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Low Frequency Noise Measurement and Noise Modeling

Johannes Fellner, Gerhard Rappitsch

BIP -AK

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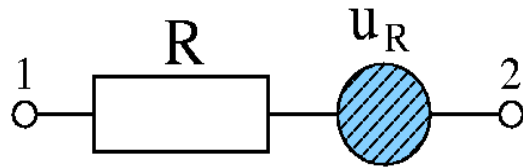
A leap ahead in mixed signal

Outline

- Noise Sources
- Measurement Principle
- Noisebox
- Noise Measurements
- Noise Parameter Extraction

Resistor Noise

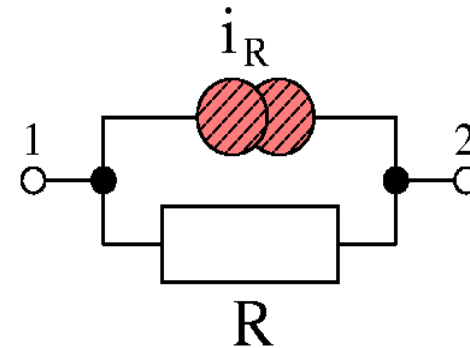
Voltage Noise Source



$$u_R = \sqrt{4kTBR}$$

$$S_{u_R} = \frac{u_R^2}{B} = 4kTR$$

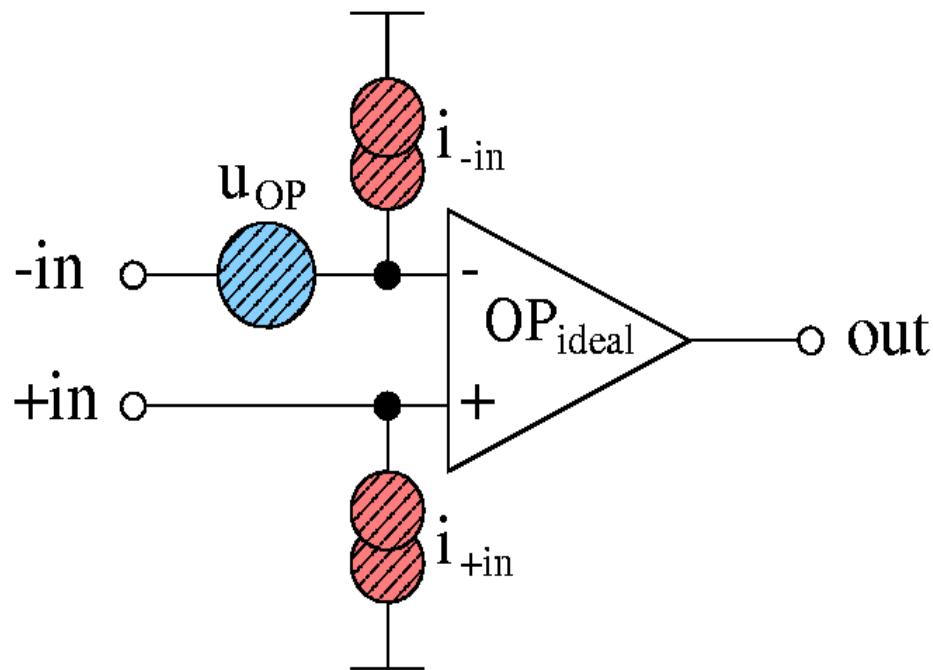
Current Noise Source



$$i_R = \sqrt{\frac{4kTB}{R}}$$

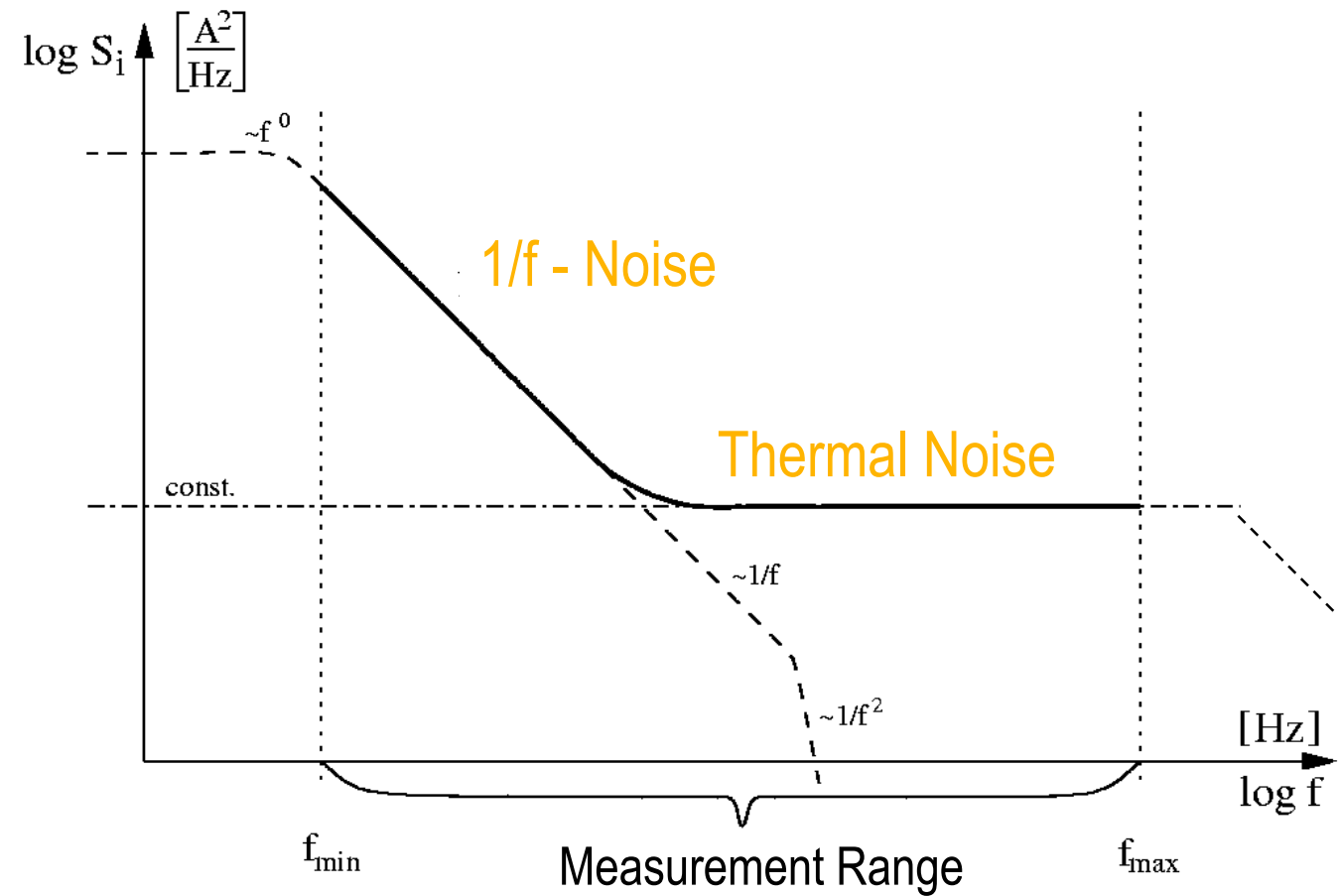
$$S_{i_R} = \frac{i_R^2}{B} = \frac{4kT}{R}$$

Operational Amplifier Noise



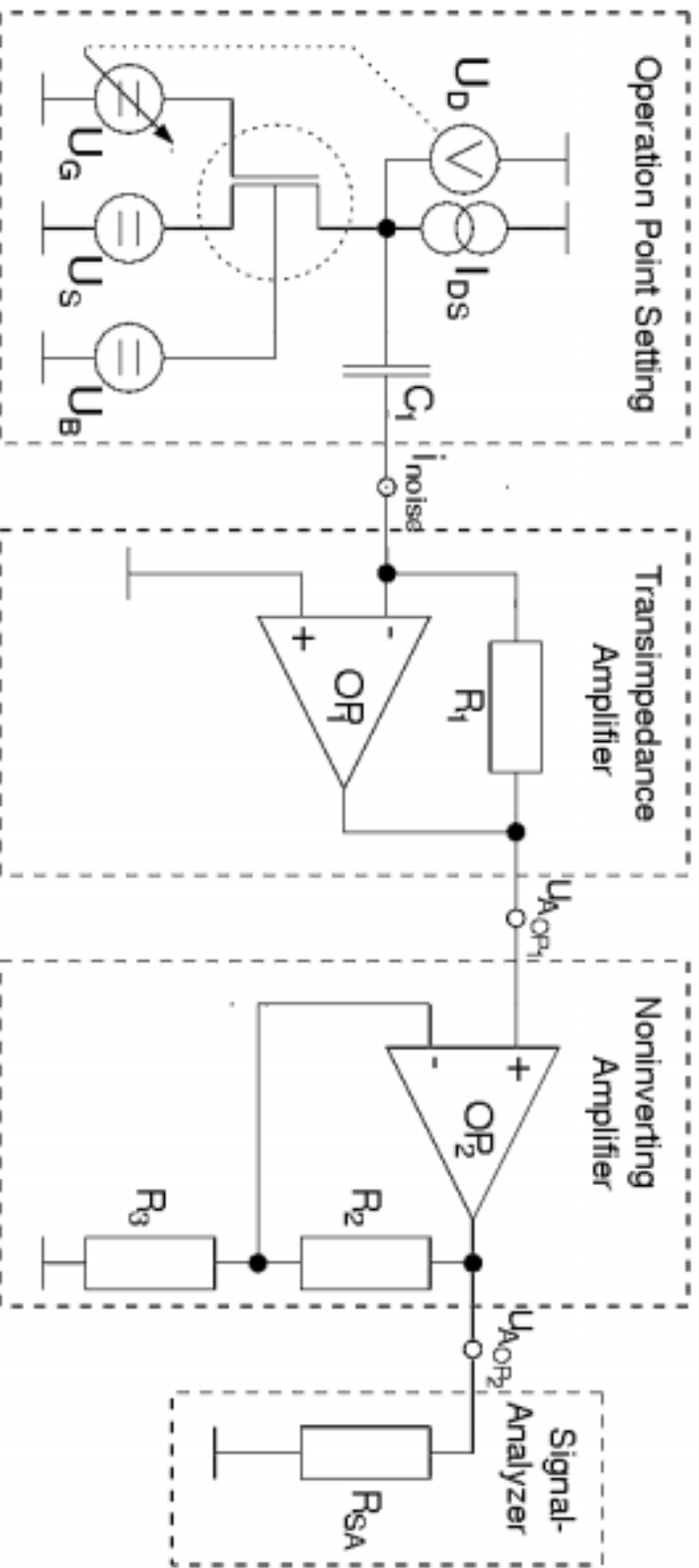
All noise sources are placed on the input of an ideal operational amplifier

Flicker Noise and Thermal Noise



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Measurement Principle



Dimensioning

- Minimum Current Noise for a BIP Transistor with $I_c=0.5\mu\text{A}$

$$i_{n,\min \text{ BIP}} = \sqrt{2 \cdot q \cdot I_c} = \sqrt{2 \cdot 1.6\text{E} - 19 \cdot 5\text{E} - 7} = 0.4 \frac{\text{pA}}{\sqrt{\text{Hz}}}$$

- The ohmic resistance on measurement node i_{NOISE} must exceed

$$R_{\text{input}} = \frac{4kT}{i_{n,\min}^2} \geq 500\text{k}\Omega$$

- A Signal Analyzer has a voltage noise range of $u_{\text{SA},\min} \approx 1 \frac{\mu\text{V}}{\sqrt{\text{Hz}}}$

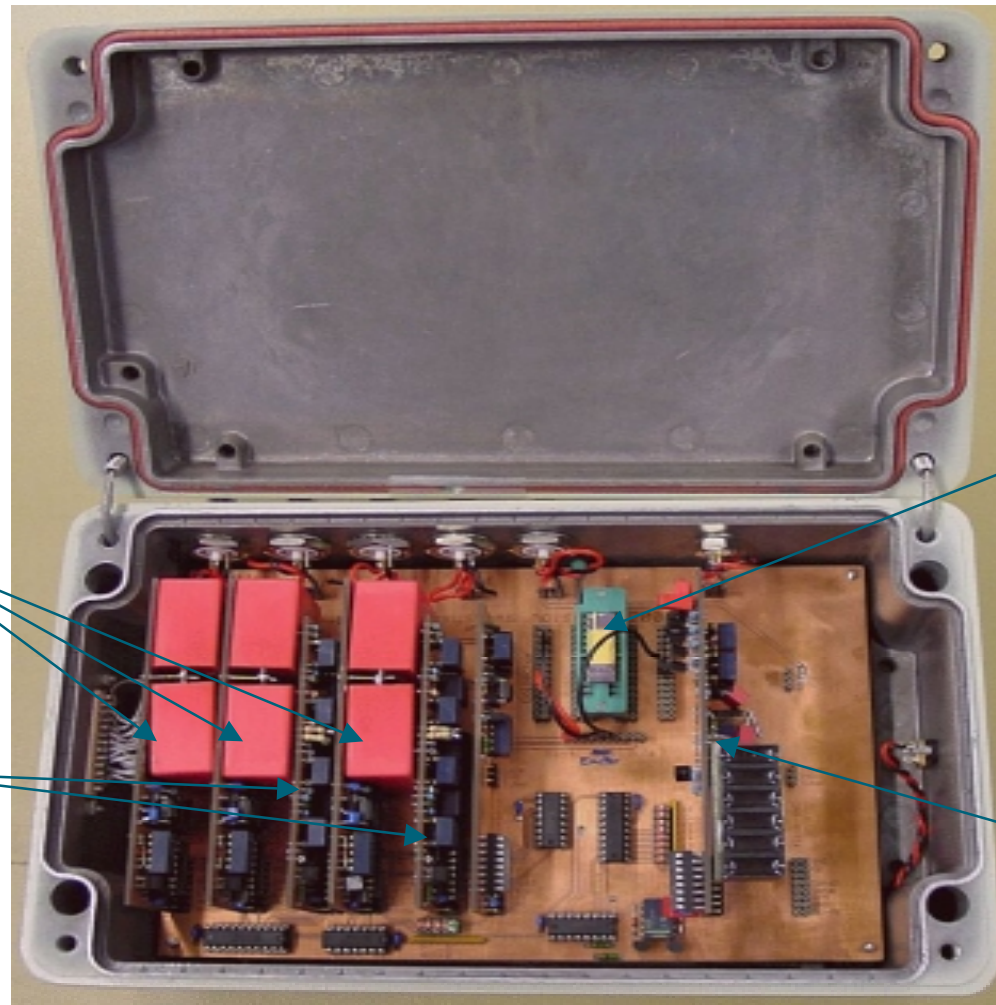
Noisebox Features

- Current Range: 500nA to 10mA
- Frequency Range: 1Hz to 100kHz
- Noise Levels down to 0.2 pA/sqrt(Hz)
- Measurement Devices MOS, BIP, Resistor
- Parameter Extraction SPICE and BSIM3V3 Model
- Rbb Extraction for BIP Transistors

Noisebox Main Parts

- Shielded Box
- Modular Design
- Active Filtered Sources
- High Resolution Noise Amplifier
- Controlled by PC Software
- Fully Automatic Measurements

Noisebox Rev.3



Active Filters

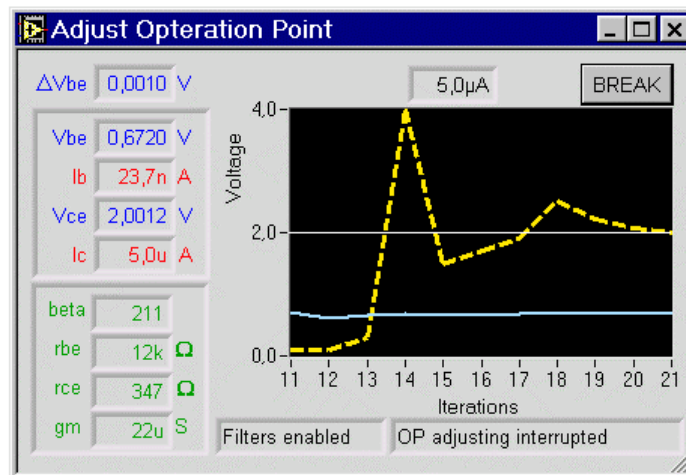
Current Regulators

Device Under Test

Noise Amplifier

Noisebox Software

- Measurement Setup
- Adjust Operation Point including Parameter Measurement
- Noise Measurement including Measurement Correction
- Parameter Extraction



Noisebox Control Panel

Measurement DATA Setup Noisebox INFO END

Control DUT Frequency Test

Ic

SHORT

5mA

2mA

1mA

500µA

200µA

100µA

50µA

20µA

10µA

5µA

2µA

1µA

0.5µA

0.2µA

OPEN

Voltages

Emitter 0,0

Collector 2,0

Base 0,7

V max 2,5V

R Base 100k Ohm

NPN Transistor

Rf = 1Meg

Transimpedance 20,5 $\mu\text{V} / \text{pA}$

Parameter

W L

100,0u 20,0u

Start Noise Measurement

Break Noise Measurement

Measurement Nr. 3 of 8

Stop Program immediately

Noise Measuring

supply main digital 88%

Vce 2,0042 V Ic 5,0u A

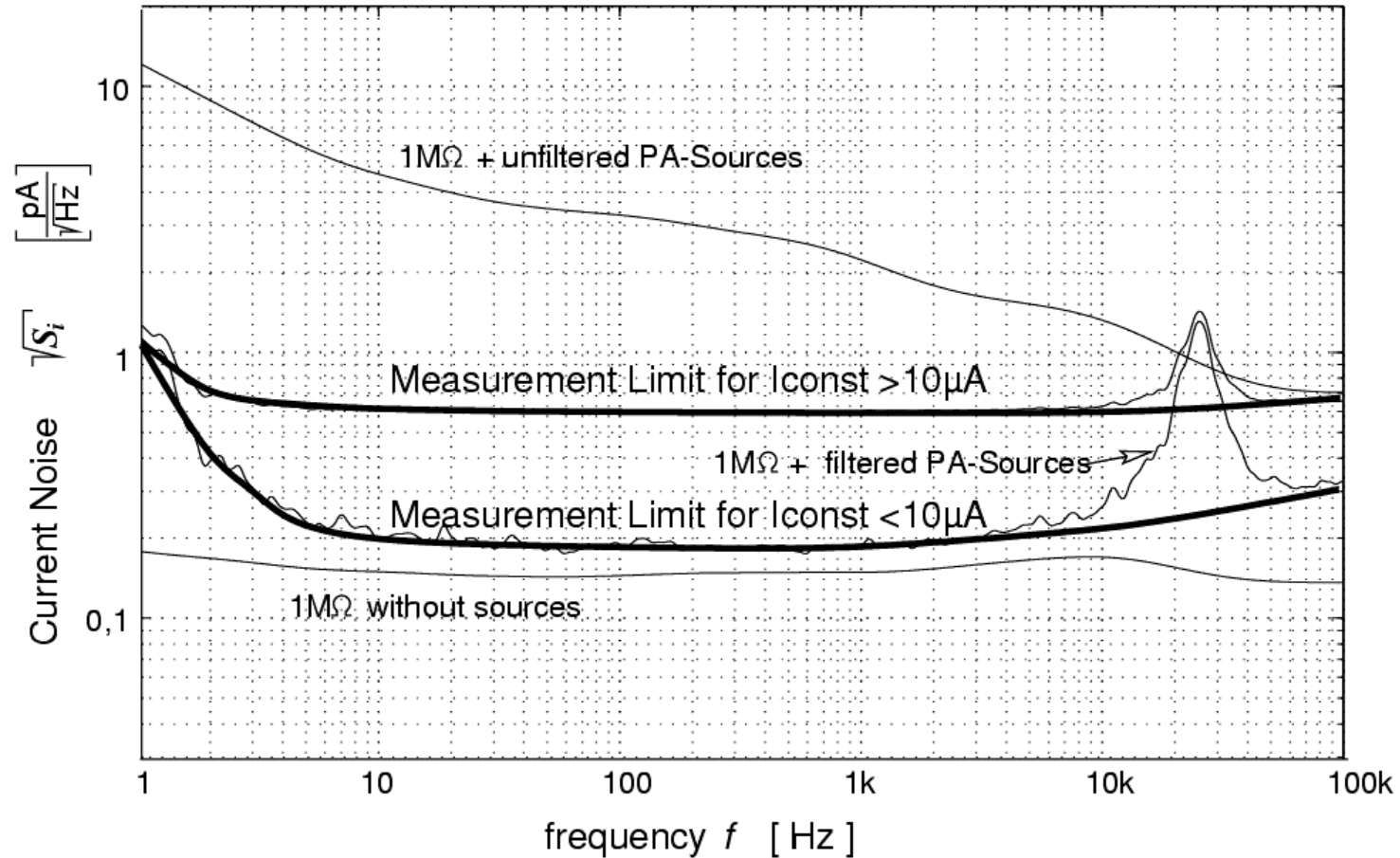
Vbe 0,6720 V Ib 23,7n A

beta 211 rbe 12,0k Ω

gm 22,4 μS rce 347,0k Ω

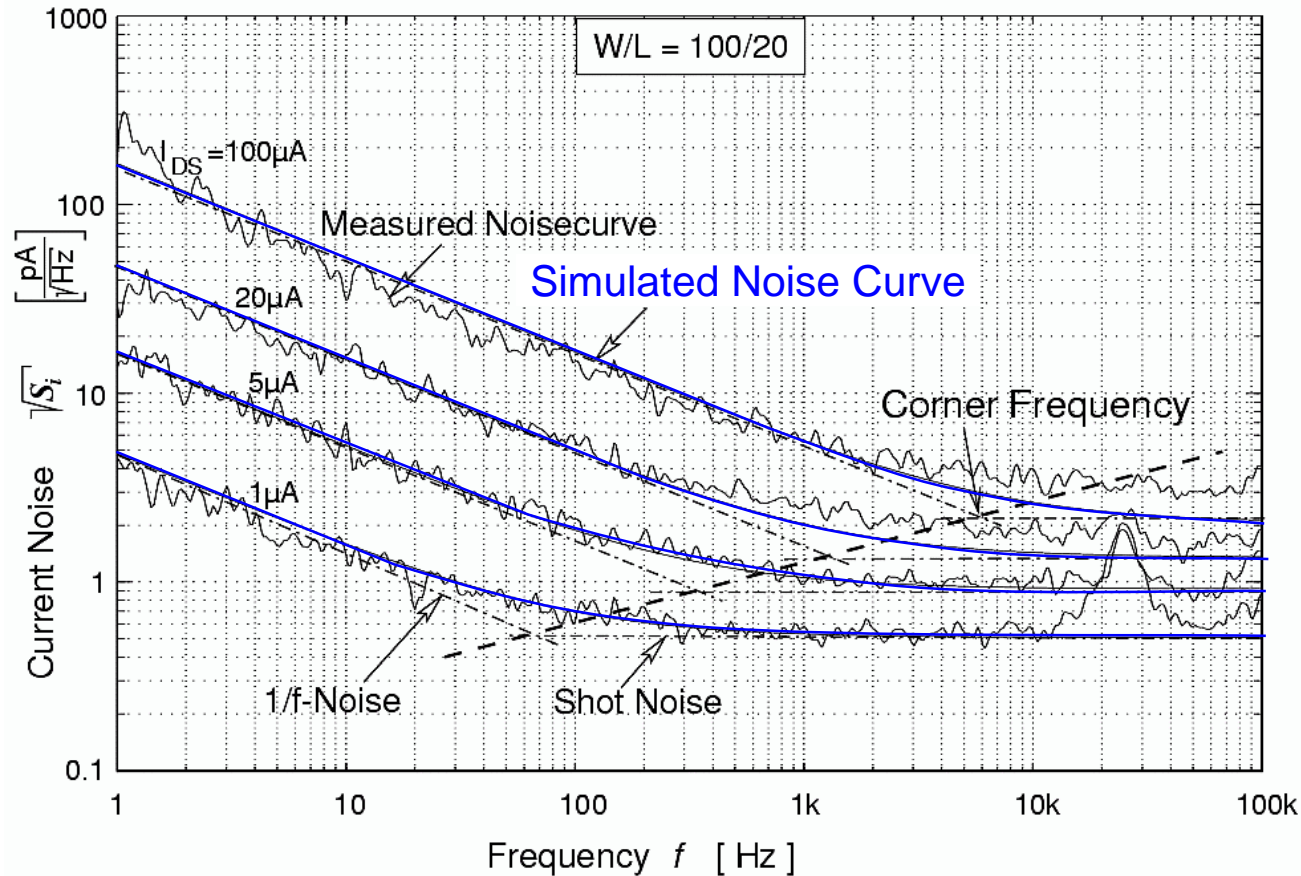
A 100,0u m L 20,0u m

Noisebox Measurement Range



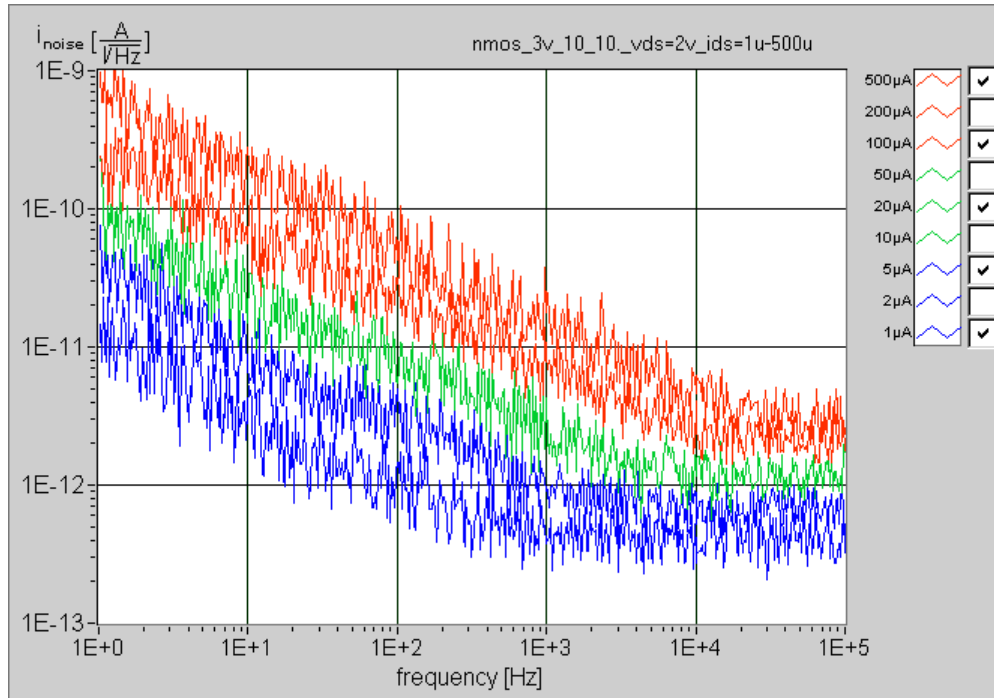
Noisebox resolution limits for different operation points

MOS Transistor



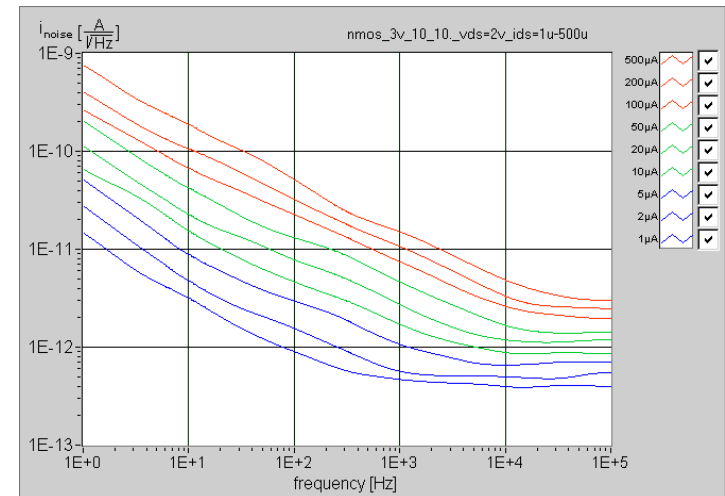
Typical current noise of a NMOS transistor for different drain currents

Measurement Correction



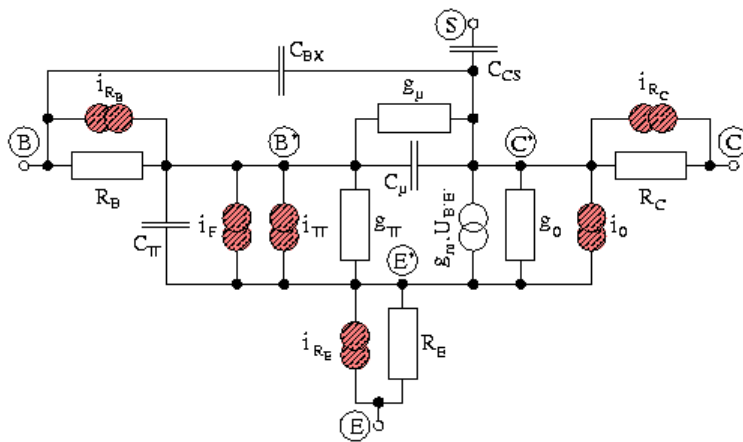
NMOS Transistor W/L = 10 μ m/10 μ m
measured and smoothed

- Elimination of Outliers
- Gain Correction
- Filter Correction
- Smooth Measurement



Noise Sources for BIP Transistor

Small Signal Equivalent Circuit



$$S_{i_{RB}} = 4 \cdot k \cdot T / R_B \cdot A^2$$

$$S_{i_{\pi}} = 2 \cdot q \cdot I_b \cdot A^2$$

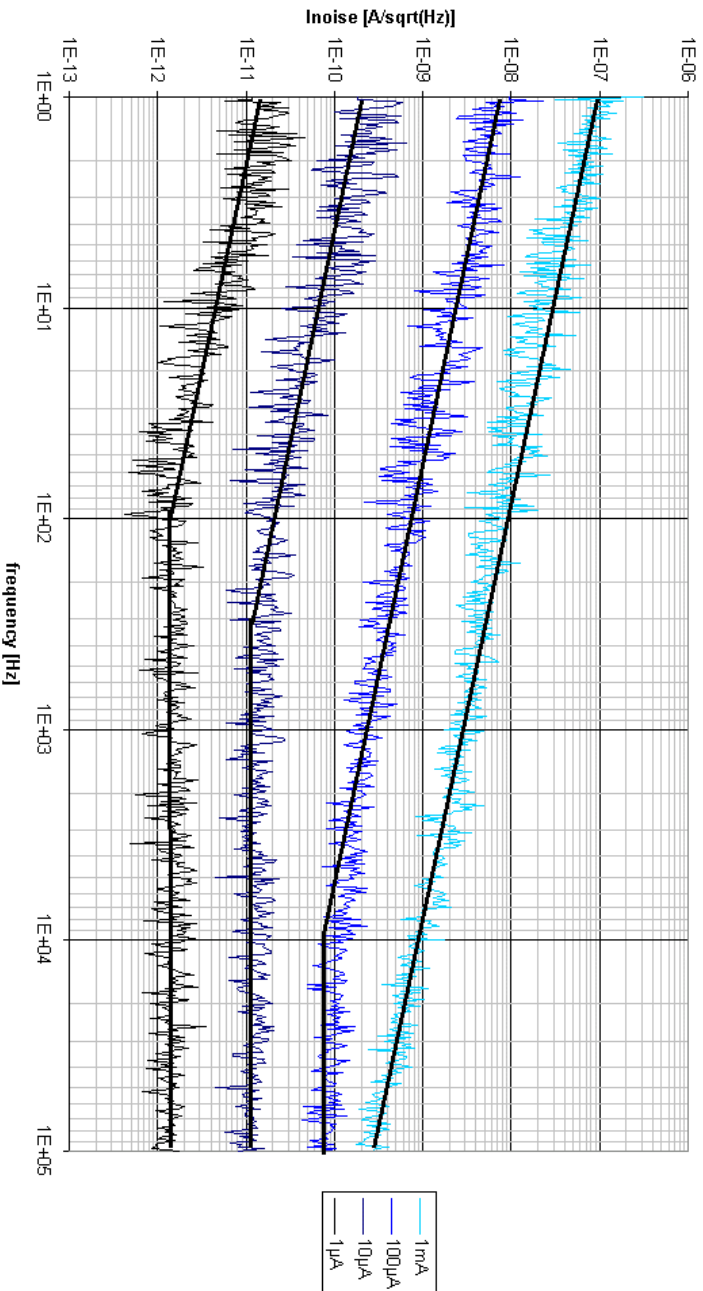
$$S_{i_f} = K_F \cdot I_b^{AF} \cdot A^2$$

$$S_{i_0} = 2 \cdot q \cdot I_c$$

$$S_4 = 4 \cdot k \cdot T / R_C$$

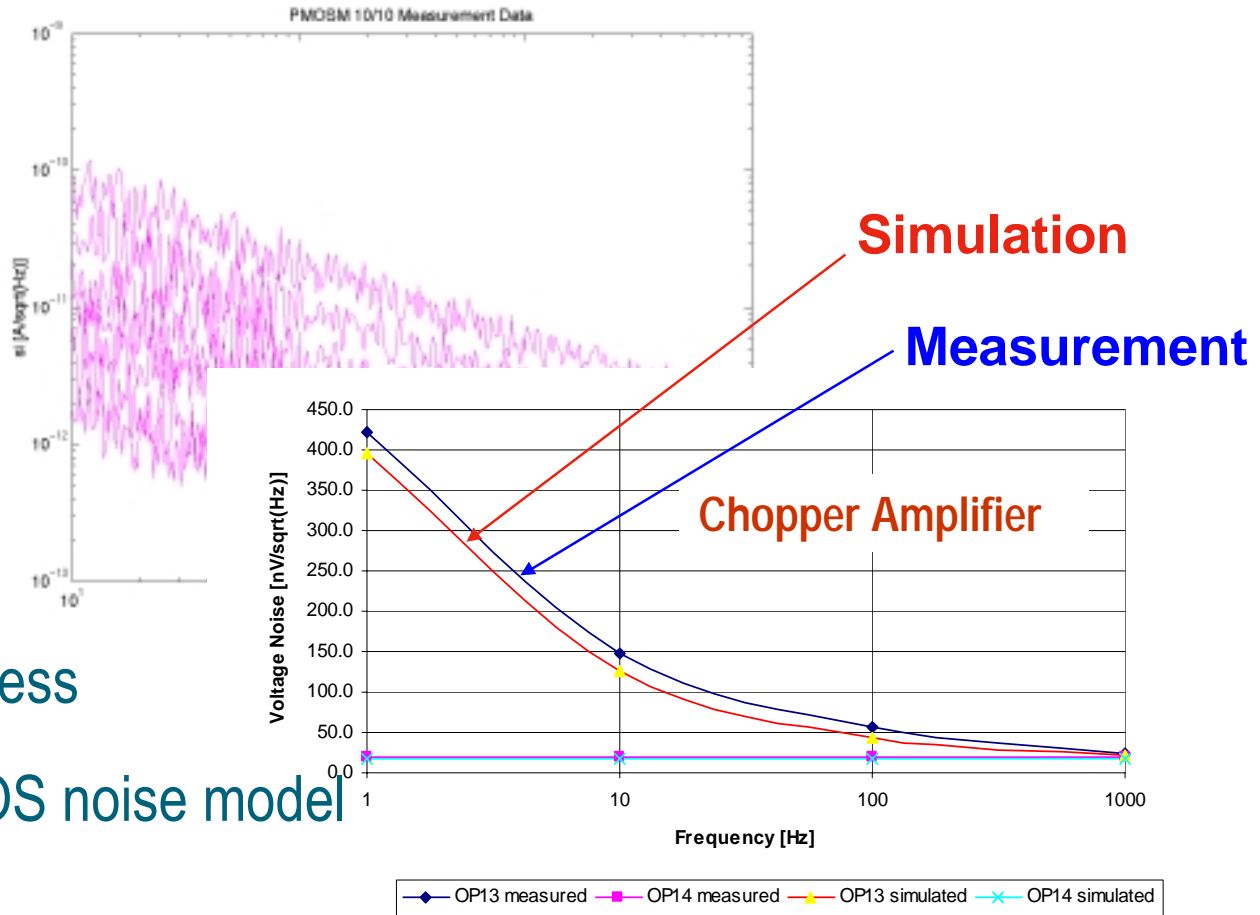
Bipolar Noise Curves

B35 NPN Area=2



Bipolar Transistor BCE121 A = 0.8µm²

Analog Simulation Results - Chopper Amplifier



0.35 μ m Process

BSIM3V3 MOS noise model

Error < 10%

Conclusion

- Fast and accurate Noise Parameter Extraction for
Analog Mixed-Signal process characterisation
- Applicable for both MOS and BIP transistors
- High resolution limit
- Adaptable for noise measurements of:
 - JFETs
 - HResPoly resistors
 - Systems (OPA, DAC, etc.)