وَمَا أُوتِيتُم مِّنَ الْعِلْمِ إِلَّا قَلِيلًا

Analog IC Design – Xschem/Ngspice and ADT
Lab 01
LPF Simulation and MOSFET Characteristics

Intended Learning Objectives

This lab is divided into two parts:

- In Part 1 you will
  - Get familiar with Xschem/Ngspice, and ADT IC design tools.
  - Learn the different types of simulations (transient, ac).
  - Learn how to run parametric sweeps.
- In Part 2 you will
  - Compare the behavior of PMOS and NMOS transistors.
  - Compare the behavior of short-channel and long-channel MOSFETs.

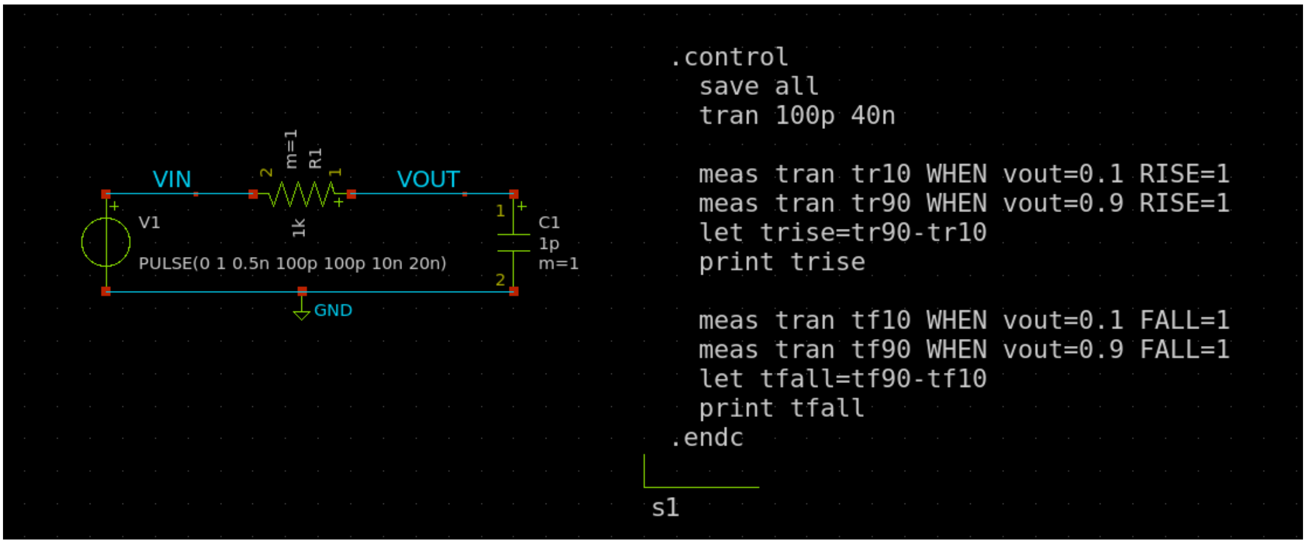
PART 1: Low Pass Filter Simulation (LPF)

1. Transient Analysis

1) Design a first order low pass filter that has $R = 1k\Omega$ and 1ns time constant.
2) Apply a square wave input with $T_{high} = Pulse\ Width = 10ns$, $T_{clk} = Period = 20ns$, and $T_{rise} = T_{fall} = 100ps$.
3) Report transient analysis results for two periods.
4) Calculate rise and fall time (10% to 90%).
5) Compare simulation with analytical results in a table.
6) Do parametric sweep for $R = 1:1:5k\Omega$. Report overlaid results. Comment on the results.

Solution Steps:

1) Create a new work directory.
2) Create the schematic of the low pass filter as shown below
   - Use shift+I to insert symbols
   - Use search bar to search for “res” (resistor), “capa” (Capacitor), and vsource (Voltage Source).
   - Use “Shift+R” to rotate symbols
   - To edit the properties of a symbol: select the symbol then press ‘Q’
   - Use “Alt+L” to label the wires
   - To create a pulse, change the “vsource” value to “PULSE(0 1 0.5n 100p 100p 10n 20n)”, refer to section 4.1.1 in ngspice manual for more details.



3) Run Simulations

- Press “Simulation”, then “configure simulators and tools”, make sure **“ngspice batch”** is selected.
- Insert “code_shown”, change its value to the following code:

```
.control
 save all
 tran 100p 40n

 meas tran tr10 WHEN vout=0.1 RISE=1
 meas tran tr90 WHEN vout=0.9 RISE=1
 let trise=tr90-tr10
 print trise

 meas tran tf10 WHEN vout=0.1 FALL=1
 meas tran tf90 WHEN vout=0.9 FALL=1
 let tfall=tf90-tf10
 print tfall
.endc
```

- Press “netlist” on the top right.
- Press “Simulate”.

4) Plot Results

- Press “Simulation” then “Add waveform graph”.
- Press “Simulation” again then “Add waveform reload launcher”.
- Press “ctrl” and “the green left arrow” to load the results.
- Double click on the waveform, choose the outputs to plot, then press add.

Calculate rise and fall time (10% to 90%).

- change simulator to interactive
- Using “meas” Command (included in the previous code)

Use the following code for parametric sweep:

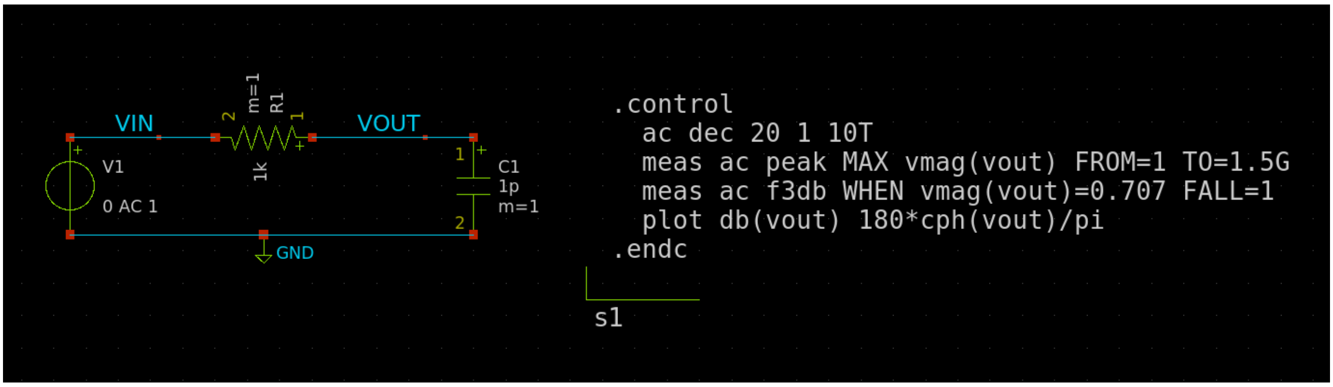
```
.control
 save all
 let Rstart=1k
 let Rstop=5k
 let Rstep=1k
 let Ract=1k
 while Ract le Rstop
  alter  R1 Ract
  tran 100p 40n
  meas tran tr10 WHEN vout=0.1 RISE=1
  meas tran tr90 WHEN vout=0.9 RISE=1
  let trise=tr90-tr10
  print trise
 let Ract=Ract+Rstep
 reset
 set appendwrite
 write RC_CKT.raw
end
plot tran1.v(vout) tran2.v(vout) tran3.v(vout)
tran4.v(vout) tran5.v(vout)
.endc
```

2. AC Analysis

1) Report Bode Plot (magnitude and phase) for the previous LPF.
2) Calculate DC gain and 3dB bandwidth.
3) Compare simulation with analytical results in a table.
4) Do parametric sweep for $R = 1{,}10{,}100{,}1000 k\Omega$. Report overlaid results. Comment on the results.

Solution Steps:

1) Change the Vsource value to “0 AC 1”
2) Change the simulator to be interactive
3) Netlist + Simulate
4) Calculate DC gain and 3 dB bandwidth using the code shown in schematic, results can be found in terminal.



5) Use “plot db(vout) 180*cph(vout)/pi” in the command to report the bodeplot.

```
.control
  save all
  ac dec 20 1 10T
  meas ac peak MAX vmag(vout) FROM=1 TO=1.5G
  meas ac f3db WHEN vmag(vout)=0.707 FALL=1
  plot db(vout) 180*cph(vout)/pi
.endc
```

6) Use the following code to perform parametric sweep:

```
.control
save all
let Rstart=1k
let Rstop=1000k
let Rstep=10
let Ract=1k

while Ract le Rstop
  alter R1 Ract
  ac dec 20 1 10T
  meas ac peak MAX vmag(vout) FROM=1 TO=1.5G
  meas ac f3db WHEN vmag(vout)=0.707 FALL=1
  let Ract=Ract*Rstep
  reset
  set appendwrite
  write RC_CKT.raw
end

let BP1=ac1.v(vout)
let BP2=ac2.v(vout)
let BP3=ac3.v(vout)
let BP4=ac4.v(vout)

plot db(BP1) db(BP2) db(BP3) db(BP4)
.endc
```

Part 2: MOSFET Characteristics

1. ID vs VGS

1) Plot $I_D - V_{GS}$ characteristics for NMOS and PMOS devices. Set $V_{DS} = V_{DD}$, and $V_{GS} = 0{:}\,10m{:}\,V_{DD}$. Use $V_{DD} = 1.2V$ for 130nm technology and $V_{DD} = 1.8V$ for 180nm technology. Plot the results overlaid for the following:
   - Short channel device: $W = 1\mu m$ and $L = 200nm$
   - Long channel device: $W = 10\mu m$ and $L = 2\mu m$. Hint: Set L as a parameter and set $W = 5 \times L$
2) Comment on the differences between short channel and long channel results.
   - Which one has higher current? Why?
   - Is the relation linear or quadratic? Why?
3) Comment on the differences between NMOS and PMOS.
   - Which one has higher current? Why?
   - What is the ratio between NMOS and PMOS currents at VGS = VDD?
   - Which one is more affected by short channel effects?

2. g_m vs VGS

1) Plot g_m vs V_{GS} for NMOS device. Set $V_{DS} = V_{DD}$, and $V_{GS} = 0{:}\,10m{:}\,V_{DD}$. Plot the results overlaid for the following:
   - Short channel device: $W = 1\mu m$ and $L = 200nm$
   - Long channel device: $W = 10\mu m$ and $L = 2\mu m$.
2) Comment on the differences between short channel and long channel results.
   - Does g_m increase linearly? Why?
   - Does g_m saturate? Why?

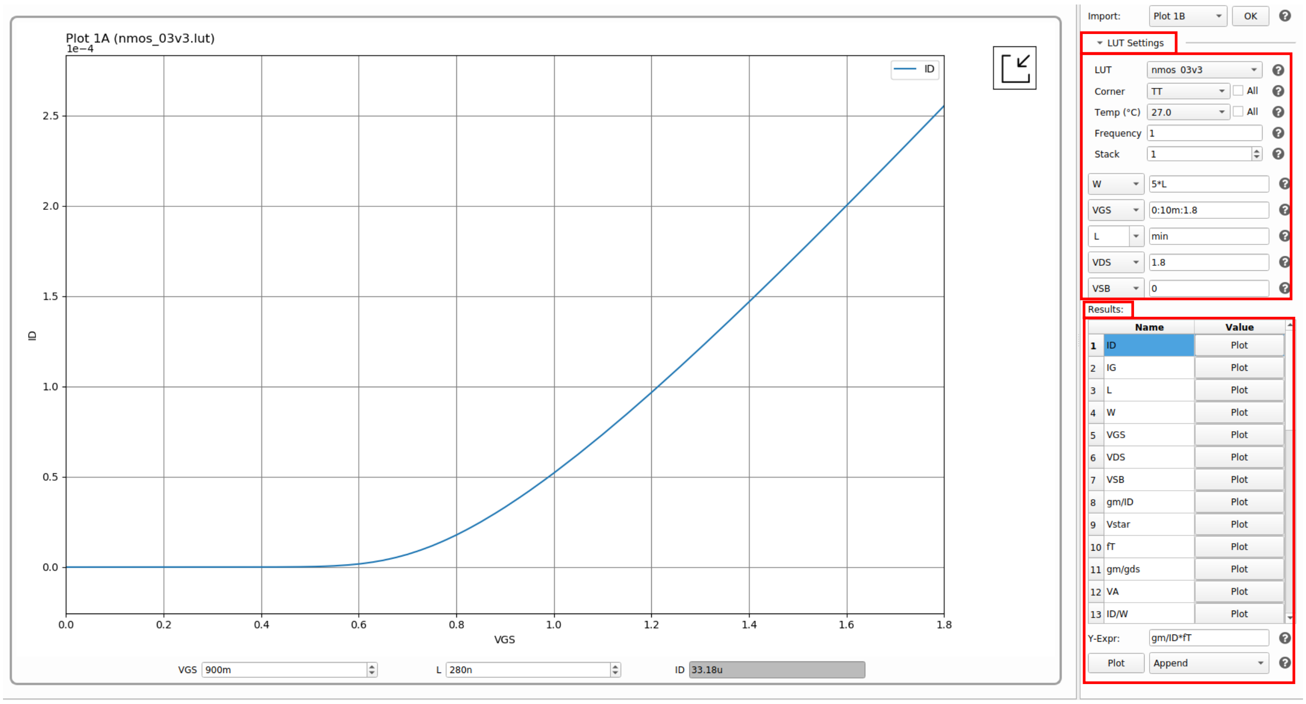
3. ID vs VDS

1) Plot $I_D - V_{DS}$ characteristics for NMOS device. Set $V_{DS} = 0{:}\,10m{:}\,V_{DD}$, and $V_{GS} = 0{:}\,0.2{:}\,V_{DD}$ (nested sweep). Plot the results overlaid for the following:
   - Short channel device: $W = 1\mu m$ and $L = 200nm$
   - Long channel device: $W = 10\mu m$ and $L = 2\mu m$.
2) Comment on the differences between short channel and long channel results.
   - Which one has higher current? Why?
   - Which one has higher slope in the saturation region? Why?

Solution Steps:

1) Open terminal in "home/tare/ADT_Working_Directory" folder
2) Type "./start_adt.sh" in the terminal to start ADT.
3) Load Luts from "home/tare/LUTs".
4) Open "Sizing Assistant" tap.
5) Edit "LUT settings" according to the required as shown on the right of the figure below.
6) Plot using the "Results" section choose appended if needed as shown in the figure.

ID vs VGS



Plot 1A (nmos_03v3.lut)
1e−4
ID
VGS
VGS 900m
L 280n
ID 33.18u
Import:
Plot 1B
OK
LUT Settings
LUT nmos_03v3
Corner TT
All
Temp (°C) 27.0
Frequency 1
Stack 1
W 5*L
VGS 0:10m:1.8
L min
VDS 1.8
VSB 0
Results:
Name
Value
1 ID Plot
2 IG Plot
3 L Plot
4 W Plot
5 VGS Plot
6 VDS Plot
7 VSB Plot
8 gm/ID Plot
9 Vstar Plot
10 fT Plot
11 gm/gds Plot
12 VA Plot
13 ID/W Plot
Y-Expr: gm/ID*fT
Plot
Append

Lab Summary

- In Part 1 you learned
  - How to run transient simulations.
  - How to run ac-analysis simulations.
  - How to run parametric sweeps.
- In Part 2 you learned
  - How to plot the transistors I/V characteristics using DC analysis.
  - How to plot the transistors I/V characteristics using parametric sweeps.
  - The difference in transistor characteristics between an NMOS and a PMOS transistor.
  - The difference in transistor characteristics between a short-channel and a long-channel MOSFET.
  - How the gm of the transistor behaves vs VGS.