Last Update: 03/16/2022
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Added Coupling Cap to Emitter Follower in Prelab.
Changed to Inverting Configuration.

ECE 2201 – PRELAB 7x

BJT APPLICATIONS

A 3-STAGE 5W AUDIO AMPLIFIER

UTILIZING

NEGATIVE FEEDBACK

INTRODUCTION

Figure P7-1 shows a ***simplified*** schematic of a 3-stage audio amplifier utilizing three BJT amplifier building blocks – a Differential Pair, a Common-Emitter Amplifier (with active current source load) and an Emitter Follower. Each stage is biased by a constant current source, and a feedback network is used to set the overall gain of the amplifier.

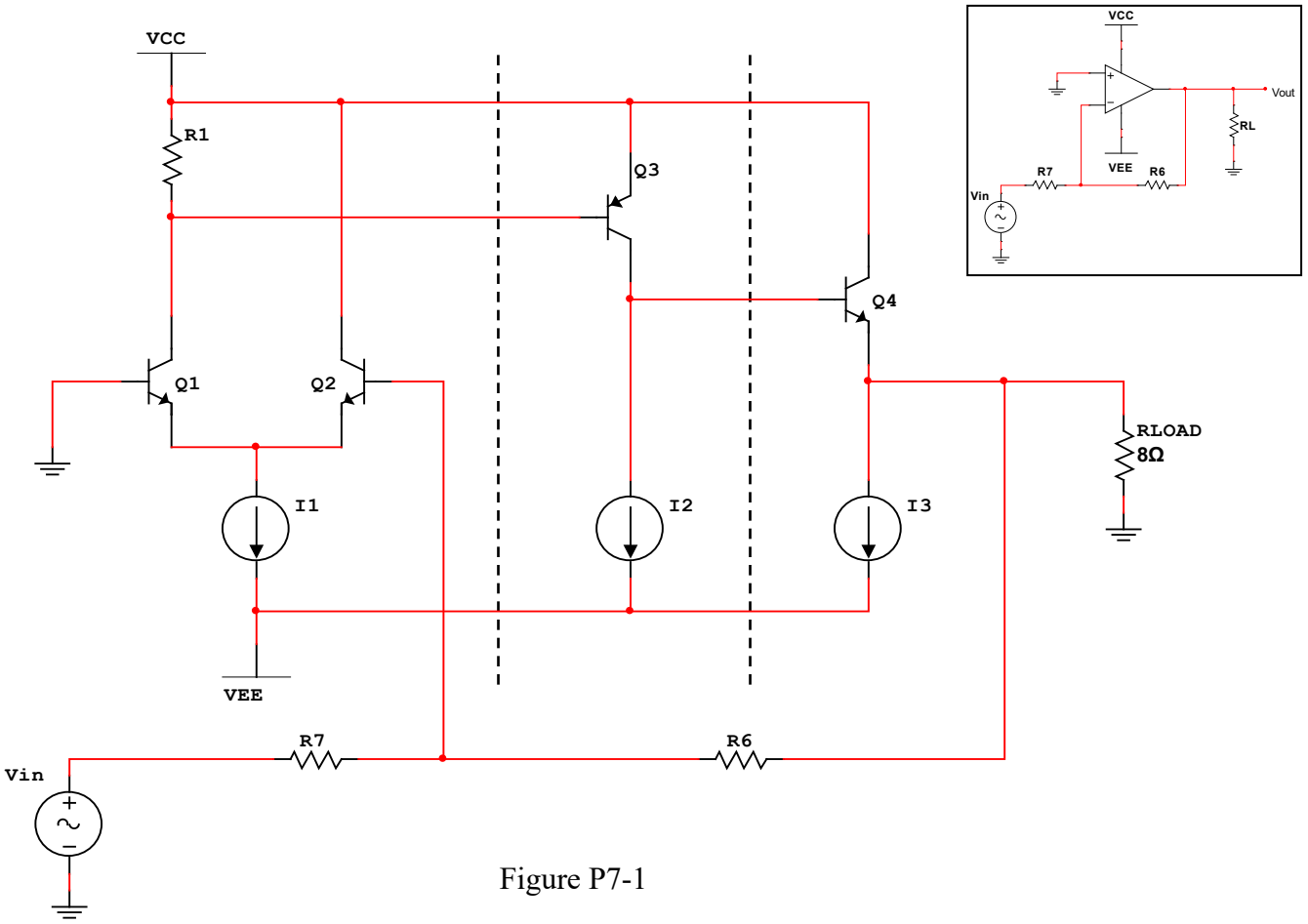

Figure P7-1

The input signal v_{in} represents any line-level audio signal generated by a function generator, guitar pick-up or mp3 player. The resistive load represents an 8Ω audio speaker.

The purpose of this pre-lab assignment will be to understand the operation of this amplifier and to determine component values for each stage.

STAGE1: THE DIFFERENTIAL PAIR

The first stage in this audio amplifier is the differential-pair circuit of Figure P7-2.

a) DC BIAS

Determine values for the resistances R_{1A}, R_{1B}, and R_2 to achieve the following bias voltages and currents (assume $\beta = 100$ for each transistor). HINTS: Apply superposition and symmetry.

- $I_{BIAS} \approx 500\mu A$
- $V_{O1} = V_{O2} \approx 9.3V$

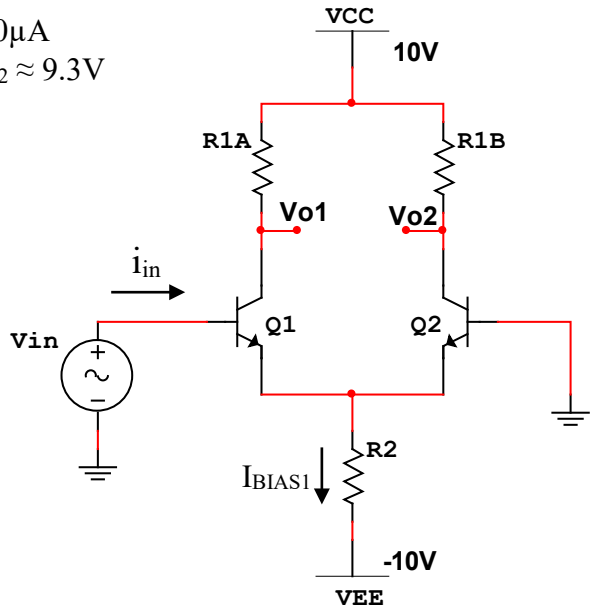

Figure P7-2

b) SMALL SIGNAL ANALYSIS

Now using small-signal analysis find the following:

- Small-signal voltage gains v_{O1}/v_{in} and v_{O2}/v_{in}.
- Differential output gain $(v_{O1}-v_{O2})/v_{in}$.
- Small-signal input resistance *Rin* at the input to the amplifier.

NOTE: In this example, since one of the inputs is tied to ground, the bias current I_{BIAS1} will remain fairly constant. Therefore, R_2 may be replaced with an *open circuit* in the small-signal ac model. Also, since only one single-ended output is required to drive the next stage, one of the collector resistors may be replaced with a short circuit without affecting the performance of this amplifier.

c) SIMULATION

Produce graphs of $v_{O1}(t)$, $v_{O2}(t)$ and for $v_{O1}(t) - v_{O2}(t)$ for an input signal of v_{in} being a 10mVpk 1kHz sine wave signal. NOTE: Expect only a small fluctuation in the output (less than a volt). **Use the 2N3904 NPN BJT model for simulation**.

STAGE 2: COMMON EMITTER BJT AMPLIFIER WITH ACTIVE LOAD

The output of the differential pair is then connected to a Common Emitter BJT Amplifier comprised of a PNP transistor with an active (current source) load as shown in Figure P7-3. This configuration relies on the high input impedance of the current source to achieve high gain.

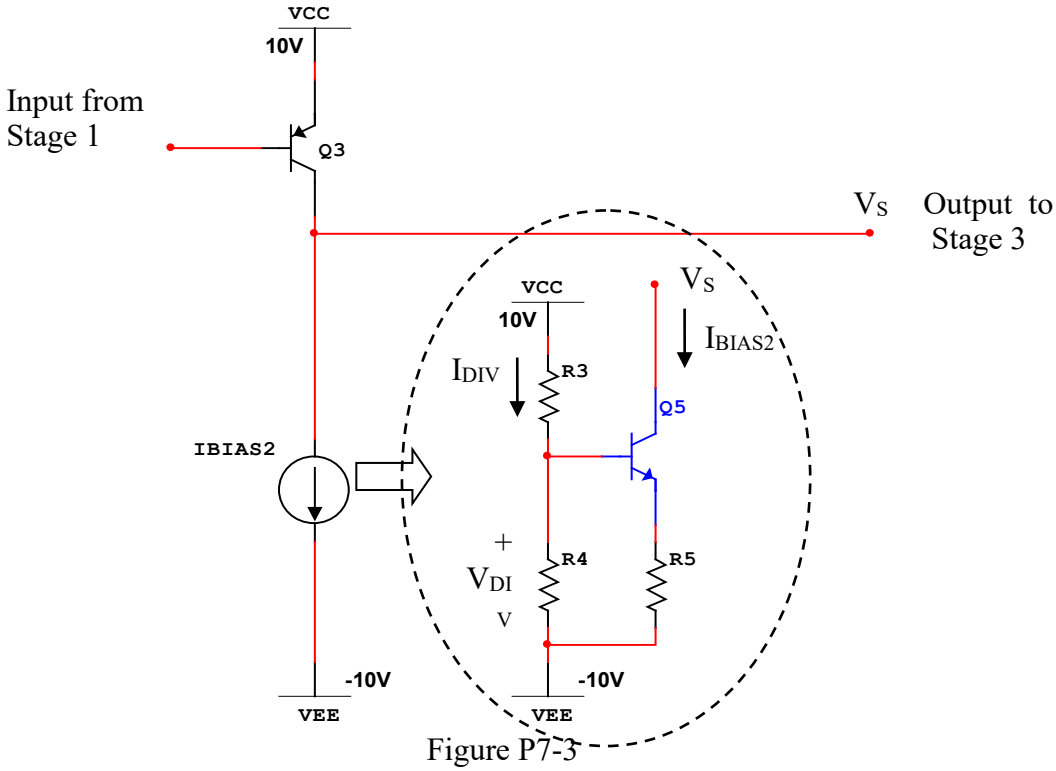

Figure P7-3

a) DC CURRENT SOURCE DESIGN

The actual current source circuit is comprised of a NPN BJT and a voltage divider network (oval insert). Choose values for the resistors R3, R4 and R5 to achieve the following specifications (assuming $\beta = 100$):

- I_{BIAS2} ≈ 20mA
- I_{DIV} ≈ 1.8mA (with Q5 disconnected)
- V_{DIV} ≈ 1.7V across R4

b) SIMULATION

- Using DC ANALYSIS in simulation, verify the values of I_{BIAS2}, I_{DIV} and V_{DIV}.
- Connect the output of the current source to a separate DC supply (V_S) and use DC SWEEP analysis to vary the voltage from -10 to +10 Volts.
- Produce a plot of I_{BIAS2} as a function of V_S. What is the dynamic voltage range of the output? (ie. Over what range of output voltage does the current source work properly?)

STAGE 3: EMITTER FOLLOWER

The final stage of the audio amplifier is the Emitter Follower circuit whose purpose is to handle the high current required by the load. To appreciate the operation of this stage, consider the circuit of Figure P7-4(a) showing a voltage source V_S with series resistance R_S connected directly to a load.

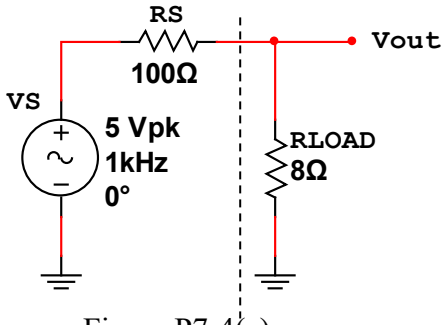

Figure P7-4(a)

a) DIRECT CONNECTION

- What is the maximum voltage that this circuit can deliver to the load?
- What percentage of the signal is this value?

b) USING THE EMITTER FOLLOWER

Figure P7-4(b) shows an Emitter Follower circuit placed between the source and the load.

- Using the small-signal model for this amplifier, determine the effective output impedance *Rout* of this stage (assume $\beta = 50$ for the power transistor Q4) .
- What is the peak voltage delivered to the load using the Emitter Follower.
- How does this output compare to the circuit without the transistor?

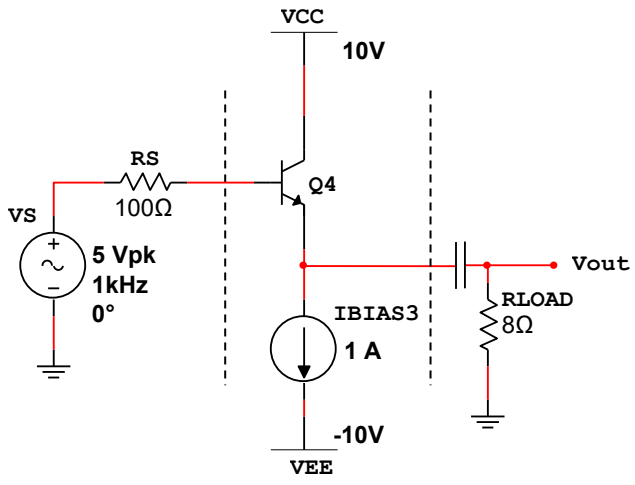

Figure P7-4(b)

c) SIMULATION

- Using TRANSIENT ANALYSIS, verify these results in simulation.

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ECE 2201 – LAB 7x

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PURPOSE:

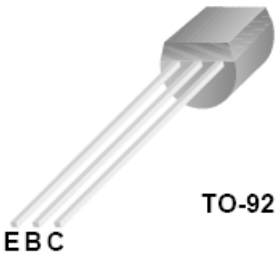
The purpose of this laboratory assignment is to investigate single-stage and multi-stage BJT amplifiers and use them to construct an audio amplifier. Upon completion of this lab you should be able to:

- Construct a 3-stage 5W audio amplifier utilizing three stages – a BJT Differential Pair (input stage), a BJT Common Emitter amplifier (gain stage) and a push-pull Emitter Follower (output stage).
- Construct an audio amplifier utilizing *negative feedback*.

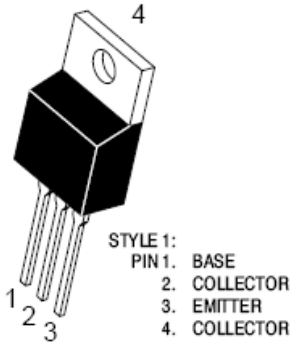
MATERIALS:

- ECE Lab Kit
- DC Power Supply
- DMM
- Function Generator
- Oscilloscope

NOTE: Be sure to record ALL results in your laboratory notebook.



2N3904 or 2N3906 Pinout



TIP31 or TIP32 Pinout

A 3-Stage 5W Audio Amplifier

Construct the complete audio amplifier shown in Figure 7-1. Use the values calculated in the prelab for resistors R1, R2, R3, R4, and R5. Refer to the following notes to understand the practical modifications made to this design.

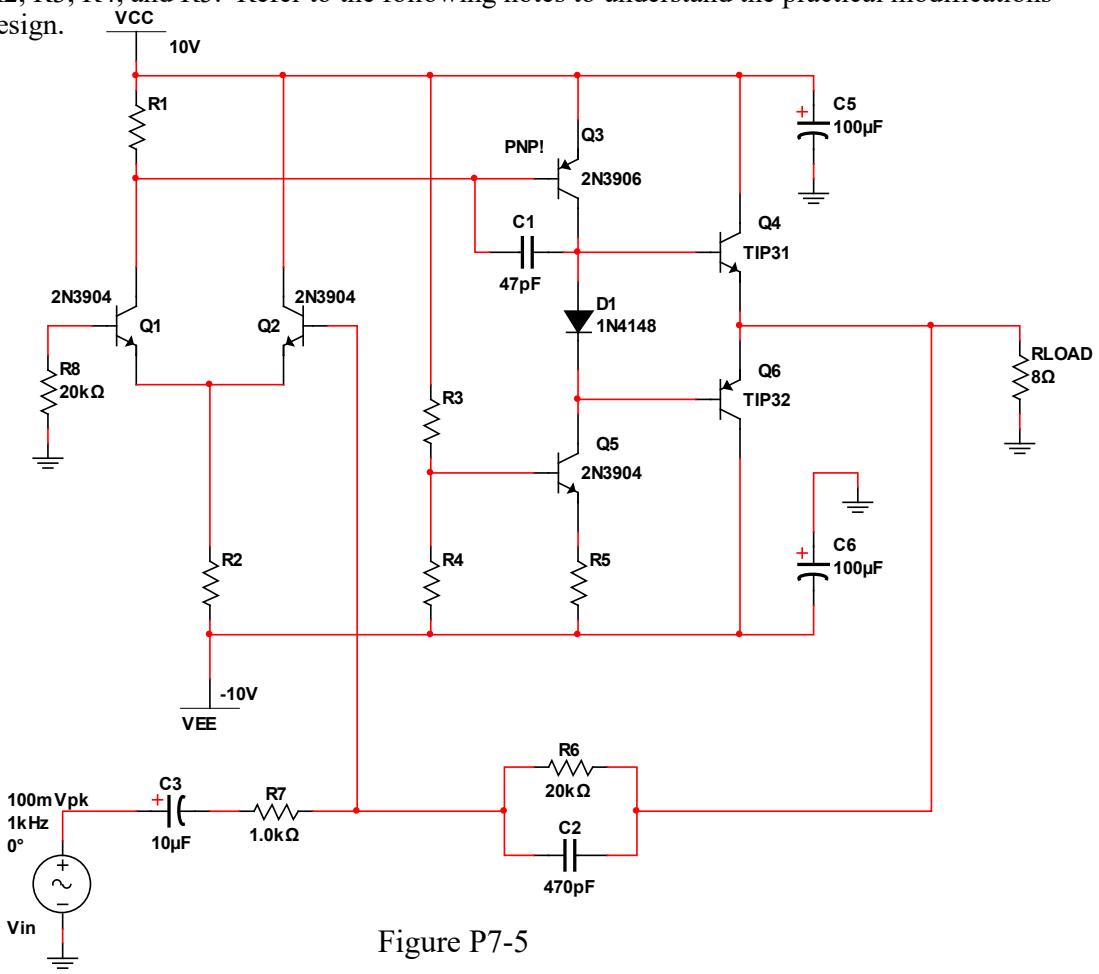


Figure P7-5

NOTES:

(1) The circuit is configured as an *inverting* amplifier with a gain of A_V = - R6/R7 or -20 V/V in the pass band.

(2) The impedance network comprised of R6, C2, R7, C3 provides a band-pass filter response with cut-off frequencies of approximately 16Hz and 16kHz, covering most of the audio frequency range.

(2) C1 provides *dominant pole compensation* to stabilize the closed-loop frequency response of the amplifier. Without this capacitor, the circuit may oscillate.

(3) The output stage has been modified to include an Emitter Follower Push-Pull Pair. By adding the complementary PNP power transistor, the circuit no longer wastes the 1A bias current required if only one Emitter Follower is used. Although this modification saves power, it introduces *cross-over distortion* since the transistors turn off when the signal voltage is below +/- 0.7 volts.

(4) D1 has been added in the second stage to provide a small DC offset when driving the Push-Pull Pair. This helps reduce cross-over distortion. Two series diodes would reduce distortion further BUT this would increase the risk of turning on both power transistors at the same time and shorting out the power supplies.

(5) Capacitors C5 and C6 have been added to filter the power supply locally near each power transistor. This helps reduce power supply bounce when the power transistors call for high current.

Construction Hints:

(1) Build and test this amplifier in stages.

(2) Make sure the DC Bias is correct before injecting the input signal.

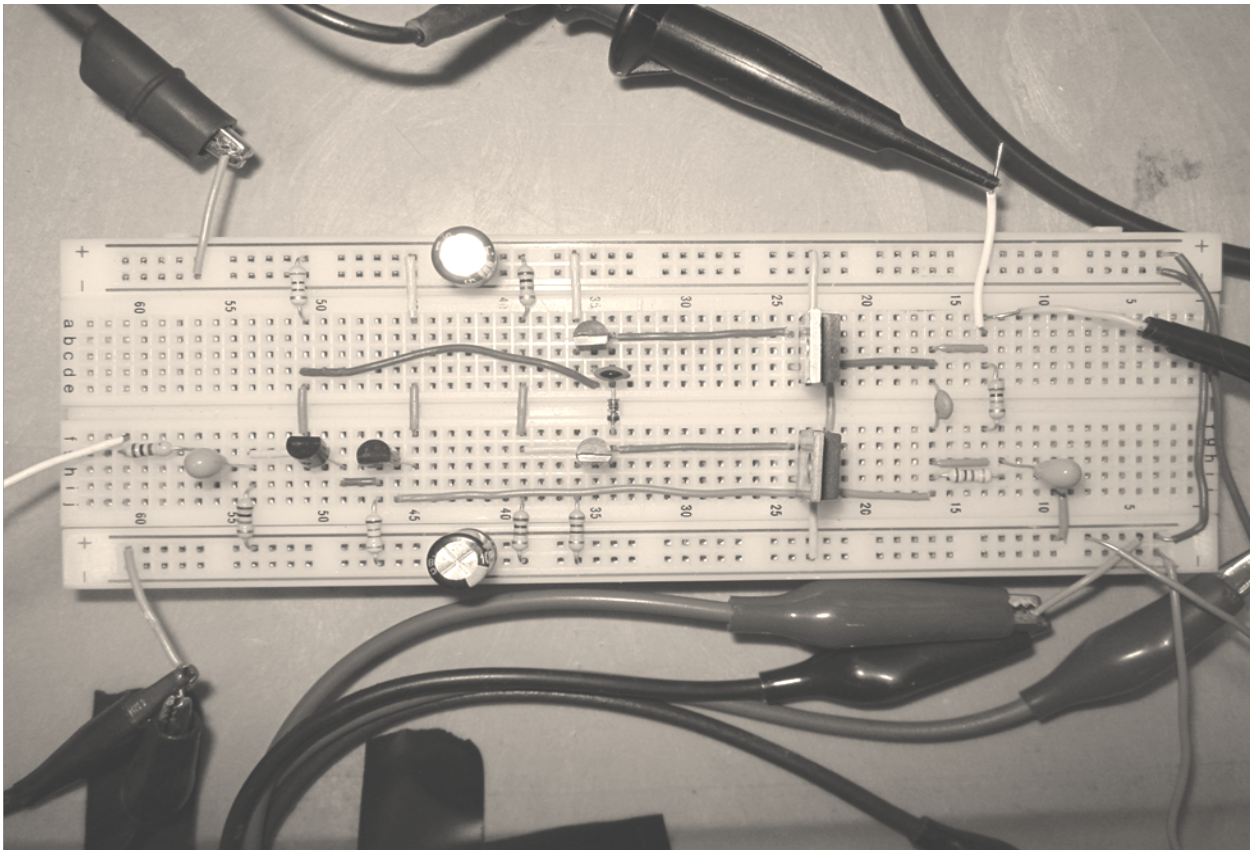
(3) Set the current limits on the power supply to no more than 200mA while checking the DC Bias.

(4) Increase the current limits to 1.5A after the DC Bias checks out.

(5) Test the amplifier with a real input signal (mp3 player, ipod, guitar pick-up, etc.)

(6) Enjoy !

Typical Breadboard Design:



Thank you Stephanie Lochowski (’14) and Jessica Pham (’13) for helping me take this pic!