

DEPARTMENT OF ELECTRICAL ENGINEERING AND COMPUTER SCIENCE
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CAMBRIDGE, MASSACHUSETTS 02139

Spring Term 2007
6.101 Introductory Analog Electronics Laboratory
Laboratory No. 6

NOTE: THIS LAB REQUIRES A CHECKOFF FOR EXPERIMENT ONE. Sign up for your checkoff time on the list posted on the TA's office door [38-544]. We will want to twiddle all your controls and try your circuits with a real microphone, CD player and loudspeaker. No credit will be given for the lab write-up if it hasn't been checked-off.

Experiment 1: A preamplifier or "front-end" for the power amplifier.

Now that you have designed an amplifier that can take a couple of volts of audio signal into a high impedance and produce a higher voltage at high current into a low [speaker] impedance, you need some kind of control section at the input to the amplifier. Traditional control design includes volume, balance, and tone controls, and facilities for switching between various signal sources, i.e. FM tuner, AM tuner, CD player, computer sound card, microphone, etc. All the preceding sources except the microphone are known as "line level" sources, that is, they produce a maximum of a couple of volts RMS from a relatively low source resistance, maybe 0Ω to the low $k\Omega$ range [usually an emitter-follower or op-amp output]. A dynamic microphone, however, produces an output of a few millivolts RMS with source impedances that may be higher than the range given for the line level sources above.

These days, many of us listen to FM or CD's while working on our computers; and since many of our computers have sound cards, it might be nice to be able to hear those cute little bells and whistles and other occasional sounds that Windows makes and still be listening to our music or talk shows. To do this, your front end should be a linear mixer type, that is, you should be able to listen to two or more inputs at once and have the ability to adjust the signal level of each input individually, and also to adjust the overall level [master gain control]. Refer to the block diagram in figure 1 [which uses your power amp from lab 5] and design your circuit to the following specifications:

- Use the least expensive op-amps for all circuits that will allow you to meet specs. Two devices in one package may save money in board layout, fewer bypassing caps, etc. Using a 741 may be the cheapest way at first, but may cause the use of extra resistors or capacitors that would be obviated by the use of a slightly more expensive op-amp.
- Provide three inputs: one for CD, one for sound card, and one for microphone.
- The line-level inputs should have a maximum A_v of 20 dB, the microphone input should have a maximum A_v of 52 dB, both at 1000 Hz.
- Each input amplifier should have either a voltage divider or a feedback gain control. A voltage divider gain control is basically a potentiometer whose fixed ends are connected between the output of a gain stage and ground, as if it were a load resistor, which, partially, it is! The wiper or variable terminal of the pot is connected to the input of the next stage. When the wiper is turned

toward the ground end of the resistance, the signal level is zero, and as the wiper is turned “up” the signal at the wiper gets larger and larger due to voltage divider action. Voltage divider volume controls may be capacitor coupled at either or both the input and the output. The main reason for eliminating DC from a volume control pot is to prevent the generation of “contact noise”, which occurs as the wiper is moved along the resistance element while DC current is flowing through the element. While this noise only occurs during control rotation, it can be irritating and loud. If capacitor coupling is used, a major issue arises around the value of capacitor needed for a given low frequency –3dB point, since the source impedance looking back from the wiper toward the voltage divider varies drastically from one end of the pot rotation to the other. This may also have implications for the load presented to the stage that drives the volume control as well. Voltage-divider gain controls should not be placed too close to the input stage of a multi-stage high gain amplifier. When high gain stages come after the volume control, turning down the control will not have any effect on noise generated in subsequent stages. One could have a situation where one has turned down the volume to produce a relatively low output signal, but that signal might be accompanied by a high level of amplifier noise which is normally masked by a high level output signal.

A feedback gain control uses a potentiometer connected as a rheostat; that is, one end of the fixed resistance is connected to the wiper. You have to be careful which end you connect to the wiper, since you want the gain to increase when you turn the pot to the right, and to decrease when you turn the pot to the left. A feedback gain control replaces the feedback resistor in an ***inverting*** amplifier. **[Q1.1 Why can't it be used in a non-inverting amplifier?]** This will only work using op-amps that are compensated for gains down to one. The LF357, for example, can't be used, because it is only internally compensated for gains down to 5. A 357 will oscillate as soon as the gain is turned down below 5. There are also issues around generating DC offset voltages as you change the value of the feedback resistor pot, at least with bipolar input op-amps.

- The three input amplifiers should feed into a summing amplifier that has a master feedback gain control and an A_v appropriate to each input.
- You should design for a maximum source impedance of 1 k Ω . That means that the highest output resistance of whatever is connected to any of your inputs will not exceed 1 k Ω . This has implications for the size of your input coupling capacitors.
- The ***minimum*** audio bandwidth of the whole preamp section should be 10 Hz to 50,000 Hz (-3dB points.)
- All inputs should be AC coupled to their sources, but you may DC couple all of the rest of the circuitry as long as you do not violate the output offset specifications for the power amp. **Q 1.2 How does a feedback gain control potentially affect the DC offset voltage of an op-amp? Q 1.3 What kind of coupling capacitor should be used in this application? Why?**

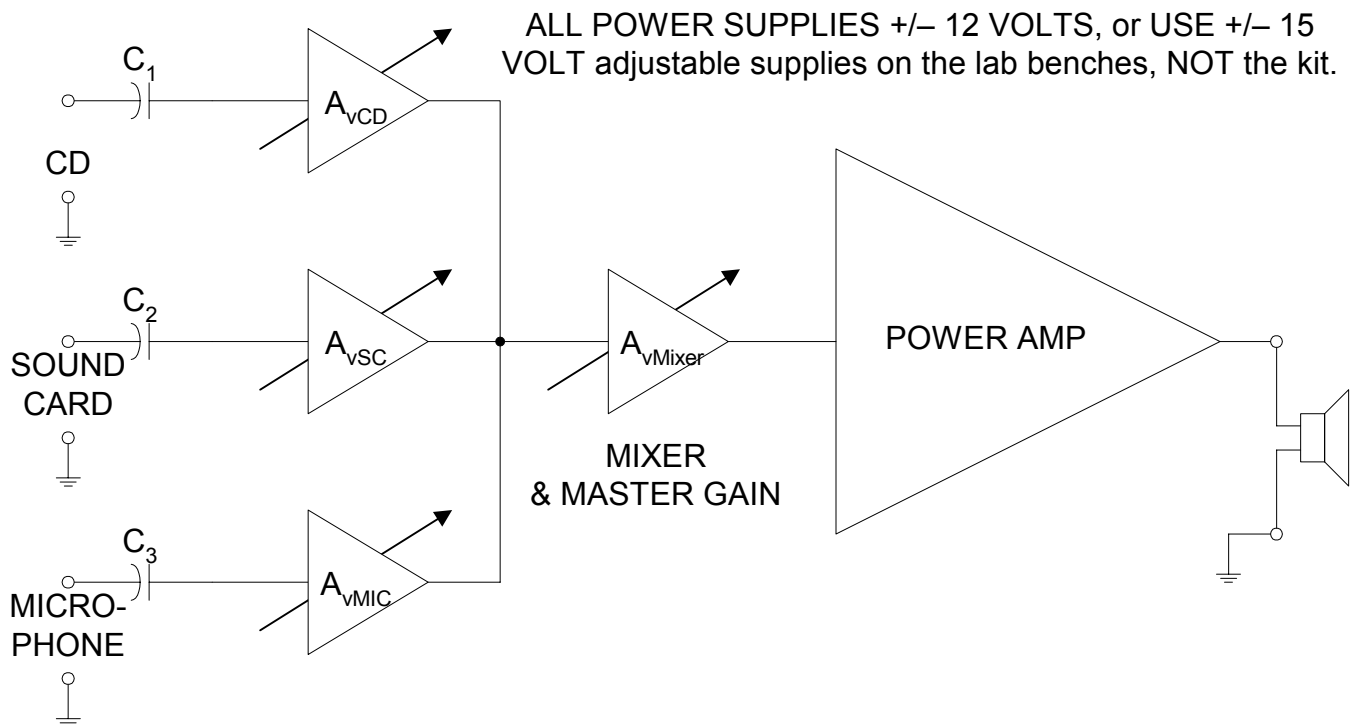


Figure 1: Control Amplifiers for Experiment 1

For the adventuresome and inquisitive, an alternate version of the control amplifier experiment is shown in Figure 2. Instead of mixing the three sources, this approach uses analog switches to switch in only one of the sources at a time. The analog switches would normally be controlled by push-pads that control a latching circuit to operate the analog switches, but you may use wires poked into your proto-board to control the switches, or use the switches built into your lab kit. Since you don't need the adder [mixing] operation, you may use a potentiometer [lossy] style of gain control in this version, instead of using an active stage for the master gain control. This type of pot usually has a logarithmic taper for audio work, but you will have to make do with the linear types in your kit or from the stockroom window. [Individual input gain controls are not needed in this version since there is no mixing and therefore no need for signal level balancing.] You may still want to use a gain stage or follower to isolate the varying impedance levels of the volume control from other stages.

The major advantage of analog switches over mechanical switches is the fact that a DC voltage is used to control the switch, and the actual signal switching is done close to the gain stages, without having to bring that signal path out to the front panel to a mechanical switch. This reduces crosstalk between channels, and hum and noise pickup.

POWER SUPPLY NOTE FOR THE 4066 ANALOG SWITCH CHIP: This device operates with a maximum 15 volt [total!] supply. Therefore, to pass signals centered around 0VDC, one must power this device from +/- 7.5 V supplies. These can be made from a 1N755 zener diode and a current limiting resistor. Since most of the gain occurs after the switch chip, the reduced headroom due to the limitations of this device should not be a problem. Any clipping problems from overload [too large an input signal] should still occur in the power amplifier. You should request a 4066 spec sheet from the instructor before you design this switch.

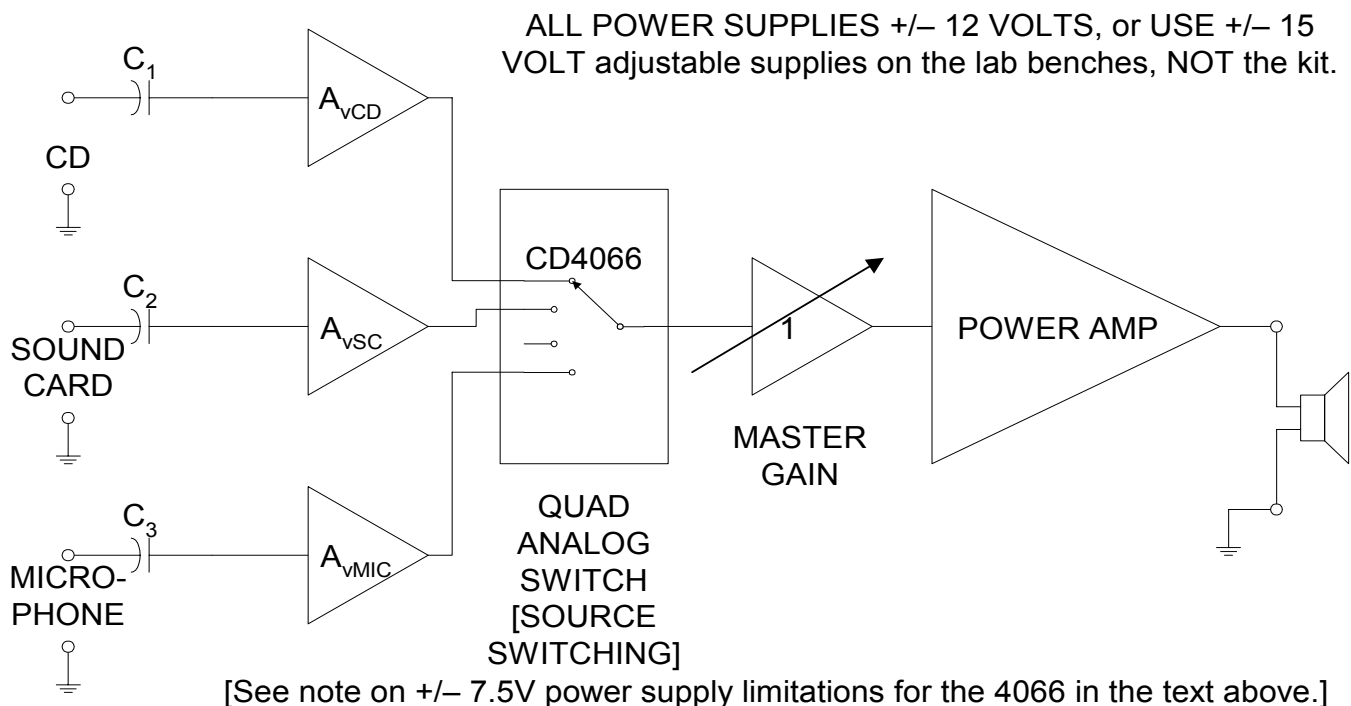


Figure 2: Alternate Control Amplifiers for Experiment 1

Experiment 2: Emitter-Follower, Series-Pass, DC Power Supply Voltage Regulator

In this experiment you will investigate the operation and design of a voltage regulator circuit. Specifically, you will look at a circuit in which a series transistor is used to absorb the difference between the unregulated DC voltage in the supply and the regulated voltage that is to be supplied to the load. The regulator also functions as a ripple reducer. This voltage difference drops as the current supplied to the load increases, due to I^2R losses in the power transformer and increased ripple voltage.

Figure 3 shows the schematic of a simple series voltage regulator. An ac voltage $v_{AC}(t)$ is rectified by the bridge rectifier, and filtered by capacitor C_1 . This voltage is applied to the collector of transistor Q_1 , which is a 2N2219 in a TO-5 case. **NOTE: This device may get hot!** If you wish, you may get a heat sink that fits the TO-5 case from the green drawers next to the soldering bench in the 6.101 lab, or from the stockroom window. This transistor is connected as an emitter follower; a constant voltage (supplied by Zener diode D_1 and resistor R_1) is applied to the base and the load resistor R_L is connected between the emitter and ground. The result is that the load voltage is held constant at a voltage equal to the Zener voltage less the base-emitter drop of transistor Q_1 .

Your objective is to design a voltage regulator of this type, subject to the following design objectives and guidelines:

- Based upon the 6.8V 1N754A Zener diode in your lab kit, your voltage regulator will have an output voltage of approximately 6V. **Q 2.1 Why?**

- The input voltage will be 60 Hz (supplied from the same 12.6 VCT RMS power transformer either built into your kit, or in the aluminum box available at the stockroom window). Do not connect the center tap. **Do not connect scope ground leads to any of the transformer terminals.**
- It should provide regulated output voltages for load resistances of 100 Ω and greater. Peak-to-peak load ripple voltage should not exceed 5 mV with this load value.
- A small output capacitor C_2 *may* be necessary to avoid high frequency oscillations that can appear on your regulated output voltage. You can determine the required capacitance empirically.

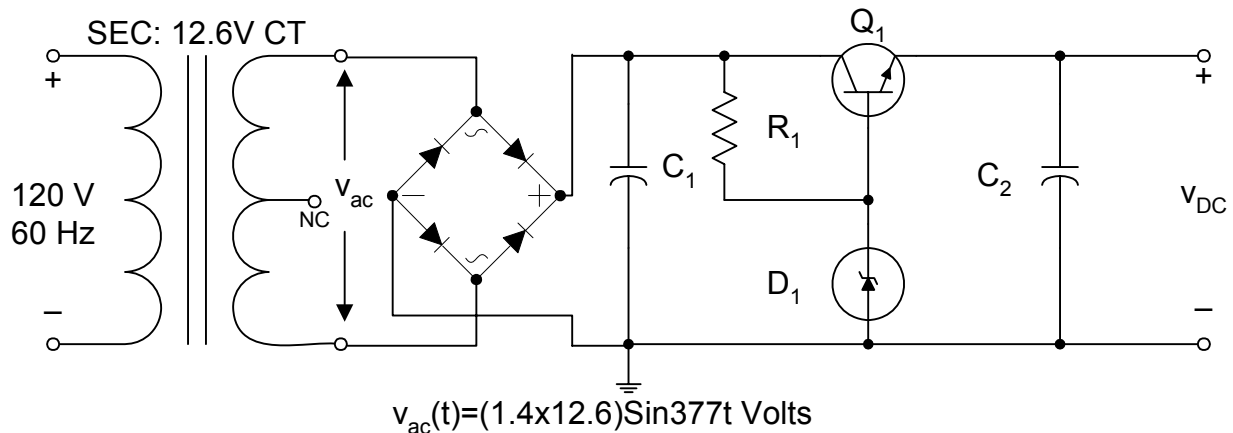


Figure 3: Voltage Regulator Circuit for Experiment 2.

- To keep costs down, you should use the smallest value of capacitance C_1 that can meet the design objectives. Be sure that the capacitor voltage rating is large enough to withstand the DC voltage *and* the ripple voltage on top of the DC voltage.
- To avoid burning up your Zener diode, the maximum current through it must be limited to 55 mA. **[Q 2.2 Do you need to run 55 mA through the Zener diode for the circuit to work or is a lower value of current in fact better?]**
- R_1 also supplies base current to the pass transistor. **Q 2.3 How will a larger value of R_1 affect the operation of the pass transistor? Q 2.4 How does the β_F of the pass transistor affect the value of R_1 ?**

Using the 100 Ω 5 watt load resistor in your kit, and using $C_1 = 100 \mu\text{F}$, fill out the following table. Note: C_1 is set to a relatively low value to allow you to observe the changes in ripple voltage as R_1 is varied. However, you may need to increase C_1 to meet the ripple spec when you are done filling out the table. Be sure to record your final value of C_1 as well as R_1 .

Load Resistor	$V_{\text{OUT DC}}$	R_1	$V_{\text{RIPPLE ac}}$ across R_L	$V_{\text{RIPPLE ac}}$ across C_1
100 Ω , 5W		510 Ω		
100 Ω , 5W		1.0 k Ω		
100 Ω , 5W		3.0 k Ω		

100 Ω , 5W		5.1 k Ω		
100 Ω , 5W		7.5 k Ω		
100 Ω , 5W		10.0 k Ω		

NOTE: If you are using one of the new Tektronix sampling oscilloscopes, you may want to average the ripple voltage signal to make it easier to read. You can do this by accessing the following menus: ACQUIRE / MENU / MODE / SAMPLE / AVERAGE. You can adjust the number of samples that are averaged by turning the topmost knob on the face of the 'scope.

Recall the analysis from lecture of how the Zener diode reduced the size of the ripple voltage. This was due to the voltage divider effect that evolved from a Thevenin analysis of the ripple source voltage and the Zener diode. **Q 2.5 Does your data in the chart support this analysis? Why or why not?**

You may be tempted to bypass the ripple at the Zener diode using a large electrolytic capacitor. However, considering the low ac impedance of the Zener, one needs a very large capacitor to have much effect on the ripple at the Zener. This capacity is much more cost effective in terms of ripple reduction if it is used to increase C_1 . However, bypassing the Zener with a small 100 nF or 10 nF capacitor can help reduce high frequency noise generated by the Zener. [Zeners make great noise generators!] Also you should realize that increasing R_1 beyond a certain value could reduce the Zener current enough to start to move the Zener operating point around the knee of the Zener curve, which means that the ac Zener impedance will start to increase dramatically.

Experiment 3: Adjustable Series-Pass Power Supply Voltage Regulator using an op-amp

THIS LAB IS OPTIONAL FOR EXTRA CREDIT. [Equivalent to 30% of one lab's total value.]

YOU MUST DEMONSTRATE THIS DESIGN TO ONE OF THE TEACHING STAFF.

Start with the transformer, bridge rectifier and input capacitor from Experiment 2 above. Keep a series resistor and Zener diode circuit as the reference voltage, but use a 741 or other suitable device to drive the pass transistor instead of driving it directly from the Zener.

Connect the 741's $+V_{CC}$ terminal to the collector side of the pass transistor. Connect the 741's $-V_{EE}$ terminal to ground.

Use the Zener reference voltage to bias the + input of the op-amp. If you now connect the - [negative feedback] input directly to the emitter [output] of the pass transistor, you will have a regulated 6.8 volt DC supply, since the feedback will correct for the base-emitter voltage just as it corrects for the diode voltage drop in the precision rectifier. **Q 3.1 What is the effect that the resistor in series with the Zener diode will have on ripple at the op-amp input? Q 3.2 What is the Zener internal impedance?**

In order to make this an adjustable supply, you will need to use your knowledge of the gain equation for the non-inverting op-amp connection to select one resistor and one potentiometer to provide some gain. For ease of adjustment, it's best to limit the maximum gain you can get to a realistic value. Your input voltage to the op-amp is 6.8 volts. The bridge circuit will give you around 16 volts input to the pass transistor at no load, so the most you can probably expect at the output under full load is around 14 volts. This would require a gain of about $14/6.8 = 2.1$ for the maximum gain adjustment.

The D44H8 or D44H11 pass transistor can handle output currents to about 8 amperes; however at the lower output voltages when the transistor collector-emitter voltage drop is high, the transistor power dissipation is high at high load currents. The power rating of the transistor is 20 watts at a case temperature of 25° C. You should make sure that your design will not exceed this rating. Draw a final circuit schematic and summarize any design calculations you have made.

Experiment 4: Low-Battery Indicator Gizmo

THIS LAB IS OPTIONAL FOR EXTRA CREDIT. [Equivalent to 30% of one lab's total value.]
YOU MUST DEMONSTRATE THIS DESIGN TO ONE OF THE TEACHING STAFF.

Design a voltage readout for the batteries on a portable 2 “zillion” candlepower spotlight. Using the parts in your lab kit, or those available at the stockroom, plus green, amber, and red LED's available from the 6.101 parts drawers or the stockroom, your design should meet the following specifications:

- The circuit must be powered only from the battery that you are testing, which is +12 volts when fully charged.
- Your circuit should turn on all three LED's when the battery voltage is 11 volts or higher.
- Your circuit should turn off the green LED when the battery voltage drops below 11 volts, leaving only the amber and red LED's “on”.
- Your circuit should turn off the amber LED when the voltage drops below 10 volts, leaving only the red LED “on”.
- The drain from the circuit on the battery should not be too great, but don't worry too much about it since you should design your indicator to work with a momentary-contact push “on” switch [SPST]. There are momentary-contact pushbutton switches on the kit. Check to see if they put out any voltages before using them!

Experiment 5: Power Amplifier Output Stage Upgrade

THIS LAB IS OPTIONAL FOR EXTRA CREDIT. [Equivalent to 30% of one lab's total value.]
YOU MUST DEMONSTRATE THIS DESIGN TO ONE OF THE TEACHING STAFF.

Design an improved output stage for the amplifier you designed in Lab 5. You may use either the Complimentary Feedback Pair [Sziklai pair] (shown) or a regular Darlington pair. The TO-220 plastic output devices shown can handle up to 8 amps and so you may now use an 8Ω load resistor. Be sure to calculate the power handling capacity needed for this resistor before you crank up this amplifier. The power output of this improved amplifier will mostly be limited by the 1 Amp current limiting built into the +/- 12V power supplies in your lab kit [The adjustable power supplies in your kit current limit at 500 mA]. You may want to use a 1000 Ω pot connected as a rheostat across the biasing diodes for easy bias adjustment. [This pot works by “stealing” current from the diodes and thus decreasing the diode forward voltage drop.] 10 mA of bias current through the output devices should still be sufficient. You should be able to increase the values of R_{B1} and R_{B2} using this output device connection. **Q 5.1 Why?** [Note: To get the most power from this circuit, use an LT1632C rail-to-rail op-amp. Don't forget to disable the unused op-amp in this dual device.] If you wish to experiment with higher power outputs from this circuit, use the bench-top power supplies in the lab that can supply up to +/- 18 volts at 4 amperes. **Warning: Be sure not to use an external power**

supply voltage greater than the absolute maximum voltage rating of the op-amp that you are using.

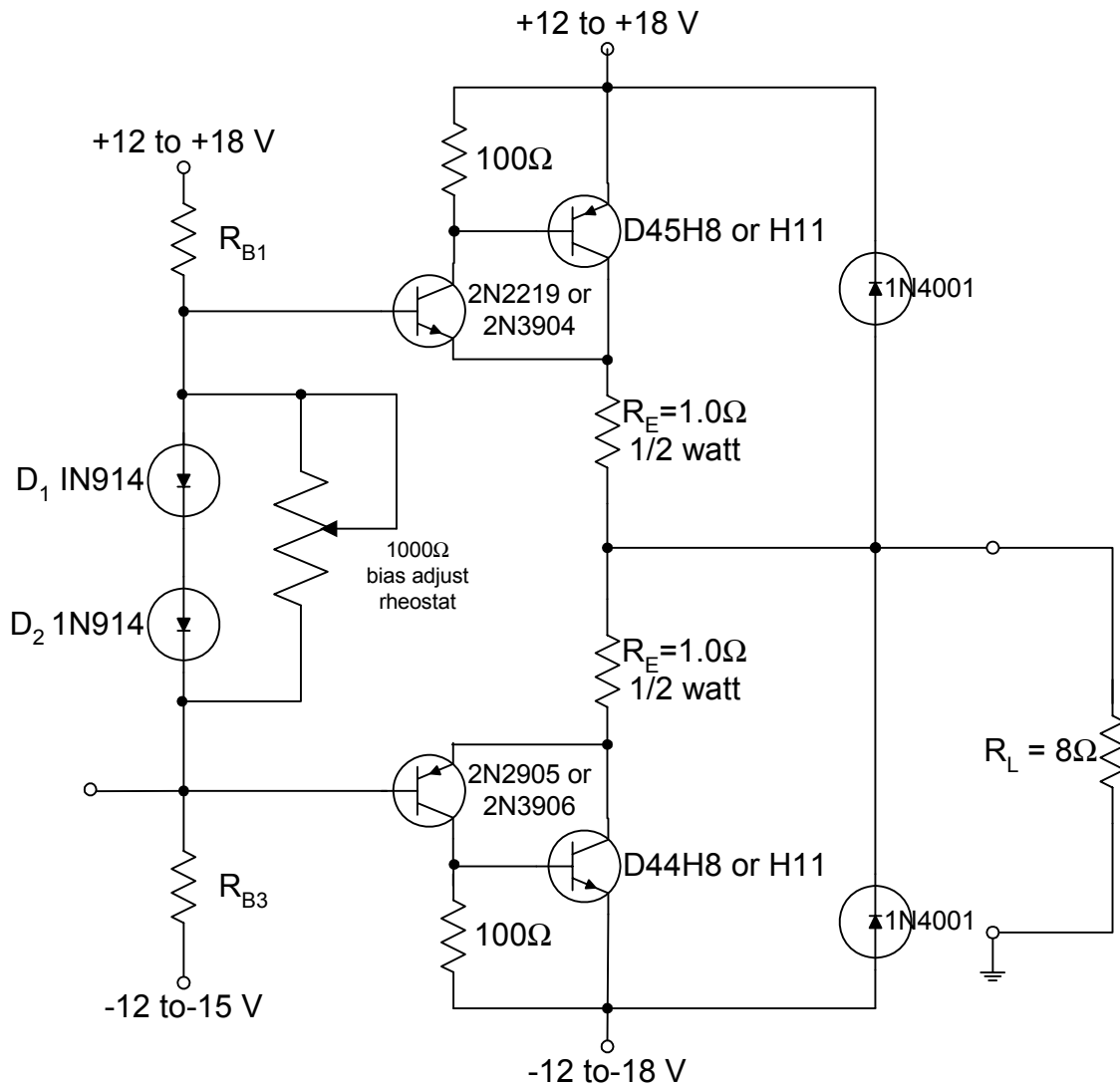


Figure 4: Power Amplifier Upgrade for optional Experiment 5