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October 18, 2000

Practical Noise Figure

Measurements

Including an example LNA design

Agenda

- Motivation
- Model a low noise amplifier block on ADS
- Practical noise figure measurements of the prototype amplifier
- Narrow band noise figure measurements
- Measurement Uncertainty



Motivation

- RF Communications
- Point to Point Radio / Wireless LAN
- Satellite Communications
- Wireless LAN
- Global Positioning System
- Defense and Radar



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ADS Presentation Windows

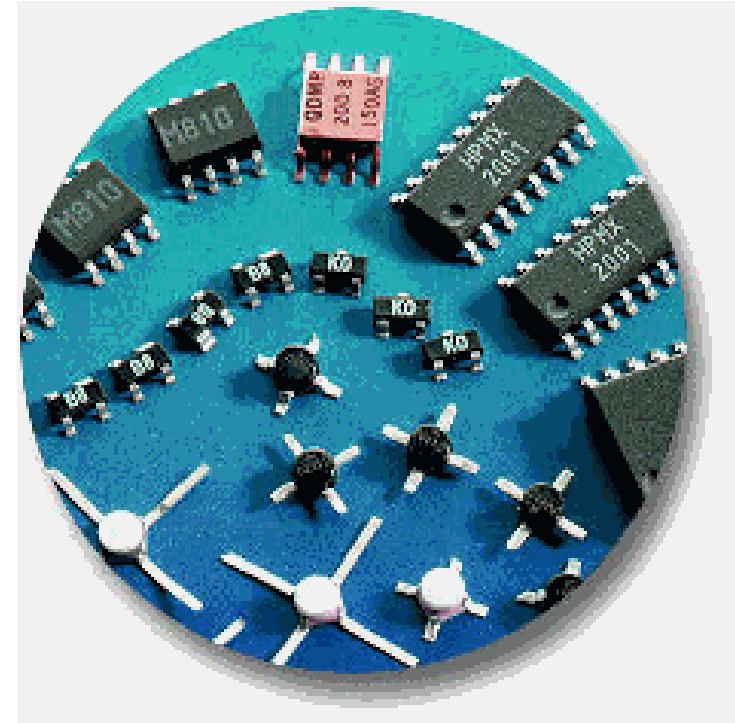
The image displays four windows from the Advanced Design System (ADS) software interface:

- Project Hierarchy:** Shows the file structure for 'cellular_pamp_prj' with subfolders for 'data', 'networks', and 'verification'. The 'Main' component is highlighted in the Project Hierarchy pane.
- Schematic & Test Bench:** Displays a circuit schematic for a pamp component. It includes a DC feed, a matching network, and a transistor (fet1301xp). Component values are listed: $C = 47\text{pF}$, $L = 15.0\text{mll}$, $L = 420.0\text{mll}$, and $L = 15.0\text{mll}$. The schematic is titled 'Schematic & Test Bench'.
- Graphics:** Shows a plot titled 'Graphics' for 'lsssp_pamp'. The y-axis is labeled '... amp...5(2,1)' and ranges from 0 to 30. The x-axis ranges from $6.0\text{E}8$ to $1.5\text{E}9$. The plot shows a curve that rises to a peak of approximately 28 at $1.0\text{E}9$ and then decays.
- Layout:** Shows a physical layout of the circuit components on a substrate. The layout is titled 'Layout' and includes a legend for components like PADI, SPAC, C CONN, and CONN. The layout is titled 'Layout'.



Example Low Noise Amplifier Design Process using ADS

- Functional requirements
- Device selection
- Design
- Layout
- Performance analysis and optimization



Amplifier Functional Requirements

- Frequency Range : 1.5GHz to 2.5GHz
- 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?
- S-Parameter/Noise data on Web
- Choose ATF34143 PHEMPT from Agilent
 - 0.5dB Noise Figure
 - Good Dynamic Range
 - Reasonably easy to match

Noise and S-Parameters File

```

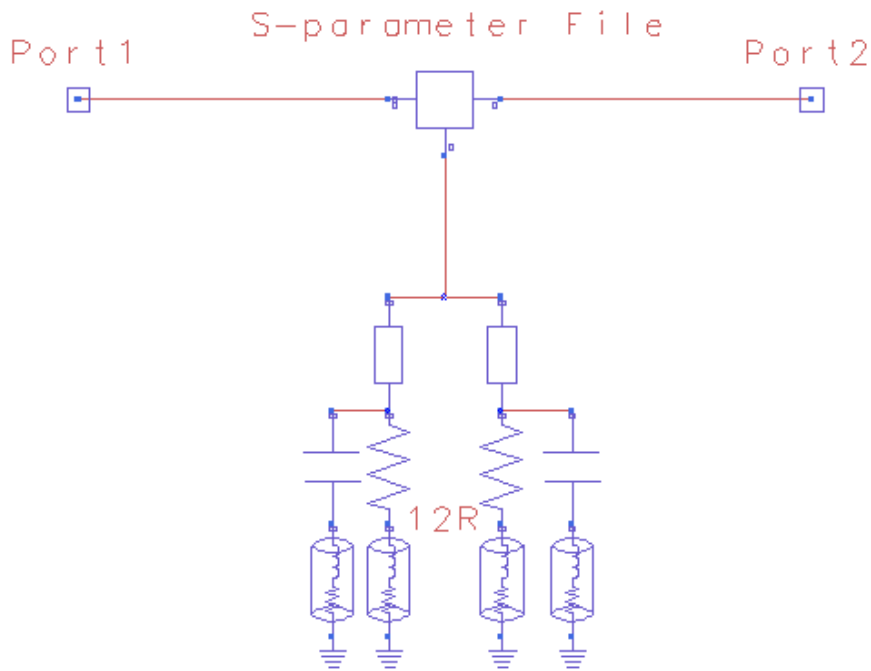
?      ATF-34143      S PARAMETERS
?      Id = 20 mA    LAST UPDATED 2/6/99

?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
  
```

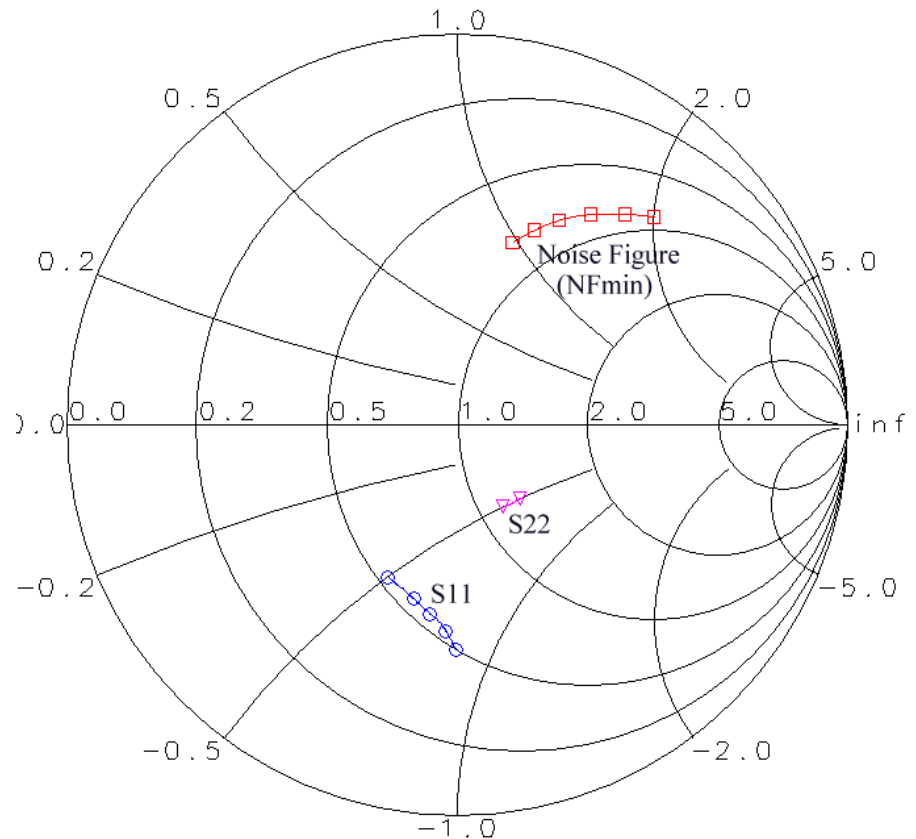


Modeling the raw device

- Model of raw device with Source Resistance for self bias



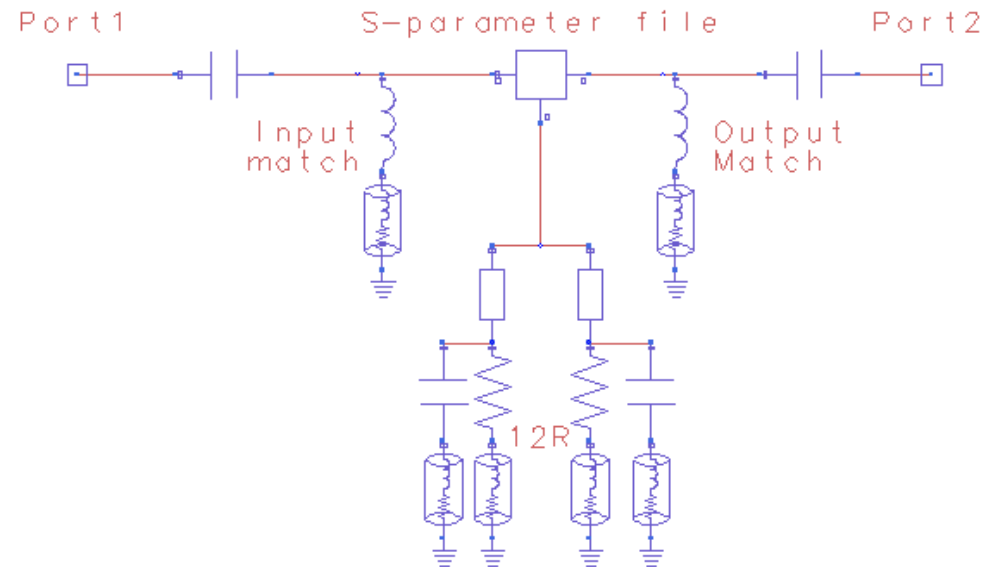
- Noise and S-Parameters



Matching the device

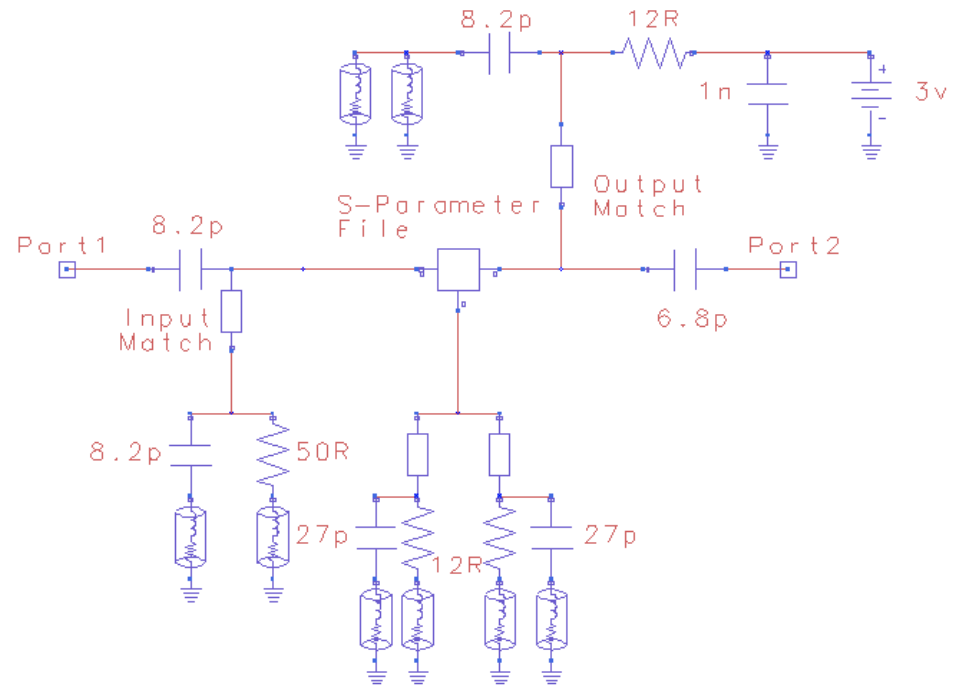
- Circuit looks capacitive
 - Use High-pass arrangement
- To synthesize matching networks
 - Calculator
 - Smith chart
 - Use Esyn in ADS
 - Use Optimizer in ADS

Simple high-pass impedance match



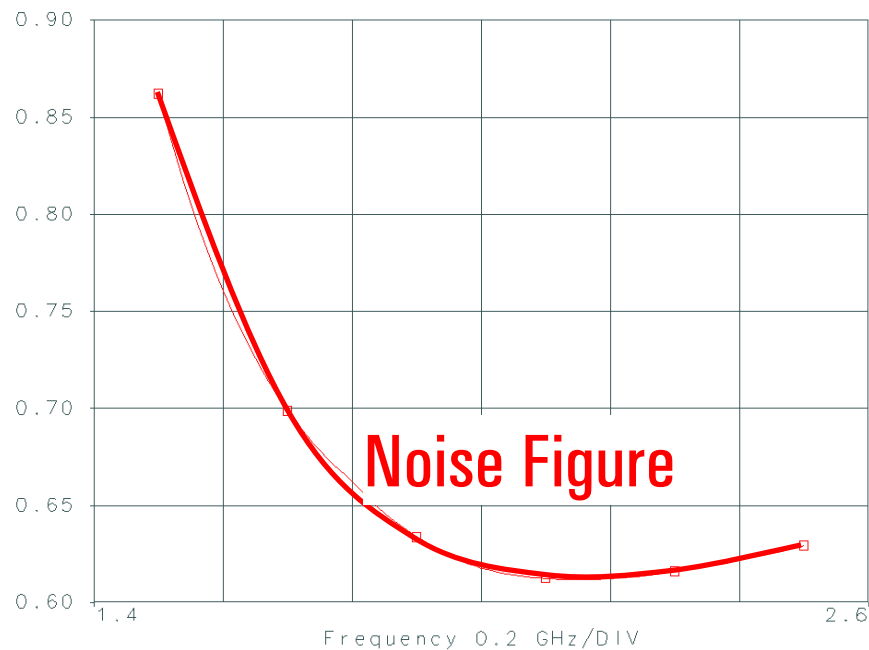
Complete Model of the Amplifier

- Inductors replaced by distributed elements
- Discretes replaced by vendor parts
- Output match
- Through hole vias included
- Stabilization added
- ADS Optimizer to re-tune values

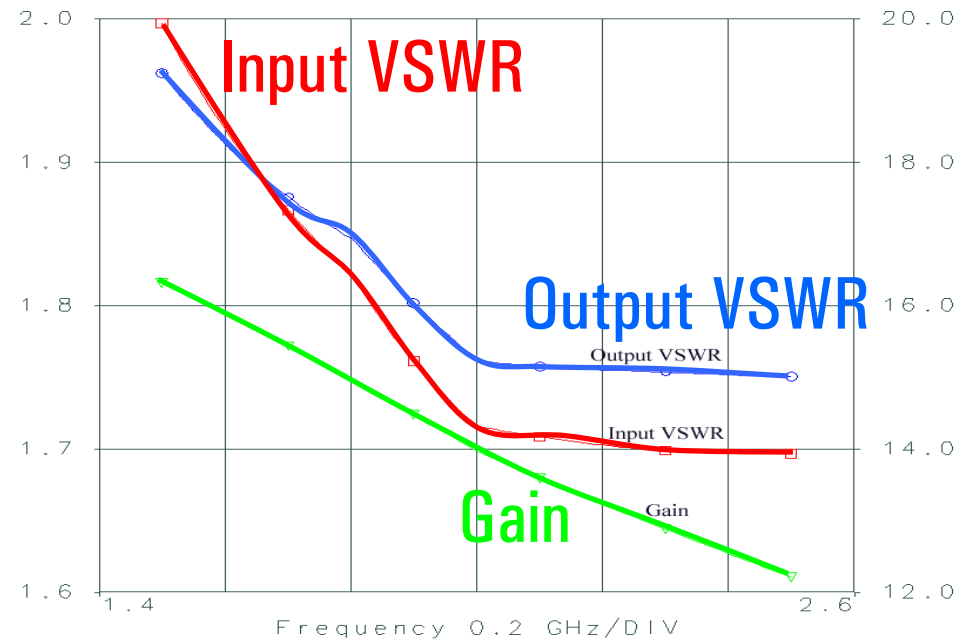


Simulation Results

Noise Figure

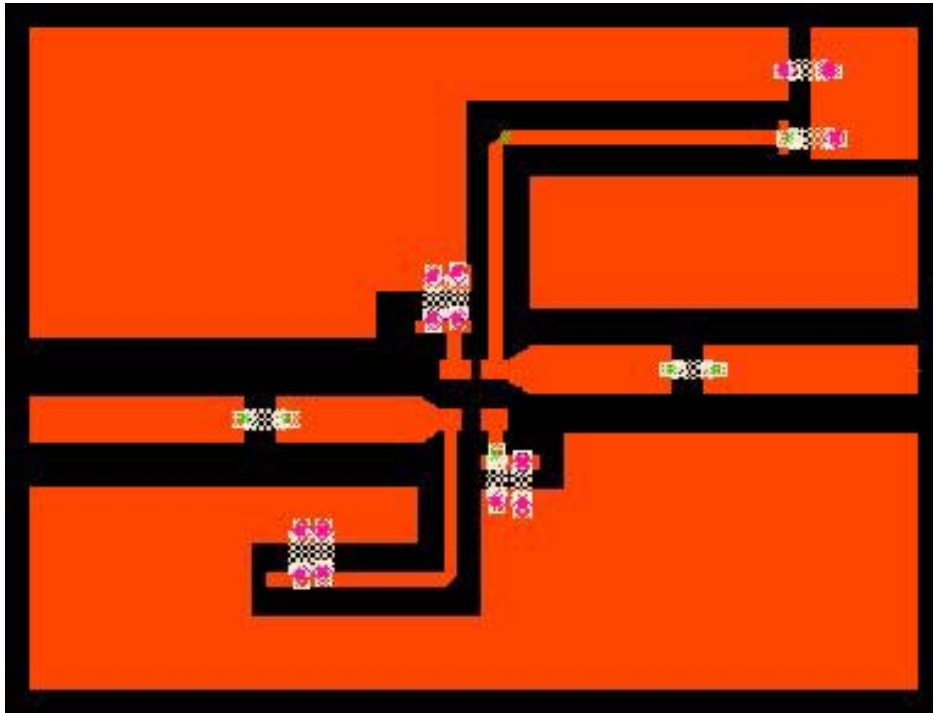


Gain and Match

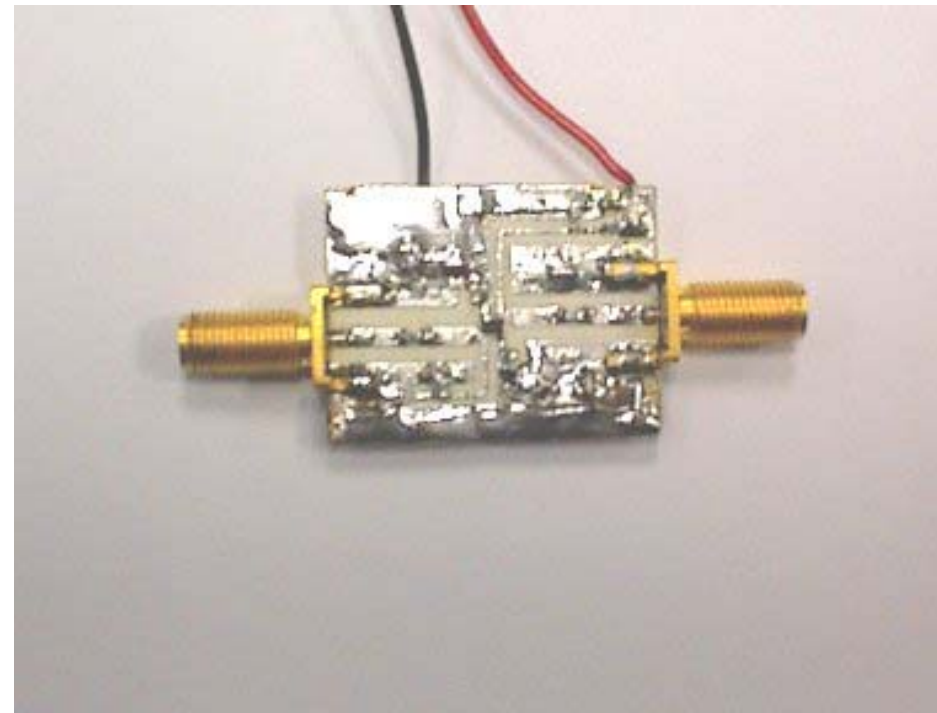


Layout and Prototype

Layout generated from schematic

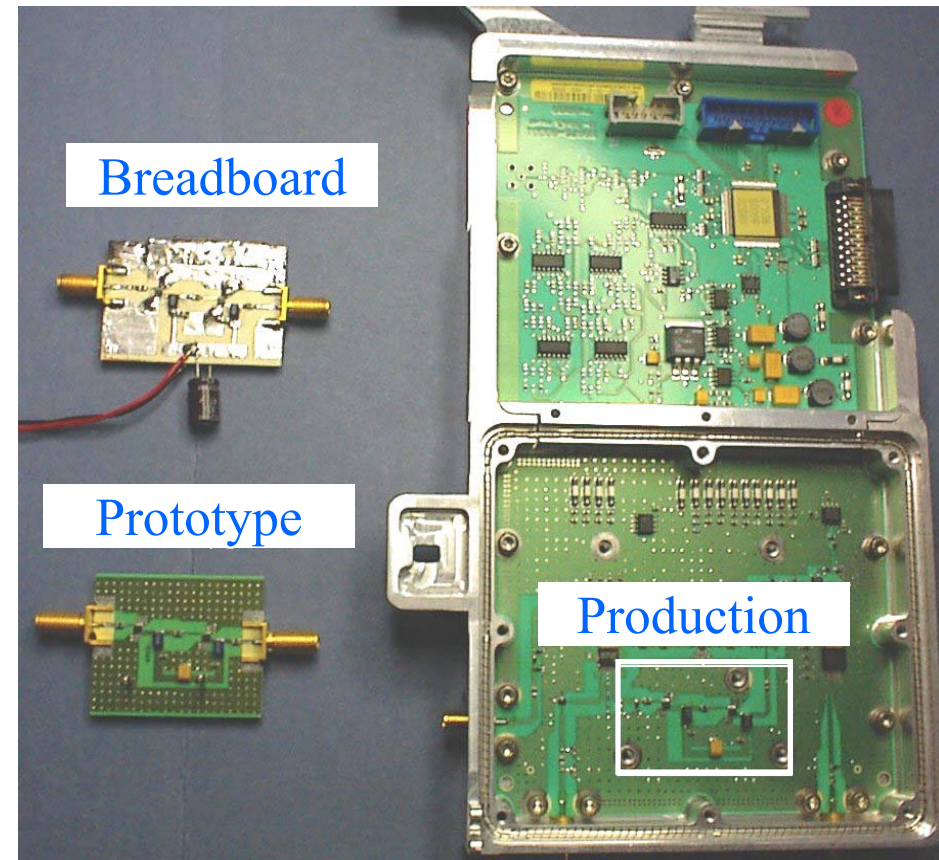


Breadboard amplifier



NFA Series RF Development Iterative design Process

- Model on ADS
- Build a breadboard
- Measure on an 8970B and make modifications
- Build a Prototype
- Measure on an 8970B and make modifications
- Production



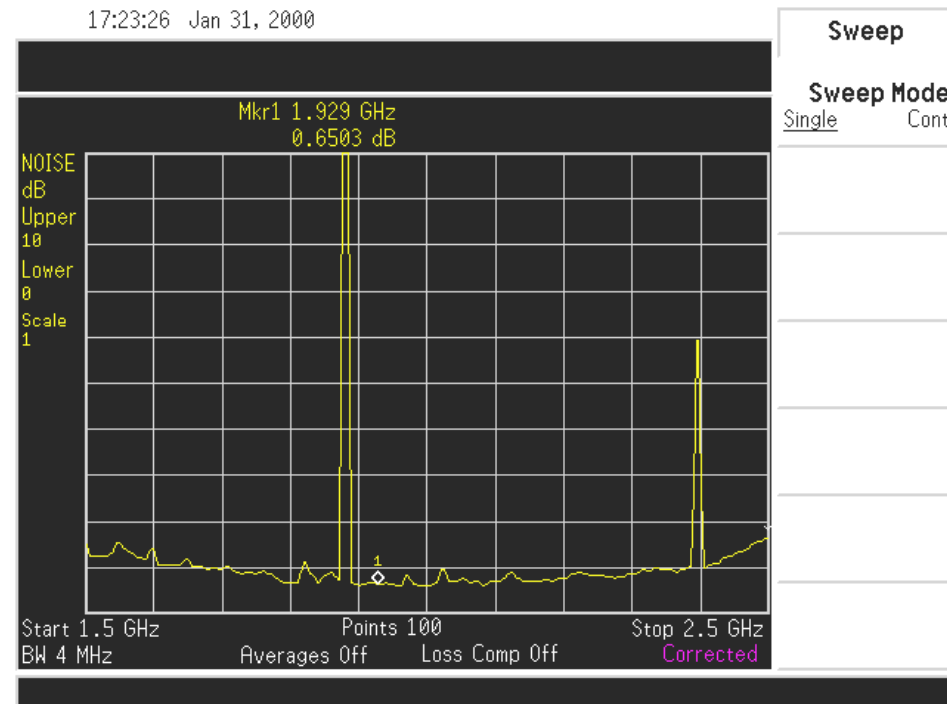
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- Narrow band noise figure measurements
- Measurement uncertainty



Noise Figure Measured on the NFA-Series N8973A

- Connect the noise source
- Perform a user calibration
- Connect the LNA between the noise source and the instrument
- Measure corrected Noise Figure, gain,
- Spikes are mobile phone transmissions getting into the unscreened circuit

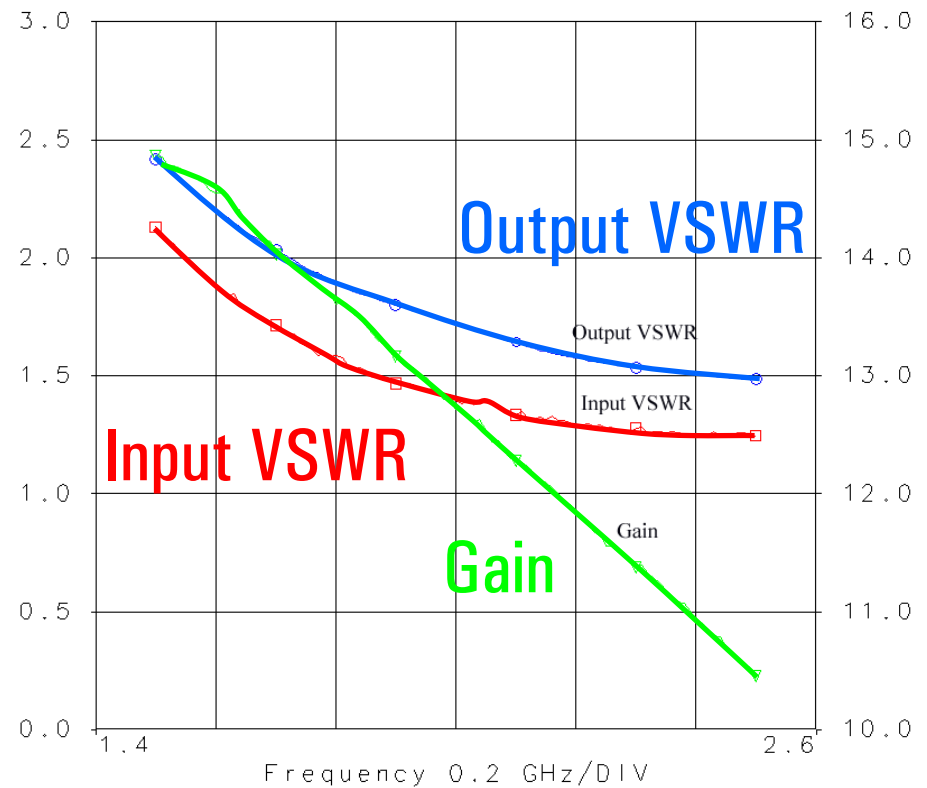


Network Measurements

- Gain and Match
- Network Analyzer connected to ADS via GPIB



- Gain and Match pulled into ADS



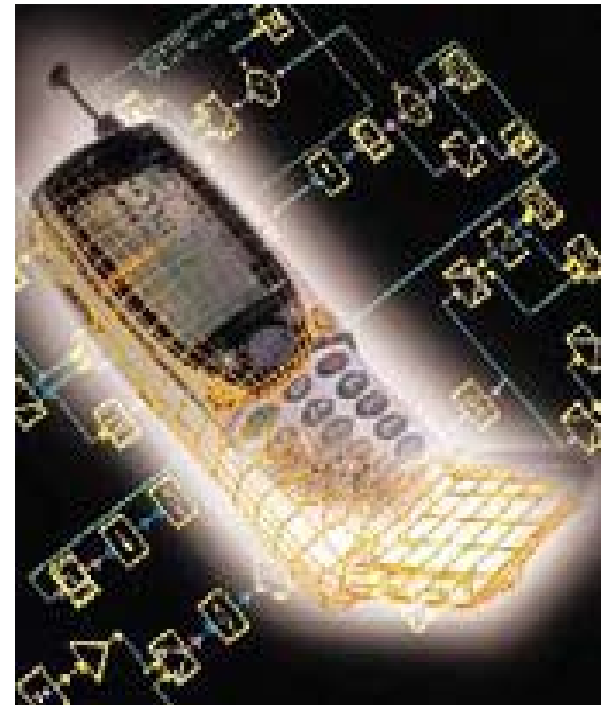
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- **Narrow band noise figure measurements**
- Measurement Uncertainty



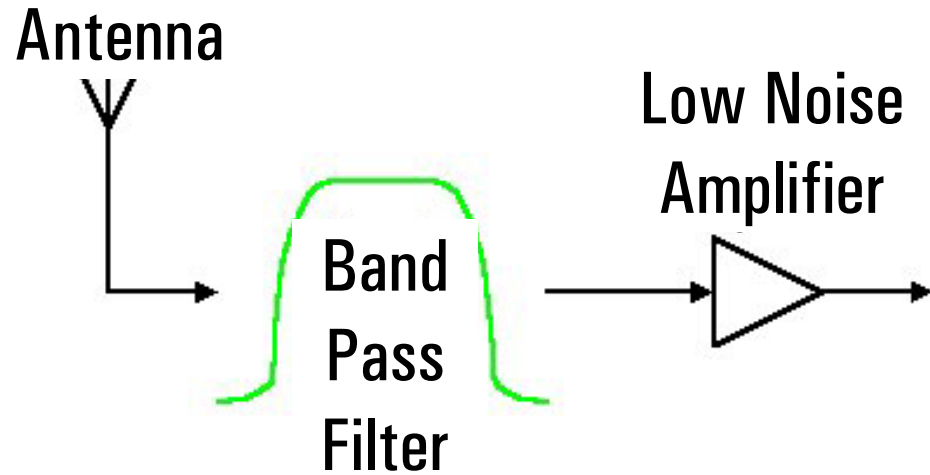
Narrow Band Noise Figure

- Noise Figure in a 4MHz band
 - Measurement time
 - Accuracy
 - Device bandwidth
- Modern applications are much more demanding
 - Measurement bandwidth
 - Narrow band measurement technique required



Base Station/Mobile Front-end

- Noise Figure critical
 - Isolator
 - High Q bandpass filter
- Very low noise amplifier
- Beyond Front-end, Noise Figure less important
 - Front-end gain reduces the effects

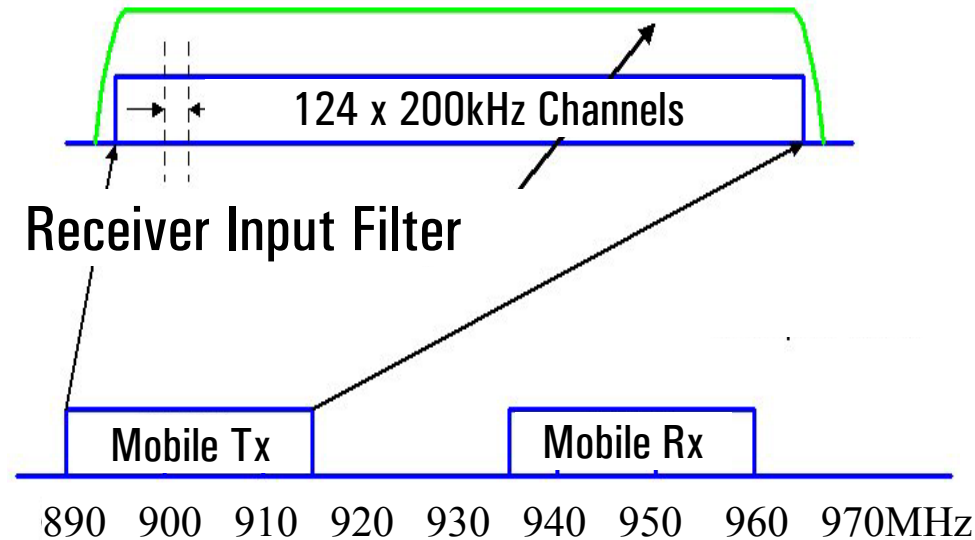


Simplified Receiver Front End



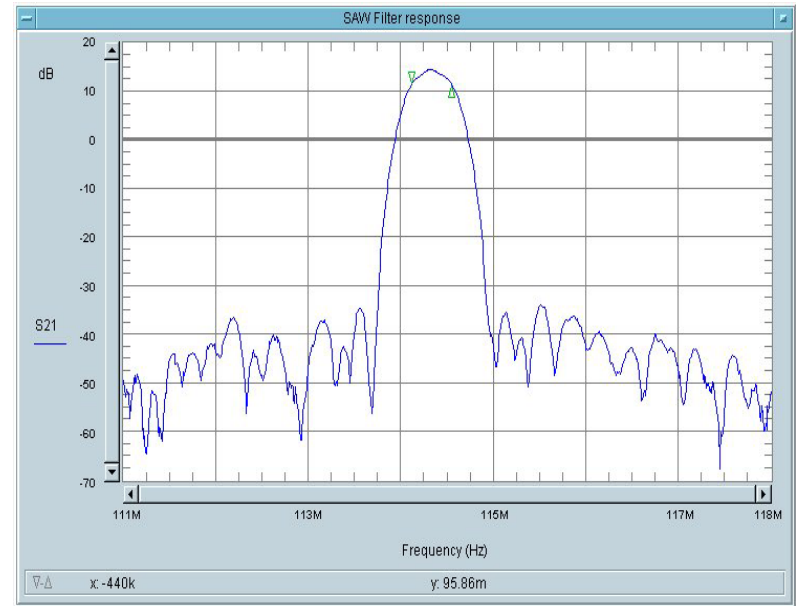
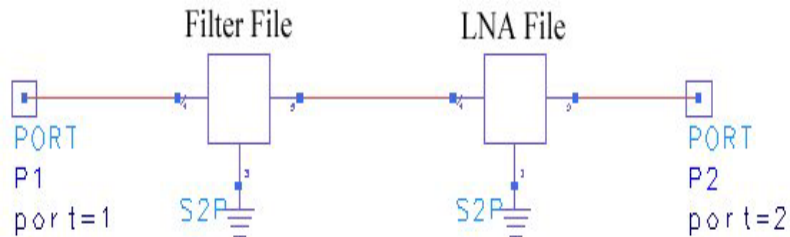
Why are Narrow Band measurements important?

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



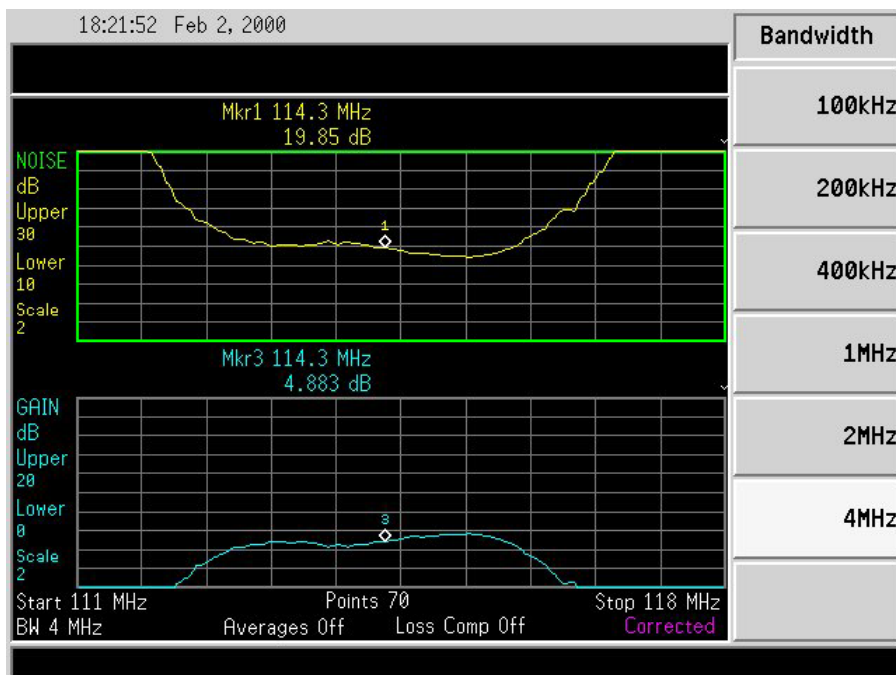
Narrow Band Example

- 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

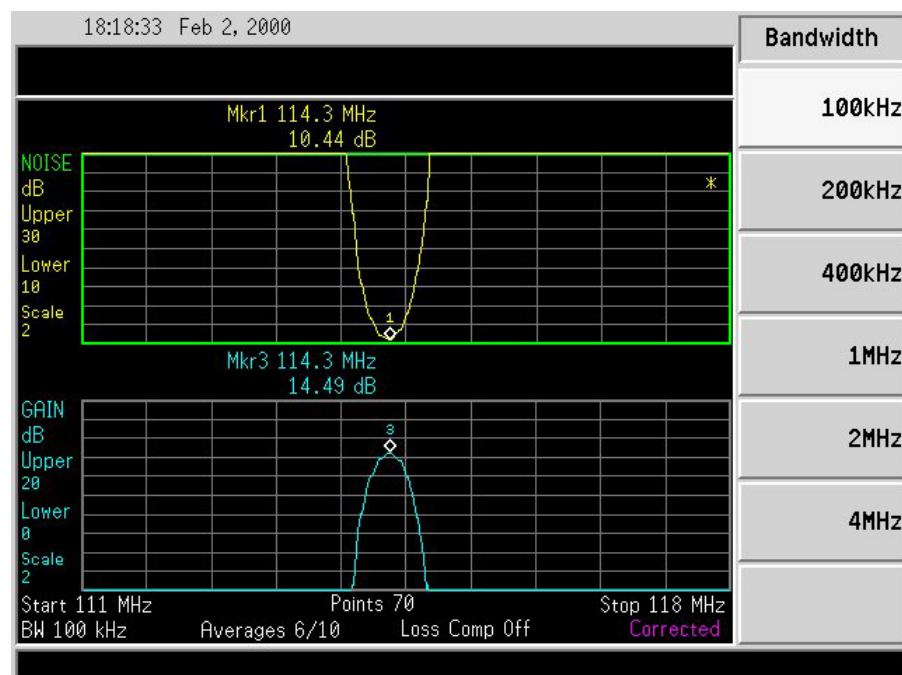


Narrow band Measurements using the NFA-Series N8973A

Measurement
with 4MHz bandwidth



Measurement
with 100kHz bandwidth



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Measurement Uncertainty

- Extraneous signals
- Non-linearity's
- Instrumentation uncertainty
- ENR uncertainty
- Mismatch
- Measurement architecture
- Instrument Noise Figure
- Unwanted in-band power

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




Web Based Measurement Uncertainty Calculator

Data Entry

Calculator Tabular Results Graphical Results

Press this to reset the form to default values

Device Under Test Amplifier Frequency Converter

Noise Source →  Instrument

Noise Source Defaults: HP346 B

ENR Uncertainty (+/-dB): 0.1

NS Match *: 1.15

DUT Noise Figure, NF1 (dB): 3

DUT Gain, G1 (dB): 20

DUT Input Match *: 1.5

DUT Output Match *: 1.5

Instrument Defaults: HP8970 B

Noise Fig. Uncertainty (+/-dB): 0.05

Gain Uncertainty (+/-dB): 0.15

Instrument Noise Fig, NF2 (dB): 5

Instrument Match *: 1.8

Sweep: NONE Lower Value: Upper Value: Number of Points:

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

Results

Calculator Tabular Results Graphical Results

Coefficient	Contributors Factors	Contribution (dB)
(F12/F1)	- Mismatch between the noise source and the DUT - Instrument noise figure measurement uncertainty	0.133
(F2/F1G1)	- Mismatch between the noise source and the instrument - Instrument noise figure measurement uncertainty	0.003
((F2 - 1)/(F1G1))	- Mismatch between the noise source and the DUT - Mismatch between the noise source and the Instrument - Mismatch between the DUT and the instrument - Instrument gain measurement uncertainty	0.006
(F12/F1)-(F2/F1G1)	- Noise source ENR uncertainty	0.099
RSS Noise Figure Measurement Uncertainty (+/-dB)		0.165

The uncertainty calculator can be found at www.agilent.com/find/nfu



Noise Figure Test Solutions from Agilent

- NFA-Series Noise Figure Analyzers

N8972A - 10MHz to 1.5GHz

N8973A - 10MHz to 3.0GHz

N8974A - 10MHz to 6.7GHz

N8975A - 10MHz to 26.5GHz

- SNS-Series Noise Sources

N4000A - 10MHz to 18GHz nominal ENR 6dB

N4001A - 10MHz to 18GHz nominal ENR 15dB

N4002A - 10MHz to 26.5GHz nominal ENR 15dB

