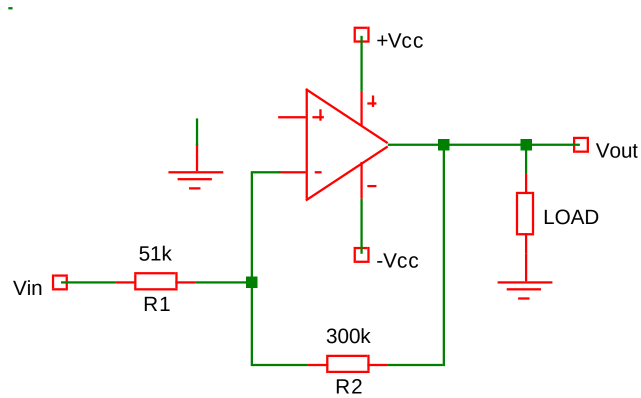
ECE 363 QUIZ 2 NAME: Solution

Problem #1: Real Op Amp Analysis

Consider an inverting amplifier using a LM318 op amp (see attachment and use values for 25°C). The (+) input is directly wired to ground.



(a) Suppose $V_{IN} = 0$ and no trimming network. Given the worst-case values for $I_{in(bias)}$, $I_{in(offset)}$, and $V_{in(offset)}$, compute the output voltage offset due to each parameter.

(b) Is the main source of error due to input bias current, input offset current, or input offset voltage?

(c) What is the worst-case output voltage offset?

a) from datasheet $I_{IN(Bias)} = 500nA$, $I_{IN(os)} = 200nA$, $V_{In(os)} = 10mV$

$R_{TH}(-) = 51k \| 300k = 43.6k\Omega$ $\quad G = -\frac{300k}{51k} = -5.88$

$R_{TH}(+) = 0\Omega$

$I_{IN(Bias)} \rightarrow \Delta V_{in} = (500nA)(43.6k - 0) = 0.0218V$

$\Delta V_{out} \cong (5.88)(0.0218V) = 0.128V = \boxed{128mV}$

$I_{IN(os)} \rightarrow \Delta V_{IN} = (200nA)\left(\frac{43.6k+0}{2}\right) = 0.00436V$

$\Delta V_{out} \cong (5.88)(4.36mV) = \boxed{25.6mV}$

$V_{in(os)} \rightarrow \Delta V_{in} = 10mV$

$\Delta V_{out} = (5.88)(10mV) = \boxed{58.5mV}$

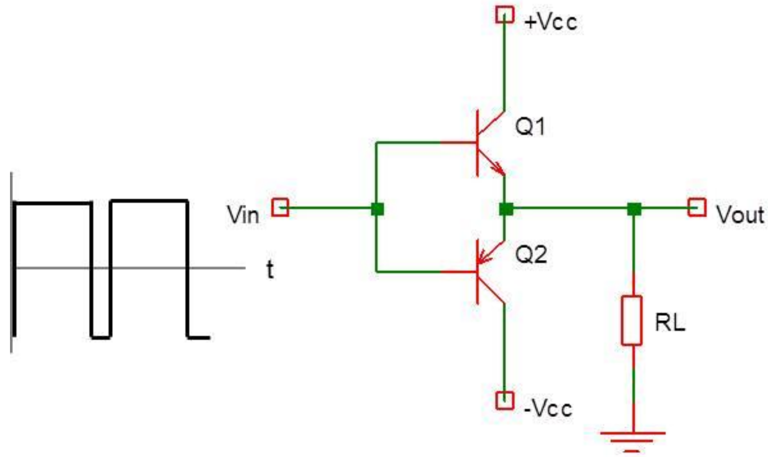
b) main source of error is input bias current.

c) worst-case output offset = 128 + 25.6 + 58.8
$= \boxed{212.4mV}$

Problem #2: Current Booster Analysis

Suppose V_{IN} is a 80% duty cycle square wave that alternates between +6V (HIGH) and -6V (LOW). The load is R_L = 50 ohm. Both transistors have $V_{BE,ON}$ = 0.75V, $V_{CE,SAT}$ = 0.4V, and β = 80.

(a) You must choose between V_{CC} = 6, 9, or 12V. Which is the best choice?
(b) Sketch V_{IN}, V_{OUT}, i_{E1} (Q1 emitter current), and i_{E2} (Q2 emitter current). Label important features.
(c) Given your choice of V_{CC}, estimate the power dissipation in Q1 and Q2.

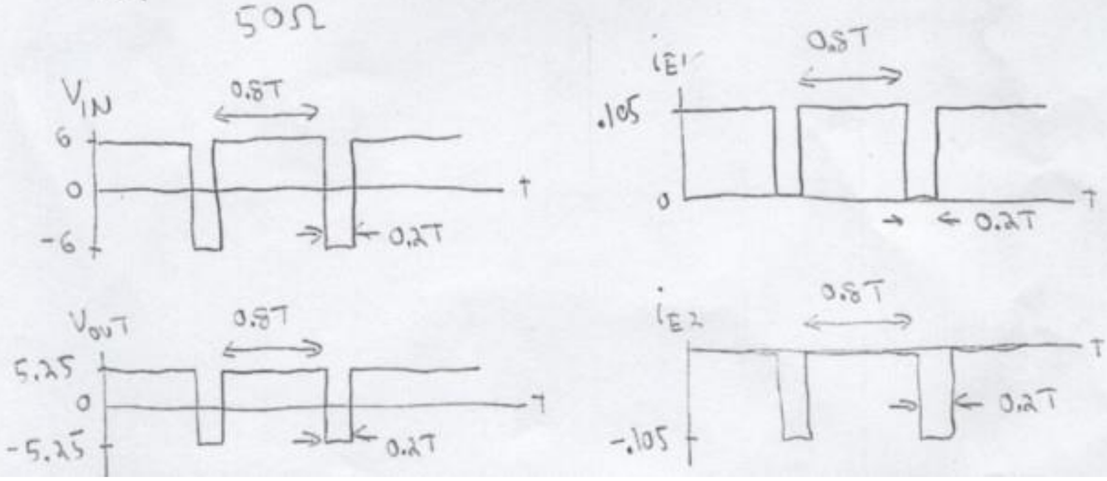


(a) When $V_{IN} = +6V \Rightarrow Q_1$ is on $\Rightarrow V_{OUT} = 6 - 0.75 = 5.25V$

Need $V_{CE} > V_{CE,SAT} + 2V$ ($V_{CE,SAT}$ = 0.4V; 2V = Headroom)

$V_{CC} - 5.25 > 2.4 \Rightarrow V_{CC} > 7.65V$ Choose $V_{CC} = 9V$

(b) $I_{OUT} = \frac{5.25V}{50\Omega} = .105A$



(c) Q_1: When on, $i_E V_{CE} = (.105A)(9-5.25) = 0.394\ W \leftarrow 80\%$ of time

$$\langle P_1 \rangle = \frac{1}{T}\int_0^{0.8T}(0.394W)\,dt + \frac{1}{T}\int_{0.8T}^{T} 0\,dt \rightarrow 0$$

$= 0.394W \times 0.8$

$= 0.315\ W = \boxed{315\ mW}$

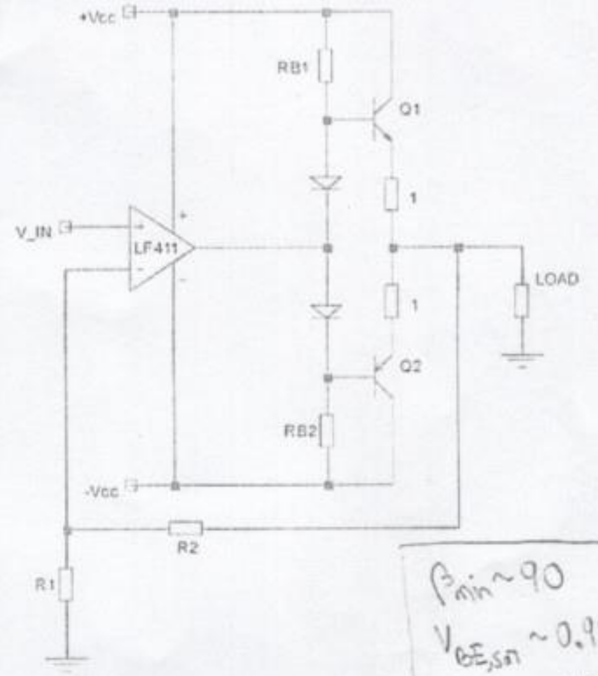
Q_2: When on, $i_E V_{CE} = 0.394W \leftarrow 20\%$ of time

$\langle P_2 \rangle = 0.394 \times 0.2 = .0788\ W = \boxed{78.8\ mW}$

Problem #3: Class AB Design

Design a non-inverting voltage amplifier to drive up to 150 mW (or slightly higher) into a 32 ohm load. The input signal is a sine wave with a maximum amplitude of 1V_{PP}. The suggested schematic is shown in the figure, where an LF411 op amp is used. Q1 is a 2N4401, and Q2 is a 2N4403.

(a) V_{CC} must be 4.5, 6, 9, or 12V. Choose one and explain why.
(b) Choose RB1 and RB2. Pick standard 5% values.
(c) Show that the op amp can provide the required output voltage and current.
(d) Choose R1 and R2. Remember that R1 should be more than a few kohm and R2 is typically less than 1 Mohm. Pick standard 5% values.
(e) Do your transistors need heat sinks? Use T_A = 60°C for your power rating calculations.



$\beta_{min} \sim 90$
$V_{BE,sat} \sim 0.95V$
$V_{CE,sat} \sim 0.4V$

(a) Max output? $0.150W = \frac{V_{MAX}^2}{2 \cdot 32\Omega}$ (for sine wave) $\Rightarrow V_{MAX} = \pm 3.1V$

$I_{MAX} = \frac{3.1V}{32\Omega} = .0968A$

Max $V_E = (.0968A)(1 + 32\Omega) = 3.2V$

Need $V_{cc} - V_E > V_{CE,sat} + 2 \Rightarrow V_{cc} > 5.6V$

(V_E = 3.2V, $V_{CE,sat}$ = 0.4V, 2 = Headroom)

Choose $V_{cc} = 6V$

(b) $\frac{V_{cc} - V_{B1,max}}{R_B} > 1mA + i_{B1,max}$

(V_{cc} = 6V, $V_{B1,max}$ = 3.2+.95 = 4.15V, $i_{B1,max} = \frac{96.8mA}{90+1}$)

$\frac{6-4.15V}{R_B} > 1mA + 1.064mA \rightarrow R_B < 0.896k$ Choose $R_{B1} = R_{B2} = 820\Omega$

(c) Max $V_{op\,amp} = V_{B1,max} - 0.7 = 4.15 - 0.7 = \underline{3.45\,V}$

$$\text{Max } I_{op\,amp} = \frac{3.45\,V}{R_{IN,AB}}$$

$$R_{IN,AB} = \underbrace{(820 \parallel 820)}_{410\Omega} \parallel \underbrace{(90+1)\left(\frac{.026V}{.0968A} + 1 + 32\right)}_{3027.4\Omega} = \underline{\underline{361.1\,\Omega}}$$

$$\text{Max } I_{op\,amp} = \frac{3.45V}{361.1\Omega} = .00955A = \underline{\underline{9.6\,mA}}$$

According to LF411 datasheet, $V_{cc} = 15V$, $V_o = 13.5V$ @ 13.5mA ($R_L = 1K$)

1.5 V difference

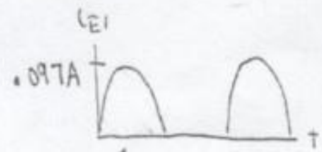
→ $V_{cc} = 6V$, $V_o = \underline{\underline{4.5V}}$ @ $\underline{\underline{13.5mA}}$

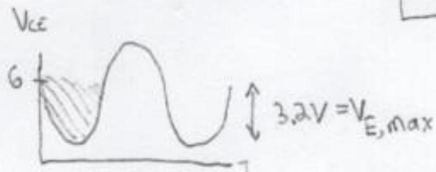
YES, op amp is OK

(d) Desired $G = \frac{3.1V}{0.5V} = 6.2 = 1 + \frac{R_2}{R_1} \rightarrow \frac{R_2}{R_1} = 5.2$

Choose $\boxed{R_2 = 68K, \; R_1 = 13K}$ } $G = 6.23$

(e)





$.097 \sin 2\pi f t$ $\quad\quad$ $6 - 3.2 \sin 2\pi f t$

$$\langle P \rangle = \frac{1}{T}\int_0^{T/2} 0.582 \sin 2\pi f t\, dt - \frac{1}{T}\int_0^{T/2} 0.31 \sin^2 2\pi f t\, dt = .582 \times \frac{1}{\pi} - 0.31 \times \frac{1}{4} = \underline{\underline{0.108\,W}}$$

$2\langle P \rangle = \boxed{0.216\,W}$

$P_{MAX} = 625\,mW - 5\frac{mW}{°C} \times (60-25) = \underline{\underline{450\,mW}}$ } $216mW < 450mW$ ✓ **No heat sink needed**