Advanced Simulations

Prof. Dr. P. Fischer

Lehrstuhl für Schaltungstechnik und Simulation
Technische Informatik der Uni Heidelberg

What we know so far

- DC Simulation
  - Determine gm, rds, …
  - Find operation points, dynamic range,…
- Transient Simulation
  - Functionality
  - Risetimes
  - Large Signal behaviour
- AC Simulation
  - Good to assess bandwidth / speed as function of parameters (results can be better extracted than in transient)
  - Faster simulation
  - Only for small subcircuits
- Mixed Mode
  - Digital blocks are described easier / sim runs faster

Furthers Simulation Tools

- Parameters, Simulation Settings
- Waveform Calculator

- AC Noise
- Transient Noise

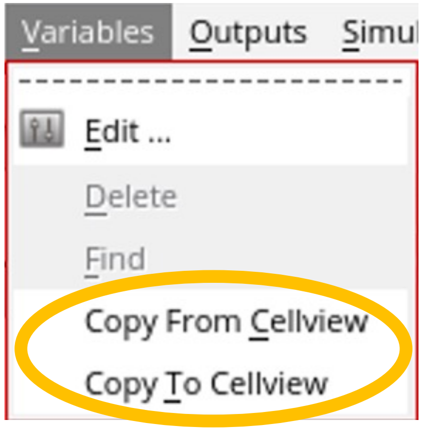
- Corner Simulation
- Monte Carlo Simulation

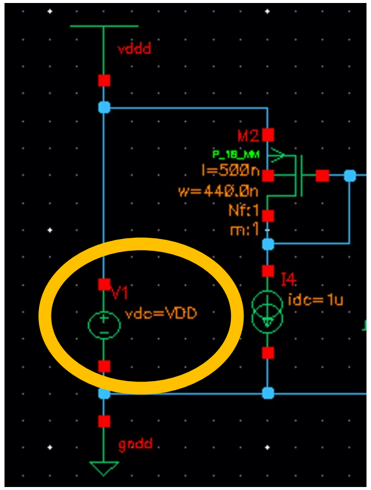
- Extracted Simulation

- Scripted Simulations with Ocean

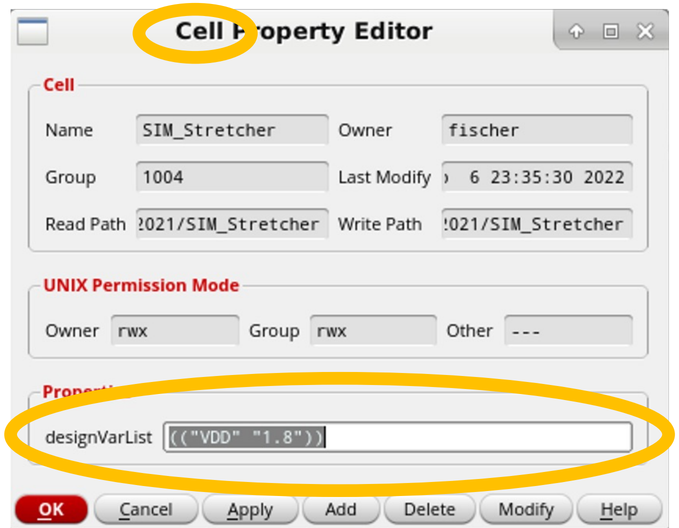
Parameters

- If parameters are used in a schematic, they can be pulled to the simulator with Variables->Copy From Cellview
- Write them back to cell with Variables->Copy To Cellview





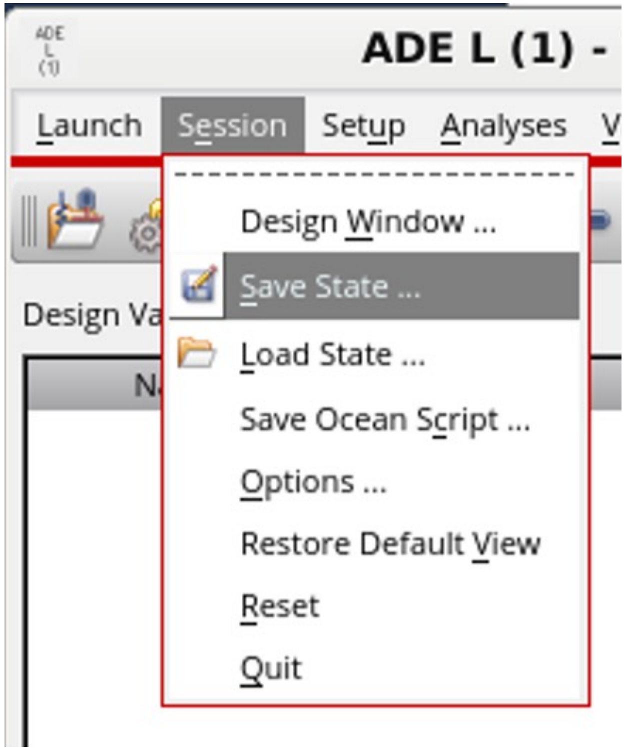
- If you do not use a parameter in the schematic any more, it is still stored and shows up when you get the parameters.
  - Delete it is the simulation window and write back to schematic

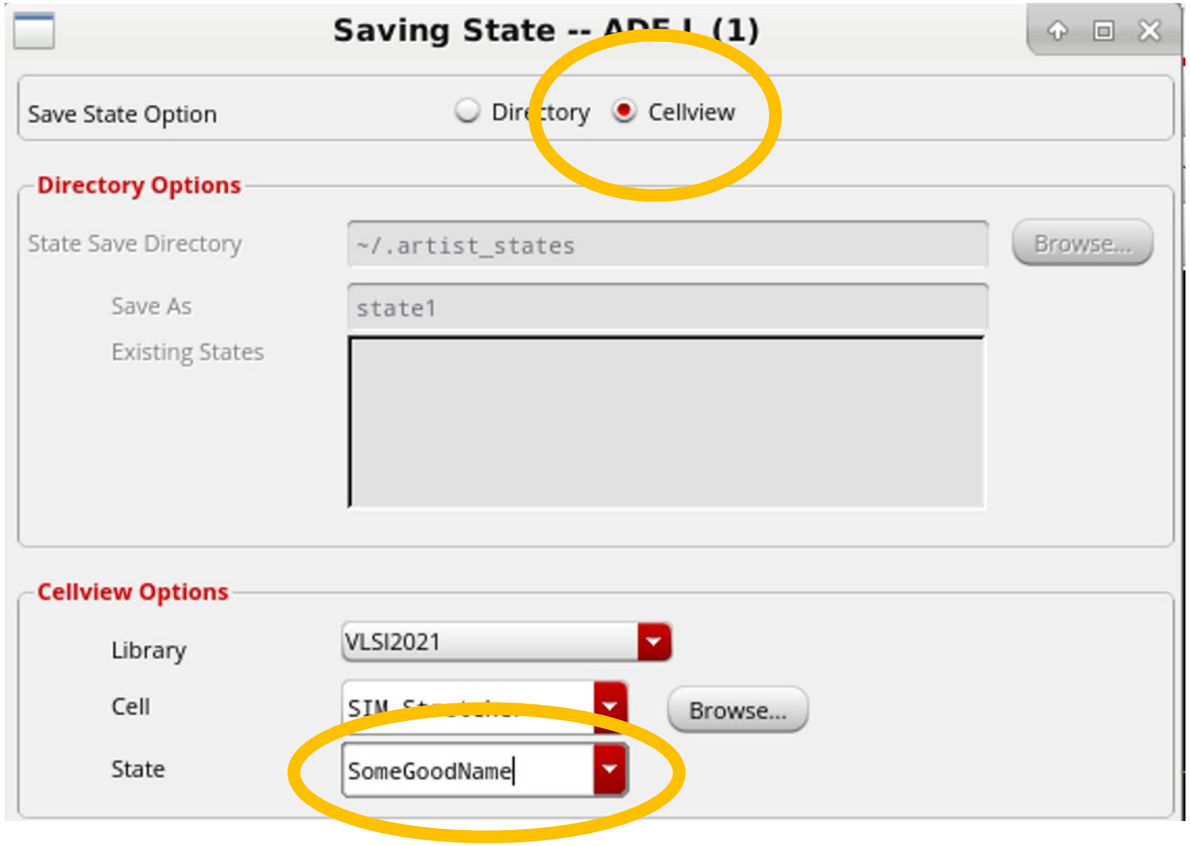


- Parameters are stored in the *cell*, not in a view (i.e. they are shared between views).
  - They can be seen in the library manager as properties of the cell (right click cell -> Properties)

Simulation Settings

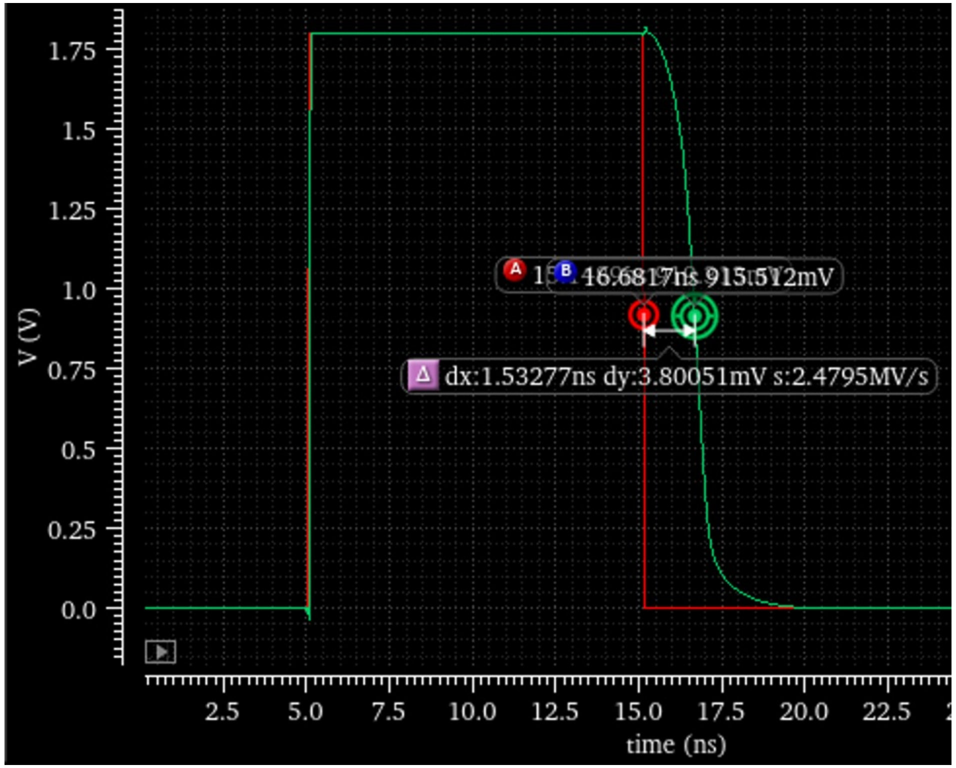
- Can be saved with Session->Save State
- Best save to *Cellview* with a clear name





Waveform Viewer

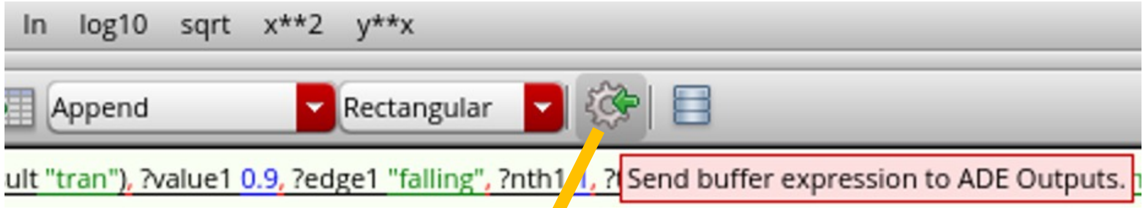
- Cursor
  - “a” -> create cursor at position
  - “b” -> differences are shown



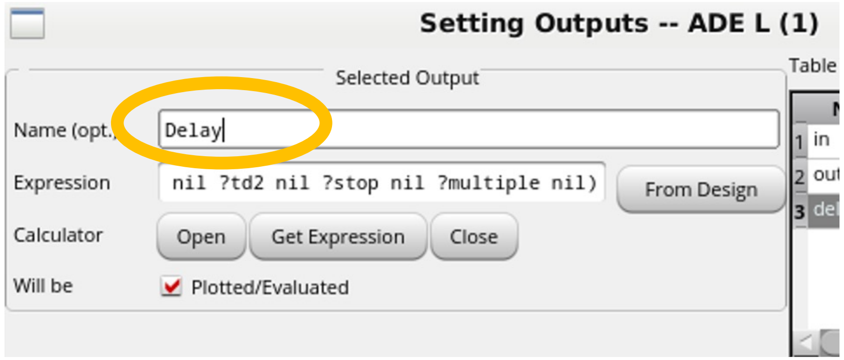
  - “v” creates a cursor with a vertical line
  - “m” adds an arbitrary number of markers

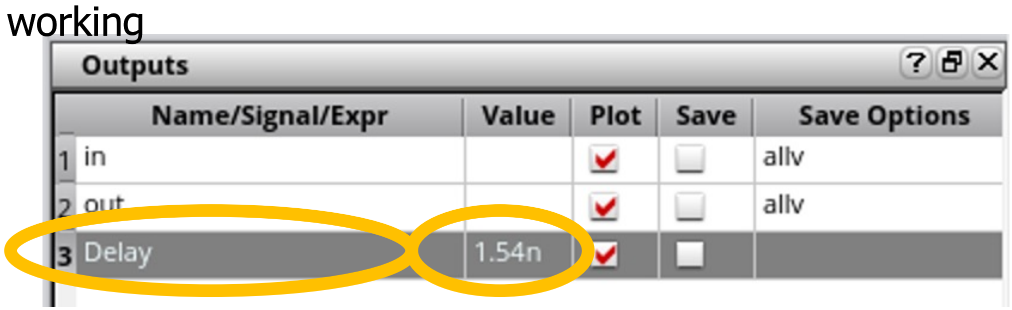
Waveform Calculator

- Can be used to analyse waveforms
  - Click on wave
  - open calculator



  - Fix expression (e.g. derivative)
  - Best send to ADE (button), so that it is conserved
  - Assign a useful name in ADE

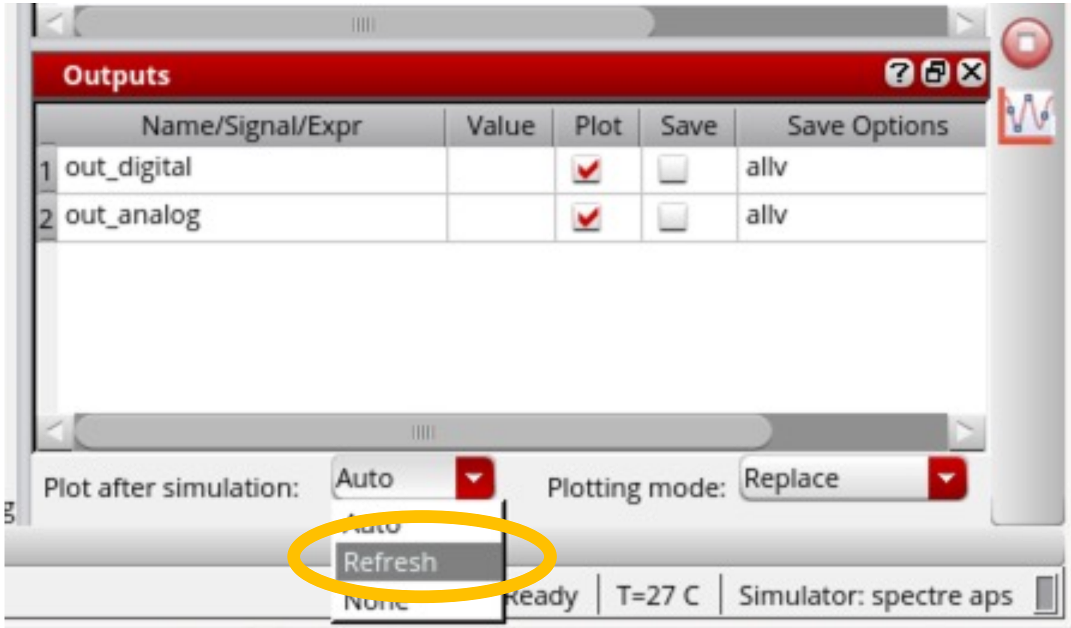




- NB: simulation variables can be accessed with
  - pv("/**name**" "value" ?result "variables") or VAR(“name”)
- Calculated expressions can be referred to just by the name

Keeping Display Order

- In the normal setting, all traces are re-drawn after a new simulation. A hand-made ordering (into sub-windows etc. gets lost
- This can be avioded by setting
- PlottingMode to ‚Refresh'



RUPRECHT-KARLS-
UNIVERSITÄT
HEIDELBERG

FURTHER SIMULATION TYPES

AC Noise

- In this simulation type, the components generate noise voltages and currents (as function of frequency)
- The 'output signal' then also has noise, coming from various sources in the circuit
  - Total noise is calculated by integration over all frequencies.
- Details:
  - The (spectral) noise density depends on the components
  - It takes 'text book' values e.g. for resistors, these can be overridden
  - Components can be made 'noiseless' so that the effect of individual components can be studied
  - MOS devices need a noise model, which contains in particular the frequency dependent 1/f noise
    - Models are often unreliable….
    - Dependencies on component parameters (L) often wrong.

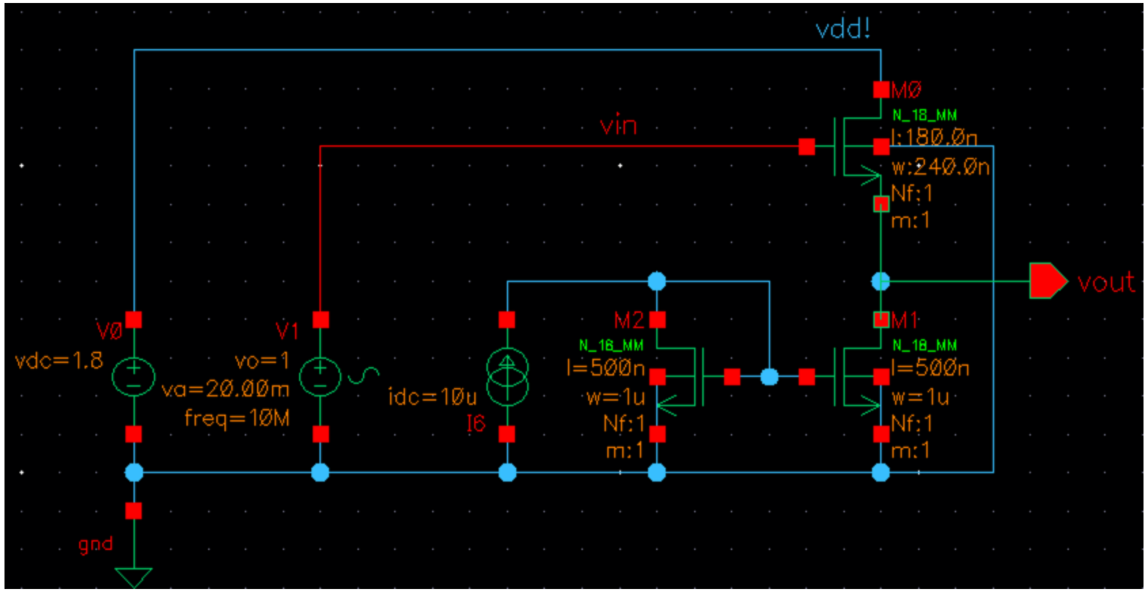
Transient Noise

- AC Noise simulation has drawbacks:
  - It is ‘abstract’ – needs clear understanding of what ‘AC’ is..
  - Needs careful analysis (integration)
  - It’s **small signal** simulation. Large signal circuits (e.g. comparators) are hard to simulate

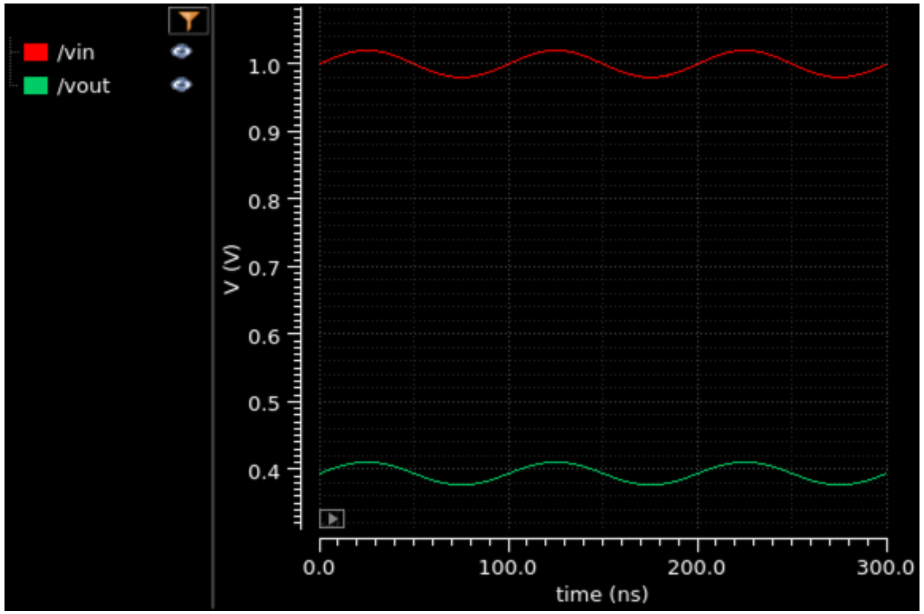
- Noise can also be generated in the time domain -> transient Noise analysis
  - ‘Easy to use’ (but noise sources must again be set up correctly!)
  - ‘direct result’
  - Very slow, because time steps must be very small to take into account high frequency noise.
    - Simulators can do no ‘tricks’ to increase time steps because all signals change all the time (from their noise…)

Transient Noise: Example

- Consider a source Follower:

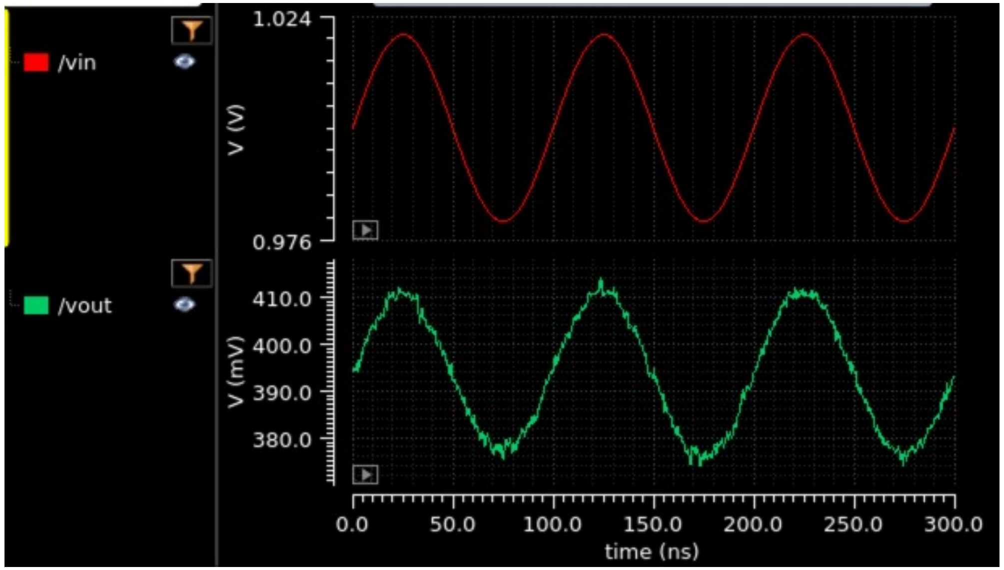


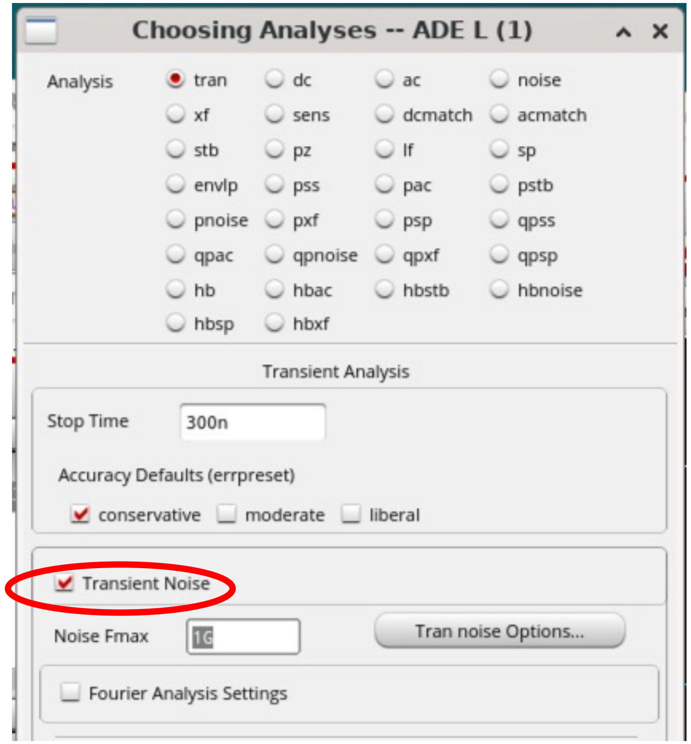
- Transient (noiseless):



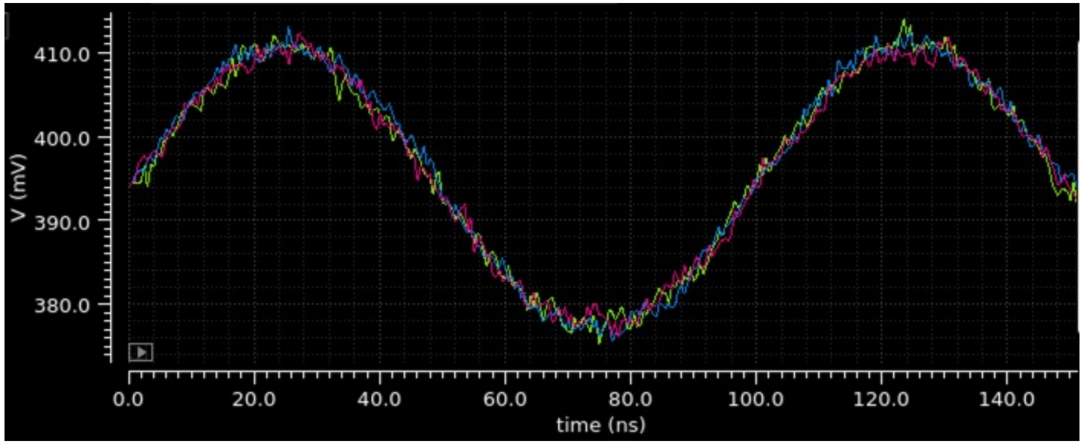
Transient Noise: Example

- Transient simulation with noise:
- Result:



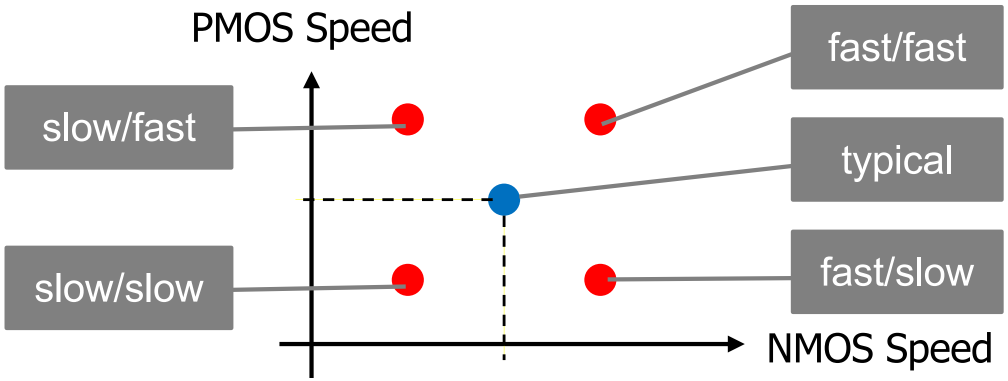


- Every Run is different ! :



Corner Simulation

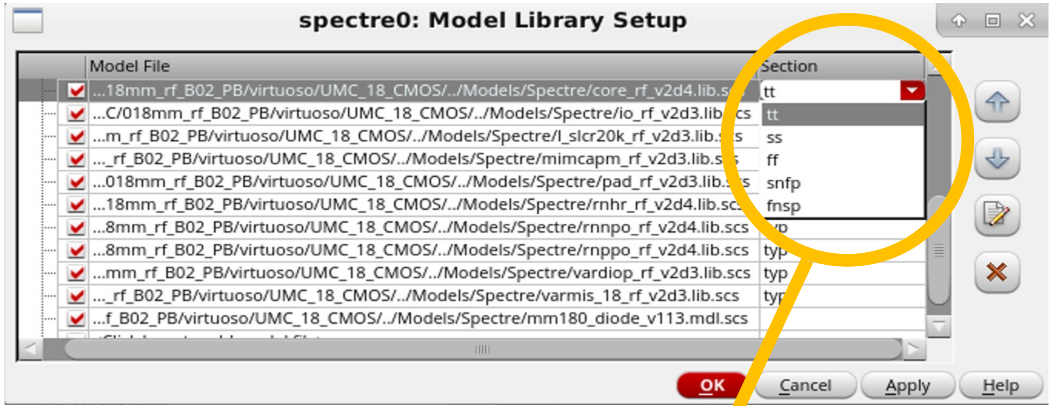
- The provided component models from the fab are for an *average* production, called a '*typical*' run.
- A production run can *systematically* deviate from 'typical' and devices behave differently. Such a run can still be 'in specs' because the vendor does not promise exact values for all parameters but ranges
  - e.g.: V_{Th} is typically 0.5 V, but can range from 0.4 … 0.6 V
- Most vendors provide additional sets of model files for such 'corner' runs (i.e. runs which are 'just ok')
  - Most critical components are NMOS and PMOS
  - Models are often
    tt – typial
    ss – slow/slow
    sf – slow/fast
    …



RUPRECHT-KARLS-
UNIVERSITÄT
HEIDELBERG

Corner Simulation

- You should simulate all 5 cases!
- ff gives '*highest speed*', but *maximal power* consumption!
  - (fast: devices with lower threshold, higher K-factor, higher supply,..)
- ss gives *critical speed* of design
- sf and fs have large asymmetries between NMOS and PMOS and can be *dangerous*!
  - e.g.: Can a SRAM cell still be written if NMOS is weak and PMOS is strong?



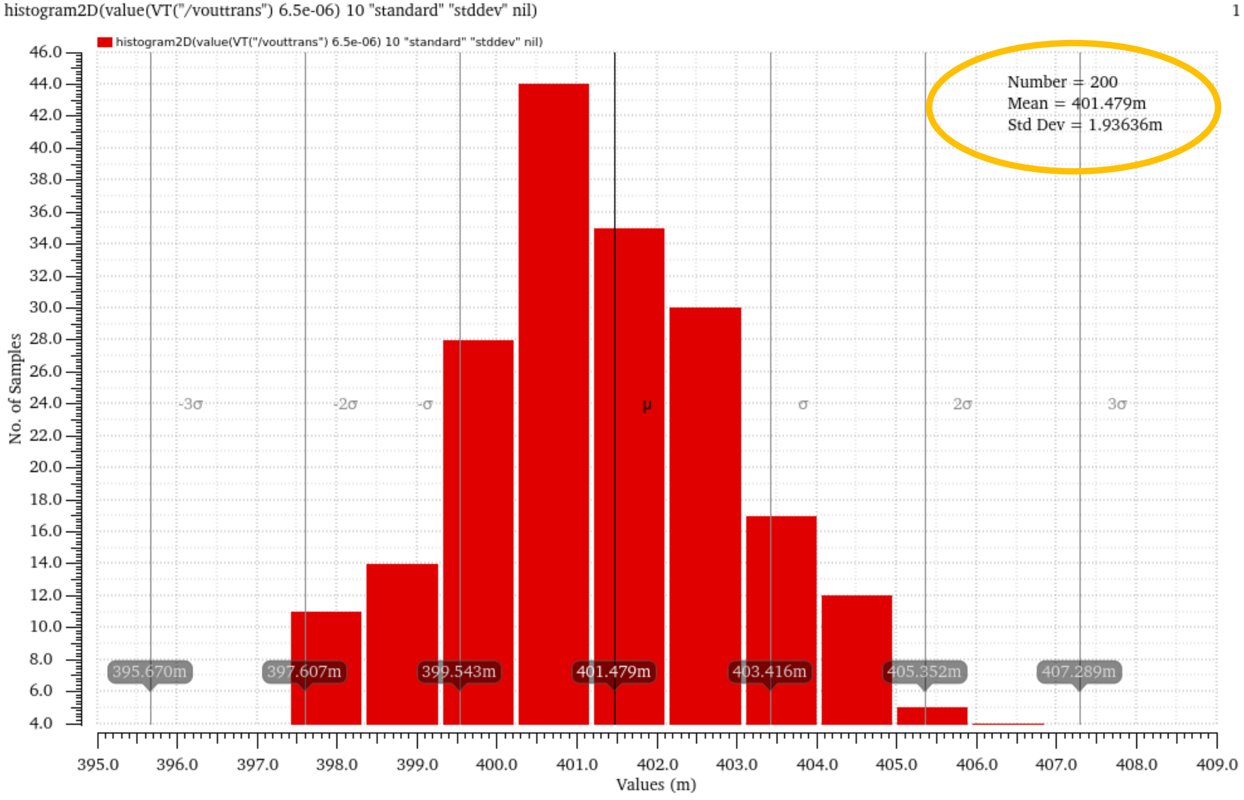
- Technically
  - Sometimes, must change model files
  - Sometimes, ONE model file has several '***sections***'
- It can be impossible or tricky to 'loop' over all 5 models to see all results in one parametric plot….

Monte Carlo Simulation

- Different (identically sized) devices on a chip are not ***exactly*** the same in reality.
- Small variations between 'identical' devices may be a problem, e.g.
  - Input offset voltage of amplifiers
  - Nonlinearity in segmented DACs
- In a 'Monte Carlo' Simulation, the parameters of ***each device in the circuit*** are varied a bit (randomly)
- By running many simulations (with new variations), the sensitivity of the circuit can be quantified.
- This needs information about the 'real' variation of all parameters, for instance average value and standard dev.
  - Quality of these parameters sometimes not clear…

Monte Carlo Simulation

- Result of a Monte Carlo Run is a ‘probability’ distribution of a certain parameter, for instance
  - DC input level of an amplifier
  - Voltage output of a voltage reference
  - Threshold of a comparator



Parasitic (Extracted) Simulation

- The interconnections in schematics are idealised.
  - MOS caps and Source/Drain diode caps are taken into account for by models!
  - (Best immediately think at ‘other cells’ that will be connected to a signal later!..)

- In reality, traces have R and C
  - This will affect (slow down) the circuit and produce crosstalk
- ‘Parasitic’ Rs and Cs are only known when layout is done.
- They can be extracted with suited tools -> ‘extracted netlist’
- This netlist can be used in simulation instead of the ideal netlist to get ‘real’ behaviour.

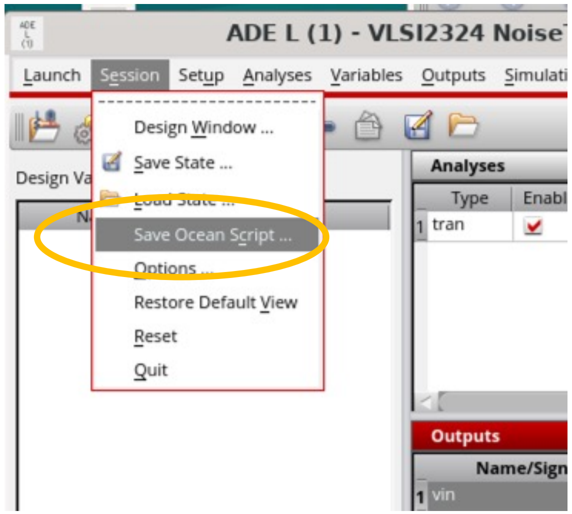
- Advice: Try to anticipate long traces and put them as extra caps in the simulation schematic right away!

Scripted Simulations with Ocean - Cool & Easy!

- Repetitive simulations can be scripted using ‘oceanscript’
- These are basically SKILL commands controlling spectre
- Start with an ADE simulation. Then export that simulation to an ocean script (.oce) from ADE->Session->Save Ocean…

```
simulator( 'spectre )
design("/tmp/ADE-Sim-
fischer/NoiseTran/spectre/schematic/netlist/netlist")
resultsDir("/tmp/ADE-Sim-fischer/NoiseTran/spectre/schematic" )
modelFile(
    '("somefile.scs" "tt") ; "tt" is the corner section typical/typical
    ; include here some more files
)
analysis('tran ?stop "300n"  ?tranNoise "Transient Noise"  ... more
parameters ...)
envOption('autoDisplay  nil 'analysisOrder  list("tran") )
saveOption( ?outputParamInfo t )  ; some options…
temp( 27 )

run()
selectResult( 'tran )
plot(getData("/vout") )
```



- Edit the skill file as you need.
- Run its from the CIW with (load “file.ocn”)
- Note: netlist must exist!

Ocean Example

- Vary dc offset of source follower (p.11) input and measure output amplitude
- Minimalistic file, writing some data to 'Results.txt'

```
simulator( 'spectre )
design("/tmp/ADE-Sim-fischer/NoiseTran/spectre/schematic/netlist/netlist") ; This netlist must exist!
resultsDir("/tmp/ADE-Sim-fischer/NoiseTran/spectre/schematic")            ; (create it by running ADE)
modelFile(
'("/opt/eda/UMC/018mm_rf_B02_PB/virtuoso/Models/Spectre/mm180_reg18_v124.lib.scs" "tt")
)
analysis('tran ?stop "300n"  )
envOption('autoDisplay  nil 'analysisOrder  list("tran") )
temp( 27 )
                                                       ; Self-made SKILL code starts here
p = outfile("Result.txt" "w")                          ; open a file for writing
(foreach os (list 0.1 0.2 0.5 0.5 0.6 0.8 1 1.2 1.6)   ; pick some offset values (here from a list)
  desVar("VOFFSET" os)                                   ; assign them to design variable
  run()                                                ; run  the simulation
  selectResult( 'tran )                                ; get the result
  (fprintf p "Offset = %5.3f, Amplitude = %5.3f\n"     ; write to file: offset
    (float os) peakToPeak(v("/vout" ?result "tran-tran")) ; and peakToPeak amplitude (from calculator)
  )                                                    ; end of (fprintf …)
)
(close p)
```

-> File Result.txt:

```
File  Edit  View  Terminal  Tabs  Help
Offset = 0.100, Amplitude = 0.000
Offset = 0.200, Amplitude = 0.000
Offset = 0.500, Amplitude = 0.015
Offset = 0.500, Amplitude = 0.015
Offset = 0.600, Amplitude = 0.022
Offset = 0.800, Amplitude = 0.032
Offset = 1.000, Amplitude = 0.034
Offset = 1.200, Amplitude = 0.034
Offset = 1.600, Amplitude = 0.034
```

NMOS Source Follower does not work for low input amplitudes

Gain <1
(Input amplitude is 40 mV_{pp})