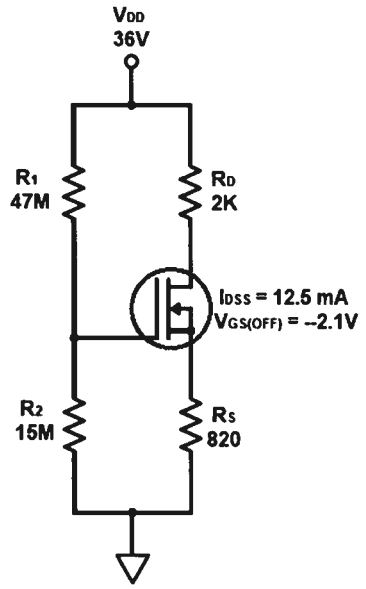
EE 3310/3510 • Exam III • 26 October 2022 NAME SOLUTION

1) Refer to the following circuit:



Which specific type of field-effect transistor is this?

depletion-mode MOSFET (+1) (+1)

N-channel or *p*-channel? (+1)

Self-bias or voltage-divider bias? (+1)

$V_{DS} \overset{?}{>} |V_{GS} - V_{GS(OFF)}|$

$5.542 > |-0.1478 - 2.$

yes, active region (+2)

Determine V_G, V_{GS}, V_S, I_S, I_D, V_D, and V_{DS}. Check P_{diss} and verify that the transistor is operating in the active region.

$$V_G = V_{DD}\left(\frac{R_2}{R_1+R_2}\right) = 36\left(\frac{15}{15+47}\right) = 8.710\ V \quad (+2)$$

$$a = \frac{I_{DSS}R_S}{V_{GS(OFF)}^2} = \frac{12.5\cdot.820}{(-2.1)^2} = 2.324$$

$$b = \frac{2I_{DSS}R_S}{|V_{GS(OFF)}|} + 1 = \frac{2\cdot12.5\cdot.820}{2.1} + 1 = 10.76$$

$$c = I_{DSS}R_S - |V_G| = 12.5\cdot.820 - 8.710 = 1.54$$

$$V_{GS}\big|_n = \frac{-b + \sqrt{b^2-4ac}}{2a} = \frac{-10.76 + \sqrt{10.76^2 - 4\cdot2.324\cdot1.5}}{2\cdot2.324}$$

$V_{GS} = -0.1478\ V$ (+2)

$$V_S = V_G - V_{GS} = 8.710 - (-0.1478) = 8.858\ V \quad (+2)$$

$$I_S = I_D = \frac{V_S - 0}{R_S} = \frac{8.858-0}{.820} = 10.80\ mA \quad (+2)$$

check: $I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_{GS(OFF)}}\right)^2 = 12.5\left(1 - \frac{-0.1478}{-2.1}\right)^2 = 10.80\ mA$ ✓

$$V_D = V_{DD} - I_D R_D = 36 - 10.80\cdot2 = 14.4\ V \quad (+2)$$

$$V_{DS} = V_D - V_S = 14.4 - 8.858 = 5.542\ V \quad (+2)$$

$P_{diss} = V_{DS} I_D = 5.542\cdot10.80 = 59.85\ mW$ (+2)

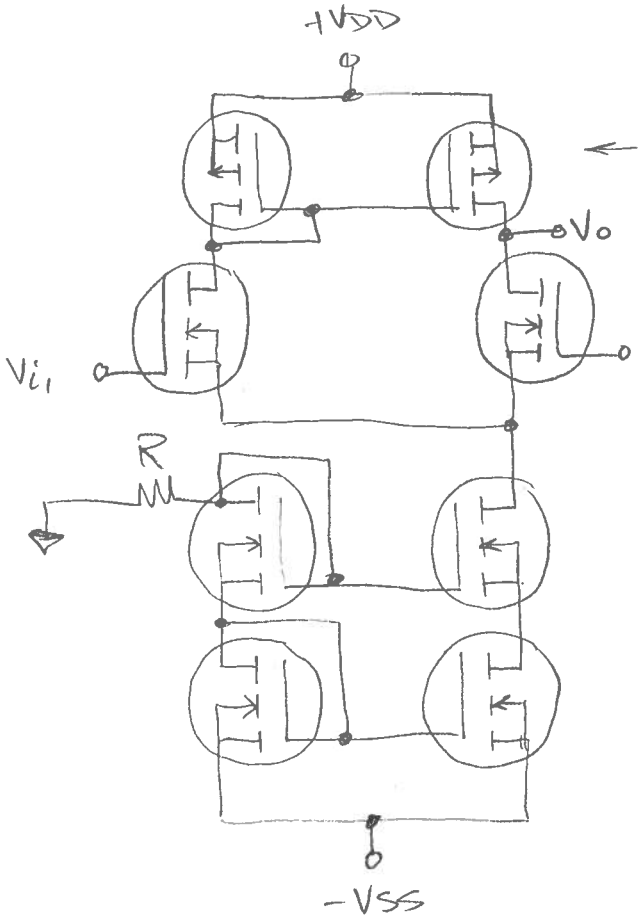
SOLUTION

+5

2) Design a CMOS differential amplifier that has a small-signal differential gain A_{dm} > **30 dB** and ***CMRR*** > **60 dB**. Draw the circuit carefully and explain your choice of active vs. passive drain load, resistive vs. current-mirror current sink, etc. Compute A_{dm} and *CMRR* for your circuit if K = 12 mA/V^2, $|V_t|$ = 1.5 V, and $|V_A|$ = 180 V. Set the total sink current to **5.6 mA** and use E96 resistors. w/ $V_{DD} = \pm 12$ V

$A_{dm} > 30$ dB → better use active drain load

CMRR > 60 dB → need cascode current mirror sink (+2)



← p-channel current mirror (+2)

← n-channel differential pair (+2)

← n-channel cascode current mirror (+2)

Current sink: $V_{GS} = \sqrt{\frac{I_D}{K}} + V_t = \sqrt{\frac{5.6}{12}} + 1.5 = 2.183$ V (+2)

$R = \frac{|V_{SS}| - 2V_{GS}}{I_{REF}} = \frac{12 - 2 \cdot 2.183}{5.6} = 1.363$ k (+2)

Use 1.37k 1% (+1)

- to compute A_{dm}, need r_{op} of current mirror and r_{on} of diff pair; assumed equal!

$$\therefore \quad r_o = \frac{|V_A|}{I_D} = \frac{180}{5.6/2} = 64.29\ k\Omega \quad (+2)$$

↳ per transistor in diff pair

$$g_m = 2\sqrt{K I_D} = 2\sqrt{12 \cdot \frac{5.6}{2}} = 11.59\ \frac{mA}{V} \quad (+2)$$

$$\therefore A_{dm} \cong \frac{g_m r_o}{4} = \frac{11.59 \cdot 64.29}{4} = 186.3 \quad (+2)$$

or 45.4 dB (+1) $>$ 30 dB (+1) ✓

- to compute CMRR, need r_{out} of current sink

- for cascode current mirror, $r_{out} = g_m r_o^2$

$$g_m = 2\sqrt{K I_D} = 2\sqrt{12 \cdot 5.6} = 16.40\ mA/V \quad (+2)$$

$$r_o = \frac{|V_A|}{I_D} = \frac{180}{5.6} = 32.14\ k\Omega \quad (+2)$$

then $r_{out} = 16.40 \cdot 32.14^2 = 16941\ k$ (+2)

or $16.94\ M\Omega$

$\longrightarrow$ CMRR $= g_m$ (of diff pair!) $r_{out} = 11.59m \cdot 16.94M = 196345$ (+2)

or 106 dB (+1) $>>$ 60 dB (+1) ✓