EE 435
Homework 4
Spring 2025

Due Wednesday Feb 19

Problem 1 and 2

The model parameters μ, C_{OX}, V_{TH} and λ are widely used in analytical formulations of the performance of analog circuits. These parameters are used to characterize how MOS transistors operate in the square-law model of the transistor.

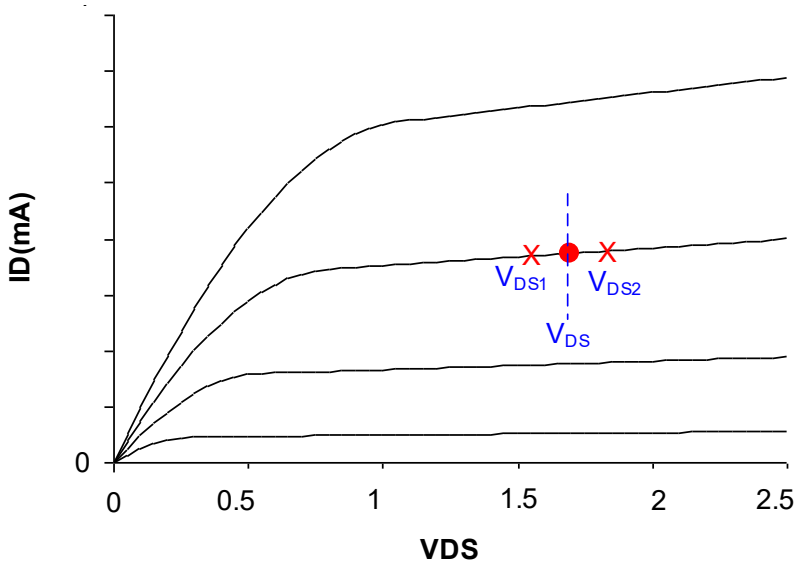
When operating in the saturation region, the square-law model for the drain current of transistors can be expressed as

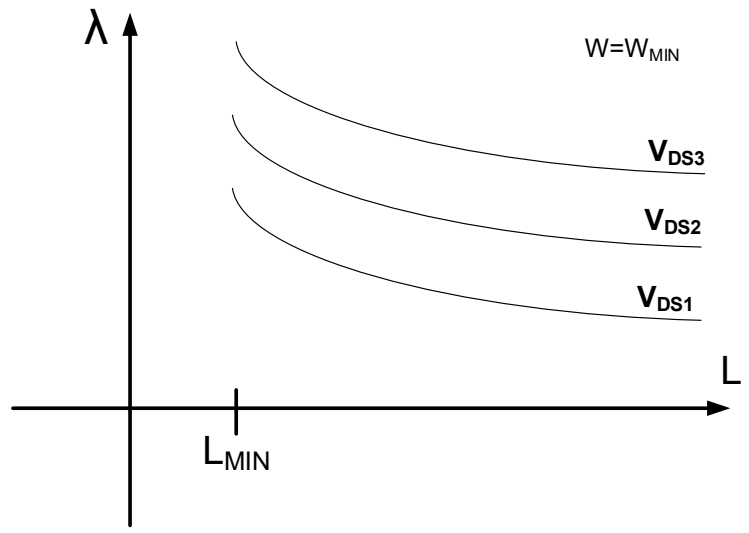
$$I_D = \begin{cases} \frac{\mu_n C_{OX} W}{2L}\left(V_{GS} - V_{THn}\right)^2\left(1+\lambda_n V_{DS}\right) & \text{for n-channel devices} \\ -\frac{\mu_p C_{OX} W}{2L}\left(V_{GS} - V_{THp}\right)^2\left(1-\lambda_p V_{DS}\right) & \text{for p-channel devices} \end{cases}$$

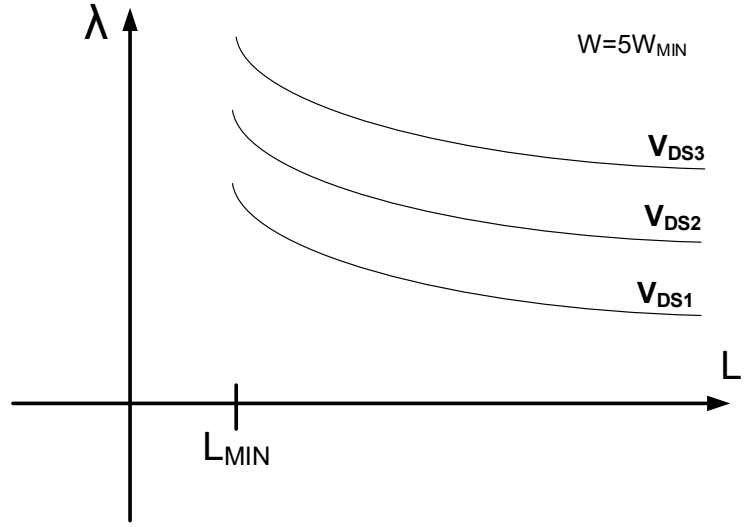
Though this square-law formulation is a simplification, it gives reasonable results that can be used for much of the design process. Better and more comprehensive models, such as the BSIM models, are then used in computer simulations to more accurately predict performance and for refining the design to meet target specifications. The BSIM models, however, are not analytically tractable and thus unsuitable for analytical formulations. Though intermediate models that are more accurate than the square-law models and less comprehensive than the BSIM models exist, there is little evidence of analytical tractability for models with complexity beyond that of the square-law model.

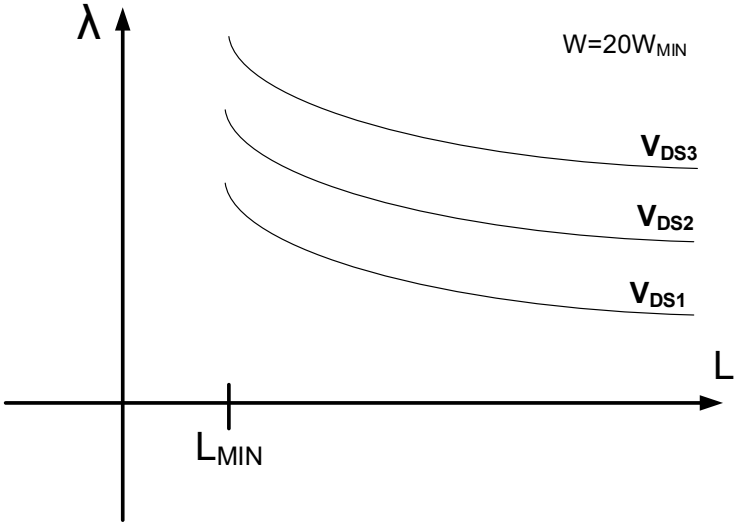
Many analog circuits are quite sensitive to the parameter λ in the square-law model. Unfortunately, the parameter λ is quite sensitive to device dimensions and operating point. As such, a table or plot of λ parameters is useful when using the square-law model for predicting the performance of many analog circuits based upon the square-law model.

Generate plots of λ for both n-channel and p-channel transistors in the 0.18μm CMOS for different lengths and for three different values of W and for three different values of V_{DS} as shown below. Comment on how λ varies with device dimensions and operating points. When determining λ, assume that the devices are modeled by the BSIM model which is embedded in the PDK file used in SPECTRE. Extract λ at a given operating point by taking two measurements (simulation results) of the drain current at values of V_{DS} slightly above and slightly below the target V_{DS} value on a constant V_{GS} locus as shown in the plot below. This is likely how you extracted the parameter λ in EE 330. The length should vary between L_{MIN} and $20L_{MIN}$ and the VDS values should be from slightly above V_{EB} to 2.5V.


ID(mA)
0
0
0.5
1
1.5
2
2.5
VDS
VDS1
VDS2
VDS

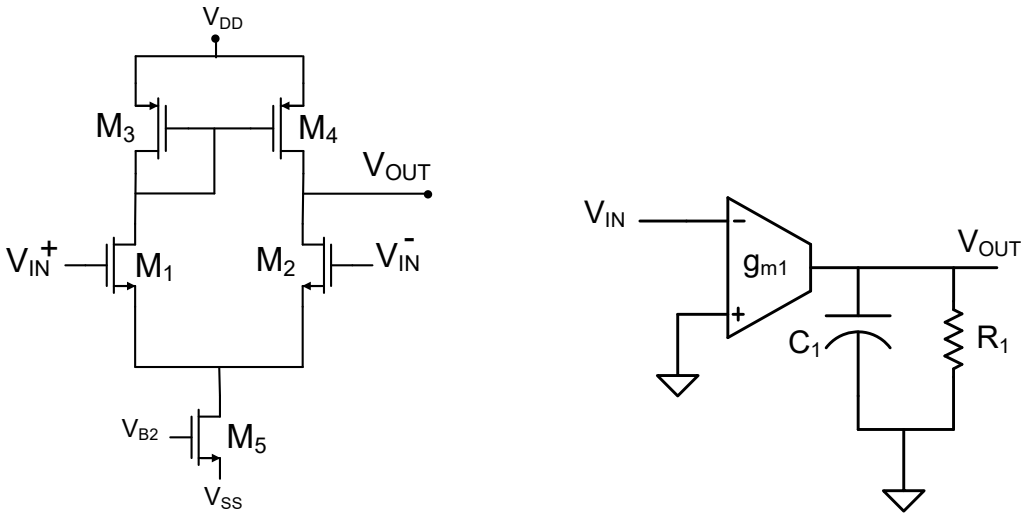

λ
W=W_MIN
V_DS3
V_DS2
V_DS1
L
L_MIN


λ
W=5W_MIN
V_DS3
V_DS2
V_DS1
L
L_MIN


λ
W=20W_MIN
V_DS3
V_DS2
V_DS1
L
L_MIN

Problem 3 Consider the 5T op amp configured used as a transconductance amplifier in the circuit shown below. Assume the op amp is designed in a 0.18µm ON CMOS process with V_{DD}=1.2V, V_{SS}=-1.2V, L=2µm and V_{EB}=100mV for all transistors, and the power in the op amp is 1mW. Assume λ=.01V^{-1}.

a) What is W_1?
b) What is the quiescent voltage at the source of M_1?
c) Obtain an expression for the small signal voltage gain of the OTA circuit in terms of the small-signal parameters g_{m1}, R_1, and C_1.
d) Numerically determine and plot the small signal frequency dependent voltage gain if R_1=50K and C_1=40pF
e) Determine the 3dB bandwidth
f) How does the 3dB bandwidth change if the power in increased by 20% by changing V_{B2}?



Problem 4 Assume an operational amplifier has gain given by the expression $A(s)=\frac{10^9}{(s+5)(s+10^4)}$ and is used in a standard feedback configuration where the gain with feedback is given by the expression $A_{FB}(s)=\frac{A(s)}{1+A(s)\beta}$.

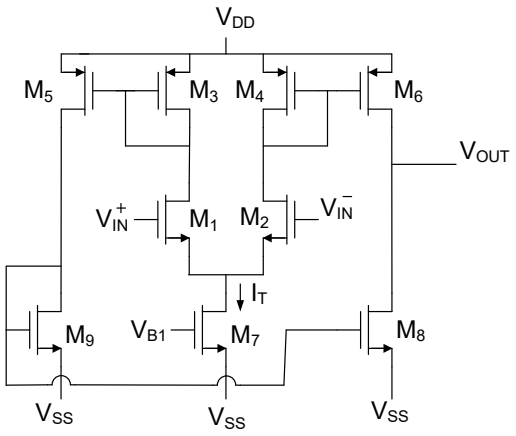
a) What is the pole spread in the open-loop amplifier
b) What is the pole Q if β=0.1
c) How much overshoot in the magnitude of the feedback gain will occur if β=0.5
d) What is the minimum closed-loop dc gain that can be achieved if there is to be no ringing in the step response
e) Assume the low frequency open loop pole at 5rad/sec can be moved without changing the dc gain or the second pole of the op amp. What is the minimum movement of the pole that is necessary to have no ringing in the step response of the closed loop amplifier is β=1.

Problem 5 Consider the current-mirror op amp shown below. Assume V_{DD}=1.2V and V_{SS}=-1.2V.

a) Size the devices if the excess bias of all transistors is to be 150 mV, the mirror gain of the two p-channel mirrors is to be 20, the n-channel mirror gain is 1, and the total power dissipation is 10mW.

b) If the amplifier designed in part a) is driving a 10pF load, determine the dc voltage gain and the GB of this amplifier.

c) Determine the transconductance gain of the amplifier designed in part a).

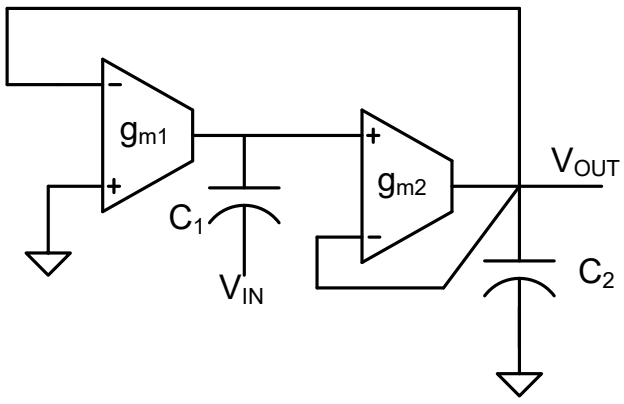


Problem 6 Consider the following circuit where the OTAs are assumed to be ideal.

a) Obtain the transfer function $T(s)=\frac{V_{OUT}}{V_{IN}}$

b) Determine the poles of the circuit in terms of the small-signal parameters g_{m1},g_{m2}, C_1 and C_2.

c) If $g_{m1}=g_{m2}=10^{-8}$A/V, C_2=500pF and C_1=50pF, plot the magnitude of the transfer function T(s) versus frequency



Problem 7 Consider the polynomial $D(s) = s^2+1500s+3000$. It was pointed out in the lecture that when a second-order polynomial has widely separated poles on the negative real axis that the high-frequency pole can be closely approximated by

considering only the s^2 and s terms and the low frequency pole can be closely approximated by considering only the constant and the s-term in this expression. Compare the actual roots and the approximate roots for D(s) and comment on how much error is introduced by using this approximation approach.

Problem 8 and 9

Consider the 7-T op amp where all transistors are sized for V_{EB}=0.1V with a power dissipation of 2mW split evenly between the first and second stage and where Miller compensation is used. Assume this is designed in a 0.18µm CMOS process with V_{DD}=1.2V, V_{SS}= -1.2V, and C_L=100fF. Assume the process is characterized by parameters $\mu_n C_{OX}$=300µAV^{-2}, V_{THn}=0.5V, V_{THp}= -0.5V, $\mu_p=\mu_n/3$, and λ=0.01V^{-1} for both the n-channel and p-channel devices.

a) Determine V_{B2} and V_{B3}
b) Determine W/L for all transistors
c) What is the dc gain of this operational amplifier?
d) Determine C_C if the feedback amplifier is to have a closed-loop pole Q of 0.707 when β=0.2.
e) What is g_{m5}?