

Analog IC Design (Xschem, Ngspice, ADT)**Lab 04****Common Drain Frequency Response****Intended Learning Objectives**

In this lab you will:

- Learn how to use the Sizing Assistant (SA) to size the transistors.
- Design and simulate a common-drain amplifier.
- Use PMOS input transistor to avoid body effect in a CD amplifier.
- Investigate the ringing and peaking problem in a capacitive-loaded CD amplifier with a large source resistance (R_{sig}) and learn how to solve it.

Part 1: Device Sizing Using SA

- 1) From the square law, we have

$$g_m = \frac{2I_D}{V_{ov}} \rightarrow V_{ov} = \frac{2}{g_m/I_D}$$

For a real MOSFET, if we compute V_{ov} and $\frac{2}{g_m/I_D}$ they will not be equal. We can define V^* (V^*), which is calculated from actual simulation data using the formula

$$V^* = \frac{2}{g_m/I_D} \leftrightarrow g_m = \frac{2I_D}{V^*}$$

The lower the V^* the higher the g_m , but the larger the area and the lower the speed. An often used sweet-spot that provides good compromise between different trade-offs is $V^* = 200mV$.

- 2) Although the V^* is a nice parameter that is inspired by the square-law, it does not have an intuitive or a physical meaning (it is not an actual voltage in the circuit). We actually defined V^* in order to be able to define a relation between the g_m and I_D . Thus, the real parameter that we should care about is the g_m over I_D ratio (g_m/I_D).

If the square-law is valid

$$g_m = \frac{2I_D}{V_{ov}} \rightarrow \frac{g_m}{I_D} = \frac{2}{V_{ov}}$$

Using V^*

$$\frac{g_m}{I_D} = \frac{2}{V^*}$$

A small g_m/I_D means large V_{ov} (biasing in strong inversion) and a large g_m/I_D means small V_{ov} (biasing in weak inversion).

- 3) There are many good things about using the g_m/I_D as a design knob:

- The g_m/I_D gives a direct relation between the most important MOSFET parameter (g_m) and the most valuable resource (I_D). For example, a $g_m/I_D = 10 \text{ S/A}$ means you get $10 \mu\text{S}$ of g_m for every $1 \mu\text{A}$ of bias current.
 - The g_m/I_D is a normalized knob: it has a limited search range (typically from 5 to 25 S/A) independent of the technology or the device type.
 - The g_m/I_D is intuitive because it tells you directly about the inversion level (bias point) and consequently all related trade-offs. For example, $g_m/I_D = 5 \text{ S/A}$ means strong inversion (SI), $g_m/I_D = 15 \text{ S/A}$ means moderate inversion (MI), and $g_m/I_D = 25 \text{ S/A}$ means weak inversion (WI).
 - The g_m/I_D is an orthogonal knob: If we define the g_m/I_D then we define the inversion level (bias point). If you change I_D or L while keeping g_m/I_D fixed, then the inversion level (bias point) is kept fixed. The W is treated as an output variable instead of being treated as an input variable.
 - The higher the g_m/I_D (the lower the V^*) the higher the efficiency and the headroom (the available swing), but the larger the area and the lower the speed. An often used sweet-spot that provides good compromise between different trade-offs is $g_m/I_D = 10 \text{ S/A}$ ($V^* = 200\text{mV}$). Larger g_m/I_D is usually used for low-voltage and low-power designs.
- 4) We want to design a CD amplifier that has ideal current source load with the parameters below.

Parameter	
Input transistor	PMOS
L^1	$1\mu\text{m}$
V^*	200mV
Quiescent (DC) input voltage	0V
Supply	1.8V
Current consumption	$10\mu\text{A}$

- 5) We assume we use a PMOS transistor that is placed in a dedicated n-well to be able to connect the body and source terminals. This will avoid the degradation of the CD amplifier gain due to body effect.
- 6) Draw the amplifier schematic. Note that the load is connected to the source, not to the drain.
- 7) Since the square-law is not accurate, we cannot use it to calculate the sizing. Instead, we will use the Sizing Assistant (SA) which is a powerful analog calculator that uses LUTs that are pre-generated from the simulations. The input of SA is shown below. Note that since both the gate and the drain are connected to ground, we can set $V_{DS} = V_{GS}$.

¹ A relatively long L is intentionally used to be able to use the simplified frequency response expressions given in the lecture slides.

LUT	pch
Corner	tt
Temp (°C)	27.0
CD_AMP	Save State
ID	10u
Vstar	200m
L	1u
VDS	VGS
VSB	0
Stack	1

Part 2: CD Amplifier

1. OP (Operating Point) Analysis

- 1) Create a new schematic for the CD amplifier (the schematic is not included in the lab document and is left for the student as an exercise). Use a PMOS transistor and use a $10\mu A$ ideal current source load for biasing (note that the current source will be connected to the source terminal). Connect the source to the bulk. Use $L = 1\mu m$ and W as determined in Part 1. Use $C_L = 2pF$, input source resistance $R_{sig} = 2M\Omega$, and a DC input voltage = 0V.
- 2) Simulate the OP point. Report a snapshot clearly showing the following parameters.

ID
VGS
VDS
VTH
VDSAT
GM
GDS
GMB
CDB
CGD
CGS
CSB

- 3) Check that the transistor operates in saturation.

2. AC Analysis

- 1) Perform AC analysis (1Hz:10GHz, logarithmic, 20points/decade) to investigate the frequency domain peaking.
- 2) Report the Bode plot magnitude.
- 3) Do you notice frequency domain peaking? How much is the peaking?
- 4) Analytically calculate the quality factor (use approximate expressions). Is the system underdamped or overdamped?
- 5) Perform parametric sweep: $C_L = 2p, 4p, 8p$.
 - Report Bode plot magnitude overlaid on same plot.
 - Report the peaking vs C_L .

- Comment on the results.
- 6) Perform parametric sweep: $R_{sig} = 20k, 200k, 2M$.
- Report Bode plot magnitude overlaid on same plot.
 - Report the peaking vs R_{sig} .
 - Comment on the results.

3. Transient Analysis

- 1) Use a pulse source as your transient stimulus and set it as follows: delay time = $2\mu s$, initial (zero value) = $0V$, period = $8\mu s$, pulse (one value) = $100mV$, fall time = $1ns$, rise time = $1ns$, pulse width = $4\mu s$.
- 2) Run transient analysis for $10\mu s$ with $10ns$ step to investigate the time domain ringing.
- 3) Report V_{in} and V_{out} overlaid vs time.
- 4) Calculate the DC voltage difference (DC shift) between V_{in} and V_{out} .
 - What is the relation between the DC shift and V_{GS} of the transistor?
 - How to shift the signal down instead of shifting it up?
- 5) Do you notice time domain ringing? How much is the overshoot?
- 6) Perform parametric sweep: $CL = 2p, 4p, 8p$.
 - Report V_{out} vs time overlaid on same plot.
 - Report the overshoot vs CL .
 - Comment.
- 7) Perform parametric sweep: $R_{sig} = 20k, 200k, 2M$.
 - Report V_{out} vs time overlaid on same plot.
 - Report the overshoot vs R_{sig} .
 - Comment on the results.

4. Z_{out} (Inductive Rise)

- 1) We want to simulate the CD amplifier output impedance. Replace CL with an AC current source with magnitude = 1. Remove the AC input signal.
- 2) Perform AC analysis ($1Hz:10GHz$, logarithmic, 10points/decade). The voltage across the AC current source is itself the output impedance.
- 3) Plot the output impedance (magnitude and phase) vs frequency. Do you notice an inductive rise? Why?
- 4) Does Z_{out} fall at high frequency? Why?
Hint: C_{gd} appears in parallel with R_{sig} .
- 5) Analytically calculate the zeros, poles, and magnitude at low/high frequency for Z_{out} . Compare with simulation results in a table.

5. [Optional] How to solve the peaking/ringing problem?

- 1) The simple solution is to place the input/output poles away from each other (as we did when we swept CL and R_{sig}).
- 2) Alternatively, a compensation network can be used to compensate for the negative input impedance and prevent overshoots. Read [Johns and Martin, 2012] Section 4.4 and try to implement the compensation network.

Lab Summary

In Part 1 you learned:

- How to find transistor sizing using the Sizing Assistant (SA).
- How to design a PMOS common-drain amplifier.

In Part 2 you learned:

- How to perform AC, DC and transient simulations of a CD amplifier.
- How the peaking in the frequency response of a CD amplifier changes with the load capacitor and source resistance.
- How the ringing in the transient response of a CD amplifier changes with the load capacitor and source resistance.
- How the output impedance of a CD amplifier shows inductive behavior.

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