# ngspice - current status and developments

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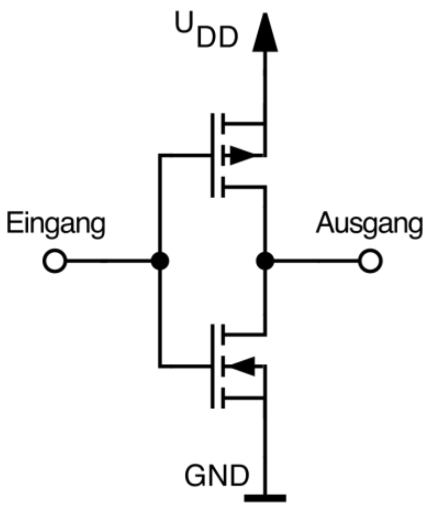
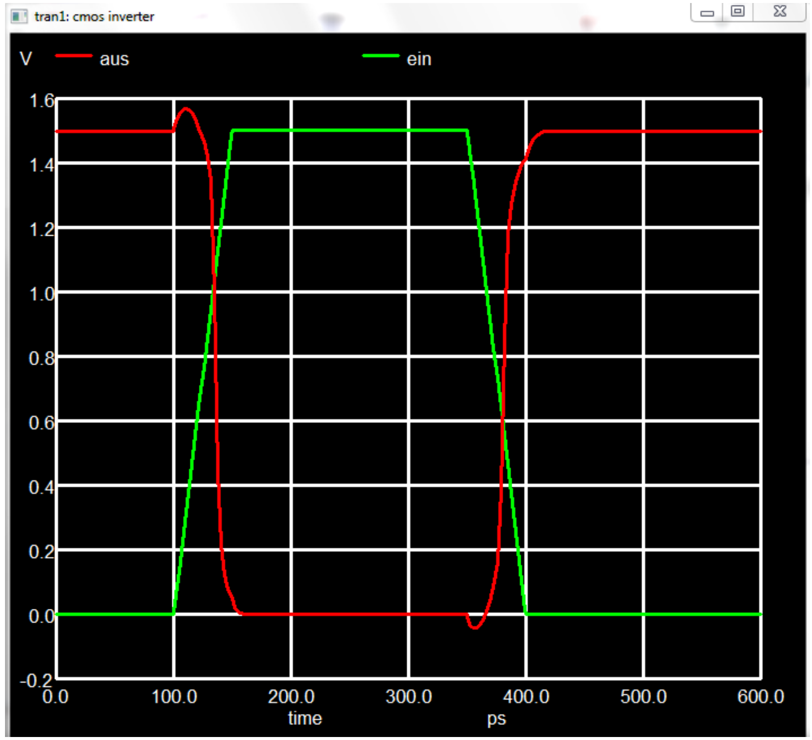
# Contents

# ngspice introduction




```
CMOS inverter

.include ./bsim4soi/nmos4p0.mod
.include ./bsim4soi/pmos4p0.mod
.option TEMP=27C

Vpower VD 0 1.5
Vgnd VS 0 0

Vgate Ein VS PULSE(0 1.5 100p 50p 50p 200p 500p)

MN0 Aus Ein VS VS N1 W=10u L=0.18u
MP0 Aus Ein VD VS P1 W=20u L=0.18u

.tran 3p 600ps

.control
  run
  plot Ein Aus
.endc

.END
```




*the circuit* *the input* *the output*

# ngspice introduction

- ngspice – what is it
  - Circuit simulator that numerically solves equations describing (electronic) circuits
  - Circuits are made of passive and active devices
  - The equations are solved for (time varying) currents and voltages
- ngspice – what does it do
  - Read and parse the circuit netlist, check for compatibility (PSPICE, HSPICE, …)
  - Set up the circuit matrixes
  - Solve the matrix, solve the device equations (for every time step)
  - Output the data (plotting, saving to disc, returning to calling program)

# The two major application areas

**PCB design support**

- Circuits are made with a mix of ICs and discrete components

*Requirements*:

- Comfortable user interface (offered by third parties)
- PSPICE and LTSPICE model compatibility

KiCad, Altium, Eagle, PartSim, CoolCAD, PSIM, WeSpice …

**IC design support**

- Circuits are made of (MOS) transistors and (parasitic) passive components

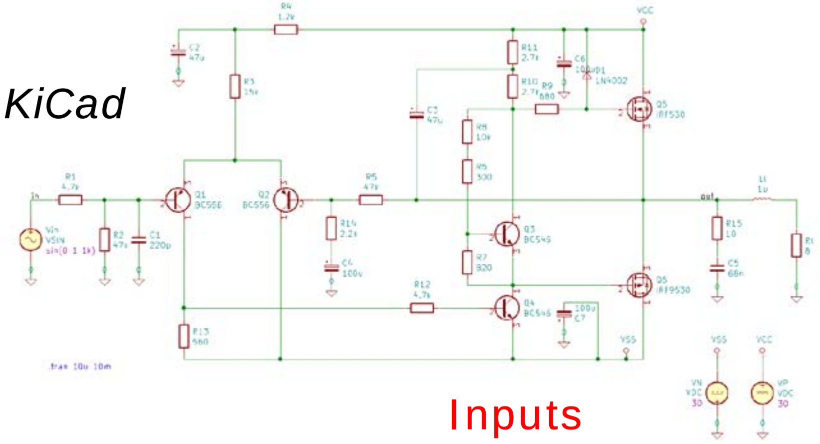
*Requirements*:

- BSIM 3, 4, HICUM models etc.
- Large circuit capability, speed
- HSPICE PDK compatibility

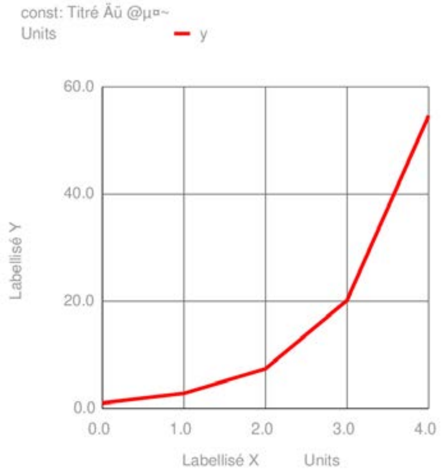
gEDA**,** Yosys, efabless, Isotel, XSCHEM, PySpice …

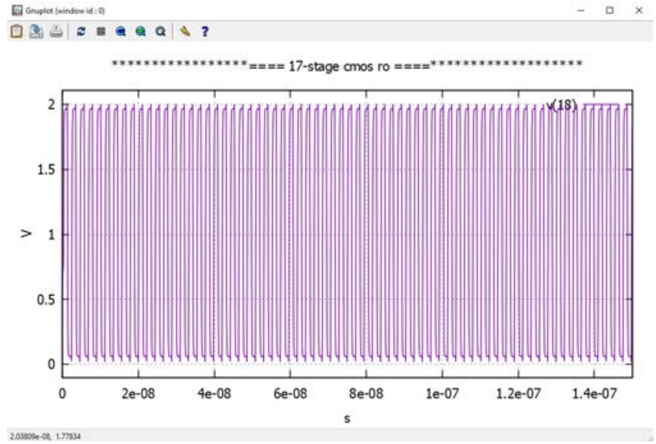
# Some impressions, ngspice-32

*KiCad*



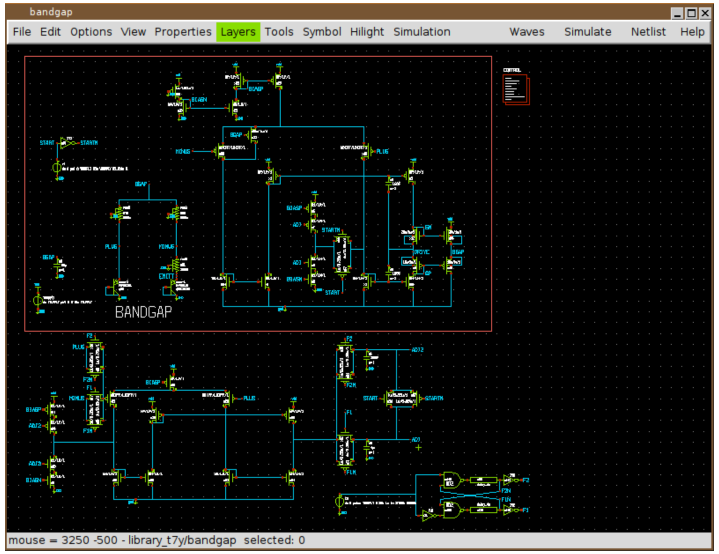
*Postscript*



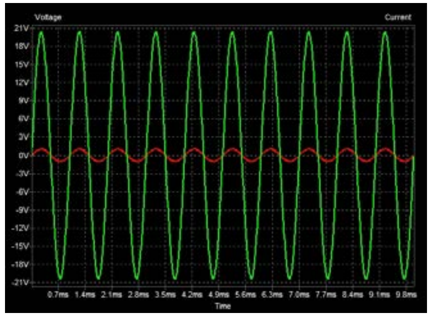




*gnuplot*

Inputs

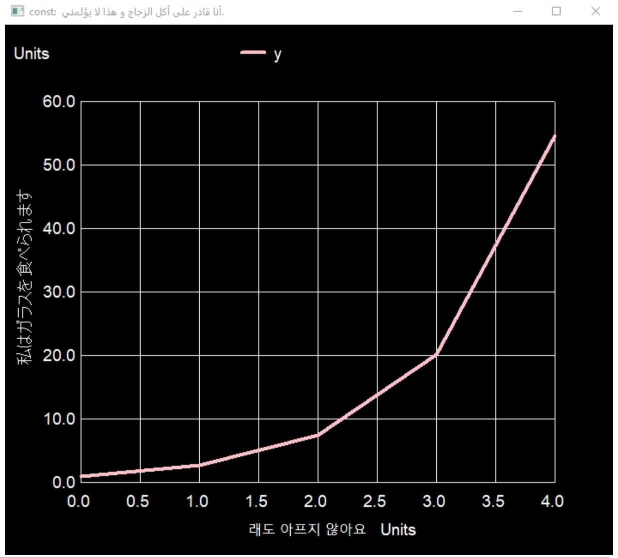



Outputs




*KiCad*

*UNICODE axis labels*




*XSchem*

# Three flavors of ngspice

Standard executable

Command line input

File and graphics output

Control language

Shared library with tcl/tk interface

Tcl command input

Controlled by tcl scripts

Blt library for graphics output

C shared library (so, dll)

Input and output via exported functions and callbacks

Caller has full control over (nearly) all internal variables

Simulation may run in its own thread

No graphics interface

OSs supported: Linux, Windows, macOS, (Solaris, BSD, Android, Wasm ...)

# Scripting with control language

**Controls**

~100 commands

62 math functions

91 internally defined user controllable variables

Loops etc.

**Applications**

To control simulation sequences, including plotting, measuring etc.

Monte Carlo simulation

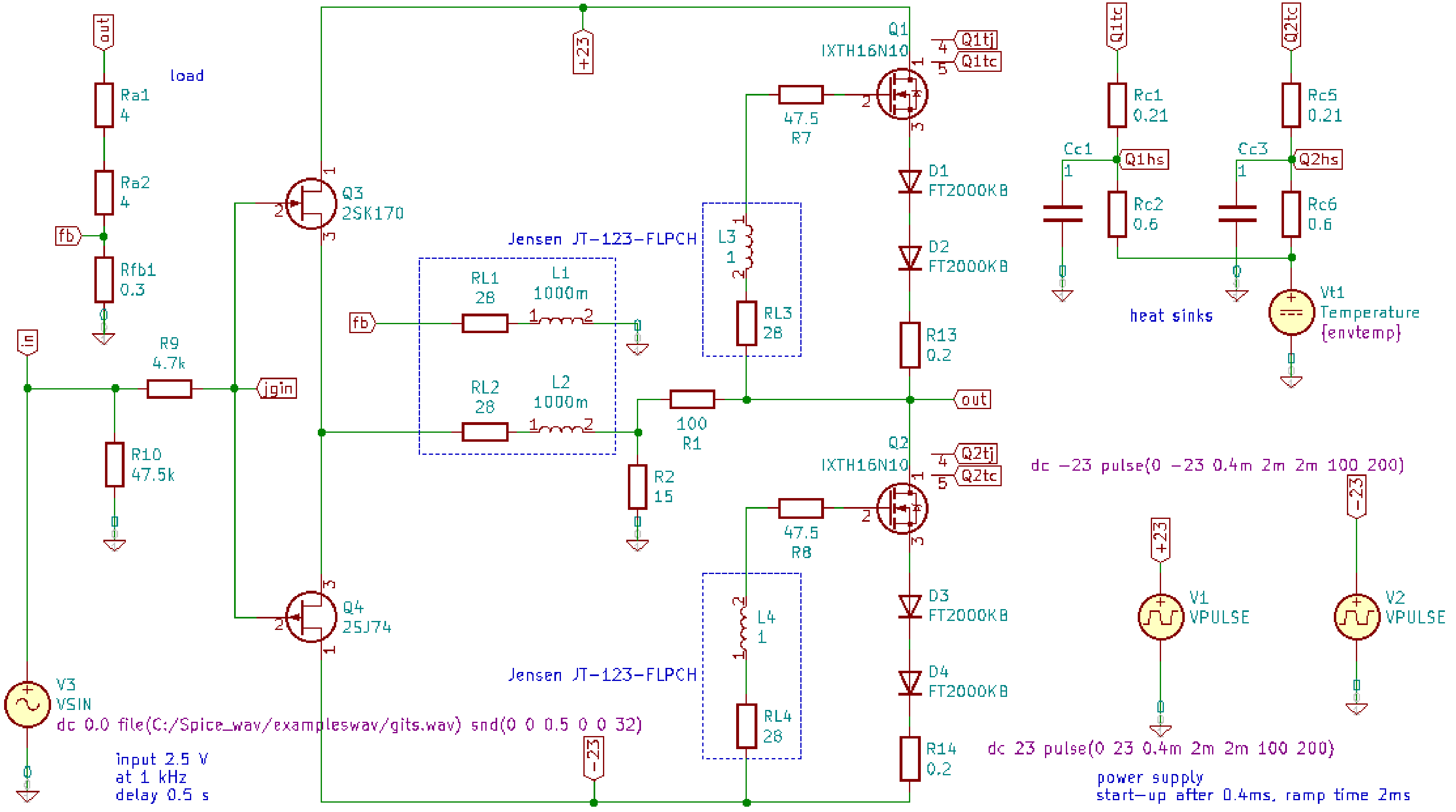
**Example script**

```
*ng_script
* Script to run transient sim of adder-digital
.control
source adder-digital.cir
tran 500p 64000n
rusage
display
edisplay
* save data to input directory
cd $inputdir
eprvcd 1 2 3 4 5 6 7 8 s0 s1 s2 s3 c3 > adder_x.vcd
* plotting the vcd file (e.g. with GTKWave)
shell start gtkwave adder_x.vcd --script nggtk.tcl
.endc
```

# KiCad/ngspice: Class A power amp example

*Archetype: F6*
*by Nelson Pass*

*KiCad/Eeschema input*



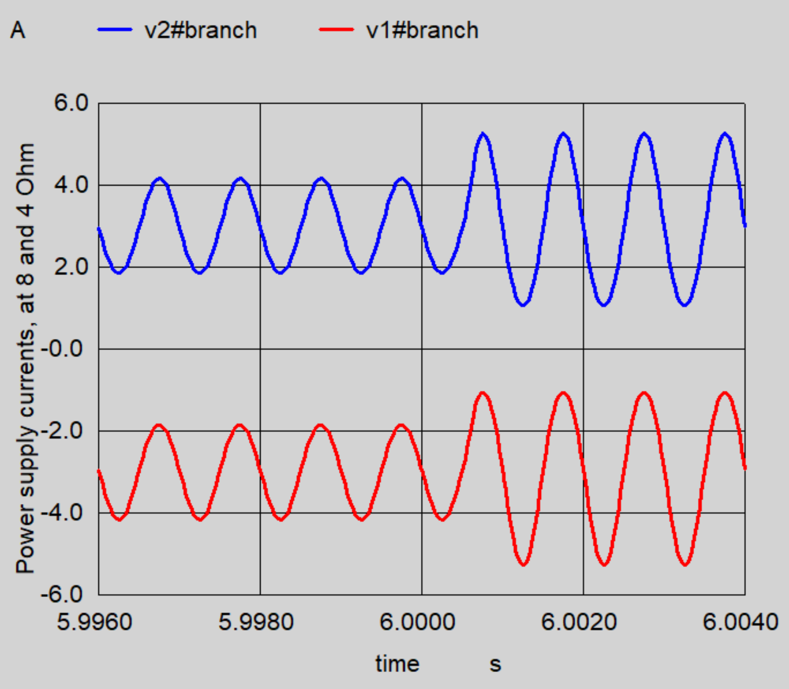
# Some results for the class A amp

**Procedure**

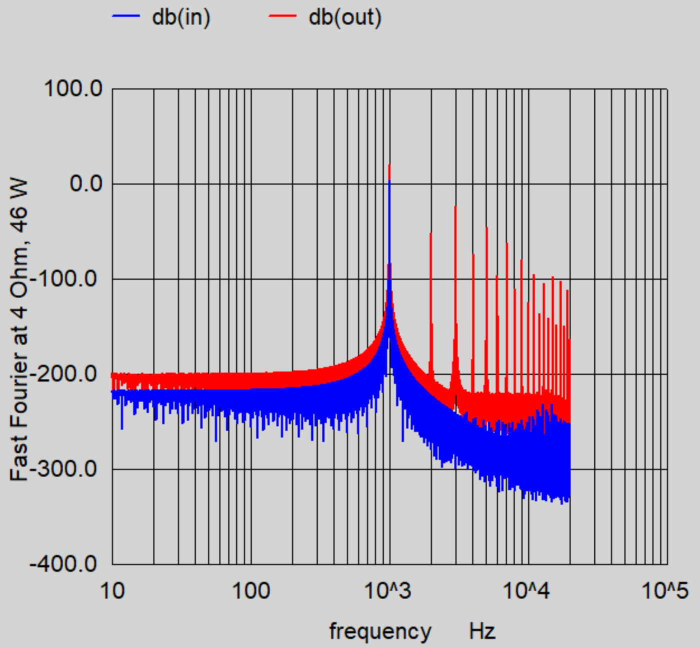
Draw the circuit

Set up a control script

Run the simulation




*True class A*




*FFT of 1 kHz at 46 W*
*Mostly 3rd harmonics*
*Ultra low noise floor*

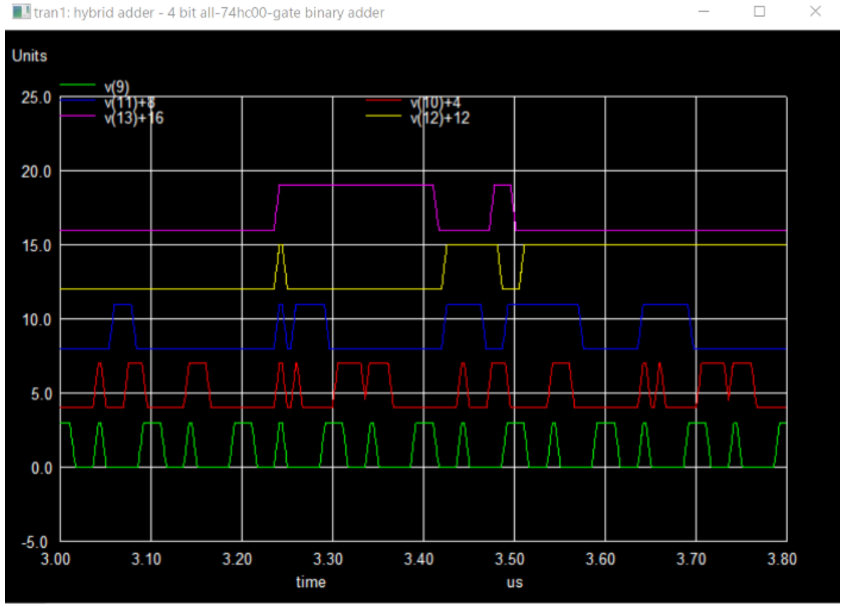
# Mixed signal simulation with XSPICE

| digital | | analog |
|---|---|---|
| event simulation<br>fast<br>no analog values, but signal strength and delays<br>23 predefined devices (gates like: nand, flip flops, latches, state machine, LUT)<br>third party interfaces to µC | 7 hybrid (interface) devices | C coded models<br>versatile<br>analog (and frequency domain)<br>29 predefined devices (e.g. limiter, multiplier, file source, integrator, table model …) |

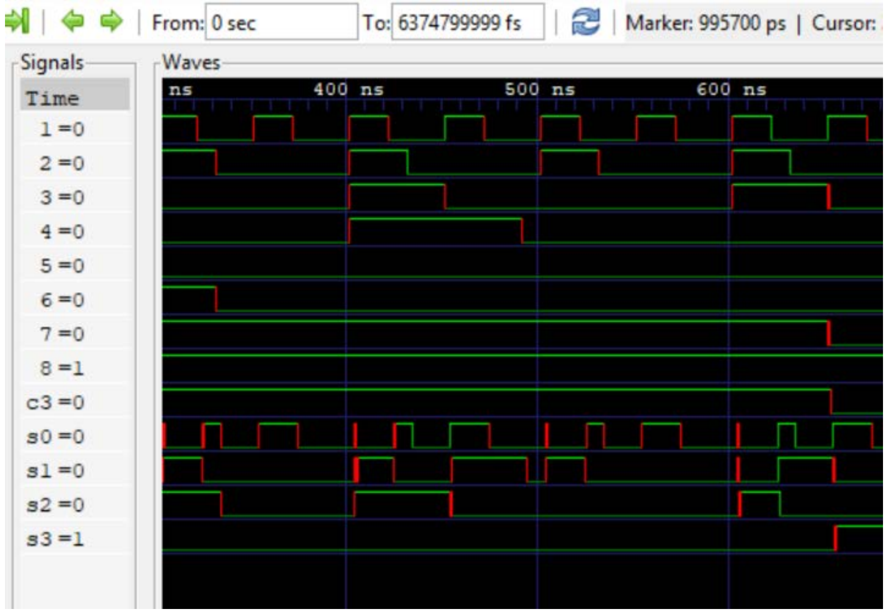
# Compare the venerable 4-bit adder

| analog | hybrid | event-based |
|---|---|---|
| 65 s | 16 s | 1.4 s |
| BSIM3 CMOS, 2-input NAND, OpenMP, 4 threads | XSPICE nand gates with analog interfaces | XSPICE nand gates, digital interconnects |

*Analog, viewed with ngspice*




*VCD file, viewed with gtkwave*



# Current developments

Thermal modeling

HICUM bjt model

Verilog A interface

KLU matrix solver

SIMD evaluation of model equations

# Thermal modeling

Things get hot when we consume electrical energy.

What about the devices and their parameters?

Let‘s model them with ngspice!

| | Thermal term | Electrical term |
|---|---|---|
| *Capacitance* | $c$ [J/K] | $C$ [A/V] |
| *Conductance* | $g$ [W/K] | $1/R$ [1/Ω] |
| *Temperature/Voltage* | $T(t)$ [K] | $V(t)$ [V] |
| *Heat/Current* | $Q$ [W] | $I(t)$ [A] |
| *Time constant* | $c/g$ [s] | $RC$ [s] |

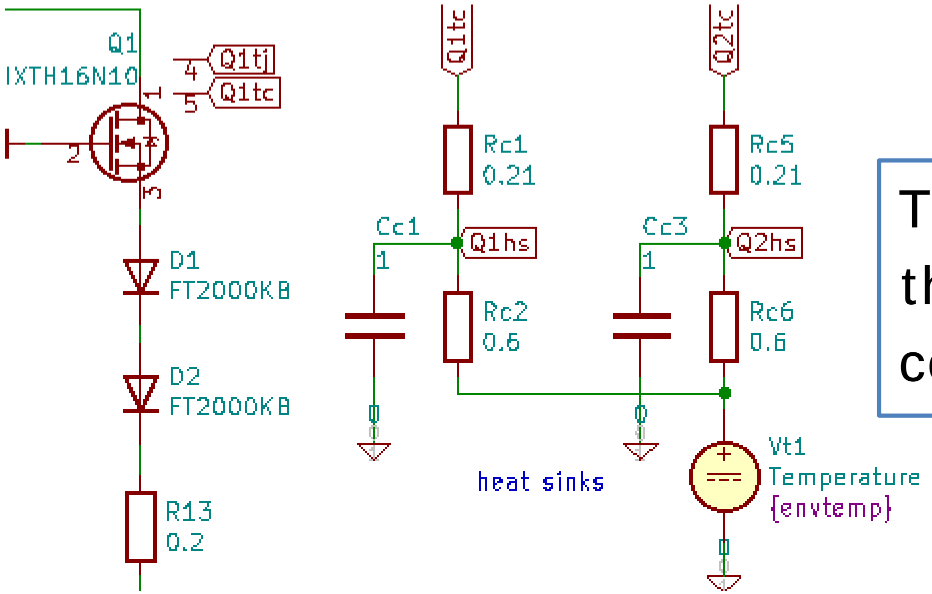
Make use of the equivalence of electronic and thermal properties (circuits).

Translate thermal to electrical circuits, run both circuit parts in ngspice

Feedback loop: Electrical power dissipation generates heat, restricted heat flow raises temperature, temperature changes power disspation.

# Thermal modeling example

*Excerpt from the previously shown power amp*

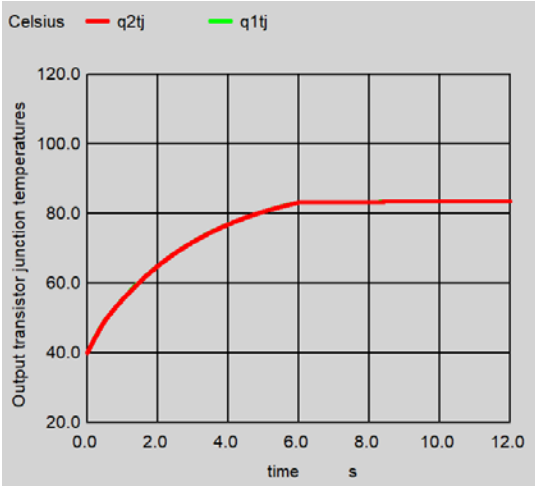



Thermal circuit for heat sink:
thermal resistances, capacitances,
connected to transistor case

Power transistor with 5 terminals
- Electrical: D, G, S
- Thermal: Junction temp, case temp.

VDMOS model with self-heating [5]

*The transistor temperature rises over time*



# Thermal runaway modeling

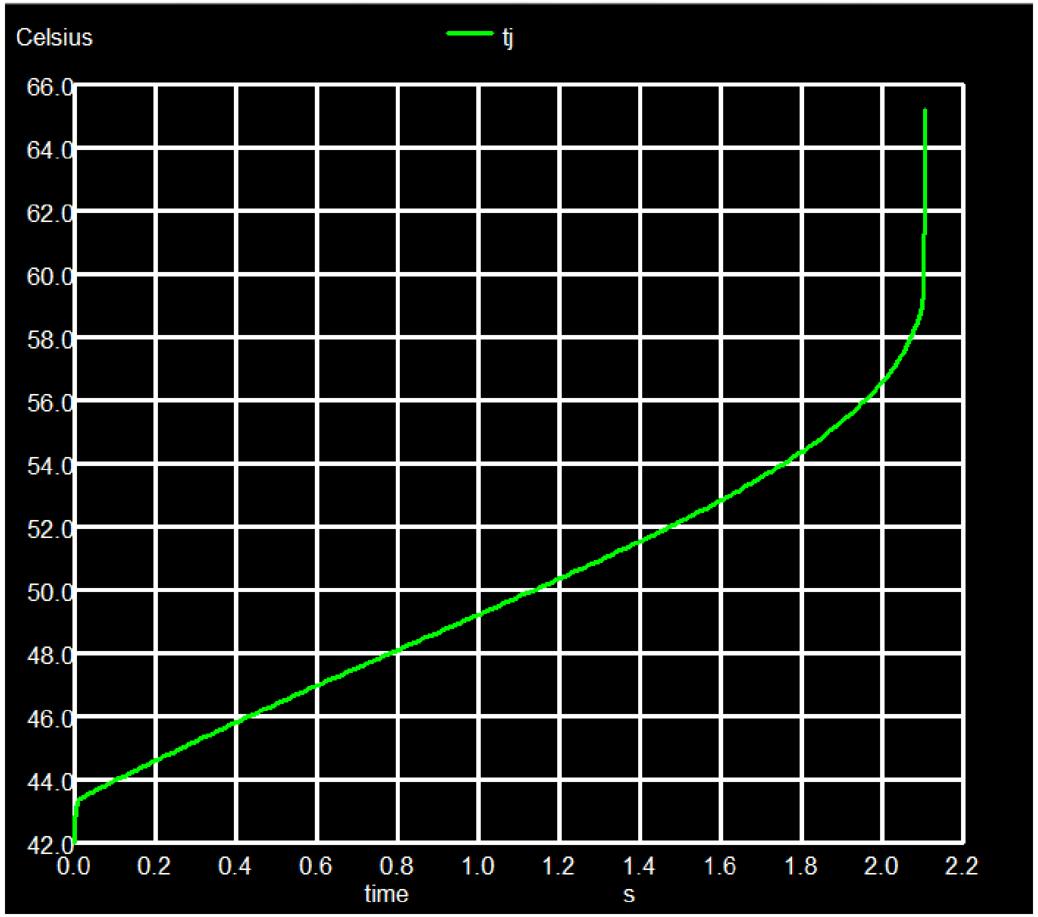
Resistor with negative temperature coefficient

1 Ω, 1 V, -0.03 Ω/K

Transient simulation: After some time the temperature rises beyond bounds

=> thermal runaway

device destruction



# HICUM

Ultra-high speed silicon circuits for RADAR etc. apply SiGe bipolar transistors.

HICUM: Proven high speed bipolar model [1].

Project: Add HICUM 2.4 to ngspice [9]

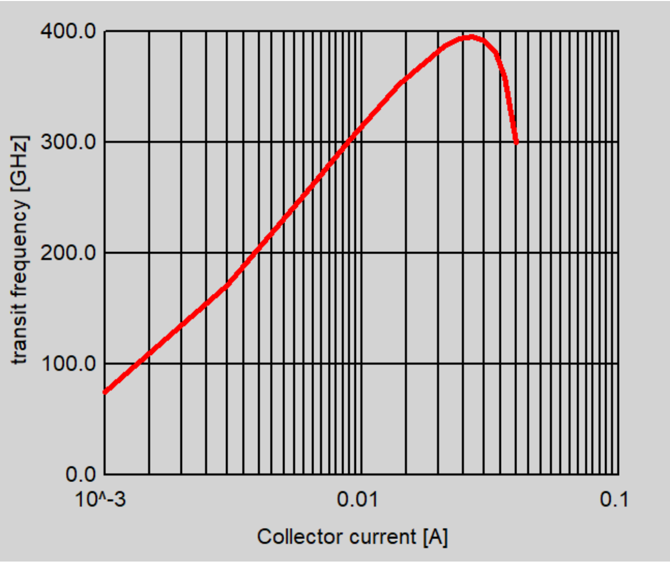
Implementation directly into the C-code ngspice model interface.

Use advanced math (Dual Numbers) for efficient calculation of derivatives.

# HICUM bipolar model overview

- Physics based, geometry scalable and large signal BJT/HBT model [1].
- Includes most to all relevant physical effects present in todays integrated BJTs:
  - Separate peripheral and internal elements for correct scaling and bias dependency
  - Self-Heating
  - Avalanche current model until BVCB0
  - Current dependent internal base resistance
  - Substrate transistor
  - Noise
- Model is CMC standard for SiGe BJT [2] and is used in industry PDKs.
- Applied and verified until 600 GHz.

*Bjt with ft 400 GHz*



# HICUM implementation uses Dual Numbers

- Dual numbers are numbers with a own algebra similar to complex numbers.
- A dual number has a real part and a dual part. The dual part is indicated by $\epsilon$.
- Dual numbers are available in C++ [4]
- The dual numbers can be used to calculate derivatives of complicated functions without having to write them out [3] $(df(x)/dx = Dual(f(x+\epsilon)))$.
- The accuracy is equal to the analytical derivative, this is an advantage compared to the already known finite difference quotients.

For example:

$$f(x) = 4x^2$$

$$f(2+\epsilon) = 16 + \underbrace{16}_{df(2)/dx}\epsilon$$

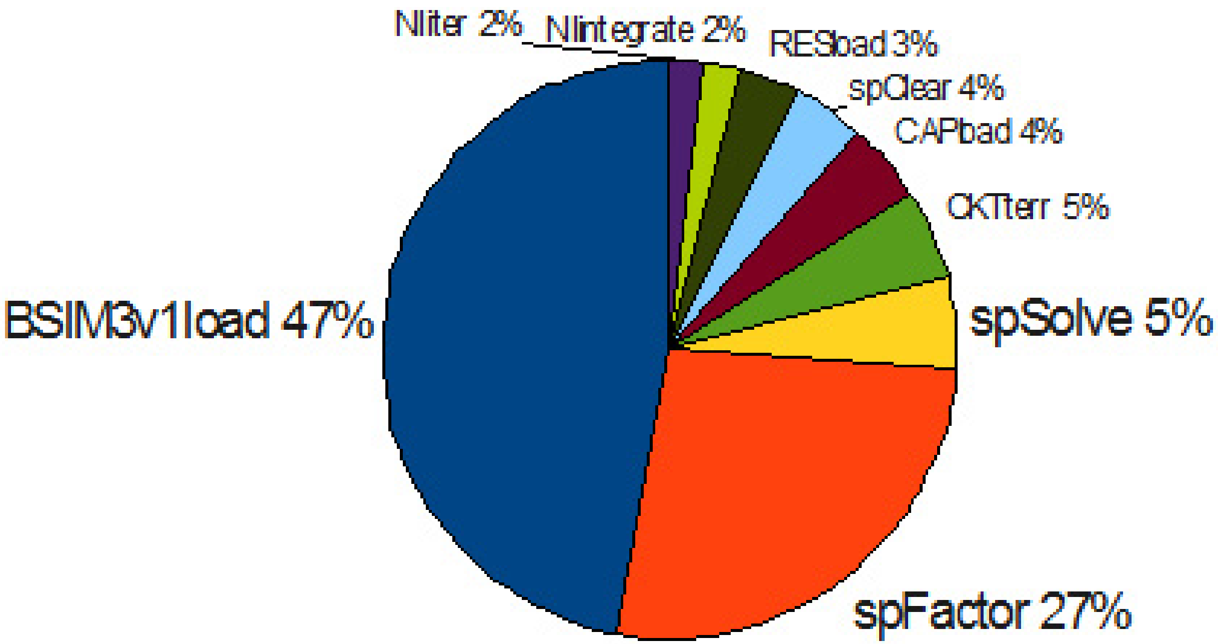
# Verilog A

**Requirement:** make modern device models written in Verilog A efficiently available to ngspice

**Status:** currently available ADMS interface is incomplete, buggy and not very well documented

**Activity:** Create a compiler reading Verilog A device models and making them available to ngspice [10]

# Simulator speed enhancements




Analysis of CPU load for digital circuit with back annotation [6]

**CPU time usage:**

~ 50% for device equations

~ 50% for solving matrix

**Developments already done:**

- OpenMP for device equations
- KLU for solving the matrix

**Research:**

SIMD for device equations

# KLU

- Alternative matrix solver [7]
- KLU or Sparse 1.3 selected by option statement
- Faster device setup with KLU
- Faster matrix solver for large circuits

Will be available with ngspice-33

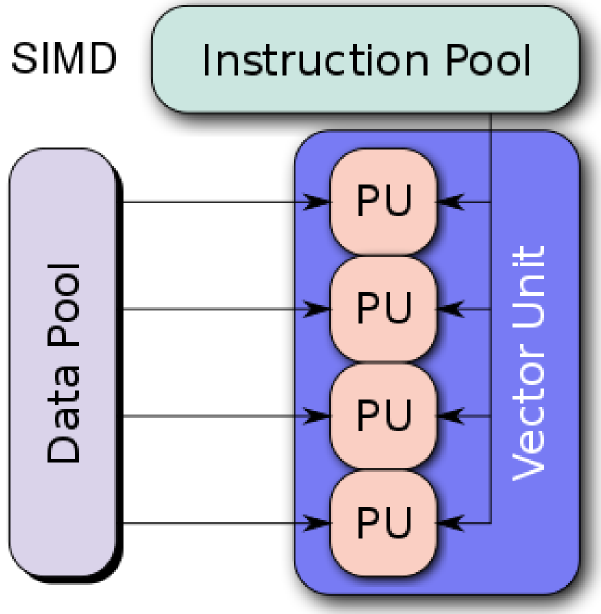
Result on circuit with 15k transistors (34k resistors, 48k capacitors)

i9 9600 8 cores, OpenMP enabled

Speed-up KLU versus Sparse by factor of 4 (transistors only)

Speed-up by factor of 3
(incl. back annotated RC parasitics)

# SIMD




wikipedia

Exploit the capability of modern computer hardware and compilers for single instruction, multiple data (SSE, AVX2 ...).

Goal for ngspice: Speed-up the device equation evaluation by parallel processing on a single core.

# SIMD

Procedure to establish SIMD:

- Replace doubles by vectors of doubles.
- Replace all math functions by their vector equivalents (using e.g. AVX2 intrinsics).
- Gather data to evaluating them in parallel.
- Scatter them back to the individual devices.

Preliminary results [8]:

Speed-up may be a factor of **3**.

Depends on environment (OS, compiler, machine).

Tools may still be buggy.

HW and SW portability issues.

# ngspice summary

ngspice is a well established, proven simulator for discrete and integrated electronics.

It has been adopted by several PCB design tool makers.

Active development is going on towards models (HICUM), speed (KLU, SIMD), interfacing (Verilog A), and usability (thermal simulation, wave audio, etc.).

ngspice-33 is scheduled for October/November 2020

# References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[2] https://si2.org/standard-models/ .

[3] https://en.wikipedia.org/wiki/Dual_number#Differentiation .

[4] https://tesch1.gitlab.io/cppduals/ .

[5] D. Warning, H. Vogt, ngspice-32 manual, chapter 11.3, 2020, http://ngspice.sourceforge.net/docs/ngspice-32-manual.pdf .

[6] F. Lannutti, P. Nenzi, M. Olivieri, KLU Sparse Direct Linear Solver Implementation into NGSPICE, MIXDES 2012, 19th International Conference "Mixed Design of Integrated Circuits and Systems", May 24-26, 2012, Warsaw, Poland

[7] F. Lannutti, private communication, 2020, https://sourceforge.net/p/ngspice/ngspice/ci/klu2rebase/tree/

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[9] D. Warning, M. Müller and M. Krattenmacher, private communication, https://sourceforge.net/p/ngspice/ngspice/ci/hicum_vae/tree/, https://sourceforge.net/p/ngspice/ngspice/ci/hicum2-mario/tree/

[10] F. Lannutti, P. Kuthe, private communication, 2020