MAE 106 Laboratory Exercise # 1 - Solution
Laboratory Tools and Control of a Motor

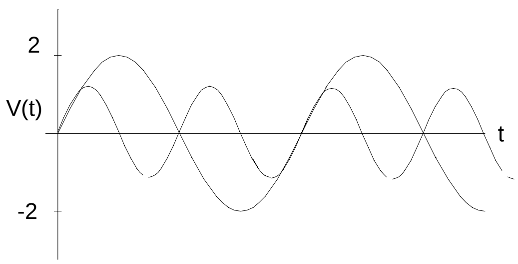
Part 1: Laboratory Tools

P1 See below P2 below

Q1 Vmax = 1V   Vavg = 0V   Duty cycle = 50%
Vmin = -1V   Frequency = 100 Hz
Vpp = 2V   Period = .01s

Q2 They do NOT adjust the amplitude, frequency, and DC offset, respectively. Rather, they adjust the voltage scale, time scale, and vertical position for the scope trace, respectively.

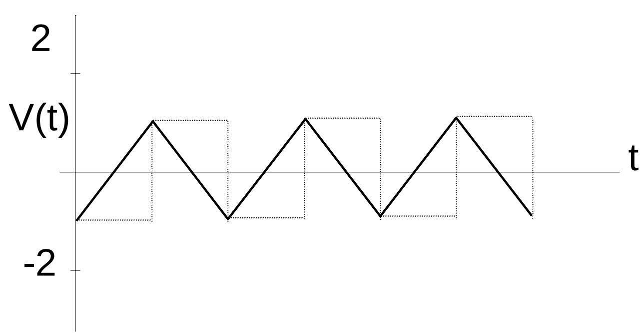
P2



Q3 The trigger is responsible for making the trace "stay still" on the screen, by capturing the signal for a fixed duration of time whenever it crosses the trigger voltage, then displaying the captured signal with a predetermined temporal offset. If the trigger channel is set to 2, than signals on channel 1 will not be triggered properly because the scope is trying to align the signal based on the (floating) voltage being input into channel 2.

Q4 AC coupling removes the DC offset from the signal.

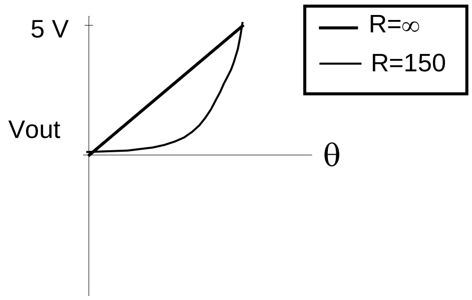
P3



Q5 Vout = {R2/(R1 + R2)} Vin

Q6 If the pot is turned to the extreme end, there is no resistance to current flow and the pot will be burned out.

P4 In **one** plot, show V_{out} vs. pot angle for both cases.



Q7 $R1 = k\theta$; $R2 = Rpot - k\theta$; with $k=(50K/\theta max)$, $Rpot = 50K$

$Vout = Vin \{(Rp)/(R1 + Rp)\}$, with $Rp = R2*R/(R+R2)$; voltage divider rule

$Vout = Vin [1/\{1 + (R1/R) + (R1/R2)\}]$

$Vout = Vin [1/\{1 + (k\theta/R) + (k\theta/(Rpot-k\theta))\}]$

$Vout = Vin[(-k)\theta/\{(-k^2/R)\theta^2 + (Rpot/R)\theta + (Rpot)\}]$

(linear divided by quadratic)

A pot is a good way of making an adjustable voltage source if its output is connected to a high resistance. On your final project, you could use one pot to specify the desired angle of the motor (i.e. the "control knob" you hold in your hand), and another to sense the actual angle of the motor (i.e. the "sensor" that senses motor angle).

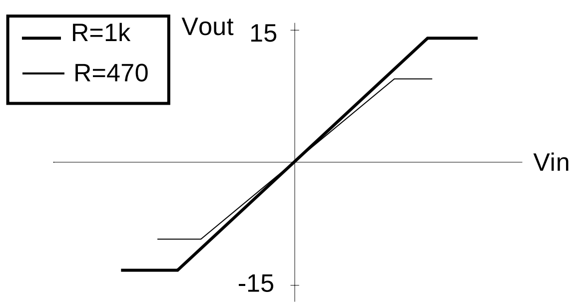
Part 2: Control of an Electric Motor

Q1 $Vout = K(V_+ - V_-)$, but $Vout = V_-$, so $Vout = K(V_+ - Vout)$, so $Vout = (K/(1+K))\ Vin$, and for $K >> 1$, $Vout \approx Vin$.

Q2 R_L cannot be so small as to draw more current than the op-amp can supply (> 20mA usually)

Vin cannot be greater than the voltage supplied to the op-amp chip.

P1



Q3 With large R_L, the plot follows better. For large R_L, Vout can go all the way to 15V (minus some loss in the op-amp) since Iout = 15V/1k = 15mA, which is less than the maximum current the op amp can supply. The small R_L draws at a maximum Iout = (observed peak voltage = 9.4V)/470Ω = 20mA peak, which is the maximum current the op-amp can supply (or "source"). Note that different op amps may have slightly different peak currents. Put another way, small R_L draws too much current for the op-amp to maintain Vout. The power drawn by the 470Ω resistor is $I^2R = 0.19$ W, which is less than the 0.25 W rating, but near it, so you should feel the resistor warming up.

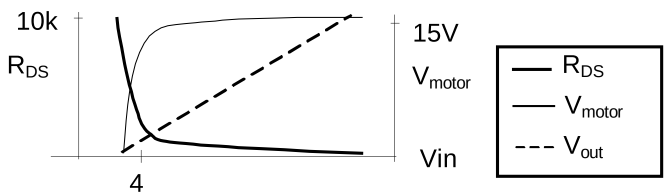
A motor with a stationary shaft acts like a resistor. A motor with R=30 ohms would initially attempt to draw way too much current (15V/30Ω = 500mA) and the output voltage from the op amp would be very small (Vout=20mA*30Ω=0.6V). You could only control the torque of the motor across a small range of currents corresponding to 0-20 mA (see Equation 2).

Q4 The op-amp can only output ~0 – 5V (minus a small voltage loss) if powered between 0V and 5V.

Q5 $R_{DS} = V_D R_L/(Vs - V_D)$ (ans: use voltage divider rule)

Q6 We control the pot angle. The pot allows us to adjust V_G. The MOSFET allows, through a corresponding change in R_{DS} the adjustment of V_D. Motor voltage is $(Vs - V_D)$, where Vs is a constant, so we ultimately control V_{motor}.

P2 V_{motor} is not linear with respect to V_G



Q7 It is difficult to make the motor turn at 1 Hz. The motor speed is not linear to V_{GS}. This results from non-linear input/output characteristics of the MOSFET (i.e., R_{DS} is not linear to V_{GS}). Since we are unable to control motor speed easily, and motor speed correlates with motor voltage in the steady state, it seems that we are able to control the voltage, but not easily.

Q8 The voltage V_D increases when you stop the motor shaft since the back EMF term no longer contributes to the voltage across the motor. Specifically, when the motor is allowed to accelerate to its no load speed, the back EMF builds up proportionally to angular velocity until $i \approx 0$ (i never goes completely to zero because some torque is needed to overcome the motor's friction). If $i \approx 0$, then $V_D \approx 0$. If you stop the motor from turning, the back EMF term goes to zero, and more current is allowed to flow through the MOSFET, increasing V_D.

Q9 We control pot angle, so we control Vin. The op-amp, having negative feedback, takes Vin and adjusts V_{GS} so that Vout = Vin. That is, V_{GS} is altered in such a way as to make the MOSFET's R_{DS} change so that Vout=Vin.

P3 See **P2** above.

Q10 It is easier due to feedback. The op-amp, since it has negative feedback, will try to adjust V_{GS} so that Vout is equal to Vin. In this way, the op-amp can "correct" for nonlinearities in the MOSFET and makes Vout linear with respect to Vin. Since we are able to get Vout to more closely parallel Vin, this is a better control system.

Q11 An improved method for controlling motor velocity would be to actually sense the motor's velocity (for example, with a tachometer), then to make feedback adjustments to the current supplied to the motor based on the difference between the actual and desired velocity. We will explore this approach in a subsequent lab.