University of Pennsylvania
Department of Electrical and Systems Engineering
ESE 319 Microelectronic Circuits

Midterm Exam #1
October 10, 2008

This exam is a closed book exam. Students are allowed to use a calculator and a single page reference sheet (two sided). Please show all work, justify all approximations and give the units for all calculated parameters.

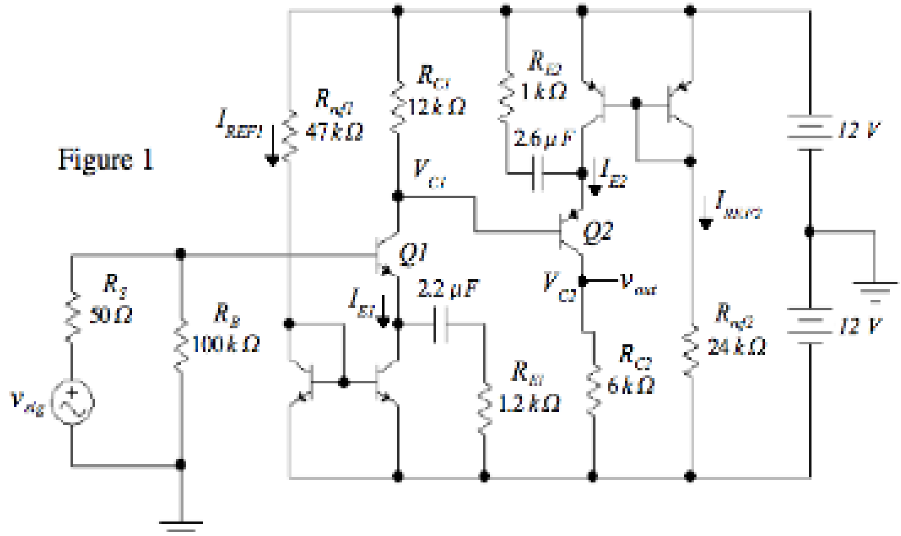


Figure 1

1. Consider the amplifier in Fig. 1 above as described in parts a) – f) below. Please make the following assumptions for transistors Q1 and Q2: $|V_{BE1}| = |V_{BE2}| = 0.7$ V, $\beta_1 = \beta_2 = \infty$, $r_{o1} = r_{o2} = \infty$, and the NPN and PNP current mirror transistors are respectively matched. In developing your answers to a) – f) below please make justifiable approximations.

a) Determine the emitter currents for Q1 and Q2, i.e. I_{E1} and I_{E2} for the amplifier in Fig. 1 (10 pts)
b) Determine the collector-to-ground voltages for Q1 and Q2 (V_{C1} and V_{C2}). (10 pts)
c) Draw the small-signal ac equivalent circuit for the amplifier in Fig.1. Use the small-signal model of your choosing to represent transistors Q1 and Q2. Calculate any small-signal model parameters needed in the equivalent circuit. (15 pts)
d) Determine the values for the mid-band gains for the Q1-stage $\{v_{c1}/v_{sig}\}$, Q2-stage $\{v_{out}/v_{c1}\}$ and the overall amplifier $\{v_{out}/v_{sig}\}$. (10 pts)
e) Determine the approximate break frequencies f_1, f_2 for stages Q1, Q2, respectively. (10 pts)
f) Estimate the value of the gain $|v_{out}/v_{sig}|$ at f = 60 Hz. (10 pts)

2. The amplifier in Fig. 1 is to be redesigned to achieve a mid-band gain that is 4x the mid-band gain achieved in Fig. 1 while keeping the operating points V_{C1}, V_{C2} and approximate break frequencies f_1, f_2 unchanged.

a) This design can be accomplished by changing the values of selected resistors in Fig.1. Using the resistor labels in Fig. 1, name the resistors that you would change to affect this design. (10 pts)
b) Determine the values for these resistors. (15 pts)
c) For the amplifier in Fig. 2 a PNP transistor was used to implement the Q2-stage in a design where it was assumed that. $\beta_1 = \beta_2 = \infty$. In practice, is this a good thing to do? Please give specific reasons for your answer. (10 pts)

SOLUTION

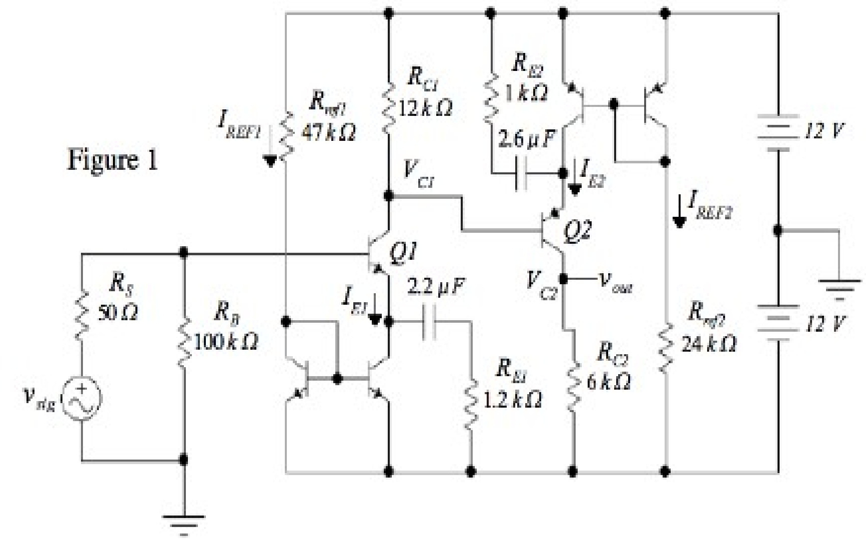


Figure 1

<u>dc analysis – tasks a) & b)</u> $(\beta 1=\beta 2=\infty \Rightarrow I_{B1}=I_{B2}=0 \Rightarrow I_{C1}=I_{E1}, I_{C2}=I_{E2})$

<u>I_{REF1}</u>: $12\,V=I_{REF1}R_{ref1}+V_{BE1}-12\text{V} \Rightarrow I_{REF1}=\dfrac{24\,V-V_{BE1}}{R_{ref1}}=\dfrac{24\,V-0.7\,V}{47\,k\Omega}=0.49\,mA$

I_{REF2}: $12\,V=V_{EB2}+I_{REF2}R_{ref2}-12\text{V} \Rightarrow I_{REF2}=\dfrac{24\,V-V_{EB2}}{R_{ref1}}=\dfrac{24\,V-0.7\,V}{24\,k\Omega}=0.97\,mA$

<u>I_{E1} & I_{E2}</u>: Since $\beta_1=\beta_2=\infty$ and $r_{01}=r_{02}=\infty$ then $\boxed{I_{E1}=I_{ref1}=0.49\,mA \quad \& \quad I_{E2}=I_{ref2}=0.97\,mA}$

Also $g_{m1}=\dfrac{I_{C1}}{V_T}=\dfrac{I_{E1}}{V_T}=\dfrac{0.49\,mA}{25\,mV}=0.02\,A/V=20\,mS$ &

$g_{m2}=\dfrac{I_{C2}}{V_T}=\dfrac{I_{E2}}{V_T}=\dfrac{0.97\,mA}{25\,mV}=0.039\,A/V=39\,mS$

<u>V_{C1}</u>: $12\,V=I_{C1}R_{C1}+V_{C1} \Rightarrow V_{C1}=12\,V-I_{C1}R_{C1}=12\,V-I\,E1\,R_{C1}=12\,V-5.88\,V=6.12\,V$

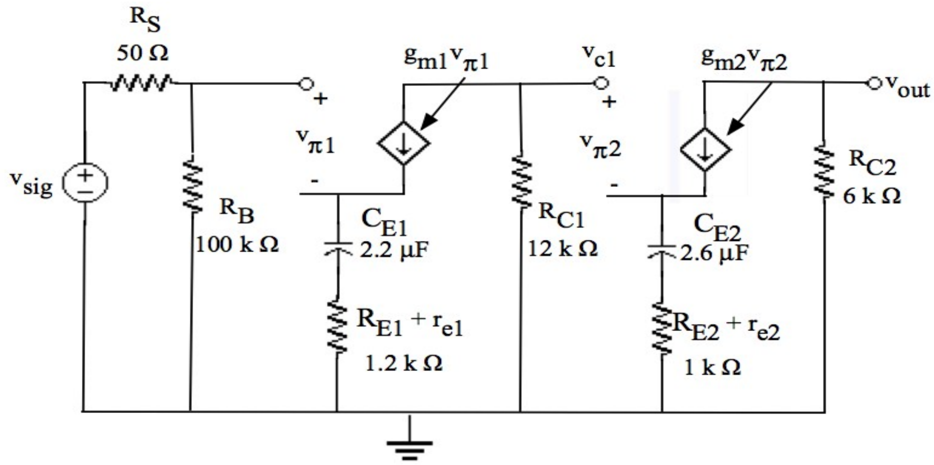
$\boxed{V_{C1}=6.12\,V}$

<u>V_{C2}</u>:

$-12\,V=-I_{C2}R_{C2}+V_{C2} \Rightarrow V_{C2}=-12\,V+I_{C2}R_{C2}=-12\,V+I_{E2}R_{C2}=-12\,V+5.82\,V=-6.18\,V$

$\boxed{V_{C2}=-6.12\,V}$

ac- analysis – tasks c – f



With $\beta_1=\beta_2=\infty \Rightarrow r_{e1}=\frac{\beta_1}{1+\beta_1}\frac{1}{g_{m1}}=\frac{1}{g_{m1}}=\frac{1}{20\,mS}=50\,\Omega$ & $r_{e2}=\frac{1}{g_{m2}}=\frac{1}{39\,mS}=24.6\,\Omega$

Hence, $R_{E1}+r_{e1}\approx R_{E1}=1.2\,k\,\Omega$ & $R_{E2}+r_{e2}\approx R_{E2}=1\,k\,\Omega$

mid-band analysis d) : C_{E1} and C_{E2} are short circuits

$$v_{sig}=v_{\pi 1}+g_{m1}v_{\pi 1}R_{E1}=(1+g_{m1}R_{E1})v_{\pi 1}$$

$$v_{c1}=-g_{m1}R_{C1}v_{\pi 1}=\frac{-g_{m1}R_{C1}v_{sig}}{1+g_{m1}R_{E1}}\Rightarrow\frac{v_{c1}}{v_{sig}}=\frac{-g_{m1}R_{C1}}{1+g_{m1}R_{E1}}\approx\frac{-R_{C1}}{R_{E1}}=-10$$

$$g_{m1}R_{E1}=20\,mS*1.2\,k\,\Omega=24\gg 1$$

$$v_{c1}=v_{\pi 2}+g_{m2}v_{\pi 2}R_{E2}=(1+g_{m2}R_{E2})v_{\pi 2}$$

$$v_{out}=v_{c2}=-g_{m2}R_{C2}v_{\pi 2}=\frac{-g_{m2}R_{C2}v_{c1}}{1+g_{m2}R_{E2}}\Rightarrow\frac{v_{out}}{v_{c1}}=\frac{-g_{m2}R_{C2}}{1+g_{m2}R_{E2}}\approx\frac{-R_{C2}}{R_{E2}}=-6$$

$$g_{m2}R_{E2}=39\,mS*1\,k\,\Omega=39\gg 1$$

$$G=\frac{v_{out}}{v_{sig}}=\frac{v_{c1}}{v_{sig}}\frac{v_{out}}{v_{c1}}=-10*-6=60$$

Low-frequency analysis e) and f):

$$v_{sig}=v_{\pi 1}+g_{m1}v_{\pi 1}(R_{E1}+\frac{1}{sC_E})=(1+g_{m1}(R_{E1}+\frac{1}{sC_E}))v_{\pi 1}$$

$$v_{c1} = -g_{m1} R_{C1} v_{\pi 1} = \frac{-g_{m1} R_{C1} v_{sig}}{1 + g_{m1}(R_{E1} + \frac{1}{sC_{E1}})} \Rightarrow \frac{v_{c1}}{v_{sig}} = \frac{-g_{m1} R_{C1}}{1 + g_{m1}(R_{E1} + \frac{1}{sC_{E1}})} \approx \frac{-R_{C1}/R_{E1} s}{s + \frac{1}{R_{E1} C_{E1}}}$$

$$v_{out} = -g_{m2} R_{C2} v_{\pi 2} = \frac{-g_{m2} R_{C2} v_{out}}{1 + g_{m2}(R_{E2} + \frac{1}{sC_{E2}})} \Rightarrow \frac{v_{out}}{v_{c1}} = \frac{-g_{m1} R_{C2}}{1 + g_{m2}(R_{E2} + \frac{1}{sC_{E2}})} \approx \frac{-R_{C2}/R_{E2} s}{s + \frac{1}{R_{E2} C_{E2}}}$$

$$f_1 = \frac{1}{2\pi R_{E1} * 2.2\,\mu F} = 60.3\ Hz \quad \text{and} \quad f_2 = \frac{1}{2\pi R_{E2} * 2.6\,\mu F} = 61.2\ Hz$$

g) With $f_1 \approx f_2 \approx 60\ Hz$ the overall voltage gain has a double pole near 6o Hz. If there were a single break-point at 60 Hz the gain would be -3 dB or $1/\sqrt{2}$ the mid-band gain. With two brek-points at near 60 Hz the gain is – 6 db or ½ the mid-band gain. Hence, the gain at 60 Hz is at

$$G(f = 60\text{Hz}) \approx \frac{G}{2} = 30$$

2. The amplifier in Fig. 1 is to be redesigned to achieve a mid-band gain that is 4x the mid-band gain achieved in Fig. 1 while keeping the operating points V_{C1}, V_{C2} and approximate break frequencies f_1, f_2 unchanged.

a) This design can be accomplished by changing the values of selected resistors in Fig.1. Using the resistor labels in Fig. 1, name the resistors that you would change to affect this design. (10 pts)
b) Determine the values for these resistors. (15 pts)
c) For the amplifier in Fig. 2 a PNP transistor was used to implement the Q2-stage in a design where it was assumed that. $\beta_1 = \beta_2 = \infty$. In practice, is this a good thing to do? Please give specific reasons for your answer. (10 pts)

a) To increase the mid-band gain achieved in Fig. 1 by 4x (quadruple the gain) while leaving unchanged the operating points and break frequencies, the design options are to increase the values of R_{C1} and/or R_{C2} to increase the gain and increasing R_{ref1} and/or R_{ref2} in concert to reduce the bias currents in a manner that keep V_{C1} and V_{C2} constant.

b) To quadruple the overall gain G, lets increase R_{C1} , R_{C2} by 2x to increase the overall gain by 4x, i.e.

$$R_{C1} = 2*12\,k\Omega = 24\,k\Omega \quad \text{and} \quad R_{C2} = 2*6\,k\Omega = 12\,k\Omega$$

and increase R_{ref1}, R_{ef2} by 2x to ½ the two bias currents, i.e.

$$R_{ref1} = 2*47\,k\Omega = 94\,k\Omega \quad \text{and} \quad R_{ref2} = 2*24\,k\Omega = 48\,k\Omega$$

c) It is not recommended to use a PNP BJT as an amplifying transistor because its actual β and unity-gain bandwidth f_T are much smaller than those for a comparable NPN transistor.