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وَمَا أُوتِيتُم مِّنَ الْعِلْمِ إِلَّا قَلِيلًا

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Analog IC Design (Xschem, Ngspice, 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 the design and simulation tools: Xschem and Ngspice.
  - Learn how to run transient and ac simulations.
  - Learn how to run parametric sweeps.
- In Part 2 you will
  - Learn the difference between dc sweep and parametric sweep.
  - Compare the behavior of PMOS and NMOS transistors.
  - Compare the behavior of short-channel and long-channel MOSFETs.
  - Get familiar with ADT.

Useful Resources

- ITI Analog IC Design Labs tutorial videos
- Xschem manual: http://repo.hu/projects/xschem/xschem_man/xschem_man.html
- Ngspice manual: https://ngspice.sourceforge.io/docs/ngspice-html-manual/manual.xhtml

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 $V1 = 0, V2 = 1, Delay\ (TD) = 5ns, Pulse\ Width\ (PW) = 10ns, Period\ (PER) = 20ns$, and $T_{rise}\ (TR) = T_{fall}\ (TF) = \frac{PW}{100} = 100ps.$

➔ Hint: Ngspice pulse source format:

```
PULSE(V1 V2 TD TR TF PW PER NP)
```

3) Report transient analysis results for two periods (use max time step $= Period/100$).

➔ Hint: Ngspice command to run transient analysis:

```
.tran tstep tstop
```

4) Calculate rise and fall time (10% to 90%) using measure command. Export the results to an output text file.

➔ Hint: Measure command example:

```
.meas tran t_rise TRIG v(vout) VAL=0.1 RISE=1 TARG v(vout) VAL=0.9 RISE=1
```

5) Derive an analytical expression for the rise and fall times as a function of the RC time constant. 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.

➔ Hint: This is an example of a control section for transient analysis parametric sweep. Modify it as needed.

```
.control

save all

let R_val = 100
let R_stop = 300
let R_step = 100

while R_val le R_stop
  alter R1 R_val
  tran 100p 4n
  meas tran t_rise TRIG v(vout) VAL=0.1 RISE=1 TARG v(vout) VAL=0.9
RISE=1
  print R_val t_rise >> tran_result.txt
  write rc_ckt.raw
  set appendwrite
  let R_val = R_val + R_step
end

.endc
```

2. AC Analysis

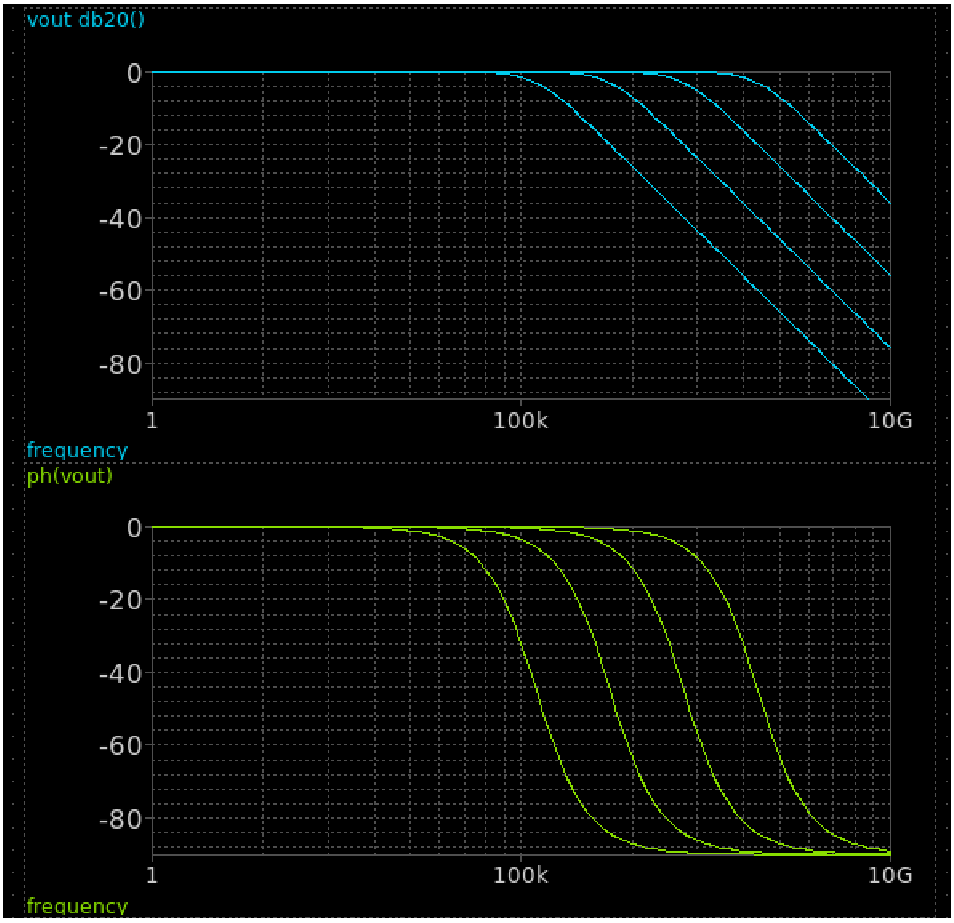
1) Report Bode Plot (magnitude and phase) for the previous LPF.
2) Calculate DC gain and 3dB bandwidth using measure command. Export the results to an output text file.
3) Derive an analytical expression for the bandwidth. Compare simulation with analytical results in a table.
4) Do parametric sweep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

➔ Hint: This is an example of a control section for ac analysis parametric sweep. Modify it as needed.

```
.control

save all

let R_val = 1k
let R_stop = 1meg
let R_mult = 10

while R_val le R_stop
  alter R1 R_val
  ac dec 10 1 10g
  meas ac MAX_GAIN MAX vmag(vout) FROM=1 TO=10G
  meas ac BW WHEN vmag(vout)=0.707 FALL=1
```

```
  print R_val MAX_GAIN BW >> ac_result.txt
  write rc_ckt_2.raw
  set appendwrite
  let R_val = R_val * R_mult
end

.endc
```

Hint: Bode plot (magnitude and phase) can be drawn using Xschem embedded graphs.



Part 2: MOSFET Characteristics

1. ID vs VGS (use Xschem)

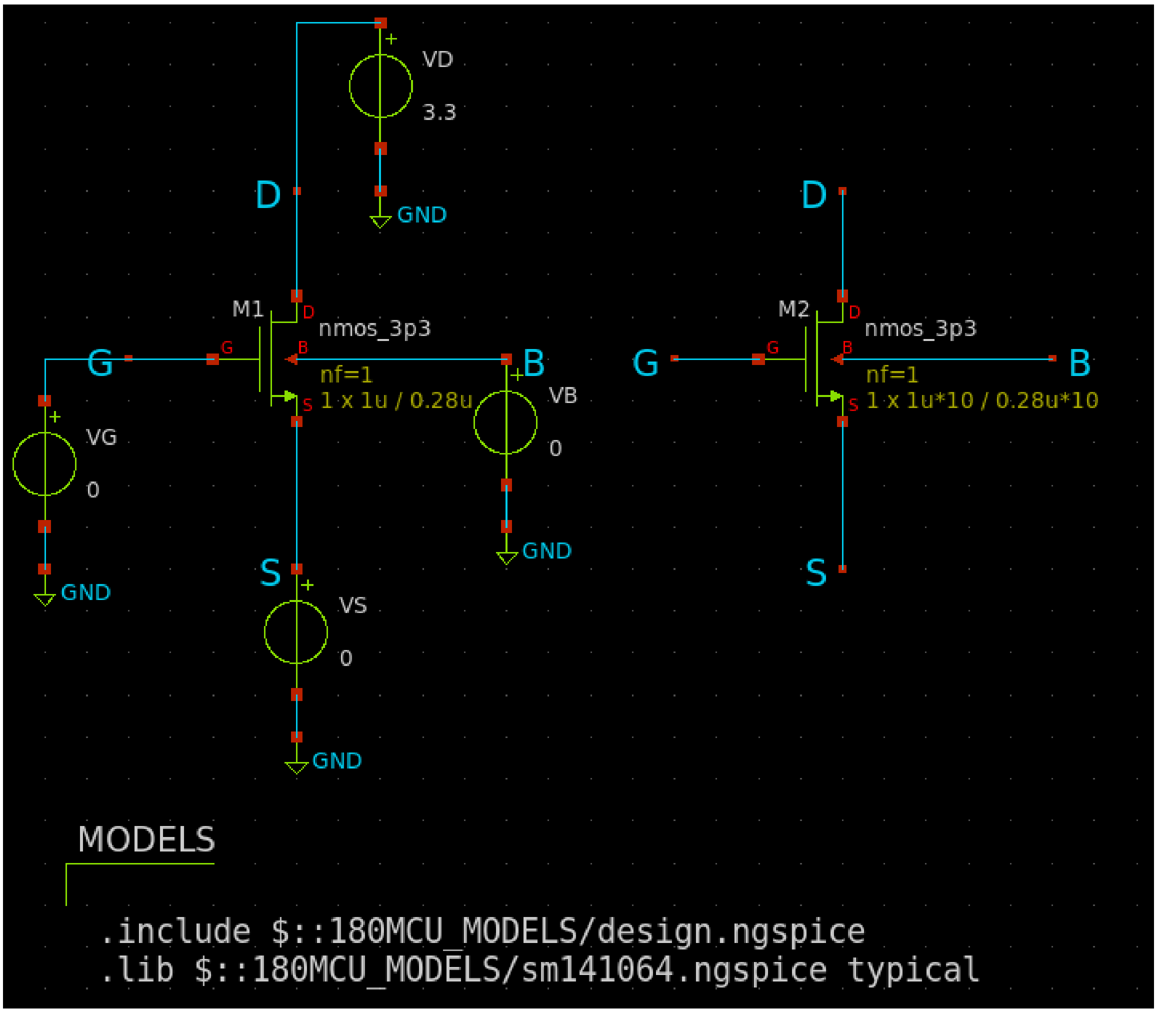
1) Create a testbench to characterize NMOS and PMOS devices.
2) Plot $I_D - V_{GS}$ characteristics for NMOS and PMOS devices. Set $V_{DS} = V_{DD}$, and $V_{GS} = 0{:}\,10m{:}\,V_{DD}$ and $W = 10 * L$. Use $V_{DD} = 3.3V$ for GF180MCU technology. Plot the results overlaid for the following:
    - Short channel device: $L = 280nm$
    - Long channel device: $L = 2.8\mu m$
    - Hint: Note that W/L is the same for both cases.

→ Hint: Use DC sweep instead of parametric sweep whenever possible. DC sweep is extremely faster, and uses much less resources and disk space. In this question you should use DC sweep for VGS.

➔ Hint: To simulate both the short channel and the long channel devices in the same simulation run you can simply create two devices.

➔ Hint: This is an example of an NMOS short channel vs long channel testbench. Modify it as needed.

```
.control
save all
+ @m.xm1.m0[id] @m.xm1.m0[gm]
+ @m.xm2.m0[id] @m.xm2.m0[gm]
dc vg 0 3.3 0.1
*dc vd 0 2 0.01 vg 0 2 0.2
write test_mos.raw
.endc
```



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 (do it using both Xschem and ADT)

1) Plot g_m vs V_{GS} for NMOS device. Set $W = 10 * L,\ V_{DS} = V_{DD}$, and $V_{GS} = 0{:}\,V_{DD}$. Plot the results overlaid for the following:
   - Short channel device: $L = 280nm$
   - Long channel device: $L = 2.8\mu m$
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 (use ADT)

1) Plot $I_D - V_{DS}$ characteristics for NMOS device. Set $W = 10 * L, V_{DS} = 0{:}\,V_{DD}$ (primary sweep variable), and $V_{GS} = 1{:}\,1{:}\,3$ (secondary sweep variable of the nested sweep). Plot the results overlaid for the following:
   - Short channel device: $L = 280nm$
   - Long channel device: $L = 2.8\mu m$
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?

4. [Optional] g_m and r_o in Triode and Saturation (use ADT)

1) Plot g_m and $r_o\ vs\ V_{DS}$ for NMOS device. Use $W = 10 * L$ and $L = 2.8\mu m, V_{DS} = 0{:}\,V_{DD}$, and $V_{GS} \approx V_{TH} + 0.5V$.
   Hint: You can get an estimate of V_{TH} from the I_D vs V_{GS} characteristics you already plotted before, or you can print the operating point parameters of the transistor.
2) Comment on the variation of g_m vs V_{DS}.
   - In the first part of the curve, is the relation linear? Why?
   - Does g_m saturate? Why?
   - How much is V_{DS} when the curve saturates?
   - Where do you want to operate the transistor for analog amplifier applications? Why?
3) Comment on the variation of r_o vs V_{DS}.
   - Does r_o saturate just after the transistor enters saturation similar to gm? Why?
   - Does r_o increase if the transistor is biased more into saturation?
   - Should we operate the transistor at the edge of saturation?
   - Where do you want to operate the transistor for analog amplifier applications? Why?

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 sweep.
  - How to plot the transistors characteristics using ADT.
  - 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 g_m of the transistor behaves vs VGS.
- How the g_m and r_o of the transistor behave in triode and in saturation.

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