UNIVERSITI SAINS MALAYSIA

First Semester Examination
Academic Session 2009/2010

November 2009

EEE 510 – ADVANCED ANALOGUE CIRCUIT DESIGN

Duration: 3 hours

INSTRUCTION TO CANDIDATE:

Please check that this examination paper contains **SIX (6)** pages of printed material before you begin the examination.

This paper contains **SIX (6)** questions.

Instructions: Answer **FIVE (5)** questions.

Answer to any question must start on a new page.

Distribution of marks for each question is given accordingly.

All questions must be answered in English.

…2/-

1. Refer to Figure 1

(a) What is input common mode range ? (5%)

(b) Draw a common mode feedback circuit topology and explain how you are going to control the operational amplifier output in reference to certain voltage level for instance VREF. (15%)

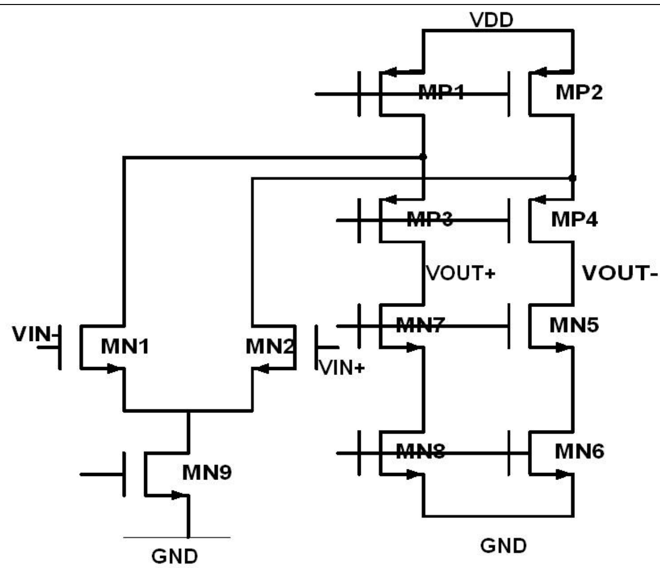

Figure 1

2. Refer to Figure 2

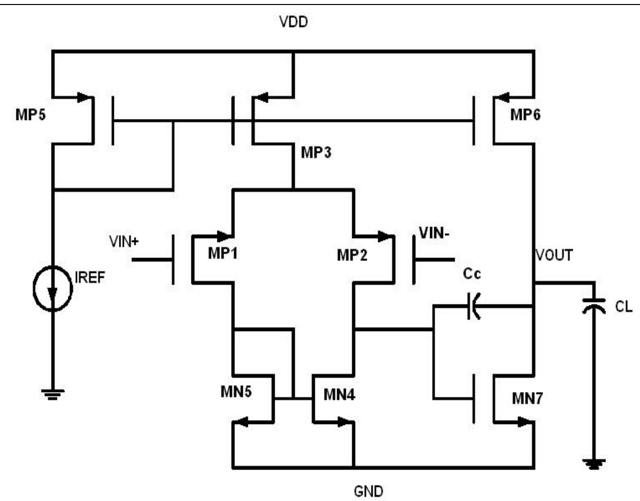

Figure 2

(a) Find expression of first dominant pole. (10%)

(b) Find the ratio of input gm first stage and second ratio if you were to place the second dominant pole 1.5 times unity frequency. Assume that Cc is equivalent to 0.5 CL. (10%)

3. State the region of operating for nmos and conditions

(a) Saturation (5%)

(b) Triode (5%)

(c) Cutoff (5%)

(d) What is the effect of threshold voltage if there exists substrate voltage. (5%)

4. (a) Proof that small-signal transfer function of small-signal differential mode half-circuit (see Figure 3) is obtained as follows.

$$A_v(s) = \frac{g_{mi}g_{mL}R_{oB}R_L(1 - s^2/(g_{mB}g_{mL}/C_BC_C))}{(1 + g_{mL}R_LR_{oB}C_Cs)(1 + (C_B(C_L + C_C)/g_{mL}C_C)s + (C_LC_B/g_{mB}g_{mL})s^2)} \qquad (1)$$

(16%)

(b) From equation [1], how many dominant pole, non-dominant pole and zeros are there?

(4%)

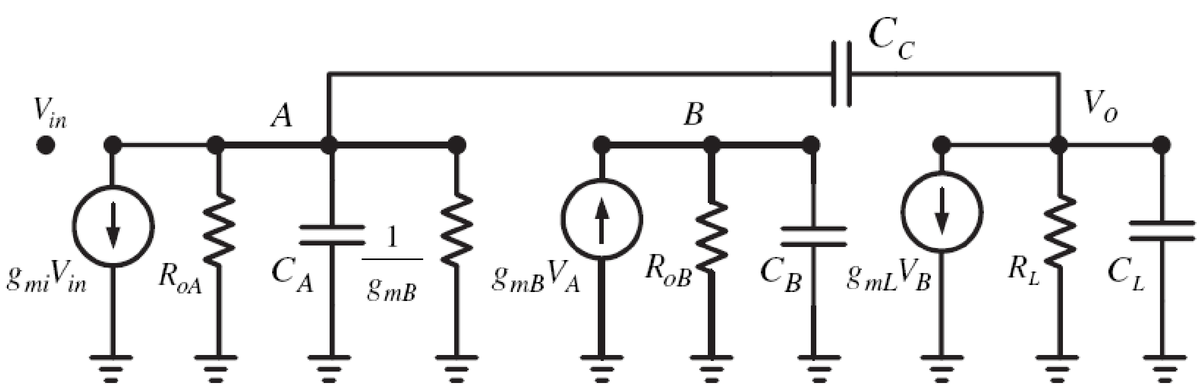

Figure 3 : Small-signal model of the differential mode half-circuit of two stage fully differential

5. (a) Draw the large signal equivalent circuit of the circuit in Figure 4. (8%)

(b) Draw the small signal equivalent circuit of the circuit in Figure 4. (8%)

(c) If R_C = 5 kΩ, I_C = 100 μA and current gain, β = 100, determine the gain, A_V of the circuit in Figure 4.

(4%)

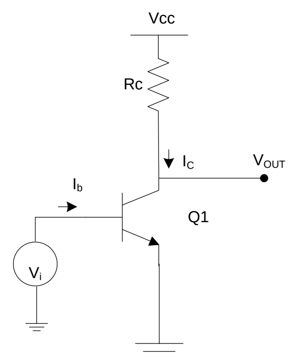

Figure 4 : Common Emitter Amplifier

6. (a) Figure 5 shows a typical Class A Bipolar amplifier. Based on the circuit, proof that the ideal efficiency of the amplifier is 25 %.

(10%).

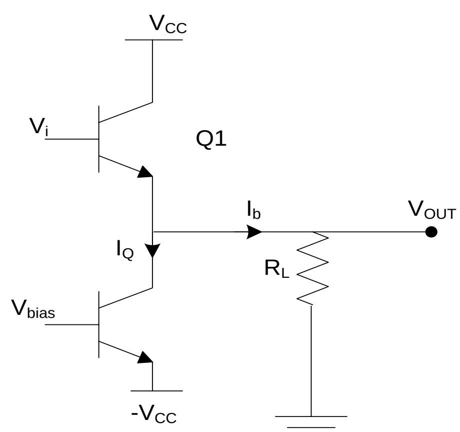

Figure 5. Class A Amplifier

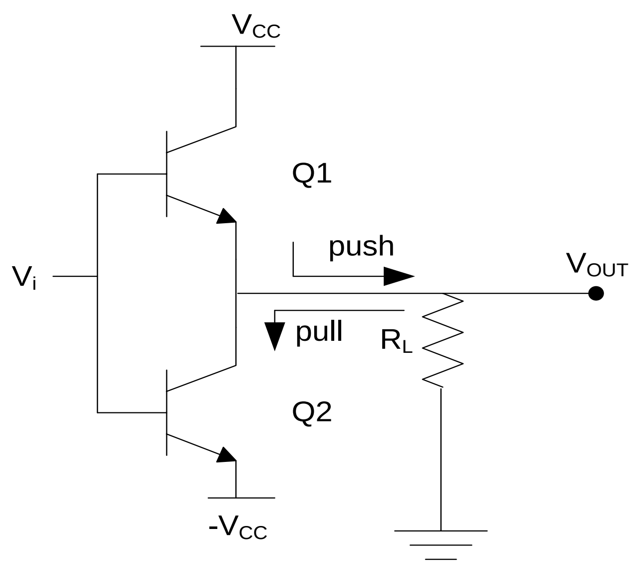

Figure 6. Class B Amplifier

(b) Figure 6 shows a typical Class B Bipolar amplifier. Based on the circuit, proof that the ideal efficiency of the amplifier is 78.6 %.

(10%)

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SOLUTIONS

Marking Scheme

1. a. Applying KCL at the two internal nodes and at output node gives three equations

$$\begin{aligned} v_o/Z_L + g_{m5}v_a &= sC_c(v_b - v_o) \\ g_{m7}v_b &= v_a/Z_A - (v_b - v_a)/r_{o7} \\ -g_{m1}v_i &= v_b/Z_B + sC_c(v_b - v_o) + (v_b - v_a)/r_{o7} + g_{m7}v_b \end{aligned}$$

where

$$\begin{aligned} Z_A &= R_{oA}/(1 + sR_{oA}C_A) \\ Z_B &= R_{oB}/(1 + sR_{oB}C_B) \\ Z_L &= R_L/(1 + sR_LC_L) \end{aligned}$$

These equations can be used to find the transfer function:

$$\frac{v_o}{v_i}(s) = G\frac{n_0 + n_1 s + n_2 s^2}{a_0 + a_1 s + a_2 s^2 + a_3 s^3}$$

$$\begin{aligned} a_0 &= 1 + \frac{R_{oA}}{g_{m7}R_{oB}r_{o7}} + \frac{1}{g_{m7}R_{oB}} + \frac{1}{g_{m7}r_{o7}} \\ a_1 &= \tau_A\left(1 + \frac{1}{g_{m7}R_{oB}} + \frac{1}{g_{m7}r_{o7}}\right) + \frac{\tau_B}{g_{m7}R_{oB}}\left(1 + \frac{R_{oA}}{r_{o7}}\right) \\ &+ \tau_L\left(1 + \frac{1}{g_{m7}R_{oB}} + \frac{1}{g_{m7}r_{o7}} + \frac{R_{oA}}{g_{m7}R_{oB}r_{o7}}\right) \\ &+ R_LC_c\left(1 + \frac{1}{g_{m7}R_{oB}} + \frac{1}{g_{m7}r_{o7}} + \frac{R_{oA}}{g_{m7}R_{oB}r_{o7}}\right) \\ &+ g_{m5}R_LR_{oA}C_c\left(1 + \frac{1}{g_{m7}r_{o7}} + \frac{1}{g_{m5}g_{m7}R_LR_{oA}} + \frac{1}{g_{m5}g_{m7}r_{o7}R_L}\right) \end{aligned}$$

$$
\begin{aligned}
a_2 &= \tau_B\tau_L\left(\frac{R_{oA}}{g_{m7}R_{oB}r_{o7}}+\frac{1}{g_{m7}R_{oB}}\right)+\tau_B R_L C_c\left(\frac{R_{oA}}{g_{m7}R_{oB}r_{o7}}+\frac{1}{g_{m7}R_{oB}}\right)\\
&+ \tau_A\tau_L\left(1+\frac{1}{g_{m7}R_{oB}}+\frac{1}{g_{m7}r_{o7}}\right)+\tau_A R_L C_c\left(1+\frac{1}{g_{m7}R_{oB}}+\frac{1}{g_{m7}r_{o7}}+\frac{1}{g_{m7}R_L}\right)\\
&+ \tau_L R_{oA} C_c\left(\frac{1}{g_{m7}r_{o7}}+\frac{1}{g_{m7}R_{oA}}\right)+\tau_B\tau_A\left(\frac{1}{g_{m7}R_{oB}}\right)\\
a_3 &= \frac{\tau_A(C_B\tau_L+C_B R_L C_c+\tau_L C_c)}{g_{m7}}\\
G &= g_{m1}g_{m5}R_{oA}R_L\\
n_0 &= 1+\frac{1}{g_{m7}r_{o7}}\\
n_1 &= -\frac{(R_{oA}+r_{o7})C_c}{g_{m5}R_{oA}g_{m7}r_{o7}}\\
n_2 &= -\frac{C_A C_c}{g_{m5}g_{m7}}
\end{aligned}
$$

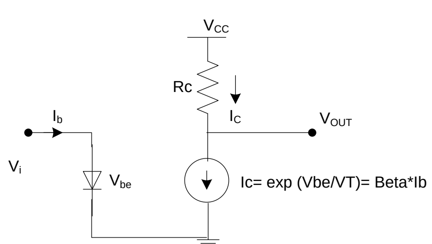
where

$$
\begin{aligned}
\tau_A &= R_{oA}C_A\\
\tau_B &= R_{oB}C_B\\
\tau_L &= R_L C_L
\end{aligned}
$$

b. one real dominant pole, two non-dominant pole and two zeros.

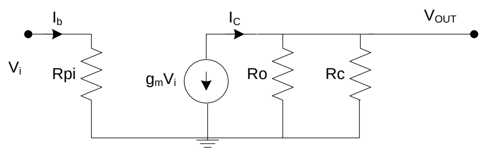
2.

a.



Students are required to explain briefly each parameters/components.

b.



Students are required to explain briefly each parameters/components.

c. Av = - gm*Rc,
gm = Ic/VT = 100 μA/ 25 mV = 4 mS
so, Av = - 4 mS* 5 kΩ = 20

3.

a.

Consider the output signal power that can be delivered to load R_L when sinusoidal input is applied at Vi. Assuming that Vo is approximately sinusoidal, the average power delivered to R_L is

P_L = (½)* Vop*Iopeak.

If the P_{Lmax} is maximum value of P_L

P_{Lmax} = (½)* Vompeak*Iompeak.

Where Vompeak = VCC-VCE(sat) and Iompeak = I_Q

Efficiency = P_L / Psupply,

Psupply = 2VCC* $I_{Q.}$

Finally, Efficiency = (½)*(VCC-VCE(sat))* I_Q / 2VCC* I_Q

We have, , Efficiency = (1/4)*(1-VCE(sat)/VCC)), because VCE(sat) <<< VCC,

Therefore Efficiency = ¼ or 25 %.

b.

Due to nature of the current waveform, integration of collector current is required to (students need to show this) establish, I_{supply} = (1/π)(Iopeak)

Thus

Psupply = $(2/\pi)$VCC* Vop / $R_{L.}$

While, the average power delivered to load R_L

P_L = (½)* Vop^2/ $R_{L.}$

Therefore, , Efficiency = $(\pi /4)$*(Vop/VCC). Student still continue further, but this expression is enough to show the efficiency is 78.6 % with some assumption.