1. (24 pts)
   a) Find: \( \frac{v_o(j\omega)}{v_{in}(j\omega)} \). Express answer in terms of \( R_1, R_2, C, \) & \( j\omega \).
   b) Find the corner frequency of this circuit, \( f_c \) in Hz.
   c) If the op-amp is ideal, what type of filter would this circuit be?
      1) high-pass  2) low-pass  3) band-pass
      4) band-reject  5) no type of filter  6) coffee
      circle one
   d) The op-amp is not ideal, it has a unity-gain bandwidth (gain-bandwidth product): \( f_T := 2 \cdot \text{MHz} \)
      Draw the Bode plot of this circuit below.

2. Problem 2 is shown on the next page (out of order).

3. (4 pts) Why is a sinusoidal waveform NOT really a signal?

4. (4 pts) If you built the circuit at right in the lab, with a real
   LM741, what should you expect to measure at the output?

5. (13 pts) The circuit at right is operated so that the \( V_{DS} \) is small.
   MOSFET characteristics: \( k' \frac{W}{L} = \frac{V_C}{V_s} \) \( V_t := 1.5 \cdot \text{V} \)
   a) Find the gain \( \frac{V_o}{V_{in}} \) of this circuit if: \( V_G := 4 \cdot \text{V} \)
   b) Find a general expression for the gain as a function of \( R_1, R_2, V_G, \) and the characteristics of the MOSFET.
2. (22 pts)
   a) Assume the op amp is ideal (doesn't even clip).
      The input waveform \( v_S \) is as shown. **Accurately**
      draw the output voltage \( v_o \) you expect to see. 
      Draw the output on the graph provided and label the
      vertical axis.
   
   b) If you actually make the circuit with an LM741, the
      output waveform may be a little different. **Accurately**
      show how the real output differs from the ideal. label
      any newly drawn lines "real".
   
   Label important voltages OR times so that each
   important point on the waveform is clear.
   
   Note: Some of the characteristics of this op amp are
   unimportant and won't significantly change the output.
   You may neglect any characteristics which will affect
   the output by less than 5% (you don't need to prove
   your assumptions).

   \[ R_2 = 180 \, k\Omega \]
   \[ R_S = 1 \, k\Omega \]
   \[ R_1 = 9 \, k\Omega \]

   **LM741 Op amp Characteristics**
   - Differential gain: \( A_v = 100000 \)
   - Unity-gain bandwidth: \( f_T = 2 \, MHz \)
   - Output swing limits: within 2 V of supplies
     \( L^+ = V^+ - 2V \)
     \( L^- = V^- + 2V \)
   - Slew rate: \( SR = 1 \, \frac{V}{\mu s} \)
   - Input bias current: \( I_B = -80 \, nA \)

   6. (14 pts) All the MOSFETS shown are built on
      the same IC, using the same process. The
      only differences between them are their
      physical dimensions and the \( k'_p, k'_n \) difference.

      \[ k'_p = 0.4 \cdot k'_n \]
      \[ \frac{W_2}{L_2} = 3 \cdot \frac{W_1}{L_1} \]
      \[ \frac{W_3}{L_3} = 2 \cdot \frac{W_1}{L_1} \]
      \[ \frac{W_4}{L_4} = 2.5 \cdot \frac{W_1}{L_1} \]
      \[ \frac{W_5}{L_5} = 6 \cdot \frac{W_1}{L_1} \]

   All transistors are operating in saturation.
   
   a) Find \( I_2 \)
   
   b) Find \( I_4 \)
   
   c) Find \( I_5 \)
   
   d) \( K_1 = 2 \cdot \frac{mA}{V^2} = k'_p \cdot \frac{W_1}{L_1} \)
   
   \[ V_{t1} = 1.5 \, V \]
   
   Find \( R_1 \)
   
   **Note**: crossing lines don't connect
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7. (8 pts) Assuming you know $V_t$, $k_nW/L$, $R_D$, and $V_{DD}$

Derive an expression for $I_D$ or show the equation that you'd have to solve in order to find $I_D$. If you leave your answer as an equation, it must be in a polynomial form for easy solution.

I suggest that you take an equation you already have and modify it to fit this circuit. Deriving it from scratch will take too long for 8 points.

8. (47 pts) You may assume all transistors are operating in the active region.

\begin{center}
\begin{tikzpicture}
\node (in) at (0,0) {$V_{in}$};
\node (Q1) at (2,1) {$Q_1$};
\node (R1) at (2,-1) {$R_1 := 3.5 \text{-} M\Omega$};
\node (R2) at (4,-1) {$R_2 := 2.5 \text{-} M\Omega$};
\node (R3) at (6,0) {$R_3 := 3.6 \text{-} k\Omega$};
\node (R4) at (8,0) {$R_4$};
\node (R5) at (10,0) {$R_5 := 12.4 \text{-} k\Omega$};
\node (R6) at (12,0) {$R_6 := 3.6 \text{-} k\Omega$};
\node (R7) at (14,1) {$R_7$};
\node (R8) at (16,1) {$R_8 := 10 \text{-} \Omega$};
\node (R9) at (18,1) {$R_9 := 2.7 \text{-} k\Omega$};
\node (R10) at (20,1) {$R_{10} := 9.3 \text{-} k\Omega$};
\node (R11) at (22,1) {$R_{11} := 2.7 \text{-} k\Omega$};
\node (R12) at (24,1) {$R_{12} := 270 \text{-} \Omega$};
\node (R13) at (26,1) {$R_{13} := 100 \text{-} \Omega$};
\node (Q2) at (28,1) {$Q_2$};
\node (Q3) at (30,1) {$Q_3$};
\node (C1) at (1,1) {$C_1$};
\node (C2) at (3,1) {$C_2$};
\node (C3) at (5,1) {$C_3$};
\node (C4) at (7,1) {$C_4$};
\node (C5) at (9,1) {$C_5$};
\node (Vcc) at (22,2) {$V_{CC} := 12 \text{-} V$};
\node (Vo) at (34,2) {$V_o$};
\node (Vdd) at (2,2) {$V_{DD}$};
\node (Rd) at (4,2) {$R_D$};
\node (Id) at (6,2) {$I_D$};
\node (Vb3) at (14,-3) {$V_{b3}$};
\node (Vb2) at (12,-3) {$V_{b2}$};
\node (Vg) at (0,-3) {$V_g$};
\node (Vb1) at (2,-3) {$V_{b1}$};
\node (Vin) at (0,-5) {$V_{in}$};
\end{tikzpicture}
\end{center}

a) For $Q_1$: $k_nW/L = K := \frac{2 \text{mA}}{V^2}$ $V_t := 2.5 \text{-} V$ Find $R_4$.

b) What is the unloaded gain of the first stage. (without the second stage connected)

$c) Find R_{in} for the second stage. \quad R_{in2} = ?$

d) The Bode plot at right represents the unloaded gain of the second stage. (without the third stage connected). Neglect $r_o$. What is the value of $R_7$?

e) Fill in the resistor blanks in the small signal model below with numbers. Neglect $r_o$ of the third stage. Fill in the dependent source blanks with gain factors. If there's no blank, don't put anything down.
9. (22 pts) A voltage waveform (dotted line) is applied to the circuits shown. Accurately draw the output waveform \((v_o)\) you expect to see. The characteristic curve for the 2.1-V silicon zener diode is also shown. Label important times and voltage levels.

\[ R_1 = 70 \, \Omega \]
\[ R_2 = 30 \, \Omega \]

10. (8pts) The MOSFETs in the circuit shown are matched and both have: \(|V_t| = 3 \, \text{V}\)

Find \(V_{IL}\), \(V_{IH}\), and the noise margins.
11. (14pts) Assume the depletion-type MOSFET shown is operating in saturation.

a) Find \( K = k' \frac{W}{L} \quad V_t := 3 \cdot V \)

b) I want the to stay in saturation. What is the biggest \( R_D \) that I can use?

12. Do you want your grade and scores posted on my door and on the internet? □ Yes □ No (Circle one)

If your answer is yes, then provide some sort of alias or password: _______________________

The grades will be posted on my door in alphabetical order under the alias that you provide here.
I will not post grades under your real name. The internet version will be an excel spreadsheet
which you can download. Both will show all your homework, lab, and exam scores.

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Answers

1.a) \( \frac{v_o(j\omega)}{v_{in}(j\omega)} = \frac{R_2}{R_1 + \frac{1}{j\omega C}} \)  b) 201Hz  c) high pass  d) 

2.a) straight lines between the following points:
   (0ms,0V), (0.2ms,-18V), (0.2ms,18V), (0.4ms,0V), repeat.
   
   b) straight lines between the following points:
   (0ms,0V), (0.144ms,-13V), (0.2ms,-13V), (0.226ms,13V),
   (0.256ms,13V), (0.4ms,0V), repeat.

3. Doesn’t carry information

4. 13V “rail”  5.a) 11  b) \( A_v = \frac{R_2}{R_1 + \frac{1}{K(V_G - V_t)}} + 1 \)  6.a) 6mA  b) 7.5mA  c) 18mA  d) 4.54kΩ

7. Solve for \( I_D \):
   \( 0 = R_D^2 I_D^2 - 2 \left( V_{DD} - V_t \right) R_D + \frac{1}{K' \frac{W}{L}} \left( V_{DD} - V_t \right)^2 \)

8.a) 1.5kΩ  b) 6.6kΩ  c) 5.25kΩ  d) 6.75kΩ  e) \( R_{in1} = 1.46kΩ \), \( R_{o1} = 3.3kΩ \), \( R_{in2} = 1.25kΩ \), \( A_{o2} = 100 \), \( R_{o3} = 270kΩ \)

9. straight lines between the following points:
   (0ms,0V), (3ms,0.9V), (10ms,7.9V), (10ms,-9.3V), (19ms,-0.3V), (20ms,0V), repeat.

10. 5.25V, 6.75V, 5.25V  11.a) 2.5mA/V²  b) 1.8kΩ