Overview
MOSFETS are voltage-controlled switches. Unlike triacs, MOSFETS have the capability of being turned on and turned off. They also switch much faster than triacs. As illustrated in Figure 1, the MOSFET acts as a unidirectional switch between the drain and source terminals, and has an internal antiparallel diode. An applied gate-to-source voltage of approximately 4 or 5 V is sufficient to turn on the MOSFET (i.e., resistance between drain and source becomes a few tenths of an ohm). Faster turn on is achieved when 12-18V is applied. Then, when the gate-to-source voltage is set to zero, the MOSFET turns off (i.e., drain-to-source resistance becomes very large).

A Warning about Static Electricity
Until they are properly mounted with a gate pull-down resistor, a MOSFET is very sensitive to burn out if its gate terminal is touched. Do not take the MOSFET out of its anti-static bag until you are ready to mount it on the PC board, and then always use a grounded static wrist strap and/or static mat when handling the MOSFET. Avoid touching the gate terminal.

When using a wrist strap, attach the wrist alligator clip end of the strap to the metal switch plate cover on the right-hand side of the lab benches. As an extra precaution, frequently touch the metal power switch plate cover with your hand.

Testing a MOSFET
If you suspect that your MOSFET has failed, perform the following test:
- Remove any connections to either the drain or source terminals, except keep the 100kΩ pull-down resistor connected from gate to source.
- With no VGS applied, measure RDS with an ohmmeter. Expect RDS → ∞ (i.e., MΩs).
- Now, while measuring RDS, temporarily connect a 6-to-18V VGS. Expect to see RDS → 0 (i.e., few tenths Ω). Remove the temporary connection, and expect to return to RDS → ∞.

This test can be also be performed with the MOSFET tester in the power lab. The tester circuit is mounted on a piece of wood and uses a 1” diameter red LED for testing under load.
The Firing Circuit
The MOSFET firing circuit used in this experiment, shown in Figure 2, contains two IC chips (i.e., a pulse-width modulator, and a MOSFET inverting driver). The pulse width modulator compares a sawtooth wave to a 0-5V\textsubscript{dc} reference voltage to produce a 5V rectangular-wave logic output with controllable duty cycle D. As the reference voltage increases, D decreases (thus, an inverted response). This output serves as the input to the inverting MOSFET driver that, in turn, provides the voltage and current to quickly switch the MOSFET.

![MOSFET Firing Circuit](image)

Figure 2. MOSFET Firing Circuit (ordered through Express PCB.com)
The voltage divider for duty cycle control consists of two resistors and either an A10kΩ (for Buck) or B10kΩ (for Boost or Buck/Boost) potentiometer. The “A” in “A10kΩ” stands for audio taper, meaning that the resistance of the potentiometer varies logarithmically. B10kΩ has linear taper. In Figure 2, as the duty cycle “D” potentiometer is turned clockwise, voltage to the “Duty” pin #1 increases, the duty cycle of the pulses to the inverting driver chip decreases, so that D of the inverting driver output increases. Another potentiometer is included to modify the maximum duty cycle that can be achieved with this circuit. The modeled variations are given in Figures 3a, 3b, and 3c.

The sawtooth wave frequency of the PWM modulator is proportional to 1/RC, where R is the series combination of an A10kΩ potentiometer and 470Ω resistor, and C is 6.8nF. Decreasing R increases frequency. In Figure 2, turning the A10kΩ “Freq” potentiometer clockwise decreases R, and thus increases frequency. As the potentiometer is turned clockwise, the amount of resistance change per angular degree of movement decreases. The nonlinear resistance variation of an audio pot yields a more linear variation of frequency than can be achieved with a linear potentiometer (see Figure 4).

Figure 3a. Duty Cycle D (and Vout/Vin) Variation in Buck Converter vs. Potentiometer Angle (EE362L_MOSFET_Firing_Circuit_Duty_Variation.xls)
**Boost Vout/Vin vs. Potentiometer Angle**

![Graph showing the variation of Vout/Vin in a Boost Converter with Potentiometer Angle. Two curves are shown: one for Audio Pot and another for Linear Pot.](EE362L_MOSFET_Firing_Circuit_Duty_Variation.xls)

Figure 3b. Vout/Vin Variation in Boost Converter vs. Potentiometer Angle  
(EE362L_MOSFET_Firing_Circuit_Duty_Variation.xls)

**Buck/Boost Vout/Vin vs. Potentiometer Angle**

![Graph showing the variation of Vout/Vin in a Buck/Boost Converter with Potentiometer Angle. Two curves are shown: one for Audio Pot and another for Linear Pot.](EE362L_MOSFET_Firing_Circuit_Duty_Variation.xls)

Figure 3c. Vout/Vin Variation in Buck/Boost Converter vs. Potentiometer Angle  
(EE362L_MOSFET_Firing_Circuit_Duty_Variation.xls)
**Circuit Construction:**

- Ohm-check the PC board **before** mounting any components. This means ohm-checking each pad for connections to the ground plane, power plane, or neither plane.

- Traces are rated per 0.025” of width. Thus, a 0.10” trace is rated 4A. The widest single trace available is 0.15”, corresponding to 6A. Traces can be paralleled.

- It is best to keep at least 0.2” between components

- Personal preference – no traces on the bottom side

- Use nylon screws and standoffs to support the PC board

- Wide traces are stronger, especially at corners, and easy to touch with a scope probe

- Personal preference – use ½ W resistors because it is easy to attach a scope probe to their leads

- Resistor bodies should be slightly elevated so they do not touch the PC board

- Use sockets for the chips so they can be easily replaced and removed for reuse.
Next: Temporarily connect a $12\text{V}_\text{dc}$ regulated wall wart to the DC jack and use a voltmeter to determine which pin is +12V, and which pin is ground. Now, disconnect the wall wart. Then,

1. Mount and solder the 100kΩ MOSFET gate-to-source pull-down resistor.

2. Mount and solder the three-terminal Phoenix Contact “green plug,” so that the tightening screws face the outer edge of the PC board.

3. Mount the 1.5” corner bracket with two #6 nylon knurled-head thumb screws, using a ¼” #6 nylon spacer between each screw and the surface of the PC board.

4. **The most important step. Use a static wristband. Avoid touching the gate terminal.** Take the MOSFET out of the pink antistatic bag, place a very thin layer of heat sink compound on the back of the MOSFET, and run a #4 nylon knurled-head thumb screw through the MOSFET and heat sink holes. Insert the MOSFET pins into the green plug and push the #4 thumb screw through the 1.5” bracket. Place a 1/8th inch, #6 nylon spacer on the back of the corner bracket, and tighten the assembly with a #4, ¾ inch threaded spacer. Then, tighten the green plug’s three screws to make a solid electrical connection with the MOSFET’s pins.

Figure 5. Example of MOSFET Assembly. Actual PCB configuration may differ from those shown in these pictures.
5. Mount the DC jack. Before soldering any leads to the jack, plug in a 12Vdc wall to determine the + and – terminals. Then, disconnect the 12Vdc wall wart.

6. Mount all remaining components.

7. Plug in the wall wart. Make sure that each chip is receiving the proper +12V supply voltage. Do this using multimeter measurements directly at the appropriate pins on the chips. Check the voltage at pin 12 of the PWM modulator chip with respect to ground. Expect 5V.

8. Connect an oscilloscope probe to the logic output of the PWM chip (i.e., pin 8). Adjust D. The waveform should vary sharply between zero and (about) 4.5V, with inverted duty cycle. Move the probe to the output of the driver to view $V_{GS}$. This $V_{GS}$ is “open circuit” because the driver is not yet connected to the MOSFET. The waveform should be switching sharply between 0 and 12V. Use the oscilloscope to measure duty cycle D and frequency f. Vary the D and F potentiometers to observe the ranges of D and f. Expect $0.05 < D < 0.95$ (for buck), and $15kHz < f < 200kHz$. D and F should increase as their respective potentiometers are rotated clockwise. Save a representative screen snapshot of $V_{GS}$ for your report, with $D \approx 0.8$, and $f \approx 150kHz$.

9. Lower D to the minimum, and unplug the wall wart.
PWM Logic Output (i.e., Pin 8)

Open-Circuited Driver Chip Output VGS
10. Before turning on the variac/transformer/DBR, connect scope leads to simultaneously view VGS and VDS. Initially consider a switching frequency of 100 kHz.

11. Set the D control to zero. Raise Vdc (i.e., the DBR voltage) to about 20V.

12. While viewing VGS and VDS, slowly raise D to about 0.5. Observe and measure the peak value and frequency of the ringing overvoltage in VDS.

13. Sweep D over the entire range and verify correct operation. Take simultaneously screen snapshots of PWM output and VGS for 100 kHz.

14. If no sign of trouble, repeat the above with the Vdc about 35 to 40V. Take a screen snapshot of VDS. Measure the peak value and frequency of the ringing overvoltage.

15. If no sign of trouble, repeat with 200kHz.

16. Ringing overvoltage is due to the MOSFET capacitance in series with the load circuit’s parasitic inductance (including DBR, wires, and resistor). Obviously, in the “hard switching” case, the ringing overvoltage can be greater than the acceptable “twice Vdc.” High ringing overvoltage “uses up” the MOSFET’s voltage rating. To reduce ringing overvoltage, “slow it down” by placing a 0.022 µF ceramic disk capacitor (a.k.a “snubber capacitor”) between the MOSFET’s drain and source terminals. Then, repeat the hard switching load test with 35-40 Vdc, D = 0.5, and re-measure the frequency and peak value of the ringing overvoltage. If removing the snubber capacitor, **turn off the DBR first**, and then remove the snubber capacitor. **Note – do not remove or connect the snubber with DBR power applied because the resulting sparks can burn out the MOSFET.**

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**Fig. 6. Testing configuration**
17. Duplicate the following conditions and discuss the results.

**Large 10Ω, 225W Resistor. 5.3Vdc. Vpeak = 200V.**

![Image of large resistor setup and waveform with MOSFET opens]

**Small 10Ω, 100W Resistor. 22Vdc. Vpeak = 240V.**

![Image of small resistor setup and waveform with MOSFET opens]
Small 10Ω, 100W Resistor. 20Vdc. $V_{peak} = 240V$.

![Graph showing MOSFET opening at 20Vdc]

Small 10Ω, 100W Resistor. 22Vdc. $V_{peak} = 40V$.

0.022μF Snubber Cap

![Graph showing MOSFET opening at 22Vdc with a snubber cap]
Small 10Ω, 100W Resistor. 22Vdc. V_{peak} = 60V

0.0068μF Snubber Cap

MOSFET opens
PWM Modulator (On Semiconductor MC34060A)

MOSFET Driver, Inverting and Non-Inverting, (MICROCHIP TC1426CPA and TC1427CPA, respectively)