X-FAB SEMICONDUCTOR FOUNDRIES

Modelling of diffused resistors

presented by Hagen Wald
X-FAB Semiconductor Foundries AG

München, 18/19.10.2007

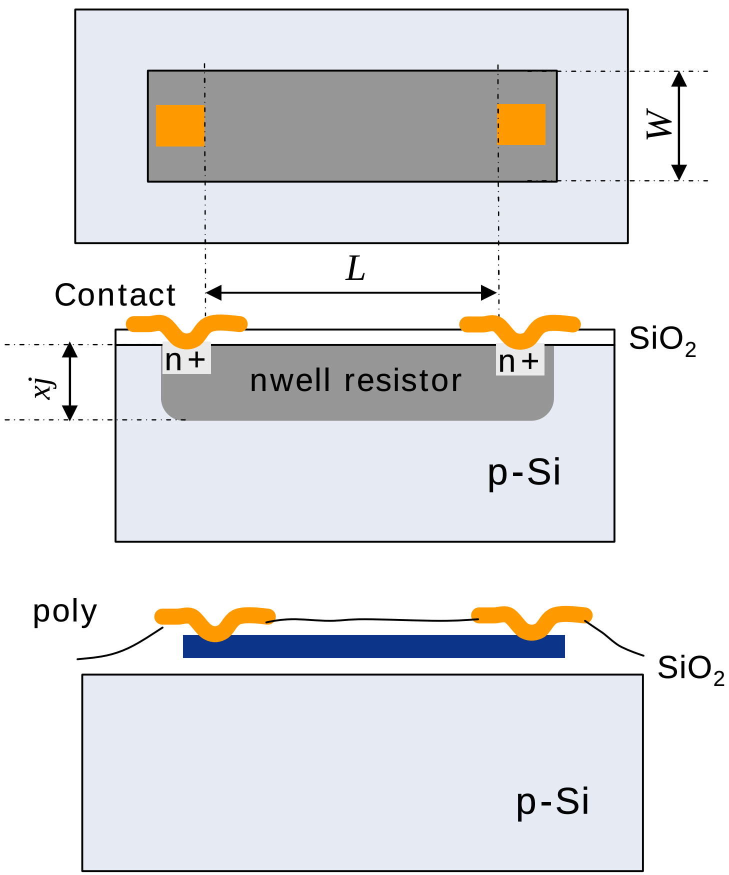
Importance

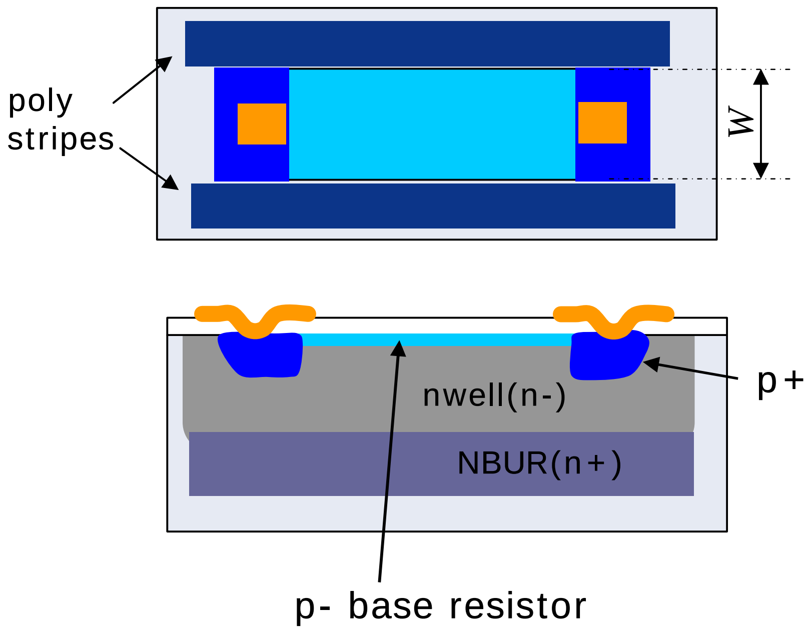
diffused resistors

- passive device, very often used
- very accurate modelling in analog design is needed
- examples: DAC, amplifier, voltage divider, sensors, etc.
- need for high precision modelling of temperature behaviour

Types of resistors

- well diffusion, n-type, p-type diffusion
- base diffusion, poly defined width
- pinch resistors
- isolated polysilicon





Electrical Issues

- depletion effects (periphery and area)
- head resistance (implant) -> very short resistors
- contact resistance -> very short resistors
- velocity saturation -> high fields
- temperature dependence (possible self-heating)
- thermal noise, noise of grain boundaries (polysilicon)
- dog bone effect
- inhomogeneous field distribution caused by resistor geometry
- ...

Modelling Issues (Foundry Business)

Model quality

- accuracy
- voltage dependence
- width, length dependence
- temperature dependence
- noise behavior

Model Efficiency

- simulation time
- convergence
- usability for different simulators
- simplicity
- usage of ‘standards’

Types of models

> JFET model

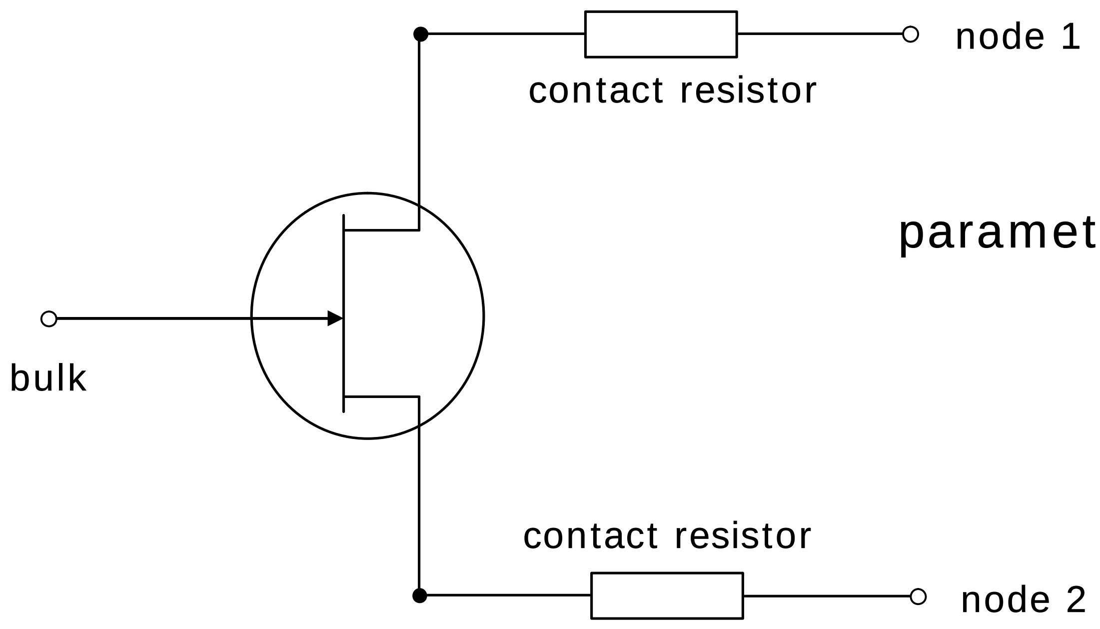
> 3 terminal Resistor equation model
  - physical based
  - phenomenological

> Voltage controlled current source

JFET model

Problems: accuracy, temperature behavior, noise

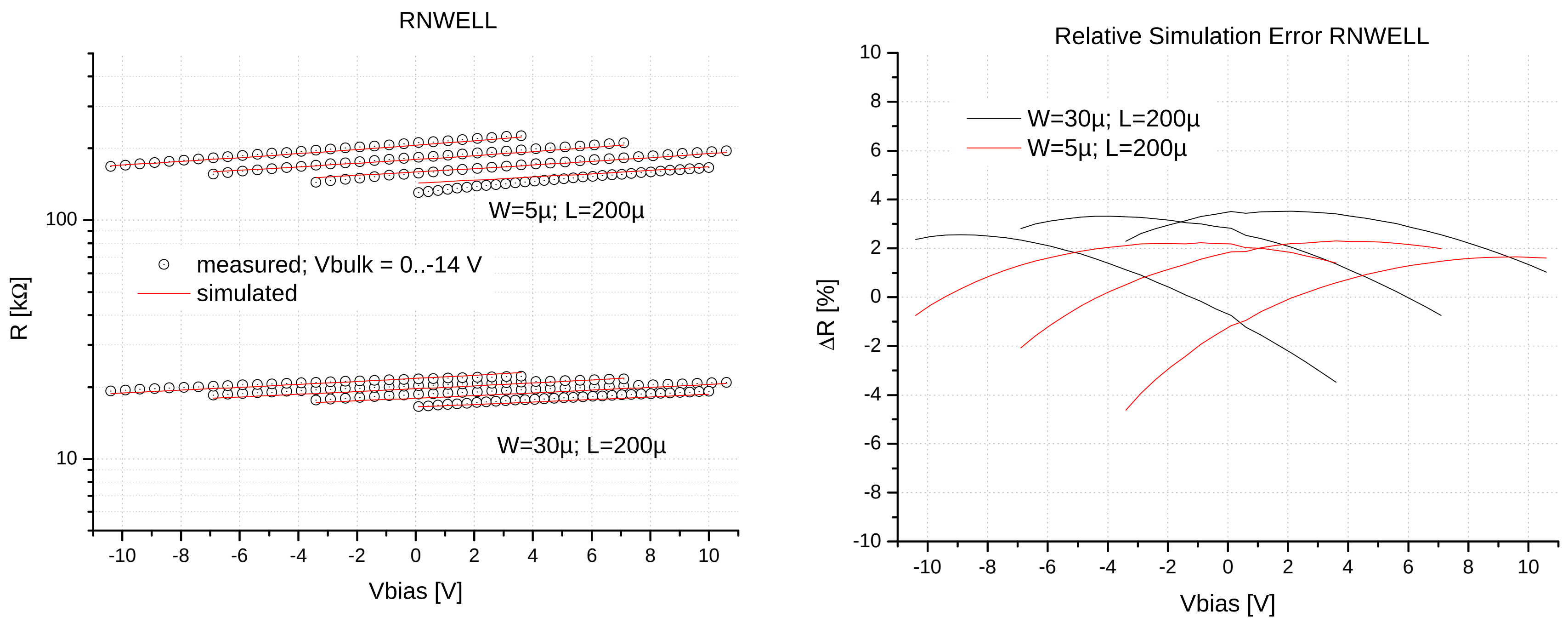
Nice: fast simulation, very good convergence, all simulators



parameter: BETA(W,L,?W,?L)
VTO(W, ?W)
BEX, BETATCE

JFET model

Accuracy



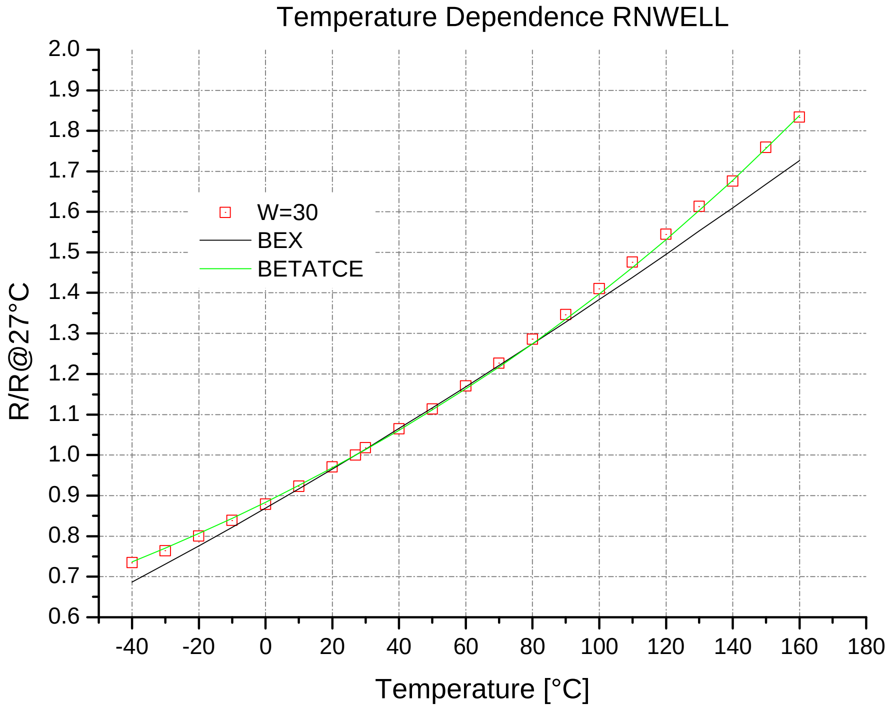
JFET model

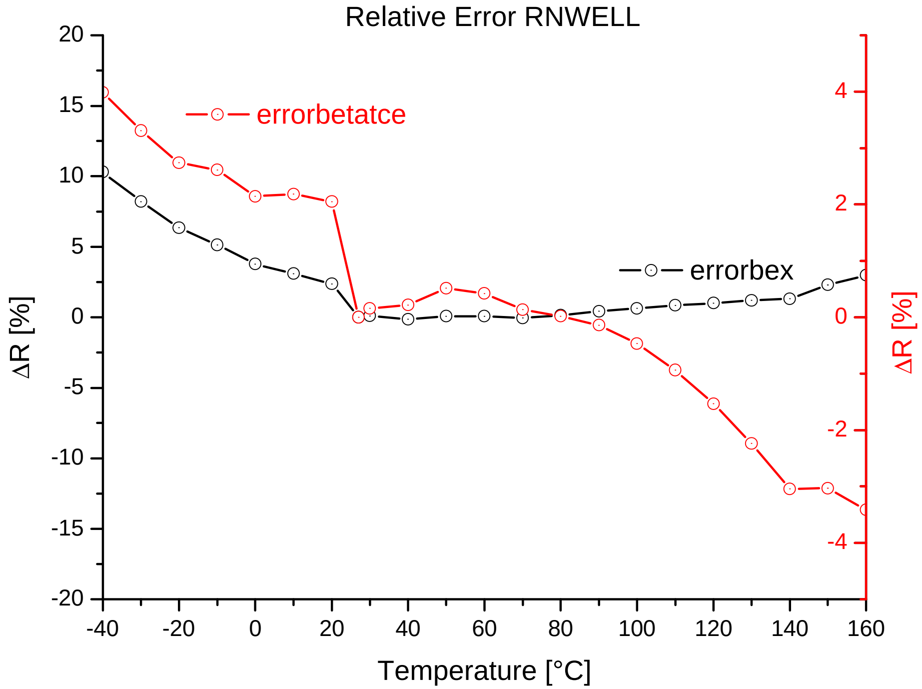
Temperature dependence

$$BETA(T) = BETA \cdot 1.01^{BETATCE(T - T_{nom})}$$

$$BETA(T) = BETA \cdot \left(\frac{T}{T_{nom}} \right)^{BEX}$$

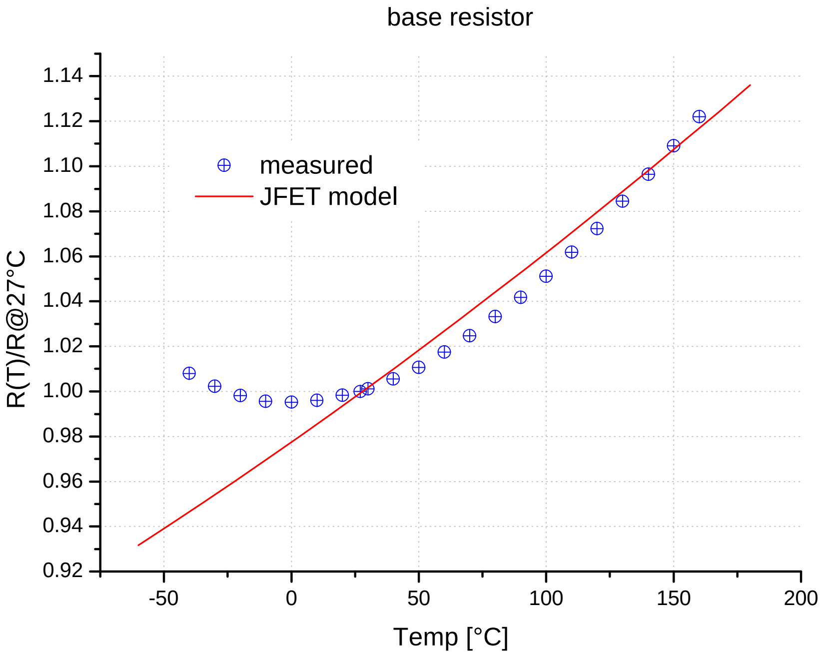
only BEX: SPECTRE
BETATCE/BEX: HSPICE, ELDO,..





JFET model

Special case: temp. dependence base resistor



Conductivity:

$$G = \frac{qW}{L}\int_0^{xj} \mu_p(x,T)\,p(x,T)\,dx$$

JFET model

Noise

Resistor (only drain and source region):

$$i_r = NOISE \cdot \sqrt{\left(\frac{4kT}{r}\right)}$$

Channel thermal:

(ELDO problem)

$$i_{ch\_th} = \sqrt{\left(\frac{8kTgm}{3}\right)}$$

Channel flicker:

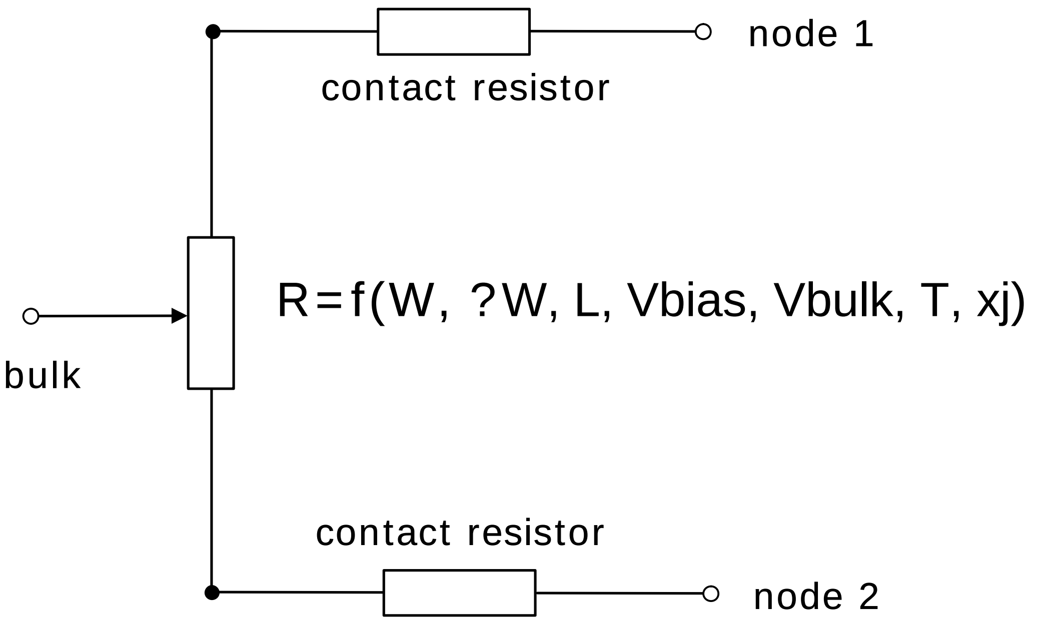
$$i_{ch\_fl} = \sqrt{\left(\frac{KF \cdot ids^{AF}}{f}\right)}$$

only poly resistors show frequency dependent noise

3-terminal Resistor model

Equation (physically based)

Problems: slow simulation, bad convergence, simulator issues
Nice: high accuracy, temperature and noise behavior correct



3-terminal Resistor model

depletion region from sides of resistor:

$$Weff = W_m + \Delta W - 2a_P \sqrt{y_P + (V(y) - V_B)}$$

depletion region from bottom of resistor:

$$x_{db} = x_j - a_a \sqrt{y_a + (V(y) - V_B)}$$

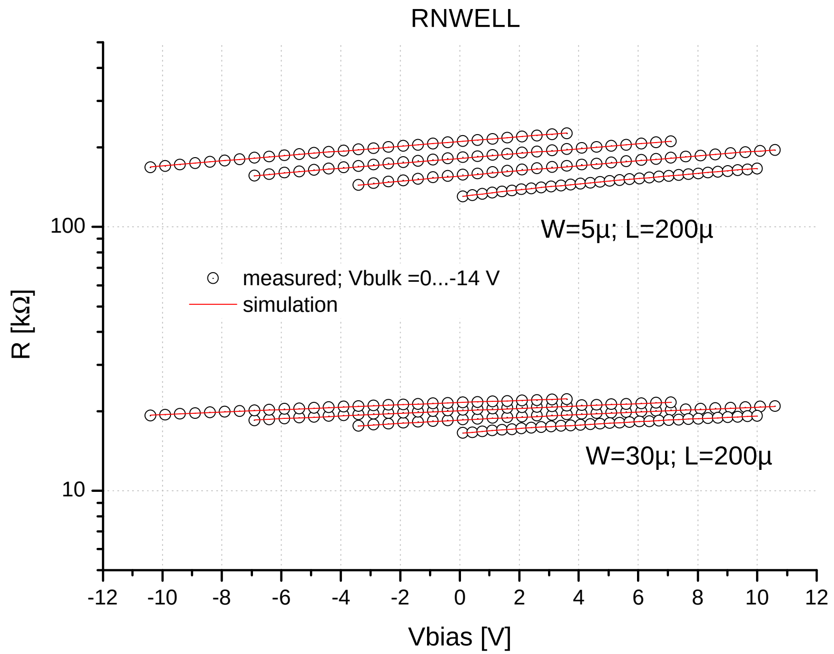
velocity saturation:

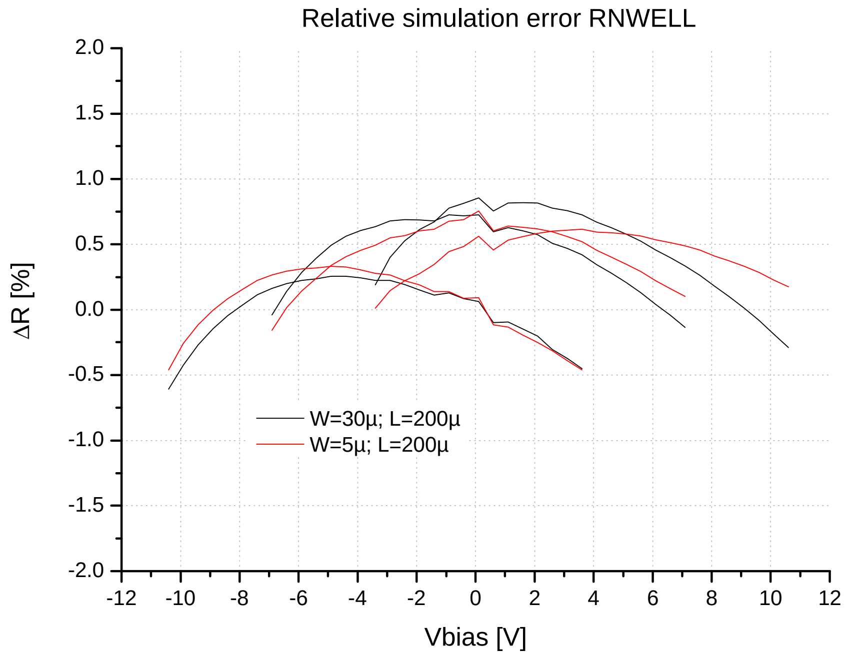
$$r = r_0 \sqrt{1 + \left(\frac{V_{DS}}{L_f E_{crit}} \right)}$$

[J. Victory, C. McAndrew, J. Hall, M. Zunino, IEEE Journal of Solid-State Circuits VOL. 33, Sep. 1998]

3-terminal Resistor model

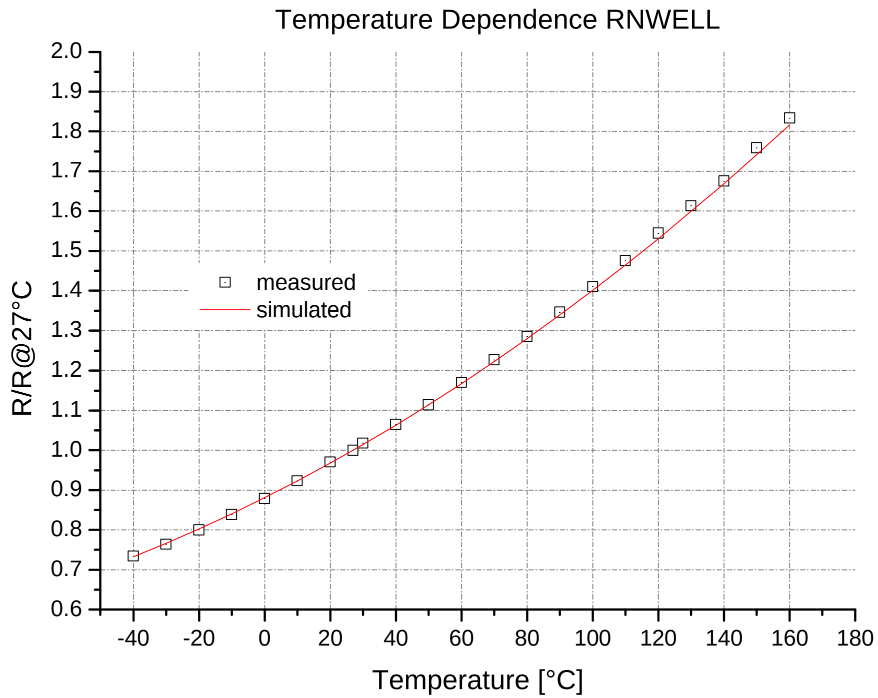
Accuracy

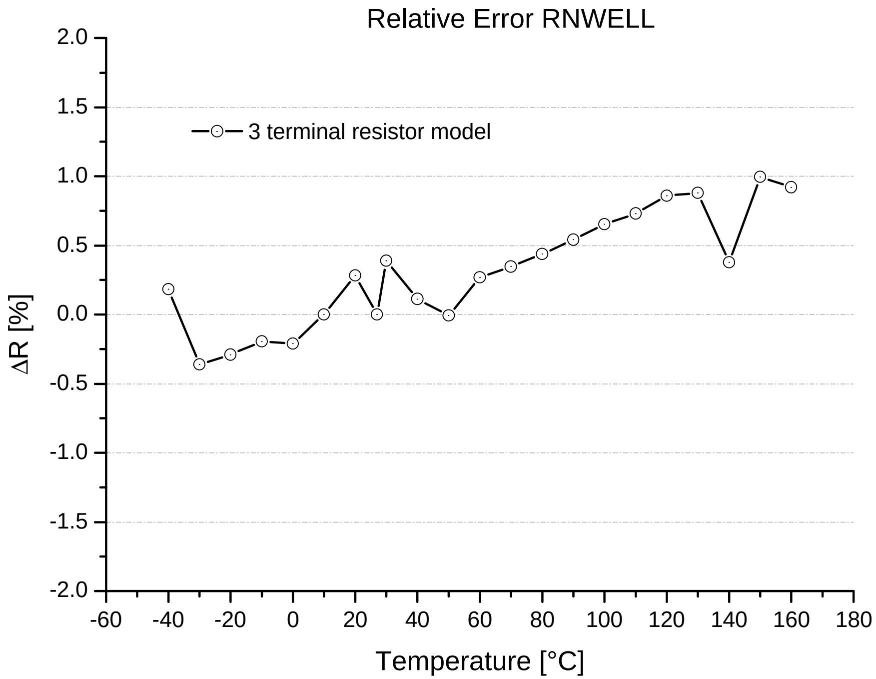




3-terminal Resistor model

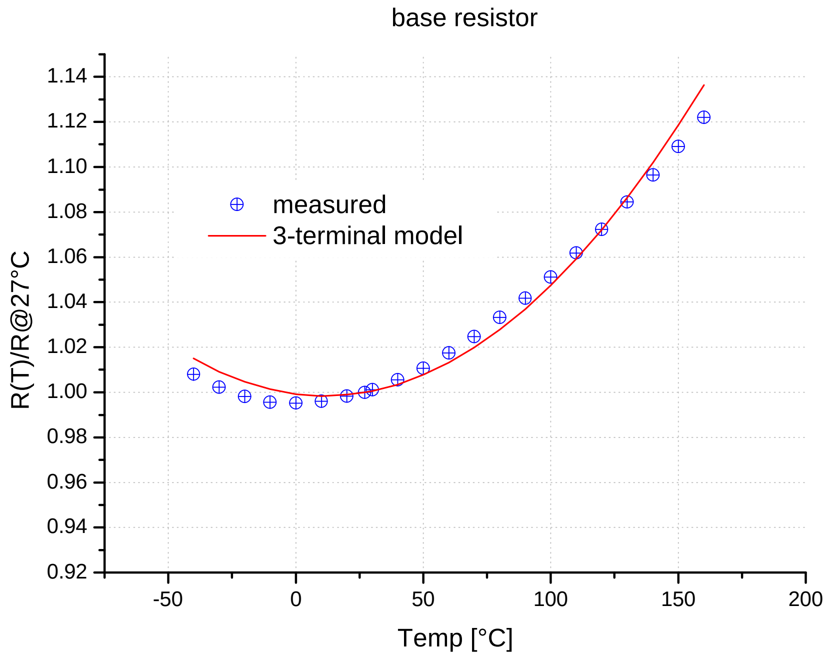
Temperature dependence

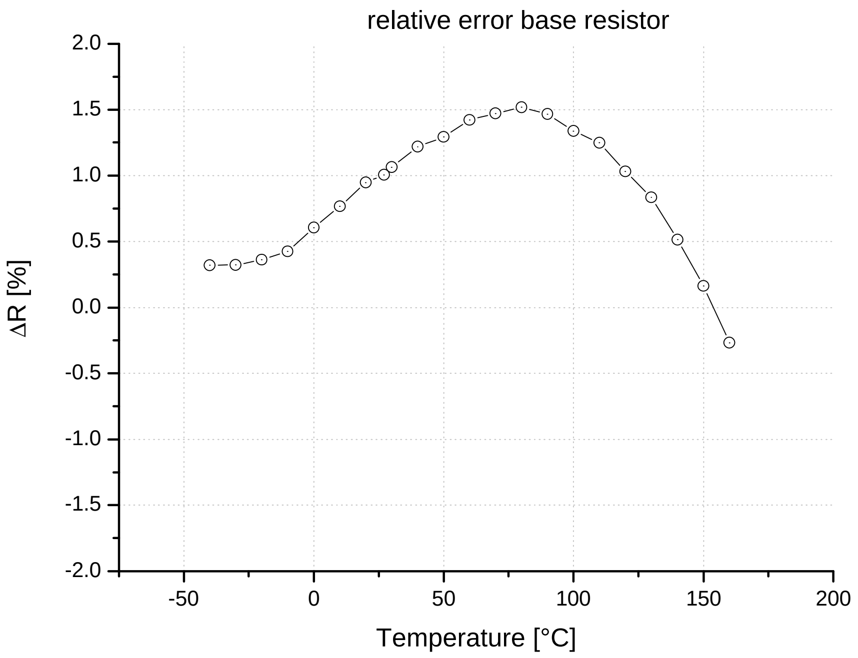




3-terminal Resistor model

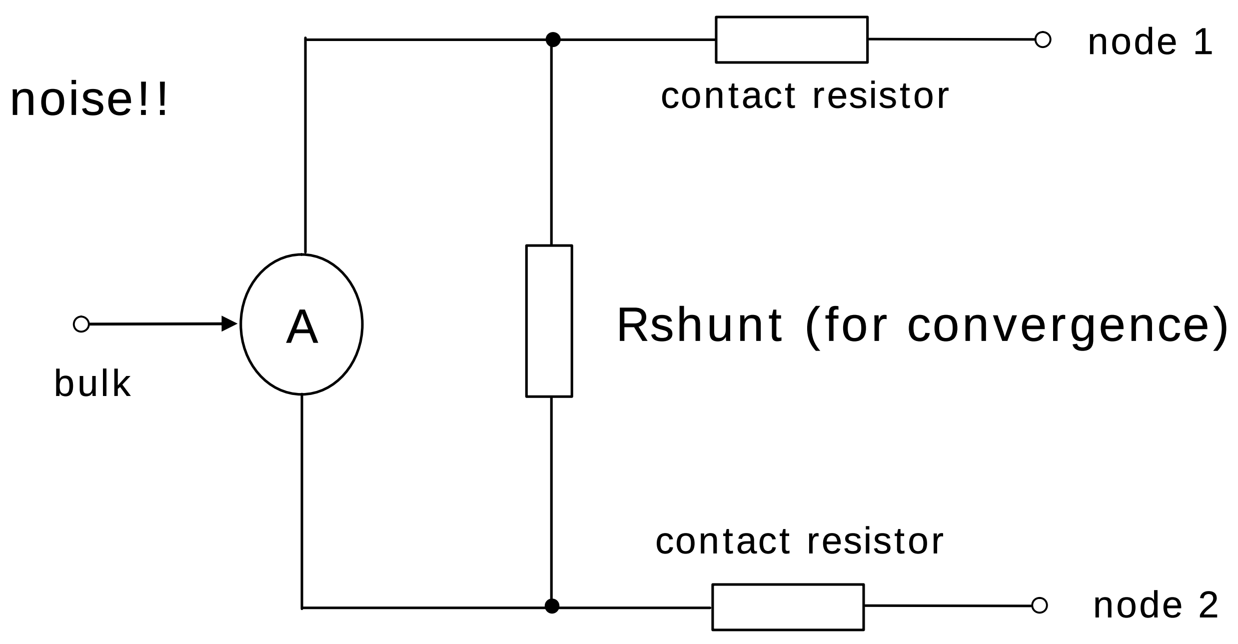
Temperature dependence





3-terminal Resistor model

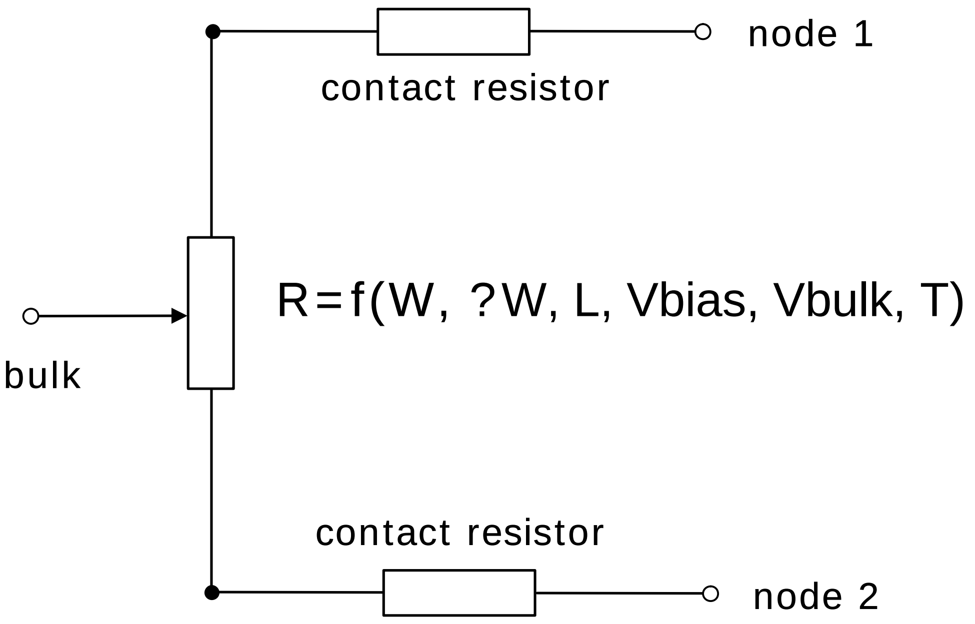
Problem: equation in resistor: PSPICE, ADS
usage of voltage controlled current source



3-terminal Resistor model

Equation (phenomenological)

Problems: slow simulation, simulator issues (PSPICE, ADS)
Nice: high accuracy, temperature and noise behavior correct



3-terminal Resistor model

approach:

$$R = f(k_1 \cdot V, k_2 \cdot V^2, k_3 \cdot V_{bulk})$$

$$k_{1,2,3} = f(W^{-1}, W^{-2}, L^{-1}, L^{-2})$$

-> results as accurate as physically based model

benchmark simulation speed

Simulation of ring oscillator with 75 transistor pairs (HSPICE) and load resistance

Model	Simulation time [s]	convergence	Remarks
Without res.	31.96	very good	
JFET model	49.39	very good	
3-term phys.	80.43	bad	
3-term phen.	79.87	good	
VCCS	167.09	bad	

reported convergence problems:
-setting dcon to 2
-no convergence with standard algorithm
-damped pseudo-transient used

conclusions

-JFET: fast simulation but not very high accuracy is achieved
-3-terminal: slow but high accurate

-JFET: temperature behavior not always correct modeled
-JFET: noise behavior (ELDO)
-3-terminal: temperature and noise correct modeled

-simulators: PSPICE and ADS need special treatment

Thank you for your attention.

http://www.xfab.com