Homework #2 (8 problems)
ECE 363
Fall 2017
Due Oct 03

A. Unidirectional Current Booster Analysis

1) Consider the current booster shown in Fig. 1. The input voltage is V_{IN} = 500 mV and the load is R_L = 75 ohm. Assume an ideal op amp with +/-V_{CC}=+/-9V. The transistor has $V_{BE,ON}$ = 0.7V and β = 100.

(a) Compute V_{OUT} and I_{LOAD}.
(b) Compute the op amp output current. Express your answer in mA.
(c) Compute the transistor power dissipation in mW. Express your answer in mW.
(d) Suppose the transistor has a power rating of 625 mW @ T_A=25°C and a derating factor of 5 mW/°C. Assuming T_A = 60°C, determine whether or not the transistor needs a heat sink.

2) Consider the current booster shown in Fig.2. The input is a 10V_{PP} triangle wave and the load is R_L = 100 ohm. Assume an ideal op amp with +/-V_{CC} = +/-15V. The transistor has $V_{BE,ON}$ = 0.7V and β = 100.

(a) Sketch V_{IN}, V_{OUT}, and I_{LOAD}. Label important features (e.g. maximum and minimum V_{OUT}).
(b) Sketch the instantaneous power dissipation of Q1. In other words, sketch P = $i_E v_{CE}$ versus time. Label important features (e.g. maximum and minimum power).
Hint: Remember that the product of two linear functions is a quadratic function!

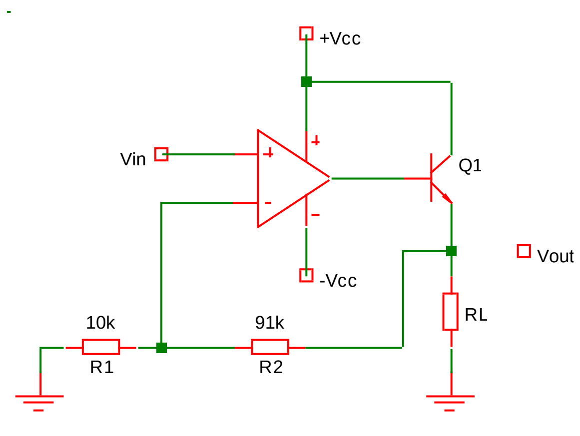


Fig. 1: V_{IN} is a constant voltage.

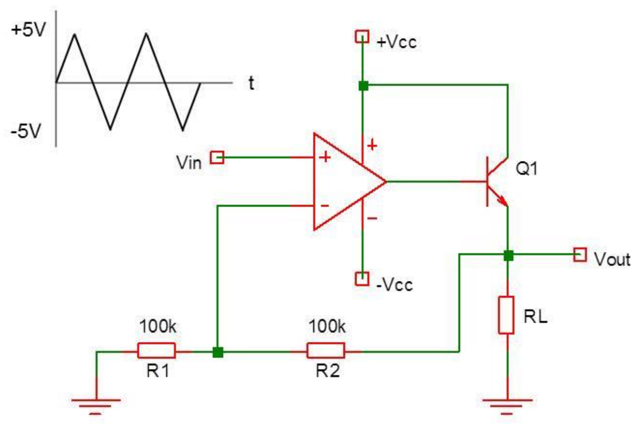


Fig. 2: V_{IN} is a triangle wave.

B. Class B Analysis

3) We've seen how a Class B push-pull stage suffers from crossover distortion for *analog* signals. However, it works very well for *digital* signals. Suppose V_{IN} is a 25% duty cycle square wave that alternates between +13V (HIGH) and -13V (LOW). The load is R_L = 1 kohm. Both transistors have $V_{BE,ON}$ = 0.7V, $V_{CE,SAT}$ = 0.3V, and β = 100.

(a) You must choose between V_{CC} = 12, 15, or 18V. 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.

4) Consider the push-pull current booster shown in Fig. 4. The input voltage is a 1 V_{PP} sine wave, the load is R_L = 75 ohm, and the power supplies are +/-V_{CC}=+/-9V. Both transistors have $V_{BE,ON}$ = 0.7V and β = 100. Both transistors have a power rating of 625 mW @ T_A=25°C and a derating factor of 5 mW/°C.

(a) Sketch V_{IN}, V_{OUT}, i_{E1}, and i_{E2}. Label important features (e.g. maximum and minimum V_{OUT}).
(b) Sketch the op amp output voltage versus time. Label important features.
(c) Compute the power dissipation of Q1. Express your answer in mW. It should be around 100 mW.
(d) Assuming T_A = 60°C, determine whether or not the transistors need a heat sink.

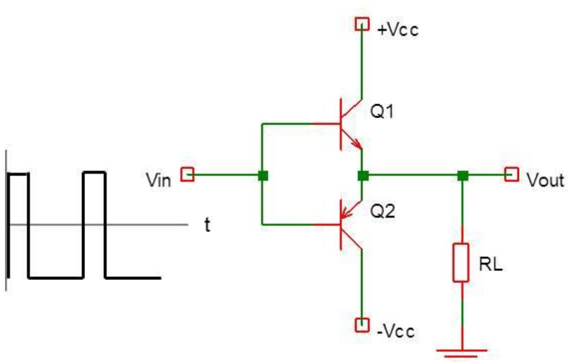


Fig. 3: V_{IN} is a 25% duty cycle square wave.

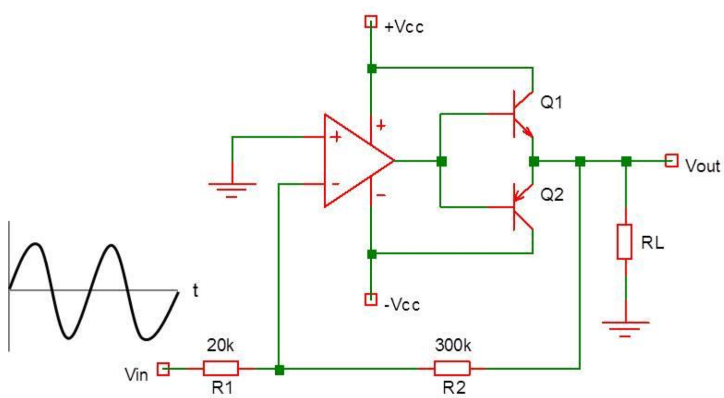


Fig. 4: V_{IN} is a sine wave.

C. Class AB Analysis

5) Consider the push-pull stage shown in Fig. 5. V_{IN} is a $12V_{PP}$ sine wave. The power supplies are +/- V_{CC} = +/- 8V. Both diodes have V_F = 0.7V. Both power transistors have $V_{BE,ON}$ = 1.2V, $V_{CE,SAT}$ = 1V, and β = 40. Both transistors have a power rating of 2W @ T_A=25°C and a derating factor of 16 mW/°C.

(a) Compute the minimum R_L that can be driven without distortion (i.e. no transistor saturation or cut-off). Make sure the biasing diodes have at least 1 mA of current.
HINT #1: See the posted Lecture 3 notes (page 3.12) for the more rigorous way to compute the minimum R_L.
HINT #2: You should get a value near 10 ohm.

(b) Assuming T_A = 60°C, determine whether or not the transistors need a heat sink when R_L is minimum.

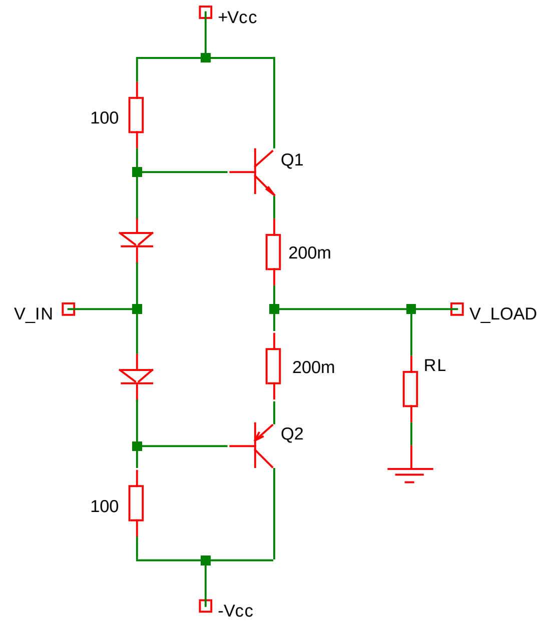
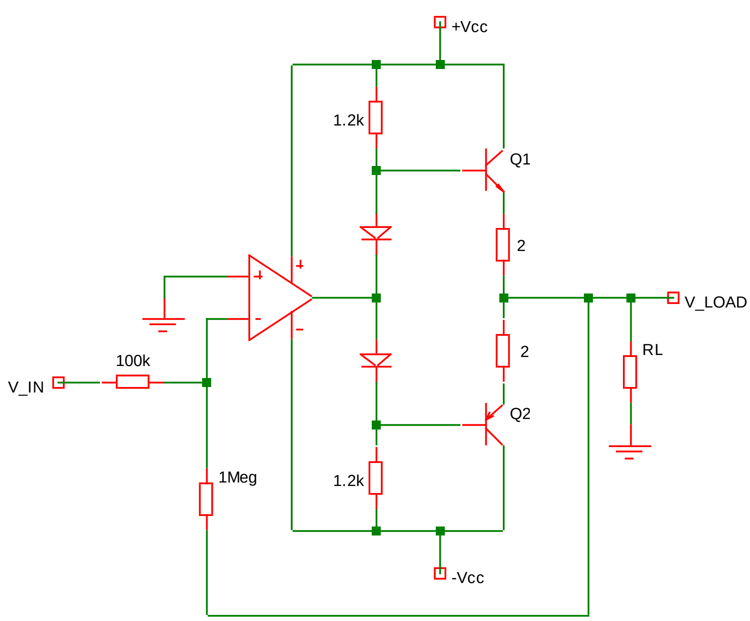


Fig. 5: V_{IN} is a 12 V_{PP} sine wave.

6) Consider the Class AB current booster in Fig. 6. The input voltage is a $1V_{PP}$ sine wave at 2 kHz, the minimum load is R_L = 50 ohm. The op amp output swing is shown in the plot below. Both diodes have V_F = 0.7V. Both transistors have $V_{BE,ON}$ = 0.7V, $V_{CE,SAT}$ = 0.3V, and β = 100.

(a) Compute the maximum load voltage and current (i.e. assume the entire circuit works properly).
(b) What is the minimum V_{CC} necessary to provide enough base current to Q1 when V_{LOAD} is maximum?
(c) Compute the peak op amp output current.
(d) You must choose between V_{CC} = 6, 9, 12, or 15V. Explain your choice.



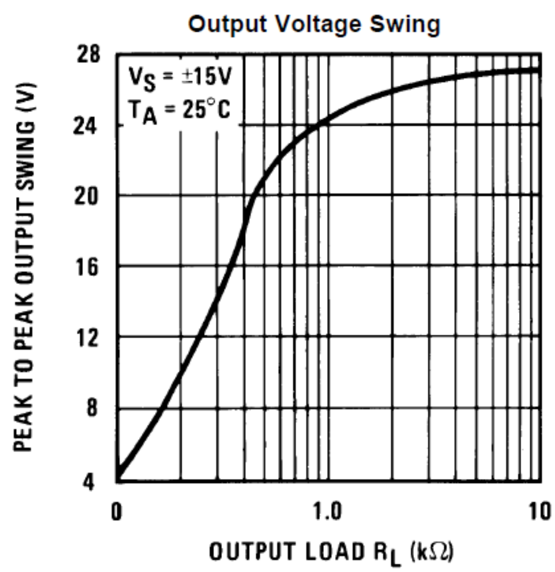


Fig. 6: (Left) Op amp with Class AB output stage. (Right) Op amp max output swing.

D. Class AB Design

7) Design an inverting voltage amplifier to drive up to 200 mW (or slightly higher) into a 50 ohm load. The input signal is a sine wave with a maximum amplitude of $1V_{PP}$. The input impedance must be $R_{IN} \geq 10$ kohm. The suggested schematic is shown in Fig. 7, where an LF356 op amp is used.

(a) Q1 must be a 2N3904, 2N4401, or TIP31A transistor. **Choose one and explain why**.
NOTE: The pnp versions are 2N3906, 2N4403, and TIP32A.

(b) V_{CC} must be 4.5, 6, 9, or 12V. **Choose one and explain why.**
NOTE: The 2V headroom is a "soft" rule, so it is OK if you reduce it by half a volt or so.

(c) Choose RB1 and RB2. Pick standard 5% values.

(d) Show that the op amp can provide the required output voltage and current. **If it does not, then you must increase V_{CC} to a higher value and repeat part (c) and (d).**

(e) Choose R1 and R2. Remember that R_{IN} = R1for an inverting amplifier. R2 should be kept below 1 Mohm. Pick standard 5% values.

(f) Do your transistors need heat sinks? Use $T_A = 60°C$ for your power rating calculations.

8) Design a non-inverting voltage amplifier to drive a DC motor rated at 5V @ 100 mA. The input signal is a DC voltage between -0.5V and +0.5V. The suggested schematic is shown in Fig. 8, where an LF411 op amp is used.

(a) Q1 must be a 2N3904, 2N4401, or TIP31A transistor. **Choose one and explain why**.
NOTE: The pnp versions are 2N3906, 2N4403, and TIP32A.

(b) V_{CC} must be 4.5, 6, 9, or 12V. **Choose one and explain why.**
NOTE: The 2V headroom is a "soft" rule, so it is OK if you reduce it by half a volt or so.

(c) Choose RB1 and RB2. Pick standard 5% values.

(d) Show that the op amp can provide the required output voltage and current. **If it does not, then you must increase V_{CC} to a higher value and repeat part (c) and (d).**

(e) Choose R1 and R2. Typically, R1 ≥ 1 kohm and R2 ≤1 Mohm. Pick standard 5% values.

(f) Do your transistors need heat sinks? Use $T_A = 60°C$ for your power rating calculations.

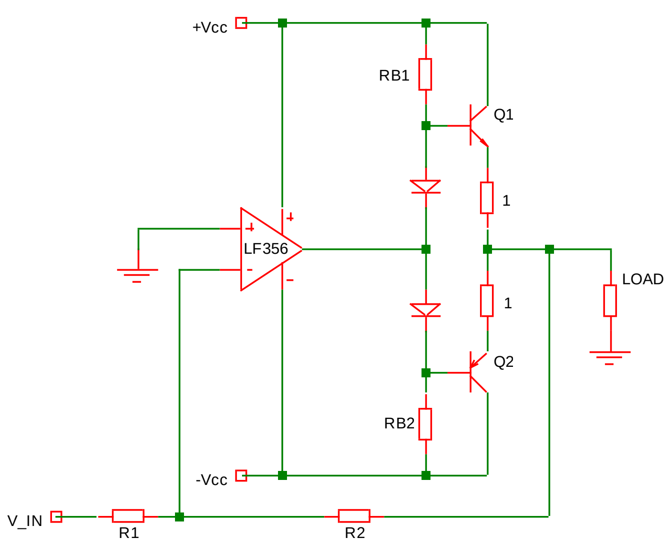


Fig. 7: Voltage amplifier using an LF356 op amp.

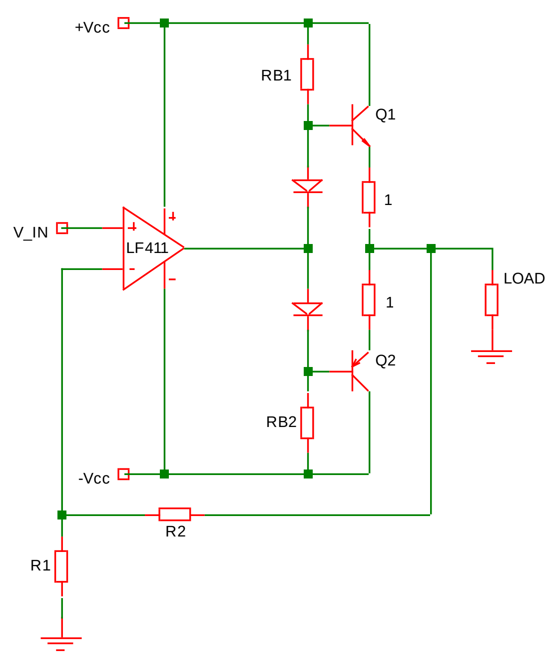


Fig. 8: Voltage amplifier using an LF411 op amp.