Motor Control Fundamentals
Power MOSFET
Lab Grade: __________ (90 maximum)

Presentation Grade: __________ (10 maximum)
(organization, clarity, neatness)

Total: __________ (100 maximum)

Grader’s Comments:

Hand in all lab and work sheets, either stapled securely or in a folder.
1 Laboratory Exercise

1.1 Purpose
We will build a DC motor controller using a power MOSFET and close its feedback loop to provide a constant current supply to the motor.

1.2 Related Reading
Textbook: Ch. 14: Op Amps

1.3 Equipment
1) Knight Electronics Circuit Board Kit
2) Oscilloscope
3) Function generator
4) Digital multimeter
5) Instrument leads and jumper wires
6) DC Motor Assembly
7) One 1458 Dual Op Amp
8) One n-Channel power MOSFET
9) Resistors: 10 kΩ (Qty. 2), 0.47Ω, 5W power resistor, 10Ω 10W power resistor

1.4 Introduction
We’ll use a DC motor assembly for this experiment. We will attach to the motor with alligator leads, bypassing control circuitry already installed on it. The polarity of the motor connection is important only because the wrong polarity will cause power to flow into the unused circuitry, not the motor!
We’ll also be using a power MOSFET for modulating the motor current. This device is shown below, including its specifications:

Power MOSFET’s are funny animals. They have extremely asymmetric source-drain characteristics. **MAKE SURE YOU CONNECT THE NEGATIVE SIDE OF YOUR CIRCUITS TO THE SOURCE!** Other than that, they behave just like any other n-channel enhancement mode MOSFET; with \( V_{GS} = 0 \), they don’t conduct. As \( V_{GS} \) rises toward about 8 volts, the transistor turns completely on with a resistance of less than 1Ω.

In addition, we’ll be using a 5W power resistor. This resistor needs to be a little beefier than normal since it will carry all of the motor current. The resistor is shown below. It has some smaller wires soldered to its leads so that it will be compatible with the circuit board.
We’re using the 1458 op amp again this time, the device pinout of which is shown below.

![Op Amp Pinout](image)

When hooking up the op amp, don’t forget to hook up +12 VDC to V+ (pin 8) and –12 VDC to V- (pin 4). The op amp output will be quite boring without power!

Do NOT hook up the power backwards! The device will be EXTREMELY exciting with the power hooked up backwards, but only for a short time.

1.5 Experimental Data and Results

1.5.1 Basic Motor Circuit

Build the circuit shown in Fig. 10-1.

![Motor Circuit Diagram](image)

Fig. 10-1

Make sure you use the 5V supply and the ground near it on the Knight kit as your “battery.” Also, make sure the ground connection is attached to the right side of the motor as it faces away from you.
Turn on the kit and the motor should run. If it does not, try reversing your motor leads. Some of the motors may be “upside-down.”

With the motor running, measure $V_a$.

$$V_a = \text{______________} \text{ (free-running)}$$

Now, stall the motor by slowly grabbing the output shaft. What happens to $V_a$?

$$V_a = \text{______________} \text{ (stalled)}$$

What is the range of motor current from free running to stalled?

$V_a$ is directly related to motor current. Motor power is just $P = (5 - V_a) i_m$ Why?

How does motor power vary from free running to stalled?

Experiment with the motor shaft so you get a feel for how torque and current are related.

Since the current increases as the shaft slows down, what do you think is happening to the motor torque output?
1.5.2 Motor Circuit with MOSFET Current Limiter

Let’s try to stabilize the motor current using a power MOSFET. A saturated MOSFET passes nearly constant current, independent of $V_{DS}$, for a given $V_{GS}$. Build the circuit in Fig. 10-2.

![Fig. 10-2](image)

Make sure the SOURCE of the MOSFET is connected to the resistor side, and the DRAIN is connected to the motor.

Measure $V_a$, and again see how it behaves as you apply more and more load to the motor.

$$V_a = \text{______________} \text{ (free running)}$$

$$V_a = \text{______________} \text{ (stalled)}$$

How have things changed? What is the new range of motor current and motor power as we go from free running to stalled?
1.5.3 Basic Motor Circuit with MOSFET/Op Amp Current Controller

Our last circuit had a couple of flaws. $V_{GS}$ was varying with motor current since $V_s$ rises with current. What we DO know is that $V_a$ is a dead-on representation of motor current. So, let’s get completely accurate current control of this motor using a 1458 op amp to close the feedback loop and stabilize the voltage drop across the power resistor. If this voltage is stable, then so is the current through the motor!

Construct the circuit in Fig. 10-3. Don’t forget to add the appropriate power connections to your op amp:

![Circuit Diagram](image)

If your circuit is wired properly, the variable resistor on the Knight kit should now be controlling your motor speed. If it isn’t working, POWER DOWN and check your circuit!

Adjust the variable resistor until the free-running $V_a$ is the same as it was in your part 2.5.2. At this point, $V_g$ should be about 5 volts and the motor should be running at the same speed as before.

Measure $V_a$ and $V_g$, and again see how they behave as you apply more and more load to the motor.

$$V_a = \underline{\quad} \quad V_g = \underline{\quad} \quad \text{(free running)}$$

$$V_a = \underline{\quad} \quad V_g = \underline{\quad} \quad \text{(stalled)}$$
How have things changed? What is the new range of motor current and motor power as we go from free running to stalled?

Now, let’s see how busy the op amp is. Connect your oscilloscope to Vg and Va. As you vary motor load, what do the waveforms do?

Now, change the Vg input to AC coupling and decrease the V/div on the scope for that channel. This will let you see the minute adjustments the op amp is continuously making to maintain motor current.

Save the display and hand in as a plot labeled **Plot 10-1**.

As the motor rotates, it is constantly changing the impedance of this leg of the circuit. Replace the motor with a 10 ohm, 10W power resistor.

Describe the Va and Vg waveforms with this constant impedance instead of the motor.

In your write-up, discuss the op amp controller and describe its virtues. Why do we need a variable resistor (the MOSFET) controller in a feedback loop to maintain a steady current through the motor? Explain what you think is happening to the motor’s impedance as we increase its load.