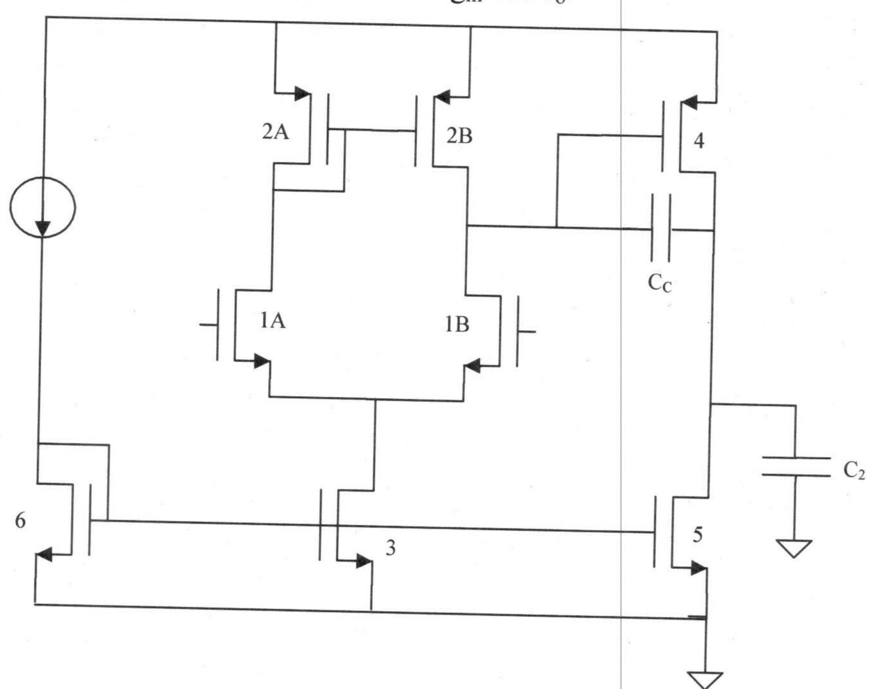
EECS140 Midterm 2
Spring 2016

Name *Key*

SID

Prob.	Score
1	/10
2	/29
3	/16
4	/10
5	/15
Total	/80

1. For the op-amp below, assume that:
   - All transistors are biased in saturation
   - All capacitors are assumed to be zero except C_C, C_2, and C_{gs} for all transistors.
   - $g_m r_o >> 1$ for all combinations of g_m and r_o



The same op-amp will be used in several different feedback circuits.

a. [2] The spec requires that the output be able to swing to within 200mV of ground, and 150mV of the positive supply. List all constraints on overdrive voltages.

missing 3,6 or 2A/B −1/2 each
constraining V_{ov1} −1

$V_{OV1,3,5} \leq 200mV$
$|V_{OV2,4}| \leq 150mV$

b. [2] When used in feedback the closed-loop gain must be 5 +/- 1%. What is the constraint on the open-loop gain of the amplifier?

$\frac{1}{Af} \leq 1\%$ $A \geq 500$

c. [2] When used in feedback with a closed-loop gain of 5, the desired bandwidth is 200M rad/s. What is the constraint on the unity-gain bandwidth?

$\omega_u \geq 1G\,rad/s$

d. The amplifier is also to be used in unity-gain feedback driving a 100pF load, and the desired open-loop phase margin is 70 degrees.

i. [2] What is minimum possible value for g_{m4}? (answer should be in Siemens)

$\frac{g_{m4}}{C_1+C_2+\frac{C_1C_2}{C_c}} \approx \omega_u \geq 10^9 \frac{rad}{s}$ $g_{m4} \geq (10^9 \frac{rad}{s})(10^{-10} F) = 100mS$

ii. [2] What are the constraints on g_{m1} and I_{tail}? (in terms of other circuit values)

$g_{m1} > \omega_u C_c$

$\frac{2I_{d1}}{V_{ov}} > \omega_u C_L \Rightarrow I_{tail} > \omega_u C_L V_{ov}$

2. A particular design of the op-amp above has the following values for parameters. You may ignore the gain and phase associated with the current mirror for this problem.

G_{m1}	R_{o1}	G_{m2}	R_{o2}	C_2	C_C	C_{gs4}
1mS	1M	1mS	100k	100p	1p	0.1p

a. [6] What are the low-frequency gains, and the locations of the uncompensated (C_C=0) poles, uncompensated second-stage unity gain frequency, and right-half-plane zero associated with C_c?

$\lvert A_{v1,0}\rvert$	$\lvert A_{v2,0}\rvert$	ω_{p1}	ω_{p2}	ω_{u2}	$\omega_{z,RHP}$
1,000	100	$10^7 \frac{rad}{s}$	$10^5 \frac{rad}{s}$	$10^7 \frac{rad}{s}$	$10^9 \frac{rad}{s}$

On the following pages,

b. [3] plot the magnitude of the second stage gain

c. [6] plot the overall impedance seen at the first stage output,

d. [2] plot the magnitude of the first stage gain,

e. [6] plot the magnitude and phase of the overall gain. **Label any poles and zeros clearly**.

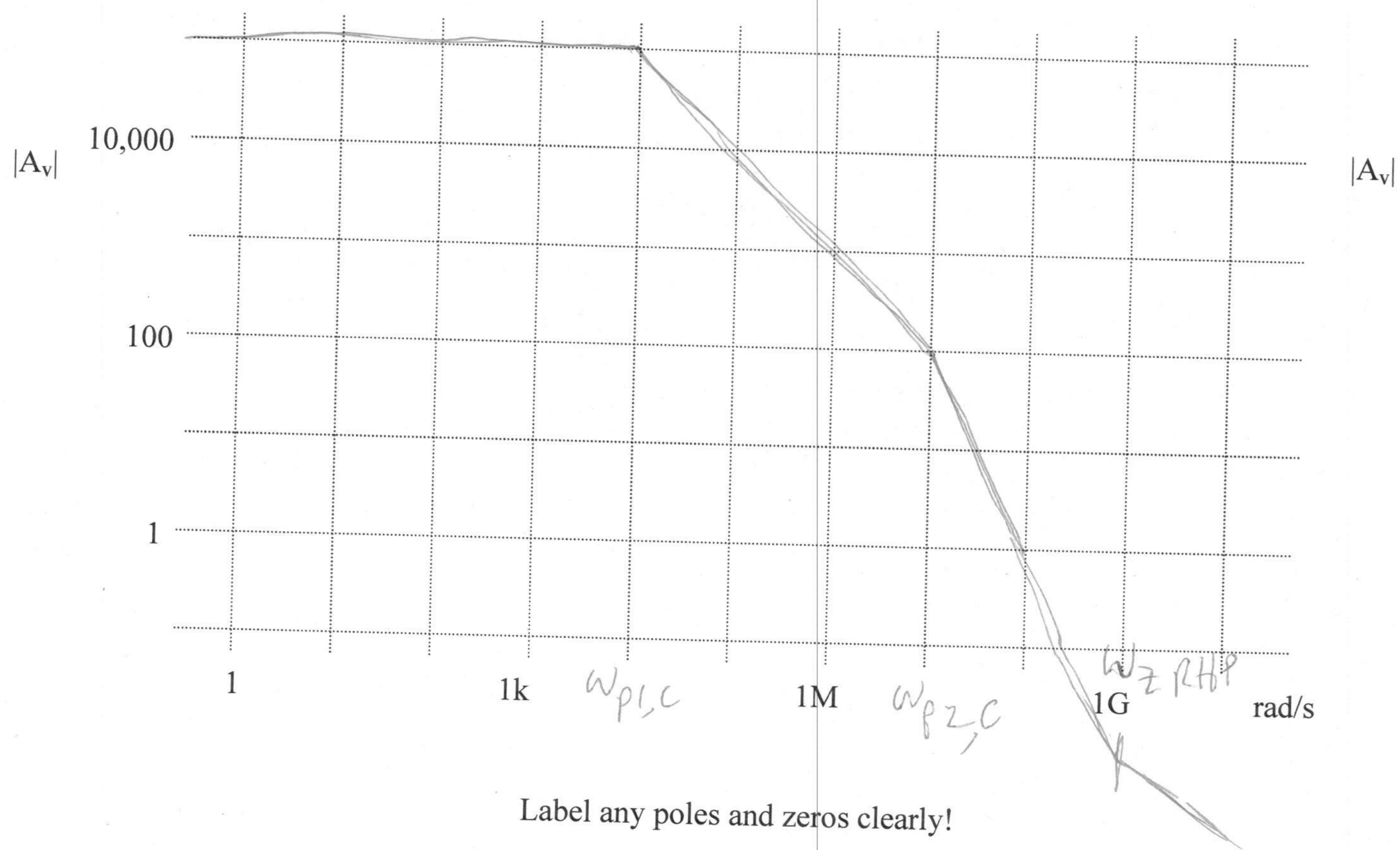
f. [4] Estimate the unity-gain phase margin for this value of C_C. What value of feedback factor f gives a 45 degree phase margin?

PM=0 f=0.01

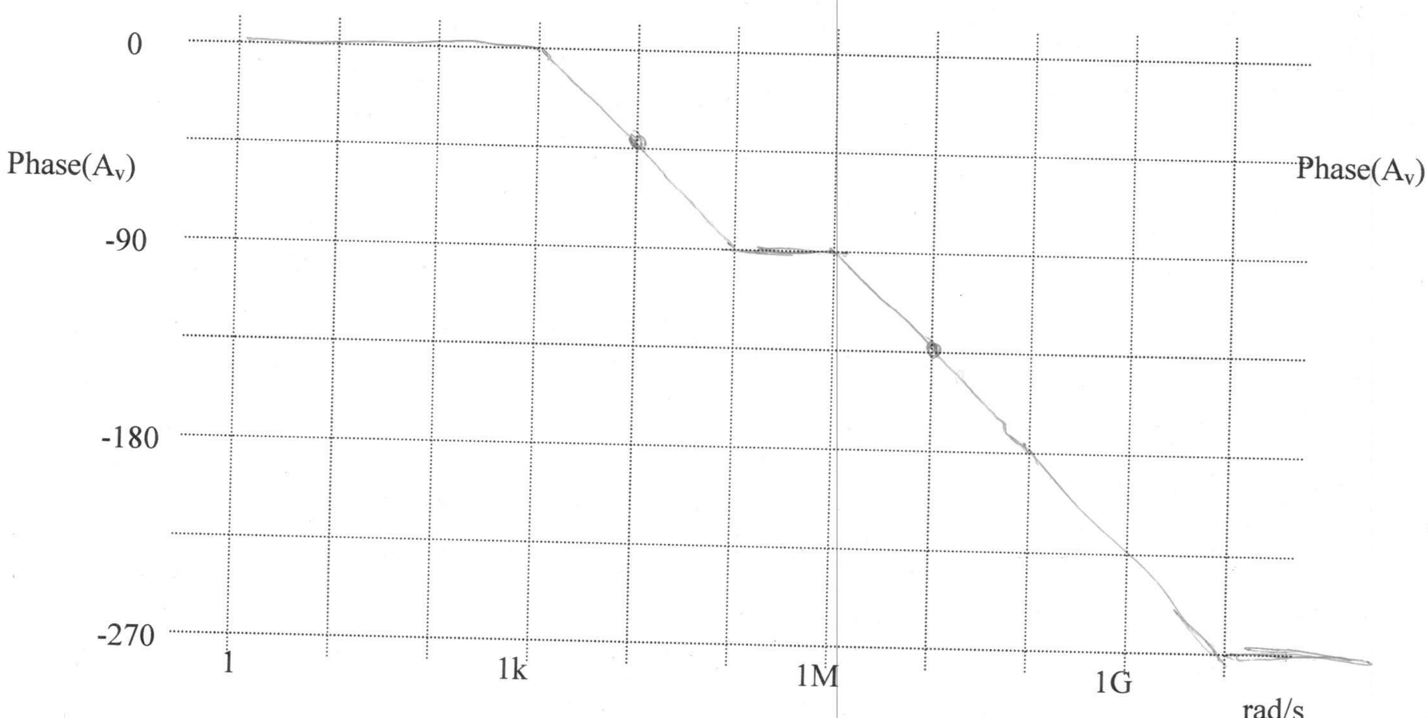
g. [2] Approximately what value of C_C is needed for a 45 degree phase margin if we can ignore $\omega_{z,RHP}$?

100pF

2E) op amp Bode plot

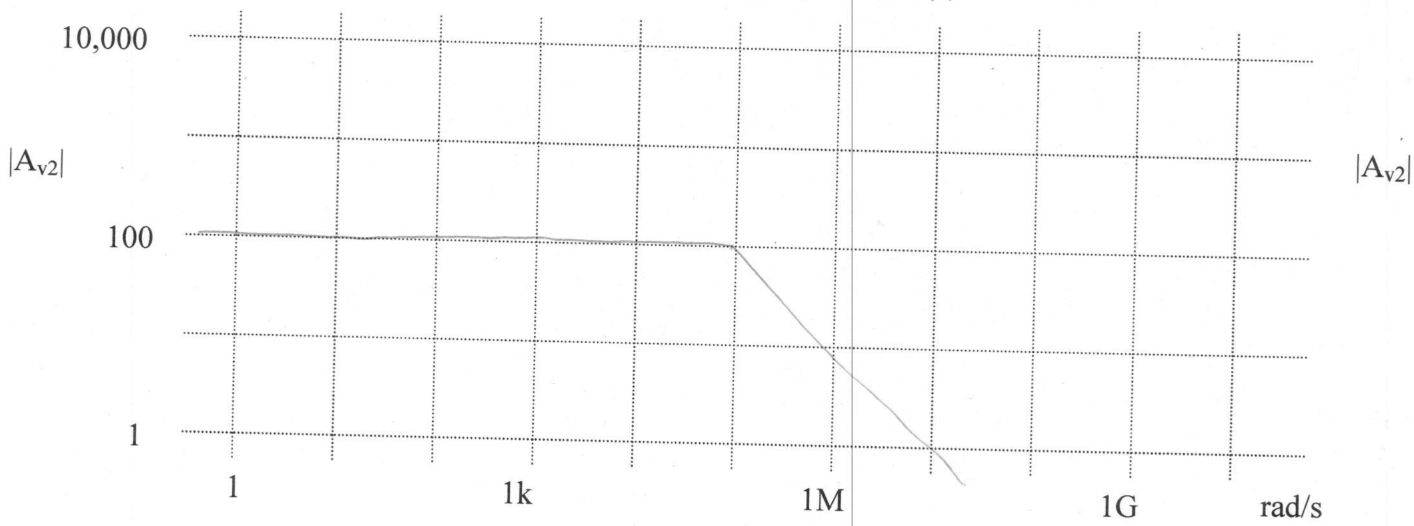


Label any poles and zeros clearly!

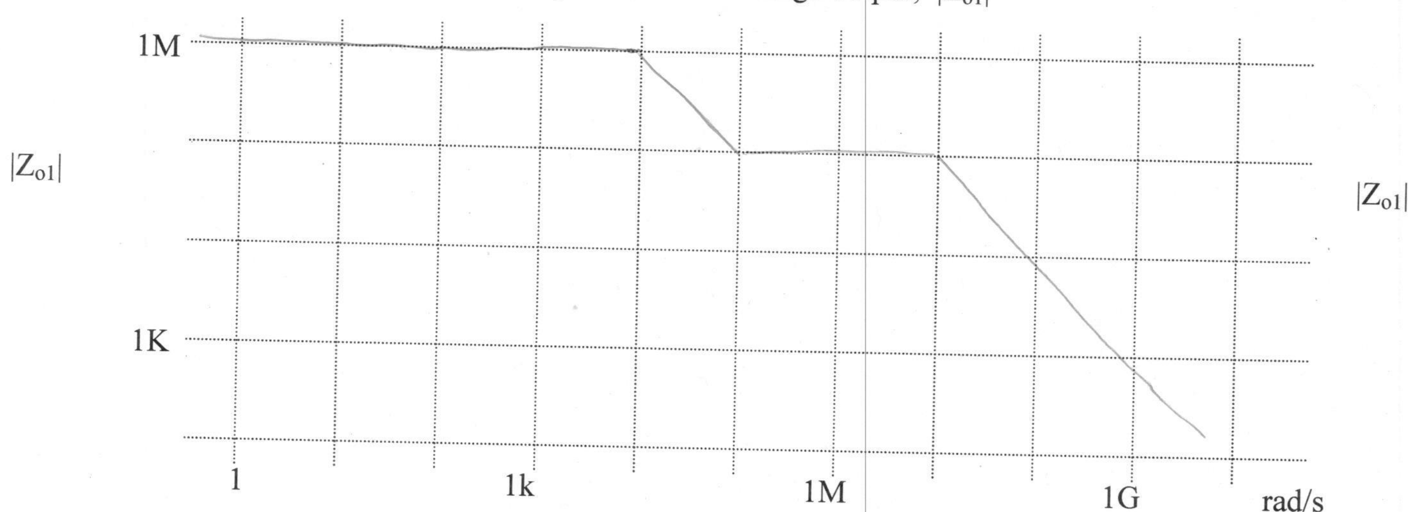


Don't forget RHP zero
Don't forget to answer 2f and 2g (phase margin questions)

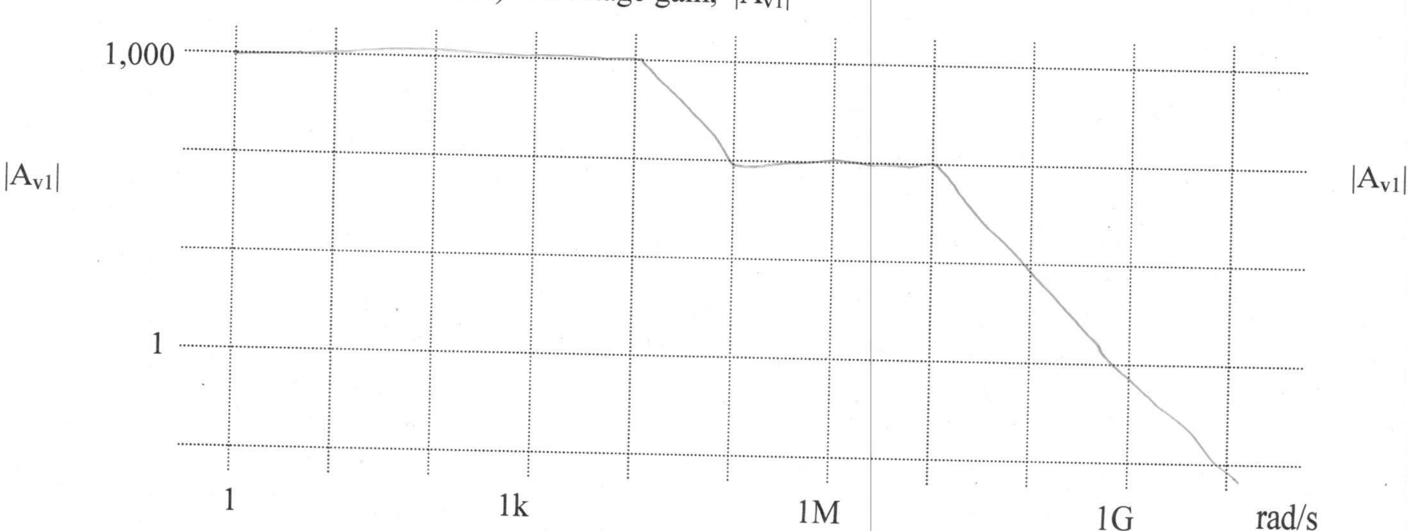
2B) Second stage gain – $|A_{v2,0}|$



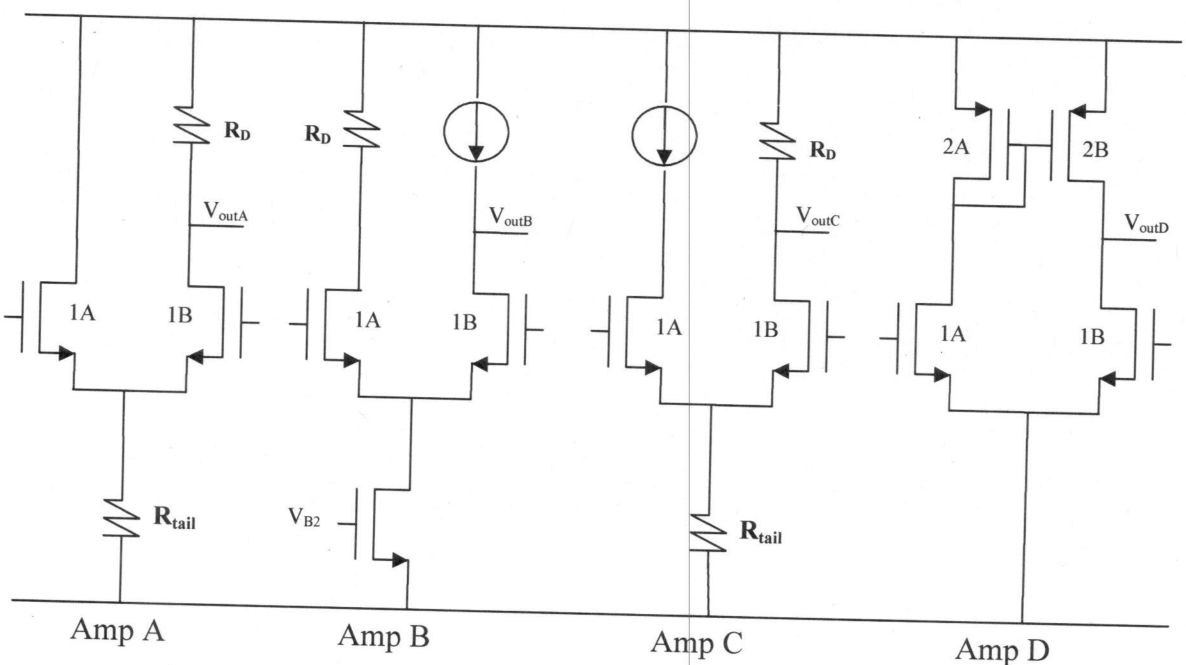
2C) Impedance at first stage output, $|Z_{o1}|$



2D) First stage gain, $|A_{v1}|$



3. [16] For the four differential amplifiers below, assume that $1/g_m << R << r_o$ for all configurations, and that current sources are ideal. Calculate the transconductance G_m and the output resistance Ro for each amplifier. Assume a **purely differential input.**



	G_m	R_o
Amp A	$g_m/2$	R_D
Amp B	$g_m/2$	$2\,r_o$
Amp C	$g_m/2(1+g_m R_{tail})$	R_D
Amp D	g_m	$r_o/2$

4. [10] The audio amplifier circuit below consists of a two-stage op-amp with an output stage. The op-amp is wired up in feedback.

   a. Which transistors make up the input differential pair?

      Q1 + Q2

   b. Estimate the tail current in terms of circuit parameters.

      VBE on Q3 / R5 (0.7 / R5 ok too)

   c. Which transistors make up the second stage?

      Q7 (and optionally Q5, Q6)

   d. Which capacitor provides Miller compensation?

      Free point! ✓ I screwed up and thought that C_5 went to the 1st stage output

   e. What component minimizes the effect of the right-half-plane zero associated with Miller compensation?

      Free point! ✓

   f. What is the DC bias voltage on the base of Q1?

      $I_B (R_1 + R_2)$ or 0

   g. What is the low-frequency feedback factor, f_{DC}? (you may ignore finite BJT input impedance)

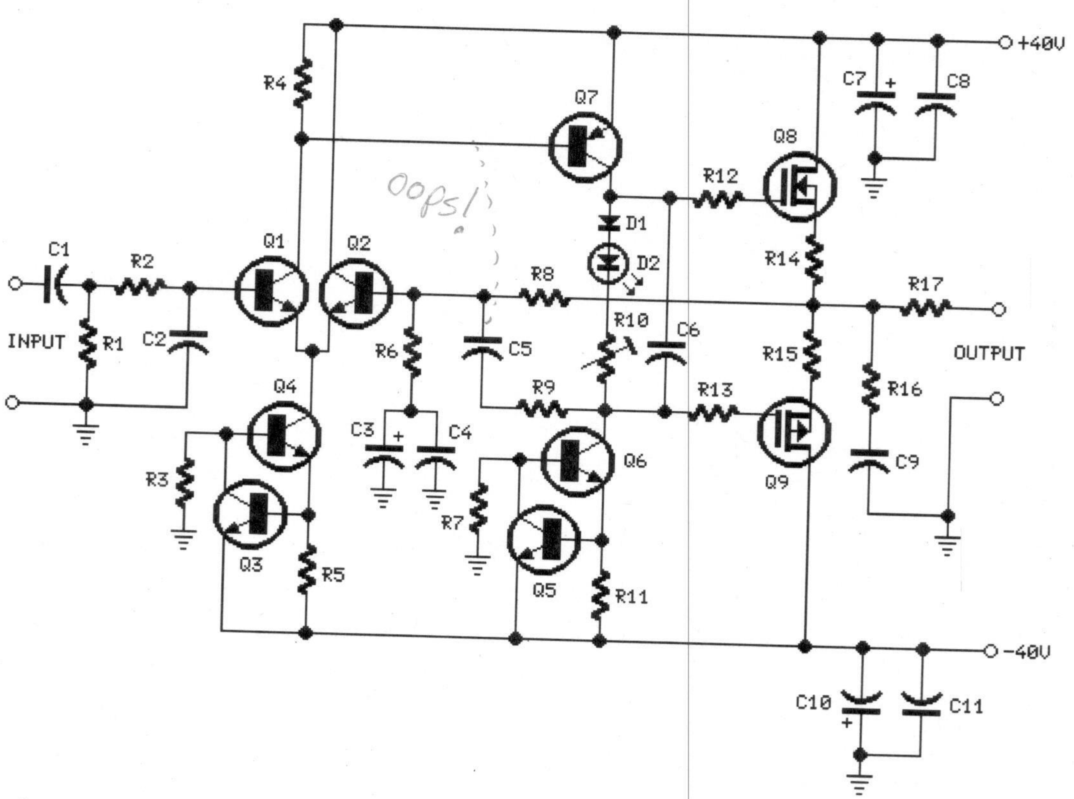
      1

   h. What is the mid-frequency feedback factor, f_{audio}?

      $R_6 / (R_6 + R_8)$

   i. What RC time constant determines the transition from low-frequency to mid-frequency?

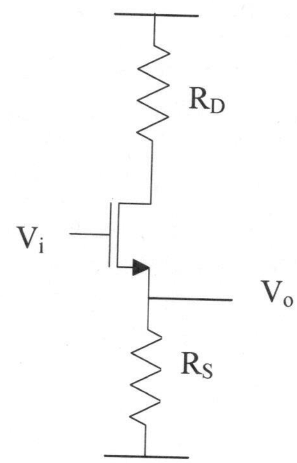
      $R_6 \cdot (C_3 + C_4)$

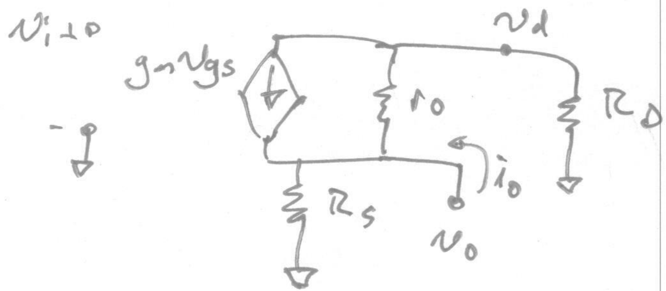


(source: eeweb.com/blog/circuit_projects)

5. For the amplifier in the figure to the right

a. [4] Draw the small signal model labeling the small signal variables v_i, v_o, i_o, v_d





b. [1] Write an expression for G_m as the ratio of two small signal parameters while a third is held equal to zero.

$$G_m = \left.\frac{i_o}{v_i}\right|_{v_o = 0}$$

c. [1] Write v_d in terms of i_o

$$v_d = i_o R_D$$

d. [4] Write KCL @ v_o and solve for G_m.

$$i_o + \frac{v_d}{r_o} + g_m (v_i - 0) = 0 \rightarrow \text{substitute (c)}$$

$$i_o + \frac{i_o R_D}{r_o} + g_m v_i = 0 \rightarrow i_o\left(1 + \frac{R_D}{r_o}\right) = -g_m v_i$$

$$\frac{i_o}{v_i} = \frac{-g_m}{\left(1 + \frac{R_D}{r_o}\right)} = \frac{-g_m r_o}{r_o + R_D} = G_m.$$

e. [3] Find the approximate value for G_m for each of three different values of R_D: much less than r_o, equal to r_o, and much greater than r_o.

R_D small: $-g_m$

R_D large: $-g_m \frac{r_o}{R_D}$

R_D equal: $-g_m/2$

f. [2] Write the full expression for R_o. (you don't need to derive it)

$$R_S \,\|\, \frac{R_D + r_o}{1 + g_m r_o}$$ → hopefully from memory!