		
Instrument NF, F2=	10	10	F2/F1G1=	0.050119		
DUT GAIN, G1=	20	100	(F2-1)/F1G1=	0.045107		
Combined NF, F12=	3.191607	2.085262	(F12/F1)-(F2/F1G1)=	0.994988		
Match	Units*	Refl Coef		Negative	Positive	Max
Noise Source=	1.1	0.047619	Uncert NS-DUT IN=	0.083119	0.082331	0.083119
DUT Input=	1.5	0.2	Uncert NS-NFA=	0.118987	0.117379	0.118987
DUT Output=	1.5	0.2	Uncert DUT OUT-NFA=	0.511082	0.482674	0.511082
Instrument=	1.8	0.285714				
Uncertainties	dB					
Instrument NF=	0.05		Uncert NF12=	0.096748		
Instrument Gain=	0.15		Uncert NF2=	0.128766		
Noise Source ENR=	0.1	(Amplifiers Only)	Uncert G1=	0.546419		
Noise Source ENR=	0	(Receivers Only)	Uncert ENR=	0.1		

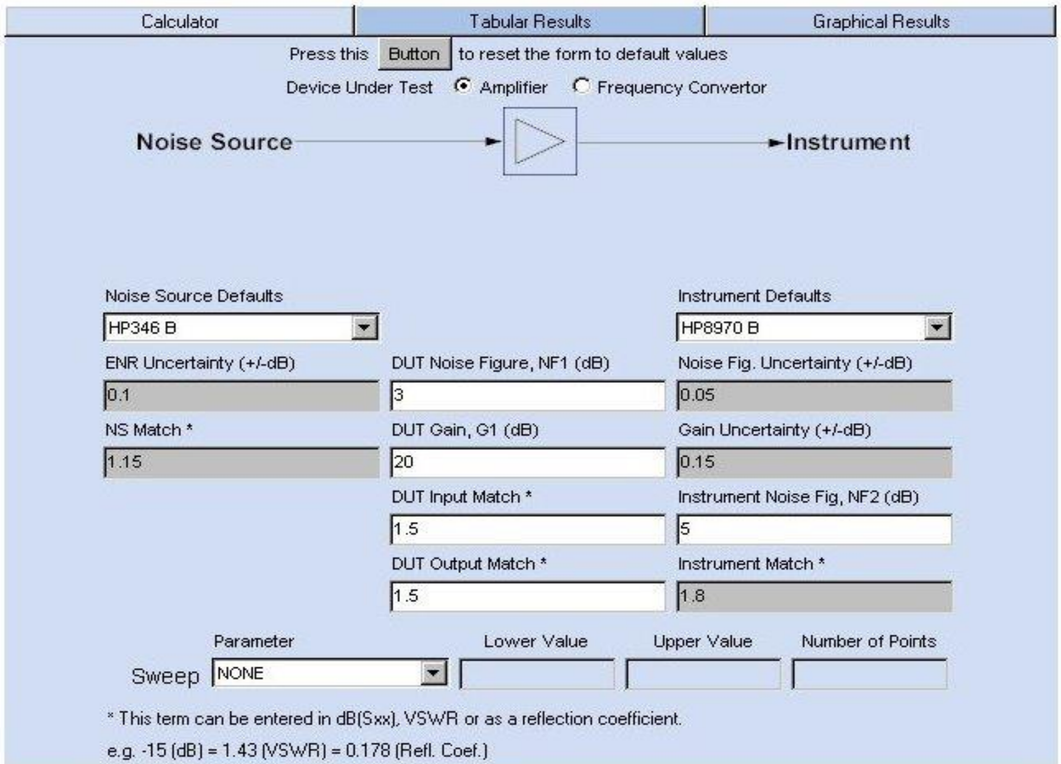
Noise Figure Uncertainty = 0.143373 dB

* This term can be entered in dB (Sxx), VSWR or as a reflection coefficient.
e.g. -15dB = 1.43 VSWR = 0.178 reflection coefficient

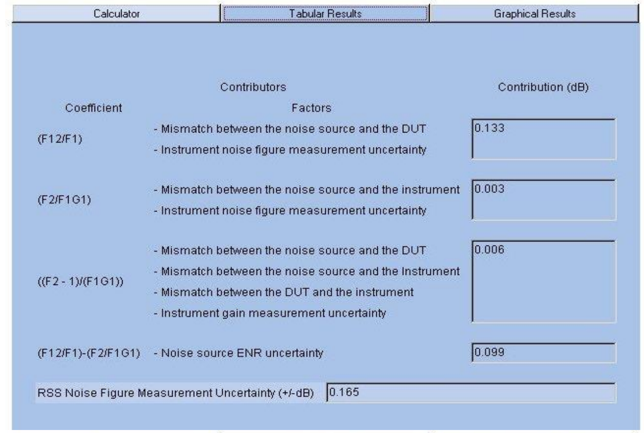
D.Boyd 1999

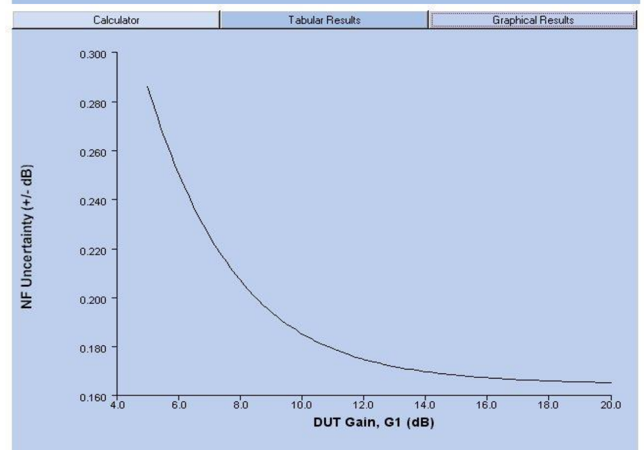
Web Based Measurement Uncertainty Calculator

Data Entry



Results





Summary

- Agilent's ADS quickly takes an RF design to the breadboard stage
- Using ADS alongside practical measurements allows a fast design cycle time
- Introduced NFA Series Noise Figure Analyzer's for modern noise figure measurements
- Concept and importance of narrow band noise figure measurements
    - Narrow band measurement functionality of the NFA Series
- Measurement uncertainties and tools for calculating the overall measurement uncertainty

Email : Duncan_Boyd@Agilent.com

Power and Noise Product Generation Unit
South Queensferry, Scotland