

University of California Berkeley  
Department of Electrical Engineering and Computer Sciences  
EECS 100, Professor Leon Chua

## LABORATORY 3 v3

### CIRCUIT ELEMENTS

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The purpose of this laboratory is to familiarize ourselves with the concept of circuit elements. Anything that has electrical connections can be viewed as a circuit element. The resistors we worked with in the first lab are circuit elements, as are the power supply and multimeter. The circuit element abstraction lets us to focus on the relationship between currents and voltages at the interface of the element without having to worry about the complex circuitry inside of it. We already made use of this abstraction in the first lab when we treated the power supply (which contains a very complex circuit inside) simply as a constant voltage or current source.

To successfully apply (complicated) circuit elements we need means to describe and measure their behavior at the terminals. In this lab we concentrate on the current versus voltage characteristics, IV curves for short. We already have seen IV characteristics of supplies and solar cells in the first lab. In this laboratory we will extend our repertoire to include the characteristics of potentiometers, an oscilloscope, a diode, and a transistor. In later laboratories we will use our understanding of circuit elements to design electronic circuits.

This laboratory also uses two new instruments: the function generator and the oscilloscope. Download and read the instructions before coming to the lab.

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LAB REPORT 3 V3

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Lab Session:

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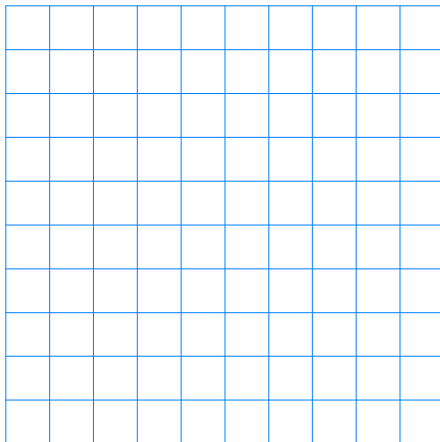
Name 2:

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**1. Oscilloscope Model**

Resistors are not only useful circuit elements, but are also good models for many electrical devices. Here we use a resistor to model a complex electronic test instrument.

- a) In the graph below plot the IV characteristic of a  $1\text{k}\Omega$  resistor for  $V = -5 \dots +5\text{V}$ . Label the axes (scale and units!).



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 of 1 **P**

Measured (optional for extra credit)

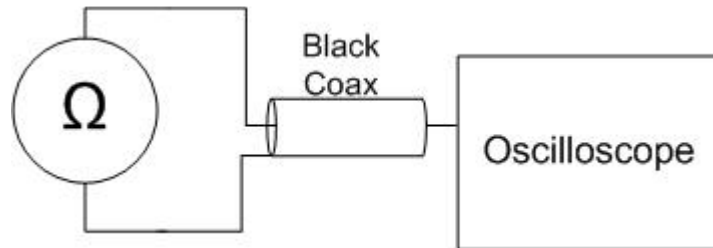
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 of 1 **M**

Oscilloscopes are complicated electronic instruments for measuring voltage versus time. We will make extensive use of an oscilloscope later in this course, but today we treat the oscilloscope as a simple circuit element without worrying about its internals. The oscilloscope can be modeled as a resistor with a linear I/V characteristic just like the resistor above.



- Turn on the oscilloscope
- Connect a black BNC cable to the oscilloscope input
- Measure the resistance of the oscilloscope with the multimeter
- See figure below for diagram



Measured resistance: \_\_\_\_\_  $\Omega$  \_\_\_\_\_ of 2 **M**

- Change the oscilloscope BNC cable to a gray 10x oscilloscope probe.
- Measure the resistance of the oscilloscope probe connected to the oscilloscope.

Measured resistance: \_\_\_\_\_  $\Omega$  \_\_\_\_\_ of 1 **M**

These are large resistor values because large resistors disturb the circuit being measured only a small amount resulting in measurements that are close to the true circuit operation.



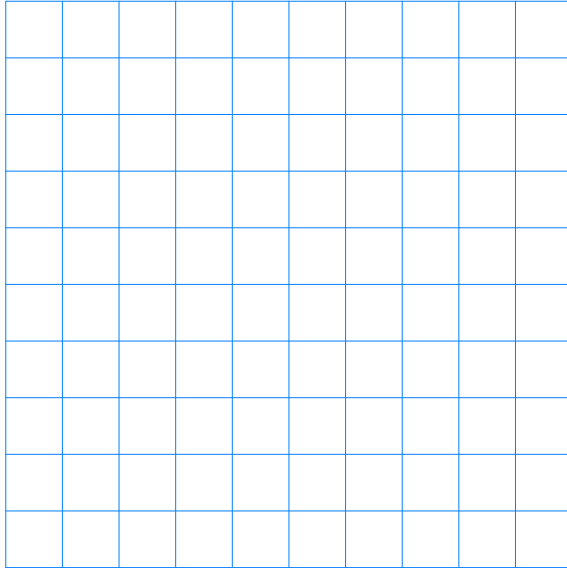
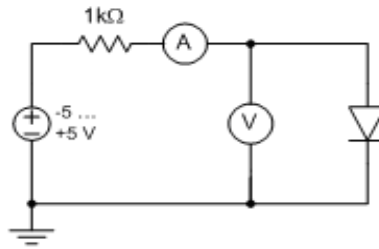
## 2. Diodes

Diodes pass current in only one direction, and you simulated this component in lab 2. The circuit symbol for a diode is shown above, and the direction of the triangle indicates which direction current can flow through it. In other words, a diode acts like a short circuit for current flowing in the direction of the arrow and like an open circuit for current flowing in the opposite direction.



- Based on the description above, plot the IV (current versus voltage) characteristic of an ideal diode in the graph below (part b). Do not simulate. Plot from -1 V to +1 V.
- Measure and graph the IV characteristic of a diode and plot the result in the graph below. Do not forget the tickmarks (0.1V, 0.2V, etc). Use the test circuit shown below. The resistor limits the current.

**Measure the voltage across the diode by itself and not the resistor and diode together!**

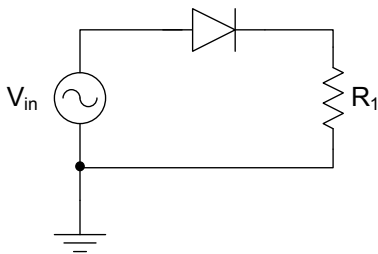


\_\_\_ of 3 **P**

Ideal and measured diode IV characteristics.

\_\_\_ of 5 **M**

- c) The circuit below is called a half wave rectifier and is used in some power conversion circuits. We will now consider how this circuit functions.



The input is a 1kHz sinusoidal voltage with a 5 V peak (10 V peak to peak, 3.5 Vrms) amplitude.

- Sketch the voltage  $V_{R1}$  across resistor  $R_1=1k\Omega$  in the circuit on a sheet of paper assuming an ideal diode.

- Simulate the operation of this circuit and plot the value of  $V_{R1}$  as a function of time. Include a copy of the output and the schematic with the prelab. Also bring an extra copy with you to lab.
- Copy your expected result from above to your prelab printout and your second printout.
- Explain why the ideal diode and the simulated diode are different using what you know about the ideal diode and the simulated diode from lab 2.
- In the laboratory, substitute the function generator for  $V_{in}$  and program it for a 1kHz sinusoidal output with 10V peak-to-peak amplitude and zero offset (verify with the oscilloscope!).
- Connect the oscilloscope across  $R_1$  (use a probe with 10x attenuation) and transfer the measured waveform to Multisim plot you brought from lab.
- Try also square wave and ramp signals.

Expected waveform

\_\_\_ of 1 **P**

Multisim simulation result

\_\_\_ of 3 **P**

Explain discrepancies:

\_\_\_ of 1 **P**

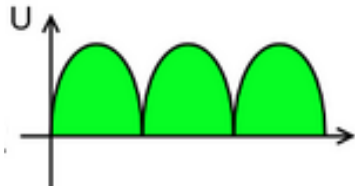
Measurement

\_\_\_ of 4 **M**

Explain discrepancies:

\_\_\_ of 1 **M**

- d) The circuit shown above is called a half wave rectifier since it passes only the positive half of the sine. A variation using 4 diodes is used in wall transformers to generate the output shown below. Can you figure out the correct circuit for extra points?



Circuit diagram (optional)

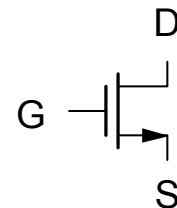
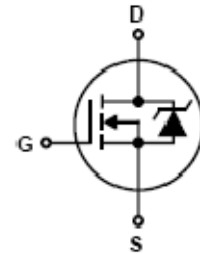
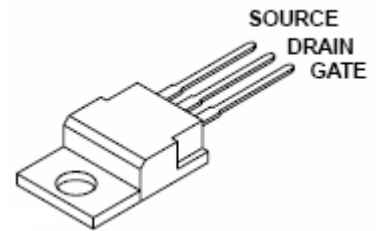
\_\_\_ of 2 **P**

### 3. Field Effect Transistor

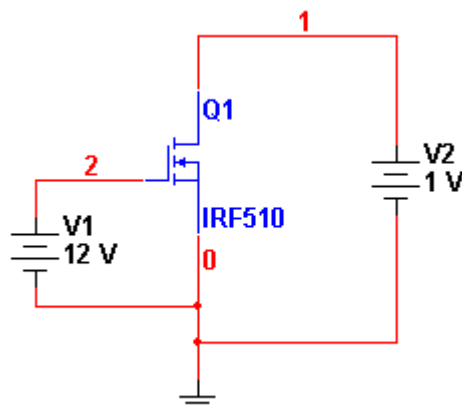
The transistor is arguably the most important circuit element. Unless you are an integrated circuit designer (a specialization within electrical engineering) you will rarely deal with individual transistors but rather use integrated circuits with several transistors inside that have more functionality than a single transistor. But sometimes a single transistor is just what we need, and in this lab we are going to measure transistor characteristics.

The picture on the right shows an IRF 510, a so-called “N-Channel enhancement mode silicon gate power field effect transistor.” It has three terminals: Drain (D), gate (G), and source (S). Corresponding circuit symbols are shown on the right. Transistors are quite universal and can be used as on/off switches, programmable resistors, or current sources.

We call the voltage difference between drain and source  $V_{DS}$ ; similarly, the voltage difference between gate and source is  $V_{GS}$ . In this section of the lab, the switch-like behavior of the transistor is demonstrated. The transistor is like a switch in the sense that it has two states, an “on” state (low resistance between drain and source) and an “off” state (high resistance between drain and source). The gate voltage determines which state the transistor is in. When  $V_{GS}$  is below some threshold, the switch is off, and the resistance between drain and source is high. When  $V_{GS}$  exceeds the threshold, the switch is on, and the resistance between drain and source is lower.

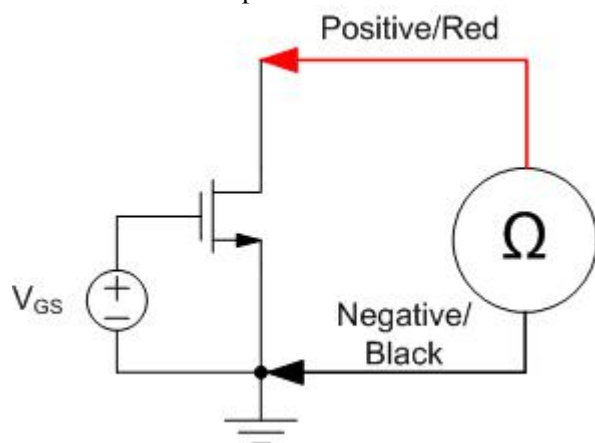


- a) Use multisim to simulate the resistance between the drain and source of the IRF510 (in the **place component** dialogue box: group = transistors, family = MOS\_3TEN, component = IRF510).
  - Use the schematic below.
  - Calculate the resistance using the voltage and current out of supply V2.
  - Use a logarithmic scale for the resistance and attach one copy of the plot to your prelab and bring the second for use in the lab.



- b) Use the multimeter to measure the resistance between the drain and source terminal as a function of  $V_{GS}$  and plot your result on the same plot you brought to lab from part a.

- Connect the positive lead of the ohmmeter to the drain of the transistor.
- Connect the negative lead of the ohmmeter to the source of the resistor. If you reverse the polarity, you will get the wrong results.
- Set the +25 V supply to 0V with a current limit of 100 mA
- Connect the +25 V supply output between the gate and source as shown.
- Measure the drain to source resistance as a function of  $V_{GS}$ .
- Use small steps up to 4V and then use 1 V steps up to 10V
- Plot the data on the printout from multisim.



| $V_{GS}$ | $R_{DS}$ |  | $V_{GS}$ | $R_{DS}$ |  | $V_{GS}$ | $R_{DS}$ |
|----------|----------|--|----------|----------|--|----------|----------|
| 0 V      |          |  |          |          |  | 4V       |          |
|          |          |  |          |          |  | 5 V      |          |
|          |          |  |          |          |  | 6 V      |          |
|          |          |  |          |          |  | 7 V      |          |
|          |          |  |          |          |  | 8 V      |          |
|          |          |  |          |          |  | 9 V      |          |
|          |          |  |          |          |  | 10 V     |          |

Multisim simulation (include printout of plot and schematic with prelab)

\_\_\_ of 5 **P**

Measurement

\_\_\_ of 5 **M**

- c) Based on your measurements from part (a), how would you use a transistor as a switch? Describe what you expect from a switch and how and to which degree the transistor meets these requirements.

\_\_\_ of 5 **M**

## SUGGESTIONS AND FEEDBACK

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Time for completing prelab:

Time for completing lab:

Please explain difficulties you had and suggestions for improving this laboratory. Be specific, e.g. refer to paragraphs or figures in the write-up. Explain what experiments should be added, modified (how?), or dropped.



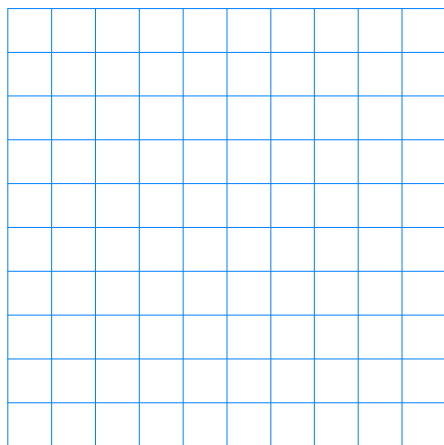
## PRELAB SUMMARY

Lab Session:

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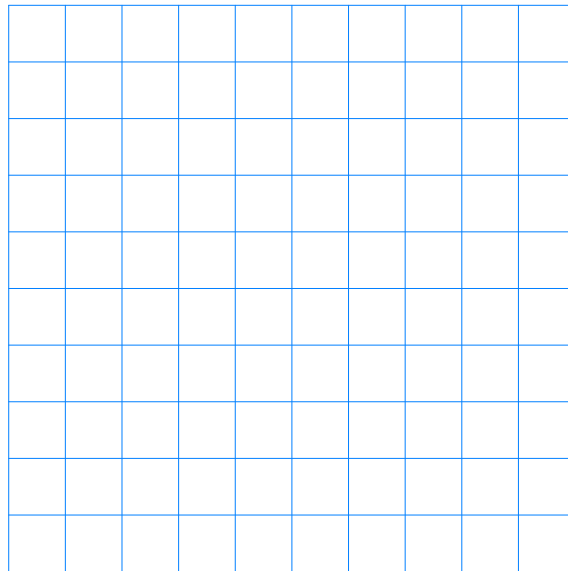
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1a) Plot of resistor I/V curve (-5V to 5V)



\_\_\_ of 1 **P**

2a) Plot of ideal diode I/V curve (-1V to 1V)



\_\_\_ of 3 **P**

2c) Draw expected waveform of half wave rectifier on a printout of your Multisim result. Also attach the schematic of your simulation.

Expected waveform:

\_\_\_ of 1 **P**

Multisim simulation result:

\_\_\_ of 3 **P**

Explain discrepancies:

\_\_\_ of 1 **P**

2d) Schematic for full wave rectifier

\_\_\_ of 2 **P**

3a) Attach a printout of the Multisim output of  $R_{DS}$  for the transistor and the schematic of your circuit.

\_\_\_ of 5 **P**