LAB 2
CLOSED-LOOP CONTROL OF A MOTOR

Objectives	To learn about the use of op amps in constructing a better current amplifier and in feedback control of a motor.
Preparation	Read Lab 2 and consult the LM348 op amp and TIP31, TIP32 data sheets. (Note: LM324 can be substituted for LM348.)
Tools	Prototyping breadboard, power supply, multimeter, function generator, oscilloscope, wire cutter/stripper.

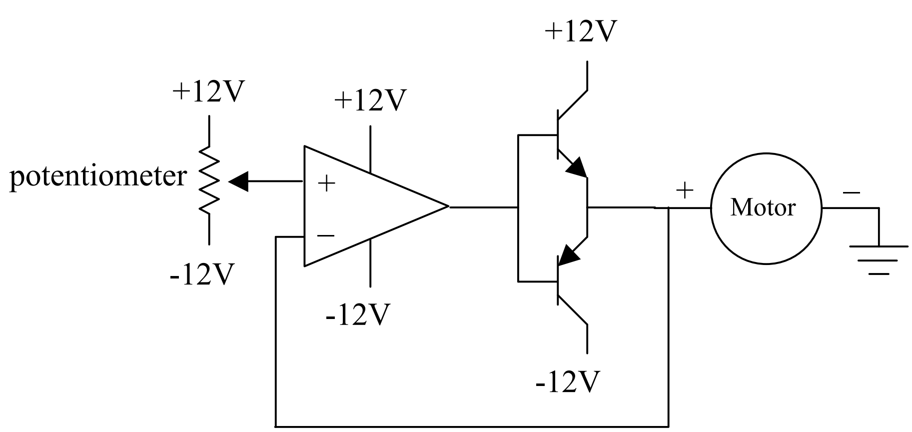
1 Introduction

In the previous lab, we used transistors to construct a simple current amplifier. This amplifier had some non-ideal behavior: crossover deadband and only a moderate current gain (meaning that the input impedance of the amplifier plus load is not as high as desired). In this lab we address these problems using an op amp to create a better linear amplifier. We also use an op amp to perform closed-loop position control of a motor using a potentiometer for position feedback.

There is no answer sheet for this lab. Prepare your own neat and carefully written answer sheet answering all the questions in **bold** and showing all your work.

2 An Improved Linear Current Amplifier

Use the pot and motor given to you by the TA, as well as an LM348 op amp and TIP31 and TIP32 transistors, to build the circuit shown below on your breadboard. Do not power your circuit yet! (Don't plug in the power adapter.) You can connect to the motor power terminals using alligator clips. The motor has a 6:1 gearhead, meaning that the internal motor shaft spins six times for every time the gearhead output shaft spins once. *Do not drop these motors!* They have optical encoder disks that can shatter.



This is the push-pull amplifier as in Lab 1, but with the addition of an op amp. Using the op amp golden rules, **explain** how this circuit improves our previous push-pull amplifier by eliminating the crossover deadband and by increasing the current gain (i.e., increasing the input impedance of the amplifier and motor).

Measure and **record** the resistance of the motor. **Calculate** the maximum current the motor can draw with 12 volts across it. Using evidence from the data sheet, **indicate** whether the TIP31 can provide this current. Then **explain** whether the LM348 can provide the necessary base current to the TIP31 for the motor to run with maximum current.

Now, instead of driving the motor, connect the transistor emitters to a 1k resistor to ground. (The 1k resistor replaces the motor.) Plug in power to your board and demonstrate that the voltage at the transistor emitters tracks the voltage at the wiper of the potentiometer (your manual "speed" input) as you turn the pot. These voltages are not equal over the entire range of the pot, however. **Record** the maximum and minimum voltage you can obtain at the motor + terminal, and, possibly using information from the LM348 and transistor data sheets, **explain** why you get this range and not the full +/-12V you see at the potentiometer wiper.

Finally, replace the 1k resistor with the motor, and demonstrate to the TA that the motor can spin in both directions as you turn the control pot. If you looked at the transistors' emitter voltage now, connected to one of the motor terminals, you would see a great deal of electrical noise. This is because a motor is an electrically messy device, with inductance and switching currents due to brushes inside the motor continually making and breaking electrical contacts.

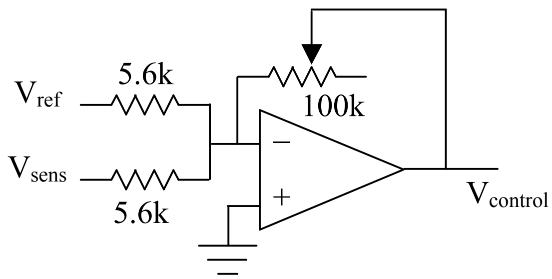
This amplifier is called a linear amplifier. Note that the transistors still waste power due to voltage drops across them when they are not saturated. *Pulse width modulation*, a topic for later in the course, is a more power-efficient way to drive motors.

3 Proportional Position Feedback Control of a Motor

We will now use a potentiometer for motor position feedback. Connect the potentiometer shaft to the motor shaft using a piece of cable insulation the TA will give you. Now when the motor turns, the potentiometer shaft also turns. The voltage at the wiper of the potentiometer gives us feedback on the position of the motor.

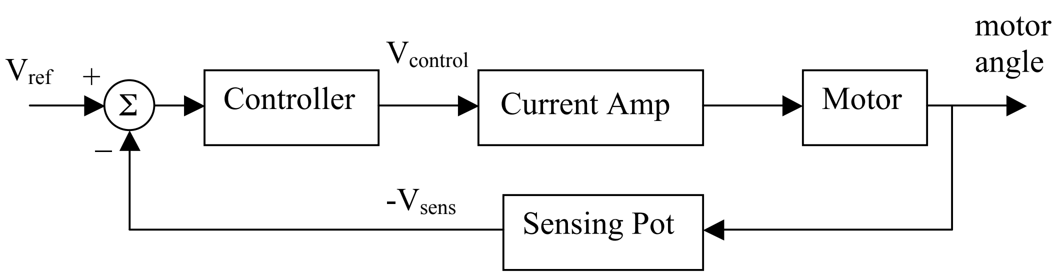
(Note: some potentiometers are made for the purpose of providing angle feedback. Our knob potentiometer is *not* made for that purpose, but we will use it that way. [If you are ever buying a pot for feedback, do not buy one of these knobs!] The insulation we are using to attach the pot to the motor acts as a simple *flexible shaft coupler*. Flexible shaft couplers allow the coupling of two shafts which are not exactly aligned.)

Build the circuit below using a 100k trimpot and another of the op amps on the same LM348 chip. Let R be the resistance (between 0 and 100k) set by the trimmer. **Give** $V_{control}$ in terms of R, V_{ref}, and V_{sens}. Note that $V_{control}$ is proportional to $V_{ref} + V_{sens} = V_{ref} - (-V_{sens})$. If V_{ref} is a desired motor position (expressed as a voltage) and $-V_{sens}$ is an actual sensed position (expressed as a voltage from the motor's potentiometer), then $V_{control}$ is proportional to the error of the actual position from the desired position. This voltage drives the motor to reduce the error (assuming the polarity of the leads to the motor is correct; if not, just switch them). This is called proportional control, or simply P control, as the control signal is proportional to the error.



Eventually V_{sens} will be the motor potentiometer's sensed voltage, between -12V and +12V. For now, set V_{sens} to ground. Send a 4 V peak-to-peak sine wave with 0 DC offset to V_{ref} using the function generator, and display both V_{ref} and $V_{control}$ on the oscilloscope. Confirm that your expression for $V_{control}$, found above, is correct.

Now we are going to assemble our feedback control system. Its block diagram looks like this:



Note that the summer and controller is implemented by one op amp, and the current amp is implemented by one op amp and two transistors

Unpower your protoboard. Now, instead of having V_{sens} be ground, set it to the signal wiper of your motor potentiometer. Set the trimpot so R = 0 ohms. (You can turn the trimpot with a screwdriver.) Send $V_{control}$ to the + terminal of your current amplifier op amp. Set the function generator signal at V_{ref} to be a 0.3 Hz square wave between +/- 8V. Use your oscilloscope to display V_{ref} and $-V_{sens}$. (To display $-V_{sens}$ instead of $+V_{sens}$, press the `Math Menu` button on your oscilloscope and change the channel displaying V_{sens} to display the inverted (negative) of the signal.) Now power your protoboard and observe how the behavior of your controller changes as you slowly increase the resistance R by turning the trimpot. (If your motor turns until the potentiometer stops it and then just stays there, reverse the polarity of the leads to your motor.) Once you are satisfied you are seeing stabilizing feedback control, try square wave, sine wave, and triangular wave reference signals between 0.3 and 3 Hz. Demonstrate to the TA. **Describe** how incereasing the trimpot resistance (the resistance R) changes the response of the motor. **Explain** what the positive and negative effects of increasing R are. **Draw** one complete cycle of the reference and (negative) sensed signals for a square wave reference with (1) a medium value of R and (2) a large value of R, and explain the reason for the differences in the sensed signals intuitively.

You can also experiment with your oscilloscope's `Math Menu` by plotting the sum of the two signals Vref and -Vsens, which is the error signal. Ideally the error would always be zero.

Note that a 5.6k resistor is only somewhat higher resistance than the 1k motor sensing pot. This means that the motor pot signal between +/-12V is somewhat affected (loaded) by the summing circuit. If this were a significant concern, we could use higher resistance or create a unity gain buffer (voltage follower) with an op amp between the motor pot wiper and the 5.6k resistor.

Summary

- Linear current amplifier using an op amp
- Proportional feedback motor control with an op amp